Claudia Frugiuele

Fermilab

Fermion hierarchy from sfermion anarchy

with W.Altmanshoffer & R.Harnik

JHEP 1412 (2014) 180

Flavor, but no signal at 100 TeV collider whatsoever!

Claudia Frugiuele

Fermilab

A natural SM-like 126 GeV Higgs via non-decoupling D-terms

with E. Bertuzzo, hep ph 1412.2765

Possible signals at 100 TeV, but no flavor..

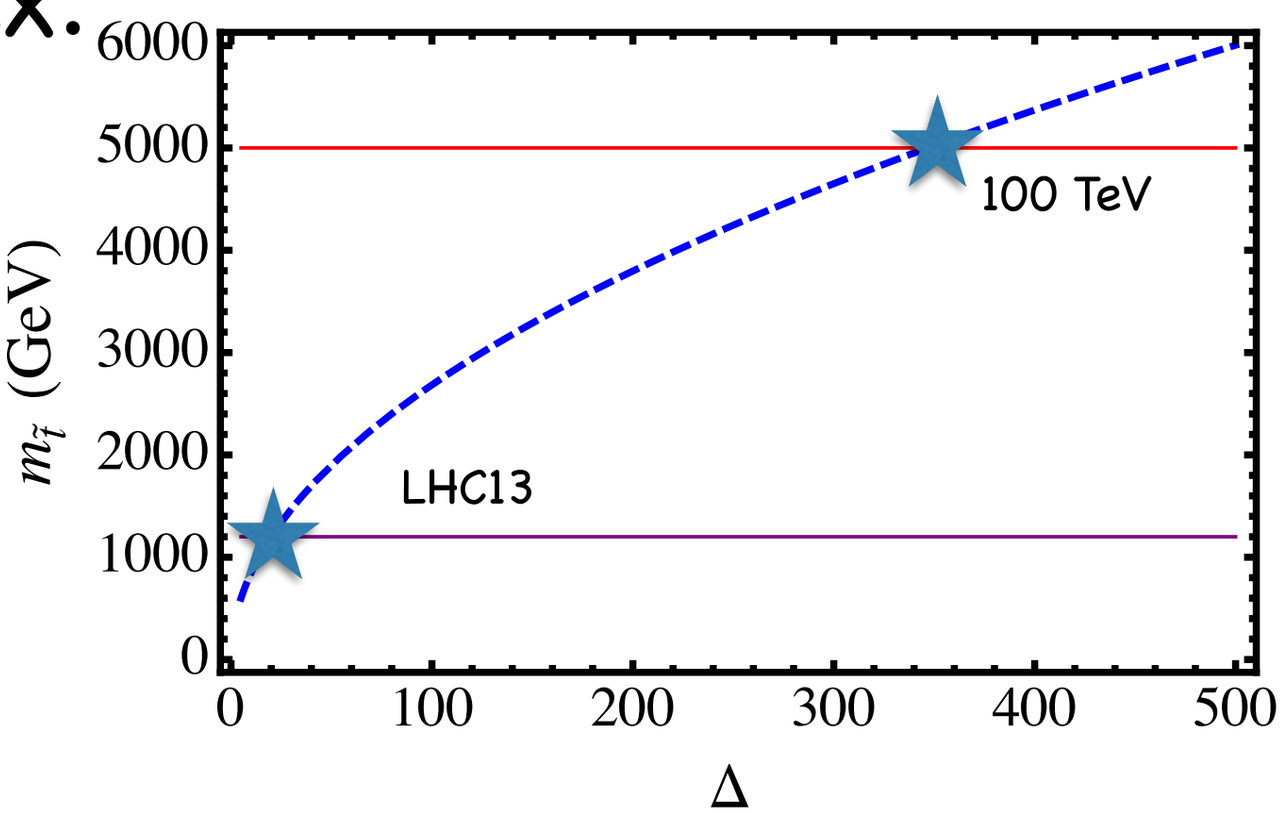
OUTLINE

- Naturalness at new machines (direct and indirect probes of natural SUSY)
- 126 GeV SM like Higgs in the MSSM & in NMSSM
- Non decoupling D terms
- Signals at CEPC & 100 TeV collider

Narturaless @ CEPC & 100 TeV collider

A more definite answer to the question about naturalness of the EW scale than the one given by the LHC

ex:



Also important indirect probes from CEPC (Higgs couplings, EWPM..)

see Fan,Reece&Wang

Narturaless @ CEPC & 100 TeV collider

A more definite answer to the question about naturalness of the EW scale than the one given by the LHC

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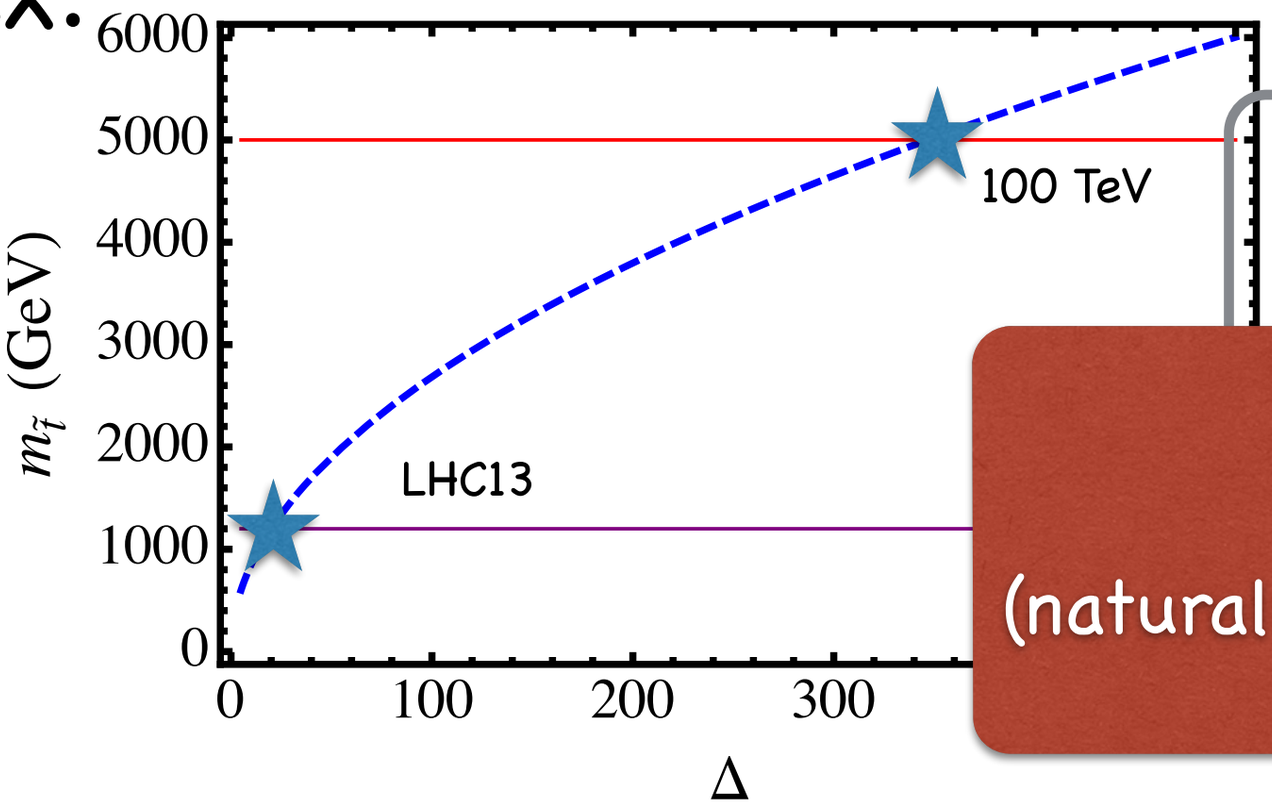


Also important indirect probes

focus of my talk

(naturalness indirect probes in SUSY)

In this regard a crucial question is:

what does the Higgs discovery tell us about natural SUSY?

* Fine tuning (FT) price to accommodate its mass?

** Fine tuning (FT) price to accommodate SM like couplings?

In this regard a crucial question is:

what ut

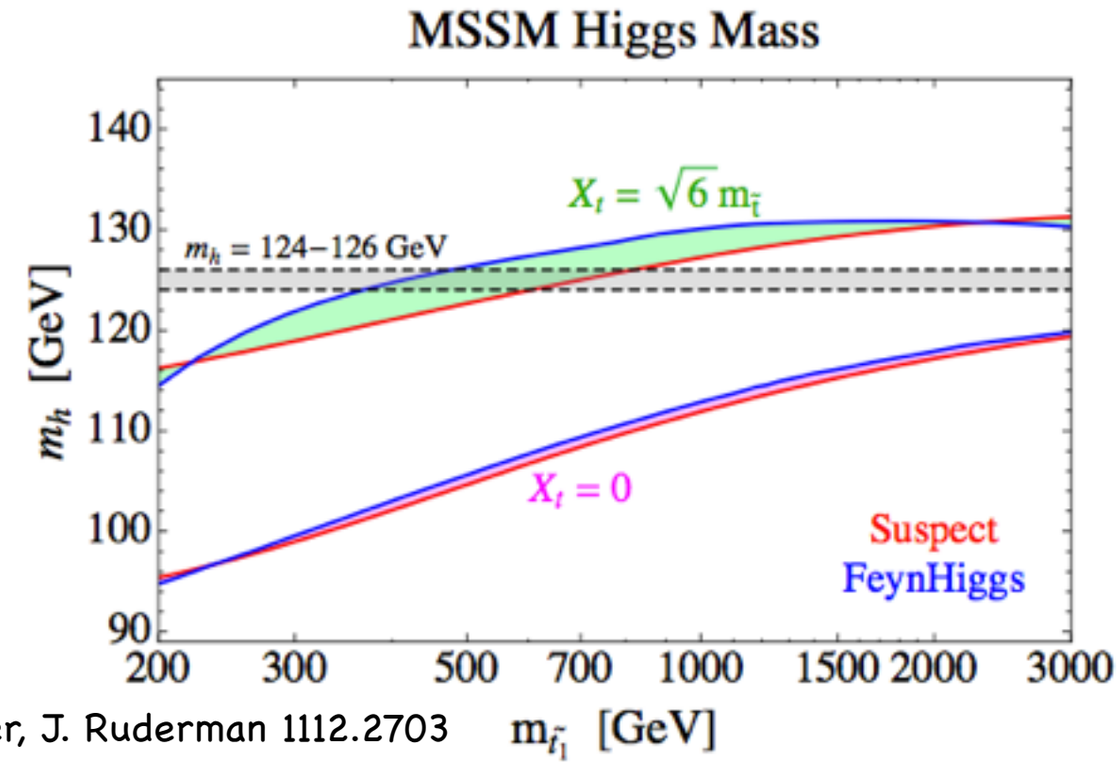
Is there always a tension between a SM like 126 GeV Higgs and natural SUSY?

