Little Higgs models and precision EW data

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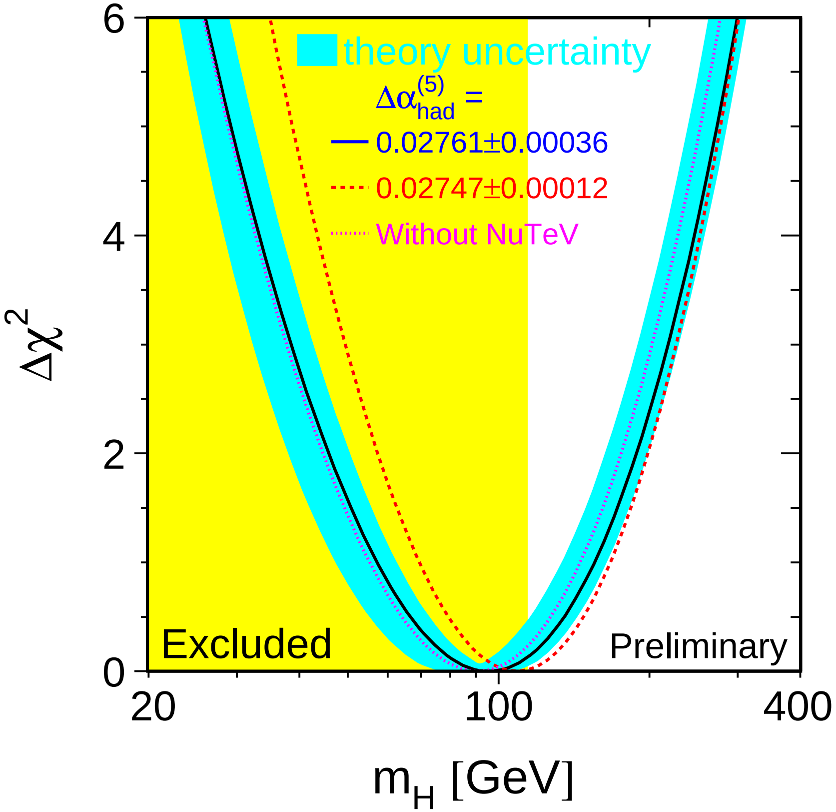
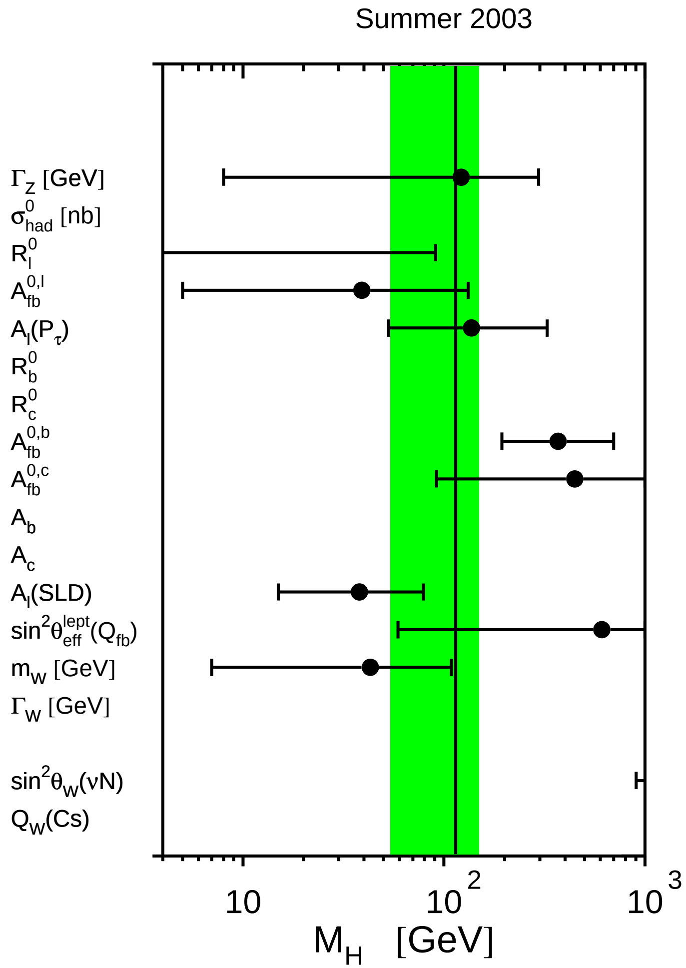
Introduction

