A New Perspective on Composite Higgses

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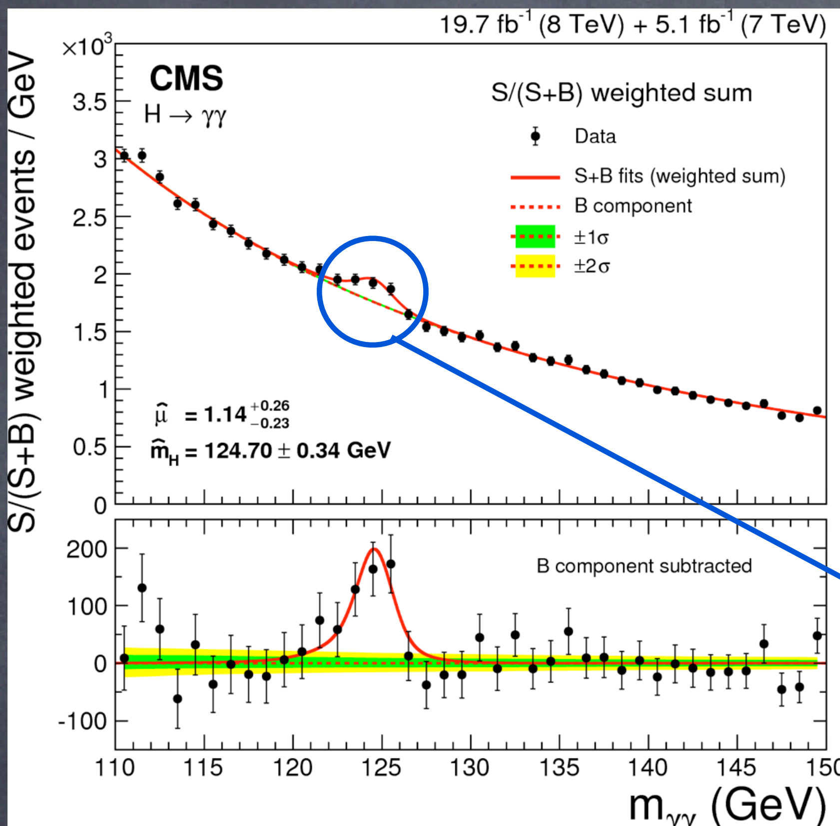
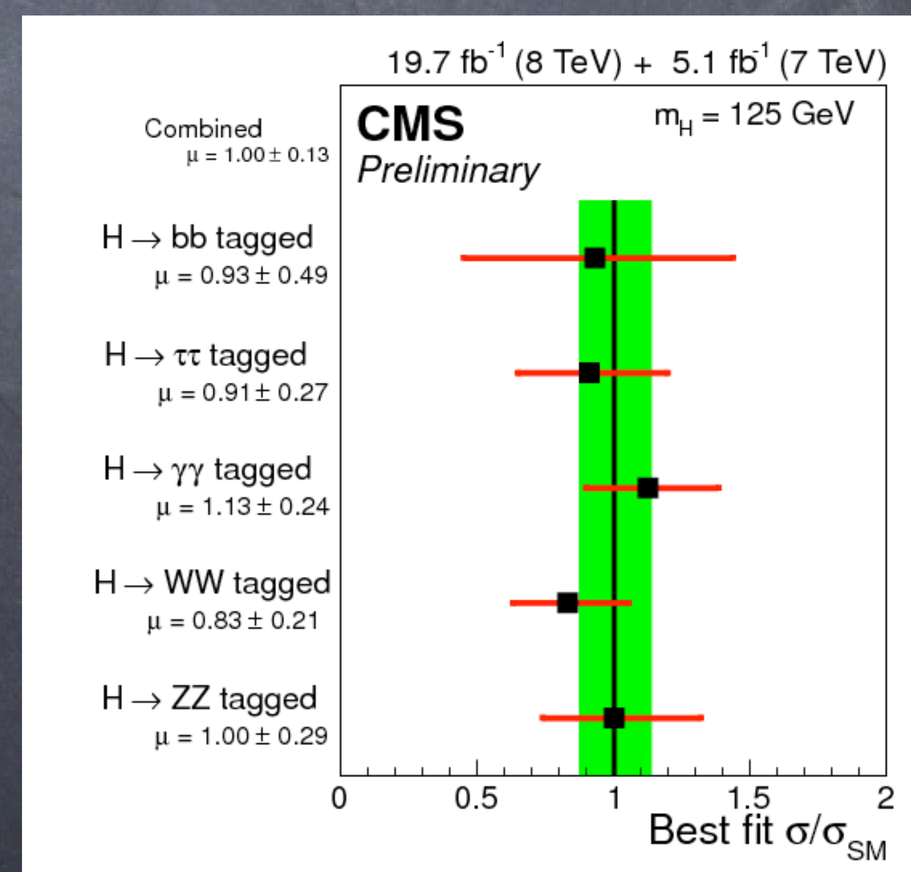
The Higgs at last!



