# About the TGD based views of family replication phenomenon and color confinement

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**Abstract**

There is 2.5 sigma evidence for the existence of a Higgs-like particle with mass 146 GeV decaying to a muon-electron pair. TGD based topological explanation of family replication phenomenon and the identification of also elementary bosons as pairs of fundamental fermions and antifermions predicts that fermions form effectively triplets under the combinatorial symmetry group $SU(3)_g$ whereas a given elementary boson (gluon, electroweak gauge boson, or Higgs) would form an octet and singlet under this group. The symmetry breaking $SU(3) \rightarrow SU(2) \times U(1) \rightarrow U(1) \times U(1)$ predicts that a given elementary boson extends to the analog of Gell-Mann octet and singlet. The reported anomaly could correspond to the analogs of $\pi^+$ and $\pi^-$.

In this article the implications of the $SU(3)_g$ symmetry for hadron physics are considered. In particular, the possibility of the existence of $SU(3)_g$ gluon octet is considered. Also the proposal that sea partons could correspond to dark quarks and possibly also dark $SU(3)_g$-gluons is developed in detail. Dark sea could solve the EMC paradox and also solve the proton spin crisis.

The basic principle is that Nature is theoretician friendly: when the perturbation series fails to converge, a phase transition increasing the value of $h_{eff} = nh_0$ takes place and reduces the value of gauge coupling strength proportional to $1/\hbar_{eff}$. The color of the ordinary quarks $q_{ord}$ must be first neutralized by color entangling them with the corresponding dark antiquarks $\overline{q}_{dark}$ at color magnetic body (MB) to form a color singlet (color for them is screened). After that one adds to color MB dark variants $q_{dark}$ of quarks. This mechanism would actually apply quite generally to all elementary particles.

It came as a surprise that this principle actually realizes holography, which is a basic principle of TGD and implied by general coordinate invariance. The good news is that there is actually experimental evidence for this holography.

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# 1 Introduction

It is a long time since I have written anything about particle physics. Now the LHC collaboration at CERN has represented evidence for a new anomaly [C1]. The evidence is 2.5 sigmas (standard deviation) so that the anomaly is much below the minimum of 5 sigma for a discovery and could quite well disappear.

What has been studied is the possible occurrence of lepton flavor violating decays of Higgs bosons in proton-proton collisions at cm energy of 13 TeV has been analyzed using data from 2016-2018 period. The integrated luminosity is 136 $\text{fb}^{-1}$.

A small anomaly has been observed. It could be due to the flavor violating decay $H \rightarrow e^{\pm}\mu^{\mp}$ of Higgs having mass 125 GeV. $e\mu$ pair could also come from the decay of a new boson, call it $X$, with mass assumed to be the range 110-160 GeV.

The dominant production modes for the Higgs boson are gluon fusion (ggH) and vector boson fusion (VBF). In both modes the interesting final state oppositely charged $e\mu$ pair. It would appear as a peak at mass $m(H)$ or $m(X)$ on top of a smoothly falling background due to the purely leptonic decays of $t\bar{t}$ and $WW$ events, plus Drell-Yan events with a misidentified lepton. Monte Carlo fit indicates a 2.5 sigma bump 146 GeV.

In this article the implications of the $SU(3)_g$ symmetry for hadron physics are considered. In particular, the possibility of the existence of $SU(3)_g$ gluon octet is considered. The basic idea behind dark matter in the TGD sense is that the phase transition increasing $h$ to $h_{eff} > h$ makes perturbation theory convergent so that Nature can be said to be theoretician friendly. At the low energy limit of hadron physics this kind of phase transition would be very natural. This motivates the proposal that sea partons could correspond to dark quarks and possibly also to dark $SU(3)_g$ gluons. Dark sea could solve the EMC paradox and also solve the proton spin crisis.

A concrete realization for the theoretician friendly character of Nature emerges. The color of the ordinary quarks $q_o$ ("o" for "ordinary") must be first neutralized by color entangling them with the corresponding dark antiquarks $\overline{q}_d$ ("d" for "dark") at color magnetic body (MB) to form a color singlet (color for them is screened). After that one adds to color MB dark variants $q_d$ of quarks. This mechanism would actually apply quite generally to all elementary particles.

It came as a surprise that this principle actually realizes holography, which is a basic principle of TGD and implied by general coordinate invariance. The good news is that there is actually experimental evidence for this holography.

# 2 About the TGD explanation of electron-muon anomaly and some other strange findings

TGD based view of family replication phenomenon predicts new exotic bosons which can explain the electron-muon anomaly also some other findings not conforming with the predictions of the standard model.

## 2.1 The newest piece to the TGD inspired model of family replication

It is appropriate to start with the newest contribution to the TGD based view of the family replication phenomenon of fermions.

The recent TGD vision of family replication phenomenon for fermions is as follows.

1. In TGD based model for family replication phenomenon [K1], fermion families correspond to the genera for partonic 2-surfaces. This predicts generation-genus correspondence. Electron and its neutrino correspond to a sphere with genus $g = 0$; muon and its neutrino to a torus with $g = 1$; $\tau$ and its neutrino to to with $g = 2$. Similar picture applies to quarks. CKM mixing corresponds to topological mixings of genera, which are different for different charged states and CKM mixing is the difference of these mixings.

   The problem is that TGD suggests an infinite number of genera. Only 3 fermion families are observed. Why?

2. The first piece of the answer is $Z_2$ conformal symmetry. It is present for the genera $g = 0, 1, 2$ but only for hyperelliptic Riemann surfaces for $g > 2$.

3. The second piece of the answer is that one regards the genera $g \geq 2$ as many-handle states. For $g \geq 2$ many-handle states would have a continuous mass spectrum and would not be elementary particles. For $g = 2$ a bound state of two handles would be possible by $Z_2$ symmetry.

Consider now the new building brick for the explanation.

1. Quantum classical correspondence is the basic principle of TGD and requires that quantum states have classical counterparts.

2. Assume that in a suitable region of moduli space it makes sense to talk of a handle as a particle moving in the geometry defined by $g - 1$ handles. One can imagine that the handle is glued by a small wormhole contact to the background defined by $g-1$ handles and behaves like a free point-like particle moving along a geodesic line of the background.

