

BSM Institute

CERN

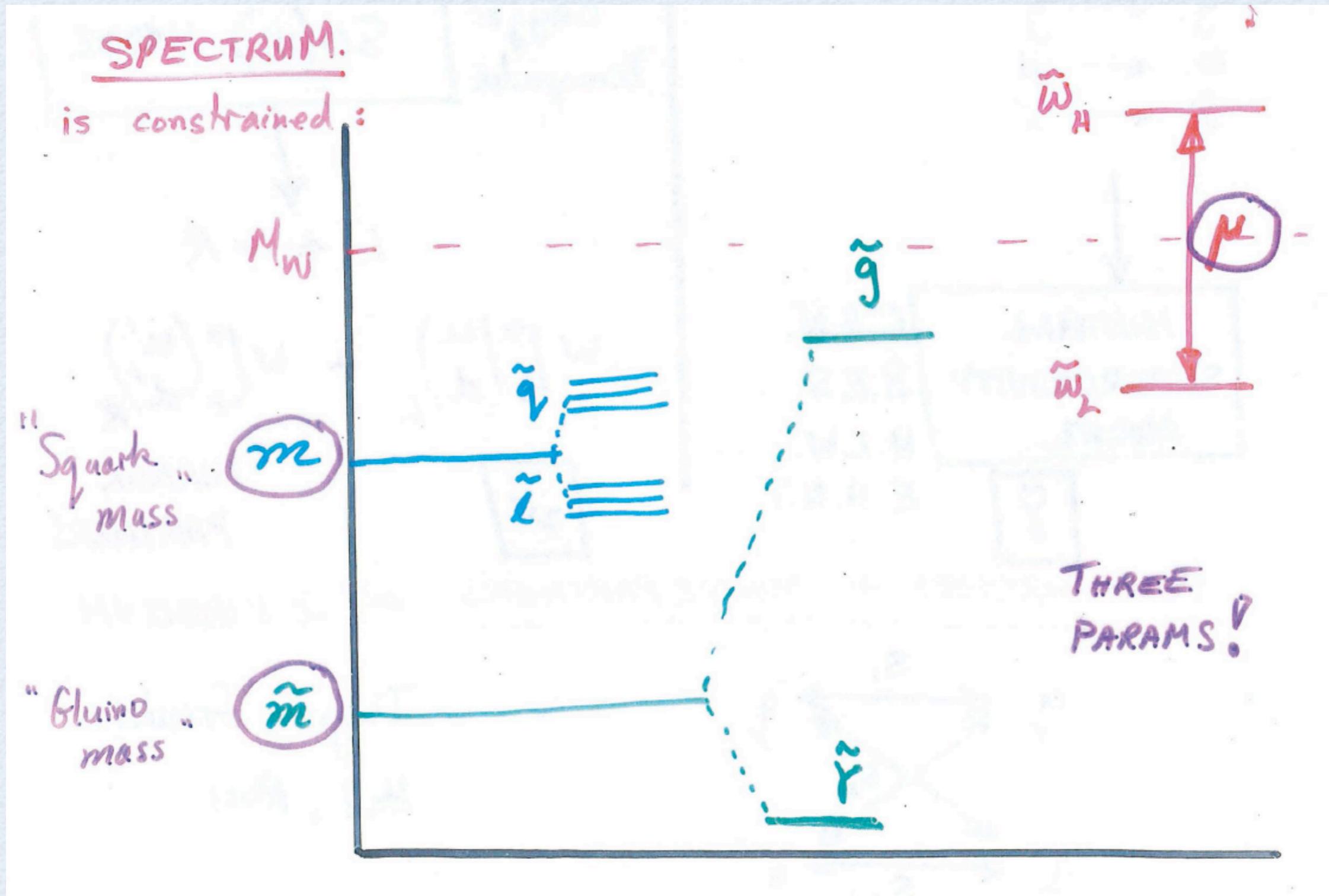
June, 2012

Where is SUSY?

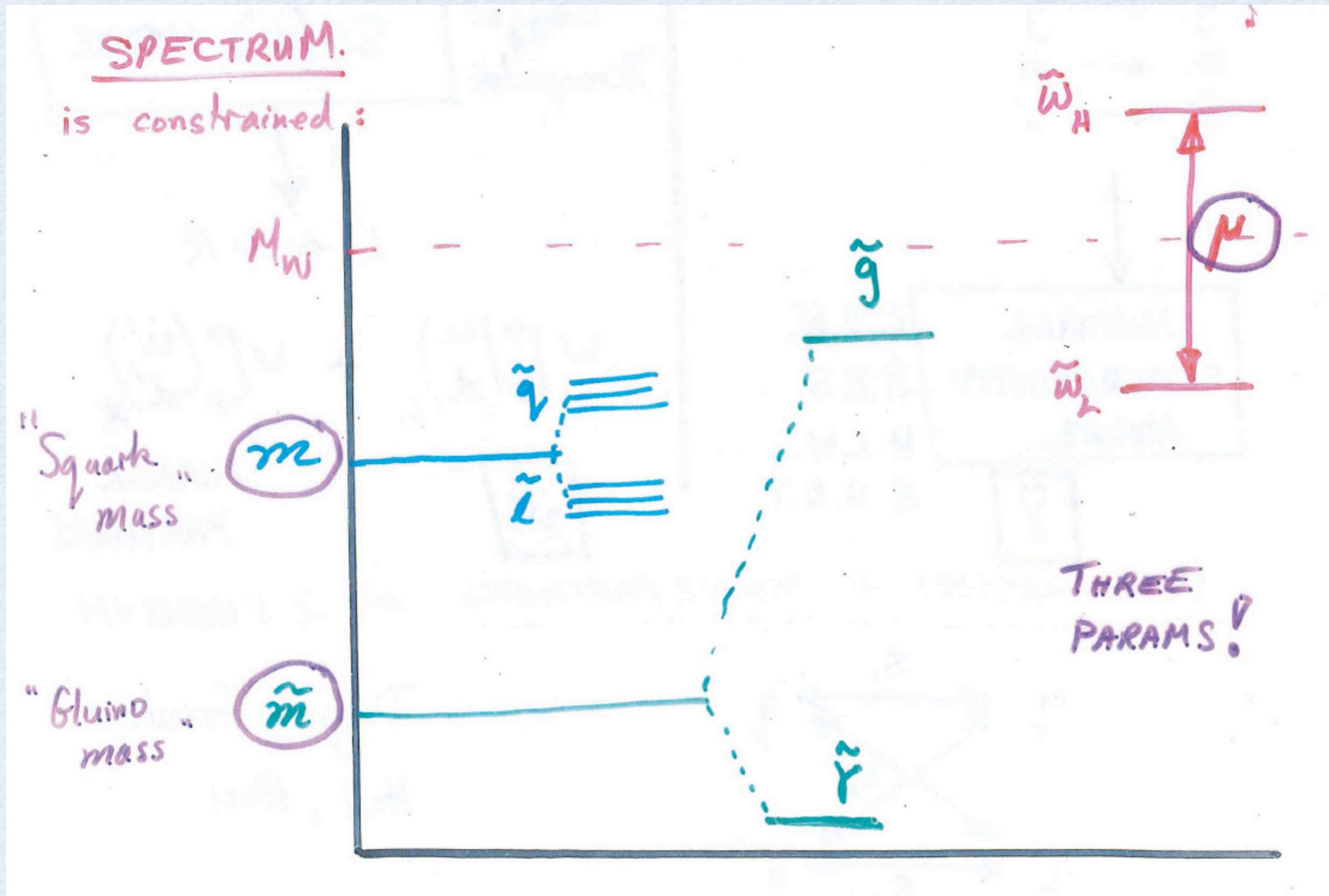
Lawrence Hall

University of California, Berkeley

SUSY Spectrum, 1984

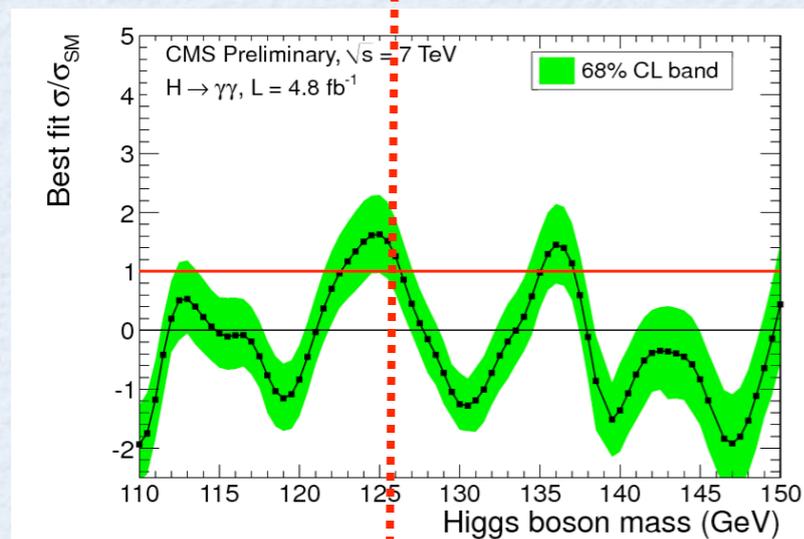
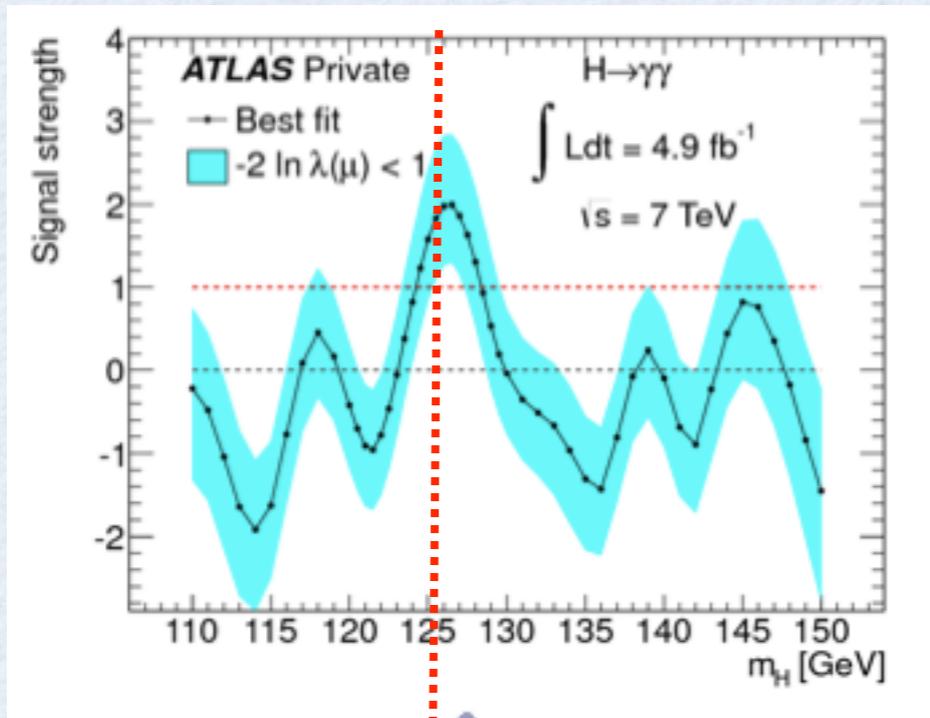


