Modeling and Testing a Composite Higgs

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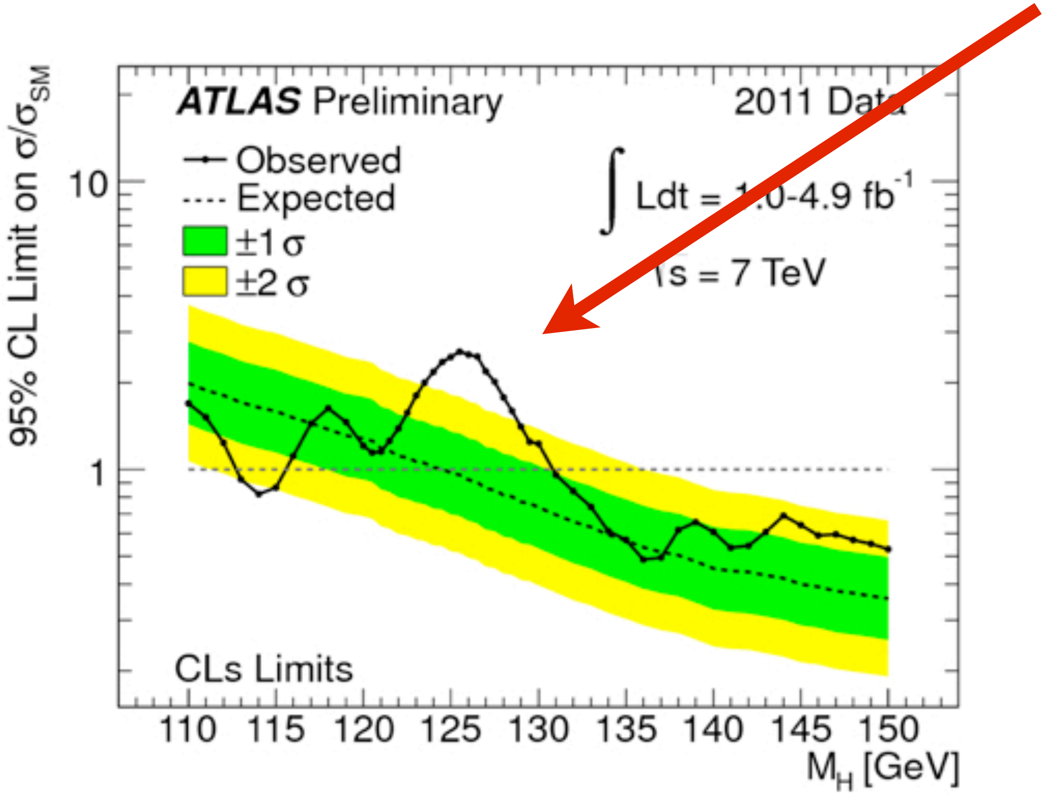
Based on:
"The Discrete Composite Higgs model", with G. Panico,
and work in progress with G.Panico and A.Matsedonski

Introduction:

Good reasons to advocate a **light Higgs**:

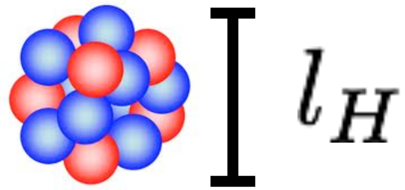
1. **EWPT**

2. We have (perhaps) almost seen one !



Introduction:

Imagine the Higgs is **Composite** (Georgi, Kaplan)



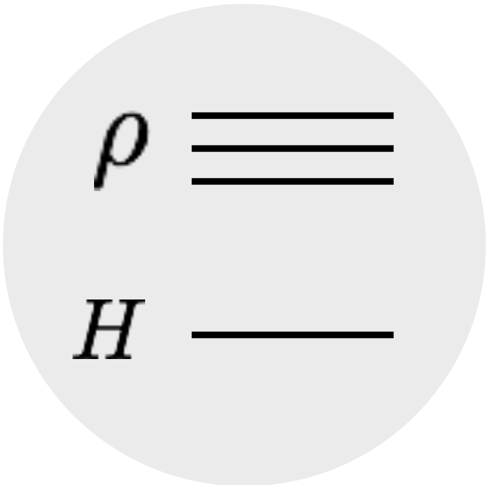
Hierarchy Problem is **solved :**

Corrections to m_H screened above $1/l_H$

m_H is **IR-saturated**

Introduction:

Postulate a **New Strong Sector**



SILH Paradigm (or Prejudice) :
(Giudice, Grojean, Pomarol, Rattazzi)

One **mass** scale m_ρ

One **coupling** $g_\rho \leq 4\pi$

(Example: $g_\rho = 4\pi/\sqrt{N_c}$)

