125 and susy naturalness

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February 27, 2012

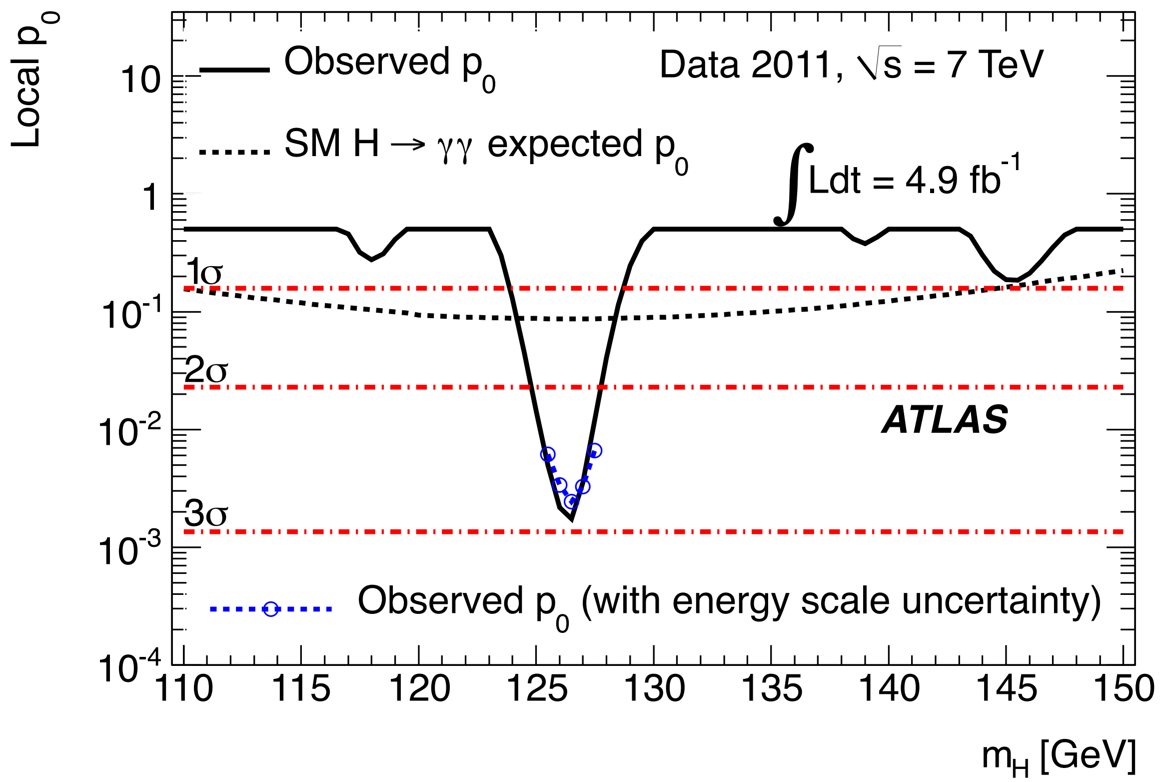
Lawrence Hall, David Pinner, JTR 1112.2703

