Implications of 125 GeV Higgs in Composite Models

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1110.1613 + 1205.0232

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OUTLINE

- Minimal Effective description of Goldstone boson Higgs

- Higgs and fermion masses in Composite Higgs

COMPOSITE HIGGS

Georgi, Kaplan '80s

Higgs doublet could be a light remnant of strong dynamics.

Strong sector:
resonances +
Higgs bound state

spin 1

spin 1/2

spin 0.... $2_{\frac{1}{2}}$

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Particularly compelling if Higgs is a Goldstone Boson.
Massless at leading order.

Ex: $$\frac{SO(5)}{SU(2)_L \otimes SU(2)_R} \longrightarrow GB = (2,2)$$

Agashe , Contino,
Pomarol, '04

$$\mathcal{L} = f^2\, D_\mu \Sigma^i D^\mu \Sigma^i + \ldots$$

Relieves hierarchy problem:

$$\sim \frac{1}{m_\rho} = \frac{1}{\mathrm{TeV}}$$

$$m_\rho = g_\rho f$$

$$1 < g_\rho < 4\pi$$

$$\delta m_h^2 \sim N_c \frac{y_t^2}{8\pi^2} m_\rho^2$$

Increasing f CH approximates SM.

$$\text{DEVIATIONS} \sim \frac{v^2}{f^2}$$

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Spectrum:

$m_\rho \sim 3\,\mathrm{TeV}$

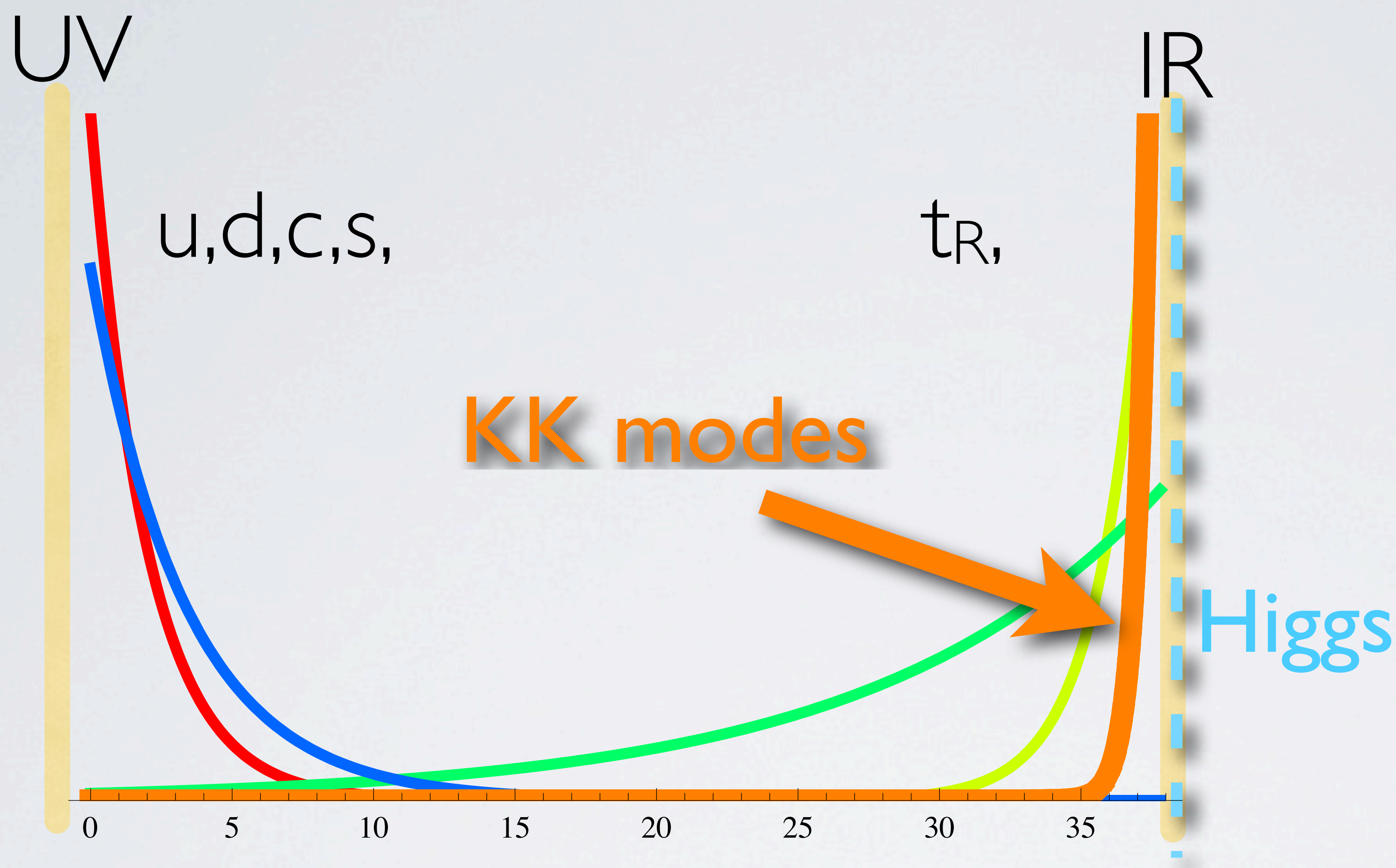
$m_h = 125\,\mathrm{GeV}$

$m_W = 80\,\mathrm{GeV}$

0

Reasonable phenomenology can be obtained for $m_\rho \sim 3\,\mathrm{TeV}$

Possible to realize it in Randall-Sundrum scenarios.



(Randall-Sundrum '99)

$$ds^2 = e^{-2kry}(-dt^2 + dx^2) + dy^2$$

Through AdS/CFT correspondence dual to 4D CFTs.
Relevant physics dominated by the lowest modes.

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MINIMAL 4D COMPOSITE HIGGS

- One resonance for each SM field

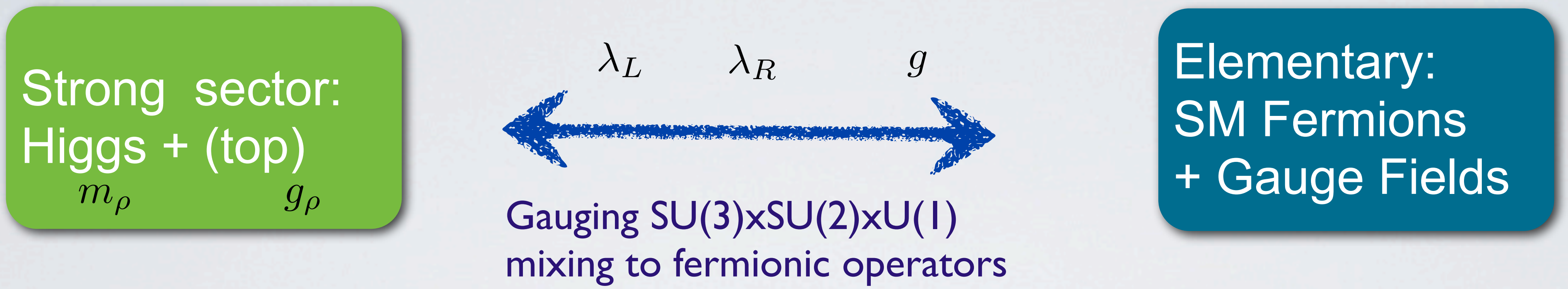
Related work:
Contino, Kramer, Son, Sundrum ’06
Panico, Wulzer ’11

