The Fragmentation in the Nucleon-Nucleon Collisions within the Scale-Symmetric Physics

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Abstract: Here, within the atom-like structure of baryons described in the Scale-Symmetric Theory, is presented the fragmentation of hadrons in the pp and Pb-Pb collisions. Applying the Stefan-Boltzmann law, the calculated production of pion/kaon/proton in pp and Pb-Pb collisions is in agreement with the ALICE data.

1. Introduction

The succeeding phase transitions of the superluminal non-gravitating Higgs field and the symmetrical decays of bosons, which lead to the atom-like structure of baryons, are the foundations of the Scale-Symmetric Theory (SST) [1].

Within SST, we described internal structure of baryonic plasma [1D, [1A], we calculated the pseudorapidity density [2] and showed that the presented structure of the baryonic plasma leads to the PHENIX data [3]. The PHENIX data, [4], suggest that in baryons instead discrete gluons are super-dense gluon fields. It is consistent with SST [3].

Here, within the atom-like structure of baryons described in the SST, is presented the fragmentation of hadrons in the pp and AA collisions. Applying the Stefan-Boltzmann law, the calculated production of pion/kaon/proton in pp and AA collisions is in an excellent agreement with the ALICE data [5]. We calculated the ratios of kaon and proton p_T spectra to the pion p_T spectra in pp and AA collisions. For the most central $(0 - 5\%)$ collisions, the fragmentation of the super-dense gluon fields in baryons is perfect.

According to SST, [1A], in each nucleon are three super-dense fields composed of the entangled and/or confined Einstein-spacetime components i.e. of the carriers of gluons i.e. of the neutrino-antineutrino pairs. There is the torus/charge responsible for the nuclear strong interactions – inside it are produced the large gluon loops carrying energy equal to $M_G \approx 67.54441$ MeV (neutral pion consists of two such gluon loops with antiparallel unitary spins). Due to fragmentation, there as well can appear neutrinos with energy about $E_{Neutrino} \approx 33.744$ MeV. Spin of the torus is half-integral. The second super-dense field is the central condensate – its rest mass is $Y = 424.1245$ MeV. Due to the four-particle symmetry, produced additional condensates can decay to four condensates each with energy $Y_{1/4} = Y / 4 = 106.0311$ MeV. Outside the core of nucleons (i.e. outside the torus plus central condensate) there is a relativistic pion in the S state. Mass of the core of nucleons is $H^+ = 727.4401$ MeV.

In the calculations appears as well the mass of the condensate in bare electron $M_{C,electron}$ = 0.2552 MeV [1A], the mass of neutral pions $M_{pion(o)}$ = 134.9766 ± 0.0006 MeV (we use the PDG, [6], data but all needed masses are calculated within SST), mass distance between charged and neutral pions ΔM_{pion} = 4.5936 ± 0.0005 MeV and mass of muons M_{muon} = 105.66 MeV. Notice that $M_{muon} \approx Y_{1/4}$.

2. The fragmentation of hadrons in *pp* and Pb-Pb (*AA*) collisions and the ratios of proton and kaon p_T spectra to the pion p_T spectra

The Stefan-Boltzmann law is a function of total emitted energy of a black body j^* proportional to its thermodynamic temperature T

$$j^* = \sigma T^4. \tag{1}$$

The fragmentation leads to the super-dense fragments composed of the carriers of gluons which behave as a black body.

Assume that a ratio of spectra, R, is directly proportional to the temperature T whereas that total emitted energy is inversely proportional to mass/energy of the super-dense fragments, M, from which are produced the resultant particles i.e. pions, kaons and protons. Then, we can rewrite formula (1) as follows

$$R = (M_1 / M_2)^{1/4}. \tag{2}$$

Emphasize that due to the very strong shortest-distance entanglement of the carriers of gluons the torus in the core of baryons consists of, its fragmentation is impossible [1A]. The central condensate, Y, is produced by the torus so destruction of the core of baryons is impossible even at very high energies of collisions. But the central condensate can produce additional condensates which can decay to 4 parts (it is due to the 4-particle symmetry [1A], [1D]).

Calculate transverse momentum, p_T, for which the fragmentation is complete. Fragmentation is complete when the S states outside the cores of baryons are destroyed. Mean momentum of the S state is $p_{S\text{-}state,mean}$ = 212.2 MeV/c [1A]. The strong momentum of S state, $p_{S\text{-}Strong}$, is

$$p_{S\text{-}Strong} = \alpha_{Strong(nucleon)}\, p_{S\text{-}state,mean} = 3.06 \text{ GeV/c}, \tag{3}$$

where $\alpha_{Strong(nucleon)} \approx 14.4$ is the coupling constant of the nuclear strong interactions for nucleons at low energy [1A]. The momentum $p_{S\text{-}Strong}$ is the transverse momentum (it is perpendicular to the direction of collision) and it is for a complete fragmentation. For transverse momentum equal to 3.06 GeV/c we should observe an extremum or saddle point in the curve ratio = ratio(transverse-momentum).

