Higgslike Dilatons

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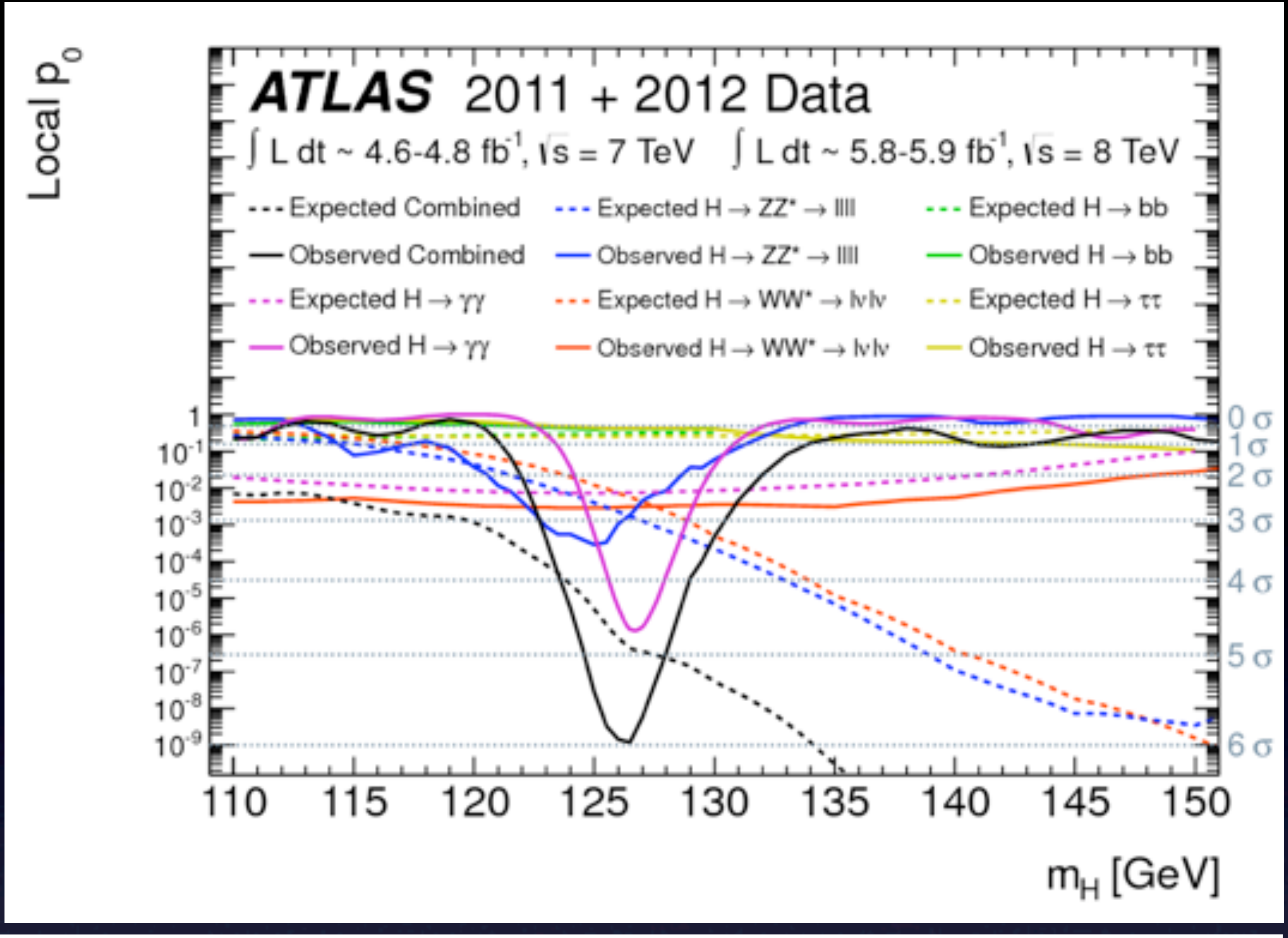
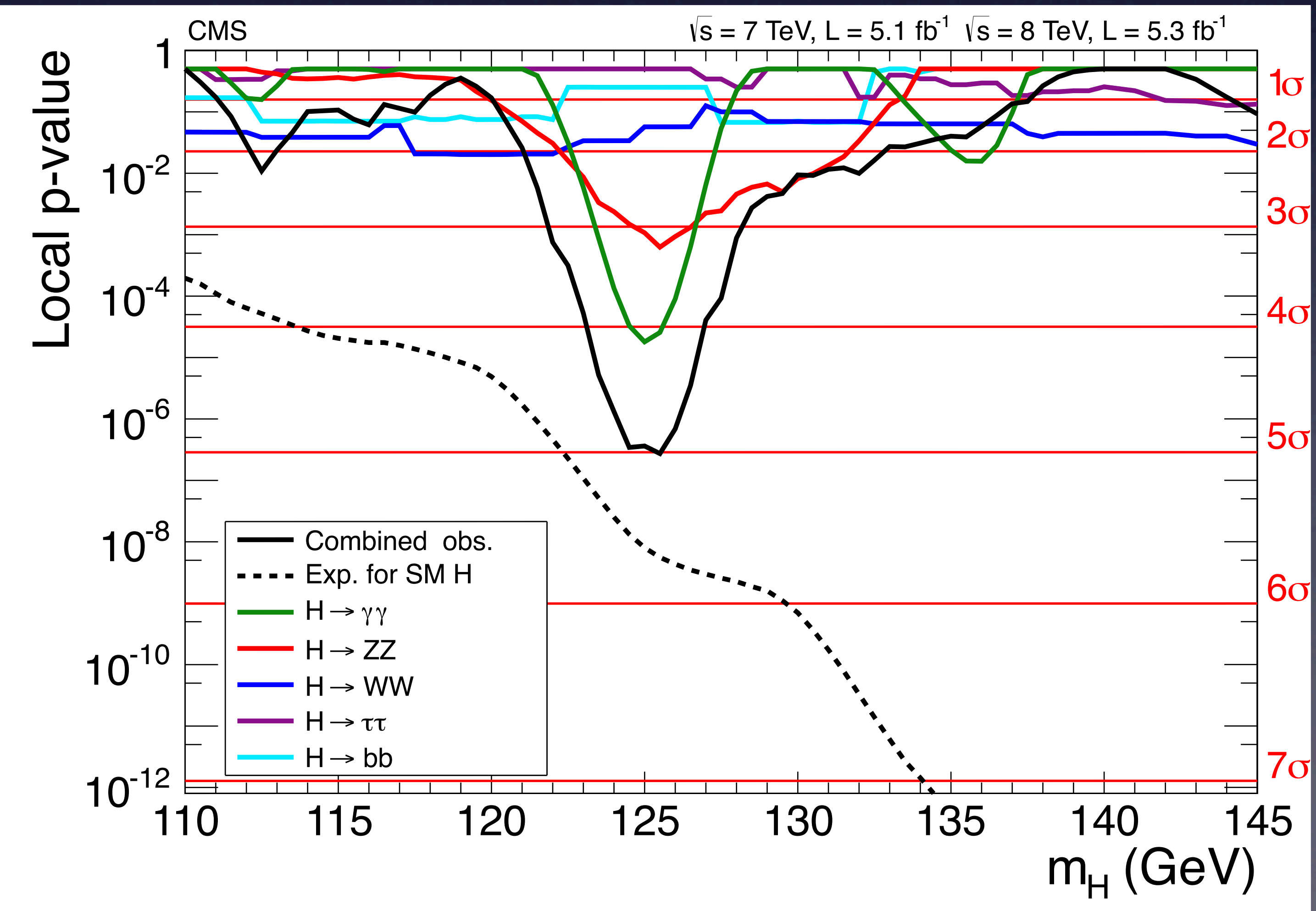
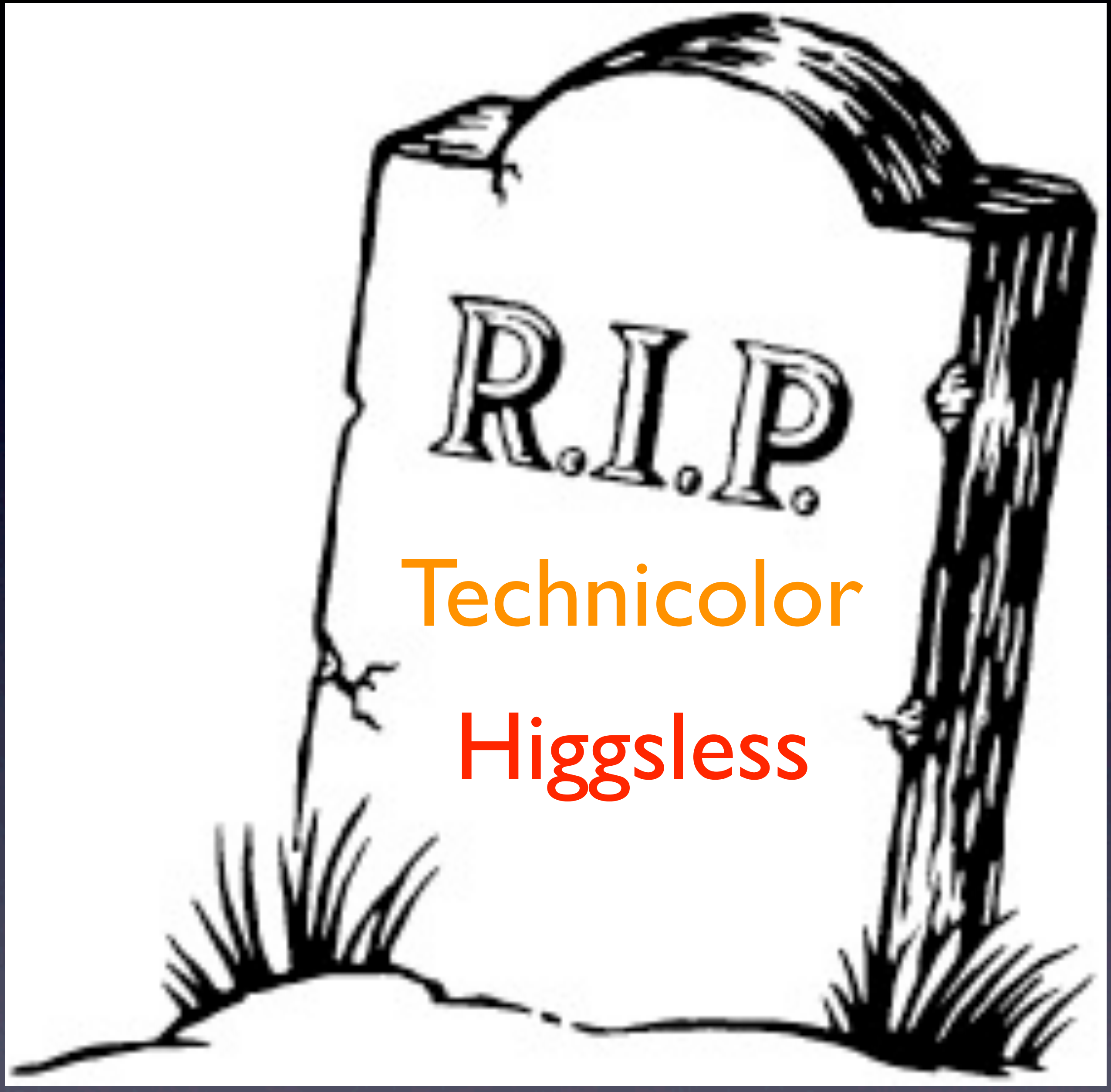
hep-ph:1209.3299

