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2400-2

Workshop on Strongly Coupled Physics Beyond the Standard Model

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Modeling and Testing a Composite Higgs

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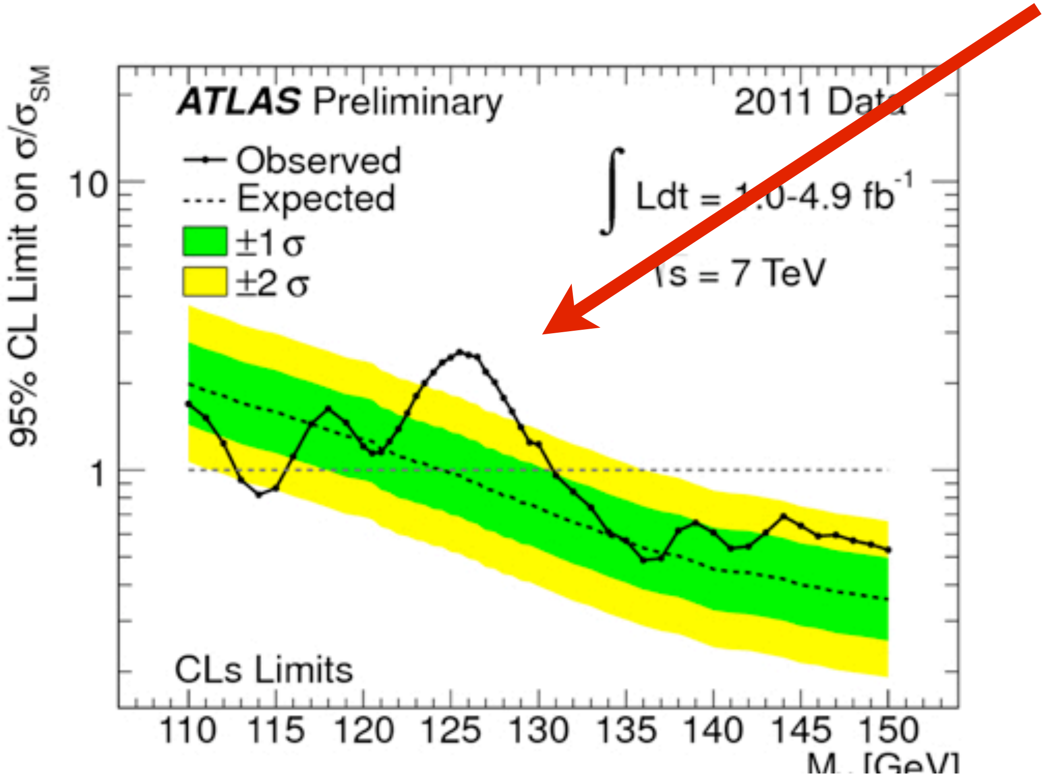
Based on:
"The Discrete Composite Higgs model", with G. Panico,
and work in progress with G.Panico and A.Matsedonski

Introduction:

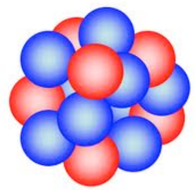
Good reasons to advocate a **light Higgs**:

1. **EWPT**
2. We have (perhaps) almost seen one !



Introduction:

Imagine the Higgs is **Composite** (Georgi, Kaplan et al.1984; Agashe, Contino, Pomarol 2004)



l_H

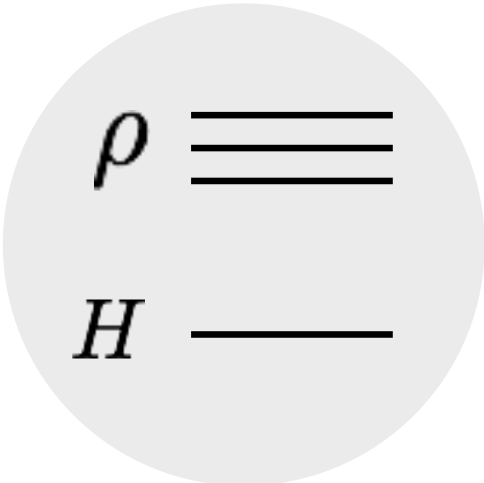
Hierarchy Problem is **solved :**

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**

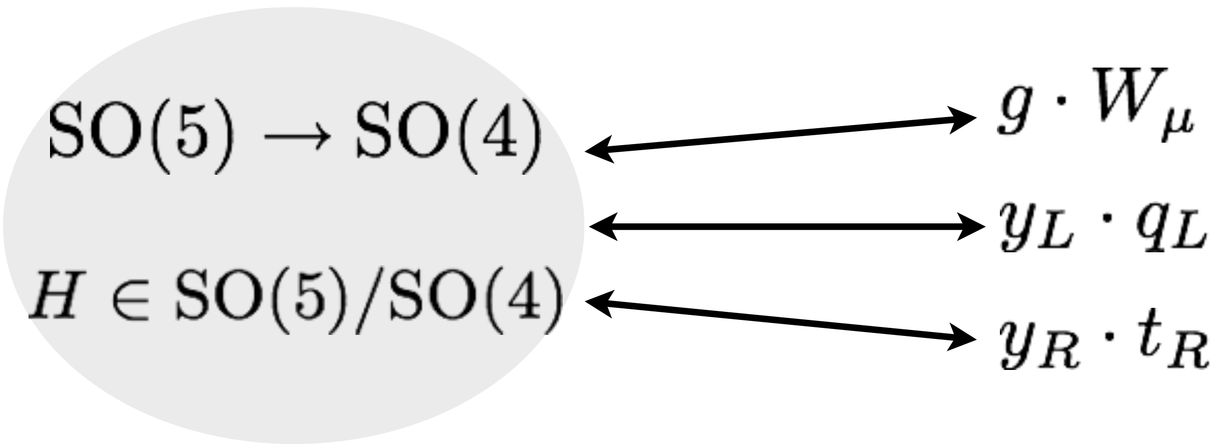
Higgs Decay Constant: $f = m_\rho / g_\rho$

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.)

