Predictive electroweak gauge model with strong spontaneous-symmetry-breaking dynamics

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Standard argumentation: There is nothing wrong with the Higgs mechanism as the origin of particle masses in SM, except:

(1) It is certainly incomplete:
- (a) neutrinos are massive
- (b) there is the dark matter
- (c) in quantum description fermion masses should be calculable

(2) It is perhaps phenomenological (pointed out by its authors !)
- (a) Higgs field is the fermion-anti-fermion composite
- (b) i.e., there is a new strong force; exceedingly difficult to handle. We defend ourselves by the Jesuit credo (F. Wilczek): "It is more blessed to ask forgiveness than permission"

Our basic references

- H. Pagels and S. Stokar, Phys. Rev.D20, 2947(1979), A. Carter and H. Pagels, Phys. Rev. Lett.43, 1845(1979) :

Analyzed consequences of an unspecified new 'quantum flavor dynamics' (QFD):

(1) Fermion masses (self-energies $\Sigma(p^2)$): finite and calculable (no counter-terms).

(2) Fermion masses m_f break spontaneously $SU(2)_L x U(1)_Y$ to $U(1)_{em}$.

(3) Hence, m_W, $m_Z \sim m_f$ (composite 'would-be' NG bosons) .

(4) Hence, the composite Higgs particle (symmetry partner).

We take the liberty of using the name QFD also for our strong dynamics.

- Famous heuristic nonrealistic (4f) „prototype" examples: BHL(1990), MTY(1989).

- T. Yanagida in Phys.Rev.D20,2986(1979):
- Gauge the flavor $SU(3)_f$ (family, generation, horizontal) symmetry; put all SM chiral fermion fields in triplets. Anomaly freedom demands one triplet of ν_R.

$$\boxed{L=-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \overline{q}_L iDq_L + \overline{u}_R iDu_R + \overline{d}_R iDd_R + \overline{l}_L iDl_L + \overline{e}_R iDe_R + \overline{\nu}_R iD\nu_R +} \text{ Higgs sector}$$

T. Yanagida's suggestion: NO ELEMENTARY HIGGS FIELDS (just 8 flavor gluons)

"…the model is a possible candidate for the spontaneous mass generation by dynamical symmetry breaking…(NJL)" OUR TASK

The attempt is immodest:
Just one free parameter in the $SU(3)_f \times SU(2)_L \times U(1)_Y$ gauge model :
Λ, e, $\sin\theta_W$, Q_i , $i = \nu, l, u, d$.
In words we proceed in the following steps (violet – degree of reliability) :

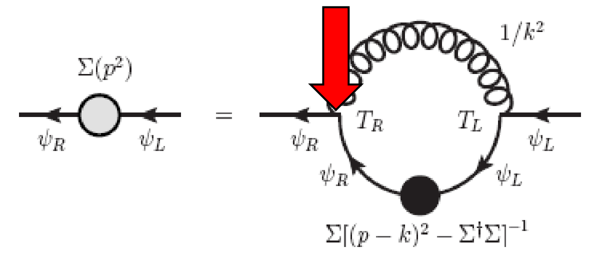
I. Strong-coupling SD equation of QFD generates spontaneously (in separable approximation for the kernel) 3 Majorana masses of ν_{fR} $M_{fR} \sim \Lambda$ and three Dirac masses m_f of the SM fermions degenerate in f, exponentially small w.r.t. Λ. (Yanagida is co-father of seesaw and baryogenesis via leptogenesis) LARGE UNCERTAINTY DUE TO THE STRONG COUPLING.

II. Goldstone theorem implies masses of all flavor gluons $\sim \Lambda$ and m_W, m_Z $\sim \Sigma m_f$ (the induced Fermi scale). VERY CONVINCING.