* Fi ass?

** Fine tuning (FT) price to accommodate SM like couplings?

126 GeV Higgs in the MSSM

$$\lambda_{tree} = \frac{g'^2+g^2}{8}\cos 2\beta$$



L. Hall, D. Pinner, J. Ruderman 1112.2703

- in the MSSM the Higgs is naturally light- tension already after LEP
- 125 GeV Higgs requires large radiative corrections from heavy stops

126 GeV Higgs in the MSSM

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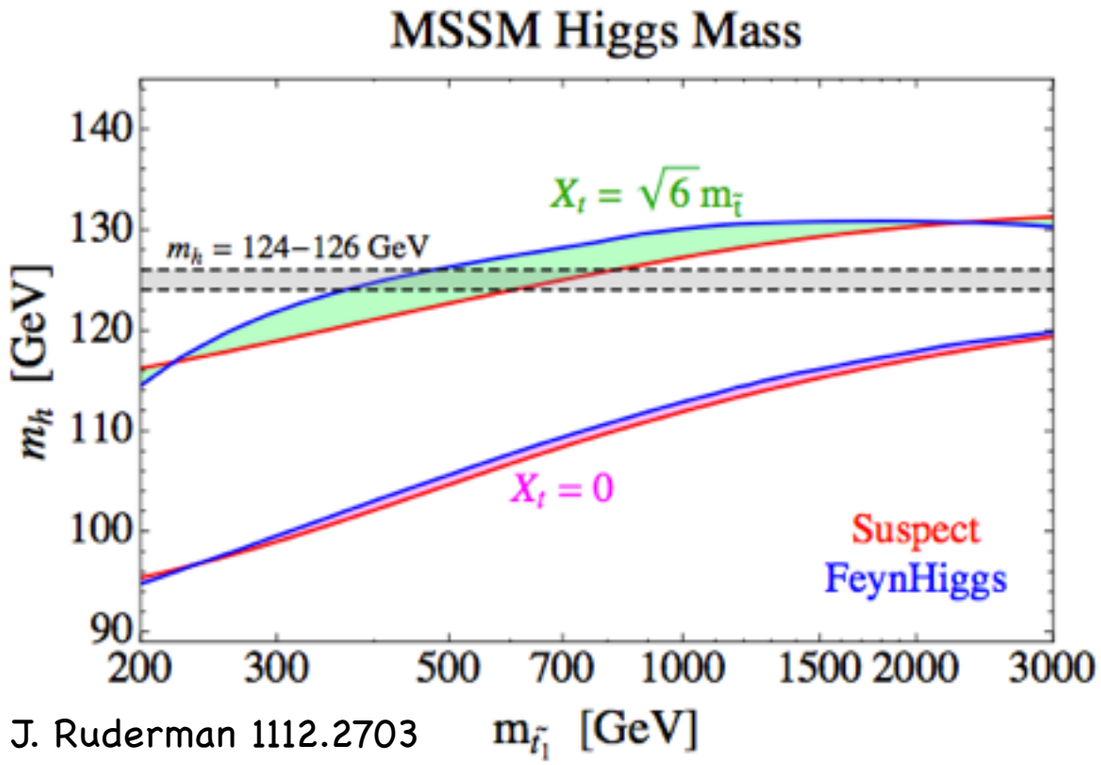


L. Hall, D. Pinner, J. Ruderman 1112.2703

- in the MSSM the Higgs is naturally light- tension already after LEP
- 125 GeV Higgs requires large radiative corrections from heavy stops

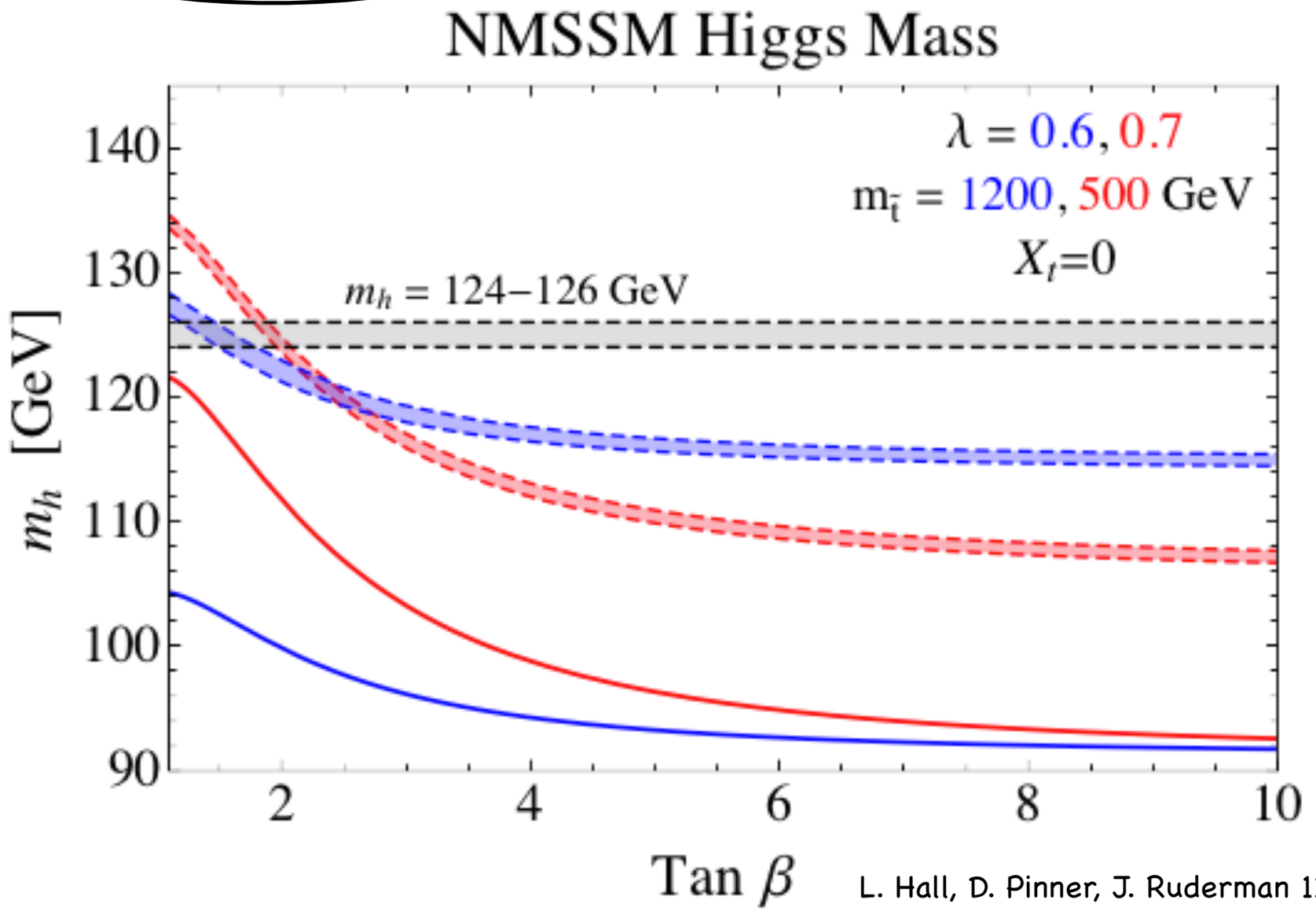
In the MSSM the Higgs mass set the strongest constraint on naturalness!!

