Little Supersymmetry with heavy sfermions

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SM Hierarchy Problem.

Standard Model provides succesfull description of fundamental interations.

If SM is not a fundamental theory it suffers from the hierarchy problem.

Quadratic divergence in Higgs mass parameter:

$$\delta m^2 = -\frac{3\lambda_t^2}{8\pi^2}\Lambda^2 = -(2\mathrm{TeV})^2$$

$$\delta m^2 = \frac{g^2}{16\pi^2}\Lambda^2 = (700\mathrm{GeV})^2$$

$$\delta m^2 = \frac{\lambda^2}{16\pi^2}\Lambda^2 = (500\mathrm{GeV})^2$$

for $\Lambda = 10$ TeV. It means fine tuning of order of 1%.

SUPERSYMMETRY .

MSSM is the best known solution to the SM hierarchy problem, but:

- The present LEP limits on the lightest Higgs mass pushes the stop masses into $500 - 1000$ GeV range, what require fine tuning of order of 1 %.
- Natural suppresion of FCNC needs heavy squarks $O(10$ Tev).

Impotant question : Is it possible to avoid quadratic dependance of Fermi scale on the stop masses?

Lesson from the Little Higgs theories.

N.Arkani-Hamed, A.Cohen, H.Georgi . . .

- Higgs is the pseudo-Goldston boson of the spontanously broken approximate global symmetry.

$$L = L_0 + \epsilon_1 L_1 + \epsilon_2 L_2$$

  If $\epsilon_1 \to 0$ or $\epsilon_2 \to 0$ Higgs is exact Goldston boson. So all corections to its mass, must be proportional to $\epsilon_1 \epsilon_2$. On the one loop level it means absence of quadratic divergence.

- Constraints from the two loop quadratic divergence:

$$\delta m^2 = \frac{\epsilon_1}{16\pi^2} \frac{\epsilon_2}{16\pi^2} \Lambda^2$$

  If $\epsilon_i \sim 1$, then Λ should be about 10 TeV.

- Examples: $SU(5) \to SO(5)$, $SU(3)^8 \to SU(3)^4$, etc.

  ,, The littlest the Higgs the bigger the group" S.Glashow

Model

Higgs field and third family of quarks are triplets of global SU(3):

$$\hat{\mathcal{H}}_u = \begin{pmatrix} \hat{H}_u \\ \hat{S}_u \end{pmatrix}, \quad \hat{\mathcal{H}}_d^T = \begin{pmatrix} \hat{H}_d \\ \hat{S}_d \end{pmatrix}^T, \quad \hat{\mathcal{Q}}^T = \begin{pmatrix} \hat{Q}_3 \\ \hat{T} \end{pmatrix}^T .$$

SUPO:

$$W = Y_T \hat{\mathcal{Q}} \hat{\mathcal{H}}_u \hat{t}^c + \mu \hat{\mathcal{H}}_d \hat{\mathcal{H}}_u + \mu_T \hat{T}^c \hat{T}$$

Gauge symmetry : $SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_E$

- Approximate $SU(3)$ global symmetry is spontanously broken at 1 TeV to $SU(2)$ subgroup. Higgs dublet is PNGB and is massles at the tree level.
- Gauge interactions and μ_T explicitly break global $SU(3)$.

One loop effective potential.

$$\Delta V_{1-\text{loop}} = \frac{1}{64\pi^2}\mathrm{STr}\left\{\mathcal{M}^4\left(\log\frac{\mathcal{M}^2}{\Lambda^2} - \frac{3}{2}\right)\right\}$$

Mass terms generated by Yukawa interactions :

$$\mathrm{Tr}\mathcal{M}^4_{\text{top}} \sim \mu^2_{\mathrm{T}}\mathrm{h}^2$$

$$\mathrm{Tr}\mathcal{M}^4_{\text{stop}} \sim \mu^2_{\mathrm{T}}\mathrm{h}^2$$

because μ_T is the only $SU(3)$ breaking parameter in Yukawa sector.

$$\mathrm{STr}\mathcal{M}^4 = 0$$

The only possibility:

$$\mathrm{STr}\mathcal{M}^4 \log \mathcal{M}^2 \sim (\mu_T^2 \log m^2_{\tilde{q}})h^2$$

Logarithmic dependence of m_h^2 in $V(h)$ on squark masses.

Global symmetry is also broken by gauge interactions, but in SUSY it causes only logarithmic divergence, and also there is no $g_2^2 m_{sq}^2$ contribution to m_h^2, and we do not have to introduce any complicated gauge group like in Little Higgs models.

SU(3) symmetry breaking

Gauge $U(1)_E$ and global symmetries are broken radiatively by $\langle S_u \rangle \neq 0$,$\langle S_d \rangle \neq 0$, and for large $\tan\beta = \frac{\langle S_u \rangle}{\langle S_d \rangle}$:

$$M_{Z'}^2 = g_E^2 f^2 \approx -\mu^2 + 0.1 m_{\tilde{q}}^2 \log \frac{\Lambda}{m_{\tilde{q}}}$$

If we take $g_E \approx 1$ and minimal allowed value of $f = 2.5$ TeV (from limits on $M_{Z'}$), we will have no fine tuning for $m_{\tilde{q}} \leq 10$ TeV , and $\Lambda \sim 100$ TeV.

Electroweak symmetry breaking

SM Higgs dublet effective potential:

$$V = m^2 h^2 + \lambda h^4 + \kappa h^4 \log \frac{h^2}{m_T^2}$$

m^2, λ and κ are calculable given the scale Λ.

$$\begin{aligned} m_H^2 \approx & -\frac{3}{4\pi^2} y_t^2 m_T^2 \log \frac{m_{\tilde{q}}}{m_T} + \frac{g_y^2}{16\pi^2} \cos(2\beta) \mathrm{Tr}[Y m^2] \log \frac{\Lambda_S}{m_{\tilde{q}}} \\ & + \frac{1}{32\pi^2} \Big[3(3g_2^2 + g_y^2)\mu^2 + 12 g_2^2 M_2^2 + 4 g_y^2 M_y^2 \\ & -4 \sin 2\beta (3 g_2^2 M_2 + g_y^2 M_y)\ \mu \\ & -g_E^2 (3g_2^2 + 4g_y^2) \cos^2 2\beta f^2 \Big] \log \frac{\Lambda_S}{\mu} \end{aligned}$$

To get a proper electroweak breaking we need $m_H^2 \sim -(0.01\mathrm{TeV}^2)$. Because the finite Yukawa contribution is 100 times bigger we need to cancel it by other terms, wich is possible at the price of fine tuning of order 1%. Moreover m_H^2 can be negative only for $\Lambda_S \leq O(100\mathrm{TeV})$.

Conclusions

- Higgs is a PNGB of an approximate global symmetry.
- Fermi scale does not depend quadraticaly on squark masses.
- Fine tuning of order 1% allows for $m_{\tilde{q}} \sim 10$TeV (in the MSSM $m_{\tilde{q}} \sim 10$TeV would require fine tuning $\sim 0.01\%$).
- Phenomenological consequences:
  - Natural suppresion of FCNC,
  - Sfermions and additional ,,heavy top" beyond reach of the LHC,
  - $m_h = 120 - 135$ GeV (for $\tan\beta \geq 5$),
  - Z' gauge boson with $M_{Z'} \sim 3$ TeV,
  - New ,,fundamental scale" at ~ 100 TeV.