# Little Hierarchy Little Higgses & A Little Symmetry

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The mystery of EWSB:

Higgs ?

$$\delta m_H^2 \sim \frac{1}{16\pi^2} \Lambda^2 \sim \mathcal{O}((100\,\text{GeV})^2)$$

Naturalness $\Rightarrow$ $\Lambda \sim 1$ TeV

OR NO Higgs ?

$$m_W^2 \sim g^2 f^2 \Rightarrow f \sim v \sim 250\,\text{G}$$

Naive dimensional analysis

$$\Rightarrow \Lambda \simeq 4\pi f \sim 1 \text{ TeV}$$

Strong reasons to expect NEW physics at 1 TeV scale.

~ Why we're excited about LHC.!!

Possible Scenarios at TeV :

- Perturbative : Weak scale SUSY, little Higgs theories
- Strong dynamics : technicolor, Compositeness, low scale gravity .....

LEP + Tevatron showed NO Serious deviations from SM ⇒ favors Weakly-coupled new physics at ~ 1 TeV

# Effects of New Physics:

$$\mathcal{L}_{eff.} = \mathcal{L}_{SM} + \sum_i \underbrace{\frac{c_i}{\Lambda^p}}_{\text{parametrize new physics}} \mathcal{O}_i^{(p+4)} \qquad c_i \sim \mathcal{O}(1)$$

$\exists$ Two classes of operators

i) those violating (approximate) symmetries of SM:

~~CP~~, ~~flavor~~, ~~B~~, ~~L~~ : $\Lambda \geq 100$ TeV or much higher!

$\Rightarrow$ TeV scale physics should respect these symmetries.

ii) those preserving these symmetries.

They are constrained by precision EW measurements.

Barbieri & Strumia found

$$\frac{c_i}{\Lambda} \lesssim \frac{1}{(5 \sim 10\ \text{TeV})}$$

Taken at face value, precision EW sees no evidence for new physics up to 10 TeV !!

Naturalness $\sim$ 1 TeV

$\not\Leftrightarrow$

precision EW $\sim$ 10 TeV.

This is the little hierarchy problem !!

$\exists$ Two attitudes

i) Only a factor of $5 \sim 10$, No big deal!!

Could be new physics at 10 TeV or higher. Maybe it's fine-tuning, or anthropic principle.

e.g. typical nuclear binding energy $\sim 10$ MeV

deuteron $\sim$ 2 MeV

ii) Maybe a factor of $5 \sim 10$ is already a hint for new physics

e.g. $\frac{m_\pi}{m_\rho} \sim \frac{1}{5}$. but pions are PNGB!!

Maybe some operators are suppressed by $5 \sim 10$ TeV because $\exists$ a <u>new</u> symmetry forbidding them at 1 TeV!

Most widely accepted candidate:

Weak scale SUSY: it is natural,

has unification, perturbative up to high energy,

has dark matter candidate, etc.

SUSY alleviate LHP by R-parity

SM: R-even ; Superpartners: R-odd

$\Rightarrow$ no tree level exchange of

superpartners

i.e., corrections are suppressed by $\left(\frac{1}{4\pi}\right)^2$!!

Therefore $C_i \sim \frac{1}{4\pi}$

$$\frac{C_i}{\Lambda} \sim \frac{0.1}{1\ \text{TeV}} \approx \frac{1}{10\ \text{TeV}}$$

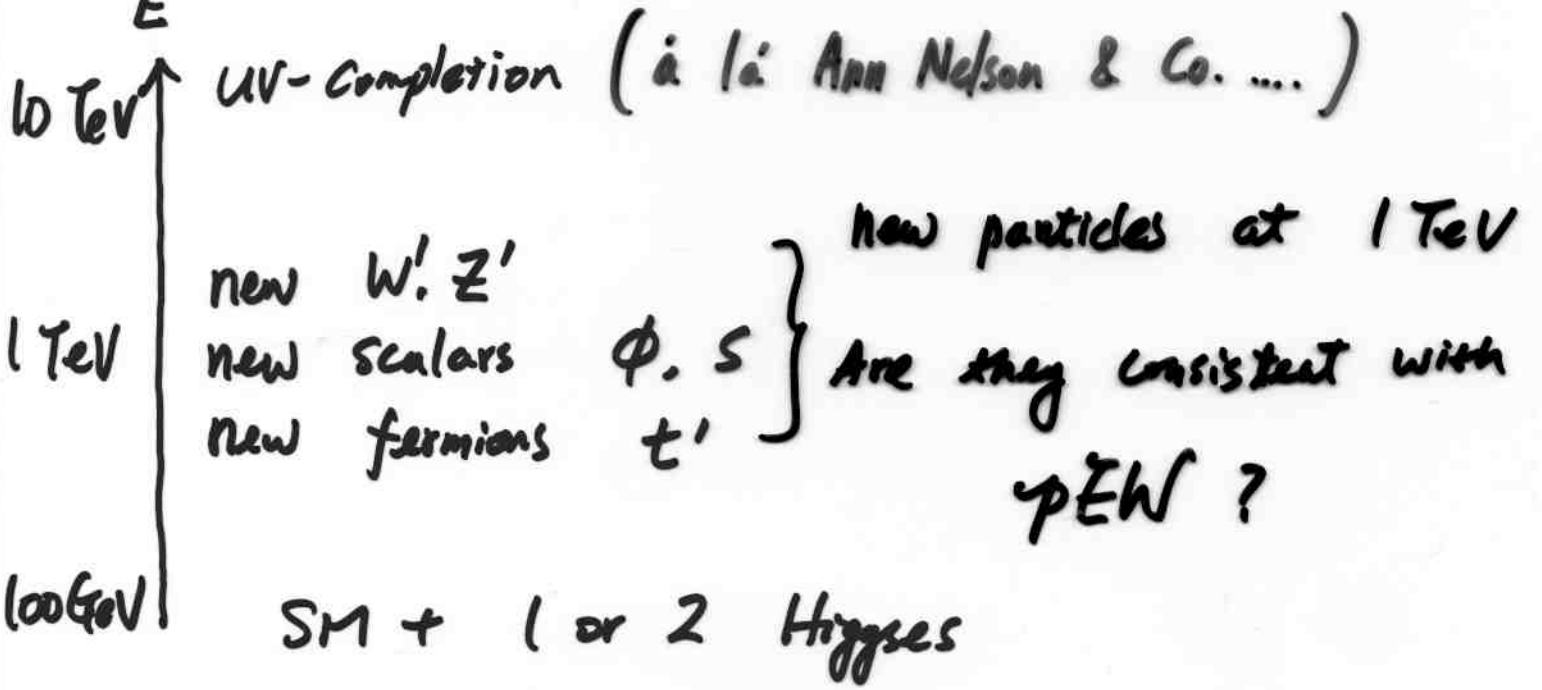
SAFE for pEW !!

