



Little(st) Higgs and LHC

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Outline

- Effective Field Theory e EWSB.
- The Littlest Higgs:
Simmetrie, Spettro and Interazioni.
- Fine-tuning: la Massa del Bosone di Higgs.
- Conclusioni.



References

- Little Higgs Models.

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Arkani-Hamed, Cohen, Georgi PLB 513, 232 (2001)
Arkani-Hamed, Cohen, Katz, Nelson, Gregoire, Wacker JHEP 0208, 021 (2002)
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Kaplan, Schmaltz, JHEP 0310, 039 (2003)
Skiba, Terning, PRD 68, 075001 (2003)
Chang, Wacker, PRD 69, 035002 (2004)
Cheng, Low, JHEP 0309, 051 (2003)
AND MORE...

- Precision Electroweak.

Csaki, Hubisz, Kribs, Meade, Terning, PRD 67, 115002 (2003)
Hewett, Petriello, Rizzo, JHEP 0310, 062 (2003)
Csaki, Hubisz, Kribs, Meade, Terning, PRD 68, 035009 (2003)
Casalbuoni, Deandrea, Oertel, JHEP 0402, 032 (2004)
Chen, Dawson, PRD 70, 015003 (2004)
Marandella, Schappacher, Strumia hep-ph/0502096
AND MORE...

- Fine Tuning.

Casas, Espinosa, Hidalgo, JHEP 0411, 057 (2004)
Casas, Espinosa, Hidalgo, hep-ph/0502066
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- Collider Physics.

Burdman, Perenstein, Pierce PRL 90, 241802, 2003
Han, Logan, McElrath, Wand PLB 563, 191, 2003
AND MORE...

- Flavor Physics.

Bazzocchi, Bertolini, Fabbriches, MP, PRD 68, 096117 2003
Lee JHEP 0412, 065, 2004
AND MORE...



EFT ed EWSB

- Settore Fermionico e Interazioni di Gauge: Standard Model.
- EWSB: Teoria Effettiva scalari.
- Interazioni Scalari rinormalizzabili ($d=2,3,4$), crescono con il cut-off (VEV e massa Higgs).
- Interazioni scalari non-rinormalizzabili ($d=5,6\dots$), soppresse dal cut-off (osservabili precisione).
- Tensione: Qual'è il cut-off naturale? Quanto fine-tuning? Come ridurre il fine-tuning?

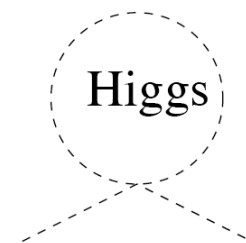
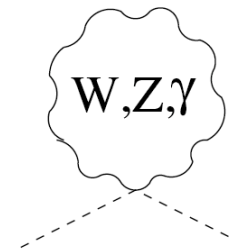
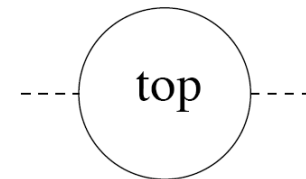
A Little Hierarchy Problem

- Direct Searches + Precision electroweak (operatori di dimensione 6):
Cut-Off ~ 10 TeV.
- Higgs VEV ~ 250 GeV
- Correzioni Radiative al Potenziale Scalare (Cut-Off ~ 10 TeV)

$$-\frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim -(2\text{ TeV})^2$$

$$\frac{1}{16\pi^2}g^2\Lambda^2 \sim (700\text{ GeV})^2$$

$$\frac{1}{16\pi^2}\lambda^2\Lambda^2 \sim (500\text{ GeV})^2$$



- Few % Fine-Tuning:
cut-off “naturale” ~ 1 TeV.



A Little Higgs Solution

- Higgs come PNGB, composito, teoria effettiva non-rinormalizzabile.
- Potenziale per l'Higgs Protetto da Simmetria Bosonica.

Georgi et al. 1974, 1975, 1984...

- Rottura Esplicita, Collective Breaking: Correzioni Radiative “Soffici”.

