Vector Bosons in the Littlest Higgs Model

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Outline

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2. The Littlest Higgs Model
3. The New Particle Spectrum
4. Free Parameters
5. The A_H, its Mass, Branching Ratios, and Cross-Section
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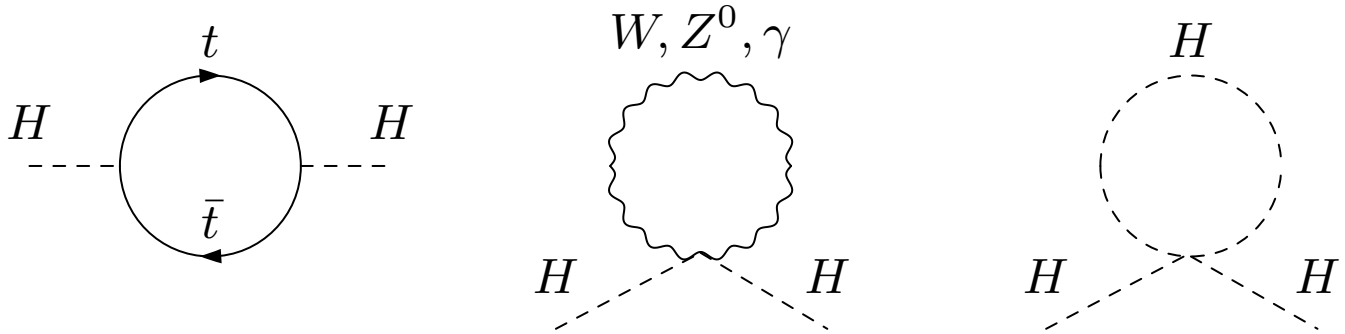
1 – The Little Hierarchy Problem

- Standard Model processes lead to quadratic divergences of the Higgs mass:



- The resulting mass is:

$$m_h^2 \approx m_{tree}^2 - [100 - 10 - 5](\frac{\Lambda}{50})^2 \ [\mathrm{TeV}^2]$$

Which is about 1% "fine-tuned" at $\Lambda = 10$ TeV.

2 – The Littlest Higgs Model

- In supersymmetric models, these quadratic divergences are cancelled by opposite-statistics contributions.
- Recently, extended gauge groups have been found which permit divergence cancellations by same-statistics contributions.
- In the Littlest Higgs model[a], the group is $SU(5)$. Fine-tuning is removed to a higher energy scale, where additional new physics is required.
- The $SU(5)$ symmetry is broken at scale f, leaving a residual $SO(5)$ symmetry. An $[SU(2) \otimes U(1)]_1 \otimes [SU(2) \otimes U(1)]_2$ subgroup is gauged.
- The coupling constants and charge assignments of these gauge groups are related to the observed Standard Model values:

$$\frac{1}{{g_1}^2} + \frac{1}{{g_2}^2} = \frac{1}{g^2} \qquad \frac{1}{{g'_1}^2} + \frac{1}{{g'_2}^2} = \frac{1}{g'^2} \qquad Y_1 + Y_2 = Y$$

[a] Arkani-Hamed,Cohen,Katz,Nelson: hep-ph/0206021

3 – The New Particle Spectrum

- The result is a set of new, heavy gauge bosons:

$$\mathbf{Z_H} \qquad \mathbf{W_H^{\pm}} \qquad \mathbf{A_H}$$

- And a complex triplet of massive scalars:

$$\mathbf{\Phi^0} \quad \mathbf{\Phi^P} \quad \mathbf{\Phi^+} \quad \mathbf{\Phi^{++}} \quad \mathbf{\Phi^-} \quad \mathbf{\Phi^{--}}$$

- A new heavy fermion is also introduced:

$$\mathbf{T}$$

4 – Free Parameters

- The $SU(5)/SO(5)$ symmetry-breaking scale f.
- Mass eigenstate mixing angles defined by the various couplings:

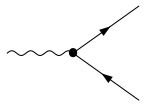
$$c = \mathrm{Cos}\,\theta = \frac{g_1}{\sqrt{{g_1}^2+{g_2}^2}} \qquad\qquad c' = \mathrm{Cos}\,\theta' = \frac{{g'}_1}{\sqrt{{g'}_1{}^2+{g'}_2{}^2}}$$

- Top sector couplings parameters λ_1 and λ_2, which are jointly constrained by:

$$\frac{1}{{\lambda_1}^2} + \frac{1}{{\lambda_2}^2} \approx \left(\frac{v}{M_t}\right)^2$$

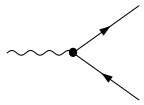
- Hypercharge parameters y_u and y_e.
- A $\mathbf{\Phi}$ complex scalar triplet vev v'.