126 GeV Higgs in the NMSSM

$$\lambda_S H_u H_d S$$

$$\lambda_S^2 (h_u h_d)^2$$

extra tree level quartic



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126 GeV Higgs in the NMSSM

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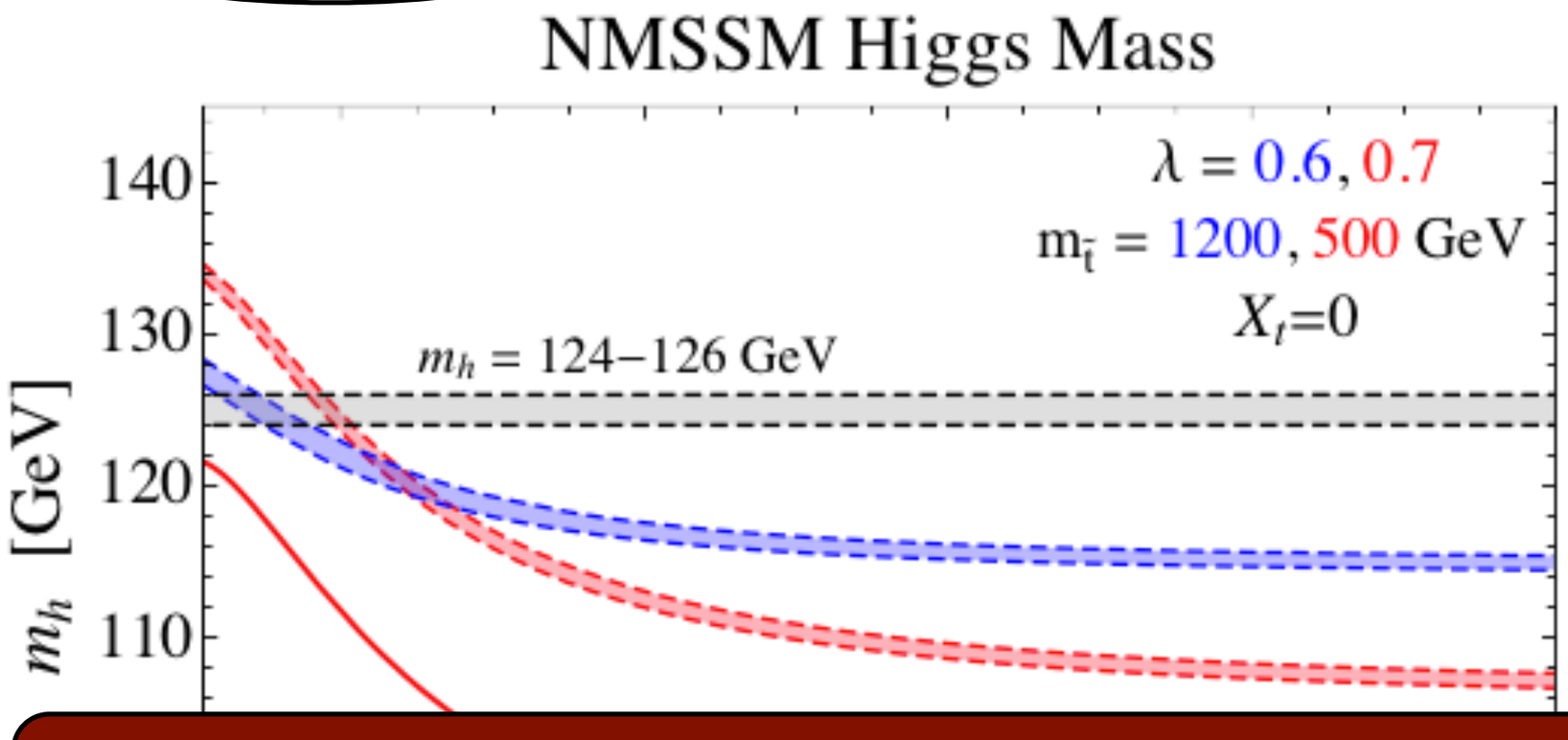


126 GeV Higgs mass at no fine tuning cost!

Model	126 GeV Higgs mass	SM like couplings
MSSM	FT	?
NMSSM	Natural	?

SM like couplings : is there also a FT price?

Yes.

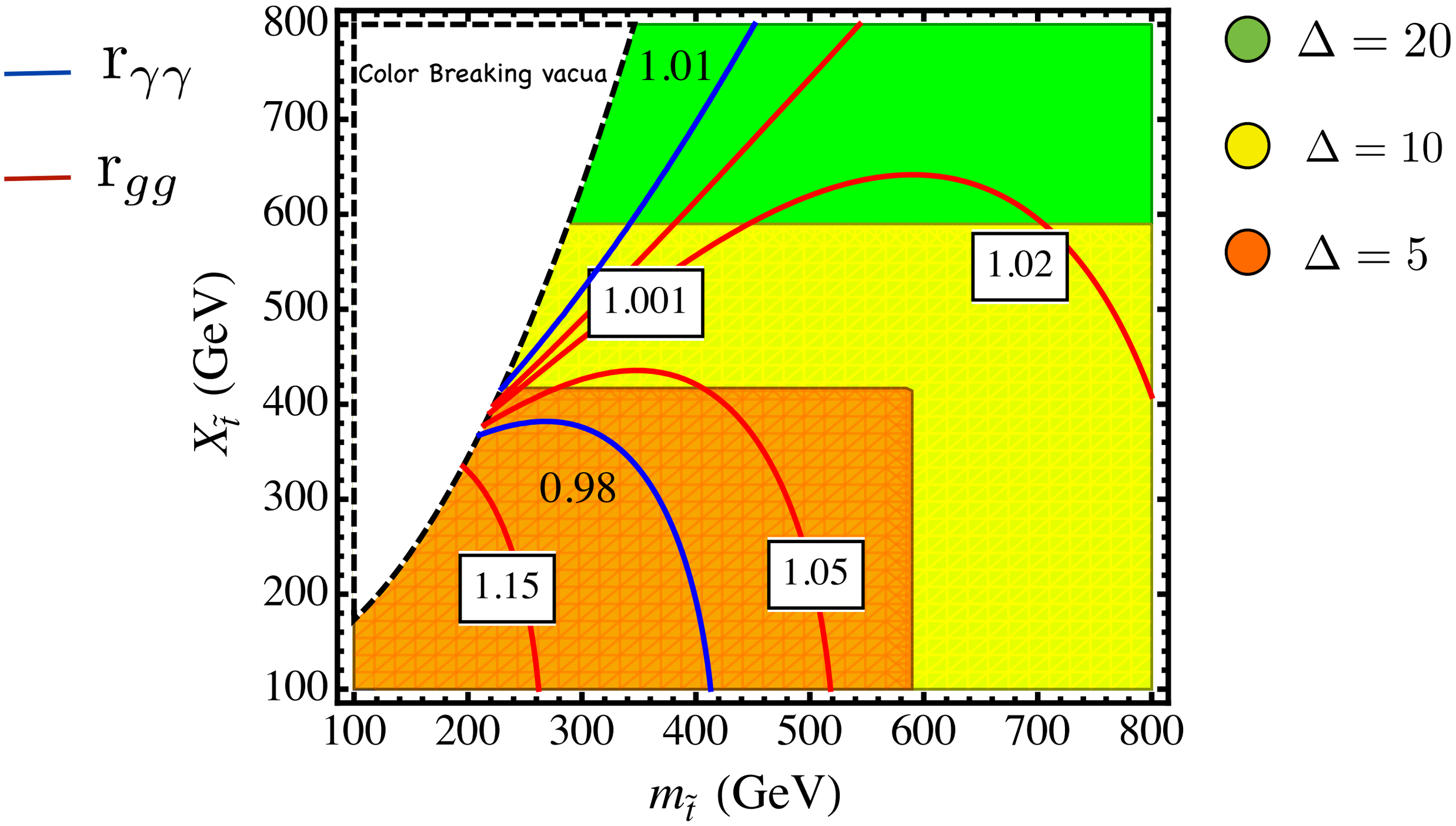
In any natural theory the Higgs is not SM like.

at what level this is true? are the deviations always testable?

In other words, is Higgs precision physics a more model independent test of naturalness?

Loop couplings

$$\delta r_G^{\tilde{t}} \simeq \frac{m_t^2}{4}\left(\frac{1}{m_{\tilde{t}_1}^2}+\frac{1}{m_{\tilde{t}_2}^2}-\frac{X_t^2}{m_{\tilde{t}_1}^2\, m_{\tilde{t}_2}^2}\right)$$



