Strong EWSB

Giuliano Panico

ETH Zürich

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Introduction

Main **goal** of the LHC:

Unveil the **nature of the EWSB mechanism**

Need for **theoretical framework** to interpret the data:

- look for a **motivated** scenario
- develop and test hypothetical **models**

Introduction

The **Standard Model** solution

- Higgs as an **elementary** scalar
- **Minimal** realization
- Excellent **agreement** with EW data

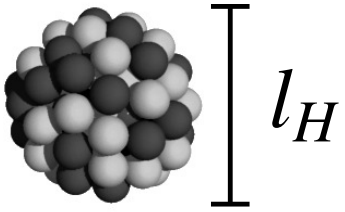
... but the **Higgs mass** is **unstable** under radiative corrections

$$\Delta m_h^2\big|_{1-loop} \sim -\frac{\lambda_{top}^2}{8\pi^2}\Lambda_{UV}^2$$

this is known as the **Hierarchy problem**

Introduction

Higgs as a **composite state** from a strong dynamics [Georgi, Kaplan]

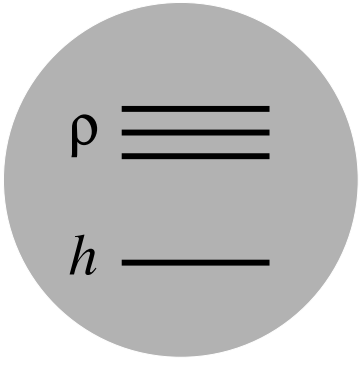


The Hierarchy Problem is **solved**

- Corrections to m_h **screened** at $1/l_H$
- Higgs mass is **IR-saturated**

Composite Higgs

Postulate a **new strong sector**



SILH paradigm

[Giudice, Grojean, Pomarol, Rattazzi]

- one **mass** scale: m_ρ
- one **coupling**: $g_\rho \lesssim 4\pi$

Higgs naturally **light** ($m_h \ll m_\rho$) if it is a **Goldstone**

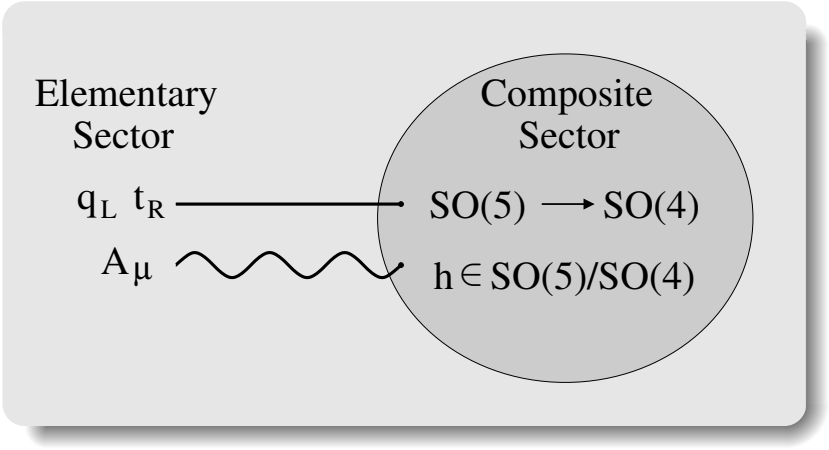
Separation of scales: $v \ll f \simeq m_\rho / g_\rho$

- improves compatibility with EWPT

Composite Higgs

Composite sector with a spontaneously broken **global symmetry**

$$SO(5) \to SO(4)$$



Higgs described by a **non-linear σ-model**

$$\mathcal{L} = \frac{f^2}{2} \sum_i D_\mu U_{i5} D^\mu U_{i5} \qquad U = \exp[i h_{\hat{a}} T^{\hat{a}}]$$

$$D_\mu U = \partial_\mu U - i g A_\mu U$$

Useful to study modified Higgs couplings

[Giudice et al., Barbieri et al., ...]