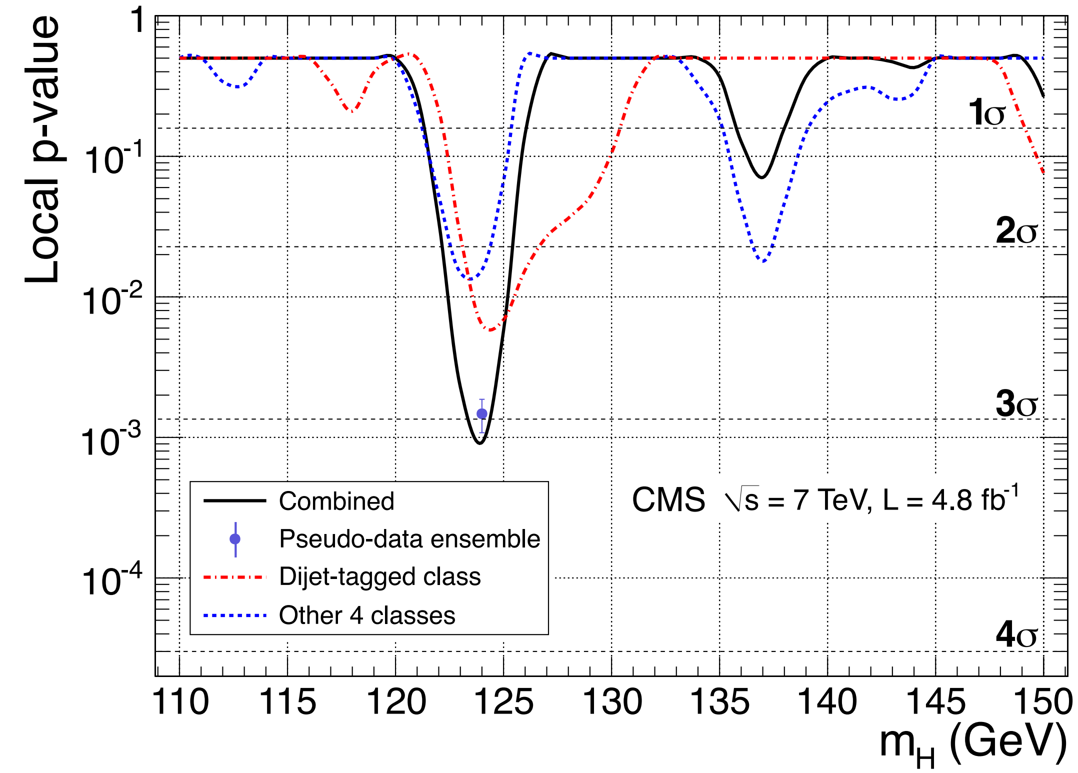
Cheomseongdae, ~640 AD

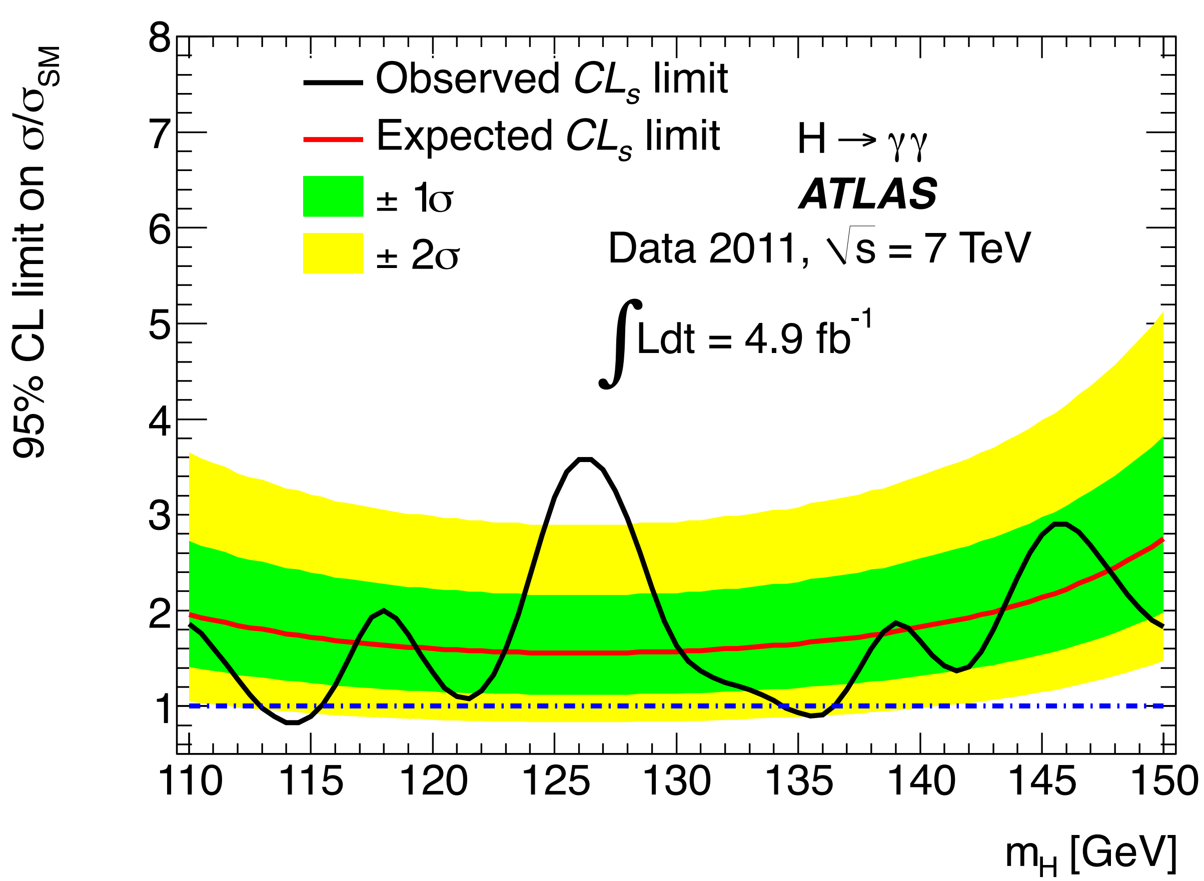
$h \to \gamma\gamma$

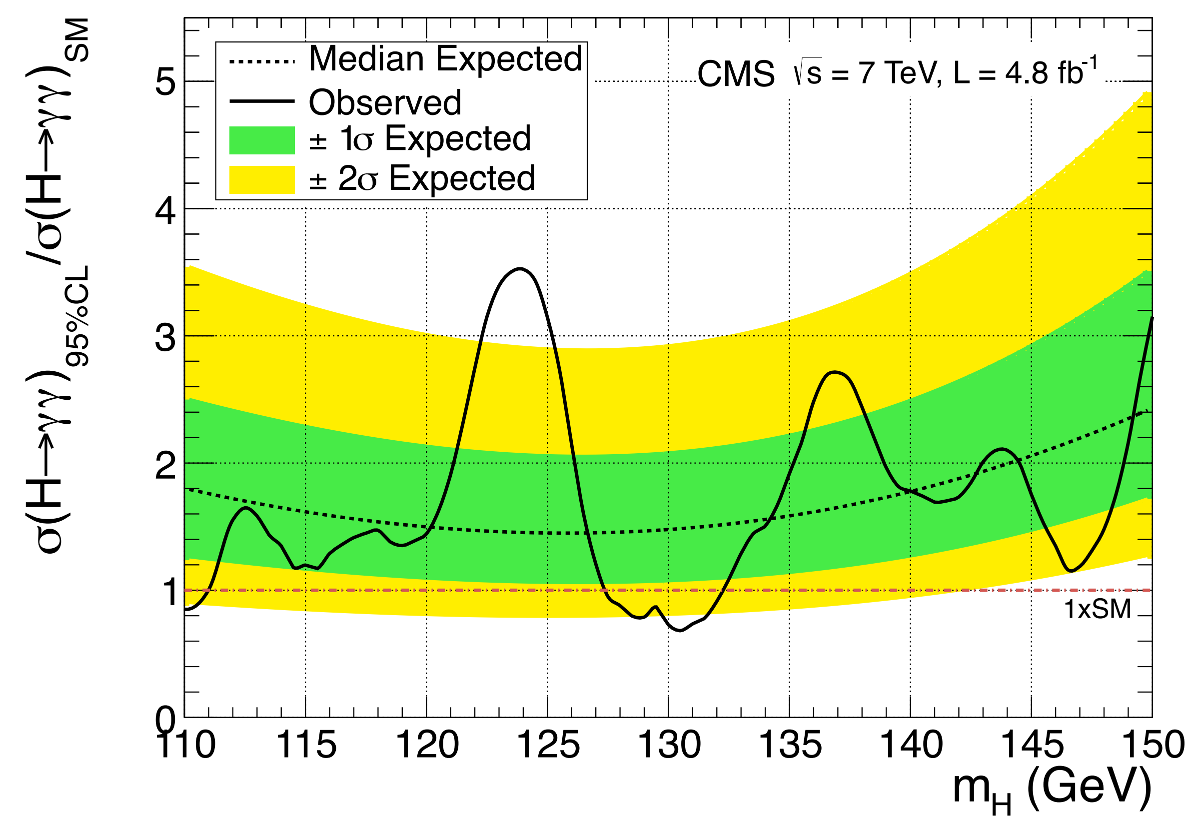
ATLAS

CMS

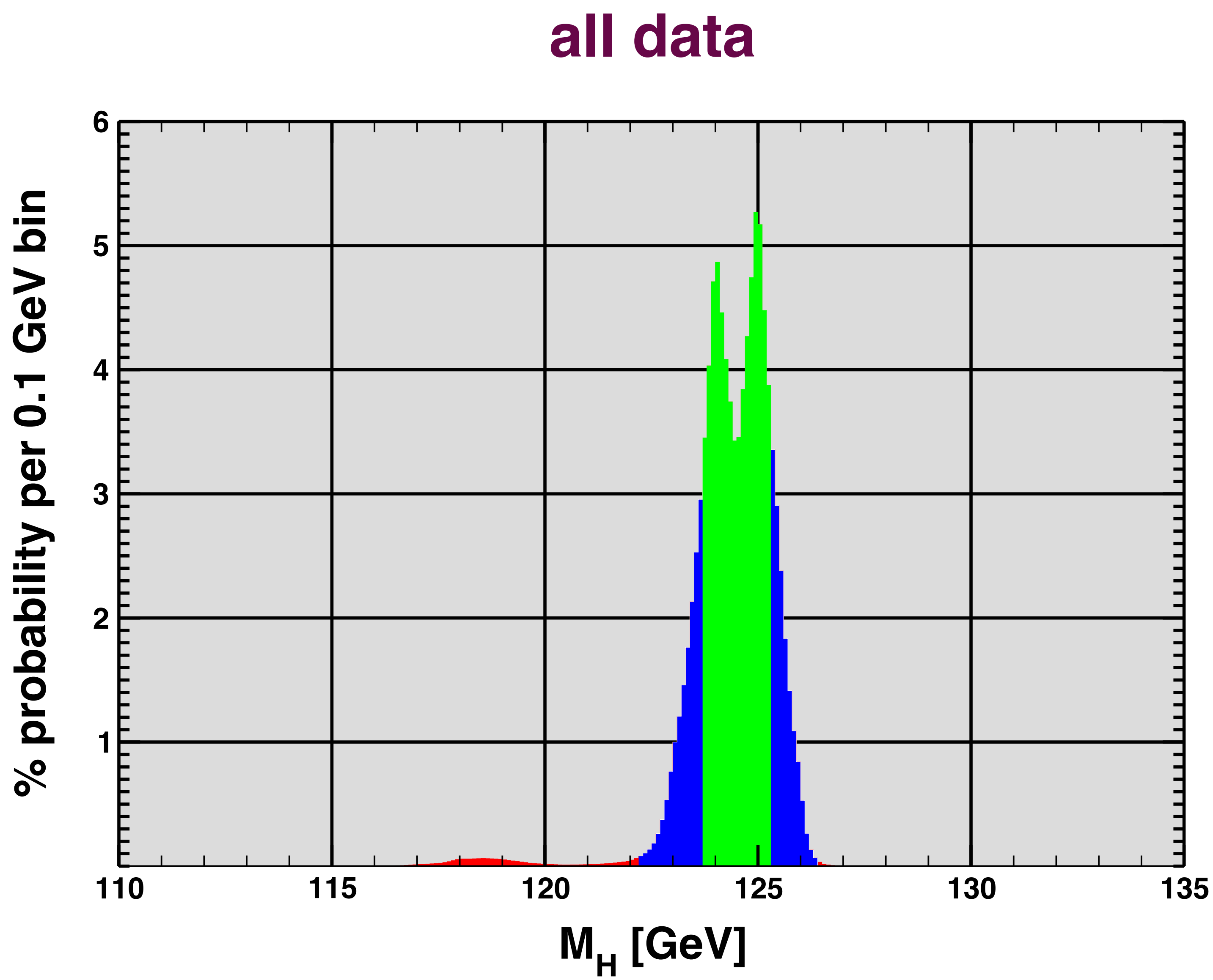








Taking these excesses seriously already allows a precise determination of the Higgs mass!



$$m_h = 124.5 \pm 0.8 \text{ GeV}$$

Jens Erler 1201.0695

- my view on the Higgs is:

  guilty until proven innocent

- for the rest of this talk: $m_h \approx 124 - 126 \text{ GeV}$

- not technicolor!

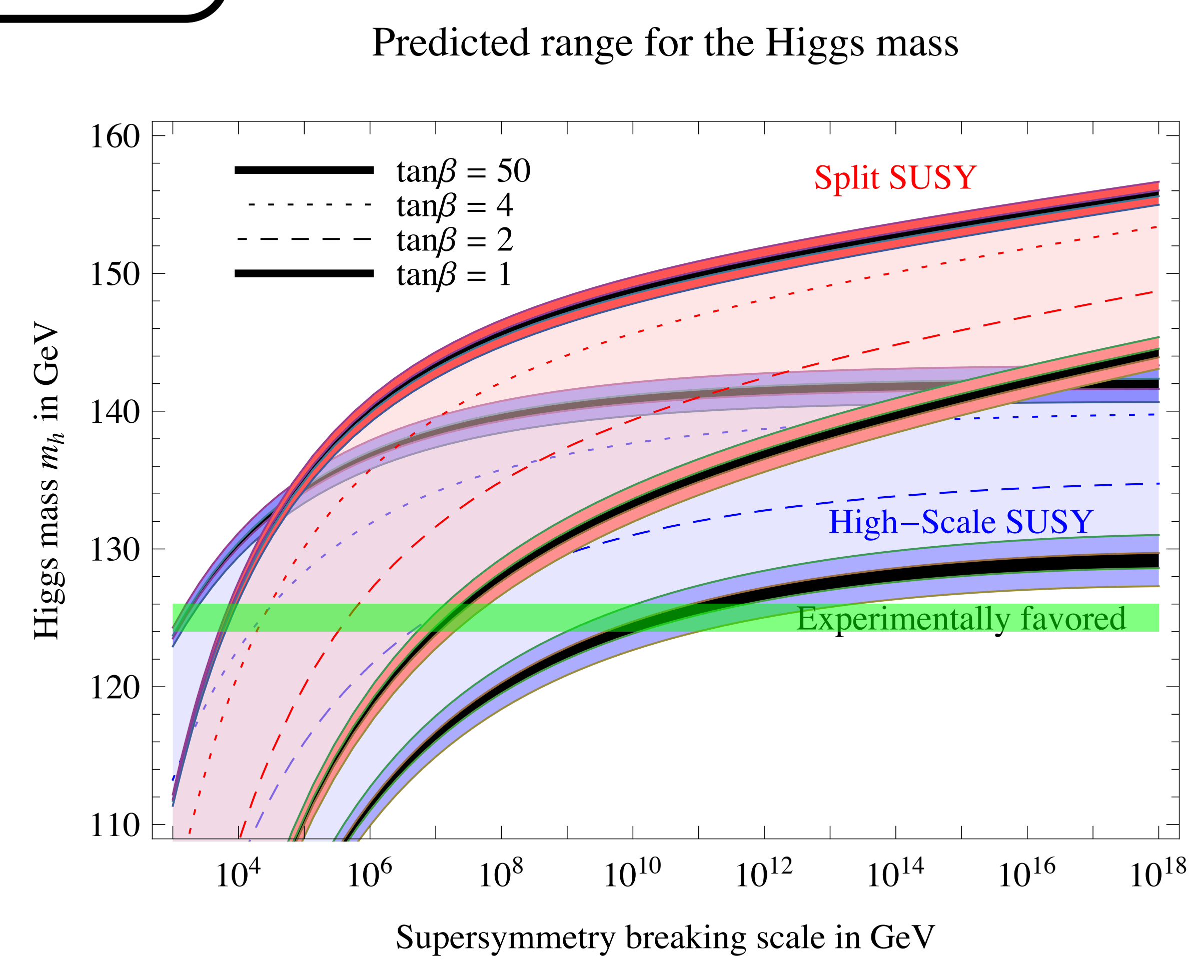
- let's explore implications for SUSY

SUSY

- 125 sits in the battleground between natural and not

natural ← $m_h = 125\ \text{GeV}$ → unnatural

★ topic of this talk



Giudice, Strumia 1108.6077

the plan:

1. MSSM
2. NMSSM
3. λSUSY

$$\lambda\, S H_u H_d$$

$\lambda \lesssim 0.7$

$\lambda > 0.7$

fine tuning in the MSSM

tree-level:

$$-\frac{m_Z^2}{2} = |\mu^2| + m_{H_u}^2 + \mathcal{O}\left(\frac{1}{\tan^2\beta}\right)$$

one-loop:

$$\delta m_{H_u}^2 \approx -\frac{3y_t^2}{8\pi^2}\left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2\right)\log\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

$$m_{\tilde{t}}^2 \lesssim (500\ \mathrm{GeV})^2\,\frac{1}{1 + A_t^2/2m_{\tilde{t}}^2}\left(\frac{10\%}{\Delta^{-1}}\right)\left(\frac{3}{\log\Lambda/m_{\tilde{t}}}\right)$$

maximal mixing has the same fine tuning cost as doubling the stop masses

$$A_t^2 \approx 6\,m_{\tilde{t}}^2$$

general bottom-up fine tuning

- write the potential in the direction of EWSB,

$$V = m_H^2 |h|^2 + \frac{\lambda_h}{4} |h|^4$$

- extremizing,

$$m_{h^0}^2 = \lambda_h v^2 = -2 m_H^2$$

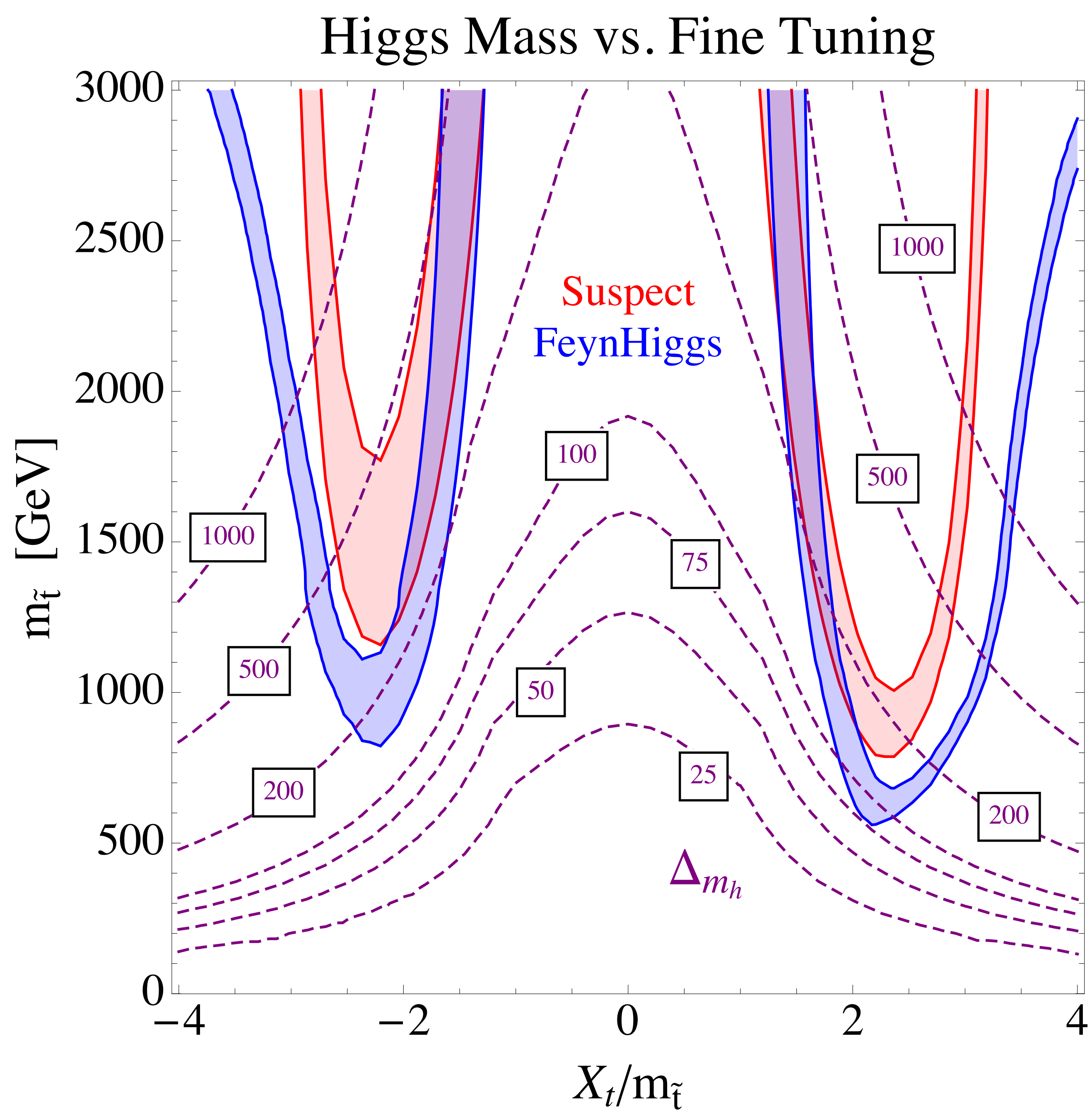
$$\frac{\delta m_H^2}{m_{h^0}^2/2} \gg 1$$

