Lepton Flavour Non-Universality from the Scale-Symmetric Theory

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Abstract: In recent years, LHCb has found hints of deviations from the Standard-Model (SM) predictions that point new physics (NP). The lepton flavour universality is violated when comparing rates of decays of B mesons into excited kaon and lepton-antilepton pair with different flavours. Here, applying the Scale-Symmetric Theory (SST), we calculated the ratio of such decay rates when there appears a pair of muons or electron-positron pair. In the low-squared-q region (0.045 < qq < 1.1 GeV^2/c^4)), we obtained ratio = 0.6603 and in the central-squared-q region (qq > 1.1), we obtained ratio = 0.6850. The SST results are consistent with the central values obtained in the LHCb experiments 0.660 and 0.685 respectively. We can compare the LHCb and SST results with the SM predictions that give values close to unity. The SM results are inconsistent with the LHCb data having a statistical significance of 2.2 - 2.5 sigma. We showed that the decrease from about 1 in SM to 0.6603 in SST follows from different structure of muon and electron and from creation of additional electron-positron pair near bare muon, whereas the increase in SST from 0.6603 to 0.6850 is a result of the weak interactions of a pair of muons with nucleon at q higher than some threshold energy equal to 1.05 or 1.06 GeV/c^2 i.e. the squared q should be higher than about 1.1. We do not need a heavy Z' boson or leptoquarks to explain the deviations from SM - we need a lacking part of SM i.e. we need the SST which is the NP.

1. Introduction

In recent years, LHCb has found hints of deviations from the Standard-Model (SM) predictions that point new physics (NP) [1]. The lepton flavour universality is violated when comparing rates of decays of B^o mesons (mass = 5279.62 ± 0.15 MeV [2]) into excited kaon $K^*(892)^o$ (mass = 895.81 ± 0.15 MeV [2]) and $\mu^+\mu^-$ pair or e^+e^- pair.

Here, applying the Scale-Symmetric Theory (SST) [3], we calculated the so-called R_{K*o} ratio of such decay rates in the low-q^2 region ($0.045 < q^2 < 1.1$ GeV^2/c^4) and in the central-q^2 region ($q^2 > 1.1$ GeV^2/c^4). Notice that the boundaries of the two q^2 regions are calculated within presented here model also. The SST results are consistent with the central values obtained in the latest LHCb experiments [1].

The succeeding phase transitions of the inflation field described within SST lead to the non-gravitating residual inflation field which is the Higgs field (HF), lead to the superluminal quantum entanglement, to the Einstein spacetime (ES) composed of the spin-1 neutrino-antineutrino pairs, and to new cosmology [3]. Additional phase transitions lead to the atom-like structure of baryons and to internal structure of mesons and leptons [3].

Here most important is the internal structure of the core of baryons and the structures of bare muon and bare electron [3]. According to SST, the three listed bare objects consist of entangled or confined ES components. All three listed objects consist of torus/electric-charge and central ES condensate which is responsible for their weak interactions [3]. Among a thousand theoretical results calculated within SST, we can find quantities we will use in this paper (we compare them with experimental central values): the mass of electron, $e^{+,-}$, $m_{electron,SST}$ = 0.5109989 MeV ($m_{electron,exp..}$= $m_{electron,SST}$ [2]), the mass of muon, $\mu^{+,-}$, $m_{muon,SST}$ = 105.6563 MeV ($m_{muon,exp.}$ = 105.6584 MeV [2]), mass of neutral pion, π^{o}, $m_{pion(o),SST}$ = 134.9767 MeV ($m_{pion(o),exp.}$ = 134.9766 MeV [2]), mass of charged pion, $\pi^{+,-}$, $m_{pion(+,-),SST}$ = 139.57041 MeV ($m_{pion(+,-),exp.}$ = 139.57013 MeV [2]), mass of neutral kaon, K^{o}, $m_{kaon(o),SST}$ = 497.760 MeV ($m_{kaon(o),exp.}$ = 497.611 MeV [2]), mass of charged kaon, $K^{+,-}$, $m_{kaon(+,-),SST}$ = 493.734 MeV ($m_{kaon(+,-),exp.}$ = 493.677 MeV [2]), mass of the central condensate in the core of baryons Y = 0.4241245 GeV ($Y_{virtual}$ = Y), the coupling constant for the weak interactions via Y: $\alpha_{w(proton)}$ = 0.0187229, and the coupling constant for the inner strong interactions of mesons with baryons via the single gluon loops $\alpha_S^{\pi\pi g}$ = 1 [3]. Notice as well that used here model of muons, contrary to the Standard-Model, leads to the correct anomalous magnetic moment of muons [3].