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

Modified couplings

The Higgs couplings are **modified**

$$\mathcal{L} = \frac{v^2}{4}\mathrm{Tr}(D_\mu \Sigma^\dagger D^\mu \Sigma)\left(1 + a\frac{h}{v}\right) - m_t \bar{q}_L \Sigma t_R \left(1 + c\frac{h}{v}\right) + \mathrm{h.c.}$$

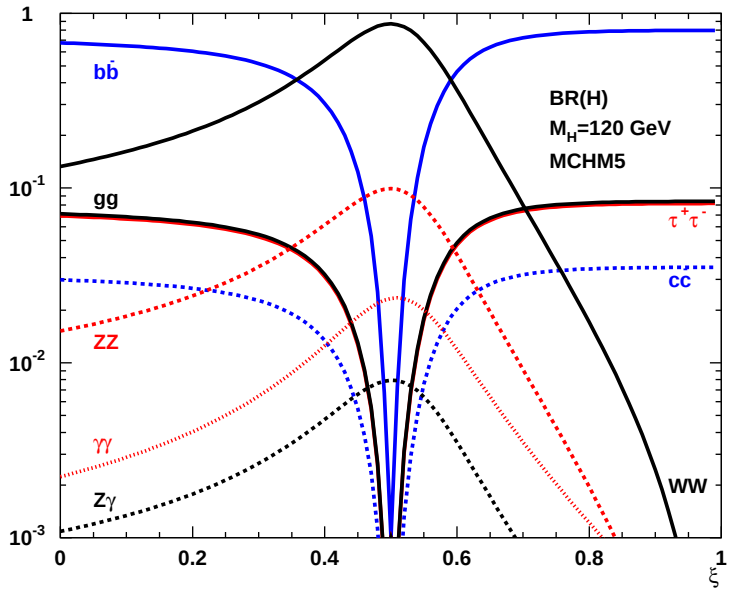
($a = c = 1$ in the SM)

- significant change of the $gg \to h$ cross section

  [Falkowski (2008), Furlan (2011)]

$$\Gamma(gg \to h) \simeq c^2 \Gamma_{SM}$$

- modification of the BR's



[Espinosa, Grojean, Mullheitner]

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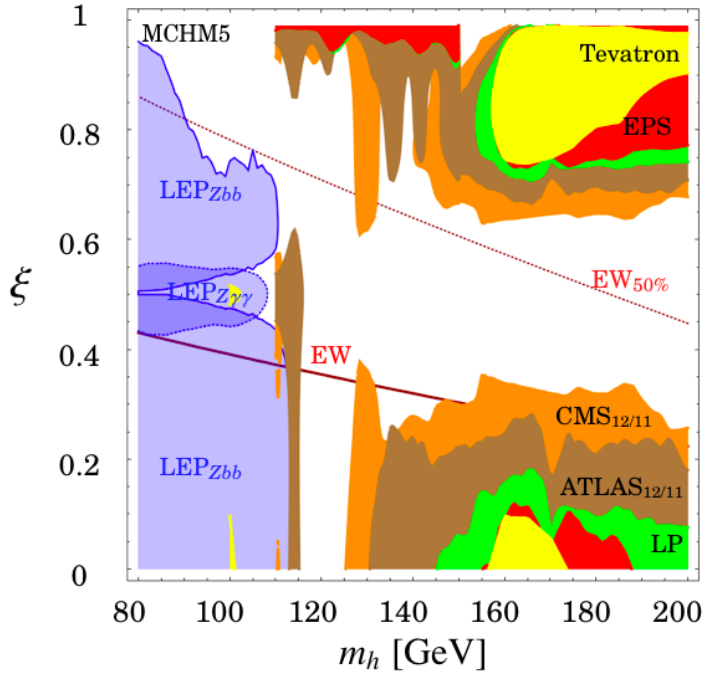
- modification of the BR's
- changes in Higgs exclusion