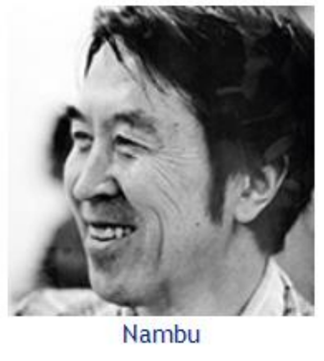
III. Symmetry partners of the composite 'would-be' NG bosons are the composite Higgs particles (the NJL idea): VERY PLAUSIBLE.

IV. SM fermion mass splitting in f is attributed to new $\Sigma_f(p^2)$-dependent vertices which necessarily emerge in the electroweak WT identities. CONFIRMED by computing m_W, m_Z ; NATURAL BUT VERY FRAGILE.

In formulas: I. Dynamical generation of Majorana and Dirac masses by QFD



vertices
entirely unknown
in the infrared


Nambu

Schwinger-Dyson (gap) equation (L-R bridge)

left-handed field !

- Majorana masses of ν_{fR} : $\overline{\nu_{fR}}\Sigma_{fg}(p^2)\ (\nu_{gR})^C$ $3^* \times 3^* = 3_a + 6^*_s$

hard Majorana masses STRICTLY PROHIBITED by QFD : key point

- Dirac masses of SM fermions

$\overline{\Psi_{fR}}\Sigma_{fg}(p^2)\psi_{gL}$ $3^* \times 3 = 1 + 8$ hard Dirac masses STRICTLY PROHIBITED by EW symmetry.

Dirac mass is identical for all fermion species in f.
Fermion masses are ultimately the calculable multiples of Λ.
(like hadron masses in QCD in the chiral limit)

Make Wick rotation, fix the external momentum p=(p,0,0,0), and integrate over angles. Integrate only up to Λ at which the coupling becomes small. Set the known asymtotically free coupling to zero: The model thus becomes not asymptotically, but strictly free above Λ. :

$$\Sigma(p) = \int_0^\Lambda k^3 dk K_{ab}(p,k) T_a(R) \Sigma(k) [k^2 + \Sigma^+ \Sigma]^{-1} T_b(L)$$

For unknown kernel make the BCS-motivated separable Ansatz

$$\boxed{K_{ab}(p,k) = \frac{3}{4\pi^2} \frac{g_{ab}}{pk}}$$

- Ansatz supported by the NJL analyses of P. Mannheim, Phys. Lett. B773(2017)604 and references therein.

- g_{ab} are the effective low-energy constants. The integral equation is immediately 'solved': the momentum dependence is $\Sigma \sim 1/p$. The difficult part is to solve the non-linear algebraic equation for the matrix structure. Neglecting the flavor mixing we obtain

Majorana masses: $\Sigma_f(p^2)=M^2_{fR}/\not{p}$ M_{fR} must be huge

$M_{fR} \sim \Lambda \sim 10^{14}$ GeV $\bar{\nu}_R \Sigma_R (\nu_R)^C$

Family-degenerate Dirac masses: $\Sigma_f(p^2)=m^2_f/\not{p}$

fortunately there are the electroweak interactions

$m_f = \Lambda \, \exp\,(-1/4\alpha_{\mathrm{f}})$ $\bar{f}_R \Sigma_D f_L$

$$\begin{aligned}
\alpha_1 &= \frac{3}{64\pi^2}\left(g_{33} + \frac{2}{\sqrt{3}} g_{38} + \frac{1}{3} g_{88}\right) \\
\alpha_2 &= \frac{3}{64\pi^2}\left(g_{33} - \frac{2}{\sqrt{3}} g_{38} + \frac{1}{3} g_{88}\right) \\
\alpha_3 &= \frac{3}{64\pi^2}\frac{4}{3} g_{88}
\end{aligned}$$

II. Which symmetry is spontaneously broken by the dynamically generated Majorana masses M_{fR} ?
III. What are the NG boson symmetry partners ?

1. M_{fR} breaks spontaneously the symmetry $SU(3)_f \times U(1)$ of the sterile neutrino sector at the scale Λ completely. Hence, there are eight 'would-be' NG bosons (eight flavor gluons with masses $\sim \Lambda$) and one pseudo-NG boson.

