Light Top Partners for the Light Higgs

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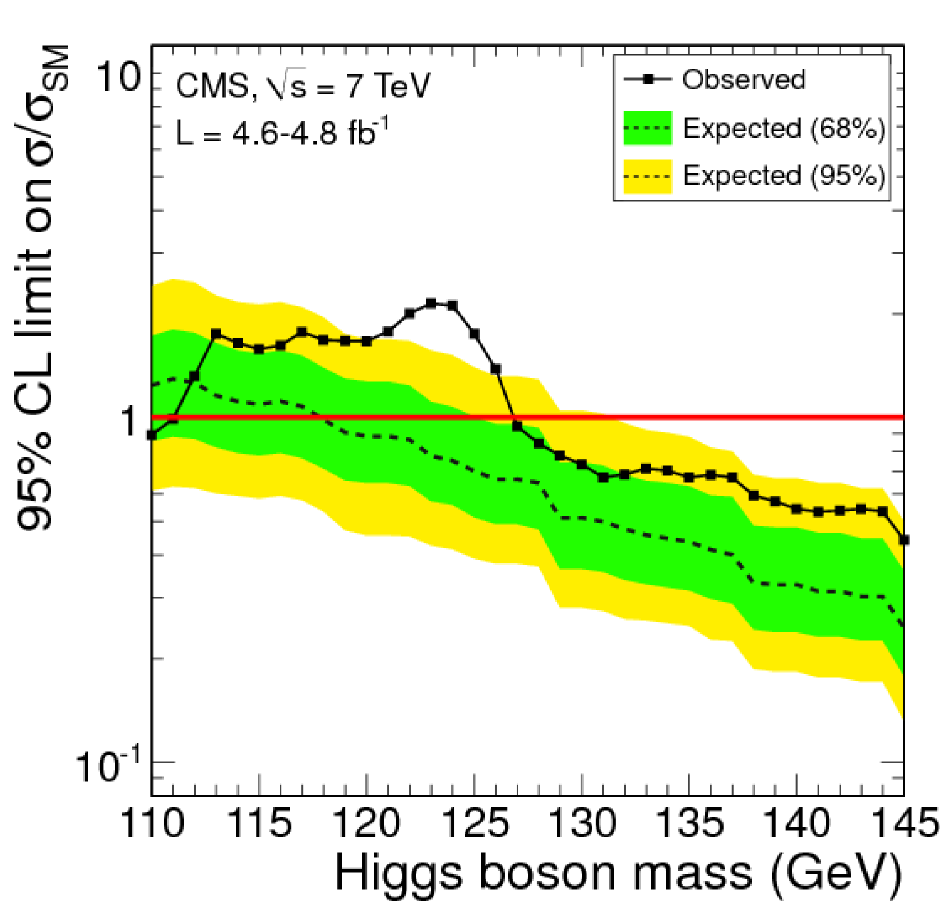
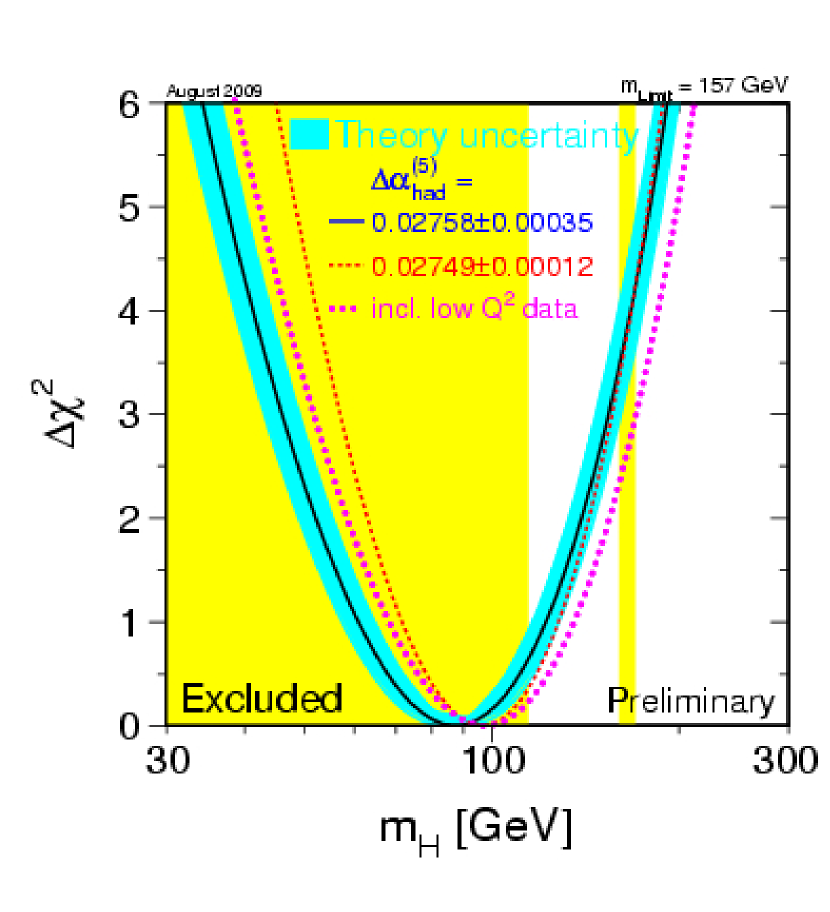
Based on the work O.M.,G. Panico and A.Wulzer
arXiv:1204.6333

