The rôle of neutrinos in the electroweak symmetry breaking

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Idea

- EWSB manifests itself by

$$m_t \doteq 172\,\mathrm{GeV}\,, \quad v \doteq 246\,\mathrm{GeV}\,, \quad M_h \doteq 125\,\mathrm{GeV}$$

- natural suspicion [Ho85,BaHiLi89,MiYa89] is that

$$\boxed{H_t \sim (\bar{t}_R q_L)}$$

- **it works well as an order of magnitude estimate but**
  - top-quark is too light to saturate the electroweak scale
  - prediction of the Higgs boson mass is too off

- **improvement** by additional source of EWSB

$$\boxed{H_\nu \sim (\bar{\nu}_R \ell_L)}$$

  - if seesaw is in work then Dirac neutrino mass can be big enough
  - type I 2HDM - Sister Higgs model [AlFoWe12]
  - lighter Higgs boson can be the $125\,\mathrm{GeV}$ boson particle

Content

1. **simple top-quark condensation model**
   - gap equation for m_t
   - Pagels-Stokar (PS) formula for v
   - Gribov (Gr) approach for M_h
2. **inclusion of neutrino condensation**
   - four-fermion interaction and symmetries
   - type I 2HDM - H_t, H_ν
   - simplifying assumptions - in order to repeat PS and Gr calculations
3. **scale setting**
   - Λ_t from $M_{h_t} = 125\,\mathrm{GeV}$ Higgs boson
   - neutrino parameters m_D, M_R, Λ_ν from $v = 246\,\mathrm{GeV}$
   - neutrino Higgs mass prediction M_{h_ν}
4. **conclusions**
   - motivation by gauge flavor model of EWSB

Top-quark condensation

$$\boxed{H \equiv \begin{pmatrix} (v + h + \pi^0)/\sqrt{2} \\ \pi^- \end{pmatrix} \sim (\bar{t}_R q_L)}$$

- bound together by some new force g (gauge, Yukawa, ...)

which can be effectively described by

$$\mathcal{L}_{4f} = \frac{g^2}{\Lambda_t^2} (\bar{q}_L t_R)(\bar{t}_R q_L)$$

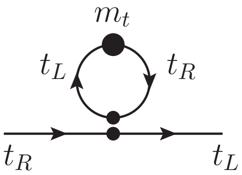
$$\boxed{v \propto \langle \bar{t}t \rangle}$$

Mass of top-quark from gap equation

below Λ_t the dynamics generates:

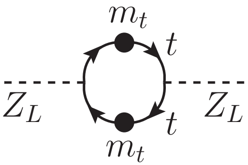
- top-quark mass – SDE

$$\boxed{m_t \equiv \Sigma_t(q^2 = m_t^2; \Lambda_t, g)}$$



Electroweak scale from Pagels-Stokar formula

the mass m_t provides the EWSB:



- W and Z boson masses – PS

$$\boxed{M_W^2 = g_2^2 \mu_W^2(m_t, \Lambda_t)} \text{ and } \boxed{M_Z^2 = (g_1^2 + g_2^2)\mu_Z^2(m_t, \Lambda_t)}$$

- triplet of NGB's forms the longitudinal components of W and Z

- for $m_t \ll \Lambda_t$ $\boxed{\mu_W \cong \mu_Z = v/2}$

Higgs boson mass

- Gribov – composite Higgs boson follows from

$$h \quad \Longleftrightarrow \quad \pi_i \qquad \text{degeneracy at UV}$$

- $M_h \sim m_t \ll \Lambda_t$ follows from h and π_i loop UV cancelation

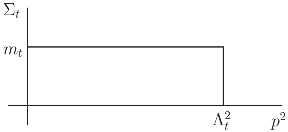
$$\boxed{M_h^2 = f(m_t, \Lambda_t)}$$

- **however** $2m_t < M_h \leq 2m_t$

Does it work?

$$m_t \doteq 172\,\mathrm{GeV}\,, \quad v \doteq 246\,\mathrm{GeV}\,, \quad M_h \doteq 125\,\mathrm{GeV}$$

pure four-fermion interaction



- from m_t and v $\boxed{\Lambda_t \sim 10^{13-14}\,\mathrm{GeV}}$
- $m_t \ll \Lambda_t$ requires fine-tuning $g - g_{\mathrm{crit.}} \to 0^+$

