New Particle Physics Predicted by TGD: Part II

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Abstract

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

1. Application of the many-sheeted space-time concept in hadron physics

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

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

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

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

4. The soft photon production rate in hadronic reactions is by an average factor of about four higher than expected. In the article soft photons assignable to the decays of $Z^0$ to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and black-holes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent. TGD based model is based on the notion of electric flux tube.

2. Quark gluon plasma

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

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

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

1.1 Application of the many-sheeted space-time concept in hadron physics

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

1. The spin puzzle of proton [32, 34] is at the time of writing a two decades old mystery with no satisfactory explanation in QCD framework. The notion of hadronic space-time sheet which could be imagined as string like rotating object suggests a possible approach to the spin puzzle. The entanglement between valence quark spins and the angular momentum states of the rotating hadronic space-time sheet could allow natural explanation for why the average valence quark spin vanishes.
2. The notion of Pomeron was invented during the Bootstrap era preceding QCD to solve difficulties of Regge approach. There are experimental findings suggesting the reincarnation of this concept [33, 27, 28]. The possibility that the newly born concept of Pomeron of Regge theory might be identified as the sea of perturbative QCD in TGD framework is considered. Geometrically Pomeron would correspond to hadronic space-time sheet without valence quarks.

3. The discovery that the charge radius of proton deduced from the muonic version of hydrogen atom is about 4 per cent smaller than from the radius deduced from hydrogen atom [38, 41] is in complete conflict with the cherished belief that atomic physics belongs to the museum of science. The title of the article Quantum electrodynamics-a chink in the armour? of the article published in Nature [35] expresses well the possible implications, which might actually go well extend beyond QED. TGD based model for the findings relies on the notion of color magnetic body carrying both electromagnetic and color fields and extends well beyond the size scale of the particle. This gives rather detailed constraints on the model of the magnetic body.

4. The soft photon production rate in hadronic reactions is by an average factor of about four higher than expected [26]. In the article soft photons assignable to the decays of $Z^0$ to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and black-holes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent. TGD based model is based on the notion of electric flux tube.

1.2 Quark gluon plasma

QCD predicts that at sufficiently high collision energies de-confinement phase transitions for quarks should take place leading to quark gluon plasma. In heavy ion collisions at RHIC [29] something like this was found to happen. The properties of the quark gluon plasma were however not what was expected. There are long range correlations and the plasma seems to behave like perfect fluid with minimal viscosity/entropy ratio. The lifetime of the plasma phase is longer than expected and its density much higher than QCD would suggest. The experiments at LHC for proton proton collisions suggest also the presence of quark gluon plasma with similar properties.

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

2 New space-time concept applied to hadrons

2.1 A new twist in the spin puzzle of proton

The so called proton spin crisis or spin puzzle of proton was an outcome of the experimental finding that the quarks contribute only 13-17 per cent of proton spin [32, 34] whereas the simplest valence quark model predicts that quarks contribute about 75 per cent to the spin of proton with the remaining 25 per cent being due to the orbital motion of quarks. Besides the orbital motion of valence quarks also gluons could contribute to the spin of proton. Also polarized sea quarks can be considered as a source of proton spin.

Quite recently, the spin crisis got a new twist [37]. One of the few absolute predictions of perturbative QCD (pQCD) is that at the limit, when the momentum fraction of quark approaches unity, quark spin should be parallel to the proton spin. This is due to the helicity conservation predicted by pQCD in the lowest order. The findings are consistent with this expectation in the case of protonic $u$ quarks but not in the case of protonic $d$ quark. The discovery is of a special interest from the point of view of TGD since it
might have an explanation involving the notions of many-sheeted space-time, of color-magnetic flux tubes, the predicted super-symplectic "vacuum" spin, and also the concept of quantum parallel dissipation.

2.1.1 The experimental findings

In the experiment performed in Jefferson Lab [37] neutron spin asymmetries $A^p$ and polarized structure functions $g_{1,2}^p$ were deduced for three kinematic configurations in the deep inelastic region from $e-^3\text{He}$ scattering using 5.7 GeV longitudinally polarized electron beam and a polarized $^3\text{He}$ target. $A^p$ and $g_{1,2}^p$ were deduced for $x = .33, .47,$ and .60 and $Q^2 = 2.7, 3.5$ and 4.8 (GeV/c)$^2$. $A^p$ and $g_{1,2}^p$ at $x = .33$ are consistent with the world data. At $x = .47$ $A^p$ crosses zero and is significantly positive at $x = .60$. This finding agrees with the predictions of the constituent quark model but disagrees with the leading order pQCD assuming hadron helicity conservation.

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

Let us denote by $q(x) = q^1 + q^i(x)$ the spin independent quark distribution function. The difference $\Delta q(x) = q^1 - q^i(x)$ measures the contribution of quark $q$ to the spin of hadron. The measurement allowed to deduce estimates for the ratios $(\Delta q(x) + \Delta \bar{q}(x))/(q(x) + \bar{q}(x))$.

The conclusion of [37] is that for proton one has

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

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

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

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

The finding is consistent with the relativistic $SU(6)$ symmetry broken by spin-spin interaction and the QCD based model interpolated from data but giving up helicity conservation [37]. $SU(6)$ is however not a fundamental symmetry so that its success is probably accidental.

It has been also proposed that the spin crisis might be illusory [10] and due to the fact that the vector sum of quark spins is not a Lorentz invariant quantity so that the sum of quark spins in infinite-momentum frame where quark distribution functions are defined is not same as, and could thus be smaller than, the spin sum in the rest frame. The correction due to the transverse momentum of the quark brings in a non-negative numerical correction factor which is in the range $(0, 1)$. The negative sign of $\Delta d/d$ is not consistent with this proposal.

2.1.2 TGD based model for the findings

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

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

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

$$ |B, \frac{1}{2}, \uparrow \rangle = a|B, 1/2, \frac{1}{2}⟩|J = J_z = 0⟩ + b|B, \frac{3}{2}, -\frac{3}{2}⟩|J = J_z = 2⟩ , $$

$$ |B, 1/2, \frac{1}{2}⟩ = \sum_{q_1,q_2,q_3} e_{q_1,q_2,q_3} q_1^i q_2^j q_3^k , $$

$$ |B, \frac{3}{2}, -\frac{3}{2}⟩ = d_{q_1,q_2,q_3} q_1^i q_2^j q_3^k . $$

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

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

4. Consider now the detailed structure of the $J = 2$ state in the case of proton. If the $d$ quark is at the rotation axis, the rotating part of the triangular flux tube structure resembles a string containing $u$-quarks at its ends and forming a di-quark like structure. Di-quark structure is taken to mean $u$-quarks at its ends and forming a di-quark like structure. Di-quark structure is taken to mean

$$ A_d = \frac{\Delta d(x) + \Delta \bar{d}(x)}{d(x) + \bar{d}(x)} = \frac{p(\Delta d_0 + \Delta \bar{d}_0) + (1 - p)(\Delta d_2 + \Delta \bar{d}_2)}{p(d_0 + \bar{d}_0) + (1 - p)(d_2 + \bar{d}_2)} , $$

$$ p = |a|^2 . $$

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

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

as a parameter, one can write

$$ A_d \to \frac{p - (1 - p)y}{p + (1 - p)y} $$

at the limit $x \to 1$. This allows to deduce the value of the parameter $y$ once the value of $p$ is known:
\[ y = \frac{p}{1 - p} \times \frac{1 - A_d}{1 + A_d}. \] (2.4)

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

\[ p \times \frac{1}{2} - (1 - p) \times \frac{3}{2} = \Sigma \] (2.5)

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

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

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

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

According to [37] \( R^{np}(x) \) is a straight line starting with \( R^{np}(x \to 0) \approx 1 \) and dropping below \( 1/2 \) as \( x \to 1 \). The behavior for small \( x \) can be understood in terms of sea quark dominance. The pQCD prediction for \( R^{np} \) is \( R^{np} \to 3/7 \) for \( x \to 1 \), which corresponds to \( d/u \to z = 1/5 \). TGD prediction for \( R^{np} \) for \( x \to 1 \)

\[ R^{np} = \frac{F_2^n}{F_2^p} = \frac{pu_0 + 4(pd_0 + (1 - p)d_2)}{4pu_0 + pd_0 + (1 - p)d_2} \]

\[ = \frac{p + 4z(p + (1 - p)y)}{4p + z(p + (1 - p)y)}. \] (2.7)

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

### 2.2 Topological evaporation and the concept of Pomeron

Topological evaporation provides an explanation for the mysterious concept of Pomeron originally introduced to describe hadronic diffractive scattering as the exchange of Pomeron Regge trajectory [43]. No hadrons belonging to Pomeron trajectory were however found and via the advent of QCD Pomeron was almost forgotten. Pomeron has recently experienced reincarnation [33, 27, 28]. In Hera [33] \( e^-p \) collisions, where proton scatters essentially elastically whereas jets in the direction of incoming virtual photon emitted by electron are observed. These events can be understood by assuming that proton emits color singlet particle carrying small fraction of proton’s momentum. This particle in turn collides with virtual photon (antiproton) whereas proton scatters essentially elastically.