General picture:

Strong sector:
Higgs + (top)
m_ρ g_ρ

Elementary:
SM Fermions
+ Gauge Fields

General picture:



They talk through linear couplings:

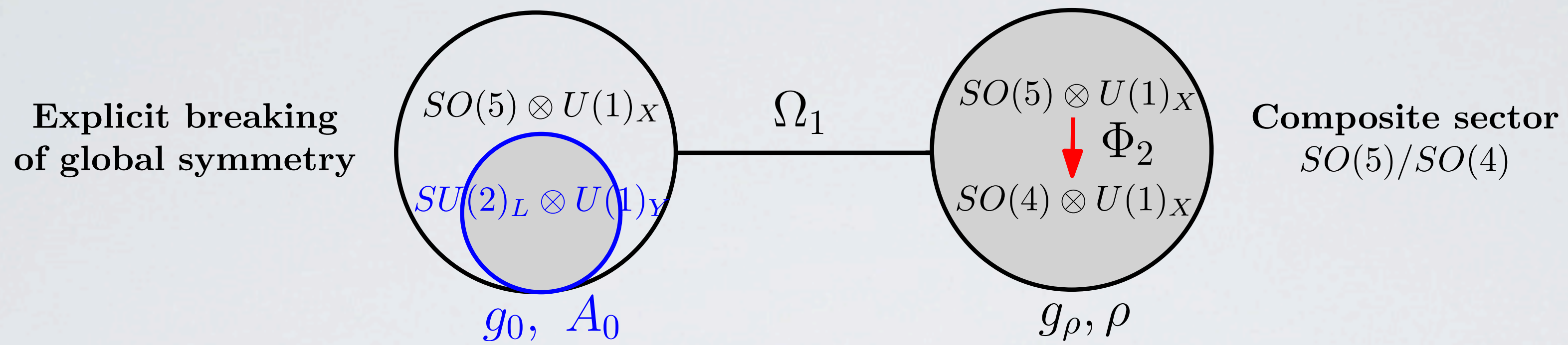
$$\mathcal{L}_{gauge} = g\, A_\mu J^\mu$$

$$\mathcal{L}_{mixing} = \lambda_L \bar{f}_L O_R + \lambda_R \bar{f}_R O_R \quad \xrightarrow{\epsilon \sim \frac{\lambda}{Y}} \quad y_{SM} = \epsilon_L \cdot Y \cdot \epsilon_R$$

Higgs potential generated at 1-loop:

$$V(h) \sim \frac{N_c}{16\pi^2} \epsilon^2_{L,R} m_\rho^4 \hat{V}\left(\frac{h}{f}\right) + \ldots$$

- SO(5)/SO(4)



Composite spin-1 lagrangian:

$$\frac{f_1^2}{4}\mathrm{Tr}\,|D_\mu\Omega|^2+\frac{f_2^2}{2}\left(D_\mu\Phi\right)^T\left(D^\mu\Phi\right)-\frac{1}{4g_\rho^2}\rho^a_{\mu\nu}\rho^{a\mu\nu}$$

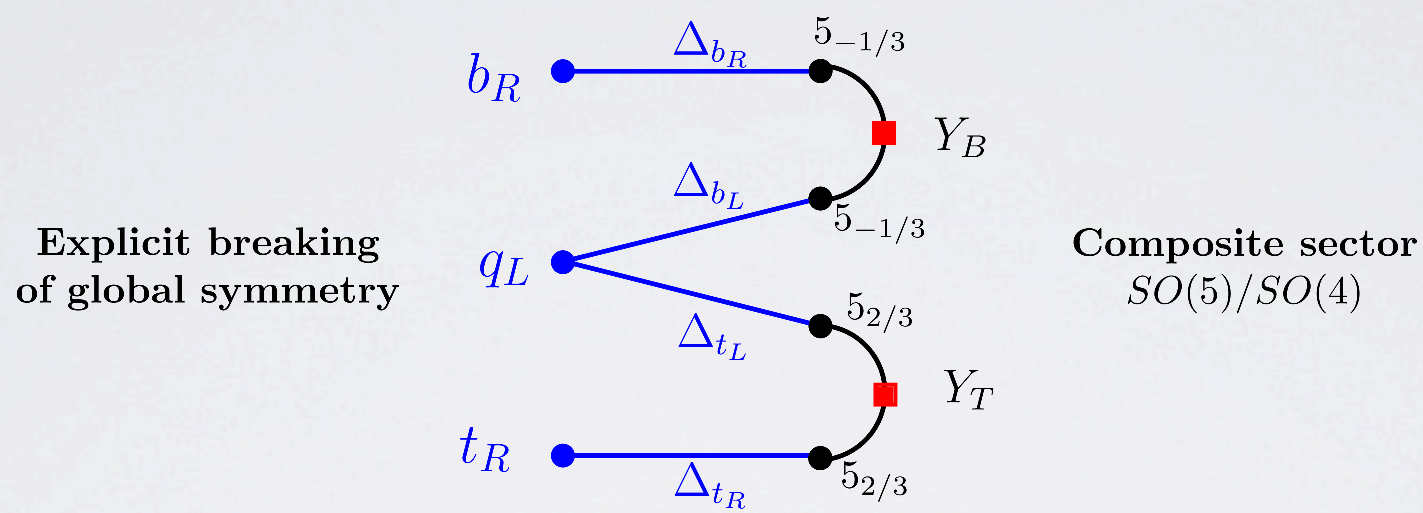
$$\Omega=\frac{SO(5)_L\times SO(5)_R}{SO(5)_{L+R}} \qquad\qquad \Phi=\frac{SO(5)}{SO(4)}$$

$$D_\mu\Omega=\partial_\mu\Omega-iA_\mu\Omega+i\Omega\rho_\mu \qquad\qquad D_\mu\Phi=\partial_\mu\Phi-i\rho_\mu\Phi$$

SO(4) and SO(5)/SO(4) spin-1 resonances.

Each SM fermion couples to Dirac fermion in a rep of SO(5).