[Espinosa, Grojean, Mullheitner]

New couplings

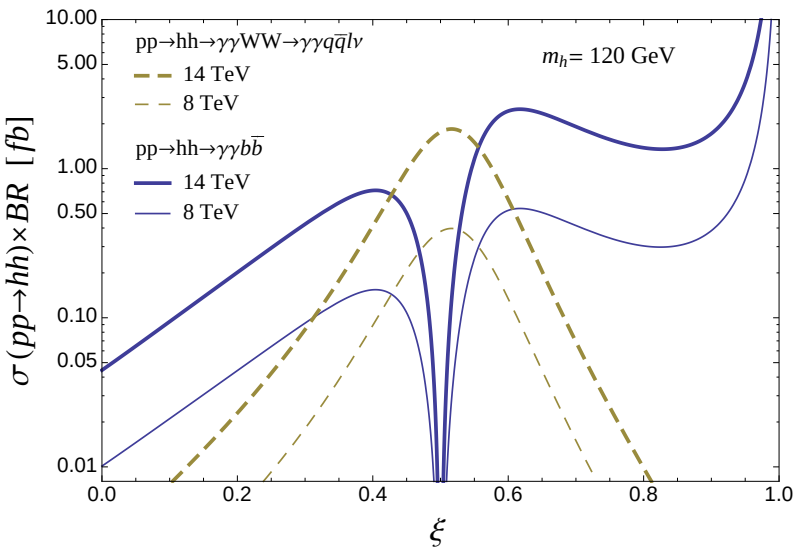
New **non-renormalizable** couplings

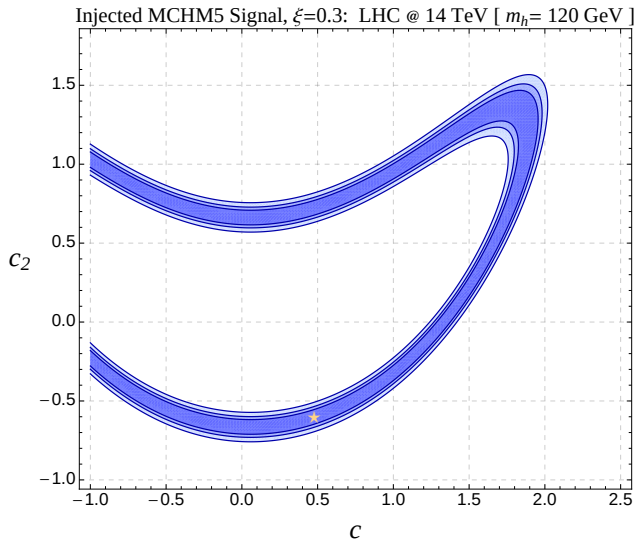
$$\mathcal{L} = -m_t \bar{q}_L \Sigma t_R \left(1 + c\frac{h}{v} + c_2\frac{h^2}{v^2} + \cdots\right) + \text{h.c.}$$

- strong **enhancement** in the $gg \longrightarrow hh$ cross section

[Grober, Muhlleitner]

- **favored** channel to test Higgs compositeness





[Contino, Ghezzi, Moretti, G. P., Piccinini, Wulzer]

Resonances

The strong sector gives rise to **resonances**

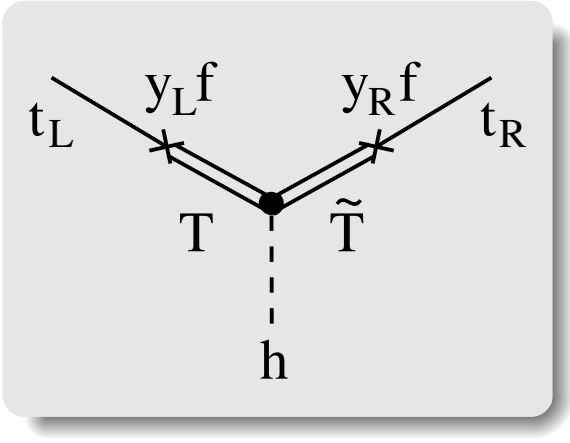
- **Heavy vectors**
  - EW neutral and charged
  - direct bound from EWPT: $m_\rho \gtrsim 2$ TeV
  - reach: ~ 2 TeV for 100 fb^{-1} at 14 TeV
- **Kaluza-Klein gluons**
  - Color octets
  - no direct bound from EWPT
  - reach: ~ 4 TeV for 100 fb^{-1} at 14 TeV
- **Fermionic resonances** (top partners)

