Dynamically generated masses from simple rotations: the 125 GeV Higgs and the 174 GeV top quark

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Abstract: A hypothesis that Higgs field is an effective, composite field obtained from rotational dynamics involving Standard Model (SM) third generation quarks is addressed using a semi classical approach. The 125 GeV Higgs mass and top quark Yukawa coupling close to one are "predicted" based on a single SM parameter, namely the Z mass. Proposed dynamics is consistent with an equal strength of gluon and scalar mediated attractive top - anti-top scattering at the Z mass. Presented model is also compatible with the Composite Particles Model (CPM) in *unbroken* electroweak (EW) phase. The CPM's largest Yukawa coupling is one third of the SM top quark Yukawa coupling hence warranting cancellation of leading order corrections to scalar potential in both 2D and 4D theory. This supports dimensional transmutation and EW symmetry breaking "driven" by slow logarithmic running of coupling constants. It suggests that Higgs and top quark may not be elementary particles.

1. Introduction

The Standard Model (SM) Higgs mechanism, the simplest theoretical model providing rationale for mass generation, is in a very good agreement with experiments. However, the Higgs field can be an elementary field or it can be an effective, possibly simplifying representation of more complex dynamics yet awaiting to be discerned.

One of the challenges for dynamical models is to have both Higgs mass and top quark mass in agreement with experiment. For example, in models with dynamical mass generation [1-3] and top condensate [4-7] electroweak symmetry breaking (EWSB), as first emphasized by Nambu, one expects the Higgs mass on the order of two top quark masses.

Strong dynamics models typically assume condensation of elementary half spin fermion constituents. These constituents may be non-SM particles, e.g. Techni-quarks interacting via new strong Techni-color forces [8], or they may be SM particles, e.g. third generation quarks interacting via non-SM forces [9,10]. The fermion mass terms, and especially those related to heavy top quark may introduce among other unwanted flavor-changing neutral currents, excessive weak isospin violations and large contributions to R_b [10].

Here, it is hypothesized that there is no fundamental Higgs and that ground state is best characterized at high energies with simple rotational dynamics of third generation quarks glued together by strong QCD force. The composite rotational structure may be due to natural dynamics of SM gauge fields, as assumed here, or it may be consequence of more exotic space-time wrinkles, new fundamental interactions, fundamental property of quantum fields or something else.

At low energies this rotational dynamics may be ignored and effective *Granular field* may be proposed to compensate for this ignorance. The effective *Granular field* must provide repulsive force between constituents to accommodate for missing centrifugal term. However, instead of *Granular field* it is easier to consider the complementary effective Higgs field that fills all space between rotational dipoles. Higgs field hence must mediate attractive force between fermions (as conventional Higgs indeed does; Yukawa interactions are always attractive) and the magnitude of this force should match centrifugal force and hence the magnitude of strong QCD force.

Previous studies [11-13] noted identical interaction strength of gluon and scalar mediated top - anti-top quark scattering at energies equal to the Z mass. However, balance condition has not been well understood as both forces are attractive. However if gluon mediated interactions are assumed to originate from "within" dipole and if scalar mediated interactions are effectively from outside dipole then these two forces can indeed balance each other and provide condition for stable dipole like ground state. If equilibrium distance is increased the attractive gluons' coupling increases (infrared slavery) and if equilibrium distance decreases the "repulsive" *Granular field* coupling or equivalently "attractive" top Yukawa coupling increases.

Here, dynamic "ground" state involving third generation quarks is proposed. It is characterized by an effective repulsive force counteracting strong attractive QCD force within small space-time volumes. Large number of these space-time granules is expected to dress physically realizable states. It is further hypothesized that at large scales this dynamic "ground" state can be equivalently represented as an effective all-embracing Higgs field surrounding granular "ground" state impurities. This scalar field is characterized by conventional attractive force. Therefore, equal strength at energies equal to the Z mass can be thought of as a consequence of matching the effective overarching Higgs scalar field with a localized granular dynamics.

A problem with dynamical mechanisms involving third generation quarks and embedded in a top color scheme is that they naturally predict too large dynamical mass of top quark [14]. For example, if the compositeness scale, the scale of new physics, is not very large, then the dynamical mass is around 600 GeV—as implied by the Pagels-Stokar relationship [15] (with the fixed vacuum expectation ~246 GeV, of the composite scalar field). One way to resolve this problem is to lower largest Yukawa coupling and hypothesize that top quark is composite particle too.

