Essay

More About Quark Gluon Plasma & M_{89} Physics

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Abstract

QCD predicts that quark gluon plasma (QGP) is is created in $p-p$, $p-A$, and $A-A$ high energy collisions. Here p denotes proton and A heavy nucleus. In the first approximation the nuclei are expected to go through each other but for high enough collision the kinetic energy of the incoming beams is expected to materialize to quarks and gluons giving rise to QGP. Various signatures of QGP such as high density, strangeness production, and the failure of quark jets to propagate have been observed. Also unexpected phenomena such as very small shear viscosity to entropy ratio η/s meaning that QGP behaves like ideal liquid and double ridge structure detected first in p-Pb collisions implying long range correlations suggesting emission of particles in opposite directions from a linear string like object. Also the predicted suppression of charmonium production seems to be absent for heavy nuclei. I have already earlier proposed explanation in terms of a creation of dark pions (and possibly also heavier mesons) of M_{89} hadron physics with Planck constant $h_{eff} = 512 \times h$. M_{89} pions would be flux tube like structures having mass 512 times that of ordinary pion but having the same Compton length as ordinary pion and being of the same size as heavy nuclei. The unexpected features of QGP, in particular long range correlations, would reflect quantum criticality. Double ridge structure would reflect the decay of dark mesons to ordinary hadrons. In this article this proposal is discussed in more detail.

Keywords: Quark Gluon plasma, M89 physics, QCD, TGD framework.

1 Introduction

I heard an excellent finnish radio program about the experimentation done by ALICE collaboration at LHC. ALICE (see `http://tinyurl.com/ybbhw2vj`) studies quark gluon plasma (QGP, see `http://tinyurl.com/yb9l6ege`) believed to be created in p-p, p-A, and A-A high energy collisions. Here p denotes proton and A heavy nucleus such as Au or Pb chosen so that it has spherical shape - this just to simplify the data analysis.

In the first approximation the nuclei are expected to go through each other but for high enough collision energy QGP is predicted to be created. The kinetic energy of the incoming beams would materialize to quarks and gluons giving rise to QGP. The high density of this phase would be one of its key signatures.

The existence of this high density phase was first shown at RHIC and at LHC its existence has been shown for p-p, p-A, and A-A collisions at ALICE. The plasma appears around $T \sim .17$ GeV (pion mass is about .14 GeV). The plasma region is cylindrical (see `http://tinyurl.com/ybbnx8sa`). In the case of Au nuclei the longitudinal radius is in the range of 7-8 fm. Transversal radii orthogonal to beam direction and orthogonal or parallel to the scattering plane are same and about 6-7 fm. All radii decrease as the transverse momentum of the jet from which it is deduced increases. The energy density of plasma is about GeV/fm^3. The total energy of plasma would be about 288 GeV.

1.1 What QCP should look like?

If QGP is what QCD predicts it to be it should have certain signatures.

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1. QCD predicts that QGP is non-Abelian analog of ordinary electromagnetic plasma: non-Abelianity implies color confinement at large distances and asymptotic freedom at small distances. These are due to the growth of color coupling strength α_s as function of the length scale.
2. Color confinement means that QQP has vanishing total color charges. Asymptotic freedom implies that the interaction becomes weak at short distances. As in ordinary plasma, color charges are screened within a sphere, whose radius is known as Debye radius.
3. Quark jets do not propagate in the plasma it which has explanation in terms of long ranged color interactions not present in hadronic phase. QGP phase is predicted to appear in high enough temperature $T \sim .17$ GeV. This temperature is higher than the rest mass of strange quarks about 100 MeV and this makes possible the production of strange hadrons.

These predictions have been verified. The QGP at criticality is however something between hadronic phase and quark gluon gas and impies new effects.

1. In QCD one expects critical phase associated with the transition from hadronic gas with very short ranged interactions to QGP having gas like behavior. The intermediate phase would be analogous to that encountered in phenomena like freezing and boiling and involve criticality meaning long range correlations and fluctuations. The transition is analogous to the formation of the ordinary electromagnetic plasma consisting of charged particles from a gas of neutral particles by ionization at some critical temperature.
2. I heavy ion collisions one expects that the formation takes place in the volume containing the nucleons of colliding nuclei so that about 400 nucleons are involved. The intermediate phase would have quite large size, and one expects that the quarks originally inside nucleons are de-localized to this volume, which is quite large and should define the size scale of QGP in the transition region. Somewhat surprisingly, also p-A collisions have show unexpected phenomena characterizing A-A collisions.
3. Could criticality and long range fluctuations appear in the scale of the entire collision region? In TGD framework one can even ask whether quantum criticality rather than only thermodynamical criticality could be considered in the scale of the collision region. This would bring in totally new quantum effects.

