Buried Higgs

under the QCD background

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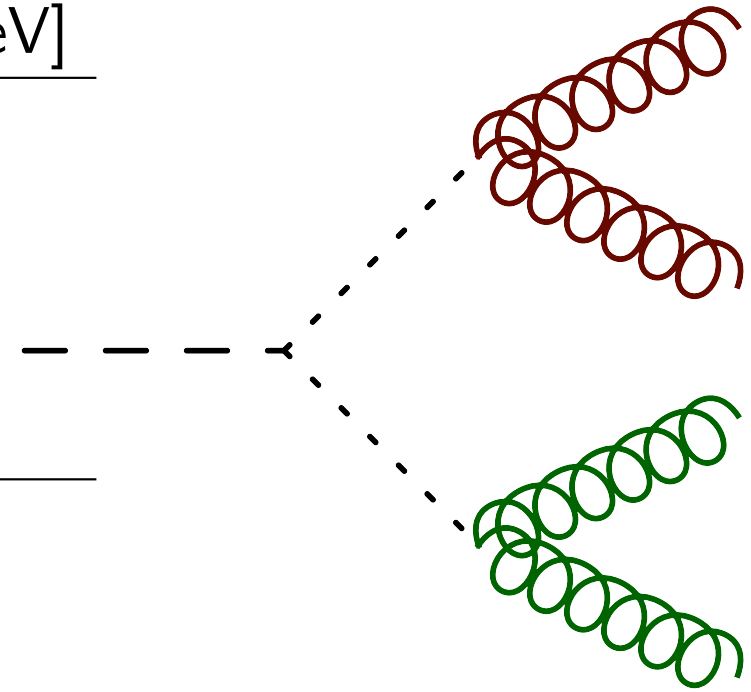
Relaxing the LEP bound

- cascade decay into 4-body visible final states (Chang, Fox, Weiner [hep-ph/0511250], Chang, Dermisek, Gunion, Weiner 0801.4554[hep-ph])

Decay channel	**Limit** [GeV]
$h \to b\bar{b}\,,\ \tau\bar{\tau}$	115
$h \to jj$	113
$h \to \gamma\gamma$	117
$h \to WW^*\,,\ ZZ^*$	110
$h \to \not{E}$	115
$h \to \eta\eta \to 4b$	110
$h \to \eta\eta \to 4\tau\,,\ 4c\,,\ 4g$	86
independent	82



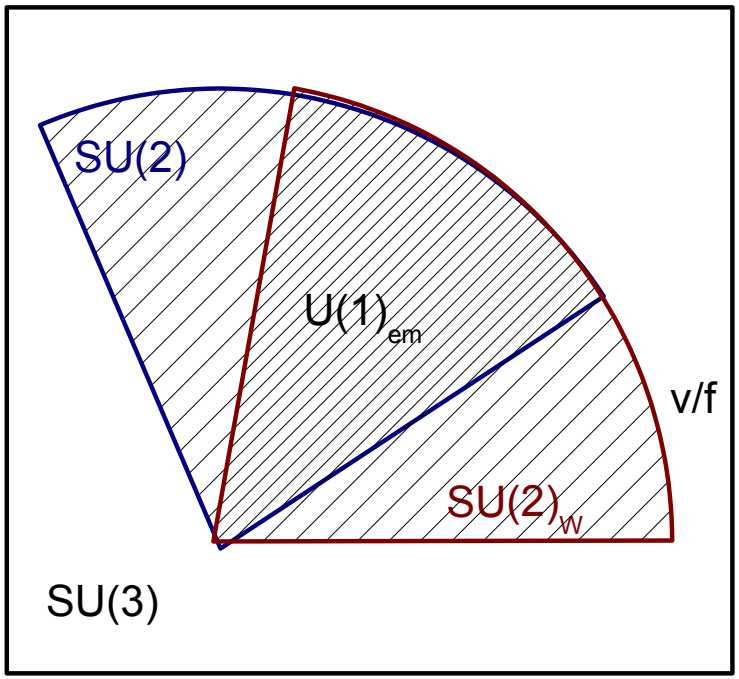
Higgs as a pGB in SU(3)/SU(2)

- Goldstone counting:

$$8 - 3 = 4 + 1 = h + \eta$$

- η is a pGB $\Rightarrow$ η is naturally light $\Rightarrow$ $\eta \not\to b\bar{b}$ (by Kinematic)

$$\mathcal{H}_{u,d} = f_{u,d} \begin{pmatrix} 0 \\ \sin(\tilde{v} + h)/f \\ e^{\pm i\eta/\sqrt{2}f} \cos(\tilde{v} + h)/f \end{pmatrix}$$