- Some relevent vertex factors include [a]



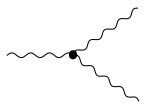
$$g_v(A_H\bar{e}e) = \frac{g'}{2s'c'}(2y_e - \frac{9}{5} + \frac{3}{2}c'^2)$$

$$g_a(A_H\bar{e}e) = \frac{g'}{2s'c'}(-\frac{1}{5} + \frac{1}{2}c'^2)$$



$$g_v(A_H\bar{t}t) = \frac{g'}{2s'c'}(2y_u + \frac{17}{15} - \frac{5}{6}c'^2 - \frac{1}{5}\frac{{\lambda_1}^2}{{\lambda_1}^2 + {\lambda_2}^2})$$

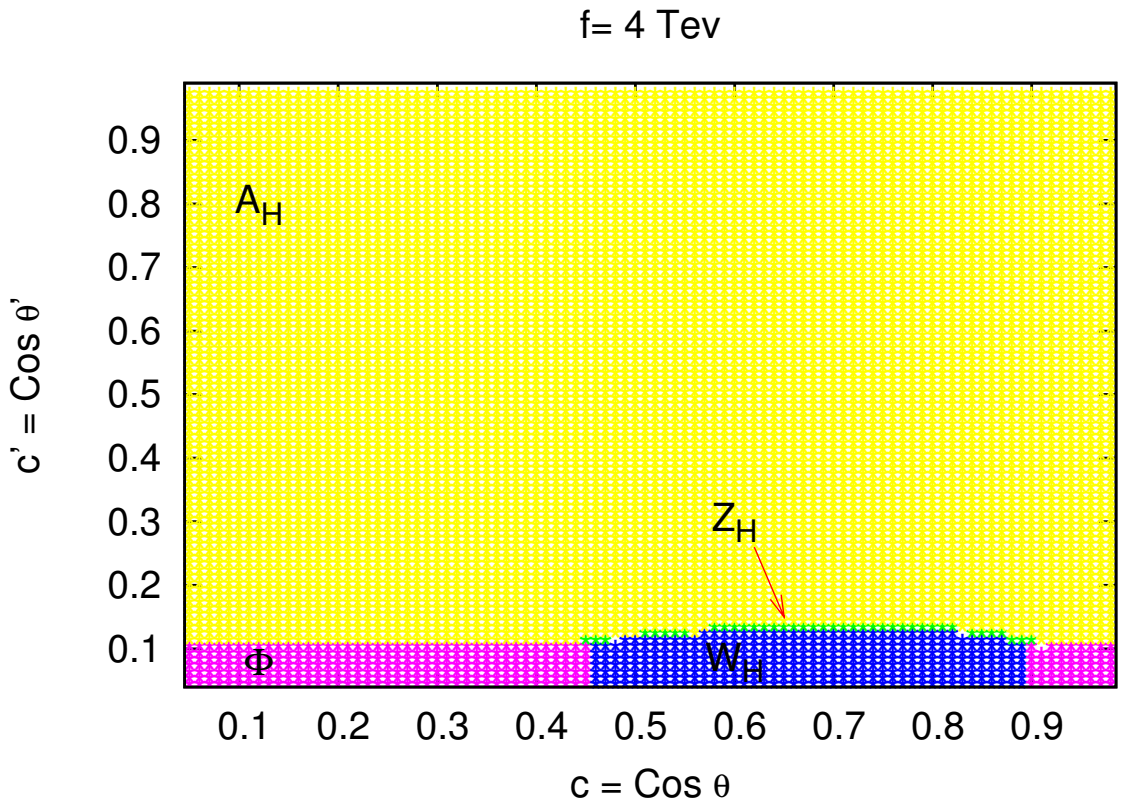
$$g_a(A_H\bar{t}t) = \frac{g'}{2s'c'}(\frac{1}{5} - \frac{1}{2}c'^2 - \frac{1}{5}\frac{{\lambda_1}^2}{{\lambda_1}^2 + {\lambda_2}^2})$$



$$g(A_H W^+W^-) = -\frac{5}{2}\frac{ec_w}{{s_w}^2}\frac{v^2}{f^2}s'c'(c'^2 - s'^2)$$

