COMPOSITE HIGGS IN THE PRECISION ERA

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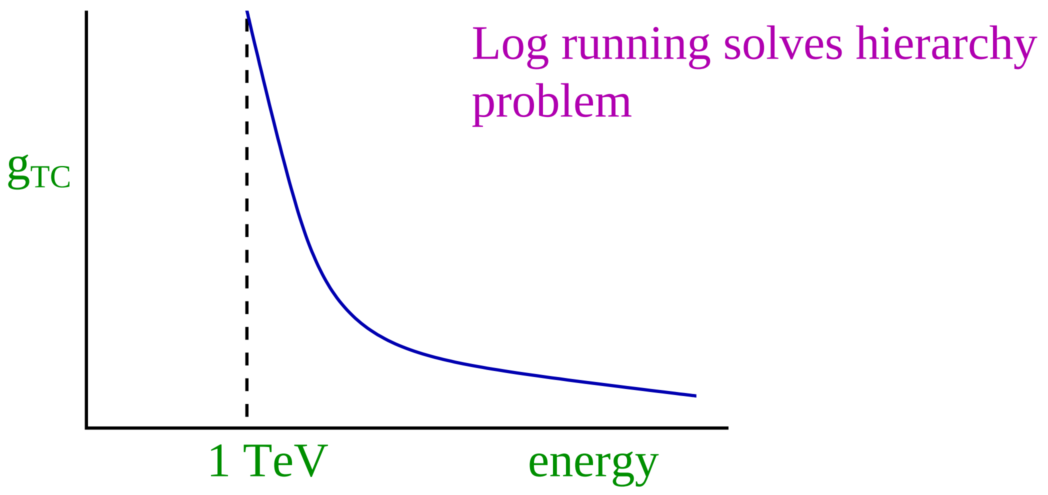
1. Motivation
2. Precision Measurements of Higgs
3. Effects of Operators at Composite Scale
4. Heavy Higgs is NOT Ruled Out
5. A LIGHT Higgs CAN be Composite
6. Tevatron Signatures of Composite Physics

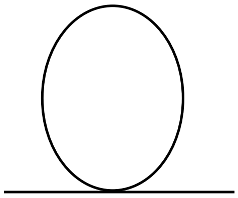
Motivation

- EW Symmetry is a broken gauged chiral symmetry of the standard model fermions.
- cf
  - QCD dynamically breaks chiral symmetry of quarks $\langle \bar{Q}_L Q_R \rangle$
  - Gauged QED is broken by dynamical formation of $\langle e^- e^- \rangle$ in superconductors
- EW Symmetry may also be broken by a dynamically generated fermion condensate!



Fine Tuning

Expect quantum corrections to higgs mass



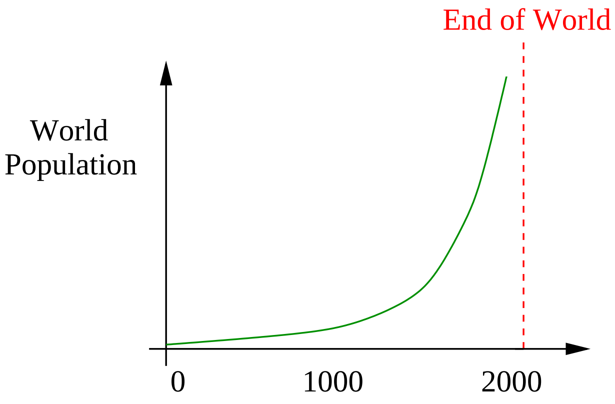
$$\sim \Lambda_{UV}^2 \sim \Lambda_{\text{Planck}}^2$$

Mass determines symmetry breaking scale so must fine tune bare mass

$$m_{\text{phys}}^2 = m_{bare}^2 + \Lambda_{\text{Planck}}^2$$

The End Of the World Is Nigh

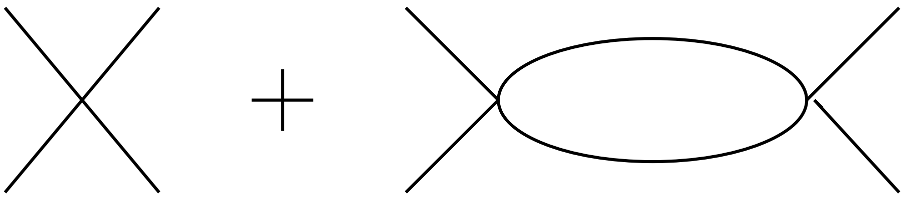
How much fine tuning is too much?



