New Particle Physics Predicted by TGD: Part II

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Abstract

In this chapter the focus is on the hadron physics. The applications are to various anomalies discovered during years.

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1. The spin puzzle of proton is a two decades old mystery with no satisfactory explanation in QCD framework. The notion of hadronic space-time sheet which could be imagined as string like rotating object suggests a possible approach to the spin puzzle. The entanglement between valence quark spins and the angular momentum states of the rotating hadronic space-time sheet could allow natural explanation for why the average valence quark spin vanishes.
2. The notion of Pomeron was invented during the Bootstrap era preceding QCD to solve difficulties of Regge approach. There are experimental findings suggesting the reincarnation of this concept. The possibility that the newly born concept of Pomeron of Regge theory might be identified as the sea of perturbative QCD in TGD framework is considered. Geometrically Pomeron would correspond to hadronic space-time sheet without valence quarks.
3. The discovery that the charge radius of proton deduced from the muonic version of hydrogen atom is about 4 per cent smaller than from the radius deduced from hydrogen atom is in complete conflict with the cherished belief that atomic physics belongs to the museum of science. The title of the article *Quantum electrodynamics-a chink in the armour?* of the article published in Nature expresses well the possible implications, which might actually go well extend beyond QED. TGD based model for the findings relies on the notion of color magnetic body carrying both electromagnetic and color fields and extends well beyond the size scale of the particle. This gives rather detailed constraints on the model of the magnetic body.
4. The soft photon production rate in hadronic reactions is by an average factor of about four higher than expected. In the article soft photons assignable to the decays of Z^0 to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and black-holes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent. TGD based model is based on the notion of electric flux tube.

2. Quark gluon plasma

QCD predicts that at sufficiently high collision energies de-confinement phase transitions for quarks should take place leading to quark gluon plasma. In heavy ion collisions at RHIC something like this was found to happen. The properties of the quark gluon plasma were however not what was expected. There are long range correlations and the plasma seems to behave like perfect fluid with minimal viscosity/entropy ratio. The lifetime of the plasma phase is longer than expected and its density much higher than QCD would suggest. The experiments at LHC for proton proton collisions suggest also the presence of quark gluon plasma with similar properties.

TGD suggests an interpretation in terms of long color magnetic flux tubes containing the plasma. The confinement to color magnetic flux tubes would force higher density. The preferred extremals of Kähler action have interpretation as defining a flow of perfect incompressible fluid and the perfect fluid property is broken only by the many-sheeted structure of space-time with smaller space-time sheets assignable to sub-CDs representing radiative corrections. The phase in question corresponds to a non-standard value of Planck constant: this could also explain why the lifetime of the phase is longer than expected.

3. Breaking of discrete symmetries

Zero energy ontology provides a fresh approach to discrete symmetries and provides also a general mechanism for their breaking. A general vision about breaking of discrete symmetries relies on quantum measurement theory: the quantum jump selecting the quantization axes induces localization to a single CD and therefore induces breaking of discrete symmetries due

to the choice of quantization axes. The time scale of CD is excellent candidate for defining mass and time scales characterizing the symmetry breaking. Entropic gravity idea has a variant in TGD framework resulting from the fact that in ZEO quantum theory is a square root of thermodynamics in a well-defined sense. Thermodynamical stability could force the generation of the arrow of time and also force it to be different for matter and antimatter inducing in this manner matter antimatter asymmetry and breaking of discrete symmetries like CP. Also CPT could be broken spontaneously and there are experimental indications that this takes place for top quark with mass difference which is surprisingly large- few per cent of top mass.

4. Are exotic Super Virasoro representations relevant for hadron physics?

In p-adic context exotic representations of Super Virasoro with $M^2 \propto p^k$, $k = 1, 2, ..m$ are possible. For $k = 1$ the states of these representations have same mass scale as elementary particles although in real context the masses would be gigantic. This inspires the question whether non-perturbative aspects of hadron physics could be assigned to the presence of these representations. Some intriguing numerical co-incidences suggest that the exotic representations of Super-Virasoro should be assigned with hadron and whereas ordinary Virasoro representations would be assigned with the quark-gluon plasma or possibly sea quarks.

1 Introduction

In this chapter the focus is on the hadron physics. The applications are to various anomalies discovered during years.

1.1 Application Of The Many-Sheeted Space-Time Concept In Hadron Physics

The many-sheeted space-time concept involving also the notion of field body can be applied to hadron physics to explain findings which are difficult to understand in the framework of standard model

1. The spin puzzle of proton [C31, C30] is at the time of writing a two decades old mystery with no satisfactory explanation in QCD framework. The notion of hadronic space-time sheet which could be imagined as string like rotating object suggests a possible approach to the spin puzzle. The entanglement between valence quark spins and the angular momentum states of the rotating hadronic space-time sheet could allow natural explanation for why the average valence quark spin vanishes.

2. The notion of Pomeron was invented during the Bootstrap era preceding QCD to solve difficulties of Regge approach. There are experimental findings suggesting the reincarnation of this concept [C38, C34, C40]. The possibility that the newly born concept of Pomeron of Regge theory might be identified as the sea of perturbative QCD in TGD framework is considered. Geometrically Pomeron would correspond to hadronic space-time sheet without valence quarks.

3. The discovery that the charge radius of proton deduced from the muonic version of hydrogen atom is about 4 per cent smaller than from the radius deduced from hydrogen atom [C47, C48] is in complete conflict with the cherished belief that atomic physics belongs to the museum of science. The title of the article *Quantum electrodynamics-a chink in the armour?* of the article published in Nature [C39] expresses well the possible implications, which might actually go well extend beyond QED. TGD based model for the findings relies on the notion of color magnetic body carrying both electromagnetic and color fields and extends well beyond the size scale of the particle. This gives rather detailed constraints on the model of the magnetic body.

4. The soft photon production rate in hadronic reactions is by an average factor of about four higher than expected [**?**] In the article soft photons assignable to the decays of Z^0 to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and black-holes

at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent. TGD based model is based on the notion of electric flux tube.

1.2 Quark Gluon Plasma

QCD predicts that at sufficiently high collision energies de-confinement phase transitions for quarks should take place leading to quark gluon plasma. In heavy ion collisions at RHIC [C32] something like this was found to happen. The properties of the quark gluon plasma were however not what was expected. There are long range correlations and the plasma seems to behave like perfect fluid with minimal viscosity/entropy ratio. The lifetime of the plasma phase is longer than expected and its density much higher than QCD would suggest. The experiments at LHC for proton proton collisions suggest also the presence of quark gluon plasma with similar properties.

TGD suggests an interpretation in terms of long color magnetic flux tubes containing the plasma so that additional support for the notion of field would would emerge. The confinement to color magnetic flux tubes would force higher density. The preferred extremals of Kähler action have interpretation as defining a flow of perfect incompressible fluid and the perfect fluid property is broken only by the many-sheeted structure of space-time with smaller space-time sheets assignable to sub-CDs representing radiative corrections. The phase in question corresponds to a non-standard value of Planck constant: this could also explain why the lifetime of the phase is longer than expected.

1.3 Breaking Of Discrete Symmetries

Zero energy ontology provides a fresh approach to discrete symmetries and provides also a general mechanism for their breaking. A general vision about breaking of discrete symmetries relies on quantum measurement theory: the quantum jump selecting the quantization axes induces localization to a single CD and therefore induces breaking of discrete symmetries due to the choice of quantization axes. The time scale of CD is excellent candidate for defining mass and time scales characterizing the symmetry breaking. Entropic gravity idea has a variant in TGD framework resulting from the fact that in ZEO quantum theory is a square root of thermodynamics in a well-defined sense. This suggests that thermodynamical stability forces the generation of the arrow of time and forces it to be different for matter and antimatter inducing in this way matter antimatter asymmetry and breaking of discrete symmetries like CP. Also CPT can be broken spontaneously and there are experimental indications that this takes place for top quark with mass difference which is surprisingly large- few per cent of top mass.

The anomalously large direct CP breaking in $K_L \rightarrow \pi\pi$ decays is included as old application of TGD. The breaking is explained in terms of loop corrections due to the predicted 2 exotic gluons having masses around 33.6 GeV. It will be also found that the TGD version of the chiral field theory believed to provide a phenomenological low energy description of QCD differs from its standard model version in that quark masses are replaced in TGD framework with shifts of quark masses induced by the vacuum expectation values of the scalar meson fields. This conforms with the TGD view about Higgs mechanism as causing only small mass shifts. It must be however emphasized that there is an argument suggesting that the vacuum expectation value of Higgs in fermionic case does not even make sense.

1.4 Are Exotic Super Virasoro Representations Relevant For Hadron Physics?

The last section of the chapter can be taken as miscellaneous material, which I have not been able to throw away yet. In p-adic context exotic representations of Super Virasoro with $M^2 \propto p^k$, $k = 1, 2, ..$m are possible. For $k = 1$ the states of these representations have same mass scale as elementary particles although in real context the masses would be gigantic. This inspires the question whether non-perturbative aspects of hadron physics could be assigned to the presence of these representations.

The prospects for this are promising. Pion mass is almost exactly equal to the mass of lowest state of the exotic representation for $k = 107$ and Regge slope for rotational excitations of hadrons is predicted with three per cent accuracy assuming that they correspond to the states of $k = 101$ exotic Super Virasoro representations. This leads to the idea that hadronization and fragmentation correspond to phase transitions between ordinary and exotic Super Virasoro representations and that there is entire fractal hierarchy of hadrons inside hadrons and QCD:s inside QCD:s corresponding to p-adic length scales $L(k)$, $k = 107, 103, 101, 97, ...$ Some intriguing numerical co-incidences suggest that the exotic representations of Super-Virasoro should be assigned with hadron and whereas ordinary Virasoro representations could be assigned with the quark-gluon plasma or possibly sea partons.

The appendix of the book gives a summary about basic concepts of TGD with illustrations. Pdf representation of same files serving as a kind of glossary can be found at http://tgdtheory.fi/tgdglossary.pdf [L4].

2 New Space-Time Concept Applied To Hadrons

2.1 A New Twist In The Spin Puzzle Of Proton

The so called proton spin crisis or spin puzzle of proton was an outcome of the experimental finding that the quarks contribute only 13-17 per cent of proton spin [C31, C30] whereas the simplest valence quark model predicts that quarks contribute about 75 per cent to the spin of proton with the remaining 25 per cent being due to the orbital motion of quarks. Besides the orbital motion of valence quarks also gluons could contribute to the spin of proton. Also polarized sea quarks can be considered as a source of proton spin.

Quite recently, the spin crisis got a new twist [C36]. One of the few absolute predictions of perturbative QCD (pQCD) is that at the limit, when the momentum fraction of quark approaches unity, quark spin should be parallel to the proton spin. This is due to the helicity conservation predicted by pQCD in the lowest order. The findings are consistent with this expectation in the case of protonic u quarks but not in the case of protonic d quark. The discovery is of a special interest from the point of view of TGD since it might have an explanation involving the notions of many-sheeted space-time, of color-magnetic flux tubes, the predicted super-symplectic "vacuum" spin, and also the concept of quantum parallel dissipation.

2.1.1 The experimental findings

In the experiment performed in Jefferson Lab [C36] neutron spin asymmetries A_1^n and polarized structure functions $g_{1,2}^n$ were deduced for three kinematic configurations in the deep inelastic region from e-^{3}He scattering using 5.7 GeV longitudinally polarized electron beam and a polarized ^3He target. A_1^n and $g_{1,2}^n$ were deduced for $x = .33, .47$, and $.60$ and $Q^2 = 2.7, 3.5$ and 4.8 (GeV/c)^2. A_1^n and g_1^n at $x = .33$ are consistent with the world data. At $x = .47$ A_1^n crosses zero and is significantly positive at $x = 0.60$. This finding agrees with the next-to-leading order QCD analysis of previous world data without the helicity conservation constraint. The trend of the data agrees with the predictions of the constituent quark model but disagrees with the leading order pQCD assuming hadron helicity conservation.

By isospin symmetry one can translate the result to the case of proton by the replacement $u \leftrightarrow d$. By using world proton data, the polarized quark distribution functions were deduced for proton using isospin symmetry between neuron and proton. It was found that $\Delta u/u$ agrees with the predictions of various models while $\Delta d/d$ disagrees with the leading-order pQCD.

Let us denote by $q(x) = q^{\uparrow} + q^{\downarrow}(x)$ the spin independent quark distribution function. The difference $\Delta q(x) = q^{\uparrow} - q^{\downarrow}(x)$ measures the contribution of quark q to the spin of hadron. The measurement allowed to deduce estimates for the ratios $(\Delta q(x) + \Delta\overline{q}(x))/(q(x) + \overline{q}(x))$.

The conclusion of [C36] is that for proton one has

$$\frac{\Delta u(x)+\Delta\overline{u}(x)}{u(x)+\overline{u}(x)} \simeq .737 \pm .007 \ \ , \ \ \text{for} \ \ x=.6 \ \ .$$

This is consistent with the pQCD prediction. For d quark the experiment gives

$$\frac{\Delta d(x)+\Delta\overline{d}(x)}{d(x)+\overline{d}(x)} \simeq -.324 \pm .083 \ \ \text{for} \ \ x=.6 \ \ .$$

The interpretation is that d quark with momentum fraction $x > .6$ in proton spends a considerable fraction of time in a state in which its spin is opposite to the spin of proton so that the helicity conservation predicted by first order pQCD fails. This prediction is of special importance as one of the few absolute predictions of pQCD.

The finding is consistent with the relativistic $SU(6)$ symmetry broken by spin-spin interaction and the QCD based model interpolated from data but giving up helicity conservation [C36]. $SU(6)$ is however not a fundamental symmetry so that its success is probably accidental.

It has been also proposed that the spin crisis might be illusory [C52] and due to the fact that the vector sum of quark spins is not a Lorentz invariant quantity so that the sum of quark spins in infinite-momentum frame where quark distribution functions are defined is not same as, and could thus be smaller than, the spin sum in the rest frame. The correction due to the transverse momentum of the quark brings in a non-negative numerical correction factor which is in the range $(0,1)$. The negative sign of $\Delta d/d$ is not consistent with this proposal.

2.1.2 TGD based model for the findings

The TGD based explanation for the finding involves the following elements.

1. TGD predicts the possibility of vacuum spin due to the super-symplectic symmetry. Valence quarks can be modelled as a star like formation of magnetic flux tubes emanating from a vertex with the conservation of color magnetic flux forcing the valence quarks to form a single coherent structure. A good guess is that the super-symplectic spin corresponds classically to the rotation of the the star like structure.

2. By parity conservation only even values of super-symplectic spin J are allowed and the simplest assumption is that the valence quark state is a superposition of ordinary $J=0$ states predicted by pQCD and $J=2$ state in which all quarks have spin which is in a direction opposite to the direction of the proton spin. The state of $J=1/2$ baryon is thus replaced by a new one:

$$\begin{aligned}
|B,\frac{1}{2},\uparrow\rangle &= a|B,1/2,\frac{1}{2}\rangle|J=J_z=0\rangle + b|B,\frac{3}{2},-\frac{3}{2}\rangle|J=J_z=2\rangle \ , \\
|B,1/2,\frac{1}{2}\rangle &= \sum_{q_1,q_2,q_3} c_{q_1,q_2,q_3} q_1^{\uparrow} q_2^{\uparrow} q_3^{\downarrow} \ , \\
|B,\frac{3}{2},-\frac{3}{2}\rangle &= d_{q_1,q_2,q_3} q_1^{\downarrow} q_2^{\downarrow} q_3^{\downarrow} \ .
\end{aligned} \tag{2.1}$$

$|B,1/2,\frac{1}{2}\rangle$ is in a good approximation the baryon state as predicted by pQCD. The coefficients c_{q_1,q_2,q_3} and d_{q_1,q_2,q_3} depend on momentum fractions of quarks and the states are normalized so that $|a|^2+|b|^2=1$ is satisfied: the notation $p=|a|^2$ will be used in the sequel. The quark parts of $J=0$ and $J=2$ have quantum numbers of proton and Δ resonance. $J=2$ part need not however have the quark distribution functions of Δ.

3. The introduction of $J=0$ and $J=2$ ground states with a simultaneous use of quark distribution functions makes sense if one allows quantum parallel dissipation. Although the system is coherent in the super-symplectic degrees of freedom which correspond to the hadron size scale, there is a de-coherence in quark degrees of freedom which correspond to a shorter p-adic length scale and smaller space-time sheets.

4. Consider now the detailed structure of the $J = 2$ state in the case of proton. If the d quark is at the rotation axis, the rotating part of the triangular flux tube structure resembles a string containing u-quarks at its ends and forming a di-quark like structure. Di-quark structure is taken to mean correlations between u-quarks in the sense that they have nearly the same value of x so that $x < 1/2$ holds true for them whereas the d-quark behaving more like a free quark can have $x > 1/2$.

   A stronger assumption is that di-quark behaves like a single colored hadron with a small value of x and only the d-quark behaves as a free quark able to have large values of x. Certainly this would be achieved if u quarks reside at their own string like space-time sheet having $J = 2$.

From these assumptions it follows that if u quark has $x > 1/2$, the state effectively reduces to a state predicted by pQCD and $u(x) \rightarrow 1$ for $x \rightarrow 1$ is predicted. For the d quark the situation is different and introducing distribution functions $q^{J)}(x)$ for $J = 0, 2$ separately, one can write the spin asymmetry at the limit $x \rightarrow 1$ as

$$\begin{aligned} A_d &\equiv \frac{\Delta d(x) + \Delta \overline{d}(x)}{d(x) + \overline{d}(x)} = \frac{p(\Delta d_0 + \Delta \overline{d}_0) + (1-p)(\Delta d_2 + \Delta \overline{d}_2)}{p(d_0 + \overline{d}_0) + (1-p)(d_2 + \overline{d}_2)} \ , \\ p &= |a|^2 \ . \end{aligned} \tag{2.2}$$

Helicity conservation gives $\Delta d_0/d_0 \rightarrow 1$ at the limit $x \rightarrow 1$ and one has trivially $\Delta d_2/d_2 = -1$. Taking the ratio

$$y = \frac{d_2}{d_0}$$

as a parameter, one can write

$$A_d \rightarrow \frac{p - (1-p)y}{p + (1-p)y} \tag{2.3}$$

at the limit $x \rightarrow 1$. This allows to deduce the value of the parameter y once the value of p is known:

$$y = \frac{p}{1-p} \times \frac{1 - A_d}{1 + A_d} \ . \tag{2.4}$$

From the requirement that quarks contribute a fraction $\Sigma = \sum_q \Delta q \in (13, 17)$ per cent to proton spin, one can deduce the value of p using

$$\frac{p \times \frac{1}{2} - (1-p) \times \frac{3}{2}}{\frac{1}{2}} = \Sigma \tag{2.5}$$

giving $p = (3 + \Sigma)/4 \simeq .75$.

Eq. 2.4 allows estimate the value of y. In the range $\Sigma \in (.13, .30)$ defined by the lower and upper bounds for the contribution of quarks to the proton spin, $A_d = -.32$ gives $y \in (6.98, 9.15)$. $d_2(x)$ would be more strongly concentrated at high values of x than $d_0(x)$. This conforms with the assumption that u quarks tend to carry a small fraction of proton momentum in $J = 2$ state for which uu can be regarded as a string like di-quark state.

A further input to the model comes from the ratio of neutron and proton F_2 structure functions expressible in terms of quark distribution functions of proton as

$$R^{np} \equiv \frac{F_2^n}{F_2 p} = \frac{u(x) + 4d(x)}{4u(x) + d(x)} \ . \tag{2.6}$$

According to [C36] $R^{np}(x)$ is a straight line starting with $R^{np}(x \to 0) \simeq 1$ and dropping below $1/2$ as $x \to 1$. The behavior for small x can be understood in terms of sea quark dominance. The pQCD prediction for R^{np} is $R^{np} \to 3/7$ for $x \to 1$, which corresponds to $d/u \to z = 1/5$. TGD prediction for R^{np} for $x \to 1$

$$\begin{aligned} R^{np} &\equiv \frac{F_2^n}{F_2^p} = \frac{pu_0 + 4(pd_0 + (1-p)d_2)}{4pu_0 + pd_0 + (1-p)d_2} \\ &= \frac{p + 4z(p + (1-p)y}{4p + z(p + (1-p)y)} \ . \end{aligned} \tag{2.7}$$

In the range $\Sigma \in (.13, .30)$ which corresponds to $y \in (6.98, 9.15)$ for $A_d = -.32$ $R^{np} = 1/2$ gives $z \simeq .1$, which is 20 per cent of pQCD prediction. 80 percent of d-quarks with large x predicted to be in $J = 0$ state by pQCD would be in $J = 2$ state.

2.2 Strange spin asymmetry at RHIC

The popular article "*Surprising result shocks scientists studying spin*" (see at`http://tinyurl.com/y9zk8xa6`) tells about a peculiar effect in p-p and p-N (N for nucleus) observed at Relativistic Heavy Ion Collider (RHIC). In p-p scattering with polarized incoming proton there is asymmetry in the sense that the protons with vertical polarization with respect to scattering plane give rise to more neutrons slightly deflected to right than to left (see the figure of the article). In p-N scattering of vertically polarized protons the effect is also observed for neutrons but is stronger and has opposite sign for heavier nuclei! The effect came as a total surprise and is not understood. It seems however that the effects for proton and nuclear targets must have different origin since otherwise it is difficult to understand the change of the sign.

The abstract of the original article [C28] (see `http://tinyurl.com/y72px42v`) summarizes what has been observed.

During 2015 the Relativistic Heavy Ion Collider (RHIC) provided collisions of transversely polarized protons with Au and Al nuclei for the first time, enabling the exploration of transverse-single-spin asymmetries with heavy nuclei. Large single-spin asymmetries in very forward neutron production have been previously observed in transversely polarized p+p collisions at RHIC, and the existing theoretical framework that was successful in describing the single-spin asymmetry in p+p collisions predicts only a moderate atomic-mass-number (A) dependence. In contrast, the asymmetries observed at RHIC in p+A collisions showed a surprisingly strong A dependence in inclusive forward neutron production. The observed asymmetry in p+Al collisions is much smaller, while the asymmetry in p+Au collisions is a factor of three larger in absolute value and of opposite sign. The interplay of different neutron production mechanisms is discussed as a possible explanation of the observed A dependence.

Since a diffractive effect in forward direction is in question, one can ask whether strong interactions have anything to do with the effect. This effect can take place at the level of nucleons and a quark level and these two effects should have different signs. Could electromagnetic spin orbit coupling (see `http://tinyurl.com/y7akvgns`) cause the effect both at the level of nucleons in p-N collisions and at the level of quarks in p-p collisions? If so, the explanation would not involved new physics. Note however that the proposed generation of dark variants of M_{89} mesons is associated with peripheral collisions to which one can assign quantum criticality [K12]. Therefore one must keep mind open.

1. Spin-orbit interaction effect is relativistic effect: the magnetic field of target nucleus in the reference frame of projectile proton is nonvanishing: $\mathbf{B} = -\gamma \mathbf{v} \times \mathbf{E}$, $\gamma = 1/\sqrt{1-v^2}$. The spin-orbit interaction Hamiltonian is

   $$H_{L-S} = -\mu \cdot \mathbf{B} \ ,$$

   where

   $$\mu = g_p \mu_N \mathbf{S} \ , \quad \mu_N = \frac{e}{2m_p}$$

is the magnetic moment of polarized proton proportional to spin S, which no has definite direction due to the polarization of incoming proton beam. The gyromagnetic factor g_p equals to $g_p = 2.79284734462(82)$ holds true for proton.

2. Only the component of $\mathbf{E}$ orthogonal to $\mathbf{v}$ is involved and the coordinates in this direction are unaffected by the Lorentz transformations. One can express the transversal component of electric field as gradient

$$E_r = -\partial_r V \frac{\mathbf{r}}{r} \quad .$$

Velocity $\mathbf{v}$ can be expressed as $\mathbf{v} = \mathbf{p}/m_p$ so the spin-orbit interaction Hamiltonian reads as

$$H_{L-S} = \gamma \frac{g_p e}{2m_p} \frac{1}{m_p} \mathbf{L} \cdot \mathbf{S} \frac{1}{r} \partial_r V \quad .$$

For polarised proton the effect of this interaction could cause the left-right asymmetry. The reason is that the sign of the interaction Hamiltonia is opposite at left and right sides of the target since the sign of $L = r \times p$ is opposite at left- and right-hand sides. One can argue as in non-relativistic case that this potential generates a force which is radial and proportional to $\partial_r[(\partial_r V(r))/r)]$.

Consider first the scattering on nucleus.

1. Inside the target nucleus one can assume that the potential is of the form $V = kr^2/2$: the force vanishes! Hence the effect must indeed come from peripheral collisions. At the periphery responsible for almost forward scattering one as $V(r) = Ze/r$ and one has $\partial_r(\partial_r V(r))/r) = 3Ze/r^4$, $r = R$, R the nuclear radius. One has $R = kA^{1/3}$ for a constant density nucleus so that one has $\partial_r(\partial_r V(r))/r) = 3k^{-4}eZA^{-4/3}$.

   The force decreases with A roughly like $A^{-1/3}$ but the scattering proton can give its momentum to a larger number of nucleons inside the target nucleus. If all neutrons get their share of the transversal momentum, the effect is proportional to neutron number $N = A - Z$ one would obtain the dependence $Z(A - Z)A^{-4/3} \sim A^{2/3}$. If no other effects are involved one would have for the ratio r of Al and Au asymmetries

$$r = \frac{Al}{Au} \sim \frac{Z(Al)N(Al)}{Z(Au)A(u)} \times [\frac{A(Au)}{A(Al)}]^{4/3} \quad .$$

   Using $(Z, A) = (13, 27)$ for Al and $(Z, A) = (79, 197)$ for Au one obtains the prediction $r = .28$. The actual value is $r \simeq .3$ by estimating from Fig. 4 of [C28] (see `http://tinyurl.com/y72px42v`) is not far from this.

2. This effect takes place only for protons but it deviates proton at either side to the interior of nucleus. One expects that the proton gives its transversal momentum components to other nucleons - also neutrons. This implies that sign of the effect is same as it would be for the spin-orbit coupling when the projectile is neutron. This could be the basic reason for the strange sign of the effect.

Consider next what could happen in p-p scattering.

1. One must explain why neutrons with R-L asymmetry with respect to the scattering axis are created. This requires quark level consideration.

2. The first guess is that one must consider spin orbit interaction for the quarks of the polarized proton scattering from the quarks of the unpolarized proton. What comes in mind is that one could in a reasonable approximation treat the unpolarized proton as single coherent entity. In this picture u and d quarks of polarized proton would have asymmetric diffractive scattering tending to go to the opposite sides of the scattering axis.

3. The effect for d quarks would be opposite to that for u quarks. Since one has $n = udd$ and $p = uud$, the side which has more d quarks gives rise to neutron excess in the recombination of quarks to hadrons. This effect would have opposite sign than the effect in the case of nuclear target. This quark level effect would be present also for nuclear targets but nucleon level effect would be possible only for nuclei with $A - Z > 0$.

As found, the model does not involve directly many-sheeted space-time except possibly via the assumption that polarized proton scatters from the entire target proton in electromagnetic sense.

2.3 Topological Evaporation And The Concept Of Pomeron

Topological evaporation provides an explanation for the mysterious concept of Pomeron originally introduced to describe hadronic diffractive scattering as the exchange of Pomeron Regge trajectory [C55]. No hadrons belonging to Pomeron trajectory were however found and via the advent of QCD Pomeron was almost forgotten. Pomeron has recently experienced reincarnation [C38, C34, C40]. In Hera [C38] $e - p$ collisions, where proton scatters essentially elastically whereas jets in the direction of incoming virtual photon emitted by electron are observed. These events can be understood by assuming that proton emits color singlet particle carrying small fraction of proton's momentum. This particle in turn collides with virtual photon (antiproton) whereas proton scatters essentially elastically.

The identification of the color singlet particle as Pomeron looks natural since Pomeron emission describes nicely diffractive scattering of hadrons. Analogous hard diffractive scattering events in pX diffractive scattering with $X = \bar{p}$ [C34] or $X = p$ [C40] have also been observed. What happens is that proton scatters essentially elastically and emitted Pomeron collides with X and suffers hard scattering so that large rapidity gap jets in the direction of X are observed. These results suggest that Pomeron is real and consists of ordinary partons.

TGD framework leads to two alternative identifications of Pomeron relying on same geometric picture in which Pomeron corresponds to a space-time sheet separating from hadronic space-time sheet and colliding with photon.

2.3.1 Earlier model

The earlier model is based on the assumption that baryonic quarks carry the entire four-momentum of baryon. p-Adic mass calculations have shown that this assumption is wrong. The modification of the model requires however to change only wordings so that I will represent the earlier model first.

The TGD based identification of Pomeron is very economical: Pomeron corresponds to sea partons, when valence quarks are in vapor phase. In TGD inspired phenomenology events involving Pomeron correspond to pX collisions, where incoming X collides with proton, when valence quarks have suffered coherent simultaneous (by color confinement) evaporation into vapor phase. System X sees only the sea left behind in evaporation and scatters from it whereas valence quarks continue without noticing X and condense later to form quasi-elastically scattered proton. If X suffers hard scattering from the sea the peculiar hard diffractive scattering events are observed. The fraction of these events is equal to the fraction f of time spent by valence quarks in vapor phase.

Dimensional argument can be used to derive a rough order of magnitude estimate for f as $f \sim 1/\alpha = 1/137 \sim 10^{-2}$ for f: f is of same order of magnitude as the fraction (about 5 per cent) of peculiar events from all deep inelastic scattering events in Hera. The time spent in condensate is by dimensional arguments of the order of the p-adic length scale $L(M_{107})$, not far from proton Compton length. Time dilation effects at high collision energies guarantee that valence quarks indeed stay in vapor phase during the collision. The identification of Pomeron as sea explains also why Pomeron Regge trajectory does not correspond to actual on mass shell particles.

The existing detailed knowledge about the properties of sea structure functions provides a stringent test for the TGD scenario. According to [C34] Pomeron structure function seems to consist of soft ($(1-x)^5$), hard ($(1-x)$) and super-hard component (delta function like component at $x = 1$). The peculiar super hard component finds explanation in TGD based picture. The structure function $q_P(x, z)$ of parton in Pomeron contains the longitudinal momentum fraction z of the Pomeron as a parameter and $q_P(x, z)$ is obtained by scaling from the sea structure function

$q(x)$ for proton $q_P(x,z) = q(zx)$. The value of structure function at $x = 1$ is non-vanishing: $q_P(x = 1, z) = q(z)$ and this explains the necessity to introduce super hard delta function component in the fit of [C34].

2.3.2 Updated model

The recent developments in the understanding of hadron mass spectrum involve the realization that hadronic $k = 107$ space-time sheet is a carrier of super-symplectic bosons (and possibly their super-counterparts with quantum numbers of right handed neutrino) [K17]. The model leads to amazingly simple and accurate mass formulas for hadrons. Most of the baryonic momentum is carried by super-symplectic quanta: valence quarks correspond in proton to a relatively small fraction of total mass: about 170 MeV. The counterparts of string excitations correspond to super-symplectic many-particle states and the additivity of conformal weight proportional to mass squared implies stringy mass formula and generalization of Regge trajectory picture. Hadronic string tension is predicted correctly. Model also provides a solution to the proton spin puzzle.

In this framework valence quarks would naturally correspond to a color singlet state formed by space-time sheets connected by color flux tubes having no Regge trajectories and carrying a relatively small fraction of baryonic momentum. In the collisions discussed valence quarks would leave the hadronic space-time sheet and suffer a collision with photon. The lightness of Pomeronandelectro-weak neutrality of Pomeron support the view that photon stripes valence quarks from Pomeron, which continues its flight more or less unperturbed. Instead of an actual topological evaporation the bonds connecting valence quarks to the hadronic space-time sheet could be stretched during the collision with photon.

The large value of $\alpha_K = 1/4$ for super-symplectic matter suggests that the criterion for a phase transition increasing the value of Planck constant [K7] and leading to a phase, where $\alpha_K \propto 1/hbar$ is reduced, could occur. For α_K to remain invariant, $\hbar_0 \rightarrow 26\hbar_0$ would be required. In this case, the size of hadronic space-time sheet, "color field body of the hadron", would be $26 \times L(107) = 46$ fm, roughly the size of the heaviest nuclei. Hence a natural expectation is that the dark side of nuclei plays a role in the formation of atomic nuclei. Note that the sizes of electromagnetic field bodies of current quarks u and d with masses of order few MeV is not much smaller than the Compton length of electron. This would mean that super-symplectic bosons would represent dark matter in a well-defined sense and Pomeron exchange would represent temporary separation of ordinary and dark matter.

Note however that the fact that super-symplectic bosons have no electro-weak interactions, implies their dark matter character even for the ordinary value of Planck constant: this could be taken as an objection against dark matter hierarchy. My own interpretation is that super-symplectic matter is dark matter in the strongest sense of the world whereas ordinary matter in the large $\hbar$ phase is only apparently dark matter because standard interactions do not reveal themselves in the expected manner.

2.3.3 Astrophysical counterpart of Pomeron events

Pomeron events have direct analogy in astrophysical length scales. In the collision of two galaxies dark and visible matter parts of the colliding galaxies have been found to separate by Chandra X-ray Observatory [C53].

Imagine a collision between two galaxies. The ordinary matter in them collides and gets interlocked due to the mutual gravitational attraction. Dark matter, however, just keeps its momentum and keeps going on leaving behind the colliding galaxies. This kind of event has been detected by the Chandra X-Ray Observatory by using an ingenious manner to detect dark matter. Collisions of ordinary matter produces a lot of X-rays and the dark matter outside the galaxies acts as a gravitational lens.

2.4 The Incredibly Shrinking Proton

The discovery by Pohl *et al* (2010) [C39] was that the charge radius of proton deduced from detuerium - the muonic version of hydrogen atom - is .842 fm and about 4 per cent smaller than .875 fm than the charge radius deduced from hydrogen atom [C47, C48] is in complete conflict with the cherished belief that atomic physics belongs to the museum of science (for details see the Wikipedia article http://tinyurl.com/jkt2mkv). The title of the article *Quantum electrodynamics-a chink in the armour?* of the article published in Nature [C39] expresses well the possible implications, which might actually go well extend beyond QED.

Quite recently (2016) new more precise data has emerged from Pohl *et al* [C42] (see http://tinyurl.com/jd2hwuq). Now the reduction of charge radius of muonic variant of deuterium is measured. The charge radius is reduced from 2.1424 fm to 2.1256 fm and the reduction is .012 fm, which is about .8 per cent (see http://tinyurl.com/j4z3yp9). The charge radius of proton deduced from it is reported to be consistent with the charge radius deduced from deuterium. The anomaly seems therefore to be real. Deuterium data provide a further challenge for various models. The finding is a problem of QED or to the standard view about what proton is. Lamb shift [C4] is the effect distinguishing between the states hydrogen atom having otherwise the same energy but different angular momentum. The effect is due to the quantum fluctuations of the electromagnetic field. The energy shift factorizes to a product of two expressions. The first one describes the effect of these zero point fluctuations on the position of electron or muon and the second one characterizes the average of nuclear charge density as "seen" by electron or muon. The latter one should be same as in the case of ordinary hydrogen atom but it is not. Does this mean that the presence of muon reduces the charge radius of proton as determined from muon wave function? This of course looks implausible since the radius of proton is so small. Note that the compression of the muon's wave function has the same effect.

Before continuing it is good to recall that QED and quantum field theories in general have difficulties with the description of bound states: something which has not received too much attention. For instance, van der Waals force at molecular scales is a problem. A possible TGD based explanation and a possible solution of difficulties proposed for two decades ago is that for bound states the two charged particles (say nucleus and electron or two atoms) correspond to two 3-D surfaces glued by flux tubes rather than being idealized to points of Minkowski space. This would make the non-relativistic description based on Schrödinger amplitude natural and replace the description based on Bethe-Salpeter equation having horrible mathematical properties.

In the following two models of the anomaly will be discussed.

1. The basic idea of the original model is that muon has some probability to end up to the magnetic flux tubes assignable to proton. In this state it would not contribute to the ordinary Schrödinger amplitude. The effect of this would be reduction of $|\Psi|^2$ near origin and apparent reduction of the charge radius of proton. The weakness of the model is that it cannot make quantitative prediction for the size of the effect. Even the sign is questionable. Only S-wave binding energy is affected considerably but does the binding energy really increase by the interaction of muon with the quarks at magnetic flux tubes? Is the average of the charge density seen by muon in S wave state larger, in other words does it spend more time near proton or do the quarks spend more time at the flux tubes?

2. Second option is inspired by data about breaking of universality of weak interactions in neutral B decays possibly manifesting itself also in the anomaly in the magnetic moment of muon. Also the different values of the charge radius deduced from hydrogen atom and muonium could reflect the breaking of universality. In the original model the breaking of universality is only effective.

3. TGD indeed predicts a dynamical U(3) gauge symmetry whose 8+1 gauge bosons correspond to pairs of fermion and antifermion at opposite throats of wormhole contact. Throats are characterized by genus $g = 0, 1, 2$, so that bosons are superpositions of states labelled by (g_1, g_2). Fermions correspond to single wormhole throat carrying fermion number and behave as U(3) triplet labelled by g.