Top partners

Top parters are **required**

by **partial compositeness**

$$|SM_n\rangle = \cos\varphi_n |elem_n\rangle + \sin\varphi_n |comp_n\rangle$$



New colored fermions

$$Q = (\mathbf{2},\mathbf{2})_{2/3} = \begin{bmatrix} T & X_{5/3} \\ B & T_{2/3} \end{bmatrix}, \qquad \widetilde{T} = (\mathbf{1},\mathbf{1})_{2/3}$$

- **Exotic states** required by custodial symmetry
- **Strongly coupled** to the top

Light top partners for a light Higgs

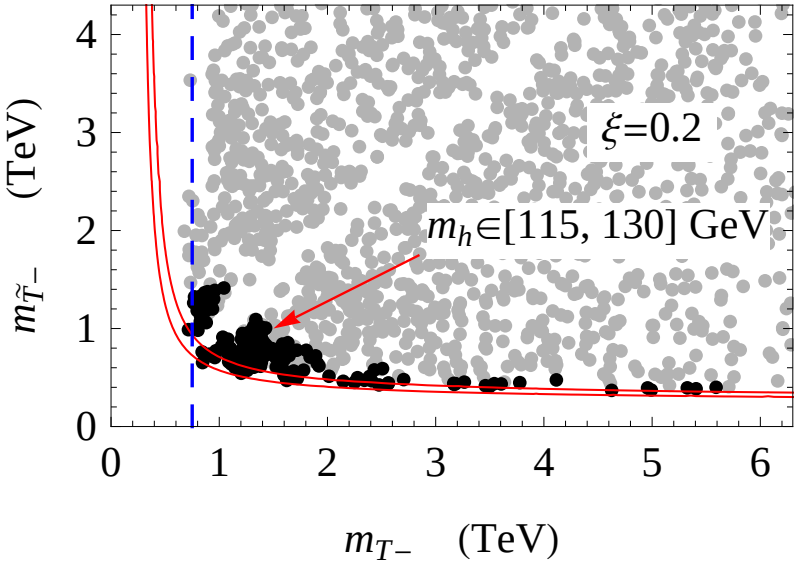
Higgs potential **radiatively generated** by resonances loops

In minimal models **structural relation** between the Higgs mass and the top partner spectrum [Matsedonskyi, G. P., Wulzer]