Hints of the light Higgs

direct + indirect





Implications of the Light Higgs

Naturalness problem:

$$m_h^2 = m_{h0}^2 + \delta m_h^2(SM) + \delta m_h^2(UV)$$

$\delta m_h(SM) \sim \Lambda$ - cutoff scale

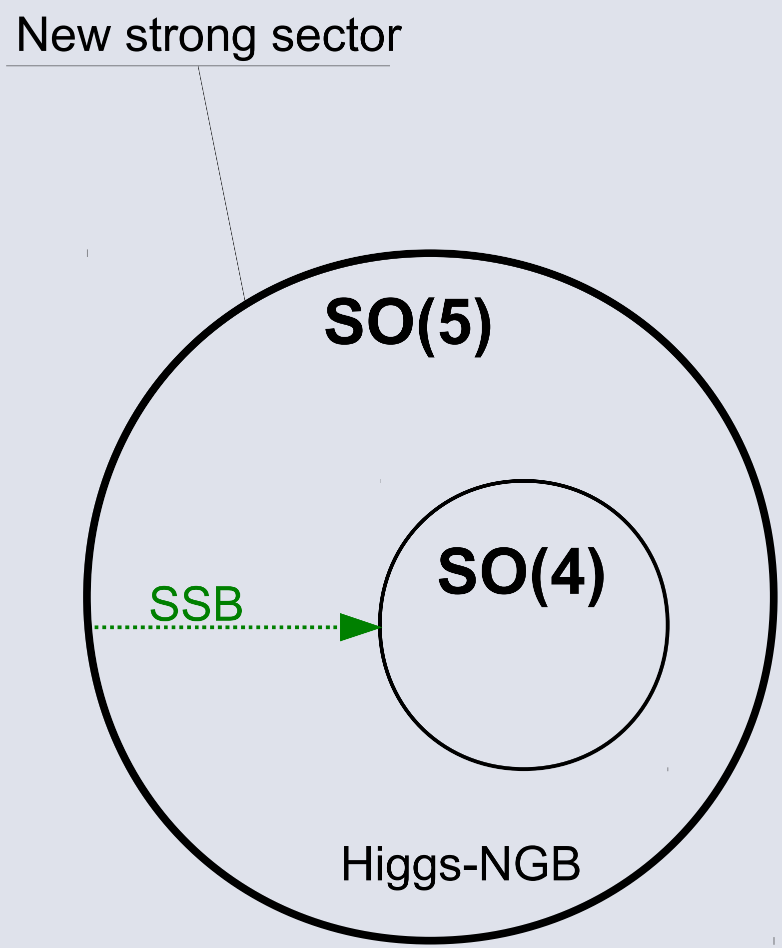
Composite Higgs Scenario

- Compositeness:
  the finite size of the particles provides
  a new cutoff m_ρ

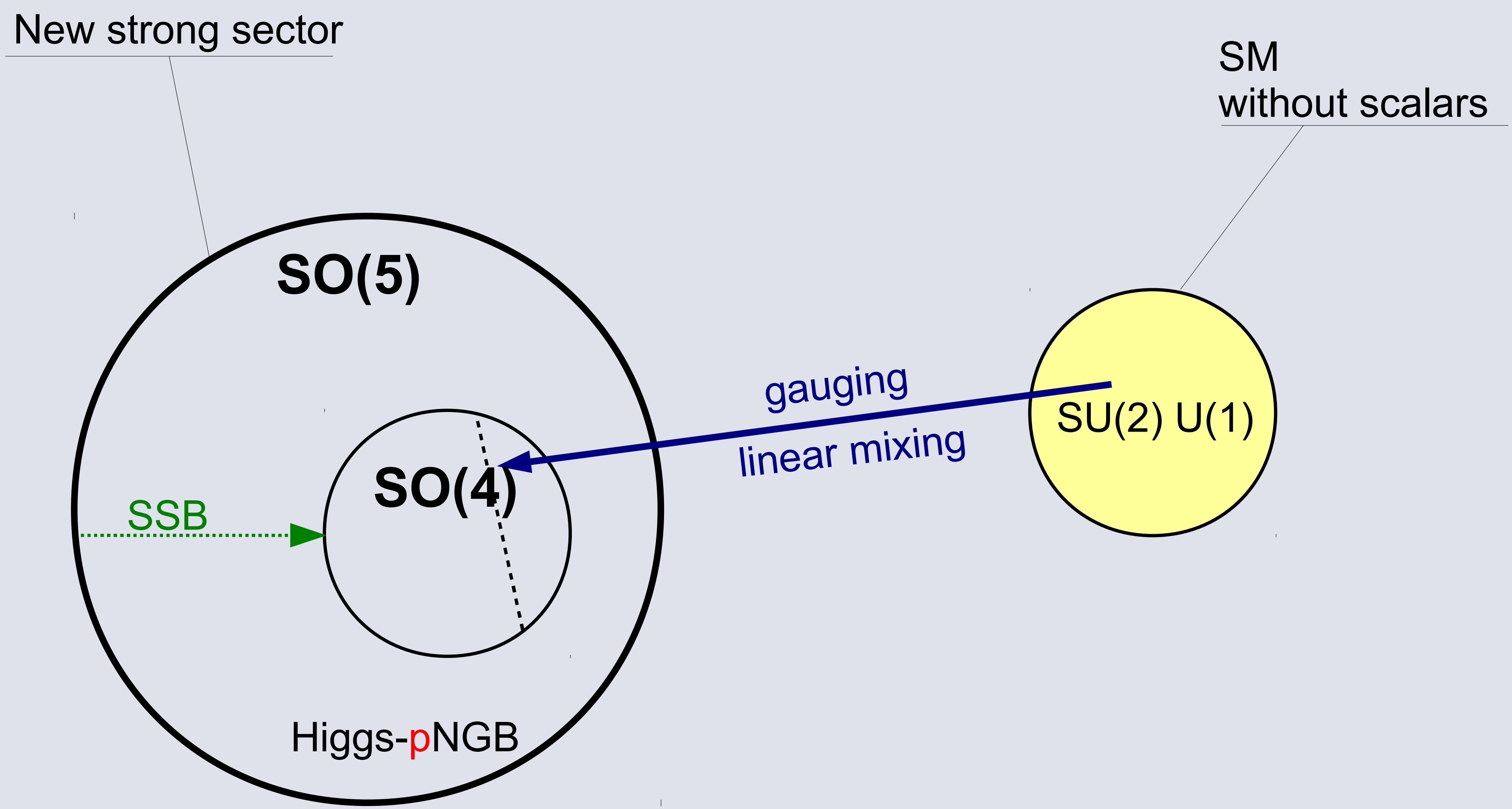
- Higgs is pNGB:
  lighter than other resonances