But $m_H \ll m_\rho$ if the Higgs is a **Goldstone**

Higgs Decay Constant: $f = m_\rho/g_\rho$

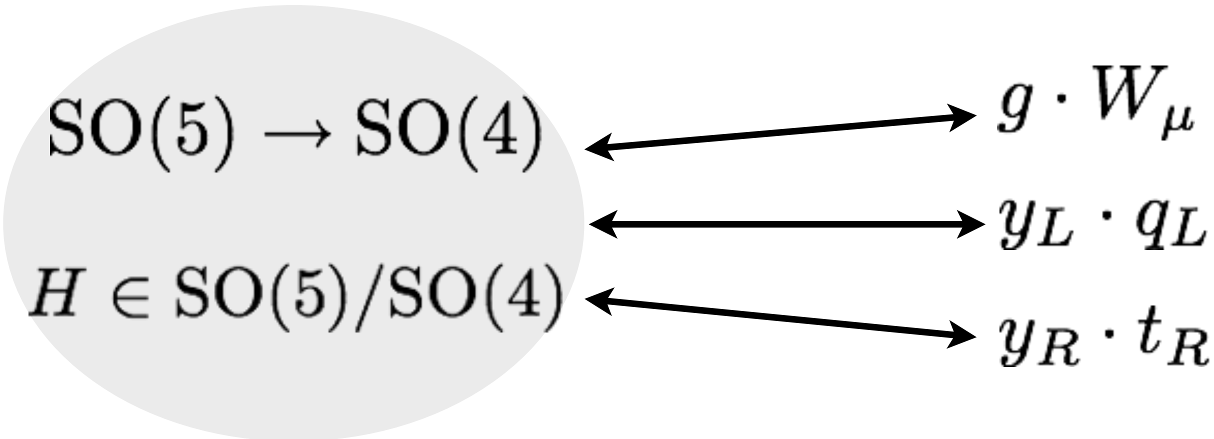
Models of Composite Higgs

The non-linear sigma-model

$$\mathcal{L} = \frac{f^2}{2} D_\mu \Sigma^t D^\mu \Sigma$$

Composite Sector

Elementary states



$$\Sigma_I = U_{I5}$$
$$U = \mathrm{Exp}\left[i h_a T^a / f \right]$$

$$D_\mu \Sigma = \partial_\mu \Sigma - i A_\mu \Sigma$$
$$A_\mu = g W_\mu^\alpha T_L^\alpha + g' B_\mu T_R^3$$

Models of Composite Higgs

The non-linear sigma-model

Perfect to study modified Higgs couplings

(Giudice et al, Barbieri et al, Espinosa et al.)

$\lambda \simeq \lambda^{\mathrm{SM}}\,(1 + c\,\xi)$ $\quad \xi = (v/f)^2$ $\quad$ EWPT suggest : $\xi = 0.2,\, 0.1$

Models of Composite Higgs

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However, it is **not** completely **predictive** framework :

Higgs Potential is **not IR-saturated**

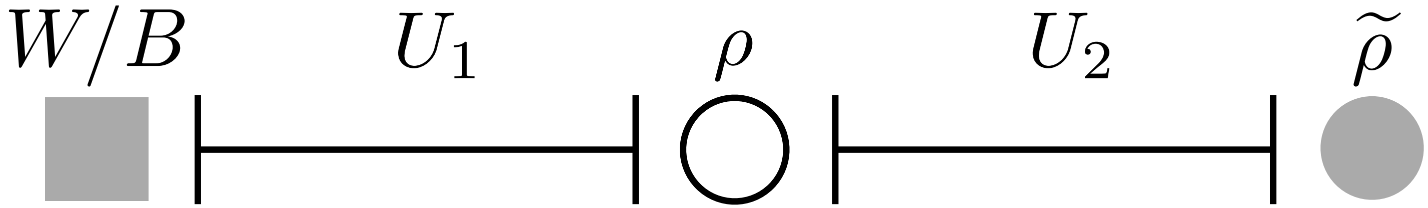
$$V^{(1)}(h/f) = \Lambda^2 f^2 \left(\frac{\Lambda}{4\pi f}\right)^2 \left(\frac{gf}{\Lambda}\right)^2 v(h/f) = g^2 \frac{\Lambda^2 f^2}{16\pi^2} v(h/f)$$

Models of Composite Higgs

G.Panico, A.W.: arXiv:1106.2719

The Discrete Composite Higgs model

Introduce resonances that **protect** the potential



$$\mathcal{L}^{\pi} = \frac{f^2}{4}\mathrm{Tr}\left[(D_\mu U_1)^t D^\mu U_1\right] + \frac{f^2}{4}\mathrm{Tr}\left[(D_\mu U_2)^t D^\mu U_2\right]$$

Each U is a Goldstone matrix of $\mathrm{SO}(5)_L \times \mathrm{SO}(5)_R/\mathrm{SO}(5)_V$