N. Arkani-Hamed et al. PLB 513
JHEP 0208

T. Gregoire et al. JHEP 0208

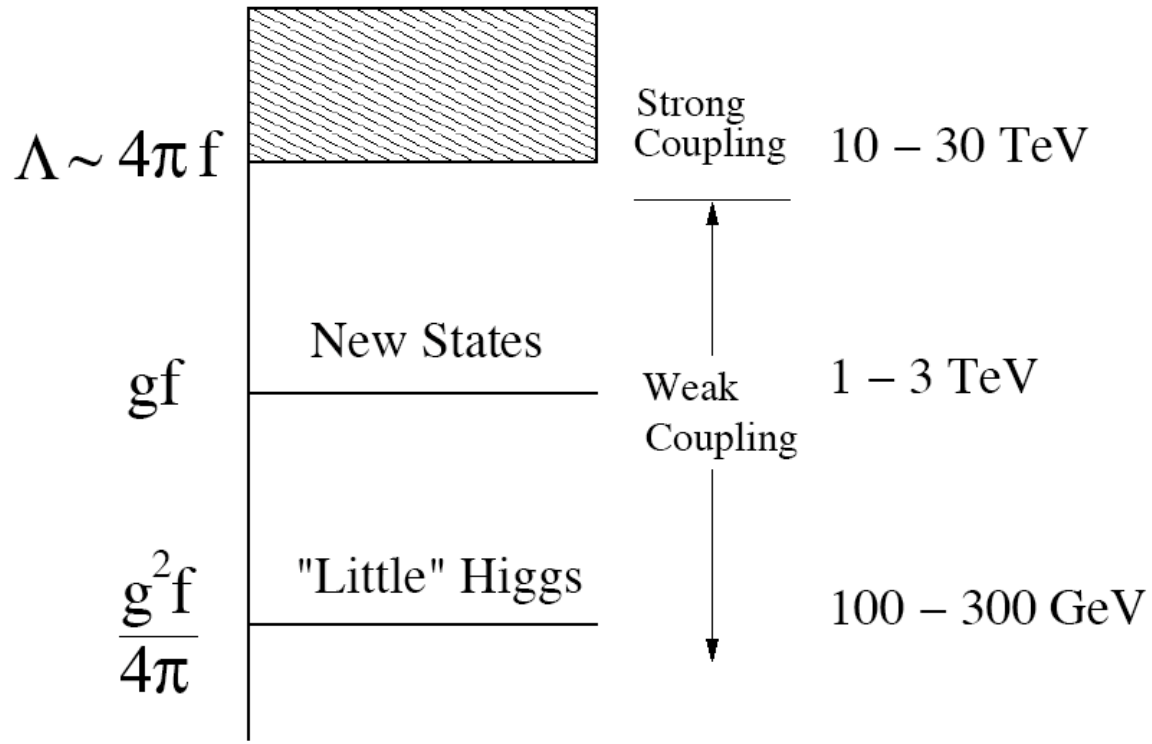
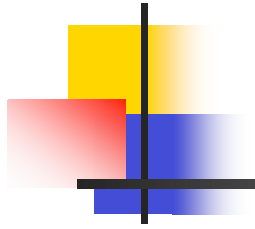
I. Low et al. PRD 66

M. Schaltz et al. JHEP 0310

W. Skiba et al. PRD68

S. Chang et al. JHEP 0312

- EFT con cut-off ~ 10 TeV Cut-Off.
- Nuove Segnature Sperimentali: Spettroscopia Nuova a ~ 1 TeV.

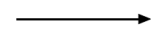


From J. Wacker Ihep-ph/0208235



The Littlest Higgs

SU(5)



SO(5)

U

U

$SU(2)_1 \times SU(2)_2 \times U(1)_1 \times U(1)_2 \longrightarrow SU(2)_L \times U(1)_Y$

- Symmetria Globale SU(5).
- Rottura Spontanea a SO(5).

$$\begin{aligned}\Sigma &\sim 15 \longrightarrow 1 + 14 \\ 14 &= 1 + 3 + 4 + 6 \\ 4 &= h \sim 2 \\ 6 &= \Phi \sim 3\end{aligned}$$

- Rottura Esplicita: Gauge e Top.



Spettro ad LHC (~ 1 TeV)

- Nuovi Scalari: Doppietto e Tripletto.
- Nuovi Bosoni di Gauge: $U(1)$ e $SU(2)$ aggiuntivi, Mixing.
- Nuovi Fermioni: Vector-Like Heavy Top.