In an increasing population you most probably are alive at the end of the world.... ?????

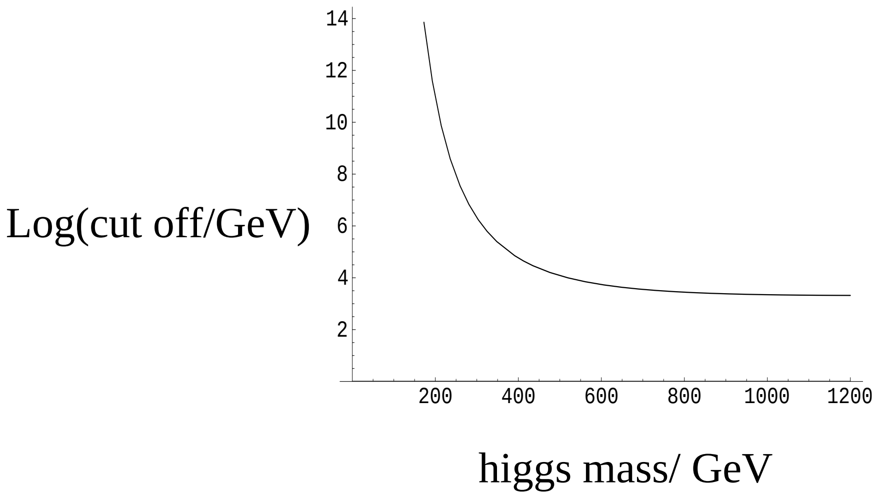
Triviality

Were a heavy higgs found we would be forced to consider strong interactions since $\lambda\phi^4$ ...



$$\beta(\lambda) = \mu\frac{d\lambda}{d\mu} = \frac{3}{2\pi^2}\lambda^2$$

$$\frac{1}{\lambda(\mu)} - \frac{1}{\lambda(\Lambda)} = \frac{3}{2\pi^2}\log\frac{\Lambda}{\mu}$$



$m_h < 180GeV, \Lambda_{UV}$ as large as $\Lambda_{\rm Planck}$

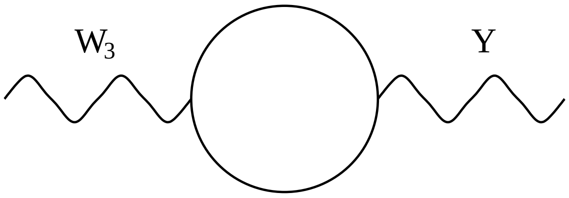
$m_h > 180GeV, \Lambda_{UV} < \Lambda_{\rm Planck}$ plus strong coupling

$m_h > 500GeV$, strong coupling at $\Lambda_{UV} < 10TeV$!

Experimental Searches - Indirect

The higgs can also be detected from its effects in radiative corrections to the Standard Model

The major source of corrections is from Oblique Corrections:



$\Pi_{3Y}(q^2)g^{\mu\nu}$

There are in fact just 3 quantities that ever enter observables - S,T,(U)

$$S = -8\pi \frac{d}{dq^2}\Pi_{3Y}|_0$$

$$T = \frac{\pi}{s_\theta^2 c_\theta^2 M_Z^2}\left(\Pi_{11}(0) - \Pi_{33}(0)\right)$$

Contributions to observables are listed in eg Burgess, London et al hep-ph/9312291

Higgs mass dependence messy (logarithmic) - see eg Hagiwara et al - hep-ph/9706331.

