The tuning and the mass of the composite Higgs

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based on O. Matsedonskyi, G. P. and A. Wulzer 1204.6333 [hep-ph]
and G. P., M. Redi, A. Tesi and A. Wulzer 1210.7114 [hep-ph]

Introduction

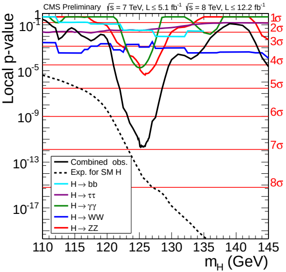
Main goal of the LHC:

Unveil the **nature of the EWSB mechanism**

First step in 2012

discovery of an Higgs-like particle

$m_h \simeq 125$ GeV



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

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

Strongly coupled solution to the Hierarchy Problem

Guideline for BSM:

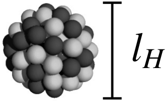
Instability of the Higgs mass: the **Hierarchy Problem**

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

Possible solution:

Higgs as a **composite state** from a strong dynamics

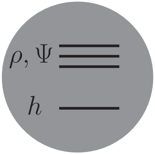
[Georgi, Kaplan]



Higgs mass **IR-saturated**, **screened** at $1/l_H$

Composite Higgs

Postulate a **new strong sector**



Modified SILH paradigm

[Giudice, Grojean, Pomarol, Rattazzi; G. P., Redi, Tesi, Wulzer]

- mass scales: $m_\rho\,,\ m_\psi$
- couplings: $g_\rho\,,\ g_\psi \lesssim 4\pi$

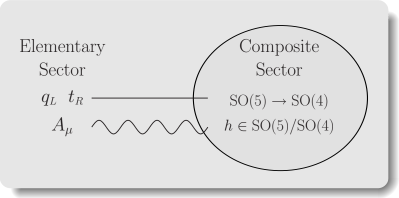
Higgs naturally **light** if it is a **Goldstone** $(m_h \ll m_\rho, m_\psi)$

- Underlying symmetry structure: $f \simeq m_\rho/g_\rho \simeq m_\psi/g_\psi$
- Separation of scales for EW precision data: $v \ll f$

Composite Higgs

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

$$\mathrm{SO}(5) \to \mathrm{SO}(4)$$



SM fields obey **partial compositeness**

$$\mathcal{L}_{mix} = y_L \overline{q}_L \mathcal{O}_L + y_R \overline{t}_R \mathcal{O}_R + \mathrm{h.c.}$$

The mixing gives a small breaking of the global symmetry

- Higgs potential **radiatively induced** (mostly by top-partners)

Higgs potential

[G. P., Redi, Tesi, Wulzer]

The quantum numbers of the $\mathcal{O}_{L,R}$ operators determine the structure of the potential in a $y_{L,R}/g_\psi$ expansion.

[Mrazek, Pomarol et al.]

All "minimal" models ($\mathcal{O}_{L,R} \in \mathbf{4}, \mathbf{5}, \mathbf{10}$) are in the same class:

$$V \simeq \frac{N_c}{16\pi^2} g_\psi^2 f^4 y^2 \left[\alpha \sin^2\left(\frac{h}{f}\right) + \beta \frac{y^2}{g_\psi^2} \sin^4\left(\frac{h}{f}\right) \right] , \quad \alpha, \beta \sim \mathcal{O}(1)$$

EW precision data require $\xi \equiv (v/f)^2 \ll 1$

The **leading** terms must be **tuned** with the **subleading** ones

- additional cancellation in the α coefficient: $\Delta \simeq \dfrac{1}{\xi} \dfrac{g_\psi^2}{y^2}$

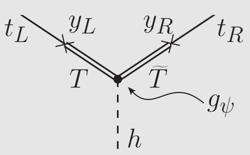
Light partners for a light Higgs

[Matsedonskyi, G. P., Wulzer]

$y_{L,R}$ are related to the generation of the top mass

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

$$y_t \simeq y_L y_R \frac{f}{m_{light}}$$



The Higgs mass is related to the mass of the lightest top partner

$$m_h \simeq \sqrt{\frac{N_c}{2\pi^2}} \frac{y_t m_{light}}{f} \simeq 100\ \mathrm{GeV} \left(\frac{m_{light}}{f}\right)$$

