Does color deconfinement really occur?

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Abstract

The origin of hadron masses is poorly understood in QCD for the simple reason that perturbative QCD does not excist at low energies. The belief is that the couplings of pions to nucleons generate the mass and sigma model provides a Higgs model type description for this. The phase transition from color confinement to quark-gluon plasma is expected to involve the restoration of chiral symmetry for quarks. In the ideal situation the outcome should be a black body spectrum with no correlations between radiated particles. In the sigma model description nucleons and pions becomes massless in good approximation. Quark gluon plasma suggests that they disappear completely from the spectrum.

The situation is however not this. Some kind of transition occurs and produces a phase, which has much lower viscosity than expected for quark-gluon plasma. Transition occurs also in much smoother manner than expected. And there are strong correlations between opposite charged particles - charge separation occurs. The simplest characterization for these events would be in terms of decaying strings emitting particles of opposite charge from their ends. Conventional models do not predict anything like this.

TGD approach strongly suggests the existence scaled up variants of ordinary hadron physics: actually two of them assignable to Mersenne prime M_{89} and Gaussian Mersenne $M_{G,79}$ respectively should make them visible at LHC and there are indications about the predicted anomalies. This picture allows to consider the possibility that instead of de-confinement a quantum phase transition from the ordinary M_{107} hadron physics to a dark variant of M_{89} hadron physics would occur.

1 Introduction

Bee had a nice blog posting related to the origin of hadron masses and the phase transition from color confinement to quark-gluon plasma involving also restoration of chiral symmetry in the sigma model description.

The origin of hadron masses is poorly understood in QCD for the simple reason that perturbative QCD does not exist at low energies. The belief is that the couplings of pions to nucleons generate the mass and sigma model provides a Higgs model type description for this. The phase transition from color confinement to quark-gluon plasma is expected to involve the restoration of chiral symmetry for quarks. In the ideal situation the outcome should be a black body spectrum with no correlations between radiated particles. In the sigma model description nucleons and pions becomes massless in good approximation. Quark gluon plasma suggests that they disappear completely from the spectrum.

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By quantum criticality M_{89} hadron physics would be characerized by the value of effective Planck constant $h_{eff} = n \times h$. $n \simeq 2^9 - 2^{10}$ guarantees that the sizes the scaled up sizes of M_{89} hadrons are of the size scale of nucleons or even nuclei. Quantum coherence in this scale explains the unexpected properties of what was expected to be quark-gluon plasma and explains charge asymmetries in terms of decay of string like color magnetic flux tubes associated with M_{89} pions.

1.1 Some background

The masses of current quarks are very small - something like 5-20 MeV for u and d. These masses explain only a minor fraction of the mass of proton. The old fashioned quark model assumed that quark masses are much bigger: the mass scale was roughly one third of nucleon mass. These quarks were called constituent quarks and - if they are real - one can wonder how they relate to current quarks.

Sigma model provide a phenomenological decription for the massivation of hadrons in confined phase. The model is highly analogous to Higgs model. The fields are meson fields and baryon fields. Now neutral pion and sigma meson develop vacuum expectation values and this implies breaking of chiral symmetry so that nucleon become massive. The existence of sigma meson is still questionable.

In a transition to quark-gluon plasma one expects that mesons and protons disappear totally. Sigma model however suggests that pion and proton do not disappear but become massless. Hence the two descriptions might be inconsistent.

The authors of the article [C1] that inspired these considerations assume that pion continues to exist as a massless particle in the transition to quark gluon plasma. The presence of massless pions would yield a small effect at the low energies at which massless pions have stronger interaction with magnetic field as massive ones. The existence of magnetic wave coherent in rather large length scale is an additional assumption of the model: it corresponds to the assumption about large h_{eff} in TGD framework, where color magnetic fields associated with M_{89} meson flux tubes replace the magnetic wave.

In TGD framework sigma model description is at best a phenomenological description as also Higgs mechanism. p-Adic thermodynamics replaces Higgs mechanism and the massivation of hadrons involves color magnetic flux tubes connecting valence quarks to color singles. Flux tubes have quark and antiquark at their ends and are mesonlike in this sense. Color magnetic energy contributes most of the mass of hadron. Constituent quark would correspond to valence quark identified as current quark plus the associated flux tube and its mass would be in good approximation the mass of color magnetic flux tube.

There is also an analogy with sigma model provided by twistorialization in TGD sense. One can assign to hadron (actually any particle) a light-like 8-momentum vector in tangent space $M^8 = M^4 \times E^4$ of $M^4 \times CP_2$ defining 8-momentum space. Massless implies that ordinary mass squared corresponds to constant E^4 mass which translates to a localization to a 3-sphere in E^4. This localization is analogous to symmetry breaking generating a constant value of π^0 field proportional to its mass in sigma model.

1.2 An attempt to understand charge asymmetries in terms of charged magnetic wave and charge separation

One of the models trying to explain the charge asymmetries is in terms of what is called charged magnetic wave effect and charge separation effect related to it. The experiment [C1] (`http://arxiv.org/pdf/1504.02175.pdf`) discussed by Bee attempts to test this model.