Loop couplings

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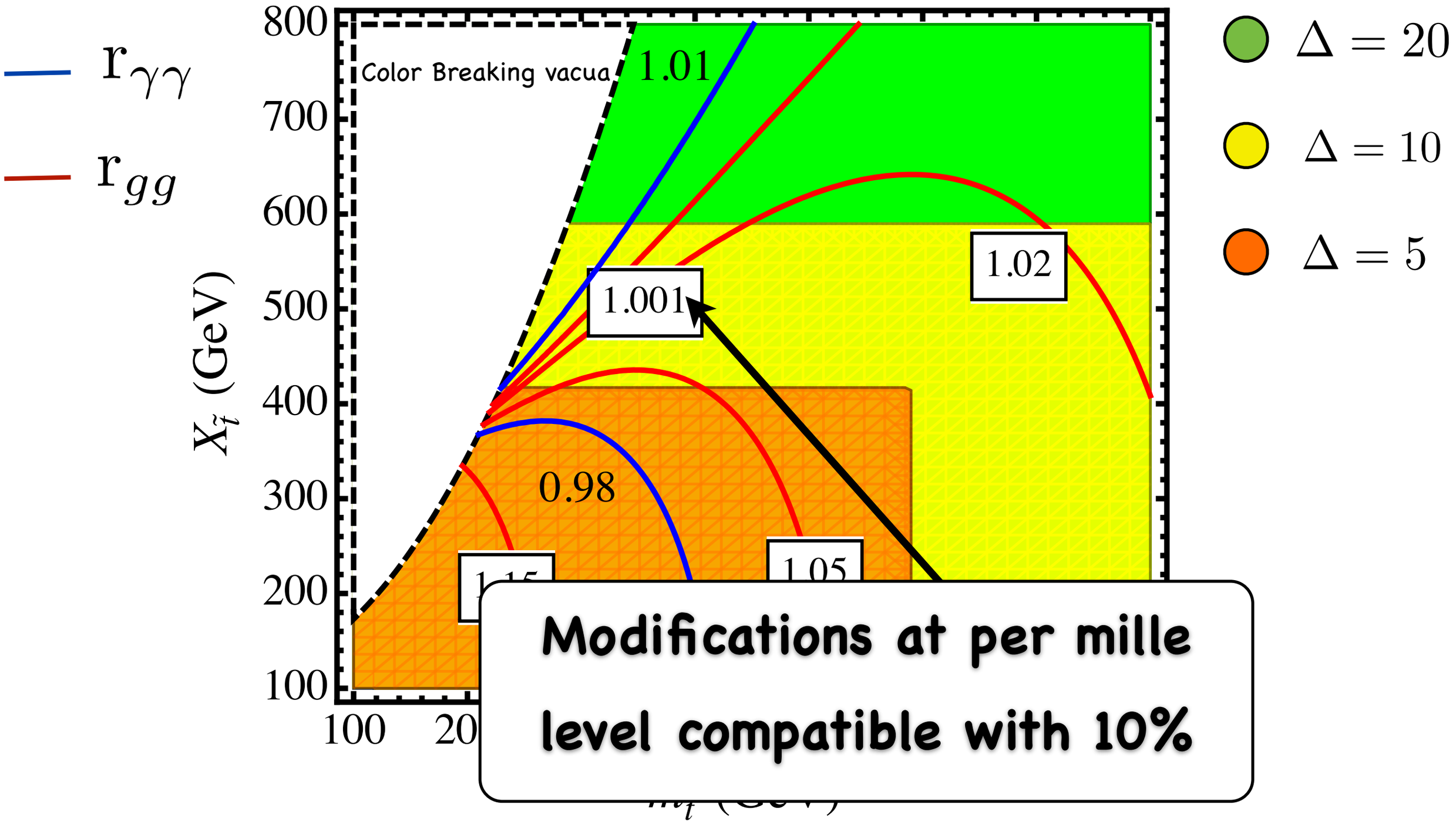
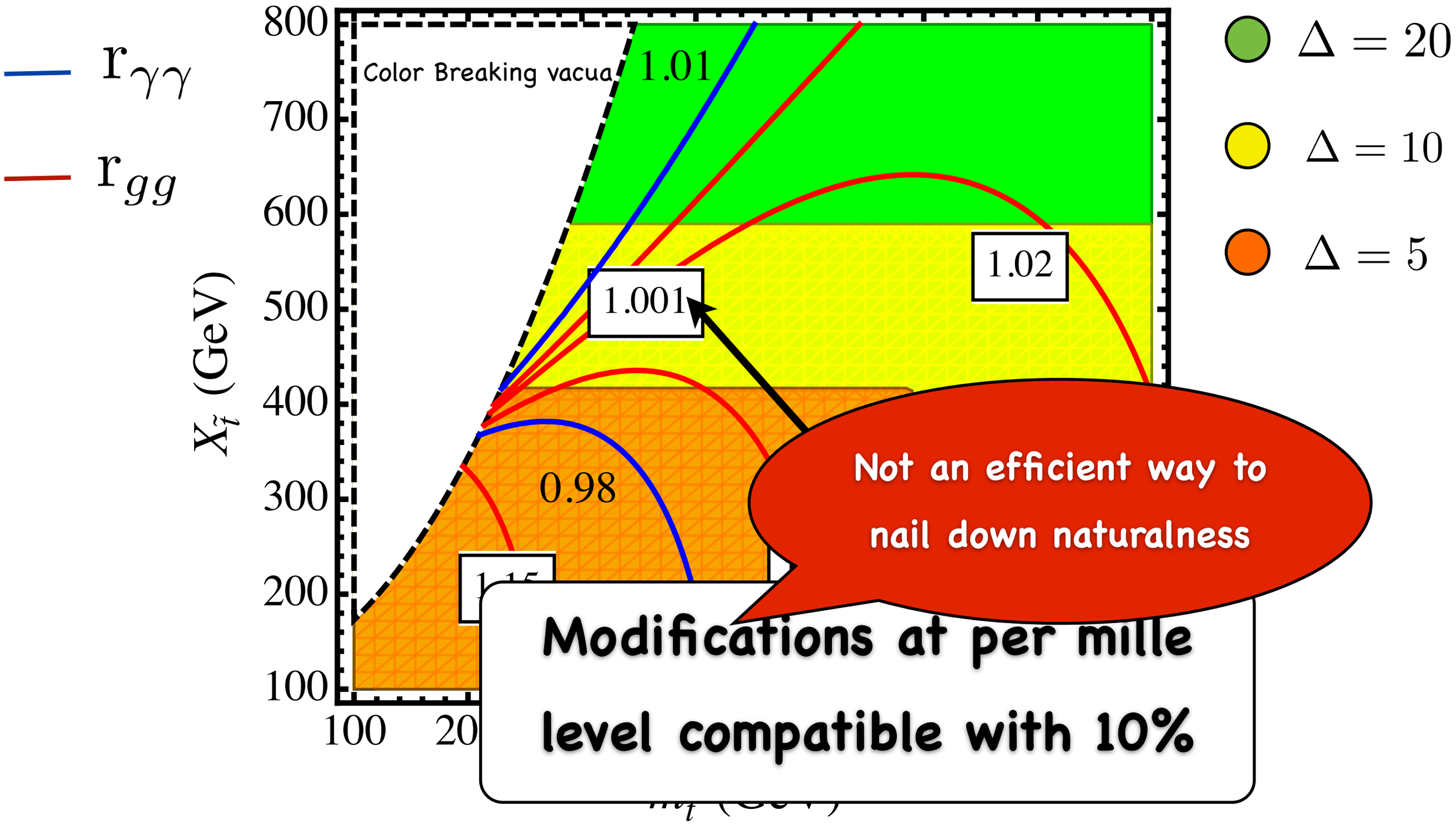


Modifications at per mille level compatible with 10%

Loop couplings

$$\delta r_G^{\tilde{t}} \simeq \frac{m_t^2}{4}\left(\frac{1}{m_{\tilde{t}_1}^2}+\frac{1}{m_{\tilde{t}_2}^2}-\frac{X_t^2}{m_{\tilde{t}_1}^2\, m_{\tilde{t}_2}^2}\right)$$



Tree level couplings

in the MSSM or in the NMSSM for a decoupled heavy singlet

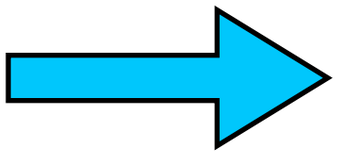
$$
\begin{aligned}
r_u &\simeq 1+\frac{1}{t_\beta}\left(\frac{\mathcal{M}^2_{hH}}{\mathcal{M}^2_{HH}}+\frac{\mathcal{M}^2_{hh}\mathcal{M}^2_{hH}}{\mathcal{M}^4_{HH}}\right)-\frac{\mathcal{M}^4_{hH}}{2\mathcal{M}^4_{HH}}\,,\\
r_d &\simeq 1-t_\beta\left(\frac{\mathcal{M}^2_{hH}}{\mathcal{M}^2_{HH}}+\frac{\mathcal{M}^2_{hh}\mathcal{M}^2_{hH}}{\mathcal{M}^4_{HH}}\right)-\frac{\mathcal{M}^4_{hH}}{2\mathcal{M}^4_{HH}}\,, \qquad (1)\\
r_V &\simeq 1-\frac{\mathcal{M}^4_{hH}}{2\mathcal{M}^4_{HH}}\,,
\end{aligned}
$$

for SM like couplings:

$$
\mathrm{M}^2=\begin{pmatrix} m^2_{hh} & m^2_{hH} \\ m^2_{Hh} & m^2_{HH}\end{pmatrix}
$$

small

large



heavy second doublet required
for SM like tree level couplings

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for SM like tree level couplings

Possible tension with naturalness!

at small TanBeta a heavy
second Higgs has a fine tuning cost

$$\mathrm{m}^2_{Hd} \lesssim m_Z^2 \tan^2 \beta$$

heavy second doublet required
for SM like tree level couplings

Possible tension with naturalness!

at small TanBeta a heavy
second Higgs has a fine tuning cost

$$\mathrm{m}^2_{Hd} \lesssim m_Z^2 \tan^2 \beta$$

- In the MSSM this tension can be avoided considering large TanBeta
- Not possible in the NMSSM!

SM like Higgs in the NMSSM

$\lambda_S H_u H_d S$ add a gauge singlet S

$\lambda_S^2 (h_u h_d)^2$ extra tree level quartic

boost of the Higgs tree level mass at small TanBeta

sizeable deviations in tree level couplings expected!!

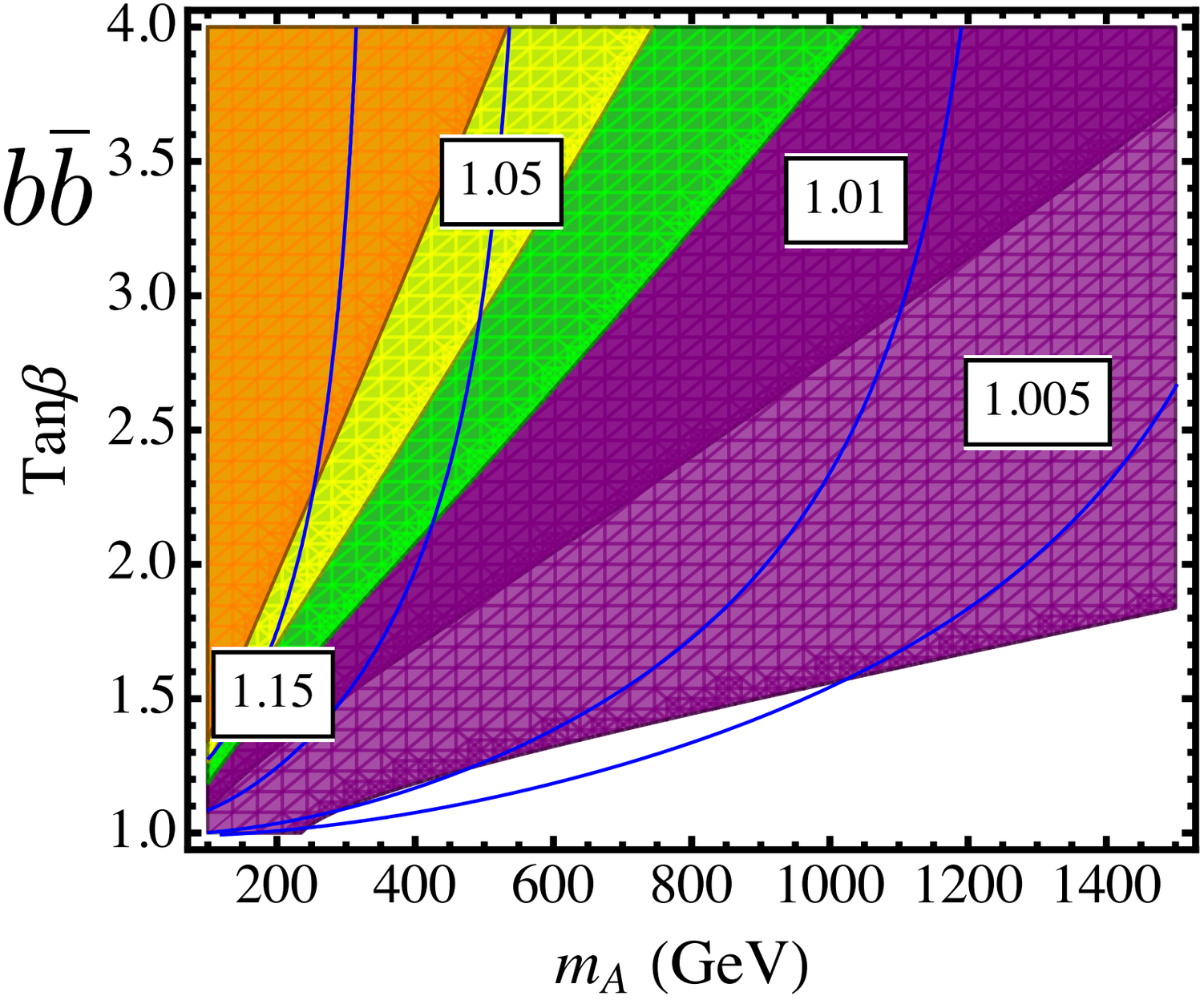
If NOT fine tuning implied!

