The Origin of the Transverse Radii of Hyperons at the LHC

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Abstract: Here we show that the effective Gaussian source radii for the proton-hyperon pairs obtained at the LHC follow from the atom-like structure of baryons which is described in the Scale-Symmetric Theory (SST). The effective radii strongly depend on the methods used, as has been proven with the proton.

1. Introduction

The ALICE team at the LHC has shown that the source radii for the proton-hyperon pairs can be determined in proton-proton collisions via a function of the transverse mass m_T [GeV/c] [1]. They obtained an effective Gaussian source radius (we will call it the transverse radius) equal to $1.02(5)$ **fm** for $p\text{-}\Xi^-$ pairs and to $0.95(6)$ **fm** for $p\text{-}\Omega^-$ pairs. The average m_T of such pairs are 1.9 **GeV/c** and 2.2 **GeV/c** respectively.

Here we show that the transverse radii and the transverse masses obtained by the ALICE team follow from the atom-like structure of baryons described in the Scale-Symmetric Theory (SST) [2].

The rest of this Introduction is taken from [3]. All SST results are from [2] and they appear in calculations.

The symmetry called *the saturation of the SST tachyon interactions* leads to the phase transitions of the initial inflation field – such phase transitions are defined by the number $K = 0.78967 \cdot !0^{10}$ which results from the initial conditions. It leads to the two fundamental radii in baryons. The first radius is the radius of the fundamental gluon loop (FGL) $R_{FGL} = 2A/3 = 0.465$ **fm** with a mass of $M_{FGL} = 67.54441$ **MeV** – it is responsible for the nuclear strong interactions inside baryons at low energies. The second is the equatorial radius $A = 0.6974425$ **fm** of the core of baryons. Notice that the nuclear strong interactions between the baryons are carried by the binary systems of FGLs, i.e. by the neutral pions with a mass of $\pi^o = 135.0$ **MeV**. Mass of the electric charge inside the core of baryons is $X^{+,-} = 318.30$ **MeV**.

The key role in the SST plays also the Titius-Bode (TB) law for the nuclear strong interactions

$$R_i = A + d\,B, \qquad (1)$$

where $B = 0.5018395$ **fm**, and $d = 0, 1, 2$ and 4.

The TB law leads to the four characteristic radii in baryons – they are the TB radii of the orbits for the nuclear strong interactions: $R_{d=0} = A$, $R_{d=1} = A + B = 1.1993$ **fm**, $R_{d=2} = A + 2B = 1.7011$ **fm** and $R_{d=4} = A + 4B = 2.7048$ **fm**. Such radii lead to following masses of gluon loops overlapping with the TB orbits: $S^{+,-}_{d=0}$ = 727.44 **MeV**, $S^{+,-}_{d=1}$ = 423.04 **MeV**, $S^{+,-}_{d=2}$ = 298.24 **MeV** and $S^{+,-}_{d=4}$ = 187.57 **MeV**.

The range of the nuclear strong interactions is L_{Strong} = 2.9582 **fm**.

The internal structure of hyperons is described in [2] and [4]. Properties of hyperons strongly depend on the $d = 2$ state.

There are experimental results which confirm that in baryons there are the listed above 5 characteristic radii in baryons.

The arithmetic mean of the radius of the last TB orbit and the range of the nuclear strong interactions is

$$L_{Strong\text{-}d=4} = (R_{d=4} + L_{Strong}) / 2 = 2.8315 \text{ fm}, \tag{2}$$

so we can write down the two results as follows

$$L_{Theory,SST} = 2.8315 \pm 0.1267 \text{ fm}. \tag{3}$$

On the other hand, the result fitted to the STAR experimental data gives the following value of the source size [5]

$$r_{o,experiment,STAR} = 2.83 \pm 0.12 \text{ fm}. \tag{4}$$

We can see that our theoretical result (3) is perfect.

So-called “hard core of nucleons” of an infinite strength was first introduced phenomenologically by Jastrow in 1950 [6]. We assume that it concerns the FGL.

When a beam is flowing in direction of the spin of a target (i.e. the spins of the target components are polarized) then we should obtain the radius of FGL – it is at the zero-temperature limit and it is the upper limit for the radius of the hard core of nucleons in our model

$$R_{Hard\text{-}core,upper} = R_{FGL} = 2A/3 = 0.465 \text{ fm}. \tag{5}$$

On the other hand, for thermal nucleons (i.e. their spins are not polarized) we obtain the lower limit for radius of the hard core of nucleons. Along the x-axis and y-axis, the radius is R_{FGL} while along the z-axis the radius is zero so an approximate mean value that is the lower limit is

$$R_{Hard\text{-}core,lower} = (2\, R_{FGL} + 0) / 3 = 0.31 \text{ fm}. \tag{6}$$

In paper [7], there are calculated the properties of a neutron star (NS) at zero-temperature limit (so spins of neutrons are polarized). They found the hard core radius for the baryons

$$0.425 \text{ fm} < R_{Hard\text{-}core,NS,[7]} < 0.476 \text{ fm}. \tag{7}$$

This result is consistent with our result (5).