signals fine tuning

Kitano and Nomura 0602096

m_{h^0} is the contribution to the Higgs mass from the direction that breaks EW

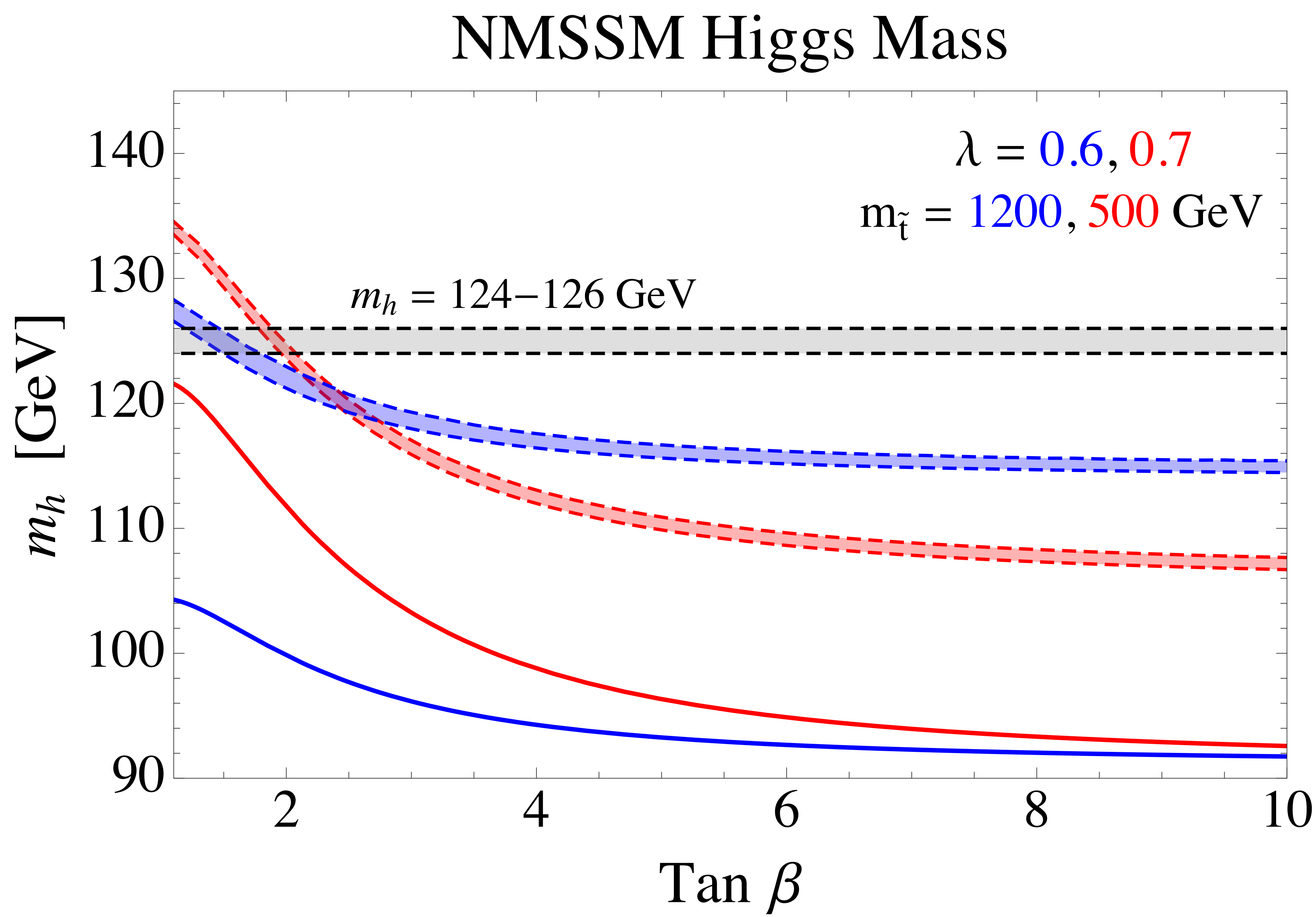
the MSSM



$$\Delta_{m_h} = \max_i \left| \frac{\partial \log m_h^2}{\partial \log p_i} \right|$$

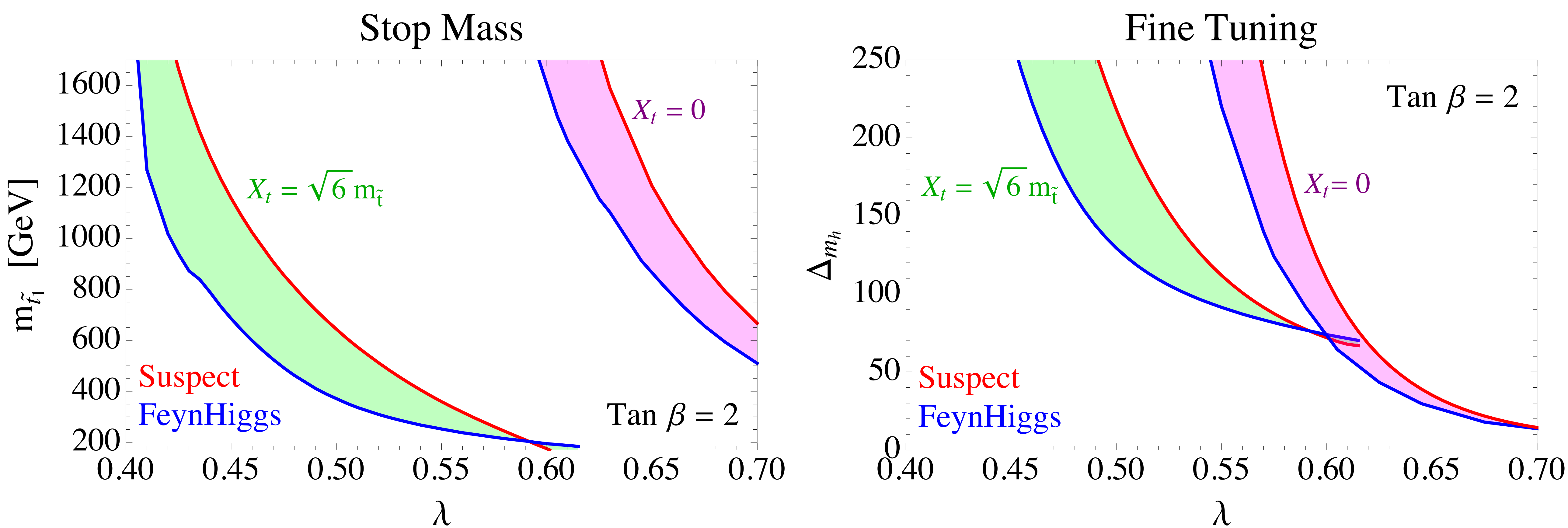
$$\Delta_{m_h} \gtrsim 100$$

$$\lambda\, S H_u H_d$$



$$m_h^2 \leq m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$$

λ



- fine tuning highly prefers large λ

  (and small mixing)

- the NMSSM is pushed to the edge of its parameter space

what about larger λ ?

$$W \supset \lambda\, S H_u H_d$$

- top-down: fat higgs

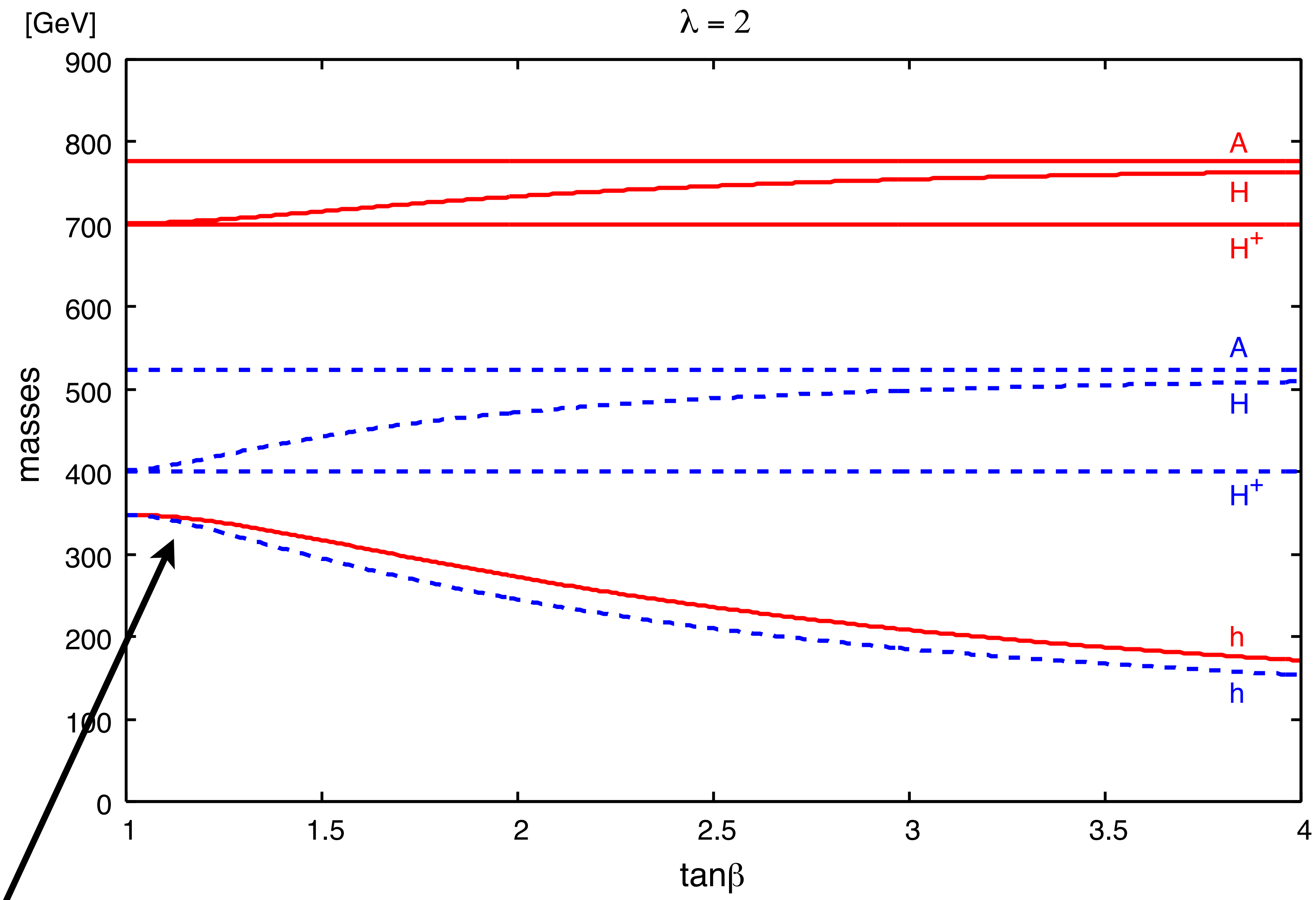
Harnik, Kribs, Larson, Murayama 0311349

- bottom-up: $\lambda\mathrm{SUSY}$

Barbieri, Hall, Nomura, Rychkov 0607332

- we restrict to $\lambda \lesssim 2$ so the theory is perturbative until $\Lambda \lesssim \mathrm{few} \times 10\ \mathrm{TeV}$