1.2 Unexpected findings

Several unexpected phenomena have been found.

1. An extremely low shear viscosity (see `http://tinyurl.com/y7kekmzm`) to entropy ratio $\eta/s \sim \hbar x/4\pi$, $x \in (1,3)$ have been observed. This ratio is essentially the ratio of entropy to the particle number density. Shear viscosity describes how effectively the velocity gradient orthogonal to flow velocity dissipates momentum. Water has low η/s, honey has high η/s.

   Hadronic gas consisting in good approximation of mesons π, ρ, K, K^* predicts η/s ratio by a factor 2 or 3 higher than the observed ratio. One expects that at higher temperatures gas behavior emerges and has higher η/s ratio proportional to $\hbar/\alpha_s^2$ as a signature. $\alpha_s \sim .1$ implies that η/s is quite large. Low value of η/s should thus relate to the criticality of the transition somehow.

   $\eta/s = \hbar/4\pi$ is a prediction of many theories such as $\mathcal{N} = 4$ SUSY but also lower values are known to be possible theoretically. Low η/s ratio means that viscosity has a small effect and one has almost ideal liquid. Liquid property means that one can speak about flow of quarks and hydrodynamics [1] (see `http://tinyurl.com/y9nwyawg`) should allow a good description of the situation.

Ideal liquid like behavior suggested by the low value of η/s conforms with the long range correlations expected at criticality. In gas phase the particles would move randomly and one could not speak about flow. What is essential is that one can assign to a system a distributed order parameter - now the flow velocity - in the scale of the plasma region. At quantum criticality this distributed parameter would be analogous to wave function characterizing quantum state and defined in the entire plasma volume.

2. Double ridge structure detected in p-Pb collisions (see `http://tinyurl.com/y8lcqbjq` and also in other collisions came as a total surprise and has no explanation in pure QCD picture. To explain what is involved, one must introduce (η,ϕ) plane, where η denotes the hyperbolic angle of 2-D Minkowski plane M^2 determined by time axis and the momentum direction of the detected particle and tells the velocity of the particle, and ϕ is the azimutal angle in the scattering plane.

   One assumes that the first particle moves in direction specified by the value of ϕ and determines the distribution of particles moving in direction $\phi+\Delta\phi$. One finds that there is high probability finding a particle in the same direction having thus $\Delta\phi = 0$ and also that the particle can have widely different value of η so that one obtains a ridge like structure in (η,ϕ)-plane with a length $\Delta\eta \sim \pm 5$ units. This is the nearside ridge. One observes also completely symmetric ridge with $\Delta\phi \sim \pi$ and particles moving to opposite direction - the awayside ridge. I have already earlier proposed that correlations reflect creation of pairs of particles in a decay of M_{89} pion modellable as a string like like object - color magnetic flux tube with length of order of the Compton length of ordinary pion.

3. In QCD picture charmoniums are expected to be produced with a slow rate since the high temperature higher than the binding energy scale should melt them. It seems that this prediction is not true in heavy ion collisions. A possible QCD based explanation would be regeneration of charmoniums or a large number of charmoniums in the initial state.

I have already earlier proposed explanation in terms of a creation of dark pions (and possibly also heavier mesons) of M_{89} hadron physics with Planck constant $h_{eff} = 512 \times h$. M_{89} pions would be flux tube like structures having mass 512 times that of ordinary pion but having the same Compton length as ordinary pion and being of the same size as heavy nuclei. The unexpected features of QGP, in particular long range correlations, would reflect quantum criticality. Double ridge structure would reflect the decay of dark mesons to ordinary hadrons. In this article this proposal is discussed in more detail.

2 Could criticality of QGP correspond to quantum criticality and dark variant of M_{89} hadron physics?

Consider first the key ideas relevant for the TGD based model.

1. p-Adic length scaled hypothesis is the first building brick of the model. TGD strongly suggests the existence of fractally scaled variants of hadron physics at p-adic length scales which correspond to Mersenne primes $M_n = 2^n - 1$ or Gaussian Mersennes $M_{G,n} = (1+i)^n - 1$. M_{89} hadron physics is especially interesting from the point of view of LHC. Bumps with masses which are obtained by scaling masses of ordinary mesons by factor 512 have been reported and could be see indications for the production of also heavier M_{89} mesons.