   This relationship must be symmetric so that the background must move along the geodesic line of the handle. This means that particles and background are glued together along the geodesic lines of both.

3. Consider now various cases.

   (a) The case $g = 0$ is trivial since one has a handle vacuum.

   (b) For $g = 1$, one has the motion of a handle in spherical geometry along a great circle, which corresponds to a geodesic line of the sphere. The torus can rotate like a rigid body and this corresponds to a geodesic line of torus characterized by two winding numbers $(m, n)$. Alternatively, one can say that the sphere rotates along a geodesic of the torus. There is an infinite but discrete number of orbits. The simplest solution is the stationary solution $(m, n) = (0, 0)$.

   (c) For $g = 2$, one has a geodesic motion of a handle in the toric geometry defined by the second handle. Now one can speak of bound states of two handles.

   One would have a gluing of two tori along geodesic lines $(m, n)$ and $(r, s)$. The ratios of these integers are rational so that one obtains a closed orbit. The simplest solution is $(m, n) = (r, s) = 0$.

   Stationary solutions are stable for constant curvature case since curvature of torus vanishes. Locally the stationary solution is like a particle at rest in Euclidian plane.

(d) For $g = 3$ one has a geodesic motion of the handle in $g = 2$ geometry or vice versa. $g = 2$ geometry has negative total scalar curvature and as a special case a constant negative curvature. This implies that all points are saddle points and therefore unstable geodesics so that two geodesics going through a given point in general diverge. This strongly suggests that only unstable geodesics are possible for $g = 2$ whether it is regarded as background or as a particle. This suggests a butterfly effect and a chaotic behavior. Even if $g = 2$ particle represents a classical bound state the third handle must move along a chaotic geodesics of $g = 2$ geometry.This could explain the absence of bound states at quantum level.

## 2.2 Electron-muon anomaly and the topological explanation of family replication phenomenon

Could TGD explain this anomaly? The TGD [L3] based topological explanation of the family replication phenomenon indeed predicts new exotic bosons [K2, K1].

1. Fundamental fermions would in TGD framework correspond to partonic 2-surfaces, whose orbits define light-like 3-surfaces identifiable ad boundaries between Minkowskian and Euclidean space-time regions. The Euclidean regions correspond to deformations of what I call $CP_2$ type extremals. Orientable 2-surfaces are characterized by the genus $g$ defined as the number of handles attached to a 2-sphere to obtain the topology in question.

2. TGD predicts that 3 lowest genera are special in the sense that they allow global $Z_2$ symmetry as a conformal symmetry unlike higher generations [K1]. This raises the 3 lowest genera in a special position. The handles behave like particles and the higher genera would not form bound states of handles and have a mass continuum characteristic for free many-particle states unlike the lowest ones corresponding to $g = 0, 1, 2$. This boils down to the assumption that only 2 handles can form a bound state.

3. The fundamental fermion would correspond to a partonic 2-surface carrying a point-like fermion and would serve as building bricks of both fermions as bosons as elementary particles. Elementary particles would correspond to closed monopole flux tube structures connecting two Euclidean wormhole contacts so that the monopole flux loop would run along the first Minkowskian space-time sheet and return along the other.

Group theoretically, the 3 fermion generations behave like an $SU(3)_g$ triplet, completely analogous to the (u,d,s) triplet introduced by Gell-Mann. This combinatorial symmetry could define an approximate dynamical symmetry involving $SU(3)_g \rightarrow U(2)_g$ symmetry breaking, analogous to that in the case of Gell-Mann's SU(3).

1. Each electroweak gauge boson and gluon would form an $SU(3)_g$ octet analogous to $(\pi, K, \eta)$ and $SU(3)_g$ singlet analogous to $\eta'$.

2. Ordinary gauge bosons would $SU(3)_g$ singlets analogous to $\eta'$. Their couplings to fermion families would be identical and thus obey fermion universality. These states would be superpositions of pairs with $g \in \{0, 1, 2\}$.

3. Besides this, 2 additional SU(3)states with vanishing SU(3)$g$ quantum number analogous to $\pi_0$ and $\eta$ are predicted. Their couplings to fermions induce a violation of fermion universality coming from the coupling to both gluons and weak bosons.

   There are some indications for this violation from the earlier experiments [K2]and the p-adic mass scales of the higher boson families as analogs of $\pi_0$ and $\eta$ correspond to p-adic length scales assignable to Mersennes or Gaussian Mersennes. The couplings of these states to fermionic loops imply deviations from the predictions of the standard model and might explain the reported anomalies.

   Here one would have a deviation from the expectations suggested by the analogy with the Gell-Mann's SU(3), which would suggest that the ordinary weak bosons are more massive than the exotic ones: this would not be the case.

4. Also non-diagonal bosons with non-vanishing $SU(3)_g$ quantum numbers, being analogous to $\pi^{\pm}$ and 2 kaon doublets, are predicted. I have earlier assumed [K2] that these states are much more massive than the $SU(3)_g$ neutral states.

   If one takes the recent finding at the face value, the situation would not be this. The analogy with the Gell-Mann's SU(3) suggests that one has a weakly broken $U(2)_g \subset SU(3)_g$ symmetry such that the two lowest generations correspond to u and d. Both gluons and electroweak gauge bosons, including Higgs, would have additional states decaying to oppositely charged $e\mu$ pairs and thus violate lepton universality. Also counterparts of kaons as pairs involving $g = 2$ partonic 2-surfaces are predicted.

5. The simplest interpretation for $X$ would be in terms of a Higgs like state analogous to $\pi^{\pm}$. The $U(2)_g$ symmetry would be violated if the mass of X is 146 GeV; $\Delta m/\langle m\rangle = 2(m(X) - m(H))/(m(X) + m(H) \simeq 15$ %.

## 2.3 Could $SU(3)_g$ gluons relate to CKM mixing?

This picture raises questions related to the CKM mixing as mixing topologies of partonic 2-surfaces [K1].

1. It is assumed to be due to topology changing time evolution for partonic 2-surfaces: a kind of dispersion in the "world of classical worlds" [L3], or more precisely in the moduli space of conformal equivalence classes of 2-surfaces consisting of Teichmüller spaces for various genera, would be in question.