In this paper, the symbols of particles denote also their mass.

2. The boundaries for q^2

According to SM, the lower boundary of the low-q^2 region, q_{LL}^2, roughly corresponds to the di-muon production threshold

$$q_{LL,SM}^2 = (2\, m_{muon,exp.})^2 = 0.04465 \text{ GeV}^2/\text{c}^4. \qquad (1)$$

According to SST, due to the weak interactions of baryons, the created virtual ES condensates with a mass of Y can decay into two virtual $\mu^+\mu^-$ pairs. It means that in SST, the threshold q_{LL} for production of $\mu^+\mu^-$ pair in collisions of nucleons is

$$q_{LL,SST}^2 = (Y / 2)^2 = 0.04497 \text{ GeV}^2/\text{c}^4. \qquad (2)$$

If it is true then the small difference in the SM and SST thresholds Δq_{LL}^2 = 0.00032 GeV^2/c^4 points NP also.

There is as well the second threshold, $q_{CL,SST}$, for the lower limit of the central-q^2 for simultaneous production of $\mu^+\mu^-$ pair and exchange of two $Y_{virtual}$ condensates between nucleon and the $\mu^+\mu^-$ pair i.e. $q_{CL,SST} = 2(Y_{virtual}\, \mu)$ = 1.06 GeV/c^2 – such exchange is the weak interaction of a nucleon with muon pair via two $Y_{virtual}$ with coupling constant equal to $2\alpha_{w(proton)}$. For $q_{CL,SST}^2$ we obtain

$$q_{CL,SST}^2 = [2\, (Y_{virtual}\, \mu)]^2 = 1.12 \text{ GeV}^2/\text{c}^4. \qquad (3)$$

In Paragraph **4**, we will show that $q_{CL,SST}$ is as well very close to the sum of the rest masses of the B^o-meson components, $B^o{}_{rest} \equiv [\pi^o \pi^+ \pi^o \pi^- K^o] = 1.05$ GeV/c^2 i.e.

$$q_{CL,SST}{}^2 = B^o{}_{rest}{}^2 \equiv [\pi^o \pi^+ \pi^o \pi^- K^o]^2 = 1.10 \text{ GeV}^2/\text{c}^4. \qquad (4)$$

Notice as well that mass of muon is very close to the mass distance between the condensate Y and the torus/charge in the core of baryons and is close to one fourth of Y. We can see that mass of muons and their production are directly associated with the core of baryons, especially with the Y condensate responsible for the weak interactions of baryons [3].

Why there appears the factor 2 in the coupling constant $2\alpha_{w(proton)}$ defining the weak interactions of a nucleon with a muon pair? According to SST, for baryon emitting one $Y_{virtual}$ is (the real Y and emitted $Y_{virtual}$ have the same mass but $Y_{virtual}$ creates a virtual "hole" in ES with negative mass equal to $-Y_{virtual}$) [3]

$$\alpha_{w(proton)} = G_W\, Y\, Y_{virtual} / (c\, \hbar), \qquad (5)$$

whereas a baryon interacting with a muon pair emits simultaneously two $Y_{virtual}$

$$2\alpha_{w(proton)} = G_W\, Y\, (Y_{virtual} + Y_{virtual}) / (c\, \hbar). \qquad (6)$$