- $g_{hWW} = g^{SM}_{hWW} \times \sqrt{1 - v^2_{EW}/f^2}$
- $g_{hf\bar{f}} = g^{SM}_{hf\bar{f}} \times \sqrt{1 - v^2_{EW}/f^2}$

Higgs decay: $h \to \eta\eta$ vs. $h \to b\bar{b}$

$$\xi^2 \mathrm{BR}(h \to b\bar{b}) = \frac{\Gamma^{SM}_{h\to b\bar{b}}}{\Gamma_{h\to\eta\eta} + \left(1 - \frac{v_{EW}^2}{f^2}\right)\sum_f \Gamma^{SM}_{h\to f\bar{f}}} \left(1 - \frac{v_{EW}^2}{f^2}\right)^2$$

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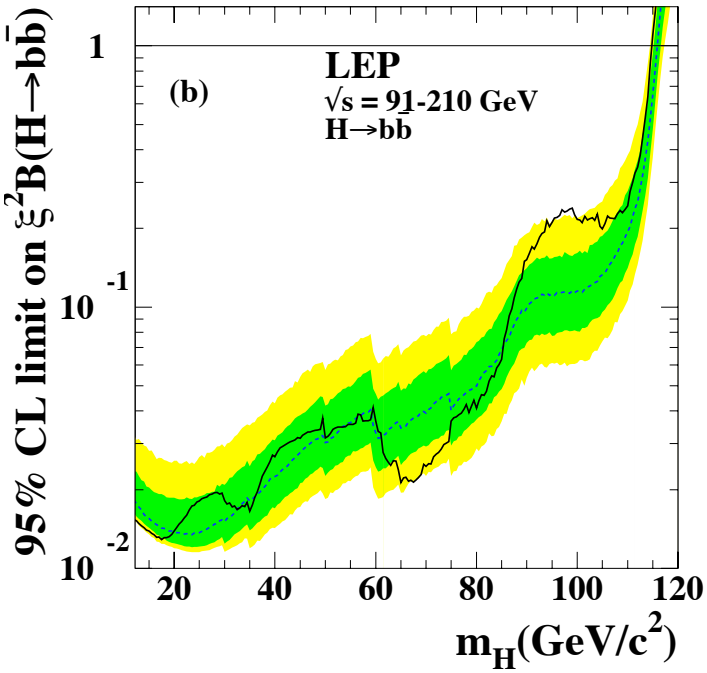


Kinetic terms $\to \mathcal{L}_{pGB} = -\, h(\partial\eta)^2 \left(\frac{\tan(\tilde{v}/f)}{\sqrt{2}f}\right)$

SU(3)/SU(2) in SUSY

Gauge group: extend MSSM

	$SU(3)_c$	$SU(3)_W$	$U(1)_X$
H_u , Φ_u	1	3	1/3
H_d , Φ_d	1	$\bar{3}$	$-1/3$

Global group

$$\mathcal{W}_\Phi + \mathcal{W}_\mathcal{H} \longleftrightarrow SU(3)_\Phi \times SU(3)_\mathcal{H}$$

- down to SM+global sym. $\longrightarrow$ a better *NMSSM*

$$\langle \Phi_{u,d} \rangle = (0, 0, F)\,, \quad \text{gauge: } SU(3)_W \times U(1)_X \to SU(2)_W \times U(1)_y$$
$$\text{global: } SU(3)_\Phi \times SU(3)_\mathcal{H} \to SU(3)_\mathcal{H}$$

- down to $U(1)_{em}$

$$\langle \mathcal{H}_{u,d} \rangle = e^{\pm i \hat{\Pi}/f} (0, 0, f_{u,d}) \quad \hat{\Pi} = 5 - 3 = h + \eta$$

