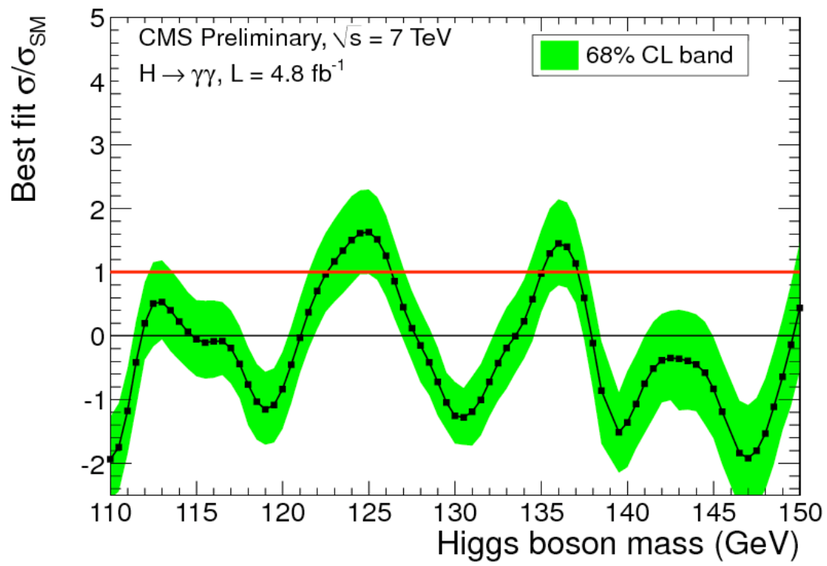
MCTP Symposium
Higgs Boson Physics
Michigan
April 2012

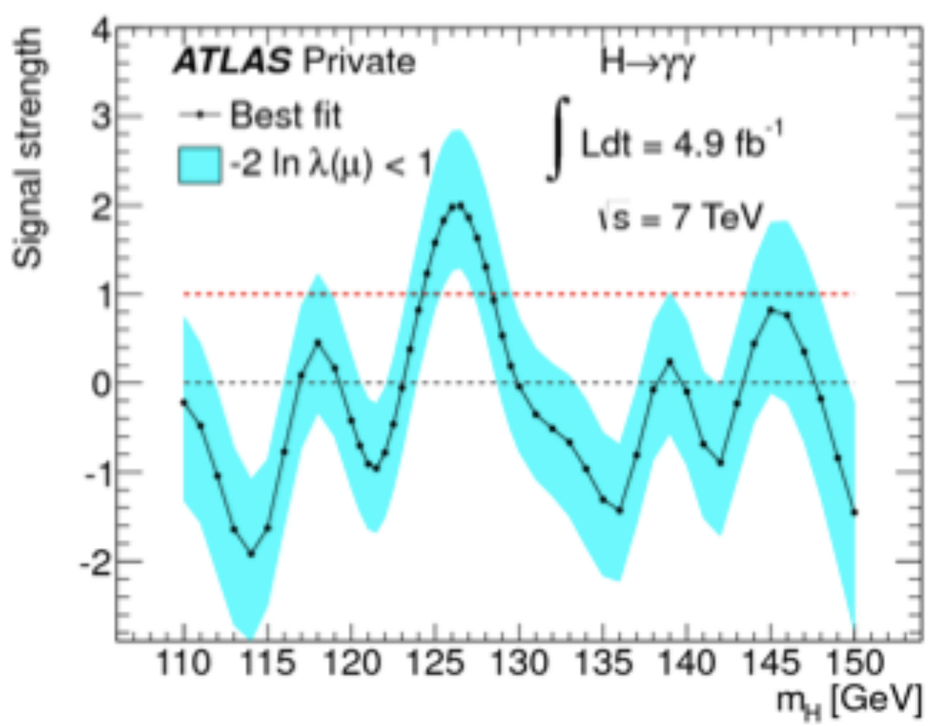
SUSY with a 125 GeV Higgs

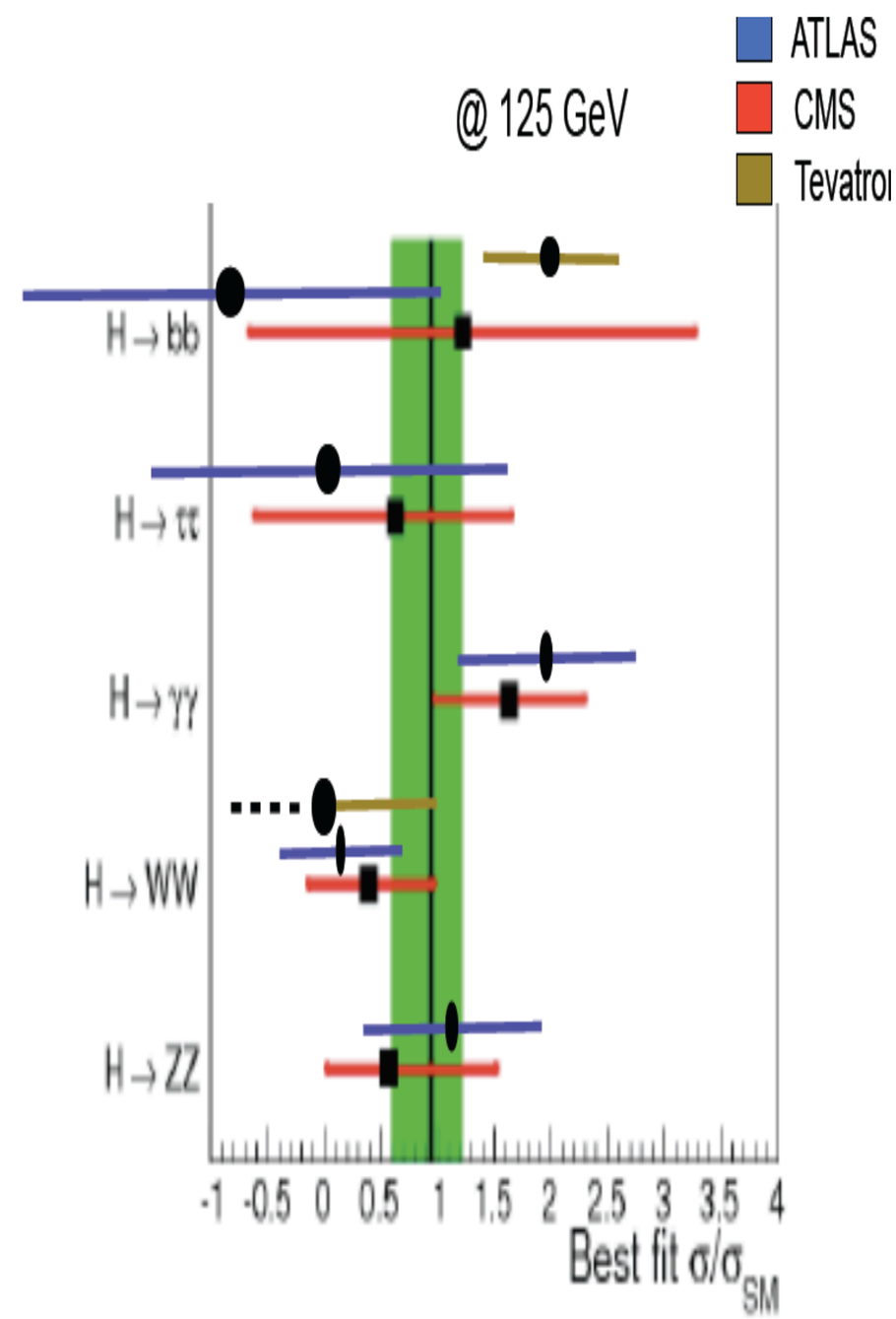
Lawrence Hall
UC Berkeley

BERKELEY CENTER FOR THEORETICAL PHYSICS

Assume 125 GeV Higgs is Real!



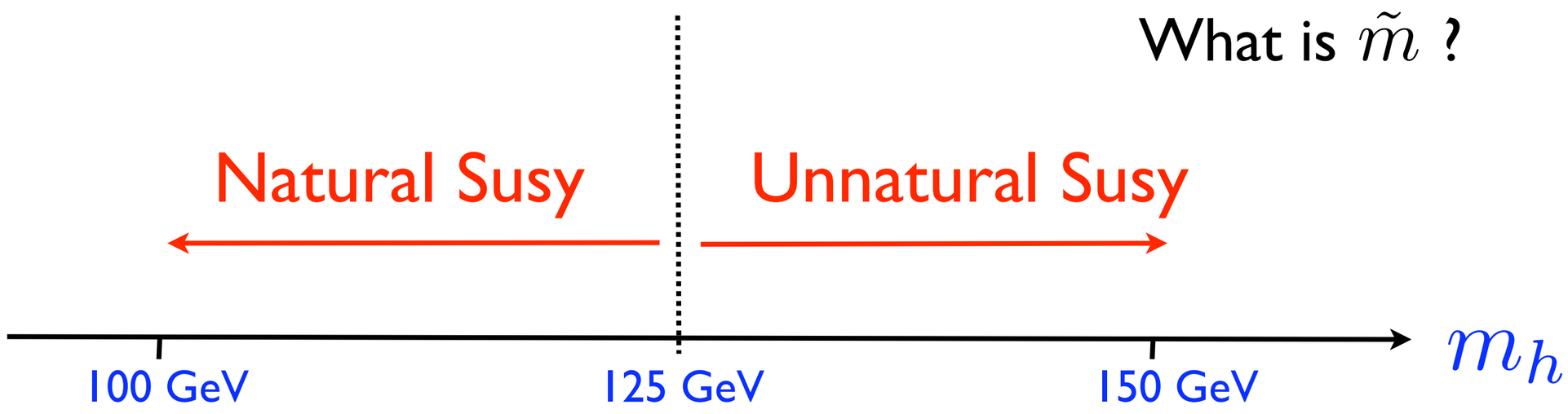




Is SUSY Natural?

Natural	Unnatural
Weak Scale: $v \sim \tilde{m} \sim \mathrm{TeV}$	$v \ll \tilde{m}$
Many superpartners at TeV scale	
LSP Dark Matter: $T_{eq} \sim \frac{v^2}{M_{Pl}}$	fixes m_{LSP}
	a few superpartners at TeV scale

What is $\tilde{m}$?



The Grand Vision of Susy Unification intact
--but details unclear!