Below $q_{CL,SST}$, a system composed of nucleon and B^o meson exchanges virtual gluon loop so the total coupling constant is $\alpha_S{}^{\pi\pi g} = 1$ whereas above $q_{CL,SST}$, the system exchanges the single virtual gluon loop and two virtual $Y_{virtual}$ so the total coupling constant is $\alpha_S{}^{\pi\pi g}$ + $2\alpha_{w(proton)}$. The ratio F_{SST} of the total coupling constants for central-q^2 ($q^2 > 1.1$ GeV^2/c^4) and low-q^2 ($0.045 < q^2 < 1.1$ GeV^2/c^4) is

$$F_{SST} = (\alpha_S{}^{\pi\pi g} + 2\alpha_{w(proton)}) / \alpha_S{}^{\pi\pi g} = 1 + 2\alpha_{w(proton)} = 1.0374458\,. \qquad (7)$$

Notice that in the LHCb experiment, the central values of R_{K*o} in the two q^2 regions are 0.660 and 0.685 [1]. On the other hand, we have $0.660 F_{SST} = 0.685$.

3. The so-called R_{K*o} ratios for the two different regions of q^2

The R_{K*o} is the ratio of the probabilities (the ratio of the branching ratios (BR)) that a B^o meson decays to $K^{*o}\mu^+\mu^-$ and $K^{*o}e^+e^-$

$$R_{K*o} = \text{BR}(B^o \rightarrow K^{*o}\mu^+\mu^-) / \text{BR}(B^o \rightarrow K^{*o}e^+e^-). \qquad (8)$$

From the LHCb experiments, in the low-q^2 region we have [1]

$$R_{K*o} = 0.660^{+0.110}_{-0.070} \pm 0.024\,, \qquad (9)$$

whereas in the central-q^2 region is [1]

$$R_{K*o} = 0.685^{+0.113}_{-0.069} \pm 0.047\,. \qquad (10)$$

The result has a statistical significance of 2.2 – 2.5 sigma so only future measurements will show whether the hints we are observing point a new physics.

On the other hand, in the Standard Model is assumed that leptons behave in the same way, i.e. they have the same couplings to gauge bosons. It means that the couplings of the leptons to gauge bosons are flavour-independent [4] – this property is called lepton-flavour universality (LFU).

According to the SM, therefore, R_{K*o} should be close to unity.

According to the SST, the bare electron consists of two parts, i.e. of the torus/charge and the central ES condensate, whereas the bare muon consists of three parts, i.e. of the torus/charge, the central ES condensate, and two entangled neutrinos with rotating unitary spin (a photon) immersed in the condensate [3]. Such model of leptons leads to properties consistent with experimental data [3]. On the other hand, branching ratio should be inversely proportional to number of massive constituents in bare lepton. This leads to conclusion that in definition of R_{K*o} should appear the factor $f = 2/3$. Moreover, the R_{K*o} should depend in some way on masses of muon and electron. Creation of additional e^+e^- pair near bare muon increases for a moment its mass at the expense of its potential energy in B^o meson – such process decreases rate of decay of B^o into muon pair and K^{*o}. Probability of creation of additional e^+e^- pair near a muon is much higher than near an electron because then the principle that sum of absolute masses of virtual objects cannot be higher than two masses of their source is, relatively, much less violated [3]. The relative change in mass of the muon is

$$R = m_{muon} / (m_{muon} + 2\, m_{electron}) = 0.99042 \,. \qquad (11)$$

The above remarks lead to following definition of $R_{K*o,\mathrm{SST}}$ for low-q^2

$$R_{K*o,SST,low} = R\, f = 0.6603 \,. \qquad (12)$$

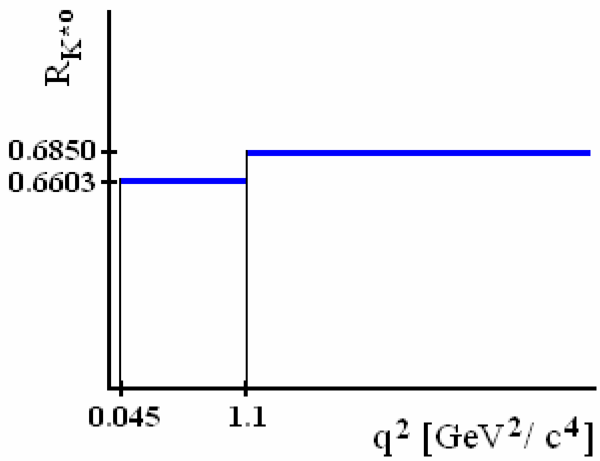

Fig.1
The relation $R_{K*o} = f\,(q^2)$ in the Scale-Symmetric Theory

Due to the different structures of muon and electron and the higher probability of creation of e^+e^- pair near bare muon, there is a significant distance between the SST value of $R_{K*o,\mathrm{SST}}$ = 0.6603 and value of R_{K*o} from the Standard Model $R_{K*o,\mathrm{SM}} \approx 1$.

