Light top partners for a light composite Higgs

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based on G. P. and A. Wulzer 1106.2719 [hep-ph]
and O. Matsedonskyi, G. P. and A. Wulzer 1204.6333 [hep-ph]

Introduction

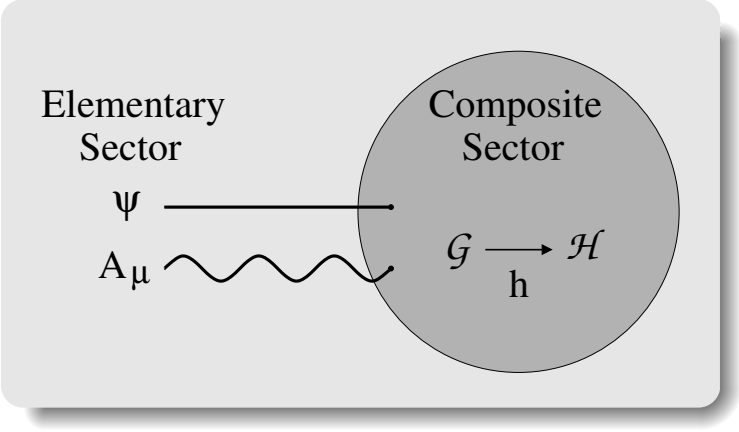
Why a **composite Higgs**?

Solution of the **Hierarchy Problem**:

new **strong sector** dynamically generates the EW scale.

[Georgi, Kaplan (1984), ...]

- **Higgs as a Goldstone** of a spontaneously broken global symmetry $\mathcal{G} \to \mathcal{H}$
  - EW symmetry breaking induced at 1-loop



- Presence of **resonances** from the strong sector

Introduction

General structure described by non-linear σ-model $SO(5)/SO(4)$

$$\mathcal{L} = \frac{f_\pi^2}{2} \sum_i (D_\mu U)^\dagger_{5i} (D^\mu U)_{i5}$$

Useful to study the **modified Higgs couplings**

[Giudice et al. (2007), Barbieri et al. (2007), Espinosa et al. (2010)]

$$\lambda \simeq \lambda_{\rm SM}(1 + c\,\xi) \qquad\qquad \xi = (v/f_\pi)^2$$

... but not completely predictive

- No description of resonances
- Higgs potential not IR-saturated: $V(h) \sim \frac{g^2 f_\pi^2}{16\pi^2} \Lambda^2 v(h/f_\pi)$

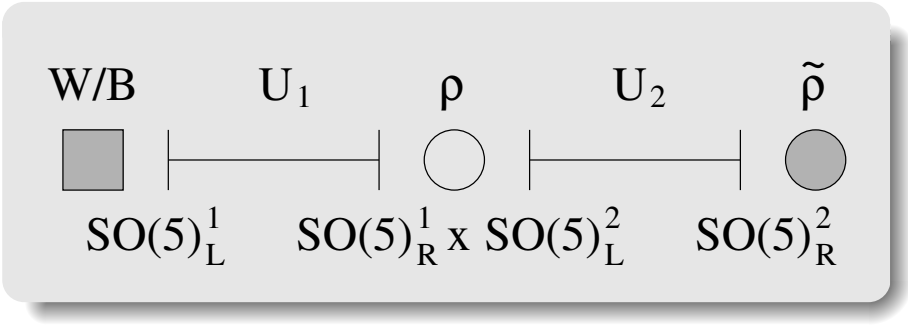
The Discrete Composite Higgs Model

Add **symmetries** to protect the potential

Two σ-models:

$SO(5)_L \times SO(5)_R / SO(5)_D$

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



New symmetries related to **composite states**

- resonances introduced by gauging: $\rho \in \mathrm{SO}(5), \quad \widetilde{\rho} \in \mathrm{SO}(4)$