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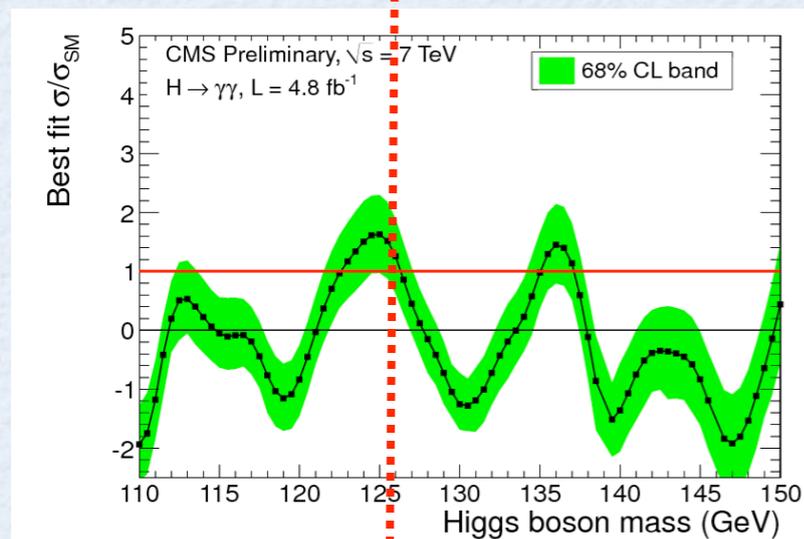
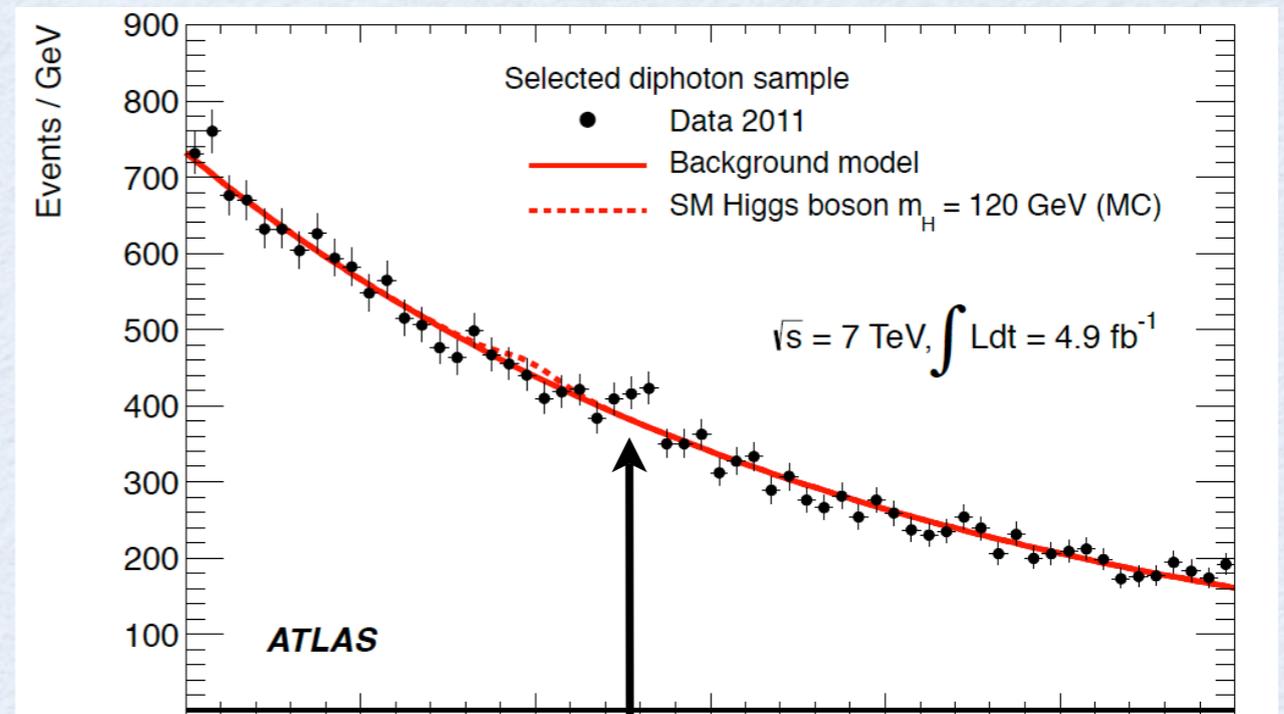
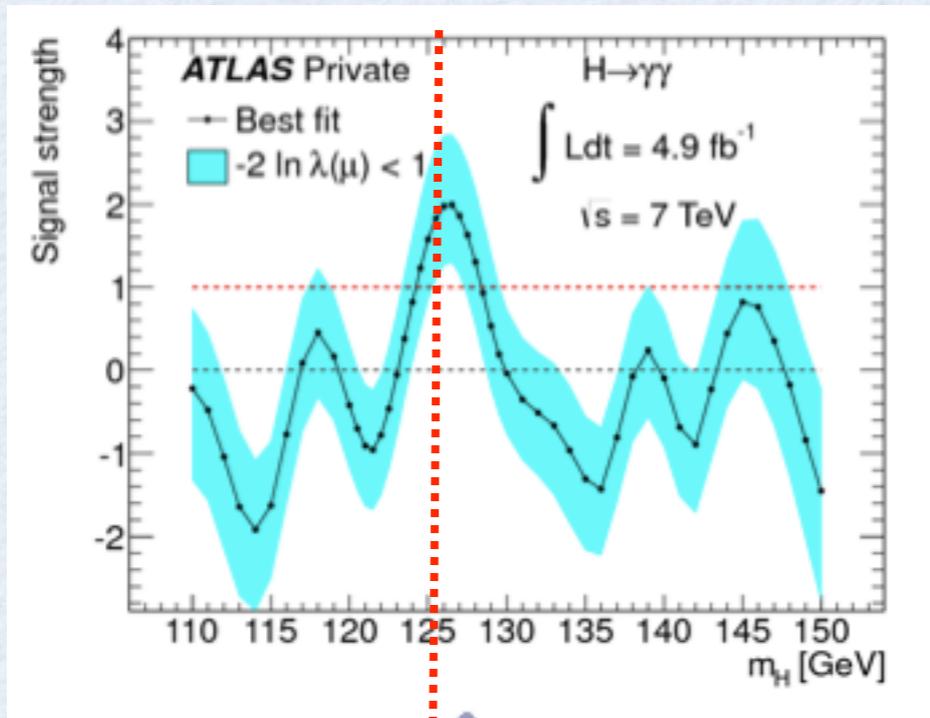
Over 3 decades of susy: seismic shifts!

Assume Higgs is near 125 GeV



Reasonable

Assume Higgs is near 125 GeV



Could go away!

Reasonable

Is SUSY Natural?

Natural

$$\tilde{m} \sim v$$

Unnatural

$$\tilde{m} \gg v$$

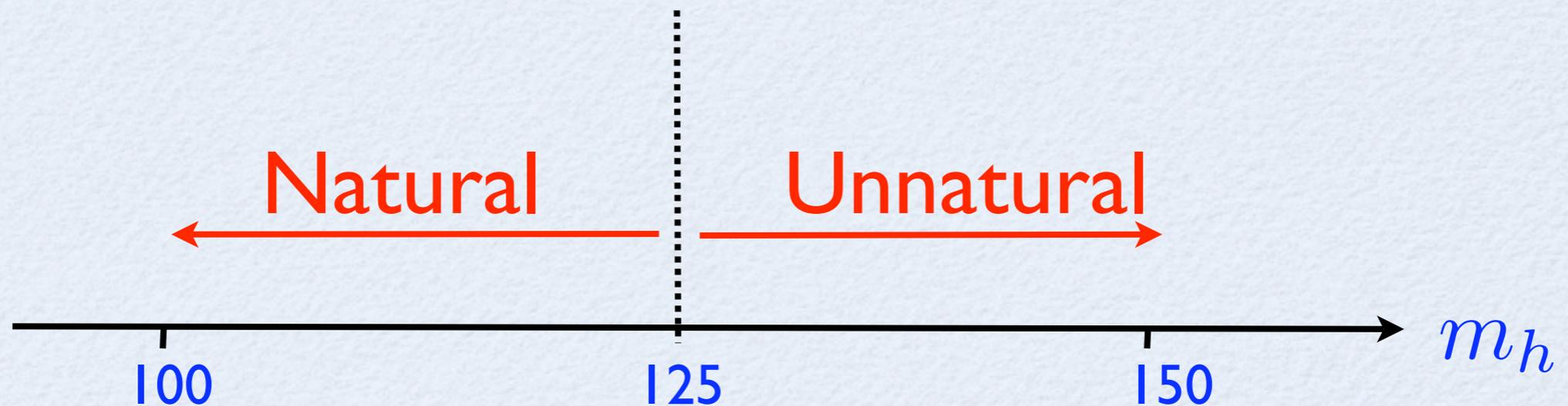
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We simply don't know

Fine-Tuning in the MSSM: 2012

David Pinner, Josh Ruderman, LJH 1112.2703

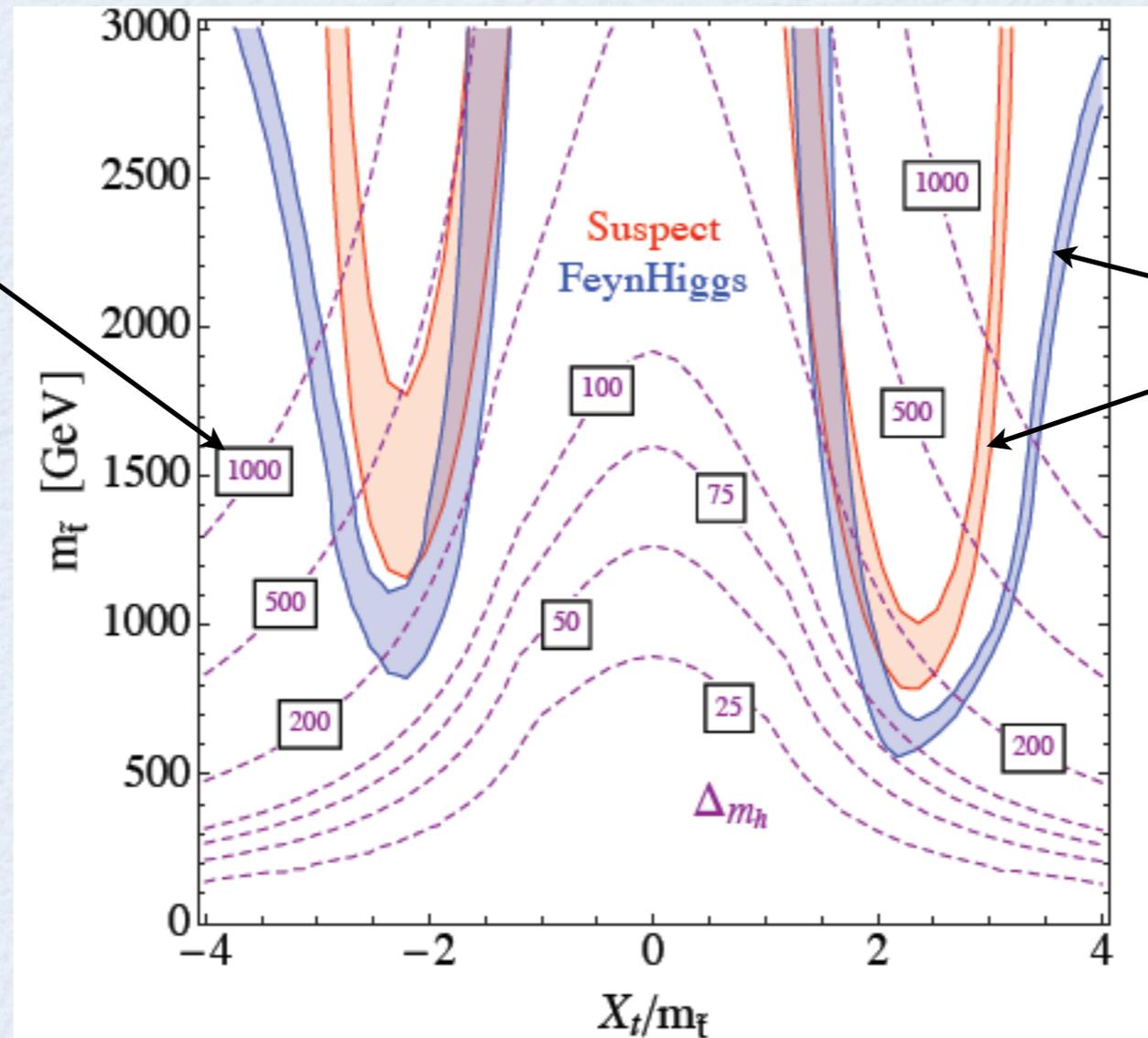
$$\Delta = \frac{\partial \ln m_h}{\partial \ln p}$$