Applying formulae (7) and (12), we obtain for central-q^2 ($q^2 > 1.1$ GeV^2/c^4)

$$R_{K^{*o},SST,central} = F\, R_{K^{*o},SST,low} = 0.6850\,. \qquad (13)$$

We can see that the 0.6603 in the low-q^2 region and the 0.6850 in the central-q^2, obtained within SST, are consistent with the central values obtained in the LHCb experiments.

4. Mass of K^{*o} and B^o

Notice that SST leads to the non-universality of leptons even when we neglect the internal structure of B^o and K^{*o} (they can appear in decays of B^o), so it can be the end of this paper but we feel that such description is not full.

At higher energies of collisions of nucleons, production of pions and kaons dominates and is higher than expected [5]. It suggests that B^o meson should be a resonance composed of pions and kaon(s).

So why there is an illusion of decay of bottom quark in B^o (according to SM, there is as well the down quark) to strange quark that is the constituent of K^{*o}? Below we give answer to this question.

In SST, neutral pions are the binary systems of the gluon loops, mentioned in Paragraph **2**, with a mass of gluon loop equal to 67.5444 MeV whereas kaons are the binary systems of pions with relativistic speeds [3]. The relativistic speeds cause that there can be produced resonances composed of pions and kaons with shifted masses. We can assume that masses of neutral pions and neutral kaons can increase $X_1 = K^o / \pi^o$ times whereas of charged ones $X_2 = K^+ / \pi^+$ times but increase in mass can be as well, for example, $X_3 = K^+ / (\pi^+ + \pi^o)$. We used the factor X_2 to explain how the Chaos Theory leads to the atom-like structure of baryons [6] (in SST, there is the second simpler solution that leads to the atom-like structure of baryons also [3]).

We can define $K^*(892)^o$ as follows

$$K^*(892)^o = K^o X_3 = K^o K^+ / (\pi^+ + \pi^o)\,. \qquad (14)$$

Applying the experimental masses of pions and kaon K^o [2], from formula (14) we obtain $K^*(892)^o = 894.78$ MeV whereas applying the SST results, we obtain $K^*(892)^o{}_{SST} = 895.15$ MeV which are very close to the experimental mass 895.81 ± 0.19 MeV [2].

We can define $B(5280)^o$ as follows

$$B(5280)^o{}_{SST} = (\pi^o + \pi^o + K^o)\, X_1 + (\pi^+ + \pi^-)\, X_2 =$$

$$= (\pi^o + \pi^o + K^o)\, K^o / \pi^o + (\pi^+ + \pi^-)\, K^+ / \pi^+ =$$

$$= 4296.48 + 987.46 \approx 5284 \text{ MeV}\,. \qquad (15)$$

Applying the experimental masses of pions and kaon K^o [2], from formula (15) we obtain $B(5280)^o \approx 5285$ MeV whereas applying the SST results, we obtain $B(5280)^o{}_{SST} \approx 5284$ MeV which are very close to the experimental mass 5279.62 ± 0.15 MeV [2].