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

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

Higgs Potential is **not IR-saturated**

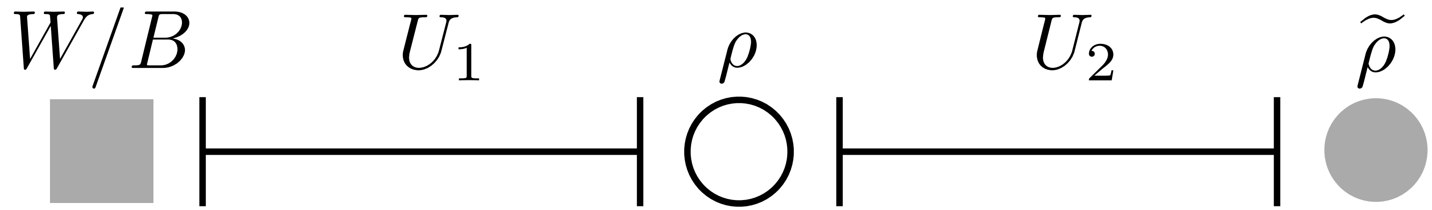
$$V^{(1)}(h/f) = \Lambda^2 f^2 \left(\frac{\Lambda}{4\pi f}\right)^2 \left(\frac{gf}{\Lambda}\right)^2 v(h/f) = g^2 \frac{\Lambda^2 f^2}{16\pi^2} v(h/f)$$

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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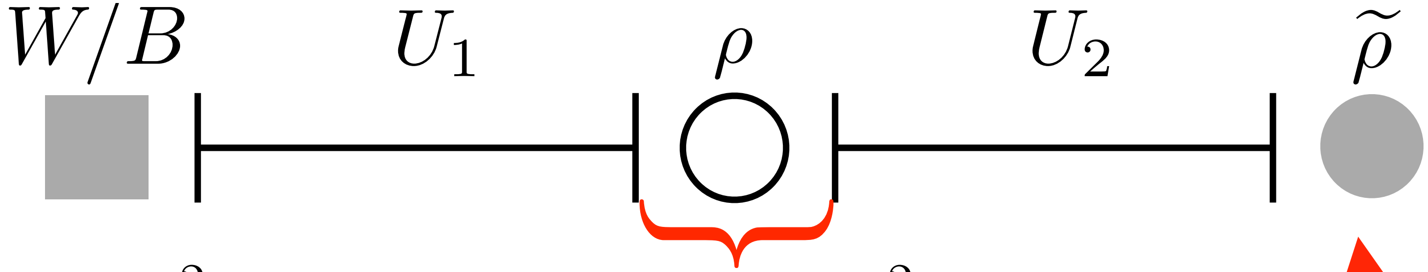

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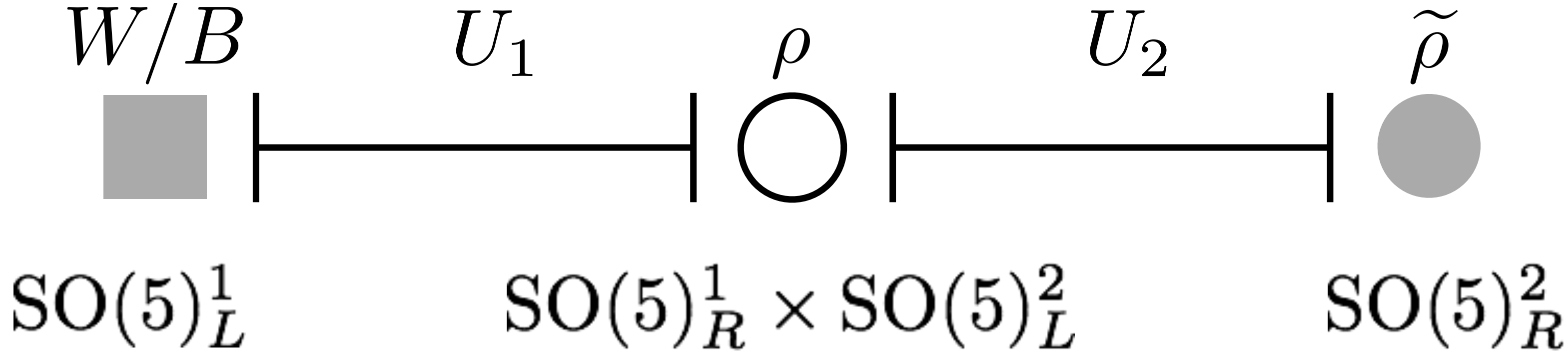
10+10 scalar d.o.f reduced to 4 by **gauging** $\rho \in \mathrm{SO}(5)\,,\ \ \widetilde{\rho} \in \mathrm{SO}(4)$

$$D_\mu U_1 = \partial_\mu U_1 - i A_\mu U_1 + i g_* U_1 \rho_\mu$$
$$D_\mu U_2 = \partial_\mu U_2 - i g_* \rho_\mu U_2 + i \widetilde{g}_* U_2 \widetilde{\rho}_\mu$$

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

Similar constructions in the framework of Little-Higgs:

Cheng et al. (2006); Foadi et al. (2010); Baumgart (2007)

Models of Composite Higgs

The Discrete Composite Higgs model

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

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

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:

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

$$\mathcal{L}_{\text{mix}} = \overline{q}_L \Delta_L U_1 \psi + \bar{t}_R \Delta_R U_1 \psi + \overline{\psi} \Delta U_2 \widetilde{\psi}$$

Partial compositeness
(Kaplan 1991; Contino et. al. 2006)

$$\Delta_{L,R} \simeq y_{L,R} f$$

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

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: $y_L \simeq 2y_R \simeq \sqrt{2y_t g_\rho}$