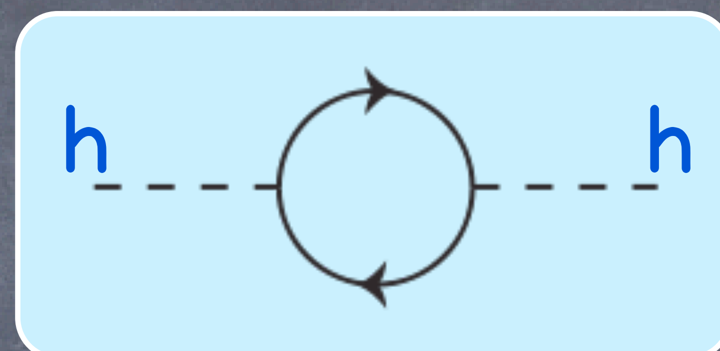
Ian MacNicol / AFP - Getty Images

- Couplings known at 15-20% level
- Plenty of space for new physics!



The Higgs ~~at last!~~ *at least!*

- The discovery of the Higgs boson has brought the **Naturalness problem** to reality!

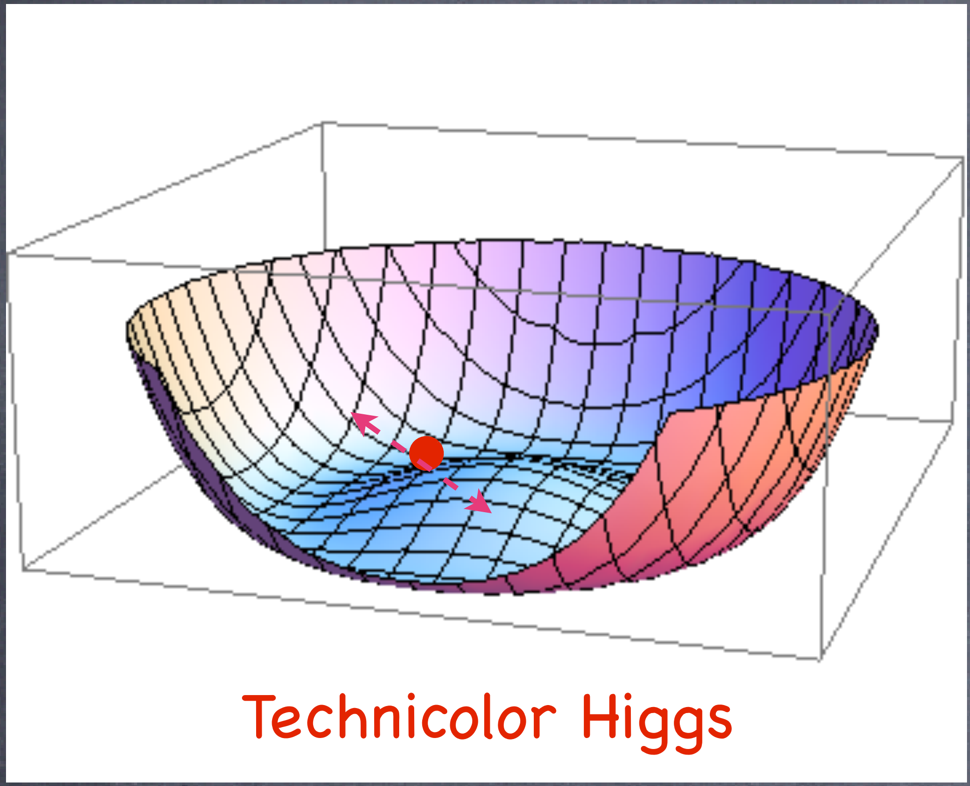


$$\delta m_H^2 \sim \frac{g^2}{16\pi^2} M_{\mathrm{NPh}}^2$$

... or there is New Physics!

Can the Higgs derive from a confining dynamics?

A composite Higgs in pictures



Large global symmetry dynamically broken.