The identification of the color singlet particle as Pomeron looks natural since Pomeron emission describes nicely diffractive scattering of hadrons. Analogous hard diffractive scattering events in \( pX \) diffractive scattering with \( X = \bar{p} \) [27] or \( X = p \) [28] have also been observed. What happens is that proton scatters essentially elastically and emitted Pomeron collides with \( X \) and suffers hard scattering so that large rapidity gap jets in the direction of \( X \) are observed. These results suggest that Pomeron is real and consists of ordinary partons.

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

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

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

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

The existing detailed knowledge about the properties of sea structure functions provides a stringent test for the TDG scenario. According to [27] Pomeron structure function seems to consist of soft \((1-x)^5\), hard \(1-x\) and super-hard component (delta function like component at \( x = 1 \)). The peculiar super hard component finds explanation in TDG based picture. The structure function \( q_P(x, z) \) of parton in Pomeron contains the longitudinal momentum fraction \( z \) of the Pomeron as a parameter and \( q_P(x, z) \) is obtained by scaling from the sea structure function \( q(x) \) for proton \( q_P(x, z) = q(zx) \). The value of structure function at \( x = 1 \) is non-vanishing: \( q_P(x = 1, z) = q(z) \) and this explains the necessity to introduce super hard delta function component in the fit of [27].

2.2.2 Updated model

The recent developments in the understanding of hadron mass spectrum involve the realization that hadronic \( k = 107 \) space-time sheet is a carrier of super-symplectic bosons (and possibly their super-counterparts with quantum numbers of right handed neutrino) [7]. The model leads to amazingly simple and accurate mass formulas for hadrons. Most of the baryonic momentum is carried by super-symplectic quanta: valence quarks correspond in proton to a relatively small fraction of total mass: about 170 MeV. The counterparts of string excitations correspond to super-symplectic many-particle states and the additivity of conformal weight proportional to mass squared implies stringy mass formula and generalization of Regge trajectory picture. Hadronic string tension is predicted correctly. Model also provides a solution to the proton spin puzzle.

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

The large value of \( \alpha_K = 1/4 \) for super-symplectic matter suggests that the criterion for a phase transition increasing the value of Planck constant [2] and leading to a phase, where \( \alpha_K \propto 1/hbar \) is reduced, could occur. For \( \alpha_K \) to remain invariant, \( h_0 \rightarrow 26h_0 \) would be required. In this case, the size of hadronic space-time sheet, "color field body of the hadron", would be \( 26 \times L(107) = 46 \) fm, roughly the size of the heaviest nuclei. Hence a natural expectation is that the dark side of nuclei plays a role in the formation of atomic nuclei. Note that the sizes of electromagnetic field bodies of current quarks u and d with masses of order few MeV is not much smaller than the Compton length of electron. This would
mean that super-symplectic bosons would represent dark matter in a well-defined sense and Pomeron exchange would represent temporary separation of ordinary and dark matter.

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

2.2.3 Astrophysical counterpart of Pomeron events

Pomeron events have direct analogy in astrophysical length scales. In the collision of two galaxies dark and visible matter parts of the colliding galaxies have been found to separate by Chandra X-ray Observatory [44].

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

2.3 The incredibly shrinking proton

The discovery that the charge radius of proton deduced from the muonic version of hydrogen atom is about 4 per cent smaller than from the radius deduced from hydrogen atom [38, 41] is in complete conflict with the cherished belief that atomic physics belongs to the museum of science. The title of the article Quantum electrodynamics-a chink in the armour? of the article published in Nature [35] expresses well the possible implications, which might actually go well extend beyond QED.

The finding is a problem of QED or to the standard view about what proton is. Lamb shift [19] is the effect distinguishing between the states hydrogen atom having otherwise the same energy but different angular momentum. The effect is due to the quantum fluctuations of the electromagnetic field. The energy shift factorizes to a product of two expressions. The first one describes the effect of these zero point fluctuations on the position of electron or muon and the second one characterizes the average of nuclear charge density as "seen" by electron or muon. The latter one should be same as in the case of ordinary hydrogen atom but it is not. Does this mean that the presence of muon reduces the charge radius of proton as determined from muon wave function? This of course looks implausible since the radius of proton is so small. Note that the compression of the muon's wave function has the same effect.

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

2.3.1 Basic facts and notions

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

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

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

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

2. Proton contains 2 quarks with charge \( 2e/3 \) and one d quark which charge \(-e/3\). These quarks are light. The last determination of u and d quark masses [31] gives masses, which are \( m_u = 2 \text{ MeV} \) and \( m_d = 5 \text{ MeV} \) (I leave out the error bars). The standard view is that the contribution of quarks to proton mass is of same order of magnitude. This would mean that quarks are not too relativistic meaning that one can assign to them a size of order Compton wave length of order \( 4 \times r_e \simeq 600 \text{ fm} \) in the case of u quark (roughly twice the Bohr radius of muonic hydrogen) and \( 10 \times r_e \simeq 24 \text{ fm} \) in the case of d quark. These wavelengths are much longer than the proton charge radius and for u quark more than twice longer than the Bohr radius of the muonic hydrogen. That parts of proton would be hundreds of times larger than proton itself sounds a rather weird idea. One could of course argue that the scales in question do not correspond to anything geometric. In TGD framework this is not the way out since quantum classical correspondence requires this geometric correlate.

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

4. The intuitive picture is that light-like 3-surfaces assignable to quarks describe random motion of partonic 2-surfaces with light-velocity. This is analogous to zitterbewegung assigned classically to the ordinary Dirac equation. The notion of braid emerging from Chern-Simons Dirac equation via periodic boundary conditions means that the orbits of partonic 2-surface effectively reduces to braids carrying fermionic quantum numbers. These braids in turn define higher level braids which would move inside a structure characterizing the particle geometrically. Internal consistency suggests that the classical radius \( r = \alpha_K \hbar/m \) characterizes the size scale of the zitterbewegung orbits of quarks.

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

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

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

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

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

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

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

3. This effect would be of course present also in the case of electron but in this case the u quarks correspond to a volume which million times smaller than the volume defined by Bohr radius so that electron does not in practice ”see” the quark sub-structure of proton. The probability $P$ for getting caught would be in a good approximation proportional to the value of $|\Psi(r_u)|^2$ and in the first approximation one would have

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

from the proportionality $\Psi \propto 1/a^{3/2}_i$, i=e,µ.

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

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

1. In the article [21] the basic theoretical results related to the Lamb shift in terms of the vacuum polarization of photon are discussed. Proton’s charge density is in this representation is expressed in terms of proton form factor in principle deducible from the scattering data. Two special cases can be distinguished corresponding to the point like proton for which Lamb shift is non-vanishing
only for S wave states and non-point like proton for which energy shift is present also for other states. The theoretical expression for the Lamb shift involves very refined calculations. Between 2P and 2S states the expression for the Lamb shift is of form

$$\Delta E(2P_{3/2} - 2S_{1/2}) = a - br_p^2 + cr_p^3 = 209.968(5) \times 2248 \times r_p^2 + 0.0347 \times r_p^3 \text{ meV}.$$ (2.8)

where the charge radius \( r_p = 0.8750 \) is expressed in femtometers and energy in meVs.

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

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

Here \( F \) is a scalar representing vacuum polarization due to decay of photon to virtual pairs.

