The findings of RHIC about quark gluon plasma from the TGD point of view

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Abstract

The study of quark gluon plasma at RHIC has revealed many surprises.

1. Jet quenching means that jets predicted by QCD lose energy much faster than expected. This would be due to the strong interactions with quark gluon plasma implying dissipation. In QCD, this interaction is modelled in terms of collisions of quarks with the quark gluon plasma formed by quarks and gluons.
2. The almost ideal perfect fluid behavior was totally unexpected. This hydrodynamic flow is known as elliptic flow. A further surprise was that heavy quarks also participate in the elliptic flow. This is like boulders flowing in a river.
3. Also light ions create the quark-gluon plasma. QGP, or whatever it is, is created even in the collisions of photons and heavy ions.
4. The basic questions concern the critical temperature and critical collision energy per nucleon at which the transition to QGP occurs. There is no consensus but the proposal is that 19.6 GeV collision energy could be a critical point. There is however a bumpy structure also below this critical point.

What can be said about these findings in the TGD framework?

1. The counterpart of quenching would be conformal dissipation or equivalently p-adic occurring for mass squared scale identifiable as conformal weight rather than energy. p-Adic temperature T_p which depends logarithmically on the p-adic mass scale has a discrete spectrum and would decrease in a stepwise manner in the p-adic cooling. T_p is naturally identifiable as the temperature of the counterpart of QGP and has also an interpretation as Hagedorn temperature.
2. p-Adic length scales hypothesis suggests that there is an entire discrete hierarchy of critical temperatures rather than only a single critical temperature. These temperatures would come as logarithms of p-adic mass squared scales proportional to 2^k.
3. In the TGD framework, the large values of h_{eff} associated with the quantum criticality and implying long scale quantum coherence could explain the perfect liquid behavior in terms of long term correlations, which are typical for hydrodynamics. Recall that at the classical level TGD is essentially a hydrodynamical theory since field equations reduce to conservation laws for the charges associated with the isometries of H.
4. The TGD based explanation for the boulders flowing in the river would be that for the TGD analog of QGP, the induced Dirac equation in X^4 implies that both leptons and quarks behave like massless particles. Masses emerge only in the hadronic initial and final states constructed as modes of the H Dirac equation.

1 Introduction

I encountered a highly interesting popular article in which the work at RHIC relating to a phase transition to quark gluon plasma (QGP) dominated phase was discussed. The title of the popular article (see this) is "Clear Sign that QGP Production 'Turns Off' at Low Energy". The title of the article (see this) published in Phys Rev Letters [L19] "Beam Energy Dependence of Fifth- and Sixth-Order Net-Proton Number Fluctuations in Au+Au Collisions at RHIC" is so technical that it does not tell much to a layman. However, since fluctuations characterize criticality, one can guess that criticality is studied.

1. Collisions of Gold ions have been studied at RHIC. The cm energy per nucleon has varied from 3 GeV to 200 GeV. At LHC the upper limit for energies is considerably higher, about 5 TeV and therefore 25 times higher. The research has shown that the behavior of the quark gluon plasma differs rather dramatically from the expectations.

2. What is the critical temperature for the transitions to quark gluon plasma? This has been one of the key questions. No definite answer has been found although $\sqrt{s_{NN}} = 19.6$ GeV is considered as a candidate for 19.6 GeV for the critical collision energy per nucleon. However, a bumpy structure is observed also below this energy down to 3 GeV. Therefore the existence of a single critical temperature can be challenged. It is also clear that a first order phase transition involving single discontinuities of various thermodynamic observables is not in question.

   A more technical way to say this is as follows. What is studied are higher order cumulants for proton number fluctuations around average. At quantum criticality they are expected to be large. At higher collision energies they deviate from those predicted by a first order phase transition. At low collision energies the "off" signal shows up as a sign change—from negative to positive—in data that describe "higher order" characteristics of the distribution of protons produced in these collisions. To sum up, a higher order statistical analysis of protons emitted from a wide range of gold-gold collision energies shows clear absence of a quark-gluon plasma (QGP) at the lowest collision energy.