$$m_h \ll m_\rho$$

General set-up



General set-up



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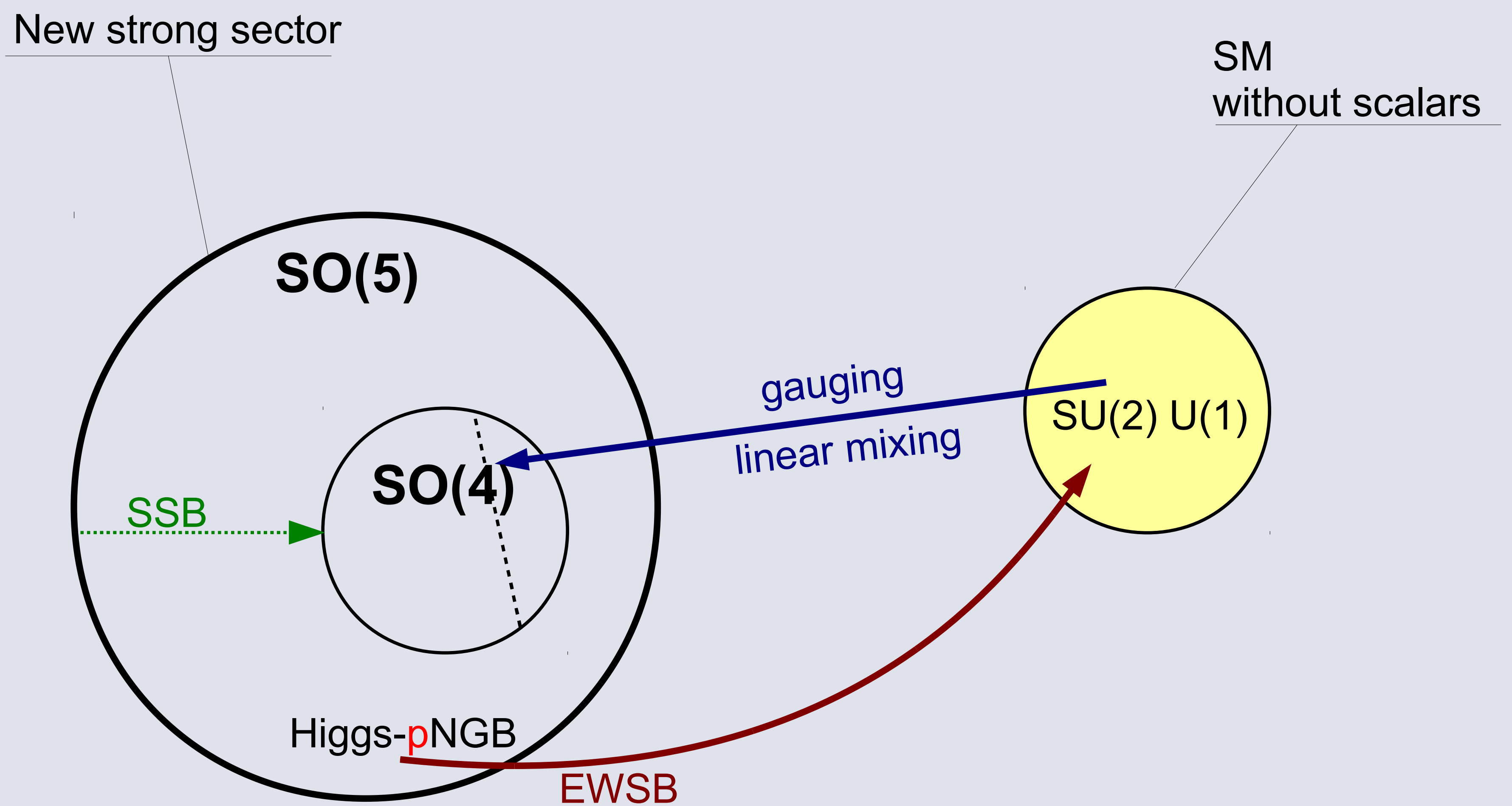


General set-up

- Higgs is a NGB

$$h \to h + c$$

- Custodial symmetry + minimality

$$U = e^{i\frac{\sqrt{2}}{f_\pi}\Pi_{\hat{a}}T^{\hat{a}}} \qquad T^{\hat{a}} \in SO(5)/SO(4)$$

- Partial compositeness

Composite operators

$$y_L\left(\bar{q}_L\right)^\alpha \Delta^L_{\alpha I}\left(\mathcal{O}_R\right)^I + y_R\left(\bar{t}_R\right)\Delta^R_I\left(\mathcal{O}_L\right)^I$$

Elementary quarks

- Higgs potential is IR saturated

Top mass from Top Partners

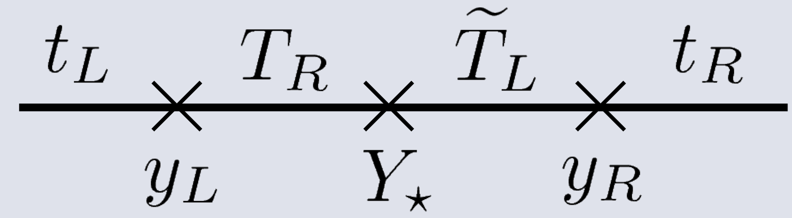
Top mass generation via interactions with the Top Partners

linear mixing

$$y_L f_\pi \bar{t}_L T_R + y_R f_\pi \bar{t}_R \widetilde{T}_L$$

proto-Yukawa

$$Y_* h \overline{T} \widetilde{T}$$



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$$\begin{cases} y_t = Y_* \sin\varphi_L \sin\varphi_R \\ \sin\varphi_{L,R} = \dfrac{y_{L,R} f_\pi}{m_{T,\widetilde{T}}} \end{cases}$$

degree of top compositeness

$$t_L^{\rm ph} = \cos\varphi_L \, t_L + \sin\varphi_L \, T_L$$

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the *smaller* is *y* the *smaller* are the masses of the top partners !

$$y^2 = \frac{y_t}{Y_*} \frac{m_T m_{\widetilde{T}}}{f^2}$$

given that the source of the goldstone symmetry breaking are mixings one could expect:

$$m_h \sim y \sim m_{T,\widetilde{T}}$$

Scalar potential

Leading contribution to the potential does not lead to a successful EWSB

$$V^{(2)}(h) = \frac{N_c M_*^4}{16\pi^2 g_*^2}\left[\frac{1}{2}c_L y_L^2 - c_R y_R^2\right]\boxed{\sin^2(h/f_\pi)}$$

typical mass of fermionic resonances

typical coupling of fermionic resonances

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Fine tuning: $\frac{1}{2}c_L y_L^2 = c_R y_R^2\left(1 + \mathcal{O}(y^2/g_*^2)\right)$