(i) They are seen as the massless poles in WT identities.

(ii) Both scalars and pseudoscalars! Chiral symmetry.

(iii) NG bosons belong to the composite complex sextet of $SU(3)_f \times U(1)$. As $2\text{x}6=12=8+1+3$, there should be (referring to NJL) in the spectrum 3 superheavy ($\sim\Lambda$) Higgs bosons χ_i and one very light pseudo-NG boson, all composed of the right-handed neutrinos.

II. Which symmetries are spontaneously broken by the dynamically generated Dirac masses m_f? $m_f = m_{(0)}\lambda_0 + m_{(3)}\lambda_3 + m_{(8)}\lambda_8$

III. What are the NG boson symmetry partners ?

1. $m_{(0)}$ is allowed by $SU(3)_f$ symmetry, but is strictly prohibited by $SU(2)_L xU(1)_Y$ which it breaks spontaneously down to unbroken $U(1)_{em}$. Hence, there are three 'would-be' NG bosons: m_W, $m_Z \sim m_{(0)} \sim \Sigma m_f$.

(i) They are visible as the massless poles in EW WT identities (shown later).

(ii) NG bosons belong to the composite multi-component complex doublet of $SU(2)_L xU(1)_Y$. As 2x2 = 4 = 3 +1, there should be in the spectrum one Higgs boson h at the Fermi scale $m_{(0)} \sim \Sigma m_f$, composed of the SM fermions.

(iii) Such a particle has been July 4, 2012 DISCOVERED at the CERN LHC !!! Hence, mandatory post-diction.

II. Which symmetries are spontaneously broken by the dynamically generated Dirac masses m_f? $m_f = m_{(0)}\lambda_0 + m_{(3)}\lambda_3 + m_{(8)}\lambda_8$
III. What are the NG boson symmetry partners ?

2. $m_{(3)}$ and $m_{(8)}$ themselves break $SU(3)_f$ symmetry in the SM sector down to unbroken U(1)xU(1). Hence, there are additional six 'would-be' NG bosons (made of SM fermions)

(i) They are seen as the massless poles in the WT identities.

(ii) NG bosons belong to the composite multi-component real octet of the group $SU(3)_f$. As 8 - 6 = 2, there should be in the spectrum two new Higgs bosons h_3, h_8 at Fermi scale composed of the SM fermions: Our (bona fide reliable) prediction! Peter Higgs, 1964 !

3. $m_{(3)}$ and $m_{(8)}$ break also $SU(2)_L \times U(1)_Y$ symmetry in the SM sector down to unbroken $U(1)_{em}$. Small additional contributions. Deserves further study (mixing of Higgses ?!)

IV. Effects of $\Sigma_f(p^2)$ on EW observables via new vertices of fermions with A,W,Z enforced by WT identities

$\partial_\mu \Gamma^\mu = 0$ in the presence of Σ implies (with some ambiguity):

$$\begin{aligned}
\Gamma^\mu_A(p',p) &= eQ_i[\gamma^\mu - (p'+p)^\mu \Sigma'(p',p)] \\
\Gamma^\mu_W(p',p) &= \tfrac{e}{2\sqrt{2} sin\theta_W}\{[\gamma^\mu - (p'+p)^\mu \Sigma'(p',p)]T^+ - [\gamma^\mu\gamma_5 T^+ - \tfrac{(p'-p)^\mu}{(p'-p)^2}(\Sigma(p')+\Sigma(p))\gamma_5 T^+]\} \\
\Gamma^\mu_Z(p',p) &= \tfrac{e}{sin 2\theta_W}\{[\gamma^\mu - (p'+p)^\mu \Sigma'(p',p)](T^i_{3L} - 2Q_i sin^2\theta_W) - [\gamma^\mu\gamma_5 - \tfrac{(p'-p)^\mu}{(p'-p)^2}(\Sigma(p')+\Sigma(p))\gamma_5] T^i_{3L}\}
\end{aligned}$$

$$\Sigma'(p',p) \equiv \frac{\Sigma(p') - \Sigma(p)}{p'^2 - p^2}$$

Use the new Σ-dependent vertices for computation of:

(1) m_W, m_Z; (2) the splitting of the fermion masses m_f into $m_f{}^i$, $i = \nu, l, u, d$ in terms of known e, Q_i, $\sin\theta_W$, $m_f/m_{W,Z}$

(1) Just reminder:
Use the axial-vector NG vertices in the W,Z polarization-tensor loops (Jackiw, Johnson,…, P. Benes,…, technicolor).