Here is the abstract of the article "Beam Energy Dependence of Fifth- and Sixth-Order Net-Proton Number Fluctuations in Au+Au Collisions at RHIC" [L19] summarizing the findings at RHIC.

We report the beam energy and collision centrality dependence of fifth and sixth order cumulants (C_5, C_6) *and factorial cumulants* (κ_5, κ_6) *of net-proton and proton number distributions, from center-of-mass energy* ($\sqrt{s_{NN}}$) *3 GeV to 200 GeV Au+Au collisions at RHIC. Cumulant ratios of net-proton (taken as proxy for net-baryon) distributions generally follow the hierarchy expected from*

QCD thermodynamics, except for the case of collisions at 3 GeV. The measured values of C_6/C_2 *for 0%-40% centrality collisions show progressively negative trends with decreasing energy, while it is positive for the lowest energy studied. These observed negative signs are consistent with QCD calculations (for baryon chemical potential,* $\mu_B leq 110 MeV$*) which contains the crossover transition range. In addition, for energies above 7.7 GeV, the measured proton , within uncertainties, does not support the two-component (Poisson + binomial) shape of proton number distributions that would be expected from a first-order phase transition. Taken in combination, the hyper order proton number fluctuations suggest that the structure of QCD matter at high baryon density,* $\mu_B \sim 750 MeV$ *at* $\sqrt{s_{NN}}$*=3GeV is starkly different from those at vanishing* $\mu_B \sim 24 MeV$ *at* $\sqrt{s_{NN}}$ *=200GeV and higher collision energies.*

1.1 A brief summary of the findings at RHIC

Consider first a brief summary of the unexpected RHIC findings (see this) concerning the creation of what is thought to be QGP. The study revealed many surprises.

1. Jet quenching means that jets predicted by QCD lose energy much faster than expected. This would be due to the strong interactions with quark gluon plasma implying dissipation. In QCD, this interaction is modelled in terms of collisions of quarks with the quark gluon plasma formed by quarks and gluons.

2. The almost ideal perfect fluid behavior was totally unexpected. This hydrodynamic flow is known as elliptic flow. A further surprise was that heavy quarks also participate in the elliptic flow. This is like boulders flowing in a river.

3. Also light ions create the quark-gluon plasma. QGP, or whatever it is, is created even in the collisions of photons and heavy ions.

4. The basic questions concern the critical temperature and critical collision energy per nucleon at which the transition to QGP occurs. There is no consensus but the proposal is that 19.6 GeV collision energy could be a critical point. There is however a bumpy structure also below this critical point.

1.2 TGD view briefly

What can be said about these findings in the TGD framework?

1. The counterpart of quenching would be conformal dissipation [L16] or equivalently p-adic occurring for mass squared scale identifiable as conformal weight rather than energy. p-Adic temperature T_p which depends logarithmically on the p-adic mass scale has a discrete spectrum and would decrease in a stepwise manner in the p-adic cooling. T_p is naturally identifiable as the temperature of the counterpart of QGP and has also an interpretation as Hagedorn temperature [B1].

2. p-Adic length scales hypothesis [L4] suggests that there is an entire discrete hierarchy of critical temperatures rather than only a single critical temperature. These temperatures would come as logarithms of p-adic mass squared scales proportional to 2^k.

3. In the TGD framework, the large values of h_{eff} associated with the quantum criticality and implying long scale quantum coherence could explain the perfect liquid behavior in terms of long term correlations, which are typical for hydrodynamics. Recall that at the classical level TGD [K1] is essentially a hydrodynamical theory since field equations reduce to conservation laws for the charges associated with the isometries of H.