Minimize Δ

$$\tan \beta > 10$$

$$m_{Q_3} = m_{U_3} = m_{\tilde{t}}$$

messenger scale
of 10 TeV



$$m_h = 124 - 126 \text{ GeV}$$

Fine-Tuning in the MSSM: 2012

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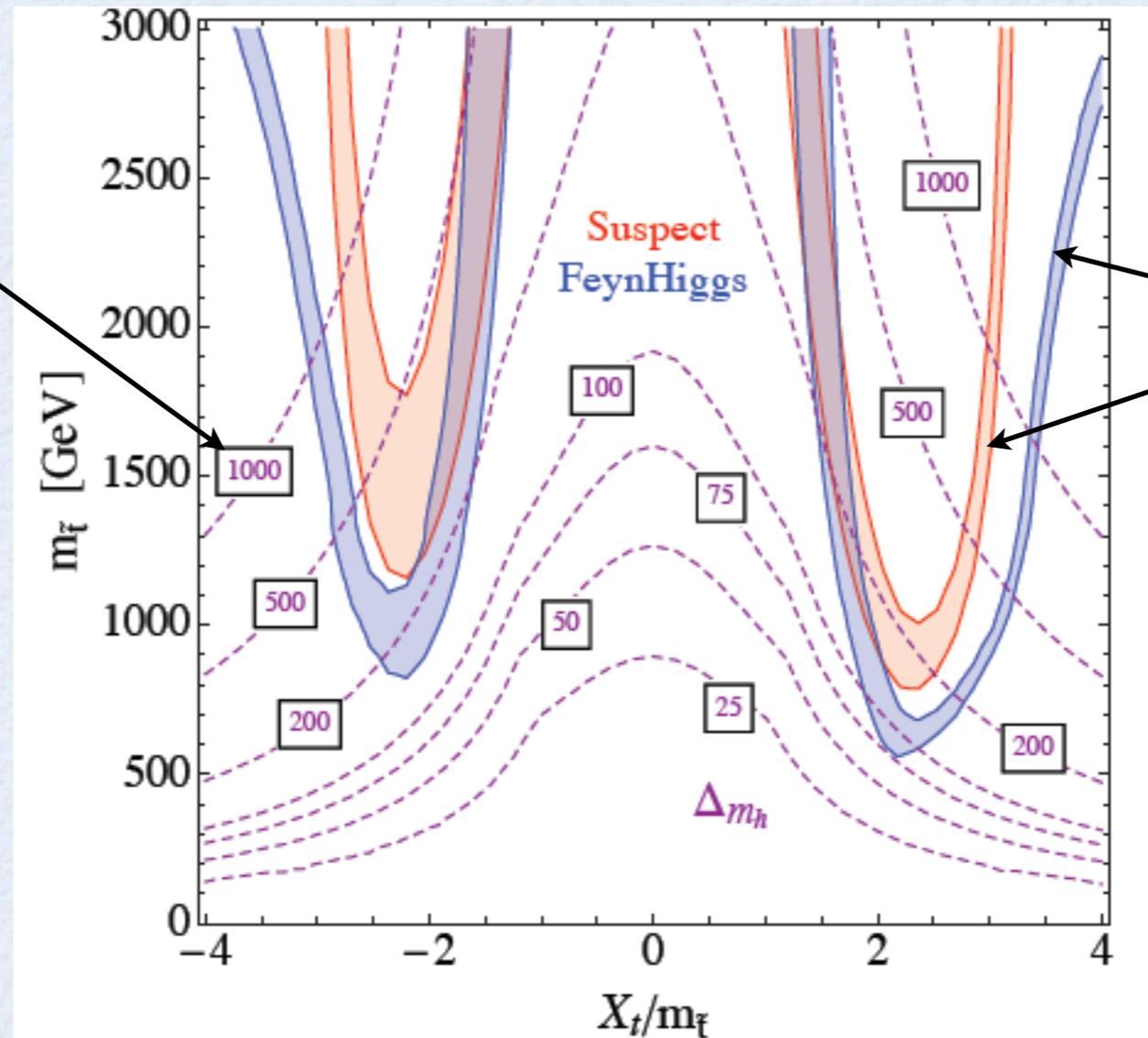
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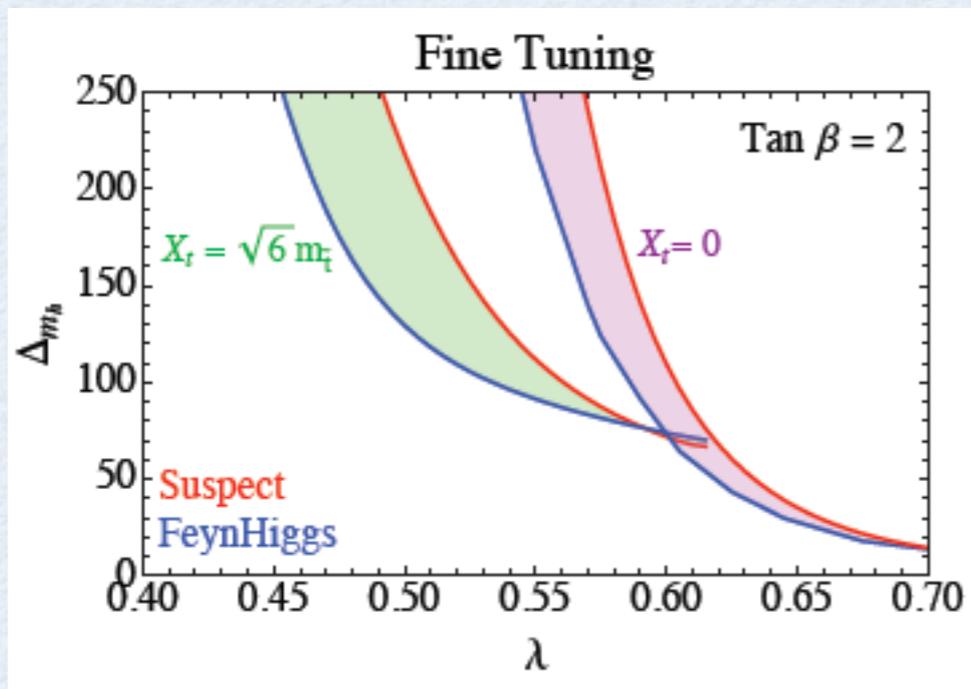
$\Delta > 100$ The MSSM is fine-tuned

Adding a Singlet:

$$\lambda S H_u H_d$$

$$\lambda < 0.7$$

David Pinner, Josh Ruderman, LJH 1112.2703

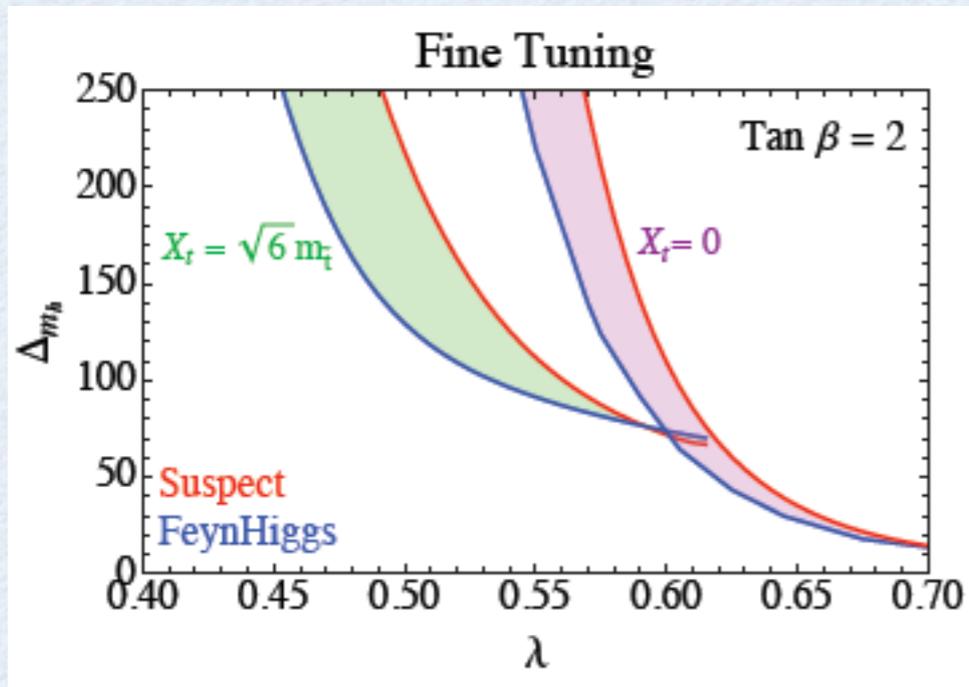


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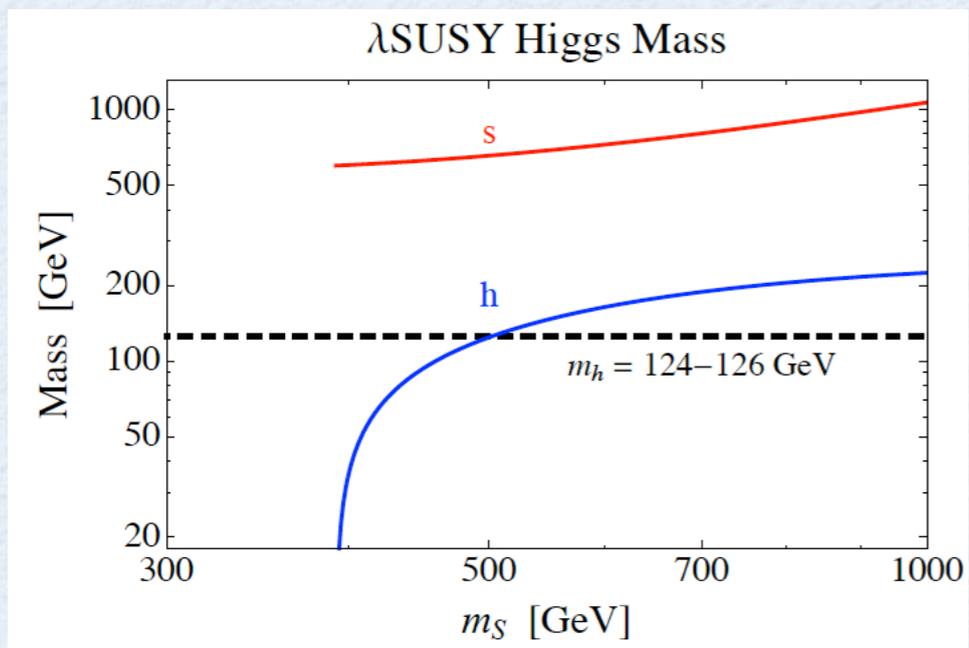
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$$1 < \lambda < 2$$