$$m_h \simeq \frac{\sqrt{3}}{\pi} \frac{\min(m_T, m_{\tilde{T}})}{f} m_t$$

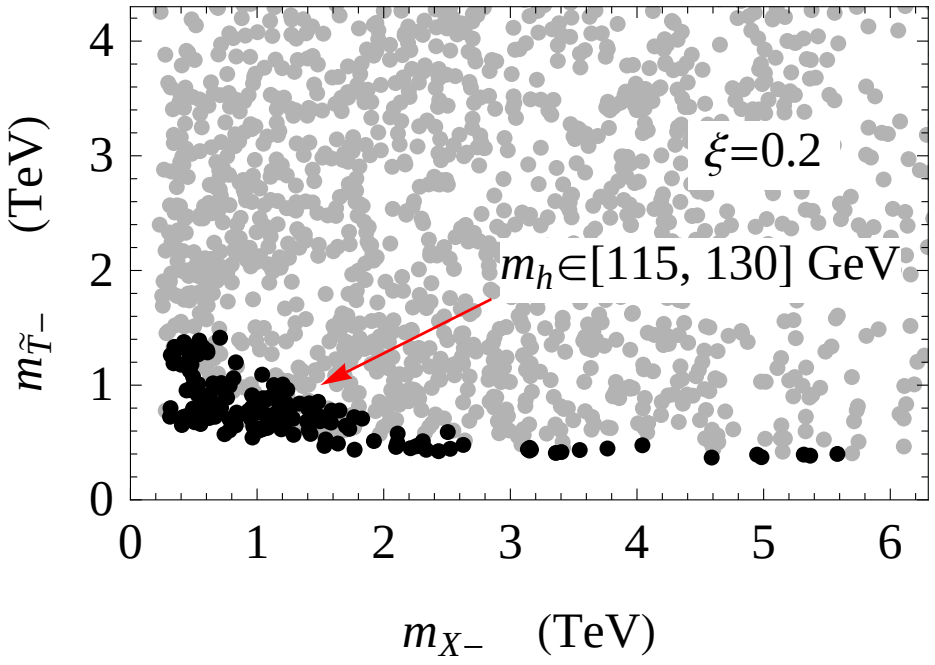
Light partners are required to get a realistic Higgs mass

- lightest states below 1 TeV



Bounds on top partners

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



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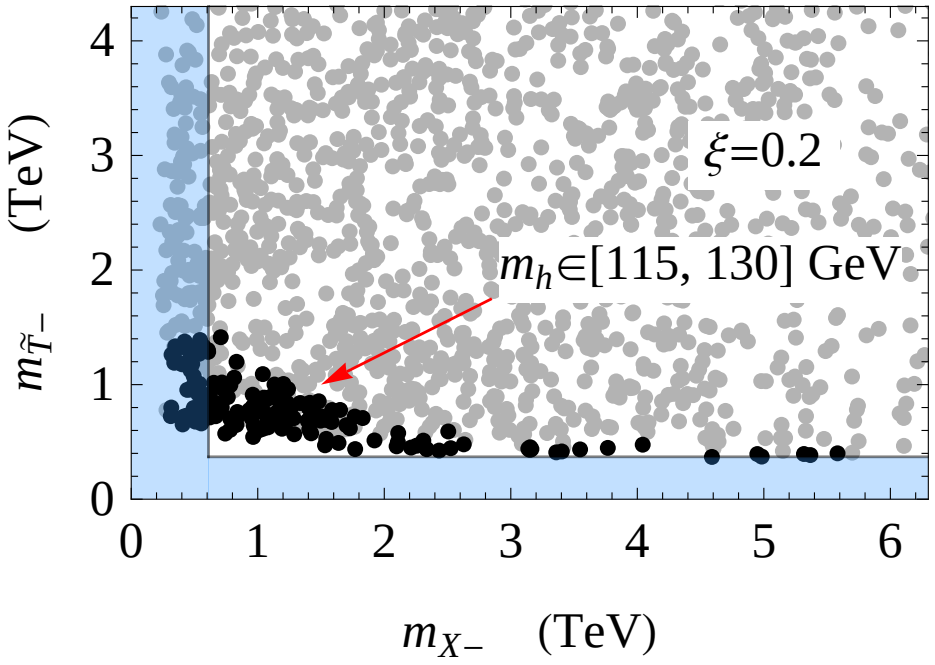

Current LHC data already give **non-trivial exclusion**

[Matsedonskyi, G. P., Wulzer]

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

Conclusions

Composite Higgs models offer a **simple** and **motivated solution** to the Hierarchy Problem

Interesting **experimental signatures**:

- **Modified couplings** in the Higgs sector
  - **Change** in the Higgs production and BR's
  - **New** non-linear couplings
- **Resonances** from the strong sector
  - **Light Higgs** accompanied by **light top partners** ($\lesssim 1$ TeV)
  - **Current data** already give non trivial **exclusion**