4. The TGD based explanation for the boulders flowing in the river would be that for the TGD analog of QGP, the induced Dirac equation in X^4 [L15] implies that both leptons and quarks behave like massless particles. Masses emerge only in the hadronic initial and final states constructed as modes of the H Dirac equation.

2 The TGD view of the RHIC findings

2.1 The TGD view of the standard model

My personal interest is to relate the overall view about the findings of RHIC to the TGD view about standard model interactions [L18]. This view differs rather dramatically from the standard view. It is good to start with a general summary of the TGD view of standard model physics.

1. The basic difference between standard model and TGD is due to the realization of color symmetries. In TGD, space-times are 4-surfaces $X^4 \in H = M^4 \times CP_2$ and color is not a spin-like quantum number at the fundamental level and both quarks and leptons move in spinor color partial waves defined in CP_2 [L17, L15].

   The states observable below CP_2 mass scale are color singlets consisting of color triplet counterparts of fundamental quarks and color singlet counterparts of fundamental leptons. Weak interactions can be regarded as color interactions in the "spin" degrees of freedom for CP_2 and this means unification of electroweak and color interactions [L18].

   At the space-time level spinor fields corresponding to the induced spinors are induced from second quantized H spinors, which behave like massless spinor fields. By holography= holomorphy principle the induced Dirac equation can be solved. One can also consider the possibility of Dirac equation inside causal diamond (CD). TheDirac equation in CD would involve a coupling to the Kähler structure of M^4 associated with its Hamilton-Jacobi structure [L6, L15].

2. p-Adic length scale hypothesis is a key prediction of the number theoretical vision, which in the TGD view is dual to the geometric vision of physics [L9, L13]. An entire hierarchy of standard model physics proposed to be labelled by Mersenne primes defining p-adic mass scales characterized the hadrons and also quarks. These standard model physics correspond to the hierarchy of irreducible representations of CP_2 and the multipletes for quarks and leptons are in 1-1 correspondence. Light many fermion states are color singlets [L15], which involve tachyonic fermions also allowed by the H Dirac equation. In the simplest model the tachyonic conformal weights would be associated with neutrinos. Free colored single particle states are possible only in CP_2 mass scales. Only right-handed neutrino can be color singlet.

3. A process that I call p-adic cooling [K5, K6] [L16] would characterize cosmic time evolution and mean a process in which hadrons with CP_2 mass scale decay in a cascade like matter to hadrons of light hadron physics. Needless to say that this view would revolutionize the views of cosmic evolution and astrophysics [L10, L7, L8].

4. Quantum criticality is a basic aspect of the TGD Universe and means that there are no continuously running coupling constants in the usual sense. Space-time surfaces obey holography = holomorphy principle [L11] and there is no path integral. All particles are bound states of fermions and the Feynman diagrammatics involves only fermionic 2-vertices so radiative corrections are absent [L16]. There is an analogy with Brownian motion and fermion pair creation is possible due to the existence of exotic smooth structures, possible only in the space-time dimension $D = 4$. Number theoretic vision predicts that coupling constant evolution is discrete and labelled by the p-adic length scales and possible other number theoretic parameters.

   Quantum criticality involves long range quantum fluctuations. In the number theoretic vision, they would correspond to large values of effective Planck constant h_{eff} having number theoretic interpretation either as the dimension of an algebraic extension characterizing the space-time surface or as the degree of the polynomial characterizing it.

   At quantum criticality for a phase transition changing the Mersenne prime characterizing the standard model physics large values of h_{eff} are possible and an interesting hypothesis is that there is a length scale resonance, the value of h_{eff}/h for the hadrons of the new hadron physics is such that the Compton scales for the ordinary hadrons and the hadrons of new hadron physics are the same.

5. p-Adic thermodynamics [L4] for mass squared, identified as a conformal weight, involves p-adic temperature T_p which is proportional to the inverse of the logarithm of the p-adic mass squared scale. The discreteness of the temperature conforms with the interpretation as a Hagedorn temperature [B1] (see this) characterizing extended objects with infinite number of degrees of freedom. In TGD, these objects would correspond to monopole flux tubes characterizing particles and also hadrons as 3-D geometric objects. A hierarchy of Hagedorn temperatures is predicted.