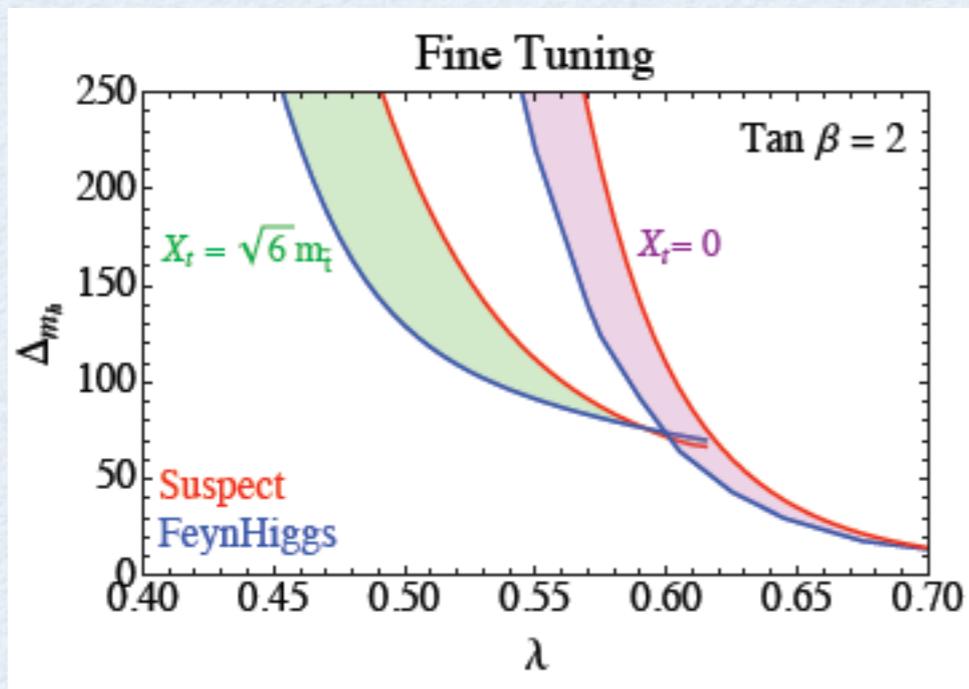


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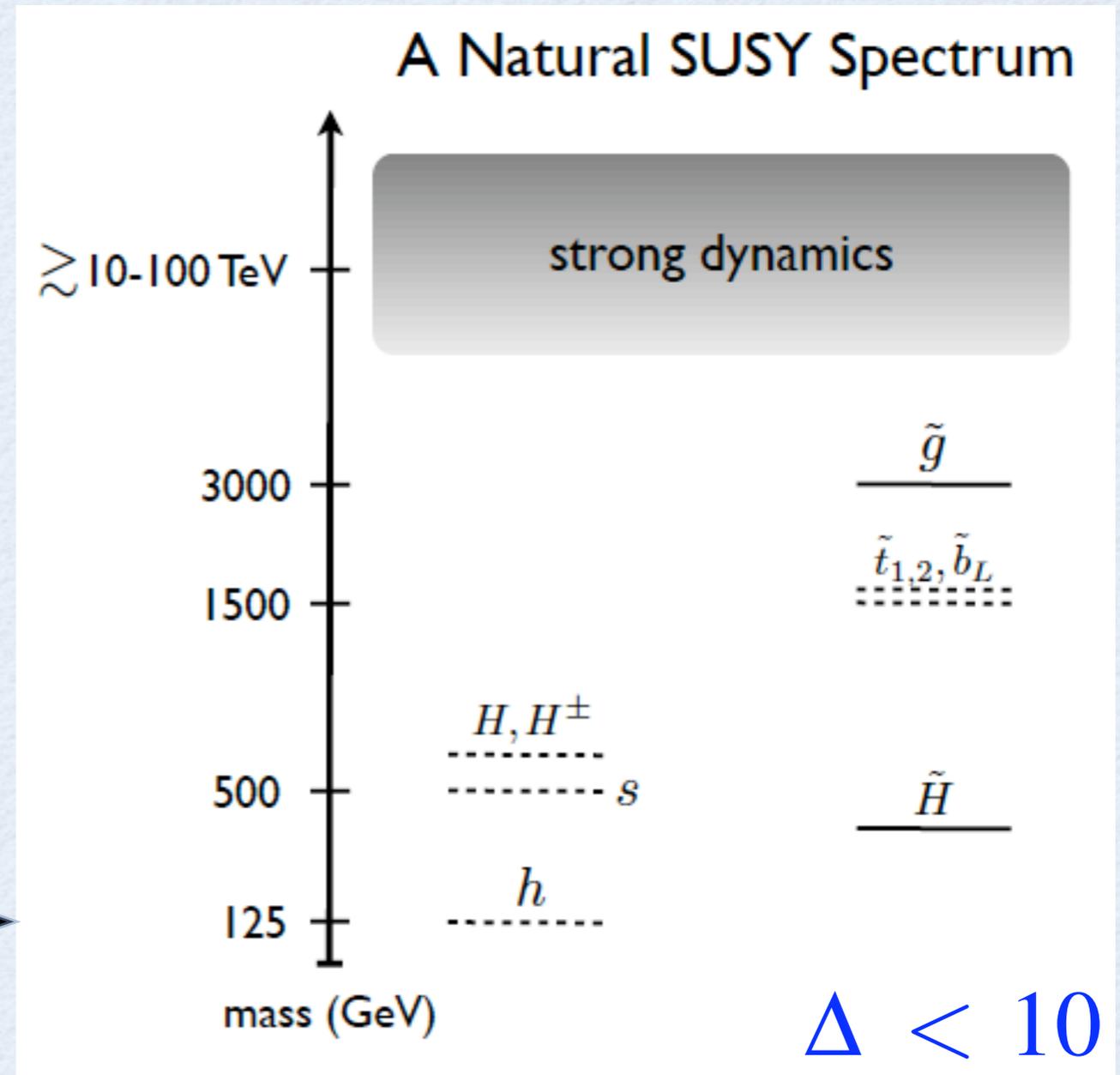
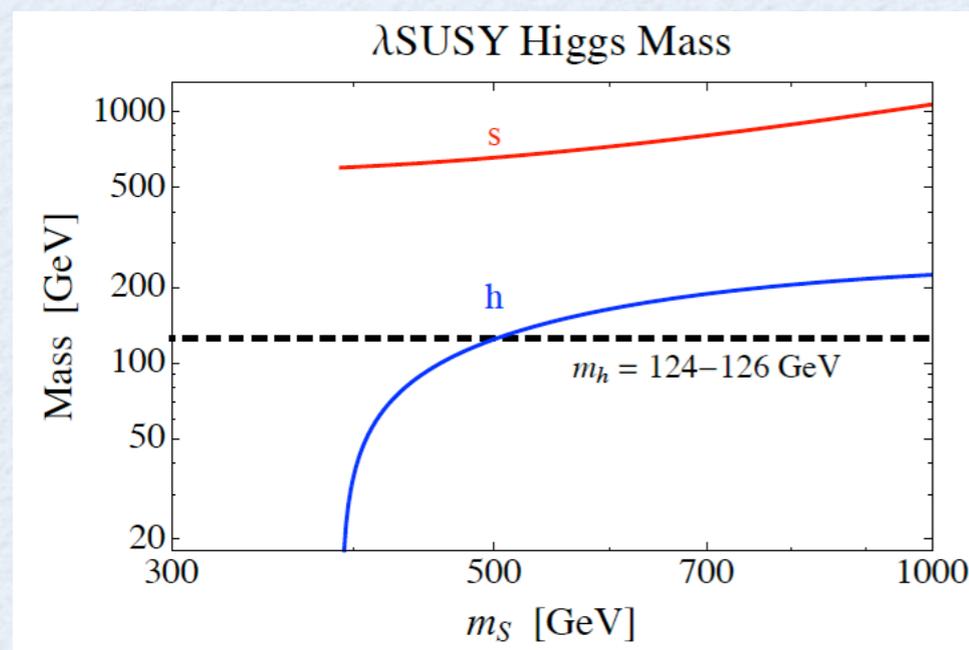
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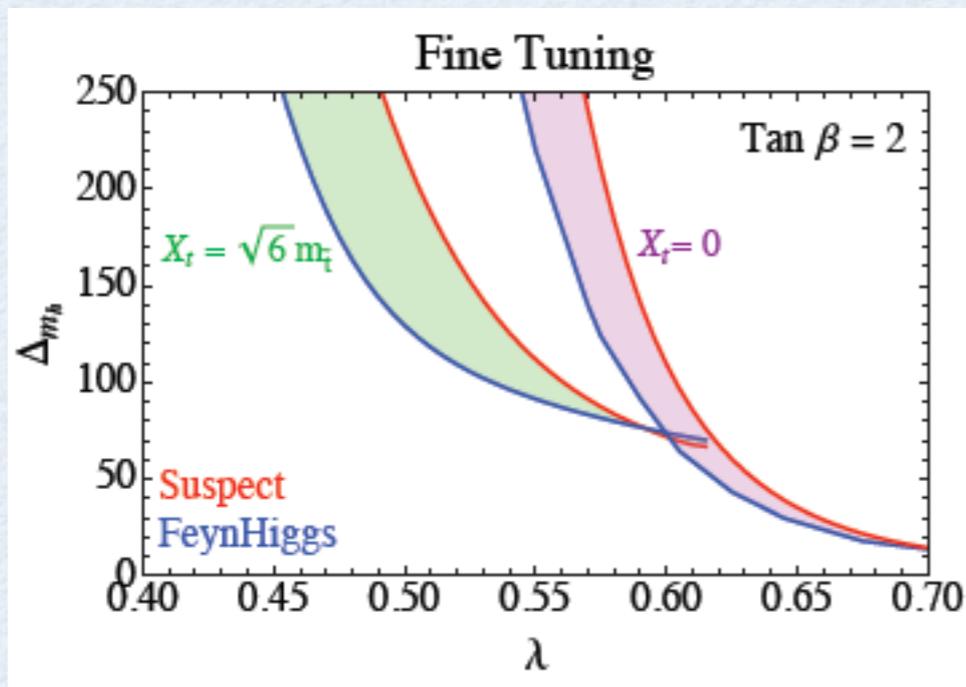


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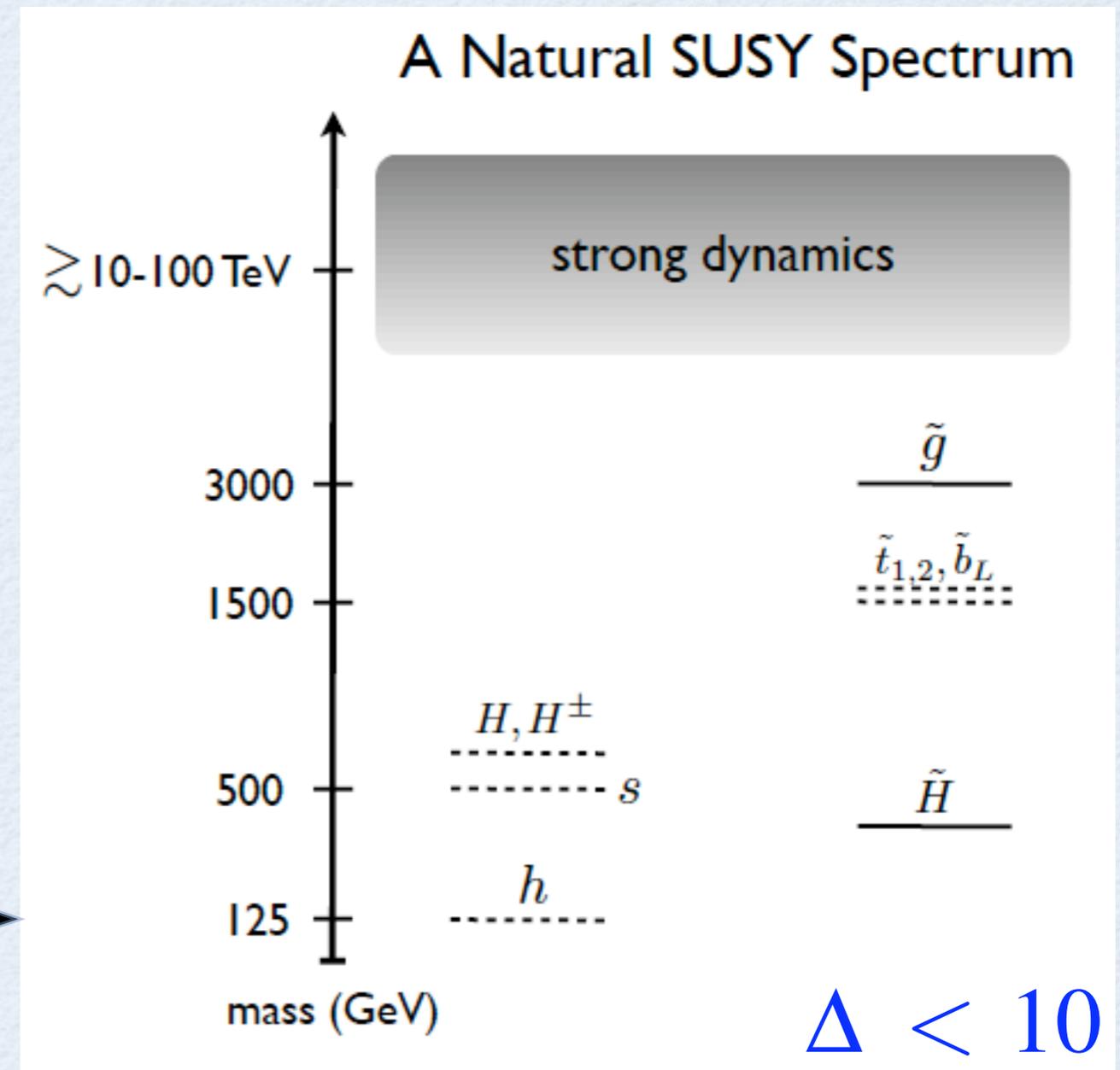
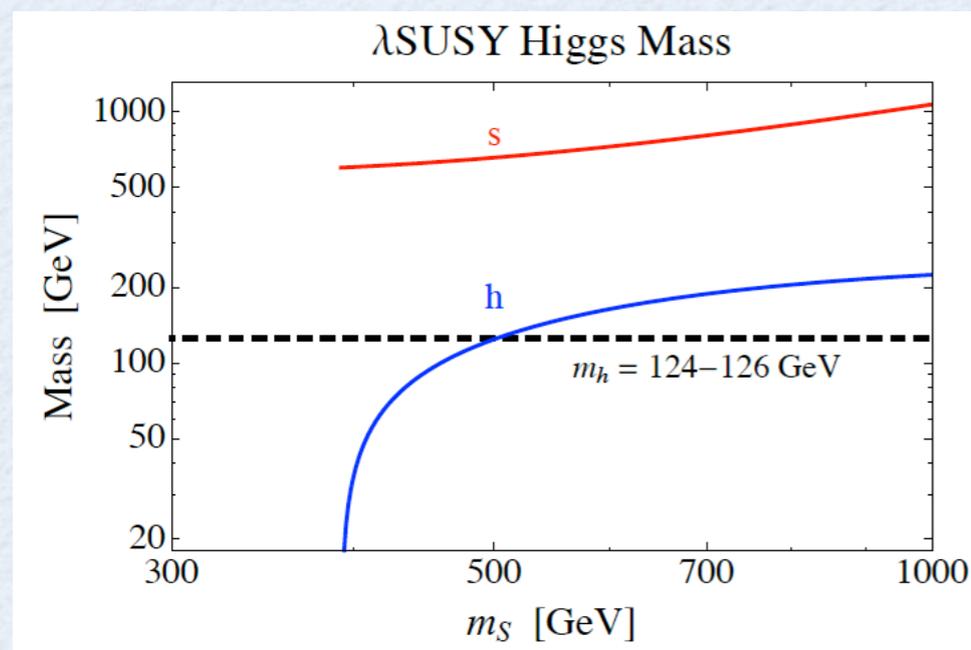
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David Pinner, Josh Ruderman, LJH 1112.2703

$$\lambda < 0.7$$



$$1 < \lambda < 2$$



Explains why we haven't seen superpartners yet

If SUSY is Split, By How Much?

I Bottom Up

II High Scale SUSY

III Top Down

I A Bottom-Up Approach

Revisit Motivation for SUSY

Natural

Unnatural

- ✱ Natural weak scale
- ✱ Gauge coupling unification
- ✱ WIMP LSP Dark Matter

I A Bottom-Up Approach

Revisit Motivation for SUSY

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Unnatural



~~Natural weak scale~~



What sets the scale
of the squark mass?