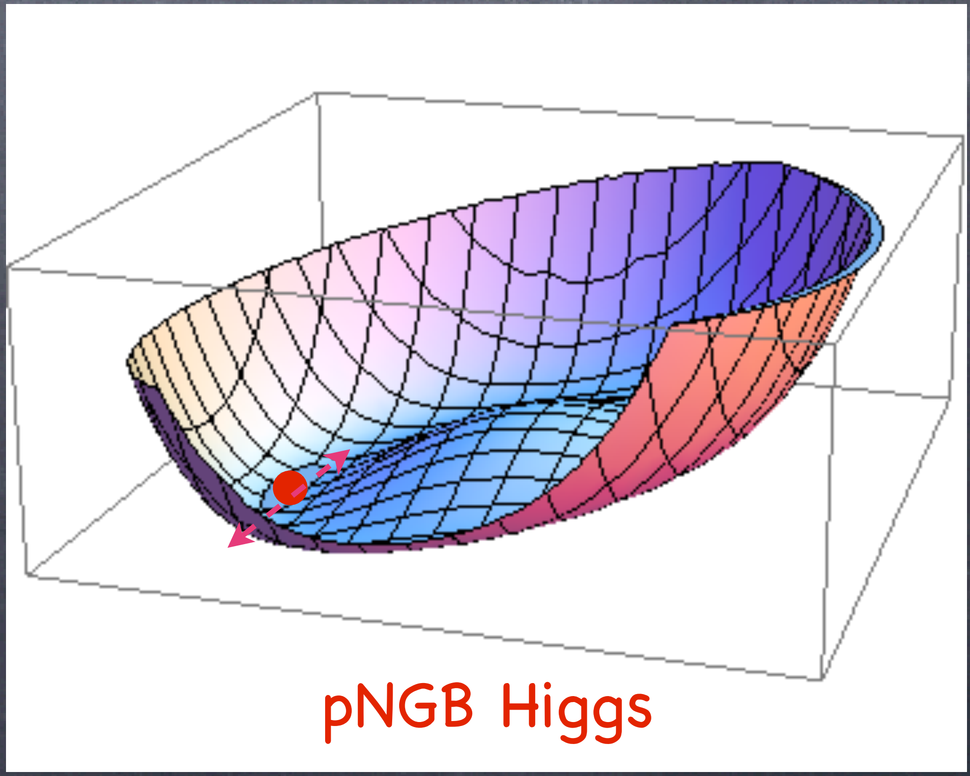
N Goldstone bosons

Mass set by the dynamics!

The global symmetry broken by quantum effects.

Some Goldstone bosons acquire mass

Mass smaller than the scale of dynamics



A dynamical model:

$G = SU(2)$ with 4 Weyl doublets Q_i

Batra, Csako 0710.0333
Ryttov, Sannino 0809.0713

$< Q_i Q_j >$ condensate forms and breaks

$SU(4) \to Sp(4) \sim SO(5)$ (proven on the lattice)

Lewis, Pica, Sannino 1109.3513
+ Hietanen 1404.2794

The minimal case:

$$SU(4) \to Sp(4) \sim SO(5)$$

Katz, Nelson, Walker hep-ph/0504252
Gripaios, Pomarol, Riva, Serra, 0902.1483
Galloway, Evans, Luty, Tacchi 1001.1361

- Sp(4) has rank = 2, and it contains an SU(2)xSU(2) subgroup
- The condensate transforms as:

$$\langle \psi^i \psi^j \rangle = \mathbf{6}_{\mathrm{SU(4)}} \to \mathbf{5}_{\mathrm{Sp(4)}} \oplus \mathbf{1}_{\mathrm{Sp(4)}}$$

Goldstone bosons: $5_{\mathrm{Sp(4)}} \to (2,2) \oplus (1,1)$ of SU(2)xSU(2): Higgs doublet + singlet