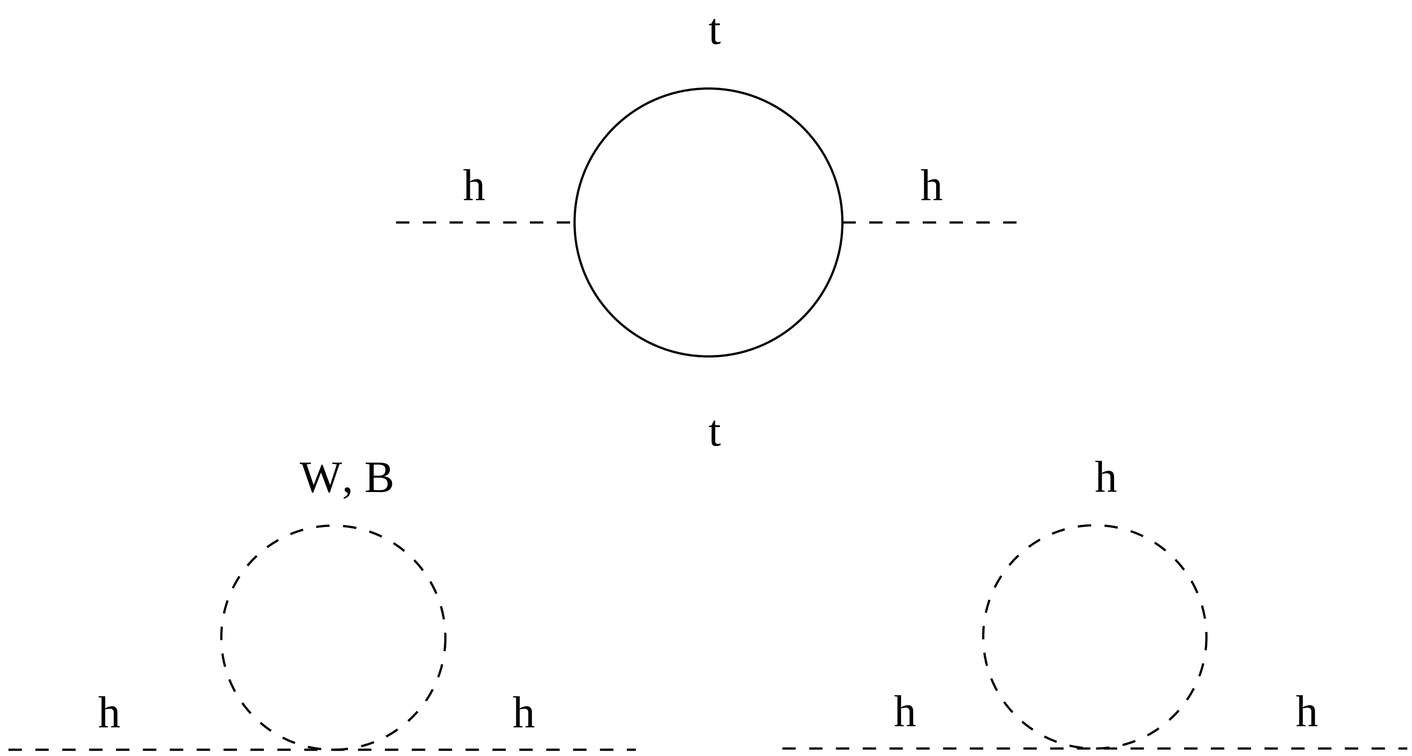




Precision EW data indicate SM with a light Higgs $m_H < 219$ GeV at 95% CL (`lepewwg.web.cern.ch/LEPEWWG`)

The naturalness problem : Higgs mass is quadratically sensitive to the cut-off scale Λ

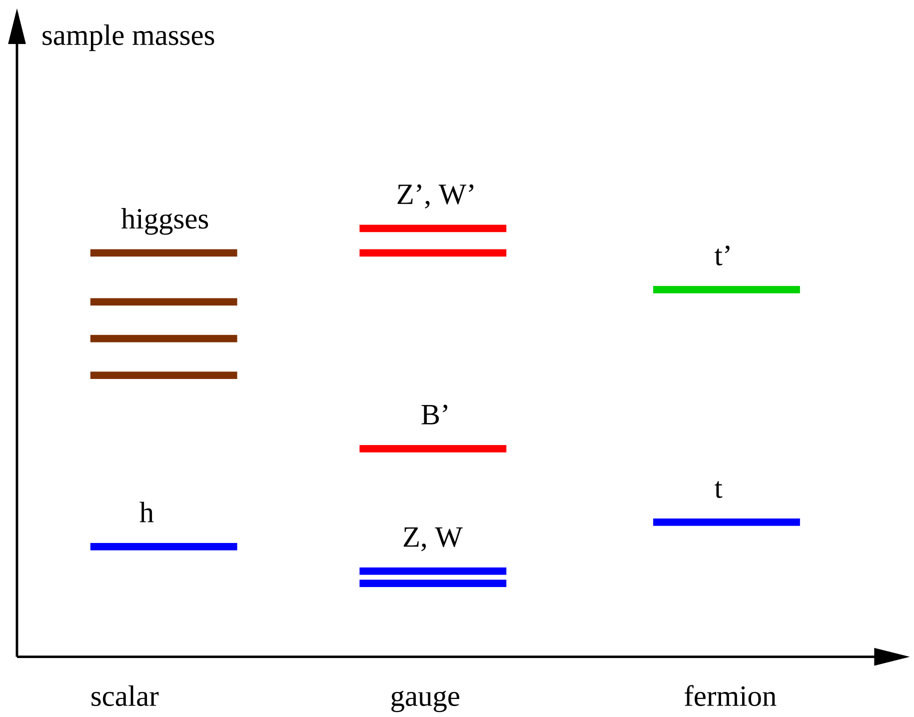
$$m_h^2 = m_{H0}^2 - \frac{3}{8\pi^2}\, y_t^2\Lambda^2 + \frac{1}{16\pi^2} g^2\Lambda^2 + \frac{1}{16\pi^2}\lambda^2\Lambda^2$$



Little Higgs approach to EW symmetry breaking

- The idea is to consider the Higgs fields as Nambu Goldstone Bosons of a global symmetry which is spontaneously broken at some higher scale f by an expectation value (Dimopoulos, Preskill 1982; Georgi, Kaplan 1984; Banks 1984).
- The Higgs field gets mass radiatively through symmetry breaking at the electroweak scale by collective breaking. It is protected by the approximate global symmetry and it remains light.
- The cancellation of the quadratic divergence is realized between particles of the same statistics (Arkani-Hamed, Cohen, Georgi, hep-ph/0105239).