2. Could the exchanges of $SU(3)_g$ octet bosons between both fermions and bosons induce the mixing dynamically or at least contribute to the mixing. This mixing is not a single particle phenomenon. It conserves $SU(3)_g$ "isospin" and "hypercharge" and essentially this means conservation of total genus as sum of signed genera, which are opposite for fermions and antifermions. If $SU(3)_g$ octet has masses above $M_{89}$ mass scale assignable to Higgs, this mixing is expected to be rather small and an effect comparable to weak interactions.

3. The mass scale of $SU(3)_g$ photon octet must be large, say $M_{89}$ mass scale: otherwise one would lose approximate conservation of various lepton numbers and a bad failure of the Universality. Color confinement would allow a light $SU(3)_g$ gluon octet. What implications could the additional light gluons have?

## 2.4 Could $g = 1$-gluons relate to the intrinsic strangeness and charm of the proton?

Strange and charmed quarks $s$ and $c$ are produced in high energy collisions of protons. The effective presence of $s$ and $c$ in the initial states can be understood in terms of radiative corrections, which affect the scale dependent parton distribution functions (PDFs) of proton, which depend on the scale of momentum exchange $Q^2$. PDFs are determined by the renormalization group evolution equations, which are differential equations with respect to $Q^2$. $Q^2 \neq 0$ is associated with interacting proton and means that the light u and d quarks are excited to strange and charmed states. The initial values of PDFs at $Q^2 = 0$ correspond to non-interacting proton.

A long standing question has been whether proton has also intrinsic strangeness and charm, which should be distinguished from the radiatively generated energy scale dependent intrinsic charm and strangeness. The intrinsic strangeness and charm cannot be calculated perturbatively and would appear in the initial values of PDFs at the limit $Q^2 = 0$

Quite recently an article with the title "Evidence for intrinsic charm quarks in the proton" [C2] appeared in Nature (`https://rb.gy/8iq9e3`). Could the intrinsic charm be seen as an evidence for the presence of light g-gluons in the octet representation of $SU(3)_g$?

Could the presence of light g-gluons make possible intrinsic valence charm and strangeness so that the proton could be a superposition of states in which parton sea contains g-gluons and and valence quarks can be strange or charmed? These states would however be superpositions of states with same $SU(3)_g$ quantum numbers?

Is this energetically possible?

1. This is impossible in the simplest model of baryon involving only on-mass-shell constituent quarks, which in the TGD framework would correspond to current quark plus color magnetic flux tube.

2. However, current quarks contribute only a small fraction to the proton total mass. In the TGD framework, the remaining mass could be assigned to the color magnetic body (MB) of proton and sea partons. One could therefore consider a superposition of states for which color MBs could have varying masses. This would allow strange valence quark with a reduced mass of the color MB. This component in the proton wave function would involve sea g-gluon(s) at a color magnetic flux tubes assignable to the sea.

3. The mass of proton is smaller than that of charmed quark so that the charmed quark is off-mass shell. What does off-mass-shell property mean in the TGD framework?

   Galois confinement generalizes the color confinement to a universal mechanism for the formation of bound states. Galois confinement states that the observed particles consist of building blocks with momenta, whose components are algebraic integers, which can be complex. Momentum components can also have negative real parts so that they would be tachyonic. The interpretation as number theoretically quantized counterparts of off-mass-shell momenta is natural. Since mass squared correspond to conformal weight, Galois confinement involves also conformal confinement stating the total conformal weights are ordinary integers.

   In this picture, virtual quarks would correspond to on-mass-shell states in a number teoretical sense. Mass squared would be an algebraic number determined as a root of a polynomial $P$ with integer coefficients smaller than the degree of $P$. Color confinement implies that it is strictly speaking not possible to talk about on-mass-shell quarks.

   For the physical states both mass squared and momentum components are ordinary integers in a scale determined by the p-adic length scale assigned to the particle: this scale is also determined by the polynomial $P$ allowing however several ramified primes defining the p-adic primes. Mass squared obeys a stringy mass formula.

4. If the off-mass-shell $g = 1$-gluon is massive enough, its decay would reduce the mass of the sea and the total energy would be conserved. $\Lambda - n$ mass difference, pion mass, and $\Lambda_{QCD}$, which are all of order 100 MeV, give a rough idea about the mass scale of $g = 1$ gluons. This would support the $d \rightarrow s$ option which however increases the contribution of the valence quarks. Therefore the proposed idea does not look attractive.

# 3 Could sea partons be dark?

The model of hadrons involves, besides valence quarks, a somewhat mysterious parton sea. Could the sea consist of partons, which are dark in the TGD sense? This proposal was actually inspired by a model of Kondo effect having strong resemblances with a model of color confinement [L7].

The basic argument in favor of the proposal that at least some quarks are dark, is based on the idea that the phase transition increasing the value of $h_{eff} > h$ allows to have a converging perturbation expansion: one one half $\alpha_s = g^2/4\pi\hbar \rightarrow g^2/4\pi\hbar_{eff}$ which is so small that perturbation theory converges. Nature would be theoretician friendly and perform a phase transition guaranteeing preventing the failure of the perturbative approach.

A stronger assumption generalizes Nottale's proposal for gravitational Planck constant [E1] and assumes $\hbar_{eff} = g_s^2/\beta_0$, $\beta_0 = v_0/c < 1$ giving $\alpha_s \rightarrow \beta_0/4\pi$. This would allow a perturbative approach to low energy hadron physics for which ordinary QCD fails.

## 3.1 Valence partons cannot be dark but sea partons can

The following argument suggests that valence quarks cannot be dark but sea partons can.

1. It is good to begin with a general objection against the idea that particles could be permanently dark.

(a) The energies of quantum states increase as a function of $h_{eff}/h_0$ defining the dimension of extension of rationals. These tend to return back to ordinary states. This can be prevented by a feed of metabolic energy.

(b) The way out of the situation is that the dark particles form bound states and the binding energy compensates for the feed of energy. This would take place in the Galois confinement. This would occur in the formation of Cooper pairs in the transition to superconductivity and in the formation of molecules as a generation of chemical bonds with $h_{eff} > h$. This would also take place in the formation of hadrons from partons.