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

The modification of the formula is due to the normalization of the 2P and 2S states. These are in general different. The normalization factor \( 1/N \) is same for all terms in the expression of Lamb shift for a given state but in general different for 2S and 2P states. Since the lowest order term dominates by a factor of \( \sim 40 \) over the second one, one can conclude that the modification should affect the lowest order term by about 4 per cent. Since the second term is negative and the modification of the first term is interpreted as a modification of the second term when \( r_p \) is estimated from the standard formula, the first term must increase by about 4 per cent. This is achieved if this state is orthogonalized with respect to the flux tube state. For states \( \Psi_0 \) and \( \Psi_{\text{tube}} \) with unit norm this means the modification

$$\Psi_0 \rightarrow \frac{1}{1 - |C|^2} (\Psi_0 - C \Psi_{\text{tube}}),$$ \( C = \langle \Psi_{\text{tube}} | \Psi_0 \rangle \). (2.10)

In the lowest order approximation one obtains

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

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

$$a - br_p^2 + cr_p^3 \rightarrow (1 + |C|^2) a - br_p^2 + cr_p^3.$$ (2.12)

This gives the equivalent conditions

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

The resulting estimate for the leakage probability is \( P_{\text{tube}} \simeq 0.0015 \). The model should be able to reproduce this probability.
2.3.2 A model for the coupling between standard states and flux tube states

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

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

\[
\Phi = -\frac{ke}{\pi R^2} |x| + \Phi_0 .
\]

The normalization factor comes from the condition that the total electric flux is \( q \). The value of the additive constant \( \Phi_0 \) is fixed by the condition that the potential coincides with Coulomb potential at \( r = r_u \), where \( r_u \) is u quark Compton length. This gives

\[
e\Phi_0 = \frac{e^2}{r_u} + Kr_u , \quad K = \frac{ke^2}{\pi R^2} .
\]

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

\[
R = z\alpha r_u .
\]

This gives

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

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

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

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

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

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

By performing a linear coordinate change

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

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one obtains

\[ \frac{d^2 \Psi}{du^2} - u \Psi = 0 . \]  

This differential equation is known as Airy equation (or Stokes equation) and defines special functions \( Ai(x) \) known as Airy functions and related functions \( Bi(x) \) referred to as "Bairy" functions \[15\]. Airy functions characterize the intensity near an optical directional caustic such as that of rainbow.

2. The explicit expressions for \( Ai(u) \) and \( Bi(u) \) are given by

\[ Ai(u) = \frac{1}{\pi} \int_0^\infty \cos \left( \frac{t^3}{3} + ut \right) dt , \]

\[ Bi(u) = \frac{1}{\pi} \int_0^\infty \left[ \exp \left( -\frac{1}{3}t^3 \right) + \sin \left( \frac{1}{3}t^3 + ut \right) \right] dt . \]  

(2.21)

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

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

\[ Ai(u) \sim \frac{1}{2^{1/2}} \exp \left( -\frac{2}{3}u^{3/2} \right) u^{-1/4} , \]

\[ Bi(u) \sim \frac{1}{\pi^{1/2}} \exp \left( \frac{2}{3}u^{3/2} \right) u^{-1/4} . \]  

(2.22)

For \( u < 0 \) one has

\[ Ai(u) \sim \frac{1}{\pi^{1/2}} \sin \left( \frac{2}{3}(-u)^{3/2} \right) (-u)^{-1/4} , \]

\[ Bi(u) \sim \frac{1}{\pi^{1/2}} \cos \left( \frac{2}{3}(-u)^{3/2} \right) (-u)^{-1/4} . \]  

(2.23)

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

\[ u_{\text{min}} \equiv u(0) = - \left( \frac{2m_u K}{\hbar^2} \right)^{1/3} x_E , \]

\[ u_{\text{max}} \equiv u(r_u) = \left( \frac{2m_u K}{\hbar^2} \right)^{1/3} (r_u - x_E) , \]

\[ x_E = \frac{-|E| + e\Phi_0}{K} . \]  

(2.24)

4. The general solution is

\[ \Psi = aAi(u) + bBi(u) . \]  

(2.25)
The natural boundary condition is the vanishing of $\Psi$ at the lower end of the flux tube giving

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

(2.26)

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

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

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

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

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

$$
\Psi_{nlm} \rightarrow N \times (\Psi_{nlm} - C(E, nlm)\Phi_{nlm}) ,
$$

$$
\Phi_{nlm} = Y_{lm} \Psi_E ,
$$

$$
C(E, nlm) = \langle \Psi_E | \Psi_{nlm} \rangle .
$$

(2.27)

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

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

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

(2.28)

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

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

1. The simplest possibility is that one takes only overlap at the upper end of the flux tube which defines 2-D surface. Second possibility is that that the overlap is over entire flux tube projection at the space-time sheet of atom.
\[
\langle \Psi_E | \Psi_{nlm} \rangle = \int_{\text{end}} \Psi_r \Psi_{nlm} dS \quad \text{(Option I)} ,
\]
\[
\langle \Psi_E | \Psi_{nlm} \rangle = \int_{\text{tube}} \Psi_r \Psi_{nlm} dV \quad \text{(Option II)} .
\] (2.29)

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

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

3. **Option I fails**

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

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

\[
C(E, nlm) = \int_{\text{tube}} \Psi_E \Psi_{nlm} dS \simeq \pi R^2 \times Y_{lm} \times C(E, nl) ,
\]
\[
C(E, nl) = \Psi_E(r_u) R_{nl}(r_u) .
\] (2.30)

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

\[
C(E, nl) = \Psi_E(r_u) R_{nl}(r_u) ,
\]
\[
\Psi_E(x) = a_E \text{Ai}(u_E) + b_E \text{Bi}(u_E) , \quad \frac{a_E}{b_E} = -\frac{\text{Bi}(u_E(0))}{\text{Ai}(u_E(0))} ,
\]
\[
u_E(x) = \left( \frac{2m_K}{\hbar^2} \right)^{1/3} (x - x_E) , \quad x_E = \frac{|E| - e\Phi_0}{K} ,
\]
\[
K = \frac{k e^2}{\pi R^2} , \quad R = z\alpha_K r_u , \quad k = \frac{2}{3} .
\] (2.31)

The normalization of the coefficients is fixed from the condition that \( a \) and \( b \) chosen in such a manner that \( \Psi \) has unit norm. For these boundary conditions \( Bi \) is expected to dominate completely in the sum and the solution can be regarded as exponentially decreasing function concentrated around the upper end of the flux tube.
In order to get a quantitative view about the situation one can express the parameters \( u_{\text{min}} \) and \( u_{\text{max}} \) in terms of the basic dimensionless parameters of the problem.

1. One obtains

\[
\begin{align*}
  u_{\text{min}} &\equiv u(0) = -2\left(\frac{k}{z\alpha}\right)^{1/3} \left[1 + \frac{z}{k}\alpha^2(1 - \frac{1}{2} \alpha r)\right] \times r^{1/3}, \\
  u_{\text{max}} &\equiv u(r_u) = u(0) + 2\left(\frac{k}{z\alpha}\right) \times r^{1/3}, \\
  r &\equiv \frac{m_p}{m_u}, \quad R = z\alpha r_u.
\end{align*}
\]

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

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

\[
N^2 \simeq \frac{dx}{du} \times \int_{u_{\text{min}}}^{u_{\text{max}}} Bi(u)^2 \, du = \frac{1}{2} \left(\frac{z^2\alpha}{k}\right)^{1/3} \times r^{1/3} r_u.
\]

By taking \( t = \exp(\frac{1}{2}u^{3/2}) \) as integration variable one obtains

\[
\int_{u_{\text{min}}}^{u_{\text{max}}} Bi(u)^2 \, du \simeq \pi^{-1} \int_{u_{\text{min}}}^{u_{\text{max}}} \exp\left(\frac{4}{3}u^{3/2}\right) u^{-1/2} \, du \simeq \frac{1}{\pi} \exp\left(\frac{4}{3}u_{\text{max}}^{3/2}\right). \tag{2.34}
\]