T. Gherghetta et al. 1212.5243

M.Farina et al. 1310.0459

Tree level couplings deviations & FT

$\mathrm{h} \longrightarrow b\bar{b}$



$\Delta = 500$

$\Delta = 20$

$\Delta = 10$

$\Delta = 5$

Naturalness predicts at least few percent level deviations- Higgs factory ideal probe of naturalness!

Summarising...

Model	126 GeV Higgs mass	SM like couplings
MSSM	FT	Natural
NMSSM	Natural	FT

Does a 126 GeV SM like Higgs always come with a fine tuning cost in SUSY?

Non decoupling D terms

- Starting point:the quartic coupling in the MSSM is set by the gauge couplings
- Can we raise the Higgs mass charging the Higgs under a new gauge group?

Yes, we can as long as the extended gauge symmetry is broken below the SUSY breaking scale

Non decoupling D-terms

Batra,Delgado,Kaplan,Tait '04

Non abelian extension

$$\mathrm{SU}(2)_A \times SU(2)_B \to SU(2)_L$$

gauge symmetry broken by the vev u
of a bi-doublet Σ

Simplest possibility:

H_u and H_d charged under $SU(2)_A$

* absence of tuning in the new scale $\mathrm{m}_\Sigma \sim u$

$\Delta = 5$

** absence of extra EW tuning $\mathrm{m}_\Sigma \lesssim 7\ \mathrm{TeV}$

Non abelian extension

$$\mathrm{SU}(2)_A \times SU(2)_B \to SU(2)_L$$

gauge symmetry broken at scale u by the vev of a

Naturalness bound on the new gauge

$\Delta = 5$

$\mathrm{m}_{W'}, m_{Z'} < 6$ TeV

for order one gauge couplings

* absence of tuning in the new scale $\mathrm{m}_\Sigma \sim u$

$\Delta = 5$

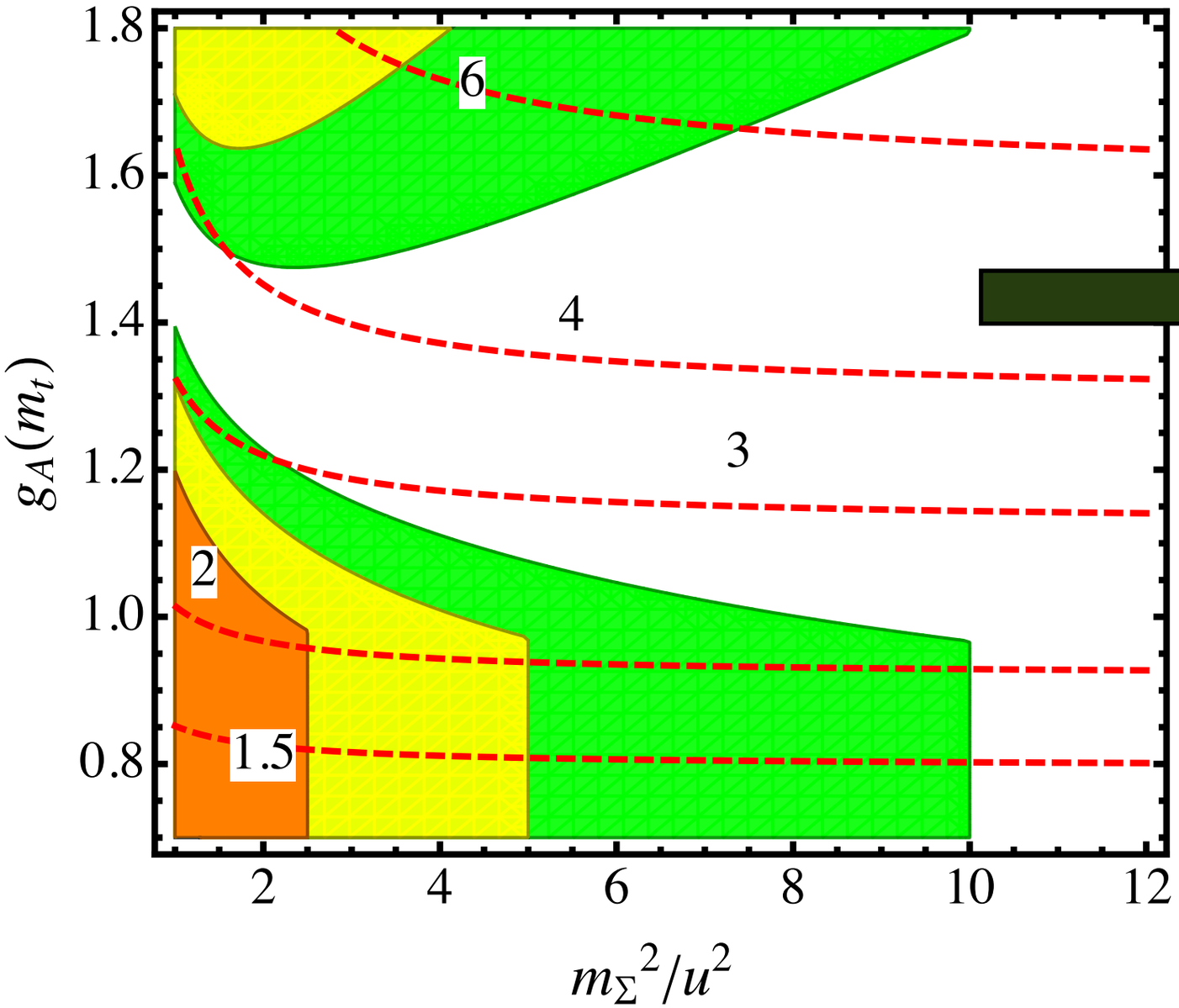
** absence of extra EW tuning $\mathrm{m}_\Sigma \lesssim 7$ TeV

Question 1: can we raise the Higgs mass naturally?

Tree level Higgs quartic

$$\lambda_{tree} = \frac{g^2\eta + g'^2\eta'}{4}\cos^2 2\beta$$

$$\eta = \frac{1+\frac{4(m_\Sigma^2/u^2)}{g_B^2}}{1+\frac{4(m_\Sigma^2/u^2)}{g_A^2+g_B^2}}$$



Imposing FT bounds

Tree level Higgs quartic

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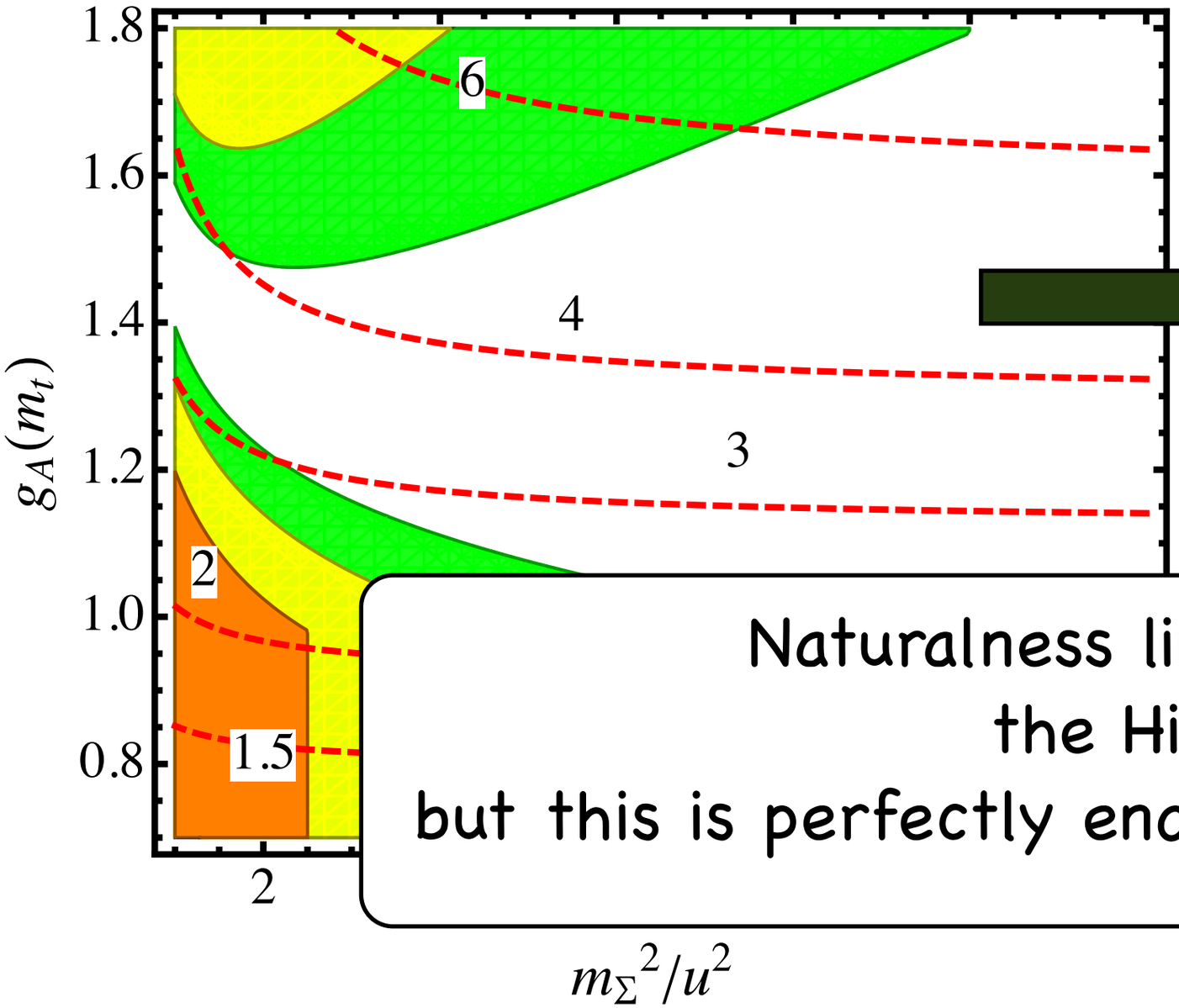