The proposed rotational dynamics model is compatible with the Composite Particles Model (CPM) [11-13] with only SM type of elementary fields and largest Yukawa coupling equal to one third of the SM top quark Yukawa coupling; in unbroken electroweak (EW) phase leading order quantum corrections to scalar potential cancel out in both 2D and 4D theory, potentially in agreement with slow logarithmic running of coupling constants responsible for dimensional transmutation, and motivating the CPM hypothesis that Higgs and top are composite particles in broken EW phase.

The CPM model structure has been matched with effective SM with standard top Yukawa coupling in broken EW phase [11-13]. Characteristic mass equation self-consistently relating scalar and top quark masses with EW gauge boson masses was obtained based on an analysis of quantum corrections. The heaviest mass matched theoretical upper bound for SM Higgs mass, ~230 GeV, obtained from requirement that there is single Higgs mass zero crossing at high energies [17]. Out of infinitely many discrete solutions only two lowest scalar masses are found to contribute to linear mass mixing resulting in the physical Higgs mass. Mixing was introduced via

Bose-Einstein statistics characterized with temperature approximated with the W mass. Reason for only two lowest mass states and the specified temperature has not been provided [11-13].

Rationale for an effective potential in massless phase proportional to r^{-2} is addressed in Section 2. Two lowest energy states are introduced in Sections 3 and 4. The corresponding scalar masses obtained based on a single mass parameter, i.e. the Z mass, are then compared with CPM values. Reason for only two mass states and reason for temperature roughly equal to the W mass are addressed in Section 5. Rationale for an effective potential in massive phase proportional to r^2 is addressed in Sections 5 and 6. Yukawa coupling close to one is obtained in Section 6 as likely consequence of the proposed model.

2. Zero Energy from Dipole Cloud

Consider dynamical particle system, cloud hereafter, instead of fundamental Higgs scalar field. The energy of probe particle is defined as sum of kinetic energy, T_{probe}, and cloud – probe potential, $U_{cloud-probe}$,

$$E_{probe} = < T_{probe} > + < U_{cloud-probe} >. \quad (1)$$

This energy is zero if

$$< T_{probe} > = - < U_{cloud-probe} > \geq 0. \quad (2)$$

According to the Viral theorem cloud-probe attractive potential is an electric dipole like potential, i.e. proportional to an inverse square of distance,

$$U_{cloud-probe} \propto r^{-2} \quad . \quad (3)$$

Here, a probe particle could be any SM physically realizable field. A probe particle could be also a dipole constituent field. Hence, as addressed next, dipole energy can be analyzed locally with only two constituent fields, i.e. without cloud considerations in a leading order.

3. Simple rotation defining light state

Consider pair of massless spin $\frac{1}{2}$ particle and antiparticle rotating with cyclic wavelength $\lambda = 2R\pi$ for radius of rotation R. The corresponding kinetic energy of each fermion is

$$pc = \frac{h}{\lambda} c = \frac{h}{2R\pi} c. \quad (4)$$

Intermediary background bosons form a standing waves across circle's diameter with largest wavelength $4R = \lambda_\Lambda = \frac{h}{M_\Lambda c}$. Here, energy of system is assumed equal to sum of kinetic energies of constituents in an analogy to two marbles connected by string; when string is cut marbles separate while each marble's momentum stays unchanged.

Hence, localized fermion appear as a massive particle with the mass

$$m_f c^2 = \frac{h}{2R\pi} c \tag{5}$$

and same for antiparticle solution. There exists a rest frame and composite scalar particle may decay to massless particle and antiparticle with appropriate energies.

If $2R \sim r_\Lambda = \frac{\lambda_\Lambda}{2} = \frac{h}{2M_\Lambda c}$ then $m_f = \frac{2M_\Lambda}{\pi}$ and the composite scalar particle mass is

$$m_1 = 2m_f = \frac{h}{R\pi c} = \frac{4M_\Lambda}{\pi}. \tag{6}$$

If $M_\Lambda \cong M_Z = 91.2\ GeV/c^2$ then $m_1 \cong \frac{4M_\Lambda}{\pi} \cong 116\ GeV/c^2$.