1. So called chiral magnetic wave effect and charge separation effects are proposed as an explanation for the the linear dependence of the asymmetry of so called elliptic flow on charge asymmetry. Conventional models explain neither the charge separation nor this dependence. Chiral magnetic wave would be a coherent magnetic field generated by the colliding nuclei in a relatively long scale, even the length scale of nuclei.

2. Charged pions interact with this magnetic field. The interaction energy is roughly $h \times eB/E$, where E is the energy of pion. In the phase with broken chiral symmetry the pion mass is non-vanishing and at low energy one has $E = m$ in good approximation. In chirally symmetric phase pion is massless and magnetic interaction energy becomes large a low energies. This could serve as a signature distginguishing between chirally symmetric and asymmetric phases.

3. The experimenters try to detect this difference and report slight evidence for it. This is change of the charge asymmetry of so called elliptic flow for positively and negatively charged pions interpreted in terms of charge separation fluctuation caused by the presence of strong magnetic field assumed to lead to separation of chiral charges (left/righ handedness). The average velocities of the pions are different and average velocity depends azimuthal angle in the collision plane: second harmonic is in question (say $sin(2\phi)$).

2 Phase transition to dark M_{89} hadron physics instead of deconfinement?

In TGD framework the explanation of the un-expected behavior of should-be quark-gluon plasma is in terms of M_{89} hadron physics.

1. A phase transition indeed occurs but means a phase transition transforming the quarks of the ordinary M_{107} hadron physics to those of M_{89} hadron physics. They are not free quarks but confined to form M_{89} mesons. M_{89} pion would have mass about 135 GeV [K1]. A naive scaling gives half of this mass but it seems unfeasible that pion like state with this mass could have escaped the attention - unless of course the unexpected behavior of quark gluon plasma demonstrates its existence! Should be easy for a professional to check. Thus a phase transition would yield a scaled up hadron physics with mass scale by a factor 512 higher than for the ordinary hadron physics.

2. Stringy description applies to the decay of flux tubes assignable to the M_{89} mesons to ordinary hadrons. This explains charge separation effect and the deviation from the thermal spectrum. The color magnetic flux flux tube corresponds to chiral magnetic wave in the model tested in the experiment. Effects caused by the presence of strong color magnetic fields in nuclear length scale could be present also now but a more feasible interpretation for the observed anomalous effects is in terms of the decays of M_{89} pions. Note that in TGD framework color gauge field associated with single space-time sheet is proportional to induced Kähler form, which contribute also the classical electromagnetic field as induced gauge field. At QFT limit effective gauge fields are independent in good approximation.

3. In the experiments discussed in the article the cm energy for nucleon-nucleon system associated with the colliding nuclei varied between 27-200 GeV so that the creation of even on mass shell M_{89} pion in single collision of this kind is possible at highest energies. If several nucleons participate simultaneosly even many-pion states are possible at the upper end of the interval.

4. These hadrons must have large $h_{eff} = n \times h$ since collision time is roughly 5 femtoseconds, by a factor about 500 (not far from 512!) longer than the time scale associated with their masses if M_{89} pion has the proposed mass of 135 MeV for ordinary Planck constant and scaling factor 2×512 instead of 512 in principle allowed by p-adic length scale hypothesis. There are some indications for a meson with this mass. The hierarchy of Planck constants allows at quantum criticality to zoom up the size of much more massive M_{89} hadrons to nuclear size! The phase transition to dark M_{89} hadron physics could take place in the scale of nucleus producing several M_{89} pions decaying to ordinary hadrons.

5. The large value of h_{eff} would mean quantum coherence in the scale of nucleus explaining why the value of the viscosity was much smaller than expected for quark gluon plasma. The expected phase transition was also much smoother than expected. Since nuclei are many-nucleon systems and the Compton wavelength of M_{89} pion would be of order nucleus size, one expects that the phase transition can take place in a wide collision energy range. At lower energies several nucleon pairs could provide energy to generate M_{89} pion. At higher energies even single nucleon pair could provide the energy. The number of M_{89} pions should therefore increase with nucleon-nucleon collision energy, and induce the increase of charge asymmetry and strength of the charge asymmetry of the elliptic flow.

6. Hydrodynamical behavior is essential in order to have low viscosity classically. Even more, the hydrodynamics had better to be that of an ideal liquid. In TGD framework the field equations have hydrodynamic character as conservation laws for currents associated with various isometries of imbedding space. The isometry currents define flow lines. Without further conditions the flow lines do not however integrate to a coherent flow: one has something analogous to gas phase rather than liquid so that the mixing induced by the flow cannot be described by a smooth map.

   To achieve this given isometry flow must make sense globally - that is to define coordinate lines of a globally defined coordinate ("time" along flow lines). In this case one can assign to the flow a continuous phase factor as an order parameter varying along the flow lines. Super-conductivity is an example of this. The so called Frobenius conditions guarantee this at least the preferred extremals could have this complete integrability property making TGD an integrable theory see the appendix of the article [L1] or section of [K2] (`http://tgdtheory.fi/public_html/articles/dynatopo.pdf`). In the recent case, the dark flux tubes with size scale of nucleus would carry ideal hydrodynamical flow with very low viscosity.

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