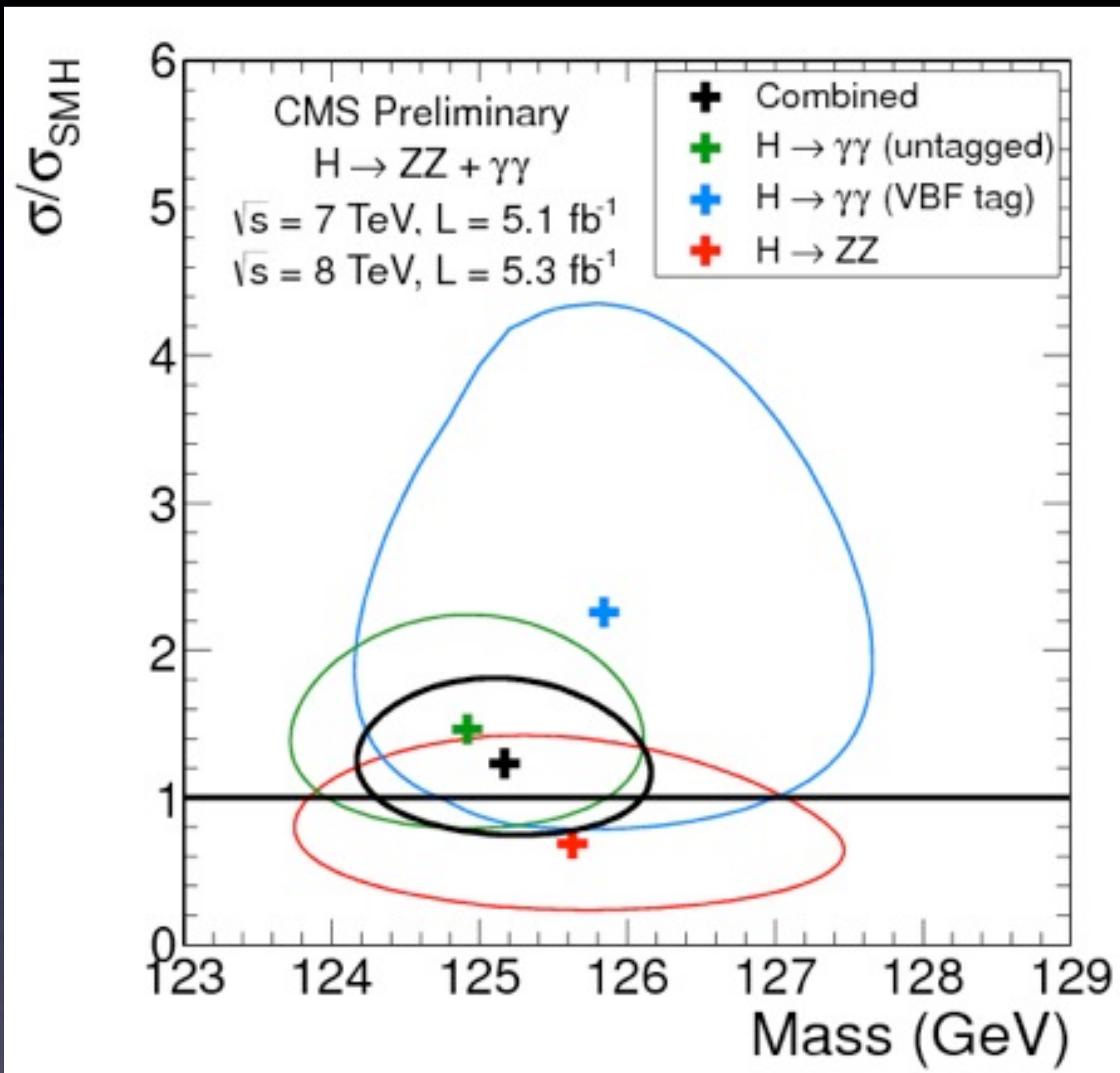
Discovery!

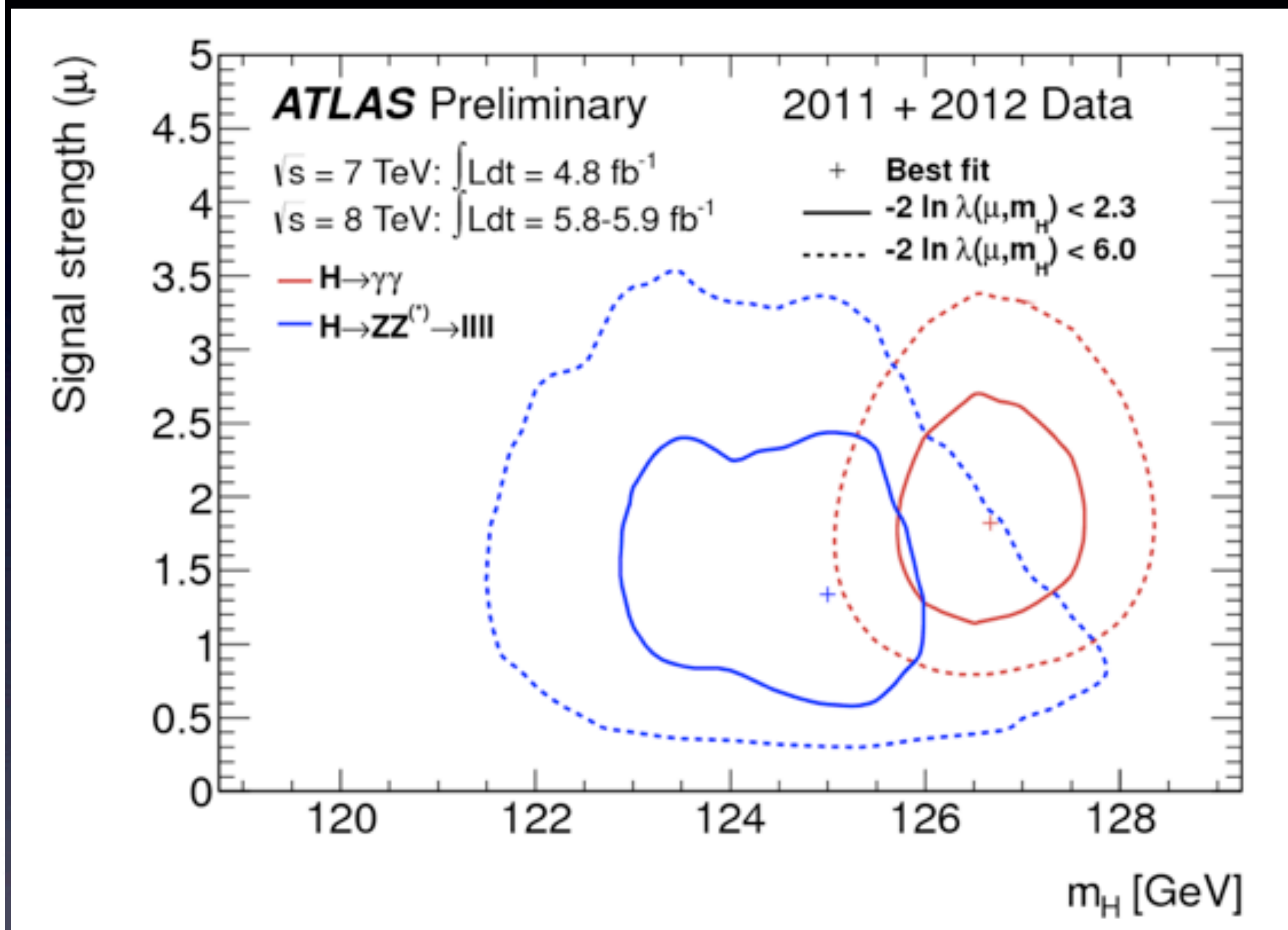

ATLAS 2011 + 2012 Data
∫ L dt ~ 4.6-4.8 fb⁻¹, √s = 7 TeV ∫ L dt ~ 5.8-5.9 fb⁻¹, √s = 8 TeV
Expected Combined
Observed Combined
Expected H → γγ
Observed H → γγ
Expected H → ZZ* → llll
Observed H → ZZ* → llll
Expected H → WW* → lνlν
Observed H → WW* → lνlν
Expected H → bb
Observed H → bb
Expected H → ττ
Observed H → ττ
Local p₀
m_H [GeV]