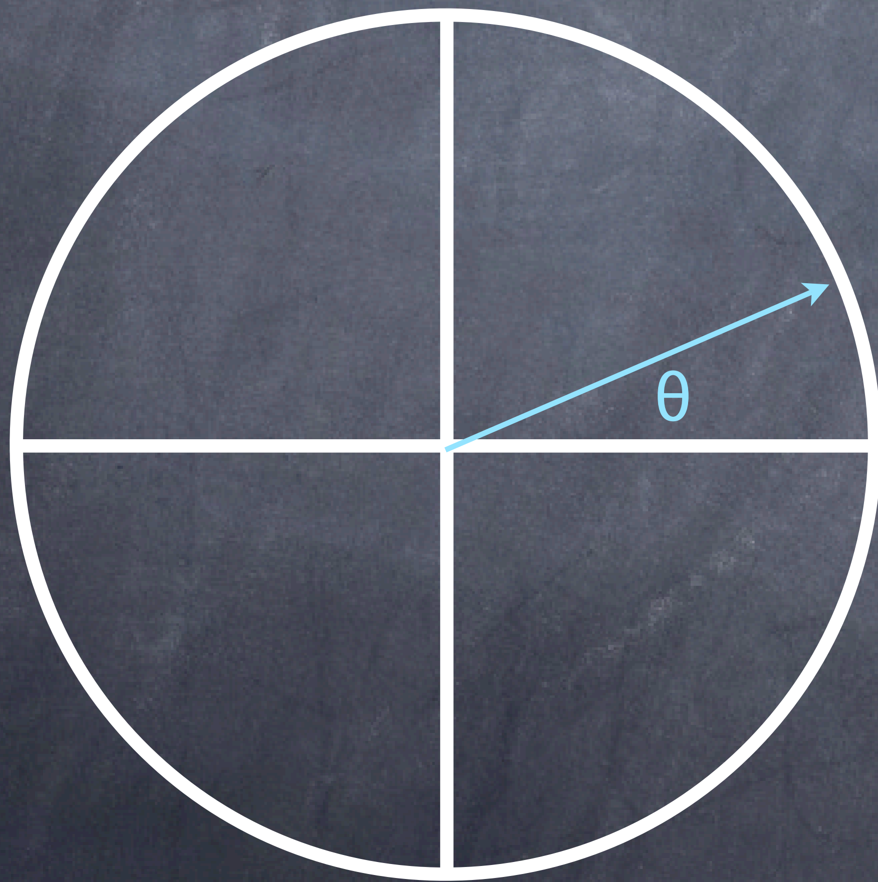
Massive scalar: $1_{\mathrm{Sp(4)}} \to (1,1)$ like the σ meson in QCD

How is EW symmetry broken?
(This is an issue of alignment!)

$\theta = \pi/2$

Technicolor

→ 2 stable light scalars
Higgs must be a "σ meson"



→ A pseudo-Goldstone (composite) Higgs
exists in between!

$\theta = 0$

No EWSB

→ 4 massless
Goldstone Bosons

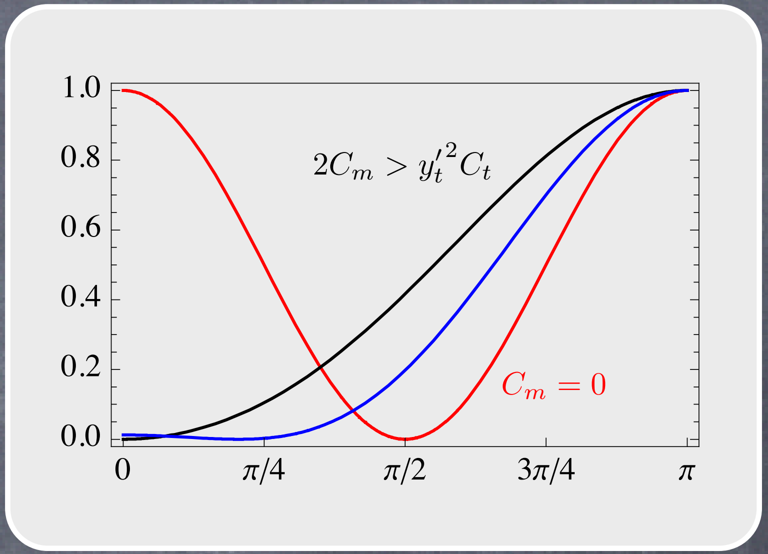
SM limit!

Cacciapaglia, Sannino
1402.0233

Introducing a potential for θ

$$V(\theta) = {y'_t}^2 C_t \cos^2\theta - 4C_m \cos\theta + \text{const.}$$

$$|\cos\theta|_{\min} = \frac{2C_m}{{y'_t}^2 C_t} \quad \text{if } {y'_t}^2 C_t > 2|C_m|$$



Note: to obtain θ~0, we need to tune ${y'_t}^2 C_t \sim 2C_m$

$$m_\eta^2 = \frac{{y'_t}^2 C_t}{4} f^2$$

$m_h = 125$ GeV for $C_t \sim 2$

$$m_h^2 = \frac{{y'_t}^2 C_t}{4} f^2 \sin^2\theta = m_\eta^2 \sin^2\theta = \frac{C_t m_t^2}{4}$$

$f^2 \sin^2\theta \sim v^2$

The Higgs mass fine-tuning

$$\delta m_h^2\big|_{\text{top}} = \frac{C_t {y'_t}^2 f^2}{8}(2\sin^2\theta - 1)$$

$$\delta m_h^2\big|_{\text{m}} = \frac{2C_m f^2}{8}\cos\theta$$

Both Order f!