   The p-adic length scale hypothesis states that primes near to some powers $p \simeq 2^k$ of 2 are physically preferred and this hypothesis has no number theoretical justification based on the naturally emerging generalization of p-adic number fields to function fields. This would suggest that the ratios of the Hagedorn temperatures are rational numbers $T_k/T_l \in \{l/k\}$.

   If the Hagedorn temperatures correspond to the temperature assigned with the high-energy collisions of nuclei, this temperature is piecewise constant and the feed of energy creates entropy but does not affect temperature. This is indeed the case: the plasma temperature assigned with the collision increases very slowly with the collision energy.

   This view leads to the notions of p-adic cooling occuring after the collision as the QGP expands and p-adic heating during which the QGP is formed [K5, K6] [L18].

6. Ordinary hadron physics would correspond to Mersenne prime M_{107} and there are indications for M_{89} hadron physics at LHC and from cosmic ray physics [K5, K6]. The proposal is that M_{89} hadron physics could play a central role in the physics of the Sun [L12].

   For the transition from M_{107} hadron physics to M_{89} hadrons physics quantum criticality, assuming that Compton lengths are same, implies $h_{eff}/h = 512$ as ration of p-adic mass scales. Interestingly, if the scaling by h_{eff}/h can occur also for the hadrons of ordinary hadron physics, the Compton length of the ordinary proton is scaled up to about 4 times Compton length of electron. This kind of scaling is assumed to occur in the TGD based model for the "cold" fusion [L1, L2, L3] as dark fusion. In the TGD based model for the Sun [L12] dark fusion would take place also at the surface of the Sun and replace the ordinary hot fusion in the solar core. It would occur after the transformation of M_{89} hadrons to ordinary hadrons by p-adic cooling at the surface of the Sun.

2.2 General TGD view of particle reactions

The general TGD based view of particle reactions generalizes the QCD view of hadronic reactions.

1. Interactions in H are contact interactions determined by the intersections of the space-time surfaces. Without additional assumptions the intersection consists in the generic case of discrete points. If the Hamilton-Jacobi structures are the same, the intersection consists of 2-D string world sheets whose dynamics is strongly restricted by the hypercomplex structure, meaning that only a second coordinate with light-like coordinate lines is dynamical. This is the case also in string models. By $M^8 - H$ duality a similar picture holds true also at the level of M^8 which corresponds to momentum space description for particles identified as Bohr orbits of 3-surfaces.

2. There would be two phases: X^4-phase as the counterpart of QGP but involving only free quarks and H-phase as counterpart of hadron phase. Hadronization leading from QGP the final state and the generation of the analog of QGP phase from hadronic initial state generalize to all standard model interactions and are universal mechanisms [L18].

3. The role of ZEO is essential. ZEO involves two kinds of state function reductions (SFRs). "Big" SFRs (BSFRs) and "small" SFRs (SSFRs). SSFRs are self measurements in the non-deterministic degrees of freedom assignable to the space-time surfaces $X^4 \subset H$ obeying holography = holomorphy principle and therefore being analogous to Bohr orbits for particles as 3-surfaces. Sequence of SSFRs defines a conscious entity, self. Slight classical non-determinism of holography= holomorphy vision accompanied by quantum non-determinism essential also for the particle reactions.

In BSFR which is the TGD counterpart for the ordinary measurement reducing the entanglement between observer and the systems, the arrow of time changes. In a hadronic reaction two BSFRs take place. In the first BSFR a p-adic cooling in a reversed time direction occurs. For an external observer it looks like heating of the system. After the second BSFR p-adic cooling in standard time direction takes place. Conformal dissipation is involved with the cooling.