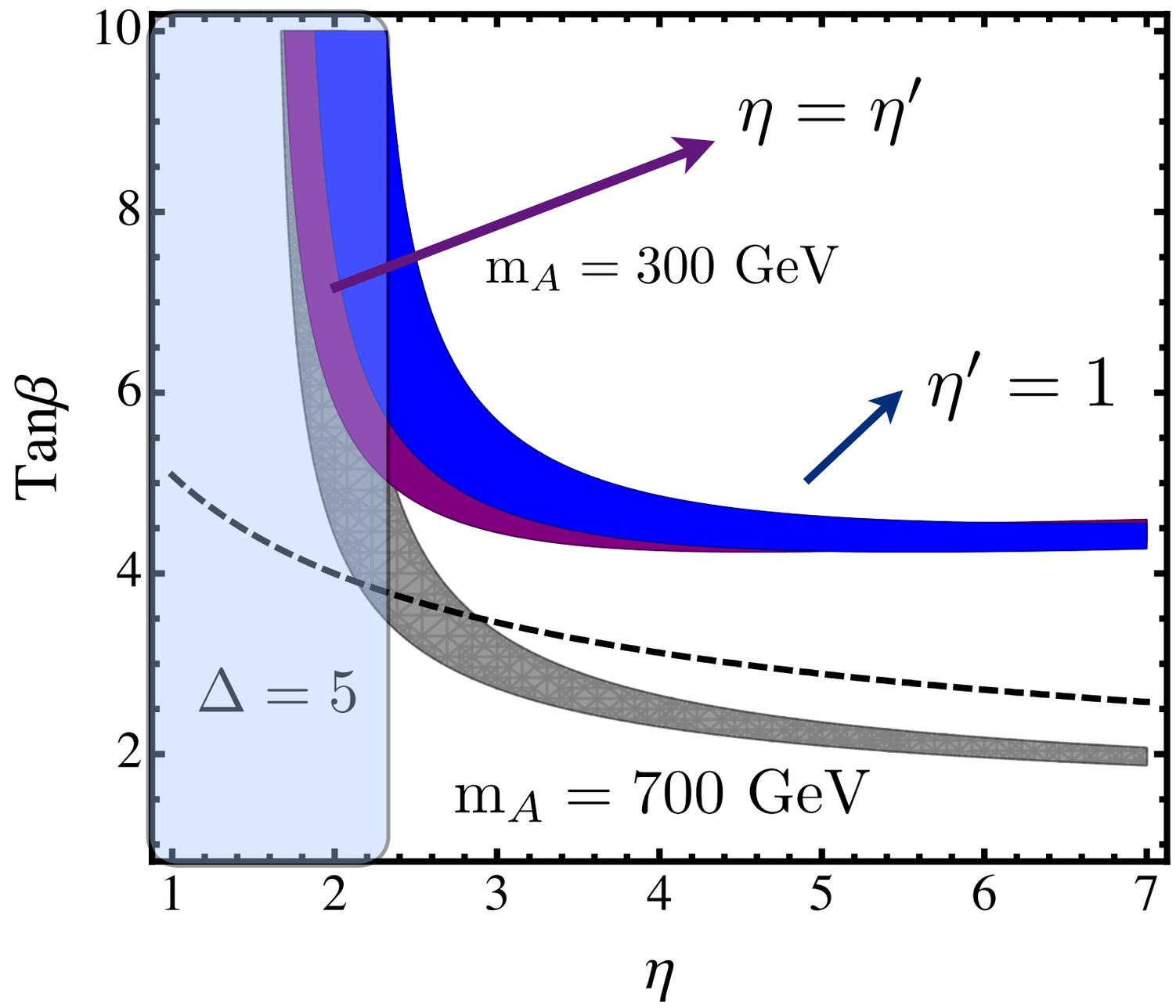
Imposing FT bounds

Naturalness limits the boost to
the Higgs mass,
but this is perfectly enough for a 126 GeV particle!

assuming $\max(\Delta_{X_t}, \Delta_{m_{\tilde{t}}}) < 5$

Tree level Higgs mass needs to be:

$$116\ \text{GeV} < m_h < 126\ \text{GeV}$$



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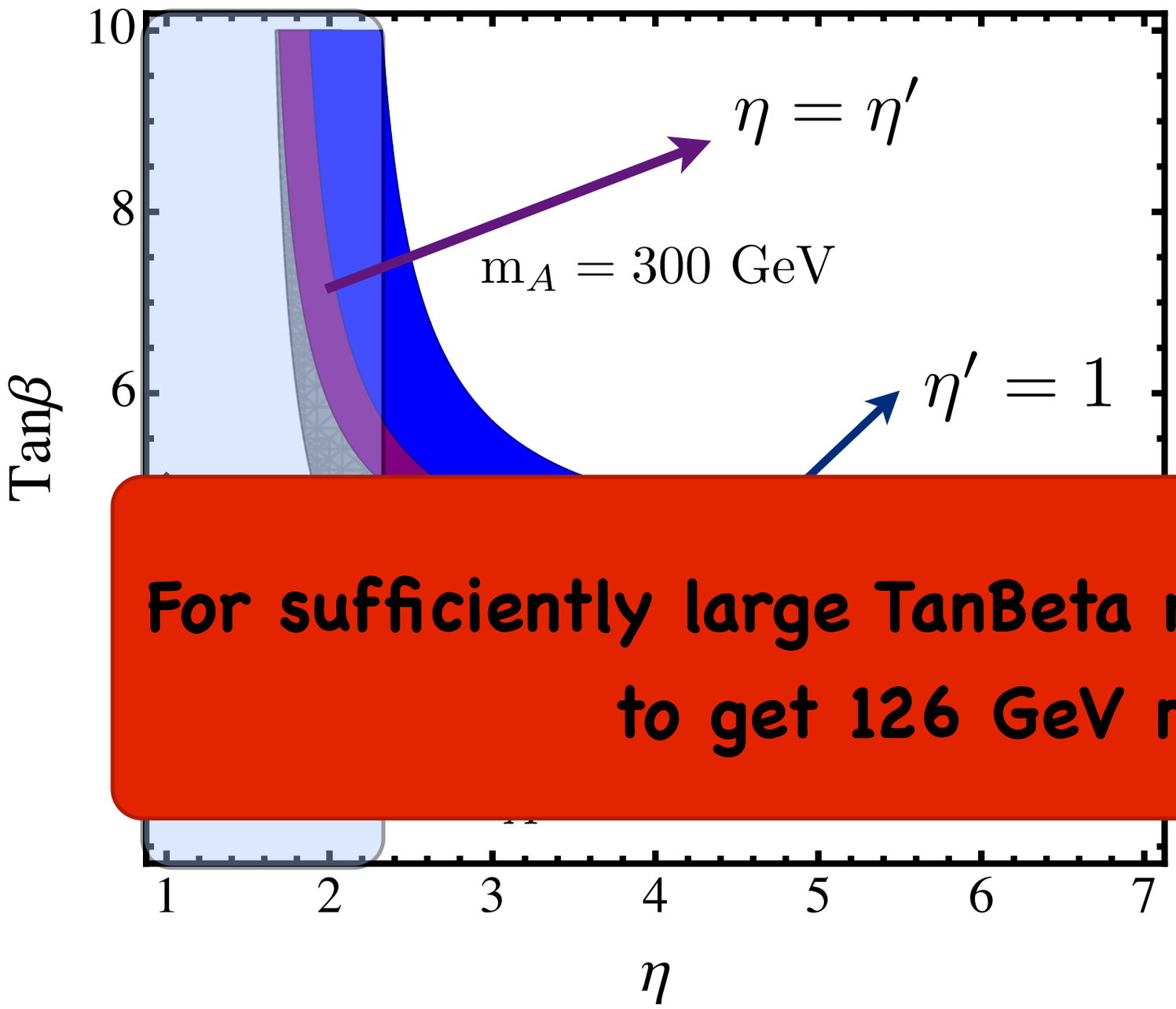