1

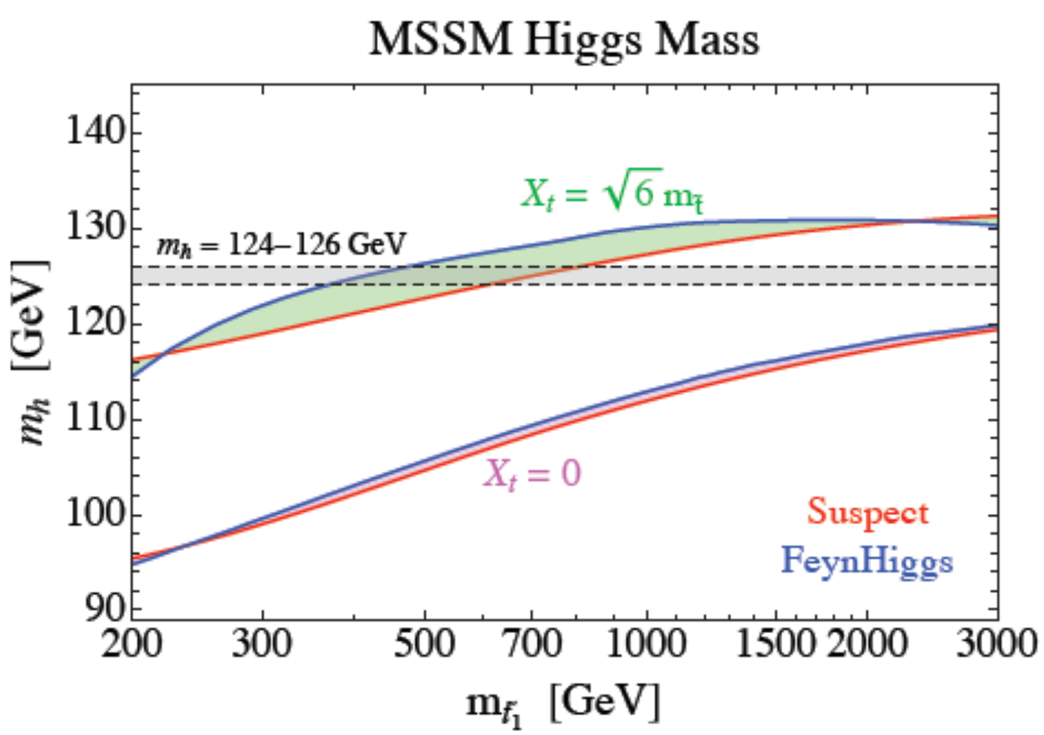
Natural Weak-Scale SUSY

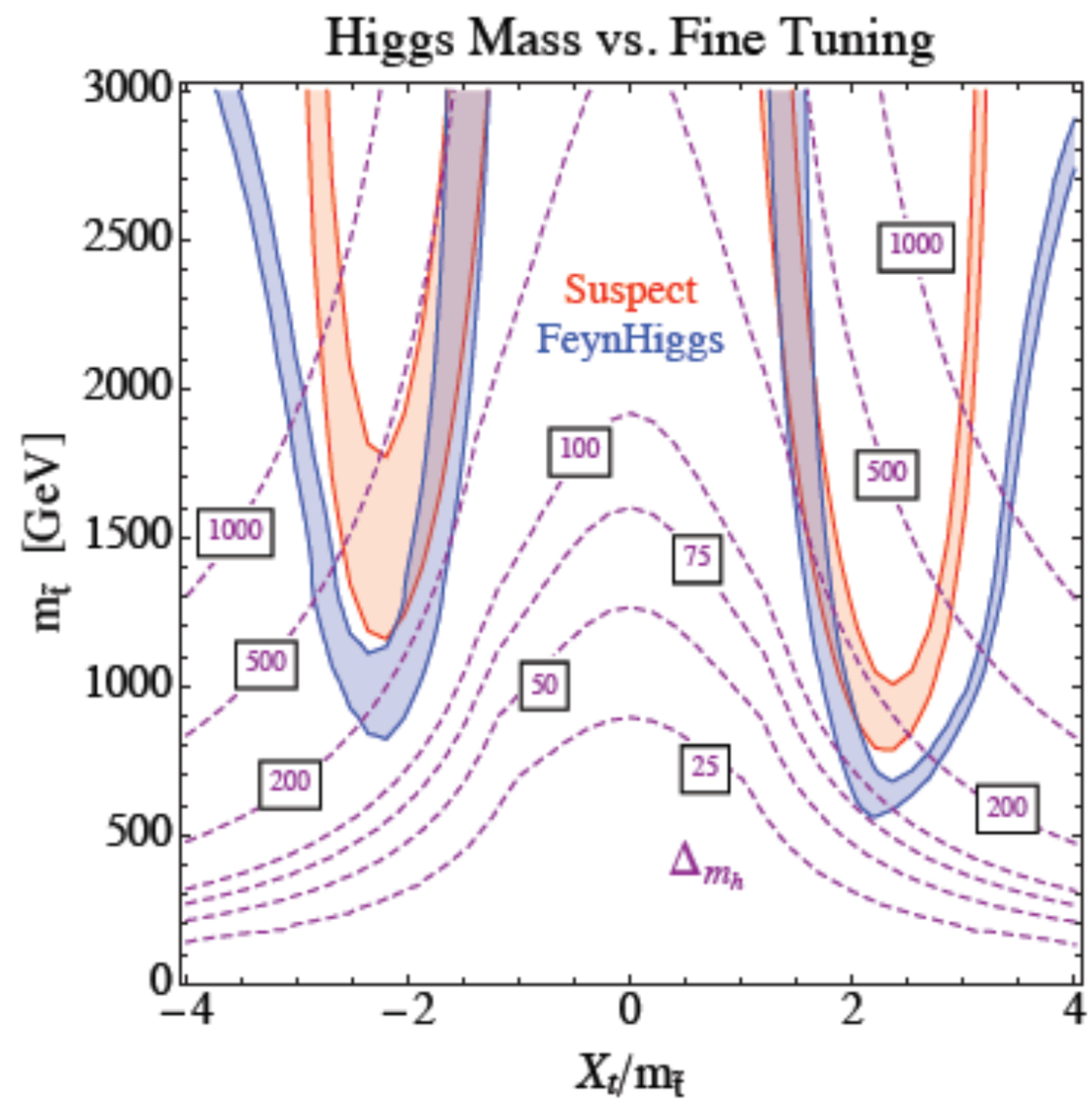
LJH
David Pinner
Josh Ruderman
1112.2703