Sigma Model

$$\mathcal{L}_K = \frac{f^2}{8} \text{Tr} (D_\mu \Sigma)(D^\mu \Sigma^*)$$

- Vector-like top, SU(3) Globali, Rottura Collettiva.

$$\mathcal{L}_t = \sqrt{2}\lambda_1 f \epsilon_{ijk} \epsilon_{xy} \chi_i \Sigma_{jx} \Sigma_{ky} u_3'^c + \sqrt{2}\lambda_2 f \tilde{t} \tilde{t}^c + h.c.$$

- Rimozione Divergenze Quadratiche (1-loop).

$$\begin{aligned} V_1[c_i, g_i, g'_i, \lambda_i; \Sigma] = & 3 \frac{c_1 \Lambda^2}{32\pi^2} \text{Tr} M_B^2(\Sigma) - 12 \frac{c_2 \Lambda^2}{32\pi^2} \text{Tr} M_F^2(\Sigma) + 3 \frac{1}{64\pi^2} \text{Tr} M_B^4(\Sigma) \log c_3 M_B^2(\Sigma) / \Lambda^2 \\ & - 12 \frac{1}{64\pi^2} \text{Tr} M_F^4(\Sigma) \log c_4 M_F^2(\Sigma) / \Lambda^2, \end{aligned} \quad (5)$$

- Radiative EWSB loops Top (log-divergent).



Fine-Tuning, VEV e Massa del Bosone di Higgs.

- Scelta del Cut-off: $\Lambda = 4\pi f$ ($f \sim 2 \text{ TeV}$).
- Studio dei Coefficienti (divergenze in loops) determinati dal UV: c_i
- Confronto con SM per stesso Cut-off:
Naturalezza $c_i \gtrsim \mathcal{O}(10^{-2})$
- Stima **quantita' osservabili**: massa e VEV dell' Higgs...
- ...independenti! Sappiamo il VEV, non la massa (EFT!)

(Remark: Electroweak Precision only Naively Taken into Account)



Ipotesi di Lavoro

- Analisi completa dell'azione effettiva ad 1-loop. Nessuna espansione, troncamento o approssimazione. (analisi numerica...).
- Accoppiamenti e parametri liberi in range “ragionevoli”: accoppiamenti perturbativi, e
$$\mathcal{O}(10^2) \gtrsim c_i \gtrsim \mathcal{O}(10^{-2})$$
- Parametri fissi per divergenze logaritmiche.