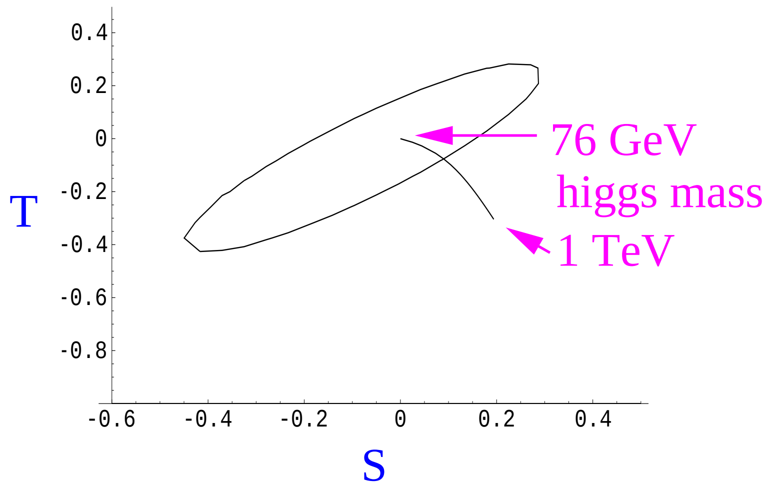
One can now do a χ^2 fit to the data....

Fitting S and T

Given contributions of S and T to shifts in SM variables, best fit point and data $\rightarrow$

$$\chi^2(S,T)$$

Compare to 95% confidence limit for S,T



S,T values for varying m_h plotted

$$\rightarrow m_h < 212 GeV$$

Are These Limits On The Higgs Fair?

- The Higgs is an effective theory.
- The cut off could be as low as 1TeV!
- $m_h > 500 GeV$ strongly coupled at $\Lambda \leq 10 TeV$

At Λ should include all higher dimension operators suppressed by Λ...

Two dimension 6 operators are of interest

$$-\frac{a}{2!\,\Lambda^2}\left\{[D_\mu, D_\nu]\phi\right\}^\dagger [D^\mu, D^\nu]\phi$$

Contributes to S $(q^2 W_3^\mu B^\mu)$

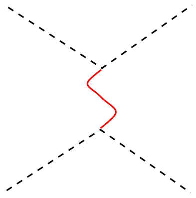
$$\frac{\tilde{b}\,\kappa^2}{2!\,\Lambda^2}(\phi^\dagger \overleftrightarrow{D}^\mu \phi)(\phi^\dagger \overleftrightarrow{D}_\mu \phi)$$

Contributes to T ($\langle\phi\rangle$ breaks custodial isospin)

How Big Are a and b?

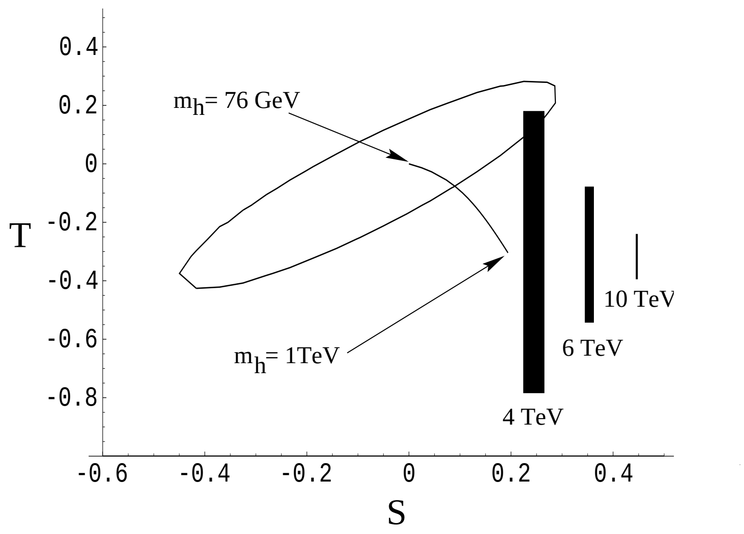
1) Perturbative

If theory above Λ is perturbative these terms are generated by new interactions of higgs



“ $\frac{g^2}{M^2}$ ”

$$a, b\kappa^2 \simeq 1, \qquad \Lambda \simeq M$$



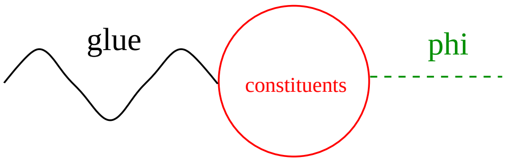
Contributions to S, T for $|a|, |b\kappa^2| \leq 1$.

If $\Lambda \leq 5TeV$ any m_h compatible with data.