   The charged gauge bosons with different genera for wormhole throats are expected to be very massive. The 3 neutral gauge bosons with same genus at both throats are superpositions of states (g, g) are expected to be lighter. Their charge matrices are orthogonal and necessarily break the universality of electroweak interactions. For the lowest boson family - ordinary gauge bosons - the charge matrix is proportional to unit matrix. The exchange of second generation bosons Z_1^0 and γ_1 would give rise to Yukawa potential increasing the binding energies of S-wave states. Therefore Lamb shift defined as difference between energies of S and P waves is increased and the charge radius deduced from Lamb shift becomes smaller.

4. The model thus predicts a correct sign for the effect but the size of the effect from naïve estimate assuming only γ_1 contribution and $\alpha_1 = \alpha$ ad $M = 2.9$ TeV is almost by an order of magnitude too small. The values of the gauge couplings α_1 and $\alpha_1 Z, 1$ are free parameters as also the mixing angles between states (g, g). The effect is also proportional to the ratio $(m_\mu/M(boson)^2$. It turns out that the inclusion of Z^0_1 contribution and assumption α_1 and $\alpha_1 Z, 1$ are near color coupling strength α_s gives a correct prediction.

2.4.1 Basic facts and notions

In this section the basic TGD inspired ideas and notions - in particular the notion of field body - are introduced and the general mechanism possibly explaining the reduction of the effective charge radius relying on the leakage of muon wave function to the flux tubes associated with u quarks is introduced. After this the value of leakage probability is estimated from the standard formula for the Lamb shift in the experimental situation considered.

1. Basic notions of TGD which might be relevant for the problem

Can one say anything interesting about the possible mechanism behind the anomaly if one accepts TGD framework? How the presence of muon could reduce the charge radius of proton? Let us first list the basic facts and notions.

1. One can say that the size of muonic hydrogen characterized by Bohr radius is by factor $m_e/m_\mu = 1/211.4 = 4.7 \times 10^{-4}$ smaller than for hydrogen atom and equals to 250 fm. Hydrogen atom Bohr radius is .53 Angstroms.

2. Proton contains 2 quarks with charge 2e/3 and one d quark which charge -e/3. These quarks are light. The last determination of u and d quark masses [C37] (see `http://tinyurl.com/zqbj7x4`) gives masses, which are $m_u = 2$ MeV and $m_d = 5$ MeV (I leave out the error bars). The standard view is that the contribution of quarks to proton mass is of same order of magnitude. This would mean that quarks are not too relativistic meaning that one can assign to them a size of order Compton wave length of order $4 \times r_e \simeq 600$ fm in the case of u quark (roughly twice the Bohr radius of muonic hydrogen) and $10 \times r_e \simeq 24$ fm in the case of d quark. These wavelengths are much longer than the proton charge radius and for u quark more than twice longer than the Bohr radius of the muonic hydrogen. That parts of proton would be hundreds of times larger than proton itself sounds a rather weird idea. One could of course argue that the scales in question do not correspond to anything geometric. In TGD framework this is not the way out since quantum classical correspondence requires this geometric correlate.

3. There is also the notion of classical radius of electron and quark. It is given by $r = \alpha\hbar/m$ and is in the case of electron this radius is 2.8 fm whereas proton charge radius is .877 fm and smaller. The dependence on Planck constant is only apparent as it should be since classical radius is in question. For u quark the classical radius is .52 fm and smaller than proton charge radius. The constraint that the classical radii of quarks are smaller than proton charge radius gives a lower bound of quark masses: p-adic scaling of u quark mass by $2^{-1/2}$ would give classical radius .73 fm which still satisfies the bound. TGD framework the proper generalization would be $r = \alpha_K\hbar/m$, where α_K is Kähler coupling strength defining the fundamental coupling constant of the theory and quantized from quantum criticality. Its value is very near or equal to fine structure constant in electron length scale.

4. The intuitive picture is that light-like 3-surfaces assignable to quarks describe random motion of partonic 2-surfaces with light-velocity. This is analogous to zitterbewegung assigned classically to the ordinary Dirac equation. The notion of braid emerges from the localization of the modes of the induced spinor field to 2-D surfaces - string world sheets and possibly also partonic 2-surfaces carrying vanishing W fields and Z^0 field at least above weak scale. It is implied by well-definedness of em charge for the modes of Kähler-Dirac action. The orbits of partonic 2-surface effectively reduces to braids carrying fermionic quantum numbers. These

braids in turn define higher level braids which would move inside a structure characterizing the particle geometrically. Internal consistency suggests that the classical radius $r = \alpha_K \hbar/m$ characterizes the size scale of the zitterbewegung orbits of quarks.

I cannot resist the temptation to emphasize the fact that Bohr orbitology is now reasonably well understood. The solutions of field equations with higher than 3-D CP_2 projection describing radiation fields allow only generalizations of plane waves but not their superpositions in accordance with the fact it is these modes that are observed. For massless extremals with 2-D CP_2 projection superposition is possible only for parallel light-like wave vectors. Furthermore, the restriction of the solutions of the Chern-Simons Dirac equation at light-like 3-surfaces to braid strands gives the analogs of Bohr orbits. Wave functions of -say electron in atom- are wave functions for the position of wormhole throat and thus for braid strands so that Bohr's theory becomes part of quantum theory.

5. In TGD framework quantum classical correspondence requires -or at least strongly suggests- that also the p-adic length scales assignable to u and d quarks have geometrical correlates. That quarks would have sizes much larger than proton itself how sounds rather paradoxical and could be used as an objection against p-adic length scale hypothesis. Topological field quantization however leads to the notion of field body as a structure consisting of flux tube-sandthe identification of this geometric correlate would be in terms of Kähler (or color-, or electro-) magnetic body of proton consisting of color flux tubes beginning from space-time sheets of valence quarks and having length scale of order Compton wavelength much longer than the size of proton itself. Magnetic loops and electric flux tubes would be in question. Also secondary p-adic length scale characterizes field body. For instance, in the case of electron the causal diamond assigned to electron would correspond to the time scale of .1 seconds defining an important bio-rhythm.

2. Could the notion of field body explain the anomaly?

The large Compton radii of quarks and the notion of field body encourage the attempt to imagine a mechanism affecting the charge radius of proton as determined from electron's or muon's wave function.

1. Muon's wave function is compressed to a volume, which is about 8 million times smaller than the corresponding volume in the case of electron. The Compton radius of u quark more that twice larger than the Bohr radius of muonic hydrogen so that muon should interact directly with the field body of u quark. The field body of d quark would have size 24 fm which is about ten times smaller than the Bohr radius so that one can say that the volume in which muons sees the field body of d quark is only one thousandth of the total volume. The main effect would be therefore due to the two u quarks having total charge of 4e/3.

   One can say that muon begins to "see" the field bodies of u quarks and interacts directly with u quarks rather than with proton via its electromagnetic field body. With d quarks it would still interact via protons field body to which d quark should feed its electromagnetic flux. This could be quite enough to explain why the charge radius of proton determined from the expectation value defined by its wave function is smaller for muonium than for hydrogen. One must of course notice that this brings in also direct magnetic interactions with u quarks.

2. What could be the basic mechanism for the reduction of charge radius? Could it be that the muon is caught with some probability into the flux tubes of u quarks and that Schrödinger amplitude for this kind state vanishes near the origin? If so, this portion of state would not contribute to the charge radius and the since the portion ordinary state would smaller, this would imply an effective reduction of the charge radius determined from experimental data using the standard theory since the reduction of the norm of the standard part of the state would be erratically interpreted as a reduction of the charge radius.

3. This effect would be of course present also in the case of electron but in this case the u quarks correspond to a volume which million times smaller than the volume defined by Bohr radius so that electron does not in practice "see" the quark sub-structure of proton. The probability

P for getting caught would be in a good approximation proportional to the value of $|\Psi(r_u)|^2$ and in the first approximation one would have

$$\frac{P_e}{P_\mu} \sim (a_\mu/a_e)^3 = (m_e/m_\mu)^3 \sim 10^{-7} \ .$$

from the proportionality $\Psi_i \propto 1/a_i^{3/2}$, i=e,$\mu$.

3. A general formula for Lamb shift in terms of proton charge radius

The charge radius of proton is determined from the Lamb shift between 2S- and 2P states of muonic hydrogen. Without this effect resulting from vacuum polarization of photon Dirac equation for hydrogen would predict identical energies for these states. The calculation reduces to the calculation of vacuum polarization of photon inducing to the Coulomb potential and an additional vacuum polarization term. Besides this effect one must also take into account the finite size of the proton which can be coded in terms of the form factor deducible from scattering data. It is just this correction which makes it possible to determine the charge radius of proton from the Lamb shift.

1. In the article [C10] the basic theoretical results related to the Lamb shift in terms of the vacuum polarization of photon are discussed. Proton's charge density is in this representation is expressed in terms of proton form factor in principle deducible from the scattering data. Two special cases can be distinguished corresponding to the point like proton for which Lamb shift is non-vanishing only for S wave states and non-point like proton for which energy shift is present also for other states. The theoretical expression for the Lamb shift involves very refined calculations. Between 2P and 2S states the expression for the Lamb shift is of form

$$\Delta E(2P^{F=2}_{3/2}2S^{F=1}_{1/2} = a - br_p^2 + cr_p^3 = 209.968(5)5.2248 \times r_p^2 + 0.0347 \times r_p^3 \ \ meV \ . \tag{2.8}$$

where the charge radius $r_p = .8750$ is expressed in femtometers and energy in meVs.

2. The general expression of Lamb shift is given in terms of the form factor by

$$\begin{aligned} E(2P-2S) &= \int \frac{d^3q}{2\pi)^3} \times (-4\pi\alpha)\frac{F(q^2)}{q^2}\frac{\Pi(q^2)}{q^2} \times X \ , \\ X &= \int (|\Psi_{2P}(r)|^2 - |\Psi_{2S}(r)|^2) exp(iq\cdot r)dV \ . \end{aligned} \tag{2.9}$$

Here Π is is a scalar representing vacuum polarization due to decay of photon to virtual pairs.

The model to be discussed predicts that the effect is due to a leakage from "standard" state to what I call flux tube state. This means a multiplication of $|\Psi_{2P}|^2$ with the normalization factor $1/N$ of the standard state orthogonalized with respect to flux tube state. It is essential that $1/N$ is larger than unity so that the effect is a genuine quantum effect not understandable in terms of classical probability.

The modification of the formula is due to the normalization of the 2P and 2S states. These are in general different. The normalization factor $1/N$ is same for all terms in the expression of Lamb shift for a given state but in general different for 2S and 2P states. Since the lowest order term dominates by a factor of $\sim$ 40 over the second one, one one can conclude that the modification should affect the lowest order term by about 4 per cent. Since the second term is negative and the modification of the first term is interpreted as a modification of the second term when r_p is estimated from the standard formula, the first term must increase by about 4 per cent. This is achieved if this state is orthogonalized with respect to the flux tube state. For states Ψ_0 and Ψ_{tube} with unit norm this means the modification

$$\begin{aligned} \Psi_0 &\rightarrow \frac{1}{1-|C|^2} \times (\Psi_i - C\Psi_{tube}) \ , \\ C &= \langle \Psi_{tube}|\Psi_0\rangle \ . \end{aligned} \quad (2.10)$$

In the lowest order approximation one obtains

$$a - br_p^2 + cr_p^3 \quad \rightarrow \quad (1+|C|^2)a - br_p^2 + cr_p^3 \ . \quad (2.11)$$

Using instead of this expression the standard formula gives a wrong estimate r_p from the condition

$$a - b\hat{r}_p^2 + c\hat{r}_p^3 \rightarrow (1+|C|^2)a - br_p^2 + cr_p^3 \ . \quad (2.12)$$

This gives the equivalent conditions

$$\begin{aligned} \hat{r}_p^2 &= r_p^2 - \frac{|C|^2 a}{b} \ , \\ P_{tube} &\equiv |C|^2 \simeq 2\frac{b}{a} \times r_p^2 \times \frac{(r_p - \hat{r}_p)}{r_p}) \ . \end{aligned} \quad (2.13)$$

The resulting estimate for the leakage probability is $P_{tube} \simeq .0015$. The model should be able to reproduce this probability.

2.4.2 A model for the coupling between standard states and flux tube states

Just for fun one can look whether the idea about confinement of muon to quark flux tube carrying electric flux could make sense.

1. Assume that the quark is accompanied by a flux tube carrying electric flux $\int EdS = -\int \nabla\Phi \cdot dS = q$, where $q = 2e/3 = ke$ is the u quark charge. The potential created by the u quark at the proton end of the flux tube with transversal area $S = \pi R^2$ idealized as effectively 1-D structure is

$$\Phi = -\frac{ke}{\pi R^2}|x| + \Phi_0 \ . \quad (2.14)$$

   The normalization factor comes from the condition that the total electric flux is q. The value of the additive constant V_0 is fixed by the condition that the potential coincides with Coulomb potential at $r = r_u$, where r_u is u quark Compton length. This gives

$$e\Phi_0 = \frac{e^2}{r_u} + Kr_u \ , \quad K = \frac{ke^2}{\pi R^2} \ . \quad (2.15)$$

2. Parameter R should be of order of magnitude of charge radius $\alpha_K r_u$ of u quark is free parameter in some limits. $\alpha_K = \alpha$ is expected to hold true in excellent approximation. Therefore a convenient parameterization is

$$R = z\alpha r_u \ . \quad (2.16)$$

   This gives

$$K = \frac{4k}{\alpha r_u^2} \ , \quad e\Phi_0 = 4(\pi\alpha + \frac{k}{\alpha})\frac{1}{r_u} \ . \quad (2.17)$$

3. The requirement that electron with four times larger charge radius that u quark can topologically condensed inside the flux tube without a change in the average radius of the flux tube (and thus in a reduction in p-adic length scale increasing its mass by a factor 4!) suggests that $z \geq 4$ holds true at least far away from proton. Near proton the condition that the radius of the flux tube is smaller than electron's charge radius is satisfied for $z = 1$.

1. Reduction of Schrödinger equation at flux tube to Airy equation

The 1-D Schrödinger equation at flux tube has as its solutions Airy functions and the related functions known as "Bairy" functions.

1. What one has is a one-dimensional Schrödinger equation of general form

$$-\frac{\hbar^2}{2m_\mu}\frac{d^2\Psi}{dx^2} + (Kx - e\Phi_0)\Psi = E\Psi \ , \ K = \frac{ke^2}{\pi R^2} \ . \quad (2.18)$$

By performing a linear coordinate change

$$u = (\frac{2m_\mu K}{\hbar^2})^{1/3}(x - x_E) \ , \ x_E = \frac{-|E| + e\Phi_0}{K} \ , \quad (2.19)$$

one obtains

$$\frac{d^2\Psi}{du^2} - u\Psi = 0 \ . \quad (2.20)$$

This differential equation is known as Airy equation (or Stokes equation) and defines special functions $Ai(x)$ known as Airy functions and related functions $Bi(x)$ referred to as "Bairy" functions [B1] . Airy functions characterize the intensity near an optical directional caustic such as that of rainbow.

2. The explicit expressions for $A_i(u)$ and $Bi(u)$ are is given by

$$\begin{aligned} Ai(u) &= \frac{1}{\pi}\int_0^\infty cos(\frac{1}{3}t^3 + ut)dt \ , \\ Bi(u) &= \frac{1}{\pi}\int_0^\infty \left[exp(-\frac{1}{3}t^3) + sin(\frac{1}{3}t^3 + ut)dt\right] \ . \end{aligned} \quad (2.21)$$

$Ai(u)$ oscillates rapidly for negative values of u having interpretation in terms of real wave vector and goes exponentially to zero for $u > 0$. $Bi(u)$ oscillates also for negative values of x but increases exponentially for positive values of u. The oscillatory behavior and its character become obvious by noticing that stationary phase approximation is possible for $x < 0$.

The approximate expressions of $Ai(u)$ and $Bi(u)$ for $u > 0$ are given by

$$\begin{aligned} Ai(u) &\sim \frac{1}{2\pi^{1/2}}exp(-\frac{2}{3}u^{3/2})u^{-1/4} \ , \\ Bi(u) &\sim \frac{1}{\pi^{1/2}}exp(\frac{2}{3}u^{3/2})u^{-1/4} \ . \end{aligned} \quad (2.22)$$

For $u < 0$ one has

$$\begin{aligned} Ai(u) &\sim \frac{1}{\pi^{1/2}}sin(\frac{2}{3}(-u)^{3/2})(-u)^{-1/4} \ , \\ Bi(u) &\sim \frac{1}{\pi^{1/2}}cos(\frac{2}{3}(-u)^{3/2})(-u)^{-1/4} \ . \end{aligned} \quad (2.23)$$

3. $u = 0$ corresponds to the turning point of the classical motion where the kinetic energy changes sign. $x = 0$ and $x = r_u$ correspond to the points

$$
\begin{aligned}
u_{min} \equiv u(0) &= -(\frac{2m_\mu K}{\hbar^2})^{1/3} x_E \ , \\
u_{max} \equiv u(r_u) &= (\frac{2m_\mu K}{\hbar^2})^{1/3} (r_u - x_E) \ , \\
x_E &= \frac{-|E| + e\Phi_0}{K} \ .
\end{aligned} \quad (2.24)
$$

4. The general solution is

$$
\Psi = aAi(u) + bBi(u) \ . \quad (2.25)
$$

The natural boundary condition is the vanishing of Ψ at the lower end of the flux tube giving

$$
\frac{b}{a} = -\frac{Ai(u(0))}{Bi(u(0))} \ . \quad (2.26)
$$

A non-vanishing value of b implies that the solution increases exponentially for positive values of the argument and the solution can be regarded as being concentrated in an excellent approximation near the upper end of the flux tube.

Second boundary condition is perhaps most naturally the condition that the energy is same for the flux tube amplitude as for the standard solution. Alternative boundary conditions would require the vanishing of the solution at both ends of the flux tube and in this case one obtains very large number of solutions as WKB approximation demonstrates. The normalization of the state so that it has a unit norm fixes the magnitude of the coefficients a and b since one can choose them to be real.

2. Estimate for the probability that muon is caught to the flux tube

The simplest estimate for the muon to be caught to the flux tube state characterized by the same energy as standard state is the overlap integral of the ordinary hydrogen wave function of muon and of the effectively one-dimensional flux tube. What one means with overlap integral is however not quite obvious.

1. The basic condition is that the modified “standard” state is orthogonal to the flux tube state. One can write the expression of a general state as

$$
\begin{aligned}
\Psi_{nlm} &\rightarrow N \times (\Psi_{nlm} - C(E, nlm)\Phi_{nlm}) \ , \\
\Phi_{nlm} &= Y_{lm}\Psi_E \ , \\
C(E, nlm) &= \langle \Psi_E | \Psi_{nlm} \rangle \ .
\end{aligned} \quad (2.27)
$$

Here Φ_{nlm} depends a flux tube state in which spherical harmonics is wave function in the space of orientations of the flux tube and Ψ_E is flux tube state with same energy as standard state. Here an inner product between standard states and flux tube states is introduced.

2. Assuming same energy for flux tube state and standard state, the expression for the total total probability for ending up to single flux tube would be determined from the orthogonality condition as

$$
P_{nlm} = \frac{|C(E, nlm)|^2}{1 - |C(E, lmn)|^2} \ . \quad (2.28)
$$

Here E refers to the common energy of flux tube state and standard state. The fact that flux tube states vanish at the lower end of the flux tube implies that they do not contribute to the expression for average charge density. The reduced contribution of the standard part implies that the attempt to interpret the experimental results in "standard model" gives a reduced value of the charge radius. The size of the contribution is given by P_{nlm} whose value should be about 4 per cent.

One can consider two alternative forms for the inner product between standard states and flux tube states. Intuitively it is clear that an overlap between the two wave functions must be in question.

1. The simplest possibility is that one takes only overlap at the upper end of the flux tube which defines 2-D surface. Second possibility is that the overlap is over entire flux tube projection at the space-time sheet of atom.

$$\begin{aligned} \langle \Psi_E | \Psi_{nlm} \rangle &= \int_{end} \overline{\Psi}_r \Psi_{nlm} dS \text{ (Option I)} \quad , \\ \langle \Psi_E | \Psi_{nlm} \rangle &= \int_{tube} \overline{\Psi}_r \Psi_{nlm} dV \text{ (Option II)} \quad . \end{aligned} \tag{2.29}$$

2. For option I the inner product is non-vanishing only if Ψ_E is non-vanishing at the end of the flux tube. This would mean that electron ends up to the flux tube through its end. The inner product is dimensionless without introduction of a dimensional coupling parameter if the inner product for flux tube states is defined by 1-dimensional integral: one might criticize this assumption as illogical. Unitarity might be a problem since the local behaviour of the flux tube wave function at the end of the flux tube could imply that the contribution of the flux tube state in the quantum state dominates and this does not look plausible. One can of course consider the introduction to the inner product a coefficient representing coupling constant but this would mean loss of predictivity. Schrödinger equation at the end of the flux tubes guarantees the conservation of the probability current only if the energy of flux tube state is same as that of standard state or if the flux tube Schrödinger amplitude vanishes at the end of the flux tube.

3. For option II there are no problems with unitary since the overlap probability is always smaller than unity. Option II however involves overlap between standard states and flux tube states even when the wave function at the upper end of the flux tube vanishes. One can however consider the possibility that the possible flux tube states are orthogonalized with respect to standard states with leakage to flux tubes. The interpretation for the overlap integral would be that electron ends up to the flux tube via the formation of wormhole contact.

3. Option I fails

The considerations will be first restricted to the simpler option I. The generalization of the results of calculation to option II is rather straighforward. It turns out that option II gives correct order of magnitude for the reduction of charge radius for reasonable parameter values.

1. In a good approximation one can express the overlap integrals over the flux tube end (option I) as

$$\begin{aligned} C(E, nlm) &= \int_{tube} \overline{\Psi}_E \Psi_{nlm} dS \simeq \pi R^2 \times Y_{lm} \times C(E, nl) \quad , \\ C(E, nl) &= \overline{\Psi}_E(r_u) R_{nl}(r_u) \quad . \end{aligned} \tag{2.30}$$

An explicit expression for the coefficients can be deduced by using expression for Ψ_E as a superposition of Airy and Bairy functions. This gives

$$\begin{aligned}
C(E,nl) &= \overline{\Psi}_E(r_u)R_{nl}(r_u) \ , \\
\Psi_E(x) &= a_E Ai(u_E) + bBi(u_E) \ , \ \frac{a_E}{b_E} = -\frac{Bi(u_E(0))}{Ai(u_E(0))} \ , \\
u_E(x) &= (\frac{2m_\mu K}{\hbar^2})^{1/3}(x - x_E) \ , \ x_E = \frac{|E| - e\Phi_0}{K} \ , \\
K &= \frac{ke^2}{\pi R^2} \ , \ R = z\alpha_K r_u \ , \ k = \frac{2}{3} \ .
\end{aligned} \tag{2.31}$$

The normalization of the coefficients is fixed from the condition that a and b chosen in such a way that Ψ has unit norm. For these boundary conditions Bi is expected to dominate completely in the sum and the solution can be regarded as exponentially decreasing function concentrated around the upper end of the flux tube.

In order to get a quantitative view about the situation one can express the parameters u_{min} and u_{max} in terms of the basic dimensionless parameters of the problem.

1. One obtains

$$\begin{aligned}
u_{min} \equiv u(0) &= -2(\frac{k}{z\alpha})^{1/3}\left[1 + \pi\frac{z}{k}\alpha^2(1 - \frac{1}{2}\alpha r)\right] \times r^{1/3} \ , \\
u_{max} \equiv u(r_u) &= u(0) + 2\frac{k}{z\alpha} \times r^{1/3} \ , \\
r &= \frac{m_\mu}{m_u} \ , \ R = z\alpha r_u \ .
\end{aligned} \tag{2.32}$$

Using the numerical values of the parameters one obtains for $z = 1$ and $\alpha = 1/137$ the values $u_{min} = -33.807$ and $u_{max} = 651.69$. The value of u_{max} is so large that the normalization is in practice fixed by the exponential behavior of Bi for the suggested boundary conditions.

2. The normalization constant is in good approximation defined by the integral of the approximate form of Bi^2 over positive values of u and one has

$$N^2 \simeq \frac{dx}{du} \times \int_{u_{min}}^{u_{max}} Bi(u)^2 du \ , \ \frac{dx}{du} = \frac{1}{2}(\frac{z^2\alpha}{k})^{1/3} \times r^{1/3} r_u \ , \tag{2.33}$$

By taking $t = exp(\frac{4}{3}u^{3/2})$ as integration variable one obtains

$$\begin{aligned}
\int_{u_{min}}^{u_{max}} Bi(u)^2 du &\simeq \pi^{-1}\int_{u_{min}}^{u_{max}} exp(\frac{4}{3}u^{3/2})u^{-1/2}du \\
&= (\frac{4}{3})^{2/3}\pi^{-1}\int_{t_{min}}^{t_{max}} \frac{dt}{log(t)^{2/3}} \simeq \frac{1}{\pi}\frac{exp(\frac{4}{3}u_{max}^{3/2})}{u_{max}} \ .
\end{aligned} \tag{2.34}$$

This gives for the normalization factor the expression

$$N \simeq \frac{1}{2}(\frac{z^2\alpha}{k})^{2/3} r^{1/3} r_u^{1/2} exp(\frac{2}{3}u_{max}^{3/2}) \ . \tag{2.35}$$

3. One obtains for the value of Ψ_E at the end of the flux tube the estimate

$$\Psi_E(r_u) = \frac{Bi(u_{max})}{N} \simeq 2\pi^{-1/2} \times (\frac{k}{z^2\alpha})^{2/3} r^{1/3} r_u^{-1/2} \ , \ r = \frac{r_u}{r_\mu} \ . \quad (2.36)$$

4. The inner product defined as overlap integral gives for the ground state

$$\begin{aligned} C_{E,00} &= \Psi_E(r_u) \times \Psi_{1,0,0}(r_u) \times \pi R^2 \\ &= 2\pi^{-1/2}(\frac{k}{z^2\alpha})^{2/3} r^{1/3} r_u^{-1/2} \times (\frac{1}{\pi a(\mu)^3})^{1/2} \times exp(-\alpha r) \times \pi z^2 \alpha^2 r_u^2 \\ &= 2\pi^{1/2} k^{2/3} z^{2/3} r^{11/6} \alpha^{17/6} exp(-\alpha r) \ . \end{aligned} \quad (2.37)$$

The relative reduction of charge radius equals to $P = C^2_{E,00}$. For $z = 1$ one obtains $P = C^2_{E,00} = 5.5 \times 10^{-6}$, which is by three orders of magnitude smaller than the value needed for $P_{tube} = C^2_{E,20} = .0015$. The obvious explanation for the smallness is the α^2 factor coming from the area of flux tube in the inner product.

4. Option II could work

The failure of the simplest model is essentially due to the inner product. For option II the inner product for the flux tube states involves the integral over the area of flux tube so that the normalization factor for the state is obtained from the previous one by the replacement $N \rightarrow N/\sqrt{\pi R^2}$. In the integral over the flux tube the exponent function is is in the first approximation equal to constant since the wave function for ground state is at the end of the flux tube only by a factor .678 smaller than at the origin and the wave function is strongly concentrated near the end of the flux tube. The inner product defined by the overlap integral over the flux tube implies $N \rightarrow NS^{1/2}$, $S = \pi R^2 = z^2\alpha^2 r_u^2$. In good approximation the inner product for option II means the replacement

$$\begin{aligned} C_{E,n0} &\rightarrow A \times B \times C_{E,n0} \ , \\ A &= \frac{\frac{dx}{du}}{\sqrt{\pi R^2}} = \frac{1}{2\sqrt{\pi}} z^{-1/3} k^{-1/3} \alpha^{-2/3} r^{1/3} \ , \\ B &= \frac{\int Bi(u)du}{\sqrt{Bi(u_{max})}} = u_{max}^{-1/4} = 2^{-1/4} z^{1/2} k^{-1/4} \alpha^{1/4} r^{-1/12} \ . \end{aligned} \quad (2.38)$$

Using the expression

$$R_{20}(r_u) = \frac{1}{2\sqrt{2}} \times (\frac{1}{a_\mu})^{3/2} \times (2 - r\alpha) \times exp(-r\alpha) \ , \ r = \frac{r_u}{r_\mu} \quad (2.39)$$

one obtains for $C_{E,20}$ the expression

$$C_{E,20} = 2^{-3/4} z^{5/6} k^{1/12} \alpha^{29/12} r^{25/12} \times (2 - r\alpha) \times exp(-r\alpha) \ . \quad (2.40)$$

By the earlier general argument one should have $P_{tube} = |C_{E,20}|^2 \simeq .0015$. $P_{tube} = .0015$ is obtained for $z = 1$ and $N = 2$ corresponding to single flux tube per u quark. If the flux tubes are in opposite directions, the leakage into 2P state vanishes. Note that this leakage does not affect the value of the coefficient a in the general formula for the Lamb shift. The radius of the flux tube is by a factor 1/4 smaller than the classical radius of electron and one could argue that this makes it impossible for electron to topologically condense at the flux tube. For $z = 4$ one would have $P_{tube} = .015$ which is 10 times too large a value. Note that the nucleus possess a wave function for the orientation of the flux tube. If this corresponds to S-wave state then only the leakage beween S-wave states and standard states is possible.

2.4.3 Are exotic flux tube bound states possible?

There seems to be no deep reason forbidding the possibility of genuine flux tube states decoupling from the standard states completely. To get some idea about the energy eigenvalues one can apply WKB approximation. This approach should work now: in fact, the study on WKB approximation near turning point by using linearization of the potential leads always to Airy equation so that the linear potential represents an ideal situation for WKB approximation. As noticed these states do not seem to be directly relevant for the recent situation. The fact that these states have larger binding energies than the ordinary states of hydrogen atom might make possible to liberate energy by inducing transitions to these states.

1. Assume that a bound state with a negative energy E is formed inside the flux tube. This means that the condition $p^2 = 2m(E-V) \geq 0$, $V = -e\Phi$, holds true in the region $x \leq x_{max} < r_u$ and $p^2 = 2m(E-V) < 0$ in the region $r_u > x \geq x_{max}$. The expression for x_{max} is

$$x_{max} = \frac{\pi R^2}{k}(-\frac{|E|}{e^2} + \frac{1}{r_u} + \frac{kr_u}{\pi R^2})\hbar \ . \qquad (2.41)$$

   $x_{max} < r_u$ holds true if one has

$$|E| < \frac{e^2}{r_u} = E_{max} \ . \qquad (2.42)$$

   The ratio of this energy to the ground state energy of muonic hydrogen is from $E(1) = e^2/2a(\mu)$ and $a = \hbar/\alpha m$ given by

$$\frac{E_{max}}{E(n=1)} = \frac{2m_u}{\alpha m_\mu} \simeq 5.185 \ . \qquad (2.43)$$

   This encourages to think that the ground state energy could be reduced by the formation of this kind of bound state if it is possible to find a value of n in the allowed range. The physical state would of course contain only a small fraction of this state. In the case of electron the increase of the binding energy is even more dramatic since one has

$$\frac{E_{max}}{E(n=1)} = \frac{2m_u}{\alpha m_e} = \frac{8}{\alpha} \simeq 1096 \ . \qquad (2.44)$$

   Obviously the formation of this kind of states could provide a new source of energy. There have been claims about anomalous energy production in hydrogen [D3] . I have discussed these claims from TGD viewpoint in [K25]

2. One can apply WKB quantization in the region where the momentum is real to get the condition

$$I = \int_0^{x_{max}} \sqrt{2m(E+e\Phi)}\frac{dx}{\hbar} = n + \frac{1}{2} \ . \qquad (2.45)$$

   By performing the integral one obtains the quantization condition

$$\begin{aligned} I &= k^{-1}(8\pi\alpha)^{1/2} \times \frac{R^2}{r_u^{3/2} r_\mu} \times A^{3/2} = n + \frac{1}{2} \ , \\ A &= 1 + kx^2 - \frac{|E|r_u}{e^2} \ , \\ x &= \frac{r_u}{R} \ , \ k = \frac{2}{3\pi} \ , \ r_i = \frac{\hbar}{m_i} \ . \end{aligned} \qquad (2.46)$$

3. Parameter R should be of order of magnitude of charge radius $\alpha_K r_u$ of u quark is free parameter in some limits. $\alpha_K = \alpha$ is expected to hold true in excellent approximation. Therefore a convenient parameterization is

$$R = z\alpha r_u \ . \tag{2.47}$$

This gives for the binding energy the general expression in terms of the ground state binging energy $E(1,\mu)$ of muonic hydrogen as

$$\begin{aligned} |E| &= C \times E(1,\mu) \ , \\ C &= D \times (1 + Kz^{-2}\alpha^{-2} - (\frac{y}{z^2})^{2/3} \times (n+1/2)^{2/3}) \ , \\ D &= 2y \times (\frac{K^2}{8\pi\alpha})^{1/3} \ , \\ y &= \frac{m_u}{m_\mu} \ , \ K = \frac{2}{3\pi} \ . \end{aligned} \tag{2.48}$$

4. There is a finite number of bound states. The above mentioned consistency conditions coming from $0 < x_{max} < r_\mu$ give $0 < C < C_{max} = 5.185$ restricting the allowed value of n to some interval. One obtains the estimates

$$\begin{aligned} n_{min} &\simeq \frac{z^2}{y}(1 + Kz^{-2}\alpha^{-2} - \frac{C_{max}}{D})^{3/2} - \frac{1}{2} \ , \\ n_{max} &= \frac{z^2}{y}(1 + Kz^{-2}\alpha^{-2})^{3/2} - \frac{1}{2} \ . \end{aligned} \tag{2.49}$$

Very large value of n is required by the consistency condition. The calculation gives $n_{min} \in \{1.22 \times 10^7, 4.59 \times 10^6, 1.48 \times 10^5\}$ and $n_{max} \in \{1.33 \times 10^7, 6.66 \times 10^6, 3.34 \times 10^6\}$ for $z \in \{1,2,4\}$. This would be a very large number of allowed bound states -about 3.2×10^6 for $z = 1$.

The WKB state behaves as a plane wave below x_{max} and sum of exponentially decaying and increasing amplitudes above x_{max}:

$$\begin{aligned} &\frac{1}{\sqrt{k(x)}}\left[Aexp(i\int_0^x k(y)dy) + Bexp(-i\int_0^x k(y)dy)\right] \ , \\ &\frac{1}{\sqrt{\kappa(x)}}\left[Cexp(-\int_{x_{max}}^x \kappa(y)dy + Dexp(\int_{x_{max}}^x \kappa(y)dy\right] \ , \\ &k(x) = \sqrt{2m(-|E| + e\Phi)} \ , \ \kappa(x)\sqrt{2m(|E| - e\Phi)} \ . \end{aligned} \tag{2.50}$$

At the classical turning point these two amplitudes must be identical.

The next task is to decide about natural boundary conditions. Two types of boundary conditions must be considered. The basic condition is that genuine flux tube states are in question. This requires that the inner product between flux tube states and standard states defined by the integral over flux tube ends vanishes. This is guaranteed if the Schrödinger amplitude for the flux tube state vanishes at the ends of the flux tube so that flux tube behaves like an infinite potential well. The condition $\Psi(0) = 0$ at the lower end of the flux tube would give $A = -B$. Combined with the continuity condition at the turning point these conditions imply that Ψ can be assumed to be real. The $\Psi(r_u) = 0$ gives a condition leading to the quantization of energy.

The wave function over the directions of flux tube with a given value of n is given by the spherical harmonics assigned to the state (n,l,m).

2.4.4 Could second generation of weak bosons explain the reduction of proton charge radius?

The above proposed speculative model is not the only one that one can imagine. The observation could be explained also as breaking of the universality of weak interactions. Also other anomalies challenging the universality exists. The decays of neutral B-meson to lepton pairs should be same apart from corrections coming from different lepton masses by universality but this does not seem to be the case [K12]. There is also anomaly in muon's magnetic moment discussed briefly in [K21]. This leads to ask whether the breaking of universality could be due to the failure of universality of electroweak interactions.

The proposal for the explanation of the muon's anomalous magnetic moment and anomaly in the decays of B-meson is inspired by a recent very special di-electron event and involves higher generations of weak bosons predicted by TGD leading to a breaking of lepton universality. Both Tommaso Dorigo (`http://tinyurl.com/pfw7qqm`) and Lubos Motl (`http://tinyurl.com/hqzat92`) tell about a spectacular 2.9 TeV di-electron event not observed in previous LHC runs. Single event of this kind is of course most probably just a fluctuation but human mind is such that it tries to see something deeper in it - even if practically all trials of this kind are chasing of mirages.

Since the decay is leptonic, the typical question is whether the dreamed for state could be an exotic Z boson. This is also the reaction in TGD framework. The first question to ask is whether weak bosons assignable to Mersenne prime M_{89} have scaled up copies assignable to Gaussian Mersenne M_{79}. The scaling factor for mass would be $2^{(89-79)/2} = 32$. When applied to Z mass equal to about .09 TeV one obtains 2.88 TeV, not far from 2.9 TeV. Eureka!? Looks like a direct scaled up version of Z!? W should have similar variant around 2.6 TeV.

TGD indeed predicts exotic weak bosons and also gluons.