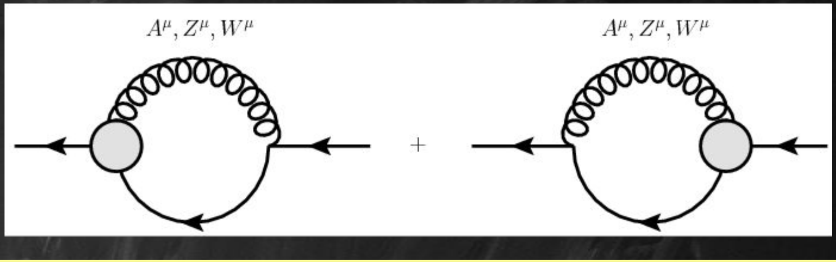
Pagels-Stokar formula

$$\boxed{F_f^2 = 8N \int \frac{d^4p}{(2\pi)^4} \frac{\Sigma_f^2(p^2) - \frac{1}{4}p^2\left(\Sigma_f^2(p^2)\right)'}{\left(p^2 + \Sigma_f^2(p^2)\right)^2}}$$

$$m_W^2 = \tfrac{1}{4}g^2 \tfrac{5}{4\pi} \sum_f m_f^2 \qquad m_Z^2 = \tfrac{1}{4}(g^2 + g'^2) \tfrac{5}{4\pi} \sum_f m_f^2$$

saturation of the sum rule by one mass: $\boxed{m_3 = 390\,\mathrm{GeV}}$

(2) Use the new polar-vector vertices
for computing the fermion
mass splitting in f (Pagels)



$$\Sigma_f^i(p^2) = -i \frac{m_f^2}{\sqrt{p^2}} A^i_f(p^2) + i \sqrt{p^2} B^i_f(p^2)$$

$$\Sigma_f^i \equiv \Sigma_f + \delta^i_{A,Z,W}\Sigma_f$$

where $A^i_f(p^2)$ and $B^i_f(p^2)$ are the explicit well-defined functions.

?1 How can the weakly coupled EW interactions give rise to the observed huge mass m_t–m_b splitting? (hope: nonlinear pole equation☆)

?2 How can the EW interactions, having the IDENTICAL couplings for all three families produce mass splitting not identical for all three families? (hope: dependence upon $m_f/m_{W,Z}$).

Unfortunately, the numerical solution of the pole equation

$$m_f^{i2} = \Sigma_f^{i+}\Sigma_f^i(p^2 = m_f^{i2}) \star$$

yields only the small unrealistic fermion mass splitting

(Bona fide) conclusions (more of a framework or scenario) (We know no way of knowing whether $M_{fR} >> m_f$ is the inherent property of QFD at strong coupling or not)

1. There is no generic electroweak (Fermi) scale. Only huge Λ.
2. Three active neutrinos are the light Majorana fermions.
3. Three superheavy Majorana neutrinos (seesaw,leptogenesis) are on the same footing with other SM fermions.
   Ordinary matter: QCD nucleons qqq;
   dark matter: QFD composites $\nu_R\nu_R\nu_R$.
4. Calculation (post-dictions) of fermion masses hampered by theoretical uncertainties. Neutrino masses predictable in terms of m_f^{ν} and M_{fR} by the seesaw formula.
5. We post-dict the composite Higgs h and predict h_3 and h_8 at Fermi scale: Not all three families are alike.
6. We don't ask forgiveness yet.

Thanks for your attention !