The Higgs mass fine-tuning

$$\delta m_h^2\big|_{\rm top} = \frac{C_t {y'_t}^2 f^2}{8}(2\sin^2\theta - 1)$$

$$\delta m_h^2\big|_{\rm m} = \frac{2C_m f^2}{8}\cos\theta = \frac{C_t {y'_t}^2 f^2}{8}(1 - \sin^2\theta)$$

Sum is Order
v = f sin θ

The tuning that keeps θ small protects the Higgs mass:

$$m_h \to 0 \quad \text{for} \quad \theta \to 0$$

Predictions from the Lattice:

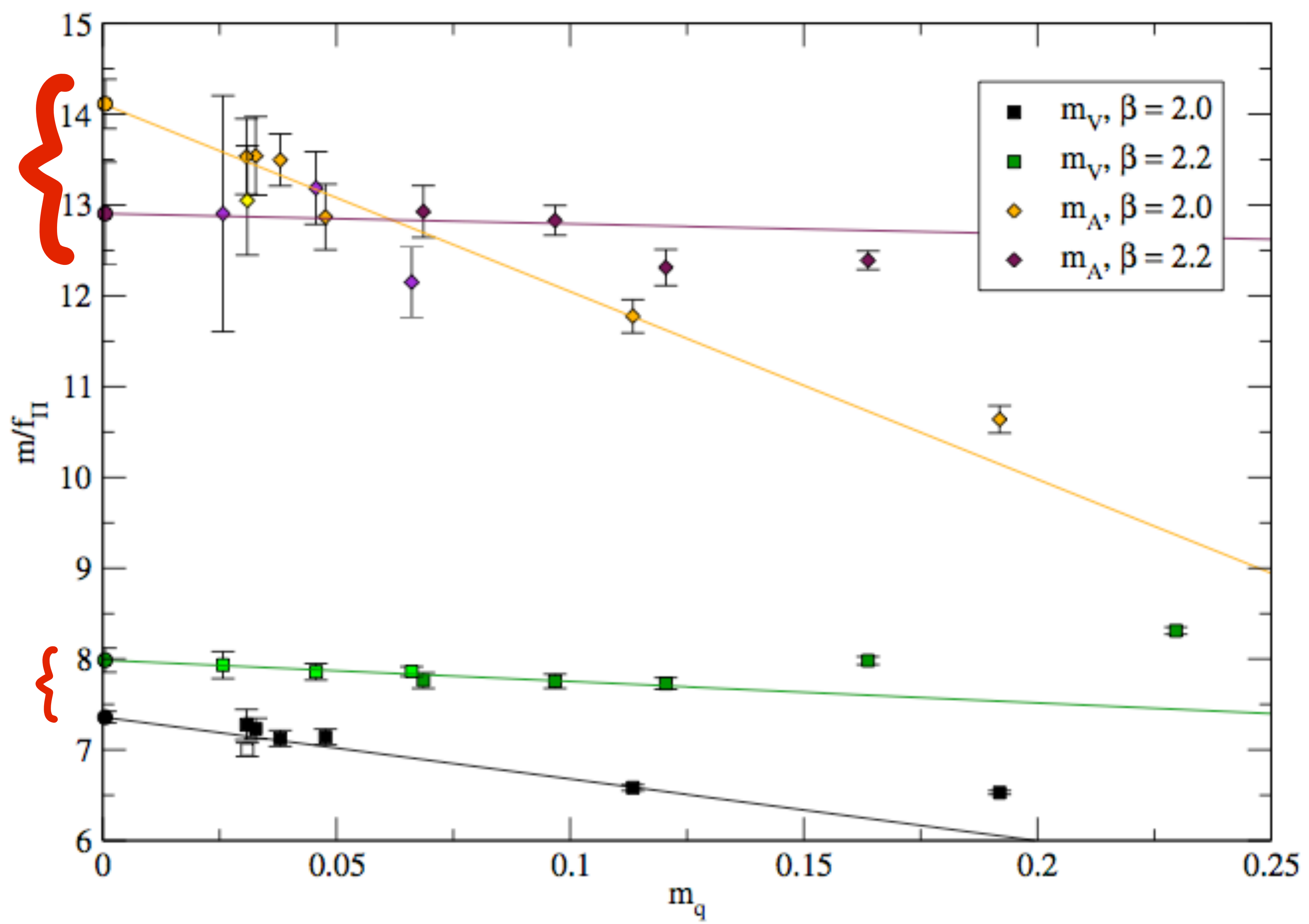


FIG. 6: The vector meson and axial vector meson masses in physical units. The chiral extrapolations have been performed using a linear fit to the points where $m_q < 0.12$.

Lewis, Pica, Sannino 1109.3513
+ Hietanen 1404.2794

Predictions from the Lattice:

No light top partners are needed to cancel the top loop!