A Perturbative to Unified Scales

125 GeV Higgs in MSSM

Decoupled region at large $\tan\beta$





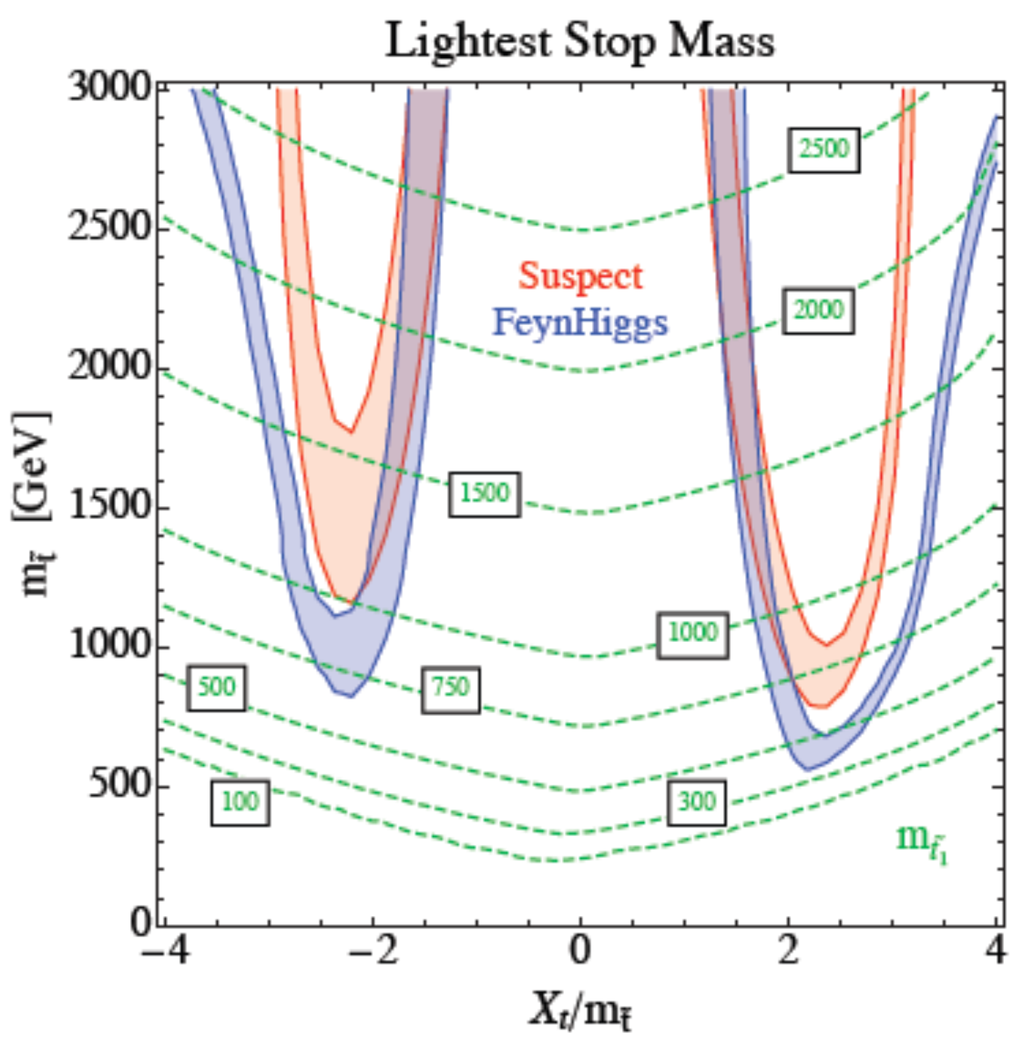
$m_{Q_3} = m_{U_3}$ to minimize Δ

Need large stop mixing

$$\Delta > 100$$

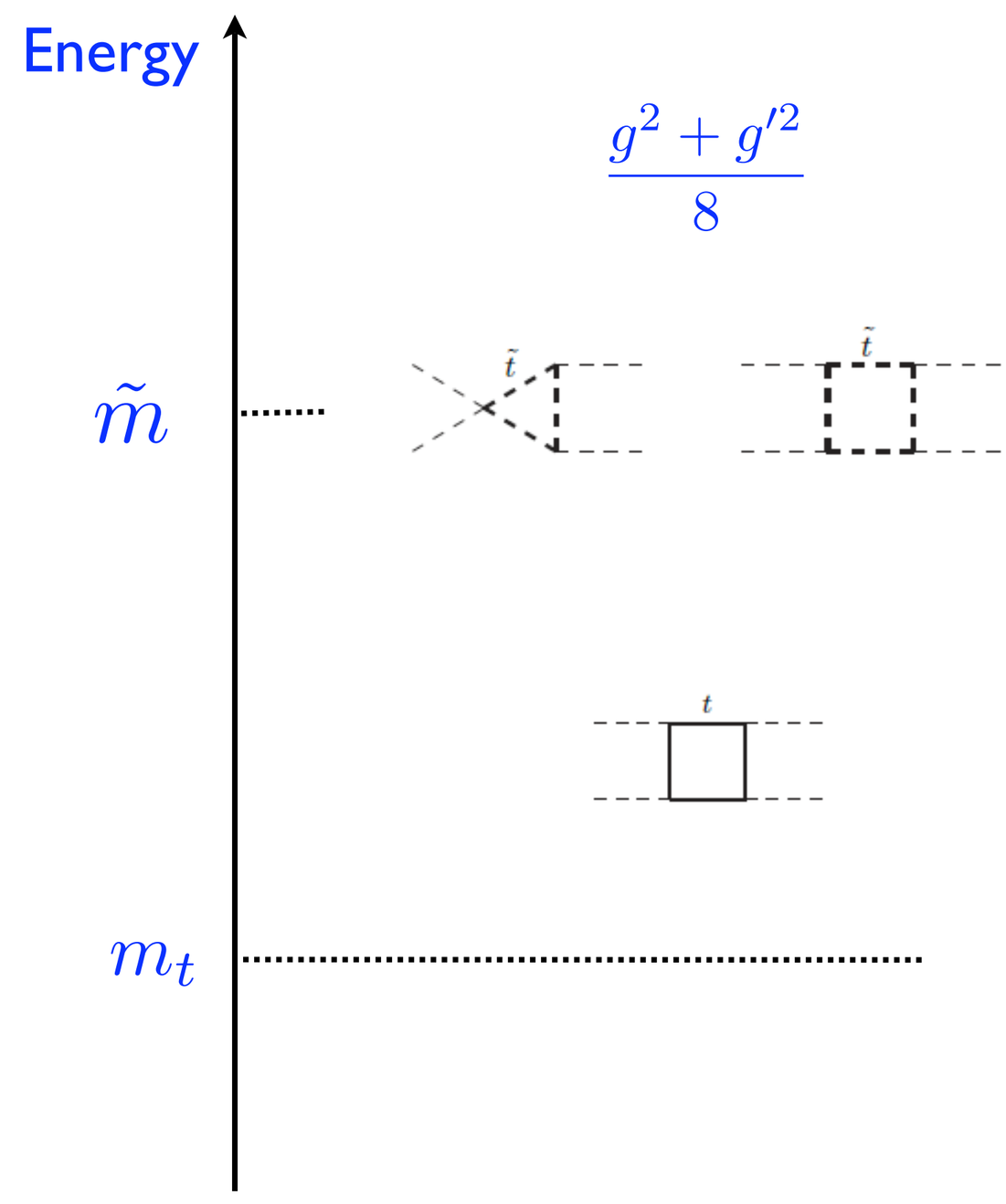
even for messenger scale of 10 TeV

Top Squarks are Heavy

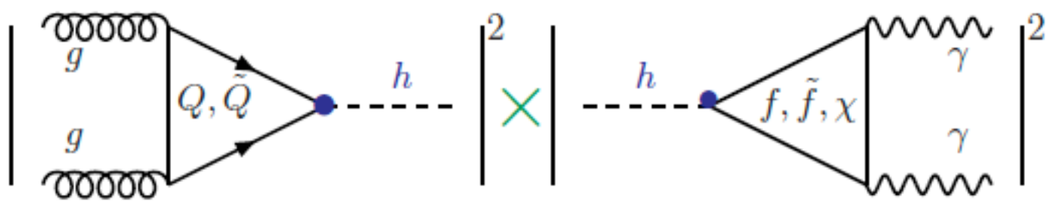


$$m_h = (124 - 126)\ \text{GeV}$$
$$\tan\beta = 20$$
$$m_A = 1\,\text{TeV}$$

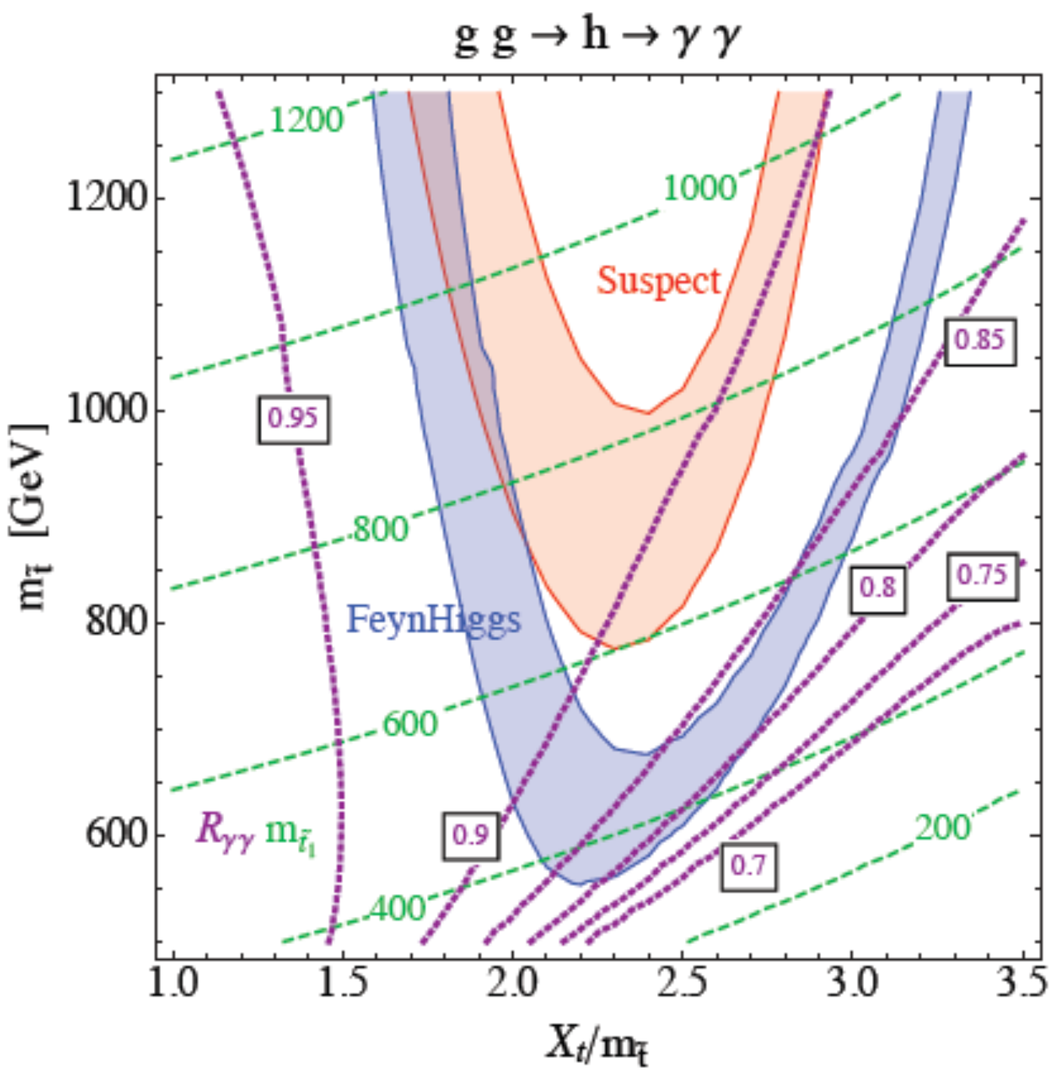
Contributions to the Higgs quartic



Effect of Stops on $h \to \gamma\gamma$ Rate



modifies rate by $B\,\sigma$



$\gamma\gamma$ rate depleted by 7% - 20% in MSSM

$$m_h = (124 - 126)\ \text{GeV}$$
$$\tan\beta = 20$$
$$m_A = 1\,\text{TeV}$$

The NMSSM: Reaching 125 GeV

$$\lambda S H_u H_d$$

$\lambda < 0.7$

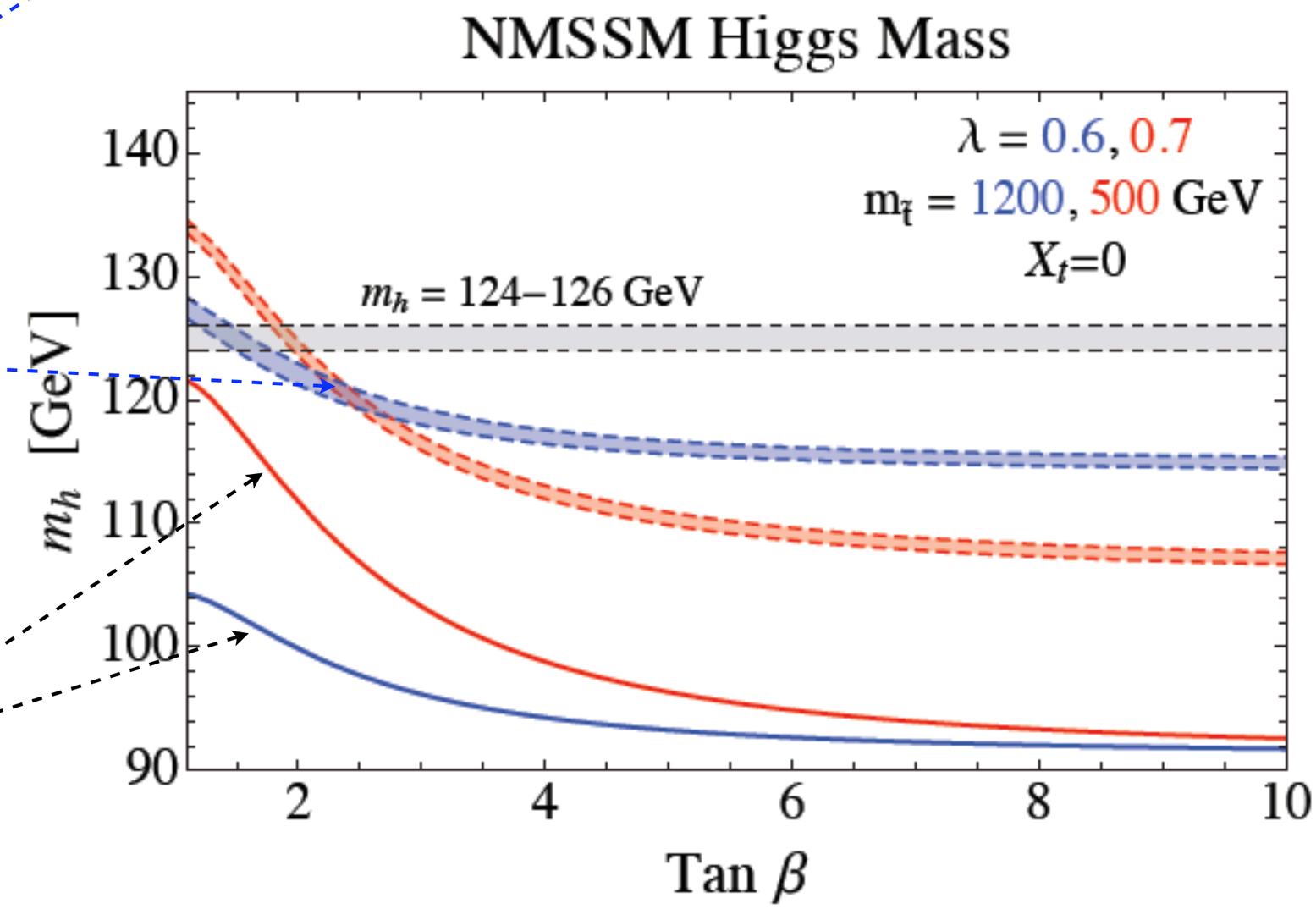
Restricted scan for a natural region

Maximize by $\kappa = 0$

$$m_h^2 = M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \delta_t$$

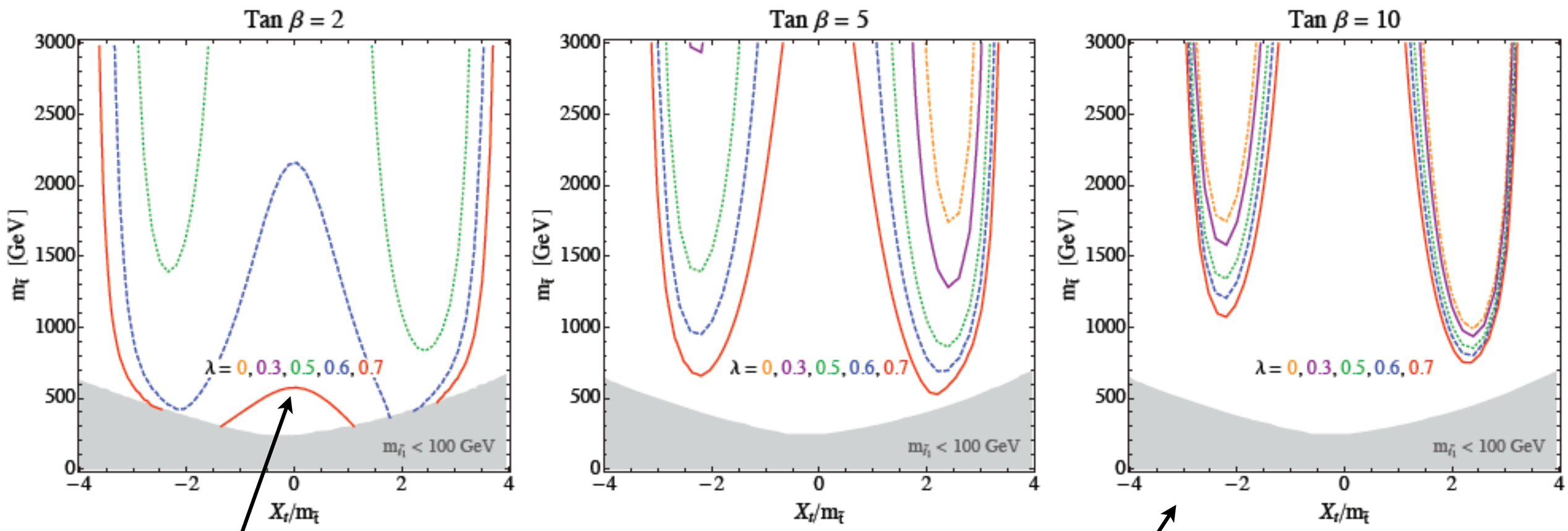
Suspect/FeynHiggs

Tree level



125 GeV Contours in the NMSSM

$$\longleftarrow \lambda^2 v^2 \sin^2 2\beta \longrightarrow$$



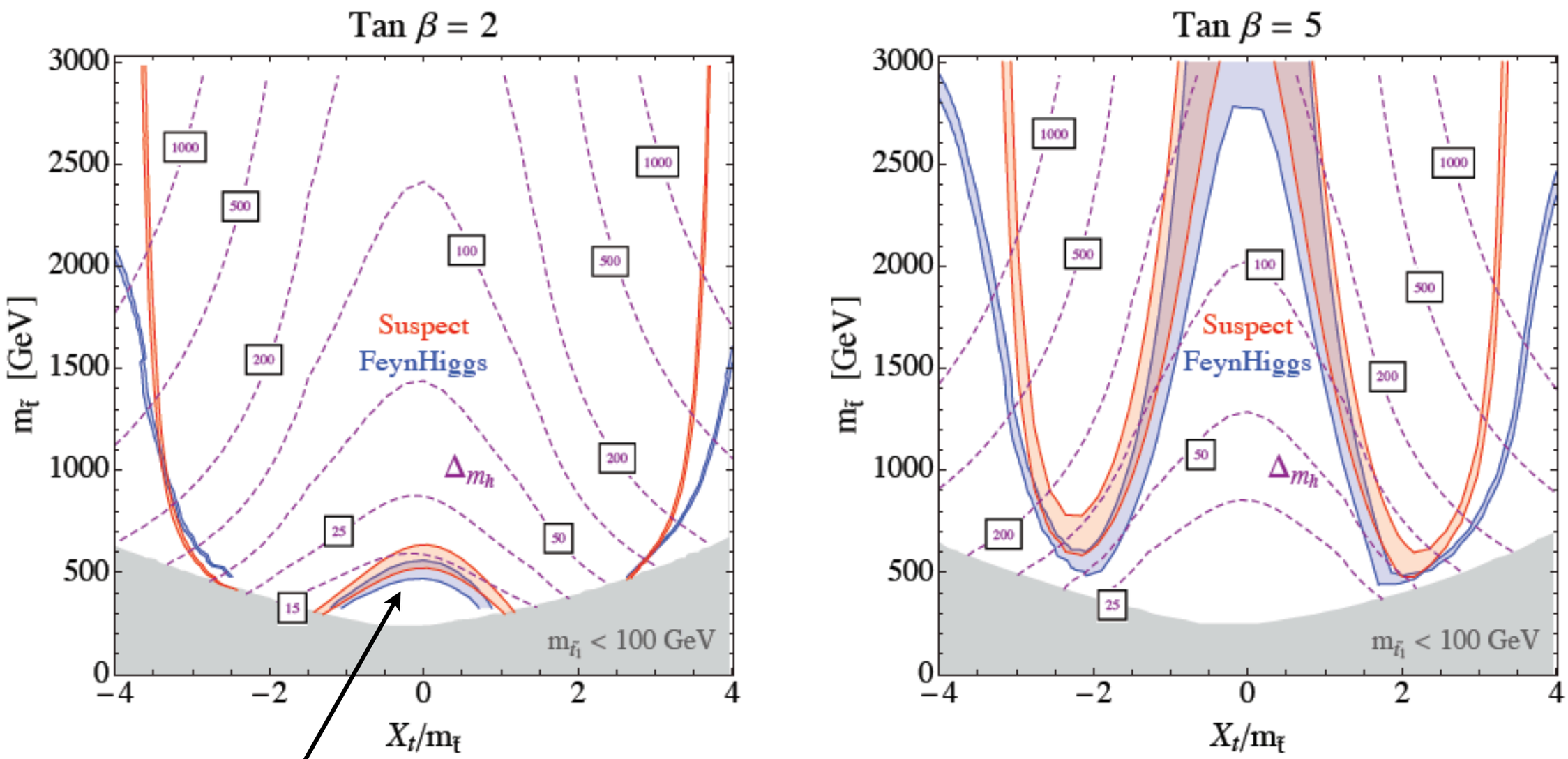
Light stop over wide range of mixing

MSSM-like

$$\mu = 200\,\mathrm{GeV} \qquad m_A = 500\,\mathrm{GeV}$$

Naturalness in NMSSM

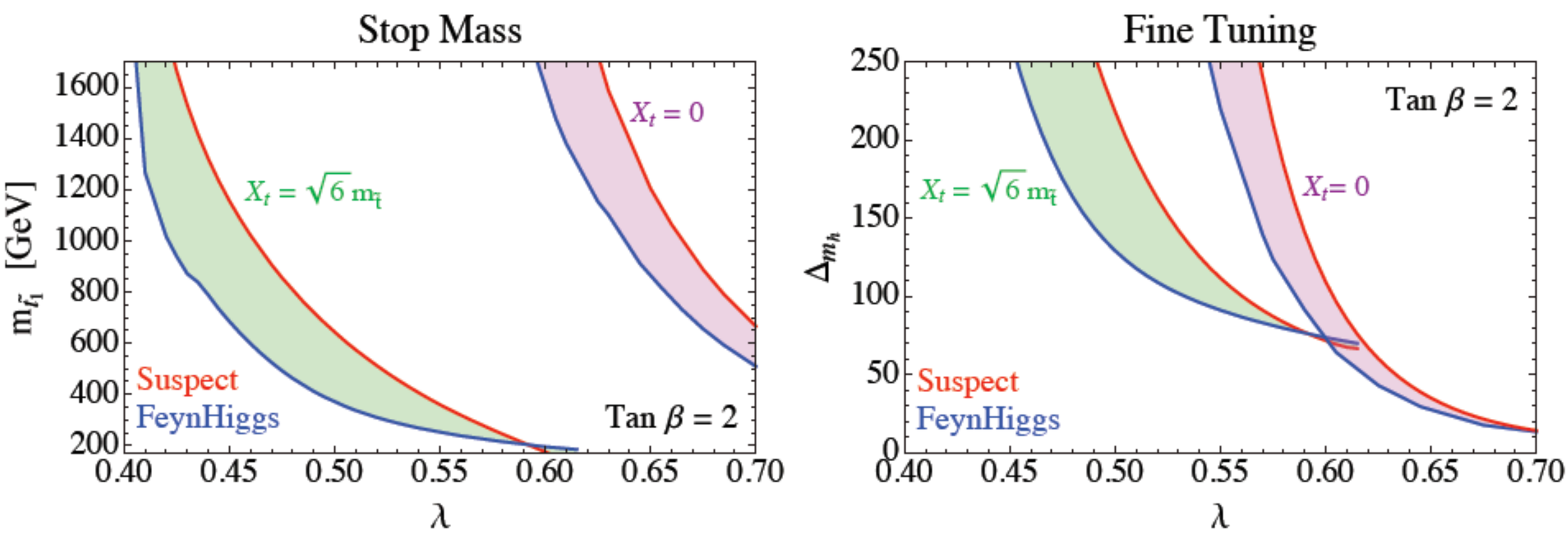
$$\lambda = 0.7$$



Factor 10 improvement over MSSM
Over wide range of mixing

$$M_{mess} = 10\,\mathrm{TeV}$$

The Need for Large λ.