CHM5:



Third generation:

$$
\begin{aligned}
\mathcal{L}^{\mathrm{CHM}_5} &= \mathcal{L}^{el}_{fermions} \\
&+ \Delta_{t_L}\, \bar{q}^{el}_L \Omega_1 \Psi_T + \Delta_{t_R}\, \bar{t}^{el}_R \Omega_1 \Psi_{\widetilde{T}} + h.c. \\
&+ \bar{\Psi}_T (i \not{D}^\rho - m_T)\Psi_T + \bar{\Psi}_{\widetilde{T}} (i \not{D}^\rho - m_{\widetilde{T}})\Psi_{\widetilde{T}} \\
&- Y_T \bar{\Psi}_{T,L} \Phi_2^T \Phi_2 \Psi_{\widetilde{T},R} - m_{Y_T} \bar{\Psi}_{T,L} \Psi_{\widetilde{T},R} + h.c. \\
&+ (T \to B)
\end{aligned}
$$

$\longrightarrow$ Explicit SO(5) breaking

$\longrightarrow$ Composite physics SO(5)/SO(4)

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Coleman-Weinberg effective potential:

$$V(h)_{fermions} = -2N_c \int \frac{d^4p}{(2\pi)^4} \left[\ln \Pi_{b_L} + \ln\left(p^2 \Pi_{t_L}\Pi_{t_R} - \Pi^2_{t_L t_R}\right)\right]$$

Contino, da Rold, Pomarol, '06

Form factors are simple functions:

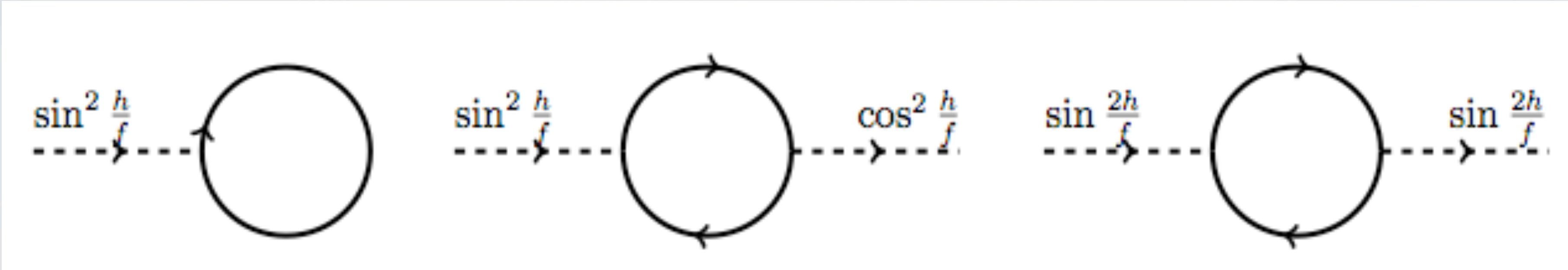
$$\widehat{\Pi}[m_1, m_2, m_3] = \frac{\left(m_2^2 + m_3^2 - p^2\right)}{p^4 - p^2(m_1^2 + m_2^2 + m_3^2) + m_1^2 m_2^2}$$

$$\widehat{M}[m_1, m_2, m_3] = -\frac{m_1 m_2 m_3}{p^4 - p^2(m_1^2 + m_2^2 + m_3^2) + m_1^2 m_2^2}$$

Potential is finite with a single SO(5) multiplet per SM field!

What is the Higgs mass?

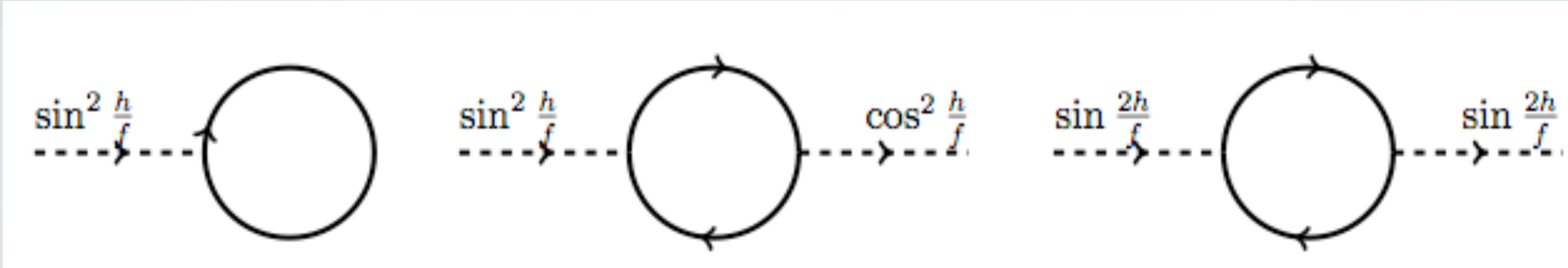
CHM5 ESTIMATES



$$\mathcal{L}_{Yuk} = y_t f \, \frac{s_h c_h}{h} (\bar{q}_L H^c t_R + h.c.) \longrightarrow V(h)_{Yuk} \sim N_c \frac{y_t^2}{16\pi^2} m_f^2 f^2 s_h^2 c_h^2$$

$$\mathcal{L}_{kin} = \epsilon_L^2 \, s_h^2 \, \bar{t}_L \; \not{D} t_L + 2 \, \epsilon_R^2 \, s_h^2 \, \bar{t}_R \; \not{D} t_R \longrightarrow V(h)_{kin} \sim N_c \frac{2\epsilon_R^2 - \epsilon_L^2}{32\pi^2} \, m_f^4 \, s_h^2$$

CHM5 ESTIMATES



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Potential:

$$V(h) \approx \alpha \, s_h^2 - \beta \, s_h^2 c_h^2 \qquad s_h \equiv \sin \frac{h}{f} = \frac{v}{f}$$