Gauge coupling unification



Gauge coupling unification



WIMP LSP Dark Matter



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b/τ

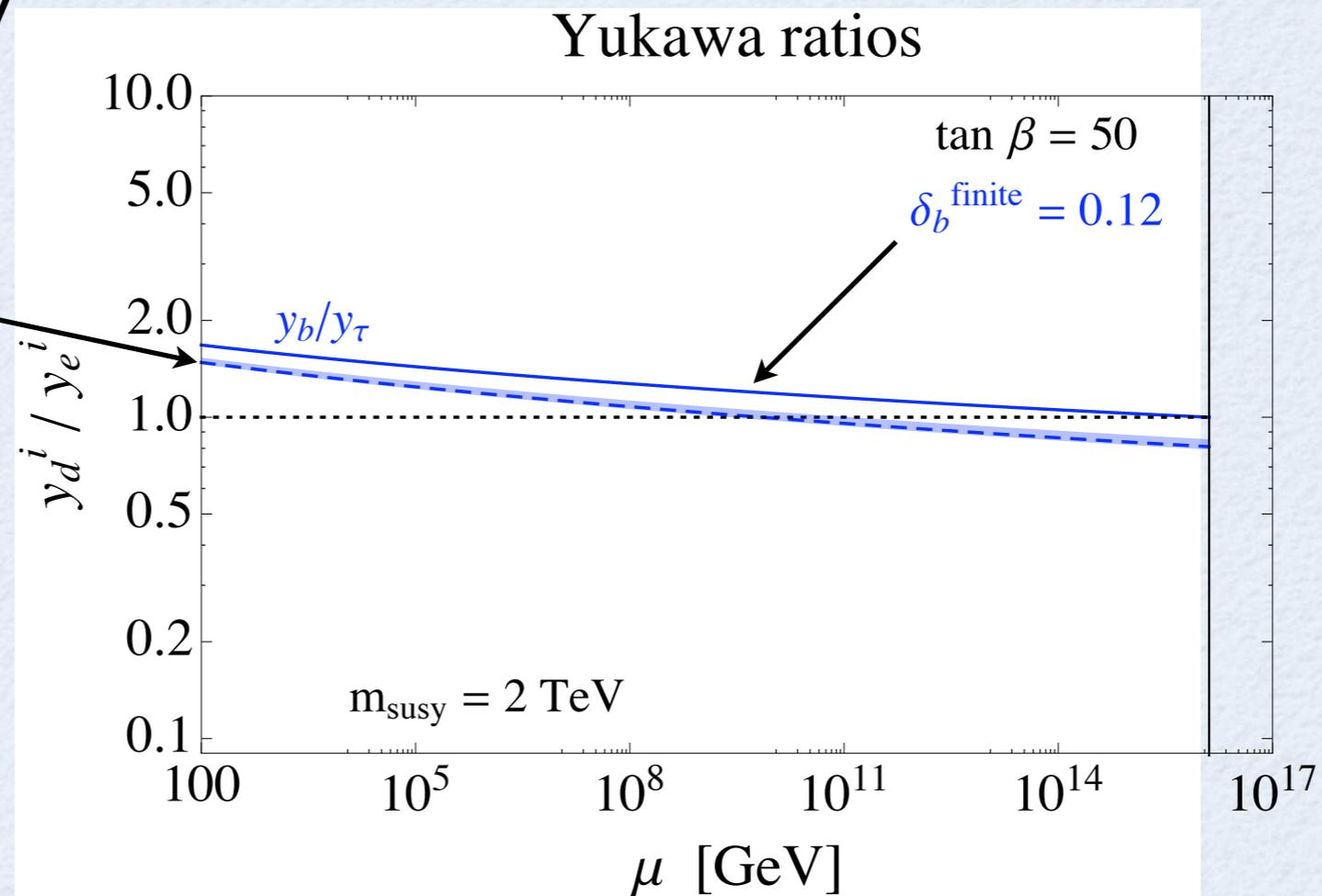
b/τ in 2012

Superpartners at 2 TeV

2 loop RGE

No susy thresholds

$\pm 2\sigma$



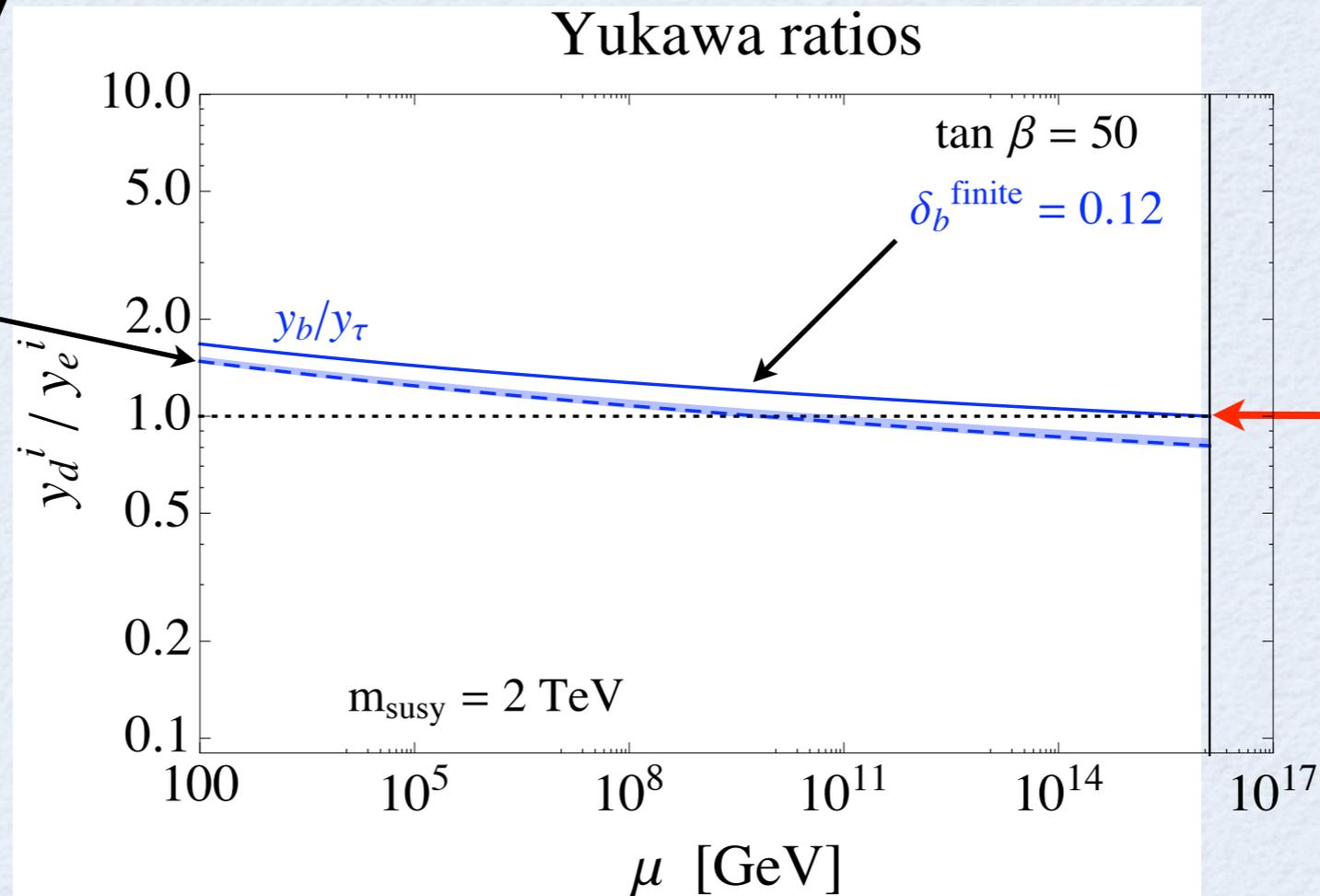
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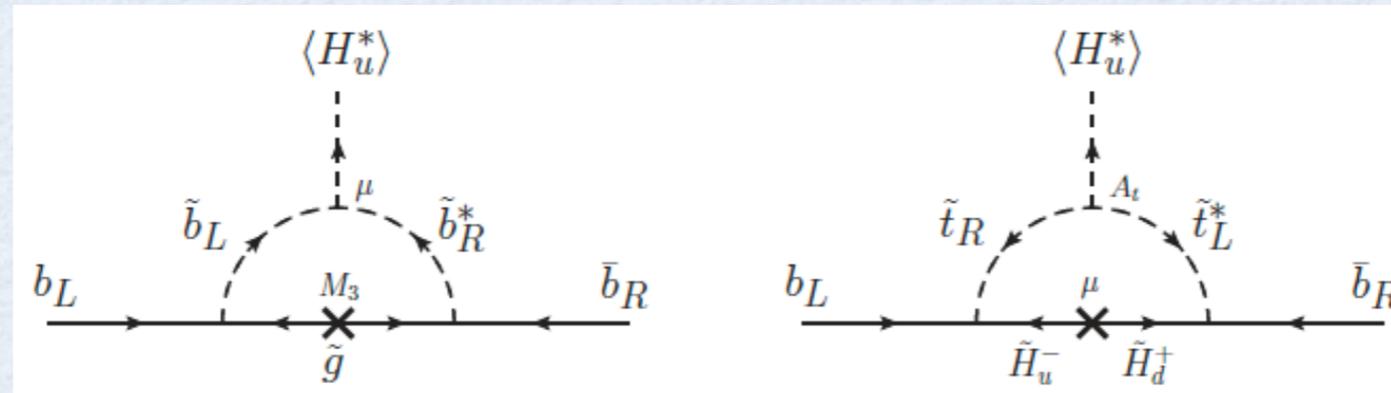


Includes
12% susy
threshold

Yukawas span 6 decades:

Is b/τ a hint?

The Finite SUSY Threshold

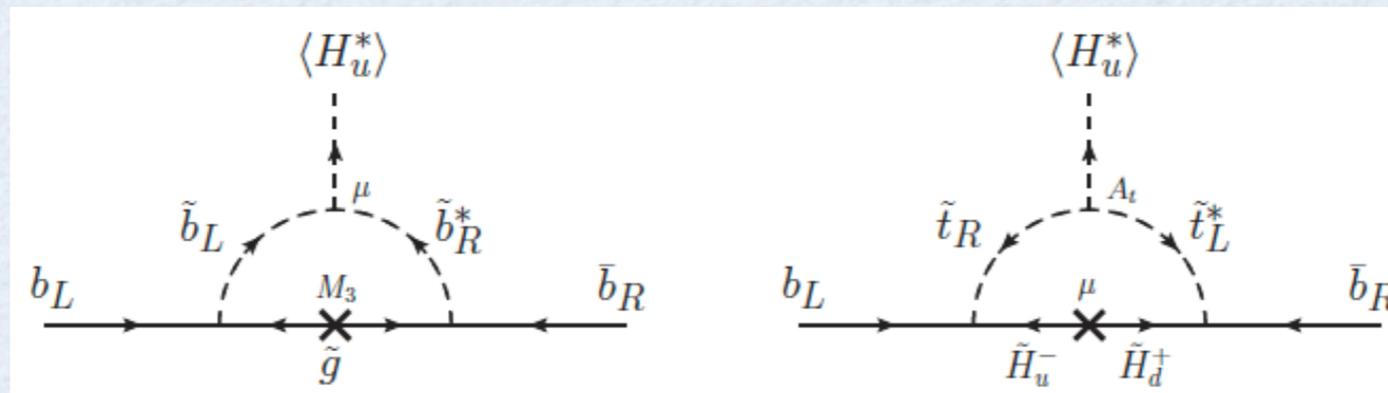
 δ_b^{fin} 

$$\delta_b^{fin} = -\frac{g_3^2}{12\pi^2} \frac{\mu M_3}{m_{\tilde{b}}^2} \tan \beta - \frac{y_t^2}{32\pi^2} \frac{\mu A_t}{m_{\tilde{t}}^2} \tan \beta$$

$$\delta_b^{fin} \propto \frac{\mu}{m_{\tilde{q}}} \tan \beta$$

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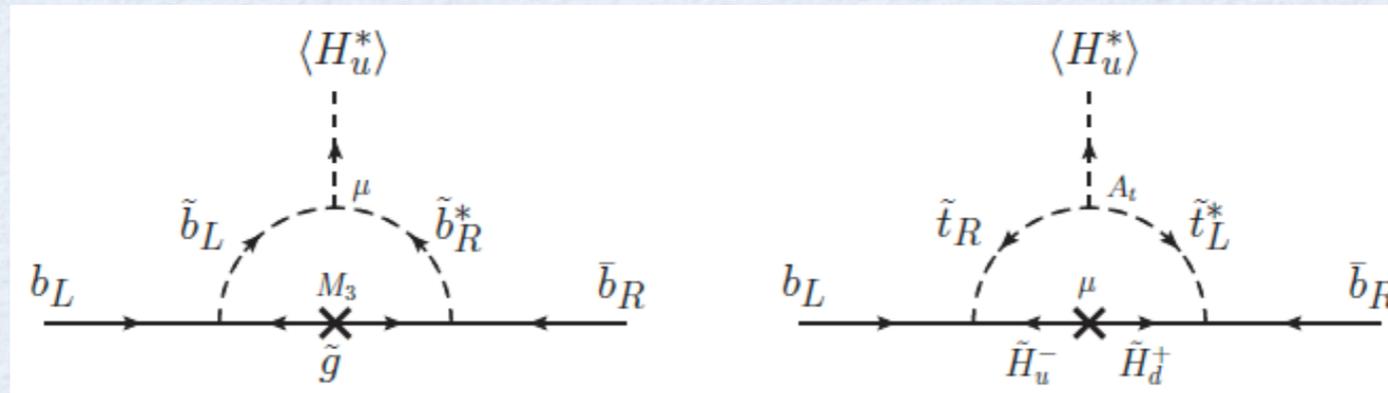
bino/Higgsino LSP
dark matter