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$$V^{(4)}(h) = \frac{N_c M_*^4}{16\pi^2 g_*^4}\left[c_1^{(4)}\, y^4 \sin^2(h/f_\pi) + c_2^{(4)}\, y^4 \sin^2(h/f_\pi)\cos^2(h/f_\pi)\right]$$

Fine tuning: $\sin^2(v/f_\pi) \ll 1$

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$$\Rightarrow \quad m_H^2 \simeq \frac{2N_c y^4}{16\pi^2} f_\pi^2 \sin^2(2v/f_\pi)$$

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Source of the goldstones symmetry breaking^4

$$\Rightarrow \quad m_H^2 \simeq \frac{2N_c y^4}{16\pi^2} f_\pi^2 \sin^2(2v/f_\pi)$$

Light Higgs wants Light Top Partners

$$m_H \simeq 4\sqrt{3} m_t \, \frac{m_T m_{\widetilde{T}}}{4\pi Y_* f_\pi^2}$$

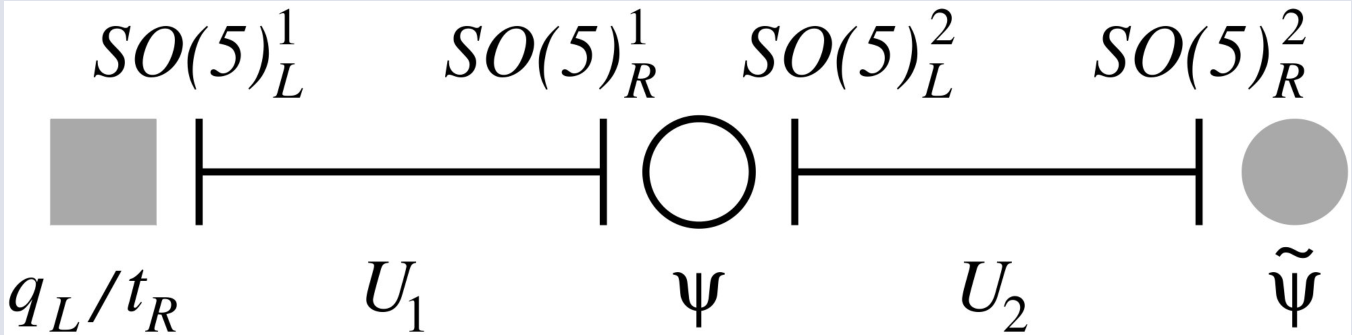
more refined formula:

$$m_H \simeq \frac{\sqrt{N_c}}{\pi} \frac{\min(m_T, m_{\widetilde{T}})}{f_\pi} m_t$$

$$f_\pi = 500\, GeV$$
$$m_f = 700\, GeV$$

accessible at the LHC !

Example: DCHM3



- 3-site model
- Higgs boson has a triple goldstone symmetry protection
- 2 layers of composite resonances