Vacuum Alignment

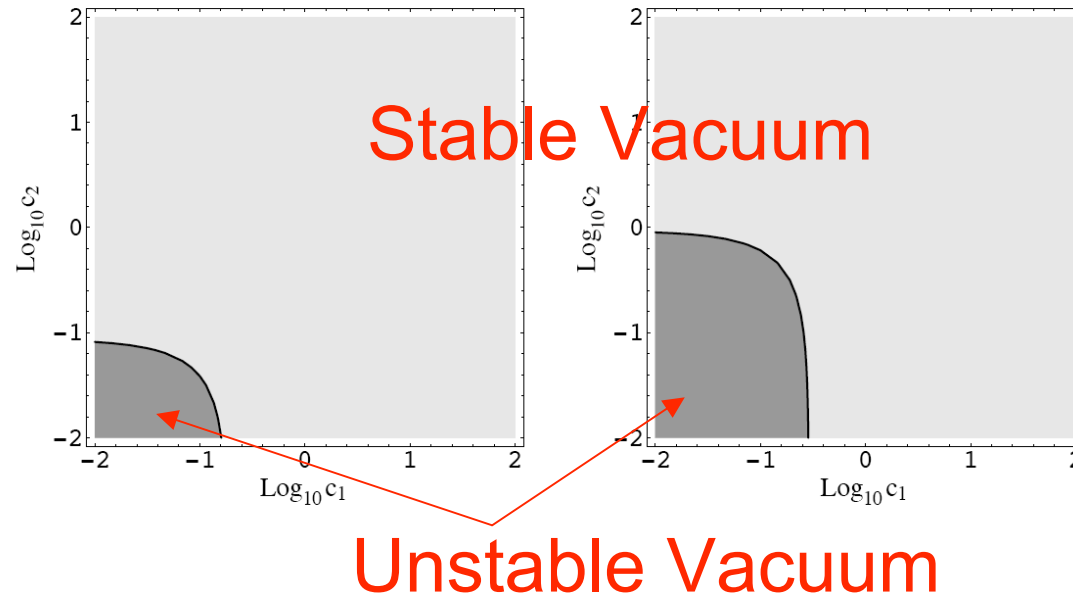


FIG. 1: Possible values (on a logarithmic scale) of the coefficients c_1 and c_2 . The two figures correspond to $G' = 0.72, x_L = 0.56$ and, respectively, two choices of $G = 3$ and $G = 8$. Each point in the light-gray region is a possible potential with a maximum at $h/f = \pi/2$, which means a possible minimum around $h = v_W/\sqrt{2}$. The darker region, where both c_i are small, corresponds to potentials with a minimum in $h/f = \pi/2$ which are not allowed.

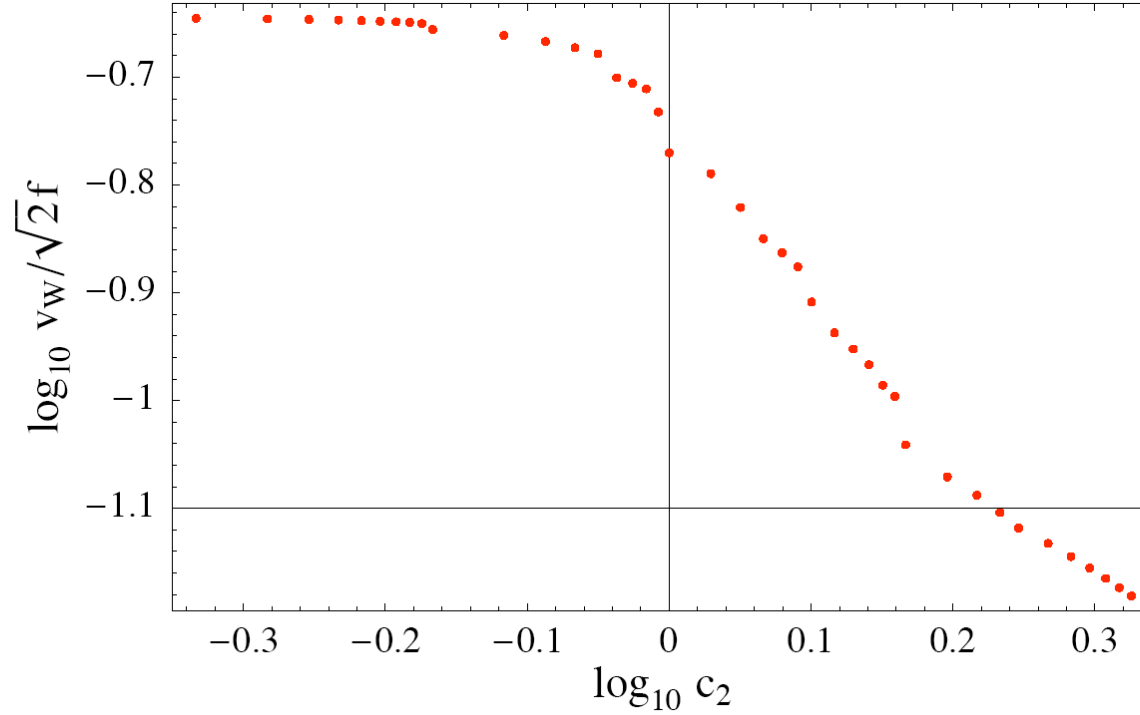


FIG. 2: Dependence (on a logarithmic scale) of the minimum on one of the coefficients after having fixed the other ($c_1 = 1$) and all parameters ($G = 3$, $G' = 0.75$ and $x_L = 0.56$). The physical region, where $f \simeq 2$ TeV, corresponds to the line $\log v_W/\sqrt{2}f = -1.1$ (lower right hand corner in the figure).



VEV dell'Higgs

- Almeno uno tra i coefficienti liberi deve essere grande, altrimenti instabilita' del vuoto nel modello.
- Il VEV dell' Higgs puo' essere stabilizzato senza fine-tuning:

$$v_W/f \sim 1/10 \text{ for } c_1 = 1 \text{ and } c_2 \simeq 1.2$$

- Il Littlest Higgs e' una buona teoria effettiva per cut-off di 20-30 TeV, senza fine-tuning.