- naively, very large λ leads to too heavy of a Higgs mass

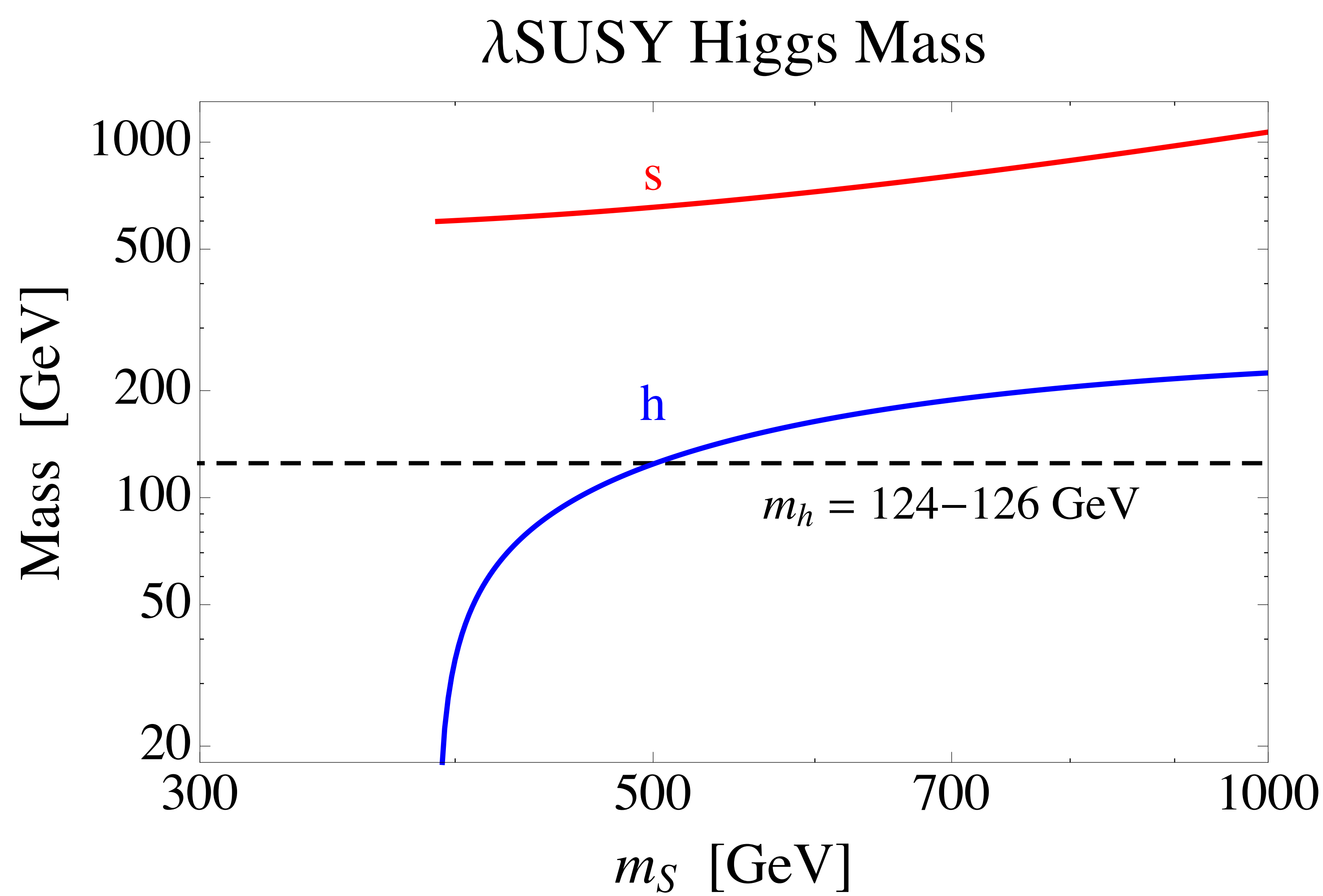


$m_h \gtrsim 300$ GeV
at low $\tan\beta$

Barbieri, Hall, Nomura, Rychkov 0607332

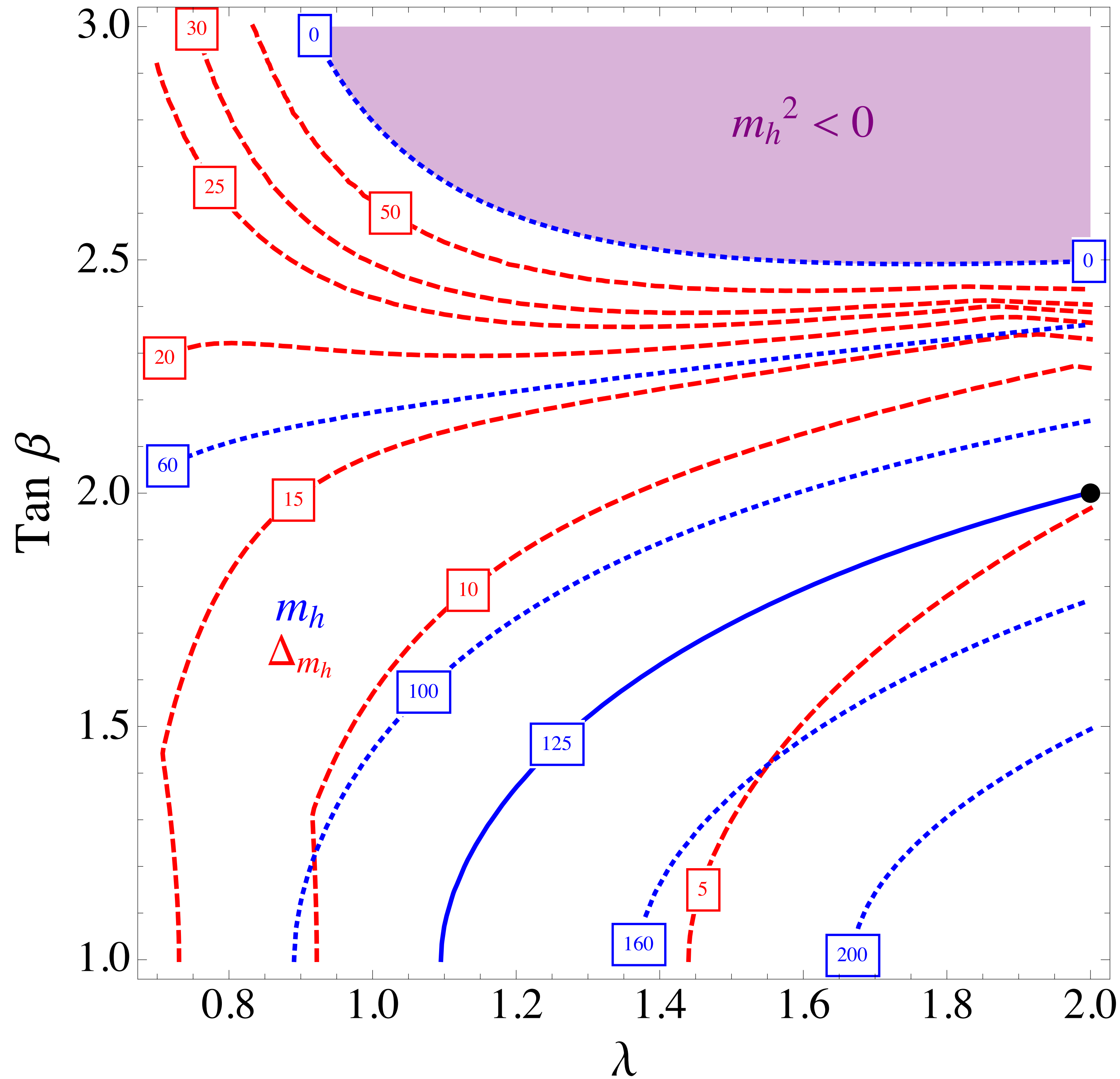
singlet-higgs mixing

$$\mathcal{M}^2 = \begin{pmatrix} \lambda^2 v^2 \sin^2 2\beta + M_Z^2 \cos^2 2\beta & \lambda v(\mu, M_S, A_\lambda) \\ \lambda v(\mu, M_S, A_\lambda) & m_s^2 \end{pmatrix}$$



naturalness says singlet cannot be decoupled:

$$\frac{dm^2_{H_{u,d}}}{dt} = \lambda^2 \frac{m_S^2}{8\pi^2} + \ldots$$

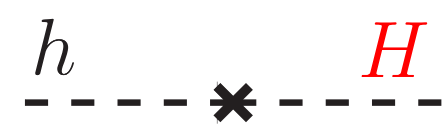


$$\Delta_{m_h} = \max_i \left| \frac{\partial \log m_h^2}{\partial \log p_i} \right|$$

125 natural across a big chunk of a parameter space

non-decoupling of H

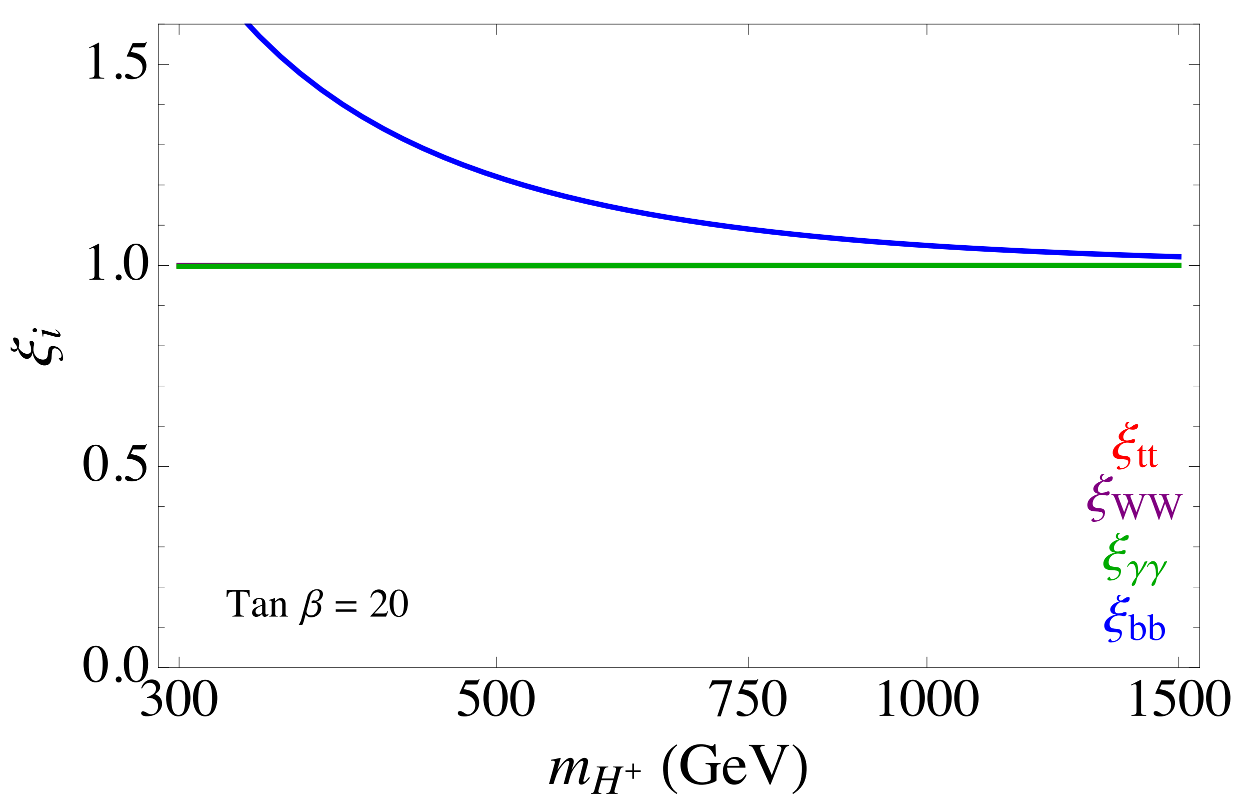
$$\xi_{bb} \equiv \frac{y_b^2}{(y_b^2)_{SM}}$$