CMS
√s = 7 TeV, L = 5.1 fb⁻¹ √s = 8 TeV, L = 5.3 fb⁻¹
Local p-value
Combined obs.
Exp. for SM H
H → γγ
H → ZZ
H → WW
H → ττ
H → bb
m_H (GeV)


R.I.P.
Technicolor
Higgsless

What is it?

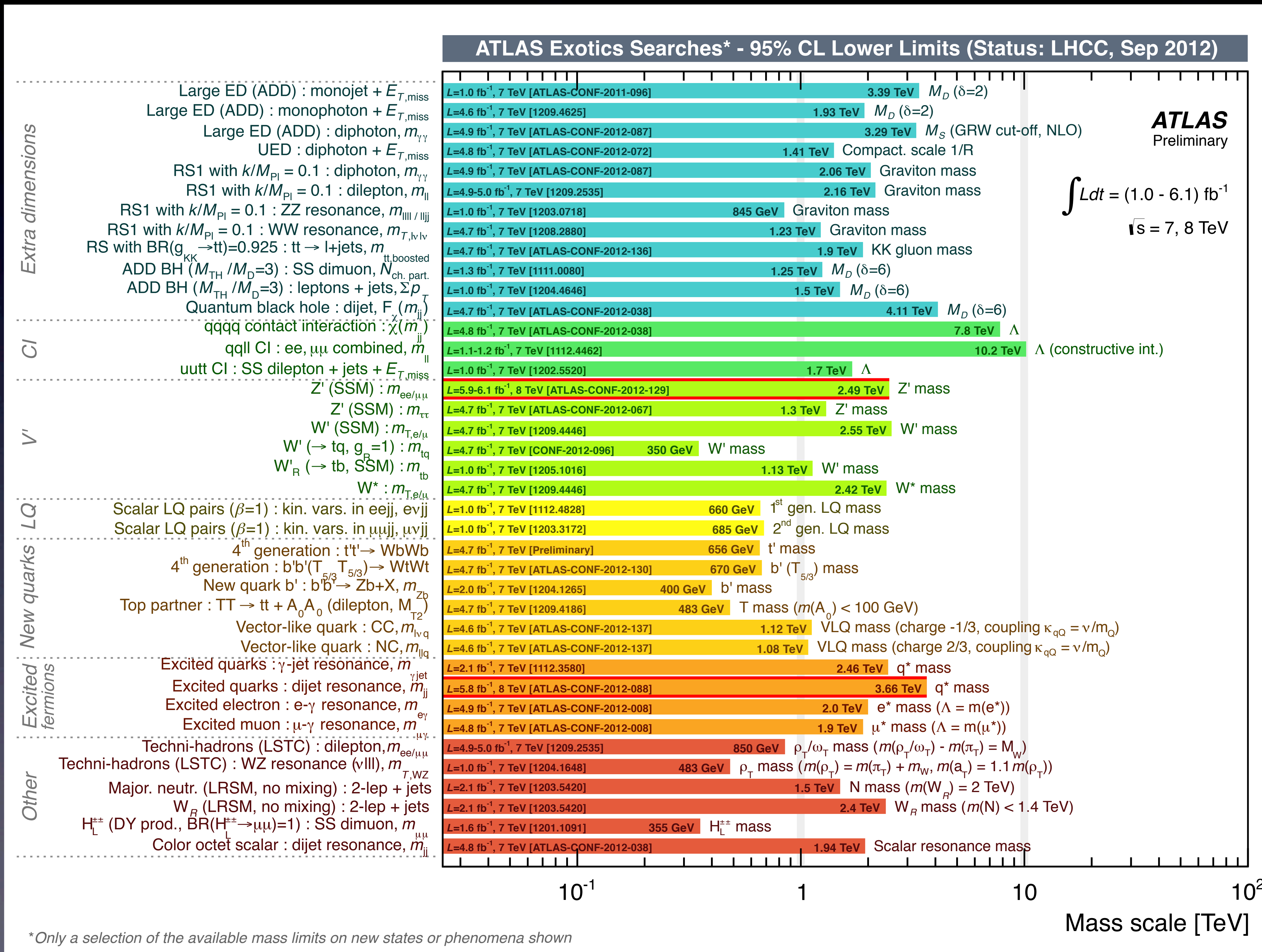




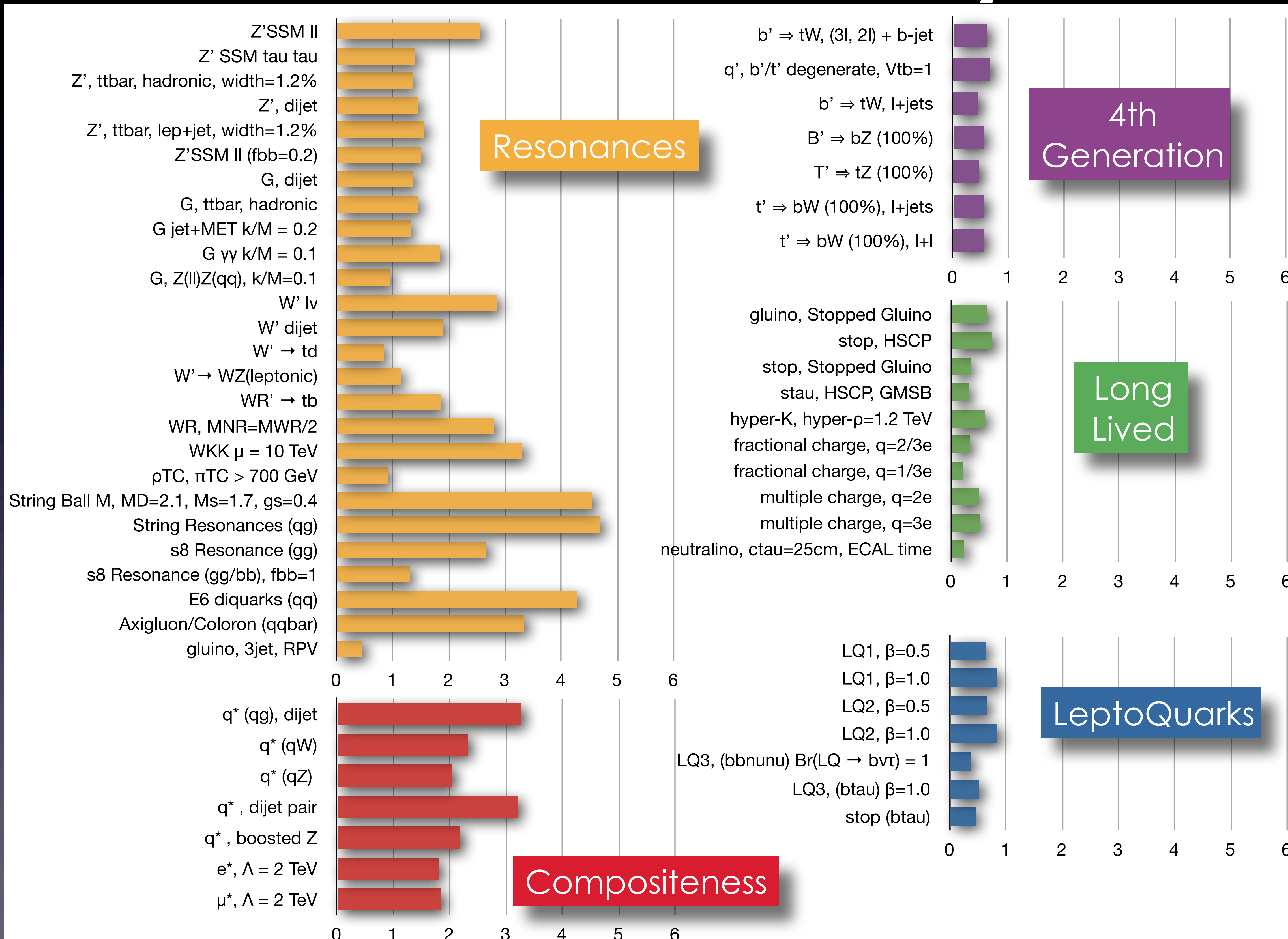
The resonance is at ~126 GeV and it is SM-Higgs-like