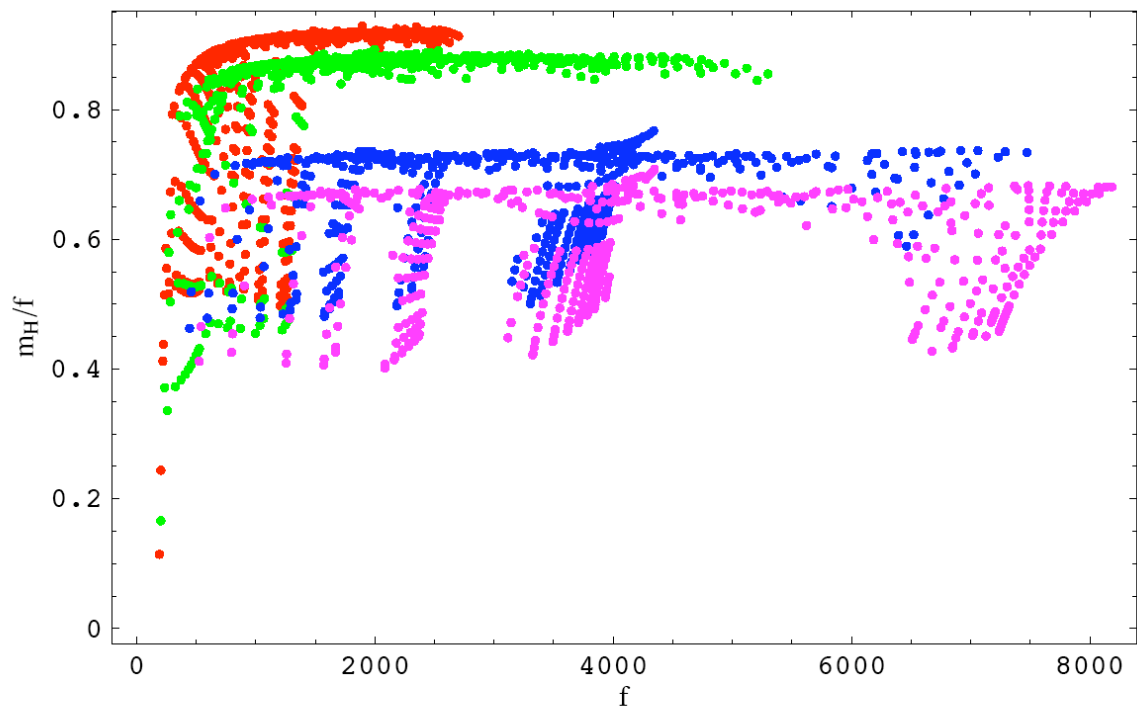


FIG. 4: m_h/f vs. f for $c_{1,2}$ between 0.01 and 100. Each point represents a choice of c_1 and c_2 with c_1 increasing from the bottom to the top and c_2 from left to right. Holes in the dots distributions are an artifact of the numerical simulation mesh. Four different values of $G = 1.3, 3, 8, 12$ (at fixed $x_L = 0.55$ and $G' = 0.72$) are shown in different colors with smaller values toward the bottom of the figure. No 2-loop contribution is included. No choice of values of these coefficients gives a light m_h and f around 2 TeV at the same time.