Cannot decouple
squarks

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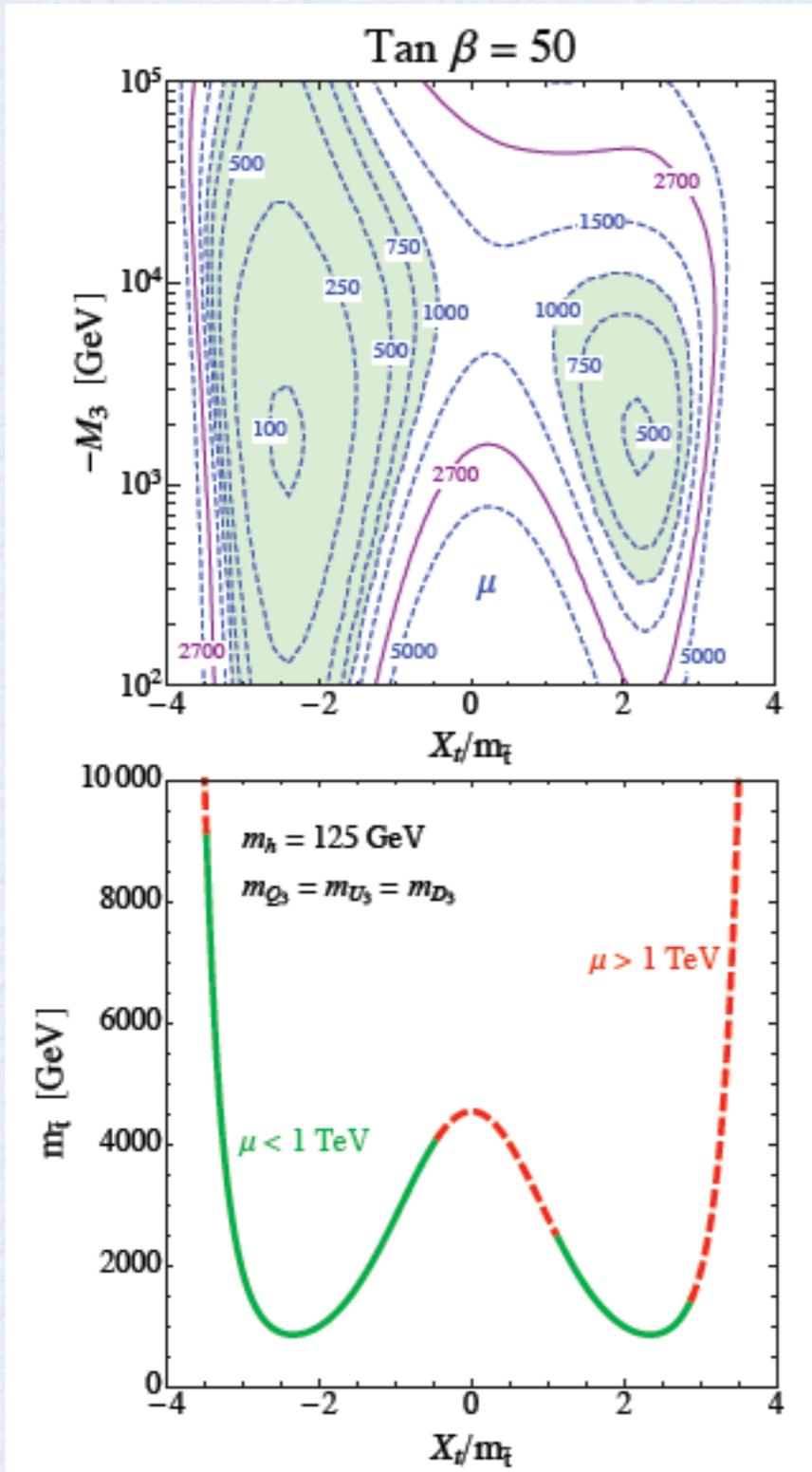
Need large $\tan \beta$

bino/Higgsino LSP
dark matter



Cannot decouple
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SUSY b/τ with a 125 GeV Higgs