Littlest Higgs*



$\tan\theta = s/c = g_2/g_1$, $\tan\theta' = s'/c' = g'_2/g'_1$ new $SU(2)$ and $U(1)$ mixing

f symmetry breaking scale $\mathcal{O}$ TeV $\qquad$ v' scalar triplet vev

m_H Higgs mass $\qquad$ m_T heavy vector top mass

* Arkani-Hamed et al. hep-ph/0206021

The model is based on $SU(5) \to SO(5)$ global symmetry breaking (24-10=14 Goldstone bosons) by a vev of the order f

$$\langle \Sigma \rangle = \begin{pmatrix} 0 & 0 & \mathbb{1}_2 \\ 0 & 1 & 0 \\ \mathbb{1}_2 & 0 & 0 \end{pmatrix} .$$

4 are eaten by the gauge bosons of the broken gauge group. The Goldstone boson matrix is

$$\Pi = \begin{pmatrix} 0 & h^\dagger/\sqrt{2} & \phi^\dagger \\ h/\sqrt{2} & 0 & h^*/\sqrt{2} \\ \phi & h^T/\sqrt{2} & 0 \end{pmatrix} .$$

h transforms as a doublet and ϕ as a triplet. The gauge symmetry breaking is $[SU(2) \times U(1)]^2 \to SU(2) \times U(1)$.

The scalar sigma model field can be written as

$$\Sigma = e^{i\Pi/f} \langle \Sigma \rangle e^{i\Pi^T/f} = e^{2i\Pi/f} \langle \Sigma \rangle$$

The kinetic term for the scalar fields is given by

$$\mathcal{L}_{kin} = \frac{1}{2} \frac{f^2}{4} \mathrm{Tr}[D_\mu \Sigma D^\mu \Sigma] \ ,$$

with the covariant derivative defined as

$$D_\mu \Sigma = \partial_\mu \Sigma - i(A_\mu \Sigma + \Sigma A_\mu^T) \ .$$

A_μ is the gauge boson matrix:

$$A_\mu = g_1 W_\mu^{1a} Q_1^a + g_2 W_\mu^{2a} Q_2^a + g_1' B_\mu^1 Y_1 + g_2' B_\mu^2 Y_2 \ ,$$

Q_i^a are the generators of the two $SU(2)$, Y_i those of the two $U(1)$ groups.

After symmetry breaking the gauge boson matrix can be diagonalized by the following transformations:

$$
\begin{aligned}
W &= sW_1 + cW_2 \qquad W' = -cW_1 + sW_2 \\
B &= s'B_1 + c'B_2 \qquad B' = -c'B_1 + s'B_2 \ .
\end{aligned}
$$

s, c, s', and c' denote the sines and cosines of two mixing angles, respectively. They can be expressed with the help of the coupling constants:

$$
\begin{aligned}
c' &= g'/g'_2 \qquad s' = g'/g'_1 \\
c &= g/g_2 \qquad s = g/g_1 \ ,
\end{aligned}
$$

with the usual SM couplings g, g', related to g_1, g_2, g'_1 and g'_2 by

$$
\frac{1}{g^2} = \frac{1}{g_1^2} + \frac{1}{g_2^2}, \qquad \frac{1}{{g'}^2} = \frac{1}{{g'_1}^2} + \frac{1}{{g'_2}^2} \ .
$$

In terms of the model parameters we obtain:

$$\frac{G_F}{\sqrt{2}} = \frac{\alpha\pi(g^2+g'^2)}{2g^2g'^2m_Z^2}\left(1 - c^2(c^2-s^2)\frac{v^2}{f^2} + 2c^4\frac{v^2}{f^2} - \frac{5}{4}(c'^2-s'^2)^2\frac{v^2}{f^2}\right)$$

and defining the Weinberg angle as

$$\frac{G_F}{\sqrt{2}} = \frac{\alpha\pi}{2s_\theta^2c_\theta^2m_Z^2} \ .$$

we have

$$\begin{aligned} m_Z^2 &= (g^2+g'^2)\frac{v^2}{4}\left[1 - \frac{v^2}{f^2}\left(\frac{1}{6} + \frac{(c^2-s^2)^2}{4} + \frac{5}{4}(c'^2-s'^2)\right) + 8\frac{v'^2}{v^2}\right] \ , \\ m_W^2 &= \frac{g^2v^2}{4}\left[1 - \frac{v^2}{f^2}\left(\frac{1}{6} + \frac{(c^2-s^2)^2}{4}\right) + 4\frac{v'^2}{v^2}\right] \ . \end{aligned}$$

The ϵ_i parameters are calculated using the effective low energy theory by integrating out the heavy states. To the order v^2/f^2 we get:

$$\begin{aligned}
\epsilon_1 &= -\frac{v^2}{f^2}\left(\frac{5}{4}(c'^2 - s'^2)^2 + \frac{4}{5}(c'^2 - s'^2)(3c'^2 - 2s'^2) + 2c^4\right) + 4\frac{v'^2}{v^2} \\
\epsilon_2 &= -2c^4\frac{v^2}{f^2} \\
\epsilon_3 &= -\frac{v^2}{f^2}\left(\frac{1}{2}c^2(c^2 - s^2) + \frac{2}{5}(c'^2 - s'^2)(3c'^2 - 2s'^2)\frac{c_\theta^2}{s_\theta^2}\right)
\end{aligned}$$

where s, c, s', and c' denote the sines and cosines of two mixing angles.