This gives for the normalization factor the expression

\[
N \simeq \frac{1}{2} \left(\frac{z^2\alpha}{k}\right)^{2/3} r^{1/3} r_u^{-1/2} \exp\left(\frac{2}{3}u_{\text{max}}^{3/2}\right). \tag{2.35}
\]

3. One obtains for the value of \( \Psi_E \) at the end of the flux tube the estimate

\[
\Psi_E(r_u) = \frac{Bi(u_{\text{max}})}{N} \simeq 2\pi^{-1/2} \left(\frac{k}{z^2\alpha}\right)^{2/3} r^{1/3} r_u^{-1/2} \, e^{\frac{1}{\alpha}r_u}. \tag{2.36}
\]

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

\[
C_{E,00} = \Psi_E(r_u) \times \Psi_{1,00}(r_u) \times \pi R^2 = 2\pi^{-1/2} \left(\frac{k}{z^2\alpha}\right)^{2/3} r^{1/3} r_u^{-1/2} \times \left(\frac{1}{\alpha(\mu^2)}\right)^{1/2} \times e^{-\alpha r} \times \pi z^2 \alpha^2 r_u^2 \simeq 2\pi^{1/2} \left(\frac{k}{z^2\alpha}\right)^{2/3} r^{1/3} r_u^{-1/2} \, e^{\frac{1}{\alpha}r_u}. \tag{2.37}
\]

The relative reduction of charge radius equals to \( P = C_{E,00}^2 \). For \( z = 1 \) one obtains \( P = C_{E,00}^2 = 5.5 \times 10^{-6} \), which is by three orders of magnitude smaller than the value needed for \( P_{\text{tube}} = C_{E,20}^2 = 0.015 \). The obvious explanation for the smallness is the \( \alpha^2 \) factor coming from the area of flux tube in the inner product.
4. Option II could work

The failure of the simplest model is essentially due to the inner product. For option II the inner product for the flux tube states involves the integral over the area of flux tube so that the normalization factor for the state is obtained from the previous one by the replacement $N \to N/\sqrt{\pi R^2}$. In the integral over the flux tube the exponent function is is in the first approximation equal to constant since the wave function for ground state is at the end of the flux tube only by a factor $0.678$ smaller than at the origin and the wave function is strongly concentrated near the end of the flux tube. The inner product defined by the overlap integral over the flux tube implies $N \to N S^{1/2}$, $S = \pi R^2 = z^2 \alpha^2 r_u^2$. In good approximation the inner product for option II means the replacement

$$ C_{E, n0} \to A \times B \times C_{E, n0} , $$

$$ A = \frac{dx}{\sqrt{\pi R^2}} = \frac{1}{2\sqrt{\pi}} z^{-1/3} k^{-1/3} \alpha^{-2/3} r^{1/3} , $$

$$ B = \frac{\int B(u) du}{\sqrt{\text{Bi}(u_{\text{max}})}} = u_{\text{max}}^{-1/4} = 2^{-1/4} z^{1/2} k^{-1/4} \alpha^{1/4} r^{-1/12} . $$

Using the expression

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

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

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

By the earlier general argument one should have $P_{\text{tube}} = |C_{E, 20}|^2 \simeq 0.0015$. $P_{\text{tube}} = 0.0015$ is obtained for $z = 1$ and $N = 2$ corresponding to single flux tube per $u$ quark. If the flux tubes are in opposite directions, the leakage into $2P$ state vanishes. Note that this leakage does not affect the value of the coefficient $a$ in the general formula for the Lamb shift. The radius of the flux tube is by a factor $1/4$ smaller than the classical radius of electron and one could argue that this makes it impossible for electron to topologically condense at the flux tube. For $z = 4$ one would have $P_{\text{tube}} = 0.015$ which is 10 times too large a value. Note that the nucleus possess a wave function for the orientation of the flux tube. If this corresponds to S-wave state then only the leakage between S-wave states and standard states is possible.

2.3.3 Are exotic flux tube bound states possible?

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

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

$$ x_{\text{max}} = \frac{\pi R^2}{k} \left( \frac{|E|}{e^2} + \frac{1}{r_u} + \frac{k r_u}{\pi R^2} \right) h . $$

$x_{\text{max}} < r_u$ holds true if one has
The ratio of this energy to the ground state energy of muonic hydrogen is from $E(1) = e^2/2a(\mu)$ and $a = ℏ/αm$ given by

$$\frac{E_{\text{max}}}{E(n = 1)} = \frac{2m_u}{αm_μ} \approx 5.185 \ .$$

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

$$\frac{E_{\text{max}}}{E(n = 1)} = \frac{8}{α} \approx 1096 \ .$$

Obviously the formation of this kind of states could provide a new source of energy. There have been claims about anomalous energy production in hydrogen [50]. I have discussed these claims from TGD viewpoint in [11].

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

$$I = \int_{0}^{x_{\text{max}}} \sqrt{2m(E + eΦ)} \frac{dx}{ℏ} = n + \frac{1}{2} \ .$$

By performing the integral one obtains the quantization condition

$$I = k^{-1}(8πα)^{1/2} \times \frac{R^2}{r_u^{3/2} r_μ} \times A^{3/2} = n + \frac{1}{2} \ ,$$

$$A = 1 + kx^2 - \frac{|E|r_u}{e^2} \ ,$$

$$x = \frac{r_u}{R} \ , \ k = \frac{ℏ}{2π} \ , \ r_i = \frac{ℏ}{m_i} \ .$$

3. Parameter $R$ should be of order of magnitude of charge radius $α_Kr_u$ of u quark is free parameter in some limits. $α_K = α$ is expected to hold true in excellent approximation. Therefore a convenient parametrization is

$$R = zαr_u \ .$$

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

$$|E| = C \times E(1, μ) \ ,$$

$$C = D \times (1 + Kz^{-2}α^{-2} - \left(\frac{K^2}{2π}\right)^{2/3} \times (n + 1/2)^{2/3}) \ ,$$

$$D = 2y \times \left(\frac{K^2}{8πα}\right)^{1/3} \ ,$$

$$y = \frac{m_u}{m_μ} \ , \ K = \frac{2}{3π} \ .$$
4. There is a finite number of bound states. The above mentioned consistency conditions coming from
0 < x_{max} < r_{\mu} give 0 < C < C_{max} = 5.185 restricting the allowed value of n to some interval. One
obtains the estimates

\[ n_{\min} \simeq \frac{z^{2}}{y}(1 + Kz^{-2}\alpha^{-2} - \frac{C_{max}}{D})^{3/2} - \frac{1}{2}, \]
\[ n_{\max} = \frac{z^{2}}{y}(1 + Kz^{-2}\alpha^{-2})^{3/2} - \frac{1}{2}. \]  

(2.49)

Very large value of n is required by the consistency condition. The calculation gives \( n_{\min} \in \{1.22 \times 10^{7}, 4.59 \times 10^{6}, 1.48 \times 10^{5}\} \) and \( n_{\max} \in \{1.33 \times 10^{7}, 6.66 \times 10^{6}, 3.34 \times 10^{6}\} \) for \( z \in \{1, 2, 4\} \).

This would be a very large number of allowed bound states-about 3.2 \times 10^{6} for \( z = 1 \).

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

\[ \frac{1}{\sqrt{k(x)}} \left[ A\exp(i \int_{0}^{x} k(y)dy) + B\exp(-i \int_{0}^{x} k(y)dy) \right], \]
\[ \frac{1}{\sqrt{k(x)}} \left[ C\exp(- \int_{x_{max}}^{x} \kappa(y)dy) + D\exp(\int_{x_{max}}^{x} \kappa(y)dy) \right], \]
\[ k(x) = \sqrt{2m(|E| - e\Phi)}, \ \kappa(x) = \sqrt{2m(|E| - e\Phi)} \]  

(2.50)

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

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

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

2.4 Explanation for the soft photon excess in hadron production

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

2.4.1 Soft photon anomaly

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

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

I try to abstract the essentials of the article.

1. One considers soft photon production in kinematic range \(2 \text{ GeV} < E < 1 \text{ GeV}, p_T < 0.08 \text{ GeV}\), where \(p_T\) is photon transverse momentum with respect to the parent jet direction. The soft photon excess is associated with hadron production only and does not appear in leptonic sector. As one subtracts the photon yield due to the decays of hadrons (mainly neutral pions), one finds that what remains is on the average 4 times larger than the photon yield by inner hadronic brehmstrahlung, which means bremsstrahlung by charged final state hadrons. This suggests that the description in terms of charged hadron bremsstrahlung is not correct and one must go to quark level.

