T-parity, known, unknown issues and a model.

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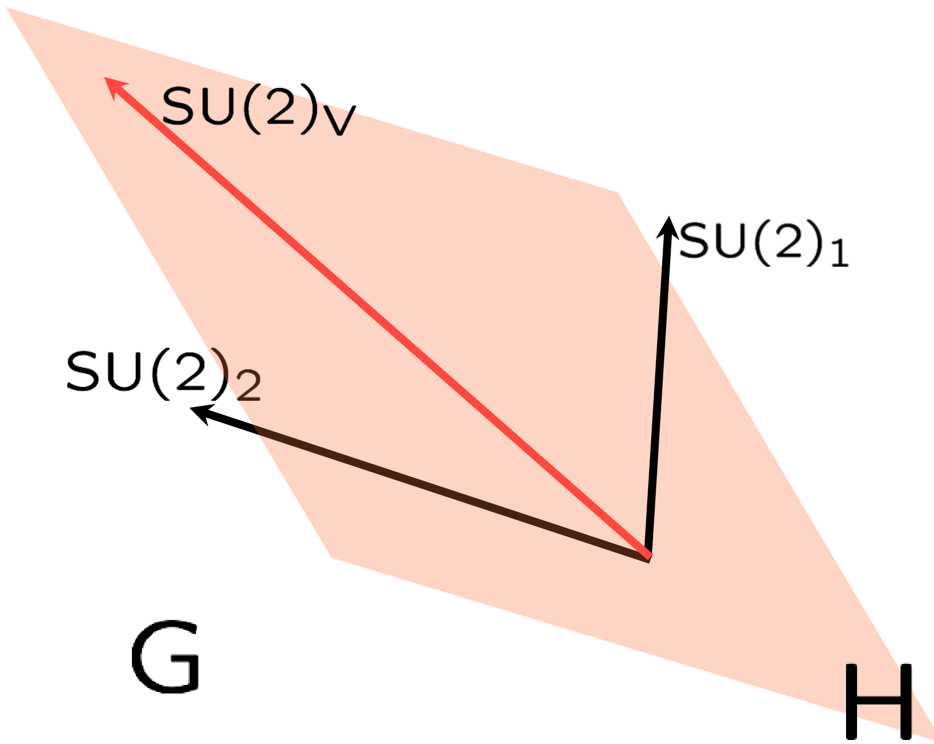
Disclaimer

Theoretical talk

The Higgs boson in Little-Higgs model is a Goldstone boson in some G/H coset.
A natural little hierarchy is generated through collective breaking.

Not trivial!

$$V(H) = \frac{g^2 g_\rho^2 f}{16\pi^2}|H \ldots|^4 \Rightarrow \frac{v^2}{f^2} \approx \frac{\alpha_\rho}{4\pi} \qquad (\alpha_\rho \to \alpha_T)$$



Minimal Moose SU(3) - Custodial symmetry
Littlest Higgs SU(5)/SO(5) - Triplets vevs, B’
SU(9)/SU(8) - Collective breaking
SO(9)/(SO(5)xSO(4)) - Collective breaking
Moose SO(5) - 2 Higgses, B’
SU(6)/Sp(6) - 2 Higgses, B’, custodial

In specific models one can calculate the amount by which specific EWPO are corrected by new physics (eg. tree-level heavy vectors exchange, weak-scale triplet VEVs), for instance

$$\delta\hat{S} \approx \frac{m_W^2}{m_W'^2} \approx \frac{\alpha}{\alpha_\rho}\frac{v^2}{f^2} \lesssim \frac{\alpha}{4\pi} \Rightarrow \frac{v^2}{f^2} \lesssim \frac{\alpha_\rho}{4\pi}$$

T-parity in words:

impose a parity making all the non-SM states odd.

$T_{\alpha\beta} H_\alpha H_\beta$

$J^\mu_{SM} Z'_\mu$

$H_\alpha \overline{Q}^\alpha_L S_R$

The NDA estimate for EW corrections tells they are under control

$$\delta \hat{S} \approx \frac{\alpha}{4\pi} \frac{m_W^2}{m_W'^2} \approx \left(\frac{\alpha}{4\pi}\right)^2$$