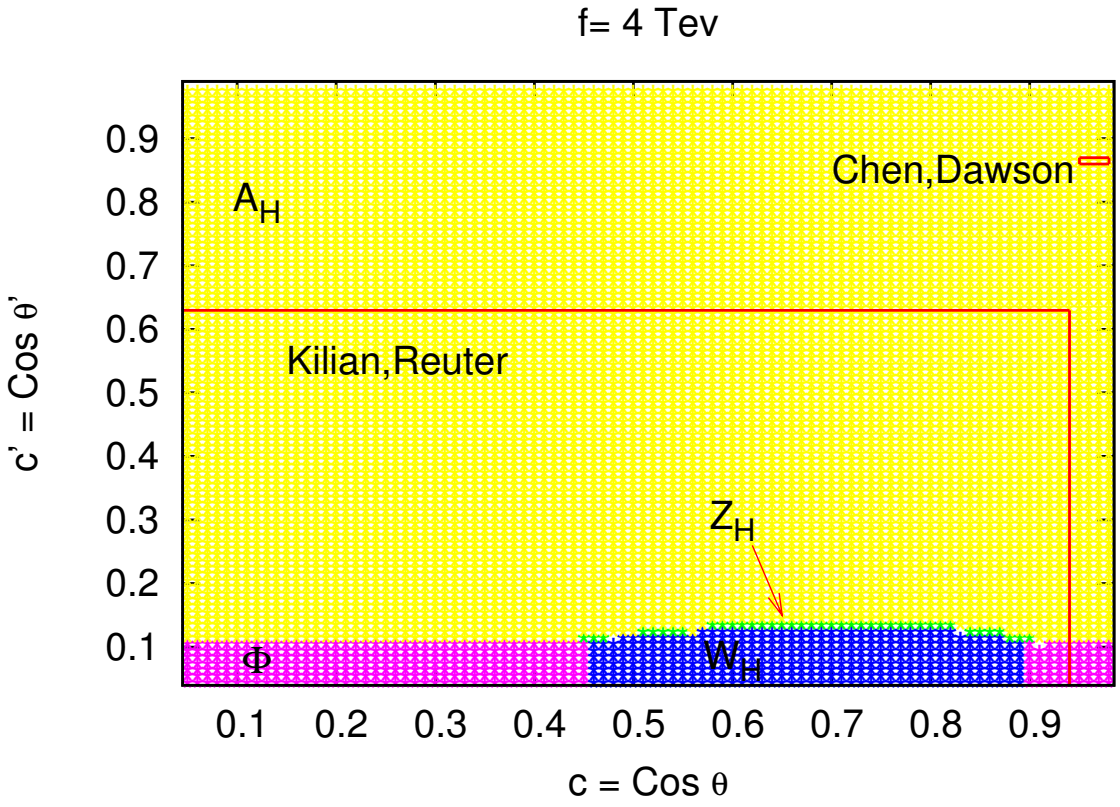
[a] Han,Logan,McElrath,Wang: hep-ph/0301040

- What is the lightest new particle?