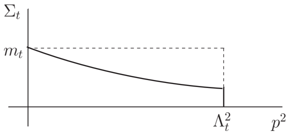
However

- $M_h = 2m_t \doteq 344\,\mathrm{GeV}$
- $\Lambda_{\mathrm{axion}} \sim \Lambda_{\mathrm{quark}}$
  $10^{10}\,\mathrm{GeV} < \Lambda_{\mathrm{axion}} < 10^{12}\,\mathrm{GeV}$ [Ra]
  $\boxed{\Lambda_t < 10^{12}\,\mathrm{GeV}}$

Try to improve

$$m_t \doteq 172\,\mathrm{GeV}\,, \quad v \doteq 246\,\mathrm{GeV}\,, \quad M_h \doteq 125\,\mathrm{GeV}$$

by including QCD effect



taking $\alpha_s(m_t^2) \doteq 0.11$

Λ_t [GeV]	10^{10}	10^{19}	10^{42}
v [GeV]	140	168	194
M_{h_t} [GeV]	258	231	205

However

- Higgs boson is too light
- top-quark is too light to saturate v alone

Invoke other fermions heavy enough

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- technicolor q_{TC}

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- fourth generation q_4

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- technicolor $q_{\rm TC}$
- fourth generation q_4

but if we believe in seesaw

- neutrino Dirac mass $m_D \propto \langle \overline{\nu_L} \nu_R \rangle + \mathrm{h.c.} \ \sim v$ [Ma91,AnKeLiRa03]

$$\Sigma_\nu = \begin{pmatrix} 0 & \Sigma_D \\ \Sigma_D & M \end{pmatrix} \quad \mathrm{at} \ \ \Lambda_\nu$$

if we want $m_\nu \sim 0.2\,\mathrm{eV}$ and $m_D \ \sim v$ $\boxed{M \sim 10^{13-14}\,\mathrm{GeV}}$

neutrino condensation condition $\boxed{M < \Lambda_\nu}$ otherwise they decouple

Underlying dynamics

$$\mathcal{L}_{4f} = G_t(\bar{t}_R q_L)(\bar{q}_L t_R) + G_\nu(\sum_s \bar{\nu}_{Rs}\ell_L)(\sum_s \bar{\ell}_L \nu_{Rs}),$$

$$\mathcal{L}_M = M\overline{\nu^c_{Rs}}\nu_{Rs}$$

$$\boxed{\left[\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y\right]_q \times \left[\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y\right]_\ell}$$

t and ν condensation generates Σ_t and Σ_ν which breaks the symmetry down to

$$\left[\mathrm{U}(1)_{\mathrm{em}}\right]_q \times \left[\mathrm{U}(1)_{\mathrm{em}}\right]_\ell$$

two sets of NG bosons and **two Higgs bosons**

Two Higgs doublets interpretation

$$H_t \sim (\bar{t}_R q_L)\,, \quad H_\nu \sim (\sum_s \bar{\nu}_{Rs} \ell_L)$$

It looks like the Type I 2HDM with sister Higgs.[AlFoWe12]

$$\begin{aligned} \mathcal{V}(H_t, H_\nu) &= -\mu_t^2 H_t^\dagger H_t - \mu_\nu^2 H_\nu^\dagger H_\nu + \lambda_t (H_t^\dagger H_t)^2 \\ &\quad +\lambda_\nu (H_\nu^\dagger H_\nu)^2 + \lambda_{t\nu} (H_t^\dagger H_t)(H_\nu^\dagger H_\nu)\,. \end{aligned}$$

$$\mathcal{V}_{\mathrm{soft}} = -\mu_{t\nu}^2 H_t^\dagger H_\nu$$

Top-quark and neutrino condensation conspiracy

$$\langle H_t \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} v_t \\ 0 \end{pmatrix}, \quad \langle H_\nu \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} v_\nu \\ 0 \end{pmatrix}, \quad \boxed{v = \sqrt{v_t^2 + v_\nu^2}}$$

$$H_{f=t,\nu} = \begin{pmatrix} (v_f + h_f + \pi_f^0)/\sqrt{2} \\ \pi_f^- \end{pmatrix}.$$

mass matrices for the bound states

$$M_\pi^2 = \frac{1}{2}\mu_{t\nu}^2 \begin{pmatrix} \frac{v_\nu}{v_t} & -1 \\ -1 & \frac{v_t}{v_\nu} \end{pmatrix}$$

$$M_h^2 = \begin{pmatrix} 2v_t^2\lambda_t + \frac{v_\nu}{2v_t}\mu_{t\nu}^2 & v_t v_\nu \lambda_{t\nu} - \frac{\mu_{t\nu}^2}{2} \\ v_t v_\nu \lambda_{t\nu} - \frac{\mu_{t\nu}^2}{2} & 2v_\nu^2\lambda_\nu + \frac{v_t}{2v_\nu}\mu_{t\nu}^2 \end{pmatrix}$$