What about larger λ ?

1

Natural Weak-Scale SUSY

$\mathcal{B}$ Non-Perturbative below Unified Scales

λ- Susy

$$\lambda S H_u H_d$$

$$0.7 < \lambda < 2$$

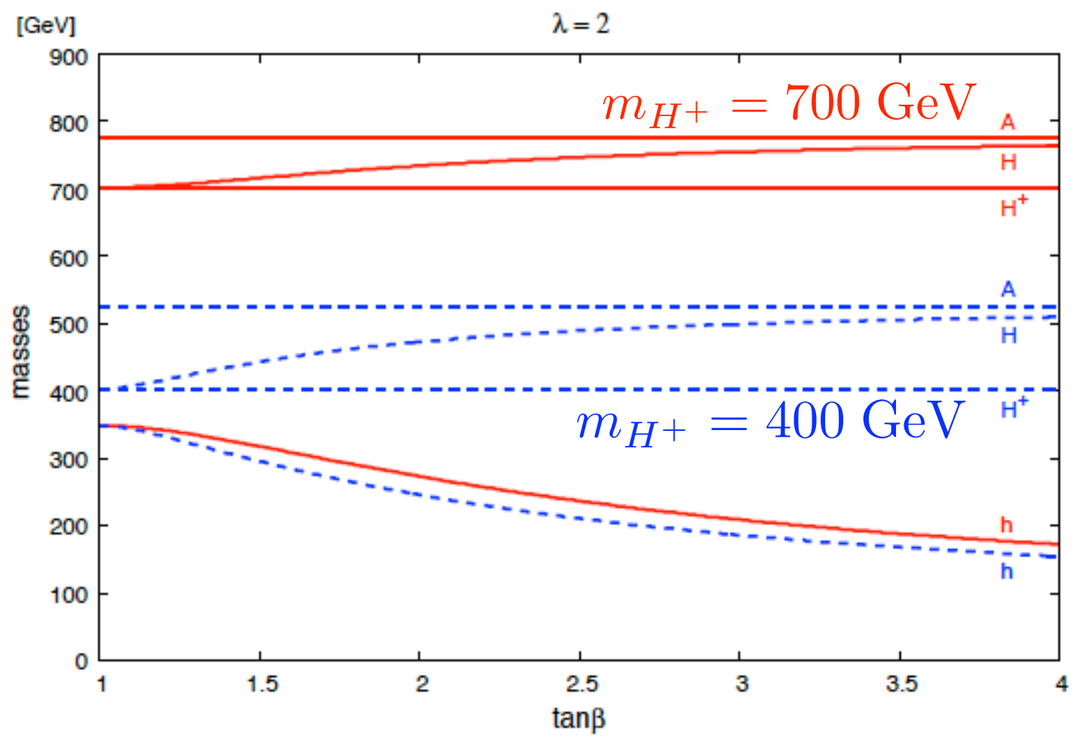
Naively expect lightest
Higgs to be heavy:

$$m_h^2 = M_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta + \delta_t$$

Improved naturalness with heavier superpartners

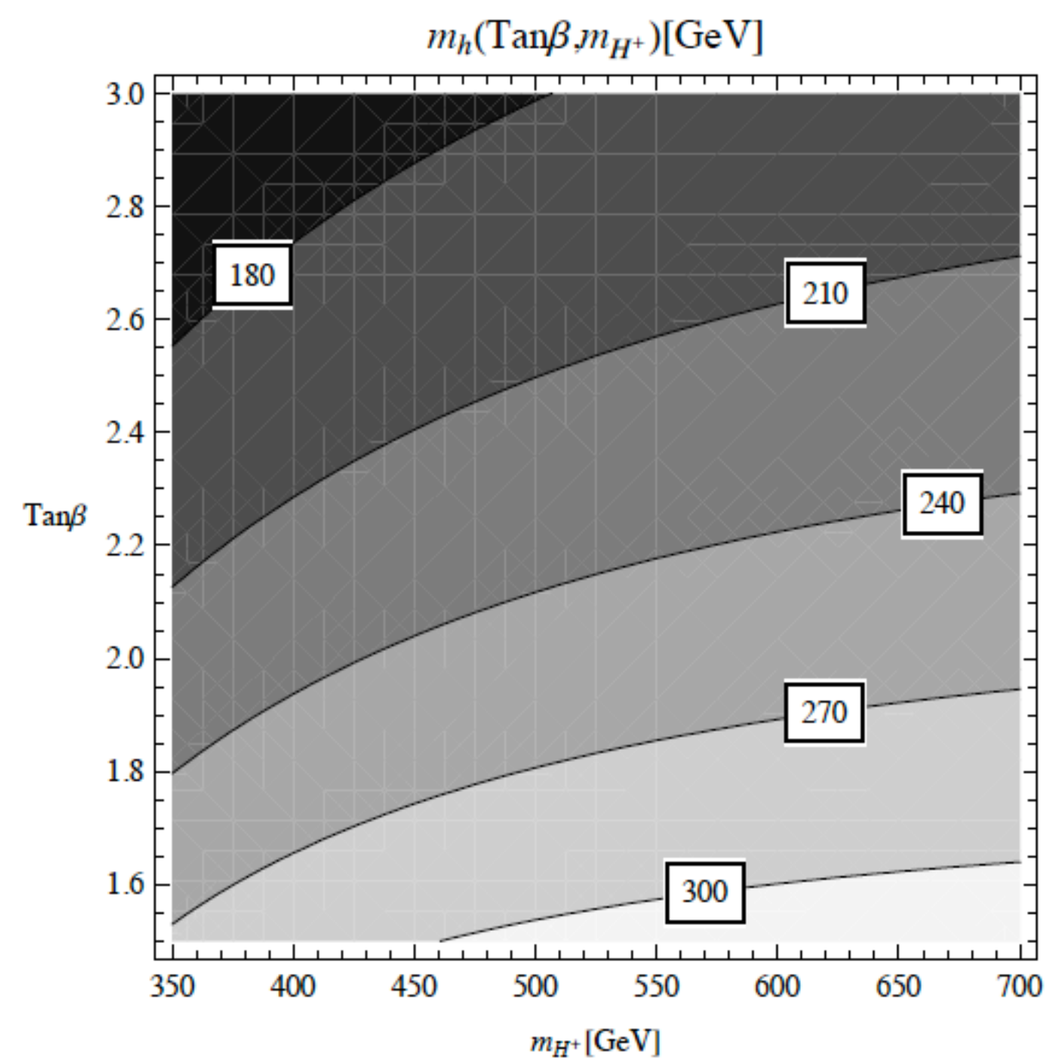
Barbieri, Hall, Nomura, Rychkov
hep-ph/0607332

The Literature: h is Too Heavy!



Barbieri, Hall, Nomura, Rychkov
hep-ph/0607332

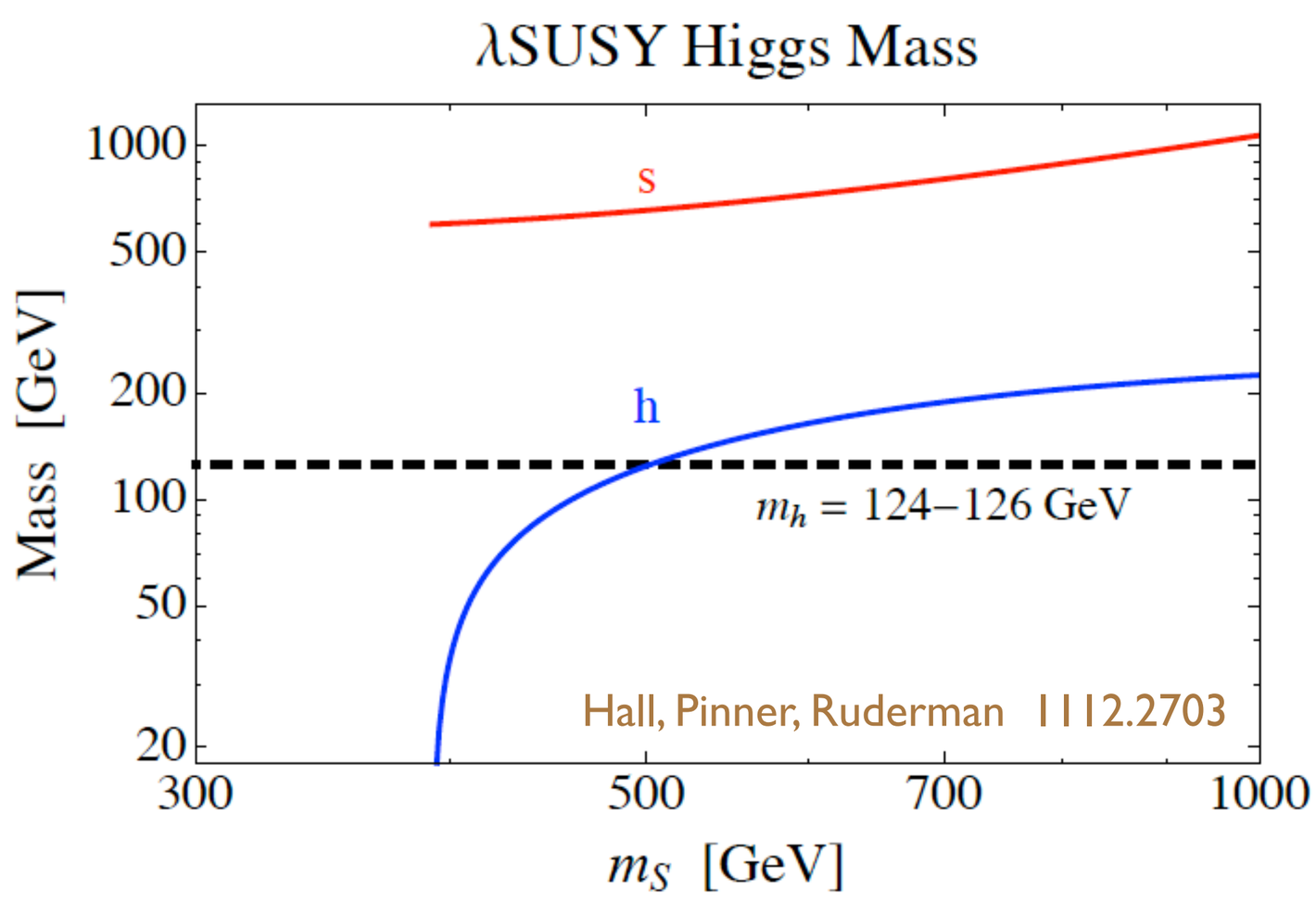
$$1.5 \lesssim \tan\beta \lesssim 3\,,$$
$$350 \text{ GeV} \lesssim m_{H^\pm} \lesssim 700 \text{ GeV}$$