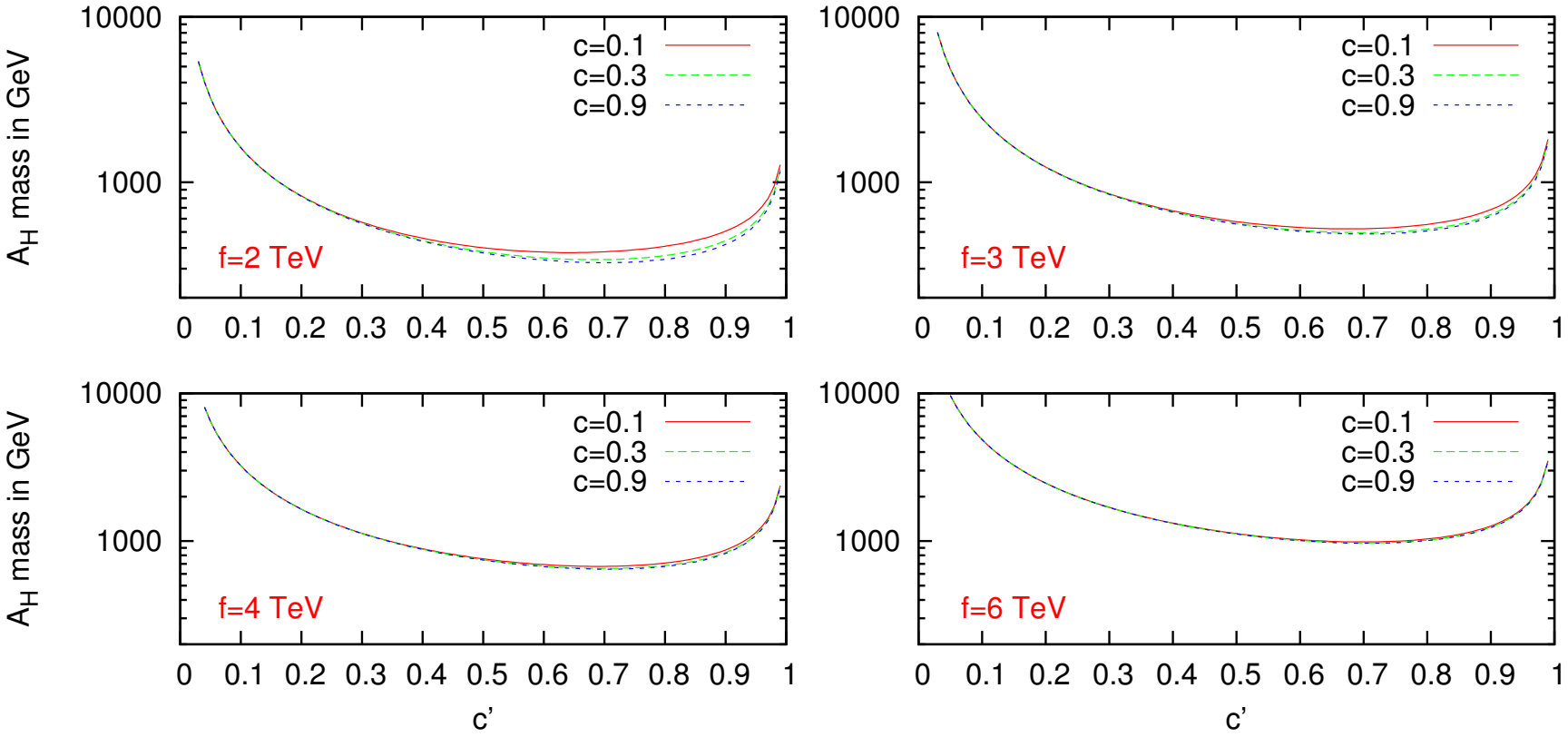


- The A_H is the lightest new particle for most values of the free parameters.

- Constraints from electroweak precision data lack consensus:
  Allowed parameter regions?
  Fine-tuned?

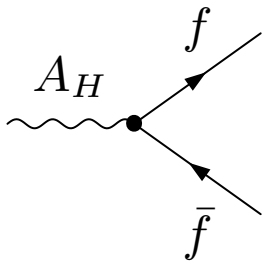


5 – The A_H, its Mass, Branching Ratios, and Cross-Section

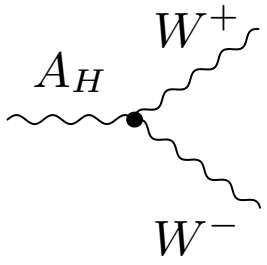


- A_H mass scales with f, and varies widely with c', but not with c.

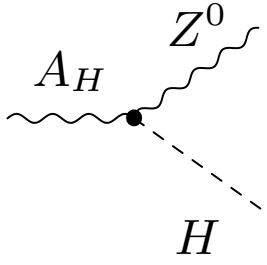
- A_H decays will be to Standard Model particles only, with a small total width ($\sim (M_A)$):



$$\Gamma(A_H \to f\bar{f}) = \frac{C\, M_A}{12\pi}(1 - 4\frac{{M_f}^2}{{M_A}^2})^{\frac{1}{2}} \cdot ({g_v}^2(1 + 2\frac{{M_f}^2}{{M_A}^2}) + {g_a}^2(1 - 4\frac{{M_f}^2}{{M_A}^2}))$$