For sin θ = 0.2 (typical value):

vector resonances ρ and a

$$m_a = 16.5 \pm 3.5 \text{ TeV}$$

$$m_\rho = 12.5 \pm 2.5 \text{ TeV}$$

Lattice results!

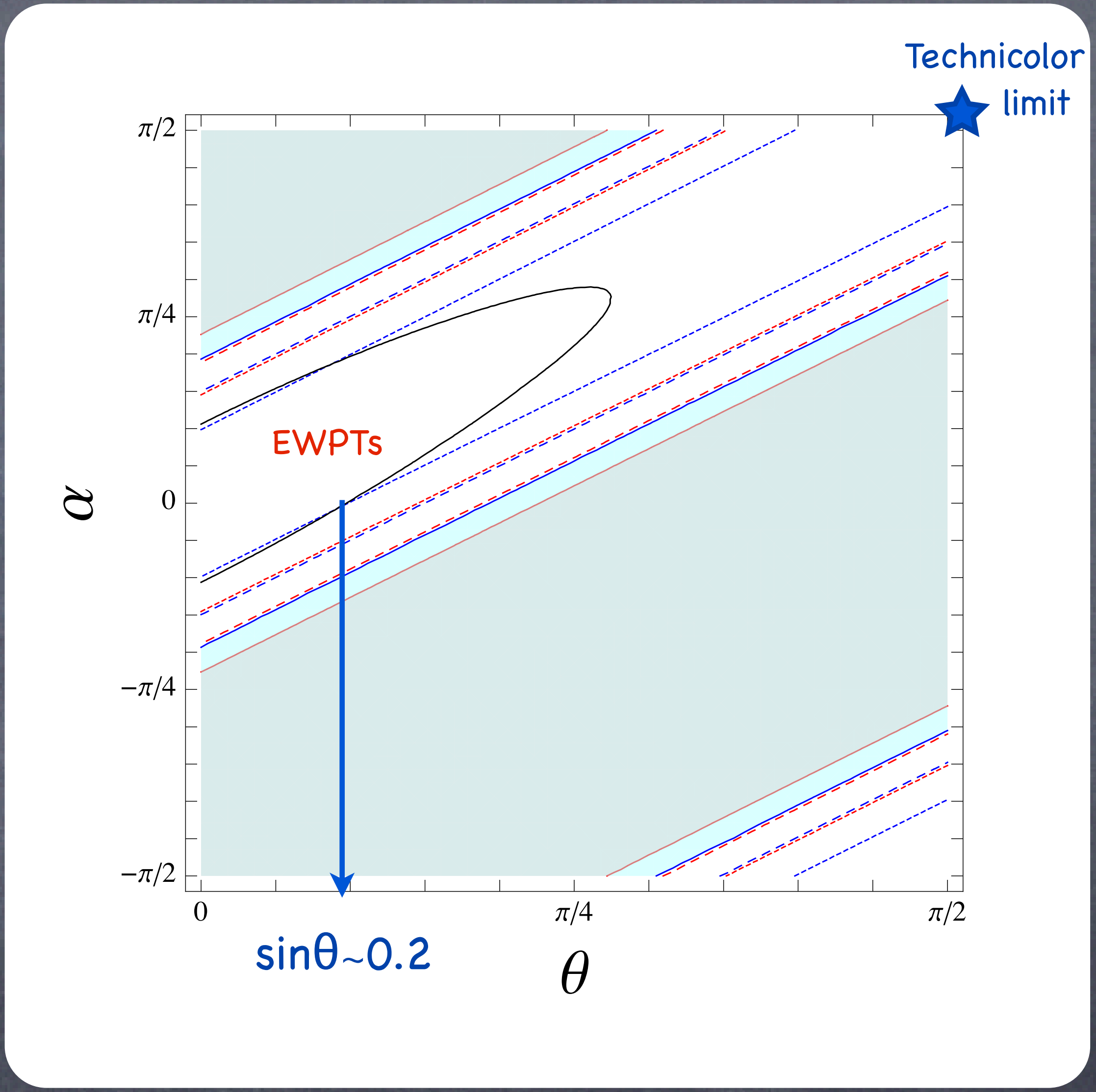
scalar singlet $\quad m_\eta = 625 \text{ GeV}$

Higgs $\quad m_H = 125 \text{ GeV}$ — Not a prediction!

EWPTs and Higgs couplings

Arbey, Cacciapaglia, Cai, Deandrea, le Corre, Sannino 1502.04718

Mixing angle between h and σ (m_σ = 1 TeV)



- A light-ish σ can help relieve the fine-tuning problem.

LHC smoking gun?