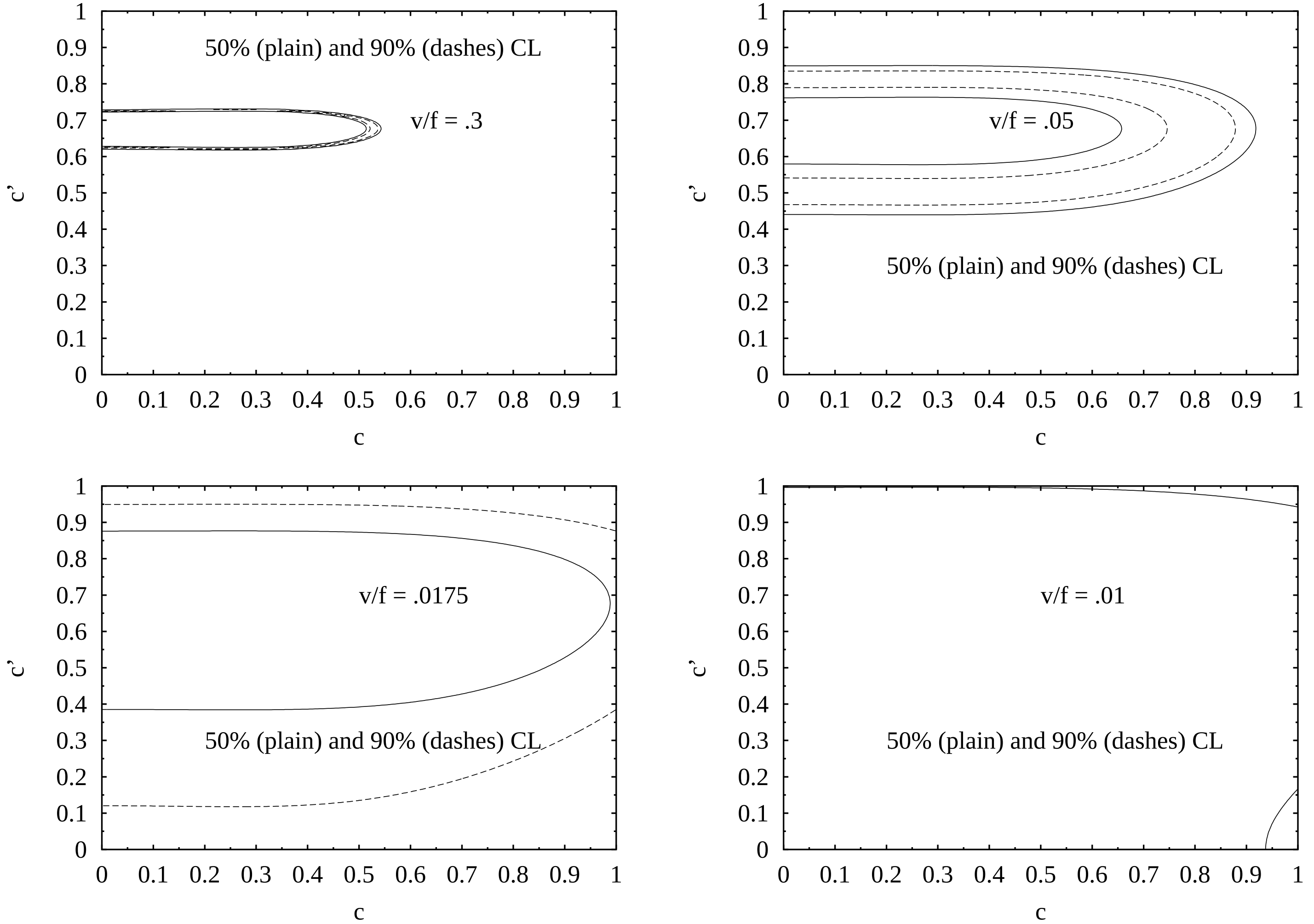


Figure 1: *90% and 50% CL exclusion contours in the plane c-c'. The value of the triplet vev v' is fixed to $v'^2/v^2 = v^2/(17f^2)$. The allowed region lies inside the 90% and 50% bands, respectively. From hep-ph/0311038.*