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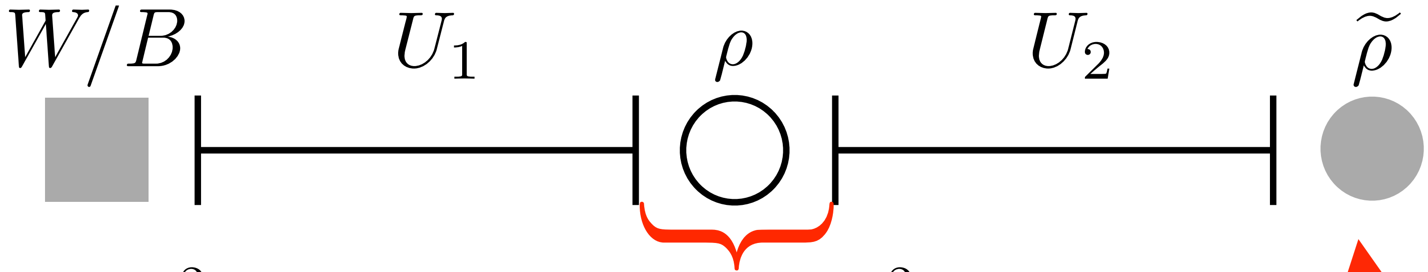

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10+10 scalar d.o.f reduced to 4 by **gauging** $\rho \in \mathrm{SO}(5)\,,\ \ \widetilde{\rho} \in \mathrm{SO}(4)$

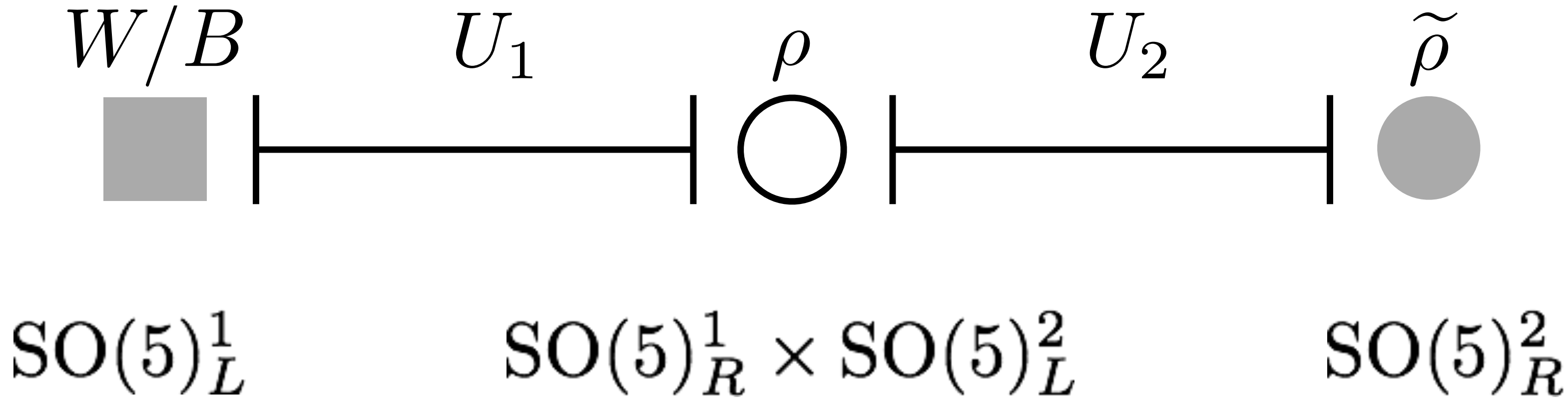
$$D_\mu U_1 = \partial_\mu U_1 - iA_\mu U_1 + ig_* U_1 \rho_\mu$$

$$D_\mu U_2 = \partial_\mu U_2 - ig_* \rho_\mu U_2 + i\widetilde{g}_* U_2 \widetilde{\rho}_\mu$$

Models of Composite Higgs

The Discrete Composite Higgs model

Higgs is Goldstone under three symmetry groups :



Collective Breaking

(Arkani-Hamed, Cohen, Georgi)

EWSB effects only through the breaking of all groups

Models of Composite Higgs

The Discrete Composite Higgs model

Higgs Potential is now **finite** at one loop

$$V^{(1)}(h/f) = \Lambda^2 f^2 \left(\frac{\Lambda}{4\pi f}\right)^2 \left(\frac{g f}{\Lambda}\right)^2 \left(\frac{g_* f}{\Lambda}\right)^2 \left(\frac{\widetilde{g}_* f}{\Lambda}\right)^2 v(h/f)$$

Careful analysis reveals stronger (g_*^4) suppression

Similar protection mechanism for S and T

Models of Composite Higgs

The Discrete Composite Higgs model

Fermionic sector :