Arbey, Cacciapaglia, Cai, Deandrea, le Corre, Sannino 1502.04718

$$\langle \psi^i \psi^j \rangle = \mathbf{6}_{\mathrm{SU(4)}} \to \mathbf{5}_{\mathrm{Sp(4)}} \oplus \mathbf{1}_{\mathrm{Sp(4)}}$$

$$5_{\mathrm{Sp(4)}} \to (2,2) \oplus (1,1)$$

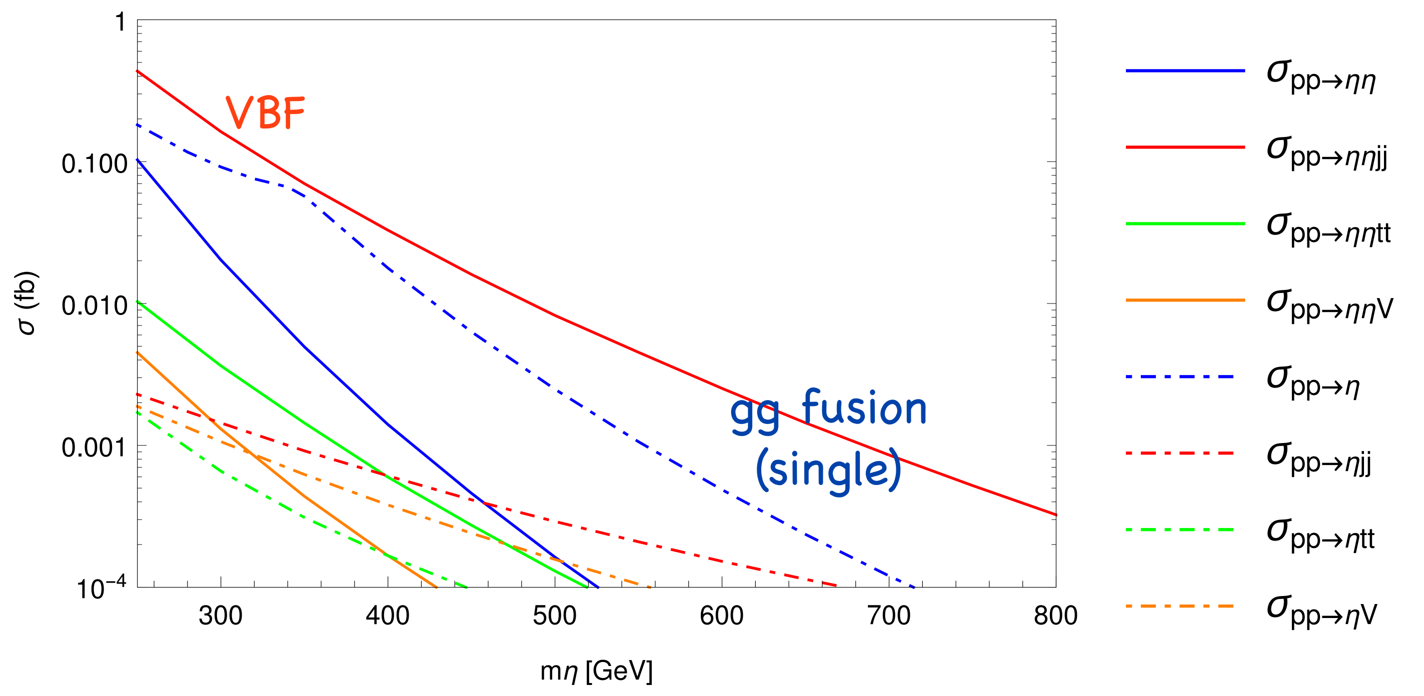
h η

$$1_{\mathrm{Sp(4)}} \to (1,1)$$

σ

LHC smoking gun?

Arbey, Cacciapaglia, Cai, Deandrea, le Corre, Sannino 1502.04718



BR ($\eta \to tt$) ~ 100%

- Very challenging (maybe VBF tag?)
- Compatible with null results of Run I

Conclusions


Credit: darkroom.baltimoresun.com

We still do not know what is hiding behind the Higgs boson!