1. TGD based explanation of family replication phenomenon in terms of genus-generation correspondence forces to ask whether gauge bosons identifiable as pairs of fermion and antifermion at opposite throats of wormhole contact could have bosonic counterpart for family replication. Dynamical SU(3) assignable to three lowest fermion generations labelled by the genus of partonic 2-surface (wormhole throat) means that fermions are combinatorially SU(3) triplets. Could 2.9 TeV state - if it would exist - correspond to this kind of state in the tensor product of triplet and antitriplet? The mass of the state should depend besides p-adic mass scale also on the structure of SU(3) state so that the mass would be different. This difference should be very small.

2. Dynamical SU(3) could be broken so that wormhole contacts with different genera for the throats would be more massive than those with the same genera. This would give SU(3) singlet and two neutral states, which are analogs of $\eta\prime$ and η and π^0 in Gell-Mann's quark model. The masses of the analogs of η and π^0 and the analog of $\eta\prime$, which I have identified as standard weak boson would have different masses. But how large is the mass difference?

3. These 3 states are expected top have identical mass for the same p-adic mass scale, if the mass comes mostly from the analog of hadronic string tension assignable to magnetic flux tube. connecting the two wormhole contacts associates with any elementary particle in TGD framework (this is forced by the condition that the flux tube carrying monopole flux is closed and makes a very flattened square shaped structure with the long sides of the square at different space-time sheets). p-Adic thermodynamics would give a very small contribution genus dependent contribution to mass if p-adic temperature is $T = 1/2$ as one must assume for gauge bosons ($T = 1$ for fermions). Hence 2.95 TeV state could indeed correspond to this kind of state.

Could the exchange of massive $M_{G,79}$ photon and Z^0 give rise to additional electromagnetic interaction inducing the breaking of Universality?

1. The additional contribution in the effective Coulomb potential is Yukawa potential. In S-wave state this would give a contribution to the binding energy in a good approximation given by the expectation value of the Yukawa potential, which can be parameterized as

$$V(r) = g^2\frac{e^{-Mr}}{r} \quad , \quad g^2 = 4\pi k\alpha \quad . \tag{2.51}$$

. The expectation differs from zero significantly only in S-wave state characterized by principal quantum number n. Since the exponent function goes exponentially to zero in the p-adic length scale associated with 2.9 TeV mass, which is roughly by a factor 32 times shorter than intermediate boson mass scale, hydrogen atom wave function is constant in excellent approximation in the effective integration volume. This gives for the energy shift

$$\begin{aligned} \Delta E &= g^2|\Psi(0|^2 \times I \ , \\ |\Psi(0|^2 &= \frac{2^2}{n^2}\frac{1}{a_0^3} \ , \ a_0 = \frac{1}{m\alpha} \ , \\ I &= \int \frac{e^{-Mr}}{r} r^2 dr d\Omega = \frac{4\pi}{M^2} \ . \end{aligned} \tag{2.52}$$

For the energy shift and its ratio to ground state energy

$$E_n = \frac{\alpha^2}{2n^2} \times m \tag{2.53}$$

on obtains the expression

$$\begin{aligned} \Delta E_n &= \frac{64\pi^2\alpha}{n^2}\alpha^3(\frac{m}{M})^2 \times m \ , \\ \frac{\Delta E_n}{E_n} &= 2^7\pi^2\alpha^2k^2(\frac{m}{M})^2 \ . \end{aligned} \tag{2.54}$$

For $k = 1$ and $M = 2.9$ TeV one has $\Delta E_n/E_n \simeq 8.9 \times 10^{-11}$ for muon.

Consider next Lamb shift.

1. Lamb shift as difference of energies between S and P wave states (see `http://tinyurl.com/y99ctyn4`) is approximately given by

$$\frac{\Delta_n(Lamb)}{E_n} = \frac{13\alpha^3}{2n} \ . \tag{2.55}$$

   For $n = 2$ this gives $\Delta_2(Lamb)/E_2 = 4.9 \times 10^{-7}$.

2. Recall that the previous parameterization for the theoretical Lamb shift reads as

$$\Delta E(r_p(th)) = a - br_p^2 + cr_p^3 = 209.968(5)5.2248 \times r_p^2 + 0.0347 \times r_p^3 \ \ meV \ . \tag{2.56}$$

   where the charge radius $r_p = .8750$ is expressed in femtometers and energy in meVs.

3. The reduction of r_p by 3.3 per cent allows to estimate the reduction of Lamb shift (attractive additional potential reduces it). The relative change of the Lamb shift is

$$\begin{aligned} x &= \frac{\Delta E(r_p(th)) - \Delta E(r_p(exp))}{\Delta E(r_p(th))} \\ &= \frac{5.2248 \times (r_p^2(th) - r_p^2(exp)) + 0.0347 \times (r_p^3(th) - r_p^3(exp))}{209.968(5)5.2248 \times r_p^2(th) + 0.0347 \times r_p^3(th)} \ . \end{aligned} \tag{2.57}$$

   The estimate gives $x = 1.2 \times 10^{-3}$.

This value can be compared with the prediction. For $n = 2$ ratio of $\Delta E_n/\Delta E_n(Lamb)/$ is

$$x = \frac{\Delta E_n}{\Delta E_n(Lamb)} = k^2 \times \frac{2^9\pi^2}{13\alpha} \times (\frac{m}{M})^2 \ . \tag{2.58}$$

For $M = 2.9$ TeV the numerical estimate gives $x \simeq k^2 \times 10^{-4}$. The value of x deduced from experimental data is $x \simeq 1.2 \times 10^{-3}$. For $k = 3$ a correct order of magnitude is obtained. There are thus good hopes that the model works.

The contribution of Z_1^0 exchange is neglected in the above estimate. Is it present and can it explain the discrepancy?

1. In the case of deuterium the weak isospins of proton and deuterium are opposite so that their contributions to the Z_1^0 vector potential cancel. If Z_1^0 contribution for proton can be neglected, one has $\Delta r_p = \Delta r_d$.

   One however has $\Delta r_p \simeq 2.75\Delta r_d$. Hence Z_1^0 contribution to Δr_p should satisfy $\Delta r_p(Z_1^0) \simeq 1.75 \times \Delta r_p(\gamma_1)$. This requires $\alpha_{Z,1} > \alpha_1$, which is true also for the ordinary gauge bosons. The weak isospins of electron and proton are opposite so that the atom is weak isospin singlet in Abelian sense, and one has $I_p^3 I_\mu^3 = -1/4$ and attractive interaction. The condition relating r_p and r_Z suggests

   $$\frac{\alpha_{Z,1}}{\alpha_1} \simeq \frac{28}{6} = 4 + \frac{1}{3} \ .$$

   In standard model one has $\alpha_Z/\alpha = 1/[sin^2(\theta_W)cos^2(\theta_W)] = 5.6$ for $sin^2(\theta_W) = .23$. One has upper bound $\alpha_{Z,1}/\alpha_1 \geq 4$ saturated for $sin^2(\theta_{W,1}) = 1/2$. Weinberg angle can be expressed as

   $$sin^2(\theta_{W,1}) = \frac{1}{2}\left[1 - \sqrt{1 - 4\frac{\alpha_1}{\alpha_{Z,1}}}\right] \ .$$

   $\alpha_{Z,1}/\alpha_1 \simeq 28/6$ gives $sin^2(\theta_{W,1}) = \frac{1}{2}[1 - \sqrt{1/7}] \simeq .31$.

   The contribution to the axial part of the potential depending on spin need not cancel and could give a spin dependent contribution for both proton and deuteron.

2. If the scale of α_1 and $\alpha_{Z,1}$ is that of $\alpha_s \simeq .1$ at TeV energy scale and if the factor 2.75 emerges in the proposed manner, one has $k^2 \simeq 2.75 \times 10 = 27.5$ rather near to the rough estimate $k^2 \simeq 27$ from data for proton. This would give $\alpha_1 \simeq 1/13.7$.

   Note however than there are mixing angles involved corresponding to the diagonal hermitian family charge matrix $Q = (a, b, c)$ satisfying $a^2 + b^2 + c^2 = 1$ and the condition $a + b + c = 0$ expressing the orthogonality with the electromagnetic charge matrix $(1, 1, 1)/\sqrt{3}$ expressing electroweak universality for ordinary electroweak bosons. For instance, one could have $(a, b, c) = (0, 1, -1)/\sqrt{2}$ for the second generation and $(a, b, c) = (2, -1, -1)/\sqrt{6}$ for the third generation. In this case the above estimate would would be scaled down: $\alpha_1 \rightarrow 2\alpha_1/3 \simeq 1/20.5$.

To sum up, the proposed model is successful at quantitative level allowing to understand the different changes for charge radius for proton and deuteron and estimate the values of electroweak couplings of the second generation of weak bosons apart from the uncertainty due to the family charge matrix. Muon's magnetic moment anomaly and decays of neutral B allow to test the model and perhaps fix the remaining two mixing angles.

2.5 Misbehaving b-quarks and the magnetic body of proton

Science news tells about misbehaving bottom quarks (see `http://tinyurl.com/jpkwey4` and ICHEP conference talk at `http://tinyurl.com/z4lqtvz`). Or perhaps one should talk about misbehaving b-hadrons - hadrons containing b- quarks. The mis-behavior appears in proton-proton collisions at LHC. This is not the only anomaly associated with proton. The spin of proton is still poorly understood and proton charge radius if quite not what it should be. Now we learn that there are more b-containing hadrons (b-hadrons) in the directions deviating considerably from the direction of proton beam: discrepancy factor is of order two.

How this could reflect the structure of proton? Color magnetic flux tubes are the new TGD based element in the model or proton: could they help? I assign to proton color magnetic flux tubes with size scale much larger than proton size - something like electron Compton length: most of the mass of proton is color magnetic energy associated with these tubes and they define the non-perturbative aspect of hadron physics in TGD framework. For instance, constituent quarks would be valence quarks plus their color flux tubes. Current quarks just the quarks whose masses give rather small contribution to proton mass.

What happens when two protons collide? In cm system the dipolar flux tubes get contracted in the direction of motion by Lorentz contraction. Suppose b-hadrons tend to leave proton along the color magnetic flux tubes (also ordinary em flux tubes could be in question). Lorentz contraction of flux tubes means that they tend to leave in directions orthogonal to the collision axis. Could this explain the misbehavior of b-hadrons?

But why only b-hadrons or some fraction of them should behave in this manner? Why not also lighter hadrons containing c and s? Could this relate to the much smaller size of b-quark defined by its Compton length $L = \hbar/m(b)$, $m(b) = 4.2GeV$, which is much shorter than the Compton length of u-quark (the mass of constituent u quark is something like 300 MeV and the mass of current u quark is few MeVs. Could it be that lighter hadrons do not leave proton along flux tubes? Why? Are these hadrons or corresponding quarks too large to fit (topologically condense) inside protonic flux tube? b-quark is much more massive and has considerably smaller size than say c-quark with mass $m(c) = 1.5$ GeV and could be able to topologically condense inside the protonic flux tube. c quark should be too large, which suggests that the radius of flux tubes is larger than proton Compton length. This picture conforms with the view of perturbative QCD in which the primary processes take place at parton level. The hadronization would occur in longer time scale and generate the magnetic bodies of outgoing hadrons. The alternative idea that also the color magnetic body of hadron should fit inside the protonic color flux tube is not consistent with this view.

2.6 Explanation For The Soft Photon Excess In Hadron Production

There is quite a recent article entitled "Study of the Dependence of Direct Soft Photon Production on the Jet Characteristics in Hadronic Z^0 Decays" (see `http://tinyurl.com/ybbd7tfy`) discussing one particular manifestation of an anomaly of hadron physics known for two decades: the soft photon production rate in hadronic reactions is by an average factor of about four higher than expected. In the article soft photons assignable to the decays of Z^0 to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and blackholes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent.

2.6.1 Soft photon anomaly

The general observations are summarized by the abstract of the paper.

An analysis of the direct soft photon production rate as a function of the par ent jet characteristics is presented, based on hadronic events collected by the DELPHI experiment at LEP1. The dependences of the photon rates on the jet kinematic characteristics (momentum, mass, etc.) and on the jet charged, neutral and total hadron multiplicities are reported. Up to a scale factor of about four, which characterizes the overall value of the soft photon excess, a similarity of the observed soft photon behaviour to that of the inner hadronic bremsstrahlung predictions is found for the momentum, mass, and jet charged multiplicity dependences. However for the dependence of the soft photon rate on the jet neutral and total hadron multiplicities a prominent difference is found for the observed soft photon signal as compared to the expected bremsstrahlung from final state hadrons. The observed linear increase of the soft photon production rate with the jet total hadron multiplicity and its strong dependence on the jet neutral multiplicity suggest that the rate is proportional to the number of quark pairs produced in the fragmentation process, with the neutral pairs being more effectively radiating than the charged ones.

I try to abstract the essentials of the article.

1. One considers soft photon production in kinematic range .2 GeV$< E <$ 1 GeV, $p_T <$ .08 GeV, where p_T is photon transverse momentum with respect to the parent jet direction. The soft photon excess is associated with hadron production only and does not appear in leptonic sector. As one subtracts the photon yield due to the decays of hadrons (mainly neutral pions), one finds that what remains is on the average 4 times larger than the photon yield by inner hadronic brehmstrahlung, which means bremsstrahlung by charged final state hadrons. This suggests that the description in terms of charged hadron bremstrahlung is not correct and one must go to quark level.

2. Up to the scale factor with average value four, the dependence of soft photon production on jet momentum, mass, and jet charged multiplicity is consistent with the inner hadronic bremsstrahlung predictions.

3. The dependence of the soft photon rate on jet neural and total hadron multiplicities differs from the expected bremsstrahlung from final state hadrons. The linear increase of the rate with the jet total hadron multiplicity and strong dependence on the jet neutral multiplicity does not conform with internal hadron bremsstrahlung prediction which suggests that the anomalous soft photon production is proportional to the number of neutral quark pairs giving rise to neutral mesons. For some reason neutral pairs would thus radiate more effectively than the charged ones. Therefore the hypothesis that sea quarks alone are responsible for anomalous brehmstrahlung cannot hold true as such.

The article discusses the data and also the models that has been proposed. Incoherent production of photons by quarks predict satisfactorily the linear dependence of total intensity of brehmstrahling on total number of jet particle if the number of quarks in jet is assumed to be proportional to the number jet particles (see **Fig.** 7 of `http://tinyurl.com/ybbd7tfy`). The model cannot however explain the deviations from the model based on charged hadron inner brehmstrahling: the problems are produced by the sensitive dependence on the number of neutral hadrons (see **Fig.** 6 of the same article.

The models assuming that jet acts as a coherent structure fail also and it is proposed that somehow neutral quark pairs must act as electric dipoles generating dipole radiation at low energies. The dipole moments assignable to neutral quark pairs $U\overline{U}$ and $D\overline{D}$. $U\overline{D}$, $D\overline{U}$ with given respect to center of mass are proportional to the difference of the quark charges $4/3, 2/3, 1/3, -1/3$ so that one might argue that the dipole radiation from neutral pairs is by a factor 16 *resp.* 4 stronger than from charged pair and authors argue that this might be part of the explanation. This would suggest that the excess radiation comes from dipole radiation from quarks inside neutral hadrons. The dipole radiation intensity is expected to be weaker than monopole radiation by a factor $1/\lambda^2$ roughly so that this line of thought does not look promising.

2.6.2 TGD based explanation of the anomaly

Could one find an explanation for the anomaly in TGD framework? The following model finds its inspiration from TGD inspired models for two other anomalies.

1. The first model explains the reported deviation of the charge radius of muonic hydrogen from the predicted radius. Key role is played by the electric flux tubes associated with quarks and having size scale of order quark Compton radius and therefore extending up to the Bohr radius of muonic hydrogen in the case of u quark.

2. Second model explains the observed anomalous behavior of the quark-gluon plasma. What is observed is almost perfect fluid behavior instead of gas like behavior reflecting itself as small viscosity to entropy ratio. The findings suggest coherence in rather long length scales and also existence of string like objects. Color magnetic (or color electric or both) flux tubes containing quarks and antiquarks are proposed as a space-time correlate for the quark gluon plasma.

Electric flux tubes as basic objects provide a promising candidate for the counterparts of dipoles now. In the case of neutral hadrons color flux tubes and em flux tubes can be one and the same thing. In the case of charged hadrons this cannot be the case and em flux tubes connect oppositely charged hadrons. This could explain the difference between neutral and charged hadrons. If the production amplitude is coherent sum over amplitudes for quarks and antiquarks inside hadron and if also sea quarks contribute, only neutral hadrons would contribute to the brehmstrahlung at long wave length limit and the excess would correspond to the contribution of sea quarks inside neutral hadrons.

A more precise argument goes as follows.

1. The first guess would be that the production amplitude of photons is sum over incoherent contributions of valence and sea quarks. This cannot be the case since both charged and neutral hadrons would contribute equally.

2. Quantum classical correspondence requires some space-time correlate for the classical electric fields. In TGD electric flux is carried by flux tubes and this suggests that flux tubes serve as this correlate. These flux tubes must begin from quark and end to an anti-quark of opposite charge. One must distinguish between the flux tubes assignable to electric field and gluon field. The flux tubes connecting charged hadrons cannot correspond to color flux tubes. For electromagnetically neutral hadrons color flux tubes and em flux tubes can be one and the same thing: this conforms with the fact that classical color fields are proportional to the induced Kähler form as is also the U(1) part of the classical em field. This will be assumed so that only the flux tubes associated with neutral quark pairs (hadrons) can contribute to the coherent dipole radiation. In particular, the sea quarks at these flux tubes can contribute. The flux tubes connecting different hadrons of the final state would not carry color gauge flux making possible materialization of sea quarks from vacuum. If the sea quarks at flux electric flux tubes are responsible for the anomaly, the excess is present only for the neutral hadrons.

3. Low energy phenomenon is in question. This means that the description of quark pairs as coherently scattering pairs of charges (dipole approximation is not necessary) should make sense only when the photon wavelength is longer than the size scale of the dipole: the relevant length scale could be expressed in terms of the distance d between the quark and antiquark of the pair. The criterion can be written as $\lambda \geq xd/2$, where x is a numerical constant of order unity whose value, which should be fixed by the precise criterion of coherence length which should be few wave lengths. For higher energies description as incoherently radiating quarks should be a good approximation. The quark and antiquark with opposite charges can belong to the same to-be-hadron or different charged to-be-hadrons. In the first case there distance remains more or less the same during fragmentation process. In the latter case it increases. In the first case the treatment of the flux tube as a coherently radiating unit makes sense for wavelengths $\lambda \geq xd/2$.

4. The assumption that the brehmstrahlung amplitude is a coherent sum over the amplitudes for the quarks and antiquarks inside to-be-hadron gives a heuristic estimate for the radiation power. Consider first the situation in which the ends of the flux tube contain quark and antiquark. Denoting by A value of the photon emission amplitude for free quark, this would give amplitude squared $|A|^2|(1 - exp(exp(ik \cdot d))|^2$, whose maximum value is by a factor 4 larger than that for a single particle. The maxima would correspond to $\lambda = 2dcos(\theta)/(2n+1)$, where θ is the angle between the wave vector of photon and d. $n = 0$ would correspond to $\lambda = 2dcos(\theta)$. For given value of λ one would obtain a diffraction pattern with maxima at $cos(\theta) = (n + 1/2)\lambda/d$. This cannot however give large enough radiation power: the angle average of the factor $|1 - exp(i\phi)|^2$ is 2 instead of 4 and corresponds to the incoherent sum of production rates.

5. More complex model would assume that the flux tubes contain quarks and antiquarks also in their interior so that one would have coherent sum of a larger number of amplitudes which would give diffraction conditions for λ analogous to those above. In this case the maximum of the diffractive factor would be N^2, where $N = 2n$ is total number of quarks and antiquarks

for mesons. For neutral baryons flux tube would contain odd number of quarks. The angle average would be in this case be equal to N. If all quarks and antiquarks inside the flux tube appear as valence quarks of the final state hadron, one obtains just the result predicted by the independent quark model. Therefore the only possible interpretation for additional contribution is in terms of sea quarks.

Consider now a more detailed quantitative estimate. Assume that the emission inside flux tubes is incoherent. Assume that the sea quarks with charges $\pm 2/3$ and $\pm 1/3$ appear with same probabilities and this is true also for valence quarks for energetic enough jets. Therefore the average quark charge squared is $\langle Q_q^2\rangle = 5/18$.

1. The model based on incoherent brehmstrahlung on quarks mentioned in [C22] assumes that the number of partons in jet is proportional to the hadrons in the jet:

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{sea,ch} + N_{val,ch}) \propto N_{tot} \quad . \tag{2.59}$$

According to [C22] the model explains the excess as a a linear function of jet total hadron multiplicity N_{tot} (see **Fig.** 7 of `http://tinyurl.com/ybbd7tfy`). This behavior is obtained if the production rate satisfies

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{sea,ch} + N_{val,ch})\langle Q_q^2\rangle \quad .$$

One however considers inclusive distribution meaning integration over the various combinations (N_{neu}, N_{ch}) and also other jet variables weighted by differential cross section so that similar result is obtained under much weaker conditions.

2. Indeed, if sea quarks and valence quarks have same p-adic mass scale, one has

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{val,ch})\langle Q_q^2\rangle \tag{2.60}$$

p-Adic length cale hypothesis however allows the sea quarks to be considerably lighter than valence quarks so that their contribution to the brehmstrahlung can be larger. This would mean the proportionality

$$\begin{aligned} R &\propto (xN_{sea,neu} + N_{val,neu} + N_{val,ch})\langle Q_q^2\rangle \quad , \\ x &= (\frac{m_{val}}{m_{sea}})^2 \quad . \end{aligned} \tag{2.61}$$

p-Adic length scale hypothesis predicts that x is power of two: $x = 2^k$, $k \in \{0, 1, 2, ..\}$.

The above constraint gives rise to the consistency condition

$$\langle R\rangle \propto \langle xN_{sea,neu} + N_{val,neu} + N_{val,ch}\rangle \propto N_{tot} \quad . \tag{2.62}$$

3. The data [C22] support the the appearance of $N_{sea,neu}$ in the rate.

   (a) The dependence on xN_{sea} could explain the exceptionally large deviation (by factor of 8, see **Fig.** 5 of `http://tinyurl.com/ybbd7tfy`) from hadronic inner bremsstrahlung for smallest charged multiplicity meaning large number sea quarks assignable to neutral hadrons. For large values of charged multiplicity the contribution of $xN_{sea,neu}+N_{val,neu}$ becomes small and the one should obtain approximate factor 4.

(b) The linear fit of the distribution in the form $R = a_1 N_{ch} + a_2 N_{neu}$ gives $a_2/a_1 \simeq 6$ so that the dependence on neutral multiplicity is six time stronger than on charged multiplicity (see table 6 of [C22]). This suggests that $xN_{sea,neu}$ dominates in the formula. The first possibility is that the parameter $r = N_{sea,neu}/N_{val,neu}$ is considerably larger than unity. Second possibility is that one has $x > 1$.

(c) The ratio of signal to bremsstrahlung prediction increases rapidly as a function of neutral jet multiplicity n_{neu} and increases from 2.5 to about 16 in the range $[0, 6]$ for the neutral multiplicity (see **Fig.** 6 of `http://tinyurl.com/ybbd7tfy`). This conforms with the dependence on $N_{sea,neu}$. Also the dependence of the signal to brehmstrahlung ratio on the core charged multiplicity is non-trivial being largest for vanishing core charge and decreasing with core n_{ch}. Also this confirms with the proposal.

To sum up, the model depends crucially on the notion of induced gauge field and proportionality of the classical color fields and U(1) part of em field to the induced Kähler form and therefore the anomaly gives support for the basic prediction of TGD distinguishing it from QCD. It is possible that two times lighter p-adic mass scale for sea quarks than for valence quarks is needed in order to explain the findings.

3 Simulating Big Bang In Laboratory

Ultra-high energy collisions of heavy nuclei at Relativistic Heavy Ion Collider (RHIC) can create so high temperatures that there are hopes of simulating Big Bang in laboratory. The experiment with PHOBOS detector [C33] probed the nature of the strong nuclear force by smashing two Gold atoms together at ultrahigh energies. The analysis of the experimental data has been carried out by Prof. Manly and his collaborators at RHIC in Brookhaven, NY [C32]. The surprise was that the hydrodynamical flow for non-head-on collisions did not possess the expected longitudinal boost invariance.

This finding stimulates in TGD framework the idea that something much deeper might be involved.

1. The quantum criticality of the TGD inspired very early cosmology predicts the flatness of 3-space as do also inflationary cosmologies. The TGD inspired cosmology is "silent whisper amplified to big bang" since the matter gradually topologically condenses from decaying cosmic string to the space-time sheet representing the cosmology. This suggests that one could model also the evolution of the quark-gluon plasma in an analogous manner. Now the matter condensing to the quark-gluon plasma space-time sheet would flow from other space-time sheets. The evolution of the quark-gluon plasma would very literally look like the very early critical cosmology.

2. What is so remarkable is that critical cosmology is not a small perturbation of the empty cosmology represented by the future light cone. By perturbing this cosmology so that the spherical symmetry is broken, it might possible to understand qualitatively the findings of [C32]. Maybe even the breaking of the spherical symmetry in the collision might be understood as a strong gravitational effect on distances transforming the spherical shape of the plasma ball to a non–spherical shape without affecting the spherical shape of its M^4_+ projection.

3. The model seems to work at qualitative level and predicts strong gravitational effects in elementary particle length scales so that TGD based gravitational physics would differ dramatically from that predicted by the competing theories. Standard cosmology cannot produce these effects without a large breaking of the cherished Lorentz and rotational symmetries forming the basis of elementary particle physics. Thus the PHOBOS experiment gives direct support for the view that Poincare symmetry is symmetry of the embedding space rather than that of the space-time.

4. This picture was completed a couple of years later by the progress made in hadronic mass calculations [K17]. It has already earlier been clear that quarks are responsible only for

a small part of the mass of baryons (170 GeV in case of nucleons). The assumption that hadronic $k = 107$ space-time sheet carries a many-particle state of super-symplectic particles with vanishing electro-weak quantum numbers (meaning darkness in the strongest sense of the word.)

5. TGD allows a model of hadrons predicting their masses with accuracy better than one per cent. In this framework color glass condensate can be identified as a state formed when the hadronic space-time sheets of colliding hadrons fuse to single long stringy object and collision energy is transformed to super-symplectic hadrons.

What I have written above reflects the situation around 2005 when RHIC was in blogs. After 5 years later (2010) LHC gave its first results suggesting similar phenomena in proton-proton collisions. These results provide support for the idea that the formation of long entangled hadronic strings by a fusion of hadronic strings forming a structure analogous to black hole or initial string dominated phase of the cosmology are responsible for the RHIC findings. In the LHC case the mechanism leading to this kind of strings must be different since initial state contains only two protons. I would not anymore distinguish between hadrons and super-symplectic hadrons since in the recent picture super-symplectic excitations are responsible for most of the mass of the hadron. The view about dark matter as macroscopic quantum phase with large Planck constant has also evolved a lot from what it was at that time and I have polished reference to some short lived ideas for the benefit of the reader and me. I did not speak about zero energy ontology at that time and the understanding of the general mathematical structure of TGD has improved dramatically during these years.

3.1 Experimental Arrangement And Findings

3.1.1 Heuristic description of the findings

In the experiments using PHOBOS detector ultrahigh energy Au+Au collisions at center of mass energy for which nucleon-nucleon center of mass energy is $\sqrt{s_{NN}} = 130$ GeV, were studied [C33].

1. In the analyzed collisions the Au nuclei did not collide quite head-on. In classical picture the collision region, where quark gluon plasma is created, can be modelled as the intersection of two colliding balls, and its intersection with plane orthogonal to the colliding beams going through the center of mass of the system is defined by two pieces of circles, whose intersection points are sharp tips. Thus rotational symmetry is broken for the initial state in this picture.

2. The particles in quark-gluon plasma can be compared to a persons in a crowded room trying to get out. The particles collide many times with the particles of the quark gluon plasma before reaching the surface of the plasma. The distance $d(z, \phi)$ from the point $(z, 0)$ at the beam axis to the point $(0, \phi)$ at the plasma surface depends on ϕ. Obviously, the distance is longest to the tips $\phi = \pm\pi/2$ and shortest to the points $\phi = 0, \phi = \phi$ of the surface at the sides of the collision region. The time $\tau(z, \phi)$ spent by a particle to the travel to the plasma surface should be a monotonically increasing function $f(d)$ of d:

$$\tau(z, \phi) = f(d(z, \phi)) \ .$$

   For instance, for diffusion one would have $\tau \propto d^2$ and $\tau \propto d$ for a pure drift.

3. What was observed that for $z = 0$ the difference

$$\Delta\tau = \tau(z = 0, \pi/2) - \tau(z = 0, 0)$$

   was indeed non-vanishing but that for larger values of z the difference tended to zero. Since the variation of z correspond that for the rapidity variable y for a given particle energy, this means that particle distributions depend on rapidity which means a breaking of the longitudinal boost invariance assumed in hydrodynamical models of the plasma. It was also found that the difference vanishes for large values of y: this finding is also important for what follows.

3.1.2 A more detailed description

Consider now the situation in a more quantitative manner.

1. Let z-axis be in the direction of the beam and ϕ the angle coordinate in the plane E^2 orthogonal to the beam. The kinematical variables are the rapidity of the detected particle defined as $y = log[E+p_z)/(E-p_z)]/2$ (E and p_z denote energy and longitudinal momentum), Feynman scaling variable $x_F \simeq 2E/\sqrt{s}$, and transversal momentum p_T.

2. By quantum-classical correspondence, one can translate the components of momentum to space-time coordinates since classically one has $x^\mu = p^\mu a/m$. Here a is proper time for a future light cone, whose tip defines the point where the quark gluon plasma begins to be generated, and $v^\mu = p^\mu/m$ is the four-velocity of the particle. Momentum space is thus mapped to an $a = constant$ hyperboloid of the future light cone for each value of a.

   In this correspondence the rapidity variable y is mapped to $y = log[(t+z)/(t-z)]$, $|z| \leq t$ and non–vanishing values for y correspond to particles which emerge, not from the collision point defining the origin of the plane E^2, but from a point above or below E^2. $|z| \leq t$ tells the coordinate along the beam direction for the vertex, where the particle was created. The limit $y \to 0$ corresponds to the limit $a \to \infty$ and the limit $y \to \pm\infty$ to $a \to 0$ (light cone boundary).

3. Quark-parton models predict at low energies an exponential cutoff in transverse momentum p_T; Feynman scaling $dN/dx_F = f(x_F)$ independent of s; and longitudinal boost invariance, that is rapidity plateau meaning that the distributions of particles do not depend on y. In the space-time picture this means that the space-time is effectively two-dimensional and that particle distributions are Lorentz invariant: string like space-time sheets provide a possible geometric description of this situation.

4. In the case of an ideal quark-gluon plasma, the system completely forgets that it was created in a collision and particle distributions do not contain any information about the beam direction. In a head-on collision there is a full rotational symmetry and even Lorentz invariance so that transverse momentum cutoff disappears. Rapidity plateau is predicted in all directions.

5. The collisions studied were not quite head-on collisions and were characterized by an impact parameter vector with length b and direction angle ψ_2 in the plane E^2. The particle distribution at the boundary of the plane E^2 was studied as a function of the angle coordinate $\phi - \psi_2$ and rapidity y which corresponds for given energy distance to a definite point of beam axis.

The hydrodynamical view about the situation looks like follows.

1. The particle distributions $N(p^\mu)$ as function of momentum components are mapped to space-time distributions $N(x^\mu, a)$ of particles. This leads to the idea that one could model the situation using Robertson-Walker type cosmology. Co-moving Lorentz invariant particle currents depending on the cosmic time only would correspond in this picture to Lorentz invariant momentum distributions.

2. Hydrodynamical models assign to the particle distribution $d^2N/dyd\phi$ a hydrodynamical flow characterized by four-velocity $v^\mu(y, \phi)$ for each value of the rapidity variable y. Longitudinal boost invariance predicting rapidity plateau states that the hydrodynamical flow does not depend on y at all. Because of the breaking of the rotational symmetry in the plane orthogonal to the beam, the hydrodynamical flow v depends on the angle coordinate $\phi - \psi_2$. It is possible to Fourier analyze this dependence and the second Fourier coefficient v_2 of $cos(2(\phi - \psi_2)$ in the expansion

$$\frac{dN}{d\phi} \simeq 1 + \sum_n v_n cos(n(\phi - \psi_2)) \tag{3.1}$$

   was analyzed in [C32].

3. It was found that the Fourier component v_2 depends on rapidity y, which means a breaking of the longitudinal boost invariance. v_2 also vanishes for large values of y. If this is true for all Fourier coefficients v_n, the situation becomes effectively Lorentz invariant for large values of y since one has $v(y, \phi) \to 1$.

   Large values of y correspond to small values of a and to the initial moment of big bang in cosmological analogy. Hence the finding could be interpreted as a cosmological Lorentz invariance inside the light cone cosmology emerging from the collision point. Small values of y in turn correspond to large values of a so that the breaking of the spherical symmetry of the cosmology should be manifest only at $a \to \infty$ limit. These observations suggest a radical re-consideration of what happens in the collision: the breaking of the spherical symmetry would not be a property of the initial state but of the final state.

3.2 TGD Based Model For The Quark-Gluon Plasma

Consider now the general assumptions the TGD based model for the quark gluon plasma region in the approximation that spherical symmetry is not broken.

1. Quantum-classical correspondence supports the mapping of the momentum space of a particle to a hyperboloid of future light cone. Thus the symmetries of the particle distributions with respect to momentum variables correspond directly to space-time symmetries.

2. The M^4_+ projection of a Robertson-Walker cosmology imbedded to $H = M^4_+ \times CP_2$ is future light cone. Hence it is natural to model the hydrodynamical flow as a mini-cosmology. Even more, one can assume that the collision quite literally creates a space-time sheet which locally obeys Robertson-Walker type cosmology. This assumption is sensible in many-sheeted space-time (see **Fig.** `http://tgdtheory.fi/appfigures/manysheeted.jpg` or **Fig.** 9 in the appendix of this book) and conforms with the fractality of TGD inspired cosmology (cosmologies inside cosmologies).

3. If the space-time sheet containing the quark-gluon plasma is gradually filled with matter, one can quite well consider the possibility that the breaking of the spherical symmetry develops gradually, as suggested by the finding $v_2 \to 1$ for large values of $|y|$ (small values of a). To achieve Lorentz invariance at the limit $a \to 0$, one must assume that the expanding region corresponds to $r = constant$ "coordinate ball" in Robertson-Walker cosmology, and that the breaking of the spherical symmetry for the induced metric leads for large values of a to a situation described as a "not head-on collision".

4. Critical cosmology is by definition unstable, and one can model the Au+Au collision as a perturbation of the critical cosmology breaking the spherical symmetry. The shape of $r = constant$ sphere defined by the induced metric is changed by strong gravitational interactions such that it corresponds to the shape for the intersection of the colliding nuclei. One can view the collision as a spontaneous symmetry breaking process in which a critical quark-gluon plasma cosmology develops a quantum fluctuation leading to a situation described in terms of impact parameter. This kind of modelling is not natural for a hyperbolic cosmology, which is a small perturbation of the empty M^4_+ cosmology.

3.2.1 The embedding of the critical cosmology

Any Robertson-Walker cosmology can be imbedded as a space-time sheet, whose M^4_+ projection is future light cone. The line element is

$$ds^2 = f(a)da^2 - a^2(K(r)dr^2 + r^2 d\Omega^2) \ . \tag{3.2}$$

Here a is the scaling factor of the cosmology and for the embedding as surface corresponds to the future light cone proper time.

This light cone has its tip at the point, where the formation of quark gluon plasma starts. (θ, ϕ) are the spherical coordinates and appear in $d\Omega^2$ defining the line element of the unit sphere. a and r are related to the spherical Minkowski coordinates (m^0, r_M, θ, ϕ) by $(a = \sqrt{(m^0)^2 - r_M^2}, r = r_M/a)$.

If hyperbolic cosmology is in question, the function $K(r)$ is given by $K(r) = 1/(1+r^2)$. For the critical cosmology 3-space is flat and one has $K(r) = 1$.

1. The critical cosmologies imbeddable to $H = M^4_+ \times CP_2$ are unique apart from a single parameter defining the duration of this cosmology. Eventually the critical cosmology must transform to a hyperbolic cosmology. Critical cosmology breaks Lorentz symmetry at space-time level since Lorentz group is replaced by the group of rotations and translations acting as symmetries of the flat Euclidian space.

2. Critical cosmology replaces Big Bang with a silent whisper amplified to a big but not infinitely big bang. The silent whisper aspect makes the cosmology ideal for the space-time sheet associated with the quark gluon plasma: the interpretation is that the quark gluon plasma is gradually transferred to the plasma space-time sheet from the other space-time sheets. In the real cosmology the condensing matter corresponds to the decay products of cosmic string in "vapor phase". The density of the quark gluon plasma cannot increase without limit and after some critical period the transition to a hyperbolic cosmology occurs. This transition could, but need not, correspond to the hadronization.

3. The embedding of the critical cosmology to $M^4_+ \times S^2$ is given by

$$\begin{aligned} sin(\Theta) &= \frac{a}{a_m} \ , \\ \Phi &= g(r) \ . \end{aligned} \tag{3.3}$$

   Here Θ and Φ denote the spherical coordinates of the geodesic sphere S^2 of CP_2. One has

$$\begin{aligned} f(a) &= 1 - \frac{R^2k^2}{(1-(a/a_m)^2)} \ , \\ (\partial_r \Phi)^2 &= \frac{a_m^2}{R^2} \times \frac{r^2}{1+r^2} \ . \end{aligned} \tag{3.4}$$

   Here R denotes the radius of S^2. From the expression for the gradient of Φ it is clear that gravitational effects are very strong. The embedding becomes singular for $a = a_m$. The transition to a hyperbolic cosmology must occur before this.