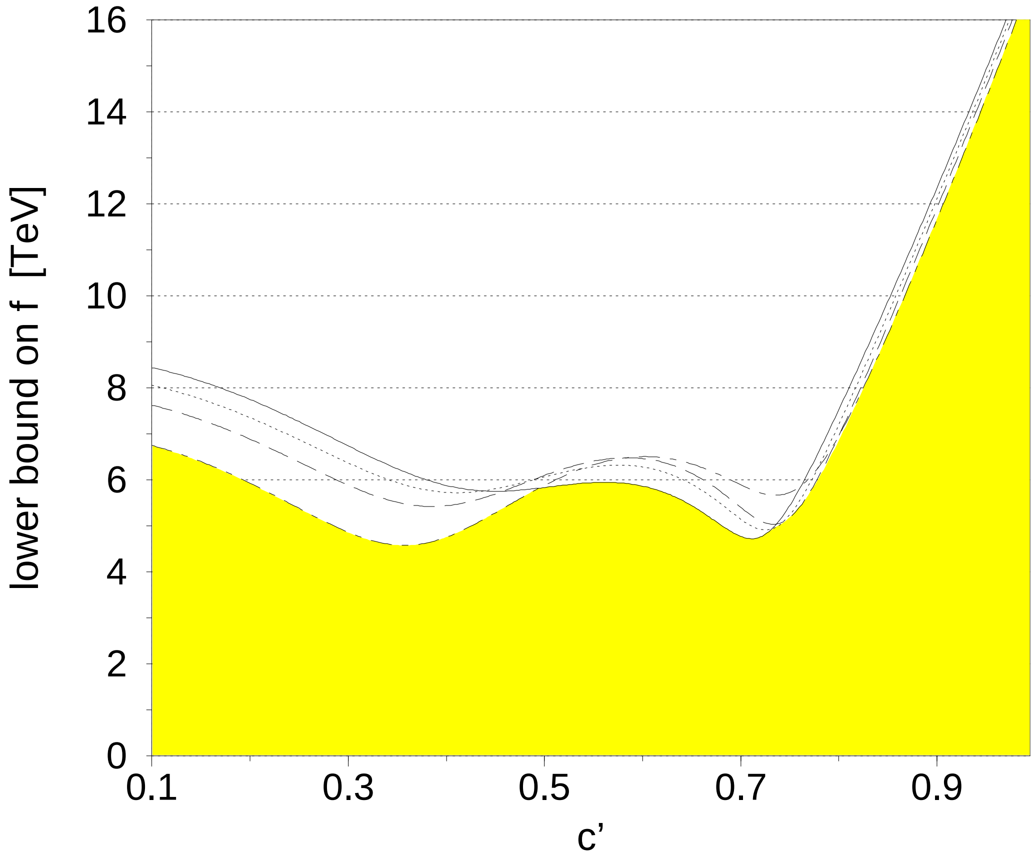


Figure 2: *The region below the contours is excluded to 95% C.L. for c equal to 0.1 (solid), 0.5 (dotted), 0.7 (dashed), 0.99 (dot-dashed). The yellow region is excluded for any choice of c. From hep-ph/0305157 based on hep-ph/0211124, hep-ph/0303236 by Csáki et al.*

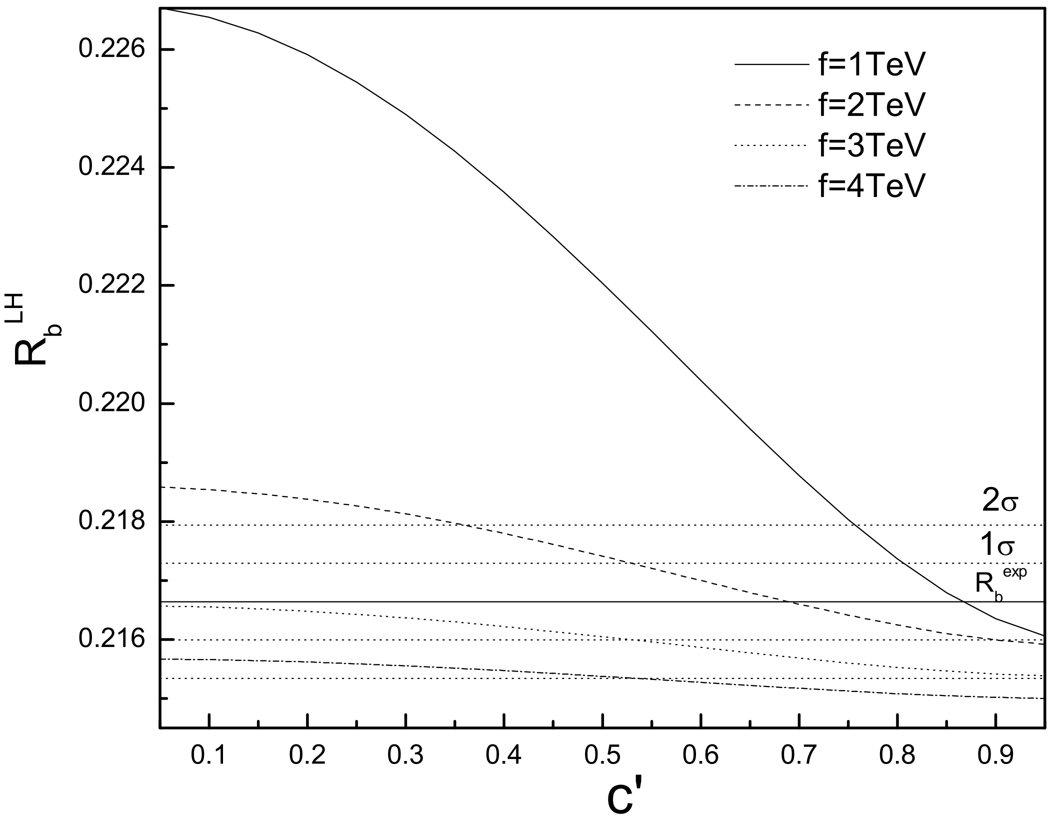


Figure 3: *The predicted value of* R_b^{LH} *in the LH model as a function of the mixing parameter* c' *for four values of the scale parameter* f*. From hep-ph/0401214 by Yue and Wang.*

Little Higgs with custodial $SU(2)^*$

$SO(9)/[SO(5) \times SO(4)]$ coset space, with $SU(2)_L \times SU(2)_R \times SU(2) \times U(1)$ subgroup of $SO(9)$ gauged. The vev is

$$\langle\Sigma\rangle = \begin{pmatrix} 0 & 0 & \mathbb{1}_4 \\ 0 & 1 & 0 \\ \mathbb{1}_4 & 0 & 0 \end{pmatrix}$$

breaking the $SO(9)$ global symmetry down to an $SO(5) \times SO(4)$ subgroup. This coset space has $20 = (36 - 10 - 6)$ light scalars. Of these 20 scalars, 6 will be eaten in the higgsing of the gauge groups down to $SU(2)_W \times U(1)_Y$. The remaining 14 scalars are : a single higgs doublet h, an electroweak singlet ϕ^0, and three triplets ϕ^{ab}.