2. It seems that valence quarks of free hadrons cannot be dark. If the valence quarks were dark, the measured spin asymmetries for the cross section would have only shown that the contribution of sea quarks to proton spin is nearly zero, which in fact could make sense. Unfortunately, the assumption that the measured quark distribution functions are determined by sea quarks seems to be inconsistent with the quark model. If only sea quarks contribute always to the lepton-hadron scattering, the deduced distribution functions would satisfy $q_i = \overline{q}_i$, which is certainly not true.

   Hence it seems that valence quarks must be ordinary but the TGD counterparts of sea partons could be dark and could have large $h_{eff}$ increasing the size of the corresponding flux tubes. The color MBs of hadrons would be key players in the strong interactions between hadrons.

3. The EMC effect in which the deep inelastic scattering from an atomic nucleus suggests that the quark distribution functions for nucleons inside nuclei differ from those for free nucleons (`https://rb.gy/ex284o`). This looks paradoxical since deep inelastic scattering probes high momentum transfers and short distances. For $h_{eff} > h$ the situation however changes since quantum scales are scaled up by $h_{eff}/h$. If sea partons are dark, the corresponding color magnetic bodies of nucleons are large and could interact with other nucleons of the nucleus so that the dark valence quark distributions could change.

4. Dark quarks and antiquarks at the magnetic body might also provide a solution to the proton spin crisis.

## 3.2 Could dark valence partons be created in hadronic collisions?

By the above arguments, the valence quarks of free hadrons have $h_{eff} = h$ but sea quarks can be dark. Could dark valence quarks be created in hadronic scattering?

1. The values of $h_{eff}$ of free particles tend to decrease spontaneously since energies increase with $h_{eff}$. The formation of bound states by Galois confinement prevents this. If not, the analog of metabolic feed increasing the value of $h_{eff}$ is necessary. It would be also needed to create dark particles, which then form bound states.

2. Could the collision energy liberated in a high energy collision serve as "metabolic" energy generating $h_{eff} > h$ phases. This could take place in a transition interpreted in QCD as color deconfinement [K2, K3].

   The first option is that the phase transition makes valence quarks dark. This could however mean that they decouple from electroweak interactions with leptons. Second option is that the phase transition increases the value of $h_{eff} > h$ for the dark partons at color MB but leaves valence quarks ordinary.

## 3.3 What does one mean with parton sea?

In the TGD framework, one must reconsider the definition of valence quarks and of parton sea.

1. Valence quarks would correspond to the directly observable degrees of freedom whereas parton sea would correspond to degrees of freedom, which are not directly observablee in physics experiments. Usually large transversal momentum transfers are assumed to correspond to short length scales but the EMC effect is in conflict with this assumption. If the unobserved

degrees of freedom correspond to $h_{eff} > h$ phase(s) forced by the requirement of perturbativity, the situation changes and these degrees of freedom can correspond to long length scales.

The mathematical treatment of the situation requires integration over the unobserved degrees of freedom and would mean a use of a density matrix related to the pairs of systems defined by this division of the degrees of freedom. This would justify the statistical approach used in the perturbative QCD.

Dark degrees of freedom associated with the color MB, possibly identifiable as parton sea at color MB, are not directly observable. The valence quarks would be described in terms of parton density distributions and quark fragmentation functions. In hadron-hadron scattering at the low energy limit, valence quarks and sea, possibly at color MB, would form a single quantum coherent unit, the hadron. In lepton-hadron scattering, the valence quarks would form the interacting unit. In hadron-hadron scattering also the dark MBs would interact.

2. Color MB could contain besides quark pairs also $g > 0$ gluons contributing to the parton sea. The naive guess is that $g = 1$ gluons are massive and correspond to the p-adic length scale $k = 113$ assignable to nuclei. Muon mass, $\Lambda_{QCD}$, and $\lambda - N$ mass difference correspond to this mass scale.

   The $g > 0$ many-gluon state must be color singlet, have vanishing spin, and have vanishing $U(2)_g$ or perhaps even $SU(3)_g$ quantum numbers, at least if $SU(3)_g$ is an almost exact symmetry in the gluonic sector. This kind of state can be built from two $SU(3)_g$ gluons as the singlet part of the representation $8_c \otimes 8_g$ with itself. The state is consistent with Bose-Einstein statistics.

   $g > 0$ gluons could be seen in hadron-hadron interactions. Perhaps as an anomalous production of strange and charmed particles and violation of fermion universality.

# 4 Could dark partons solve the proton spin crisis?

The proton spin crisis (`https://rb.gy/imz7ls`) was discovered in the EMC experiment, which demonstrated that the quark spin in the spin direction of polarized protons was almost the same as in the opposite direction.

## 4.1 Basic facts about proton spin crisis

In the EMC experiment the contributions of u,d, and s quarks to the proton spin were deduced from the deep inelastic scattering of muons from polarized proton target (`https://rb.gy/ktm2tw`). What was measured, were spin asymmetries for cross sections and the conclusions about parton distribution functions (`https://rb.gy/vcpths`) were deduced from the experimental data from the muon scattering cross sections using Bjorken sum rule testing QCD and Ellis-Yaffe sum rule assuming vanishing strange quark contribution and testing the spin structure of the proton. Bjorken sum rule was found to be satisfied reasonably well. Ellis-Yaffe sum rules related to the spin structure of the proton were violated.

It was found that the contributions of $u$ quarks were positive and those of $s$ quarks (assuming that they are present) and $d$ quarks negative and the sum almost vanished when the presence of $s$ was assumed. The Gell-Mann quark model predicts that u-quarks contribute spin $2/3$ and d-duarks $-1/6$ units ($\hbar$) to the proton spin. For the fit allowing besides $u$, $d$ contributions, also $s$ contributions, the contributions were found to be 0.373, $-0.254$ and $-0.113$. The sum was 0.006 and nearly zero. For protons the contribution is roughly one half of Gell-Mann prediction. For $d$ quark the magnitude of the contribution is considerably larger than the Gell-Mann prediction $-1/6 \simeq -.16$.