   This model for the quark-gluon plasma would predict Lorentz symmetry and $v = 1$ (and $v_n = 0$) corresponding to head-on collision so that it is not yet a realistic model.

3.2.2 TGD based model for the quark-gluon plasma without breaking of spherical symmetry

There is a highly unique deformation of the critical cosmology transforming metric spheres to highly non–spherical structures purely gravitationally. The deformation can be characterized by the following formula

$$sin^2(\Theta) = (\frac{a}{a_m})^2 \times (1 + \Delta(a,\theta,\phi)^2) \ . \tag{3.5}$$

1. This induces deformation of the g_{rr} component of the induced metric given by

$$g_{rr} = -a^2 \left[1 + \Delta^2(a,\theta,\phi)\frac{r^2}{1+r^2} \right] \ . \tag{3.6}$$

   Remarkably, g_{rr} does not depend at all on CP_2 size and the parameter a_m determining the duration of the critical cosmology. The disappearance of the dimensional parameters can be understood to reflect the criticality. Thus a strong gravitational effect independent of the gravitational constant (proportional to R^2) results. This implies that the expanding plasma space-time sheet having sphere as M^4_+ projection differs radically from sphere in the induced metric for large values of a. Thus one can understand why the parameter v_2 is non-vanishing for small values of the rapidity y.

2. The line element contains also the components g_{ij}, $i,j \in \{a,\theta,\phi\}$. These components are proportional to the factor

$$\frac{1}{1-(a/a_m)^2(1+\Delta^2)} \ , \tag{3.7}$$

which diverges for

$$a_m(\theta,\phi) = \frac{a_m}{\sqrt{1+\Delta^2}} \ . \tag{3.8}$$

Presumably quark-gluon plasma phase begins to hadronize first at the points of the plasma surface for which $\Delta(\theta,\phi)$ is maximum, that is at the tips of the intersection region of the colliding nuclei. A phase transition producing string like objects is one possible space-time description of the process.

3.3 Further Experimental Findings And Theoretical Ideas

The interaction between experiment and theory is pure magic. Although experimenter and theorist are often working without any direct interaction (as in case of TGD), I have the strong feeling that this disjointness is only apparent and there is higher organizing intellect behind this coherence. Again and again it has turned out that just few experimental findings allow to organize separate and loosely related physical ideas to a consistent scheme. The physics done in RHIC has played completely unique role in this respect.

3.3.1 Super-symplectic matter as the TGD counterpart of CGC?

The model discussed above explained the strange breaking of longitudinal Lorentz invariance in terms of a hadronic mini bang cosmology. The next twist in the story was the shocking finding, compared to Columbus's discovery of America, was that, rather than behaving as a dilute gas, the plasma behaved like a liquid with strong correlations between partons, and having density 30-50 times higher than predicted by QCD calculations [C26]. When I learned about these findings towards the end of 2004, I proposed how TGD might explain them in terms of what I called conformal confinement [K10]. This idea - although not wrong for any obvious reason - did not however have any obvious implications. After the progress made in p-adic mass calculations of hadrons leading to highly successful model for both hadron and meson masses [K17], the idea was replaced with the hypothesis that the condensate in question is Bose-Einstein condensate like state of super-symplectic particles formed when the hadronic space-time sheets of colliding nucleons fuse together to form a long string like object.

A further refinement of the idea comes from the hypothesis that quark gluon plasma is formed by the topological condensation of quarks to hadronic strings identified as color flux tubes. This would explain the high density of the plasma. The highly entangled hadronic string would be analogous to the initial state of TGD inspired cosmology with the only difference that string tension is extremely small in the hadronic context. This structure would possess also characteristics of blackhole.

3.3.2 Fireballs behaving like black hole like objects

The latest discovery in RHIC is that fireball, which lasts a mere 10^{-23} seconds, can be detected because it absorbs jets of particles produced by the collision [C27]. The association with the notion black hole is unavoidable and there indeed exists a rather esoteric M-theory inspired model "The RHIC fireball as a dual black hole" by Hortiu Nastase [C45] for the strange findings.

The Physics Today article [C50] "What Have We Learned From the Relativistic Heavy Ion Collider?" gives a nice account about experimental findings. Extremely high collision energies are in question: Gold nuclei contain energy of about 100 GeV per nucleon: 100 times proton mass. The expectation was that a large volume of thermalized Quark-Gluon Plasma (QCP) is formed in which partons lose rapidly their transverse momentum. The great surprise was the suppression of high transverse momentum collisions suggesting that in this phase strong collective interactions are present. This has inspired the proposal that quark gluon plasma is preceded by liquid like phase which has been christened as Color Glass Condensate (CGC) thought to contain Bose-Einstein condensate of gluons.

3.3.3 The theoretical ideas relating CGC to gravitational interactions

Color glass condensate relates naturally to several gravitation related theoretical ideas discovered during the last year.

1. *Classical gravitation and color confinement*

Just some time ago it became clear that strong classical gravitation might play a key role in the understanding of color confinement [K24]. Whether the situation looks confinement or asymptotic freedom would be in the eyes of beholder: this is one example of dualities filling TGD Universe. If one looks the situation at the hadronic space-time sheet or one has asymptotic freedom, particles move essentially like free massless particles. But - and this is absolutely essential- in the induced metric of hadronic space-time sheet. This metric represents classical gravitational field becoming extremely strong near hadronic boundary. From the point of view of outsider, the motion of quarks slows down to rest when they approach hadronic boundary: confinement. The distance to hadron surface is infinite or at least very large since the induced metric becomes singular at the light-like boundary! Also hadronic time ceases to run near the boundary and finite hadronic time corresponds to infinite time of observer. When you look from outside you find that this light-like 3-surface is just static surface like a black hole horizon which is also a light-like 3-surface. This gives confinement.

2. *Dark matter in TGD*

The evidence for hadronic black hole like structures is especially fascinating. In TGD Universe dark matter can be (not always) ordinary matter at larger space-time sheets in particular magnetic flux tubes. The mere fact that the particles are at larger space-time sheets might make them more or less invisible.

Matter can be however dark in much stronger sense, should I use the word "black" ! The findings suggesting that planetary orbits obey Bohr rules with a gigantic Planck constant [K22] , [E1] would suggest quantum coherence of dark matter even in astrophysical length scales and this raises the fascinating possibility that Planck constant is dynamical so that fine structure constant. Dark matter would correspond to phases with non-standard value of Planck constant. This quantization saves from black hole collapse just as the quantization of hydrogen atom saves from the infrared catastrophe.

The basic criterion for the transition to this phase would be that it occurs when some coupling strength - say fine structure constant multiplied by appropriate charges or gravitational constant multiplied by masses- becomes so large that the perturbation series for scattering amplitudes fails to converge. The phase transition increases Planck constant so that convergence is achieved. The attempts to build a detailed view about what might happen led to a generalization of the embedding space concept by replacing M^4 (or rather the causal diamond) and CP_2 with their singular coverings. During 2010 it turned out that this generalization could be regarded as a conventional manner to describe a situation in which space-time surface becomes analogous to a multi-sheeted Riemann surface. If so, then Planck constant would be replaced by its integer multiple only in effective sense.

The obvious questions are following. Could black hole like objects/magnetic flux tubes/cosmic strings consist of quantum coherent dark matter? Does this dark matter consist dominantly from hadronic space-time sheets which have fused together and contain super-symplectic bosons and their super-partners (with quantum numbers of right handed neutrino) having therefore no electro-weak interactions. Electro-weak charges would be at different space-time sheets.

1. Gravitational interaction cannot force the transition to dark phase in a purely hadronic system at RHIC energies since the product GM_1M_2 characterizing the interaction strength of two masses must be larger than unity ($\hbar = c = 1$) for the phase transition increasing Planck constant to occur. Hence the collision energy should be above Planck mass for the phase transition to occur if gravitational interactions are responsible for the transition.

2. The criterion for the transition to dark phase is however much more general and states that the system does its best to stay perturbative by increasing its Planck constant in discrete steps and applies thus also in the case of color interactions and governs the phase transition to the TGD counterpart of non-perturbative QCD. Criterion would be roughly $\alpha_s Q_s^2 > 1$ for two color charges of opposite sign. Hadronic string picture would suggests that the criterion is equivalent to the generalization of the gravitational criterion to its strong gravity analog $nL_p^2M^2 > 1$, where L_p is the p-adic length scale characterizing color magnetic energy density (hadronic string tension) and M is the mass of the color magnetic flux tube and n is a numerical constant. Presumably L_p, $p = M_{107} = 2^{107} - 1$, is the p-adic length scale since Mersenne prime M_{107} labels the space-time sheet at which partons feed their color gauge fluxes. The temperature during this phase could correspond to Hagedorn temperature (for the history and various interpretations of Hagedorn temperature see the CERN Courier article [B7]) for strings and is determined by string tension and would naturally correspond also to the temperature during the critical phase determined by its duration as well as corresponding black-hole temperature. This temperature is expected to be somewhat higher than hadronization temperature found to be about $\simeq 176$ MeV. The density of inertial mass would be maximal during this phase as also the density of gravitational mass during the critical phase.

Lepto-hadron physics [K26], one of the predictions of TGD, is one instance of a similar situation. In this case electromagnetic interaction strength defined in an analogous manner becomes larger than unity in heavy ion collisions just above the Coulomb wall and leads to the appearance of mysterious states having a natural interpretation in terms of lepto-pion condensate. Lepto-pions are pairs of color octet excitations of electron and positron.

3. Description of collisions using analogy with black holes

The following view about RHIC events represents my immediate reaction to the latest RHIC news in terms of black-hole physics instead of notions related to big bang. Since black hole collapse is roughly the time reversal of big bang, the description is complementary to the earliest one.

In TGD context one can ask whether the fireballs possibly detected at RHIC are produced when a portion of quark-gluon plasma in the collision region formed by to Gold nuclei separates from hadronic space-time sheets which in turn fuse to form a larger space-time sheet separated from the remaining collision region by a light-like 3-D surface (I have used to speak about light-like causal determinants) mathematically completely analogous to a black hole horizon. This larger space-time sheet would contain color glass condensate of super-symplectic gluons formed from the collision energy. A formation of an analog of black hole would indeed be in question.

The valence quarks forming structures connected by color bonds would in the first step of the collision separate from their hadronic space-time sheets which fuse together to form color glass condensate. Similar process has been observed experimentally in the collisions demonstrating the experimental reality of Pomeron, a color singlet state having no Regge trajectory [C38] and identifiable as a structure formed by valence quarks connected by color bonds. In the collision it temporarily separates from the hadronic space-time sheet. Later the Pomeron and the new mesonic and baryonic Pomerons created in the collision suffer a topological condensation to the color glass condensate: this process would be analogous to a process in which black hole sucks matter from environment.

Of course, the relationship between mass and radius would be completely different with gravitational constant presumably replacement by the the square of appropriate p-adic length scale presumably of order pion Compton length: this is very natural if TGD counterparts of black-holes are formed by color magnetic flux tubes. This gravitational constant expressible in terms of hadronic string tension of.9 GeV^2 predicted correctly by super-symplectic picture would characterize the strong gravitational interaction assignable to super-symplectic $J = 2$ gravitons. I have long time ago in the context of p-adic mass calculations formulated quantitatively the notion of elementary particle black hole analogy making the notion of elementary particle horizon and generalization of Hawking-Bekenstein law [K18].

The size L of the "hadronic black hole" would be relatively large using protonic Compton radius as a unit of length. For instnce, for $\hbar = 26\hbar_0$ the size would be $26 \times L_e(107) = 46$ fm and correspond to a size of a heavy nucleus. This large size would fit nicely with the idea about nuclear sized color glass condensate. The density of partons (possibly gluons) would be very high and large fraction of them would have been materialized from the brehmstrahlung produced by the de-accelerating nuclei. Partons would be gravitationally confined inside this region. The interactions of partons would lead to a generation of a liquid like dense phase and a rapid thermalization would occur. The collisions of partons producing high transverse momentum partons occurring inside this region would yield no detectable high p_T jets since the matter coming out from this region would be somewhat like a thermal radiation from an evaporating black hole identified as a highly entangled hadronic string in Hagedorn temperature. This space-time sheet would expand and cool down to QQP and crystallize into hadrons.

4. Quantitative comparison with experimental data

Consider now a quantitative comparison of the model with experimental data. The estimated freeze-out temperature of quark gluon plasma is $T_f \simeq 175.76$ MeV [C50, C45], not far from the total contribution of quarks to the mass of nucleon, which is 170 MeV [K17]. Hagedorn temperature identified as black-hole temperature should be higher than this temperature. The experimental estimate for the hadronic Hagedorn temperature from the transversal momentum distribution of baryons is $\simeq 160$ MeV. On the other hand, according to the estimates of hep-ph/0006020 the values of Hagedorn temperatures for mesons and baryons are $T_H(M) = 195$ MeV and $T_H(B) = 141$ MeV respectively.

D-dimensional bosonic string model for hadrons gives for the mesonic Hagedorn temperature the expression [B7]

$$T_H = \frac{\sqrt{6}}{2\pi(D-2)\alpha'} , \tag{3.9}$$

For a string in $D = 4$-dimensional space-time and for the value $\alpha' \sim 1$ GeV^{-2} of Regge slope, this would give $T_H = 195$ MeV, which is slightly larger than the freezing out temperature as it indeed should be, and in an excellent agreement with the experimental value of [B11]. It deserves to be noticed that in the model for fireball as a dual 10-D black-hole the rough estimate for the temperature of color glass condensate becomes too low by a factor 1/8 [C45]. In light of this I would not yet rush to conclude that the fireball is actually a 10-dimensional black hole.

Note that the baryonic Hagedorn temperature is smaller than mesonic one by a factor of about $\sqrt{2}$. According to [B11] this could be qualitatively understood from the fact that the number of degrees of freedom is larger so that the effective value of D in the mesonic formula is larger. $D_{eff} = 6$ would give $T_H = 138$ MeV to be compared with $T_H(B) = 141$ MeV. On the other hand, TGD based model for hadronic masses [K17] assumes that quarks feed their color fluxes to $k = 107$ space-time sheets. For mesons there are two color flux tubes and for baryons three. Using the same logic as in [B11], one would have $D_{eff}(B)/D_{eff}(M) = 3/2$. This predicts $T_H(B) = 159$ MeV to be compared with 160 MeV deduced from the distribution of transversal momenta in p-p collisions.

3.4 Are Ordinary Black-Holes Replaced With Super-Symplectic Black-Holes In TGD Universe?

Some variants of super string model predict the production of small black-holes at LHC. I have never taken this idea seriously but in a well-defined sense TGD predicts black-holes associated with super-symplectic gravitons with strong gravitational constant defined by the hadronic string tension. The proposal is that super-symplectic black-holes have been already seen in Hera, RHIC, and the strange cosmic ray events.

Baryonic super-symplectic black-holes of the ordinary M_{107} hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their M_{89} counterparts would be 512 times higher, about 478 GeV if quark massses scale also by this factor. This need not be the case: if one has $k = 113 \rightarrow 103$ instead of 105 one has 434 GeV mass. "Ionization energy" for Pomeron, the structure formed by valence quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for M_{89} proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

An interesting question is whether the ultrahigh energy cosmic rays having energies larger than the GZK cut-off of 5×10^{10} GeV are baryons, which have lost their valence quarks in a collision with hadron and therefore have no interactions with the microwave background so that they are able to propagate through long distances.

In neutron stars the hadronic space-time sheets could form a gigantic super-symplectic black-hole and ordinary black-holes would be naturally replaced with super-symplectic black-holes in TGD framework (only a small part of black-hole interior metric is representable as an induced metric). This obviously means a profound difference between TGD and string models.

1. Hawking-Bekenstein black-hole entropy would be replaced with its p-adic counterpart given by

$$S_p = (\frac{M}{m(CP_2)})^2 \times log(p) \ , \tag{3.10}$$

where $m(CP_2)$ is CP_2 mass, which is roughly 10^{-4} times Planck mass. M is the contribution of p-adic thermodynamics to the mass. This contribution is extremely small for gauge bosons but for fermions and super-symplectic particles it gives the entire mass.

2. If p-adic length scale hypothesis $p \simeq 2^k$ holds true, one obtains

$$S_p = klog(2) \times (\frac{M}{m(CP_2)})^2 , \tag{3.11}$$

$m(CP_2) = \hbar/R$, R the "radius" of CP_2, corresponds to the standard value of $\hbar_0$ for all values of $\hbar$.

3. Hawking-Bekenstein area law gives in the case of Schwartschild black-hole

$$S = \frac{A}{4G} \times \hbar = \pi G M^2 \times \hbar \ . \tag{3.12}$$

For the p-adic variant of the law Planck mass is replaced with CP_2 mass and $klog(2) \simeq log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if k is prime and wormhole throats have M^4 radius given by p-adic length scale $L_k = \sqrt{k}R$ which is exponentially smaller than L_p. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [K27] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses M and m [K22] reads as

$$\hbar_{gr} = \frac{GMm}{v_0}\hbar_0 \ .$$

$v_0 = 2^{-11}$ is the preferred value of v_0. One could argue that the value of gravitational Planck constant is such that the Compton length $\hbar_{gr}/M$ of the black-hole equals to its Schwartshild radius. This would give

$$\hbar_{gr} = \frac{GM^2}{v_0}\hbar_0 \ , \ v_0 = 1/2 \ . \tag{3.13}$$

The requirement that $\hbar_{gr}$ is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole [K22]. Even without this constraint M^2 is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

5. The gravitational collapse of a star would correspond to a process in which the initial value of v_0 , say $v_0 = 2^{-11}$, increases in a stepwise manner to some value $v_0 \leq 1/2$. For a supernova with solar mass with radius of 9 km the final value of v_0 would be $v_0 = 1/6$. The star could have an onion like structure with largest values of v_0 at the core as suggested by the model of planetary system. Powers of two would be favored values of v_0. If the formula holds true also for Sun one obtains $1/v_0 = 3 \times 17 \times 2^{13}$ with 10 per cent error.

6. Black-hole evaporation could be seen as means for the super-symplectic black-hole to get rid of its electro-weak charges and fermion numbers (except right handed neutrino number) as the antiparticles of the emitted particles annihilate with the particles inside super-symplectic black-hole. This kind of minimally interacting state is a natural final state of star. Ideal super-symplectic black-hole would have only angular momentum and right handed neutrino number.

7. In TGD light-like partonic 3-surfaces are the fundamental objects and space-time interior defines only the classical correlates of quantum physics. The space-time sheet containing the highly entangled cosmic string might be separated from environment by a wormhole contact with size of black-hole horizon.

This looks the most plausible option but one can of course ask whether the large partonic 3-surface defining the horizon of the black-hole actually contains all super-symplectic particles so that super-symplectic black-hole would be single gigantic super-symplectic parton. The interior of super-symplectic black-hole would be a space-like region of space-time, perhaps resulting as a large deformation of CP_2 type vacuum extremal. Black-hole sized wormhole contact would define a gauge boson like variant of the black-hole connecting two space-time sheets and getting its mass through Higgs mechanism. A good guess is that these states are extremely light.

3.5 Very Cautious Conclusions

The model for quark-gluon plasma in terms of valence quark space-time sheets separated from hadronic space-time sheets forming a color glass condensate relies on quantum criticality and implies gravitation like effects due to the presence of super-symplectic strong gravitons. At space-time level the change of the distances due to strong gravitation affects the metric so that the breaking of spherical symmetry is caused by gravitational interaction. TGD encourages to think that this mechanism is quite generally at work in the collisions of nuclei. One must take seriously the possibility that strong gravitation is present also in longer length scales (say biological), in particular in processes in which new space-time sheets are generated. Critical cosmology might provide a universal model for the emergence of a new space-time sheet.

The model supports TGD based early cosmology and quantum criticality. In standard physics framework the cosmology in question is not sensible since it would predict a large breaking of the Lorentz invariance, and would mean the breakdown of the entire conceptual framework underlying elementary particle physics. In TGD framework Lorentz invariance is not lost at the level of embedding space, and the experiments provide support for the view about space-time as a surface and for the notion of many-sheeted space-time.

The attempts to understand later strange events reported by RHIC have led to a dramatic increase of understanding of TGD and allow to fuse together separate threads of TGD.

1. The description of RHIC events in terms of the formation of hadronic black hole and its evaporation seems to be also possible and essentially identical with description as a mini bang.

2. It took some time to realize that scaled down TGD inspired cosmology as a model for quark gluon plasma predicts a new phase identifiable as color glass condensate and still a couple of years to realize the proper interpretation of it in terms of super-symplectic bosons having no counterpart in QCD framework.

3. There is also a connection with the dramatic findings suggesting that Planck constant for dark matter has a gigantic value.

4. Black holes and their scaled counterparts would not be merciless information destroyers in TGD Universe. The entanglement of particles having particle like integrity would make black hole like states ideal candidates for quantum computer like systems. One could even imagine that the galactic black hole is a highly tangled cosmic string in Hagedorn temperature performing quantum computations the complexity of which is totally out of reach of human intellect! Indeed, TGD inspired consciousness predicts that evolution leads to the increase of information and intelligence, and the evolution of stars should not form exception to this. Also the interpretation of black hole as consisting of dark matter follows from this picture.

Summarizing, it seems that thanks to some crucial experimental inputs the new physics predicted by TGD is becoming testable in laboratory.

3.6 Five Years Later

The emergence of the first interesting findings from LHC by CMS collaboration [C18, C3] provide new insights to the TGD picture about the phase transition from QCD plasma to hadronic phase and inspired also the updating of the model of RHIC events (mainly elimination of some remnants from the time when the ideas about hierarchy of Planck constants had just born).

3.6.1 Anomalous behavior of quark gluon plasma is observed also in proton proton collisions

In some proton-proton collisions more than hundred particles are produced suggesting a single object from which they are produced. Since the density of matter approaches to that observed in heavy ion collisions for five years ago at RHIC, a formation of quark gluon plasma and its subsequent decay is what one would expect. The observations are not however quite what QCD plasma picture would allow to expect. Of course, already the RHIC results disagreed with what QCD expectations. What is so striking is the evolution of long range correlations between particles in events containing more than 90 particles as the transverse momentum of the particles increases in the range 1-3 GeV (see the excellent description of the correlations by Lubos Motl in his blog [C9]).

One studies correlation function for two particles as a function of two variables. The first variable is the difference $\Delta\phi$ for the emission angles and second is essentially the difference for the velocities described relativistically by the difference $\Delta\eta$ for hyperbolic angles. As the transverse momentum p_T increases the correlation function develops structure. Around origin of $\Delta\eta$ axis a widening plateau develops near $\Delta\phi = 0$. Also a wide ridge with almost constant value as function of $\Delta\eta$ develops near $\Delta\phi = \pi$. The interpretation is that particles tend to move collinearly and or in opposite directions. In the latter case their velocity differences are large since they move in opposite directions so that a long ridge develops in $\Delta\eta$ direction in the graph.

Ideal QCD plasma would predict no correlations between particles and therefore no structures like this. The radiation of particles would be like blackbody radiation with no correlations between photons. The description in terms of string like object proposed also by Lubos Motl on basis of analysis of the graph showing the distributions as an explanation of correlations looks attractive.

The decay of a string like structure producing particles at its both ends moving nearly parallel to the string to opposite directions could be in question.

Since the densities of particles approach those at RHIC, I would bet that the explanation (whatever it is!) of the hydrodynamical behavior observed at RHIC for some years ago should apply also now. The introduction of string like objects in this model was natural since in TGD framework even ordinary nuclei are string like objects with nucleons connected by color flux tubes [L2] , [L2]: this predicts a lot of new nuclear physics for which there is evidence. The basic idea was that in the high density hadronic color flux tubes associated with the colliding nucleon connect to form long highly entangled hadronic strings containing quark gluon plasma. The decay of these structures would explain the strange correlations. It must be however emphasized that in the recent case the initial state consists of two protons rather than heavy nuclei so that the long hadronic string could form from the QCD like quark gluon plasma at criticality when long range fluctuations emerge.

The main assumptions of the model for the RHIC events and those observed now deserve to be summarized. Consider first the "macroscopic description".

1. A critical system associated with confinement-deconfinement transition of the quark-gluon plasma formed in the collision and inhibiting long range correlations would be in question.

2. The proposed hydrodynamic space-time description was in terms of a scaled variant of what I call critical cosmology defining a universal space-time correlate for criticality: the specific property of this cosmology is that the mass contained by comoving volume approaches to zero at the initial moment so that Big Bang begins as a silent whisper and is not so scaring. Criticality means flat 3-space instead of Lobatchevski space and means breaking of Lorentz invariance to SO(4). Breaking of Lorentz invariance was indeed observed for particle distributions but now I am not so sure whether it has much to do with this.

3. The system behaves like almost perfect fluid in the sense that the viscosity entropy ratio is near to its lower bound whose values is predicted by string theory considerations to be $\eta/s = \hbar/4\pi$.

The microscopic level the description would be like follows.

1. A highly entangled long hadronic string like object (color-magnetic flux tube) would be formed at high density of nucleons via the fusion of ordinary hadronic color-magnetic flux tubes to much longer one and containing quark gluon plasma. In QCD world plasma would not be at flux tube.

2. This geometrically (and perhaps also quantally!) entangled string like object would straighten and split to hadrons in the subsequent "cosmological evolution" and yield large numbers of almost collinear particles. The initial situation should be apart from scaling similar as in cosmology where a highly entangled soup of cosmic strings (magnetic flux tubes) precedes the space-time as we understand it. Maybe ordinary cosmology could provide analogy as galaxies arranged to form linear structures?

3. This structure would have also black hole like aspects but in totally different sense as the 10-D hadronic black-hole proposed by Nastase to describe the findings. Note that M-theorists identify black holes as highly entangled strings: in TGD 1-D strings are replaced by 3-D string like objects.

This picture leaves does not yet make the perfect fluid behavior obvious. The following argument relates it to the properties of the preferred extremals of Kähler action.

Almost perfect fluids seems to be abundant in Nature. For instance, QCD plasma was originally thought to behave like gas and therefore have a rather high viscosity to entropy density ratio $x = \eta/s$. Already RHIC found that it however behaves like almost perfect fluid with x near to the minimum predicted by AdS/CFT. The findings from LHC gave additional conform the discovery [C15]. Also Fermi gas is predicted on basis of experimental observations to have at low temperatures a low viscosity roughly 5-6 times the minimal value [D2] . In the following the argument that the preferred extremals of Kähler action are perfect fluids apart from the symmetry breaking to space-time sheets is developed. The argument requires some basic formulas summarized first.

The detailed definition of the viscous part of the stress energy tensor linear in velocity (oddness in velocity relates directly to second law) can be found in [D1] .

1. The symmetric part of the gradient of velocity gives the viscous part of the stress-energy tensor as a tensor linear in velocity. Velocity gradient decomposes to a term traceless tensor term and a term reducing to scalar.

$$\partial_i v_j + \partial_j v_i = \frac{2}{3}\partial_k v^k g_{ij} + (\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{3.14}$$

   The viscous contribution to stress tensor is given in terms of this decomposition as

$$\sigma_{visc;ij} = \zeta \partial_k v^k g_{ij} + \eta(\partial_i v_j + \partial_j v_i - \frac{2}{3}\partial_k v^k g_{ij}) \ . \tag{3.15}$$

   From $dF^i = T^{ij}S_j$ it is clear that bulk viscosity ζ gives to energy momentum tensor a pressure like contribution having interpretation in terms of friction opposing. Shear viscosity η corresponds to the traceless part of the velocity gradient often called just viscosity. This contribution to the stress tensor is non-diagonal and corresponds to momentum transfer in directions not parallel to momentum and makes the flow rotational. This term is essential for the thermal conduction and thermal conductivity vanishes for ideal fluids.

2. The 3-D total stress tensor can be written as

$$\sigma_{ij} = \rho v_i v_j - p g_{ij} + \sigma_{visc;ij} \ . \tag{3.16}$$

   The generalization to a 4-D relativistic situation is simple. One just adds terms corresponding to energy density and energy flow to obtain

$$T^{\alpha\beta} = (\rho - p) u^\alpha u^\beta + p g^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{3.17}$$

   Here u^α denotes the local four-velocity satisfying $u^\alpha u_\alpha = 1$. The sign factors relate to the concentrations in the definition of Minkowski metric $((1, -1, -1, -1))$.

3. If the flow is such that the flow parameters associated with the flow lines integrate to a global flow parameter one can identify new time coordinate t as this flow parameter. This means a transition to a coordinate system in which fluid is at rest everywhere (comoving coordinates in cosmology) so that energy momentum tensor reduces to a diagonal term plus viscous term.

$$T^{\alpha\beta} = (\rho - p) g^{tt} \delta^\alpha_t \delta^\beta_t + p g^{\alpha\beta} - \sigma^{\alpha\beta}_{visc} \ . \tag{3.18}$$

   In this case the vanishing of the viscous term means that one has perfect fluid in strong sense.

   The existence of a global flow parameter means that one has

$$v_i = \Psi \partial_i \Phi \ . \tag{3.19}$$

   Ψ and Φ depend on space-time point. The proportionality to a gradient of scalar Φ implies that Φ can be taken as a global time coordinate. If this condition is not satisfied, the perfect fluid property makes sense only locally.

AdS/CFT correspondence allows to deduce a lower limit for the coefficient of shear viscosity as

$$x = \frac{\eta}{s} \geq \frac{\hbar}{4\pi} . \tag{3.20}$$

This formula holds true in units in which one has $k_B = 1$ so that temperature has unit of energy.

What makes this interesting from TGD view is that in TGD framework perfect fluid property in appropriately generalized sense indeed characterizes locally the preferred extremals of Kähler action defining space-time surface.

1. Kähler action is Maxwell action with U(1) gauge field replaced with the projection of CP_2 Kähler form so that the four CP_2 coordinates become the dynamical variables at QFT limit. This means enormous reduction in the number of degrees of freedom as compared to the ordinary unifications. The field equations for Kähler action define the dynamics of space-time surfaces and this dynamics reduces to conservation laws for the currents assignable to isometries. This means that the system has a hydrodynamic interpretation. This is a considerable difference to ordinary Maxwell equations. Notice however that the "topological" half of Maxwell's equations (Faraday's induction law and the statement that no non-topological magnetic are possible) is satisfied.

2. Even more, the resulting hydrodynamical system allows an interpretation in terms of a perfect fluid. The general ansatz for the preferred extremals of field equations assumes that various conserved currents are proportional to a vector field characterized by so called Beltrami property. The coefficient of proportionality depends on space-time point and the conserved current in question. Beltrami fields by definition is a vector field such that the time parameters assignable to its flow lines integrate to single global coordinate. This is highly non-trivial and one of the implications is almost topological QFT property due to the fact that Kähler action reduces to a boundary term assignable to wormhole throats which are light-like 3-surfaces at the boundaries of regions of space-time with Euclidian and Minkowskian signatures. The Euclidian regions (or wormhole throats, depends on one's tastes) define what I identify as generalized Feynman diagrams.

   Beltrami property means that if the time coordinate for a space-time sheet is chosen to be this global flow parameter, all conserved currents have only time component. In TGD framework energy momentum tensor is replaced with a collection of conserved currents assignable to various isometries and the analog of energy momentum tensor complex constructed in this manner has no counterparts of non-diagonal components. Hence the preferred extremals allow an interpretation in terms of perfect fluid without any viscosity.

This argument justifies the expectation that TGD Universe is characterized by the presence of low-viscosity fluids. Real fluids of course have a non-vanishing albeit small value of x. What causes the failure of the exact perfect fluid property?

1. Many-sheetedness of the space-time is the underlying reason. Space-time surface decomposes into finite-sized space-time sheets containing topologically condensed smaller space-time sheets containing.... Only within given sheet perfect fluid property holds true and fails at wormhole contacts and because the sheet has a finite size. As a consequence, the global flow parameter exists only in given length and time scale. At embedding space level and in zero energy ontology the phrasing of the same would be in terms of hierarchy of causal diamonds (CDs).

2. The so called eddy viscosity is caused by eddies (vortices) of the flow. The space-time sheets glued to a larger one are indeed analogous to eddies so that the reduction of viscosity to eddy viscosity could make sense quite generally. Also the phase slippage phenomenon of super-conductivity meaning that the total phase increment of the super-conducting order parameter is reduced by a multiple of 2π in phase slippage so that the average velocity proportional to the increment of the phase along the channel divided by the length of the channel is reduced by a quantized amount.

The standard arrangement for measuring viscosity involves a lipid layer flowing along plane. The velocity of flow with respect to the surface increases from $v = 0$ at the lower boundary to v_{upper} at the upper boundary of the layer: this situation can be regarded as outcome of the dissipation process and prevails as long as energy is fed into the system. The reduction of the velocity in direction orthogonal to the layer means that the flow becomes rotational during dissipation leading to this stationary situation.

This suggests that the elementary building block of dissipation process corresponds to a generation of vortex identifiable as cylindrical space-time sheets parallel to the plane of the flow and orthogonal to the velocity of flow and carrying quantized angular momentum. One expects that vortices have a spectrum labelled by quantum numbers like energy and angular momentum so that dissipation takes in discrete steps by the generation of vortices which transfer the energy and angular momentum to environment and in this manner generate the velocity gradient.

3. The quantization of the parameter x is suggestive in this framework. If entropy density and viscosity are both proportional to the density n of the eddies, the value of x would equal to the ratio of the quanta of entropy and kinematic viscosity η/n for single eddy if all eddies are identical. The quantum would be $\hbar/4\pi$ in the units used and the suggestive interpretation is in terms of the quantization of angular momentum. One of course expects a spectrum of eddies so that this simple prediction should hold true only at temperatures for which the excitation energies of vortices are above the thermal energy. The increase of the temperature would suggest that gradually more and more vortices come into play and that the ratio increases in a stepwise manner bringing in mind quantum Hall effect. In TGD Universe the value of h_{eff} can be large in some situations so that the quantal character of dissipation could become visible even macroscopically. Whether this a situation with large h_{eff} is encountered even in the case of QCD plasma is an interesting question.

The following poor man's argument tries to make the idea about quantization a little bit more concrete.

1. The vortices transfer momentum parallel to the plane from the flow. Therefore they must have momentum parallel to the flow given by the total cm momentum of the vortex. Before continuing some notations are needed. Let the densities of vortices and absorbed vortices be n and n_{abs} respectively. Denote by $v_{\parallel}$ *resp.* $v_{\perp}$ the components of cm momenta parallel to the main flow *resp.* perpendicular to the plane boundary plane. Let m be the mass of the vortex. Denote by S are parallel to the boundary plane.

2. The flow of momentum component parallel to the main flow due to the absorbed at S is

$$n_{abs} m v_{\parallel} v_{\perp} S \ . \tag{3.21}$$

This momentum flow must be equal to the viscous force

$$F_{visc} = \eta \frac{v_{\parallel}}{d} \times S \ . \tag{3.22}$$

From this one obtains

$$\eta = n_{abs} m v_{\perp} d \ . \tag{3.23}$$

If the entropy density is due to the vortices, it equals apart from possible numerical factors to

$$s = n$$

so that one has

$$\frac{\eta}{s} = mv_{\perp}d \ . \tag{3.24}$$

This quantity should have lower bound $x = \hbar/4\pi$ and perhaps even quantized in multiples of x, Angular momentum quantization suggests strongly itself as origin of the quantization.

3. Local momentum conservation requires that the comoving vortices are created in pairs with opposite momenta and thus propagating with opposite velocities $v_{\perp}$. Only one half of vortices is absorbed so that one has $n_{abs} = n/2$. Vortex has quantized angular momentum associated with its internal rotation. Angular momentum is generated to the flow since the vortices flowing downwards are absorbed at the boundary surface.

   Suppose that the distance of their center of mass lines parallel to plane is $D = \epsilon d$, ϵ a numerical constant not too far from unity. The vortices of the pair moving in opposite direction have same angular momentum $mv \ \ D/2$ relative to their center of mass line between them. Angular momentum conservation requires that the sum these relative angular momenta cancels the sum of the angular momenta associated with the vortices themselves. Quantization for the total angular momentum for the pair of vortices gives

$$\frac{\eta}{s} = \frac{n\hbar}{\epsilon} \tag{3.25}$$

   Quantization condition would give

$$\epsilon = 4\pi \ . \tag{3.26}$$

   One should understand why $D = 4\pi d$ - four times the circumference for the largest circle contained by the boundary layer- should define the minimal distance between the vortices of the pair. This distance is larger than the distance d for maximally sized vortices of radius $d/2$ just touching. This distance obviously increases as the thickness of the boundary layer increases suggesting that also the radius of the vortices scales like d.

4. One cannot of course take this detailed model too literally. What is however remarkable that quantization of angular momentum and dissipation mechanism based on vortices identified as space-time sheets indeed could explain why the lower bound for the ratio η/s is so small.

3.7 Evidence For TGD View About QCD Plasma

The emergence of the first interesting findings from LHC by CMS collaboration [C18, C3] provide new insights to the TGD picture about the phase transition from QCD plasma to hadronic phase and inspired also the updating of the model of RHIC events (mainly elimination of some remnants from the time when the ideas about hierarchy of Planck constants had just born).

