Could second generation of weak bosons explain the reduction of proton charge radius?

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Abstract

The discovery of Pohl et al that the charge radius of proton deduced from muonic atom is smaller that predicted by QED applied to hydrogen atom seems to be established now. The finding can be interpreted in terms of breaking of universality of electroweak interactions. Also the anomalous value of the magnetic moment of muon and decays of neutral B meson give evidence for the breaking of universality caused by a coupling to a new heavy boson.

TGD predicts two new gauge boson families and there is an experimental indication suggests that the mass scale of second electroweak boson generation is 2.9 TeV also predicted by assuming that these bosons correspond to p-adic length scale assignable to Gaussian Mersenne $M_{G,79}$ so that mass scale would be 32 times that of weak bosons assignable to Mersenne prime M_{89}. The charge matrices of the higher boson generations are mutually orthogonal and necessarily break universality.

The exchange of second generation photon and Z^0 boson might explain the anomaly by introducing Yukawa term to the Coulomb potential. It is found that the sign and the order of magnitude for the effect are correct for reasonable choices of the unknown parameters.

Contents

1 Introduction

The discovery by Pohl et al (2010) [C2] was that the charge radius of proton deduced from the muonic version of hydrogen atom - is .842 fm and about 4 per cent smaller than .875 fm than the charge radius deduced from hydrogen atom [C4, C5] is in complete conflict with the cherished belief that atomic physics belongs to the museum of science (for details see the Wikipedia article http://tinyurl.com/jkt2mkv). The title of the article *Quantum electrodynamics-a chink in the armour?* of the article published in Nature [C2] expresses well the possible implications, which might actually go well extend beyond QED.

Quite recently (2016) new more precise data has emerged from Pohl et al [C3] (see http://tinyurl.com/jd2hwuq). Now the reduction of charge radius of muonic variant of deuterium is measured. The charge radius is reduced from 2.1424 fm to 2.1256 fm and the reduction is .012 fm, which is about .8 per cent (see http://tinyurl.com/j4z3yp9). The charge radius of proton deduced from it is reported to be consistent with the charge radius deduced from deuterium. The anomaly seems therefore to be real. Deuterium data provide a further challenge for various models.

The finding is a problem of QED or to the standard view about what proton is. Lamb shift [C1] is the effect distinguishing between the states hydrogen atom having otherwise the same energy but different angular momentum. The effect is due to the quantum fluctuations of the electromagnetic field. The energy shift factorizes to a product of two expressions. The first one describes the effect of these zero point fluctuations on the position of electron or muon and the second one characterizes the average of nuclear charge density as "seen" by electron or muon. The latter one should be same as in the case of ordinary hydrogen atom but it is not. Does this mean that the presence of muon reduces the charge radius of proton as determined from muon wave function? This of course looks implausible since the radius of proton is so small. Note that the compression of the muon's wave function has the same effect.

Before continuing it is good to recall that QED and quantum field theories in general have difficulties with the description of bound states: something which has not received too much attention. For instance, van der Waals force at molecular scales is a problem. A possible TGD based explanation and a possible solution of difficulties proposed for two decades ago is that for bound states the two charged particles (say nucleus and electron or two atoms) correspond to two 3-D surfaces glued by flux tubes rather than being idealized to points of Minkowski space. This would make the non-relativistic description based on Schrödinger amplitude natural and replace the description based on Bethe-Salpeter equation having horrible mathematical properties.

The basic idea of the original model of the anomaly [K2] is that muon has some probability to end up to the magnetic flux tubes assignable to proton. In this state it would not contribute to the ordinary Schrödinger amplitude. The effect of this would be reduction of $|\Psi|^2$ near origin and apparent reduction of the charge radius of proton. The weakness of the model is that it cannot make quantitative prediction for the size of the effect. Even the sign is questionable. Only S-wave binding energy is affected considerably but does the binding energy really increase by the interaction of muon with the quarks at magnetic flux tubes? Is the average of the charge density seen by muon in S wave state larger, in other words does it spend more time near proton or do the quarks spend more time at the flux tubes?

In the following a new model for the anomaly will be discussed.

1. The model is inspired by data about breaking of universality of weak interactions in neutral B decays possibly manifesting itself also in the anomaly in the magnetic moment of muon. Also the different values of the charge radius deduced from hydrogen atom and muonium could reflect the breaking of universality. In the original model the breaking of universality is only effective.

2. TGD indeed predicts a dynamical U(3) gauge symmetry whose 8+1 gauge bosons correspond to pairs of fermion and anti-fermion at opposite throats of wormhole contact. Throats are characterized by genus $g = 0, 1, 2$, so that bosons are superpositions of states labelled by (g_1, g_2). Fermions correspond to single wormhole throat carrying fermion number and behave as U(3) triplet labelled by g.