η DECAY I: THE MATTER CONTENT

	$SU(3)_C$	$SU(3)_W$	$U(1)_X$
$Q = (t^Q, b^Q, \hat{b}^Q)$	3	3	0
t_c	$\bar{3}$	1	$-2/3$
$b_c^{1,2}$	$\bar{3}$	1	$1/3$
$V = (b^V, t^V, \hat{t}^V)$	3	$\bar{3}$	$1/3$
$V_c = (b_c^V, t_c^V, \hat{t}_c^V)$	$\bar{3}$	3	$-1/3$
$L_{1,2} = (\tau_{1,2}^L, \nu_{1,2}^L, \hat{\nu}_{1,2}^L)$	1	$\bar{3}$	$-1/3$
$E_c = (\nu_c^E, \tau_c^E, \hat{\tau}_c^E)$	1	$\bar{3}$	$2/3$
$\nu_c^{1,2,3}$	1	1	0

$$\mathcal{W}_{collect.} = y_1 t_c V \Phi_u + y_2 \mathcal{H}_u V_c Q + \mu_V V V_c + \dots$$

$$\Lambda_{Landau} = 10^8 \text{ TeV}$$

η DECAYS II

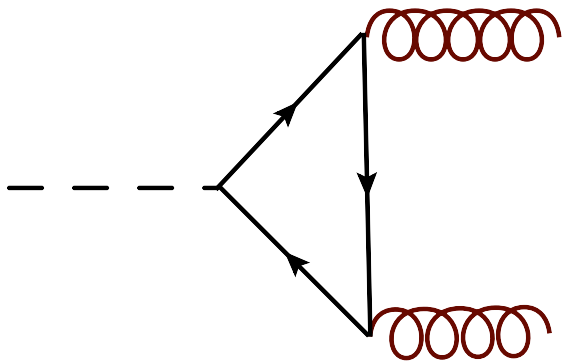
- coupling to SM-fermions:
  - top-bottom dominates