Top Partners: $\psi,\, \widetilde{\psi} \in \mathbf{5} = \begin{pmatrix} T & X_{5/3} \\ B & T_{2/3} \end{pmatrix} \otimes \widetilde{T}$

$$\mathcal{L}_{\text{mix}} = \overline{q}_L{}^i\, \Delta_L^{iI}\, (U_1)_{IJ}\, \psi^J + \bar{t}_R\, \Delta_R^I\, (U_1)_{IJ}\, \psi^J + \overline{\psi}^I \Delta_I^{\ J}\, (U_2)_{JK}\, \widetilde{\psi}^K$$

Partial compositeness (Kaplan 1991;)

$$\Delta \simeq y f$$

$$y_t \simeq y_L y_R / g_\rho$$

The Higgs Potential

Dominated by fermionic contribution

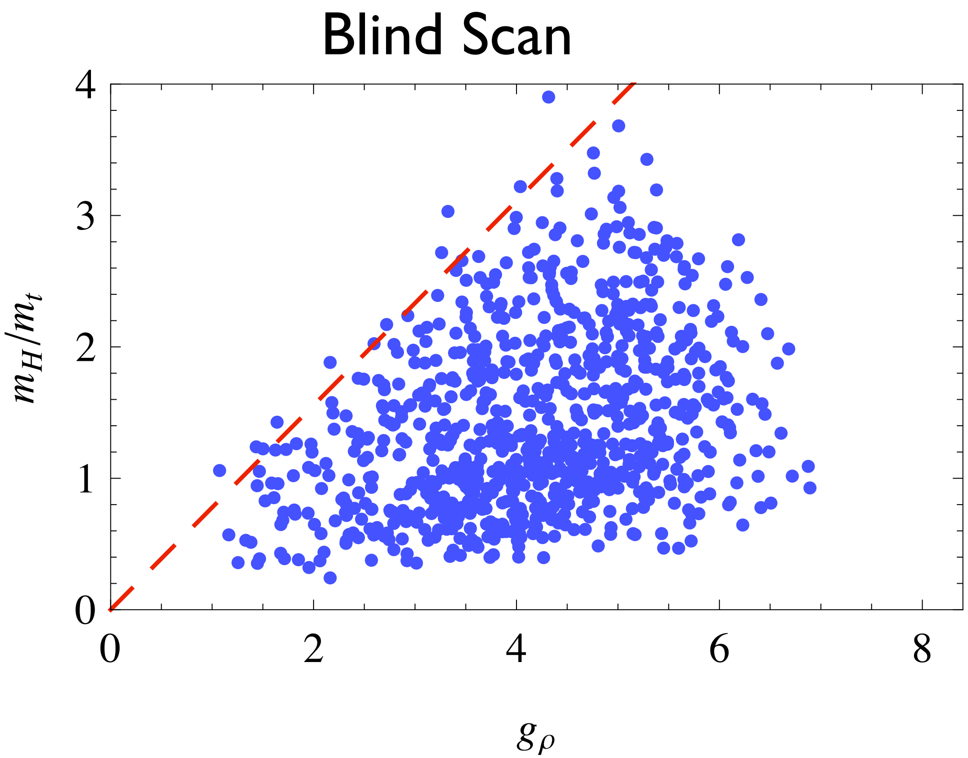
Gives realistic EWSB only if : $y_L \simeq 2y_R \simeq \sqrt{y_t g_\rho}$

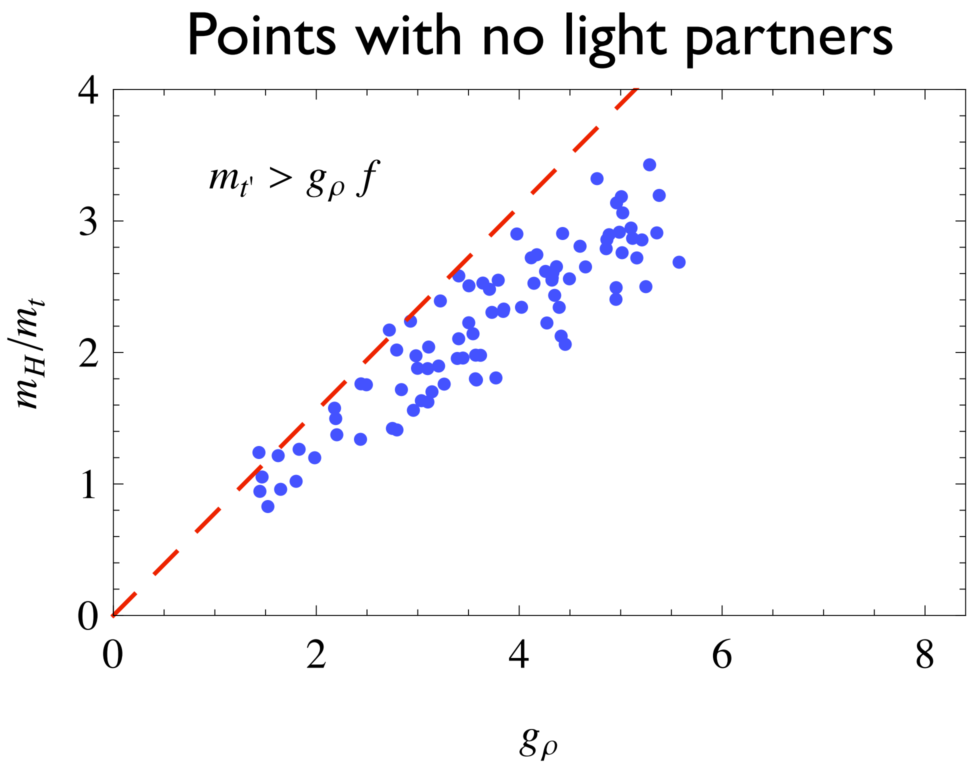
The Higgs quartic is of order $V^{(4)} \sim \frac{N_c}{16\pi^2} y^4 \langle h \rangle^4$