   The charged gauge bosons with different genera for wormhole throats are expected to be very massive. The 3 neutral gauge bosons with same genus at both throats are superpositions of states (g, g) are expected to be lighter. Their charge matrices are orthogonal and necessarily break the universality of electroweak interactions. For the lowest boson family - ordinary gauge bosons - the charge matrix is proportional to unit matrix. The exchange of second generation bosons Z_1^0 and γ_1 would give rise to Yukawa potential increasing the binding energies of S-wave states. Therefore Lamb shift defined as difference between energies of S and P waves is increased and the charge radius deduced from Lamb shift becomes smaller.

3. The model thus predicts a correct sign for the effect but the size of the effect from naive estimate assuming only γ_1 contribution and $\alpha_1 = \alpha$ ad $M = 2.9$ TeV is almost by an order of magnitude too small. The values of the gauge couplings α_1 and $\alpha_1 Z, 1$ are free parameters as also the mixing angles between states (g, g). The effect is also proportional to the ratio $(m_\mu/M(boson)^2$.

2 The model

The speculative model discussed in [K2] is not the only one that one can imagine. The anomaly could be explained also as breaking of the universality of weak interactions. Also other anomalies challenging the universality exists. The decays of neutral B-meson to lepton pairs should be same apart from corrections coming from different lepton masses by universality but this does not seem to be the case [K1]. There is also anomaly in muon's magnetic moment discussed briefly in [K3]. This leads to ask whether the breaking of universality could be due to the failure of universality of electroweak interactions.

2.1 About motivations

The proposal for the explanation of the muon's anomalous magnetic moment and anomaly in the decays of B-meson is inspired by a recent very special di-electron event and involves higher generations of weak bosons predicted by TGD leading to a breaking of lepton universality. Both Tommaso Dorigo (`http://tinyurl.com/pfw7qqm`) and Lubos Motl (`http://tinyurl.com/hqzat92`) tell about a spectacular 2.9 TeV di-electron event not observed in previous LHC runs. Single event of this kind is of course most probably just a fluctuation but human mind is such that it tries to see something deeper in it - even if practically all trials of this kind are chasing of mirages.

Since the decay is leptonic, the typical question is whether the dreamed for state could be an exotic Z boson. This is also the reaction in TGD framework. The first question to ask is whether weak bosons assignable to Mersenne prime M_{89} have scaled up copies assignable to Gaussian Mersenne M_{79}. The scaling factor for mass would be $2^{(89-79)/2} = 32$. When applied to Z mass equal to about .09 TeV one obtains 2.88 TeV, not far from 2.9 TeV. Eureka!? Looks like a direct scaled up version of Z!? W should have similar variant around 2.6 TeV.

TGD indeed predicts exotic weak bosons and also gluons.

1. TGD based explanation of family replication phenomenon in terms of genus-generation correspondence forces to ask whether gauge bosons identifiable as pairs of fermion and antifermion at opposite throats of wormhole contact could have bosonic counterpart for family replication. Dynamical SU(3) assignable to three lowest fermion generations labelled by the genus of partonic 2-surface (wormhole throat) means that fermions are combinatorially SU(3) triplets. Could 2.9 TeV state - if it would exist - correspond to this kind of state in the tensor product of triplet and antitriplet? The mass of the state should depend besides p-adic mass scale also on the structure of SU(3) state so that the mass would be different. This difference should be very small.

2. Dynamical SU(3) could be broken so that wormhole contacts with different genera for the throats would be more massive than those with the same genera. This would give SU(3) singlet and two neutral states, which are analogs of $\eta\prime$ and η and π^0 in Gell-Mann's quark model. The masses of the analogs of η and π^0 and the the analog of $\eta\prime$, which I have identified as standard weak boson would have different masses. But how large is the mass difference?

3. These 3 states are expected top have identical mass for the same p-adic mass scale, if the mass comes mostly from the analog of hadronic string tension assignable to magnetic flux tube. connecting the two wormhole contacts associates with any elementary particle in TGD framework (this is forced by the condition that the flux tube carrying monopole flux is closed and makes a very flattened square shaped structure with the long sides of the square at different space-time sheets). p-Adic thermodynamics would give a very small contribution genus dependent contribution to mass if p-adic temperature is $T = 1/2$ as one must assume for gauge bosons ($T = 1$ for fermions). Hence 2.95 TeV state could indeed correspond to this kind of state.