In paper [8], authors claim that a comparison with the phenomenology of neutron stars implies that the hard-core radius of nucleons has to be temperature and density dependent. Their result for the hard-core radius of nucleons is

$$0.3\ \mathbf{fm} < R_{\text{Hard-core,NS,[15]}} < 0.36\ \mathbf{fm}\ . \qquad (8)$$

This result is consistent with our result (6).

In the spin-triplet state, the effective range for the neutron-proton scattering is [9]

$$r_{ot} = 1.7606(35)\ \mathbf{fm}\ . \qquad (9)$$

It relates to the $R_{d=2} \approx 1.7$ **fm** in our model.

In the spin-singlet state, the effective range for the neutron-proton scattering is [9]

$$r_{os} = 2.706(67)\ \mathbf{fm}\ . \qquad (10)$$

It relates to the $R_{d=4} = 2.7048$ **fm** in our model.

Notice also that the experimental muon radius of proton [10] and its electron radius [11] indirectly lead to the radius $R_{d=1} = A + B = 1.1993$ **fm** [12].

2. Calculations

In the relativistic proton-proton collisions, spins of protons are parallel or antiparallel to the direction of the collisions. On the other hand, the created gluon loops are in planes perpendicular to the direction of collisions. Thus, the breakdown of the gluon loops (or annihilation of the X^+X^- pairs) causes their masses to appear as transverse masses.

In interacting strongly hyperons, the gluon loops appear on the first four orbits with the radii equal to R_{FGL}, $R_{d=0}$, $R_{d=1}$ and $R_{d=2}$ so the mean transverse radius of all hyperons, $R_{T,hyperons,SST}$, should be

$$R_{T,hyperons,SST} = (R_{FGL} + R_{d=0} + R_{d=1} + R_{d=2}) / 4 = 1.0157\ \mathbf{fm} \approx 1.02\ \mathbf{fm}\ . \qquad (11)$$

We can see that our result is equal to the central value for the LHC $p\text{-}\Xi^-$ pairs.

The SST transverse mass for all proton-hyperon pairs, $m_{T,hyperons,SST}$, should be (the hyperon interacts strongly with proton via π^o)

$$m_{T,hyperons,SST} = X^{+,-} + \pi^o + S^{+,-}_{d=0} + S^{+,-}_{d=1} + S^{+,-}_{d=2} = 1902\ \mathbf{MeV} \approx 1.9\ \mathbf{GeV}\ . \qquad (12)$$

Why did the LHC experiment get different results for the $p\text{-}\Omega^-$ pairs?

Mass of the hyperon Ω^- is [13]

$$\Omega^- = 1672.45(29)\ \mathbf{MeV}\ . \qquad (13)$$

It means that a $p\text{-}S^{+,-}_{d=0}$ pair can mimic the mass of the hyperon Ω^- because the mass distance is very low

$$p + S^{+,-}_{d=0} = 1665.71\ \mathbf{MeV}\ . \qquad (14)$$

In the $p\text{-}pS^{+,-}_{d=0}$ pair, there are occupied only the states $d = 0$ and $d = 1$ (there does not appear an additional pion π^o but there are two the $S^{+,-}_{d=0}$ gluon loops) so we have

$$R_{T,p\text{-}pS(+,-),SST} = (R_{d=0} + R_{d=1}) / 2 = 0.948\ \mathbf{fm} \approx 0.95\ \mathbf{fm}\ . \qquad (15)$$

We can see that our result is equal to the central value for the LHC p-Ω^- pairs.

The SST transverse mass for the p-p$S^{+,-}_{d=0}$ pairs, $m_{T,p-\Omega(-),SST}$, should be

$$m_{T,p-pS(+,-),SST} = X^+ + S^{+,-}_{d=0} + S^{+,-}_{d=0} + S^{+,-}_{d=1} = 2196 \textbf{ MeV} \approx 2.2 \textbf{ GeV} . \qquad (16)$$

Both results (15) and (16) are consistent with the LHC results.

3. Summary

On the basis of the atom-like structure of baryons, we showed that the effective radii strongly depend on the methods used.

We showed that the mean transverse radius of hyperons should be 1.0157 **fm**.

The electron equatorial radius of hyperons should be equal to the upper limit of the transverse radius, i.e. it should be $R_{d=2} = 1.7011$ **fm**.

The mean electron radius of hyperons should be

$$[2 (A + 2 B) + A / 3] / 3 = 1.212 \textbf{ fm} . \qquad (17)$$

We can compare it with the mean electron radius of proton

$$[2 (A + B) + A / 3] / 3 = 0.877 \textbf{ fm} . \qquad (18)$$

It is consistent with the experimental data [11].

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