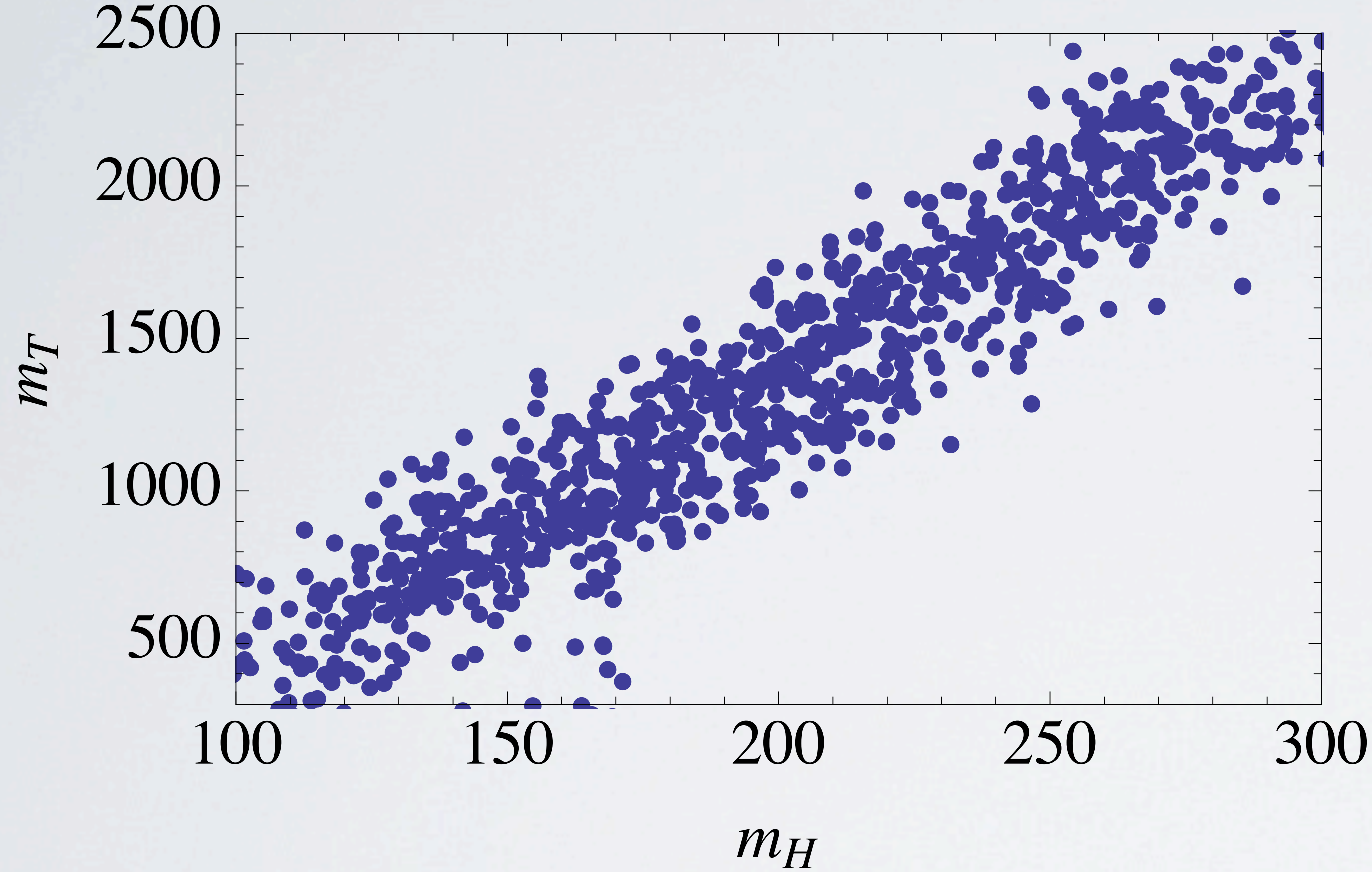
Quartic is determined by top Yukawa,

$$m_h \sim \sqrt{\frac{N_c}{2} \frac{y_t}{\pi} \frac{m_f}{f}} v$$

- CHM5

General scan:

$f = 500\,\text{GeV}$



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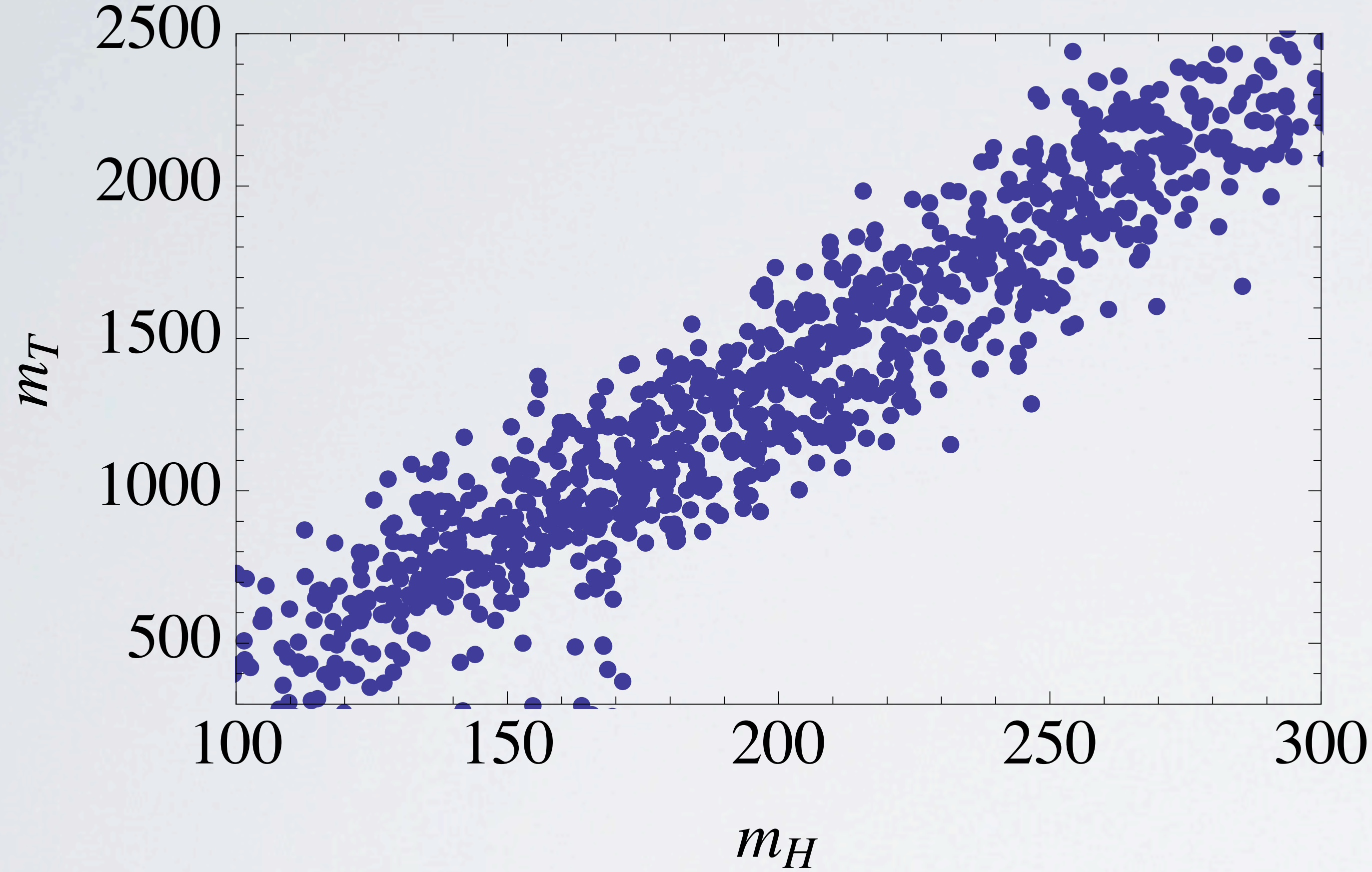
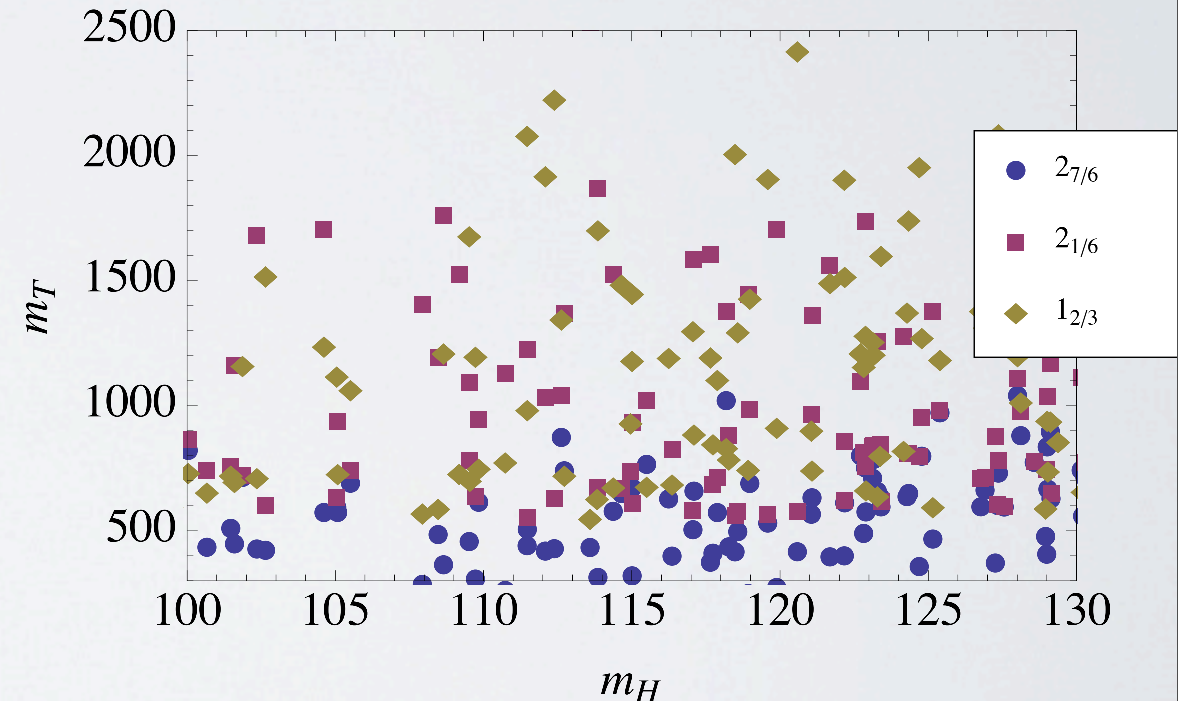