2.2 The sign and size of the effect is correct

Could the exchange of massive $M_{G,79}$ photon and Z^0 give rise to additional electromagnetic interaction inducing the breaking of Universality? The first observation is that the binding energy of S-wave state increases but there is practically no change in the energy of P wave state. Hence the effective charge radius r_p as deduced from the parameterization of binding energy different terms of proton charge radius indeed decreases.

Also the order of magnitude for the effect must come out correctly.

1. The additional contribution in the effective Coulomb potential is Yukawa potential. In S-wave state this would give a contribution to the binding energy in a good approximation given by the expectation value of the Yukawa potential, which can be parameterized as

$$V(r) = g^2\frac{e^{-Mr}}{r} \quad , \quad g^2 = 4\pi k\alpha \quad . \tag{2.1}$$

. The expectation differs from zero significantly only in S-wave state characterized by principal quantum number n. Since the exponent function goes exponentially to zero in the p-adic length scale associated with 2.9 TeV mass, which is roughly by a factor 32 times shorter than intermediate boson mass scale, hydrogen atom wave function is constant in excellent approximation in the effective integration volume. This gives for the energy shift

$$\begin{aligned} \Delta E &= g^2|\Psi(0|^2 \times I \ , \\ |\Psi(0|^2 &= \frac{2^2}{n^2}\frac{1}{a_0^3} \ , \ a_0 = \frac{1}{m\alpha} \ , \\ I &= \int \frac{e^{-Mr}}{r} r^2 dr d\Omega = \frac{4\pi}{M^2} \ . \end{aligned} \tag{2.2}$$

For the energy shift and its ratio to ground state energy

$$E_n = \frac{\alpha^2}{2n^2} \times m \tag{2.3}$$

on obtains the expression

$$\begin{aligned} \Delta E_n &= \frac{64\pi^2\alpha}{n^2}\alpha^3(\frac{m}{M})^2 \times m \ , \\ \frac{\Delta E_n}{E_n} &= 2^7\pi^2\alpha^2k^2(\frac{m}{M})^2 \ . \end{aligned} \tag{2.4}$$

For $k = 1$ and $M = 2.9$ TeV one has $\Delta E_n/E_n \simeq 8.9 \times 10^{-11}$ for muon.

Consider next Lamb shift.

1. Lamb shift as difference of energies between S and P wave states (see `https://en.wikipedia.org/wiki/Lamb_shift`) is approximately given by

$$\frac{\Delta_n(Lamb)}{E_n} = \frac{13\alpha^3}{2n} \ . \tag{2.5}$$

For $n = 2$ this gives $\Delta_2(Lamb)/E_2 = 4.9 \times 10^{-7}$.

2. Recall that the previous parameterization for the theoretical Lamb shift reads as

$$\Delta E(r_p(th)) = a - br_p^2 + cr_p^3 = 209.968(5)5.2248 \times r_p^2 + 0.0347 \times r_p^3 \ meV \ . \tag{2.6}$$

where the charge radius $r_p = .8750$ is expressed in femtometers and energy in meVs.

3. The reduction of r_p by 3.3 per cent allows to estimate the reduction of Lamb shift (attractive additional potential reduces it). The relative change of the Lamb shift is

$$\begin{aligned} x &= \frac{\Delta E(r_p(th)) - \Delta E(r_p(exp))}{\Delta E(r_p(th))} \\ &= \frac{5.2248 \times (r_p^2(th) - r_p^2(exp)) + 0.0347 \times (r_p^3(th) - r_p^3(exp))}{209.968(5)5.2248 \times r_p^2(th) + 0.0347 \times r_p^3(th)} \quad . \end{aligned} \tag{2.7}$$

The estimate gives $x = 1.2 \times 10^{-3}$.

This value can be compared with the prediction. For $n = 2$ ratio of $\Delta E_n/\Delta E_n(Lamb)/$ is

$$x = \frac{\Delta E_n}{\Delta E_n(Lamb)} = k^2 \times \frac{2^9\pi^2}{13\alpha} \times (\frac{m}{M})^2 \quad . \tag{2.8}$$

For $M = 2.9$ TeV the numerical estimate gives $x \simeq k^2 \times 10^{-4}$. The value of x deduced from experimental data is $x \simeq 1.2 \times 10^{-3}$. For $k = 3$ a correct order of magnitude is obtained. There are thus good hopes that the model works.

The contribution of Z_1^0 exchange is neglected in the above estimate. Is it present and can it explain the discrepancy?

1. In the case of deuterium the weak isospins of proton and deuterium are opposite so that their contributions to the Z_1^0 vector potential cancel. If Z_1^0 contribution for proton can be neglected, one has $\Delta r_p = \Delta r_d$.