A symmetric coset already possesses an intrinsic Z_2 parity

$$[T, T/X] = T/X, \quad [X, X] = T$$

$$T \to T, \quad X \to -X$$

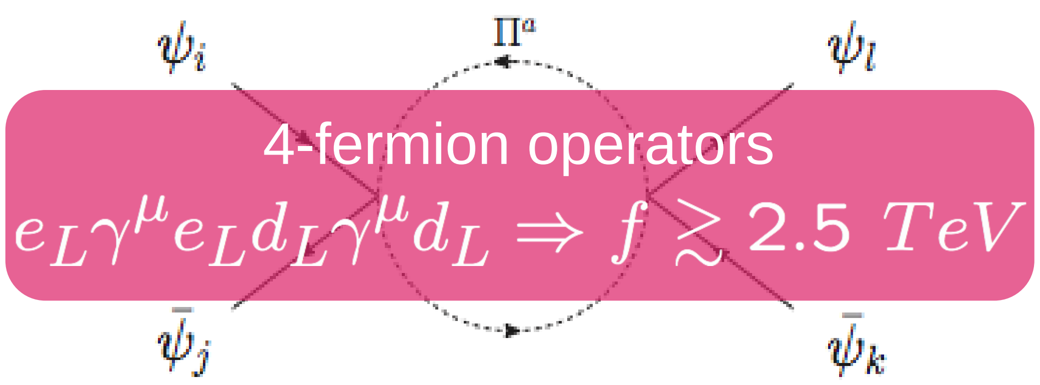
Under this automorphism all the GB are odd (also the Higgs). Define T-parity as the composition with a 2π isospin rotation: T-even integer isospins, T-odd half-integer isospin. T-even Higgs boson.

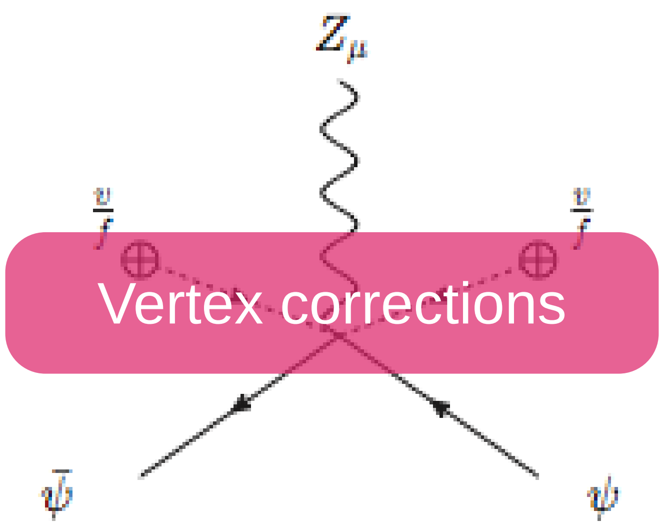
In the presence of gauging the symmetry is preserved if $g_1 = g_2 = \sqrt{2} g_{SM}$

$$A^\mu_{SM} = \frac{A^\mu_1 + A^\mu_2}{\sqrt{2}}, \quad A^\mu_H = \frac{A^\mu_1 - A^\mu_2}{\sqrt{2}}$$

After the G/H symmetry breaking the heavy vectors get a mass $O(g_{SM} f)$.

The SM fermion doublets must be introduced in such a way to get a T-invariant spectrum. Representations of H "composite representations" are eigenstates of T-parity but have non minimal interactions with the Higgs and get strongly coupled to the GB.





If representations of G "elementary representation" are used they must at least represent the full $SU(2)_1 \times SU(2)_2 \rtimes Z_2$. Once such a representation is reduced to $SU(2)_V$ it will always contain an even number of doublets.

One T-even combination of fermions is identified with the SM field to the remainings (at least one, T-odd) a mass term must be somehow provided.

CRUCIAL POINT!

(forget Yukawas, even the top one).

Take the Littlest Higgs as a working example (the one tipically used in pheno studies)

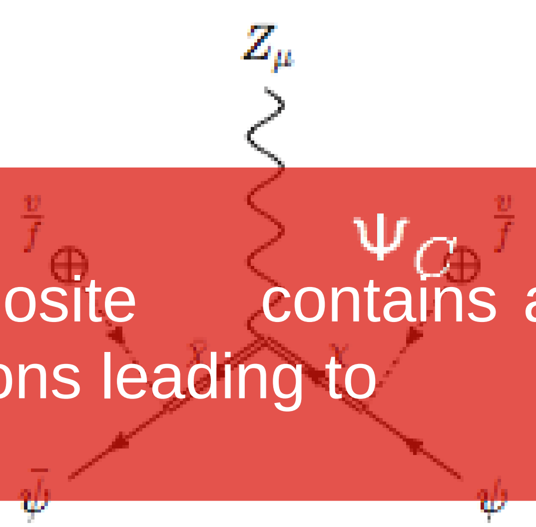
$$\kappa f(\overline{\Psi}_1 \Sigma_0 \xi^{+} \Psi_C + \overline{\Psi}_2 \xi \Psi_C)$$

$$\Psi_{1,2} = (\psi_1, 0, \psi_2), \qquad \Psi_C = (\psi_{C_1}, \chi_C, \psi_{C_2})$$

$$\psi_{SM} = (\psi_1 + \psi_2)/\sqrt{2}, \quad \chi_C, \quad \psi_{C_1} : \quad \text{massless fermions}$$

One extra singlet (T-even) and one (T-odd) doublet are left massless after G/H breaking both L-handed).