Cavicchia, Franceschini, Rychkov
0710.5750

Singlet-Doublet Higgs Mixing

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

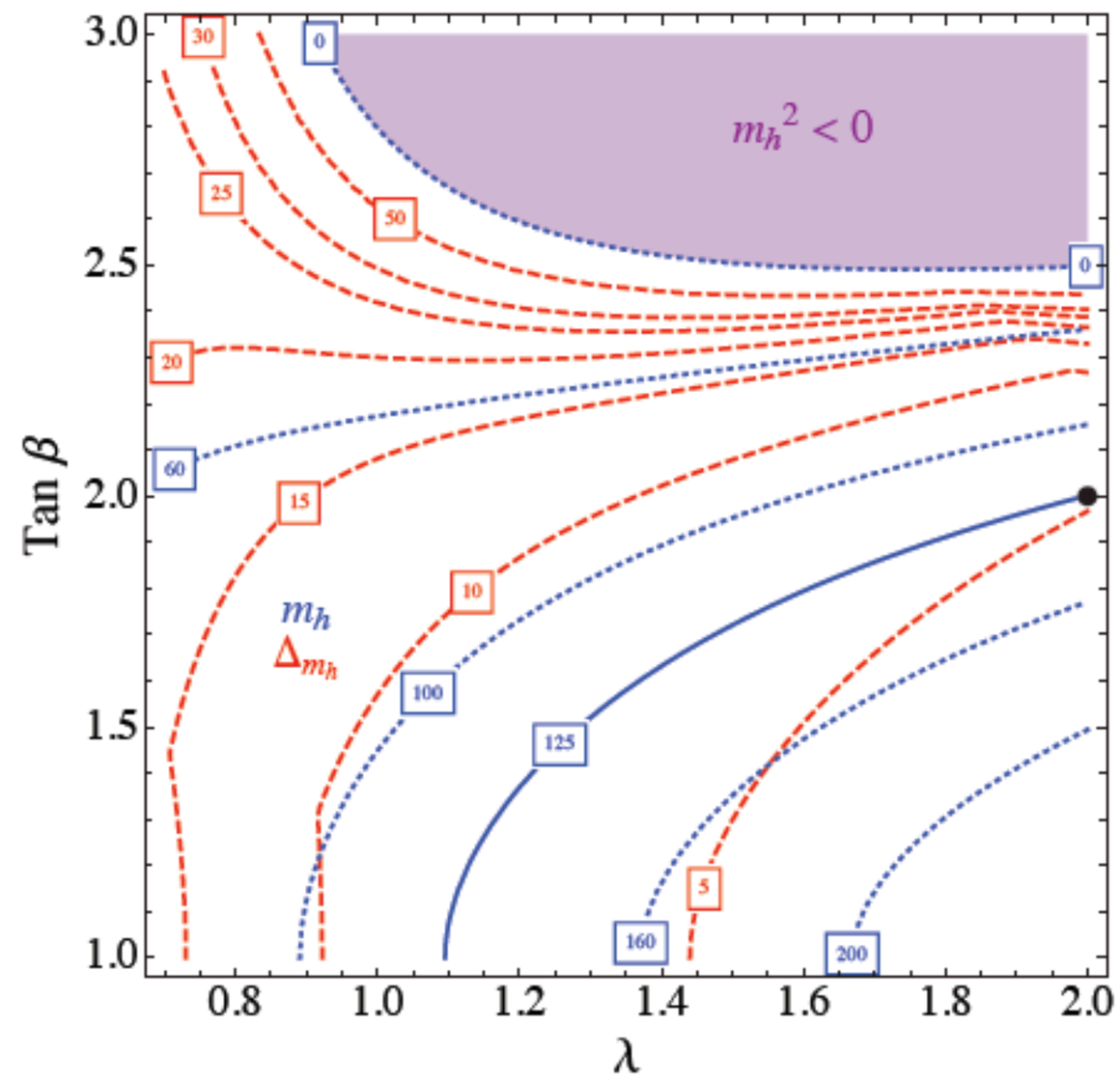


Higgs Mass and Fine-Tuning

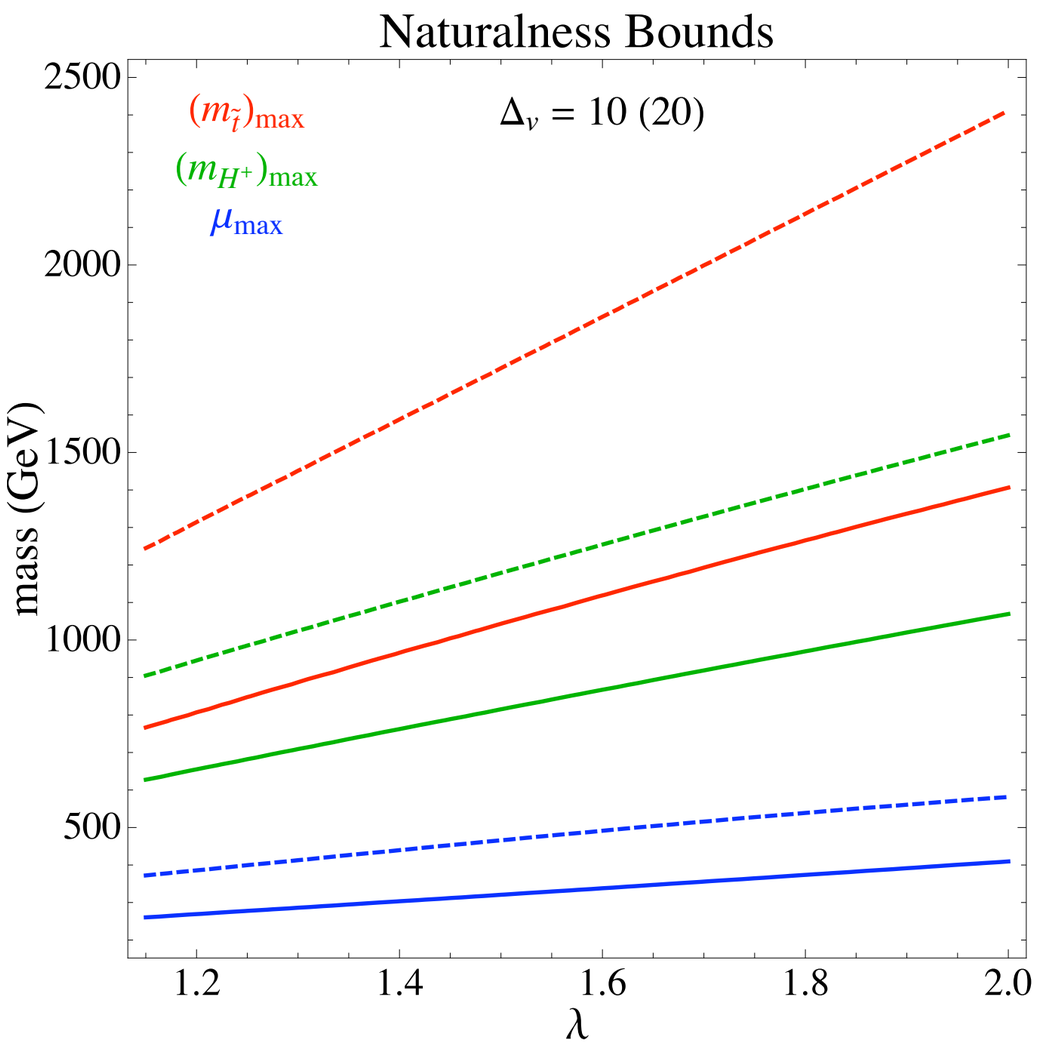
Reference point

parameters	
$\lambda = 2$	$\tan\beta = 2$
$\mu = 200$ GeV	$M_S = 0$ GeV
$m_S = 510$ GeV	$m_{H^+} = 470$ GeV
$m_{Q_3} = m_{u_3} = 500$ GeV	
$A_t, A_\lambda = 0$	

$$m_h = 125 \text{ GeV} \qquad \theta_{hs} = 0.12$$
$$m_{h_{2,3}} = 521, 662 \text{ GeV}$$
$$m_{A_{1,2}} = 579, 617 \text{ GeV}$$
$$\Delta_{m_h} = 5.2$$

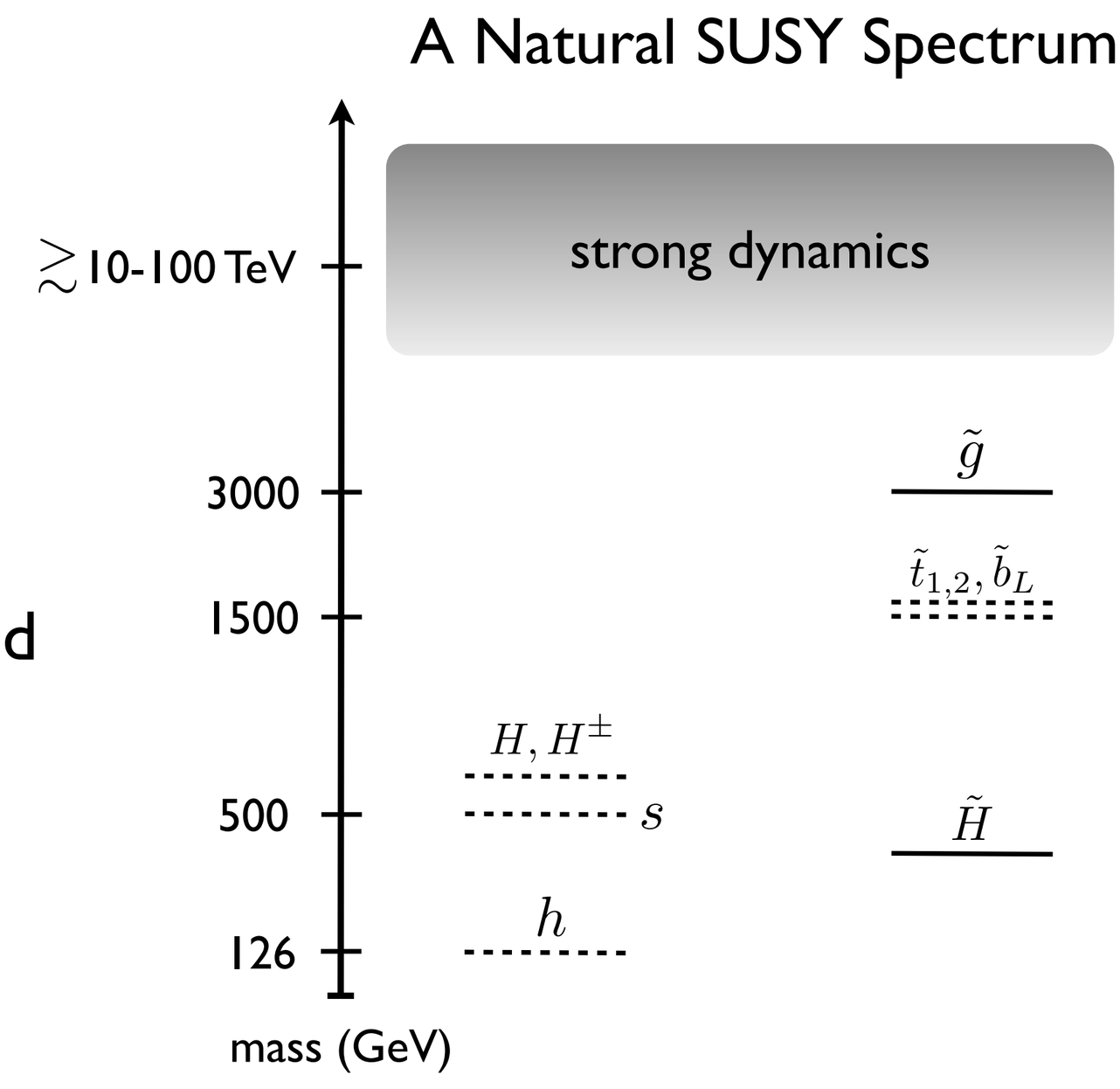


Naturalness Bounds on Spectrum



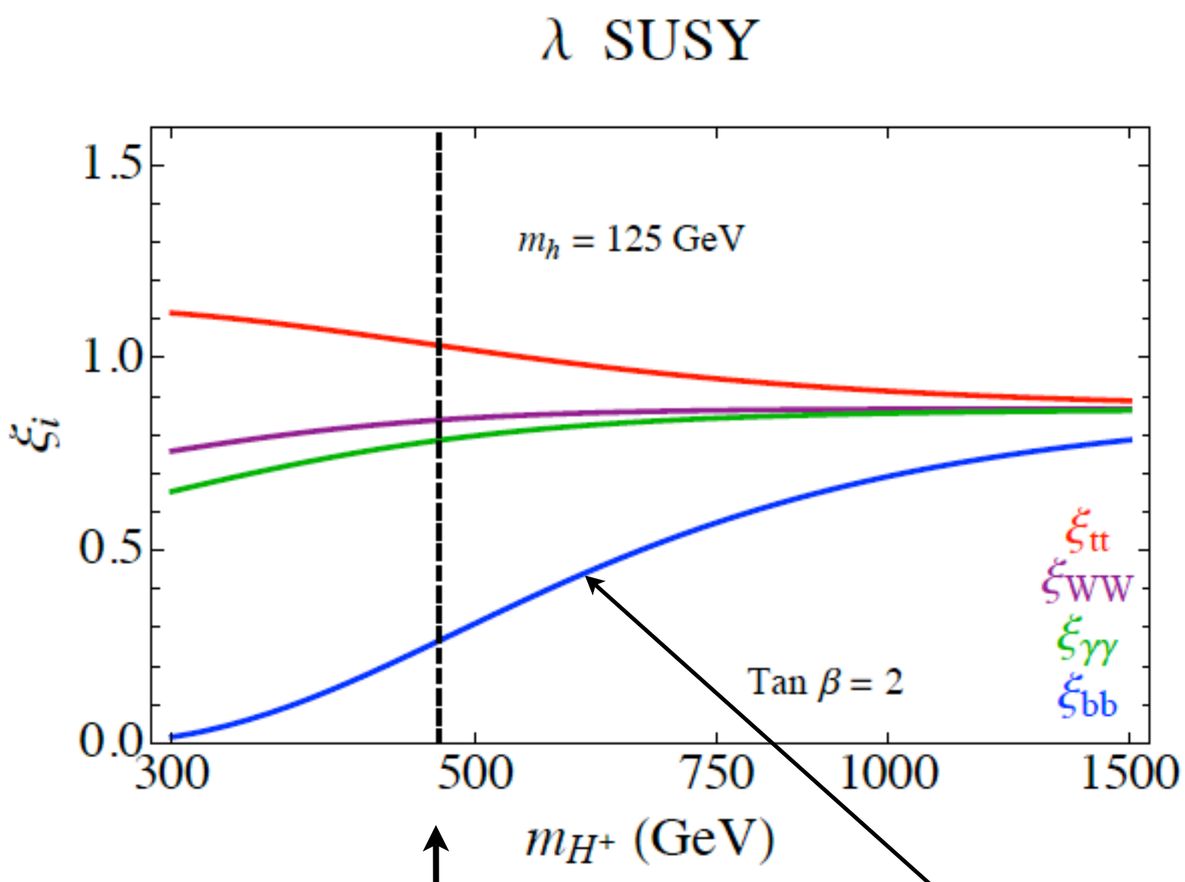
Natural theory with all colored superpartners above 1 TeV!