Now we can answer the question. Masses of the quarks are calculated within SST [3], [7] – they are very close to the Standard-Model masses of quarks [2]. But SST shows that quarks are the very unstable objects so they can be in existence only as the quark-antiquark pairs, not as the single objects [7]. On the other hand, mass of the first expression in formula (15) (4296.48 MeV) is close to the mass of the bottom quark that in SST is about 4190 MeV [3], [7]. Notice that mass of the second expression in formula (15) (987.46 MeV) is close to the mass of $K^*(892)^o$ and in SM it is assumed that such kaon contains the strange quark. We can see that the real structure of the B^o meson (in reality, it consists of 4 relativistic pions and one relativistic kaon and there are two different relativistic speeds) leads to an illusion of following decay

$$b \rightarrow s\, l\, l\,. \qquad (16)$$

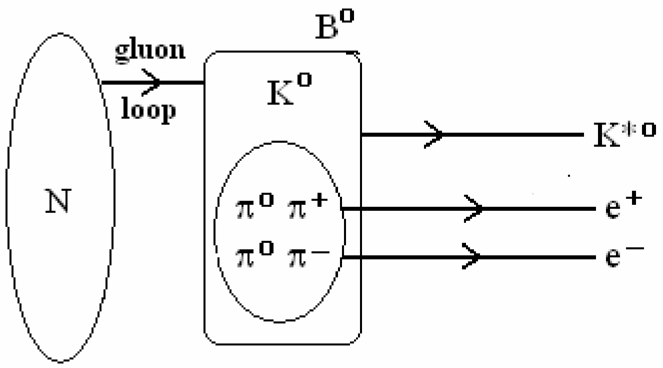

Fig.2
The $B^o \rightarrow K^{*o}\ e^+\ e^-$ decay in the Scale-Symmetric Theory

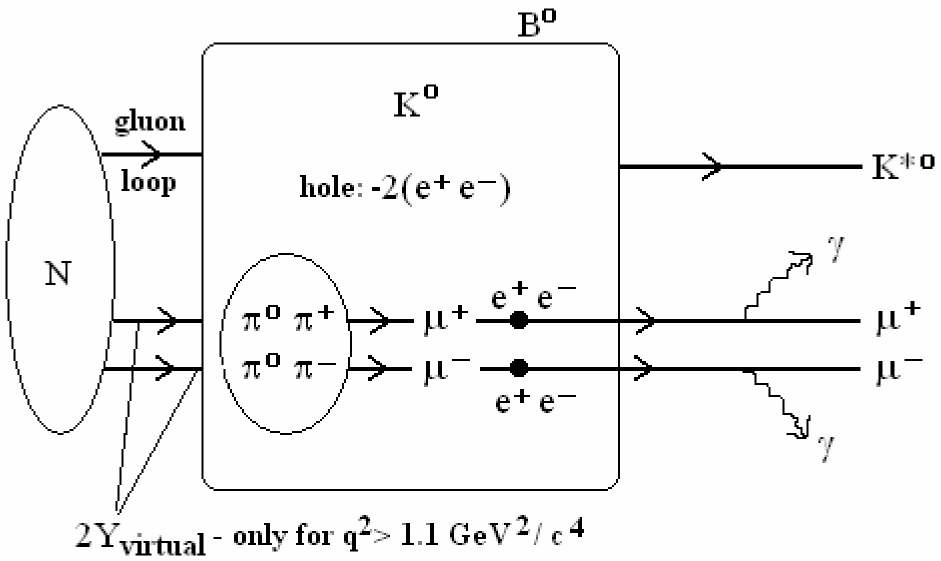

Fig.3
The $B^o \rightarrow K^{*o}\ \mu^+\ \mu^-$ decay in the Scale-Symmetric Theory

5. Summary

Notice that the two different radii of proton, i.e. the electron radius of proton and the muon radius of proton, strongly suggest that the bare leptons are not some sizeless objects as it is assumed in the Standard Model. We solved the proton-radius problem within SST [8].

The LHCb data have a statistical significance of 2.2 - 2.5 sigma so the results can be due to statistical fluctuations. But perfect compliance of the LHCb central values for R_{K*o} with the results obtained within the Scale-Symmetric Theory and the proton-radius problem suggest that there is a violation of the lepton-flavour universality i.e. suggest that there is some fundamental difference in structures of the charged bare leptons.

On the other hand, the increase in R_{K*o} for $q^2 > 1.1$ GeV^2/c^4 suggests that we must as well modify the structure of baryons.

Here we showed how such modification for leptons and baryons should look and we showed why the real decay of B^o leads to an illusion of following decay: $b \rightarrow s\ l\ l$.

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