2) Strong Coupling

Learning from QCD: there is extra scale

$$f_\pi^2 = N_c N_f \frac{\Lambda^2}{(4\pi)^2}$$



"loop creation of Goldstone"

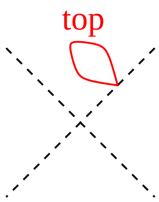
Naive Dimensional Analysis: extra ϕs in $\mathcal{L}$ suppressed by f_π.

$$a, b \simeq 1,\ \kappa^2 \simeq (4\pi)^2$$

But... QCD does not violate custodial isospin

ie $\langle\phi\rangle = \langle(\bar{u}u, \bar{d}d)\rangle = (1,1)$ $\rightarrow b = 0$

BUT.. the EW theory MUST violate custodial isospin - $m_t \gg m_b$



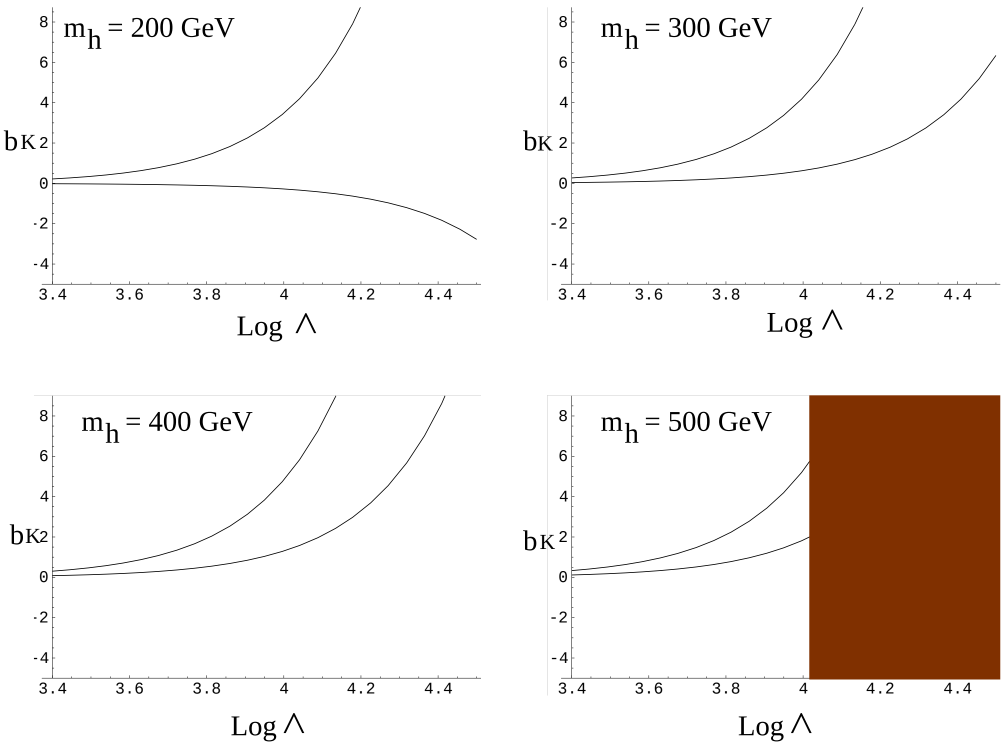
suppressed by $\frac{Y_t}{g^2_{\rm strong}} \sim \frac{1}{4\pi}$

$$b \simeq 1 \qquad\qquad \kappa^2 \simeq 4\pi$$

Bigger T than perturbative theory!

Natural Scale of New Physics

T contributions so large that strongly coupled theory at $\Lambda = 1TeV$ requires unnatural fine tuning!



