Phase Transitions in Nucleon-Nucleon Collisions

Sylwester Kornowski

Abstract: Here, applying the classical/statistical/non-perturbative Scale-Symmetric Theory (SST), we calculated the threshold (centre-of-mass) energies and corresponding to them values of the rho parameter. The qualitative description is very detailed and in the quantitative description there are incorporated the coupling constants calculated within SST.

1. Introduction

The cross sections, σ, and rho parameter, ρ, as a function of the centre-of-mass energy, $E = s^{1/2}$ [GeV], for the nucleon-nucleon (NN; $N \approx 939$ MeV) collisions we widely described qualitatively and quantitatively in paper [1]. Here the qualitative description is more detailed and in the quantitative description there are incorporated the coupling constants calculated within the classical/statistical/non-perturbative Scale-Symmetric Theory (SST) [2], [3].

Here the symbols of particles denote their masses as well.

SST leads to the atom-like structure of baryons [3]. There is the core with a mass of $H^{+,-} = 727.4401$ MeV. It consists of the electric-charge/torus $X^{+,-} = 318.2955$ MeV and the central condensate $Y = 424.1245$ MeV. The large loops $m_{LL} = 67.54441$ MeV with a radius of $2A/3$, where $A = 0.6974425$ fm, are produced inside the electric-charge/torus – the neutral pions are built of two such loops. In the $d = 1$ state (it is the S state i.e. the azimuthal quantum number is $l = 0$) there is a relativistic pion. Here π^o denotes the neutral pion whereas $p^{+,-}$ denotes the proton.

The calculated within SST values of the coupling constants are as follows [3]:

- for the nuclear weak interactions is $\alpha_{w(proton)} = 0.0187228615$,
- for the nuclear strong interactions via the large loop is $\alpha_{S(LL)} = 1$,
- for the fine structure constant is $\alpha_{em} = 1/137.0360$.

The parameter ρ is the ratio of the real to the imaginary part of the forward nuclear elastic scattering amplitude at $t = 0$.

2. Phase transitions in nucleon-nucleon collisions

According to SST, relativistic nucleon has spin overlapping with its velocity i.e. the plane of the equator of the spinning torus/electric-charge with a radius equal to A and with mean radius equal to $2A/3$ is perpendicular to velocity. In an accelerating nucleon, the spin speed of the torus decreases. Since spin must be conserved so mass of the torus must increase – it is the spinning relativistic mass which appears due to the condensation of the spacetime – it is because of the nuclear weak interactions ($\alpha_{w(proton)} = 0.0187228615$). This means that at $t = 0$ for colliding nucleons there at first is created a weak vortex-like condensate from the spinning relativistic mass. On the other hand, the loop-like interactions are characteristic for the nuclear strong interactions (according to SST, for the nuclear strong interactions via the exchanged large loop is $\alpha_{S(LL)} = 1$) and for the electromagnetic interactions ($\alpha_{em} = 1/137.0360$). Outside the nuclear strong fields, the gluon loops behave as photon loops [3].

The phase transition from the vortex-like nuclear weak interactions to the loop-like nuclear strong interactions increases mass of the loop $f_1 = \alpha_{S(LL)} / \alpha_{w(proton)} = 53.4105$ times. But the vortices/loops, due to the NN collisions, must transform into discs i.e. the vortices and loops are flattened. This means that we have a transition from one dimension (loop) to two dimensions (disc). It causes that the total energy of the disc interacting strongly increases $f_1^2 = 2852.68$ times.

Assume that E_o denotes the mass of the initial vortex interacting weakly whereas $E = s^{1/2}$ denotes the mass of the disc interacting strongly so for disc with increasing radius (on assumption that density of the disc is invariant – SST shows that it is valid [3]) there is satisfied following proportionality

$$E / E_o \sim (R / R_o)^2 , \tag{1}$$

where $R_o = 2A/3$. When we take into account the above remarks and formula (1), we obtain

$$E_{Strong} = f_1^2 \, [R / (2 \, A / 3)]^2 \, E_o \, . \tag{2}$$

When the strongly interacting disc reaches the $d = 1$ orbit (its radius is $R = A + B = 1.1993$ fm [3]) or the Schwarzschild surface for the nuclear strong interactions (its radius is $R = 2 \, A$ [3]) then the orbit is destroyed. The characteristic initial weak condensate has energy $E_o = Y$ so from (2) we obtain that the orbit is destroyed when E_{Strong} reaches 8.05 TeV or 10.89 TeV. Then, instead the virtual p^+p^- pairs exchanging simultaneously two real neutral pions there are created the virtual X^+X^- pairs exchanging one real large loop.

From (2), for $R = 2 \, A / 3$ and $E_o = Y$, we obtain $E_{Strong} = 1.21$ TeV.

In reality, the virtual pairs have positive mass but there simultaneously are created the “holes” in the disc so they have negative mass and their absolute mass is equal to the mass of the virtual particles. This means that at low (the centre-of-mass) energy, the pions are exchanged between the “holes”.

At low (the centre-of-mass) energy, there can be a phase transition from the large loop interacting strongly to the large loop interacting electromagnetically. Such transition decreases energy of the loop 137.036 times. Introducing $f_2 = \alpha_{em} / \alpha_{S(LL)} = 1 / 137.036$ we can rewrite formula (2) as follows

$$E_{em} = f_1^2 \, f_2 \, [R / (2 \, A / 3)]^2 \, E_o \, . \tag{3}$$

From (3), for $R = 2 \, A / 3$ and $E_o = Y$, we obtain $E_{em} = 8.83$ GeV = 0.00883 TeV. For such centre-of-mass energy we should obtain negative/minimum value for the rho parameter.