Low mass:



For mH=125 GeV, fermionic partners VERY close.

Should be visible at LHC7!

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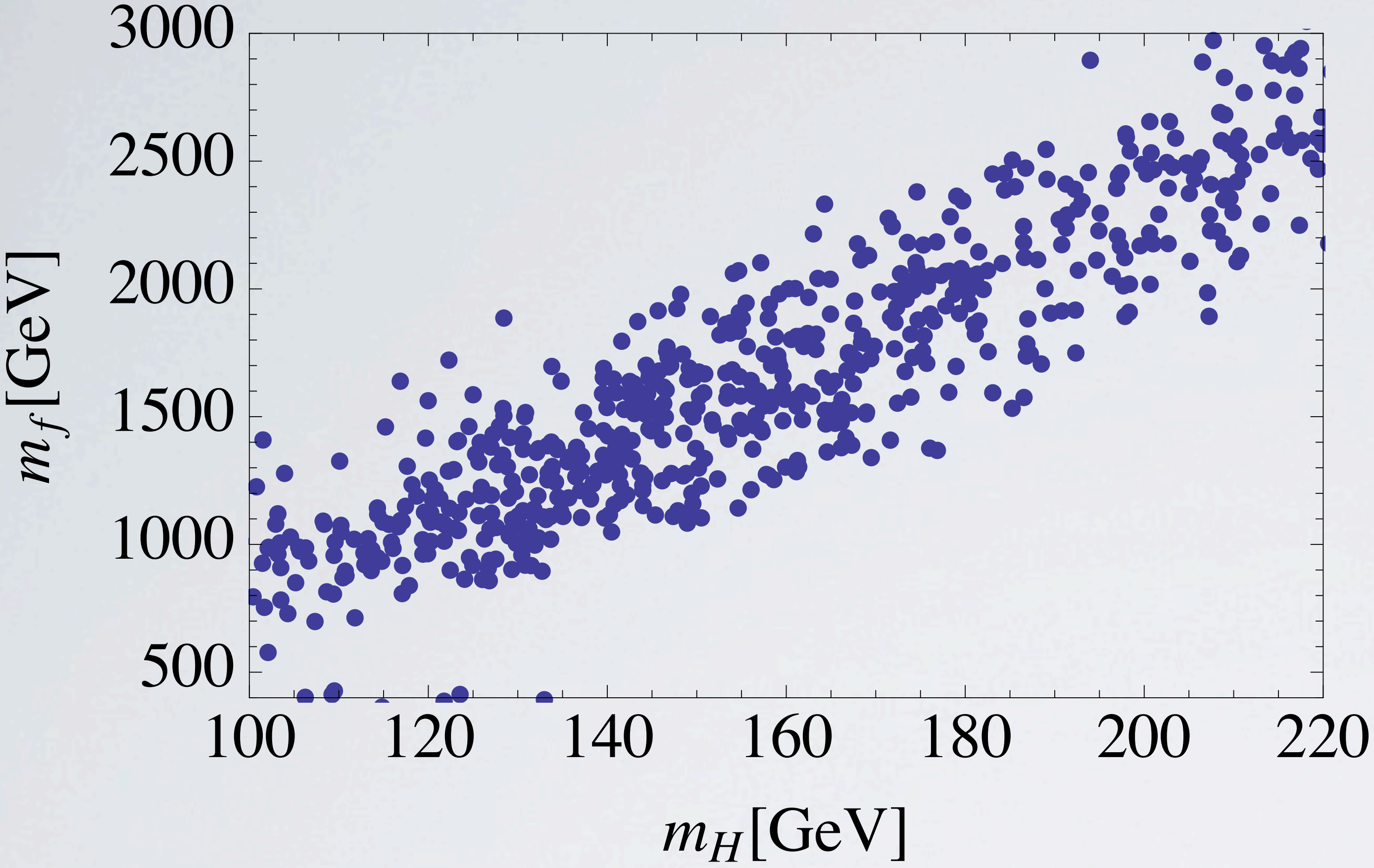
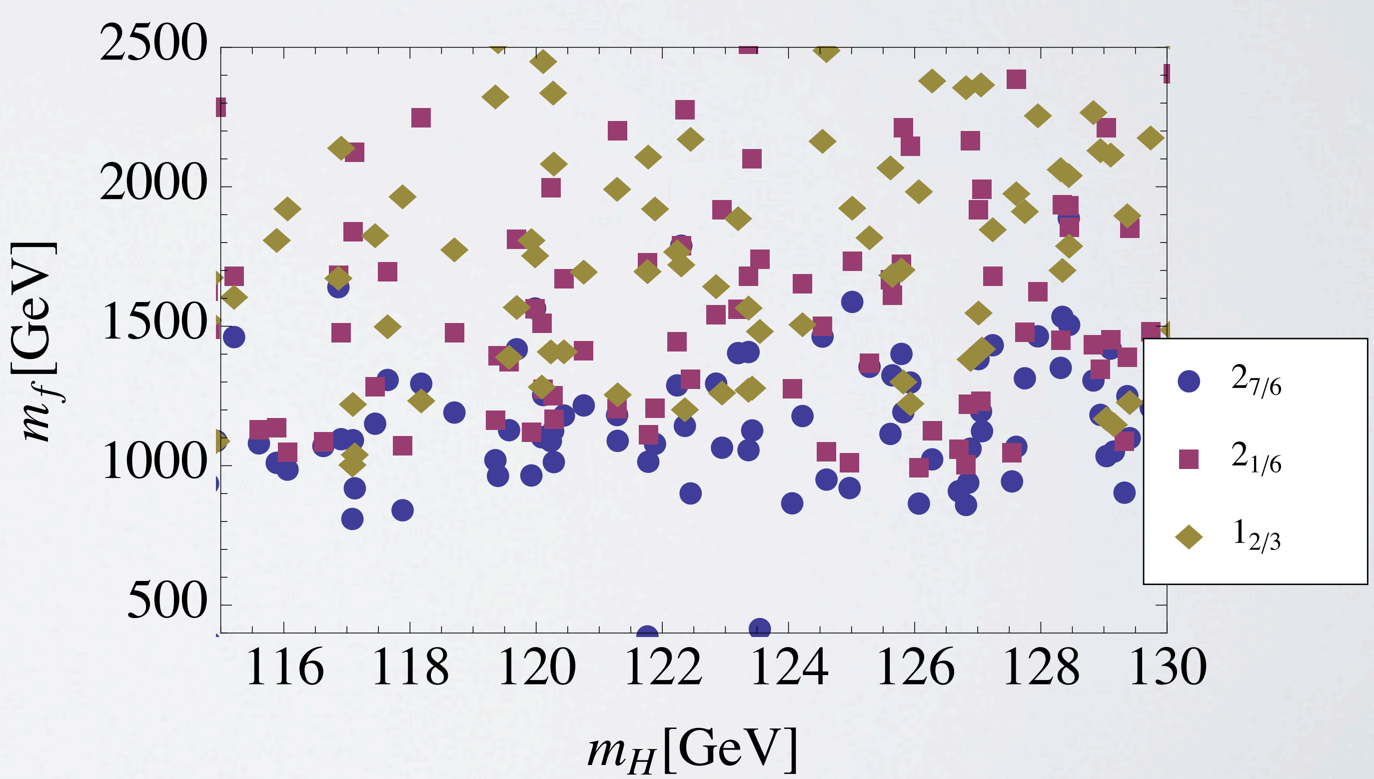