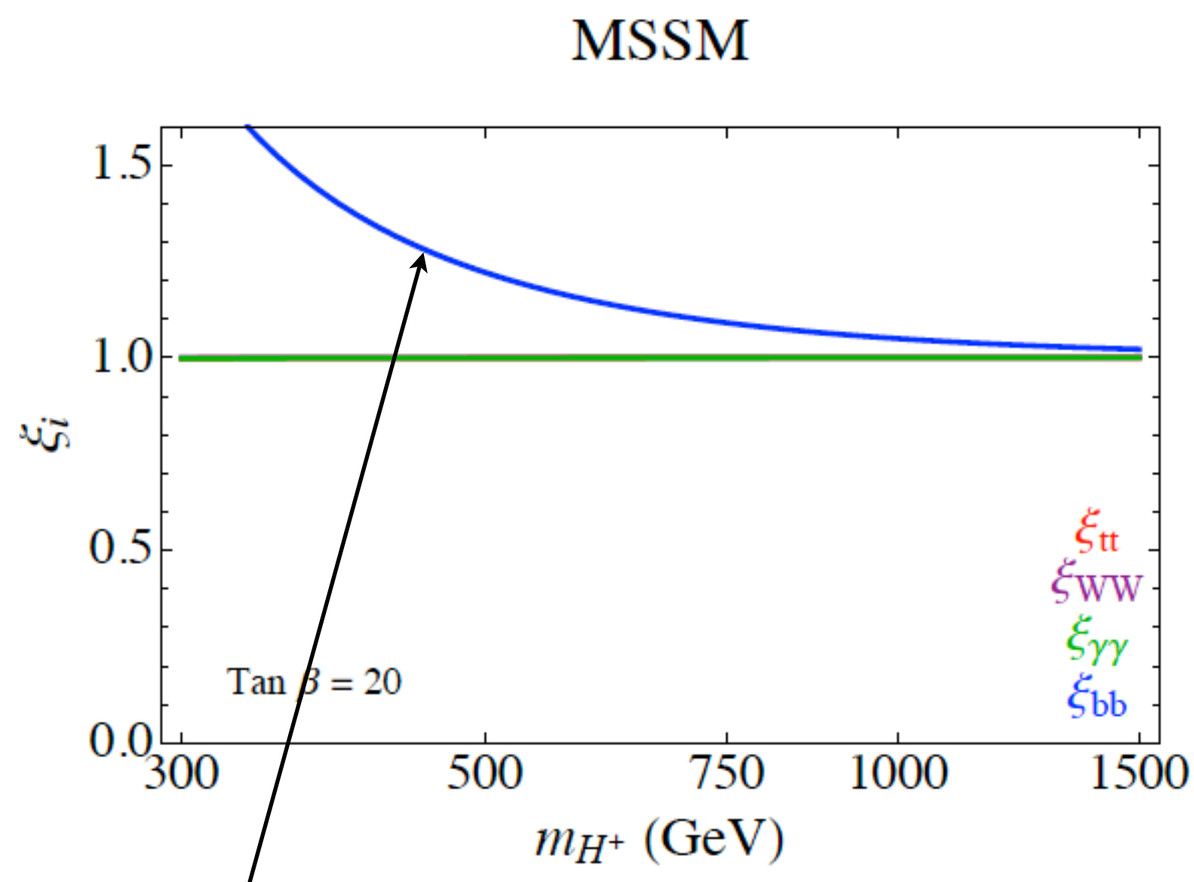
These are bounds
-- stops can be light!!



Modification of Higgs Couplings

Large non-decoupling effects
as mass of second doublet reduced





Reference point

Bigger and opposite sign in λ-SUSY

$$\xi_{b\bar{b},t\bar{t},\gamma\gamma,WW} = (0.27, 1.03, 0.79, 0.84)$$

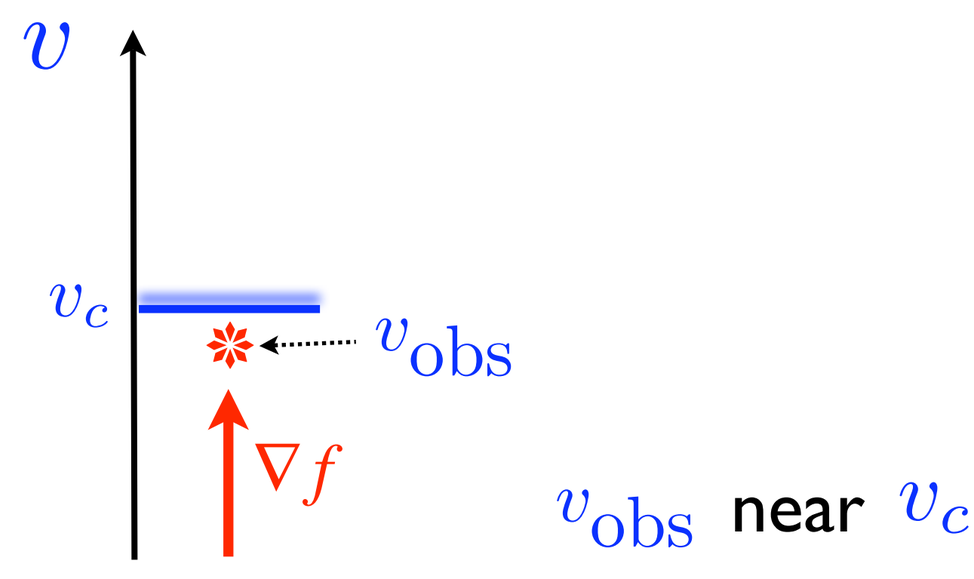
$$R_{\gamma\gamma} = 1.67 \quad R_{WW} = 1.79 \quad R_{bb} = 0.46$$

II

SUSY with

Unnatural Weak Scale

eg The Multiverse

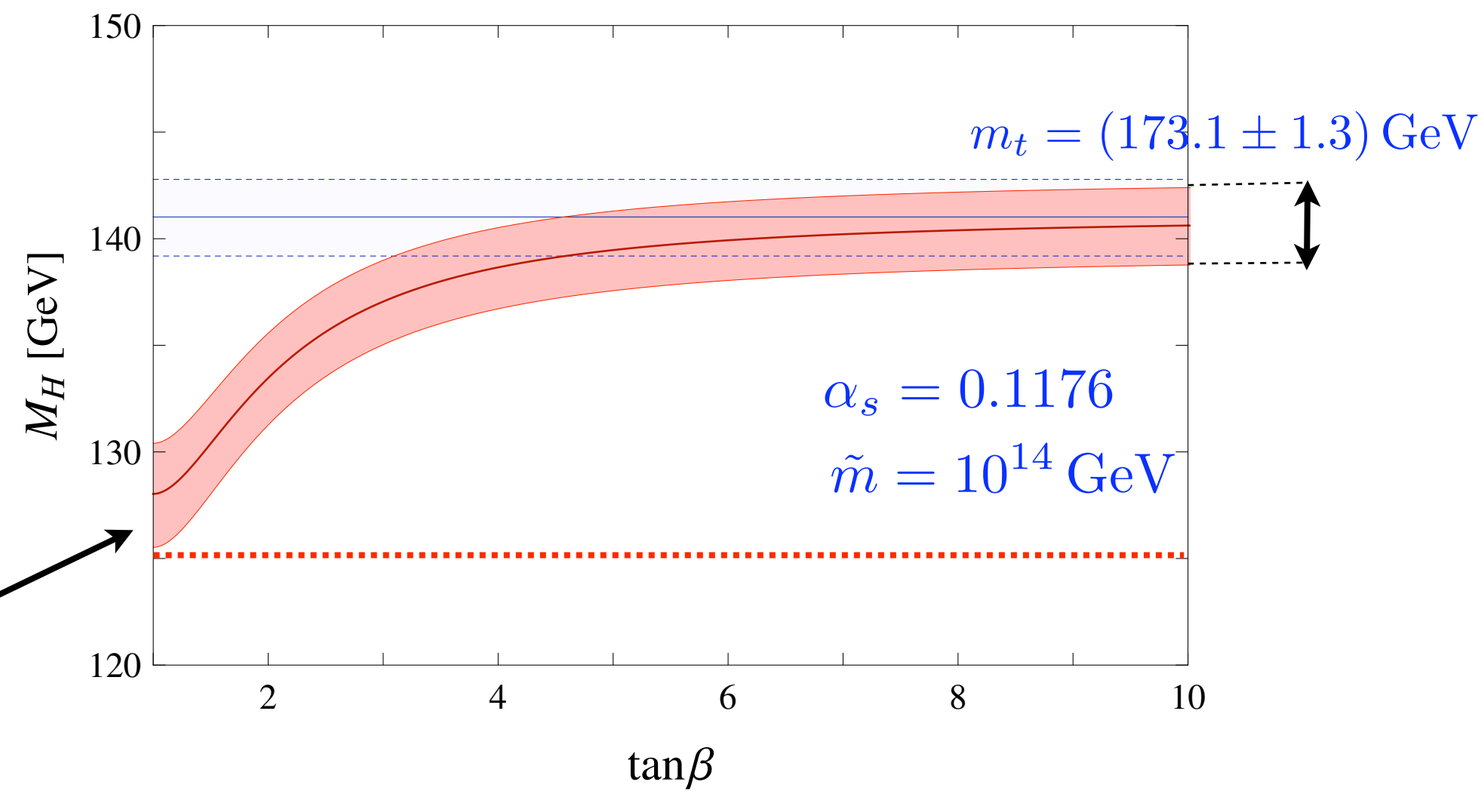


High-Scale Susy

Hall, Nomura 0910.2235

SM up to $\tilde{m} = 10^{14}\,\mathrm{GeV}\,(\sim M_u)$

$$\lambda(\tilde{m}) = \frac{g^2(\tilde{m}) + g'^2(\tilde{m})}{8}\cos^2 2\beta$$



Uncertainties from

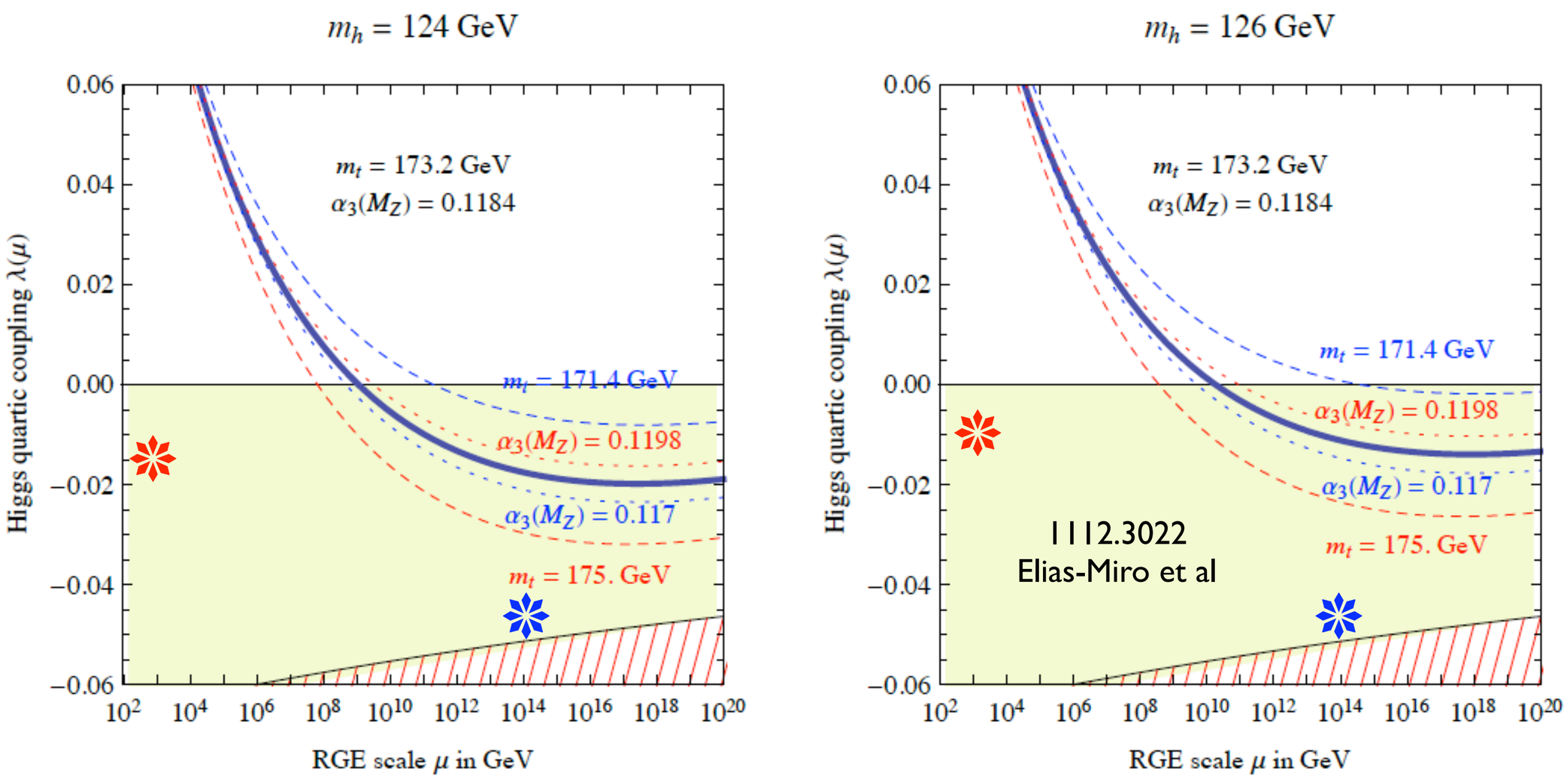
α_s, m_t

m_h

unified thresholds

An Alarming Possibility!!