Sizeable deviations still allowed

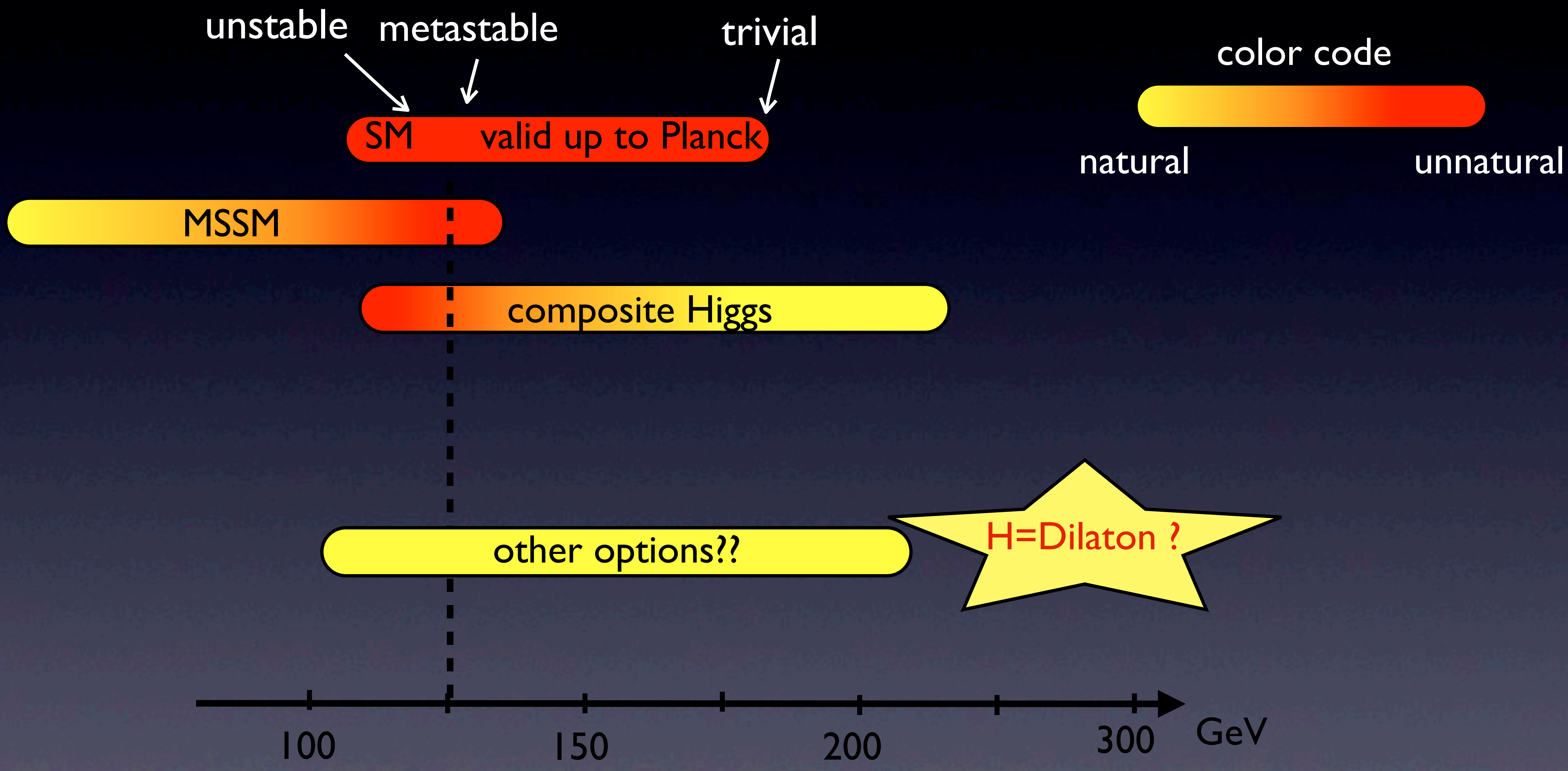
Non-discovery



Non-discovery



Status of light scalars



All models seem to be under strain

Strongly coupled EWSB

- Higgsless and Technicolor models are dead
- Composite Higgs models fine tuned
- Give up on SC-EWSB?

The Higgs:

- Couplings determined by ~ conformal invariance of SM (e.g. low energy theorems)
  - m_H is only tree-level explicit breaking
- VEV breaks conformality spontaneously

Higgs-like dilaton

- Can envision a model of strong dynamics at at conformal fixed point
- To reproduce data need conformal symmetry spontaneously broken at $f \sim v$

Questions I will address:

- Can a dilaton fit the data?
- Can a dilaton be light? (below $\Lambda = 4\pi f$)

Scale Transformations

Dilatations:

$$x \to x' = e^{-\alpha} x$$

Operators transform:

$$\mathcal{O}(x) \to \mathcal{O}'(x) = e^{\alpha\Delta} \mathcal{O}(e^{\alpha} x)$$

Δ is the full quantum operator dimension

Linearized transformation of action:

$$S \longrightarrow S + \sum_i \int d^4x \, \alpha g_i (\Delta_i - 4) \mathcal{O}_i(x)$$

Spontaneous breaking

CFT operator gets VEV:

$$\langle \mathcal{O}(x) \rangle = f^{\Delta}$$

Corresponding goldstone boson:

$$\sigma(x) \to \sigma(e^{\alpha} x) + \alpha f$$

Non-linear realization in effective theory:

$$f \to f\,\chi \equiv f\,e^{\sigma/f}$$

Restores symmetry to LEEFT

The Dilaton Quartic

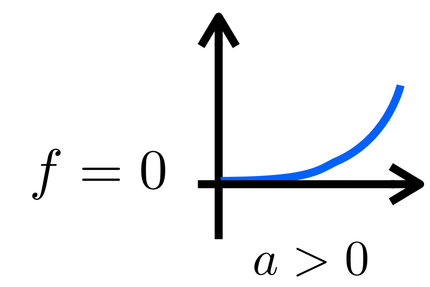
Most general terms invariant under dilatations:

$$\mathcal{L}_{eff} = \sum_{n,m\geqslant 0} \frac{a_{n,m}}{(4\pi)^{2(n-1)}\, f^{2(n-2)}} \frac{\partial^{2n}\chi^m}{\chi^{2n+m-4}}$$

$$= -a_{0,0}\,(4\pi)^2 f^4\chi^4 + \frac{f^2}{2}(\partial_\mu\chi)^2 + \frac{a_{2,4}}{(4\pi)^2}\frac{(\partial\chi)^4}{\chi^4} + \ldots$$

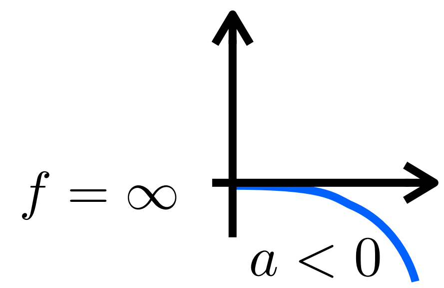
Large dilaton quartic

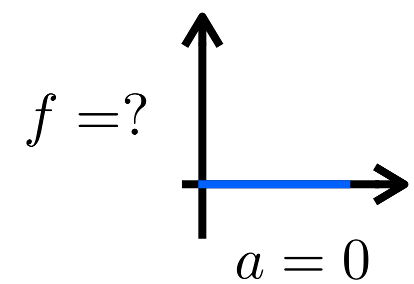
$$S = \int d^4x \frac{f^2}{2}(\partial\chi)^2 - a f^4\chi^4 + \text{higher derivatives}$$



Obstruction to SBSI:

- a > 0 → f = 0 (no breaking)
- a < 0 → f = ∞ (runaway)
- a = 0 → f = anything (flat direction)





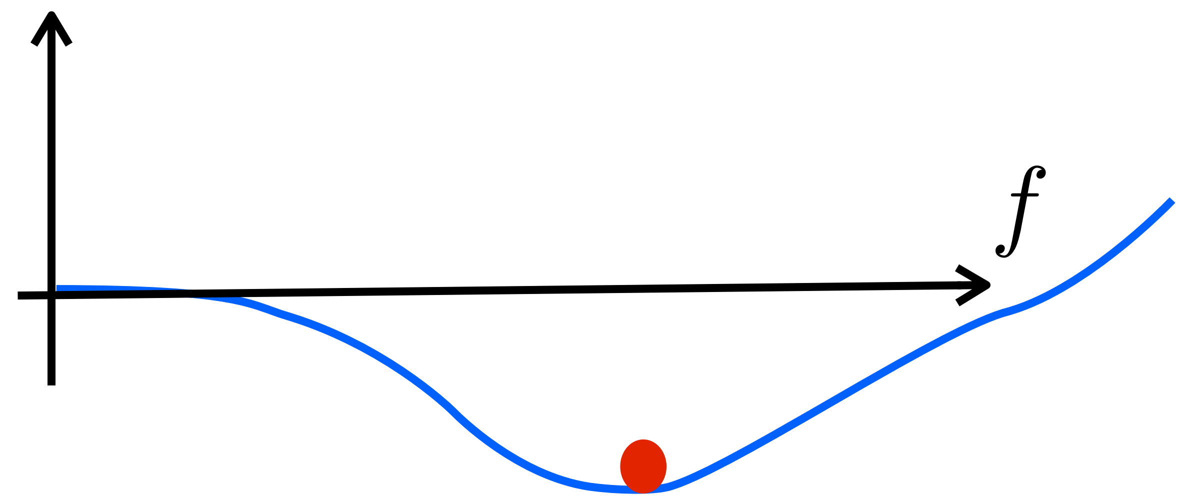
Near-Marginal Deformation

$$\delta S = \int d^4x \lambda(\mu)\mathcal{O}$$

Quartic has dependence on near marginal coupling:

$$V(\chi) = a\chi^4 \longrightarrow V = \chi^4 F(\lambda(\chi))$$

slowly varying function of f



Deformation can stabilize f away from origin

$$V' = f^3\left[4F(\lambda(f)) + \beta F'(\lambda(f))\right] = 0$$

The Dilaton Mass

Expanding the potential:

$$m_{dil}^2 = f^2\beta\left[\beta F'' + 4F' + \beta' F'\right] \simeq 4f^2\beta F'(\lambda(f)) = -16 f^2 F(\lambda(f))$$

small, so dilaton is light, right?