* S.Chang hep-ph/0306034

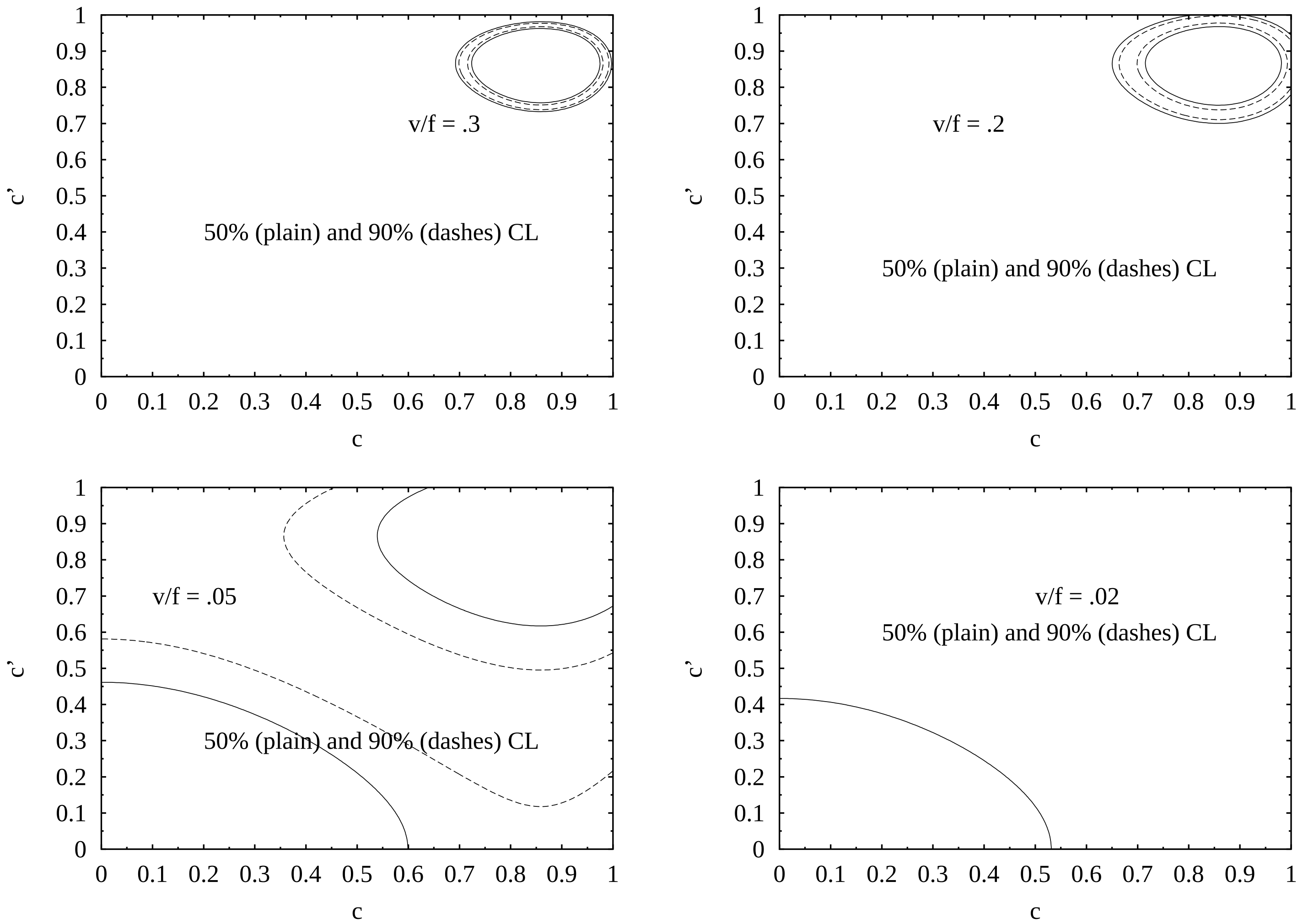


Figure 4: *90% and 50% CL exclusion contours in the plane c-c' of the $SO(9)/[SO(5) \times SO(4)]$ model. The value of the triplet vev v' is fixed to $v'^2/v^2 = v^2/(17f^2)$. The allowed region lies inside the 90% and 50% bands.*