In some proton-proton collisions more than hundred particles are produced suggesting a single object from which they are produced. Since the density of matter approaches to that observed in heavy ion collisions for five years ago at RHIC, a formation of quark gluon plasma and its subsequent decay is what one would expect. The observations are not however quite what QCD plasma picture would allow to expect. Of course, already the RHIC results disagreed with what QCD expectations. What is so striking is the evolution of long range correlations between particles in events containing more than 90 particles as the transverse momentum of the particles increases in the range 1-3 GeV (see the excellent description of the correlations by Lubos Motl in his blog [C9]).

One studies correlation function for two particles as a function of two variables. The first variable is the difference $\Delta\phi$ for the emission angles and second is essentially the difference for the velocities described relativistically by the difference $\Delta\eta$ for hyperbolic angles. As the transverse momentum p_T increases the correlation function develops structure. Around origin of $\Delta\eta$ axis a widening plateau develops near $\Delta\phi = 0$. Also a wide ridge with almost constant value as function of $\Delta\eta$ develops near $\Delta\phi = \pi$. The interpretation is that particles tend to move collinearly and or in opposite directions. In the latter case their velocity differences are large since they move in opposite directions so that a long ridge develops in $\Delta\eta$ direction in the graph.

Ideal QCD plasma would predict no correlations between particles and therefore no structures like this. The radiation of particles would be like blackbody radiation with no correlations between photons. The description in terms of string like object proposed also by Lubos Motl on basis of analysis of the graph showing the distributions as an explanation of correlations looks attractive. The decay of a string like structure producing particles at its both ends moving nearly parallel to the string to opposite directions could be in question.

Since the densities of particles approach those at RHIC, I would bet that the explanation (whatever it is!) of the hydrodynamical behavior observed at RHIC for some years ago should apply also now. The introduction of string like objects in this model was natural since in TGD framework even ordinary nuclei are string like objects with nucleons connected by color flux tubes [L2] , [L2] : this predicts a lot of new nuclear physics for which there is evidence. The basic idea was that in the high density hadronic color flux tubes associated with the colliding nucleon connect to form long highly entangled hadronic strings containing quark gluon plasma. The decay of these structures would explain the strange correlations. It must be however emphasized that in the recent case the initial state consists of two protons rather than heavy nuclei so that the long hadronic string could form from the QCD like quark gluon plasma at criticality when long range fluctuations emerge.

The main assumptions of the model for the RHIC events and those observed now deserve to be summarized. Consider first the "macroscopic description".

1. A critical system associated with confinement-deconfinement transition of the quark-gluon plasma formed in the collision and inhibiting long range correlations would be in question.

2. The proposed hydrodynamic space-time description was in terms of a scaled variant of what I call critical cosmology defining a universal space-time correlate for criticality: the specific property of this cosmology is that the mass contained by comoving volume approaches to zero at the initial moment so that Big Bang begins as a silent whisper and is not so scaring. Criticality means flat 3-space instead of Lobatchevski space and means breaking of Lorentz invariance to SO(4). Breaking of Lorentz invariance was indeed observed for particle distributions but now I am not so sure whether it has much to do with this.

The microscopic level the description would be like follows.

1. A highly entangled long hadronic string like object (color-magnetic flux tube) would be formed at high density of nucleons via the fusion of ordinary hadronic color-magnetic flux tubes to much longer one and containing quark gluon plasma. In QCD world plasma would not be at flux tube.

2. This geometrically (and perhaps also quantally!) entangled string like object would straighten and split to hadrons in the subsequent "cosmological evolution" and yield large numbers of almost collinear particles. The initial situation should be apart from scaling similar as in cosmology where a highly entangled soup of cosmic strings (magnetic flux tubes) precedes the space-time as we understand it. Maybe ordinary cosmology could provide analogy as galaxies arranged to form linear structures?

3. This structure would have also black hole like aspects but in totally different sense as the 10-D hadronic black-hole proposed by Nastase to describe the findings. Note that M-theorists identify black holes as highly entangled strings: in TGD 1-D strings are replaced by 3-D string like objects.

4 Duality Between Low Energy And High Energy Descriptions Of Hadron Physics

I found the talk of Matthew Schwartz titled *The Emergence of Jets at the Large Hadron Collider* (see `http://tinyurl.com/y98o9hg4`) [C51] belonging to the Monday Colloqium Series at Harward. The talk told about the history of the notion of jet and how it is applied at LHC. The notion of jet is something between perturbative and non-perturbative QCD and therefore not a precisely defined concept as one approaches small mass limit for jets.

The talk inspired some questions relating to QCD and hadron physics in general. I am of course not competent to say anything interesting about jet algorithms. Hadronization process is however not well understood in the framework of QCD and uses phenomenological fragmentation functions. The description of jet formation in turn uses phenomenological quark distribution functions. TGD leads to a rather detailed fresh ideas about what quarks, gluons, and hadrons are and stringy and QFT like descriptions emerge as excellent candidates for low and high energy descriptions of hadrons. Low energies are the weakness of QCD and one can well ask whether QCD fails as a physical theory at infrared. Could TGD do better in this respect?

Only a minor fraction of the rest energy of proton is in the form of quarks and gluons. In TGD framework these degrees of freedom would naturally correspond to color magnetic flux tubes carrying color magnetic energy and in proton-proton collisions the color magnetic energy of p-p system in cm system is gigantic. The natural question is therefore about what happens to the "color magnetic bodies" of the colliding protons and of quarks in proton-proton collision.

In the sequel I will develop a simple argument leading to a very concrete duality between two descriptions of hadron reactions manifest at the level of generalized Feynman graphs. The first description is in terms of meson exchanges and applies naturally in long scales. Second one is terms of perturbative QCD applying in short scales. The basic ingredients of the argument are the weak form of electric-magnetic duality [K29] and bosonic emergence leading to a rather concrete view about physical particles, generalized Feynman diagrams reducing to generalized braid diagrams in the framework of zero energy ontology (ZEO), and reconnection of Kähler magnetic flux tubes having interpretation in terms of string diagrams providing the mechanism of hadronization. Basically the prediction follows from the dual interpretations of generalized Feynman diagrams either as stringy diagrams (low energies) or as Feynman diagrams (high energies).

It must be emphasized that this duality is something completely new and a simple prediction of the notion of generalized Feynman diagram. The result is exact: no limits (such as large N limit) are needed.

4.1 Weak Form Of Electric Magnetic Duality And Bosonic Emergence

The weak form of electric magnetic duality allows the identification of quark wormhole throats as Kähler magnetic monopoles with non-vanishing magnetic charges Q_m. The closely related bosonic emergence effectively eliminates the fundamental BFF vertices from the theory.

1. Elementary fermion corresponds to single wormhole throat with Kähler magnetic charge. In topological condensation a wormhole throat is formed and the working hypothesis is that the second throat is Kähler magnetically neutral. The throats created in topological condensation (formation of topological sum) are always homologically trivial since purely local process is in question.

2. In absence of topological condensation physical leptons correspond to string like objects with opposite Kähler magnetic charges at the ends. Topologically condensed lepton carries also neutralizing weak isospin carried by neutrino pair at the throats of the neutralizing wormhole contact. Wormhole contact itself carries no Kähler magnetic flux. The neutralization scale for Q_m and weak isospin could be either weak length scale for both fermions and bosons. The alternative option is Compton length quite generally - this even for fermions since it is enough that the weak isospin of weak bosons is neutralized in the weak scale. The alert reader have of course asked whether the weak isospin of fermion must be neutralized at all if this is the case. Whether this really happens is not relevant for the following arguments.

3. Whether a given quark is accompanied by a wormhole contact neutralizing its weak isospin is not quite clear: this need not be the case since the Compton length of weak bosons defines the range of weak interactions. Therefore one can consider the possibility that physical quarks have non-vanishing Q_m and that only hadrons have $Q_m = 0$. Now the Kähler magnetic flux tubes would connect valence quarks. In the case of proton one would have three of them. About 31 year old proposal is that color hyper charge is proportional to Kähler magnetic charge. If so then color confinement would require Kähler magnetic confinement.

4. By bosonic emergence bosons correspond to wormhole contacts or pairs of them. Now wormhole throats have opposite values of Q_m but the contact itself carries vanishing Kähler magnetic flux. Fermion and anti-fermion are accompanied by neutralizing Kähler magnetic charge at the ends of their flux tubes and neutrino pair at its throats neutralizes the weak charge of the boson.

4.2 The Dual Interpretations Of Generalized Feynman Diagrams In Terms Of Hadronic And Partonic Reaction Vertices

Generalized Feynman diagrams are defined in the framework of zero energy ontology (ZEO). Bosonic emergence eliminates fundamental BFF vertices and reduces generalized Feynman diagrams to generalized braid diagrams. This is essential for the dual interpretation of the qqg vertex as a meson emission vertex for hadron. The key idea is following.

1. Topologically condensed hadron - say proton- corresponds to a double sheeted structure: let us label the sheets by letters A and B. Suppose that the sheet A contains wormhole throats of quarks carrying magnetic charges. These wormhole throats are connected by magnetically neutral wormhole contact to sheet B for which wormhole throats carry vanishing magnetic charges.

2. What happens when hadronic quark emits a gluon is easiest to understand by considering first the annihilation of topologically non-condensed charged lepton and antilepton to photon - that is $L+\overline{L} \rightarrow \gamma$ vertex. Lepton and antilepton are accompanied by flux tubes at different space-time sheets A and B and each has single wormhole throat: one can speak of a pair of topologically condensed deformations of CP_2 type vacuum extremals as a correlate for single wormhole throat. At both ends of the flux tubes deformations o fCP_2 type vacuum extremals fuse via topological sum to form a pair of photon wormhole contacts carrying no Kähler magnetic flux. The condition that the resulting structure has the size of weak gauge boson suggests that weak scale defines also the size of leptons and quarks as magnetic flux tubes. Quarks can however carry net Kähler magnetic charge (the ends of flux tube do not have opposite values of Kähler magnetic charge.

3. With some mental gymnastics the annihilation vertex $L+\overline{L} \rightarrow \gamma$ can be deformed to describe photon emission vertex $L \rightarrow L + \gamma$: The negative energy antilepton arrives from future and positive energy lepton from the past and they fuse to a virtual photon in the manner discussed.

4. qqg vertex requires further mental gymnastics but locally nothing is changed since the protonic quark emitting the gluon is connected by a color magnetic flux tube to another protonic quark in the case of incoming proton (and possibly to neutrino carrying wormhole contact with size given by the weak length scale). What happens is therefore essentially the same as above. The protonic quark has become part of gluon at space-time sheet A but has still flux tube connection to proton. Besides this there appears wormhole throat at space-time sheet B carrying quark quantum numbers: this quark would in the usual picture correspond to the quark after gluon emission and antiquark at the same space-time sheet associated with the gluon. Therefore one has proton with one quark moving away inside gluon at sheet A and a meson like entity at sheet B. The dual interpretation as the emission of meson by proton makes sense. This vertex does not correspond to the stringy vertex $AB + CD \rightarrow AD + BC$ in which strings touch at some point of the interior and recombine but is something totally new and made possible by many-sheeted space-time. For gauge boson magnetically charge throats are at different space-time sheets, for meson they at the same space-time sheet and connected by Kähler magnetic flux tube.

5. Obviously the interpretation as an emission of meson like entity makes sense for any hadron like entity for which quark or antiquark emits gluon. This is what the duality of hadronic and parton descriptions would mean. Note that bosonic emergence is absolutely essential element of this duality. In QCD it is not possible to understand this duality at the level of Feynman diagrams.

4.3 Reconnection Of Color Magnetic Flux Tubes

The reconnection of color magnetic flux tubes is the key mechanism of hadronization and a slow process as compared to quark gluon emission.

1. Reconnection vertices have interpretation in terms of stringy vertices $AB+CD \rightarrow AD+BC$ for which interiors of strings serving as representatives of flux tubes touch. The first guess is that reconnection is responsible for the low energy dynamics of hadronic collisions.

2. Reconnection process takes place for both the hadronic color magnetic flux tubes and those of quarks and gluons. For ordinary hadron physics hadrons are characterized by Mersenne prime M_{107}. For M_{89} hadron physics reconnection process takes place in much shorter scales for hadronic flux tubes.

3. Each quarks is characterized by p-adic length scales: in fact this scale characterizes the length scale of the magnetic bodies of the quark. Therefore Reconnection at the level of the magnetic bodies of quarks take places in several time and length scales. For top quark the size scale of magnetic body is very small as is also the reconnection time scale. In the case of u and d quarks with mass in MeV range the size scale of the magnetic body would be of the order of electron Compton length. This scale assigned with quark is longer than the size scale of hadrons characterized by M_{89}. Classically this does not make sense but in quantum theory Uncertainty Principle predicts it from the smallness of the light quark masses as compared to the hadron mass. The large size of the color magnetic body of quark could explain the strange finding about the charge radius of proton [K12].

4. For instance, the formation of quark gluon plasma would involve reconnection process for the magnetic bodies of colliding protons or nuclei in short time scale due to the Lorentz contraction of nuclei in the direction of the collision axis. Quark-gluon plasma would correspond to a situation in which the magnetic fluxes are distributed in such a way that the system cannot be decomposed to hadrons anymore but acts like a single coherent unit. Therefore quark-gluon plasma in TGD sense does not correspond to the thermal quark-gluon plasma in the naïve QCD sense in which there are no long range correlations.

   Long range correlations and quantum coherence suggest that the viscosity to entropy ratio is low as indeed observed [K12]. The earlier arguments suggest that the preferred extremals of Kähler action have interpretation as perfect fluid flows [K29]. This means at given space-time sheet allows global time coordinate assignable to flow lines of the flow and defined by conserved isometry current defining Beltrami flow. As a matter fact, all conserved currents are predicted to define Beltrami flows. Classically perfect fluid flow implies that viscosity, which is basically due to a mixing causing the loss of Beltrami property, vanishes. Viscosity would be only due to the finite size of space-time sheets and the radiative corrections describable in terms of fractal hierarchy CDs within CDs. In quantum field theory radiative corrections indeed give rise to the absorbtive parts of the scattering amplitudes.

4.4 Hadron-Parton Duality And TGD As A "Square Root" Of The Statistical QCD Description

The main result is that generalized Feynman diagrams have dual interpretations as QCD like diagrams describing partonic reactions and stringy diagrams describing hadronic reactions so that these matrix elements can be taken between either hadronic states or partonic states. This duality is something completely new and distinguishes between QCD and TGD.

I have proposed already earlier this kind of duality but based on group theoretical arguments inspired by what I call $M^8-M^4\times CP_2$ duality [K29] and two hypothesis of the old fashioned hadron physics stating that vector currents are conserved and axial currents are partially conserved. This duality suggests that the group $SO(4) = SU(2)_L \times SU(2)_R$ assignable to weak isospin degrees of freedom takes the role of color group at long length scales and can be identified as isometries of $E^4 \subset M^8$ just like $SU(3)$ corresponds to the isometries of CP_2.

Initial and final states correspond to positive and negative energy parts of zero energy states in ZEO. These can be regarded either partonic or hadronic many particle states. The inner products between *positive* energy parts of partonic and hadronic state basis define the "square roots" of the parton distribution functions for hadrons. The inner products of between *negative* energy parts of hadronic and partonic state basis define the "square roots" of the fragmentations functions to hadrons for partons. M-matrix defining the time-like entanglement coefficients is representable as product of hermitian square root of density matrix and S-matrix is not time reversal invariant and this partially justifies the use of statistical description of partons in QCD framework using distribution functions and fragmentation functions. Decoherence in the sum over quark intermediate states for the hadronic scattering amplitudes is essential for obtaining the standard description.

5 Quark Gluon Plasma In TGD Framework

This section was inspired by an an excellent talk by Dam Thanh Son (see `http://tinyurl.com/y9o87jz2`) in Harward Monday seminar series [C25]. The title of the talk was *Viscosity, Quark Gluon Plasma, and String Theory.* What the talk represents is a connection between three notions which one would not expect to have much to do with each other.

In the following I shall briefly summarize the basic points of Son's talk which I warmly recommend for anyone wanting to sharpen his or her mental images about quark gluon plasma.

1. Besides this I discuss a TGD variant of AdS/CFT correspondence (see `http://tinyurl.com/2zuek8`) based on string-parton duality allowing a concrete identification of the process leading to the formation of strongly interacting quark gluon plasma.

   "Strongly interacting" means that partonic 2-surfaces are connected by Kähler magnetic flux tubes making the many-hadron system single large hadron in the optimal case rather than a gas of uncorrelated partons. This allows a concrete generalization of the formula of kinetic gas theory for the viscosity.

3. One ends up also to a concrete interpretation for the formula for the η/s ratio in terms of TGD variant of Einsteinian gravitation and the analogs of black-hole horizons identified as partonic 2-surfaces. This gravitation is not fictive gravitation in 10-D space but real sub-manifold gravitation in 4-D space-time.

4. It is essential that TGD does not assume gravitational constant as a fundamental constant but as a prediction of theory depending on the p-adic length scale and the typical value of Kähler action for the lines of generalized Feynman graphs. Feeding in the notion of gravitational Planck constant, one finds beautiful interpretation for the lower limit viscosity which is smaller than the one predicted by AdS-CFT correspondence.

5.1 Some Points In Son's Talk

Son discusses first the notion of shear viscosity at undergraduate level - as he expresses it. First the standard Wikipedia definition for shear viscosity (see `http://tinyurl.com/6exr4l`) is discussed in terms of the friction forces created in a system consisting two parallel plates containing liquid between them as one moves a plate with respect to another parallel plate.

Son explains how Maxwell explains the viscosity of gases in terms of kinetic gas theory and entered with a strange result: the estimate $\eta = \rho v l_{free}$ leads to the conclusion that the viscosity has no pressure dependence: Maxwell himself verified the result experimentally. Imagining that the interaction of gas molecules can be reduced to zero leads to a paradox: the viscosity of the ideal gas is infinite. The solution of the paradox is simple: the theory applies only if l_{free} is considerably smaller than the size scale of the system, say the distance between the two plates, one of which is moving.

Son discusses the viscosity for some condensed matter systems and finds that the value of viscosity increases very rapidly as a function of temperature: does this mean a rapid increase of l_{free} with temperature? Son also notices that the viscosity seems to be bounded from below. Son discusses also η/s ratio for the condensed matter systems and finds that it is typically by a factor 10-100 larger than the minimal values $\hbar/4\pi$ suggested by AdS/CFT correspondence (see http://tinyurl.com/2zuek8) [B9].

Son describes gauge-gravity duality briefly. AdS/CFT approach does not allow simple arguments analogous to those used in the kinetic theory of gases.

1. One central formula is Kubo's formula giving viscosity as the low frequency limit for the Fourier component of the component of energy momentum tensor commutation $[T^{yx}(x,t), T^{yx}(0,0)]$ as

   $$\eta = \frac{1}{2\hbar\omega}\int \langle [T^{yx}(x,t), T^{yx}(0,0)]\, d^4x\rangle_{\omega\rightarrow 0}$$

   for$\mathcal{N}=4$ SUSY defined in M^4. Now this theory is $\mathcal{N}=4$ SUSY so that there is no hope about simple interpretation. Note that the formula is consistent with the dimensions of viscosity which is M/L^3. I confess that I do not understand the origin of the formula at the level details. Green-Kubo relations (see http://tinyurl.com/ybzv2kkh) [B4] are certainly the starting point having very general justification as an outcome of fluctuation theorem (see http://tinyurl.com/cs24x4) [B3] allowing understood relatively easily in Gaussian model for thermodynamics. Since energy momentum tensor serves as a source of gravitons and is the basic observable in hydrodynamics, it is clear that this formula is consistent with gauge theory-gravity correspondence. $\omega \rightarrow 0$ limit means that the low energy sector of the gauge theory is in question so that the perturbative approach fails.

2. In TGD framework the analog of this formula need not be useful. If it apply it should apply to partonic 2-surfaces and $AdS_5\times S_5$ should be replaced with space-time surface. The energy momentum tensor should be the energy momentum tensor of partonic 2-surface fixed to a high degree by conformal invariance. One should sum over all partonic 2-surfaces. The partonic 2-surfaces would correspond to both ends of a braid strands at the opposite light-like boundaries of CD. The integral at the level of the partonic 2-surface is now only 2-dimensional and the dimension of η would be $1\hbar/L$ in this case. In the kinetic gas theory formula this follows from the fact that mass density has now dimension m/L rather than m/L^3. The summation over the partonic 2-surfaces could correspond in many particle system integration. I tend to see this kind of approach as too formal.

AdS/CFT duality [B9] reduces the calculation of the viscosity to that for the graviton absorption cross section for $AdS_5\times S_5$ black hole when the N-stack of branes is replaced with a brane black hole in $AdS_5\times S^5$. Viscosity is is reduced essentially to the area of the black-hole multiplied by Planck constant. Since the dimension of 4-D viscosity is $\hbar/L^3$, the area must be measured using Planck length squared G as a unit. Is viscosity the number density multiplied by this dimensionless quantity? I must admit that I do not really understand this result.

5.2 What Is Known About Quark-Gluon Plasma?

Son sums up some facts about quark-gluon plasma and they are included in the following summary about what little I know.

1. The first surprise was produced by RHIC (see http://tinyurl.com/y8n2kaxo) observing that the viscosity to entropy density ratio for quark gluon plasma is near $\hbar/4\pi$ -its lower limit as predicted by AdS/CFT duality. The low value of η/s ratio does not mean that the viscosity would be low. As a matter fact it is gigantic - of order 10^{14} centipoise and therefore 14 orders of magnitude higher than for water! Glass is the the only condensed matter system possessing a higher viscosity in the list of Son. The challenge is to understand why the ratio is so small in terms of QCD or perhaps a theory transcending the limitations of QCD at low energies. From Kubo's formula it is clear that the low energy limit of QCD is indeed needed to understand the viscosity.

2. In the nuclear collisions allowing to deduce information about viscosity the nuclei do not collide quite head on. The time of collision is short due to the Lorentz contraction. The projection of the collision region in the plane orthogonal to the collision axes is almond shaped so that rotational symmetry is lost and implies that viscous forces enters the game. If the system reaches thermal equilibrium, the notion of pressure make senses. The force caused by the pressure gradient is stronger in transversal than longitudinal direction of almond since the almond in transversal direction is shorter than in longitudinal direction. That jets in this direction are more energetic supports the view that pressure is a well-defined concept. On the other hand, the viscous force in the longitudinal direction is large and tends to compensate this effect. This effect gives hopes of measuring the viscosity.

3. η/s ratio seems to be near $\hbar/4\pi$ for the quark-gluon plasma formed in both heavy ion collisions and in proton-proton collisions although the energy scales are quite different. This is not expected on basis of the strong temperature dependence of viscosity in condensed matter systems.

4. On basis of RHIC results ee `http://tinyurl.com/y8n2kaxo`) [C8, C45] for heavy ion collisions and the LHC results for proton-proton collisions, which unexpectedly demonstrated similar plasma behavior for proton-proton collisions one can conclude that quark gluon plasma is a strongly interacting system. The temperature assignable to the quark-gluon plasma possibly formed in proton-proton collisions is of course must higher than at RHIC. Recently also the results from lead-lead collisions at LHC have emerged: the temperature of the plasma should be about 500 MeV as compared to the temperature 250 MeV at RHIC. In this case AdS/CFT duality gives hopes for describing the non-perturbative aspects of the system. This is just a hope: AdS/CFT correspondence requires many assumptions which might not hold true for the quark-gluon plasma and there are preliminary indications (see `http://tinyurl.com/or669lc`) [C57], which do not support AdS/CFT duality (see `http://tinyurl.com/yaseslrn`) [C1, C2]. The experiments favor a model in which the situation is described based old-fashioned Lund model (see `http://tinyurl.com/ycwv5ebe`) [C5] treating gluons as strings. This description is a a simplified version of the description provided by TGD.

5.3 Gauge-Gravity Duality In TGD Framework

AdS/CFT duality is one variant of a more general gauge-gravity duality. Gauge-gravity in turn involves several variants depending on whether one assumes that Einstein's curvature scalar provides a good approximation to the description of gravitational sector. This requires that higher spin excitations of string like objects are very heavy and can be neglected. It might be that since low energy limit is in question as is clear from Kubo's formula, the use of Einstein's action makes sense very generally.

5.3.1 String-gauge theory duality in TGD framework

If I were enemy of string theory and follower of the usual habits of my species, I would be very skeptic from the beginning. There are however no rational reasons to be hostile since string worlds sheets at 4-D space time sheets appear also in TGD and there very strong reasons to expect duality between QFT like descriptions and stringy description. I indeed discussed in previous section how this duality can be understood directly at the level of generalized Feynman diagrams as a kind of combinatorial identity. There is no need to introduce strings in $AdS_5 \times S^5$ as in the usual AdS/CFT approach and $N_c \to \infty$ implying the vanishing of the contribution of non-planar Feynman diagrams is not needed.

5.3.2 The reduction to Einsteinian gravity need not take place

String-gauge theory duality need not reduce QCD to Einsteinian gravity allowing modelling in terms of curvature scalar.

1. In TGD framework the physics for small deformations of vacuum extremals - whose number is gigantic (any Lagrangian sub-manifold of CP_2 defines a vacuum sector of the theory) -

would be governed by Einstein's equations. The value of gravitational constant is however dynamical and a little dimensional analysis argument suggests that the gravitational constant satisfies [K18]

$$G_{eff}(p) = L^2(k)exp(-2S_K) \ ,$$

where L_p is p-adic length scales associated with p-adic prime $p \simeq 2^k$ and S_K is the Kähler action for a deformation of CP_2 type vacuum extremal in general smaller than for full CP_2.

2. Ordinary gravitational constant would correspond to $p = M_{127} = 2^{127} - 1$ assignable to electron: M_{127} is the largest Mersenne prime which does not define a completely super-astrophysical p-adic length scale. The value of S_K would be almost maximal and induce an enormous reduction of the value of G.

3. For hadron physics S_K should not be large and in reasonable approximation this would give $G_{eff} \simeq \hbar L^2(k = 107)$. The deformations of CP_2 type vacuum extremals, whose M^4 projections are random light-like curves. are assignable to elementary particles such as gluons. In the case of hadrons these projections are expected to be short and so that the exponent is expected to be near unity. One might hope that these contributions dominate in the calculation of viscosity so that Einstein's picture indeed works.

4. In the case of hadron physics there are no strong reason to expect a general reduction to Einsteinian gravity. Higher spin states at the hadronic Regge trajectories are important and hadron physics does not reduce to gravitational theory involving the exchanges of only spin two strong gravitons.

   This requires additional assumption which the lecture of Son tried to clarify. The assumption is that the coordinate of AdS_5 orthogonal to its boundary M^4 representing 4-D Minkowski space represents scaling of the physical system and that the interactions in the bulk are ultra-local with respect to this coordinate. Only systems with same scale size interact. This assumption looks very strange to me but has analog in quantum TGD. Personally I would take this argument with a big grain of salt.

5.3.3 Reduction to hydrodynamics

The AdS_5/CFT duality in the strong form reduces the dynamics at the boundary of AdS_5 to Einstein's gravity in the interior of AdS and the N-stack of 3-branes corresponds to brane black-hole in $AdS_5 \times S_5$. There are also good reasons to expect that Einstein's gravity in turn reduces to hydrodynamics.

The field equations of TGD are conservation laws for isometry currents and Kähler currents plus their super counterparts. Also in hydrodynamics the basic equations reduce to conservation laws. The structural equations of hydrodynamics correspond to the identification of gauge fields and metrics as induced structures.

The reduction to 4-D hydrodynamics in much stronger sense is suggestive since a large class of preferred extremals of Kähler action have interpretation as hydrodynamic flows for which flow lines define coordinate curves of a global coordinate [K29]. Beltrami flows are in question. For instance, a magnetic field for which Lorentz force vanishes is a good example of 3-D Beltrami flow. There are good arguments in favor of the existence of a unique preferred coordinate system defined in terms of light-like local direction and its dual direction plus two orthogonal local polarization directions.

5.3.4 Could AdS/CFT duality have some interpretation in TGD framework?

In TGD framework the duality between strings and particles replacing AdS/CFT duality means the replacement of $AdS \times S_5$ with space-time surface represented as surface in $M^4 \times CP_2$. Furthermore M^4 is replaced with partonic 2-surfaces the super-conformal invariance of $\mathcal{N} = 4$ SUSY in M^4 is replaces with 2-D super-conformal invariance. Therefore the attempts to build analogies with AdS/CFT duality type description might be waste of time. The temptation for the search of analogies is however too high.

In the case of AdS/CFT duality for Minkowski space that coordinate of AdS_5 orthogonal to its M^4 boundary is interpreted as a scale parameter for the system and also has interpretation as a scalar field in M^4. Could this scaling degree have some sensible interpretation in TGD framework. What about the N-stack of 3-branes representing a copy of M^4 identified as the boundary of AdS_5?

1. In TGD framework the only physically sensible interpretation would be in terms of the hierarchy of Planck constants [K7]. The quantum size of the particle scales like $\hbar$ and is therefore integer valued. This suggests that the continuous AdS_5 coordinate orthogonal to M^4 could be replaced with the integer labeling the effective values of Planck constant and hence the local coverings of $M^4 \times CP_2$ providing a convenient description for the fact that -due to the enormous vacuum degeneracy of Kähler action- the time derivatives of the embedding space coordinates are multi-valued functions of the canonical momentum densities. Different coverings that they effectively correspond to different sectors of the effective embedding space which can be seen as a finite covering of $M^4 \times CP_2$. Only the particles with the same value of Planck constant can appear in the same vertex of generalized Feynman diagrams and this is nothing but the strange assumption made to guarantee the locality of AdS dynamics.

2. Same collapse of the sheets of the covering actually applies in the directions transversal to space-like and light-like 3-surfaces so that both of them represent branchings and the total number of branches in the interior os $n_1 n_2$.

3. One must assume that the sheets of the covering collapse at the partonic 2-surfaces and perhaps also at the string world sheets. This strange orbifold property brings strongly in mind the stack of N-branes which collapse to single 3 brane however remembering its N-stack property: for instance, a dynamical gauge group $SU(N) \times U(1)$ describing finite measurement resolution emerges. The loss of the infinitely thin stack property in the interior guarantees that N-stack property is not forgotten. I have indeed proposed that similar emergence of gauge groups allowing to represent finite measurement resolution in terms of gauge symmetry emerges also in TGD framework.

4. The effective dimensionless coupling in the perturbative expansion is $g^2 N/\hbar$ and for large N limit the series does not converge. If N corresponds to the number of colors for dynamically generated gauge group labeling colors, the substitution $\hbar = N\hbar_0$ however implies that the expansion parameter does not change at all so that the limit would be different from the usual $N \to \infty$ limit used to derive AdS/CFT duality.

An integrable QFT in M^2 identified as hyper-complex plane in number theoretic vision is necessary for interpreting generalized Feynman diagrams as generalized braids. One can of course ask whether one would have super-conformal QFT in M^2 and wheter AdS_3 could be replaced with its discrete version with normal coordinate identified as the integer characterizing the value of Planck constant. To me this approach seems highly artificial although it might make sense formally.

One can of course ask whether $M^4 \times CP_2$ could have some deep connection with $AdS_5 \times S_5$. This might be the case: CP_2 is obtained from S^5 by identifying all points of its geodesic circles and M^4 is obtained from AdS_5 by identifying all points of radial geodesics in the scaling direction.

5.3.5 Do black-holes in $AdS_5 \times S_5$ have TGD counterpart?

The black-holes in $AdS_5 \times S_5$ have very natural counterparts as regions of the space-time surfaces with Euclidian signature of the induced metric. These regions represent generalized Feynman diagrams. By holography one could restrict the consideration also to the partonic 2-surfaces at the ends of CDs and if string world sheets and partonic 2-surfaces are dual to string world sheets coming as Minkowskian and Euclidian variants.

Black-holes in TGD framework would have Euclidian metric and their presence is absolutely essential for reducing the functional integral to a genuine integral. Otherwise one would have the analog of path integral with the exponential of Kähler action defining a mere phase factor.

The entropy area law for the black-holes generalizes to p-adic thermodynamics and the p-adic mass squared value for the particle predicted by p-adic thermodynamics is essentially the p-adic entropy: both are mapped to the real sector by canonical identification. Also the black hole entropy is proportional to mass squared.

The gigantic value of the gravitational Planck constants brings in additional interpretational issues to be discussed later.

5.4 TGD View About Strongly Interacting Quark Gluon Plasma

The magnetic flux tubes/strings connecting quarks make the QCD plasma strongly interacting in TGD framework.

1. In the hadronic phase the network formed by these flux tubes decomposes to sub-networks assignable to the colliding protons. In the final state the sub-networks are associated with the outgoing hadrons. In the collision a network is formed in which the flux tubes can connect larger number of quarks and one obtains much longer cycles in the network as in the initial and final states. This can be regarded as a defining property of strongly interaction quark gluon plasma. In quantum world one obtains a quantum superposition over networks with different connectedness structures. The quark-gluon plasma is not ideal in quantum sense.

2. The presence of plasma blob predicts the reduction of jet production cross section. Typically a pair of jets is produced. If this occurs in deep interior of the plasma, the jets cannot escape the plasma. If this occurs near the surface of the plasma, the other jet escapes. This predicts reduction of the jet production cross section.

3. The decomposition to connected flux tube networks could explain why the experimentally detected ratio for jet production cross section nucleonic total scattering cross section is larger than the predicted one: the flux tube network would consist of disconnected network with a considerably property and for these the jet production cross section would not be so dramatically reduced by the fact that the other member of the never gets out from the plasma blob.

In TGD context the basic process leading to the formation of the quark-gluon plasma is reconnection for the flux tubes describable in terms of string diagrams $AB - CD \rightarrow AD + BC$. In the case of ordinary quark gluon plasma the density is so high that nucleons overlap geometrically and lead to the formation of the plasma. In TGD framework the magnetic bodies of quarks having size scale characterized by quark Compton length would overlap. The Compton lengths for light quarks with masses estimated to be of order 10 MeV are much larger than the size scale of nucleon and even that of nucleus. What does this mean? Does the reconnection process take place in several scales so that the notion of quark gluon plasma would be fractal? Note that in the recent proton-proton collisions the energy per nucleon is about 200 GeV. Does quark gluon plasma at LHC involve the fusion of the flux tubes of the color magnetic bodies of nucleons? Do these form connected structures.

In the kinetic gas theory viscous force in the system of parallel plates is caused by the diffusion of particles moving with velocity u which depends on the coordinate orthogonal to the parallel plates. One can imagine a fictive plane through which the particles diffuse in both directions and the forces is due to that fact that the diffusing particles have different velocities differing by $\Delta u_x = \partial_y u_x l_{free}$ on the average. In the case of magnetic flux tubes the presence of magnetic flux tube connection the two quarks at the opposite sides of the fictive plane leads to a stretching of the flux tube and this costs energy. This favors the diffusion of either quark to the other side of the fictive plane and this induces the transformed of momentum parallel to the plates. Similar argument could apply also in the case of the ordinary liquids if one allows also electric flux tubes.

5.4.1 Jets and flux tubes structures

Magnetic flux tube provide also a more concrete vision about the notion of jet.

1. Jets are collinear particle like objects producing collinear hadrons. The precise definition of jets is however problematic in QCD framework. TGD suggests a more precise definition of jets as connected sub-networks formed by partons and by definition having vanishing total Kähler magnetic charge. Jet would be kind of super-hadron which decays to ordinary nearly

collinear hadrons as the flux tube structure decomposes by reconnection process to smaller connected flux tube structures during hadronization.

2. Factorization theorems of QCD discussed in very clear manner by Ian Stewart (see `http://tinyurl.com/y9wj55vz`) [C46] state that the dynamics at widely different scales separate for each other so that quantum mechanical interference effects can be neglected and probabilistic description applies in long length scales and quantal effects reduce to non-perturbative ones. The initial and final stages of the collision process proceed slowly as compared to those describable in terms of perturbative QCD. Hence one can apply partonic distribution functions and fragmentation functions. These functions should have a description in terms of reconnection process.

3. The presence of different scales means in TGD framework to p-adic length scale hierarchy assignable to flux tubes gives a much more precise articulation for the notion of scale. No quantum interference effects can take place between different p-adic scales if the real amplitudes are obtained from p-adic valued amplitudes by a generalization of canonical identification discussed in [K20]. For instance, in p-adic mass calculations the values p-adic mass squared are summed for for given p-adic prime before the mapping to real mass squared by canonical identification. For different values of p-adic primes the additive quantities are the real masses.

5.4.2 Possible generalizations of Maxwell's formula formula for the viscosity

Could one understand the viscosity if one assumes that the reconnection of the magnetic flux tubes replaces the collisions of particles in the kinetic theory of gases? One can imagine several alternatives.

1. The free path of the particle appears in the kinetic gas theory estimate $\eta = nmvl_{free}$ for the viscosity. If this decomposition makes sense now, l_{free} should correspond to the size scale of the magnetic body of light quark and if its size corresponds to the Compton length of the quark one would have $l_{free} \sim \hbar/m$. If one assumes $s \sim n$ one has $\eta = nv\hbar$. For $v = c = 1$ this would give $\eta/s \sim \hbar/4\pi$ apart from numerical constant.