This solution closely matches $m_1 \cong 2\frac{m_t}{3} \cong 116\ GeV/c^2$composite mass with $m_t \cong 174\ GeV/c^2$, [11-13, 16]. This solution also matches the 2D k=1 mode of full SM quantum field theory calculation in the context of the CPM with $m_H = 113.0\ GeV/c^2$, [11-13]. There, quantum loops could be simply interpreted as classical rotations from higher dimensional (in this case 4D) space.

4. Additional rotations defining heavy state

The mass state, $m_{2,2D}$, in 2D is obtained by superimposing additional rotations with axis of rotation perpendicular to original axis. The corresponding momentum of scalar field with mass m_1 is $\sqrt{m_{2,2D}^2 - m_1^2}\ c$. The de Broglie wavelength

$$\lambda_{scalar} = \frac{h}{\sqrt{m_{2,2D}^2 - m_1^2}\ c} \tag{7}$$

is assumed equal to λ_Λ as condition for stability and assumption that intermediary bosons propagate along the circular path of scalar particle. Hence, it is anticipated that

$$m_{2,2D} = \sqrt{m_1^2 + M_\Lambda^2}\ . \tag{8}$$

If $M_\Lambda \cong M_Z = 91.2\ GeV/c^2$ then $m_{2,2D} \cong \sqrt{m_1^2 + M_\Lambda^2} \cong 148\ GeV/c^2$. However, if figure "8" cyclic condition $\lambda_{scalar} = \frac{4R\pi}{3} = \frac{2R\pi}{3/2} = \frac{\pi}{3}\lambda_\Lambda$ is assumed then $m_{2,2D} \cong 145\ GeV/c^2$.

Alternatively, consider original fermion - anti-fermion system in context of independent rotations about two perpendicular axis. Projecting linear superposition of original motions onto plane formed by two axis of rotation will give motion similar to the simple state with mass m_1. Hence this excited state may be addressed as two vibrating strings or equivalently two 2D particles in an infinite square well potential. The mass excitation along each dimension is $\frac{m_1}{2}$ and strings can vibrate between infinite walls separated by distance

$$r_\Lambda = \frac{\lambda_\Lambda}{2} = \frac{\hbar}{2M_\Lambda c}. \qquad (9)$$

For vibrations along each available dimension the energy is quantized and equal to

$$E_n = \frac{n^2\pi^2\hbar^2}{2\frac{m_1}{2}{r_\Lambda}^2} = \frac{n^2\pi^2\hbar^2}{2\frac{m_1}{2}\frac{\hbar^2}{4\,M_\Lambda^2\,c^2}} = \frac{n^2 M_\Lambda^2\,c^2}{m_1}\,. \qquad (10)$$

Hence the lowest energy excitation is interpreted as

$$m_{2,2D} = 2E_1 = \frac{2M_\Lambda^2}{m_1}. \qquad (11)$$

If $M_\Lambda \cong M_Z = 91.2\ GeV/c^2$ then $m_{2,2D} = 143.4\ GeV$.

This solution closely matches the 2D k=2 mode of full SM quantum field theory calculation in the context of the CPM with $m_H = 143.4\ GeV/c^2$. There, the quantum loops could be simply interpreted as classical rotations from higher dimensional (in this case 4D) space. Hence, k=2 mode corresponds to two possible rotations. This explains why no independent contributions from k=3 or higher modes are used for the Higgs mass mixing [11-13].

5. Unobservable vacuum temperature: mixing of light and heavy scalar states

In 4D theory the physical scalar is expected to appear as superposition of m_1 and $m_{2,4D} = 3m_1$, obtained by rotational dynamics about all three spatial axis. It is impossible to invoke only rotations about two axis without invoking rotations about third axis, hence there is no $2m_1$ state. The ratio of masses closely relates to ratio of energies of $L = 2$ and $L = 1$ quantum rotor states.

In 2D theory two states corresponds to m_1, state with plane of rotation perpendicular to single spatial direction of 2D theory and to $m_{2,2D}$, with two axis of rotation perpendicular to single spatial direction of 2D theory (which effectively can form m_1 state in plane perpendicular to single spatial direction of 2D theory plus two vibrating strings along single spatial direction of 2D theory).