$$m_H \sim 4\sqrt{2N_c}\left(\frac{g_\rho}{4\pi}\right) m_t$$

The Higgs Potential

However ....



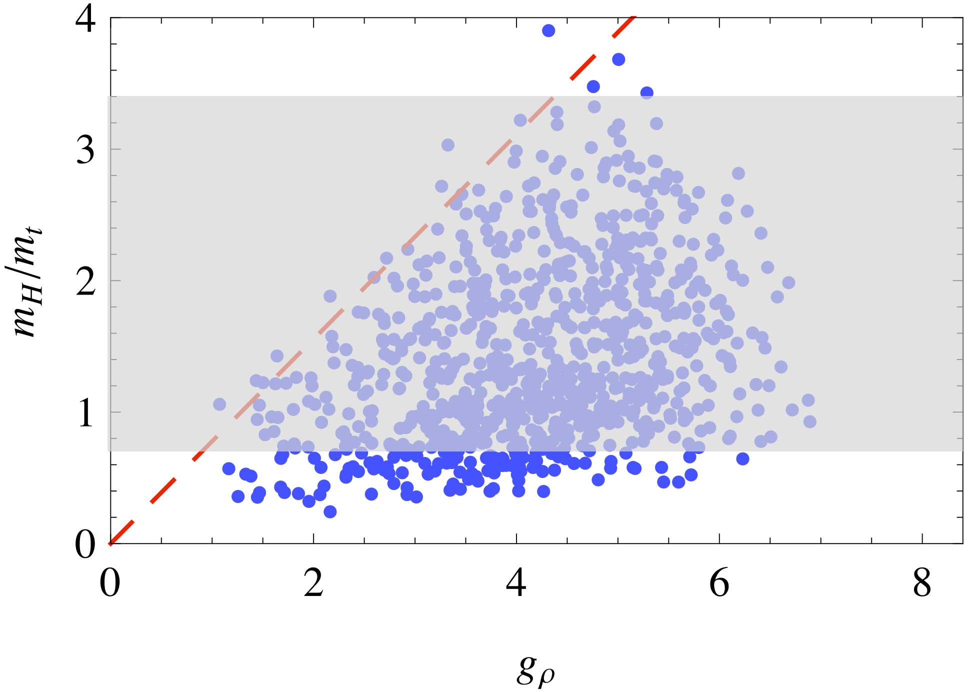


The naive estimate fails if there are light top partners

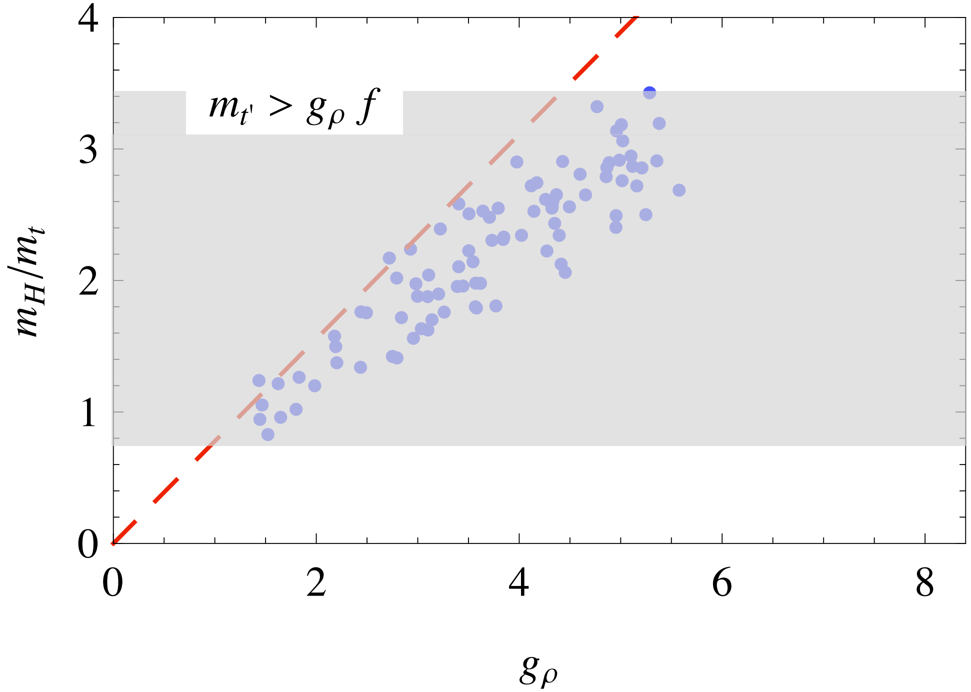
The Higgs Potential

However ....

