The Structure of Proton, Spin Crisis and Partonic Plasma

Sylwester Kornowski

Abstract: Here, within the Scale-Symmetric Physics/Theory (S-ST), is presented some recapitulation concerning structure of proton. It shows that distribution of gluons described within the Quantum Chromodynamics is incorrect - there appears the spin crisis. The S-ST shows that there appear three super-dense fields composed of the carriers of gluons i.e. of the luminal Einstein-spacetime components. The three super-dense gluon fields follow from the short-distance quantum entanglement and/or confinement of the Einstein-spacetime components and they are as follows: the torus/strong-charge (its mass density is about 37 powers of ten kilograms per cubic meter; external radius is about 0.7 fm), central condensate (its mass density is about 3 times greater than 23 powers of ten kilograms per cubic meter; radius is about 0.009 fm) and relativistic pion on the S orbit (radius of the orbit is about 1.2 fm). Range of the strong interactions is about 2.9 fm. Within such model we calculated the rigorous mass, spin and two radii (the electron radius and muon radius) of proton. The torus/strong-charge is spinning and its spin is half-integral. We can compare the densities of the super-dense gluon fields with the mean mass density of proton on assumption that its radius is the range of the strong interactions: about 1.6 times greater than 16 powers of ten kilograms per cubic meter. Barbara Jacak, a professor of physics at the University of California, Berkeley, claims that the much faster than expected formation of baryonic-plasma droplets and the spin crisis follow from existence of a super-dense gluon field instead discrete gluons - it is consistent with S-ST. Here as well are calculated the fundamental quantities characteristic for partonic plasma - they are consistent with the PHENIX data. Among other things, a puzzle of anomalous enhancement of (anti)protons relative to pions is solved.

1. Introduction

Here [1], we can find a description of scientific program of the Relativistic Heavy Ion Collider (RHIC). Barbara Jacak, a professor of physics at the University of California, Berkeley, claims that the much faster than expected formation of baryonic-plasma droplets and the spin crisis concerning proton (within the QCD we still cannot show the origin of the half-integral spin of proton) follow from existence of a super-dense gluon field instead discrete gluons - it is consistent with S-ST presented here [2].

The Scale-Symmetric Theory (S-ST), [2], starts from the succeeding phase transitions of the Higgs field. The third phase transition leads to the internal structure of the core of baryons (the torus/strong-charge and the central condensate). Due to the symmetrical decays of bosons, on equator of the torus and outside it there appear the orbits/shells. In the d = 1 state of proton (it is the S state) there is relativistic pion. Proton is the black hole in respect of the strong interactions. We can see that in a proton, at low energy, we can distinguish three super-dense gluon fields i.e. the condensate, torus and the relativistic pion on the d = 1 orbit. The torus is spinning and its spin is half-integral.

The gluons and photons are the rotational energies of the Einstein-spacetime components i.e. the gluons and photons are the rotational energies of the neutrino-antineutrino pairs – they are the Feynman partons. At high energy of colliding nucleons, there appear the parton showers. Outside the strong fields the gluons behave as photons – it is due to the fact that the strong fields have internal helicity (the color) whereas the electromagnetic fields are colorless.

When distance between the Einstein-spacetime components is a few times greater than the Planck length, there appears the shortest-distance entanglement which leads to the super-dense gluon fields (more precisely: leads to the super-dense fields composed of the carriers of gluons) – such distances between the carriers of gluons are on surface of the torus.

When distance between the Einstein-spacetime components is smaller than about $3.5 \cdot 10^{-32}$ m, there appears the confinement which follows from the Mexican-hat mechanism concerning the Einstein-spacetime components. The confinement leads to super-dense gluon field also and they as well are composed of the carriers of gluons – in such a way behaves the carriers of gluons in the central condensate.

The mass density of the surface of the torus is about 10^{37} kg/m^3 (external radius of the torus is about 0.7 fm) whereas mass density of the central condensate is about $3 \cdot 10^{23}$ kg/m^3 (radius is about 0.0087 fm).

Radius of the d = 1 orbit (the S state) of the relativistic pion is about 1.2 fm.

Range of the strong interactions is about 2.9 fm.

Within such model we calculated the rigorous mass and spin of proton [2], and two radii (the electron radius and muon radius) of proton [3].

We can compare the densities of the super-dense gluon fields with the mean mass density of proton on assumption that its radius is the range of the strong interactions (about 2.9 fm): the mean proton mass density is about $1.6 \cdot 10^{16}$ kg/m^3. This density is much lower than the super-dense gluon fields.

At high energy collisions of nucleons the external orbits/shells are destroyed whereas the cores of nucleons are packed to maximum – it is the baryonic plasma. Its minimum mean mass density is about $1.8 \cdot 10^{18}$ kg/m^3. But inside the cores of nucleons the baryonic plasma consists of can be produced particles so resultant mean density can be higher.