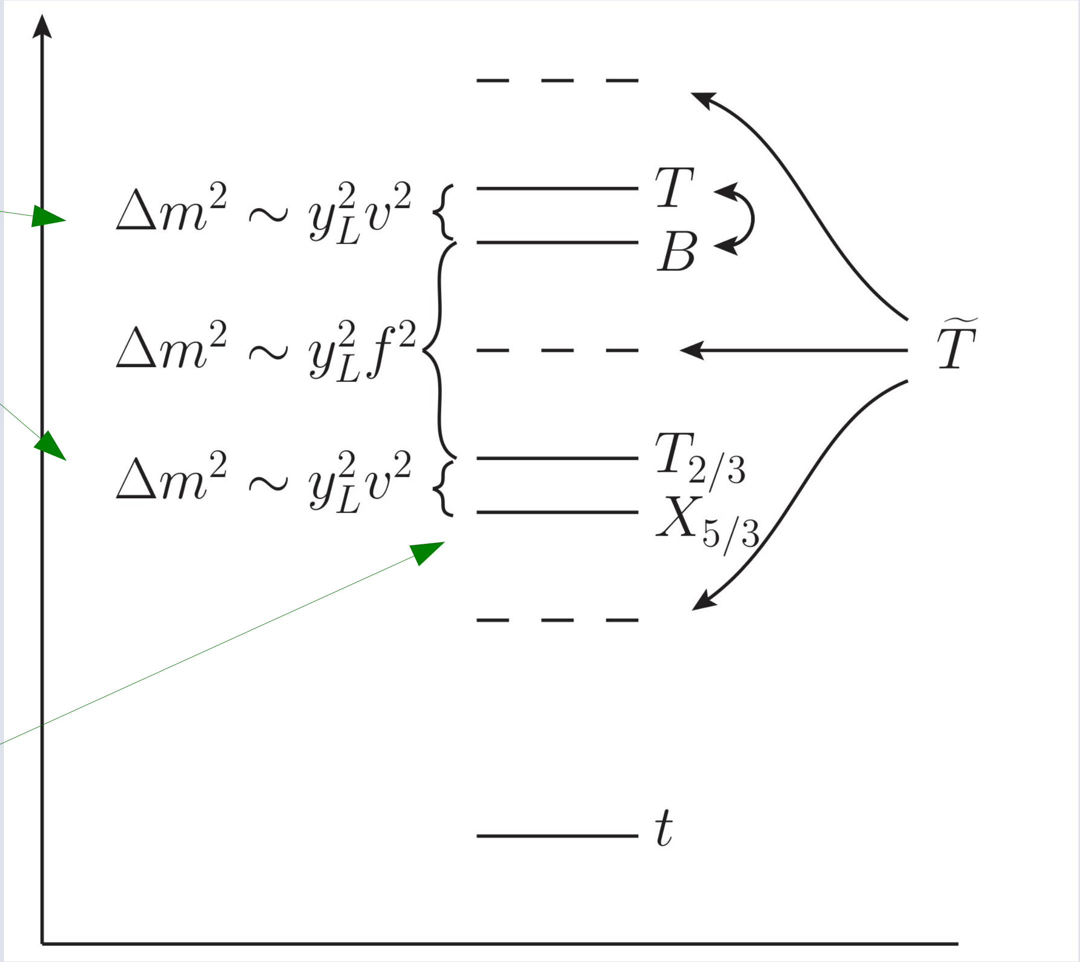
  $\psi,\ \widetilde{\psi} \in \mathbf{5}$ of SO(5)