Blind Scan



Points with no light partners



The naive estimate fails if there are light top partners

Higgs is **too heavy** without light partners!

The Higgs Potential

The Light Top Partners **enhance** m_t :

$$\Delta \cdot \bar{t} T + m_T \cdot \overline{T} T \quad \longrightarrow \quad \tan\theta = \frac{\Delta}{m_T} = \frac{yf}{m_T}$$

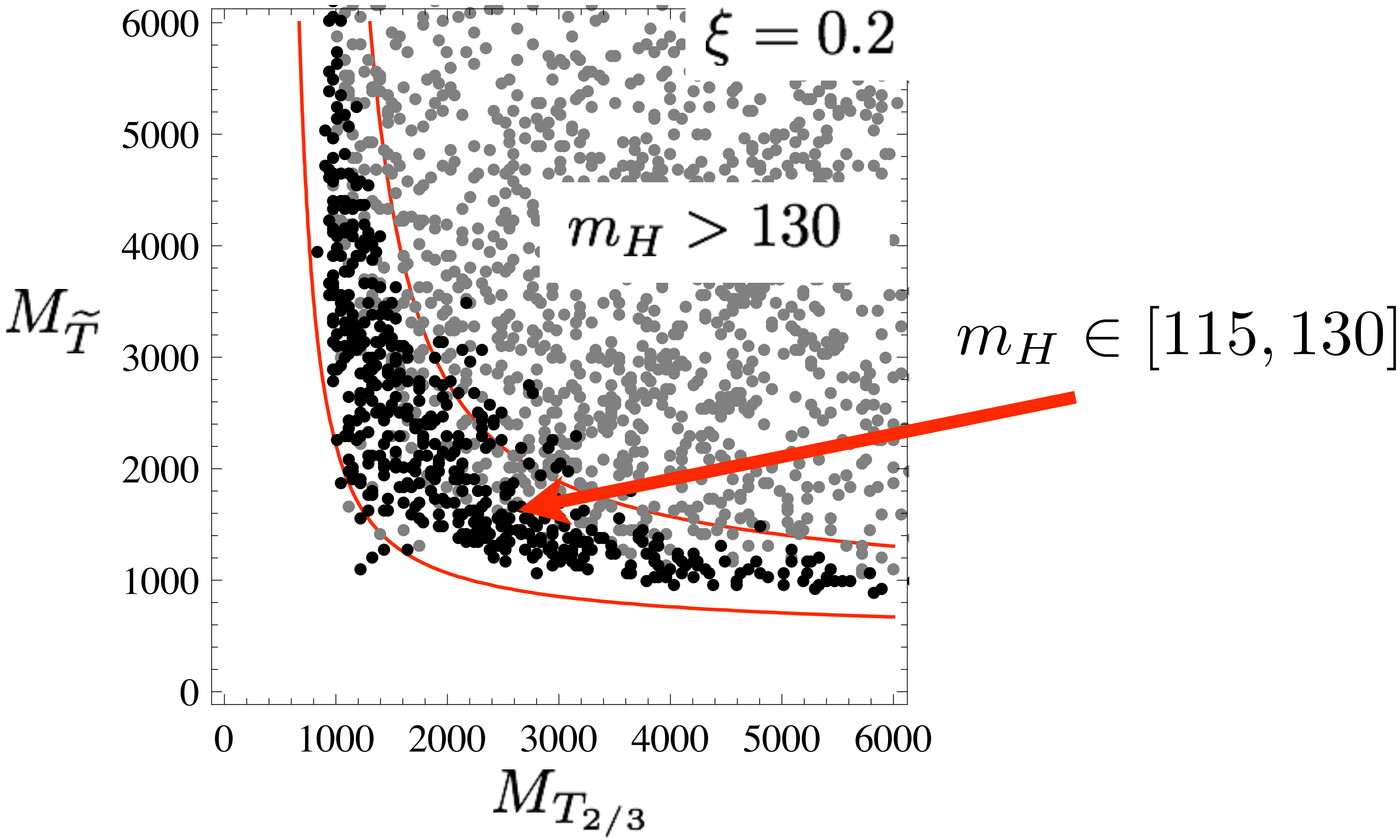
$$m_t \sim M_T \frac{y_L y_R f^2}{m_{T_-} m_{\widetilde{T}_-}} \sqrt{\xi}$$