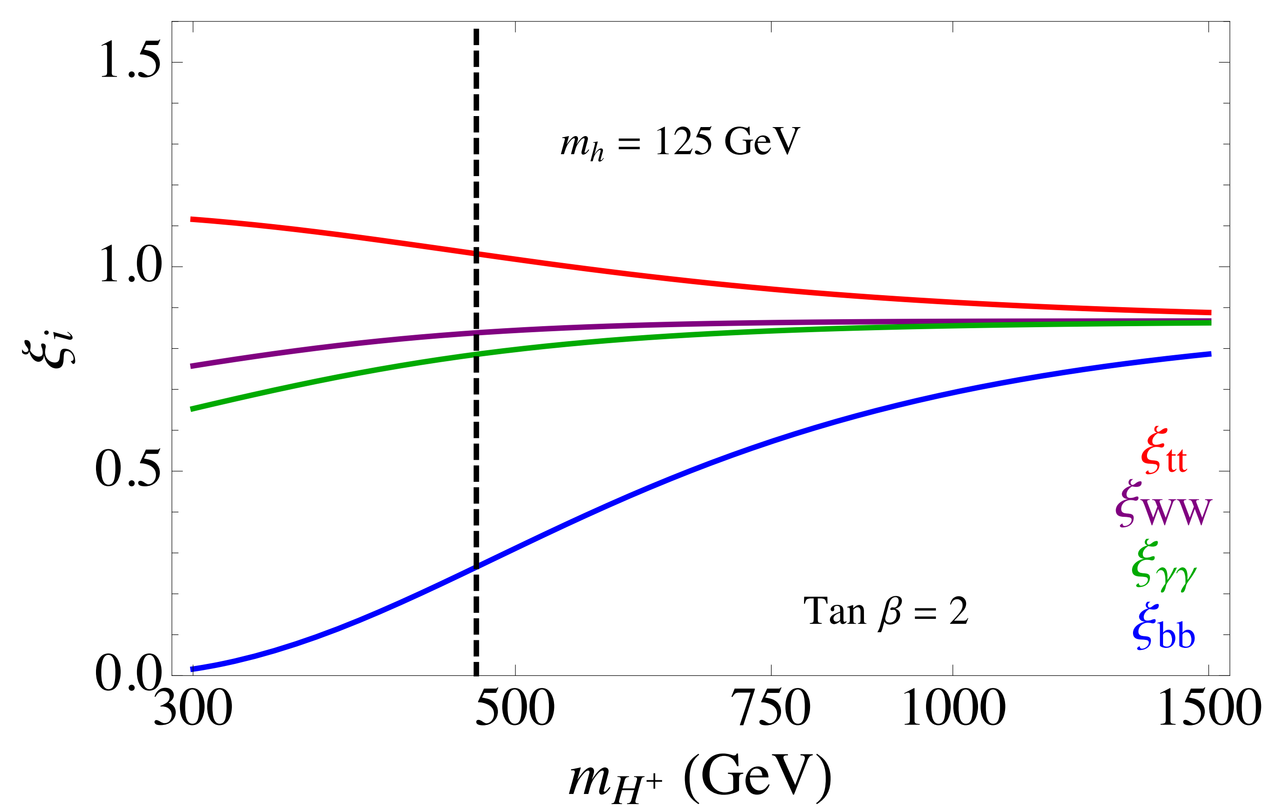
$$\xi_{bb} = 1 + |\sin 4\beta| \tan\beta \left(\frac{m_Z}{m_{H^\pm}}\right)^2$$

$$\xi_{bb} = 1 - |\sin 4\beta| \tan\beta \left(\frac{\lambda v}{m_{H^\pm}}\right)^2$$