$g - 2$ of the muon

The relevant one-loop Feynman diagrams are

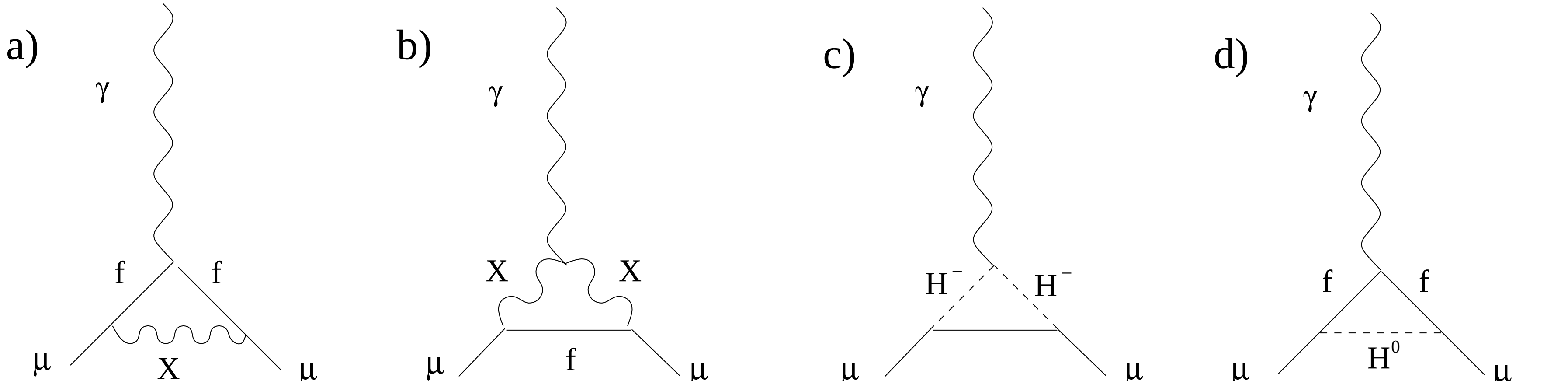


Figure 5: *Loop graphs contributing to the weak correction to Δg. a) and b) correspond to the exchange of a vector boson X while c) and d) are the Higgs sector contributions.*

The difference between experiment and the standard model prediction for a_μ is

$$\delta a_\mu = a_\mu^{exp} - a_\mu^{\rm SM} = 17(18) \times 10^{(-10)} \ .$$

The numerical results within the littlest Higgs model are relatively insensitive to the choice of parameter values of the model. We obtain a difference from the standard model value of at most $\delta a_\mu = a_\mu^{\rm LH} - a_\mu^{\rm SM}$ of the order of 1×10^{-10}. The contributions of the additional heavy particles are thereby completely negligible and the dominant contributions arise from the corrections to the light Z and W couplings. Similar results are obtained in the custodial model.

Weak charge of cesium atoms

At low energy, parity violation in atoms is due to the electron-quark effective Lagrangian

$$\mathcal{L}_{eff} = \frac{G_F}{\sqrt{2}} (\bar{e}\gamma_\mu\gamma_5 e)(C_{1u}\bar{u}\gamma^\mu u + C_{1d}\bar{d}\gamma^\mu d) \ .$$

The experimentally measured quantity is the so-called “weak charge” defined as

$$Q_W = -2\left(C_{1u}(2Z+N) + C_{1d}(Z+2N)\right) \ ,$$

where Z, N are the number of protons and neutrons of the atom, respectively.