$f = 800\,\text{GeV}$

Low mass:



Partners above experimental bound ~ TeV

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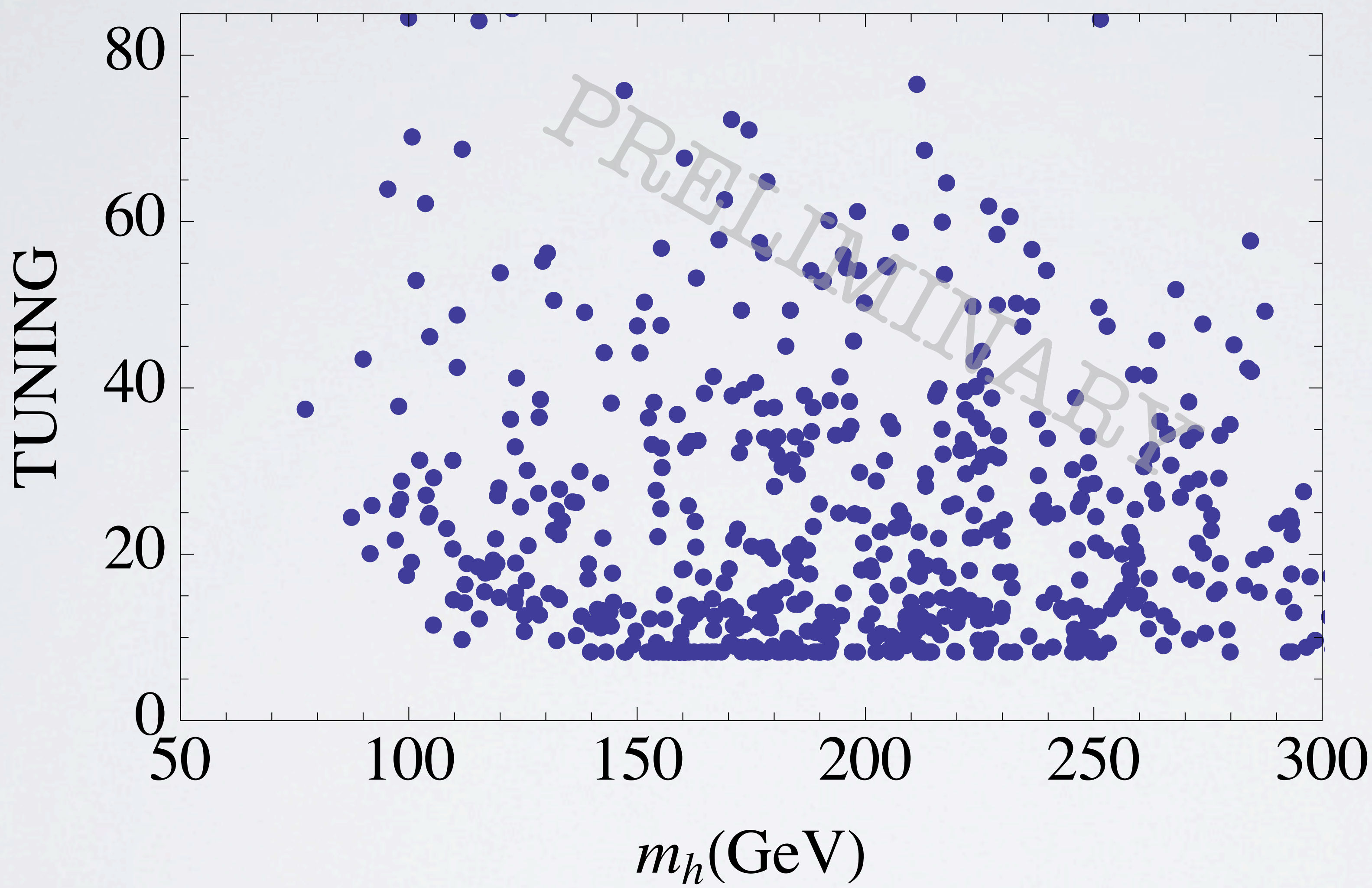
Tuning:

$$\Delta = \mathrm{Max_i} \left| \frac{\partial \log m_Z}{\partial \log x_i} \right|$$



$$f = 800\,\mathrm{GeV}$$

$$\Delta_{avg} \sim 30$$

SO(6)/SO(5):