F is the cosmological constant in f units:

$$F_{NDA} \sim \frac{\Lambda^4}{16\pi^2 f^4} \sim 16\pi^2$$

Need *large* β to find minimum $V' = f^3\left[4F(\lambda(f)) + \beta F'(\lambda(f))\right] = 0$

Theory not conformal at scale f - **no light dilaton**

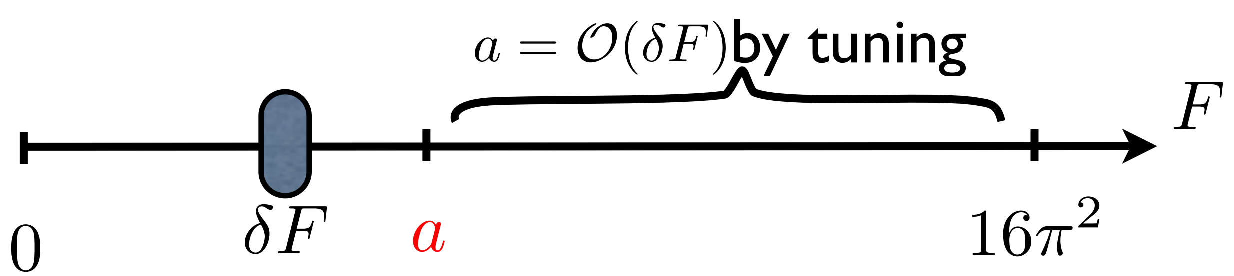
$$m_{dil}^2 \sim 256\pi^2 f^2 \sim \Lambda^2$$ **3 TeV *not* 125 GeV**

OR we can *tune* away the quartic to get a nearly flat-direction

Light Dilaton?

Non-SUSY light dilaton:

$F(\lambda) = a + \delta F(\lambda)$



- Generically, dilaton is not light unless the quartic is suppressed relative to NDA
- To get a light dilaton, need flat direction in vicinity of near-zero in β-function
- While this is natural in SUSY theories, it is not the case in non-supersymmetric ones

The 3-2 Model

light dynamical perturbative dilaton

	$SU(3)$	$SU(2)$	$U(1)$	$U(1)_R$
Q	$\square$	$\square$	$1/3$	1
L	$\mathbf{1}$	$\square$	-1	-3
$\overline{U}$	$\overline{\square}$	$\mathbf{1}$	$-4/3$	-8
$\overline{D}$	$\overline{\square}$	$\mathbf{1}$	$2/3$	4

classical flat directions:

$$Q\bar{D}L,\; Q\bar{U}L\; \det(\bar{Q}Q)$$

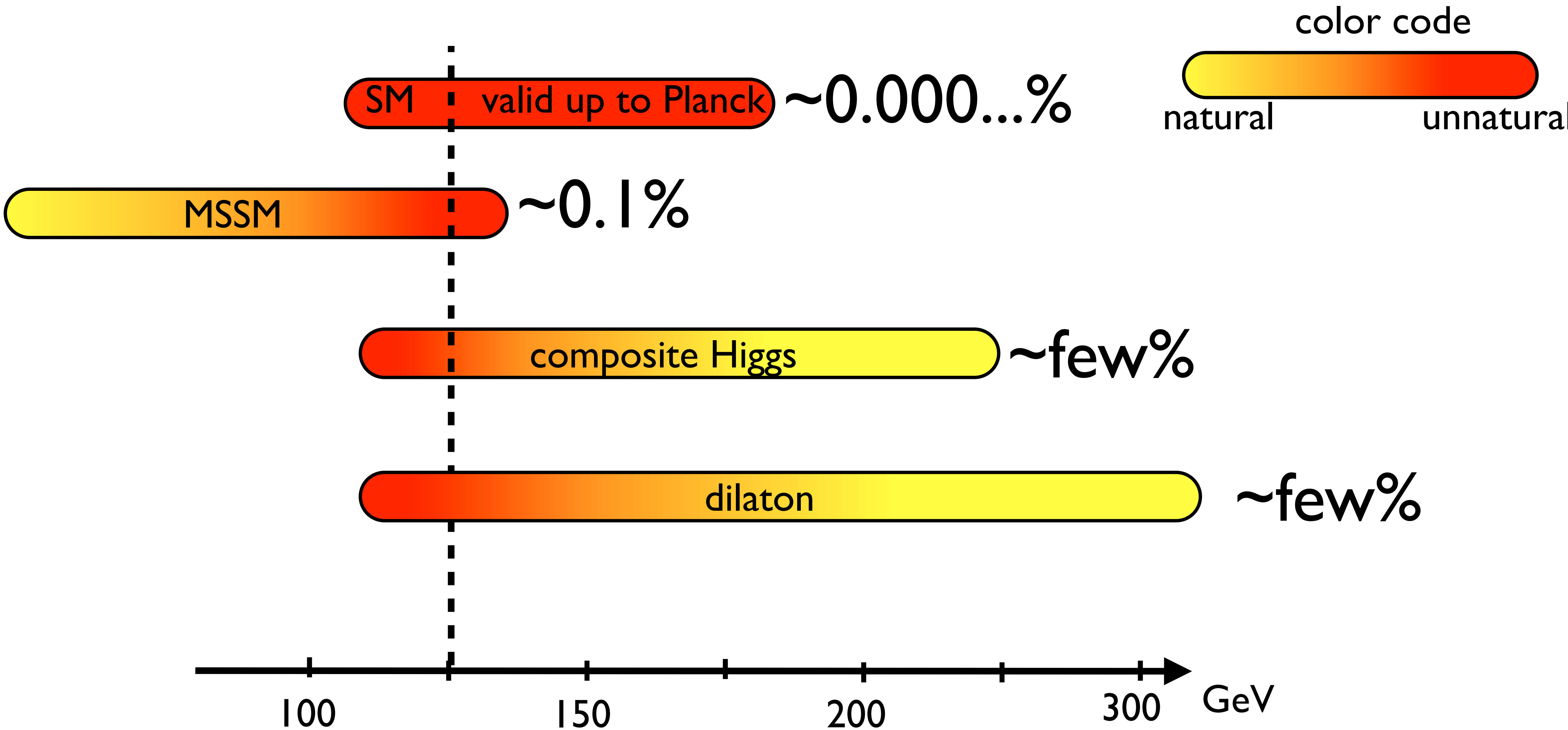
lifted by non-perturbative ADS superpotential and tree level perturbative superpotential:

$$W_{\rm dyn} = \frac{\Lambda_3^7}{\det(\overline{Q}Q)} \qquad W = \lambda Q\bar{D}L$$

light dilaton: $m_{dil} \approx \lambda f \approx \lambda^{\frac{6}{7}}\Lambda_3$

But SUSY played crucial role here

The EWSB line-up



dilaton and composite Higgs in a similar strained state

Dilaton Couplings

- Presume have a strongly coupled conformal sector coupled to weak fundamental sector
- Strong sector has SBSI
- derive interactions of mass eigenstates with dilaton

Dilaton-Composite Couplings

UV lagrangian

$$\mathcal{L}_{CFT}^{UV} = \sum_i g_i \mathcal{O}_i^{UV}$$

Allow explicit breaking

$$[g_i] = 4 - \Delta_i^{UV}$$

In IR, different dof

$$\mathcal{L}_{CFT}^{IR} = \sum_j c_j \left(\Pi g_i^{n_i}\right) \mathcal{O}_j^{IR} \chi^{m_j}$$

$$m_j = 4 - \Delta_j^{IR} - \sum_i n_i (4 - \Delta_i^{UV})$$

compensate

Single power of exp. breaking: $\mathcal{L}_{breaking}^{IR} = \sum_j c_j \, g_i \, \left(\Delta_i^{UV} - \Delta_j^{IR}\right) \mathcal{O}_j^{IR} \frac{\sigma}{f}$