The Higgs Potential

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

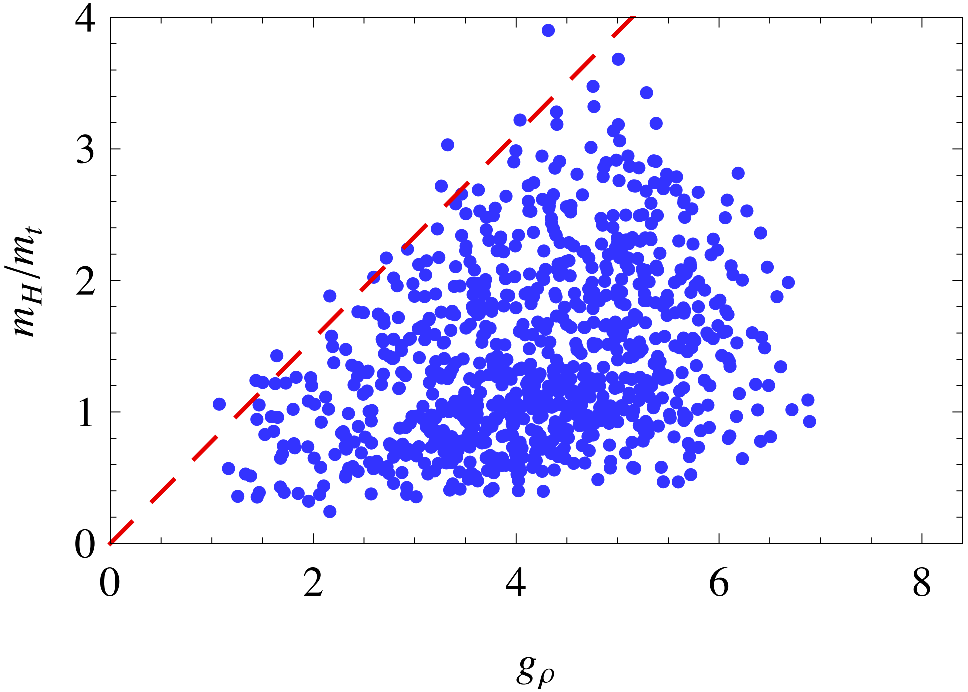
The Higgs quartic from the subleading term : $V^{(4)} \simeq \dfrac{N_c}{16\pi^2} y_L^4 h^4$

$$m_H \simeq \sqrt{8N_c}\frac{y_L^2}{4\pi} v \simeq 4\sqrt{2N_c}\frac{g_\rho}{4\pi} m_t$$

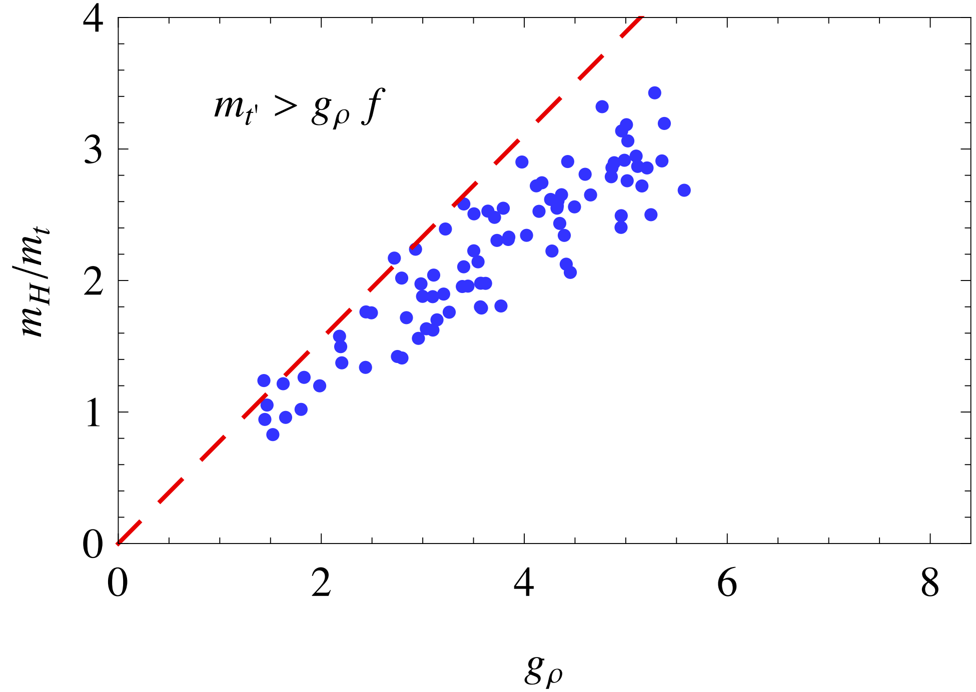
The Higgs Potential

However ....