The Wikipedia article creates the impression that the proton spin crisis has been solved: the orbital angular momentum would significantly contribute to the spin of the proton. Also sea partons, in particular gluon helicity polarization would contribute to the proton spin. This might well be the case.

## 4.2 Dark sea partons and proton spin crisis

I have considered possible TGD inspired solutions of the proton spin crisis already earlier. One can however also consider a new version involving dark sea quarks.

1. The possibility that sea partons are dark in the TGD sense, forces us to ask what was really measured in the EMC experiment leading to the discovery of the proton spin crisis. If sea partons are dark, only the quark distribution functions corresponding to quarks with ordinary value of $h_{eff}$ appearing in the coupling to muon would contribute? This should be the case in all experiments in which incoming particles are leptons.

   Assuming that also valence quarks can be part of time strange, the results of the EMC experiment assume that most of the proton spin could reside at the polarized dark sea. Note however that also orbital angular momentum can explain the finding and in the TGD framework color magnetic flux tubes could carry "stringy" angular momentum.

2. For this option one could identify the measured cross section in terms of scattering from quarks with $h_{eff} = h$. It has been proposed that valence quarks are large scale structures (low energy limit) and sea quarks are small scale structures (high energies) inside valence quarks.

   In the TGD framework, this suggests that valence quarks correspond to a larger p-adic prime than sea quarks. This does not imply that valence quarks have large $h_{eff}$. Large $h_{eff}$ for the sea partons would increase their size so that, contrary to the expectations from the Uncertainty Principle, they could contribute to hadron-hadron scattering with large momentum transfer in long length scales.

### 4.2.1 How to represent ordinary quarks at the level of color MB?

One should understand how the color interactions for which the perturbation series does not converge at the level of ordinary matter are transferred to the dark magnetic body at which the perturbation series converges. The color of the ordinary quarks should be neutralized and transferred to the color of dark quarks at color MB.

1. The valence quarks have an ordinary value of $h_{eff}$ and the perturbation series does not converge. One should have a concrete realization for the transfer of color interactions at the level of valence quark to the level of the sea quarks with large $h_{eff}$. If only dark gluons exist, the color interactions take place at the level of the color MB and one the perturbation theoretic coupling would be $\alpha_s = \beta_0/4\pi$.

   The physical mechanism in question should map valence quarks to dark valence quarks at the MB.

   Also color confinement could take place at the level of the color MB and induce it at the valence quark level. The ordinary electroweak interactions should take place between valence quarks $q_o$ ("o" for "ord") but also a dark variant of ew interactions between dark quarks is possible and indeed assumed in TGD inspired quantum biology. Could the mechanism be as follows?

2. Consider a free hadron. The color MB contains dark sea quark $q_d$ ("d" for "dark") and antiquark $\overline{q}_d$ with opposite charges and spins such that $\overline{q}_d$ combines with $q_o$ to form an entangled color singlet meson-like state.

   $q_d$ would carry the same quantum numbers as $q_o$. Quark quantum numbers would be transferred by entanglement to the color MB! Color confinement would take place at the level of MB and induce color confinement at the level of valence quarks.

   A stronger assumption would be that this state is spin singlet: this would imply automatically a vanishing average spin for the valence quarks but would not be consistent with the EMC determination of $\Delta S_i$. This suggests that only color singlet entanglement between $q_d$ and antiquark $\overline{q}_d$ makes sense. This option might be consistent with the QCD picture about the spin crisis of the proton.

An open question is whether the MB of a particle can also contain other particles, such as $SU(3)_g$ bosons in the case of hadrons. As will be found, the simplest option in which they are not present allows one to understand CKM mixing in terms of $SU(3)_g$ gluon exchanges.

#### 4.2.2 How to understand the standard QCD view about the proton spin crisis in the TGD framework?

If spin-isospin quantum entanglement gives a spin singlet, valence quark spin does not contribute to proton spin at all. This view is in conflict with the QCD view about the values of $\Delta s$ and their summation to a small value. Could one understand the QCD values in the TGD framework by giving up the assumption of spin singlet property of entanglement? There would be only color entanglement between $q_o$ and $q_d$, and spins would be opposite but the state would belong to a direct sum of vector and singlet representation of $SU(2)$.

Could one modify the entanglement between quarks $q_o$ such that one can explain the EMC findings?

1. Gell-Mann model cannot be correct at the level of details but would predict correctly that baryons correspond to irreps of spin and isospin. In particular, protons would be spin- and isospin doublets. The entanglement between spin degrees of freedom and between isospin degrees of freedom of quarks should be more general than that in the Gell-Mann model. Is this possible?

2. Consider the nucleon as a tensor product of 3 quarks as tensor products of 3 spin and isospin doublets giving rise to a spin and isospin doublet. The sums of individual isospin and spin components correspond to those of baryon: for the proton uud, udu, and duu can serve as building bricks of the state. The needed antisymmetrization is in color degrees of freedom.

   In the case of a nucleon, the spin $S_z$ and isospins $I_3$ must sum up to $\pm$ 1/2. This leaves $3 \times 3 = 9$ complex coefficients in case of proton/neutron (uud/udd). The state is defined only modulo anoverall complex coefficient: this leaves 7 complex coefficients.

   The values of Casimir operators $S(S+1)$ and $I(I+1)$ are fixed: these conditions can be written as eigenvalue conditions for $\sum_i (S_i(S_i+1) + 2\sum_{i\neq j} s_i \cdot s_j = S(S+1)$ and $\sum I_i(I_i + 1) + 2\sum_{i\neq j} I_i \cdot I_j = I(I+1)$. These 2 conditions leave 5 complex parameters.

3. A more straightforward approach is group theoretic. The tensor product $2\otimes 2\otimes 2$ decomposes as $4 \oplus 2_1 \oplus 2_2$. 4 is totally symmetric and the doublets have mixed symmetries. At least formally, one can construct from $2_1 \oplus 2_2$ a proton state for which the conditions for $\Delta s$ from the EMC experiment hold true?

   The superposition of these representations can be parametrized as $cos(\theta)exp(i\phi)2_1 \oplus sin(\theta)exp(i\phi)2_2$. Same applies in the isospin degrees of freedom so that one would have 4 parameters. In Nature, only single nucleon doublet appears and there might be some trivial reason for this. Could the superposition of these two representations be selected by some principle or could also the other representation and therefore also superposition be realized in Nature.