Imagine next that temperature is defined with unspecified "background" *massless* particles that carry identical energy per particle in the local center of mass frame. The fast "background" *massless* particles are in thermal equilibrium with slow (or static) scalar states. If angular distribution of "background" particles' 3-momenta, with identical 3-momentum magnitude, is uniform it follows that temperature is two thirds of their average kinetic energy, $kT = \frac{2}{3}\langle K\rangle$.

Imagine next that pairs of "background" particles are created or absorbed during transition between $m_{2,4D}$ and m_1, with back to back 3-momenta in the center of mass frame. Hence, each 3-momentum magnitude is $\frac{1}{2}\left(2m_t - \frac{2}{3}m_t\right) = \frac{2}{3}m_t c$ and temperature of background field is $kT = \frac{2}{3}\langle K\rangle = \frac{4}{9}m_t c^2 \sim \frac{v_{EW}}{3} \sim M_W c^2$. This temperature then defines the mixing by application of Bose-Einstein distribution on scalar sector with difference between energy and chemical potential of the form $\epsilon - \mu = mass\ c^2$. Hence, the physical mass of scalar field in 4D is

$$m_{H,4D} = \frac{\frac{m_1}{e^{\frac{m_1 c^2}{kT}}-1} + \frac{m_{2,4D}}{e^{\frac{m_{2,4D} c^2}{kT}}-1}}{\frac{1}{e^{\frac{m_1 c^2}{kT}}-1} + \frac{1}{e^{\frac{m_{2,4D} c^2}{kT}}-1}}. \tag{12}$$

Note that masses are added linearly to describe mixing between fast "background" *massless* particles and slow (or static) scalar states. Physical state is thought of as collective phenomena involving both slow "background" *massless* particles and slow (or static) scalar states. If this was mixing only between two scalar states within Lagrangian the masses would be added in quadrature.

For $M_\Lambda \cong M_Z = 91.2\ GeV/c^2$, $m_1 \cong \frac{4M_\Lambda}{\pi} \cong 116\ GeV/c^2$, $m_{2,4D} \cong 3m_1 \cong \frac{12M_\Lambda}{\pi} \cong 348\ GeV/c^2$, $kT = \frac{4}{9} m_t c^2 \cong 77.3\ GeV$, one obtains $m_{H,4D} \cong 124.7\ GeV$.

Similarly, one could calculate $m_{H,2D}$ by exchanging $m_{2,4D}$ with $m_{2,2D}$ and by assuming same temperature for both theories. If 2D theory is true 2D projection of 4D theory then one expects that physical quantities like physical Higgs mass should agree, i.e. $m_{H,2D} = m_{H,4D}$. For $M_\Lambda \cong M_Z = 91.2\ GeV/c^2$, $m_1 \cong \frac{4M_\Lambda}{\pi} \cong 116\ GeV/c^2$, $m_{2,2D} \cong \sqrt{m_1^2 + M_\Lambda^2} \cong 148\ GeV/c^2$, $kT \cong 77.3\ GeV$, one obtains $m_{H,2D} \cong 128.0\ GeV/c^2$. Note that better agreement is obtained with $m_{2,2D} = 143.4\ GeV/c^2$ leading to $m_{H,2D} \cong 126.7\ GeV/c^2$.

Finally, even better agreement is obtained for $kT = M_W \sim \frac{v_{EW}}{3} \cong 82\ GeV$ leading to $m_H \cong 125\ GeV/c^2$ for both 2D and 4D theories [11].

The temperature can be defined with "background" *massless* particles or with massive basis within the non-relativistic framework. Hence, for non-relativistic massive Higgs one expects average energy per particle $< E > = m_H c^2 + \frac{3}{2} kT \cong v_{EW} \cong 246\ GeV$. This is also indicative of quadratic potential, $V \propto r^2$, according to the Viral theorem and in agreement with centrifugal potential, $\frac{1}{2} m\omega^2 r^2$, balancing QCD effective potential discussed next.

6. Top Yukawa coupling close to one

Yukawa forces are always attractive as well as gluon mediated interactions between top and anti-top quark. Hence, although gluon mediated interactions at tree level are exactly equal in strength to scalar mediated interactions between top and anti-top quarks at Z mass these two interactions cannot balance themselves at any energy scale, in difference to what has been suggested elsewhere [11-13]. But, centrifugal forces can balance gluon mediated attractive forces.