   If $\hbar$ indeed appears in l_{free} and the magnetic flux tube size scales as $\hbar$, the minimum value for the viscosity would scale as $\hbar$. It is difficult to say whether one should regard this as good or bad prediction from the point of view of the hierarchy of Planck constants. Over-optimistically one might ask whether large $\hbar$ could explain the non-minimal values of η/s in terms of large $\hbar$. Note however that the minimal value of η/s can be smaller than $\hbar/4\pi$ in some systems.

2. One could consider the replacement of the Compton length $r_C = \hbar/m_q$ with the classical charge radius of quark defined as $r_{cl} = g^2/m_q$. In this case the size scale of the magnetic body would not depend on $\hbar$. For color coupling strength $\alpha_s = .1$ one would have $r_{cl}/r_C = 1.26$ so that experimental data do not allow to distinguish between these options. At low energies r_{cl} would grow and therefore also the viscosity since the lengths of flux tubes would get longer.

3. One can also purely gravitational view about single partonic 2-surface. Taking the notion of gravitational Planck constant seriously [K22], one can consider the replacement of v with the velocity parameter v_0 (dimensionless in the units used) appearing in the gravitational Planck constant $\hbar_{gr} = G_{eff}M^2/v_0$ and the identification $l_{free} = 2r_S = 4G_{eff}M$: the diameter of the black hole identified as partonic 2-surface. Note that Schwartchild radius would be equal to Planck length. Entropy would be given $4\pi(2G_{eff}M)^2/\hbar G_{eff}$ multiplied by the number $N = \hbar/\hbar_0$ of the sheets of the covering. This would give the lower bound $\hbar_0 v_0/4\pi$ which is smaller than that provided by AdS/CFT approach. This option looks the most attractive one.

For all three options one would expect that η/s ratio is same for the quark-gluon plasma formed in heavy ion collisions and in proton-proton collisions. The critical reader probably wonders what one means with the entropy in the strongly interacting system. Magnetic flux tubes could be seen as space-time correlates for entanglement. Can one regard the entropy as a single particle observable? Can one assign to each partonic 2-surfaces an entanglement entropy or does the entropy characterizes pairs of parton surfaces being analogous to potential energy rather than kinetic energy?

5.4.3 The formula for viscosity based on black-hole analogy

The following argument is a longer version of very concise argument of previous section suggesting that the notion of gravitational Planck constant allows to generalize the formula of the kinetic gas theory to give viscosity in the more general case. Partonic 2-surface is regarded as an analog the horizon of a black-hole. The interior of the black-hole corresponds to a region with an Euclidian signature of the induced metric. The space-time metric in question could be either the induced metric or the effective metric defined by the Kähler-Dirac gamma matrices defined by Kähler action [K29]. Induced metric seems to be the correct option since it is non-trivial for vacuum extremals of Kähler action but also the effective metric probably has physical meaning. Only the data at horizon having by definition degenerate four-metric appear in the formula for η/s.

1. The notion of gravitational Planck constant for space-time sheets carrying self gravitational interaction is given by $\hbar_{gr} = kGM^2/v_0$, where $v_0 < c = 1$ has dimensions of velocity. The interpretation is in terms of Planck constant assignable with flux tubes mediating self gravitation and carrying dark energy identified as magnetic energy. The enormous value of Planck constant means cosmological quantum coherence explaining why this energy density is very slow varying and can be therefore described in terms of cosmological constant in good approximation. Negative "pressure" corresponds to magnetic tension.

2. Suppose that v_0 is identified as the velocity appearing as typical velocity in the kinetic theory estimate $\eta = Mnvl_{free}$. Suppose that l_{free} corresponds to Schwartschild radius for the effective gravitational constant $l_{free} = 2r_s = 4G_{eff}M$. Another possible identification is as the scaled up Planck length $l_{free} = l_P = \sqrt{\hbar G} = GM/\sqrt{v_0}$. Suppose that the formula for black hole entropy holds true and gives for the entropy of single particle the expression $S = 4\pi(2G_{eff}M)^2/\hbar G_{eff}$. This gives $\eta/s = \hbar v_0/4\pi$ for the first option (note that v_0 dependence disappears. One obtains $\eta/s = \hbar/16\pi\sqrt{v_0}$ for the second option so that v_0 dependence remains.

3. The objection is that black hole entropy goes to zero as $\hbar$ increases. One can indeed argue that the $S = 4\pi(2G_{eff}M)^2/\hbar G_{eff}$ gives only the contribution of single sheet in the $N = hbar/\hbar_0$ fold covering of $M^4 \times CP_2$ so that one must multiply this entropy with N. This would give

$$\frac{\eta}{S} = \frac{\hbar_0}{4\pi} \times \frac{v_0}{c} \ .$$

   The minimum viscosity can be smaller than $\hbar_0/4\pi$ and the essential parameter is the velocity parameter $v_0 = v_0 < c = 1$. This is true also in AdS-CFT correspondence.

This argument suggests that the Einsteinian dark gravity with gravitational gauge coupling having as parameters p-adic length scale and the typical Kähler action of deformed CP_2 type vacuum extremal could allow to understand viscosity in terms of string-QFT duality in the idealization that the situation reduces to a black-hole physics with partonic 2-surfaces taking the role of black holes. This proposal might make even in the case of condensed matter if one one gives up the assumption that the basic objects are more analogous to stars than black-holes.

5.5 Ads/CFT Is Not Favored By LHC

As already noticed that the first (see `http://tinyurl.com/or669lc`) experimental results from LHC (see `http://tinyurl.com/or669lc`) [C57] do not favor AdS/CFT duality but are qualitatively consistent with TGD view about gauge-gravity duality. Because of the importance of the results I add a version of my blog posting (see `http://tinyurl.com/yaseslrn`) [C2] about these results.

Sabine Hossenfelder told in BackReaction blog (see `http://tinyurl.com/65gkpkj`) about the first results enthusiasts. Or summarizing it in the words of Sabine Hossenfelder:

As the saying goes, a picture speaks a thousand words, but since links and image sources have a tendency to deteriorate over time, let me spell it out for you: The AdS/CFT scaling does not agree with the data at all.

5.5.1 The results

The basic message is that AdS/CFT fails to explain the heavy ion collision data about jets at LHC. The model should be able to predict how partons lose their momentum in quark gluon plasma assumed to be formed by the colliding heavy nuclei. The situation is of course not simple. Plasma corresponds to low energy QCD and strong coupling and is characterized by temperature. Therefore it could allow description in terms of AdS/CFT duality allowing to treat strong coupling phase. Quarks themselves have a high transversal momentum and perturbative QCD applies to them. One has to understand how plasma affects the behavior of partons. This boils to simple question: What is the energy loss of the jet in plasma before it hadronizes.

The prediction of AdS/CFT approach is a scaling law for the energy loss $E \propto L^3T$, where L is the length that parton travels through the plasma and the temperature T is about 500 MeV is the temperatures of the plasma (at RHIC it was about 350 MeV). The figure in the posting of Sabine Hossenfelder (see `http://tinyurl.com/65gkpkj`) [C1] compares the prediction for the ratio R_{AA} of the predicted nuclear cross section for jets in lead-lead collisions to those in proton-proton collisions to experimental data normalized in such a manner that if the nucleus behaved like a collection of independent nucleons the ratio would be equal to one.

That the prediction for R_{AA} is too small is not so bad a problem: the real problem is that the curve has quite different shape than the curve representing the experimental data. In the real situation R_{AA} as a function of the average transversal momentum p_T of the jets approaches faster to the "nucleus as a collection of independent nucleons" situation than predicted by AdS/CFT approach. Both perturbative QCD and AdS/CFT based model fail badly: their predictions do not actually differ much.

An imaginative theoretician can of course invent a lot of excuses. It might be that the number $N_c = 3$ of quark colors is not large enough so that strong coupling expansion and AdS/CFT fails. Supersymmetry and conformal invariance actually fail. Maybe the plasma temperature is too high (higher that at RHIC where the observed low viscocity of gluon plasma motivated AdS/CFT approach). The presence of both weak coupling regime (high energy partons) and strong coupling regime (the plasma) might have not been treated correctly. One could also defend AdS/CFT by saying that maybe one should take into account higher stringy corrections for strings moving in 10 dimensional $AdS_5 \times S^5$. Why not branes? Why not black holes? And so on....

5.5.2 Could the space-time be 4-dimensional after all?

What is remarkable that a model called "Yet another Jet Energy-loss Model" (YaJEM) based on the simple old Lund model (see `http://tinyurl.com/ycwv5ebe`) [C5] treating gluons as strings in 4-D space-time works best! Also the parameters derived for RHIC do not need large re-adjustment at LHC.

4-D space-time has been out of fashion for decades and now every-one well-informed theoretician talks about emergent space-time. Don't ask what this means. Despite my attempts to understand I (and very probably any-one) do not have a slightest idea. What I know is that string world sheets are 2-dimensional and the only hope to get 4-D space-time is by this magic phenomenon of emergence. In other worlds, 3-brane is what is wanted and it should emerge "non-perturbatively" (do not ask what *this* means!).

Since there are no stringy authorities nearby, I however dare to raise a heretic question. Could it be that string like objects in 4-D space-time are indeed the natural description? Could strings, branes, blackholes, etc. in 10-D space-time be completely un-necessary stuff needed to keep several generations of misled theoreticians busy? Why not to start by trying to build abstraction from something which works? Why not start from Lund model or hadronic string model and generalize it?

This is what TGD indeed was when it emerged some day in October year 1977: a generalization of the hadronic string model by replacing string world sheets with space-time sheets. Another motivation for TGD was as a solution to the energy problem of GRT. In this framework the notion of (color) magnetic flux tubes emerges naturally and magnetic flux tubes are one of the basic structures of the theory now applied in all length scales. The improved mathematical understanding of the theory has led to notions like effective 2-dimensionality and stringy worlds sheets and partonic 2-surfaces at 4-D space-time surface of $M^4 \times CP_2$ as basic structures of the theory.

5.5.3 What TGD can say about the situation?

In TGD framework a naïve interpretation for LHC results would be that the colliding nuclei do not form a complete plasma and this non-ideality becomes stronger as p_T increases. As if for higher p_T the parton would traverse several blobs rather than only single big one and situation would be between an ideal plasma and to that in which nucleus form collections of independent nucleons. Could quantum superposition of states with each of them representing a collection of some number of plasma blobs consisting of several nucleons be in question. Single plasma blob would correspond to the ideal situation. This picture would conform with the vision about color magnetic flux tubes as a source of long range correlations implying that what is called quark-gluon plasma is in the ideal case like single very large hadron and thus a diametrical opposite for parton gas.

In TGD framework where hadrons themselves correspond to space-time sheets, this interpretation is suggestive. The increase of the temperature of the plasma corresponds to the reduction of α_s suggesting that with at T=500 GeV at LHC the plasma is more "blobby" than at T=350 GeV at RHIC. This would conform with the fact that at lower temperature at RHIC the AdS/CFT model works better. Note however that at RHIC the model parameters for AdS/CFT are very different from those at LHC [C1]: not a good sign at all.

I have also discussed the TGD based explanation of RHIC results for heavy ion collisions and the unexpected behavior of quark-gluon plasma in proton-proton (rather than heavy ion) collisions at LHC [K13].

6 Breaking Of Discrete Symmetries

Zero energy ontology provides a fresh approach to the rather poorly understood breaking patterns of discrete symmetries. In the following TGD based vision about breaking of discrete symmetries is discussed and some examples are considered. The old quantitative model for anomalously large CP breaking in kaon-antikaon system is in need of updating and is left to a separate section.

6.1 Experimental Inputs

There are several findings which do not fit with the picture about the breaking of discrete symmetries provided by standard model.

1. The large parity breaking in living matter manifesting itself as chiral selection remains a mystery in standard model framework. In TGD framework the possibility of classical weak fields in macroscopic scales combined with the hierarchy of Planck constants suggests a solution of this parity breaking and also a connection with the breaking of matter antimatter asymmetry is suggestive.

2. KTeV collaboration in Fermilab [C29] has measured the parameter $|\epsilon'/\epsilon|$ characterizing the size of the direct CP violation in the decays of kaons to two pions. The value of the parameter was found to be $|\epsilon'/\epsilon| = (2.8 \pm .1)10^{-3}$ and is almost by an order of magnitude larger than the naïve standard model expectations based on the hypothesis that direct CP breaking is induced by CKM matrix. In [C49] it was shown that the value of the parameter could be understood without introducing any new physics if the value of running strange quark mass at m_c is about $m_s(m_c) = .1$ GeV and $m_d << m_s$ holds true.

3. During year 2010 also large CP breaking in$B - \overline{B}$ system was reported by D0 collaboration [C20].The claimed symmetry breaking is about 50 times larger than the breaking predicted by the standard model, and manifests itself as an asymmetry in the production of $\mu^+\mu^+$and $\mu^-\mu^-$pairs in the decays producing $B^0\overline{B}^0$ pairs. The asymmetry is due to the oscillations between almost mass degenerate states B^0 and $\overline{B}^0$. It is the mass difference which is much larger than predicted one.

There has been also claims for the breaking of CPT symmetry which is regarded as cherished in Lorentz invariant quantum field theories,

1. There are indications that the mixing is different for muonic neutrinos and antineutrinos [C24, C7, C23] meaning that the masses of neutrino and antineutrino are different. In TGD framework a possible explanation is obtained by assuming different p-adic length scales for neutrinos and antineutrinos in turn dictated by the interactions with environment which could be different for neutrinos and antineutrinos by the nature of measurement apparatus used to detect them. Hence a spontaneous breaking induced by environment could be in question [K12].

   Remark: The improved analysis (see `http://tinyurl.com/ycyex95e`) of MINOS collaboration using larger statistics than half year ago has led to the evaporation of the evidence for different masses for muonic neutrinos and antineutrinos [?] The values for Δm^2 and mixing angle parameter $sin^2(2\theta)$ for muonic antineutrino are consistent with the values of these parameters for the muonic neutrino.

2. 2 sigma evidence for a gigantic CPT breaking in top-antitop system have been claimed. *Measurement of the mass difference between t and $\bar{t}$ quarks* (see `http://tinyurl.com/y9t39wcp`) [C17] is the title of the e-print by a group working in Fermilab. The finding of the group is that $t-\bar{t}$ mass difference is

   $$\Delta M = M_t - M_{\overline{t}} = -3.3 \pm 1.7 \ \text{GeV} \ .$$

   The best fit is obtained with

   $$\Delta M = -4 \ \ GeV \ .$$

   For top quark mass M_t= 170 GeV this means $\Delta M/M \simeq 2.3$ per cent and is the scale for electromagnetic mass splittings. The result deviates from CPT-symmetric expectation $\Delta M = 0$ at 2σ level. Also D0 collaboration has reportded similar results two years earlier (see `http://tinyurl.com/yax6j7wd`) (PRL 103, 132001 (2009)) but at time the errors bars were so large that the finding was consistent with CPT symmetry. The last twist in the story is the eprint of D0 collaboration (see `http://tinyurl.com/yd3wdeqz`) reporting that the value of the mass difference is consistent with zero [C21]. The huge value of the CPT breaking suggest for a conservative mind that the issue is settled. At this time I will adopt the conservative approach.

3. The findings encourage to consider the possibility of CPT breaking seriously [B8, B2]. In TGD framework a very strong form of apparent CPT breaking results if fermion and antifermion correspond to different values of p-adic prime so that mass scales differ by a multiple of half octave. The different choices of the p-adic mass scale would be induced by the interaction with environment. This option might explain the observations suggesting that neutrino and antineutrino masses and mixing matrices are different without introducing sterile neutrino: sterile neutrino would correspond to neutrino but in different p-adic length scale. In the recent case this option is excluded by the smallness of the mass difference. In zero energy ontology, which assigns to elementary particles size scale which which is macroscopic, one can however consider a more delicate breaking of CPT induced by the interactions with environment.

If one takes conservative attitude only the anomalously large CP breaking in B-Bbar system remains to be explained.

6.2 Discrete Symmetries In Zero Energy Ontology

Discrete symmetries C, P, T, CP, and even CPT are not too well-understood in standard model and zero energy ontology combined with the various experimental inputs (many of them still uncertain) leads to a vision about the breaking of discrete symmetries in TGD Universe.

Years after writing this section, the development of detailed view about basic action principle behind TGD led to the realization that CP and T breaking could emerge at fundamental level in TGD. The basic variational principle involves Kähler action and Kähler-Dirac action. Chern-Simons Dirac terms to which Kähler action reduces by the vanishing of $j \cdot A$ term in action and weak form of electric magnetic duality could be responsible for the breaking of CP and T symmetries as they appear in CKM matrix.

6.2.1 CP breaking and ground state degeneracy

6.2.2 CP breaking and ground state degeneracy

The Minkowskian contribution of Kähler action is imaginary due to the negativity of the metric determinant and gives a phase factor to vacuum functional reducing to Chern-Simons terms at wormhole throats. Ground state degeneracy due to the possibility of having both signs for Minkowskian contribution to the exponent of vacuum functional provides a general view about the description of CP breaking in TGD framework.

1. In TGD framework path integral is replaced by inner product involving integral over WCV. The vacuum functional and its conjugate are associated with the states in the inner product so that the phases of vacuum functionals cancel if only one sign for the phase is allowed. Minkowskian contribution would have no physical significance. This of course cannot be the case. The ground state is actually degenerate corresponding to the phase factor and its complex conjugate since $\sqrt{g}$ can have two signs in Minkowskian regions. Therefore the inner products between states associated with the two ground states define 2×2 matrix and non-diagonal elements contain interference terms due to the presence of the phase factor. At the limit of full CP_2 type vacuum extremal the two ground states would reduce to each other and the determinant of the matrix would vanish.

2. A small mixing of the two ground states would give rise to CP breaking and the first principle description of CP breaking in systems like $K - \overline{K}$ and of CKM matrix should reduce to this mixing. K^0 mesons would be CP even and odd states in the first approximation and correspond to the sum and difference of the ground states. Small mixing would be present having exponential sensitivity to the actions of CP_2 type extremals representing wormhole throats. This might allow to understand qualitatively why the mixing is about 50 times larger than expected for B^0 mesons.

3. There is a strong temptation to assign the two ground states with two possible arrows of geometric time. At the level of M-matrix the two arrows would correspond to state preparation at either upper or lower boundary of CD. Do long- and shortlived neutral K mesons correspond to almost fifty-fifty orthogonal superpositions for the two arrow of geometric time or almost completely to a fixed arrow of time induced by environment? Is the dominant part of the arrow same for both or is it opposite for long and short-lived neutral measons? Different lifetimes would suggest that the arrow must be the same and apart from small leakage that induced by environment. CP breaking would be induced by the fact that CP is performed only K^0 but not for the environment in the construction of states. One can probably imagine also alternative interpretations.

6.2.3 What CPT and CPT breaking do mean?

To begin, recall that CPT breaking would mean that the invariance condition

$$P(\Psi_i, \Psi_f) = P(\theta\Psi_f, \theta\Psi_i) \tag{6.1}$$

for probabilities fails to be satisfied. Here θ is a shorthand for CPT. The permutation of initial and final states is what distinguishes T and thus CPT from ordinary symmetries and means that T must be realized anti-linearly. In standard QFT P and T have geometric meaning whereas C does not. In TGD framework also C is geometric and this means that one must reconsider CPT and its tests based on phenomenological models.

CPT symmetry is one of the basic tenets of quantum field theory. In particular, the breaking of CPT requires the breaking of Lorentz invariance in standard QFT framework. In TGD framework the situation is actually different as I realized only now! The reason is that also charge conjugation is induced by a geometric transformation just like P and T. C indeed involves complex conjugation of CP_2 coordinates, and one can quite well consider a situation in with T and P are unbroken and only C is broken so that CPT is broken. What actually happens depends on the detailed action of the symmetries on the Kähler-Dirac action.

6.2.4 Some factd about zero energy ontology

Before one one can proceed, one must consider in more detail the notion of CD. CD is a product of CD proper defined as intersection of future and past directed light-cones of M^4 and of CP_2. The scales of CDs are assumed to come in powers of two of CP_2 scale to explain p-adic length scale hypothesis (one can consider also prime and even integer multiples). What is of utmost significance is that these scales are macroscopic. Poincare transformations affect CDs and give rise to a moduli space for CDs. In the case of CP_2 this is not the case unless one introduces additional physically well motivated structure.

Quite generally, this additional structure corresponds to the choice choice of quantization axes for various isometry currents realized at the level of the geometry of world of classical worlds which decomposes to a union of the geometries assigned with difference CDs labelled by moduli specifying the choice of quantization axes. In the case of M^4 the line joining the tips of CD defines a unique rest system with origin at the middle point of the line and selects quantization axes of energy. The direction of spin quantization axes is fixed if one introduces preferred plane M^2 physically analogous to the preferred plane of unphysical polarizations. This plane is fixed also by number theoretical vision and correspond to hyper-octonionic plane of complexified octonions highly relevant for the number theoretic formulation of TGD.

One must also introduce CP_2 coordinates transforming linearly with respect to U(2) sub-group. The choice of preferred point of CP_2 at either boundary of CD allows to fix complex coordinates of CP_2 only apart from U(2) rotation. Hyper-charge quantization axes is fixed but color isospin direction remains free. In fact, there is a preferred color isospin generator leaving the points of the geodesic sphere invariant whereas hypercharge generator induces phase multiplication. By choosing two preferred points of CP_2 assigned to the opposite boundaries of CD one can identify the geodesic line connecting the points as a flow line of color isospin rotations so that the quantization axes are fixed.

The choices of preferred plane M^2 and preferred geodesic sphere S^2 make sense also at the level of the preferred extremals of Kähler action and this leads to a concrete realization of the conjectured slicing of the space-time surface by string world sheets having braid strands at their ends at light-like wormhole throats carrying particle quantum numbers.

The vision about how quantum TGD gives rise to symplectic theory of knots, braids, braid cobordisms, and of two-knots [K9] led to the realization that preferred extremals should involve preferred geodesic sphere of CP_2, whose inverse image under embedding map assigns to the space-time surface unique complex of stringy two surfaces. These stringy two-surfaces define braid cobordisms and 2-knots and provide also the reduction of quantum TGD to string theory like structure in finite measurement resolution meaning the replacement of the orbits of partonic 2-surfaces with braids.

6.2.5 Charge conjugation is geometric in TGD framework

Charge conjugation in TGD Universe involves complex conjugation of CP_2 coordinates. Complex conjugation commutes with color rotations only if they belong to a subgroup $U(2) \subset SU(3)$ leaving a preferred point of CP_2 invariant remaining invariant also under C just like the origin of M^4 remains invariant under P and T. The situation differs from that for P and T decisively since the scale of CP_2 is about 10^4 Planck lengths. More general color rotations acting non-linearly and affecting non-trivially on the preferred point do not commute with C.

A simple example is provided by sphere. In this case C would act in complex coordinates as $\phi \rightarrow -\phi$, where ϕ is the phase angle of the complex coordinate with origin at the preferred point of the sphere. The action obviously depends on the choice of the preferred point.

The situation is therefore same as for P and T which also fail to commute with Poincare group and commute only with Lorentz transformations leaving the selected space-time point fixed. In TGD framework this point would correspond naturally to the center of the line connecting the tips of the causal diamond proper.

The action of C on physical states involves a linear transformation of spinors transformation besides the geometric action. The details of this action were discussed already in my thesis for almost three decades ago and the reader can consult the little article titled "The Geometry of CP_2 and its Relationship to Standard Model" (see `http://tinyurl.com/y8uowccy`) as the appendix of an article series summarizing Quantum TGD published in Prespace-time Journal. What is essential is that the action of C does does not commute with color rotations acting on the moduli of CD unless they belong to the U(2) subgroup leaving the geodesic sphere invariant. One can define C for the two boundaries of CD by requiring that the corresponding geodesic spheres remain invariant under C.

6.2.6 The action of CPT in zero energy ontology

The action of CPT is following.

1. First one applies P and T. If one assumes that the preferred point of M^4 corresponds to the middle point of the line connecting the tips of CD proper, these transformations permute upper and lower boundaries of CD proper. This is indeed a very natural requirement and means that positive and negative energy parts of the quantum state serving as counterparts of initial and finals states in positive energy ontology are permuted just as they are permuted in CPT. That T is realized anti-linearly conforms with the fact that T does leave invariant the boundary of CD proper.

2. Next one applies C involving complex conjugation which in general affects the moduli of CD. If C is chosen differently at the opposite boundaries it leaves the corresponding moduli invariant but since CPT involves the permutation of positive and negative energy states the moduli of CD are changed since the preferred point of upper boundary becomes the preferred point of the lower boundary and vice versa.

   Only in the case that the preferred points assigned to the upper and lower boundaries are same, this does not happen but in this case the quantization axes are not completely fixed which could make sense only if color isospin of all particles or at least of the positive (and negative) energy part of the zero energy state vanishes. Unless the CD has a wave function in the space of moduli which is constant, a spontaneous and a purely geometric breaking of C symmetry is induced. The breaking would be highly analogous to the breaking of rotational symmetry in spontaneous magnetization taking place in many particle systems.

3. The size scale of the CD proper is macroscopic even for elementary particles and corresponds to the secondary p-adic length scale associated with the particle. For electron with $p = M_{127} = 2^{127} - 1$ this time scale is $T(2,127) = .1$ seconds, defining the fundamental biological rhythm. For u and d quarks it is of order millisecond and for t quark characterized by $p \simeq 2^{93}$ it is given by

   $$T(2,93)2^{-127+93} \times T(2,127) \simeq 5.8 \times 10^{-12} \text{ seconds } .$$

   The corresponding length scale is 1.74 mm and is macroscopic. There are very many particles in CD of this size scale which suggests the possibility of spontaneous C breaking inducing by a localization in the moduli space of CDs implying the breaking of the CPT invariance condition. The many-particle system would be present since the CDs assignable to individual quarks intersect which suggests that they correspond to common CD. The non-invariance of the many-particle system under CPT could also result from that under PT operation in macroscopic situation.

Building a quantitative picture about CPT breaking requires answering many questions. The mass difference should depend on the moduli of CDs characterizing color quantization axes and characterize by preferred points of CP_2 assigned with future and past boundaries of CD. A natural measure for the symmetry breaking is defined by the geodesic distance -call it s - between the preferred points so that one expects that the mass of a fermion assigned with a particular CD involves a small contribution depending on s. This distance is however not changed in C.

The additional contribution to the mass should contain a term which is odd under C (most naturally), CP, or CPT. Could the oddness come from the spontaneous symmetry breaking giving rise to an interaction term with environment affecting the mass of particle and antiparticle in different manner? This oddness would be analogous to the oddness of the interaction energy of magnetic dipole with an external magnetic field.

6.2.7 Questions

This picture inspires several questions.

1. Can one consider C breaking without the presence of P and T breakings? If the CP breaking assigned with kaon-antikaon system and other neutral meson systems is CP breaking in TGD sense, does it involve the breaking of T at all? The answers to these questions are not obvious since the tests of discrete symmetries rely on the standard view about charge conjugation lacking totally the geometric aspect of C in TGD Universe.

2. Could it be that the different topological mixings of U and D quarks inducing in turn CKM mixing are induced by C breaking basically so that the mass differences would correlate directly with CKM mixing parameters?

3. Is the geometric view about about breaking of C relevant for the understanding of matter antimatter asymmetry? I have considered several models fro the generation of matter antimatter asymmetry, one of them assuming that antimatter is eaten by long cosmic strings with breaking induced by the Kähler electric fields inducing small difference in the densities of fermions and anti-fermions outside cosmic strings. Could matter antimatter asymmetry be mathematically analogous to chiral selection in living matter so that P would be only replaced with C? Whether the geometric view about C is relevant for the understanding of the matter antimatter asymmetry must be however left open question. Different masses for fermions anti-fermions could however help to understand why this kind of separation takes place.

4. C acts in CP_2 and in color degrees of freedom. Does this mean that for non-colored states C is not broken and that CP breaking is present only for quarks but not for leptons? The answers to these questions are not obvious since in TGD framework $M^4 \times CP_2$ spinor harmonics correspond to color partial waves which have wrong correlation with electro-weak quantum numbers. Only covariantly constant right-handed neutrino spinor generating supersymmetry can move in color single partial wave. The physical color assignments are the result of a state construction involving super-conformal algebra with algebra elements carrying color.

6.3 An Attempt To Build A Concrete Model For The Breaking Of Discrete Symmetries

In the following a concrete proposal for the mechanism for the breaking of discrete symmetries is considered in the case of hadrons.

6.3.1 How zero energy ontology could help?

The experimental findings about breaking of CP and other discrete symmetries suggest that new physics is involved and zero energy ontology (ZEO) suggests what might be involved. In ZEO the notion of causal diamond (CD) is central. Causal diamonds form a fractal hierarchy with CDs within CDs. The most general assumption is that size scales of CDs come as integer multiples of CP_2 size scale. p-Adic length scale hypothesis would suggest that the integers correspond to powers of two but the recent construction of U-matrix and M-matrices leaves only integer multiples as the only mathematically elegant option [K4, K15]. Discrete Lorentz boosts of CDs are allowed and the condition that the geometry of CDs represents symmetry breaking representing the choice of quantization axes implies rather rich moduli space for CDs.

One can say that WCW decomposes into a union of WCWs associated with various CDs and that the choice quantization axes in quantum measurement implies a localization to a WCW with definite quantization axes. The geometry of CD breaks Lorentz invariance although the entire WCW geometry is Poincare and color invariant.

In order to obtain non-trivial fermionic propagators one must add to Kähler-Dirac action Chern-Simons Dirac term at partonic orbits at which the signature of the induced metric changes. By super-symmetry one must add Chern-Simons term to Kähler action cancelling that the partonic Chern-simons terms so that only Chern-Simons terms localized at the space-like ends of the space-time surfaces survive. What is important that Chern-Simons and Chern-Simons-Dirac terms explicitly break CP and T symmetries and one can understand CP breaking at elementary particle level and has also hopes about understanding of matter antimatter asymmetry. Already the reduction of Kähler action to Chern-Simons terms by the vanishing of $j \cdot A$ term and weak form of electric magnetic duality could give rise to CP breaking.

Even CPT could be broken since the breaking of Lorentz invariance necessary for CPT breaking takes place. If this mechanism is at work the secondary p-adic time scale characterizing the CD characterizing particle should characterize the energy and time scales of CP breaking. This is quite strong a prediction since in the existing models one must take CP breaking parameters as given and coded by the CKM matrix.

1. In the case of $K-\overline{K}$ system the scale of the mass splitting comes out correctly: the scale for the mass difference between short and long lived kaons is about 10^{-6} eV and corresponds to the Mersenne prime M_{107} characterizing hadrons.

2. For $B-\overline{B}$ the secondary p-adic length scale deduced from the mass difference of order 10^{-2} eV would however correspond to M_{89}, which suggests that M_{89} hadron physics is somehow involved. Could M_{89} hadrons appear in the loops giving rise to the symmetry breaking? This kind of difference between kaons and B mesons looks strange.

Zero energy ontology implies that quantum theory can be regarded as a square root of thermodynamics in a well-define sense. M-matrices forming the rows of the unitary U-matrix acting between zero energy states define the counterpart of ordinary S-matrix and are expressible as products of Hermitian square root of density matrices and unitary S-matrix. An attractive hypothesis is that Hermitian square roots of density matrices commute with S-matrix and therefore form a symmetry algebra of S-matrix. One can even consider the possibility that the M-matrices define Kac-Moody type algebra with integer powers of S-matrix defining the analog for the powers of phase for Kac-Moody algebras. This hierarchy of U-matrices would make sense for the hierarchy CDs for which scales are integer multiples of a fundamental scale. One could say that zero energy states would represent their own symmetry algebra.

ZEO leads to a variant of entropic gravity [B5] in which one does not assume that space-time emerges and that gravitons are absent [K27], [L3] Gravitons arriving along flux tubes from the source are simply thermalized when the distance of the source is much longer than the wavelength of the gravitons and this explains the basic formulas for the temperature and entropy. The arguments however apply also to electromagnetic interaction [B10] but imply that the temperature is negative either for particle or antiparticle. This suggests that thermal instability of antimatter for the standard arrow of geometric time and that antimatter resides at space-time regions with opposite arrow of geometric time. The arrow of geometric time in turn would be realized at the level of quantum states as a property of zero energy states. One can localize either the future or past part of zero energy state so that it has well define particle number and various other quantum numbers and represents naturally the incoming state of particle reaction.

The natural expectation is that the breaking of CP and T at the fundamental level relate to the thermodynamical instability of the antimatter explaining also why it is so difficult to manufacture dark matter in laboratory. Also the recently observed strange behavior of positronium atom [C44, C35] could relate to this asymmetry.

This framework suggests also a more concrete view abot the breaking of discrete symmetries.

1. Gravitons are still there but in thermal equilibrium at flux tubes along which their travel and also photons are in similar thermal equilibrium so all interactions are entropic in TGD sense as the vision about quantum theory as a square root of thermodynamics suggests.

2. Entropic gravity and electromagnetism would provide a phenomenological view about what happens and would also suggests a general view about how discrete symmetries break down. Charged matter and antimatter could obey different arrow of geometric time by the requirement of thermal stability (temperatures are proportional to the normal component of electric field have opposite sign for charged particle and antiparticle).

3. The arrow of geometric time is a property of zero energy states rather than dynamics and realized as a property of M-matrix for which states are localized with respect to various quantum numbers (in particular particle- and fermion numbers) at the second end of the causal diamond defining the counterpart of initial state).

6.3.2 CPT, T and CPT breaking in zero energy ontology

CPT breaking [B2] requires the breaking of Lorentz invariance. Zero energy ontology could therefore allow a spontaneous breaking of CP and CPT. This might relate to matter antimatter asymmetry at the level of given CD.

There is some evidence that the mixing matrices for neutrinos and antineutrinos are different in the experimental situations considered [C7, C24]. This would require CPT breaking in the standard QFT framework. In TGD p-adic length scale hypothesis allowing neutrinos to reside in several p-adic mass scales. Hence one could have apparent CPT breaking if the measurement arrangements for neutrinos and antineutrinos select different p-adic length scales for them [K12].

Could one understand the breaking of CP and T at fundamental level in TGD framework?

1. In standard QFT framework Chern-Simons term breaks CP and T. Kähler action indeed reduces to Chern-Simons terms for the proposed ansatz for preferred extremals assuming that weak form of electric-magnetic duality holds true. This does not however need mean CP breaking. One must however add to the Kähler-Dirac action Chern-Simons Dirac term at the parton orbits in order to obtain non-trivial fermion propagator by requiring that spinor modes are generalized eigenstates of C-S-D operator with eigenvalues $p^k\gamma_k$ given by virtual momenta. One obtains thus perturbation theory and a connection with twistor Grassmannian approach. By supersymmetry one must add Chern-Simons term to Kähler action too so that it reduces to Chern-Simons terms at the space-like ends of space-time surface by weak form of electric magnetic duality. Chern-Simons Dirac terms could be responsible for the breaking of CP and T symmetries as they appear in CKM matrix.

   In TGD framework one must however distinguish between space-time coordinates and embedding space coordinates. CP breaking occurs at the embedding space level but instanton term and Chern-Simons term are odd under P and T only at the space-time level and thus distinguish between different orientations of space-time surface. Only if one identifies P and T at space-time level with these transformations at embedding space level, one has hope of interpreting CP and T breaking as spontaneous breaking of these symmetries for Kähler action and basically due to the weak form of electric-magnetic duality and vanishing of $j \cdot A$ term for the preferred extremals. This identification is possible for space-time regions allowing representation as graphs of maps $M^4 \rightarrow CP_2$.

2. The GRT-QFT limit of TGD obtained by lumping together various space-time sheets to a region of Minkowski space with effective metric defined by the sum of Minkowski metric and deviations of the induced metrics of sheets from Minkowski metric. Gauge potentials for the effective space-time would identified as sums of gauge potentials for space-time sheets. At this limit the identification of P and T at space-time level and embedding space level would be natural. Could the resulting effective theory in Minkowski space or GRT space-time break CP and T slightly? If so, CKM matrices for quarks and fermions would emerge as a result of representing different topologies for wormhole throats with different topologies as single point like particle with additional genus quantum number.

3. Could the breaking of CP and T relate to the generation of the arrow of time? The arrow of time relates to the fact that state function reduction can occur at either boundary of CD [K1]. Zero energy states do not change at the boundary at which reduction occurs repeatedly but the change at the other boundary and also the wave function for the position

of the second boundary of CD changes in each quantum jump so that the average temporal distance between the tips of CD increases. This gives to the arrow of psychological time, and in TGD inspired theory of consciousness "self" as a counterpart of observed can be identified as sequence of quantum jumps for which the state function reduction occurs at a fixed boundary of CD. The sequence of reductions at fixed boundary breaks T-invariance and has interpretation as irreversibility. The standard view is that the irreversibility has nothing to do with breaking of T-invariance but it might be that in elementary particle scales irreversibility might manifest as small breaking of T-invariance.

6.3.3 Anomalously high asymmetry production of top pairs in proton-antiproton collisions and CP breaking in B-Bbar system

The above theoretical arguments do not help in attempts to build a concrete model for CP breaking in say B-Bbar system. Something more concrete is needed. Here the two anomalies discovered in the production of top pairs in ppbar collisions at Tevatron come in rescue. At first they do not seem to have anything to do with the CP breaking in BBbar system.