   One however has $\Delta r_p \simeq 2.75\Delta r_d$. Hence Z_1^0 contribution to Δr_p should satisfy $\Delta r_p(Z_1^0) \simeq 1.75 \times \Delta r_p(\gamma_1)$. This requires $\alpha_{Z,1} > \alpha_1$, which is true also for the ordinary gauge bosons. The weak isospins of electron and proton are opposite so that the atom is weak isospin singlet in Abelian sense, and one has $I_p^3 I_\mu^3 = -1/4$ and attractive interaction. The condition relating r_p and r_Z suggests

$$\frac{\alpha_{Z,1}}{\alpha_1} \simeq \frac{28}{6} = 4 + \frac{1}{3} \quad .$$

   In standard model one has $\alpha_Z/\alpha = 1/[sin^2(\theta_W)cos^2(\theta_W)] = 5.6$ for $sin^2(\theta_W) = .23$. One has upper bound $\alpha_{Z,1}/\alpha_1 \geq 4$ saturated for $sin^2(\theta_{W,1}) = 1/2$. Weinberg angle can be expressed as

$$sin^2(\theta_{W,1}) = \frac{1}{2}\left[1 - \sqrt{1 - 4\frac{\alpha_1}{\alpha_{Z,1}}}\right] \quad .$$

   $\alpha_{Z,1}/\alpha_1 \simeq 28/6$ gives $sin^2(\theta_{W,1}) = \frac{1}{2}[1 - \sqrt{1/7}] \simeq .31$.

   The contribution to the axial part of the potential depending on spin need not cancel and could give a spin dependent contribution for both proton and deuteron.

2. If the scale of α_1 and $\alpha_{Z,1}$ is that of $\alpha_s \simeq .1$ at TeV energy scale and if the factor 2.75 emerges in the proposed manner, one has $k^2 \simeq 2.75 \times 10 = 27.5$ rather near to the rough estimate $k^2 \simeq 27$ from data for proton. This would give $\alpha_1 \simeq 1/13.7$.

   Note however than there are mixing angles involved corresponding to the diagonal hermitian family charge matrix $Q = (a, b, c)$ satisfying $a^+b^2 + c^2 = 1$ and the condition $a + b + c = 0$ expressing the orthogonality with electromagnetic charge matrix $(1, 1, 1)/\sqrt{3}$ expressing electroweak universality for ordinary electroweak bosons. For instance, one could have $(a, b, c) = (0, 1, -1)/\sqrt{2}$ for the second generation and $(a, b, c) = (2, -1, -1)/\sqrt{6}$ for the third generation. In this case the above estimate would would be scaled down: $\alpha_1 \rightarrow 2\alpha_1/3 \simeq 1/20.5$.

To sum up, the proposed model is successful at quantitative level allowing to understand the different changes for charge radius for proton and deuteron and estimate the values of electroweak couplings of the second generation of weak bosons apart from the uncertainty due to the family charge matrix. Muon's magnetic moment anomaly and decays of neutral B allow to test the model and perhaps fix the remaining two mixing angles.

REFERENCES

Particle and Nuclear Physics

[C1] Lamb shift. Available at: `http://en.wikipedia.org/wiki/Lamb_shift`.

[C2] Pohl R et al. The size of proton. *Nature.* Available at: `http://www.nature.com/nature/journal/v466/n7303/full/nature09250.html`, 466, 2010.

[C3] Pohl R et al. The CREMA Collaboration. Laser spectroscopy of muonic deuterium. *Science.* *http://science.sciencemag.org/content/353/6300/669*, 353(6300):669–673, 2016.

[C4] Flowers J. Quantum electrodynamics: A chink in the armour? *Nature.* Available at: `http://www.nature.com/nature/journal/v466/n7303/pdf/466195a.pdf`, 466, 2010.

[C5] McAlpine K. Incredible shrinking proton raises eyebrows. Available at: `http://tinyurl.com/3yf4n77`, 2010.

Books related to TGD

[K1] Pitkänen M. New Particle Physics Predicted by TGD: Part I. In *p-Adic Physics*. In online book. Available at: `http://tgdtheory.fi/public_html/padphys/padphys.html#mass4`, 2006.

[K2] Pitkänen M. New Particle Physics Predicted by TGD: Part II. In *p-Adic Physics*. In online book. Available at: `http://tgdtheory.fi/public_html/padphys/padphys.html#mass5`, 2006.

[K3] Pitkänen M. SUSY in TGD Universe. In *p-Adic Physics*. In online book. Available at: `http://tgdtheory.fi/public_html/padphys/padphys.html#susychap`, 2012.