Imagine introducing at small energies, i.e. large scales, a fictive repulsive scalar field and a fictive Yukawa coupling that interpret effects of top – anti-top rotational dynamics at large energies, i.e. small scales. This localized non-zero repulsive scalar field could be then exchanged with an attractive overarching "mirror" scalar field. As argued next the top Yukawa coupling close to one might be a simple consequence of that rotational "ground" state.

If massless fermions, top quark and anti-quark, are cycling with the speed of light at radius R such that wavelength corresponds to circumference $2\pi R$ and fictive Yukawa force is assumed mediated over distance $2R$ then matching condition in the case of fundamental Higgs is

$$p\omega = \frac{h}{2\pi R}\frac{c}{R} = \frac{g^2}{4\pi(2R)^2}\left(1+\frac{mc}{h}2R\right)e^{-\frac{mc}{h}2R} \qquad (13)$$

with Yukawa coupling g and with mass of effective scalar field m. This equation equates centrifugal force on the left-hand side with standard (up to sign) Yukawa force on the right-hand side. Though $(1+x)e^{-x} \approx 1$ for $x \ll 1$ it is important to keep track of mass. For $m = 0$ one obtains $g \cong 2\sqrt{2}$. For $\frac{h}{4R} = M_\Lambda \cong M_Z = 91.2\ GeV/c^2$ and $m = m_1 \cong \frac{4M_\Lambda}{\pi} \cong 116\ GeV/c^2$ one obtains $g \cong 3 > 1$.

What went wrong? Note that it was assumed that Higgs is fundamental field.

Imagine next that Higgs is not a fundamental field. In that case the composite scalar field could have been originated from different plane of rotations, and there are π of those (that contain scalar propagator 3D momentum), and there are N=3 colors that could have independently contributed. Hence, in the case of composite Higgs, correct matching is

$$p\omega = \frac{h}{2\pi R}\frac{c}{R} = \frac{3\pi g^2}{4\pi(2R)^2}\left(1+\frac{mc}{h}2R\right)e^{-\frac{mc}{h}2R} \qquad (14)$$

Now for $m = 0$ one obtains $g \cong \frac{2\sqrt{2}}{\sqrt{3\pi}} \cong 0.92155$. For $\frac{h}{4R} = M_\Lambda \cong M_Z = 91.2\ GeV/c^2$ and $m = m_1 \cong \frac{4M_\Lambda}{\pi} \cong 116\ GeV/c^2$ one obtains $g \cong \frac{2\sqrt{2}}{\sqrt{3\pi}}1.0745 \cong 0.99021$. Finally for $\frac{h}{4R} = M_\Lambda \cong M_Z = 91.2\ GeV/c^2$ and $m = 125\ GeV/c^2$ one obtains $g \cong \frac{2\sqrt{2}}{\sqrt{3\pi}}1.0851 \cong 0.99997$.

The additional important subtlety is that this Yukawa coupling, corresponding to heaviest fermion, corresponds to “scalar” field that is limited in propagation to single direction perpendicular to fermion momentum. However there are three linearly independent “scalar" fields of this kind and each contributes same amount to the “vacuum expectation value”, $\cong \frac{v_{EW}}{3}$. They add linearly both for the top quark mass and for Z, W boson masses (all three polarizations receive the same amount by symmetry argument).

Hence, the Yukawa coupling being close to one seems to be an inevitable feature of this model with Higgs field being an effective composite field, i.e. just an interpretation of simple rotational dynamics in agreement with the 125 GeV Higgs mass.

7. Conclusion

Several relationships between experimentally measured, fundamental parameters of the SM are obtained as prediction of the rotational model. This model suggests that scalar sector of the SM is simple representation of large number of dynamical, localized granules. Rotational model suggests that the top – anti-top pairs define condensates leading to an effective scalar field at large scales.

In the SM the M_Z is defined by $U(1) \times SU(2)$ gauge couplings and v_{EW}. Here M_Z is defined by strength of $SU(3)$ and v_{EW} it is obtained as a consequence of the theory. Hence this suggests that all three gauge couplings of SM are entangled and leading to dimensional transmutation. Future studies will address if gauge sector of the theory needs to be revised in the context of the rotational “ground” state of the theory.

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