2. Partonic plasma (PP)

The calculated within the S-ST mass of the charged core of baryons is $M_{Core} = 0.72744$ GeV [2]. The maximum radius of the core (it is the equatorial radius of the torus composed of the entangled partons/Einstein-spacetime-components) is $A = 0.6974425$ fm [2]. Radius of the d = 1 orbit (the S state) on which is relativistic pion is $R = A + B = 1.1993$ fm [2]. The core is the torus and central condensate but we can assume that in a partonic plasma (PP) the core is a cylinder with the circle in the base with radius equal to A and height equal to $2A/3$ [2]. It leads to conclusion that volume of the core is in an approximation equal to

$$V_{Core} = 2 \pi A^3 / 3 = 0.7184 \text{ fm}^3. \quad (1)$$

The rest mass of the torus is $X = 0.3182955$ GeV [2].

A nominal energy density for a nucleus at rest, ρ_o, is close to (S-ST) [2]

$$\rho_o = M_{nucleon} / [(A+ 4B) / \text{sqrt}(2)]^3 = 0.134 \text{ GeV / fm}^3, \quad (2)$$

where $M_{nucleon} \approx 0.939$ GeV. Relativistic energy density of nucleons in colliding nuclei is much higher. Such energy density leads to very short lifetime so a scattering cannot occur unless secondary particles are created.

Thermalization is the process of physical bodies reaching thermal equilibrium through mutual interaction. Due to the secondary-particles creation, the nucleons lose energy and become thermal particles. There appears partonic plasma produced as the result of the pairs and partonic-jets production with transverse momentums.

Energy can be an energetic loop and we can assume, for example, that a loop with radius A + B has mass equal to the mass of nucleon at rest i.e. we can assume that length of strong wave associated with $M_{nucleon}$ is $\lambda_{nucleon} = 2\pi (A + B)$. What is the length of strong wave characteristic for partonic plasma? In PP, the d = 1 states are destroyed whereas the cores of nucleons are packed to maximum so we can assume that the characteristic length of wave is $\lambda_{initial} = A$. Energy is inversely proportional to length of wave so the characteristic initial energy per one core of nucleon in partonic plasma is

$$E_{initial} = M_{nucleon}\, 2\pi (A + B) / A = 10.15 \text{ GeV}. \quad (3)$$

Calculate the peak energy density, ε, in created secondary particles

$$\varepsilon = E_{initial} / V_{Core} = 14.12 \text{ GeV / fm}^3. \quad (4)$$

The radius of the initial energetic loop can be reduced maximum to 2A/3 so $\varepsilon_{maximum}$ = 21.18 GeV / fm^3.

This is much higher energy density than the ~1 GeV / fm^3 required, according to lattice QCD predictions, to drive a QCD transition to the quark-gluon plasma (QGP; here we refer it to as the partonic plasma (PP)) [4].

Calculate radius of a sphere with volume equal to the volume of the core of baryons

$$R_C = [3 V_{Core} / (4\pi)]^{1/3} = 2\pi A^3 / 3 = 0.5556 \text{ fm}. \quad (5)$$

Due to the collision, the initial radius R = A + B is reduced to R_C i.e. the change in radius, ΔR, is

$$\Delta R = R - R_C = 0.6437 \text{ fm}. \quad (6)$$

It leads to conclusion that the thermalization time, τ_o, in order to reproduce the magnitude of elliptic flow of a partonic-plasma droplet is

$$\tau_o = \Delta R / c = 0.6437 \text{ fm / c}. \quad (7)$$

The initial energy loss per unit length should be

$$E_{Loss} = E_{initial} / \Delta R = 15.76 \text{ GeV / fm}. \quad (8)$$

This initial-energy-loss value is much larger than the time-averaged energy loss extracted from the QCD calculation, 0.85 ± 0.24 GeV/fm [4].

Due to the collisions of ions, there are created the core-anticore pairs. In each creation of new (anti)core is produced gluon with energy equal to the nuclear binding energy $E_{binding}$ = 14.98 MeV per gluon [2] so there must be following initial gluon-number density

$$dn_g / dy = E_{Loss} / E_{binding} = 1052 \text{ gluons / fm}. \quad (9)$$

Neutral pion consists of two large loops produced inside the torus of the core of baryons (mass is m_{LL} = 0.0675444 GeV [2]). The latent heat is associated with the large-loop production so we obtain

$$E_{Latent\text{-}heat} = m_{LL}\, \varepsilon / M_{nucleon} = 1.02 \text{ GeV / fm}^3. \quad (10)$$

The anomalous enhancement of (anti)protons relative to pions at intermediate transverse momentum, p_T = 2 – 5 GeV, follows from the internal structure of the core of baryons. Production of protons increases for energies from the mass of the torus (318.3 MeV) to the mass of the core (727.44 MeV). Applying formula which transforms circumference of a circle into its radius, we obtain following relation

$$E_{end} = 2\, \pi\, E_{start}. \quad (11)$$

If E_{start} is the interval (318.3 MeV, 727.44 MeV) then the E_{end} is (2 GeV, 4.6 GeV) – it solves the anomalous enhancement of (anti)protons relative to pions.

All obtained here theoretical results are consistent with the RHIC data [4]. We can see that the produced at RHIC a state of matter characterized by very high energy densities and observed early thermalization leads to the atom-like structure of nucleons presented within the Scale-Symmetric Physics/Theory.

References

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