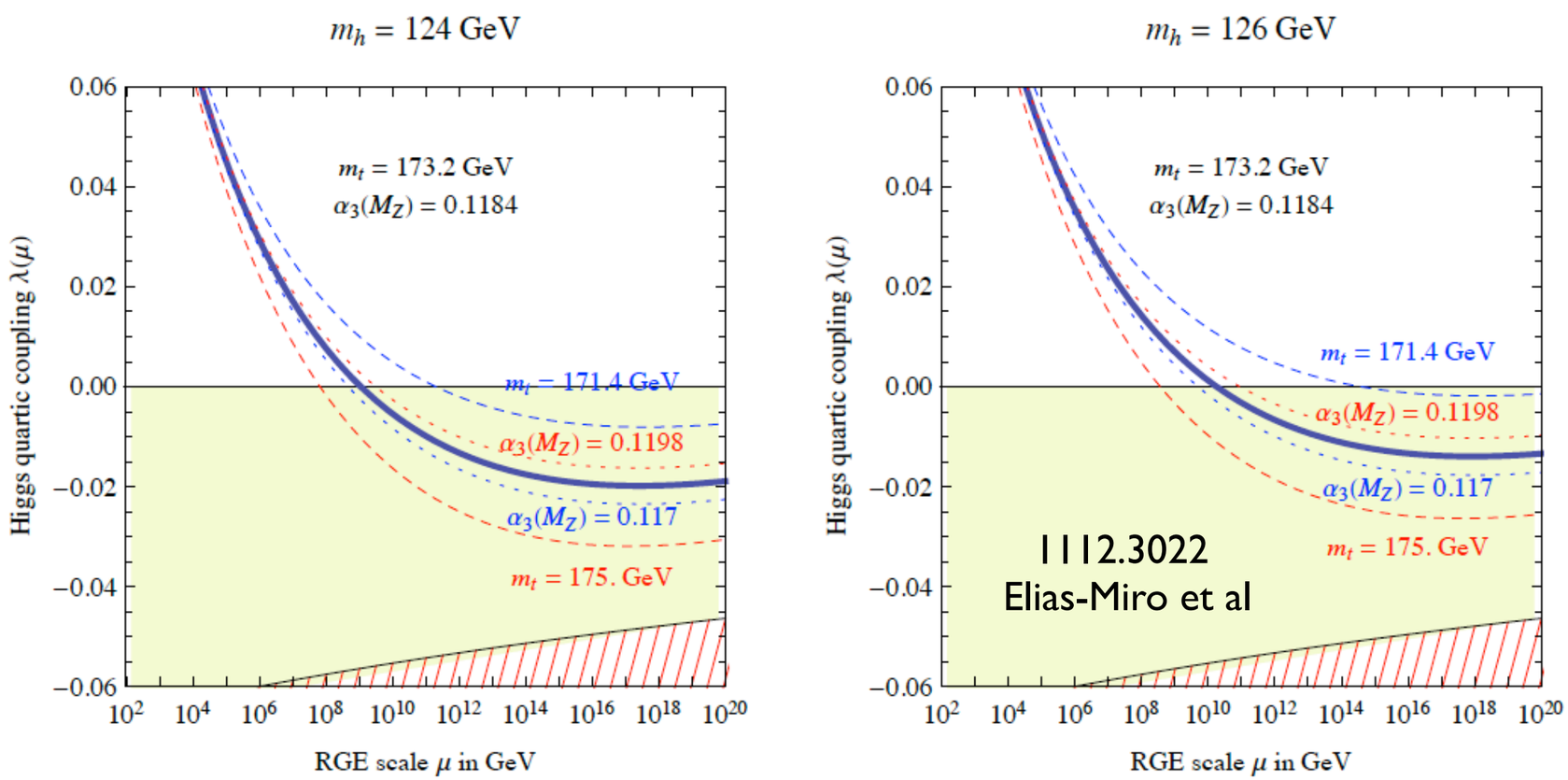
SM Quartic Trajectory



- Close to zero
- Close to Catastrophic Vacuum Tunneling

Hall, Salem, Watari hep-ph/0608121

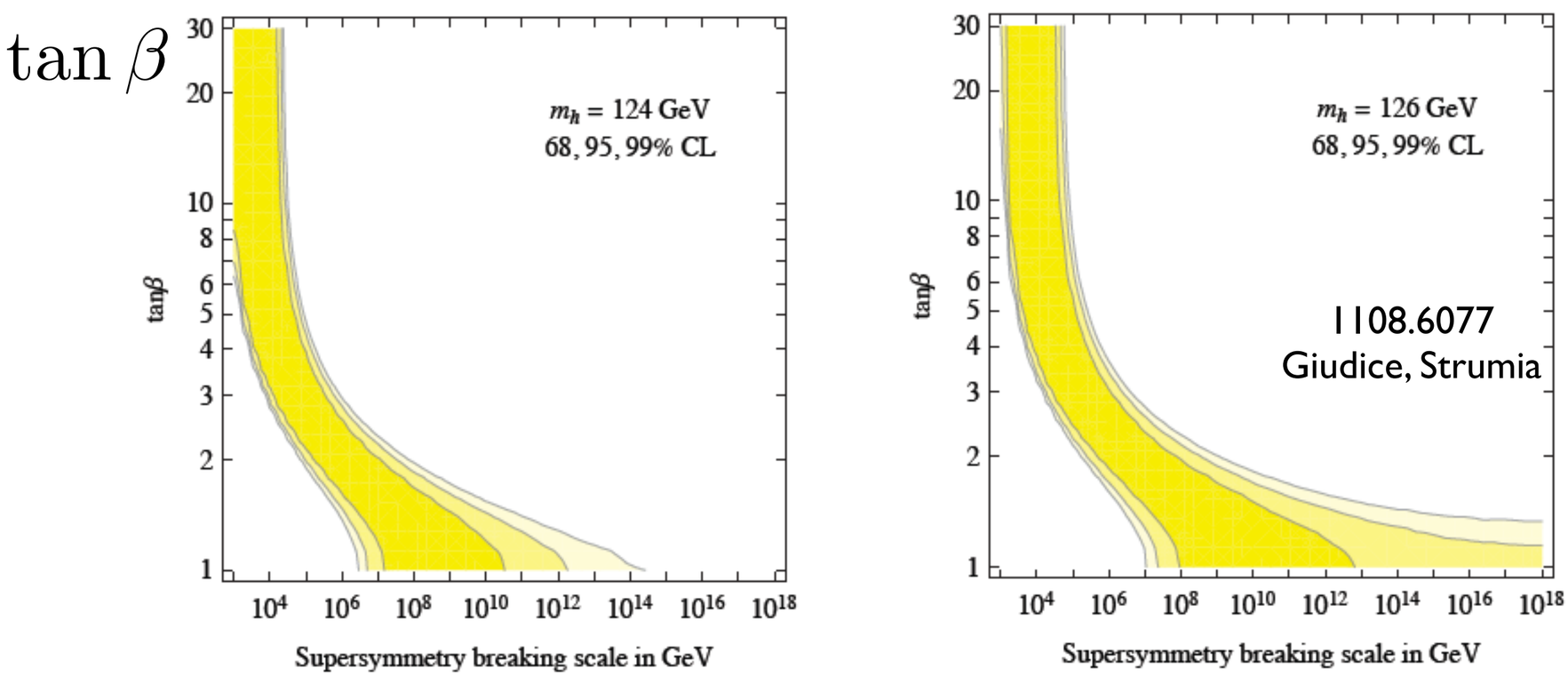
Matching SM to MSSM



Large range of

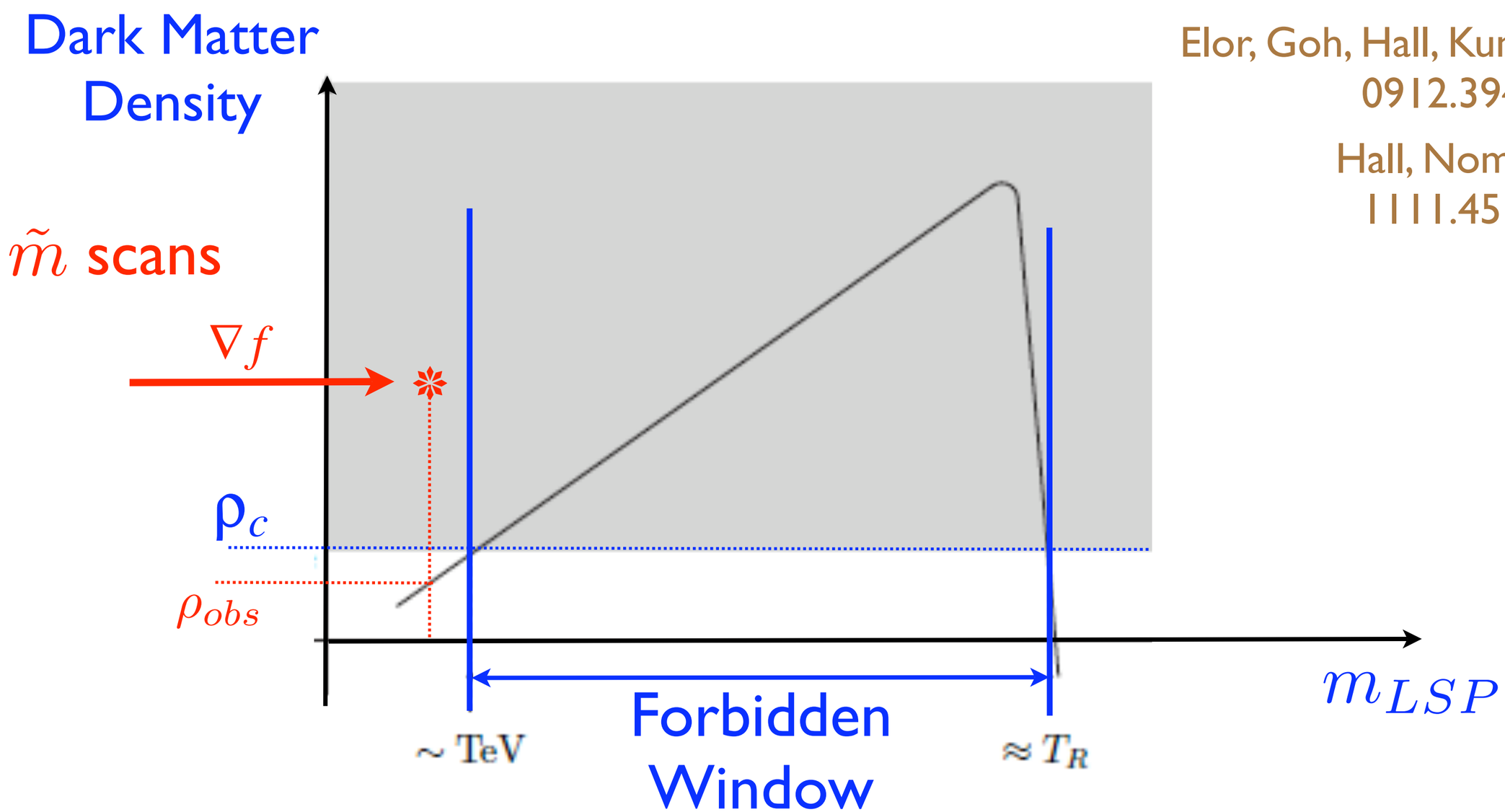
$\tilde{m},\ \tan\beta$

are possible!