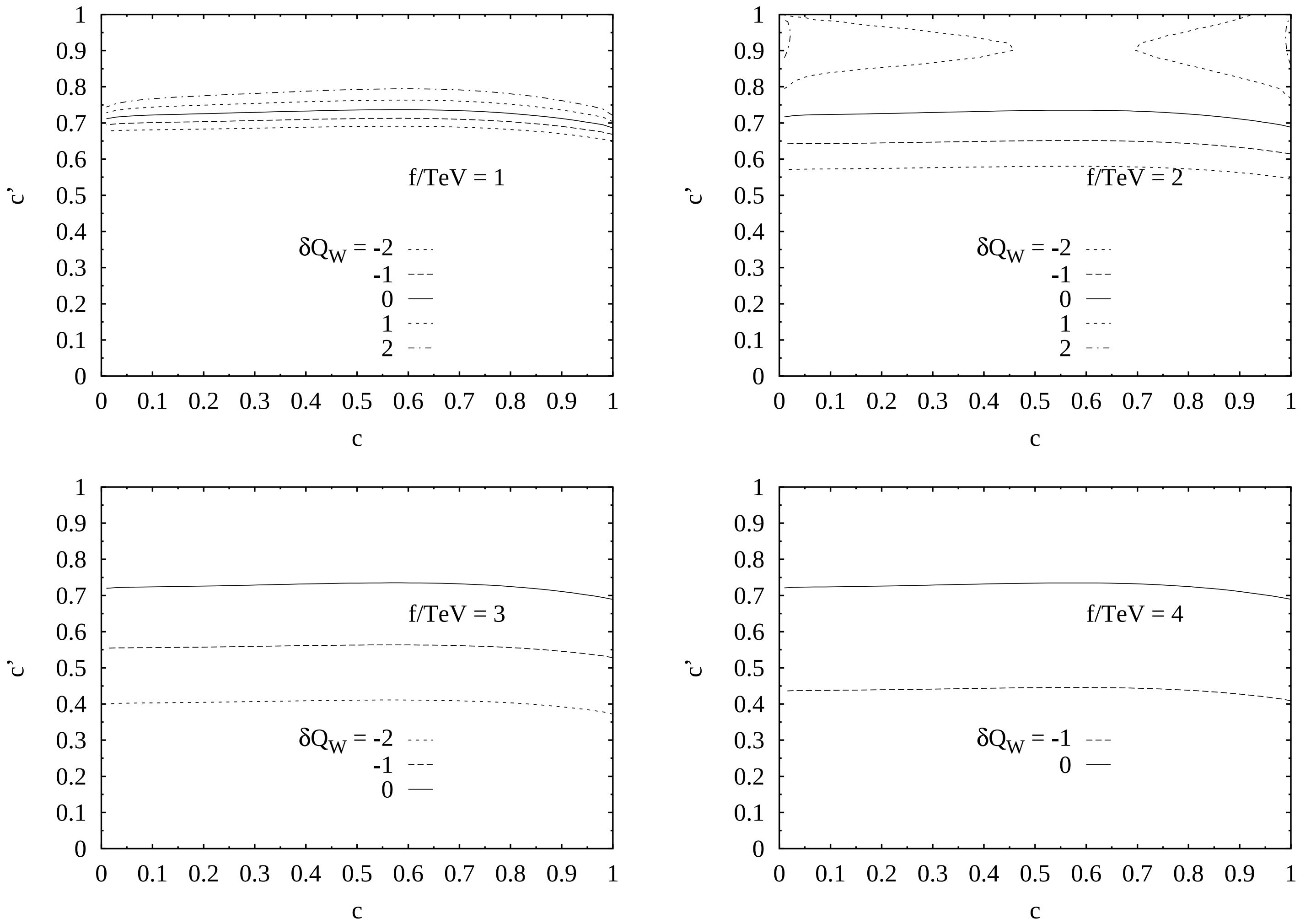


Figure 6: *Corrections to the weak charge of cesium atoms as a function of c and c' in the littlest Higgs model.*

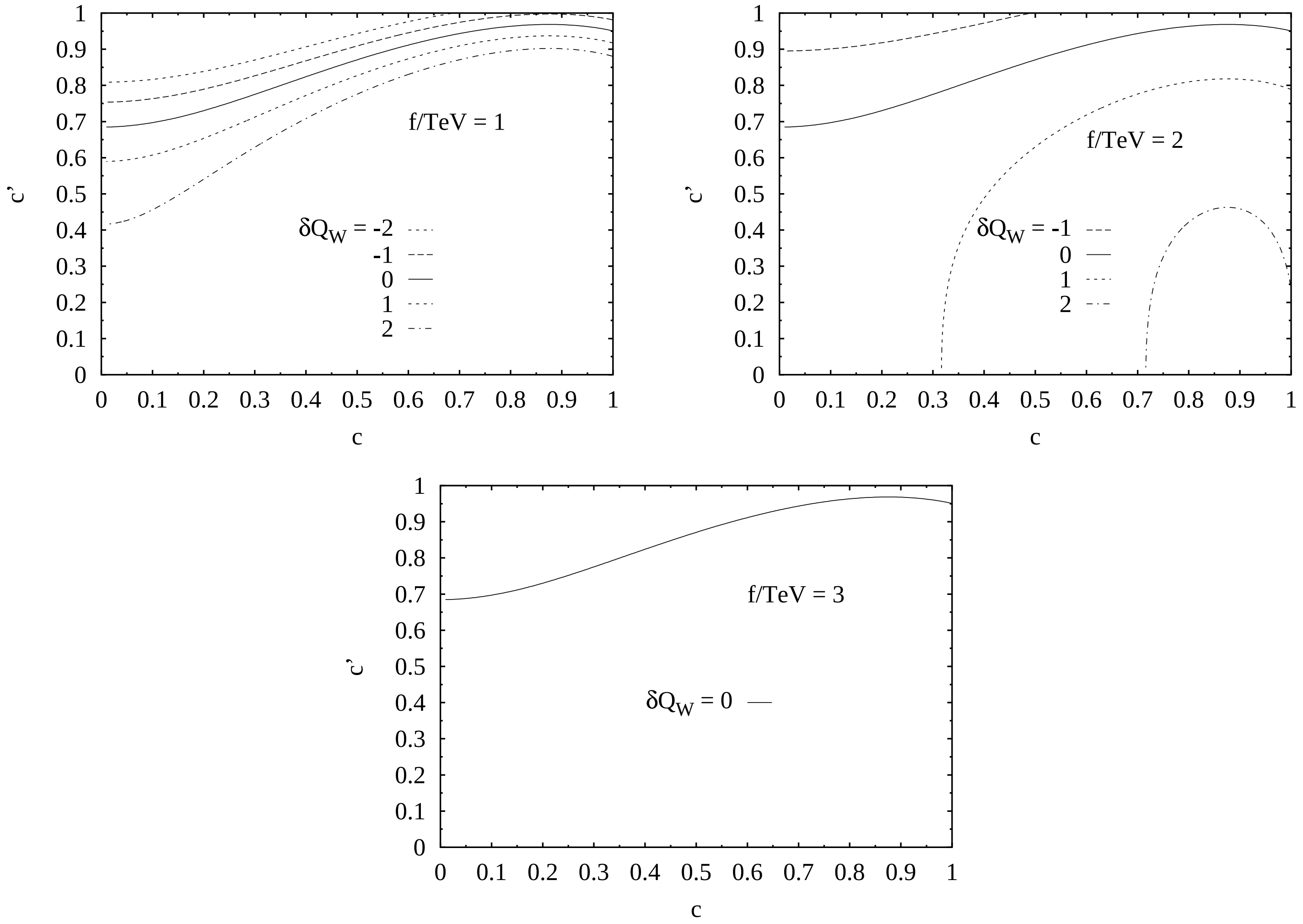


Figure 7: *Corrections to the weak charge of cesium atoms as a function of c and c' in the little Higgs model with approximate custodial symmetry.*

Conclusions

In the model without custodial symmetry a considerable fine tuning is necessary in order to satisfy the constraints imposed by LEP data. This problem is to a large extent avoided for the model with approximate custodial symmetry.

Low energy precision data does not change the above conclusions. For $g-2$ of the muon the corrections are too small. The weak charge does not allow for establishing new constraints either, even if the corrections are not negligible.

However the TeV region is expected to be rich in LH scenarios : new vectors and scalars, extended top sector (see the talk by J.Garcia this afternoon).