- **simplification** by no-mixing condition: $\lambda_{t\nu} = \frac{\mu_{t\nu}^2}{2v_t v_\nu}$

$$\boxed{M_\pi^2 = \lambda_{t\nu} v^2} \qquad \lambda_{t\nu} > 1$$

Parameters of the model

- **input**

  $m_t \doteq 172\,\mathrm{GeV}\,, \quad v \doteq 246\,\mathrm{GeV}\,, \quad M_h \doteq 125\,\mathrm{GeV}\,, \quad m_\nu \doteq 0.2\,\mathrm{eV}$

- **constrained output**
  - $m_D(M) \sim v$
  - $\Lambda_t \leq \Lambda_{\mathrm{axion}}$
  - $\Lambda_{\mathrm{Planck}} > \Lambda_\nu > M$

- **“prediction”**
  - interval of M_{h_ν}

Top-quark condensation scale from top-Higgs mass

light Higgs boson mass:

$$M_{H_t} \doteq 125\,\mathrm{GeV} \qquad \boxed{\Lambda_t = 10^{6.5}\,\mathrm{GeV}}$$

electroweak scale:

$$v = \sqrt{v_t^2 + v_\nu^2} \doteq 246\,\mathrm{GeV}$$

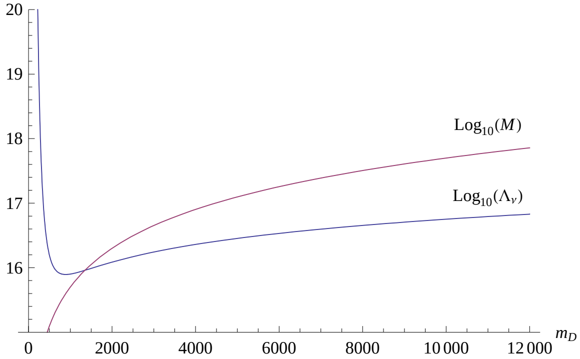
$$m_t,\ \Lambda_t \quad \Longrightarrow \quad \boxed{v_t \doteq 112\,\mathrm{GeV}}$$

the rest is left for neutrinos

Neutrino condensation scale and right-handed neutrino mass fixing

From

$$v = \sqrt{v_t^2 + v_\nu^2} \doteq 246\,\mathrm{GeV}$$



$$\Lambda_\nu^2 = \left(\mathrm{e}^{\frac{8\pi^2 (v^2 - v_t^2)}{3 m_D}} - 1 \right) \frac{m_D^4}{m_\nu^2}$$

$$M = \frac{m_D^2}{m_\nu}$$

Neutrino-Higgs mass

$$M_{h_\nu}^2 = \frac{3m_D^2}{2\pi^2 v^2}\Big[\ln\frac{\Lambda_\nu^2 + M^2}{M^2} - 2\frac{\Lambda_\nu^2}{\Lambda_\nu^2 + M^2}\Big]$$

$\log_{10}(\Lambda_\nu[\mathrm{GeV}])$	16.0	16.6	17.2	17.8
m_D [GeV]	609	403	334	294
$\log_{10}(M[\mathrm{GeV}])$	15.3	14.9	14.7	14.6
M_{h_ν} [GeV]	711	619	539	486

Conclusions

COMMON PREJUDICE

- idea that **standard fermions are behind EWSB** could seem to be old-fashion
- it could seem to fall into category of models ruled out by 1995

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OUR CONCLUSION strong dynamics is not fully understood

- we demonstrated that neutrinos with seesaw mechanism keep it viable
- it is related to the existence of the neutrino-Higgs next to the $125\,\mathrm{GeV}$ top-Higgs
- we were lead by underlying SU(3) gauge flavor strong dynamics which provided us by all necessary ingredients