- I presented a very simple model of composite Higgs (pNGB)
- which is still viable experimentally
- and we have Lattice calculations of the spectrum.
- No light top partners are needed!
- The smoking guns are additional light scalars (pNGB) - maybe one DM candidate

Back up

S and T

Loop of techni-quarks:
spin1-loop contribution

$$\Delta S = \frac{1}{6\pi}\left[(1-k_{h_1}^2)\ln\frac{\Lambda}{m_{h_1}} - k_{h_2}^2\ln\frac{\Lambda}{m_{h_2}} + N_D\sin^2\theta\right], \qquad (2.36)$$

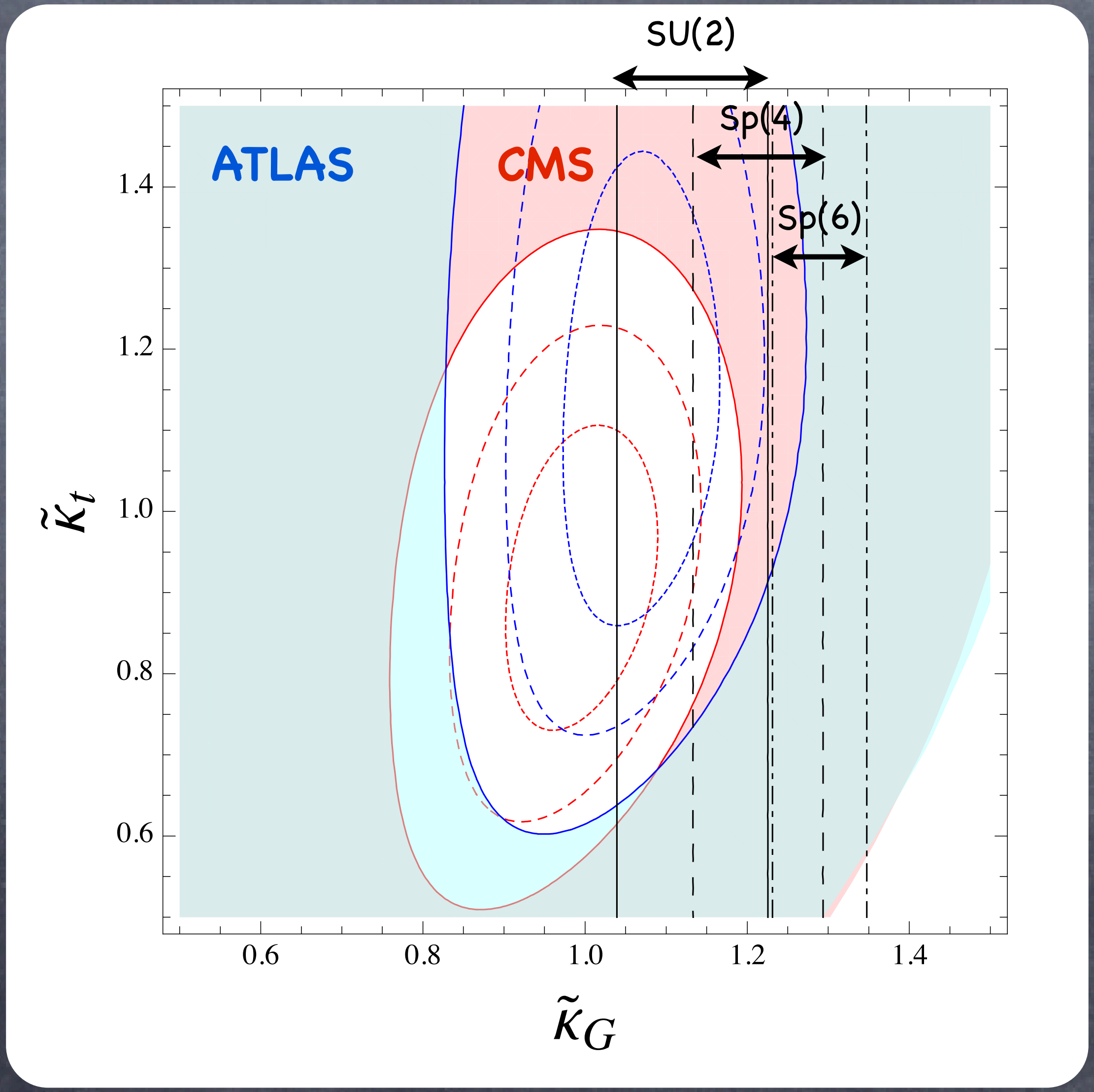
$$\Delta T = -\frac{3}{8\pi\cos^2\theta_W}\left[(1-k_{h_1}^2)\ln\frac{\Lambda}{m_{h_1}} - k_{h_2}^2\ln\frac{\Lambda}{m_{h_2}}\right], \qquad (2.37)$$

where

$$k_{h_1} = \cos(\theta-\alpha) + (\tilde{\kappa}_G - 1)\sin\theta\sin\alpha\,, \quad k_{h_2} = \sin(\theta-\alpha) + (\tilde{\kappa}_G - 1)\sin\theta\cos\alpha\,, \qquad (2.38)$$

EW fit: technicolor

EWP bounds



Couplings of the σ in SM units