$\tilde{m}$

Environmental MSSM



Elor, Goh, Hall, Kumar, Nomura
0912.3942

Hall, Nomura
1111.4519

Sets the normalization of $\tilde{m}$

eg all superpartners 1-10 TeV

125 GeV Higgs is fine

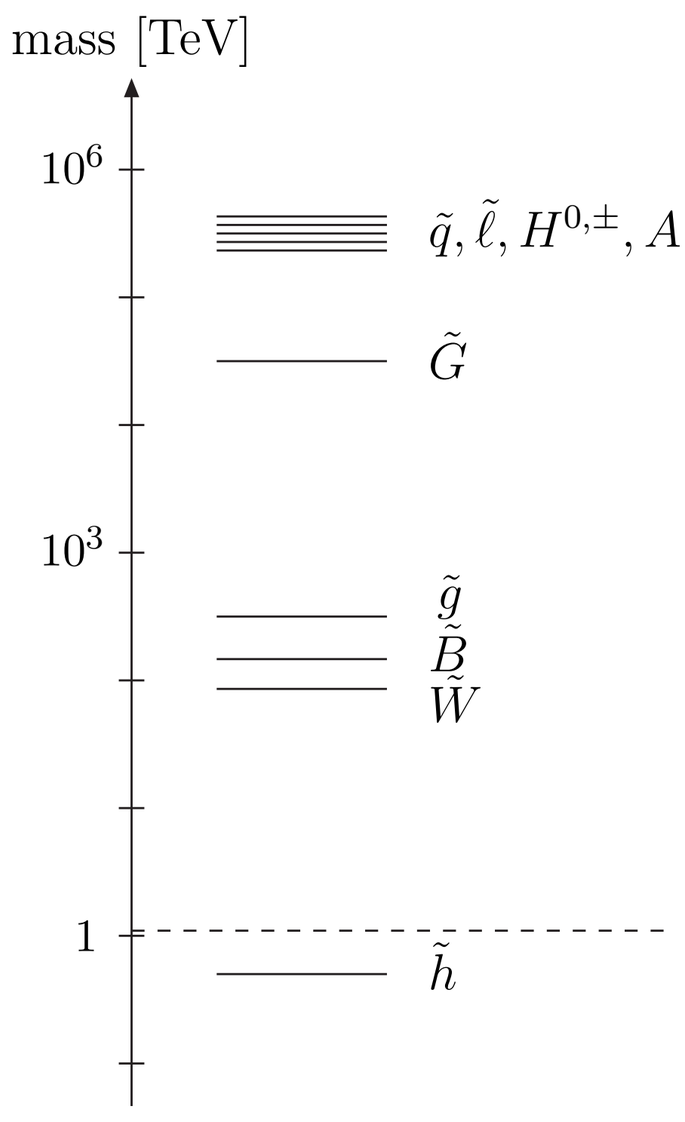
Spread Supersymmetry

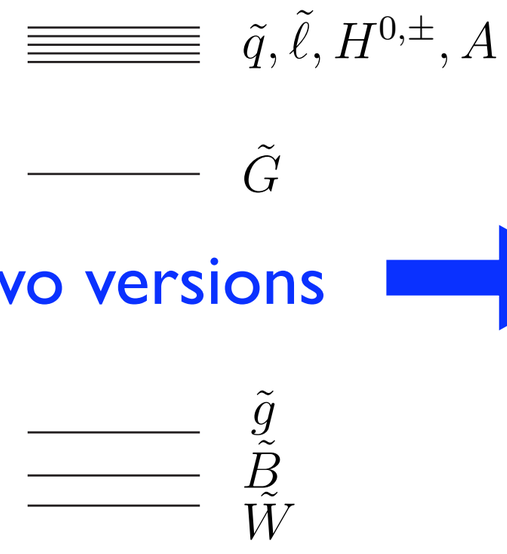
Hall, Nomura 1111.4519

$\tilde{m}$ scans

High scale messenger couples directly only to scalar masses

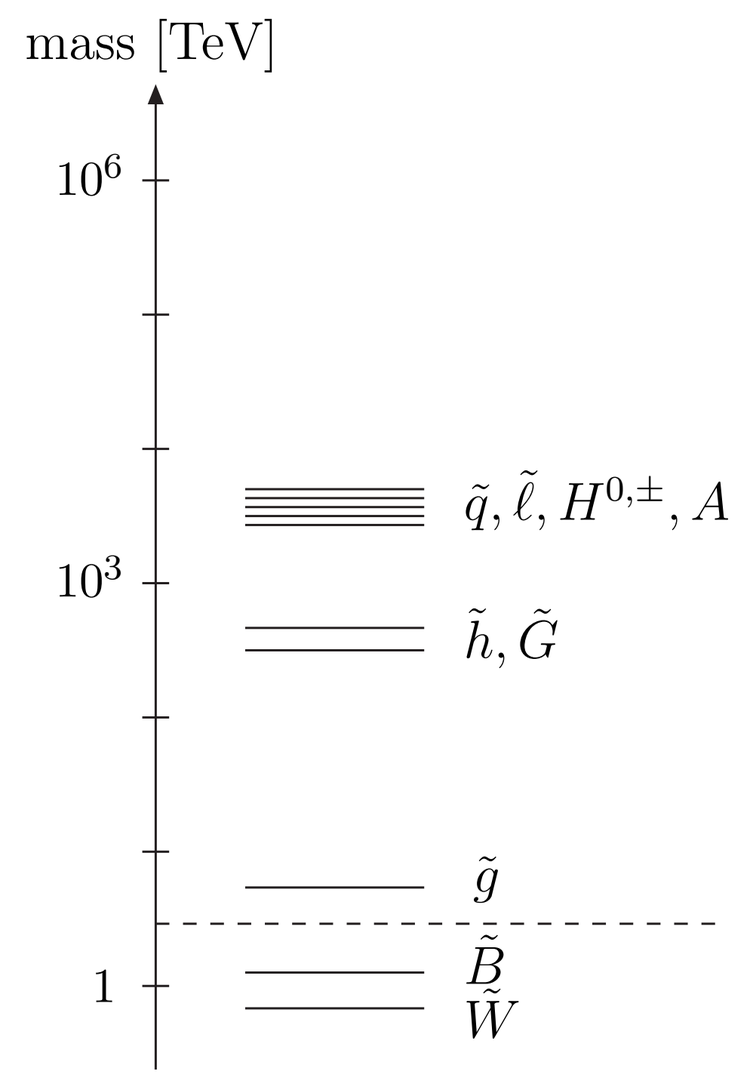
Higgsino LSP





Two versions

Wino LSP

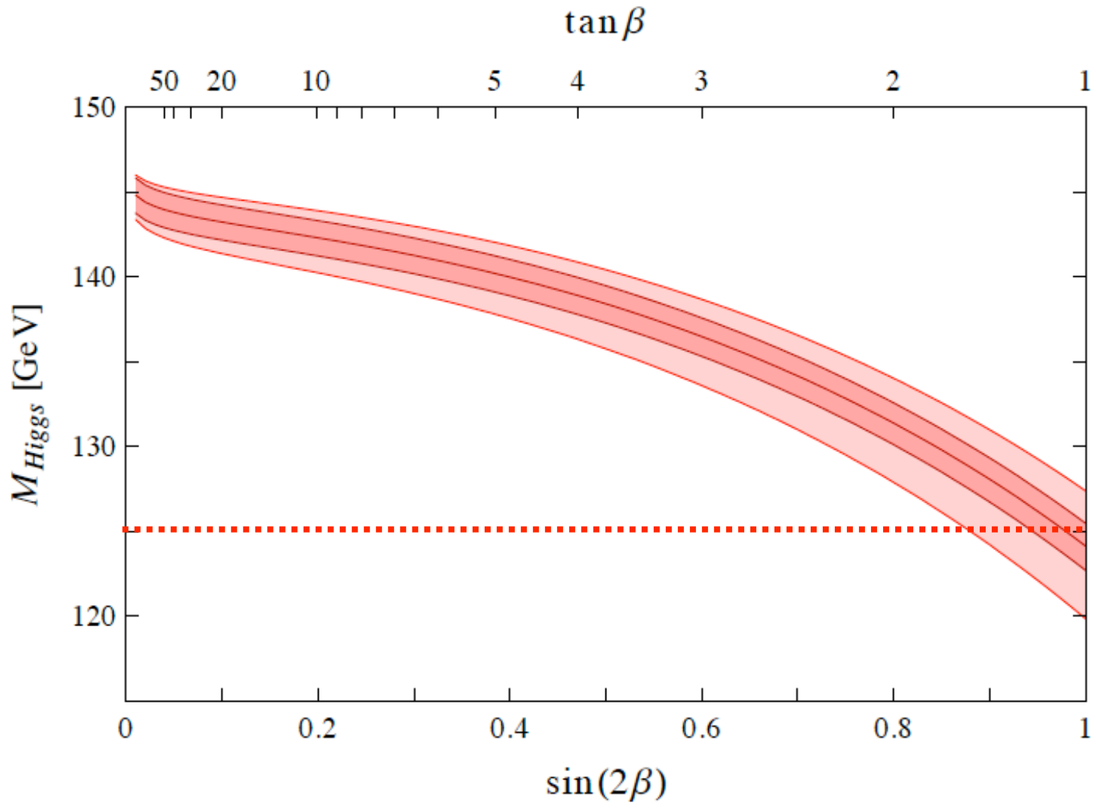


cf Wells hep-ph/0411041

Normalization set by forbidden dark matter window

Higgs Mass in Spread Susy

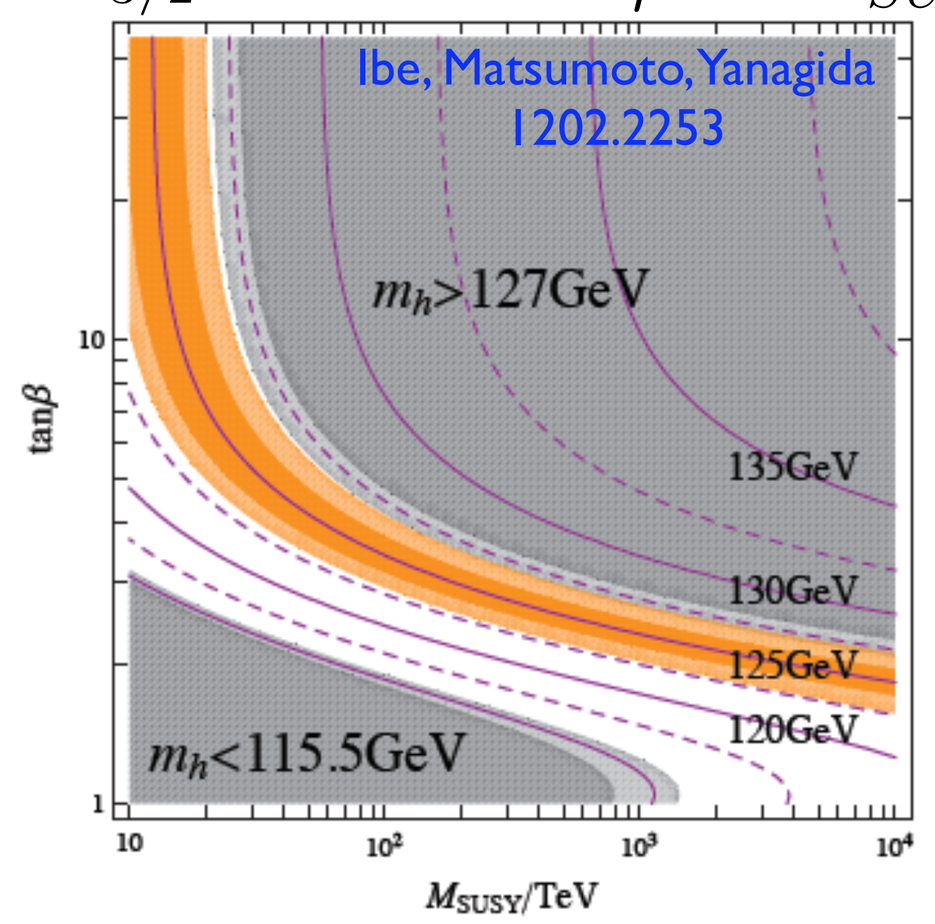
Higgsino LSP



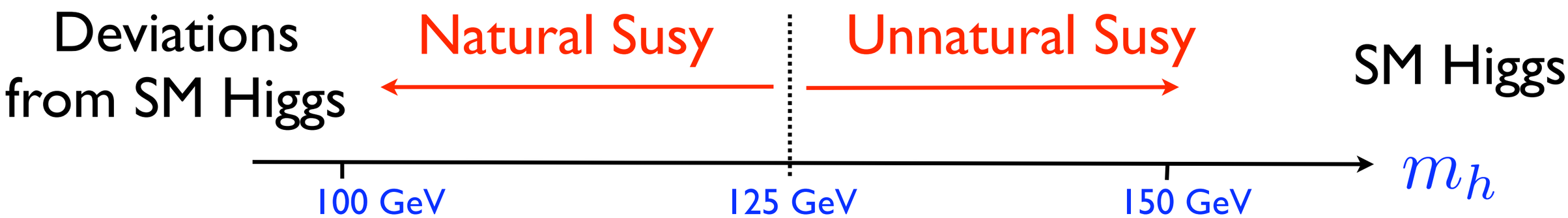
Wino LSP

$$M_{\rm Higgs} \approx (110 - 140)\ {\rm GeV}$$

$$m_{3/2} = 50\,{\rm TeV} \qquad \mu = M_{SUSY}$$

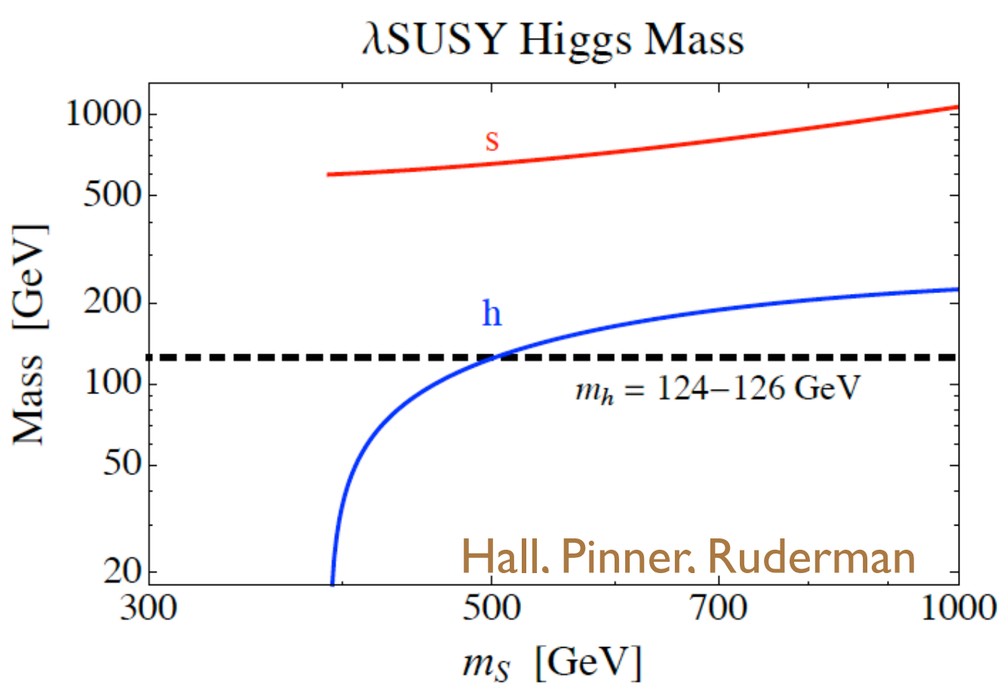


Conclusions



(I) Natural Weak Scale

eg $\lambda S H_u H_d$



(II) Unnatural Weak Scale

Split Susy

WIMP LSP

High Scale Susy

Axion

Environmental MSSM, Spread Susy

WIMP LSP + Axion