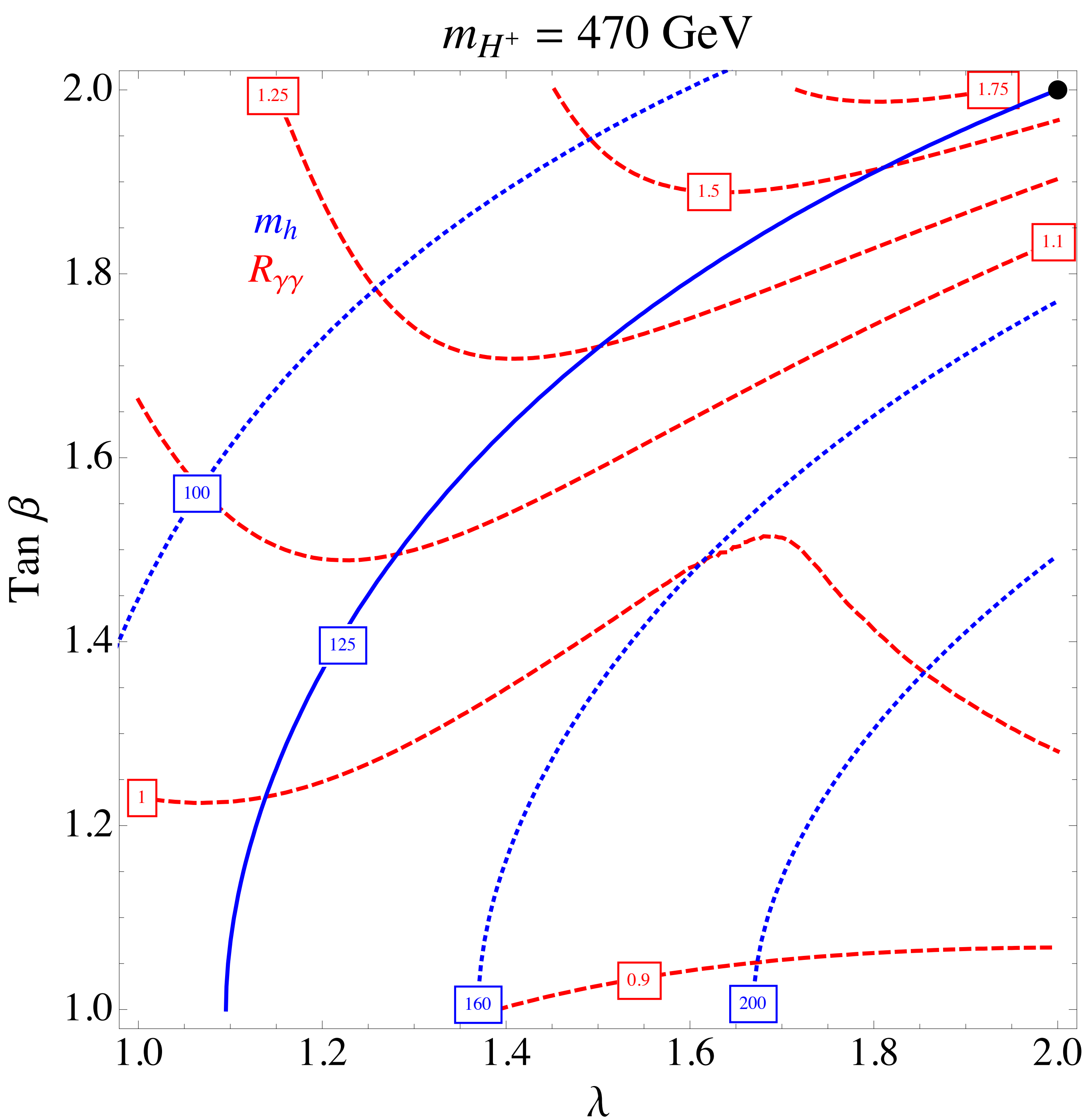
MSSM



λ SUSY



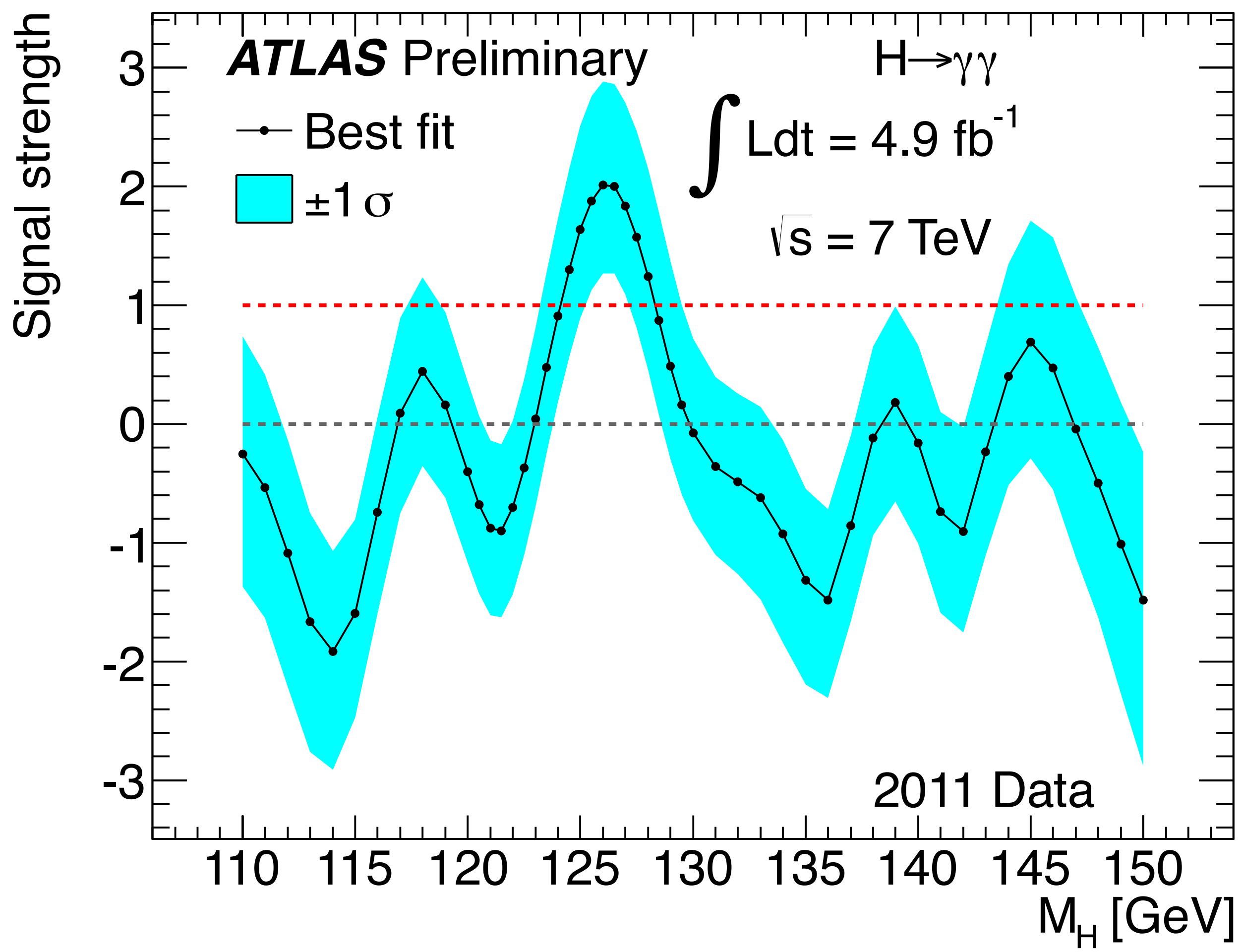
non-decoupling of H



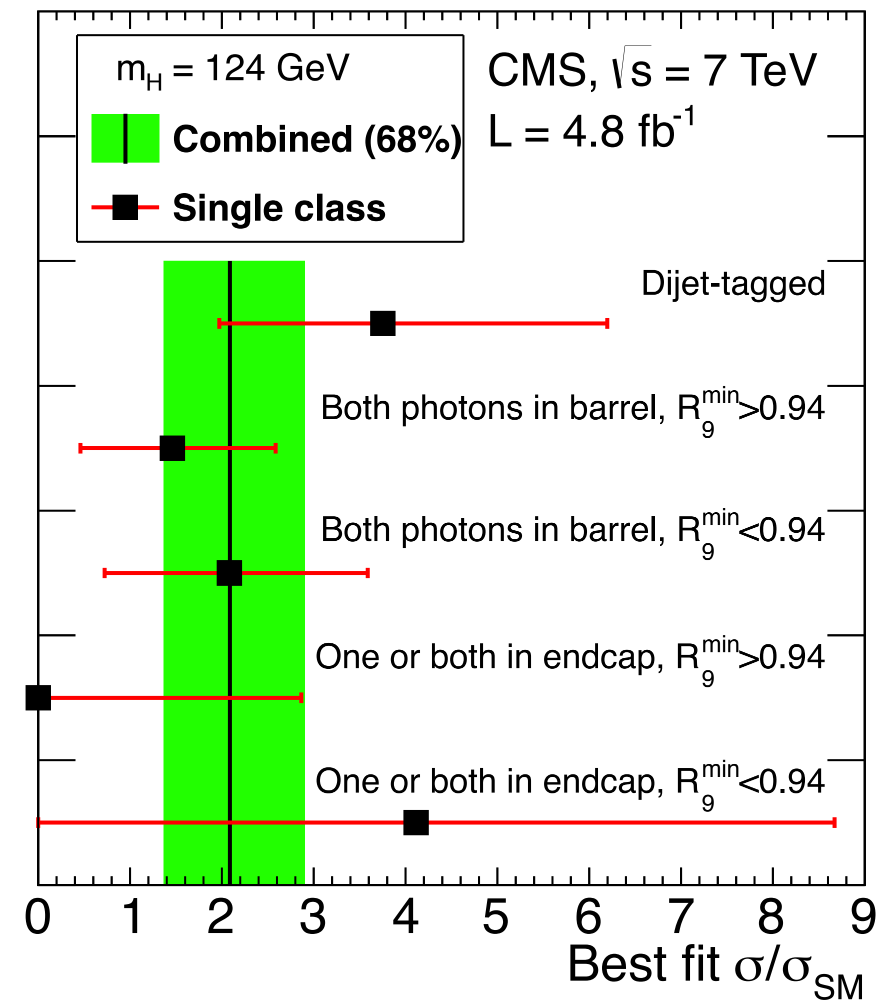
$$R_{\gamma\gamma} = \frac{(\sigma_{gg\to h} \times \mathrm{Br}_{h\to\gamma\gamma})_{\lambda SUSY}}{(\sigma_{gg\to h} \times \mathrm{Br}_{h\to\gamma\gamma})_{SM}}$$

non-decoupling of H?

ATLAS

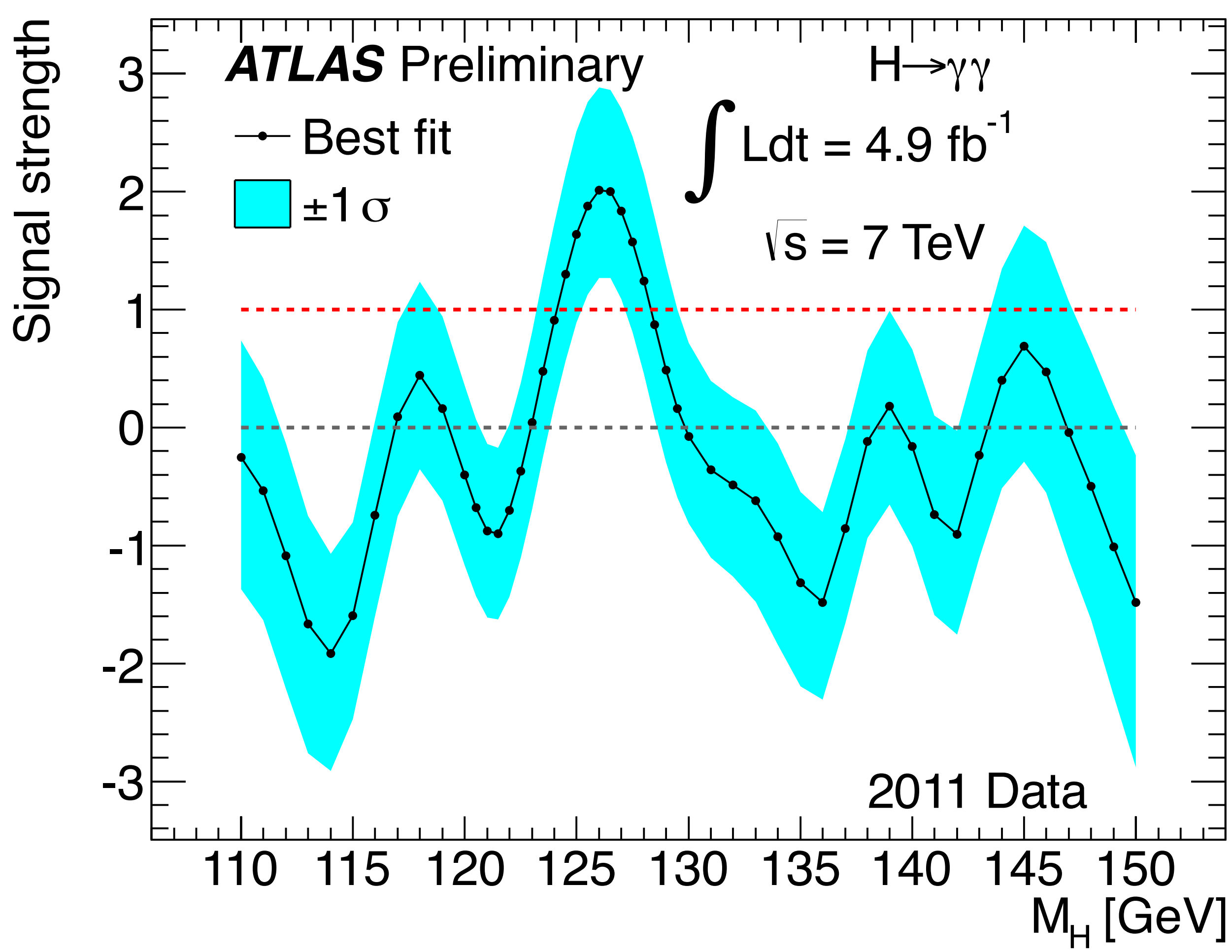


CMS

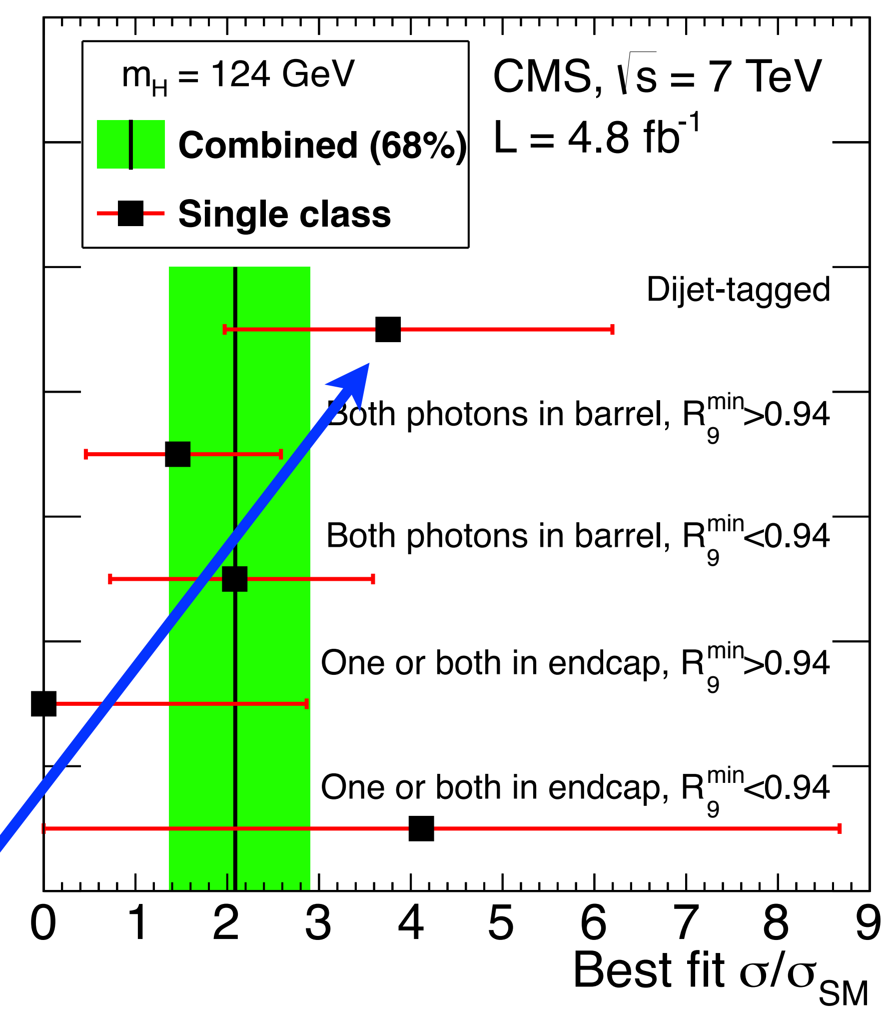


non-decoupling of H?

ATLAS

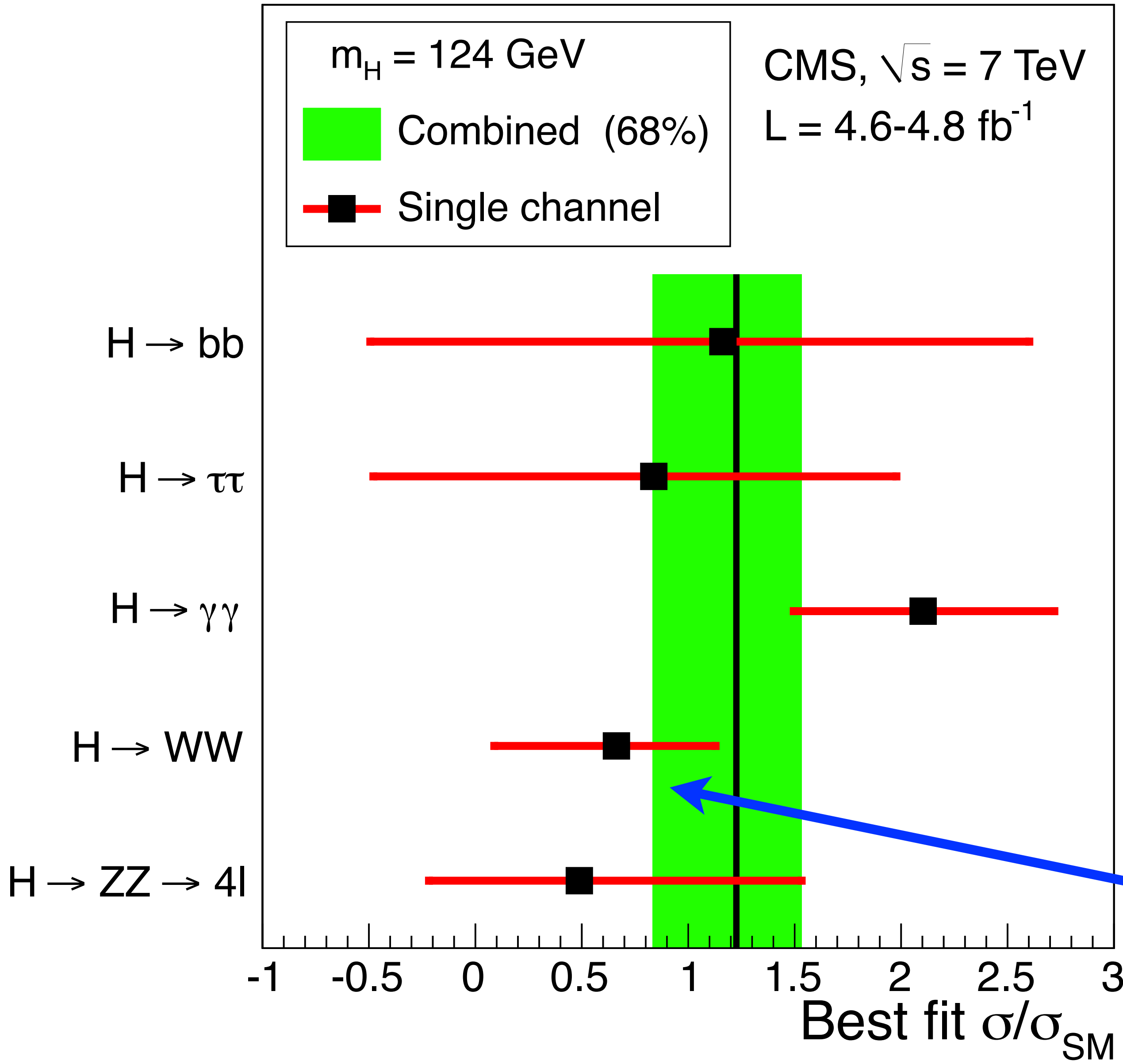


CMS



VBF can tell apart an enhanced g-g-h

from a depleted b-b-h coupling



however, also expect enhancement to WW, ZZ

- too early to tell, but watch for deviations!