- Higgs potential is calculable at one loop

Example: DCHM3

Simplified mass spectrum

approx. doublet structure remains after EWSB

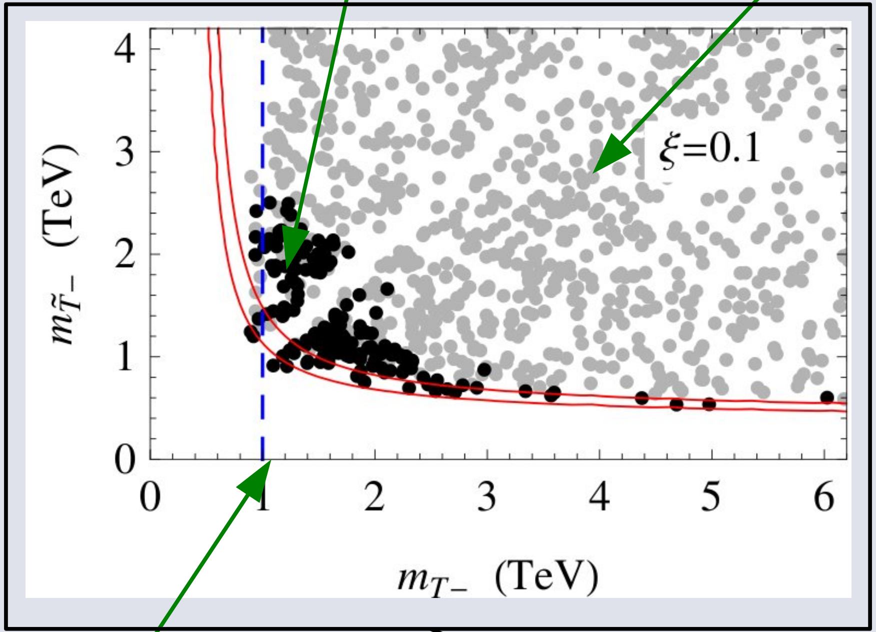


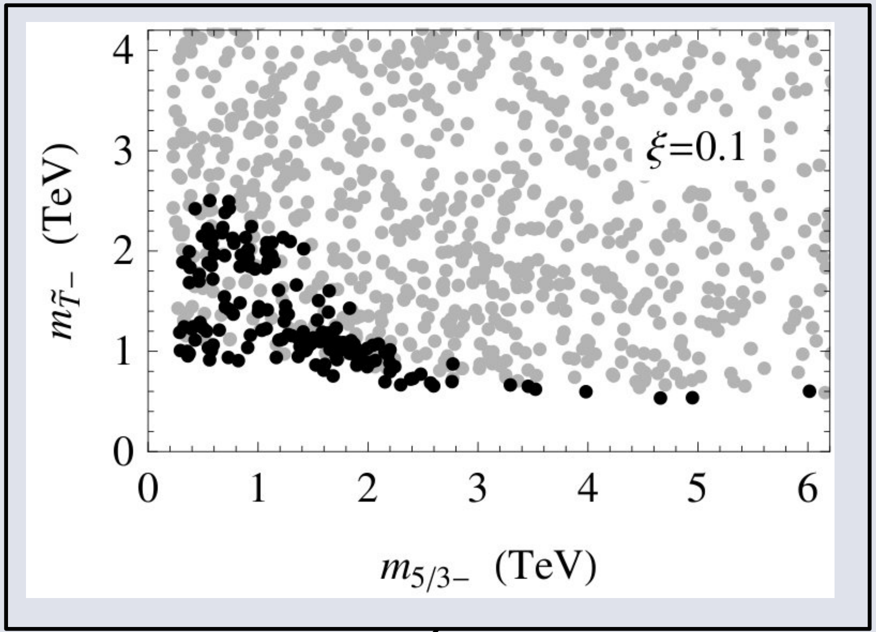
lightest state in the bidoublet has exotic charge 5/3