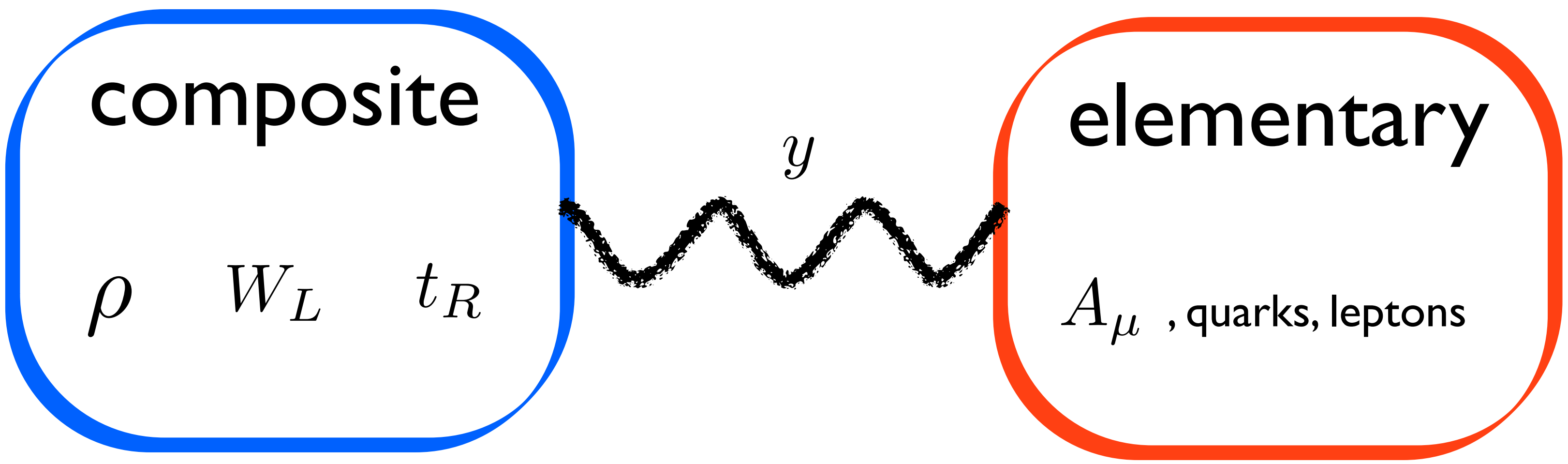
No exp. breaking: $\mathcal{L}_{symmetric}^{IR} = \sum_j c_j \, \left(4 - \Delta_j^{IR}\right) \mathcal{O}_j^{IR} \frac{\sigma}{f}$

rescaled tree-level SM

SM beta-functions

$$\frac{\sigma}{f} T_\mu^\mu = \frac{v}{f}\sigma \left\{ \left[2 m_W^2 W_\mu^2 + m_Z^2 Z^2 + m_\psi \psi\psi \ldots\right] + 2\frac{\beta_s}{g} G_{\mu\nu}^2 + 2\frac{\beta}{e} F_{\mu\nu}^2 \right\}$$

Dilaton couplings
Partial Compositeness



$$\mathcal{L}^{UV}_{CFT} + \mathcal{L}_{elem} + \sum_i y_i \mathcal{O}_{elem,i} \mathcal{O}^{UV}_{CFT,i}$$

$\Delta^{UV}_{elem,i}$ $\Delta^{UV}_{CFT,i}$

spurion dimensions

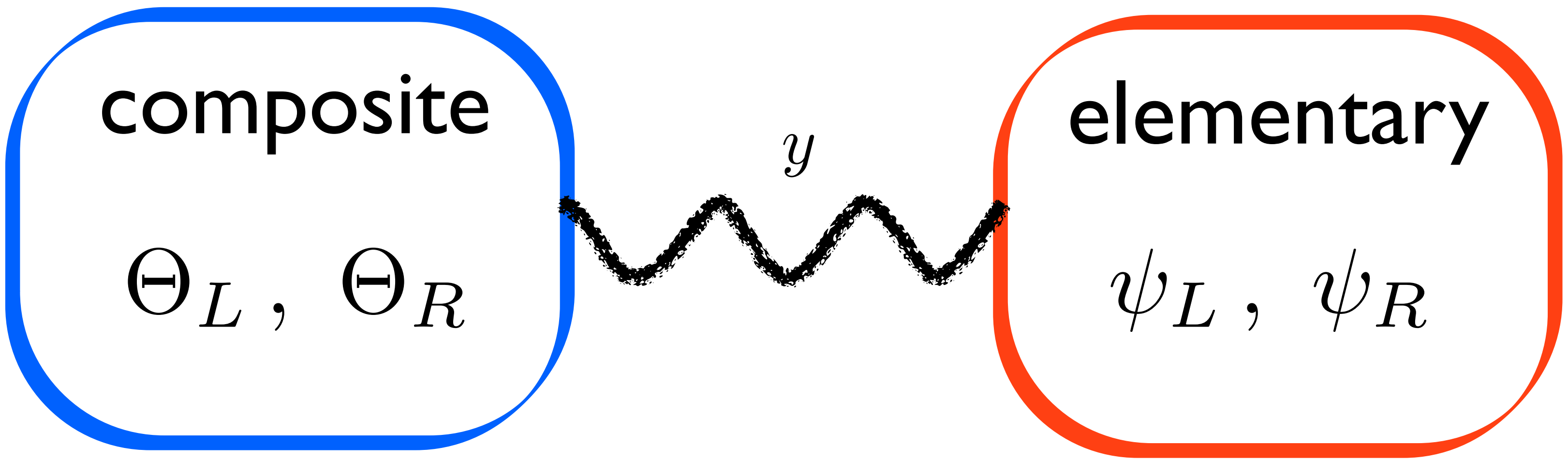
$$[y_i] = 4 - \Delta^{UV}_{CFT,i} - \Delta^{UV}_{elem,i}$$

VEV: $\langle \mathcal{O}(x) \rangle = f^{\Delta}$

compensate

$$\mathcal{L}^{IR}_{CFT} + \mathcal{L}_{elem} + \sum_i y_i \mathcal{O}_{elem,i} \mathcal{O}^{IR}_{CFT,i} \times \chi^{\overbrace{\left(\Delta^{UV}_{CFT,i} - \Delta^{IR}_{CFT,i} + \Delta^{UV}_{elem,i} - \Delta^{IR}_{elem,i}\right)}}$$

Dilaton-Fermion Couplings



$$\mathcal{L}_{mix} = y_L \psi_L \Theta_R + y_R \psi_R \Theta_L$$

$[y_{R,L}] = -\gamma_{L,R}$ $\quad$ $3/2$ $\quad$ $5/2 + \gamma_R$

Exponential running of y's generates large mass hierarchies

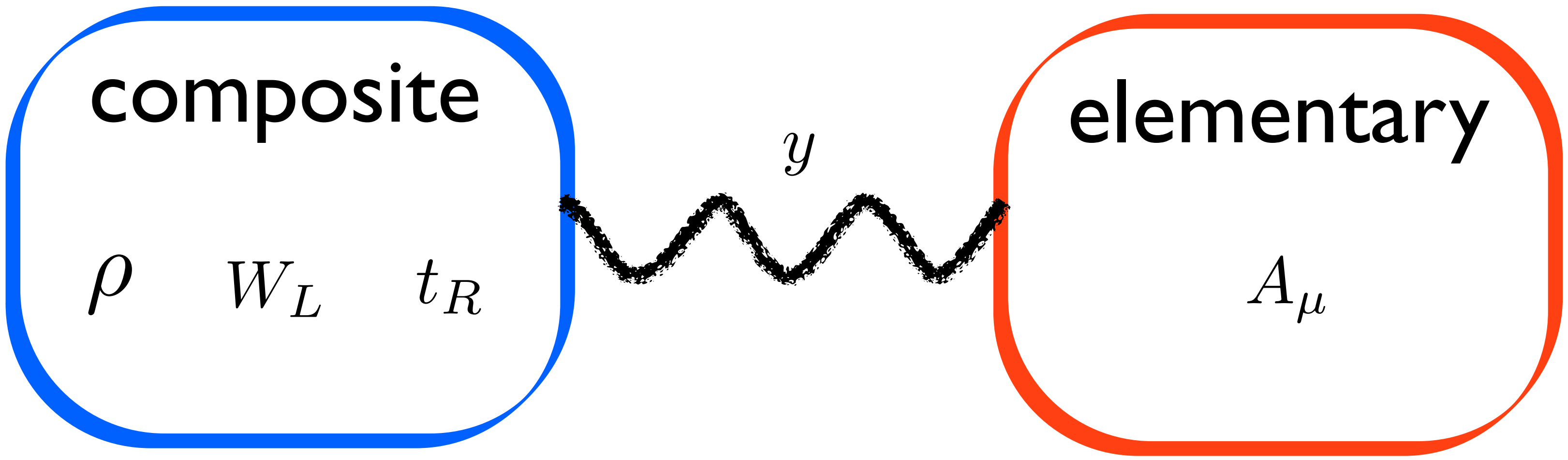
integrate out heavy composites and compensate:

$$\mathcal{L}_{eff} = -M\, y_L\, y_R\, \psi_L \psi_R \chi^m \qquad m \;=\; \Delta^{UV}_{\psi_L} - \Delta^{IR}_{\psi_L} + \Delta^{UV}_{\psi_R} - \Delta^{IR}_{\psi_R} + \Delta^{UV}_{\Theta_L} + \Delta^{UV}_{\Theta_R} - 4$$

$$\mathcal{L} \supset m_\psi\, \psi_L \psi_R \left[1 + \frac{\sigma}{f}(1 + \gamma_L + \gamma_R)\right]$$