1. Both Jester (see `http://tinyurl.com/y7ybabsj`) and Lubos Motl (see `http://tinyurl.com/y8epcrmb`) tell about top quark related anomaly in proton-antiproton collisions at Tevatron reported by CDF collaboration. The anomaly has been actually reported already last summer but has gone un-noticed. For more detailed data see [C6] (see `http://tinyurl.com/ybvzrtpa`).

   What has been found is that the production rate for jet pairs with jet mass around 170 GeV, which happens to correspond to top quark mass, the production cross section is about 3 times higher higher than QCD simulations predict. 3.44 sigma deviation is in question meaning that its probability is same as for the normalized random variable x/σ to be larger than 3.44 for Gaussian distribution $exp(-(x/\sigma)^2/2)/(2\pi\sigma^2)^{1/2}$. Recall that 5 sigma is regarded as so improbable fluctuation that one speaks about discovery. If top pairs are produced by some new particle, this deviation should be seen also when second top decays leptonically meaning a large missing energy of neutrino. There is however a slight deficit rather than excess of these events.

2. There is also a second anomaly involved with top pair production. Jester (see `http://tinyurl.com/4b622rx`) reports new data [C41] about the strange top-pair forward-backward asymmetry in top pair production in p-pbar collisions already mentioned [C16]. In Europhysics 2011 conference D0 collaboration reported the same result. CMS collaboration found however no evidence for the asymmetry (see `http://tinyurl.com/ydxe5n8o`) in p-p collisions at LHC [C19]. For top pairs with invariant mass above 450 GeV the asymmetry is claimed by CDF to be stunningly large 48+/-11 per cent. 3 times more often top quarks produced in qqbar annihilation prefer to move in the direction of quark. Note that this experiment would have reduced the situation from the level of ppbar collisions to the level of quark-antiquark collisions and the negative result suggests that valence quarks might play an essential role in the anomaly.

The TGD based explanation for the finding would relation on the flavor octet of gluons and the new view about Feynman diagrams.

1. The identification of family replication phenomenon in terms of genus of the wormhole throats [K3] predicts that family replication corresponds to a dynamical SU(3) symmetry (having nothing to do with color SU(3)or Gell-Mann's SU(3)) with gauge bosons belonging to the octet and singlet representations. Ordinary gauge bosons would correspond besides the familiar singlet representation also to exotic octet representation for which the exchanges induce neutral flavor changing currents in the case of gluons and neutral weak bosons and charge changing ones in the case of charged gauge bosons. The exchanges of the octet representation for gluons could explain both the anomalously high production rate of top quark pairs and the anomalously large forward backward asymmetry! Also electroweak octet could of course contribute.

2. One could say that top quark from the geometric future transforms at exchange line to space-like t-quark (genus $g = 2$) and returns to future. The quark from the geometric past does the same and returns back to the past as antiquark of antiproton. In the exchange line this quark combines with t-quark to form a virtual color octet gluon.

This mechanism could also give additional contributions to the mechanism generating CP breaking since new box diagrams involving two exchanges of flavor octet weak boson contribute to the mixings of quark pairs in mesons. The exchanges giving rise to an intermediate state of two top quarks are expected to give the largest contribution to the mixing of the neutral quark pairs making up the meson. This involves exchange of a member W boson flavor octet boson analogous to the usual exchange of the flavor singlet boson. This might relate to the reported anomalous like sign muon asymmetry in BBbar decay [?]uggesting that the CP breaking in this system is roughly 50 times larger than predicted by CKM matrix. The new diagrams would only amplify the CP breaking associated with CKM matrix rather than bringing in any new source of CP breaking. This mechanism increases also the CP breaking in KKbar system known to be also anomalously high.

7 TGD Based Explanation For The Anomalously Large Direct CP Violation In $K \to 2\Pi$ Decay

KTeV collaboration in Fermilab [C29] has measured the parameter $|\epsilon'/\epsilon|$ characterizing the size of the direct CP violation in the decays of kaons to two pions. The value of the parameter was found to be $|\epsilon'/\epsilon| = (2.8 \pm .1)10^{-3}$ and is almost by an order of magnitude larger than the naïve standard model expectations based on the hypothesis that direct CP breaking is induced by CKM matrix. In [C49] it was shown that the value of the parameter could be understood without introducing any new physics if the value of running strange quark mass at m_c is about $m_s(m_c) = .1$ GeV and $m_d << m_s$ holds true.

7.1 How To Solve The Problems In TGD Framework

7.1.1 Problems

Also in TGD framework the situation looks confusing.

1. The TGD based prediction for the value of the CP breaking parameter for CKM matrices satisfying the constraints coming from p-adicity is within the experimental constraints $1.0 \times 10^{-4} \leq J \leq 1.7 \times 10^{-4}$ coming from the standard model so that J produces no problems (see [K17] or Appendix for the CKM matrix as predicted by TGD).

2. The dominating contributions of the chiral field theory to $Re(\epsilon'/\epsilon)$ are proportional to $1/(m_s + m_d)^2$. The predictions of p-adic thermodynamics for s and d quark masses for $k(d) = k(s) = 113$ are $m_d(113) = m_s(113) = 90$ MeV and if this mass can be interpreted as $m_s(m_c) \simeq 0.1$ GeV, the prediction is too small by a factor 1/4. Even worse, if m_s corresponds to the scaled up mass $m_s(109) \simeq 360$ MeV of the s quark inside kaon, the situation changes completely and ϵ'/ϵ is too small by a factor $\sim 1/4.5^2 \simeq .05$.

3. TGD predicts that family replication phenomenon has also a bosonic counterpart. In the original scenario gauge bosons had single light-like wormhole throat as space-time correlate just like fermions and two exotic gluons were predicted corresponding to $g = 1$ and $g = 2$. The assumption that fermions at partonic space-time sheets are free fermions however forces to identify gauge bosons as wormhole contacts such that the two light-like wormhole throats carry quantum numbers of fermion and anti-fermion. Gauge bosons can be arranged into SU(3) singlet corresponding to ordinary gauge bosons and octet, where SU(3) states correspond to pairs (g_1, g_2) of handle numbers $0 \leq g_i \leq 2$.

   The experimental non-existence of flavor changing currents suggest strongly that the masses of octet gauge bosons are high. This requires that they correspond to $L(89)$ or even shorter p-adic length scale. Hence these gauge bosons are not interesting from the point of view of CP breaking.

4. The recent breakthrough in p-adic mass calculations for hadrons [K17] led also the understanding of non-perturbative aspects of hadron physics in terms of super-symplectic bosons which correspond to single light-like wormhole throat so that they couplings to quarks in the sense of generalized Feynman diagrams do not imply flavor changing neutral currents.

The basic prediction is that topologically mixed super-symplectic bosons are responsible for the most of the mass of proton and that it is possible to deduce the super-symplectic content of hadrons from their masses if their topological mixing is assumed to be same as for U type quarks. The masses of these bosons correspond to p-adic length scale $L(107)$ and are small in length scale $L(89)$ relevant for CP breaking. These observations suggest that higher gluon genera of the earlier model should be replaced with super-symplectic gluons.

In the standard diagrammatic expression for the CP breaking parameter gluon propagators are replaced by a sum of ordinary massless and two exotic gluon massive gluon propagators. The fact that the matrix elements relevant for the estimation of the CP breaking parameter are estimated at momentum transfer of order $\mu = m_W$, implies that gluon masses do not significantly change the contribution of the super-symplectic gluons to the amplitude apart from the change in value of color coupling strength. Hence the penguin amplitudes are simply multiplied by some factor X determined by the number of super-symplectic gluons light in length scale $L(89)$ and by the coupling constants of these gluons and the ratio ϵ'/ϵ is multiplied by a factor X. Unfortunately, it is not possible to calculate this factor at this stage.

7.1.2 The model based on exotic gluons and current quarks

It is essential that exotic gluons correspond to single light-like wormhole throat and thus have family replication phenomenon analogous to that of fermions. Two models can be considered.

1. The original model based on the assumption that ordinary gauge bosons correspond to single wormhole throat. There are good reasons to believe that this interpretation is wrong.

2. The new model based on super-symplectic exotic gluons whose number is not known but is multiple of 3. The couplings to quarks are not known. Also color single super-symplectic bosons could be also present.

1. The difficulty of the original model

The problem of this model is that assuming exotic gluons in sense 1) ϵ'/ϵ would be still by a factor.15 too small for $m_s(109)$ relevant for kaons.

The basic observation is that the gluon contribution is proportional to $1/(m_s + md)^2$ and for $m_s(113)$ instead of $m_s(119)$ ϵ'/ϵ would be a fraction $(16 + 1)/2 = 8.5$ large and by a factor 1.275 larger than the experimental value since $m_d = m_s$ rather than $m_d << m_s$ holds true.

This observation stimulated the idea that a transition $s_{109} \rightarrow s_{113}$ occurs before electro-weak process and would have an interpretation as a transformation of a constituent quark to current quark. This requires that the amplitudes for the transition $s(109) \rightarrow s(113)$ and its reversal are near to unity.

The question is why $s(109) \rightarrow s(113)$ constituent-current transformation should occur in electro-weak interactions and why it occurs with amplitude $A \sim 1$. Of course it could also be that also d quark is transformed to a very low mass variant with mass about 4 MeV predicted by chiral field theory. This would correspond to $k = 125$. As a result the amplitude would be multiplied by a factor 4 and $A = 1/2$ would become possible.

For some reason the flux tubes feeding em gauge flux of s quark to $k = 109$ space-time sheet would be transferred to nuclear space-time sheets with $k = 113$ before the electro-weak scattering process responsible for the CP breaking. Note that the value of strange quark mass about 176 MeV deduced from τ lepton decay rate corresponds to $m_s(111)$ in a good approximation. Also this indicates that various scaled up variants of quark masses can appear in the electro-weak dynamics as intermediate states.

The assumption for the proportionality $\epsilon'/\epsilon \propto 1/(m_s + m_d)^2$ derivable from chiral field theory can be criticized. Finding a justification for this assumption seems to be a non-trivial challenge since it is not at all clear that chiral field theory based on $SU(3)$ flavor symmetry makes sense in TGD context.

2. Super-symplectic variant of the original model

For super-symplectic gluons one can predict only that the relevant gluon exchange amplitude increases by a factor

$$X = \sum_{i,j} \alpha_s(B_{i,j})) \ ,$$

where $\alpha_s(B_{i,j})$ is the color coupling strength to j: th generation of the super-symplectic gluon B_i. In principle also color neutral super-symplectic bosons having spin might contribute.

For $\alpha_s(B_{i,j}) = \alpha_s(B_i)$ one would have

$$X = 3\sum_{i} \alpha_s(B_i) \ .$$

If the number of light super-symplectic gluons large enough, it is possible to have a large enough value of X to compensate for the factor .14 so that the assumption about the transformation $s(109) \rightarrow s(113)$ from constituent quark to current quark would become un-necessary. $X \sim 8$ would be needed.

Recall that super-symplectic algebra is analogous to Kac-Moody algebra in the sense that finite-dimensional Lie-group is replaced with symplectic group. Super-symplectic gluons correspond to states created by super-algebra generators, which are in one-one correspondence Hamiltonians of $\delta M^4_+ \times CP_2$ subject to some additional conditions making subset of states zero norm states. Therefore more than single octet of super-symplectic bosons and also higher dimensional representations might be possible.

All depends on which of these super-symplectic states correspond to light particles. This in turn depends on the details of super-symplectic representations (they correspond to the states of negative conformal weight annihilated by Virasoro generators L_n, $n < 0$ [K5]). Here the help of a mathematician specialized to the representations of super-conformal algebras would be needed.

At this moment it is not possible to know whether the transformation to current quark is needed or even possible and this motivates the following discussion of the basic notions and chiral field theory approach in more detail in order to clarify what is involved.

7.2 Basic Notations And Concepts

Until 1963 CP symmetry was believed to be an exact symmetry of Nature. In this year it was however observed by Christensen, Cronin, Fitch and Turlay that CP symmetry is violated in hadronic decays of neutral kaons. In order to interpret the experimental evidence one must consider the strong Hamiltonian eigen states K^0 and its CP conjugate $\bar{K}^0$ as a mixture of physical short lived K_S decaying predominantly to two pions and long-lived K_L decaying mostly semi-leptonically and into 3 pion states. Two- and three pion final states have odd and even CP parity. In absence of CP breaking one would identify K_S and K_L as the CP even and CP odd states

$$\begin{aligned} K_1 &= (K^0 + \bar{K}^0)/\sqrt{2} \ , \\ K_2 &= (K^0 - \bar{K}^0)/\sqrt{2} \ . \end{aligned} \tag{7.1}$$

What was observed in 1963 was that K_L decays also to two-pion final states.

There are two mechanisms of CP violation. The indirect mechanism involves a slight mixing of K^1 and K^2 characterized by a complex mixing parameter $\bar{\epsilon}$

$$\begin{aligned} K_S &= \frac{K_1 + \bar{\epsilon}K_2}{1+|\bar{\epsilon}|^2} \ , \\ K_L &= \frac{K_2 + \bar{\epsilon}K_1}{1+|\bar{\epsilon}|^2} \ . \end{aligned} \tag{7.2}$$

Direct mechanism involves the direct decay of K_2 to two pion state and is induced by the weak interaction Lagrangian L_W directly. Both mechanisms can be parameterized in terms of the small ratios

$$\begin{aligned}\eta_{00} &= \frac{\langle \pi^0\pi^0|L_W|K_L\rangle}{\langle \pi^0\pi^0|L_W|K_S\rangle} \ , \\ \eta_{+-} &= \frac{\langle \pi^+\pi^-|L_W|K_L\rangle}{\langle \pi^+\pi^-|L_W|K_S\rangle} \ .\end{aligned} \tag{7.3}$$

Here L_W represents the $\Delta S = 1$ part of the weak Lagrangian. The equations for η parameters can be also written as

$$\begin{aligned}\eta_{00} &= \epsilon - \frac{2\epsilon'}{1-\omega\sqrt{2}} \simeq \epsilon - 2\epsilon' \ , \\ \eta_{+-} &= \epsilon - \frac{2\epsilon'}{1+\omega/\sqrt{2}} \simeq \epsilon + \epsilon' \ .\end{aligned} \tag{7.4}$$

Parameter $\bar{\epsilon}$ is simply related to ϵ. The parameter ω measures the ratio

$$|\omega| = \frac{|\langle (\pi\pi)_{I=2}|L_W|K_S\rangle|}{|\langle (\pi\pi)_{I=0}|L_W|K_S\rangle|} \simeq 1/22.2 \ . \tag{7.5}$$

$I = 0$ and $I = 2$ denote the isospin states of final state pions.

The CP violating parameters are expressible in terms of $K_{S,L}$ decay amplitudes as

$$\begin{aligned}\epsilon &= \frac{\langle (\pi\pi)_{I=0}|L_W|K_L\rangle}{\langle (\pi\pi)_{I=0}|L_W|K_S\rangle} \ , \\ \epsilon' &= \frac{\epsilon}{\sqrt{2}}\left[\frac{\langle (\pi\pi)_{I=2}|L_W|K_L\rangle}{\langle (\pi\pi)_{I=0}|L_W|K_L\rangle} - \frac{\langle (\pi\pi)_{I=2}|L_W|K_S\rangle}{\langle (\pi\pi)_{I=0}|L_W|K_S\rangle}\right] \ .\end{aligned} \tag{7.6}$$

By Watson's theorem one can write the generic amplitudes for K^0 and $\bar{K}^0$ decay as

$$\begin{aligned}\langle (\pi\pi)_I|L_W|K^0\rangle &= -iA_I exp(i\delta_I) \ , \\ \langle (\pi\pi)_I|L_W|\bar{K}^0\rangle &= -iA_I^* exp(i\delta_I) \ ,\end{aligned} \tag{7.7}$$

where the phases δ_I arise from the pion finals state interactions. In good approximation ($|\bar{\epsilon} ImA_0| \ll |ReA_0|$, $|\bar{\epsilon}|^2 \ll 1$) one can write

$$\begin{aligned}\epsilon' &= exp(i(\pi/2 + \delta_2 - \delta_1)) \times \frac{\omega}{\sqrt{2}} \times (\frac{ImA_2}{ReA_2} - \frac{ImA_0}{ReA_0}) \ , \\ \omega &= \frac{ReA_2}{ReA_0} \ .\end{aligned} \tag{7.8}$$

With the approximations used one obtains a relationship

$$\epsilon' = \bar{\epsilon} + i\frac{ImA_0}{ReA_0} \ . \tag{7.9}$$

One can find a more detailed representation of the subject in various review articles [C54, C12, C11]. The standard model of CP breaking is based on the presence of complex phases in CKM matrix.

The value of the parameter ϵ describing indirect CP violation is well established and given by

$$|\epsilon| = (2.266 \pm .017) \times 10^{-3} \ .$$

The phases of ϵ and ϵ' are in good approximation identical so that their signs are same. The value of $Re(\epsilon'/\epsilon)$ was finally established by KTeV collaboration at Fermi Lab to be

$$Re(\frac{\epsilon'}{\epsilon}) = (2.8 \pm .01) \times 10^{-3} \ .$$

The measurement is consistent with the result of the CERN experiment NA31, which has also found a non-vanishing value for this parameter.

There are several theories of CP violation. The so called milliweak theory predicts vanishing value of ϵ'. The model based on the presence of CP breaking phases in three-generation CKM matrix predicts non-vanishing value for the parameter. Also Higgs particles can effect the value of the parameter in standard model. Standard model predicts this parameter to be nonzero but the expectation has been that the value is roughly ten times smaller than the measured value.

A possible explanation of the effect which does not introduce new physics is based on the hypothesis that the mass of s quark is smaller than the mass of d quark: the running mass $m_s(2\ GeV) \simeq .1$ GeV is needed to explain the anomaly if CP breaking parameter J is taken to be in the range $(1 - 1.7) \times 10^{-4}$ claimed in [C13] to follow from unitarity. There is however experimental evidence from τ decays for $m_s(m(\tau)) = (172 \pm 31)\ MeV$. This suggests that some new short length scale physics is involved.

Standard model prediction for $Re(\epsilon'/\epsilon)$ [C49] can be summarized in a handy formula

$$\begin{aligned} Re(\frac{\epsilon'}{\epsilon}) &= J \times \left[-1.35 + R_s \left(A_6 B_6^{1/2} + A_8 B_8^{3/2}\right)\right] \ , \\ A_6 &= 1.1|r_Z^8| \ , \\ A_8 &= 1.0 - .67|r_Z^8| \ . \end{aligned} \qquad (7.10)$$

The subscript Z refers to renormalization mass m_Z. The parameter R_s is given by

$$R_s \simeq \left[\frac{150\ MeV}{m_s(m_c) + m_d(m_c)}\right]^2 \ . \qquad (7.11)$$

The dominating contributions to $Re(\frac{\epsilon'}{\epsilon})$ come from second (A_6) and third terms (A_8). These terms correspond to gluonic and electro-weak penguin diagram contributions to the CP breaking decays and of opposite sign. Clearly, the sum of the two terms is roughly one third of the gluonic term alone.

7.3 Separation Of Short And Long Distance Physics Using Operator Product Expansion

The calculation of CP breaking parameters involves physics in very wide energy scale. The strategy is to derive low energy effective action by functionally integrating over the short distance effects coming from energies larger than m_c. This leads to Wilson expansion for the low energy electro-weak effective Lagrangian

$$L_{low,W} = -\sum_i C_i(\mu, m_c, m_b, m_t, m_W, ...)Q_i(\mu) \ . \qquad (7.12)$$

The coefficients C_i of the operators Q_i in the low energy effective action for light quarks (u, d, s) are functionals of various parameters characterizing short distance physics. The coefficients $C_i(\mu)$ in Wilson expansion of electro-weak effective action can be written as

$$C_i(\mu) = \frac{G_F}{\sqrt{2}} V_{ud} V_{us}^* \left[x_i(\mu) + \tau y_i(\mu)\right] \ . \qquad (7.13)$$

Here x_i and y_i are Wilson coefficients. V_{ij} denotes CKM matrix and τ is defined as $\tau = V_{td}V_{ts}^*/V_{ud}V_{us}^*$. $V_{td}V_{ts}^*$ is identical with CP breaking invariant J in standard parameterization. Coefficients $y_i(\mu)$ summarize short distance CP breaking physics and in order to determine CP breaking one needs to consider only the coefficients y_i.

Long distance physics is the difficult part of the calculation since it involves calculation of matrix elements of the quark operators Q_i between initial kaon state and final two-pion state. There are several approaches to the problem. Chiral field theory [C43] is phenomenological approach and relies on the idea that low energy effective action for quarks can be expressed in a good approximation using meson fields. Lattice QCD is believed to provide a more fundamental direct method for the calculation of the correlation functions of Q_i.

7.3.1 Short distance physics

In present initial states are kaons and μ denotes the momentum exchange for a typical diagram associated with the scattering of $d\bar{s}$ quark to final state consisting of of light quarks. μ is taken to be of order m_W and by using renormalization group equations one can deduce the values of the coefficients $C_i(\mu)$ at energy scales, typically of order 1 GeV.

The basic standard diagrams contributing to the $\Delta S = 1$ and $\Delta S = 2$ processes are given by the figure below.

The quark operators Q_i appearing in the expansion can be classified. In present case the list of relevant operators correspond to various terms possible in four-fermion Fermi interaction and are given by the following list.

$$Q_1 = (\bar{s}_\alpha u_\beta)_{V-A}(\bar{u}_\beta d_\alpha)_{V-A} \ , \tag{7.14}$$

$$Q_2 = (\bar{s}u)_{V-A}(\bar{u}d)_{V-A} \ , \tag{7.15}$$

$$\begin{aligned} Q_{3,5} &= (\bar{s}d)_{V-A}\sum_q(\bar{q}q)_{V\mp A} \ , \\ Q_{4,6} &= (\bar{s}_\alpha d_\beta)_{V-A}\sum_q(\bar{q}_\beta q_\alpha)_{V\mp A} \ , \\ Q_{7,9} &= \frac{3}{2}(\bar{s}d)_{V-A}\sum_q \hat{e}_q(\bar{q}q)_{V\pm A} \ , \\ Q_{8,10} &= \frac{3}{2}(\bar{s}_\alpha d_\beta)_{V-A}\sum_q \hat{e}_q(\bar{q}_\beta q_\alpha)_{V\pm A} \ . \end{aligned} \tag{7.16}$$

α,β denote color indices and $\hat{e}_q$ denote quark charges. $V\pm A$ refers to the Dirac structure $\gamma_\mu(1\pm\gamma_5)$. Q_2 is induced by mere W exchange whereas gluonic loop corrections to Q_2 induce Q_1. QCD through penguin loop induces the penguin operators Q_{3-6}. Electro-weak loops, in which penguin gluon is replaced with electro-weak gauge boson, induce $Q_{7,9}$ and part of Q_3. The operators $Q_{8,10}$ are induced by the QCD renormalization of the electro-weak loop operators $Q_{7,9}$.

As far as the calculation of ϵ'/ϵ is considered, the dominating contributions come from the penguin diagrams, which are proportional to the vertices $s\bar{d}V$, where V is either gluon or electro-weak gauge boson and to the propagator denominator of V with momentum squared equal to momentum exchange between initial state quarks, which equals to $(p_i - p_j)^2 = \mu^2$. For option 2) the standard gluon contribution is replaced with a sum over contributions of ordinary and exotic gluons. For option 1) situation is more complicated since $g > 0$ gluons can change the genus of the fermion.

The operators Q_6 and Q_8 give the dominating contributions to ϵ'/ϵ and these contributions are competing. Q_6 and Q_8 differ only by the fact that in Q_8 penguin gluon is replaced with penguin electro-weak boson γ or Z^0. For neutral kaon initial state electro-weak penguin diagram is proportional to the product $e_q e_{\bar{q}} = -e_q^2$ of the virtual quark whereas in case of gluons the factor $Tr(T^aT^a) > 0$ appears. Therefore the contributions associated with Q_6 and Q_8 are of opposite sign and mutually competing.

Detailed calculations lead to the formula already described:

$$\begin{aligned} Re(\frac{\epsilon'}{\epsilon}) &= J \times \left[-1.35 + R_s\left(A_6 B_6^{1/2} + A_8 B_8^{3/2}\right)\right] \ , \\ A_6 &= 1.1|r_Z^8| \ , \\ A_8 &= 1.0 - .67|r_Z^8| \ . \end{aligned} \tag{7.17}$$

for $Re(\epsilon'/\epsilon)$. The coefficients B_6 and B_8 code the long distance physics and their values do not differ too much from $B_6 = B_8 = 1$. Clearly, the sum of Q_6 and Q_8 contributions is roughly one third of the Q_6 contribution alone. From the general structure of Feynman diagrams it ss clear that for option 2) the effect caused by the introduction of exotic gluons is in a good approximation a simple scaling of the Q_6 contribution by a factor 3 in the approximation that gluon masses are negligible as compared to W mass, and that this new contribution can enhance direct CP breaking dramatically.

7.3.2 Chiral field theory approach

The basic problem is to calculate electro-weak matrix elements of the quark effective action between hadronic states. These matrix elements reduce to vacuum expectation values of various quark bilinears appearing in four-fermion Fermi interaction Lagrangian. This problem is very difficult since non-perturbative QCD is involved in an essential manner. An attempt to circumvent this problem [C43] is based on the hypothesis that low energy effective action for quarks is essentially equivalent with the low energy effective action, where pseudo-scalar meson fields as dynamical fields and scalar, vector and axial vector meson fields occur as external fields not subject to variations. Quark masses are identified as vacuum expectation values of the external scalar meson field. The approximate symmetry of the chiral field theory is flavor $SU(3)_L \times SU(3)_R$ which is exact symmetry at the limit of massless quarks. This symmetry can be realized if mesons are represented by an element U of $SU(3)$ regarded as a dynamical field: the two $SU(3)$: s act on U from left and right respectively. For small perturbations around ground state mesons correspond to various Lie-algebra generators of $SU(3)$. Chiral field develops vacuum expectation value. If vacuum expectation is not proportional to unit matrix it corresponds to the presence of coherent states associated with the neutral components of the pseudo scalar meson field.

The basic formulation of the chiral field theory approach is described in [C43] whereas its application to the calculation of ϵ'/ϵ is described in [C12]. The strong part of the chiral action [C43] is given by the formula

$$\begin{aligned} L_S &= \frac{f^2}{4}\left[Tr\{D_\mu U^\dagger D^\mu U\} + 2B_0 Tr\{(s-ip)U\} + 2B_0^* Tr\{(s+ip)U^\dagger\}\right] \\ &+ \frac{1}{12} H_0 D_\mu \theta D^\mu \theta \ . \end{aligned} \tag{7.18}$$

D_μ denotes the covariant derivative defined by the couplings to the left and right handed gauge bosons L_μ and R_μ defined as superpositions $R_\mu = v_\mu + a_\mu$ and $L_\mu = v_\mu - a_\mu$ of the vector and axial vector mesons fields v and a. Action contains three coupling constant parameters: f, B_0 and H_0, which is present because the presence of color instantons can lead to a non-vanishing value of the θ parameter in QCD. In lowest order f is pion decay constant f_π and B_0 sets the scale in the formula $M_M^2 = B_0(\sum_i m(q_i))$ inspired by broken $SU(3)$ symmetry and resulting as a prediction of the model. The components for the non-vanishing vacuum expectation value for the external scalar field are identified as quark masses. The generation of vacuum expectation value of s implies that quark condensates are developed:

$$\begin{aligned} \langle \bar{q}_i q_j \rangle &= B_0 f^2 \delta_{i,j} \ , \\ B_0 f^2 &= \frac{f_\pi^2 m_\pi^2}{(m_u+m_d)} = \frac{f_K^2 m_K^2}{(m_s+m_d)} \ . \end{aligned} \tag{7.19}$$

Note that the strong part of the chiral Lagrangian is invariant under the overall scaling of quark masses.

The weak part of the chiral action corresponds to the sigma model counterpart of the most general electro-weak four-fermion action. The recipe for constructing this action is described in more detail in [C12] and can be summarized as rules associating with various fermionic bi-linears appearing in the generalized Fermi action corresponding terms of the weak part of the chiral action. In particular, the following rules hold true:

$$\begin{aligned} \bar{q}_L^j\gamma^\mu q_L^i &\rightarrow -if_\pi^2(U^\dagger D_\mu U)_{ij} \ , \\ \bar{q}_R^j\gamma^\mu q_R^i &\rightarrow -if_\pi^2(UD_\mu U^\dagger)_{ij} \ , \\ \bar{q}_L^j\gamma^\mu q_R^i &\rightarrow -2B_0\left[\frac{f^2}{4}U + \text{higher order terms}\right]_{ij} \ , \\ \bar{q}_R^j\gamma^\mu q_L^i &\rightarrow -2B_0\left[\frac{f^2}{4}U^\dagger + \text{higher order terms}\right]_{ij} \ . \end{aligned} \quad (7.20)$$

The chiral counterparts of the left and right handed currents are proportional to BM and depend on the ratios of quark masses only. The terms giving dominating contribution to the $\Delta S = 1$ part of the weak effective action involve the chiral counterparts of terms $\bar{q}_L^j q_R^i$ breaking chiral invariance. The chiral counterparts of these terms are proportional to B and, in accordance with expectations, fail to be invariant under the overall scaling of quark masses. The higher order contributions to these terms are important for the calculations of direct CP breaking effects but are not written explicitly here because they are not needed in the estimate for how the predictions of the standard model are modified in TGD framework. The terms breaking chiral symmetry give rise to ϵ'/ϵ a contribution, which is proportional to $1/(m_s + m_d)^2$.

The $\Delta S = 2$ part of effective quark action is involved with $K^0 \rightarrow \bar{K}^0$ transitions and the corresponding quark operator is given by

$$Q_{S2} = (\bar{s}_L\gamma^\mu d_L)(\bar{s}_L\gamma^\mu d_L) \ . \quad (7.21)$$

The chiral counterpart of this operator is obviously invariant under overall scaling of quark masses.

7.3.3 Does chiral theory approach make sense in TGD framework?

The TGD based model for the large direct CP breaking based on exotic gluons and on the transformation of s_{109} to s_{113} has been already discussed. The open question is whether the $1/(m_s + m_d)^2$ proportionality of the CP breaking amplitude can be justified in TGD context where it is not at all clear that chiral theory approach makes sense.

In standard model framework chiral field theory provides a phenomenological description of the low energy hadron physics and makes possible the calculation of various hadronic matrix elements needed to derive the predictions for CP breaking effect.

Chiral field theory limit however involves some questionable assumptions about the relationship between QCD and low energy hadron physics.

1. $SU(3)$ symmetry is assumed and allows description of light mesons in terms of $SU(3)$ valued chiral field U possessing $SU(3)_R \times SU(3)_R$ symmetry broken only by quark mass matrix. In TGD framework $SU(3)$ symmetry is purely phenomenological symmetry since the fundamental gauge group is the gauge group of the standard model.

2. The generation of quark masses is described as effective spontaneous symmetry breaking caused by the vacuum expectation value of $SU(3)$ Lie-algebra valued external scalar field s. Quark masses are identified as the components of the diagonal vacuum expectation value of this field. Physically the scalar field corresponds to scalar meson field so that quark masses would result from the coupling of the quarks to coherent states of scalar mesons. This cannot be a correct physical description in TGD framework, where p-adic thermodynamics gives rise to quark masses. Of course, the presence of the scalar field can give rise to a small shift in the values of the quark masses. Also Higgs field could be in question.

3. The coupling of the field s to chiral field U implies in the standard model context that the mass squared values of mesons are proportional to the sums of masses of the mesonic quarks: for instance, $M_\pi^2 = B_0(m_u + m_d)$ and $M_K^2 = B_0(m_s + m_d)$, where B_0 is one of the basic coupling constants of the chiral field theory. This formula is not consistent with the p-adic mass calculations, where quark mass squared is additive for quarks with the same value of k_q and quark mass for different values of k_q. Indeed, the formulas $M_\pi^2 = m_u^2 + m_d^2$ and $M_K^2 = (m_s + m_d)^2$ are true. The chiral field formula predicts $m_s/m_d \simeq 24$ requiring $m_u = m_d \simeq 13$ MeV ($k = 121$) for $m_s(113) = 320$ MeV whereas TGD predicts $m_s(109)/m_d(107) = 4$. For $m_s \simeq 100$ MeV the prediction is $m_d \simeq 4.2$ MeV. This looks suspiciously small.

To sum up, although the basic assumptions of chiral field theory limit look too specific in TGD framework, its predictions for low energy hadron physics are well-tested and TGD could be consistent with them. If this the case, the assumption about $s_{109} \rightarrow s_{107}$ transition allows a correct prediction of direct CP breaking amplitude using chiral field theory limit.

7.4 Very Special Relativity As Justification For The Special Role Of M^2

The preferred role of M^2 in the construction of generalized Feynman diagrams could be used as a criticism. Poincare invariance is lost. The first answer to the criticism is that one integrates of the choices of M^2 so that Poincare invariance is lost. One can however defend this assumption also from different view point. Actually Glashow and Cohen did this in their Very Special Relativity proposal (see `http://tinyurl.com/ybevr5bk`) [B6] ! While scanning old files, I found an old text about Very Special Relativity of Glashow and Cohen, and realized that it relates very closely to the special role of M^2 in the construction of generalized Feynman diagrams. There is article “Very Special Relativity and TGD” (see `http://tinyurl.com/yaf8laym`) [L1] at my homepage but for some reason the text has disappeared from the book that contained it. I add the article more or less as such here.

WCW (“world of classical worlds”, WCW) decomposes into a union of sub- WCW s associated with future and past light-cones and these in turn decompose to sub-sub- WCW s characterized by selection of quantization axes of spin and color quantum numbers. At this level Poincare and even Lorentz group are reduced. The possibility that this kind of breaking might be directly relevant for physics is discussed below.

One might think that Poincare symmetry is something thoroughly understood but the Very Special Relativity [B6] proposed by nobelist Sheldon Glashow and Andrew Cohen suggests that this might belief might be wrong. Glashow and Cohen propose that instead of Poincare group, call it P, some subgroup of P might be physically more relevant than the whole P. To not lose four-momentum one must assume that this group is obtained as a semi-direct product of some subgroup of Lorentz group with translations. The smallest subgroup, call it L_2, is a 2-dimensional Abelian group generated by $K_x + J_y$ and $K_y - J_x$. Here K refers to Lorentz boosts and J to rotations. This group leaves invariant light-like momentum in z direction. By adding J_z acting in L_2 like rotations in plane, one obtains L_3, the maximal subgroup leaving invariant light-like momentum in z direction. By adding also K_z one obtains the scalings of light-like momentum or equivalently, the isotropy group L_4 of a light-like ray.

The reasons why Glashow and Cohen regard these groups so interesting are following.

1. All kinematical tests of Lorentz invariance are consistent with the reduction of Lorentz invariance to these symmetries.

2. The representations of group L_3 are one-dimensional in both *massive* and massless case (the latter is familiar from massless representations of Poincare group where particle states are characterized by helicity). The mass is invariant only under the smaller group. This might allow to have left-handed massive neutrinos as well as massive fermions with spin dependent mass.

3. The requirement of CP invariance extends all these reduced symmetry groups to the full Poincare group. The observed very small breaking of CP symmetry might correlate with a small breaking of Lorentz symmetry. Matter antimatter asymmetry might relate to the reduced Lorentz invariance.

The idea is highly interesting from TGD point of view. The groups L_3 and L_4 indeed play a very prominent role in TGD.

1. The full Lorentz invariance is obtained in TGD only at the level of the entire WCW which is union over sub- WCW s associated with future and past light-cones (space-time sheets inside future or past light-cone) [K8, K6]. These sub- WCW s decompose further into a union of sub-sub- WCW s for which a choice of quantization axes of spin reflects itself at the level of generalized geometry of the embedding space (quantum classical correspondence requires that the choice of quantization axes has embedding space and space-time correlates) [K28, K7]. The construction of the geometry for these sub-worlds of classical worlds reduces to light-cone boundary so that the little group L_3 leaving a given point of light-cone boundary invariant is in a special role in TGD framework.

2. The selection of a preferred light-like momentum direction at light-cone boundary corresponds to the selection of quantization axis for angular momentum playing a key role in TGD view about hierarchy of Planck constants associated with a hierarchy of Jones inclusions implying a breaking of Lorentz invariance induced by the selection of quantization axis [K28, K7]. The number theoretic vision about quantum TGD implies a selection of two preferred axes corresponding to time-like and space-like direction corresponding to real and preferred imaginary unit for hyper-octonions [K24, K23]. In both cases L_4 emerges naturally.

3. The TGD based identification of Kac-Moody symmetries as local isometries of the embedding space acting on 3-D light-like orbits of partonic 2-surfaces involves a selection of a preferred light-like direction and thus the selection of L_4.

4. Also the so called massless extremals representing a precisely targeted propagation of patterns of classical gauge fields with light velocity along typically cylindrical tubes without a change in the shape involve L_4. A very general solution ansatz to classical field equations involves a local decomposition of M^4 to longitudinal and transversal spaces and selection of a light-like direction [K2].

5. The parton model of hadrons assumes a preferred longitudinal direction of momentum and mass squared decomposes naturally to longitudinal and transversal mass squared. Also p-adic mass calculations rely heavily on this picture and thermodynamics mass squared might be regarded as a longitudinal mass squared [K16]. In TGD framework right handed covariantly constant neutrino generates a super-symmetry in CP_2 degrees of freedom and it might be better to regard left-handed neutrino mass as a longitudinal mass.