2.3 Conformal dissipation, p-adic length scale hypothesis and quantum ciriticality

Could quantum quantum criticality involving conformal invariance and quantum coherence play a central role in jet quenching. M^8-H duality inspires the notion of conformal dissipation [L16] as a dissipation in which energy is replaced with conformal weight, which is essentially mass squared. Could conformal dissipation interpreted as p-adic cooling help in the attempts to understand quenching?

1. Conformal dissipation [L16] is suggested by the M^8-H duality and would be described in terms of 4-surface Y^4 in M^8 as dual of space-time surface and defining the analog of momentum space defining dispersion relation. The time evolution at space-time level would correspond to p-adic momentum space evolution as a decrease of the mass scale and ending up to an evolution at mass shells of final state particles identifiable as ordinary dissipation. This could correspond to p-adic cooling. p-Adic heating can be considered would correspond to p-adic cooling with a reversed arrow of time and occur after the first BSFR. The p-adic cooling could be synonymous to a conformal dissipation.

2. Two kinds of number theoretic phase transitions and their combination are possible. The decrease of the p-adic mass scale of hadrons and quarks can take place as the collision energy increases. Quantum criticality in turn induces the increase of h_{eff}. A physically attractive proposal is that the increase of h_{eff} compensates the decrease of the Compton scales due to the shortening of the p-adic length scale. Frequency and wavelength resonance between initial and final states would become possible.

3. The TGD based proposal is that the Nature is theoretician friendly [K4] [L5]: when interactions get so strong that perturbation series fails to converse, a phase transition increasing the value of h_{eff} takes place implying the reduction of α_s. This allows converging perturbation series but the states are changed. Also the interaction range as a scale of quantum coherence increases. This could lead to the formation of perfect liquid.

   Also the Compton scales of quarks could increase. For 4 MeV quark the Compton scale for $h_{eff}/h=512$ corresponding to M_{89} and scaling by $h_{eff}=512h$ would be proton Compton length.

4. The basic steps of the process would be p-adic heating as a cooling with a reversed arrow of time initiated by the first BSFR followed by p-adic cooling initiated by the second BSFR. Cooling would be a stepwise process and there would be a hierarchy of criticalities. Are p-adically scaled up variants of hadron physics with $p \simeq 2^k$ for all values of k be involved as intermediate states in the cooling and heating. Or are only those values of k which can be assigned with quarks involved?

   Sequence of critical temperatures depending logarithmically on the p-adic mass scale increasing as powers of 2. The fact that T_p has logarithmic dependences of the discrete p-adic mass scale would explain the bumpiness at low energies.

5. What p-adic temperature does the mass scale 19.6 GeV correspond to? p-Adic length scale hypothesis predicts $T=log((M/m_p)^2/log(2)$. This predicts $T(19.6GeV)=214.5$ MeV, which is surprisingly near to the estimate for QCD Λ. p-Adic cooling suggests that the bumpiness between 3.6 GeV and 20 GeV could correspond to sequence of phase transition temperatures $T(127-k)$, $k=4,5,6,7,8$. For 200 GeV energy one would have $T\sim 379.36$ MeV. Note that M_{89} hadron physics corresponds to a considerably lower temperature $T=285.39$ MeV.

It should be also noticed that quite recently 20 GeV gamma rays have been reported (see this). This is discussed in [K3]. In TGD they could correspond to decay products of a pion-like state with mass of 40 GeV about 286 pion masses.

2.4 Heavy ion collision as a p-adic heating followed by p-adic cooling

enumerate

p-Adic mass scale as octaves or half octaves 2^k. The most general option is that all values of k are possible. p-Adic length scales come as powers of 2 for odd k and of $\sqrt{2}$ in the general case! The strongest restriction is that the p-adic primes correspond to Mersenne primes for stable hadrons and leptons. The transitions between these M_{89} hadron physics and M_{107} hadron physics could occur via p-adic cooling via unstable intermediate states as cascades in with k decreases in a stepwise manner.