$$\tilde{y}_b \sim (m_b m_t^2)/(v_{EW} M_T^2)$$

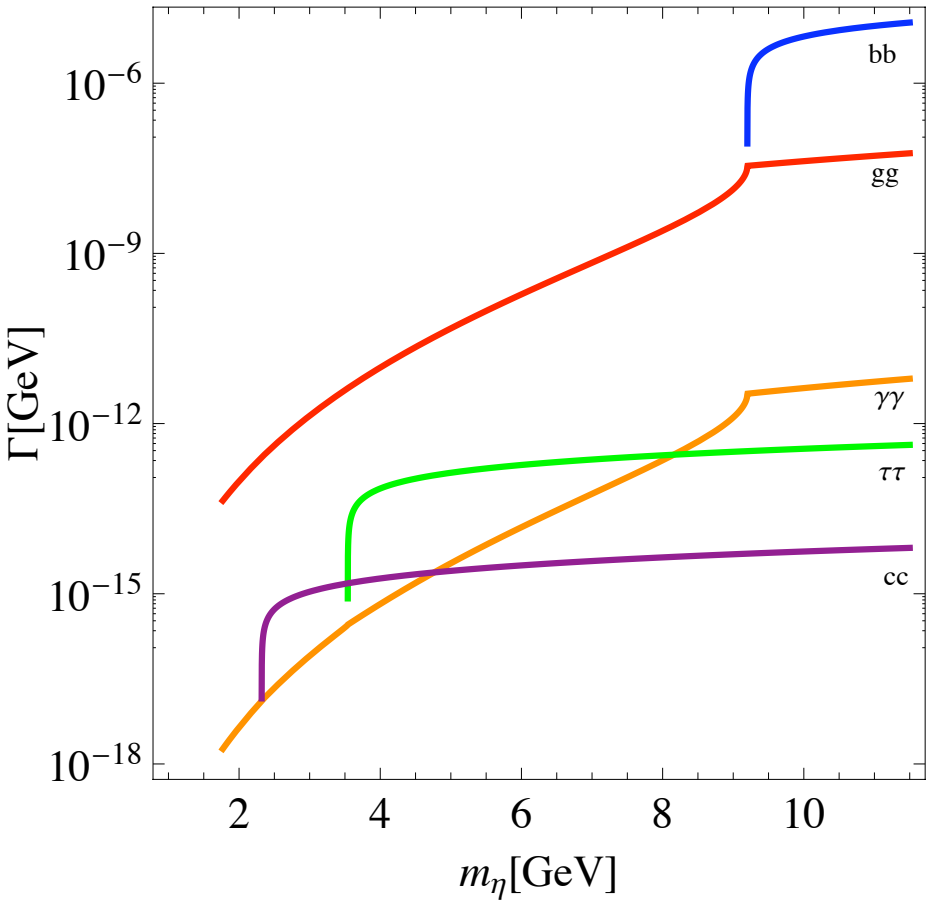
  - other fermions suppressed

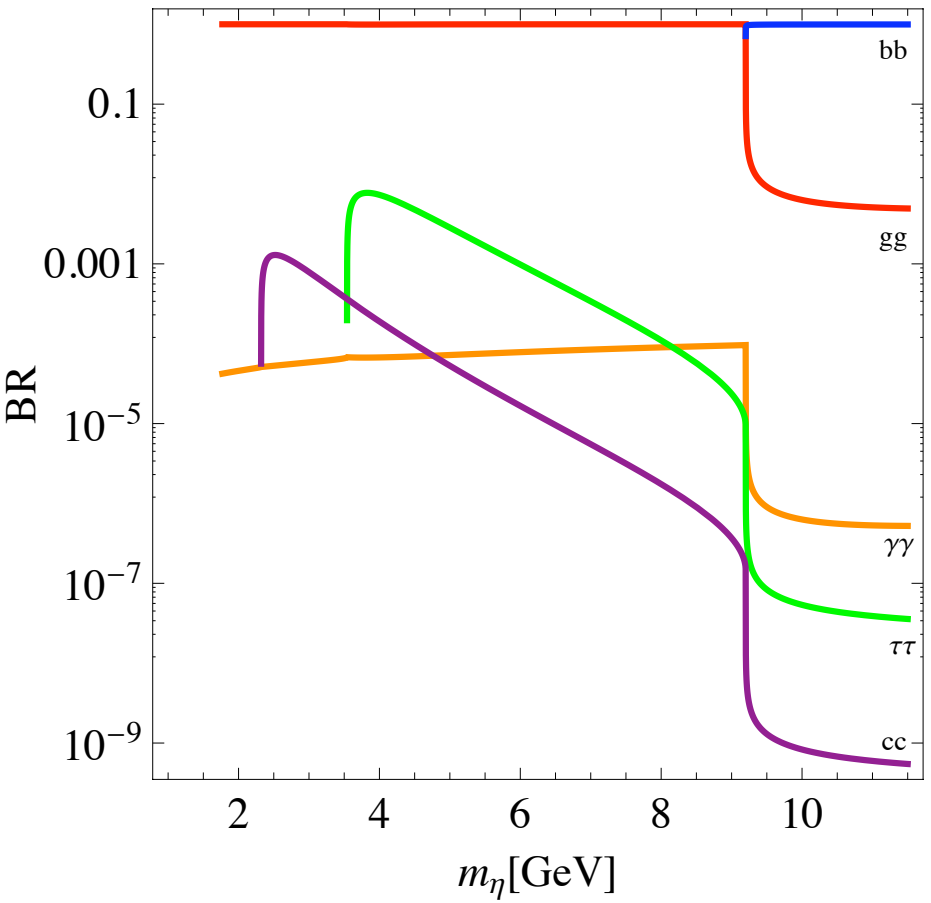
$$\tilde{y}_f \sim m_f^3/(v_{EW} M_F^2)$$

- coupling to *gluons*
  - at 1-loop: $\longrightarrow k^g \Box \eta G \tilde{G}$
  - dominated by the bottom: $k^g \propto (N_c^2 - 1) g_s^2 m_\eta^2 \sum_i \tilde{y}_i / m_i^3$