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

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

The article discusses the data and also the models that has been proposed. Incoherent production of photons by quarks predict satisfactorily the linear dependence of total intensity of bremsstrahlung on total number of jet particle if the number of quarks in jet is assumed to be proportional to the number jet particles (see Fig. 7 of [26]). The model cannot however explain the deviations from the model based on charged hadron inner bremsstrahlung: the problems are produced by the sensitive dependence on the number of neutral hadrons (see Fig. 6 of [26]).

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

2.4.2 TGD based explanation of the anomaly

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

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

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

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

A more precise argument goes as follows.

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

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

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

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

5. More complex model would assume that the flux tubes contain quarks and antiquarks also in their interior so that one would have coherent sum of a larger number of amplitudes which would give diffraction conditions for \(\lambda\) analogous to those above. In this case the maximum of the diffractive factor would be \(N^2\), where \(N = 2n\) is total number of quarks and antiquarks for mesons. For neutral baryons flux tube would contain odd number of quarks. The angle average would be in this case be equal to \(N\). If all quarks and antiquarks inside the flux tube appear as valence quarks of the final state hadron, one obtains just the result predicted by the independent quark model. Therefore the only possible interpretation for additional contribution is in terms of sea quarks.

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

1. The model based on incoherent bremsstrahlung on quarks mentioned in \textsuperscript{26} assumes that the number of partons in jet is proportional to the hadrons in the jet:

\[
R \propto (N_{\text{sea,neu}} + N_{\text{val,neu}} + N_{\text{sea,ch}} + N_{\text{val,ch}}) \propto N_{\text{tot}}.
\]  

According to \textsuperscript{26} the model explains the excess as a a linear function of jet total hadron multiplicity \(N_{\text{tot}}\) (see Fig. 7 of \textsuperscript{26}). This behavior is obtained if the production rate satisfies

\[
R \propto (N_{\text{sea,neu}} + N_{\text{val,neu}} + N_{\text{sea,ch}} + N_{\text{val,ch}})\langle Q^2_q \rangle.
\]

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

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

\[
R \propto (N_{\text{sea,neu}} + N_{\text{val,neu}} + N_{\text{val,ch}})\langle Q^2_q \rangle.
\]  

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

\[
R \propto (xN_{\text{sea,neu}} + N_{\text{val,neu}} + N_{\text{val,ch}})\langle Q^2_q \rangle,
\]

\[
x = \left(\frac{m_{\text{val}}}{m_{\text{sea}}}\right)^2.
\]  

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

The above constraint gives rise to the consistency condition

\[
\langle R \rangle \propto (xN_{\text{sea,neu}} + N_{\text{val,neu}} + N_{\text{val,ch}}) \propto N_{\text{tot}}.
\]  

3. The data \textsuperscript{26} support the appearence of \(N_{\text{sea,neu}}\) in the rate.
(a) The dependence on $xN_{sea}$ could explain the exceptionally large deviation (by factor of 8, see Fig. 5 of [26]) from hadronic inner bremsstrahlung for smallest charged multiplicity meaning large number sea quarks assignable to neutral hadrons. For large values of charged multiplicity the contribution of $xN_{sea, neu} + N_{val, neu}$ becomes small and one should obtain approximate factor 4.

(b) The linear fit of the distribution in the form $R = a_1 N_{ch} + a_2 N_{neu}$ gives $a_2/a_1 \simeq 6$ so that the dependence on neutral multiplicity is six time stronger than on charged multiplicity (see table 6 of [26]). This suggests that $xN_{sea, neu}$ dominates in the formula. The first possibility is that the parameter $r = N_{sea, neu}/N_{val, neu}$ is considerably larger than unity. Second possibility is that one has $x > 1$.

(c) The ratio of signal to bremsstrahlung prediction increases rapidly as a function of neutral jet multiplicity $n_{neu}$ and increases from 2.5 to about 16 in the range $[0, 6]$ for the neutral multiplicity (see Fig. 6 of [26]). This conforms with the dependence on $N_{sea, neu}$. Also the dependence of the signal to bremsstralung ratio on the core charged multiplicity is non-trivial being largest for vanishing core charge and decreasing with core $n_{ch}$. Also this confirms with the proposal.

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

### 3 Simulating Big Bang in laboratory

Ultra-high energy collisions of heavy nuclei at Relativistic Heavy Ion Collider (RHIC) can create so high temperatures that there are hopes of simulating Big Bang in laboratory. The experiment with PHOBOS detector [30] probed the nature of the strong nuclear force by smashing two Gold atoms together at ultrahigh energies. The analysis of the experimental data has been carried out by Prof. Manly and his collaborators at RHIC in Brookhaven, NY [29]. The surprise was that the hydrodynamical flow for non-head-on collisions did not possess the expected longitudinal boost invariance.

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

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

2. What is so remarkable is that critical cosmology is not a small perturbation of the empty cosmology represented by the future light cone. By perturbing this cosmology so that the spherical symmetry is broken, it might possible to understand qualitatively the findings of [20]. Maybe even the breaking of the spherical symmetry in the collision might be understood as a strong gravitational effect on distances transforming the spherical shape of the plasma ball to a non-spherical shape without affecting the spherical shape of its $M_4^+$ projection.

3. The model seems to work at qualitative level and predicts strong gravitational effects in elementary particle length scales so that TGD based gravitational physics would differ dramatically from that predicted by the competing theories. Standard cosmology cannot produce these effects without a large breaking of the cherished Lorentz and rotational symmetries forming the basis of elementary particle physics. Thus the the PHOBOS experiment gives direct support for the view that Poincare symmetry is symmetry of the imbedding space rather than that of the space-time.
4. This picture was completed a couple of years later by the progress made in hadronic mass calculations. It has already earlier been clear that quarks are responsible only for a small part of the mass of baryons (170 GeV in case of nucleons). The assumption that hadronic space-time sheet carries a many-particle state of super-symplectic particles with vanishing electro-weak quantum numbers (meaning darkness in the strongest sense of the word.)

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

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

3.1 Experimental arrangement and findings

3.1.1 Heuristic description of the findings

In the experiments using PHOBOS detector ultrahigh energy $Au+Au$ collisions at center of mass energy for which nucleon-nucleon center of mass energy is $\sqrt{s_{NN}} = 130$ GeV, were studied.[30]

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

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

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

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

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

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

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

Consider now the situation in a more quantitative manner.

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

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

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

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

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

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

The hydrodynamical view about the situation looks like follows.

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

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

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

was analyzed in [29].
3. It was found that the Fourier component $v_2$ depends on rapidity $y$, which means a breaking of the longitudinal boost invariance. $v_2$ also vanishes for large values of $y$. If this is true for all Fourier coefficients $v_n$, the situation becomes effectively Lorentz invariant for large values of $y$ since one has $v(y, \phi) \to 1$.

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

3.2 TGD based model for the quark-gluon plasma

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

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

2. The $M_4^+\times \mathbb{CP}^2$ projection of a Robertson-Walker cosmology imbedded to $H = M_4^+ \times \mathbb{CP}^2$ is future light cone. Hence it is natural to model the hydrodynamical flow as a mini-cosmology. Even more, one can assume that the collision quite literally creates a space-time sheet which locally obeys Robertson-Walker type cosmology. This assumption is sensible in many-sheeted space-time and conforms with the fractality of TGD inspired cosmology (cosmologies inside cosmologies).

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

4. Critical cosmology is by definition unstable, and one can model the Au+Au collision as a perturbation of the critical cosmology breaking the spherical symmetry. The shape of $r = \text{constant}$ sphere defined by the induced metric is changed by strong gravitational interactions such that it corresponds to the shape for the intersection of the colliding nuclei. One can view the collision as a spontaneous symmetry breaking process in which a critical quark-gluon plasma cosmology develops a quantum fluctuation leading to a situation described in terms of impact parameter. This kind of modelling is not natural for a hyperbolic cosmology, which is a small perturbation of the empty $M_4^+$ cosmology.