Blind Scan



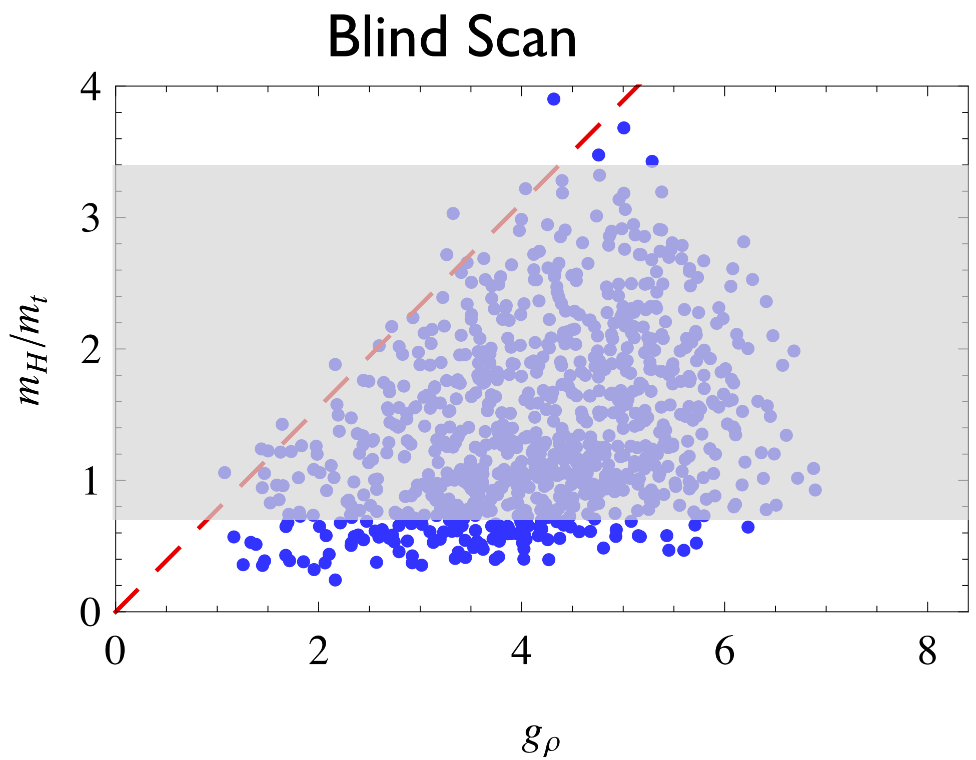
Points **without** light partners

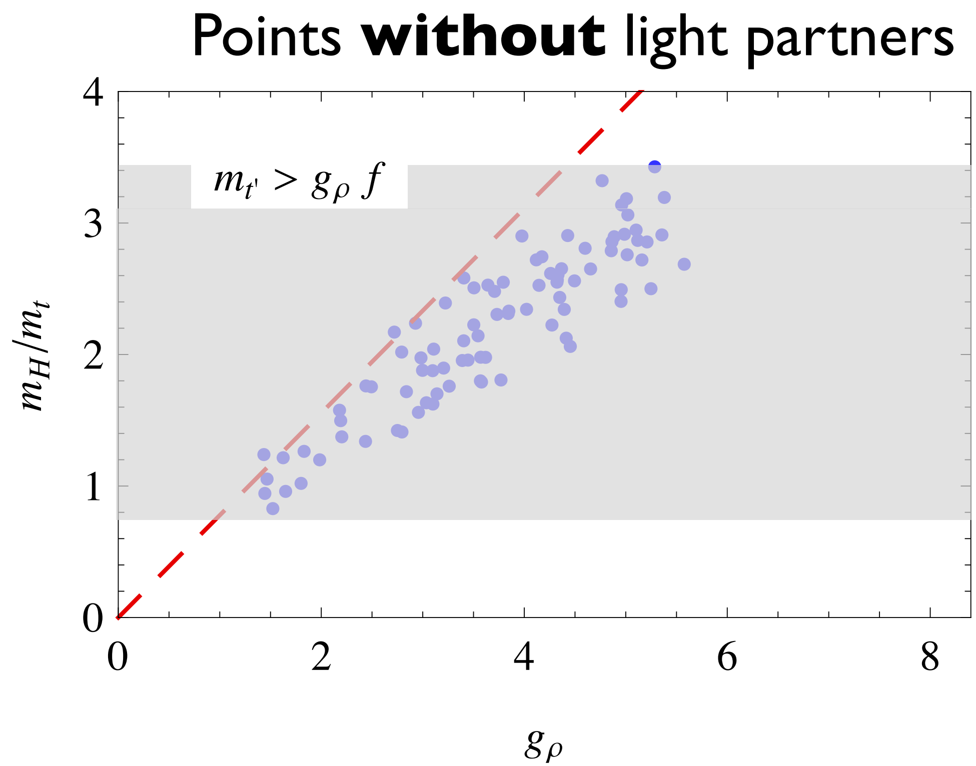


The naive estimate fails if there are light top partners

The Higgs Potential

However ....





The naive estimate fails if there are light top partners

Higgs is **heavy** without light partners!
(and typically excluded)

Top Partners

The light top partners **enhance** m_t :

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

$$y_t \simeq \frac{y_L y_R f}{m_T} \quad \xrightarrow{(y_L = 2y_R)} \quad y_L \simeq \sqrt{2y_t \frac{m_T}{f}}$$

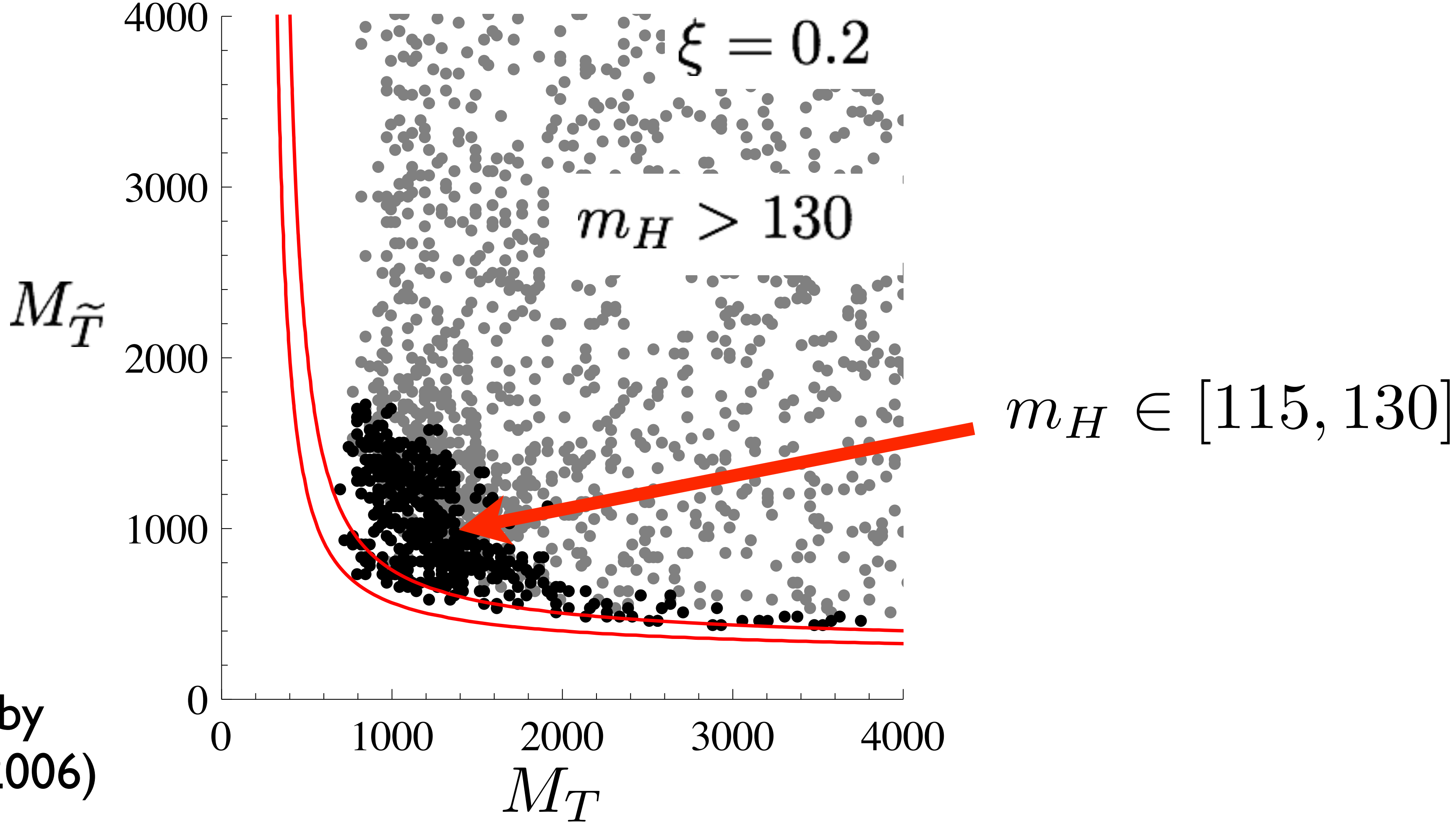
The quartic stays the same:

$$V^{(4)} \simeq \frac{N_c}{16\pi^2} y_L^4 h^4 \quad \longrightarrow \quad m_H \simeq \sqrt{8N_c \frac{y_L^2}{4\pi}} v \simeq 4\sqrt{2N_c \frac{m_T}{4\pi f}} m_t$$

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

Top Partners

Light Higgs wants **Light Partners** :

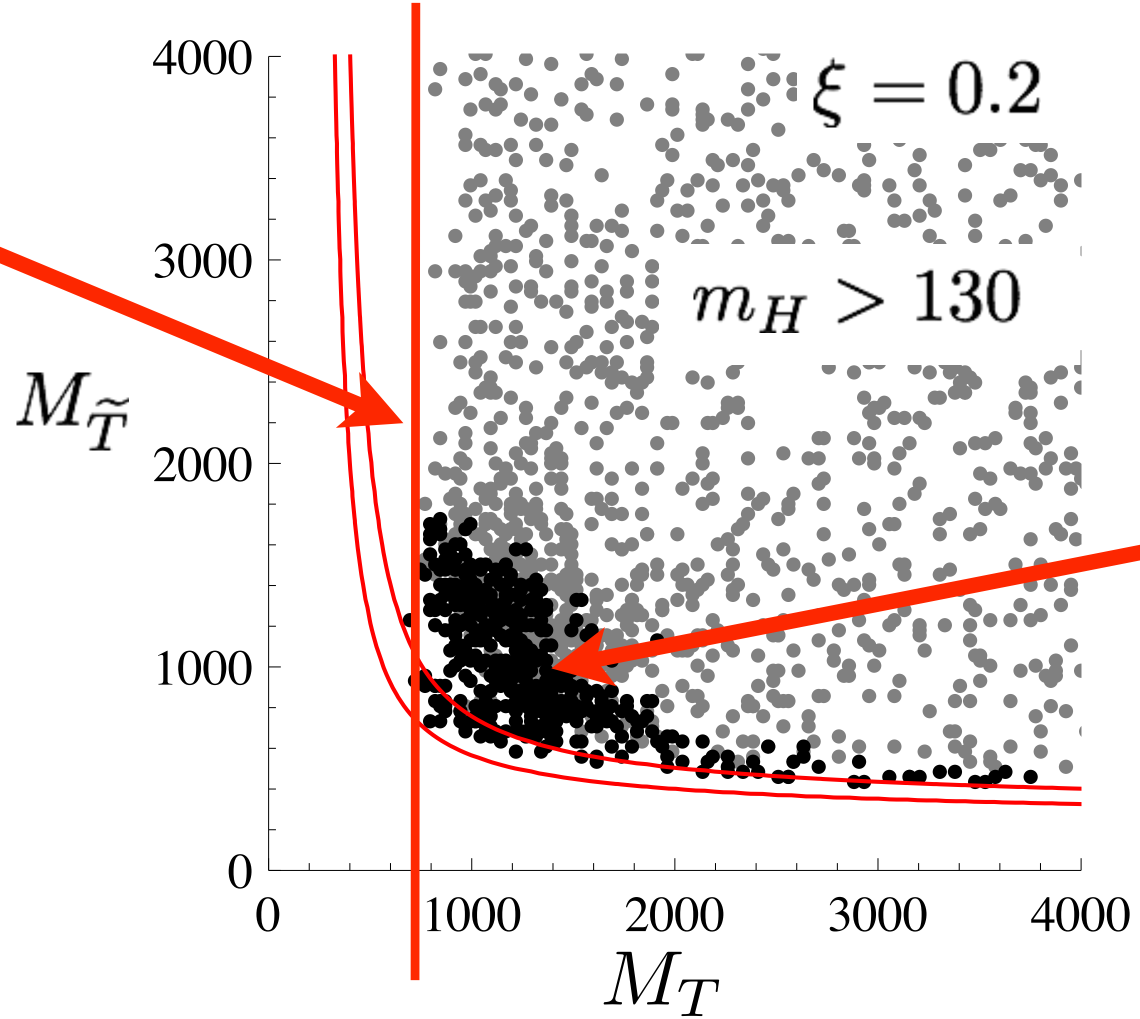


First noticed by
Contino et. al (2006)