2. Second key notion is quantum criticality characterized by $h_{eff}/h_0 = n$ [5]. on basis of quantum criticality, which is basic aspect of TGD based physics at the level of single space-time sheet. Many-sheeted space-time is replaced at QFT limit by a region of Minkowski space since the sheets are lumped together. Therefore quantum criticality is in general lost at this liit.

   Quantum criticality at QFT limit requires that single sheet dominates the dynamics. More generally, single sheet can correspond to n-sheeted covering of M^4 with sheets related by Galois symmetry and characterized by $h_{eff}/h_0 = n$ telling the order of the extension of rationals involved and the order of the Galois groups in case of Galois extension. By Galois symmetry one has single sheet but h is replaced with $h_{eff} = nh_0$.

3. Twistor lift of TGD is the third key element. $\mathcal{N} = 4$ SUSY predicting $\eta/s = 1/4\pi$ is characterized by Yangian symmetry, which more or less dictates the twistorial scattering amplitudes [4, **?**]. Twistor Grassmann approach generalizes in TGD framework as also the twistorial construction of scattering amplitudes, which suggests that it might be possible to understand the low value of η/s.

4. The notion of magnetic body (MB) carrying dark matter is central in the applications of quantum TGD. For instance, in cosmology the Kähler magnetic energy of flux tubes carrying monopole flux would decay to ordinary matter during cosmic expansion and this process would be analogous to the decay of the vacuum expectation value of inflaton field.

   In the case of hadrons MB would correspond to a color magnetic body carrying most of the energy of hadron with quarks contributing only a tiny fraction to the rest energy. Also the parton sea could give only a small fraction to the rest energy of hadron. As a matter of fact, all elementary particles correspond in TGD to closed flux tubes carrying monopole flux and also dark M_{89} meson would be such flux tube like structure.

   Could the entities overlapping in the collisions above critical temperature be color magnetic body associated with the colliding systems possibly formed during the collision? Could the color magnetic bodies of nucleons fuse together to form a larger color magnetic body having size of order pion Compton length consisting of M_{89} mesons? Could the decay of the color magnetic energy of M_{89} mesons materialized from the collision energy of the nuclei to ordinary quarks and leptons produce QGP?

2.1 Could dark M_{89} hadron physics explain the strange findings about QGP candidate?

Could the phase transition correspond to a transition to M_{89} quantum critical phase decaying to ordinary QGP predicted by QCD?

1. The mass of M_{89} pion is estimated to be $m_{\pi_{89}} = 512 \times m_\pi \sim 70$ GeV so that the mass 288 GeV of the plasma region of volume about 288 fm^3 created in Au-Au collisions would correspond to about 4 M_{89} pions. This allows to consider the possibility that a few meson state of M_{89} hadrons is formed at quantum criticality and decays to the ordinary quark gluon plasma.

   The strange properties of the observed state could be induced from the properties of this quantum critical quantum state. The unexpectedly low value of η/s indeed suggests the existence of an order parameter in the scale of colliding nuclei and the wave function for the quantum critical M_{89} few-meson state would correspond to this parameter.

2. M_{89} dark particles must however have so large value of $n = h_{eff}/h$ that their scaled up Compton length $\lambda_{89,n} = n \times \lambda_{89} = n \times \lambda 107/512$ of M_{89} pion is of the order of the transversal size of the colliding particles. One can argue that for p-p collisions the scaled up Compton length could of the order of the Compton length of the ordinary pion about 8 fm: this would give $n = 2^{(107-89)/2} = 512$. The radius of Gold nucleus about 7 fm. Heaviest nuclei have radius about 7.5 fm so that this seems to make sense.

   The simplest assumption is that $\lambda_{89,512}$ characterizes also p-A collisions and perhaps even p-p collisions. This could explain the observation of effects expected to be present only for A-A collisions also in p-p and p-A collisions. One must however remember that also other values of n can be considered and the long range quantum fluctuations realized at quantum criticality could corresponds to a spectrum for n.

One could also consider A-A collisions and argue that heavy nuclei are characterized by the nuclear p-adic length scale $L(113) = 2^{(127-113)/2}L(127) = 128L(127)$. If one identifies $L(127)$ as electron Compton length $L_e \sim 2.4 \times 10^{-12}$ m this gives, $L(113) = 19$ fm. If Compton length corresponds to diameter geometrically then this would give scale 9.5 fm marginally consistent with the above estimate.