4. The conditions on the values of $\Delta s_i$ coming from the EMC experiment give 2 constraints leaving a 3-D complex space of solutions.

#### 4.2.3 A model for the representation of a general particle at its magnetic body

The challenge is to generalize the model for baryons so that it would also apply to bosons and leptons.

1. The vision about MB as a receiver of sensory information from the biological body and control of it has been applied in biology and the fractality of the TGD Universe suggests that this picture applies in all scales. Hence the idea that MB of the particle carrying dark matter serves a universal representation of the ordinary particle is attractive.

2. Color entanglement can bind the $q_o$ and $\overline{q}_d$ in a stable way. What about leptons which are color singlets? The TGD view of color comes to rescue here. In TGD, color is not a spin-like

quantum number but at the level of $H$ corresponds to color partial waves for $H$ spinor fields. There are two alternative proposals for what leptons could be.

(a) For the first option, leptons correspond to second $H$-chirality for $H$ spinors. The color partial waves correlate with the electroweak quantum numbers in a wrong way for both quarks and lepton chiralities. The physical states assignable to partonic 2-surfaces involve super symplectic generators carrying color in such a way that physical leptons are color singlets and quarks are color triplets.

Lepton states involve an action of super symplectic generator $O$ on the lepton spinor $OL_o^c$ such that the $O$ transforms as the conjugate of the color representation associated with color partial wave $L_o^c$. $L_o$ would be essentially the inner product of $O$ and color partial wave $L_o^c$ and therefore a color singlet. In the case of quark $q$, $q_o$ would be obtained by projection color triplet from $q_o = P_3(Oq)$.

The inner product of $L_o^c$ and $\overline{L}_d^c$ defines a color entangled color singlet.

(b) The second option is that fundamental leptons correspond to color singlets formed from 3 antiquarks. The 3 leptonic antiquarks do not reside at separate wormhole contacts having two wormhole throats identified as partonic 2-surfaces but reside at a single partonic wormhole. The mechanism proposed for hadrons can be applied to quarks. This option can explain matter antimatter asymmetry: antimatter as antiquarks could bind to leptons. A small CP breaking predicted by TGD in principle allows this.

3. This approach works also for bosons since all bosons can be realized as a quantum superposition of fermion-antifermion pairs in the TGD framework (note that graviton involves two pairs). Electroweak bosons involve pairs $q_o\overline{q}_o$: the contraction with respect to color gives entanglement. Also lepton pairs are involved: now the contractions are of the form $L_o^c\overline{L}_o^c$.

   The construction of $B_o^c\overline{B}_d^c$ reduces to the formation of color entangled pairs $q_o\overline{q}_d$ and $L_o^c\overline{L}_d^c$. Gluons, with $SU(3)_g$ gluons included, can be formed as a color octet pairing of quarks and antiquarks and $G_o^c\overline{G}_d^c$ pairing can be formed as in the case of baryons.

One can argue that the construction of the scattering amplitudes in this framework looks rather complex. The other option would be however nonconvergent perturbation series.

#### 4.2.4 Nature is theoretician friendly and realizes holography

The two key ideas behind the proposal deserve restating.

1. Nature is theoretician friendly and guarantees the convergence of perturbation theory by $h \rightarrow h_{eff}$ phase transition. The simple and perturbatively convergent dynamics at the level of MBs for the dark images $X_d$ of the particles induces the dynamic of particles $X_o$ by stable color quantum entanglement. The MB of the dark particle would be the boss and the dynamics of the ordinary particle would be shadow dynamics in accordance with the general vision about induction as the basic dynamical principle of TGD.

   One open question is whether the ordinary matter follows the dynamics of dark particles instantaneously or whether the time scales of the dynamics of dark matter and ordinary matter can be different in which case only the asymptotic states would realize the proposed correspondence between $X_d$ and $X_o$.

2. It took some time to realize that the map of $X_o$ to $X_d$ based on colored entanglement is nothing but a concrete actualization of the quantal version of the TGD based holography. In the classical realization of this holography, the 3-D boundary of the space-time surface determines the space-time surface (tangent space data are not needed). In quantum realization, the states $X_o$ are analogous to states at the 3-D boundary of space-time surface and states $X_d$ to those in its interior. Instead of strings in the interior $AdS_5$ as in AdS/CFT correspondence, one has monopole flux tubes, indeed string like objects) in the interior of space-time carrying state $X_d$ and $\overline{X}_o$ determine the dark state.

3. In the classical holography 3-D surfaces carry holographic data fixing the 4-D complement of 4-surface [L3] [L6]. Also 2-D string world sheets are involved and 1-D surfaces as orbits of boundaries of string world sheets at the light-like orbits of partonic 2-surfaces fix the interiors of string world sheets. An additional condition could be that the string world sheets are surfaces in $H^3 \subset M^4 \subset M^8$. The pair of dark sea quarks and leptons would be delocalized at string worlds sheets associated with the color magnetic flux tubes. This is in accordance with the hadronic string model, which was one of the original motivations for TGD.

Theoretician friendly Nature would realize the quantum variant of the holography. An information theoretic view of elementary particles and of the relationship between ordinary and dark matter is suggestive. There is also an analogy with blackholes. States $X_d$ are analogous to states in blackhole interior and states $X_o$ to those at horizon.

#### 4.2.5 Experimental support for the holography and for proton as an analog of blackhole

There is experimental evidence for the analogy of protons with a blackhole (https://rb.gy/o0sl3o) found from deep inelastic electron-proton scattering (DIS). The report [C3] of the research group led by theorists Krzysztof Kutak and Martin Hentschinski, published in European Physical Journal C, provides evidence for the claim that portions of proton's interior exhibit maximal quantum entanglement between constituents of photon.

The following statement of the report gives a rough idea of what is claimed.

*"If a photon is 'short' enough to fit inside a proton, it begins to 'resolve' features of its internal structure. The proton may decay into particles as a result of colliding with this type of photon. We've demonstrated that the two scenarios are intertwined. The number of particles originating from the unobserved section of the proton is determined by the number of particles seen in the observed part of the proton if the photon observes the interior part of the proton and it decays into a number of particles, say three."*

The abstract of [C3] gives a technical summary of the article.

