Electroweak Interactions as the Origin of the Proton Charge Radius Puzzle

Sylwester Kornowski

Abstract: Here we show that the charge radius of proton depends on kind of measurement – it solves the proton charge radius puzzle. The key role plays the virtual leptonic field which interacts with proton via the electroweak force.

1. Introduction

There are three kinds of measurements of the proton radius [1]: via transitions in atomic hydrogen, via electron scattering off hydrogen, and via muonic hydrogen Lamb shift.

Here we show that the charge radius of proton depends on kind of measurement.

We know that range/radius of interaction is inversely proportional to mass so an increase in mass due to some additional interactions causes that effective radius (for example, of proton), R_{eff}, decreases. It follows from the conservation of the angular momentum of a loop for an invariant spin speed of the loop – it can be a virtual photon loop or virtual gluon loop with energy equal to a characteristic mass that carries an interaction. It leads to following relationship

$$R_{eff} = R_o M_o / (M_o + \Sigma_i m_i) , \quad (1)$$

where R_o is the initial radius, M_o is the initial mass carrying an initial interaction, and $\Sigma_i m_i$ is the sum of masses of carriers of additional interactions.

On the other hand, coupling constants, α_i, are directly proportional to masses of carriers of interactions, m_i, [2]

$$\alpha_i = G_i M m_i / (c \hbar) , \quad (2)$$

so

$$\alpha_i \sim m_i . \quad (3)$$

From (3) and (1) we have

$$R_{eff} = R_o \alpha_o / (\alpha_o + \Sigma_i \alpha_i) , \quad (4)$$

where α_o is the initial coupling constant, and $\Sigma_i\alpha_i$ is the sum of coupling constants for additional interactions.

2. The real mean charge radius of proton (the upper limit), $R_{o,p}$, that results only from the nuclear strong interactions

The symmetry called *the saturation of the SST tachyon interactions* leads to the phase transitions of the initial inflation field [2]. It leads to the radius of the fundamental gluon loop (FGL) $R_{FGL} = 2A/3 = 0.4649617$ **fm**, where $A = 0.6974425$ **fm** is the equatorial radius of the torus/electric-charge in the core of baryons – the FGL is responsible for the nuclear strong interactions inside baryons [2]. The height of the torus/electric-charge is R_{FGL} [2].

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

$$R_i = A + d\,B, \qquad (5)$$

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

In the proton, there is occupied only the $d = 1$ state [2], i.e. $R_{d=1} = A + B = 1.199282$ **fm**, – it is occupied by positively charged relativistic pion, π^+, or neutral pion π^o.

There are experimental results that confirm the atom-like structure of baryons [3].

From the sizes of the torus/electric-charge follows that the charge radius of proton along the z-axis is

$$R_z = A / 3\,. \qquad (6)$$

The charged pion in the $d = 1$ state causes that the charged radius of proton along the x-axis and y-axis is

$$R_x = R_y = A + B\,. \qquad (7)$$

The virtual gluons are emitted especially in directions parallel to the plane of the equator of the torus/electric-charge so the nuclear strong field has a shape of a cylinder.

The arithmetic mean of the orthogonal radii, which is the real mean charge radius of proton, $R_{o,p}$, is

$$R_{o,p} = (R_x + R_y + R_z) / 3 = [2\,(A + B) + A / 3] / 3 = 0.8770149\ \mathbf{fm}\,. \qquad (8)$$

This value is consistent with the result obtained by Fleurbaey, *et al.* (2018) [4] – the result is $r_p = 0.877(13)$ **fm**. It is based on the 1S – 3S transition in hydrogen.

This value is consistent also with the result obtained by Sick (2018) [5] – the result is $r_p = 0.887(12)$ **fm**. It is based on the electron scattering.

3. The virtual leptonic field in baryons

The virtual nuclear strong field creates the virtual charged pion-antipion pairs (the $\pi^-\pi^+$ pairs). Decays of such pairs into muons cause that there appear the muon-antimuon pairs (the $\mu^-\mu^+$ pairs). On the other hand, the decays of the $\pi^-\pi^+$ pairs into the neutral pions cause that there appears a virtual cloud composed of the electron-electron antineutrino pairs and the positron-electron neutrino pairs – they are the $e^-\nu_{e,anti}e^+\nu_e$ lepton quadrupoles with a mass of Δm

$$\Delta m = \pi^{-,+} - \pi^o = 4.5936(5)\ \text{MeV [6]}. \qquad (9)$$

4. The mean muon charge radius, $R_{p(\mu)}$, of proton

In measurements based on, for example, the muonic hydrogen Lamb shift, the virtual leptonic quadrupoles are forced to interact with the virtual $\mu^-\mu^+$ pairs. It causes that the effective charge radius of proton decreases – by applying formula (1) we obtain

$$R_{p(\mu)} = R_{o,p}\, \mu^{-,+} / (\mu^{-,+} + \Delta m) = 0.8404745(38)\ \mathbf{fm}\,, \tag{10}$$

where $\mu^{-,+} = 105.6583745(24)$ **MeV** [6].

This value is consistent with the result obtained by Antognini, *et al.* (2013) [7] – the result is $r_p = 0.84087(39)$ **fm**. It is based on the μp – atom Lamb shift.

5. The lower limit for the charge radius of proton

Applying formula (4) we obtain

$$R_{p(lower\text{-}limit)} = R_{o,p}\, \alpha_S / [\alpha_S + 2\, (\alpha_{w(proton)} + \alpha_{em})] = 0.833632\ \mathbf{fm}\,, \tag{11}$$

where $\alpha_S = 1$ is the coupling constant for the nuclear strong interactions inside baryons at low energy, $\alpha_{w(proton)} = 0.0187229$ is the coupling constant for the nuclear weak interactions, and $\alpha_{em} = 1 / 137.036$ is the fine-structure constant [2]. The factor 2 in formula (11) appears because the virtual leptonic field interacts with proton via the particle-antiparticle pairs, not via single particles.

This value is consistent with the result obtained by Bezginov, *et al.* (2019) [8] – the result is $r_p = 0.833(10)$ **fm**. It is based on the 2S-2P transition in hydrogen.

6. Summary

On the basis of the atom-like structure of baryons, we showed that the effective charge radii of proton strongly depend on the kinds of measurements.

We claim that the measurements based on the nS – mS transitions in hydrogen, where n and m are the natural numbers, and based on the elastic electron-proton scattering in the low momentum transfer region, practically eliminate the electroweak interactions of the virtual leptonic field with proton. It causes that the nuclear strong interactions lead to the real charge radius of proton equal to 0.8770149 **fm** – it is the upper limit.

The electroweak interactions of proton with the virtual leptonic field composed of the muon-antimuon pairs ($\mu^-\mu^+$) and the lepton quadrupoles ($e^-\nu_{e,anti}e^+\nu_e$) from the decays of the virtual charged pion-antipion pairs ($\pi^-\ \pi^+$), cause that the effective charge radius of proton decreases to $0.8404745(38)$ **fm** so we indeed can call such a radius the muon charge radius of proton.

The lower limit for the effective charge radius of proton we obtain using the coupling constants for the nuclear-strong, nuclear-weak and electromagnetic interactions – it is 0.833632 **fm**.

The listed above three values should dominate because of a resonance but there can be also some mixtures of them.

References

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