η DECAYS III

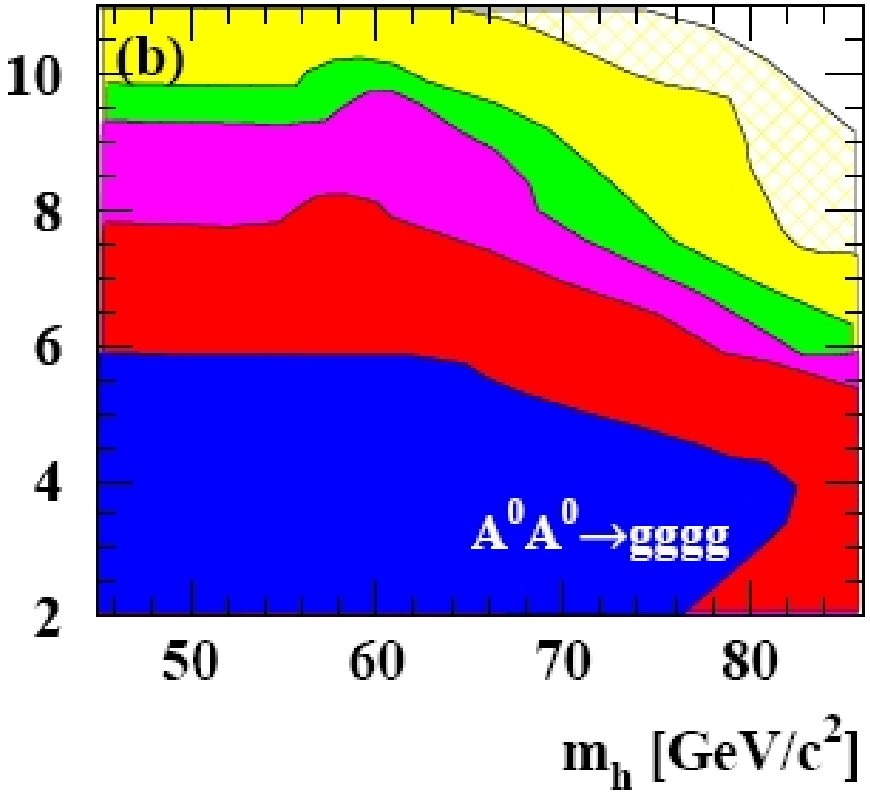


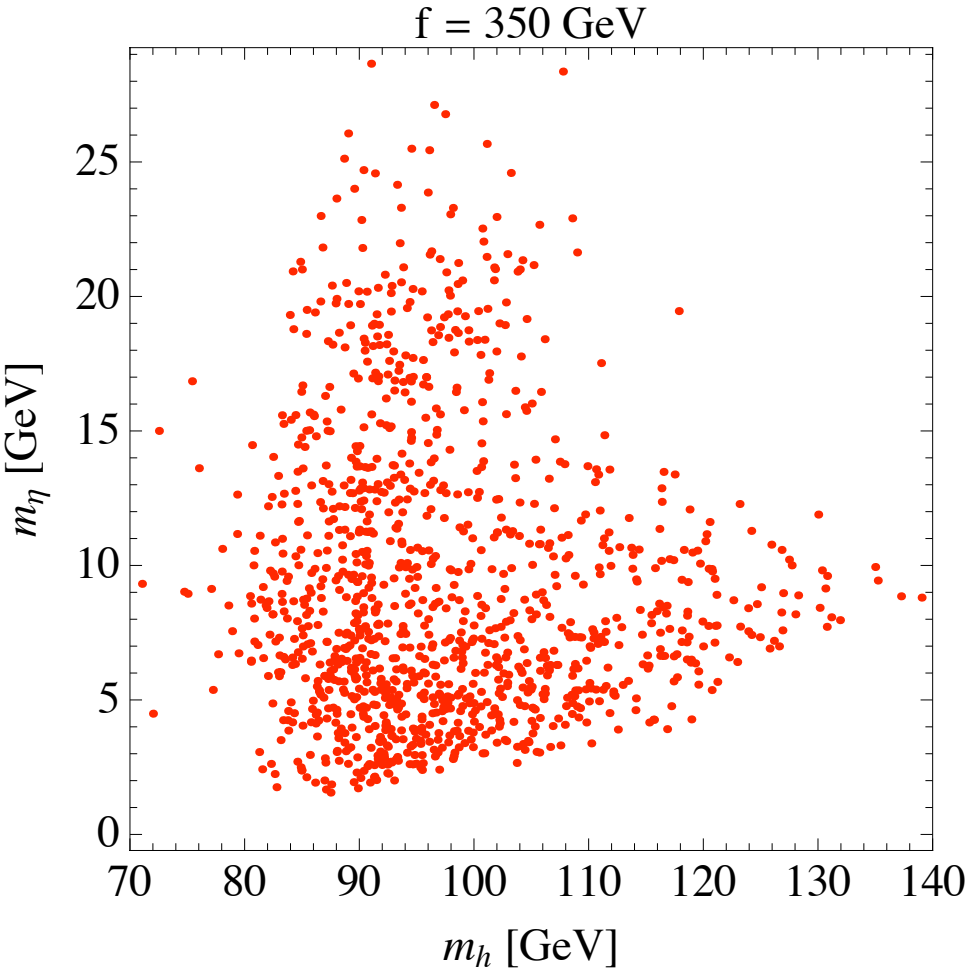


Direct searches in $h \to 2\eta \to 4g$