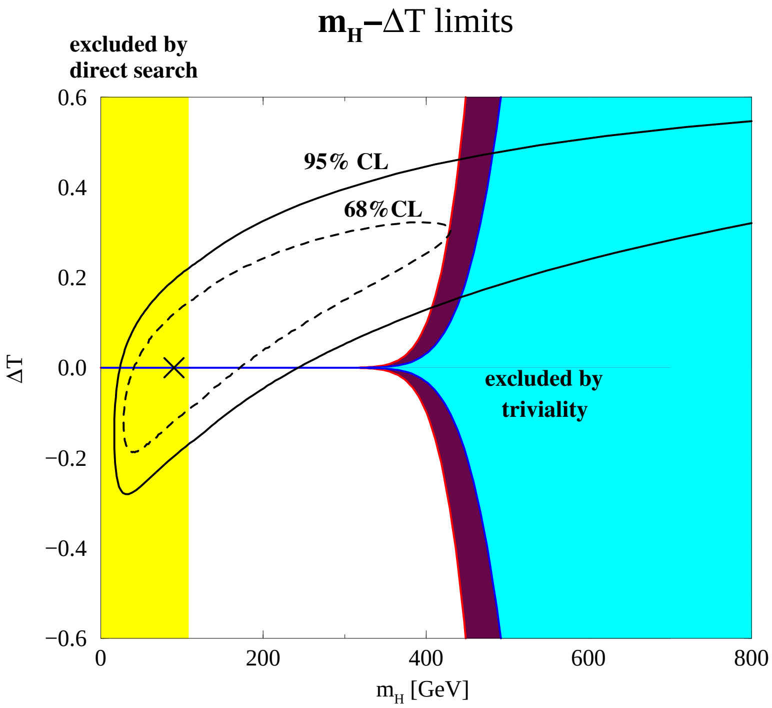
The value of $b\kappa$ compatible with the precision bounds as a function of Λ for different values of m_h. The blocked off area in the last plot is forbidden by triviality. The values of cut off on the x axis varies logarithmically between 2500 – 25000 GeV.

Higgs mass up to 500 GeV in theory with cut off of 10 TeV appears natural.

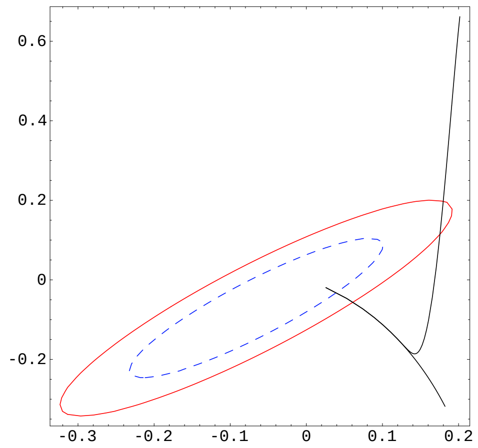
m_h Bounds Including T

$m_h \to \Lambda_{\mathrm{triv}} \to$ minimum T contribution

$(b\kappa^2 = 4\pi, 4\pi^2)$



Can also plot S-T trajectory including triviality corrections (assuming +ve $b\kappa^2 = 4\pi$)

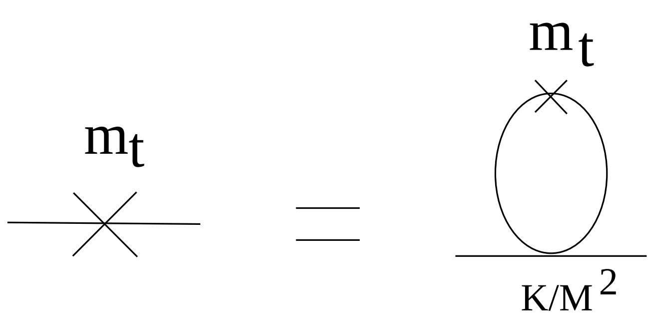


Models of a Composite Higgs

Composite higgs boson abound:

- Top Condensation (Nambu)

A new top interaction $\frac{\kappa}{M^2}\bar{t}_L t_R \bar{t}_R t_L$



(At large N_c)

Predicts $m_t \sim 250+$ GeV

$$m_h \sim 2m_t$$

- Top Seesaw (Dobrescu, Hill)

Introduces extra singlets so $m_t \sim$ anything.

- Flavour Univeral Seesaw (Burdman, NE)

All SM fermions contribute to higgs sector $\rightarrow$ all fermions can acquire masses.

$$m_h \sim 350 \text{ GeV}$$

A Light Composite Higgs

eg Georgi's Vacuum Misalignment model....