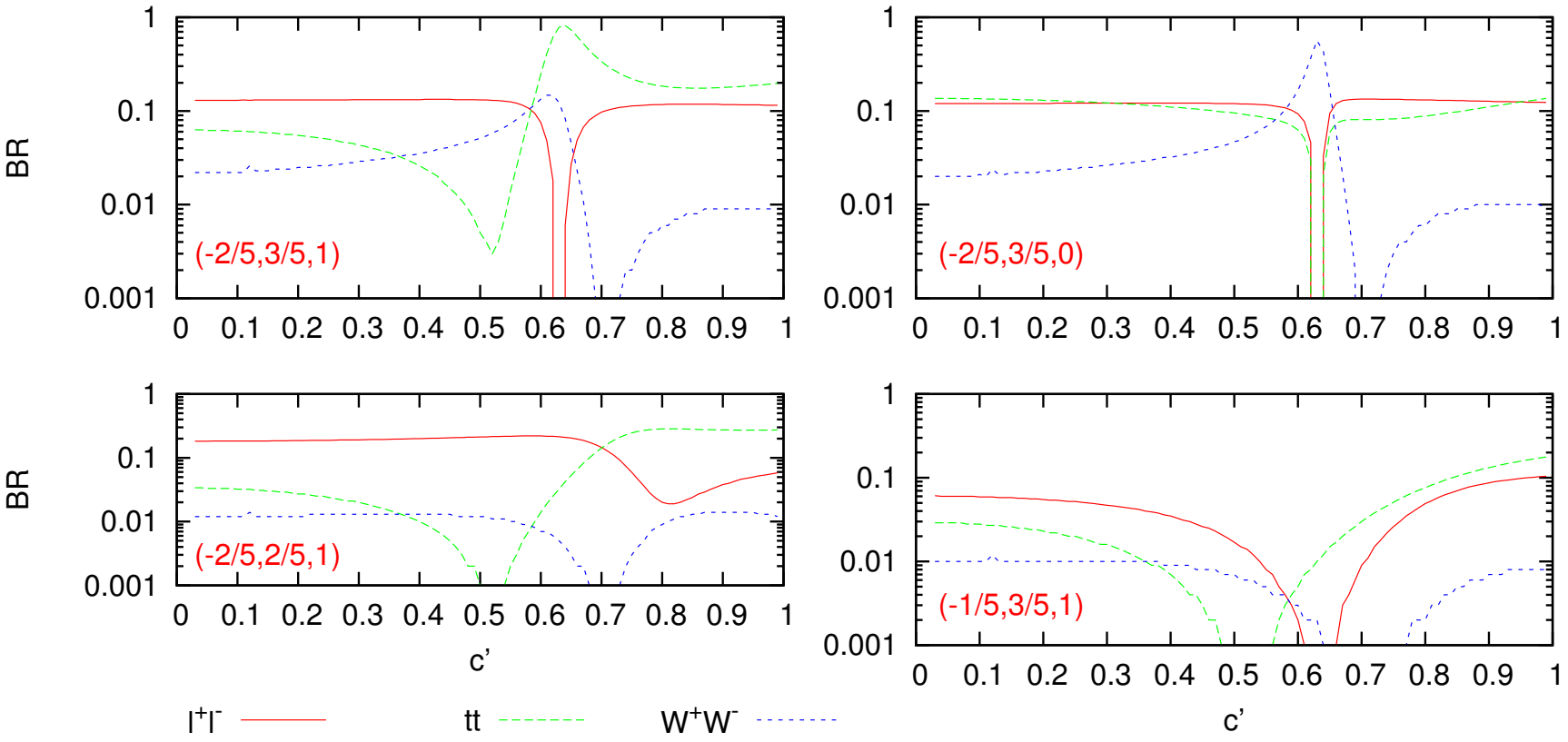


$$\Gamma(A_H \to W^+W^-) = g^2_{WWA}\frac{1}{192\pi}M_A(\frac{M_A}{M_W})^4(1 - 4\frac{{M_W}^2}{{M_A}^2})^{\frac{3}{2}} \cdot (1 + 20\frac{{M_W}^2}{{M_A}^2} + 12\frac{{M_W}^4}{{M_A}^4})$$