The p-adic temperature T_p appearing in p-adic mass calculations corresponds to the integer valued inverse temperature of p-adic thermodynamics for mass squared identified as conformal weight is naturally identifiable Hagedorn temperature. Since Boltzman weights as exponential $e^{-E/T}$ are for number theoretical existence reasons replaced by powers p^{m^2/T_p}, $T_p = 1/n$, the real counterpart of $1/T_p$ $k/log(p)$ meaning that it depends logarithmically on mass squared scale. For fermions $k = 1$ is realized.

Conformal invariance motivates the guess that T_p corresponds to the hadronic temperature T. p-Adic temperature is not the same thing as the ordinary temperature. T_p scales like $1/log(p) \propto 1/k$ if the p-adic length scale hypothesis $p \simeq 2^k$ and supported by the function field generalization of p-adic numbers holds true.

$1/p$ scales like mass squared and p-adic temperature T_p scales like logarithm of the mass squared scale and is discrete. If the p-adic length scale hypothesis is true, the ratio of p-adic temperatures equals to $T_k/T_l = l/k$. The piecewise constancy justifies the interpretation as Hagedorn temperature. For instance, $T_{89}/T_{127} = 127/89 = 1.42$ so that the scaling is very slow. M_{89} corresponds to 284 MeV if M_{107} corresponds to 200 MeV.

Quantum criticality is associated with the transition changing the p-adic length scales Compton lengths for the scaled up hadron physics would be the same as for the M_{107} hadron physics at quantum criticality. Critical points could correspond to the temperatures of quark gluon plasmas characterized by the p-adic temperature depending logarithmically on the p-adic mass scale. This predicts that critical collision energies $\sqrt{s_{NN}}$ come as powers of 2.

3 Official top quark and toponium as particles of M_{89} hadron physics?

I watched an excellent video about what we have learned at LHC (see). Three runs RUN1, RUN2, and RUN3 have been completed and now we know where the limits for the applicability of the Standard Model are.

3.1 What did we learn at LHC?

The immediate successor of LHC will be high-luminosity LHC operating from 2029- 2030 onwards for ten years. Future circular collider (FCC) will start to operate in the late 2040s. Electrons and positrons will collide and the collider (Higgs factory) will act as a high precision collider.

The philosophy is that high precision might allow us to develop a theory allowing us to solve the various anomalies of the standard model. In future, the experimentalists would not be merely testing whether a given extension of the standard model might solve some anomalies but trying to identify more general deviations from the standard model. But is this enough? What has been lacking from theoretical physics since the times of Einstein and his contemporaries, is philosophical thinking challenging the basic assumptions. Can one make progress by merely measuring more precisely?

The video explains the basic anomalies. The anomalies are also discussed in detail by Crivellin and Mellado [C2]. The following list defines the boundaries of the region of phenomena that the standard model can explain.

1. Toponium exists although it should not.
2. W mass deviates from the predicted mass.
3. g-2 anomaly of muon is claimed to disappear in lattice calculations using only quarks and gluons but does not disappear when hadronic data are used as an input.
4. Lepton universality is violated in some meson decays.
5. Penta and tetra quarks, whose existence is not denied but not predicted by the standard model.
6. There are anomalies associated with the CP violation of the CKM matrix.
7. The axions, proposed to solve the problem due to the strong CP violation predicted by QCD, have not been found and the strong CP violation is too weak to explain matter antimatter asymmetry.
8. Quark-gluon plasma predicted by QCD did not behave like gas but a perfect liquid and the transition to quark gluon plasma seems to occur at several energies rather than single phase transition point.
9. SUSY was believed to solve the hierarchy problem involving the fine tuning of the Higg couplings but no evidence for SUSY particles was found.
10. WIMPs as candidates for galactic dark matter have not been found.