3.2.1 The imbedding of the critical cosmology

Any Robertson-Walker cosmology can be imbedded as a space-time sheet, whose $M_4^+$ projection is future light cone. The line element is

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

(3.2)

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

This light cone has its tip at the point, where the formation of quark gluon plasma starts. $(\theta, \phi)$ are the spherical coordinates and appear in $d\Omega^2$ defining the line element of the unit sphere. $a$ and $r$
are related to the spherical Minkowski coordinates \((m^0, r_M, \theta, \phi)\) by \((a = \sqrt{(m^0)^2 - r_M^2}, r = r_M/a)\). If hyperbolic cosmology is in question, the function \(K(r)\) is given by \(K(r) = 1/(1 + r^2)\). For the critical cosmology 3-space is flat and one has \(K(r) = 1\).

1. The critical cosmologies imbeddable to \(H = M_4^+ \times \text{CP}_2\) are unique apart from a single parameter defining the duration of this cosmology. Eventually the critical cosmology must transform to a hyperbolic cosmology. Critical cosmology breaks Lorentz symmetry at space-time level since Lorentz group is replaced by the group of rotations and translations acting as symmetries of the flat Euclidian space.

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

3. The imbedding of the critical cosmology to \(M_4^+ \times S^2\) is given by

\[
\sin(\Theta) = \frac{a}{a_m}, \quad \Phi = g(r). \quad (3.3)
\]

Here \(\Theta\) and \(\Phi\) denote the spherical coordinates of the geodesic sphere \(S^2\) of \(\text{CP}_2\). One has

\[
f(a) = 1 - \frac{R^2 k^2}{(1 - (a/a_m)^2)},
\]

\[
(\partial_r \Phi)^2 = \frac{a_m^2}{R^2} \times \frac{r^2}{1 + r^2}. \quad (3.4)
\]

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

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

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

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

\[
\sin^2(\Theta) = \left(\frac{a}{a_m}\right)^2 \times (1 + \Delta(a, \theta, \phi))^2. \quad (3.5)
\]

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

\[
g_{rr} = -a^2 \left[1 + \Delta^2(a, \theta, \phi) \frac{r^2}{1 + r^2}\right]. \quad (3.6)
\]
Remarkably, $g_{rr}$ does not depend at all on $CP_2$ size and the parameter $a_m$ determining the duration of the critical cosmology. The disappearance of the dimensional parameters can be understood to reflect the criticality. Thus a strong gravitational effect independent of the gravitational constant (proportional to $R^2$) results. This implies that the expanding plasma space-time sheet having sphere as $M_4^+$ projection differs radically from sphere in the induced metric for large values of $a$. Thus one can understand why the parameter $v_2$ is non-vanishing for small values of the rapidity $y$.

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

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

which diverges for

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

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

3.3 Further experimental findings and theoretical ideas

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

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

The model discussed above explained the strange breaking of longitudinal Lorentz invariance in terms of a hadronic mini bang cosmology. The next twist in the story was the shocking finding, compared to Columbus’s discovery of America, was that, rather than behaving as a dilute gas, the plasma behaved like a liquid with strong correlations between partons, and having density 30-50 times higher than predicted by QCD calculations [47]. When I learned about these findings towards the end of 2004, I proposed how TGD might explain them in terms of what I called conformal confinement [4]. This idea - although not wrong for any obvious reason - did not however have any obvious implications. After the progress made in $p$-adic mass calculations of hadrons leading to highly successful model for both hadron and meson masses [7], the idea was replaced with the hypothesis that the condensate in question is Bose-Einstein condensate like state of super-symplectic particles formed when the hadronic space-time sheets of colliding nucleons fuse together to form a long string like object.

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

3.3.2 Fireballs behaving like black hole like objects

The latest discovery in RHIC is that fireball, which lasts a mere $10^{-23}$ seconds, can be detected because it absorbs jets of particles produced by the collision [10]. The association with the notion black hole is
unavoidable and there indeed exists a rather esoteric M-theory inspired model "The RHIC fireball as a dual black hole" by Hortiu Nastase [45] for the strange findings.

The Physics Today article [39] "What Have We Learned From the Relativistic Heavy Ion Collider?" gives a nice account about experimental findings. Extremely high collision energies are in question: Gold nuclei contain energy of about 100 GeV per nucleon: 100 times proton mass. The expectation was that a large volume of thermalized Quark-Gluon Plasma (QGP) is formed in which partons lose rapidly their transverse momentum. The great surprise was the suppression of high transverse momentum collisions suggesting that in this phase strong collective interactions are present. This has inspired the proposal that quark gluon plasma is preceded by liquid like phase which has been christened as Color Glass Condensate (CGC) thought to contain Bose-Einstein condensate of gluons.

3.3.3 The theoretical ideas relating CGC to gravitational interactions

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

1. Classical gravitation and color confinement

Just some time ago it became clear that strong classical gravitation might play a key role in the understanding of color confinement [10]. Whether the situation looks confinement or asymptotic freedom would be in the eyes of beholder: this is one example of dualities filling TGD Universe. If one looks the situation at the hadronic space-time sheet or one has asymptotic freedom, particles move essentially like free massless particles. But - and this is absolutely essential- in the induced metric of hadronic space-time sheet. This metric represents classical gravitational field becoming extremely strong near hadronic boundary. From the point of view of outsider, the motion of quarks slows down to rest when they approach hadronic boundary: confinement. The distance to hadron surface is infinite or at least very large since the induced metric becomes singular at the light-like boundary! Also hadronic time ceases to run near the boundary and finite hadronic time corresponds to infinite time of observer. When you look from outside you find that this light-like 3-surface is just static surface like a black hole horizon which is also a light-like 3-surface. This gives confinement.

2. Dark matter in TGD

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

Matter can be however dark in much stronger sense, should I use the word "black"! The findings suggesting that planetary orbits obey Bohr rules with a gigantic Planck constant [9, 51] would suggest quantum coherence of dark matter even in astrophysical length scales and this raises the fascinating possibility that Planck constant is dynamical so that fine structure constant. Dark matter would correspond to phases with non-standard value of Planck constant. This quantization saves from black hole collapse just as the quantization of hydrogen atom saves from the infrared catastrophe.

The basic criterion for the transition to this phase would be that it occurs when some coupling strength - say fine structure constant multiplied by appropriate charges or gravitational constant multiplied by masses- becomes so large that the perturbation series for scattering amplitudes fails to converge. The phase transition increases Planck constant so that convergence is achieved. The attempts to build a detailed view about what might happen led to a generalization of the imbedding space concept by replacing \( M^4 \) (or rather the causal diamond) and \( CP^2 \) with their singular coverings. During 2010 it turned out that this generalization could be regarded as a conventional manner to describe a situation in which space-time surface becomes analogous to a multi-sheeted Riemann surface. If so, then Planck constant would be replaced by its integer multiple only in effective sense.

The obvious questions are following. Could black hole like objects/magnetic flux tubes/cosmic strings consist of quantum coherent dark matter? Does this dark matter consist dominantly from hadronic space-time sheets which have fused together and contain super-symplectic bosons and their super-partners (with quantum numbers of right handed neutrino) having therefore no electro-weak interactions. Electro-weak charges would be at different space-time sheets.
1. Gravitational interaction cannot force the transition to dark phase in a purely hadronic system at RHIC energies since the product \( GM_1 M_2 \) characterizing the interaction strength of two masses must be larger than unity \((h = c = 1)\) for the phase transition increasing Planck constant to occur. Hence the collision energy should be above Planck mass for the phase transition to occur if gravitational interactions are responsible for the transition.