Higgs is a Goldstone with respect to **three** symmetry groups

$\Downarrow$

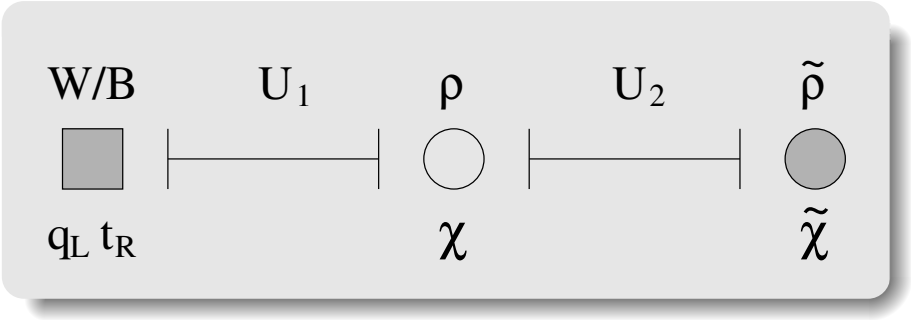
EWSB effects through **collective breaking**:

cancellation of divergences [Arkani-Hamed et al. (2001), ...]

The Discrete Composite Higgs Model

Elementary fermions transform under $SO(5)^1_L$:

$$q_L, t_R$$



Composite states in representations that allow mixing

$$\chi, \widetilde{\chi} \in \mathbf{5} = (\mathbf{2},\mathbf{2}) \oplus (\mathbf{1},\mathbf{1}) = \begin{pmatrix} T & X_{5/3} \\ B & T_{2/3} \end{pmatrix} \oplus (\widetilde{T})$$

Linear mixing implement **partial compositeness**

[Kaplan (1991), Contino et al. (2007)]

$$\mathcal{L}^{mix} \sim y_L\, f_\pi\, \overline{q}_L\, U_1 \chi_R + y_R\, f_\pi\, \overline{t}_R\, U_1 \chi_L + \text{h.c.}$$

The Higgs mass

Using the standard estimates $m_{res} \sim g_\rho f$, we get

$$y_t \simeq \frac{y_L y_R}{g_\rho} \qquad V^{(4)}(h) \simeq \frac{N_c}{16\pi^2} y_L^2 y_R^2 h^4$$

a **heavy Higgs** is expected: $m_h \simeq 4\sqrt{2N_c}\,\frac{g_\rho}{4\pi}\, m_t$

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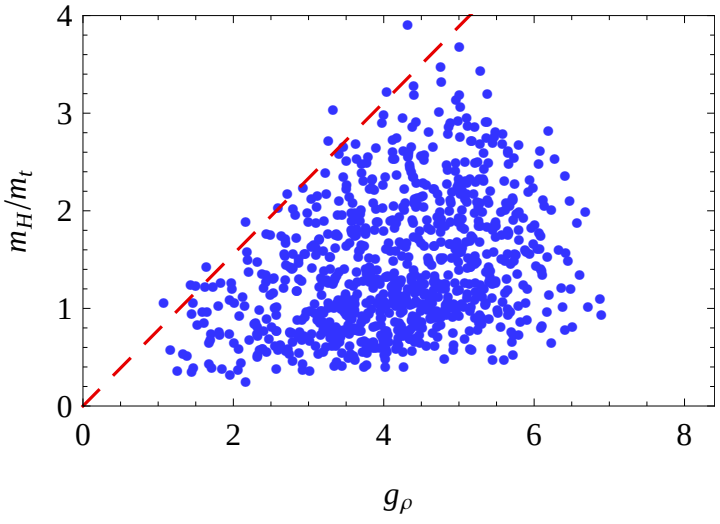
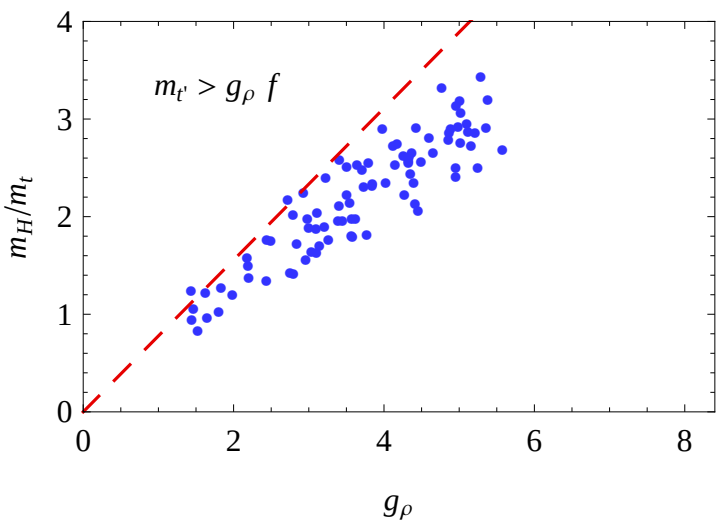
Blind scan