Here we obtained following threshold (centre-of-mass) energies: 0.00883 TeV, 1.21 TeV, 8.05 TeV and 10.89 TeV. Corresponding to them values of the rho parameter are calculated in paper [1] (see Fig. 1 in this paper)

$$\rho_{above\ 8.05\ TeV<E<10.89\ TeV} = m_{LL} / (X^{+} + X^{-}) = 0.1061 . \qquad (4)$$

$$\rho_{min,max} = 2\,\pi^{o} / [\pm (p^{+} + p^{-})] = \pm\, 0.1439 . \qquad (5)$$

Initially, i.e. at low energies, the two neutral pions are exchanged between the "holes" so the rho parameter is negative (see formula (5)) – it starts from ρ_{min} = – 0.1439 for E = 0.00883 TeV. Next there is more and more neutral pions exchanged between the virtual $p^{+}p^{-}$ pairs so ρ becomes positive and reaches the maximum value ρ_{max} = + 0.1439 for E = 1.21 TeV (see formula (5)). When the centre-of-mass energy reaches E = 8.05 TeV or 10.89 TeV, the d = 1 orbit is destroyed so instead the $p^{+}p^{-}$ pairs there are created the $X^{+}X^{-}$ pairs which exchange the large loops (see formula (4)).

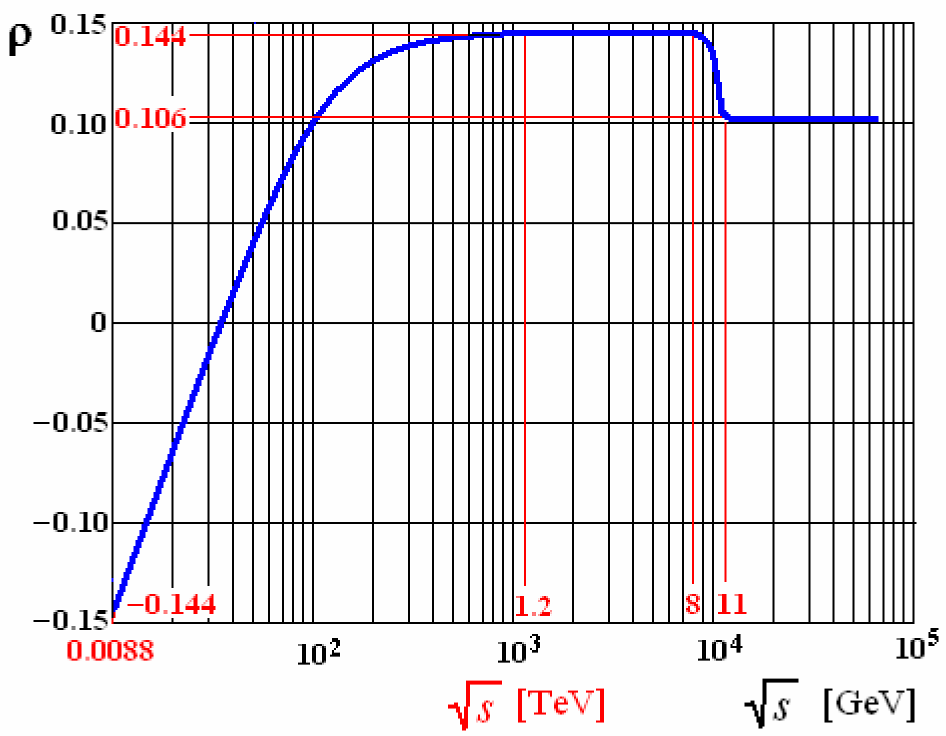

Fig.1
Dependence of the rho parameter on the centre-of-mass energy from the Scale-Symmetric Theory.

3. Summary

Here, applying the classical/statistical/non-perturbative Scale-Symmetric Theory, we calculated the threshold (centre-of-mass) energies and corresponding to them values of the rho parameter. The qualitative description is very simple and the derived formulae lead to theoretical results consistent with experimental data.

Described here phase transitions show that most important are the transitions of the weakly interacting vortex-like relativistic masses into strongly interacting spinning discs in which are created the virtual fermion-antifermion pairs and associated with them the “holes” which carry negative mass. There are exchanged the real large loops and their pairs (i.e. pions) – at low energies, they are exchanged between the “holes” whereas at high energies they are exchanged between the virtual fermion-antifermion pairs.

Above the threshold energy $8.05 \text{ TeV} < s^{1/2} < 10.89 \text{ TeV}$, the $d = 1$ state is destroyed so instead the virtual p^+p^- pairs there are created the X^+X^- pairs.

References

[1] Sylwester Kornowski (10 February 2018). “Cross Section and Rho Parameter versus the Centre-of-Mass Energy for Proton-Proton Collisions”
http://vixra.org/abs/1802.0125

[2] Sylwester Kornowski (11 May 2017). “Initial Conditions for Theory of Everything”
http://vixra.org/abs/1705.0176

[3] Sylwester Kornowski (6 June 2016). “Foundations of the Scale-Symmetric Physics (Main Article No 1: Particle Physics)”
http://vixra.org/abs/1511.0188

[4] The TOTEM Collaboration (16 December 2017). “First determination of the ρ parameter at √s = 13 TeV – probing the existence of a colourless three-gluon bound state”
CERN-EP-2017-335
https://cds.cern.ch/record/2298154?ln=pl