Enhancement in couplings to partially composite fermions

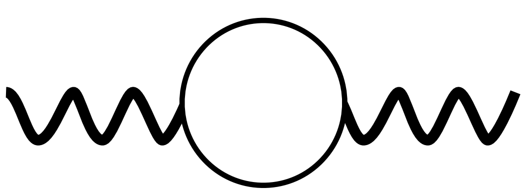
Couplings to massless gauge fields



$$\mathcal{L}_{mix} \supset -\frac{1}{4g^2} F_{\mu\nu}^2 + A_\mu \mathcal{J}^\mu$$

coupling to CFT and fundamental currents

integrate out the CFT: $-\frac{1}{4g^2(\mu)} F_{\mu\nu}^2$



$$\frac{1}{g^2(\mu)} = \frac{1}{g^2(\Lambda)} - \frac{b_{UV}}{8\pi^2}\log\frac{\Lambda}{f} - \frac{b_{IR}}{8\pi^2}\log\frac{f}{\mu} - \frac{b_{elem}}{8\pi^2}\log\frac{\Lambda}{\mu}$$

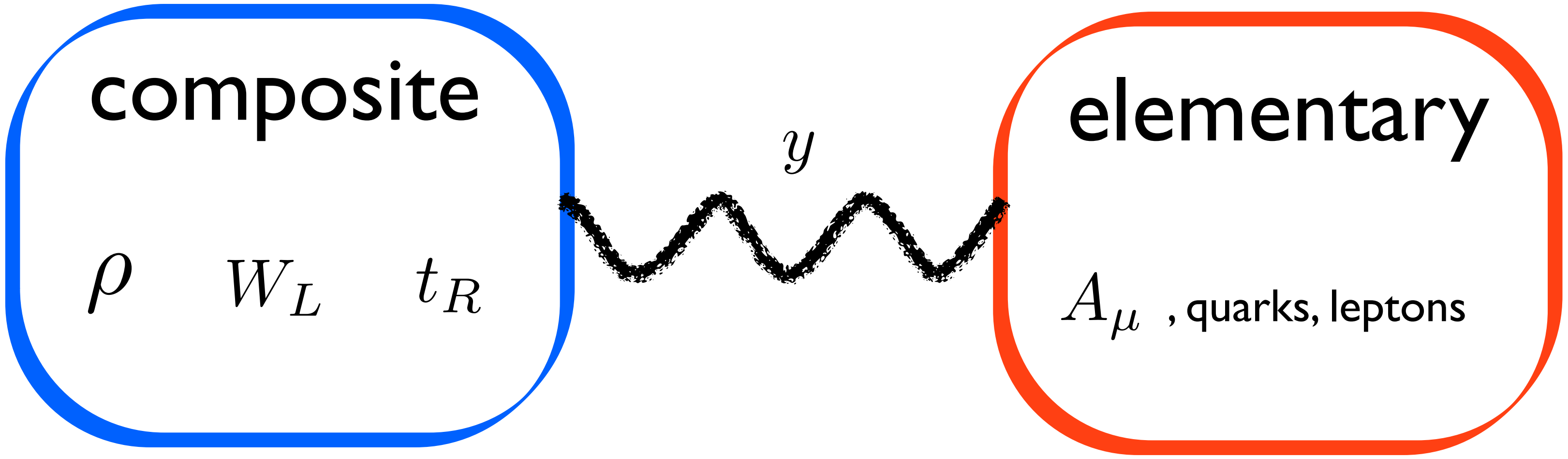
compensate: $f \longrightarrow f\chi = f e^{\sigma/f}$ ⟶

$$\mathcal{L} = -\frac{1}{2}\left(\frac{\beta_{IR}}{g} - \frac{\beta_{UV}}{g}\right)\frac{\sigma}{v} F_{\mu\nu}^2$$

Depends on UV contributions to β-function

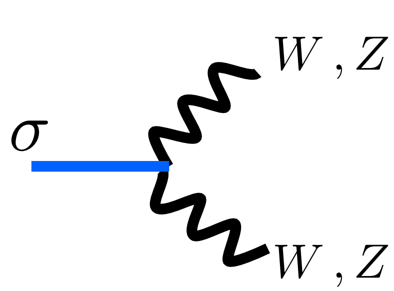
UV completion - embedding of SM gauge group

Couplings - Summary

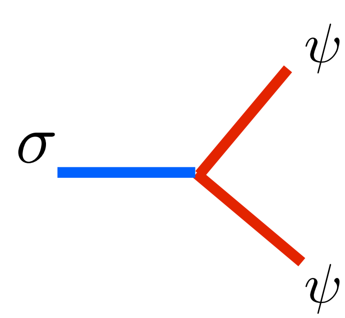


overall rescaling — anomalous dim. — beta-functions

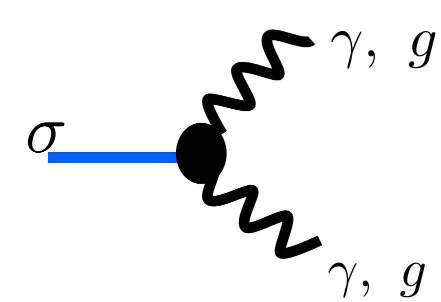
$$\mathcal{L} = \underbrace{\frac{v}{f}}_{\text{overall rescaling}}\sigma\left\{\left[2m_W^2 W_\mu^2 + m_Z^2 Z^2 + m_\psi \psi \underbrace{(1+\gamma)}_{\text{anomalous dim.}}\psi \ldots\right] + 2\underbrace{(\beta_{UV} - \beta_{IR})}_{\text{beta-functions}}/g\, F_{\mu\nu}^2\right\}$$