In *pp* collisions, for a complete fragmentation, the charged pions decay to neutral pions and the fragments with mass ΔM_{pion}.

Calculate the ratio $R = (p + p_{anti}) / (\pi^+ + \pi^-)$ for *pp* collisions for complete fragmentation (protons are produced from Y whereas charged pions from ΔM_{pion}). Applying formula (2) we obtain

$$R_{3.06\ GeV/c}(pp) = (p + p_{anti}) / (\pi^+ + \pi^-) = (\Delta M_{pion} / Y)^{1/4} = 0.282. \quad (4)$$

For $p_T >> 3.06$ GeV/c, the number density of the electron condensates dominates so charged pions are produced from masses of such condensates (we obtain an asymptote)

$$R_{p(T)>>3.06\ GeV/c}(pp) = (p + p_{anti}) / (\pi^+ + \pi^-) = (M_{C,electron} / Y)^{1/4} = 0.137. \quad (5)$$

Calculate the ratio $R = (K^+ + K^-) / (\pi^+ + \pi^-)$ for pp collisions for complete fragmentation (kaons are produced from pions whereas charged pions from ΔM_{pion}). Applying formula (2) we obtain

$$R_{3.06\ GeV/c}(pp) = (K^+ + K^-) / (\pi^+ + \pi^-) = (\Delta M_{pion} / M_{pion(o)})^{1/4} = 0.430. \quad (6)$$

For $p_T >> 3.06$ GeV/c, the number density of the neutrinos from decays of pions dominates so charged pions are produced from such neutrinos (we obtain an asymptote)

$$R_{p(T)>>3.06\ GeV/c}(pp) = (K^+ + K^-) / (\pi^+ + \pi^-) = (E_{Neutrino} / M_{pion(o)})^{1/4} = 0.707. \quad (7)$$

The neutron-proton pairing (the np pairing) in a nucleus causes that in the Pb-Pb collisions (generally, in the AA collisions) there appears new fragmentation of pions which is absent in pp collisions (it is due to the lack of neutrons). It is because the exchanged pions between nucleons in a nucleus have transverse momentums already before collisions. The spins of the tori of colliding nucleons are parallel to velocities of the nucleons (it is to conserve the spin of nucleons) whereas pions are exchanged along directions perpendicular to the direction of motion [1A]. On the other hand, in the collisions are produced pions with longitudinal momentums so the 90^o change in direction of the momentums leads to fragmentation of the pions into 2 gluons. Fragmentation of pions to gluons is richer for better centrality.

Calculate the ratio $R = (p + p_{anti}) / (\pi^+ + \pi^-)$ for AA collisions for complete fragmentation (protons are produced from Y whereas charged pions from neutrinos $E_{Neutrino}$). Applying formula (2) we obtain (we can compare this result with the ALICE data for most central (0 – 5%) Pb-Pb collisions)

$$R_{3.06\ GeV/c}(AA) = (p + p_{anti}) / (\pi^+ + \pi^-) = (E_{Neutrino} / Y)^{1/4} = 0.531. \quad (8)$$

Calculate the ratio $R = (K^+ + K^-) / (\pi^+ + \pi^-)$ for AA collisions for complete fragmentation (kaons are produced from muons M_{muon} whereas charged pions from neutrinos $E_{Neutrino}$). Applying formula (2) we obtain

$$R_{3.06\ GeV/c}(AA) = (K^+ + K^-) / (\pi^+ + \pi^-) = (E_{Neutrino} / M_{muon})^{1/4} = 0.752. \quad (9)$$

3. Summary

Here, within the atom-like structure of baryons described in the Scale-Symmetric Theory, is presented the fragmentation of hadrons in the pp and AA collisions. Applying the Stefan-Boltzmann law the calculated production of pion/kaon/proton in pp and AA collisions is in agreement with the ALICE data.

Experiments at Brookhaven's RHIC observed an enhancement in transverse-momentum-dependent baryon/meson ratios for central AA collisions in comparison with pp collisions. Here we showed that the difference follows from the different dominating channels of fragmentation of hadrons in AA and pp collisions. In pp collisions dominate the decays of charged pions into neutral pions and the remnant with energy/mass equal to the mass distance between pions. There as well is destroyed the S state of nucleons so their rest mass is reduced to 727.44 MeV. On the other hand, in AA collisions dominate the decays of pions into two gluons and decays of the additional central condensates into 4 fragments.

The curve ratio = ratio(transverse-momentum) follows from the Stefan-Boltzmann law. It is because the fragmentation leads to super-dense condensates composed of the carriers of gluons which behave as a black body in respect of weak interactions.

Emphasize that due to the very strong shortest entanglement of the carriers of gluons on the surface of the torus/charge, any fragmentation of the core of baryons is impossible.

Notice that we calculated the ratios for transverse momentum with complete fragmentation (about 3 GeV) and the asymptotic values for higher transverse momentums so we can draw the curve ratio = ratio(transverse-momentum).

References

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