One could visualize dark M_{89} pion as 512 ordinary pions on top of each other (in CP_2 degrees of freedom) and forming 512-sheeted structure as ca overing of M^4 defined by the space-time surface.

3. The observed ridges would reflect the decays of M_{89} pion identified as a string like object (color magnetic flux tube) with length of order ordinary pion Compton length but with mass of about 70 GeV to ordinary quarks and gluons. There are also indications for the bumps assignable to other M_{89} mesons [3].

4. There is a general order of magnitude estimate for η/s (see `http://tinyurl.com/y9nwyawg`) as

$$\eta/s = \tau_R T = \hbar\tau_R/\tau_q \ ,$$

where τ_R is particle relaxation time and $\tau_q = \hbar/T$ is thermodynamial quantum time scale: it should be difficult to transfer energy with rate higher than $1/\tau_q$.

The estimate for η/s is proportional to $\hbar$. If τ_R is assignable to dark M_{89} phase, it should be proportional to $\hbar_{eff}$ and $\hbar_{eff} = 512\hbar$ would make η/s very large. Therefore the quantum critical state cannot correspond to the observed plasma state. Rather, the observed state (as ordinary matter) would correspond to ordinary matter produced in the phase transition reducing the value of h_{eff} and giving rise to ordinary quarks and gluons transforming to hadrons.

The interpretation of τ_R could be as a time scale for the decay of the dark quantum critical M_{89} few meson state to ordinary quarks and gluons.

5. The production of charmoniums in p-A and A-A collisions is in conflict with the QCD expectations. A possible explanation is suggested by TGD based explanation of family replication phenomenon in terms of generation-genus correspondence [2, 3]. Fermion generations would correspond to the topologies of orientable partonic 2-surfaces with genera $g = 0, 1, 2$ distinguished from the higher genera because they allow always global Z_2 as conformal symmetry. Different fermion genera form effectively a triplet representation of a dynamical gauge group $U(3)_g$.

Ordinary gauge bosons as fermion-antifermion pairs would correspond to a singlet of $U(3)_g$. Besides this there would be also an octet consisting of two $SU(3)_g$ neutral gauge bosons and 3+3 $SU(3)_g$ charged gauge bosons assumed to be heavy. The $U(3)_g$ charge matrices of $SU(3)_g$ boson generations are orthogonal to that assignable to the ordinary gauge bosons (unit matrix implying the universality of standard model interactions). This predicts breaking of universality for which there are some indications as also for the predicted 2 $SU(3)_g$ neutral generations of electroweak gauge boson [3].

M_{89} gluons need not be exact fractally scaled up copies of ordinary gluons but could correspond to second generation gluons and therefore break the universality of the ordinary color interactions - there are indications also for this [3]. This could lead to a higher rate for the production of higher quark generations in the decay of M_{89} pions if it involves M_{89} gluons as intermediate states and could perhaps explain higher rate for charmonium production. The quarks forming M_{89} mesons should be ordinary quarks and only the color magnetic energy (the counterpart of gluonic ground state energy in QCD) would distinguish them from the ordinary mesons.

The proposed option is perhaps the simplest one found hitherto. On can consider also different options.

1. Could the quantum coherence in the scale of colliding nuclei correspond to the formation of dark M_{107} hadronic phase with $n = 2^{(113-107)/2} = 8$ corresponding to the ratio of nuclear and hadronic scales? Amusingly, this would scale up nuclear volume by a factor 512. Could one imagine in many-sheeted space-time that also $M_{107,8}$ dark level is present besides $M_{89,512}$?

2. I have earlier [3] considered the possibility that peripheral collisions as quantum critical events could give rise to the generation of M_{89} mesons with mass above 70 GeV. However, in peripheral collisions ordinary ordinary short range strong interactions are absent, and one can argue that the energy transfers involved are so small that the formation of plasma phase with total energy of about 288 GeV from the kinetic energy of the colliding particles is highly implausible.

   The formation of dark quantum critical phase in the length scale defined by the volume of the colliding nuclei would be required and this looks infeasible unless new physics is involved. The miracle would require that the color magnetic bodies of the colliding nuclei overlap considerably also in the peripheral collisions. This would predict the detection of QGP also in peripheral collisions. This prediction very probably kills this idea using the existing data.

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