$SM \times \frac{v}{f}$



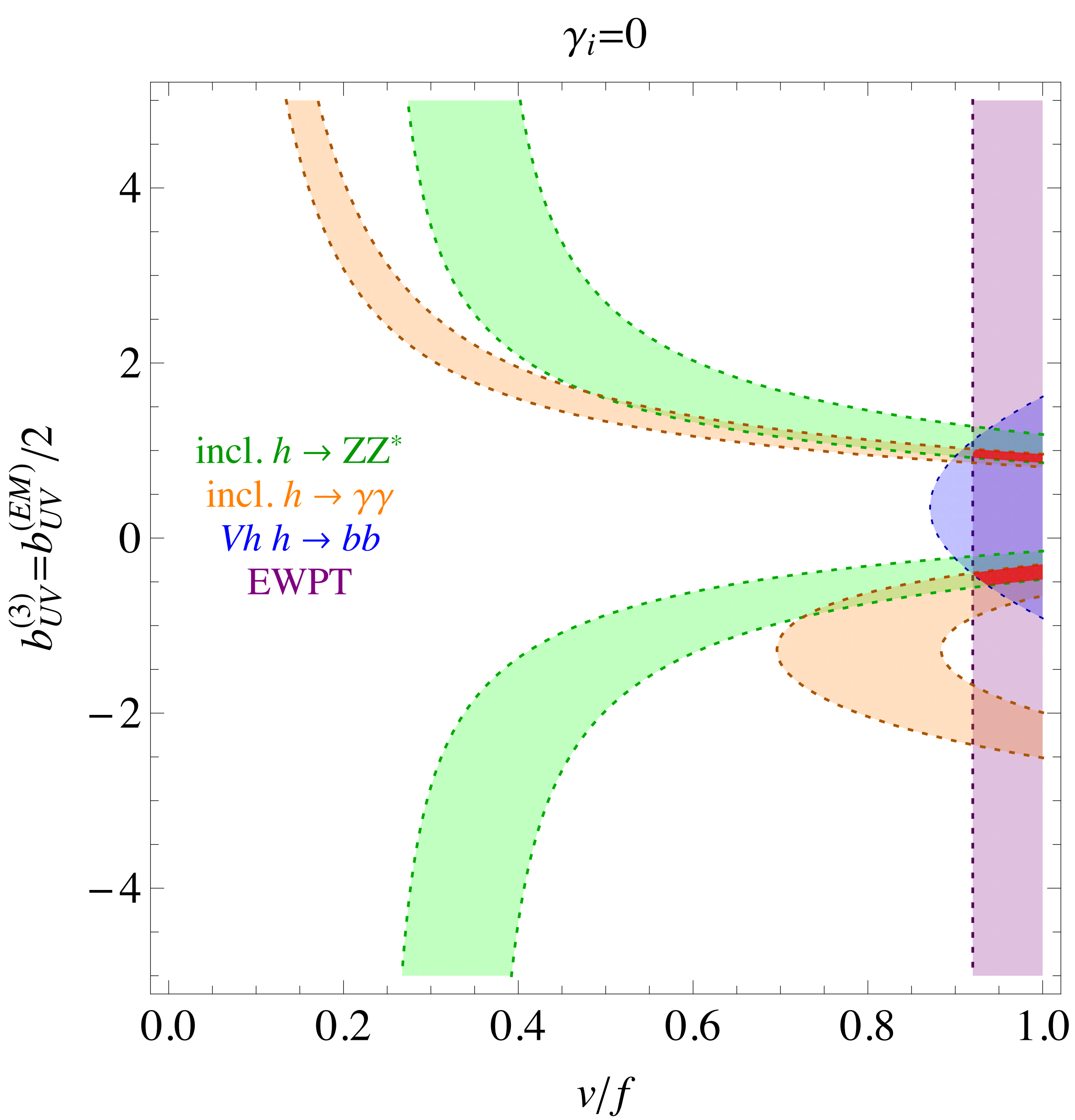
$SM \times \frac{v}{f}(1+\gamma)$

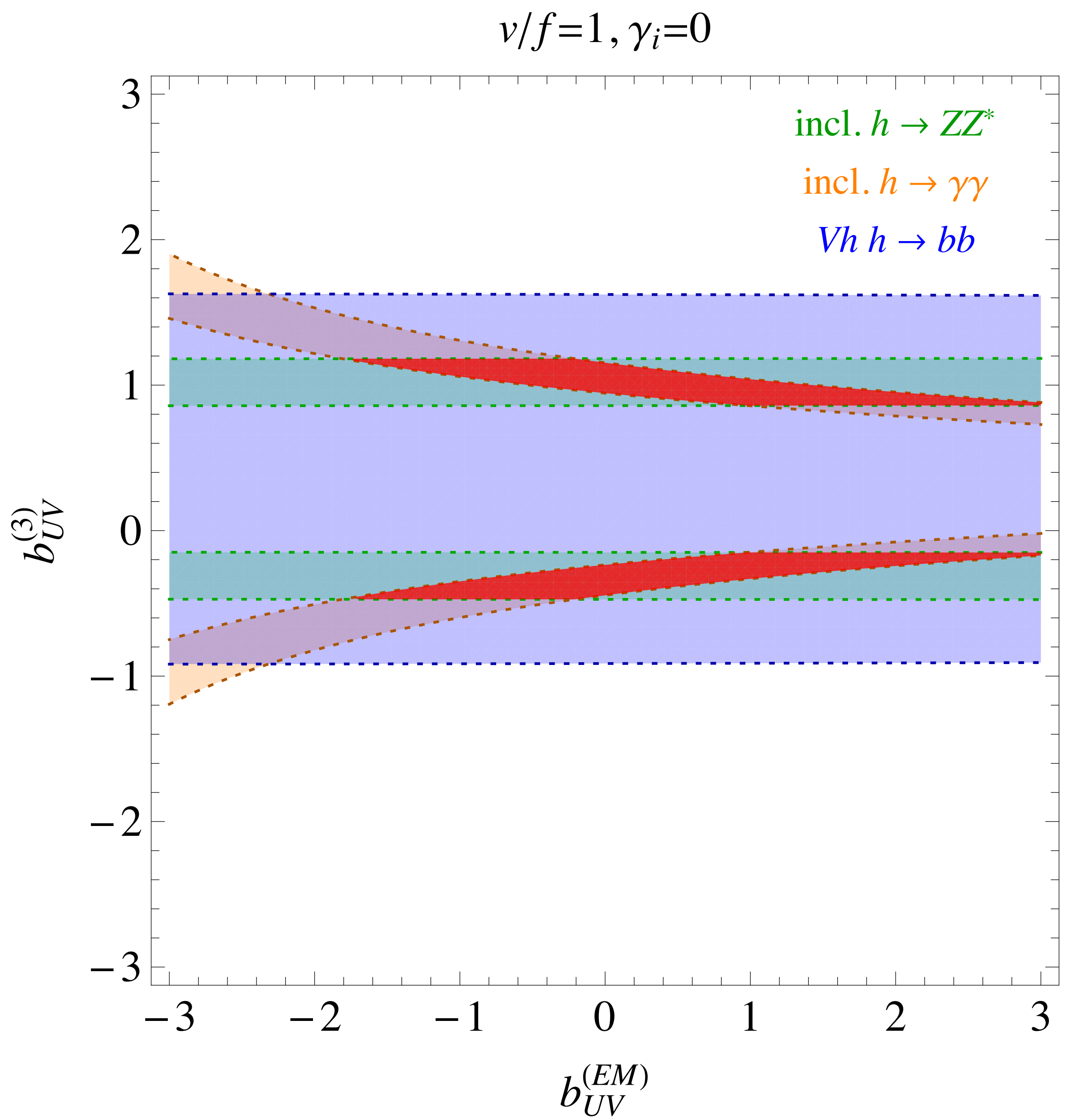


$\frac{v}{f}(\beta_{UV} - \beta_{IR} + loops)$

'Fitting' the data

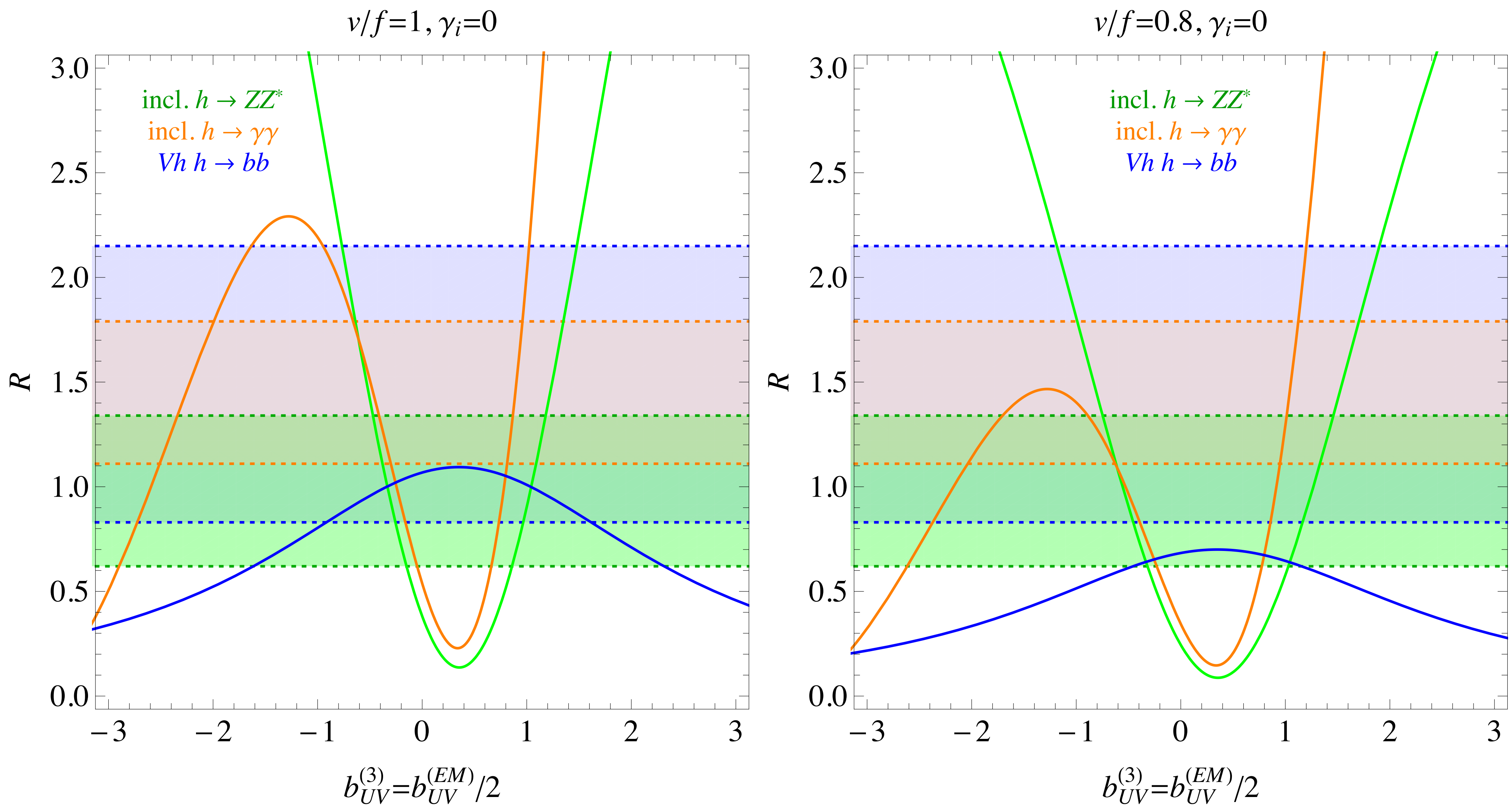
$$\Delta\hat{T} = -\frac{3\alpha}{16\pi\cos^2\theta_W}(1-c_V^2)\log\left(\frac{\Lambda^2}{m_h^2}\right)\,,\quad \Delta\hat{S} = +\frac{\alpha}{48\pi\sin^2\theta_W}(1-c_V^2)\log\left(\frac{\Lambda^2}{m_h^2}\right)$$





Clearly require v/f ~ 1

Rates



Enhanced diphoton may be telling us about matter content

New 2012 data will put stronger constraints on UV parameters

Conclusions

- The 125 GeV resonance may be a dilaton - well motivated
- Large NDA quartic in non-SUSY theories
  - hard to stabilize without raising mass - Fine tuning
  - need flat direction in vicinity of near-marginality
- Once it is light, couplings fixed up to a few parameters associated with conformal dynamics and embedding
  - v/f suppressed, β's and γ's fix the rest
- "Higgs" is a chance to probe strong sector!