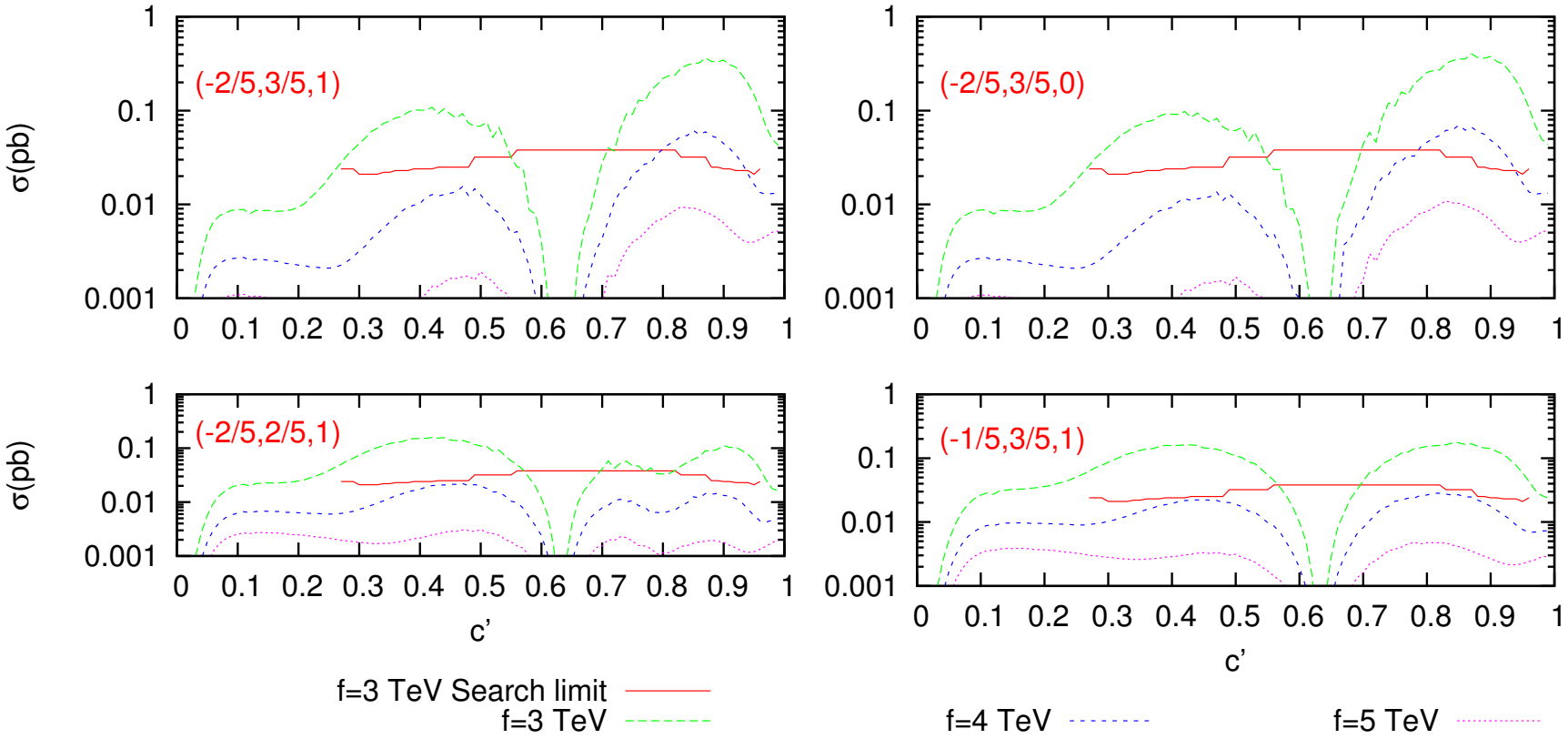


$$\Gamma(A_H \to Z^0H) = \frac{{g'}^2\mathrm{Cot}^2(2\theta')|\vec{P}|}{96\pi}(\frac{8{M_A}^2{M_Z}^2 + ({M_A}^2 + {M_Z}^2 - {M_H}^2)^2}{{M_A}^4})$$

- Branching ratios vary greatly with (y_u, y_e, λ_1):



- The $\sigma(p\bar{p} \to A_H X \to l^+ l^- X)$ cross section bounds, but does not fine-tune, the parameters[a].



- At $f = 3\,TeV$, large ranges of c' are allowed, either because the mass becomes large, or the light fermions decouple.

[a]LO + K-factor. c=0.3. CTEQ6L. CDF search limit from hep-ex/0507104.

6 – Conclusions

- The original Littlest Higgs model as a solution to the little hierarchy problem is not excluded by dilepton data.
- At $f = 3\ \mathrm{TeV}$, direct dilepton searches bound, but do not fine-tune, the allowed free parameter values.
- At $f = 4\,\mathrm{TeV}$, direct dilepton searches only modestly bound the range of free parameters.
- Other decay branches will likely provide further constraints.