Top Partners

Light Higgs wants **Light Partners** :

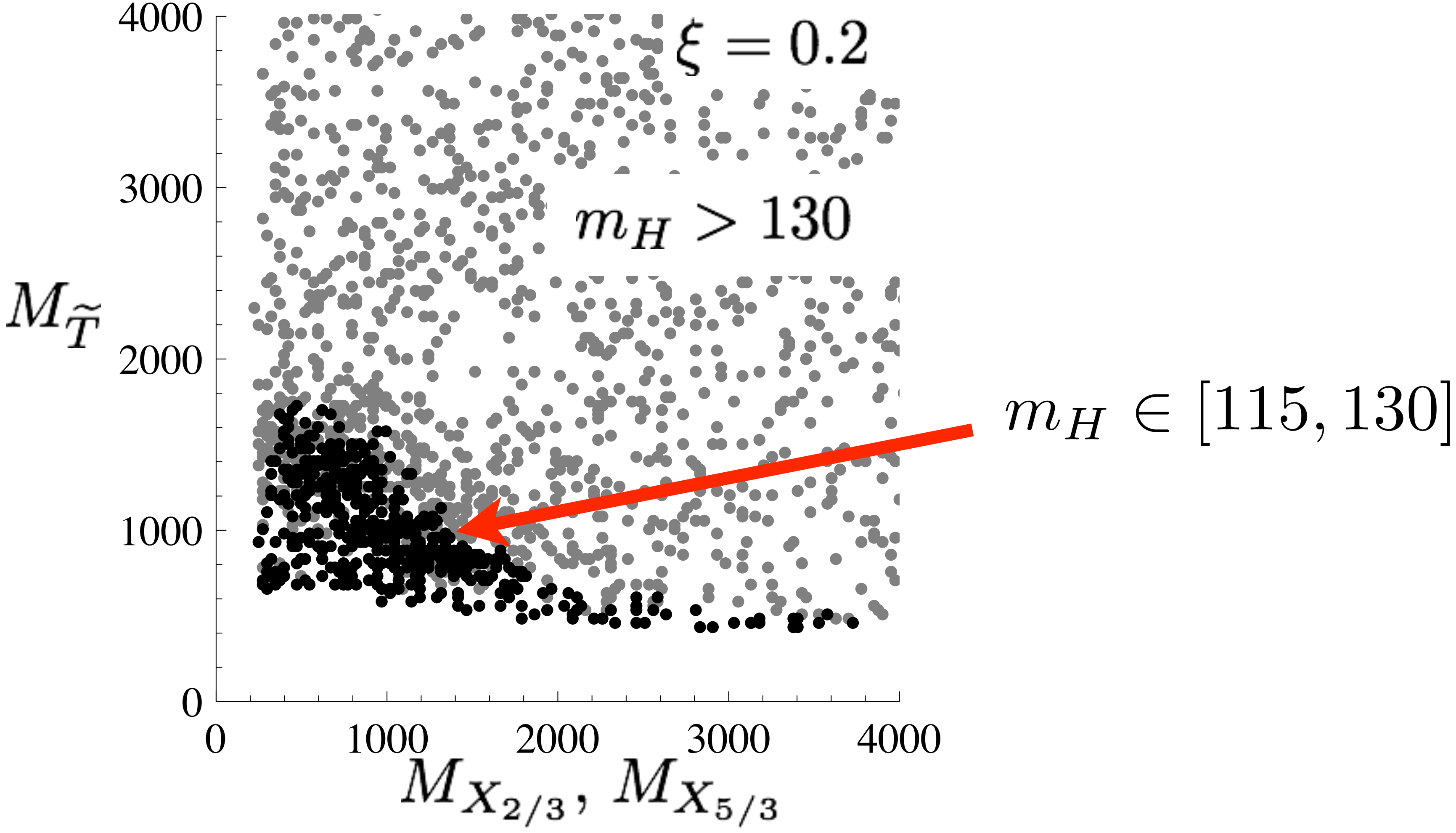
bound from m_t saturation



$m_H \in [115, 130]$

Top Partners

Exotic Bidoublet is even **lighter :**



Top Partners

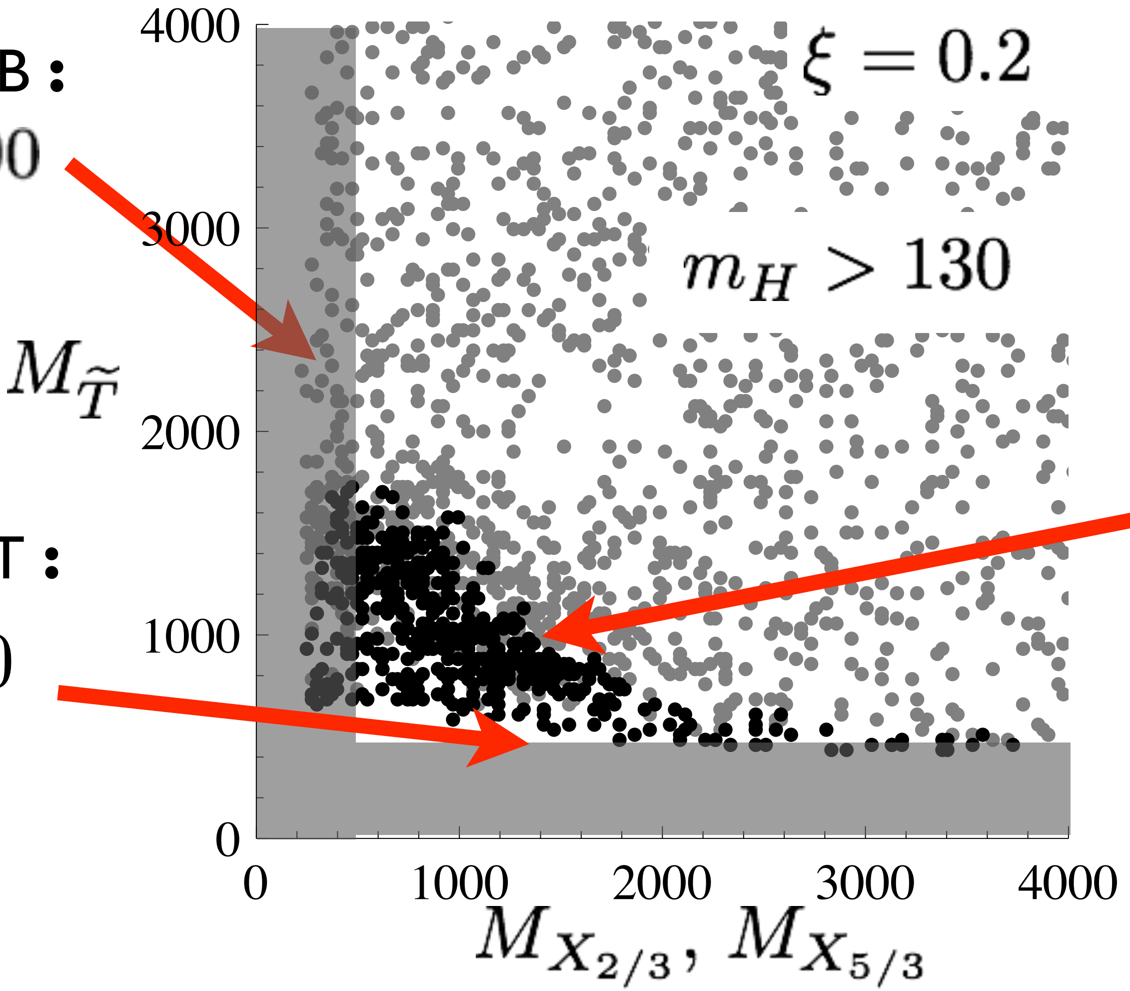