Gripaios, Pomarol, Riva, Serra '09

5 GBs:

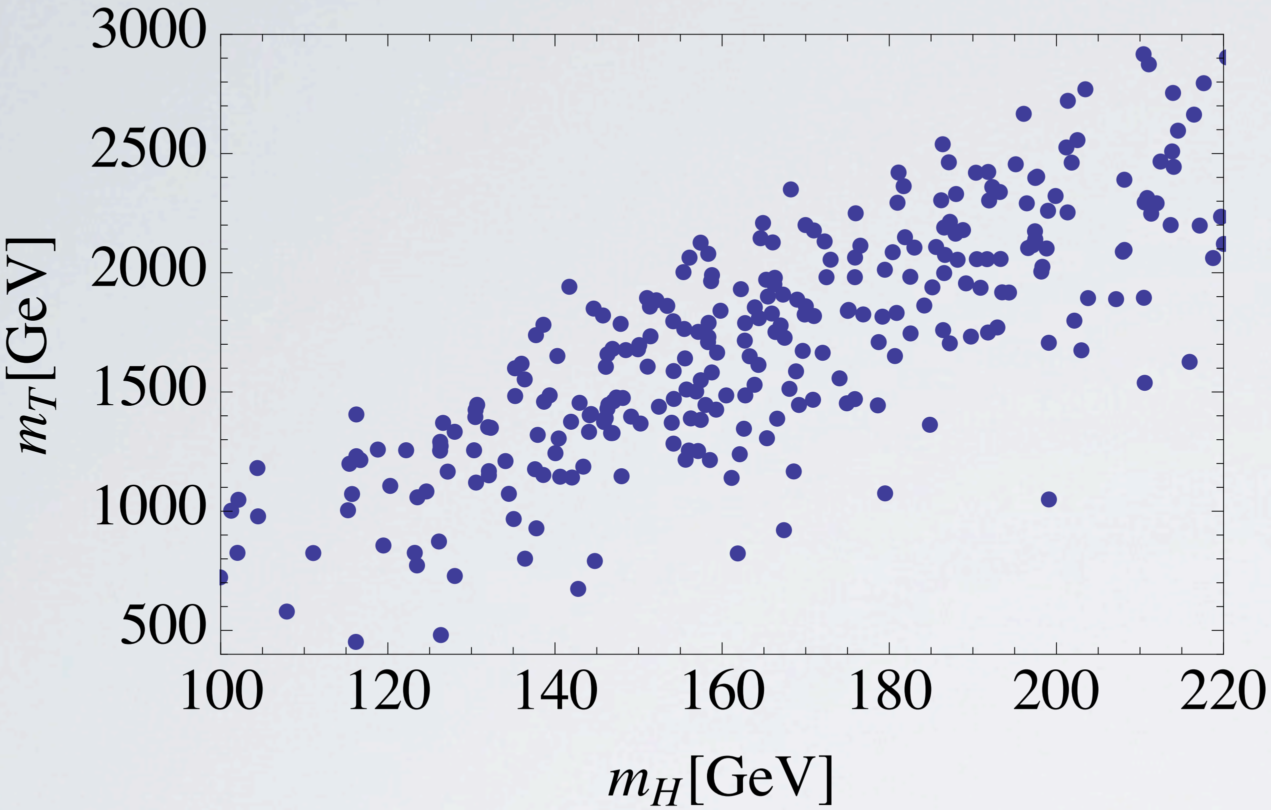
$$5 = (2,2) + 1$$

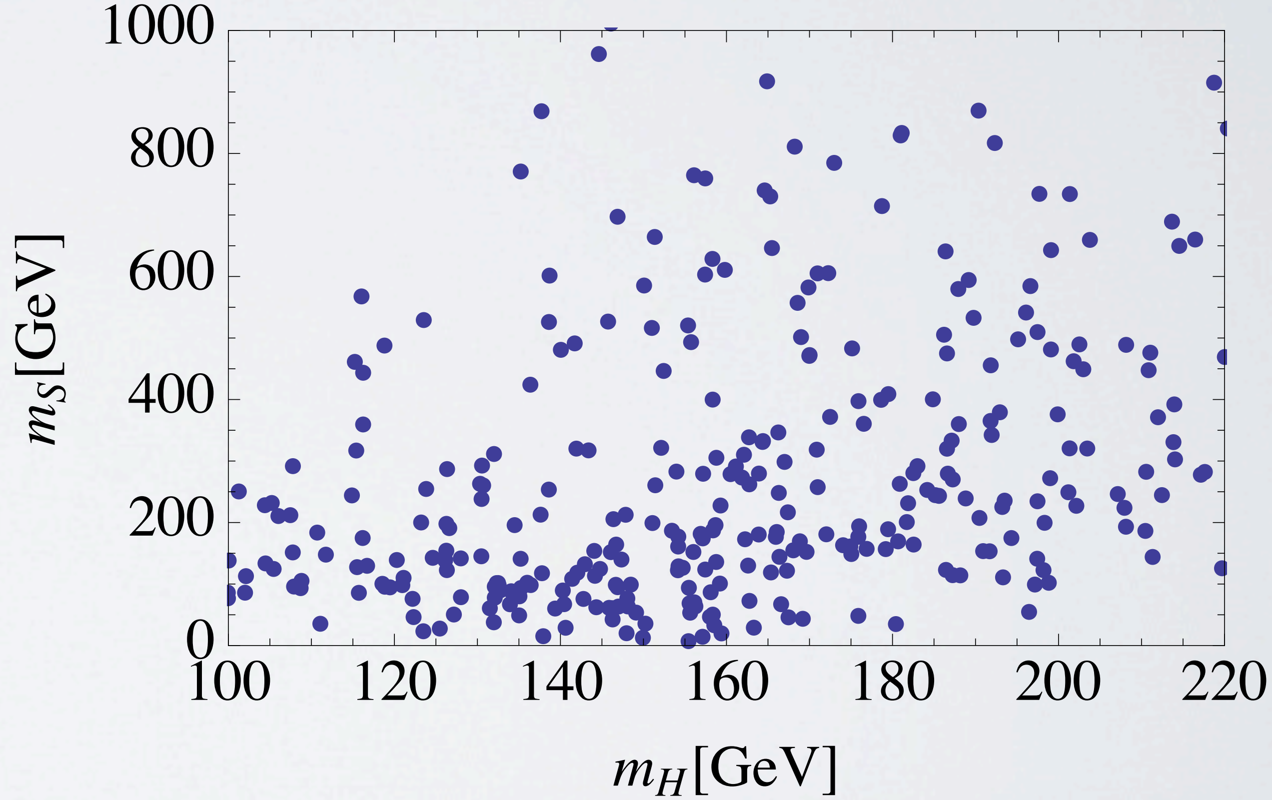
Fermions can be coupled to the 6=(2,2)+2 × 1

$$q_L \to \frac{1}{\sqrt{2}} \begin{pmatrix} b_L \\ -ib_L \\ t_L \\ it_L \\ 0 \\ 0 \end{pmatrix} \qquad\qquad t_R \to \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ i\cos\theta\, t_R \\ \sin\theta\, t_R \end{pmatrix}$$

For $\theta = \frac{\pi}{4}$ singlet becomes exact GB.

$$f = 800\,\mathrm{GeV}$$





Same correlation Higgs-fermions.