3.2 Toponium anomaly as an indication for M_{89} hadron physics

I have discussed various anomalies from the TGD point of view in various articles. Here I will consider only the discovery of the toponium, which is one of the latest surprises. The Standard model does not deny toponium's existence but according to the standard intuition it should not exist.

1. The lifetime of the top quark is too short for the formation of toponium. There are of course proposals for solving this and also other anomalies but the problem is that these proposals typically solve only one anomaly. The lifetime of the standard top quark candidate with mass $m \simeq 172.5$ GeV is $\tau = 5\times 10^{-25}$ s. This time is shorter than required for QCD hadronization processes ($10^{-23}-10^{-24}$ s). This is why it has been believed that toponium does not exist.
2. The toponium was however discovered both by LHC and ATLAS and its lifetime is estimated to be 2.5×10^{-25} s. Toponium is suggested to be a quasi-bound state or a resonance appearing when top quarks are produced very near to the threshold energy (see this and this). Toponium decay is triggered by a weak decay of one of its constituents rather than being a strong decay. Both ATLAS and CMS verified the existence of this state with a resonance width of about 3 GeV.

Consider now the basic ideas of TGD view of hadron physics and standard model in general. TGD leads to almost inescapable conclusion that there must exist an entire hierarchy of standard model physics assignable to the triality ±1 color representations defined by color partial waves of quarks and antiquarks in CP_2. Leptons would appear in triality 0 color partial waves [L17, ?].

1. The color multiplets of quarks of a given standard model physics would combine to form color triplets, which would serve as building bricks of hadrons of a given hadron physics [L18, L21, L14, L20]. These hadrons would correspond to a hierarchy of p-adic mass

scales, proposed to be labelled by ordinary and Gaussian Mersenne primes. The longer the p-adic scale, the higher the dimension of the color multiplet.

For the observed leptons, color representations would combine to form color singlets but also analogs of mesons as bound states of colored leptons might be possible [K8]. Only at energies near CP_2 mass would color deconfinement for incoming and outgoing states be possible.

2. Ordinary hadrons would correspond to the Mersenne prime M_{107}. The nucleon of M_{89} hadron physics would correspond to the mass scale $512m_n$ and therefore to the LHC energy scale. The transition from M_{107} hadron physics to M_{89} hadron physics would take place at quantum criticality. The phase transition usually interpreted as a creation of the quark-gluon phase could correspond to this phase transition [L19]. At quantum criticality the value h_{eff}/h would scale up the Compton length scale of M_{89} hadrons. This would reflect long range quantum fluctuations. This re-interpretation of what has been identified as quark gluon-plasma would solve various anomalies associated with this identification mentioned already in the list of anomalies [L19, L18]. The existence of M_{89} hadron physics can have dramatic implications. For instance, a dramatic modification of the model of the Sun [L12] can be considered.

3. The ratio of the p-adic length scales associated with M_{107} and M_{89}, characterizing the Compton lengths and also defining the geometric size of nucleons as 3-surfaces, is 512. The assumption is that the geometric size of the M_{89} hadron with a large h_{eff} is the same as for M_{107} hadron at quantum criticality implies $h_{eff}/h = 512$. The sizes of M_{89} hadrons would be the same as for ordinary hadrons at quantum criticality for the transition from M_{89} hadron physics to M_{107} hadron physics.

4. I have proposed the identification of various bumps observed at LHC, originally identified first as candidates for SUSY particles but then rejected, in terms of M_{89} mesons [K5, K6].

The large mass of the official top quark raises the question whether it could be M_{89} quark created at quantum criticality.

1. A natural guess is that the lifetime of top quark at quantum criticality is scaled up $h_{eff}/h = 512$ to $.25 \times 10^{-21}$ s. The corresponding distance scale would be $.75 \times 10^{-13}$ m, which is longer than the nuclear size scale!