Put just a single doublet inside Ψ_C: a composite incomplete representation breaks completely the global symmetry leading to a failure of collective breaking.
Use a spinorial representation ($\mathbf{4} \to \mathbf{2} \oplus \mathbf{1} \oplus \mathbf{1}$): this is the usually quoted solution, however a spinorial cannot be introduced consistently with the SU(5)/SO(5) structure. [Hubisz,Meade('04)]



In any case the composite Ψ_C contains a singlet mixing with the ordinary SM fermions leading to $O(v^2/f^2)$ vertex corrections.

The moral is that in order to obtain a complete model one has to extend the coset. [Csaki et al. ('08)][DP, A.Vichi ('10)]

$$\frac{SU(5)}{SO(5)} \to \frac{SU(5) \times [SU(2) \times U(1)]^2}{SO(5) \times [SU(2) \times U(1)]}$$

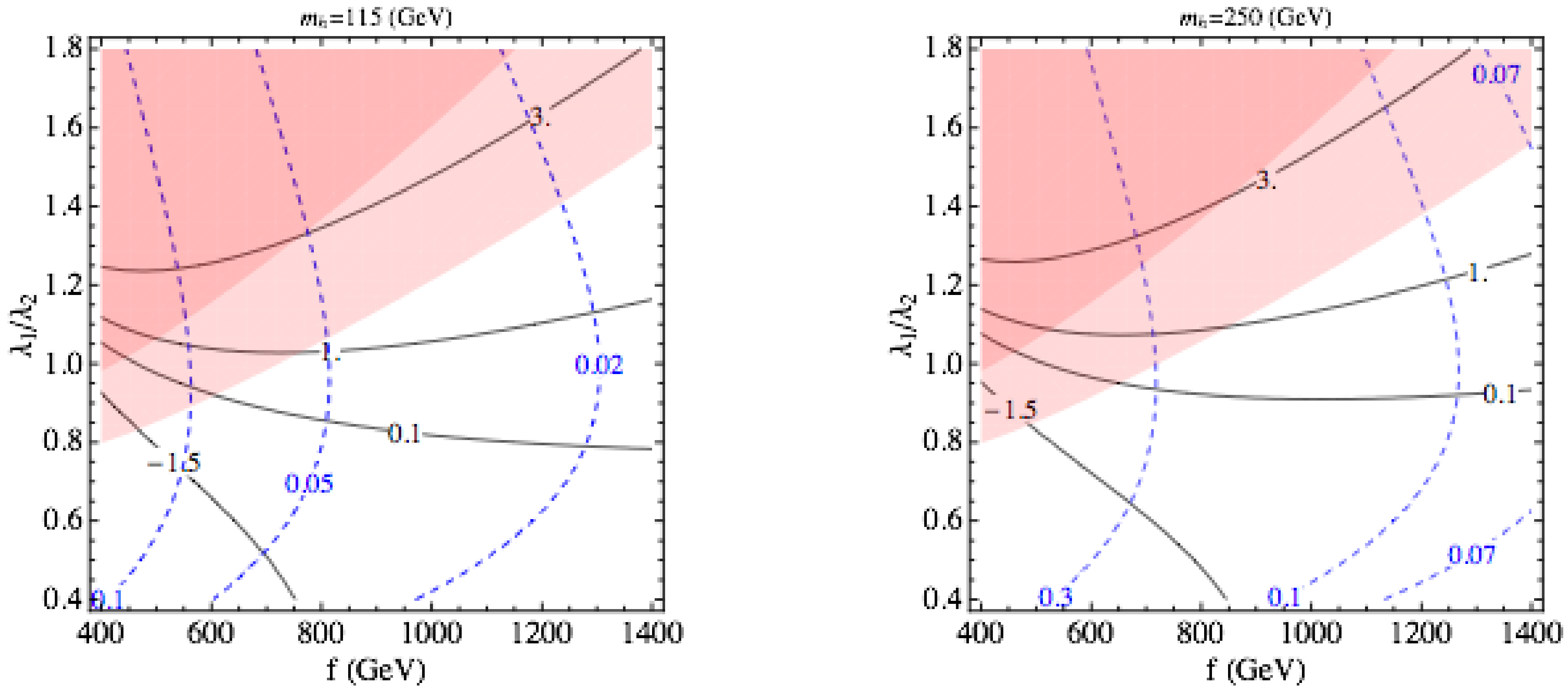
The new coset allows to solve the issues with fermions. Together with the two left handed doublet $\psi_{1,2}$, one can introduce a single composite R-handed doublet charged under the extra unbroken SU(2) factor, to give mass to the T-odd combination. No T-even singlet is present.