Since the estimate of the quartic is unchanged :

$$\frac{m_H}{m_t} \simeq \frac{\sqrt{N_c}}{\pi} \frac{m_{T_-} m_{\widetilde{T}_-}}{f} \sqrt{\frac{\log\left(m_{T_-}/m_{\widetilde{T}_-}\right)}{m_{T_-}^2 - m_{\widetilde{T}_-}^2}}$$

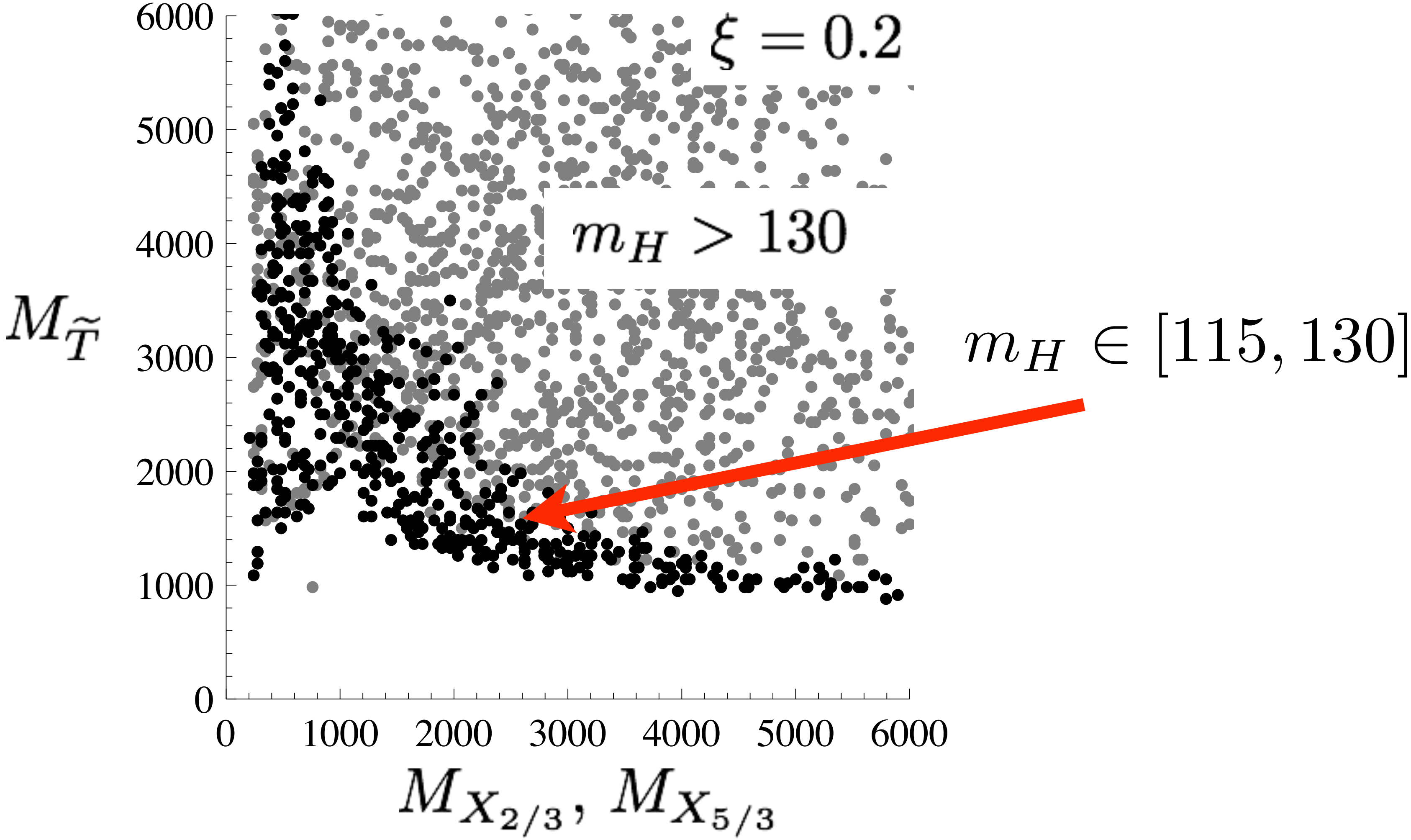
The Higgs Potential

Light Higgs wants **Light Partners** :