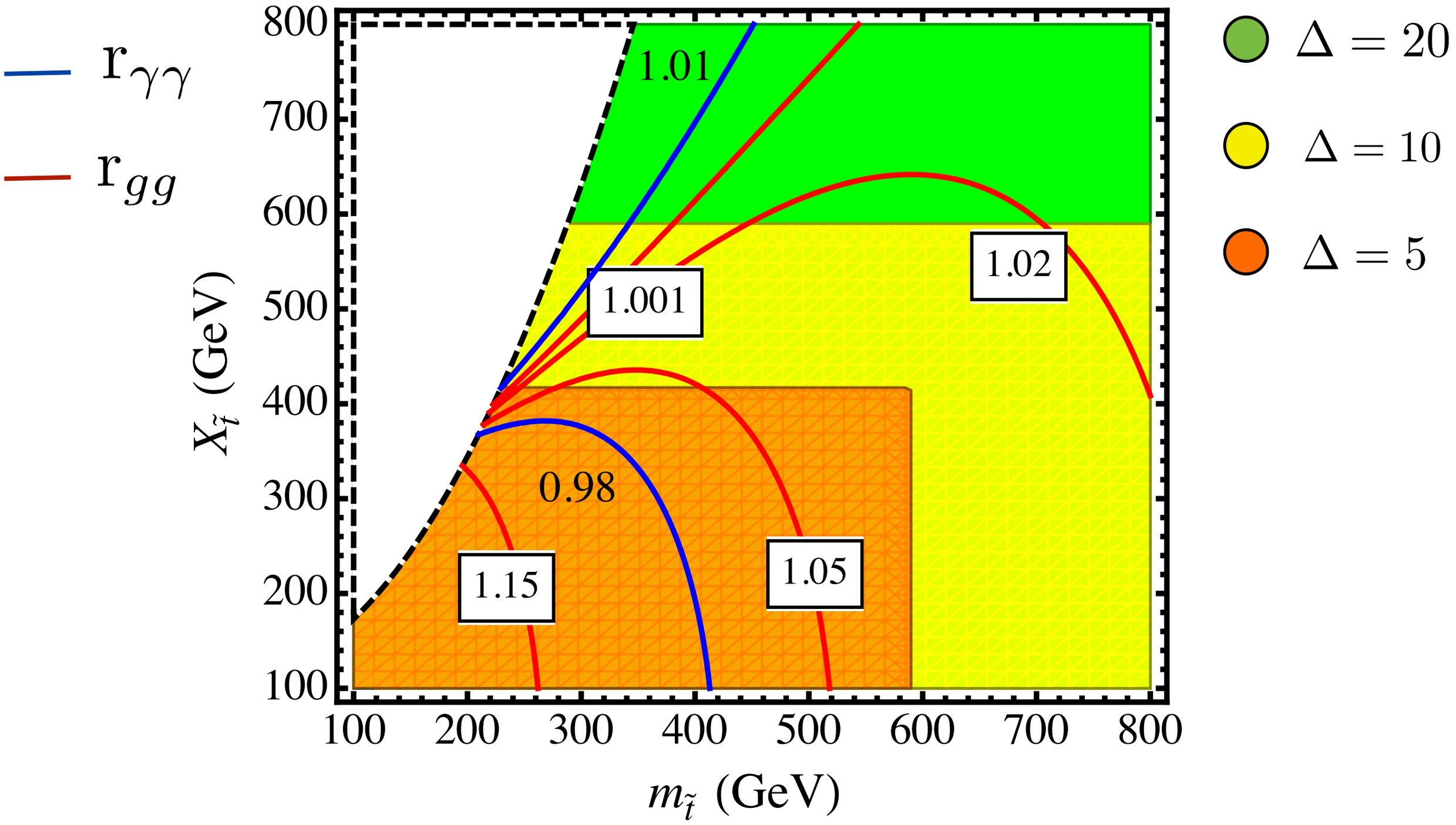
For sufficiently large TanBeta no fine tuning cost to get 126 GeV mass!

Model	126 GeV Higgs mass	SM like couplings
MSSM	FT	Natural
NMSSM	Natural	FT
DMSSM	Natural	?

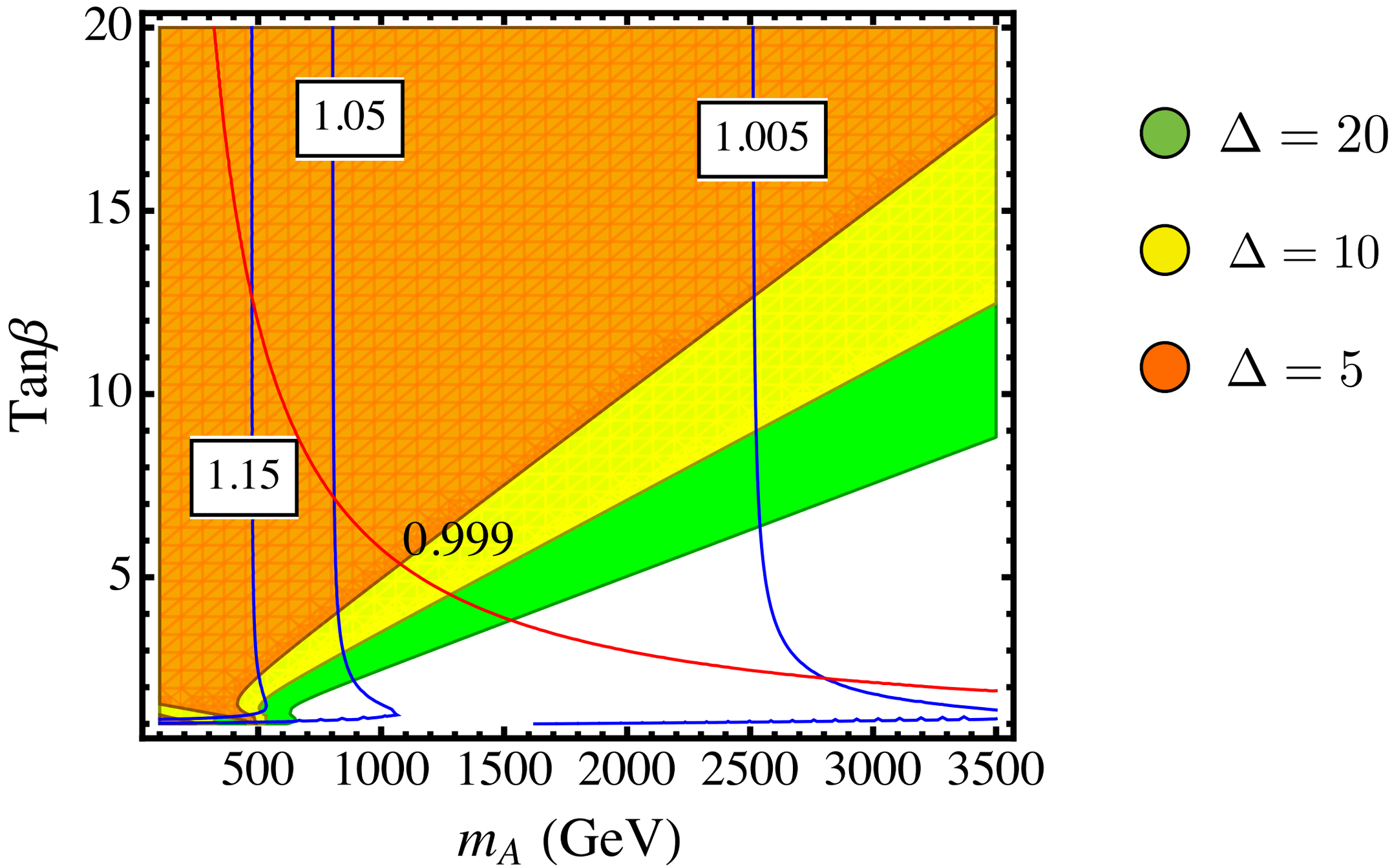
Question 2: SM like Higgs couplings & tuning cost

Loop couplings

$$\delta r_G^{\tilde{t}} \simeq \frac{m_t^2}{4}\left(\frac{1}{m^2_{\tilde{t}_1}}+\frac{1}{m^2_{\tilde{t}_2}}-\frac{X_t^2}{m^2_{\tilde{t}_1}\,m^2_{\tilde{t}_2}}\right)$$



Tree level Higgs couplings



No deviations necessarily expected

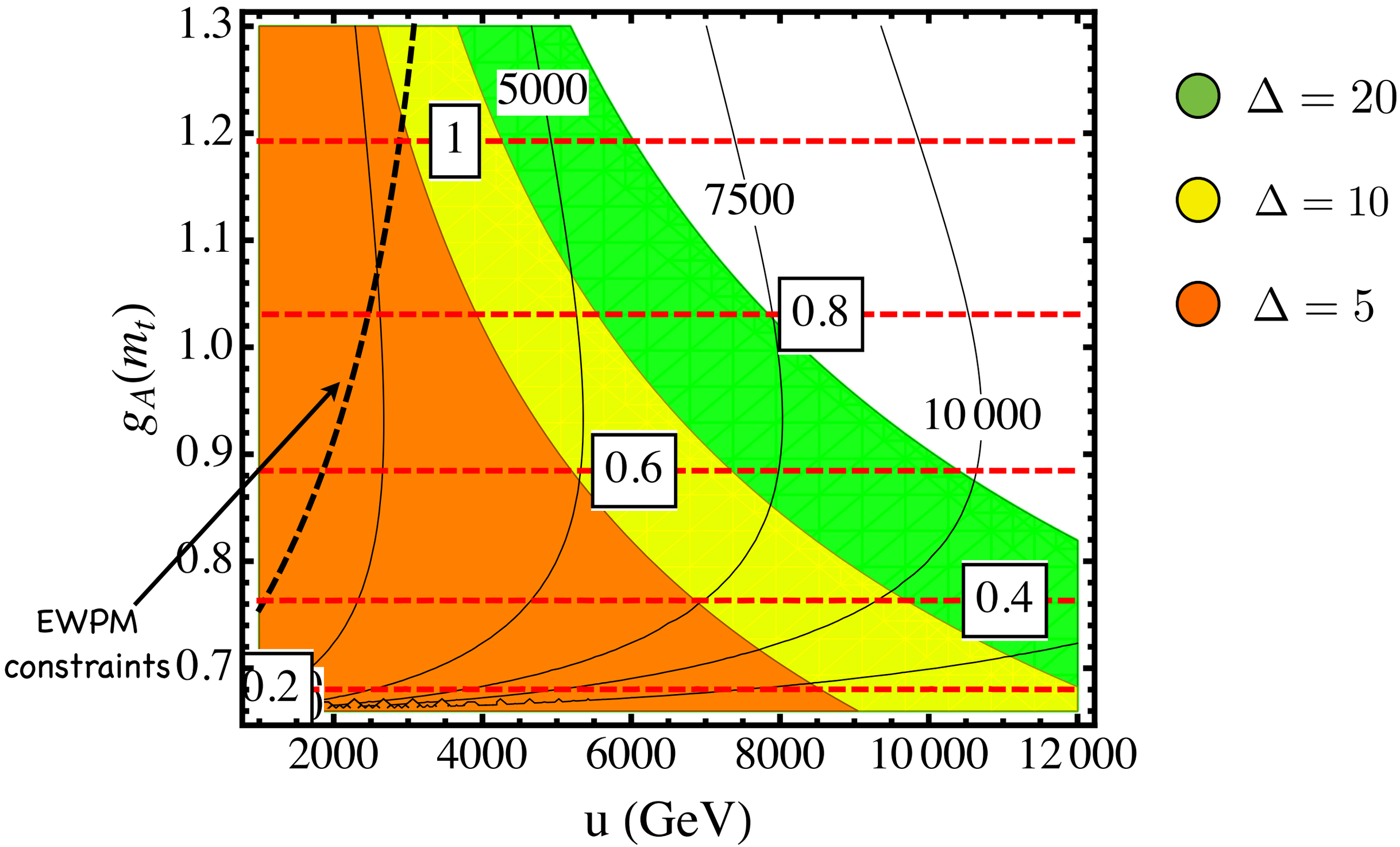
Tension solved!