Phys. Lett. B136 183 (1984)

Strongly interacting gauge theory produces

$$(u_L d_L s_L) \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\theta & i s_\theta \\ 0 & i s_\theta & c_\theta \end{pmatrix} \begin{pmatrix} u_R \\ d_R \\ s_R \end{pmatrix}$$

$\mathrm{SU}(2)_L$ broken at scale $s_\theta F_\pi$

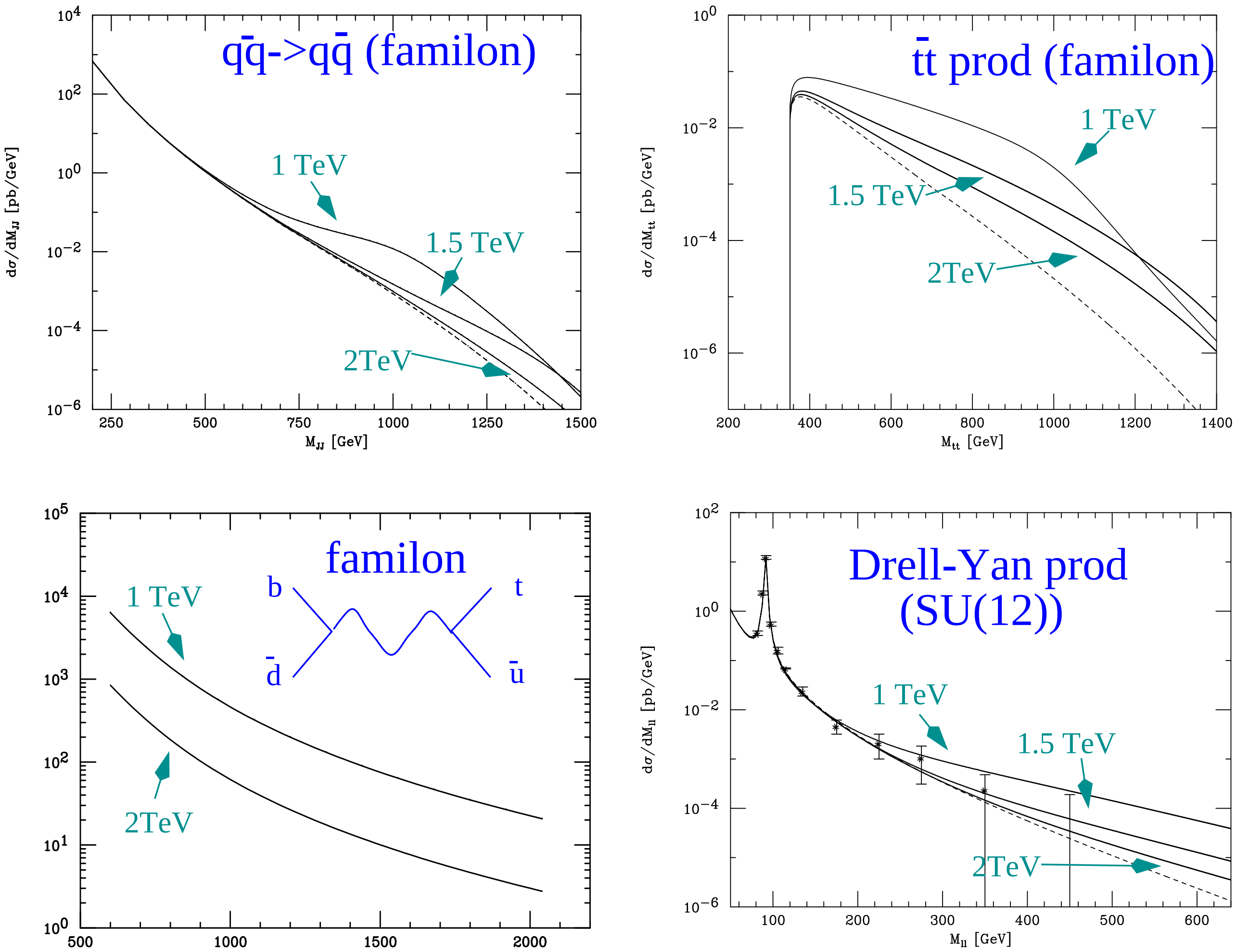
Misalignment induced by new physics.

Higgs is the "K^0" and its mass can be arranged to be

$$0 < m_h < 3 \text{ TeV}$$

Flavourons at the Tevatron

These models need new interactions.... gauging the flavour symmetries of SM fermions is natural since the higgs must give them mass....



Run 2 limit expectations $\geq 4TeV$

(Cross sections from: Phys. Rev. D62 075007 (2000); hep-ph/0005098)