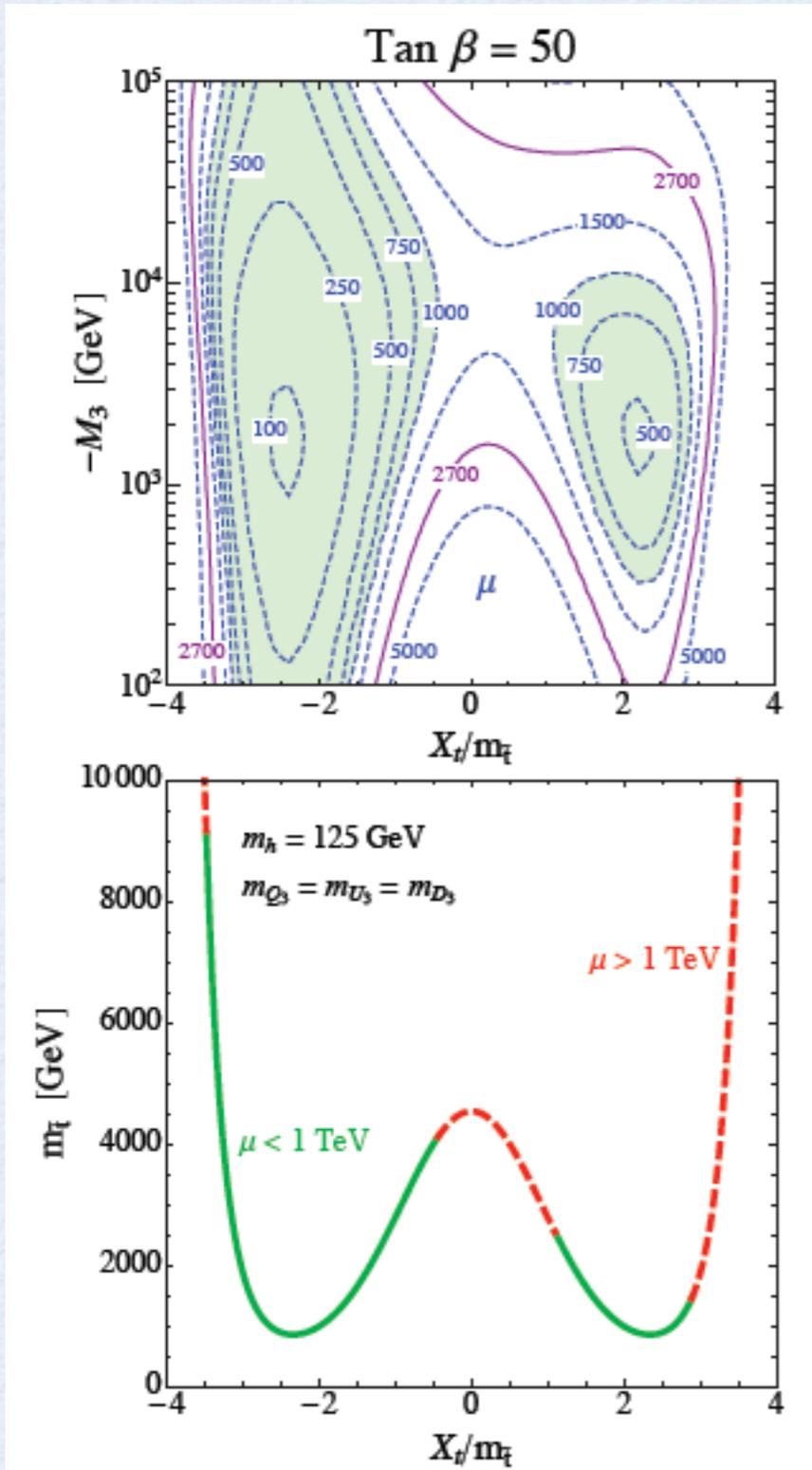


Parameter space

$M_3, X_t, \mu, \tan \beta$

$m_{Q_3} = m_{U_3} = m_{D_3} = m_{\tilde{t}}$

SUSY b/τ with a 125 GeV Higgs



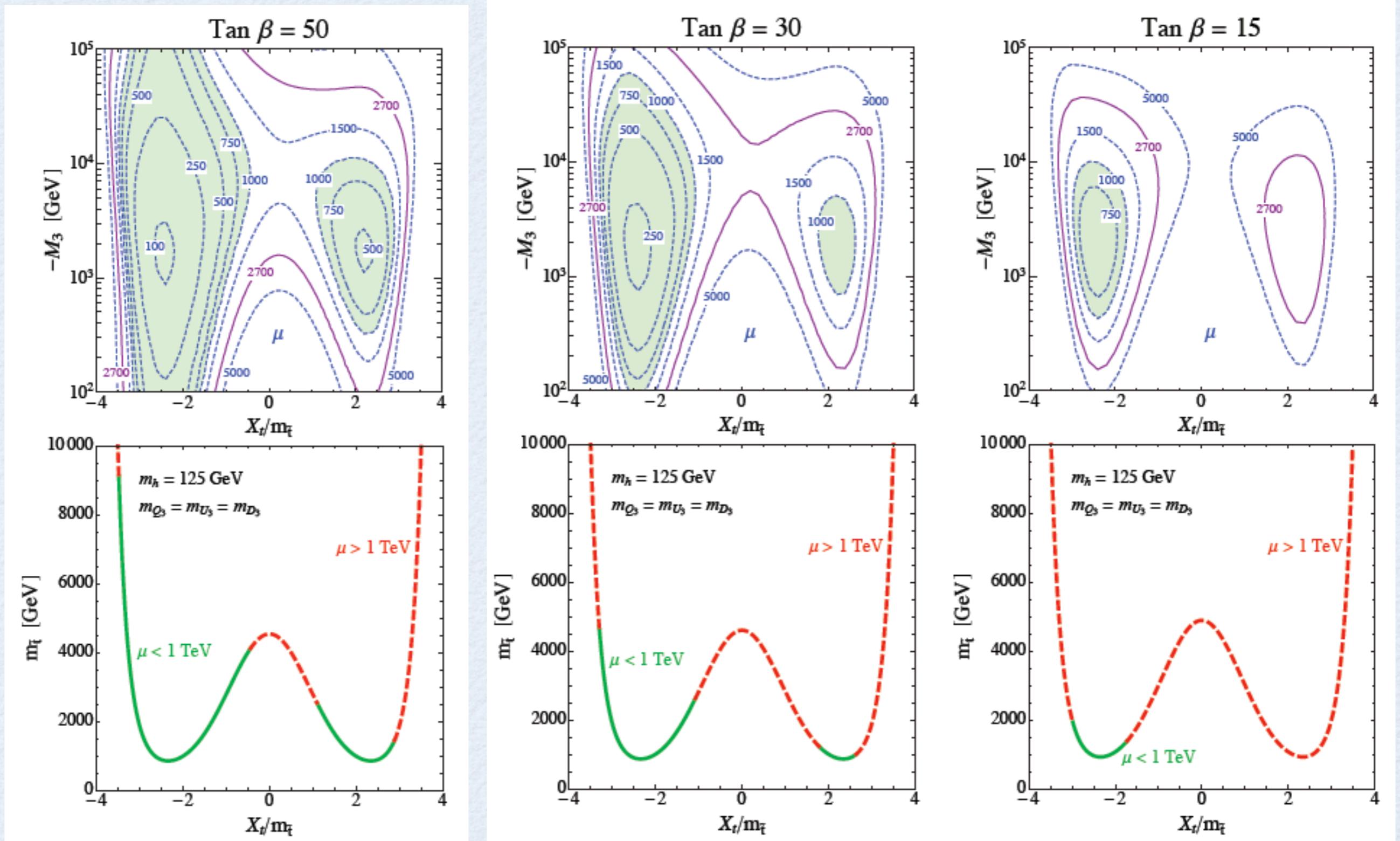
← RGE prefer right lobe

Parameter space

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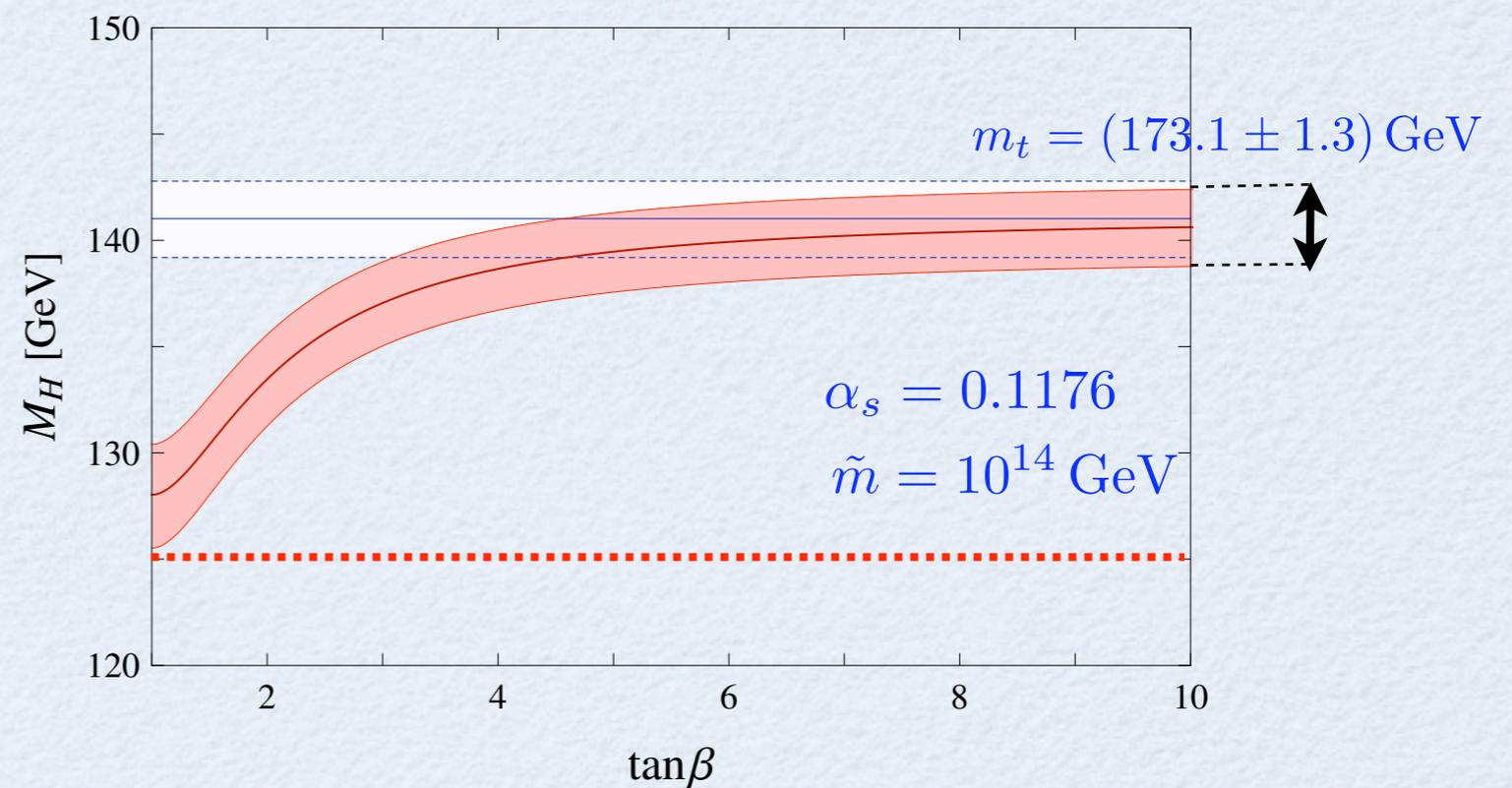


II High Scale SUSY

Hall, Nomura 0910.2235

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

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

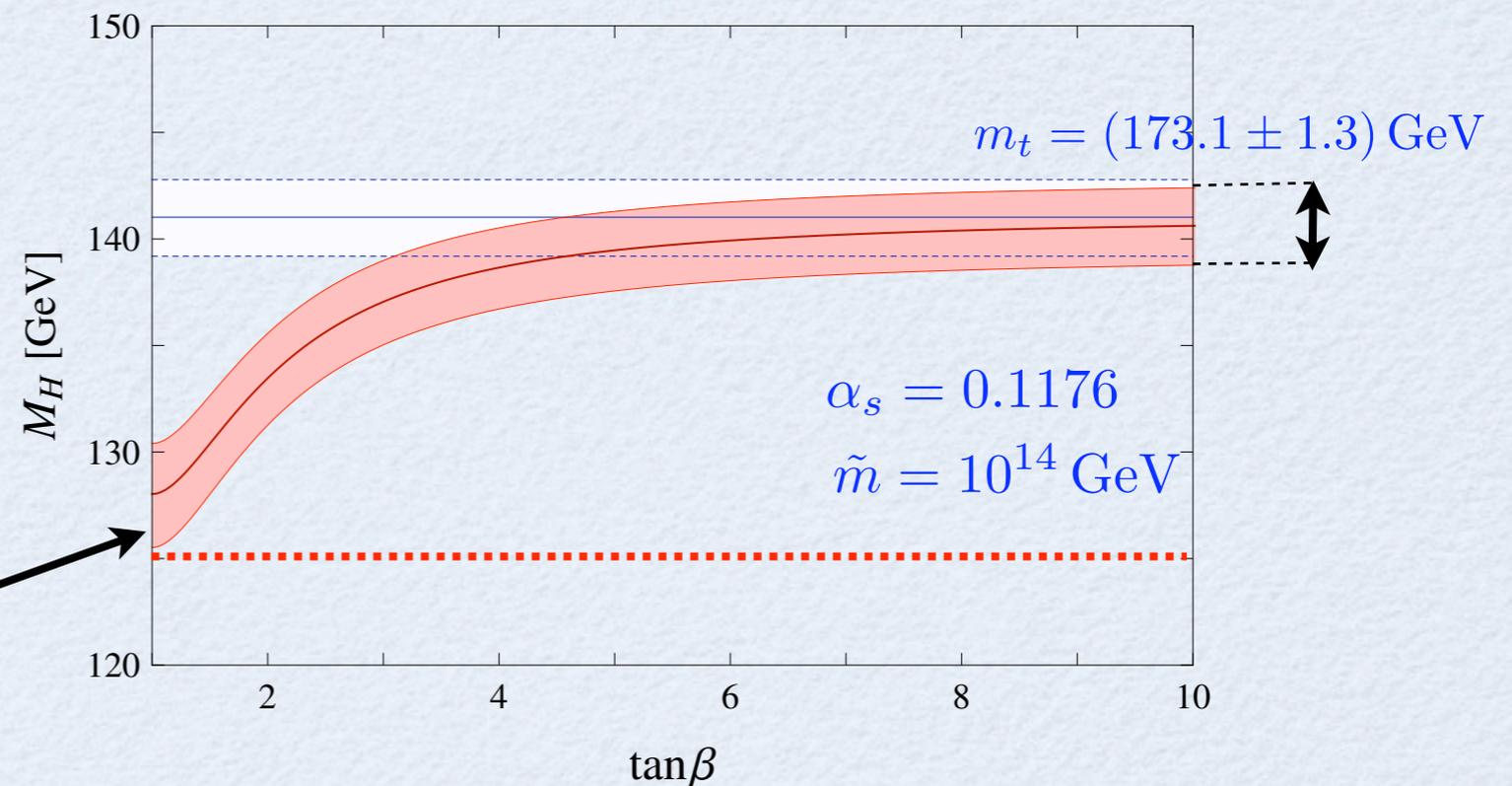


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Uncertainties from

α_s, m_t

NNLO (A. Strumia)