Model	126 GeV Higgs mass	SM like couplings
MSSM	FT	Natural
NMSSM	Natural	FT
DMSSM	Natural	Natural

Non decoupling D-terms can lead to a natural 126 GeV Higgs!!

What are the probes of naturalness in this scenario?

Mass of extra gauge bosons and naturalness



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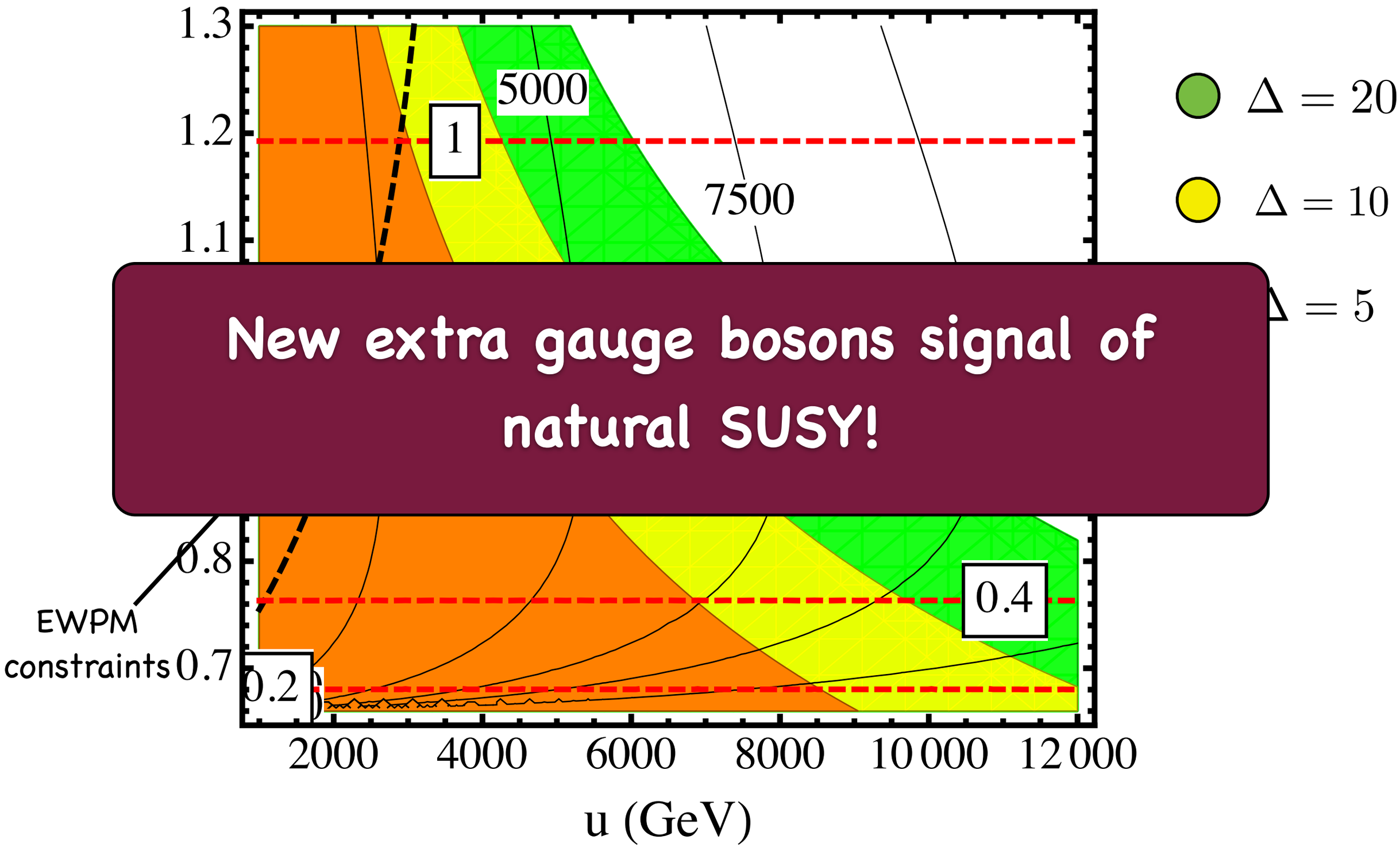
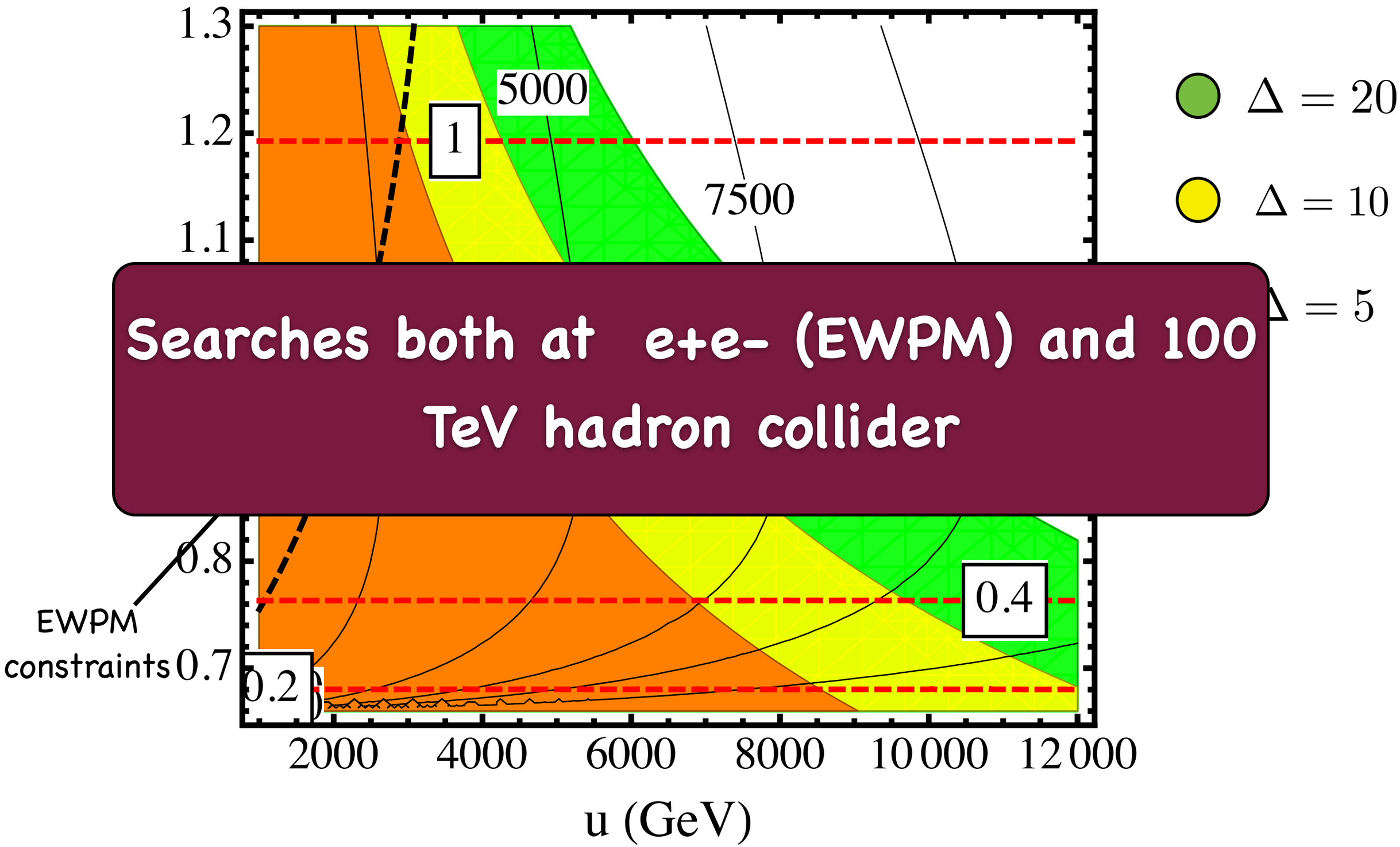


New extra gauge bosons signal of natural SUSY!

Mass of extra gauge bosons and naturalness



Searches both at e+e- (EWPM) and 100 TeV hadron collider

Summary

- Non decoupling D-terms lead to a natural 126 GeV Higgs possibly SM like!
- New gauge bosons as signal of natural SUSY at LHC 13 or 100 TeV collider