*"We investigate the proposal by Kharzeev and Levin of a maximally entangled proton wave function in Deep Inelastic Scattering at low x and the proposed relation between parton number and final state hadron multiplicity. Contrary to the original formulation we determine partonic entropy from the sum of gluon and quark distribution functions at low x, which we obtain from an unintegrated gluon distribution subject to next-to-leading order Balitsky–Fadin–Kuraev–Lipatov evolution. We find for this framework very good agreement with H1 data. We furthermore provide a comparison based on NNPDF parton distribution functions at both next-to-next-to-leading order and next-to-next-to-leading with small x resummation, where the latter provides an acceptable description of data."*

The following is my rough view of what the article says.

1. Deep inelastic scattering (DIS) is described in terms of photon exchange with momentum $q$ a large value of $q^2 = Q^2$. The parton distribution functions at the low $x$ limit, where $x = X^2/2p \cdot q$, ($p$ denotes proton momentum). This limit corresponds to the perturbative high energy limit at which $\alpha_s \leq\leq 1$ is true. The theoretical proposal is that DIS would only probe the parts of the proton wave function, which give rise to entanglement entropy. This entanglement characterizes correlation between the two parts of the system.

2. By theoretical arguments authors end up with a proposal that DIS at low $x$ limit probes a maximally entangled state and a relation between parton number and final state hadron multiplicity. A more precise statement is that the partonic entropy $S(x, Q^2)$ coincides with the entropy $S(h)$ of the final state hadrons in DIS. This means that parton and hadron pictures are dual. Mathematically this corresponds to the simple fact that entanglement entropies obtained by tracing over either entangled system are identical.

3. More concretely, the partonic entropy is given by $S(x, Q^2) = ln(\langle n(ln(1/x, Q^2)\rangle)$, where $\langle n(ln(1/x, Q^2)\rangle$ is the average number of partons with longitudinal momentum fraction $x$. $S(x, Q^2)$ is deducible from the measured parton distribution functions. Also $S(h)$ is deducible from experimental data.

With my amateurish understanding, I try to translate the proposed parton-hadron duality to the TGD framework.

1. The unseen parts of the proton are probed by virtual photons inducing a large enough momentum transfer $Q^2$. In standard quantum theory this corresponds by Uncertainty Principle to short distances. In TGD, large $h_{eff}$ means that the size of the color MB of protons is scaled up by $h_{eff}/h$ so that distances can be rather large as in the case of EMC effect.

2. Low $x$ large $Q^2$ limit would more or less correspond to the dark part of proton for which $h_{eff}$ is larger and $\alpha_s \propto 1/\hbar_{eff}$ small. This suggests that the situation would be described in terms of dark scattering. This might hold true quite generally if the dynamics of the color magnetic MB dictates the dynamics of ordinary quarks.

3. The portions of proton would correspond to ordinary and dark parts of the proton. The maximal entanglement would correspond to the color entanglement between ordinary and dark quarks/partons. The counterpart of the blackhole entropy would be the entanglement entropy obtained when one integrates over the invisible dark degrees of freedom, which might, but need not, correspond to the parton sea. The integration over the dark degrees of freedom justifies the statistical approach of QCD used to describe hadrons.

4. The equality of partonic and hadronic entropies states simply the fact that the integration over partonic degrees of freedom (ordinary quarks) gives the same density matrix as the integration over hadronic degrees of freedom. Dark degrees of freedom would correspond to hadronic ones and ordinary degrees of freedom to partonic ones.

#### 4.2.6 Could $SU(3)_g$ gluons induce CKM mixing of quarks and leptons?

The above simple model did not say anything about the possible presence of $SU(3)_g$ gluons at the color magnetic MB. Even if they are not present, the exchange of $SU(3)_g$ $g > 0$-bosons between entangled $q_o$ and $\overline{q}_d$ could increase the genus of both $q_o$ and $\overline{q}_d$ (note the genus is counted as negative for antiquarks).

At the level of the ordinary matter this could give rise to what looks like CKM mixing whereas no mixing would take place for $q_d$. This process generalizes to the case of leptons since $L_o^c$ and $\overline{L}_d^c$ are colored states for both identifications of leptons.

The $g > 0$ gluon exchange involves a transformation of the dark $g > 0$ gluon to an ordinary $g > 0$ gluon. This process is assumed to occur for dark photons in the TGD inspired model for quantum biology: bio-photons would be an outcome of this process for dark photons.

Some CKM mixing angles are rather large. If the CKM mixing is solely due to this process, the masses of the $SU(3)_g$ gluons must be considerably smaller than weak boson masses so that mass scale could be around 100 MeV, say.

### 4.3 How to generalize the proposed quantum holography?

It is convenient to call the pair of a fermion and antifermion with vanishing total quantum numbers (apart from momentum) a "glue particle" . Galois singlet property would be a natural additional property of the glue particles formed by fermion antifermion pairs. One can also imagine a generalization of the proposed equivalence between "Mother Nature who likes her theorists" principle and holography principle.

#### 4.3.1 Could "glue particles" be also Galois singlets

For hadrons, and perhaps quite generally, they would be color entangled color singlets with vanishing total quantum numbers (momentum forms an exception) but without any other kind of entanglement.

Galois confinement implies that the components of momentum are integers in the scale determined by the causal diamond (CD). Without this condition, the momentum components would be in general complex algebraic numbers. The 4-momenta can be however tachyonic so that analogs of virtual particles with quantized 4-momenta and negative mass squared value (integer) would be in question. The virtual masses of the glue particles could be tachyonic suggesting and interpretation as an analog of Coulomb potential.

This suggests that color singlet property could be strengthened with the Galois singlet property.

### 4.3.2 Hierarchy of pairings associated with a hierarchy of MBs

Number theoretic view [L1, L2, L3, L4, L5] of TGD predicts hierarchies of magnetic bodies (MBs) with levels labelled increasing value of $h_{eff}$. Galois confinement as a candidate for a universal mechanism for the formation of bound states predicts a hierarchy of Galois singlets as physical states.