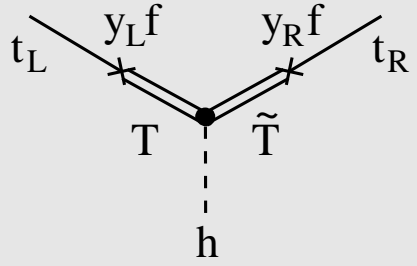
Points without light partners



- The naive estimate fails with **light partners**

Light top partners for a light Higgs

The presence of **light partners** **enhances** the top Yukawa



$$y_t \simeq \frac{|b_L m_T - a_R m_{\tilde{T}}|}{m_T m_{\tilde{T}}} y_L y_R f_\pi \quad \Rightarrow \quad y_t \simeq \frac{y_L y_R f_\pi}{min\{m_T, m_{\tilde{T}}\}}$$

The quartic term in the Higgs potential is not modified

$$V^{(4)}(h) \simeq \frac{N_c}{16\pi^2} y_L^2 y_R^2 h^4$$

The Higgs mass scales **linearly** with the mass of the **lightest resonance**

$$\frac{m_h}{m_t} \simeq \frac{\sqrt{2N_c}}{\pi} \frac{min\{m_T, m_{\tilde{T}}\}}{f_\pi}$$

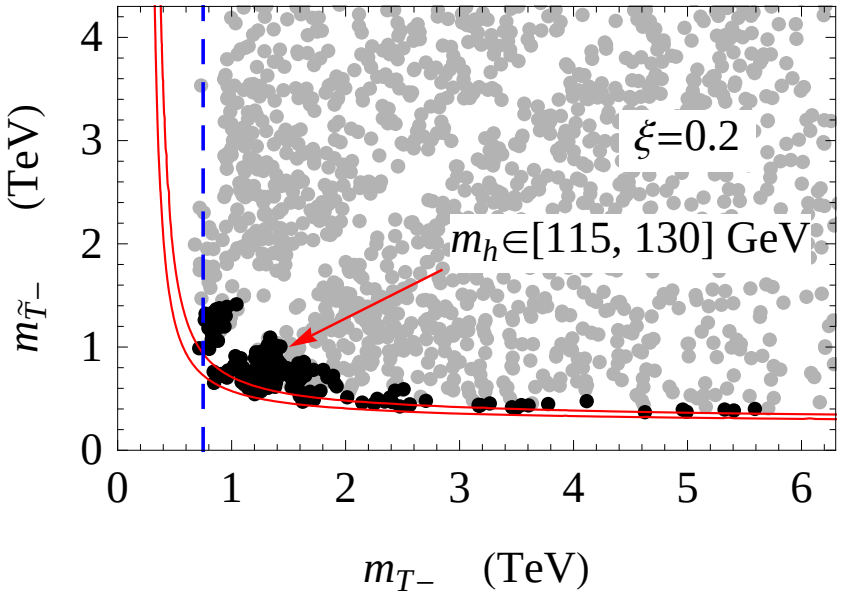
Light top partners for a light Higgs

More refined result in explicit model

$$\frac{m_h}{m_t} \simeq \frac{\sqrt{2N_c}}{\pi} \frac{m_T m_{\widetilde{T}}}{f_\pi} \sqrt{\frac{\log(m_T/m_{\widetilde{T}})}{m_T^2 - m_{\widetilde{T}}^2}}$$