2. The criterion for the transition to dark phase is however much more general and states that the system does its best to stay perturbative by increasing its Planck constant in discrete steps and applies thus also in the case of color interactions and governs the phase transition to the TGD counterpart of non-perturbative QCD. Criterion would be roughly \( \alpha_s Q_s^2 > 1 \) for two color charges of opposite sign. Hadronic string picture would suggest that the criterion is equivalent to the generalization of the gravitational criterion to its strong gravity analog \( nL_p^2 M^2 > 1 \), where \( L_p \) is the p-adic length scale characterizing color magnetic energy density (hadronic string tension) and \( M \) is the mass of the color magnetic flux tube and \( n \) is a numerical constant. Presumably \( L_p = M_{107} = 2^{107} - 1 \), is the p-adic length scale since Mersenne prime \( M_{107} \) labels the space-time sheet at which partons feed their color gauge fluxes. The temperature during this phase could correspond to Hagedorn temperature (for the history and various interpretations of Hagedorn temperature see the CERN Courier article \( \text{[17]} \) ) for strings and is determined by string tension and would naturally correspond also to the temperature during the critical phase determined by its duration as well as corresponding black-hole temperature. This temperature is expected to be somewhat higher than hadronization temperature found to be about \( \approx 176 \text{ MeV} \). The density of inertial mass would be maximal during this phase as also the density of gravitational mass during the critical phase.

Lepto-hadron physics \( \text{[12]} \), one of the predictions of TGD, is one instance of a similar situation. In this case electromagnetic interaction strength defined in an analogous manner becomes larger than unity in heavy ion collisions just above the Coulomb wall and leads to the appearance of mysterious states having a natural interpretation in terms of lepto-pion condensate. Lepto-pions are pairs of color octet excitations of electron and positron.

3. Description of collisions using analogy with black holes

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

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

The valence quarks forming structures connected by color bonds would in the first step of the collision separate from their hadronic space-time sheets which fuse together to form color glass condensate. Similar process has been observed experimentally in the collisions demonstrating the experimental reality of Pomeron, a color singlet state having no Regge trajectory \( \text{[33]} \) and identifiable as a structure formed by valence quarks connected by color bonds. In the collision it temporarily separates from the hadronic space-time sheet. Later the Pomeron and the new mesonic and baryonic Pomerons created in the collision suffer a topological condensation to the color glass condensate: this process would be analogous to a process in which black hole sucks matter from environment.

Of course, the relationship between mass and radius would be completely different with gravitational constant presumably replacement by the the square of appropriate p-adic length scale presumably of order p ion Compton length: this is very natural if TGD counterparts of black-holes are formed by color magnetic flux tubes. This gravitational constant expressible in terms of hadronic string tension of \( .9 \text{ GeV}^2 \) predicted correctly by super-symplectic picture would characterize the strong gravitational interaction assignable to super-symplectic \( J = 2 \) gravitons. I have long time ago in the context of p-adic
mass calculations formulated quantitatively the notion of elementary particle black hole analogy making the notion of elementary particle horizon and generalization of Hawking-Bekenstein law \[\text{[5]}\].

The size \(L\) of the ”hadronic black hole” would be relatively large using protonic Compton radius as a unit of length. For instance, for \(\hbar = 26 a_0\) the size would be \(26 \times L(107) = 46 \text{ fm}\) and correspond to a size of a heavy nucleus. This large size would fit nicely with the idea about nuclear sized color glass condensate. The density of partons (possibly gluons) would be very high and large fraction of them would have been materialized from the brehmsstrahlung produced by the de-accelerating nuclei. Partons would be gravitationally confined inside this region. The interactions of partons would lead to a generation of a liquid like dense phase and a rapid thermalization would occur. The collisions of partons producing high transverse momentum partons occurring inside this region would yield no detectable high \(p_T\) jets since the matter coming out from this region would be somewhat like a thermal radiation from an evaporating black hole identified as a highly entangled hadronic string in Hagedorn temperature. This space-time sheet would expand and cool down to QQP and crystallize into hadrons.

4. Quantitative comparison with experimental data

Consider now a quantitative comparison of the model with experimental data. The estimated freeze-out temperature of quark gluon plasma is \(T_f \simeq 175.76 \text{ MeV} \text{ [39, 45]},\) not far from the total contribution of quarks to the mass of nucleon, which is 170 MeV \([7]\). Hagedorn temperature identified as black-hole temperature should be higher than this temperature. The experimental estimate for the hadronic Hagedorn temperature from the transversal momentum distribution of baryons is \(\simeq 160 \text{ MeV}\). On the other hand, according to the estimates of hep-ph/0006020 the values of Hagedorn temperatures for mesons and baryons are \(T_H(M) = 195 \text{ MeV}\) and \(T_H(B) = 141 \text{ MeV}\) respectively.

D-dimensional bosonic string model for hadrons gives for the mesonic Hagedorn temperature the expression \([17]\)

\[
T_H = \frac{\sqrt{6}}{2\pi(D-2)\alpha'},
\]

For a string in \(D = 4\)-dimensional space-time and for the value \(\alpha' \sim 1 \text{ GeV}^{-2}\) of Regge slope, this would give \(T_H = 195 \text{ MeV}\), which is slightly larger than the freeze-out temperature as it indeed should be, and in an excellent agreement with the experimental value of \([16]\). It deserves to be noticed that in the model for fireball as a dual 10-D black-hole the rough estimate for the temperature of color glass condensate becomes too low by a factor \(1/\sqrt{2}\). In light of this I would not yet rush to conclude that the fireball is actually a 10-dimensional black hole.

Note that the baryonic Hagedorn temperature is smaller than mesonic one by a factor of about \(\sqrt{2}\). According to \([16]\) this could be qualitatively understood from the fact that the number of degrees of freedom is larger so that the effective value of \(D\) in the mesonic formula is larger. \(D_{eff} = 6\) would give \(T_H = 138 \text{ MeV}\) to be compared with \(T_H(B) = 141 \text{ MeV}\). On the other hand, TGD based model for hadronic masses \([7]\) assumes that quarks feed their color fluxes to \(k = 107\) space-time sheets. For mesons there are two color flux tubes and for baryons three. Using the same logic as in \([16]\), one would have \(D_{eff}(B)/D_{eff}(M) = 3/2\). This predicts \(T_H(B) = 159 \text{ MeV}\) to be compared with 160 MeV deduced from the distribution of transversal momenta in p-p collisions.

3.4 Are ordinary black-holes replaced with super-symplectic black-holes in TGD Universe?

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

Baryonic super-symplectic black-holes of the ordinary \(M_{107}\) hadron physics would have mass 934.2 MeV, very near to proton mass. The mass of their \(M_{99}\) counterparts would be 512 times higher, about 478 GeV if quark masses scale also by this factor. This need not be the case: if one has \(k = 113 \rightarrow 103\) instead of 105 one has 434 GeV mass. "Ionization energy" for Pomeron, the structure formed by valence
quarks connected by color bonds separating from the space-time sheet of super-symplectic black-hole in the production process, corresponds to the total quark mass and is about 170 MeV for ordinary proton and 87 GeV for $M_{89}$ proton. This kind of picture about black-hole formation expected to occur in LHC differs from the stringy picture since a fusion of the hadronic mini black-holes to a larger black-hole is in question.

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

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

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

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

(3.10)

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

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

$$S_p = k \log(2) \times \left( \frac{M}{m(CP_2)} \right)^2,$$

(3.11)

$m(CP_2) = h/R$, $R$ the "radius" of $CP_2$, corresponds to the standard value of $h_0$ for all values of $h$.

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

$$S = \frac{A}{4G} \times h = \pi GM^2 \times h.$$

(3.12)

For the p-adic variant of the law Planck mass is replaced with $CP_2$ mass and $k \log(2) \simeq \log(p)$ appears as an additional factor. Area law is obtained in the case of elementary particles if $k$ is prime and wormhole throats have $M^4$ radius given by p-adic length scale $L_p = \sqrt{k}R$ which is exponentially smaller than $L_p$. For macroscopic super-symplectic black-holes modified area law results if the radius of the large wormhole throat equals to Schwartschild radius. Schwartschild radius is indeed natural: in [13] I have shown that a simple deformation of the Schwartschild exterior metric to a metric representing rotating star transforms Schwartschild horizon to a light-like 3-surface at which the signature of the induced metric is transformed from Minkowskian to Euclidian.