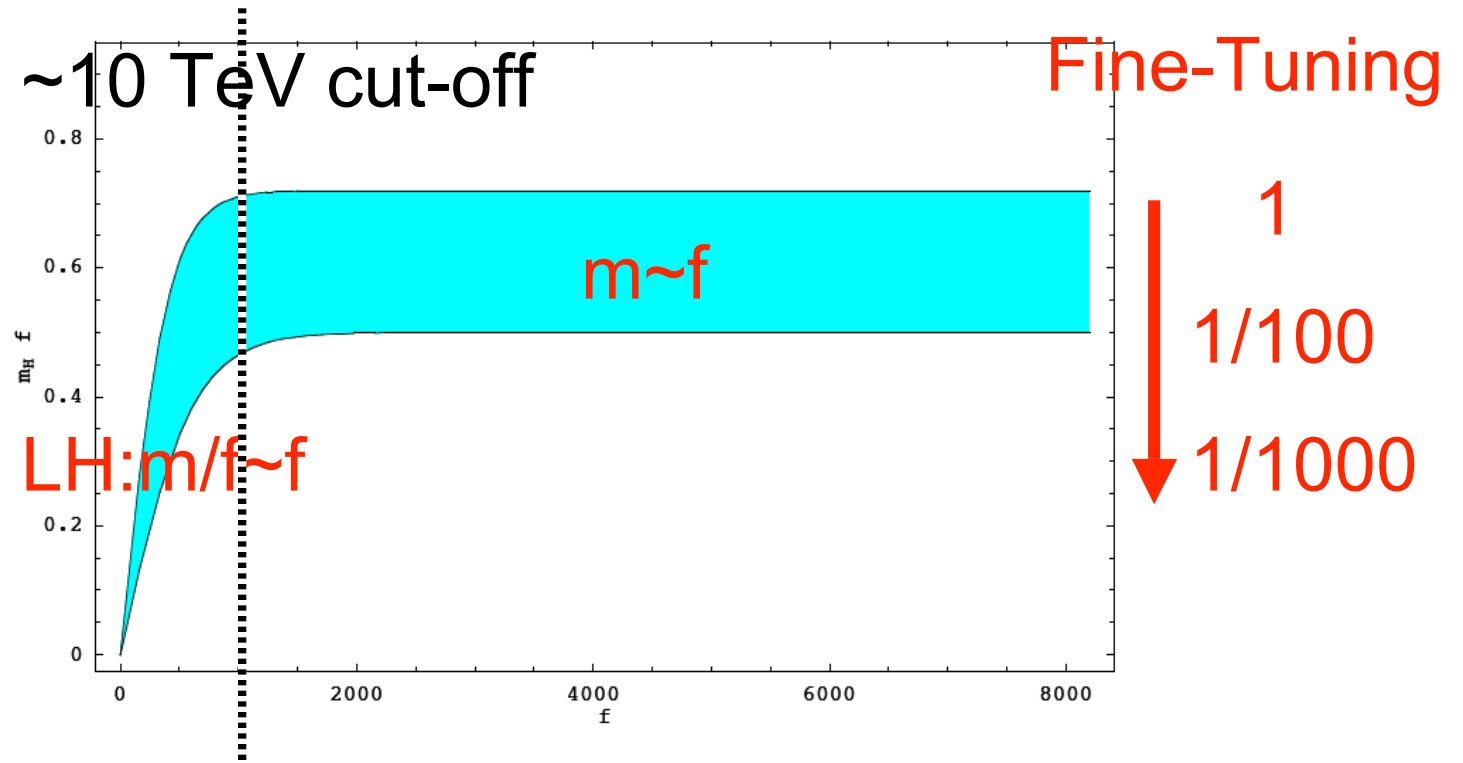


FIG. 4: m_h/f vs. f for $c_{1,2}$ between 0.01 and 100. Each point represents a choice of c_1 and c_2 with c_1 increasing from the bottom to the top and c_2 from left to right. Holes in the dots distributions are an artifact of the numerical simulation mesh. Four different values of $G = 1.3, 3, 8, 12$ (at fixed $x_L = 0.55$ and $G' = 0.72$) are shown in different colors with smaller values toward the bottom of the figure. No 2-loop contribution is included. No choice of values of these coefficients gives a light m_h and f around 2 TeV at the same time.