large λ protects against fine tuning

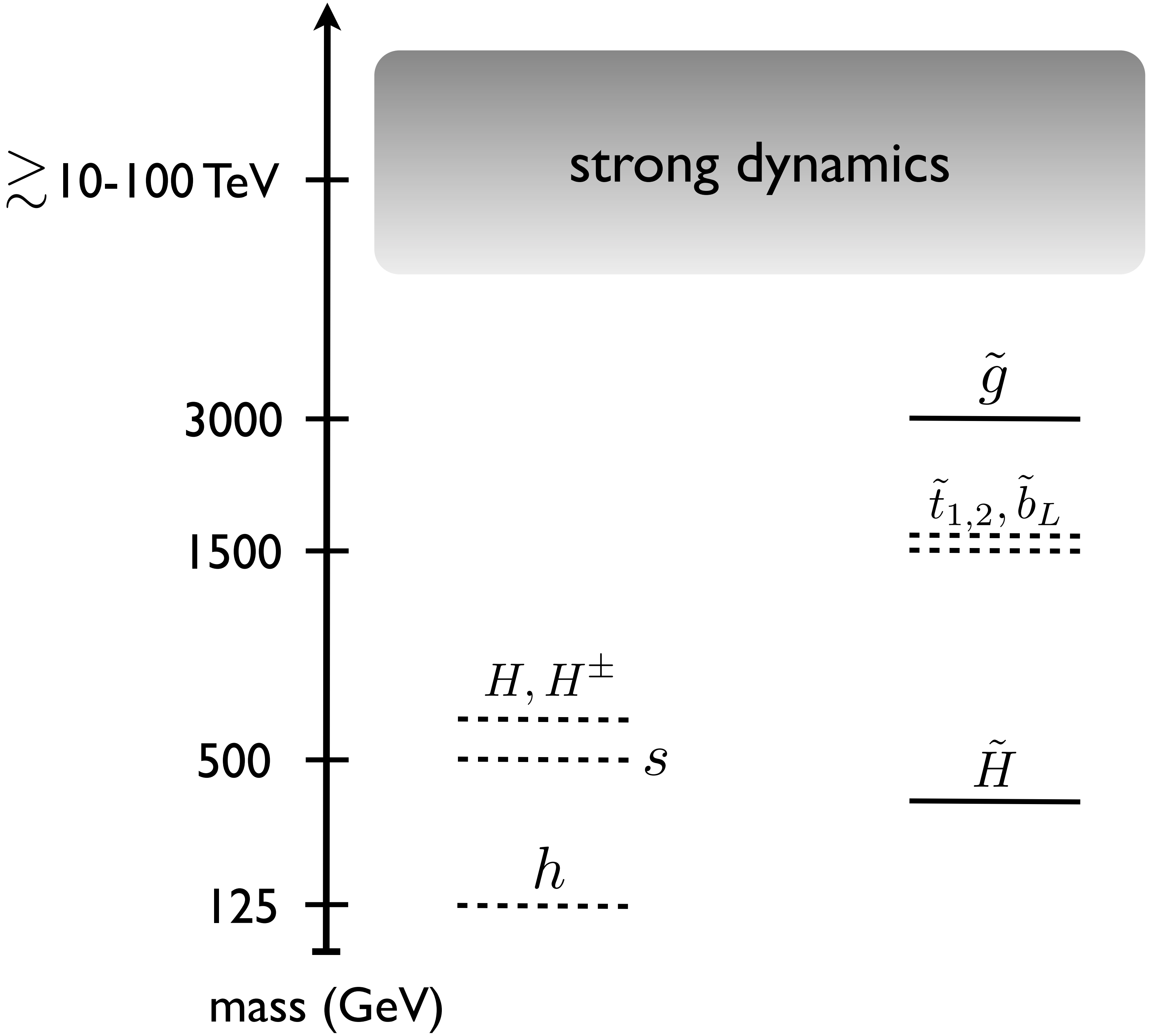
$$V = m_H^2 |h|^2 + \frac{\lambda_h}{4} |h|^4$$

$$\Delta \approx \frac{\delta m_H^2}{m_{h_0}^2/2}$$

where m_{h_0} is the higgs mass before mixing

this means that the stops can be $\sim \lambda/g$ times heavier than the MSSM with the same tuning

A Natural SUSY Spectrum



flavor degen squarks above
current LHC limits are natural!

take away points

- the MSSM requires maximal stop mixing and is ~1% tuned or worse

- the NSSM can be ~10% tuned at the edge of its parameter space,

$$\lambda \approx 0.7, \quad \tan\beta \lesssim 3$$

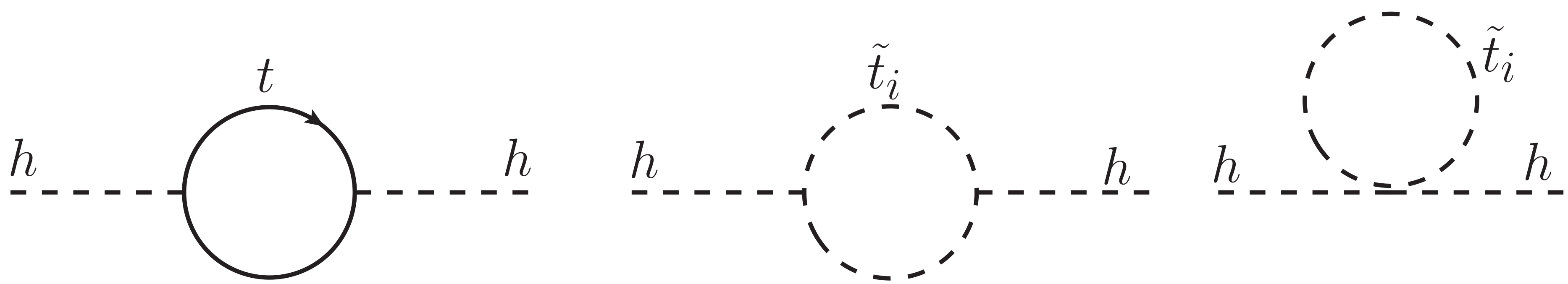
- mh = 125 GeV is natural in $\lambda\mathrm{SUSY}$ with large λ because of singlet-doublet mixing

- in $\lambda\mathrm{SUSY}$, $R_{\gamma\gamma}$ can be enhanced and flavor degen squarks are naturally accommodated

backup

higgs mass in MSSM

- 1-loop:



$$m_h^2 \approx m_Z^2 \cos^2 2\beta + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$

$$\begin{pmatrix} m_{Q_3}^2 + m_t^2 + t_L m_Z & m_t X_t \\ m_t X_t & m_{U_3}^2 + m_t^2 + t_R m_Z^2 \end{pmatrix} \qquad X_t = A_t - \frac{\mu}{\tan\beta}$$

maximal mixing: $|X_t| = \sqrt{6}\, m_{\tilde{t}}$

NSSM

- consider the superpotential:

$$W \supset \lambda\, S H_u H_d + \mu\, H_u H_d + M_S\, S^2$$

which generates:

$$|F_S|^2 \supset \lambda^2 |H_u H_d|^2$$

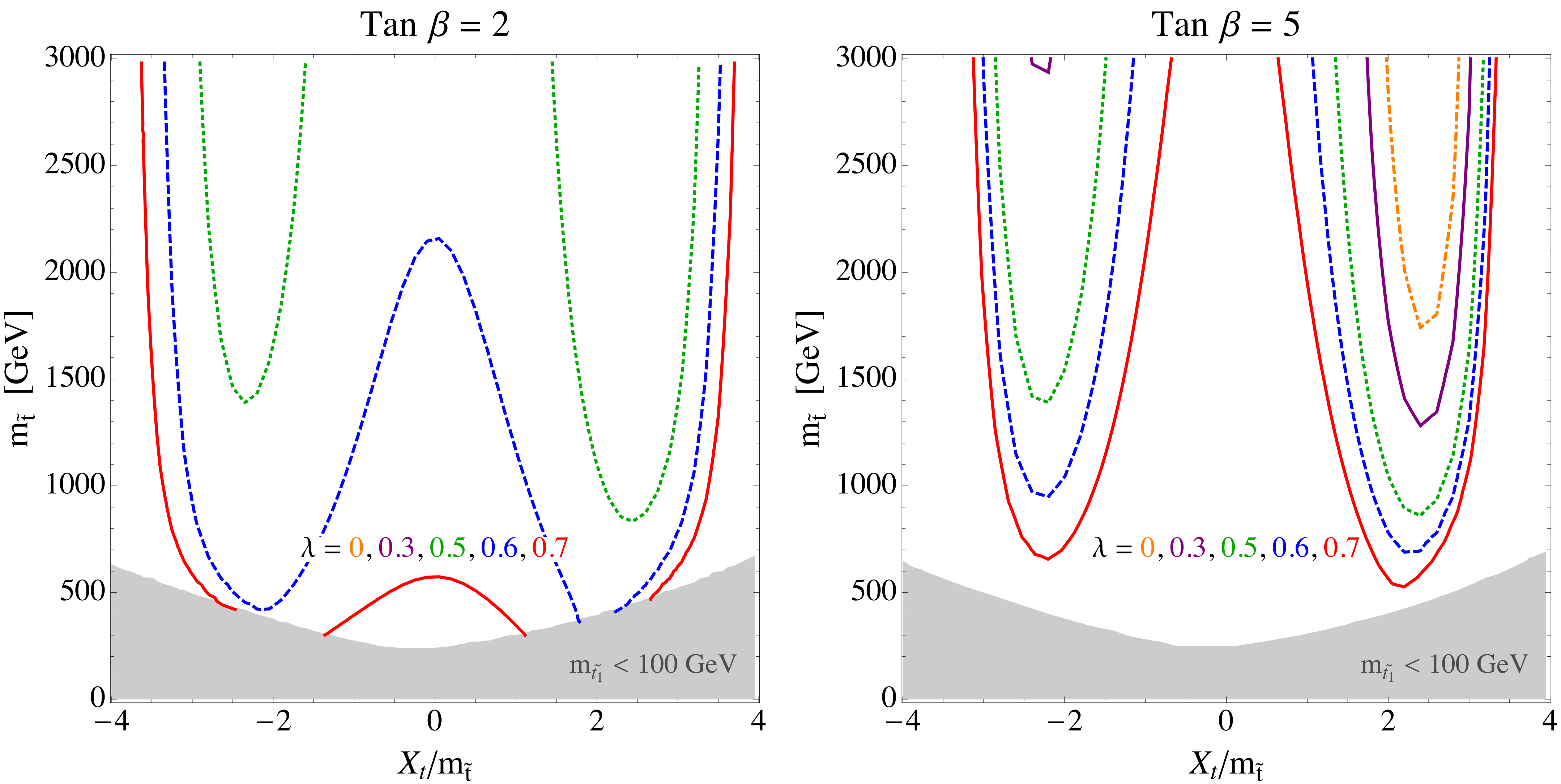
- and soft terms:

$$V_{\rm soft} \supset m_S |S|^2 + (\lambda A_\lambda\, S H_u H_d + {\rm h.c.})$$