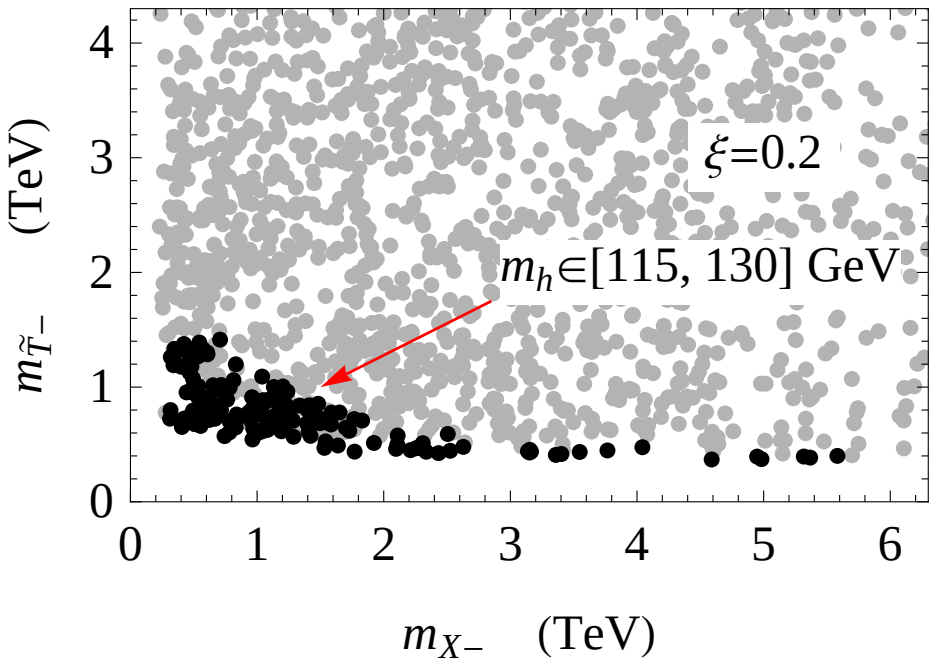
The analytic formula is in **good agreement** with numerical results

- top partners **below 1 TeV** are predicted
- Some corrections from the second level of resonances
- lower bound on m_{T_-} from top mass saturation



Light top partners for a light Higgs

An **exotic doublet** $X = (X_{5/3}, T_{2/3})$ can be much lighter



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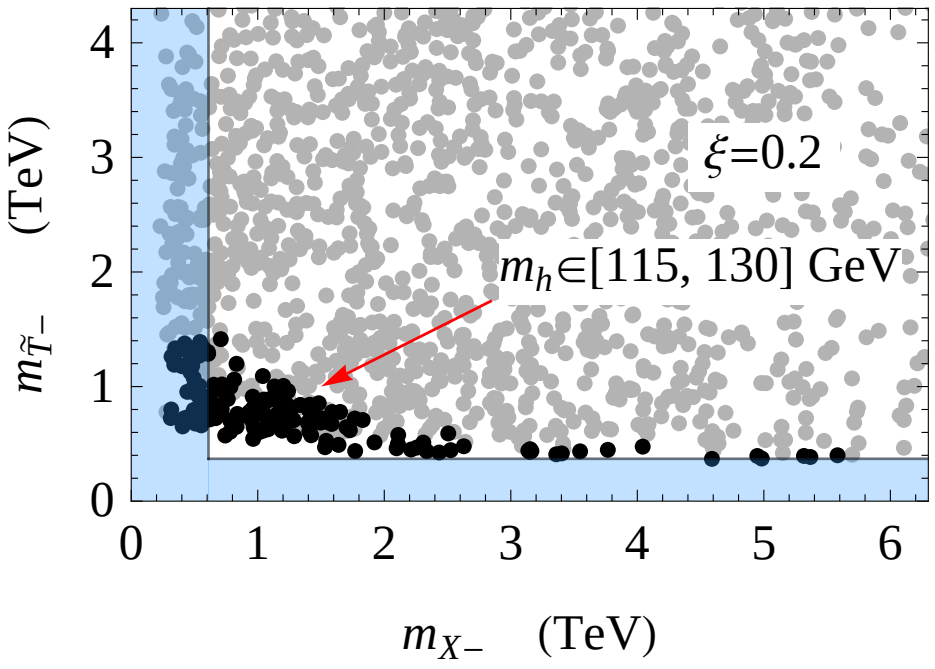