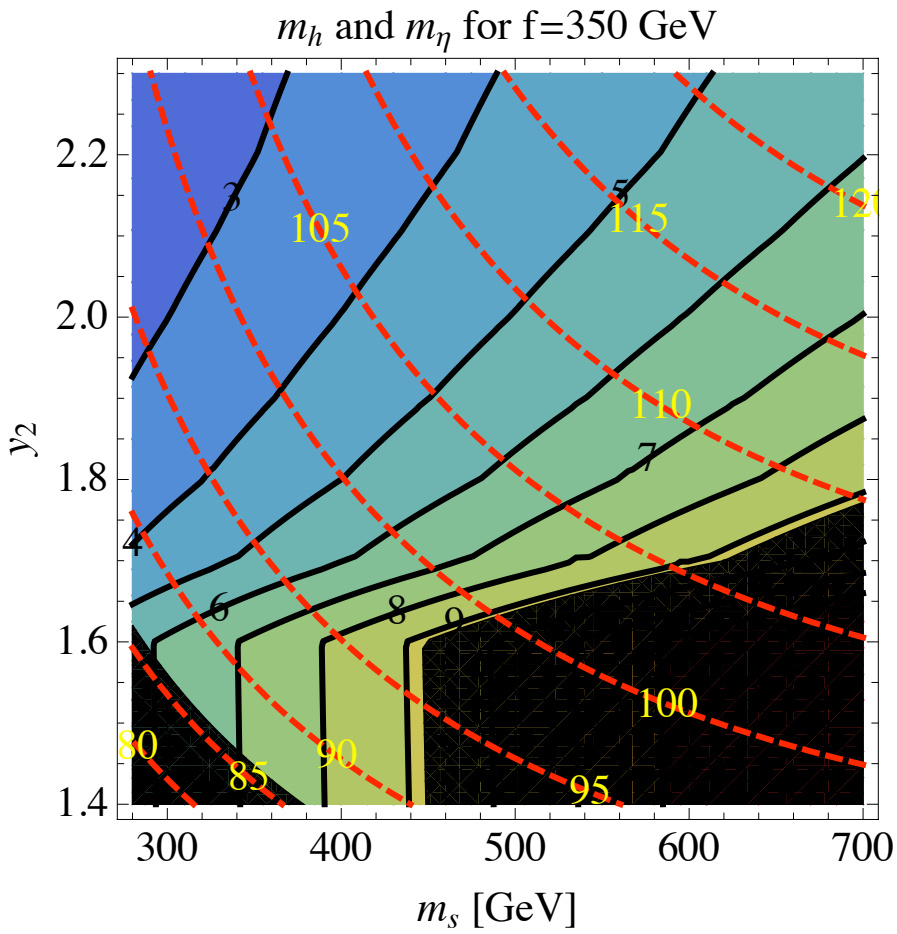
Higgs mass	η mass
$78\,\text{GeV} < m_h < 86\,\text{GeV}$	$m_\eta > 6\,\text{GeV}$
$m_h > 86\,\text{GeV}$	No limit