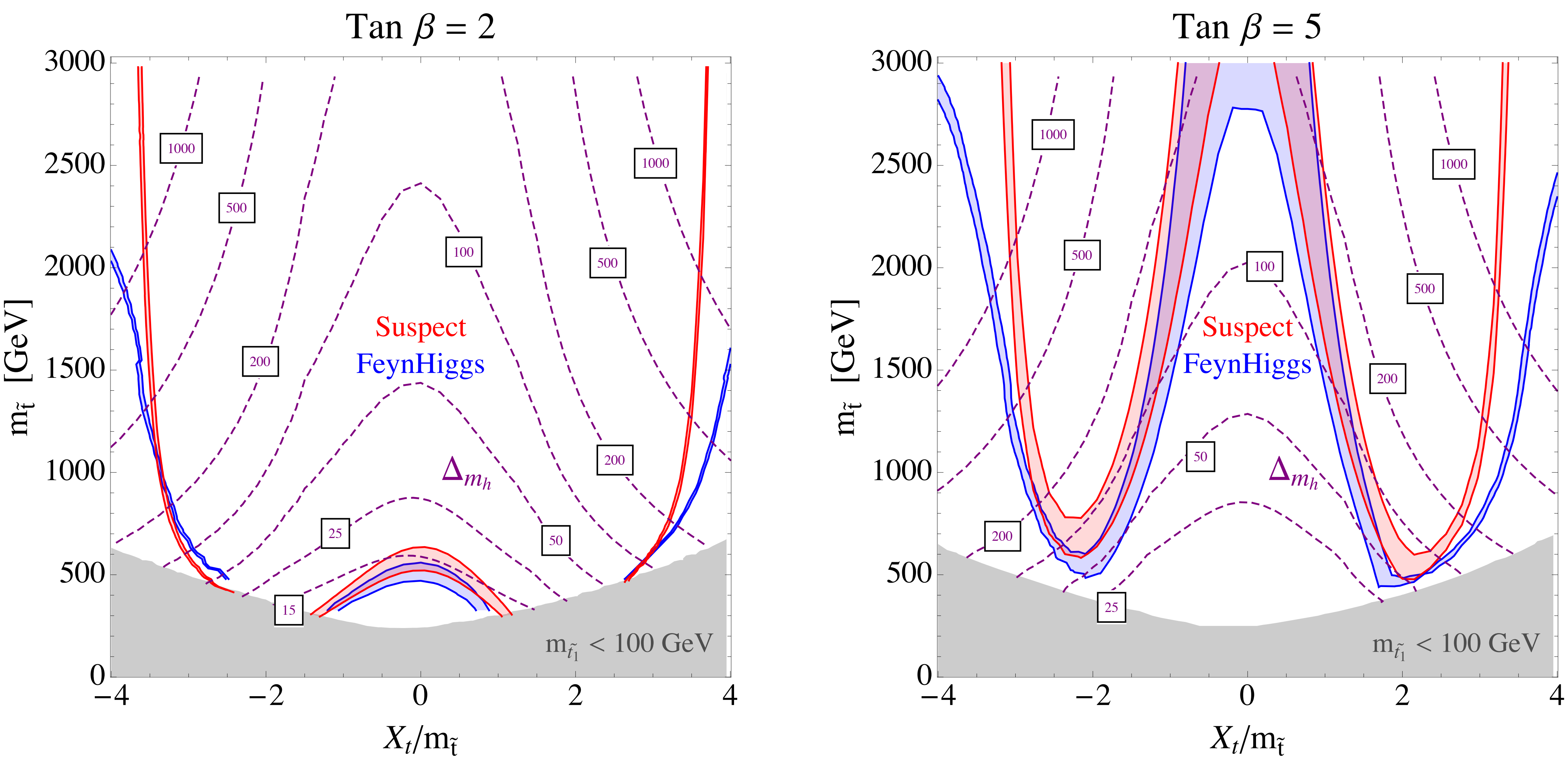
- the lightest CP even eigenvalue satisfies the bound:

$$m_h^2 \le m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta$$

saturated when $m_s \gg M_S$

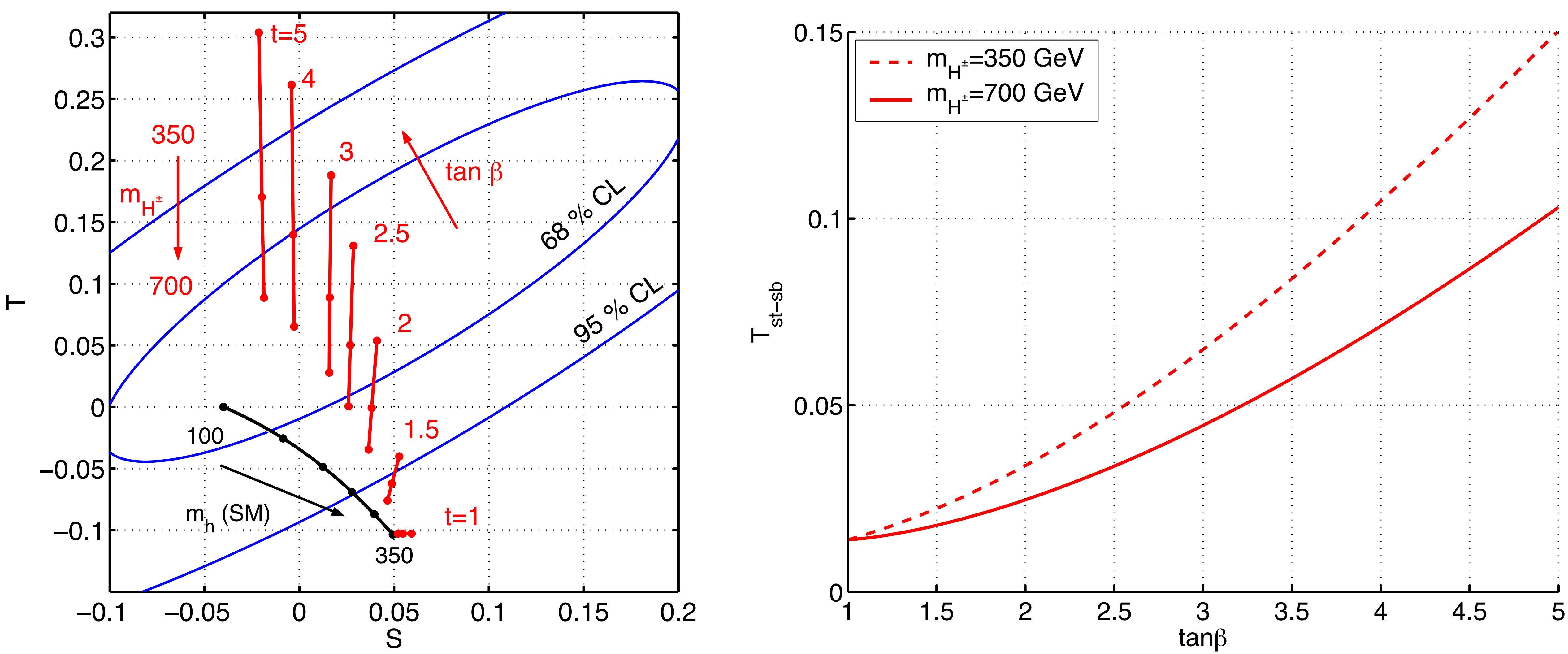


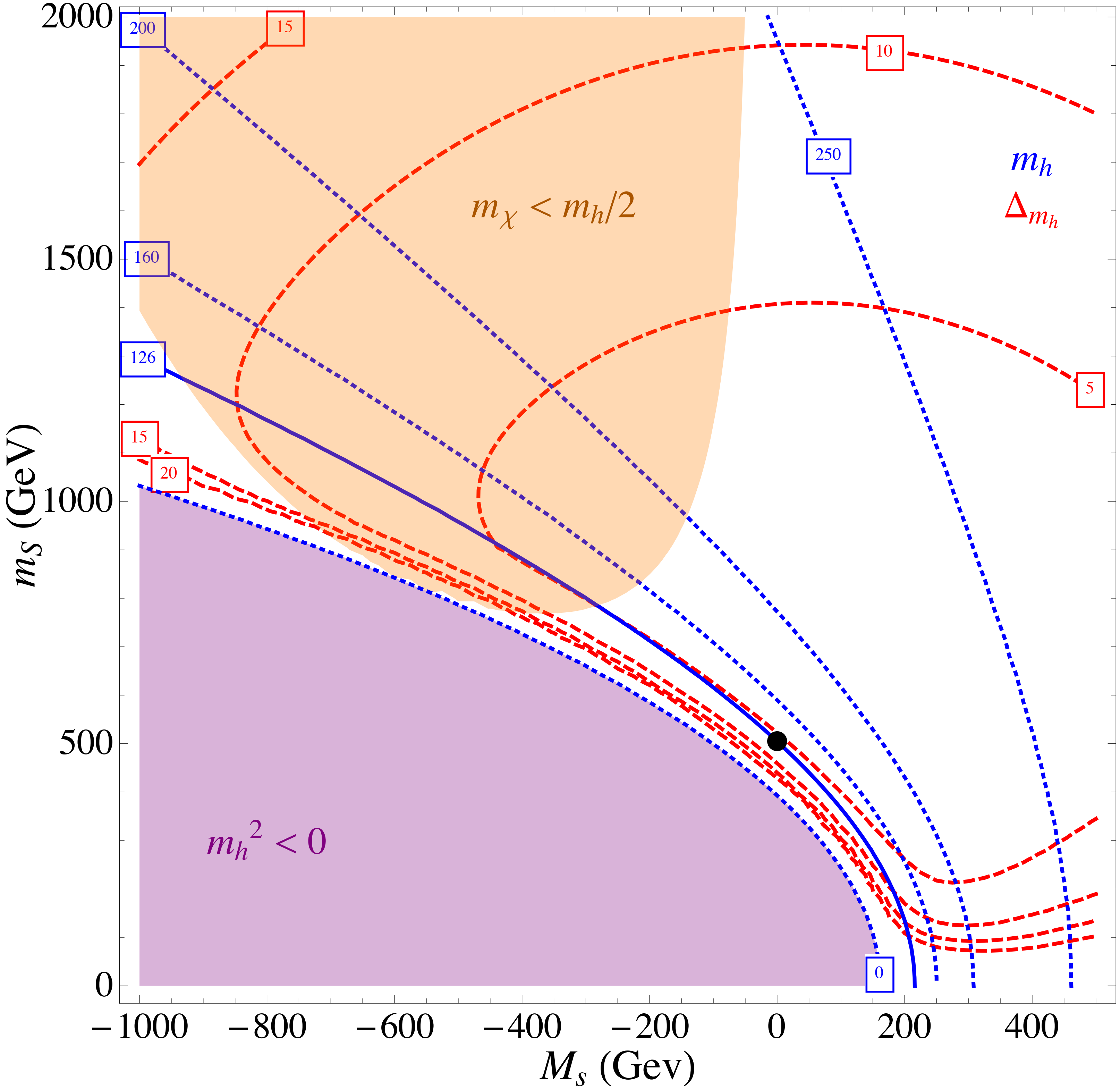
Tan $\beta = 2$
Tan $\beta = 5$
$\lambda = 0, 0.3, 0.5, 0.6, 0.7$
$m_{\tilde{t}_1} < 100$ GeV
$m_{\tilde{t}}$ [GeV]
$X_t/m_{\tilde{t}}$



Tan β = 2
Tan β = 5
$m_{\tilde{t}}$ [GeV]
$X_t/m_{\tilde{t}}$
Suspect
FeynHiggs
Δ_{m_h}
$m_{\tilde{t}_1}$ < 100 GeV
1000
500
200
100
50
25
15

precision electroweak





2000
1500
1000
500
0
−1000
−800
−600
−400
−200
0
200
400
m_S (GeV)
M_s (Gev)
200
15
10
250
160
126
5
15
20
0
m_h
Δ_{m_h}
$m_\chi < m_h/2$
$m_h{}^2 < 0$

large λ protects against fine tuning