Singlet typically heavier than Higgs unless $\theta \approx \frac{\pi}{4}$

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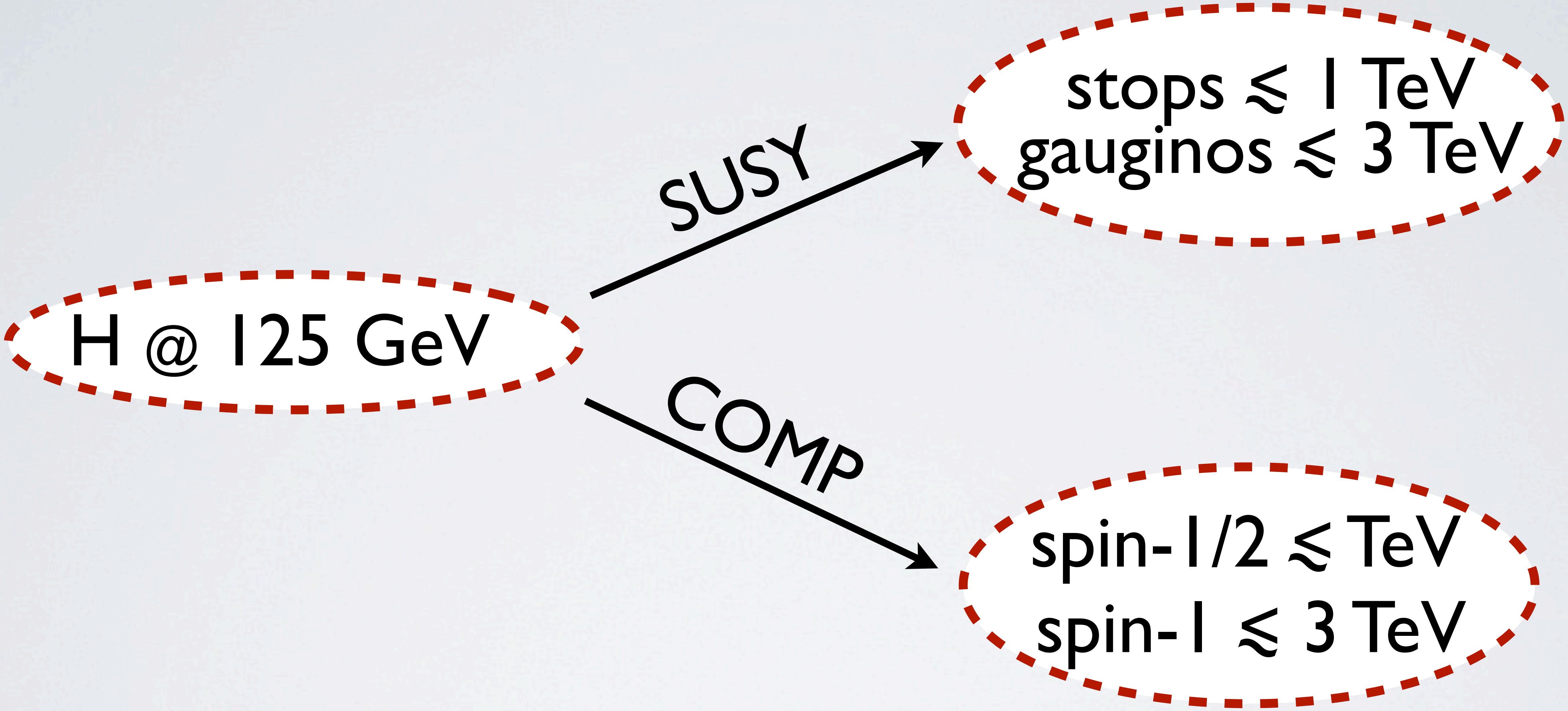
H @ 125 GeV
SUSY
COMP
stops ≲ 1 TeV
gauginos ≲ 3 TeV
spin-1/2 ≲ TeV
spin-1 ≲ 3 TeV

CONCLUSIONS

- All relevant features of CHM can be reproduced from a 4D point view. First resonance sufficient for theory & LHC.
- 125 GeV Higgs requires light fermionic partners that may be seen in 2012 or early LHC14.
- Not all models have been fully explored.

ESTIMATES

$$\mathcal{L} = \left(1 + \epsilon_L^2 \sum_i I_L^{(i)}(s_h)\right) \bar{q}_L \partial q_L + \left(1 + \epsilon_R^2 \sum_i I_R^{(i)}(s_h)\right) \bar{t}_R \partial t_R$$
$$+ y_t f\, M(s_h) \bar{t}_L t_R + h.c.\,,$$

Loops of SM fields generate:

$$V_{\text{leading}} \sim \frac{N_c}{16\pi^2} m_\psi^4 \sum_i \left[\epsilon_L^2\, I_L^{(i)}(s_h) + \epsilon_R^2\, I_R^{(i)}(s_h)\right]$$

$$V_{\text{sub-leading}} \sim \frac{N_c}{16\pi^2} m_\psi^2 f^2\ \left[y_t^2\, M^2(s_h) + \ldots\right] \qquad \left(y_t \sim \epsilon_L \epsilon_R \frac{m_\psi}{f}\right)$$

$$s_h \equiv \sin\frac{h}{f} = \frac{v}{f}$$

Two different trigonometric structures needed to tune.

- Tuning at leading order

$$m_h^2 \sim \frac{N_c}{2\pi^2} y_t \frac{m_\psi^3}{f^3} v^2 \longrightarrow \Delta = \frac{\delta m_h^2}{m_h^2} \sim \frac{f^2}{v^2}$$

- Tuning with sub-leading terms (CHM5, CHM10...)

$$m_h^2 \sim \frac{N_c}{2\pi^2} y_t^2 \frac{m_\psi^2}{f^2} v^2 \longrightarrow \Delta = \frac{\delta m_h^2}{m_h^2} \sim \frac{m_\psi}{y_t f} \times \frac{f^2}{v^2}$$

- Composite tR

$$m_h^2 \sim \frac{N_c}{2\pi^2} y_t^2 \frac{m_\psi^2}{f^2} v^2 \longrightarrow \Delta = \frac{\delta m_h^2}{m_h^2} \sim \frac{f^2}{v^2}$$