$$\kappa f (\overline{\psi}_1 \sigma_2 X \psi_C + \overline{\psi}_2 \sigma_2 X^+ \psi_C)$$

$$\psi_{SM} = (\psi_1 + \psi_2)/\sqrt{2} : \quad \text{massless}, \quad \psi_- = (\psi_1 - \psi_2)/\sqrt{2} : \quad m_- = \kappa f$$

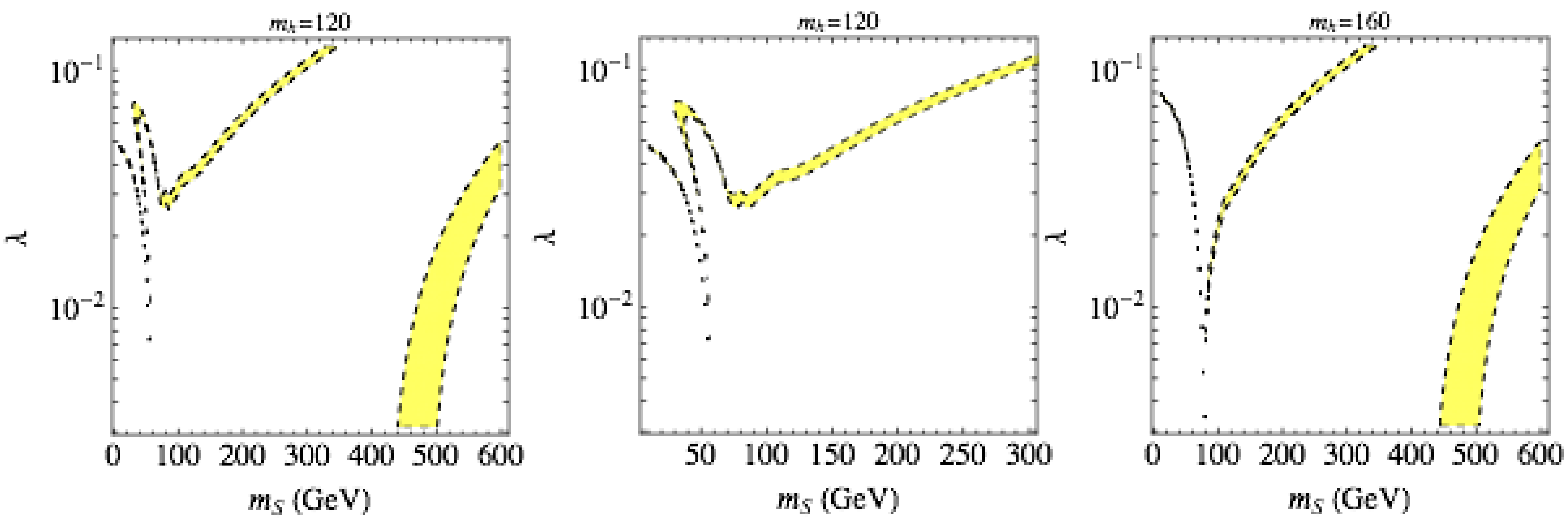
No extra gauge boson. The coset contains 2 new T-odd GB, a real singlet and triplet, coming from the new link field X. Both with masses protected by collective breaking in the O(100 GeV) range.

Expected agreement with EWPT



The scalar singlet is an alternative to the B' as a DM candidate

$$\mathscr{L} = \lambda S^2|H|^2 + \text{nl}\sigma\text{m}, \quad \lambda = O(\text{few } \%)$$



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T-parity @ LC

The Higgs boson is composite. Best tested by looking at WW scattering at CLIC

$$\mathcal{A}(W^+W^- \to hh),\ \mathcal{A}(W^+W^- \to \pi\pi) \propto \left(\frac{v^2}{f^2}\right)\frac{\hat{s}}{v^2}$$

Collective breaking. Test the couplings in the gauge and top sector to verify the cancellation of the quadratic divergences.

Gauge sector:

$$g_{hZZ} + g_{hW_H^3 W_H^3} + g_{hB_H B_H} = 0$$
$$g_{hW^+W^-} + g_{hW_H^+ W_H^-} = 0$$

easy to do at ILC or CLIC (?)

Top sector: check the relation among the various top-higgs couplings

$$\lambda_1 qHu + \lambda_1 \chi H^+ Hu$$

look at gluon-gluon fusion at LHC (?)

T-parity. T-parity modifies the spectrum (T-odd fermionic partners that must not be too heavy). Relation among masses and couplings of the heavy gauge bosons.