The Higgs Potential

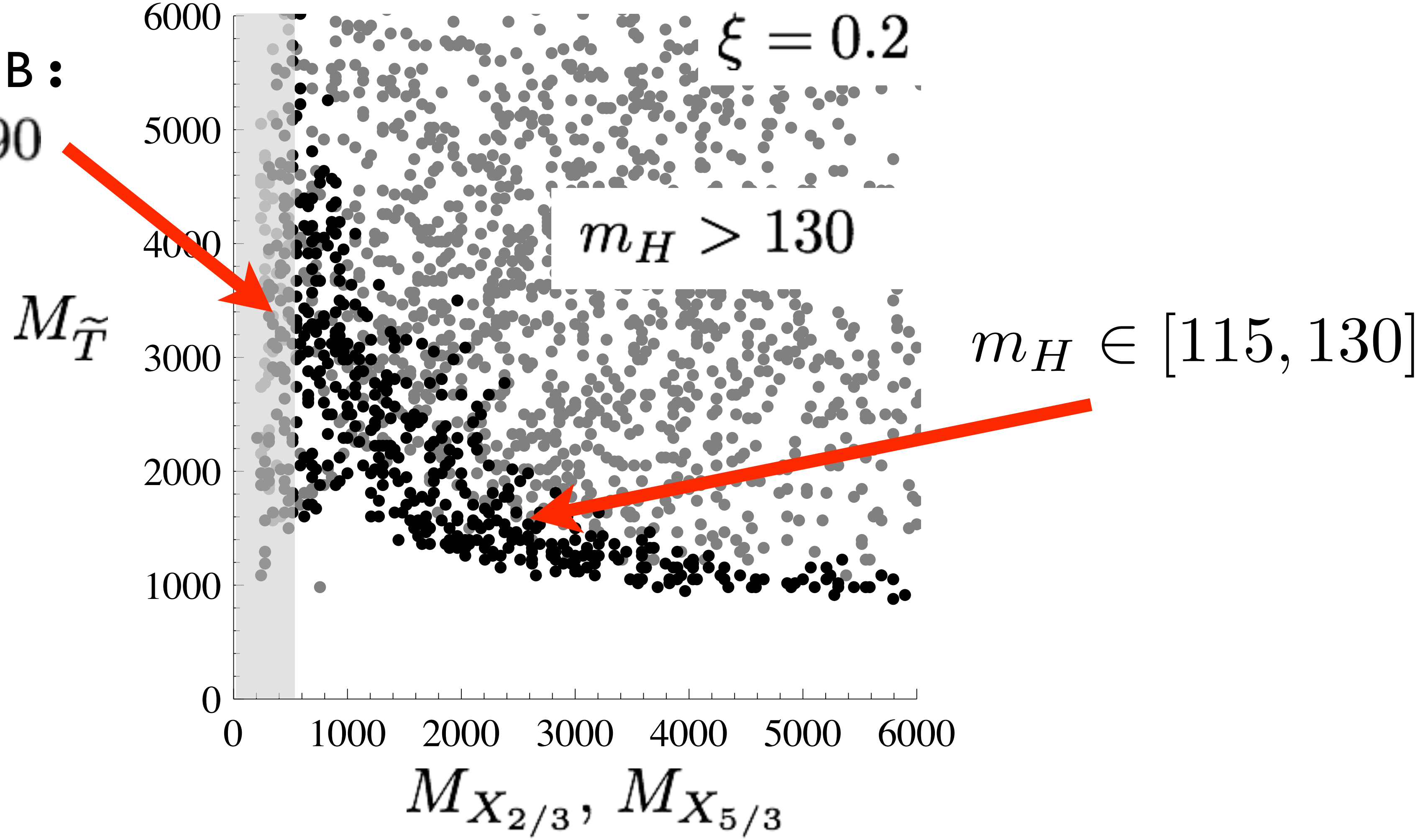
Exotic Bidoublet is even **lighter :**



The Higgs Potential

LHC has **already probed** part of this plot :

CMS search of B **:**
$M_{X_{5/3}} > 490$



Conclusions and Outlook

◆ The DCHM is a complete, minimal model of CH
(simple enough to be implemented in a MG card)

◆ Applications:

1) Provide a **benchmark model** to visualize impact of exclusion

2) **Playground** for verifying (discovering) general aspects of CH

3) **Parametrize the data !** in case of discovery

Conclusions and Outlook

◆ LHC is already testing the CH, much more at 14 TeV:

1) Top Partners

2) Higgs couplings

3) KK-Gluons

4) EW resonances

The Higgs Potential

Dominated by fermionic contribution :

$$V(h/f) = c\,\left[(y_L)^2 - 4(y_R)^2\right] \frac{N_c}{16\pi^2} \frac{m_\rho^4}{g_\rho^2} \sin^2\left(\frac{h}{f_\pi}\right) + \frac{N_c}{16\pi^2} m_\rho^4 \left(\frac{y^2}{g_\rho^2}\right)^2 v(h/f)$$

Cancel the leading term in order to get realistic EWSB: $y_L \simeq 2y_R \simeq \sqrt{y_t g_\rho}$

The Higgs quartic must therefore be estimated from the subleading term :

$$V^{(4)} \sim \frac{N_c}{16\pi^2} y^4 \langle h \rangle^4 \quad \rightarrow \quad m_H \sim 4\sqrt{2N_c}\left(\frac{g_\rho}{4\pi}\right) m_t$$