Current LHC data already give **non-trivial exclusion**

- from CMS search of b': $m_X > 611$ GeV
- from CMS search of t': $m_{\tilde{T}} > 370$ GeV

Conclusions

The Discrete Composite Higgs model is a **complete**, **minimal description** of the composite Higgs framework

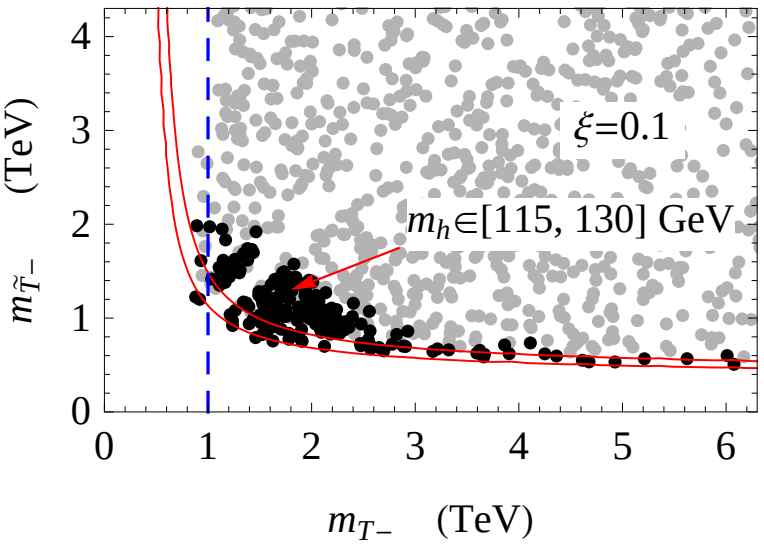
- provide a benchmark model to visualize the impact of exclusions
- playground for verifying (discover) general properties
- parametrize the data in case of discovery

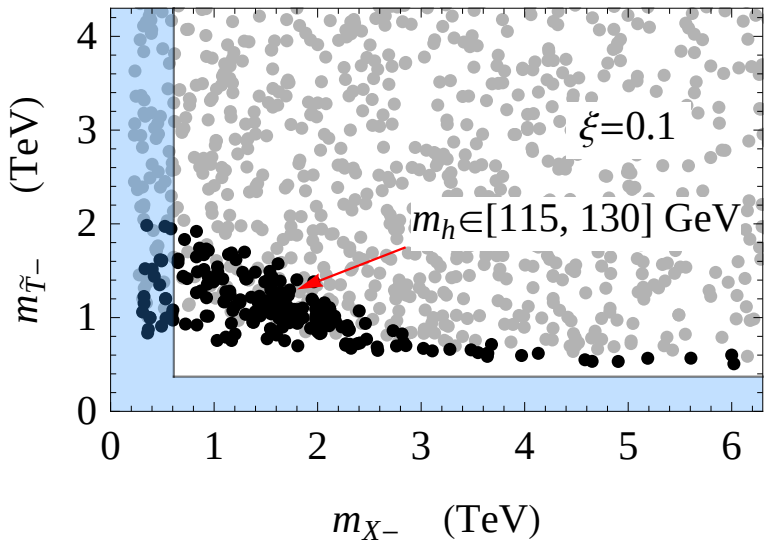
A **light Higgs** can be obtained in minimal scenarios only if **light top partners** are present

- resonances below $\sim 1\ \mathrm{TeV}$ (accessible at the LHC)
- current data already give some non-trivial exclusion

Light top partners for a light Higgs

Similar results obtained for $\xi = 0.1$





- resonances below 1.5 TeV
- some points with light exotic states already excluded
- $\xi = 0.1$ implies a **significant fine-tuning**

The Higgs potential

Potential dominated by top partners

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

Cancel the leading term for realistic EWSB

"preliminary" tuning: $y_L \simeq \sqrt{2} y_R$

- Higgs quartic from subleading terms

$$V^{(4)}(h) \simeq \frac{N_c}{16\pi^2} y_L^2 y_R^2 h^4$$