This list justifies my own hunch that Glashow and Cohen might have discovered something very important.

8 Wild Speculations About Non-Perturbative Aspects Of Hadron Physics And Exotic Super Virasoro Representations

If the canonical correspondence mapping the p-adic mass squared values to real numbers is taken completely seriously, then TGD predicts infinite hierarchy of exotic light representations of Super Virasoro. These exotic states are created by sub-algebras of Super Kac-Moody and SKM algebras whose generators have conformal weights divisible by p^n, $n = 1, 2, ...$ Ordinary representations would correspond to $n = 0$.

8.1 Exotic Super-Virasoro Representations

For the exotic representations the p-adic mass squared of the particle is proportional to Virasoro p^n. When the value of the p-adic mass squared is power of p: $M^2 \propto p^n$, $n = 1, 2, ..$, the real counterpart of the mass squared in canonical identification is extremely small since it is proportional to $1/p^n$ in this case. It is of course not at all clear whether these representations have have any real counterpart and if even this the case the could be thermally unstable in an environment with higher p-adic temperature.

Also ordinary low temperature ($T_p = 1/n$) Super Virasoro representations allow extremely light states but in this case there is no subalgebra generating these states. If these representations exist they could correspond to low energy-long length scale fractal copies of elementary particles. Due to the state degeneracy providing an enormous information storage capacity associated with these states these representations, if realized in nature, might have biological relevance [K11, K19].

There is however an objection against this idea: these representations are possible also in elementary particle length scales and for $M^2 \propto L_0 = npm_0^2$ the representations have same mass scale as ordinary elementary particles. These representations couple to ordinary elementary particles via classical gauge fields and could therefore be present also in elementary particle physics. For reasons which become clear below, exotic Super Virasoro representations might provide a model for low energy hadron physics.

1. The formula

$$M_R^2 = \frac{nm_0^2}{p}$$

is generalization of the mass formula of hadronic string models and reduces to it when the angular momentum

$$J = \alpha' M^2$$

of the hadronic state satisfies $J = n$. From this Regge slope α' and string tension T are given by

$$T = \frac{1}{2\pi\alpha'} \quad , \quad \frac{1}{\alpha'} = \frac{m_0^2}{p} \quad .$$

The observed value of the Regge slope is $\alpha' = .9/GeV^2$.

2. The value of the predicted string tension is easily found. The prediction of TGD based mass calculations for the value of the p-adic pion mass squared is

$$m_\pi^2 = pm_0^2 + O(p^2) \simeq pm_0^2 \quad , \quad p = M_{107} \quad .$$

$m_\pi \geq m_0/\sqrt{M_{107}}$ and $m_\pi = 134$ MeV gives upper bound for m_0 which is consistent with the prediction for the mass of electron. For $k = 107$ the value of α' would be roughly 64 times too large as simple calculation shows. For $k = 101$ one has

$$\alpha' = \frac{.87}{GeV^2} \quad ,$$

which deviates from the value $\alpha' = .9/GeV^2$ determined from ρ Regge trajectory only by three per cent.

3. This would suggest that excited states of ordinary hadrons contain $k = 101$ space-time sheets with p-adic length scale of .3 fm condensed on $k = 107$ hadronic space-time sheet with 8 times larger p-adic length scale and that the angular momentum of these excitations is not assignable to the ordinary quarks but to the states of $k = 101$ exotic Super Virasoro representation. The slight deviation from $.9/GeV^2$ could be explained if the contribution of quarks and gluons to the mass squared decreases as a function of J so that the effective value of α' increases and effective string tension increases. This might be due to the transformation of parton mass squared to the mass squared associated with $k = 101$ exotic Super Virasoro states. Note that $n = 1$ excitation of $k = 101$ Super Virasoro has mass $m_1 = 1.07$ GeV, which is larger than proton mass: therefore the spin of these excitations cannot resolve the spin crisis of proton.

4. For $k = 103$ the predicted value of string tension is by a factor 1/4 smaller. An interesting question is whether $k = 107$ and $k = 103$ excitations might be observable in low energy hadron physics.

8.2 Could Hadrons Correspond To Exotic Super-Virasoro Representations And Quark-Gluon Plasma To The Ordinary Ones?

The second thought provoking observation is that pion mass squared corresponds in excellent approximation to that for $n = 1$ state of exotic Super Virasoro representation for $k = 107$. This suggests that in case of pion quark masses are compensated apart from $O(p^2)$ contributions completely by various interaction energy and the energy associated with exotic Super Virasoro representation contributes to the mass squared. This would be p-adic articulation for the statement that pion is massless Goldstone boson. Since pion represents essentially non-perturbative aspects of QCD, this raises the possibility that exotic Super Virasoro representations could provide the long sought first principle theory of low energy hadronic physics.

1. In this theory hadrons would correspond to exotic Super Virasoro representations whereas quark-gluon plasma would correspond to ordinary p-adic Super Virasoro representations. In color confined phase p-adic α_c would have increased to the critical value $\alpha_c = p + O(p^2)$ implying dramatic drop of the real counterpart of α_c to $\alpha_c^R \simeq 1/p$ so that color interactions would disappear effectively and only electro-weak interactions and the geometric interactions between the space-time sheets would remain. What is important is that these phases can exist inside hadron for several values of p. This suggests a fractal hierarchy of hadrons inside hadrons and QCD: s inside QCD: s with the values of $\Lambda(k) \propto 1/L^2(k)$, $k = 107, 103, 101, ...$ In particular, rotational excitations would mean generation of $k = 101$ hadrons inside $k = 107$ hadrons.

2. Hadronization and fragmentation are semi-phenomenological aspects of QCD and would correspond at fundamental level to the phase transitions between the exotic Super Virasoro representations and ordinary Super Virasoro representations. Also the concepts of sea and Pomeron could be reduced the states of exotic Super Virasoro representations associated with $k = 107, 103, 101, 97, ...$

In light of the successes of the hadron model based on super-symplectic many-particle states assigned to hadrons [K17] the exotic Super Virasoro representations do not look attractive from the point of view of ordinary hadron physics. Also the thermal instability is a good objection against them.

9 Appendix

9.1 Effective Feynman Rules And The Effect Of Top Quark Mass On The Effective Action

The effective low energy field theory relevant for $K - \bar{K}$ systems is in the standard model context summarized elegantly using the Feynman rules of effective field theory deriving from box and penguin diagrams. The rules in t'Hooft-Feynman gauge are summarized in excellent review article of Buras and Fleischer [C14]. For box diagrams the rules are following:

$$\begin{aligned} Box(\Delta S = 2) &= \lambda_i^2 \frac{G_F^2}{16\pi^2} M_W^2 S_0(x_i) (\bar{s}d)_{V-A} (\bar{s}d)_{V-A} \ , \\ Box(T_3 = -1/2) &= \lambda_i \frac{G_F}{\sqrt{2}} \frac{\alpha}{sin^2(\theta_W)} B_0(x_i) (\bar{s}d)_{V-A} (\bar{\mu}\mu)_{V-A} \ , \\ Box(T_3 = 1/2) &= \lambda_i \frac{G_F}{\sqrt{2}} \frac{\alpha}{sin^2(\theta_W)} \left[-4B_0(x_i)\right] (\bar{s}d)_{V-A} (\bar{\nu}\nu)_{V-A} \ , \\ \lambda_i &= V_{is}^* V_{id} \ . \end{aligned} \tag{9.1}$$

The box vertices listed here describe the decays $K_0 \rightarrow \bar{K}_0$ and contribute to $K_0 \rightarrow \bar{\mu}\mu$ and $K_0 \rightarrow \bar{\nu}\nu$ decays. $(\bar{q}_1 q_2)_{V-A}$ is shorthand notation for the left handed weak current involving gamma matrices and the products of fermionic bi-linears actually involve contraction of the gamma matrix indices.

Penguin diagrams can be characterized by the effective vertices $\bar{s}dB$, where B is photon, Z boson or gluon, which is treated as usual in effective field theory

$$\begin{aligned}
\bar{s}Zd &= i\lambda_i \frac{G_F}{\sqrt{2}} \frac{g_Z}{2\pi^2} M_Z^2 g_Z C_0(x_i) \bar{s}\gamma^\mu (1-\gamma_5) d \ , \\
\bar{s}\gamma d &= -i\lambda_i \frac{G_F}{\sqrt{2}} \frac{e}{8\pi^2} D_0(x_i) \bar{s}(q^2\gamma^\mu - q^\mu q^\nu \gamma_\nu)(1-\gamma_5) d \ , \\
\bar{s}G^a d &= -i\lambda_i \frac{G_F}{\sqrt{2}} \frac{g_s}{8\pi^2} E_0(x_i) \bar{s}(q^2\gamma^\mu - q^\mu q^\nu \gamma_\nu)(1-\gamma_5) T^a d \ .
\end{aligned} \tag{9.2}$$

The vertices above correspond to the exchange of Z, photon and gluon between the quarks. Boson propagator and second vertex is constructed using the standard Feynman rules. The counterparts of the sdB vertices are easily constructed for $g > 0$ gluons. The orthogonality of single hadron states requires that flavor is conserved for $g > 0$ exchanges.

The functions $B_0, C_0, ...$ characterize the low energy effective action at mass scale $\mu = m_W$. The subscript "0" refers to the values of these functions without QCD corrections, which are taken into account using renormalization group equations to deduced the functions at mass scale of order 1 GeV. The functions are listed below:

$$\begin{aligned}
B_0(x_t) &= \frac{1}{4}\left[\frac{x_t}{y_t} + \frac{x_t log(x_t)}{y_t^2}\right] \ , \\
C_0(x_t) &= \frac{x_t}{8}\left[-\frac{x_t - 6}{y_t} + \frac{3x_t + 2}{y_t^2} log(x_t)\right] \ , \\
D_0(x_t) &= -\frac{4}{9} log(x_t) - \frac{25x_t^2 - 19x_t^3}{36y_t^3} + \frac{x_t^2(-6 - 2x_t + 5x_t^2)}{18y_t^3} log(x_t) \ , \\
E_0(x_t) &= -\frac{2}{3} log(x_t) + \frac{x_t^2(15 - 16x_t - 4x_t^2)}{6y_t^4} log(x_t) + \frac{x_t(18 - 11x_t - x_t^2)}{12y_t^3} \ , \\
S_0(x_t) &= \frac{4x_t - 11x_t^2 + x_t^3}{4y_t^2} - \frac{3x_t^2 log(x_t)}{2y_t^3} \ , \\
S_0(x_c, x_t) &= x_c\left[log(\frac{x_t}{x_c}) - \frac{3x_t}{4y_t} - \frac{3x_t^2 log(x_t)}{4y_t^2}\right] \ , \\
& x_c = (\tfrac{m_c}{m_W})^2 \quad x_t = (\tfrac{m_t}{m_W})^2 \ , \quad y_t = 1 - x_t \ .
\end{aligned} \tag{9.3}$$

Although x_t, being the interesting parameter, appears as the only argument of these functions, also the contributions coming from light quarks propagating in the loops are included. For comparison purposes it is useful to give the explicit relations between electro-weak coupling parameters and G_F.

$$\begin{aligned}
\frac{G_F}{\sqrt{2}} &= \frac{g_W^2}{8m_W^2} \ , \\
g_W &= \frac{e}{sin(\theta_W)} \ , \\
g_Z &= \frac{e}{sin(\theta_W)cost(\theta_W)} \ .
\end{aligned} \tag{9.4}$$

The following equations summarize the effect of the change of the top quark mass on the functions $B_0, C_0, ...$ What is given are the ratios $r(f) = f(55)/f(175)$ of the functions $B_0, C_0, ..$ evaluated for top quark masses 55 GeV and 175 GeV respectively.

$$\begin{array}{ccccccc} f & B_0(x_t) & C_0(x_t) & D_0(x_t) & E_0(x_t) & S_0(x_t) & S_0(x_c, x_t) \\ r & .51 & .09 & -.70 & 3.44 & .15 & .81 \end{array} \quad (9.5)$$

These results leave allow only the identification of the experimental candidate as a realistic candidate for top quark.

1. The function B_0 is reduced only by a factor of 1/2 and there are no new physics contributions to B_0 in the lowest order. The function C_0 characterizing Z penguin diagrams is reduced by an order of magnitude. The coefficient $C_0(x_t) - 4B_0(x_t)$ characterizes the dominating contribution to $K \rightarrow \mu^+\mu^-$ decay in standard model and the decay amplitude is reduced by a factor .27 so that this decay would provide a stringent test selecting between 55 GeV top quark and 175 GeV top quark. Unfortunately, the predicted $K \rightarrow \mu^+\mu^-$ rate is still by several orders of magnitude below the experimental upper bound.

2. The function $S_0(x_t)$ characterizing $B - \bar{B}$ and $K - \bar{K}$ mass differences is reduced almost by an order of magnitude. Note that in case of Δm_K the ratio $r(tt/ct)$ of the WW box diagram amplitudes with two top quarks and c and t in internal fermion lines is $r(tt/ct) \sim 738$ for $m_t = 175$ GeV and $r(tt/ct) \sim 138$ for $m_t = 55$ GeV (the moduli of the factors coming from CKM matrix are taken into account). Thus $m_t = 175$ GeV is the only sensible choice.

9.2 U And D Matrices From The Knowledge Of Top Quark Mass Alone?

As already found, a possible resolution to the problems created by top quark is based on the additivity of mass squared so that top quark mass would be about 230 GeV, which indeed corresponds to a peak in mass distribution of top candidate, whereas $t\bar{t}$ meson mass would be 163 GeV. This requires that top quark mass changes very little in topological mixing. It is easy to see that the mass constraints imply that for $n_t = n_b = 60$ the smallness of V_{i3} and $V(3i)$ matrix elements implies that both U and D must be direct sums of 2×2 matrix and 1×1 unit matrix and that V matrix would have also similar decomposition. Therefore $n_b = n_t = 59$ seems to be the only number theoretically acceptable option. The comparison with the predictions with pion mass led to a unique identification $(n_d, n_b, n_b) = (5, 5, 59)$, $(n_u, n_c, n_t) = (4, 6, 59)$.

9.2.1 U and D matrices as perturbations of matrices mixing only the first two genera

This picture suggests that U and D matrices could be seen as small perturbations of very simple U and D matrices satisfying $|U| = |D|$ corresponding to $n = 60$ and having$(n_d, n_b, n_b) = (4, 5, 60)$, $(n_u, n_c, n_t) = (4, 5, 60)$ predicting V matrix characterized by Cabibbo angle alone. For instance, CP breaking parameter would characterize this perturbation. The perturbed matrices should obey thermodynamical constraints and it could be possible to linearize the thermodynamical conditions and in this manner to predict realistic mixing matrices from first principles. The existence of small perturbations yielding acceptable matrices implies also that these matrices be near a point at which two different matrices resulting as a solution to the thermodynamical conditions coincide.

D matrix can be deduced from U matrix since $9|D_{12}|^2 \simeq n_d$ fixes the value of the relative phase of the two terms in the expression of D_{12}.

$$\begin{aligned} |D_{12}|^2 &= |U_{11}V_{12} + U_{12}V_{22}|^2 \\ &= |U_{11}|^2|V_{12}|^2 + |U_{12}|^2|V_{22}|^2 \\ &+ 2|U_{11}||V_{12}||U_{12}||V_{22}|cos(\Psi) = \frac{n_d}{9} \ , \\ \Psi &= arg(U_{11}) + arg(V_{12}) - arg(U_{12}) - arg(V_{22}) \ . \end{aligned} \quad (9.6)$$

Using the values of the moduli of U_{ij} and the approximation $|V_{22}| = 1$ this gives for $cos(\Psi)$

$$
\begin{aligned}
\cos(\Psi) &= \frac{A}{B} \ , \\
A &= \frac{n_d - n_u}{9} - \frac{9-n_u}{9}|V_{12}|^2 \ , \\
B &= \frac{2}{9|V_{12}|}\sqrt{n_u(9-n_u)} \ .
\end{aligned} \tag{9.7}
$$

The experimentation with different values of n_d and n_u shows that $n_u = 6, n_d = 4$ gives $cos(\Psi) = -1.123$. Of course, $n_u = 6, n_d = 4$ option is not even allowed by $n_t = 60$. For $n_d = 4, n_u = 5$ one has $cos(\Psi) = -0.5958$. $n_d = 5, n_u = 6$ corresponding to the perturbed solution gives $cos(\Psi) = -0.6014$.

Hence the initial situation could be $(n_u = 5, n_s = 4, n_b = 60)$, $(n_d = 4, n_s = 5, n_t = 60)$ and the physical U and D matrices result from U and D matrices by a small perturbation as one unit of t (b) mass squared is transferred to u (s) quark and produces symmetry breaking as $(n_d = 5, n_s = t, n_b = 59)$, $(n_u = 6, n_c = 4, n_t = 59)$.

The unperturbed matrices $|U|$ and$|D|$ would be identical with $|U|$ given by

$$|U_{11}| = |U_{22}| = \tfrac{2}{3} \ , \quad |U_{12}| = |U_{21}| = \tfrac{\sqrt{5}}{3} \ , \tag{9.8}$$

The thermodynamical model allows solutions reducing to a direct sum of 2×2 and 1×1 matrices, and since $|U|$ matrix is fixed completely by the mass constraints, it is trivially consistent with the thermodynamical model.

9.2.2 Direct search of U and D matrices

The general formulas for p^U and p^D in terms of the probabilities p_{11} and p_{21} allow straightforward search for the probability matrices having maximum entropy just by scanning the (p_{11}, p_{21}) plane constrained by the conditions that all probabilities are positive and smaller than 1. In the physically interesting case the solution is sought near a solution for which the non-vanishing probabilities are $p_{11} = p_{22} = (9 - n_1)/9$, $p_{12} = p_{21} = n_1/9$, $p_{33} = 1$, $n_1 = 4$ or 5. The inequalities allow to consider only the values $p_{11} \geq (9 - n_1)/9$.

1. Probability matrices p^U and p^D

The direct search leads to maximally entropic p^D matrix with $(n_d, n_s) = (5, 5)$:

$$p^D = \begin{pmatrix} 0.4982 & 0.4923 & 0.0095 \\ 0.4981 & 0.4924 & 0.0095 \\ 0.0037 & 0.0153 & 0.9810 \end{pmatrix} \ , \quad p_0^D = \begin{pmatrix} 0.5556 & 0.4444 & 0 \\ 0.4444 & 0.5556 & 0 \\ 0 & 0 & 1 \end{pmatrix} \ . \tag{9.9}$$

p_0^D represents the unperturbed matrix p_0^D with $n(d = 4), n_s = 5$ and is included for the purpose of comparison. The entropy $S(p^D) = 1.5603$ is larger than the entropy $S(p_0^D) = 1.3739$. A possible interpretation is in terms of the spontaneous symmetry breaking induced by entropy maximization in presence of constraints.

A maximally entropic p^U matrix with $(n_u, n_c) = (5, 6)$ is given by

$$p^U = \begin{pmatrix} 0.5137 & 0.4741 & 0.0122 \\ 0.4775 & 0.4970 & 0.0254 \\ 0.0088 & 0.0289 & 0.9623 \end{pmatrix} \tag{9.10}$$

The value of entropy is $S(p^U) = 1.7246$. There could be also other maxima of entropy but in the range covering almost completely the allowed range of the parameters and in the accuracy used only single maximum appears.

The probabilities p_{ii}^D *resp.* p_{ii}^U satisfy the constraint $p(i,i) \geq .492$ *resp.* $p_{ii} \geq .497$ so that the earlier proposal for the solution of proton spin crisis must be given up and the solution discussed in [**?**] remains the proposal in TGD framework.

2. Near orthogonality of U and D matrices

An interesting question whether U and D matrices can be transformed to approximately orthogonal matrices by a suitable $(U(1) \times U(1))_L \times (U(1) \times U(1))_R$ transformation and whether CP breaking phase appearing in CKM matrix could reflect the small breaking of orthogonality. If this expectation is correct, it should be possible to construct from $|U|$ ($|D|$) an approximately orthogonal matrix by multiplying the matrix elements $|U_{ij}|$, $i,j \in \{2,3\}$ by appropriate sign factors. A convenient manner to achieve this is to multiply $|U|$ ($|D|$) in an element wise manner ($(A \circ B)_{ij} = A_{ij}B_{ij}$) by a sign factor matrix S.

1. In the case of $|U|$ the matrix $U = S \circ |U|$, $S(2,2) = S(2,3) = S(3,2) = -1$, $S_{ij} = 1$ otherwise, is approximately orthogonal as the fact that the matrix U^TU given by

$$U^TU = \begin{pmatrix} 1.0000 & 0.0006 & -0.0075 \\ 0.0006 & 1.0000 & -0.0038 \\ -0.0075 & -0.0038 & 1.0000 \end{pmatrix}$$

is near unit matrix, demonstrates.

2. For D matrix there are two nearly orthogonal variants. For $D = S \circ |D|$, $S(2,2) = S(2,3) = S(3,2) = -1$, $S_{ij} = 1$ otherwise, one has

$$D^TD = \begin{pmatrix} 1.0000 & -0.0075 & 0.0604 \\ -0.0075 & 1.0000 & 0.0143 \\ 0.0604 & 0.0143 & 1.0000 \end{pmatrix} .$$

The choice $D = S \circ D$, $S(2,2) = S(2,3) = S(3,3) = -1$, $S_{ij} = 1$ otherwise, is slightly better

$$D^TD = \begin{pmatrix} 1.0000 & -0.0075 & 0.0604 \\ -0.0075 & 1.0000 & 0.0143 \\ 0.0601 & 0.0143 & 1.0000 \end{pmatrix} .$$

3. The matrices U and D in the standard gauge

Entropy maximization indeed yields probability matrices associated with unitary matrices. 8 phase factors are possible for the matrix elements but only 4 are relevant as far as the unitarity conditions are considered. The vanishing of the inner products between row vectors, gives 6 conditions altogether so that the system seems to be over-determined. The values of the parameters s_1, s_2, s_3 and phase angle δ in the "standard gauge" can be solved in terms of r_{11} and r_{21}.

The requirement that the norms of the parameters c_i are not larger than unity poses non-trivial constraints on the probability matrices. This should should be the case since the number of unitarity conditions is 9 whereas probability conservation for columns and rows gives only 5 conditions so that not every probability matrix can define unitary matrix. It would seem that the constraints are satisfied only if the 2 mass squared conditions and 2 conditions from the entropy maximization are equivalent with 4 unitarity conditions so that the number of conditions becomes 5+4=9. Therefore entropy maximization and mass squared conditions would force the points of complex 9-dimensional space defined by 3×3 matrices to a 9-dimensional surface representing group $U(3)$ so that these conditions would have a group theoretic meaning.

The formulas

$$\begin{aligned} r_{i2} &= \sqrt{[-\frac{n_i}{51} + \frac{20}{17}(1 - r_{i1}^2)]} \ , \\ r_{i3} &= \sqrt{[\frac{n_i}{51} - \frac{3}{17}(1 - r_{i1}^2)]} \ . \end{aligned} \tag{9.11}$$

and

$$U = \left[\begin{array}{ccc} c_1 & s_1c_3 & s_1s_3 \\ -s_1c_2 & c_1c_2c_3 - s_2s_3exp(i\delta) & c_1c_2s_3 + s_2c_3exp(i\delta) \\ -s_1s_2 & c_1s_2c_3 + c_2s_3exp(i\delta) & c_1s_2s_3 - c_2c_3exp(i\delta) \end{array} \right] \quad (9.12)$$

give

$$\begin{array}{ll} c_1 = r_{11} \ , & c_2 = \frac{r_{21}}{\sqrt{1-r_{11}^2}} \ , \\ s_3 = \frac{r_{13}}{\sqrt{1-r_{11}^2}} \ , & cos(\delta) = \frac{c_1^2c_2^2c_3^2+s_2^2s_3^2-r_{22}^2}{2c_1c_2c_3s_2s_3} \ . \end{array} \quad (9.13)$$

Preliminary calculations show that for $n_1 = n_2 = 5$ case the matrix of moduli allows a continuation to a unitary matrix but that for $n_1 = 4, n_2 = 6$ the value of $cos(\delta)$ is larger than one. This would suggest that unitarity indeed gives additional constraints on the integers n_i. The unitary (in the numerical accuracy used) $(n_d, n_s) = (5,5)$ D matrix is given by

$$D = \left(\begin{array}{lll} 0.7059 & 0.7016 & 0.0975 \\ -0.7057 & 0.7017 - 0.0106i & 0.0599 + 0.0766i \\ -0.0608 & 0.0005 + 0.1235i & 0.4366 - 0.8890i \end{array} \right) \ .$$

The unitarity of this matrix supports the view that for certain integers n_i the mass squared conditions and entropy maximization reduce to group theoretic conditions. The numerical experimentation shows that the necessary condition for the unitarity is $n_1 > 4$ for $n_2 < 9$ whereas for $n_2 \geq 9$ the unitarity is achieved also for $n_1 = 4$.

9.2.3 Direct search for CKM matrices

The standard gauge in which the first row and first column of unitary matrix are real provides a convenient representation for the topological mixing matrices: it is convenient to refer to these representations as U_0 and D_0. The possibility to multiply the rows of U_0 and D_0 by phase factors $(U(1) \times U(1))_R$ transformations) provides 2 independent phases affecting the values of $|V|$. The phases $exp(i\phi_j)$, $j = 2,3$ multiplying the second and third row of D_0 can be estimated from the matrix elements of $|V|$, say from the elements $|V_{11}| = cos(\theta_c) \equiv v_{11}$, $sin\theta_c = .226 \pm .002$ and $|V_{31}| = (9.6 \pm .9) \cdot 10^{-3} \equiv v_{31}$. Hence the model would predict two parameters of the CKM matrix, say s_3 and δ_{CP}, in its standard representation.

The fact that the existing empirical bounds on the matrix elements of V are based on the standard model physics raises the question about how seriously they should be taken. The possible existence of fractally scaled up versions of light quarks could effectively reduce the matrix elements for the electro-weak decays $b \to c + W$, $b \to u + W$ *resp.* $t \to s + W$, $t \to d + W$ since the decays involving scaled up versions of light quarks can be counted as decays $W \to bc$ *resp.* $W \to tb$. This would favor too small experimental estimates for the matrix elements V_{i3} and V_{3i}, $i = 1,2$. In particular, the matrix element $V_{31} = V_{td}$ could be larger than the accepted value.

Various constraints do not leave much freedom to choose the parameters n_{q_i}. The preliminary numerical experimentation shows that the choice $(n_d, n_s) = (5,5)$ and $(n_u, n_c) = (5,6)$ yields realistic U and D matrices. In particular, the conditions $|U(1,1)| > .7$ and $|D(1,1)| > .7$ hold true and mean that the original proposal for the solution of spin puzzle of proton must be given up. In [?] an alternative proposal based on more recent findings is discussed. Only for this choice reasonably realistic CKM matrices have been found. For $n_t = 58$ the mass of $t\bar{t}$ meson mass is reduced by one percent from 2×163 GeV for $n(5) = 59$ so that $n_t = 58$ is still acceptable if the additivity of conformal weight rather than mass is accepted for diagonal mesons.

1. The requirement that the parameters $|V_{11}|$ (or equivalently, Cabibbo angle) and $|V_{31}|$ are produced correctly, yields CKM matrices for which CP breaking parameter J is roughly one half of its accepted value. The matrix elements $V_{23} \equiv V_{cb}$, $V_{32} \equiv V_{tc}$, and $V_{13} \equiv V_{ub}$ are roughly twice their accepted value. This suggests that the condition on V_{31} should be loosened.

2. The following equations summarize the results of the search requiring that
   (a) the value of the Cabibbo angle s_{Cab} is within the experimental limits $s_{Cab} = .223 \pm .002$,
   (b) $V_{31} = (9.6 \pm .9) \cdot 10^{-3}$, is allowed to have value at most twice its upper bound,
   (c) V_{13} whose upper bound is determined by probability conservation, is within the experimental limits $.42 \cdot 10^{-3} < |V_{ub}| < 6.98 \cdot 10^{-3}$ whereas $V_{23} \simeq 4 \times 10^{-3}$ should come out as a prediction,
   (d) the CP breaking parameter satisfies the condition $|(J - J_0)/J_0| < .6$, where $J_0 = 10^{-4}$ represents the lower bound for J (the experimental bounds for J are $J \times 10^4 \in (1-1.7)$).

The pairs of the phase angles (ϕ_1, ϕ_2) defining the phases $(exp(i\phi_1), exp(i\phi_2))$ are listed below

$$\begin{array}{llllll} class\ \ 1: & \phi_1 & 0.1005 & 0.1005 & 4.8129 & 4.8129 \\ & \phi_2 & 0.0754 & 1.4828 & 4.7878 & 6.1952 \\ class\ \ 2: & \phi_1 & 0.1005 & 0.1005 & 4.8129 & 4.8129 \\ & \phi_2 & 2.3122 & 5.5292 & 0.7414 & 3.9584 \end{array} \tag{9.14}$$

The phase angle pairs correspond to two different classes of U, D, and V matrices. The U, D and V matrices inside each class are identical at least up to 11 digits(!). Very probably the phase angle pairs are related by some kind of symmetry.

The values of the fitted parameters for the two classes are given by

$$\begin{array}{lllll} & |V_{11}| & |V_{31}| & |V_{13}| & J/10^{-4} \\ class\ 1 & 0.9740 & 0.0157 & 0.0069 & .93953 \\ class\ 2 & 0.9740 & 0.0164 & 0.0067 & 1.0267 \end{array}$$

V_{31} is predicted to be about 1.6 times larger than the experimental upper bound and for both classes V_{23} and V_{32} are roughly too times too large. Otherwise the fit is consistent with the experimental limits for class 2. For class 1 the CP breaking parameter is 7 per cent below the experimental lower bound. In fact, the value of J is fixed already by the constraints on V_{31} and V_{11} and reduces by a factor of one half if V_{31} is required to be within its experimental limits.

U, D and $|V|$ matrices for class 1 are given by

$$U = \begin{bmatrix} 0.7167 & 0.6885 & 0.1105 \\ -0.6910 & 0.7047 - 0.0210i & 0.0909 + 0.1310i \\ -0.0938 & 0.0696 + 0.1550i & 0.1747 - 0.9653i \end{bmatrix}$$

$$D = \begin{bmatrix} 0.7059 & 0.7016 & 0.0975 \\ -0.6347 - 0.3085i & 0.6358 + 0.2972i & 0.0203 + 0.0951i \\ -0.0587 - 0.0159i & -0.0317 + 0.1194i & 0.6534 - 0.7444i \end{bmatrix}$$

$$|V| = \begin{bmatrix} 0.9740 & 0.2265 & 0.0069 \\ 0.2261 & 0.9703 & 0.0862 \\ 0.0157 & 0.0850 & 0.9963 \end{bmatrix} \tag{9.15}$$

U, D and $|V|$ matrices for class 2 are given by

$$U = \begin{bmatrix} 0.7167 & 0.6885 & 0.1105 \\ -0.6910 & 0.7047 - 0.0210i & 0.0909 + 0.1310i \\ -0.0938 & 0.0696 + 0.1550i & 0.1747 - 0.9653i \end{bmatrix}$$

$$D = \begin{bmatrix} 0.7059 & 0.7016 & 0.0975 \\ -0.6347 - 0.3085i & 0.6358 + 0.2972i & 0.0203 + 0.0951i \\ -0.0589 - 0.0151i & -0.0302 + 0.1198i & 0.6440 - 0.7525i \end{bmatrix}$$

$$|V| = \begin{bmatrix} 0.9740 & 0.2265 & 0.0067 \\ 0.2260 & 0.9704 & 0.0851 \\ 0.0164 & 0.0838 & 0.9963 \end{bmatrix} \tag{9.16}$$

What raises worries is that the values of $|V_{23}| = |V_{cb}|$ and $|V_{32}| = |V_{ts}|$ are roughly twice their experimental estimates. This, as well as the discrepancy related to V_{31}, might be understood in terms of the electro-weak decays of b and t to scaled up quarks causing a reduction of the branching ratios $b \rightarrow c + W$, $t \rightarrow s + W$ and $t \rightarrow t + d$. The attempts to find more successful integer combinations n_i has failed hitherto. The model for pseudo-scalar meson masses, the predicted relatively small masses of light quarks, and the explanation for $t\bar{t}$ meson mass supports this mixing scenario.

10 Figures And Illustrations

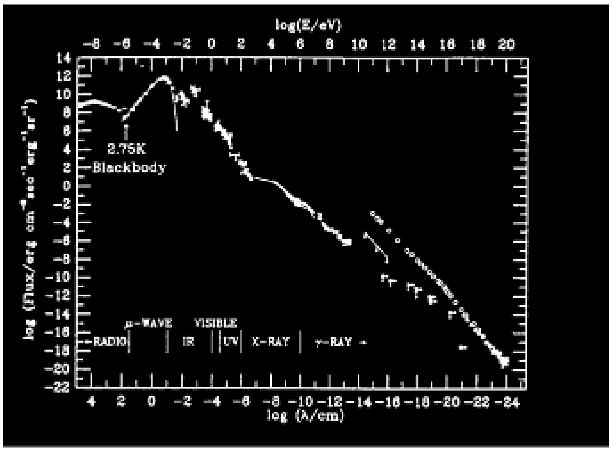

Figure 1: There are some indications that cosmic gamma ray flux contains a peak in the energy interval $10^{10} - 10^{11}$ eV. Figure is taken from [C56].

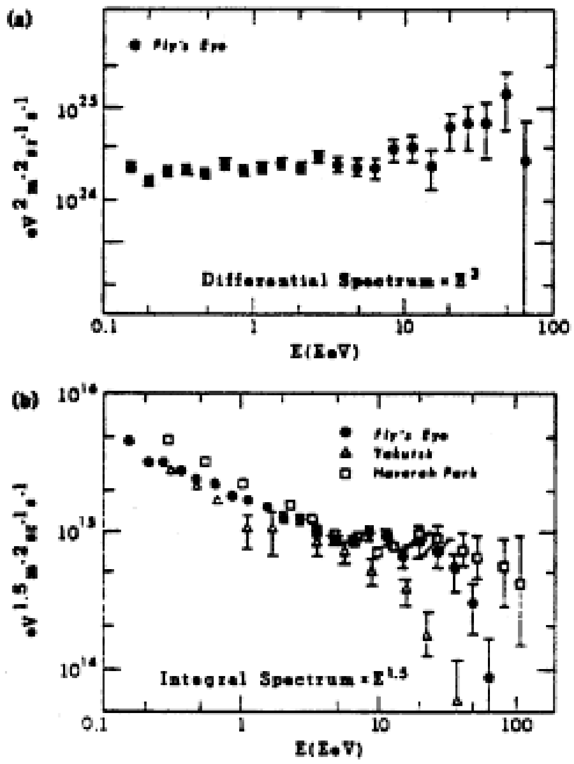

FIG. 2. (a) Differential spectrum $J(E)$ plotted as $E^3J(E)$. A power-law best fit of the form $J(E) = aE^{-\gamma}$ yields $a = 109.6 \pm 2.2$ EeV^{-1} km^{-2} sr^{-1} yr^{-1} and $\gamma = 2.94 \pm 0.02$ for events at $E < 10$ EeV. Between 10 and 50 EeV we obtain $a = 34 \pm 17$ EeV^{-1} km^{-2} sr^{-1} yr^{-1} and $\gamma = 2.42 \pm 0.27$. The lack of events above 50 EeV indicates that the flattened slope does not continue. (b) Integral spectrum $I(>E)$ plotted as $E^{1.5}I(>E)$. Data from both Haverah Park and Yakutsk (Refs. 10, 12, and 13) experiments are also shown.

Figure 2

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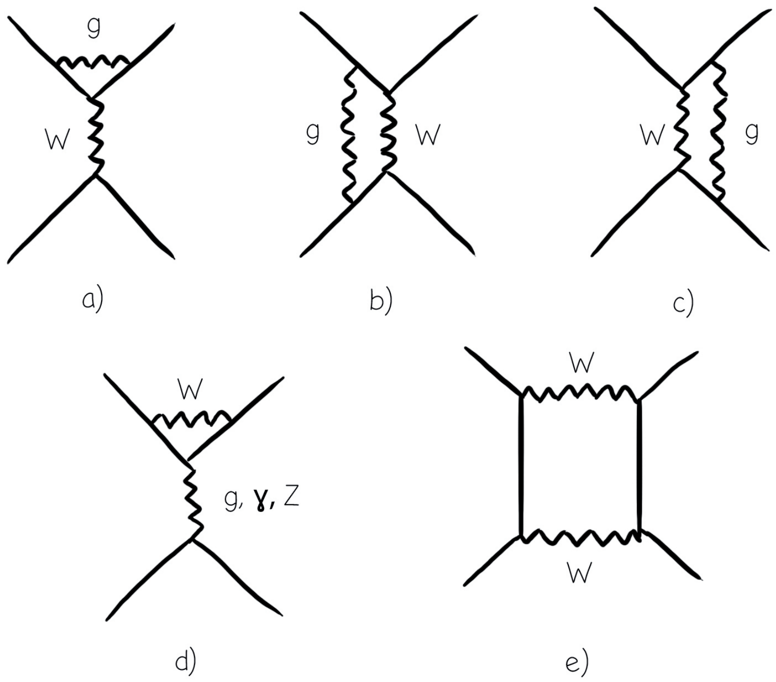

Figure 3: Standard model contributions to the matching of the quark operators in the effective flavor-changing Lagrangian

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