Example: DCHM3

$$m_H = 115..130\,GeV \qquad m_H > 130\,GeV$$

$$\xi = \left(\frac{v}{f}\right)^2$$

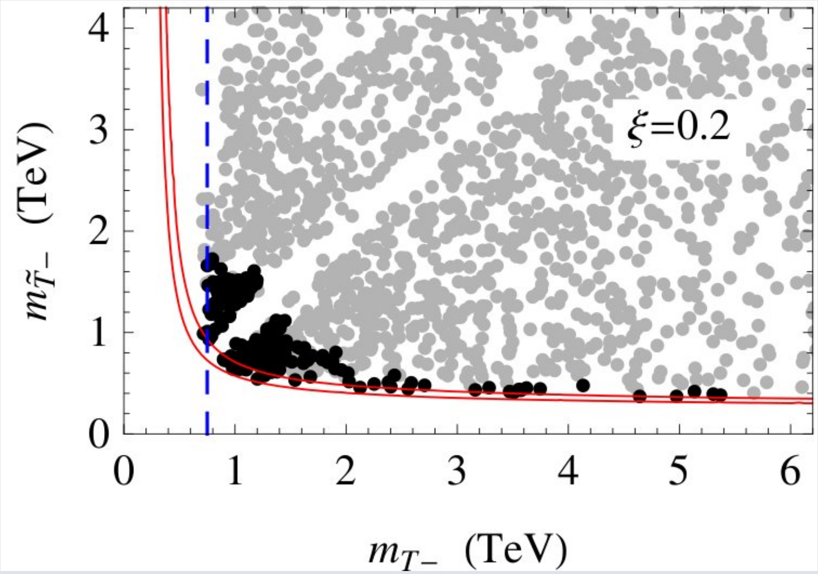


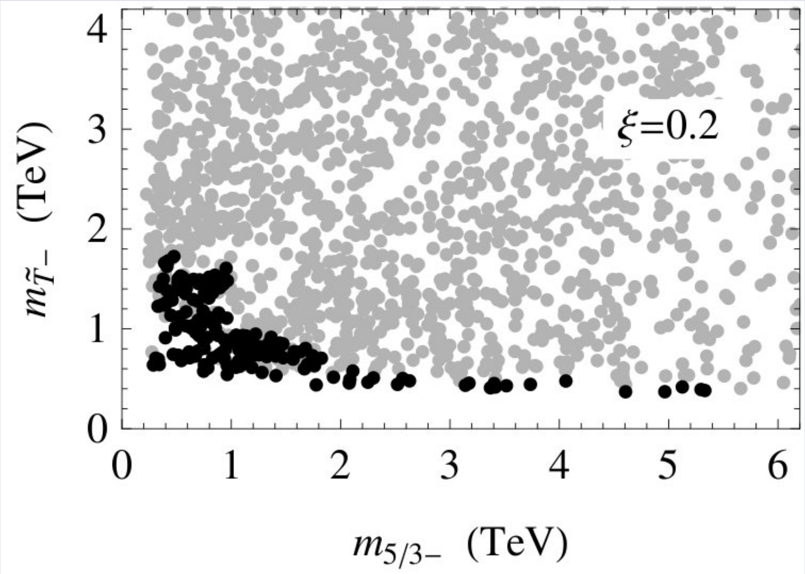


min mass needed for correct m top

Light Higgs always requires Light Partners

Example: DCHM3



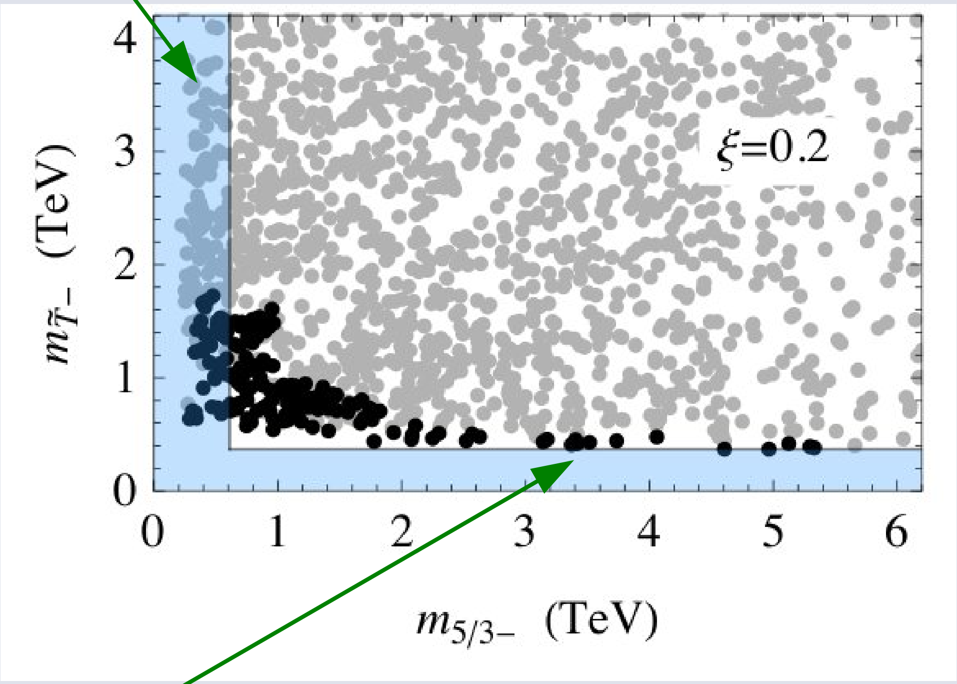


Example: DCHM3

Bounds from direct searches

$b'b' \to WtWt \to$ same-sign dileptons and trileptons

$\Rightarrow m_{5/3} > 611\, GeV$

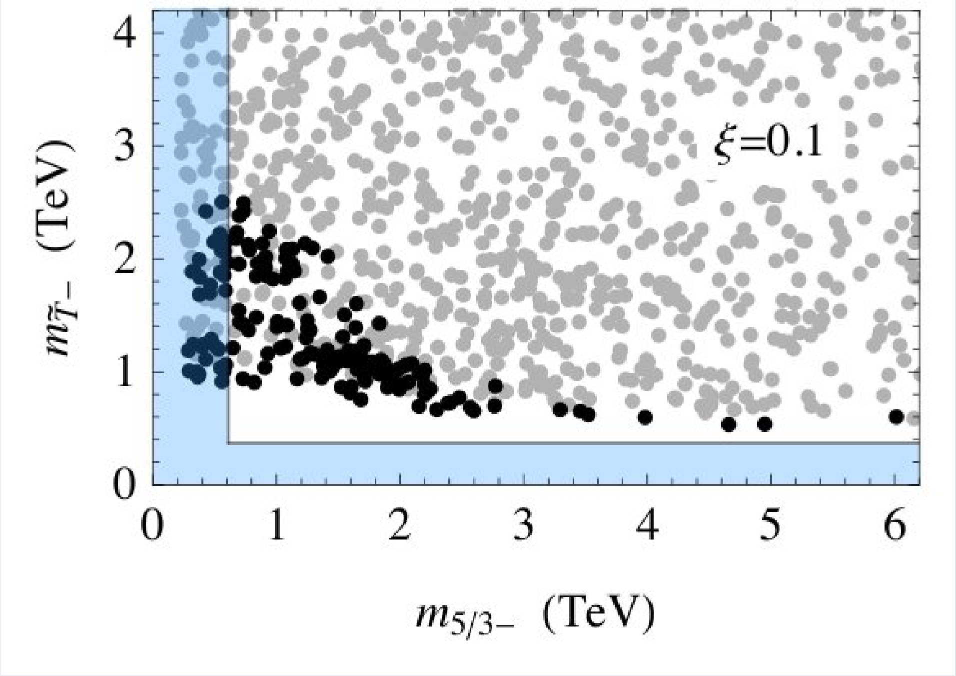


$t't' \to WbWb \to$ dileptons

$\Rightarrow m_{\tilde{T}} > 370\, GeV$

Example: DCHM3

Bounds from direct searches



Conclusions

- In a broad class of models where the Higgs boson is realized as pNGB there is a structural correlation between the Higgs mass and the masses of composite fermionic resonances

- This correlation typically requires the presence of the light resonances below 1TeV if the Higgs is light

- Present experimental bounds on the fermionic resonances together with the light Higgs mass put significant constraints on the allowed parameter space of considered type of models