LHC has **already probed** part of this plot :

CMS search of B :

$M_{X_{5/3}} > 490$

CMS search of T :

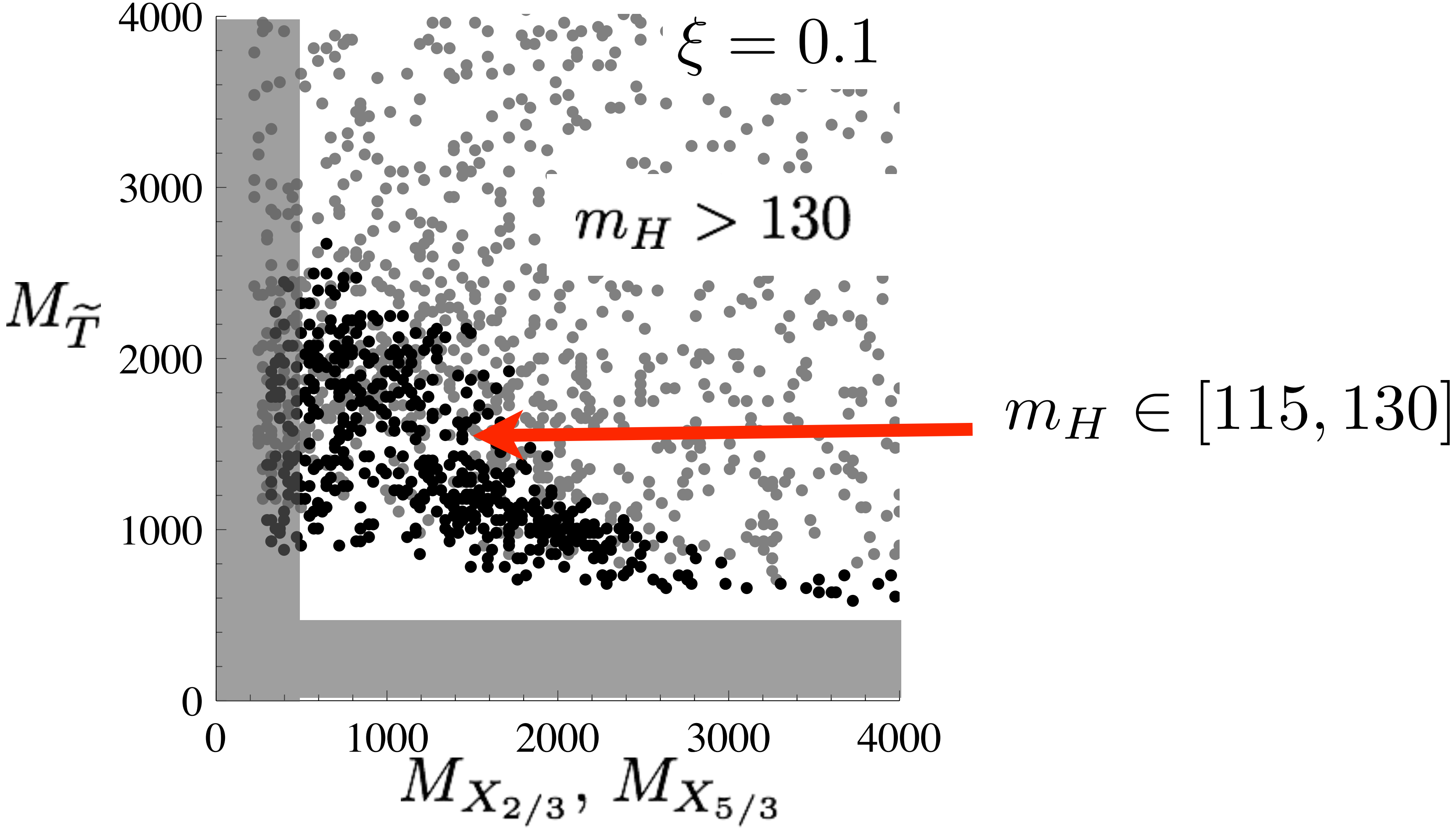
$M_T \gtrsim 450$



$m_H \in [115, 130]$

Top Partners

For $\xi = 0.1$:

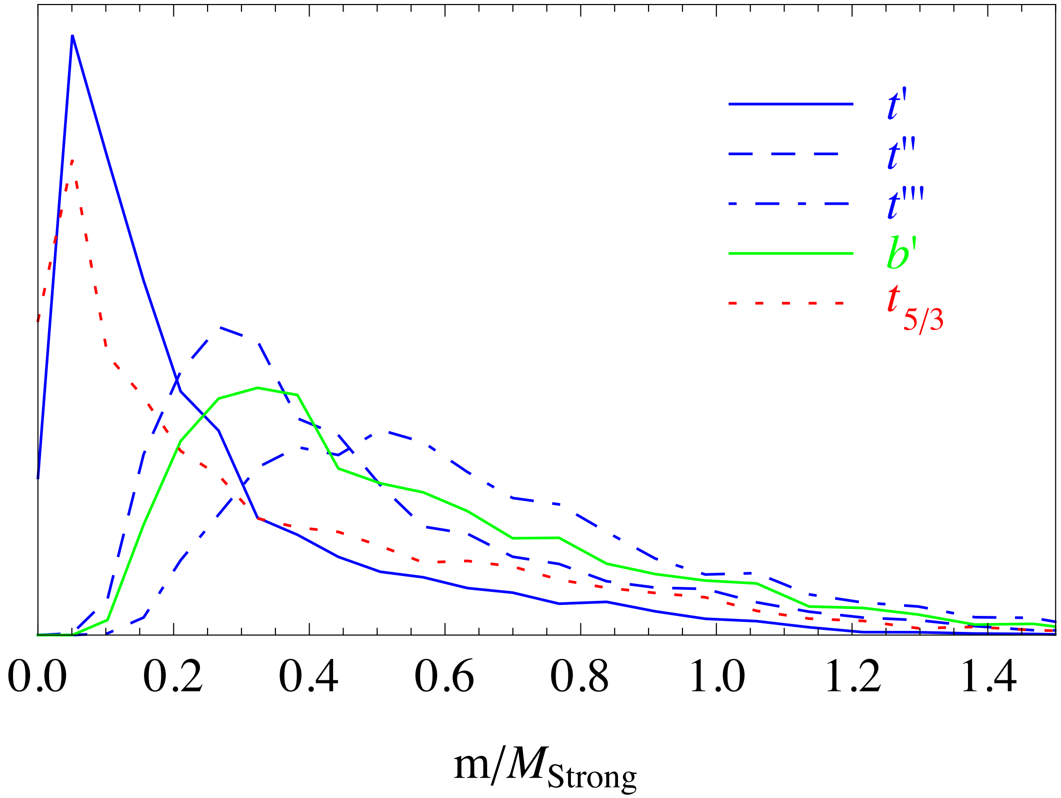


Top Partners

Two more comments :

1) easy to make the partners light:

flat-prior scan with no constraint on m_H



Top Partners

Two more comments :

2) partners have a peculiar spectrum:

doublet-doublet splitting from the mixing:

$$\begin{pmatrix} T & X_{5/3} \\ B & X_{2/3} \end{pmatrix} \quad \longrightarrow \quad \Delta m \simeq (y_L f)^2 / m$$

y_L

q_L

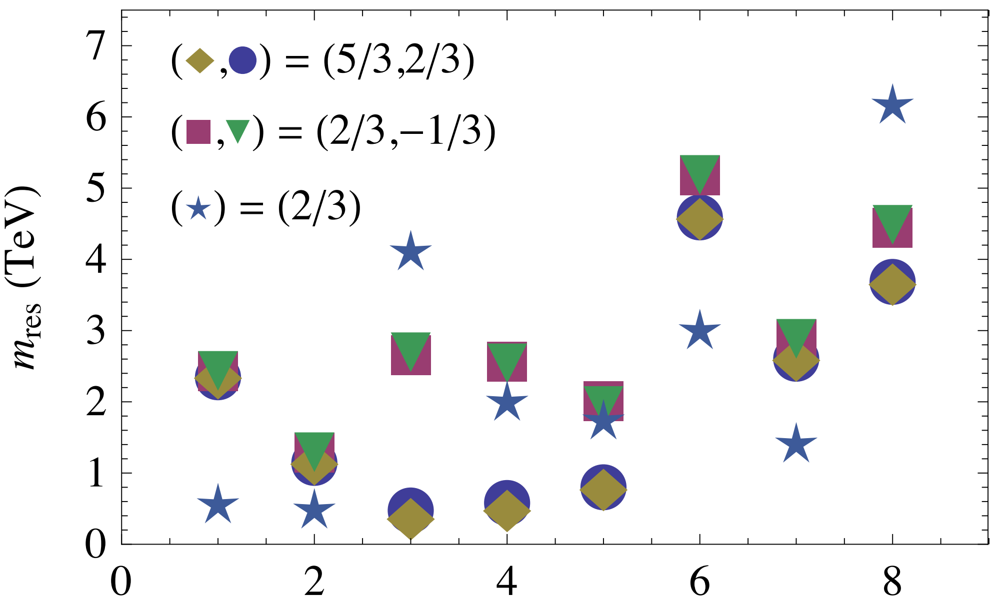
EWSB **only after** Goldstone symm. breaking :

$$\Delta m_{\text{EWSB}} \simeq (y_L f)^2 / m \cdot \left(\frac{v}{f}\right)^2$$

Top Partners

Two more comments :

2) have a peculiar spectrum:



characteristic of a Goldstone boson Higgs

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

◆ Some deformation will be described in Redi's talk

(De Curtis, Redi, Tesi 2011)

Conclusions and Outlook

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

1) Top Partners: Contino et al. 2008; Aguilar-Saavedra 2009; Mrazek et al. 2009; Dissertori et al. 2010;

2) Higgs couplings: SILH; Espinosa et al. 2010; Contino et al.

3) KK-Gluons: Barcelo et al. 2010; Bini et al. 2010

4) EW resonances: Agashe et al. 2006/2007; Contino et al. 2011