2. A reasonable guess is that the hadronization time scale for M_{89} is for h_{eff}/h scaled down by factor 1/512 due to decrease of the p-adic length scales. This p-adic length scale corresponds to the geometric size scale of the causal diamond $CD = cd \times CP_2$ assignable to the region in which the phase transition occurs. This local phase transition is discussed in [L21]. The increase $h_{eff} \rightarrow 512h_{eff}$ keeps the geometric time scale associated for hadronization the same as it would be for ordinary hadrons and determined by the p-adic time scale $L(107)$ assignable to ordinary hadrons.

   What happens to the rate of hadronization? The phase transition increasing the value of h_{eff} guarantees that the TGD counterpart of perturbative theory,, still applies. "Mother Nature loves her theoreticians" [L5] is one way to express this principle. Since the zeroth order term in the TGD counterpart of the perturbative expansion, giving the classical approximation, does not depend on h_{eff}, the classical approximation improves as h_{eff} increases.

   The rate for M_{89} hadronization is proportional to the hadronic mass scale $m(89) = 512m(107)$. Since the geometric time scale is $L(107)$ by quantum criticality, the short lifetime of top does not prevent the formation of toponium. Quantum criticality could quite generally increase the probabilities for the formation of bound states of very short-lived particles.

The basic objection is that the official top quark as M_{89} quark would most naturally correspond to genus $g = 0$ for the partonic 2-surface and serve as a counterpart of u quark. The actual $g = 2$ U type quark should have a lower mass.

1. There is indeed evidence for a top quark-like state at much lower mass from Aleph. The mass is estimated to be about 30 GeV or 28 GeV [C1, **?**]. This has motivated the question whether the two candidates for the top quark could correspond to a scaled variant of the top. In the TGD framework, the p-adic length scale hypothesis might allow this [K5] [L14].
2. What about the toponium in this case? There is an old anomaly reported by Aleph at 56 GeV (see `https://arxiv.org/pdf/hep-ph/9608264.pdf`) and there is reference to an old paper: ALEPH Collaboration, D. Buskulic *et al*, CERN preprint PPE/96–052. What was observed was 4-jet events consisting of dijets with invariant mass around 55 GeV. What makes this interesting is that the mass of 28 GeV particle candidates would be one half of the mass of a particle with a mass of 56 GeV particle, quite near to 55 GeV. Could this state be the toponium as $g = 2$ U quark [K5] [L14]?

If this picture is correct, the official top quark would more naturally correspond to the genus $g = 0$ and therefore to M_{89} u quark. Could the poor understanding of the family replication phenomenon and of the origin of the CKM mixing explain this mis-interpretation?

1. The CKM matrix V is empirically determined from charged currents (W decays). The matrix elements of type V_D^U, $U \in \{u, c\}$, $V \in \{d, s\}$ reflect the CKM mixing of d and s quarks. Unitary conditions bring in the matrix elements V_D^t and dependence on top quark mass. Both beta decays and kaon decays provide information about V_D^U, $U \in \{u, c\}$, $V \in \{d, s\}$. These two kinds of constraints lead to slightly different outcomes [C2] for V.
2. Could a wrong identification of the top quark mass cause the discrepancy? In TGD, the official top as the $g = 0$ quark of "dark" M_{89} hadron physics created in the transition to quark-gluon plasma would induce a leakage of probability inducing a genuine violation of the unitary for the CKM matrix.
3. In TGD, the description of family replication has topological explanation and CKM mixing reduces to topological mixing discussed in [K2, K7]. A model for the transition between M_{107} and M_{89} is needed to see whether the new interpretation can be consistent with what is known about creation of official top quarks.
4. The prediction is that the official top as an M_{89} u quark is accompanied by an M_{89} d quark so that toponium should be a member of an isospin triplet. The M_{89} counterparts of π and ρ mesons should exist. The discovery of the M_{89} d quark, perhaps through the discovery of an isospin triplet for toponium, with nearly the same mass as the official top quark, would force us to take the TGD view seriously.

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