A **light Higgs** requires **light partners**

Light partners for a light Higgs

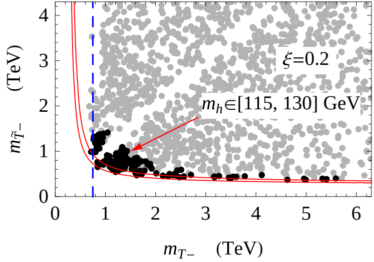
[Matsedonskyi, G. P., Wulzer]

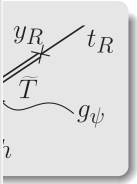
$y_{L,R}$ are related to t

The presence of l
enhances the

$y_t \simeq y_L$

Light partners: $m_{light} \lesssim 1$ TeV





The Higgs mass is r … partner

$$m_h \simeq \sqrt{\frac{N_c}{2\pi^2}}\frac{y_t m_{light}}{f} \simeq 100 \text{ GeV} \left(\frac{m_{light}}{f}\right)$$

A **light Higgs** requires **light partners**

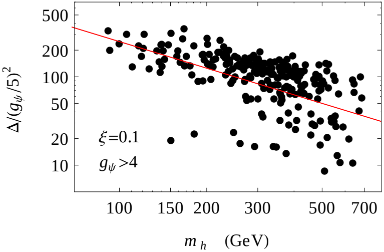
The degree of tuning

[G. P., Redi, Tesi, Wulzer]

We can also estimate the amount of tuning

$$\Delta \simeq \frac{1}{\xi}\frac{g_\psi^2}{y_t}\frac{f}{m_{light}} \simeq \frac{1}{\xi}20\left(\frac{125\ \mathrm{GeV}}{m_h}\right)\left(\frac{g_\psi}{5}\right)^2$$

- A **large** fermion scale $m_\psi \simeq g_\psi f$ implies **tuning**
- The tuning **does not** improve if **only one** state becomes light



- for the numerical analysis we use $\Delta \equiv d\log(v/f)/d\log i$

[Barbieri, Giudice]

Minimal tuning

In general a **low amount of tuning** requires the presence of **light fermionic resonances**

A simple reason is the quadratic divergence in the Higgs mass

- the top partners regulate the divergence
- Λ_{NP} is related to the fermion mass scale: $\Lambda_{NP} \simeq m_\psi = g_\psi f$

The **minimal** amount of tuning is

$$\Delta \gtrsim \left(\frac{\Lambda_{NP}}{400\ \mathrm{GeV}}\right)^2 \simeq \left(\frac{m_\psi}{400\ \mathrm{GeV}}\right)^2$$

A bound on the partners implies a bound on the tuning

Natural SUSY: light stops	$\Leftrightarrow$	**Natural CH**: light top partners

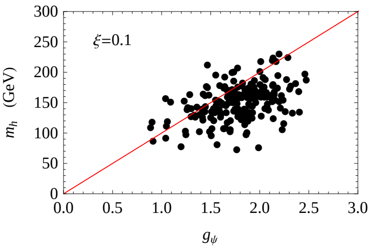
The limit of small fermionic scale

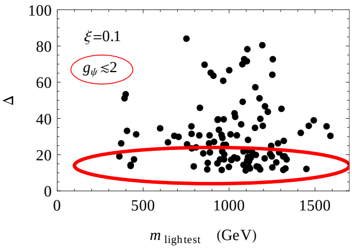
Configuration with **minimal tuning** can be obtained only if the fermionic scale is small: $g_\psi \lesssim 2$.

In this case all the terms in the y expansion are of the same order

$$\frac{y_L}{g_\psi} \sim \frac{y_R}{g_\psi} \sim 1$$

- **all** models share **similar properties**





Conclusions

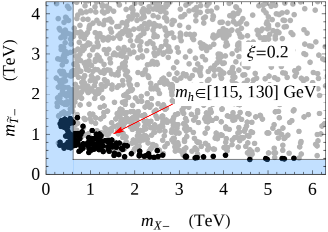
Composite Higgs models offer a **simple** and **motivated** solution to the Hierarchy problem

- In "minimal" models a **light Higgs** is tightly connected with the presence of **light top partners**

Minimal tuning $\Delta \simeq 1/\xi$ can be obtained

only for a **small** fermionic mass scale: $g_\psi = m_\psi/f \sim 1$

- Current LHC data already give **non-trivial exclusion** on the top partners



Conclusions

The analysis of the tuning is a **key** to identify interesting **alternative scenarios** [Pomarol, Riva; G. P., Redi, Tesi, Wulzer]

- "Non-minimal" models
- Totally composite t_R
- ...