Unfortunately, SUSY (MSSM) has a different fine-tuning problem, due to non-observance of Higgs & superpartners so far....

Desirable to find alternatives !!

One possibility is the little Higgs theories !!

Generic Spectrum :



What is a little Higgs theory?

Higgs is a PNGB such that

$$\delta m_h^2 \propto \left(\frac{1}{16\pi^2}\right)^2 \Lambda^2 \sim \Theta((100\,\text{GeV})^2)$$

$$\Rightarrow \Lambda \sim 10\ \text{TeV}!$$

It's an effective theory (non-linear sigma model) with a cutoff $\sim$ 10 TeV.

What's so big deal about raising the cutoff from 1 TeV to 10 TeV?

Little Higgs was invented to solve the little hierarchy problem!!!!

The question is DOES IT?

The Answer is quite model dependent!!

For the most popular "Littlest Higgs"

based on $SU(5)/SO(5)$

$$f \gtrsim 4 \text{ TeV} \Rightarrow \Lambda \sim 4\pi f \geq 50 \text{ TeV}$$

Largest Constraints:

i) Direct couplings of SM to W', Z'

ii) triplet scalar $\langle \phi \rangle$

Need a model-independent way to relax the pEW constraints!!

Introduce T-parity:

SM: T-even ; $W', Z', \phi$ : T-odd

Works almost like R-parity in SUSY & KK-parity in UED

Can implement T-parity in a wide class of Little Higgs theories.

$SU(5)/SO(5)$, $SU(6)/Sp(6)$,

$SU(3) \times SU(3)/SU(3)$, $SO(5) \times SO(5)/SO(5)$,

etc.

Only exceptions are those based on "Simple groups"

As long as the Coset space is

Symmetric :

$$[T, T] \sim T; \quad [T, X] \sim X, \quad [X, X] \sim \cancel{X} \overset{0}{+} T$$

$\exists$ a $Z_2$ automorphism : $T \to T$

$X \to -X$

eg. the T-invariant $SU(5)/SO(5)$ model:

Scalar & Gauge Sectors are easy to implement.

Fermions are trouble!

They transform under the $SO(5)$ only!!

( Coleman, Callan, Wess & Zumino. )

The square root formalism :

$\Sigma(x) = e^{2i\pi/f} \Delta_0$ — the original

$\xi = e^{i\pi/f}$ ~ T-invariant model

Phenomenology :

1) All the T-odd particles need to be pair-produced. ($W'$, $Z'$, $\phi$, ...)

To 1st order approx, hard distinguish from SUSY w/ R parity or UED w/ KK-parity.

2) The lightest T-odd particle is stable. Dark matter candidate !! Most likely to be $B'$.

3) LTP results in missing energies in Collider experiments.

4) The top sector remains unchanged.

Spectrum of T-inv. SU(5)/SO(5)

| | T-even | T-odd |
|---|---|---|
| 10 TeV | | |
| 1 TeV | doublet fermions $t'$ | $W', Z', \phi$ singlet fermions |
| 100 GeV | SM + 1 Higgs | |

Strongest pEW constraint:

$\Delta\rho$ from $W', Z'$

$$\Delta\rho_{W'} = -0.002 \left( \frac{450\ \text{GeV}}{f} \right)^2$$

$$\Rightarrow \quad f \gtrsim 450\ \text{GeV} \quad !!$$

(v.s. 4 TeV without T-parity)

$\Delta\rho_t$, $Zb\bar{b}$ both give weaker bounds.

$\langle\phi\rangle = 0$ :

## Conclusions :

i) Little hierarchy problem can be resolved by little higgs theories w/ a little symmetry, the T-parity.

ii) Can implement T-parity in a majority of little higgs models.

iii) T-odd particles need to be pair-produced LTP is stable and a dark matter candidate

iv) Negate all previous studies on little Higgs phenomenoly, except those on the top sector or loop-induced processes !!