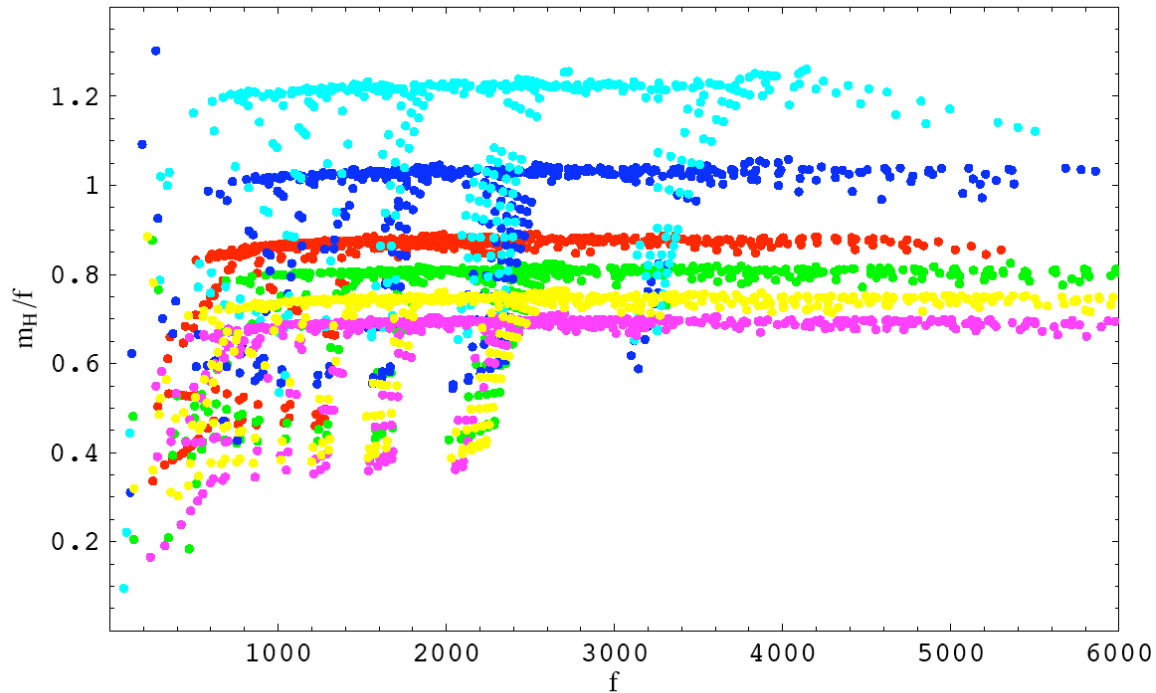


FIG. 5: Same as Fig. 4. Four different values of $x_L = 0.55, 0.71, 0.91, 1.05, 1.55, 2.05$ (at fixed $G = 3$ and $G' = 0.72$) are shown in different colors with the largest value of x_L on top, smallest values corresponding to $x_L = 0.71$. No 2-loop contribution is included. No choice of values of these coefficients gives a light m_h and f around 2 TeV at the same time.



Massa dell'Higgs e VEV

- Il VEV non richiede fine-tuning.

$$\langle h \rangle = v_W / \sqrt{2},$$

- Correzioni dal top grandi: Massa alla scala f .
- Limitando Fine-Tuning, per $f \sim 2 \text{ TeV}$ (electroweak precision tests):

$$m_h \simeq 1 \text{ TeV}$$



Summary and Discussion

- Il Littlest Higgs STABILIZZA la scala elettrodebole, permettendo di scrivere una teoria effettiva SENZA FINE-TUNING con un cut-off >10 TeV.
- La massa (naturale) dell'Higgs e' grande, alla stessa scala delle particelle nuove, ben al di la' dei limiti di Lep.
- Studi in cui la massa del Littlest Higgs e' piccola sono innaturali: il fine-tuning "nascosto" nel termine di massa e' molto maggiore di quello del Modello Standard (a parita' di cut-off).
- Caveat: usare modelli in cui il cut-off e' piu' basso (4 TeV?).
- Esempio: Littlest Higgs + T-parity



Model Dependence and LHC

- Littlest Higgs:
 1. Heavy Higgs (TeV scale, osservabile?)
 2. Spettroscopia ad LHC: Bosoni Vettore, Top pesante, Tripletto Scalare.
 3. Accoppiamenti (effettivi) forti.
 4. Osservabili precisione (stati nuovi).
- Littlest Higgs + T-parity:
 1. Higgs Leggero (come MSSM?)
 2. Stati Stabili: Missing Energy (T-parity).
 3. Accoppiamenti (effettivi) deboli.
 4. Osservabili Precisione (cut-off basso)



Conclusioni

- LH as EFT of EWSB: approccio meno ambizioso, importanza del fine-tuning.
- Nuove Simmetrie e Nuove Particelle: Bosoni di Gauge, Top pesanti, Scalari.
- Model Dependence: Fenomenologia LHC Dipende dal Modello.
- Fine Tuning: Higgs Pesante Favorito nel Littlest Higgs.