4. The formula for the gravitational Planck constant appearing in the Bohr quantization of planetary orbits and characterizing the gravitational field body mediating gravitational interaction between masses $M$ and $m$ [9] reads as

$$h_{gr} = \frac{GMm}{v_0 h_0}.$$ 

$v_0 = 2^{-11}$ is the preferred value of $v_0$. One could argue that the value of gravitational Planck constant is such that the Compton length $h_{gr}/M$ of the black-hole equals to its Schwartschild radius. This would give
\( h_{gr} = \frac{GM^2}{v_0} h_0, \quad v_0 = 1/2 \) . \hspace{1cm} (3.13)

The requirement that \( h_{gr} \) is a ratio of ruler-and-compass integers expressible as a product of distinct Fermat primes (only four of them are known) and power of 2 would quantize the mass spectrum of black hole \([9]\). Even without this constraint \( M^2 \) is integer valued using p-adic mass squared unit and if p-adic length scale hypothesis holds true this unit is in an excellent approximation power of two.

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

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

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

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

3.5 Very cautious conclusions

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

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

The attempts to understand later strange events reported by RHIC have led to a dramatic increase of understanding of TGD and allow to fuse together separate threads of TGD.
1. The description of RHIC events in terms of the formation of hadronic black hole and its evaporation seems to be also possible and essentially identical with description as a mini bang.

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

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

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

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

3.6 Five years later

The emergence of the first interesting findings from LHC by CMS collaboration [24, 18] provide new insights to the TGD picture about the phase transition from QCD plasma to hadronic phase and inspired also the updating of the model of RHIC events (mainly elimination of some remnants from the time when the ideas about hierarchy of Planck constants had just born).

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

In some proton-proton collisions more than hundred particles are produced suggesting a single object from which they are produced. Since the density of matter approaches to that observed in heavy ion collisions for five years ago at RHIC, a formation of quark gluon plasma and its subsequent decay is what one would expect. The observations are not however quite what QCD plasma picture would allow to expect. Of course, already the RHIC results disagreed with what QCD expectations. What is so striking is the evolution of long range correlations between particles in events containing more than 90 particles as the transverse momentum increases in the range 1-3 GeV (see the excellent description of the correlations by Lubos Motl in his blog [12]).

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

Ideal QCD plasma would predict no correlations between particles and therefore no structures like this. The radiation of particles would be like blackbody radiation with no correlations between photons. The description in terms of string like object proposed also by Lubos on basis of analysis of the graph showing the distributions as an explanation of correlations looks attractive. The decay of a string like structure producing particles at its both ends moving nearly parallel to the string to opposite directions could be in question.
Since the densities of particles approach those at RHIC, I would bet that the explanation (whatever it is!) of the hydrodynamical behavior observed at RHIC for some years ago should apply also now. The introduction of string like objects in this model was natural since in TGD framework even ordinary nuclei are string like objects with nucleons connected by color flux tubes \( [6] \) : this predicts a lot of new nuclear physics for which there is evidence. The basic idea was that in the high density hadronic color flux tubes associated with the colliding nucleon connect to form long highly entangled hadronic strings containing quark gluon plasma. The decay of these structures would explain the strange correlations. It must be however emphasized that in the recent case the initial state consists of two protons rather than heavy nuclei so that the long hadronic string could form from the QCD like quark gluon plasma at criticality when long range fluctuations emerge.

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

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

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

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

The microscopic level the description would be like follows.

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

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

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

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

### 3.6.2 Preferred extremals as perfect fluids

Almost perfect fluids seems to be abundant in Nature. For instance, QCD plasma was originally thought to behave like gas and therefore have a rather high viscosity to entropy density ratio \( x = \frac{\eta}{s} \). Already RHIC found that it however behaves like almost perfect fluid with \( x \) near to the minimum predicted by AdS/CFT. The findings from LHC gave additional confirm the discovery \([22]\). Also Fermi gas is predicted on basis of experimental observations to have at low temperatures a low viscosity roughly 5-6 times the minimal value \([10]\). In the following the argument that the preferred extremals of Kähler action are perfect fluids apart from the symmetry breaking to space-time sheets is developed. The argument requires some basic formulas summarized first.
The detailed definition of the viscous part of the stress energy tensor linear in velocity (oddness in velocity relates directly to second law) can be found in [48].

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

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

(3.14)

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

\[ \sigma_{\text{visc},ij} = \zeta \partial_k v^k g_{ij} + \eta (\partial_i v_j + \partial_j v_i - \frac{2}{3} \partial_k v^k g_{ij}) . \]  

(3.15)

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

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

\[ \sigma_{ij} = \rho v_i v_j - pg_{ij} + \sigma_{\text{visc},ij} . \]  

(3.16)

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

\[ T^{\alpha\beta} = (\rho - p) u^\alpha u^\beta + pg^{\alpha\beta} - \sigma^{\alpha\beta}_{\text{visc}} . \]  

(3.17)

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

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

\[ T^{\alpha\beta} = (\rho - p) g^{tt} \delta^\alpha_\alpha \delta^\beta_\beta + pg^{\alpha\beta} - \sigma^{\alpha\beta}_{\text{visc}} . \]  

(3.18)

In this case the vanishing of the viscous term means that one has perfect fluid in strong sense. The existence of a global flow parameter means that one has

\[ v_i = \Psi \partial_i \Phi . \]  

(3.19)

\( \Psi \) and \( \Phi \) depend on space-time point. The proportionality to a gradient of scalar \( \Phi \) implies that \( \Phi \) can be taken as a global time coordinate. If this condition is not satisfied, the perfect fluid property makes sense only locally.
AdS/CFT correspondence allows to deduce a lower limit for the coefficient of shear viscosity as

$$ x = \frac{\eta}{s} \geq \frac{\hbar}{4\pi} . \quad (3.20) $$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$n_{abs}mv_\parallel v_\perp S .$$

This momentum flow must be equal to the viscous force

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

From this one obtains

$$\eta = n_{abs}mv_\perp d .$$

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

$$s = n$$

so that one has

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

This quantity should have lower bound $x = \hbar/4\pi$ and perhaps even quantized in multiples of $x$. Angular momentum quantization suggests strongly itself as origin of the quantization.
3. Local momentum conservation requires that the comoving vortices are created in pairs with opposite momenta and thus propagating with opposite velocities \( v_\perp \). Only one half of vortices is absorbed so that one has \( n_{\text{abs}} = n/2 \). Vortex has quantized angular momentum associated with its internal rotation. Angular momentum is generated to the flow since the vortices flowing downwards are absorbed at the boundary surface.

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

\[
\frac{\eta}{s} = \frac{n\hbar}{\epsilon}
\]

Quantization condition would give

\[
\epsilon = 4\pi
\]

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

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

3.7 Evidence for TGD view about QCD plasma

The emergence of the first interesting findings from LHC by CMS collaboration [24, 18] provide new insights to the TGD picture about the phase transition from QCD plasma to hadronic phase and inspired also the updating of the model of RHIC events (mainly elimination of some remnants from the time when the ideas about hierarchy of Planck constants had just born).

In some proton-proton collisions more than hundred particles are produced suggesting a single object from which they are produced. Since the density of matter approaches to that observed in heavy ion collisions for five years ago at RHIC, a formation of quark gluon plasma and its subsequent decay is what one would expect. The observations are not however quite what QCD plasma picture would allow to expect. Of course, already the RHIC results disagreed with what QCD expectations. What is so striking is the evolution of long range correlations between particles in events containing more than 90 particles as the transverse momentum of the particles increases in the range 1-3 GeV (see the excellent description of the correlations by Lubos Motl in his blog [42]).

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

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

Since the densities of particles approach those at RHIC, I would bet that the explanation (whatever it is!) of the hydrodynamical behavior observed at RHIC for some years ago should apply also now. The introduction of string like objects in this model was natural since in TGD framework even ordinary nuclei are string like objects with nucleons connected by color flux tubes [6,6] : this predicts a lot of new nuclear physics for which there is evidence. The basic idea was that in the high density hadronic color flux tubes associated with the colliding nucleon connect to form long highly entangled hadronic strings containing quark gluon plasma. The decay of these structures would explain the strange correlations. It must be however emphasized that in the recent case the initial state consists of two protons rather than heavy nuclei so that the long hadronic string could form from the QCD like quark gluon plasma at criticality when long range fluctuations emerge.

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

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

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

The microscopic level the description would be like follows.

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

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

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

References

Books related to TGD


**Articles about TGD**


**Theoretical Physics**


Particle and Nuclear Physics


**Condensed Matter Physics**


**Cosmology and Astro-Physics**