1. One could take Galois singlets at a given level of the hierarchy with $h_{eff} \geq h$ and deform them to Galois non-siglets, and form their bound states as Galois singlets. This would give an entire hierarchy of bound states formed by the proposed mechanism of quantum holography and assignable to the slaving hierarchy of MBs.

2. The holographic pairing would be only between the fundamental fermions and antifermions assignable to the MBs which are nearest neighbours in the hierarchy. The pairs, "glue particles", would have vanishing net quantum numbers other than four-momenta.

   The total energy would be sum over contributions from various levels in the magnetic hierarchy. The masses of the fundamental fermions are very small as compared to the magnetic energies, and the color magnetic energies for the nucleons would give a dominant contribution. Higher hierarchy levels would give only a small contribution.

3. At least in the case of hadrons, the holography would be by a formation of glue particles as meson-like pairs of a quark at with $h_{eff,1}$ and dark quark with $h_{eff,2} > h_{eff,1}$, having vanishing electroweak quantum numbers and spin and being color entangled color singlets. Also Galois singlet property looks very natural.

4. For example, U-shaped radial gravitational flux tube loops mediating gravitational interaction and also other interacting flux tubes could realize the holography. The fermion and antifermion at flux tube would be located at strings connecting wormhole contacts so that one would have direct analogy with the AdS/CFT holography but AdS interior replaced by the interior of the space-time surface.

### 4.3.3 Physical interpretation of the glue particles

What could be the physical interpretation of the pairing of quarks and antiquarks to glue particles. In the case of leptons the simplest scenario would be that leptons are bound states of quarks in $CP_2$ scale so that the pairing would reduce to quark-antiquark pairing also in this case.

1. Could the glue particles defining the holography correspond to an interaction potential energy in the classical description? In accordance with the string model picture, the pairs would reside at strings inside monopole flux tubes. Glue particles could also be seen as analogs of virtual boson-like particles with vanishing quantum numbers (total momenta could be non-vanishing) responsible for the binding between fermions and antifermions.

2. If gluons and even electroweak bosons appear as partons also their pairs are formed. It has been proposed that gravitons can be expressed as pairs of gauge bosons (gravitation is "square" of gauge theory). Could these pairs have interpretation as virtual (possibly "strong") gravitons with a vanishing spin. This is analogous to AdS/CFT correspondence.

3. Black hole evaporation can be formally regarded as a generation of pairs with the members of pair going to opposite sides of the horizon. Could one regard the glue particles as analogs of virtual pairs of this kind.

#### 4.3.4 Symmetry breaking is necessary

At least at the hadron level, quarks and antiquarks and perhaps also gluons are involved, but pair into color singlets by quantum entanglement in color degrees of freedom. Other forms of entanglement are not allowed by the proposed form of holography.

1. The glue particles are entangled only in color degrees of freedom and differ from gauge bosons and Higgs, which are in TGD framework superpositions of fermion pairs and are quantum entangled with respect to spin and weak isospin.

2. The total quantum numbers of glue particles vanish but symmetry breaking $SO(3) \rightarrow SO(2)$ takes place. $SO(2)$ would naturally correspond to the direction of the magnetic field in the flux tube. The same happens also in the case of weak interactions and could correspond to electroweak symmetry breaking.

3. Could the Bose-Einstein condensate for glue particles made of gauge bosons serve an analogue of the sigma meson condensate in hadron physics. The sigma analogy would be a scalar only with respect to the $SO(2) \subset SO(3)$. Could sigma mesons be associated with the pairing of hadrons and its magnetic body?

#### 4.3.5 How could one understand masses?

A test for the proposal is whether one can understand the masses of macroscopic systems.

1. If the paired fundamental fermions are each other's antiparticles, they must be fundamental fermions or bosons such as gluons (which also reduce to fermion-antifermion pairs).

   Sensible values of mass are expected if one has a hierarchy in levels such that the energies are sums of the magnetic energies and fermionic energies from various levels. Given level would give only the magnetic contribution and fermion contribution of fermions at it. Its scale would be determined by the p-adic scale assignable to the level.

2. Virtual dark quarks at the strands and their ordinary counterparts at the ends of the strands, have very low-mass compared to the contribution of Kähler magnetic energy to the mass. The color magnetic energy at the hadron level would practically give almost the entire mass. This could hold true also at higher levels of the hierarchy of layers of MB with decreasing magnetic energies.

3. The hierarchy of magnetic bodies would give a dominant contribution to the mass at the lowest level and the contribution of the few lowest levels could dominate the mass because the energy/strand tension of the magnetic flux tube quickly approaches zero as the strand thickens.

#### 4.3.6 Earth as an example

It is instructive to consider the Earth as an example.

1. The mass of the Earth's MB in the exterior of Earth is negligible when compared to the mass of the Earth as a simple order of magnitude estimate shows. The assumption that the monopole flux tubes with magnetic field strength of order of Earth's magnetic field carry quantized monopole flux implies that their radii are at least of the of order magnetic length of order cell size and fixes the string tension as the density of magnetic energy per unit length. The mass of the flux tube of length $L$ is proportional to $L/S$, where $S$ the transverse area of the flux tube. Assume that the flux tubes have length $L$ of order of the size of the magnetosphere. Assume that the flux tubes fill the entire volume with scale given by the radius of the magnetosphere.

   With these assumptions the total magnetic assignable to the monopole flux tubes is a negligible fraction of the mass of Earth determined by the lowest, nucleonic level of the hierarchy.

2. In the interior of the Earth one would have a flux tube spaghetti and flux tubes within flux tubes corresponding to the magnetic slaving hierarchy. The color magnetic energy associated with nucleonic monopole flux tubes would give a dominating contribution to the Earth's mass. There would be atomic nuclei with mass number $A$ with nucleon flux tubes with radius of order nucleon size. The flux tubes with a thickness of the order of the size of an atom would give a much smaller contribution to the magnetic energy. Fractality would therefore reduce the situation to nucleon level as far as masses are considered.

   This idea is actually already old: also the interior of a star would be like this. In condensed matter for a region with size of an atom, the number of nucleon flux tubes equals the atomic weight $A$ of the nucleus.

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