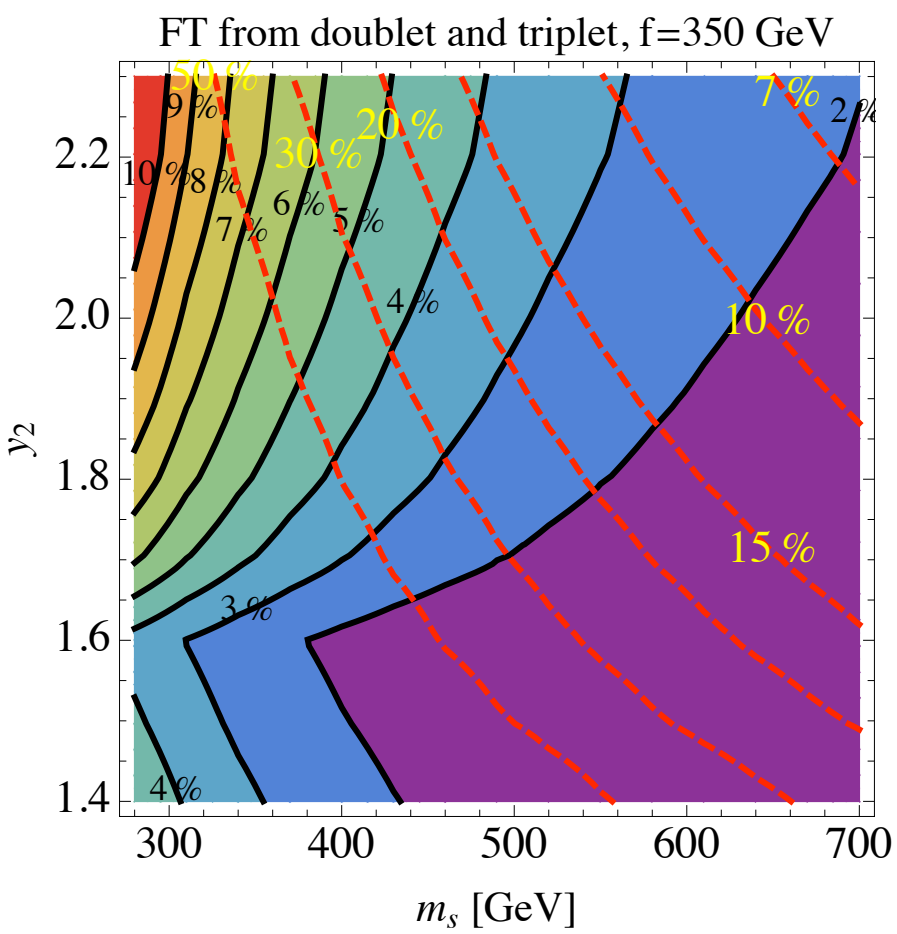
[Opal:hep-ex/0209068]





Masses and FT





Perturbativity

$$y_2 \simeq 1.83 \rightarrow \Lambda = 10^4 \text{ TeV}$$

$$y_2 \simeq 1.64 \rightarrow \Lambda = 10^8 \text{ TeV}$$

Conclusions

- SUSY+global symmetry: NMSSM with a $SU(3)$ rationale
  - Higgs is a light pGB, $m_h \in 90 - 110$ GeV
  - η is a pGB and SM-singlet
  - Cascade decays, $h \to \eta\eta \to 4g$
  - High cutoff, $\Lambda \approx 10^8$ TeV
  - Low Tuning
- Higgs deeply buried under QCD background at LHC
- Many global- and super- partners visible at LHC

Backup slides I: radiative potential

	$SU(3)_C$	$SU(3)_W$	$U(1)_X$
$Q = (t^Q, b^Q, \hat{b}^Q)$	3	3	0
$V = (b^V, t^V, \hat{t}^V)$	3	$\bar{3}$	$1/3$
$V_c = (b_c^V, t_c^V, \hat{t}_c^V)$	$\bar{3}$	3	$-1/3$
t_c	$\bar{3}$	1	$-2/3$
$b_c^{1,2}$	$\bar{3}$	1	$1/3$
$L_{1,2} = (\tau_{1,2}^L, \nu_{1,2}^L, \hat{\nu}_{1,2}^L)$	1	$\bar{3}$	$-1/3$
$E_c = (\nu_c^E, \tau_c^E, \hat{\tau}_c^E)$	1	$\bar{3}$	$2/3$
$\nu_c^{1,2,3}$	1	1	0

$$\mathcal{W}_{collect.} = y_1 t_c V \Phi_u + y_2 \mathcal{H}_u V_c Q + \mu_V V V_c + y_{b1} \Phi_d Q b_c^1 + y_{b2} \mathcal{H}_d Q b_c^2 + y_{\tau 1} \Phi_d L_1 E_c + y_{\tau 2} \mathcal{H}_d L_2 E_c$$

$$\delta m_{\mathcal{H}}^2 \approx -\frac{3y_2^2}{2\pi^2} m_s^2 \ln[\Lambda/M_T], \quad \delta\lambda_{\mathcal{H}} \approx \frac{3y_2^4}{8\pi^2} \ln[(m_s^2 + M_T^2)/M_T^2]$$

Backup slides II: EWPTs

- h has suppressed couplings to W and Z
- radial mode
  - $m_r \approx 300 - 400$ GeV
  - $g_{rWW} = g_{hWW} \times v_{EW}/f \longrightarrow$ cancellation IR div.
  - $S\,,\ T \rightarrow m_{EWPT} = m_h \left(\frac{m_r}{m_h}\right)^{v_{EW}^2/f^2} \approx 110 - 135$ GeV
- $Zb\bar{b} \rightarrow \delta g/g = a(y_i)\cos^2\beta m_b^2/m_B^2 \sim 10^{-7}$