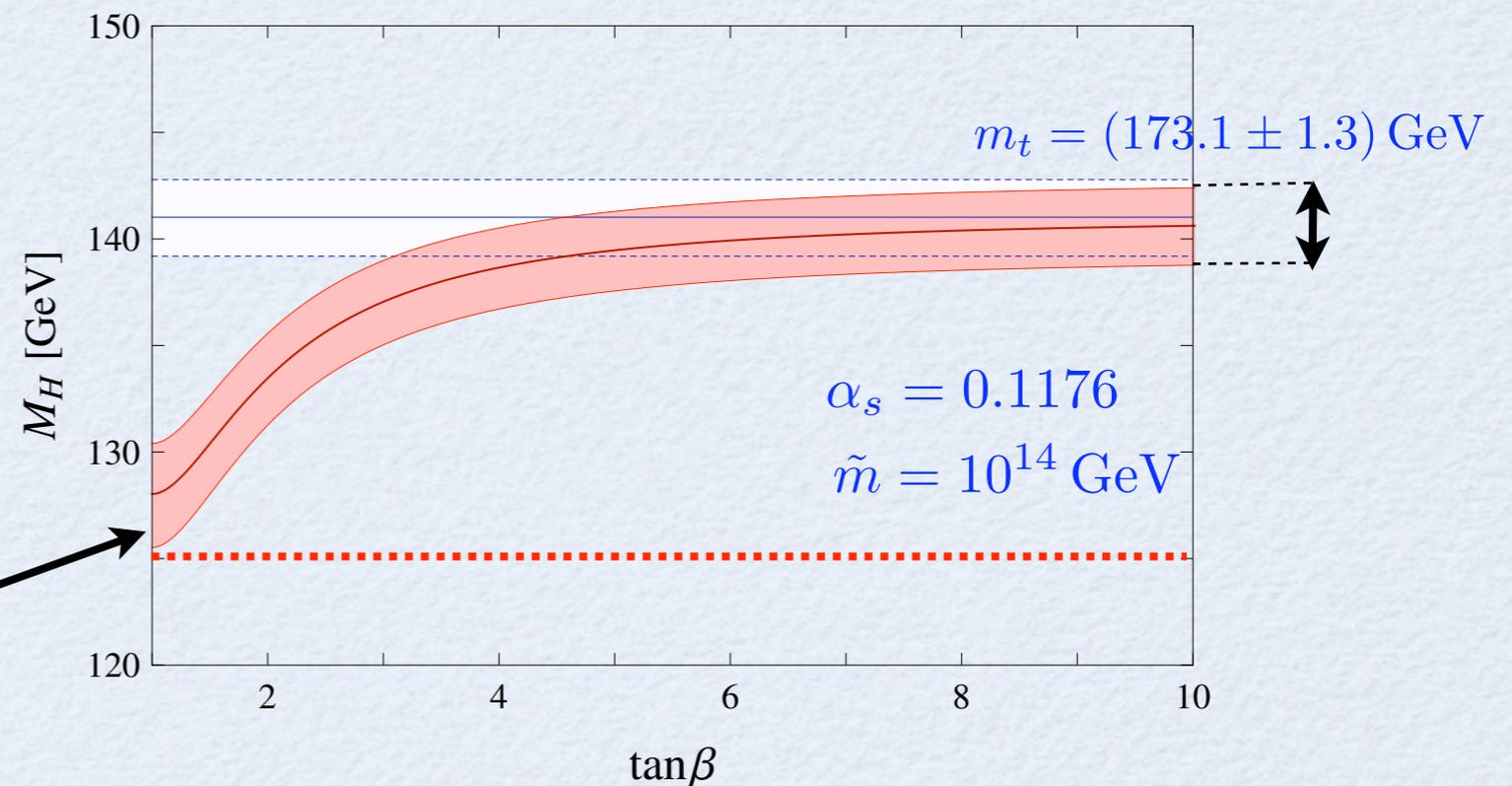
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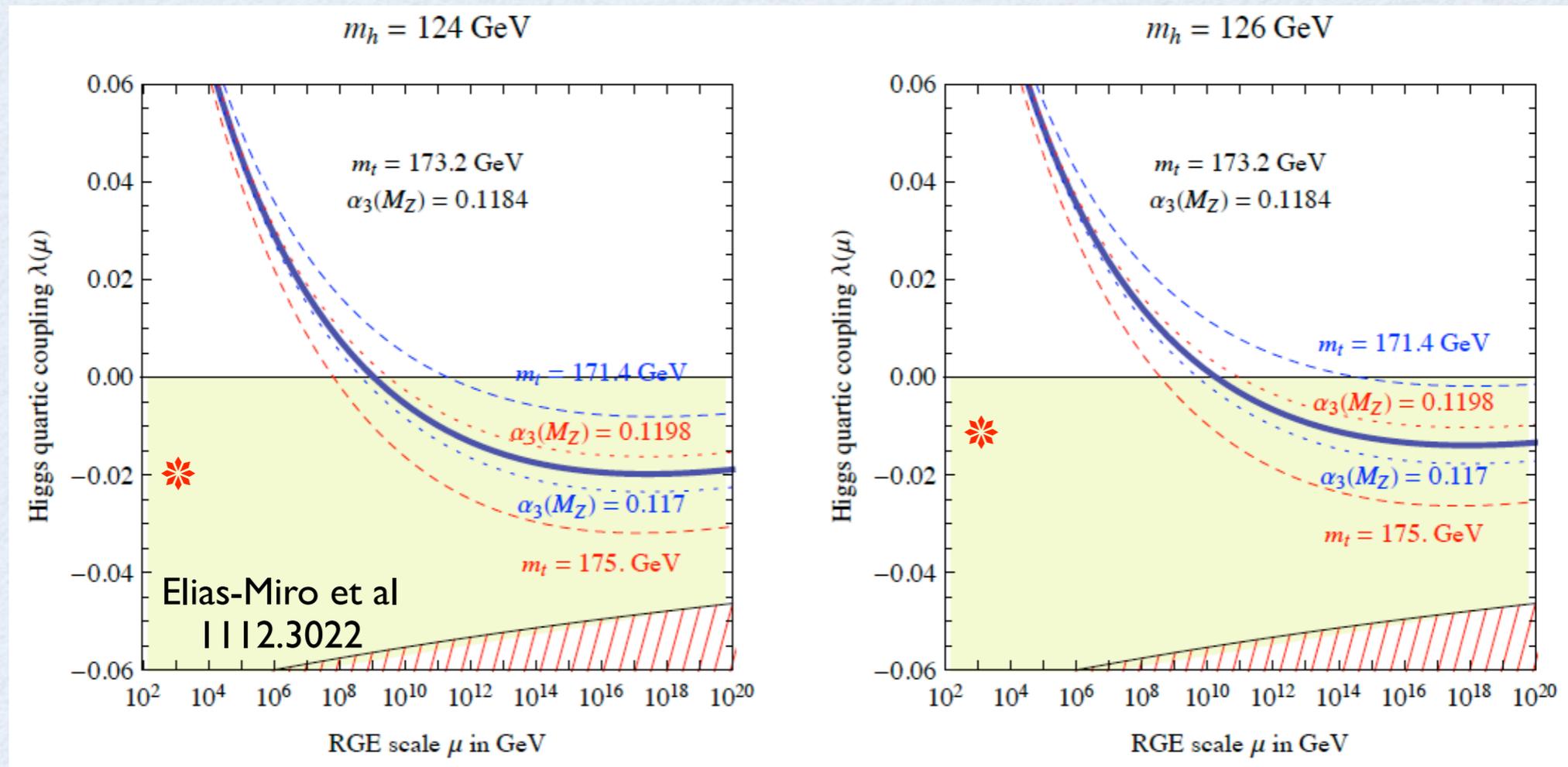
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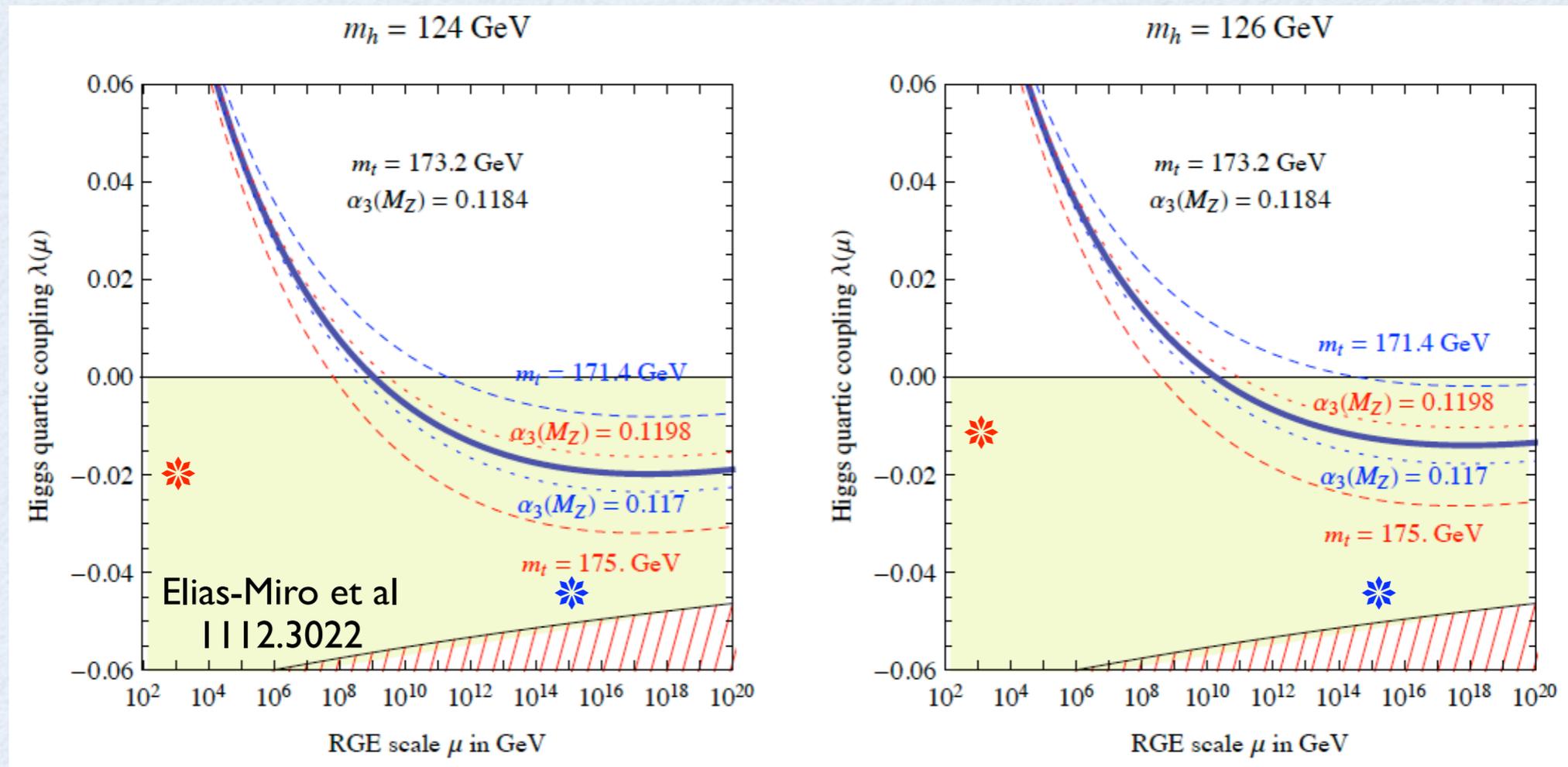
An Alarming Possibility!!

SM Quartic Trajectory



$*$ Close to zero

SM Quartic Trajectory



- * Close to zero
- * Close to catastrophic vacuum tunneling

III Split SUSY from Anomaly Mediation

High scale messengers
couple directly only
to scalar masses

==== $\tilde{q}, \tilde{\ell}, H^{0,\pm}, A$

— \tilde{G}

— \tilde{g}
— \tilde{B}
— \tilde{W}

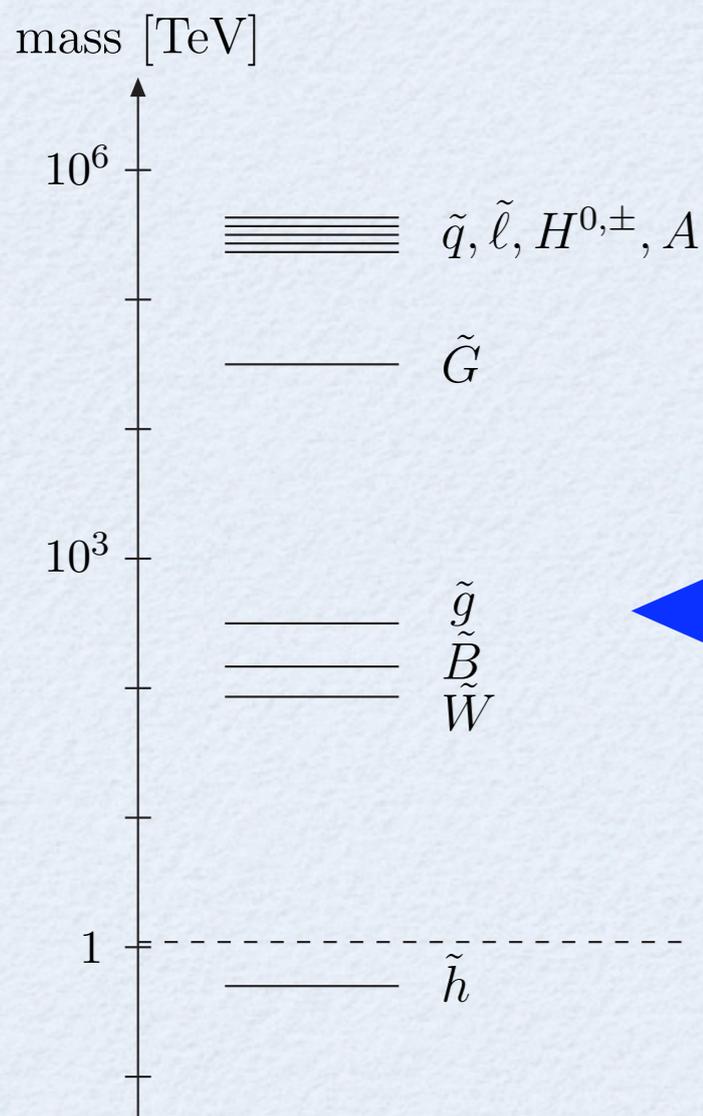
Anomaly Mediation
with unsuppressed scalar masses

III Split SUSY from Anomaly Mediation

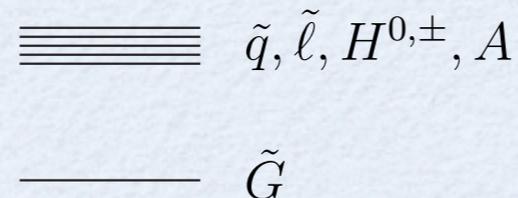
Higgsino LSP

Spread SUSY

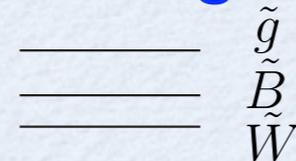
Yasunori Nomura, LJH 1111.4519



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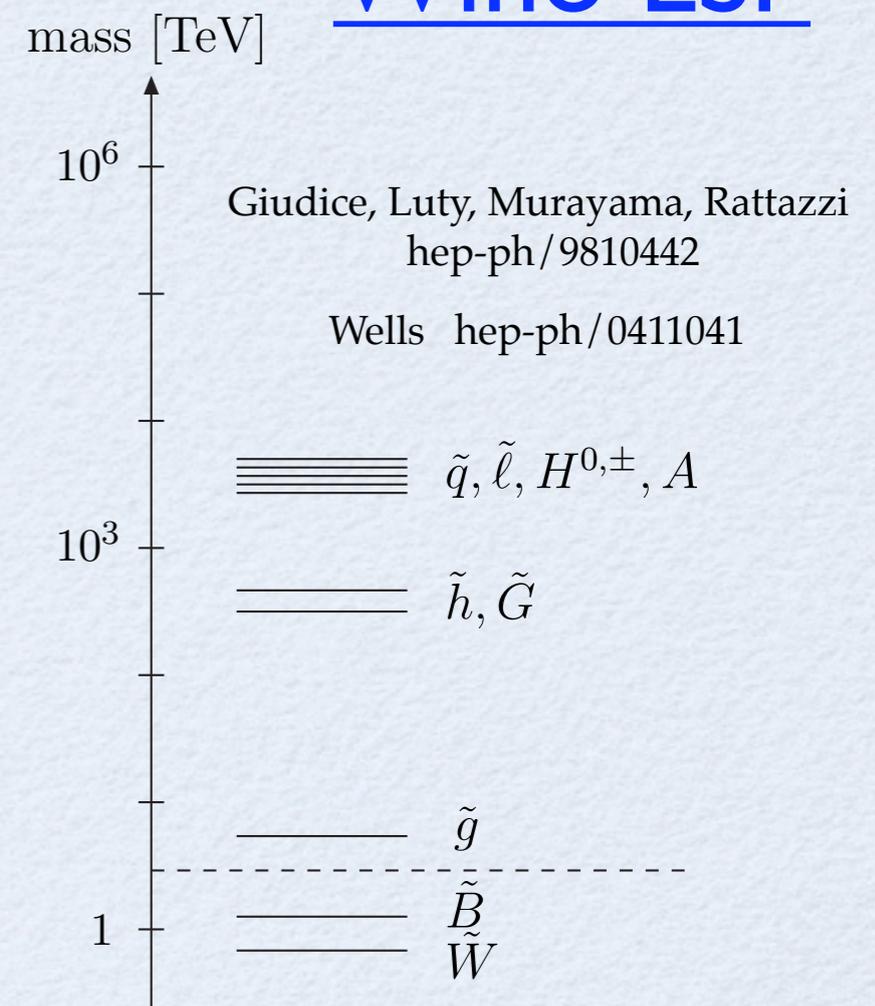


Two versions
depending on μ



Anomaly Mediation
with unsuppressed scalar masses

Wino LSP



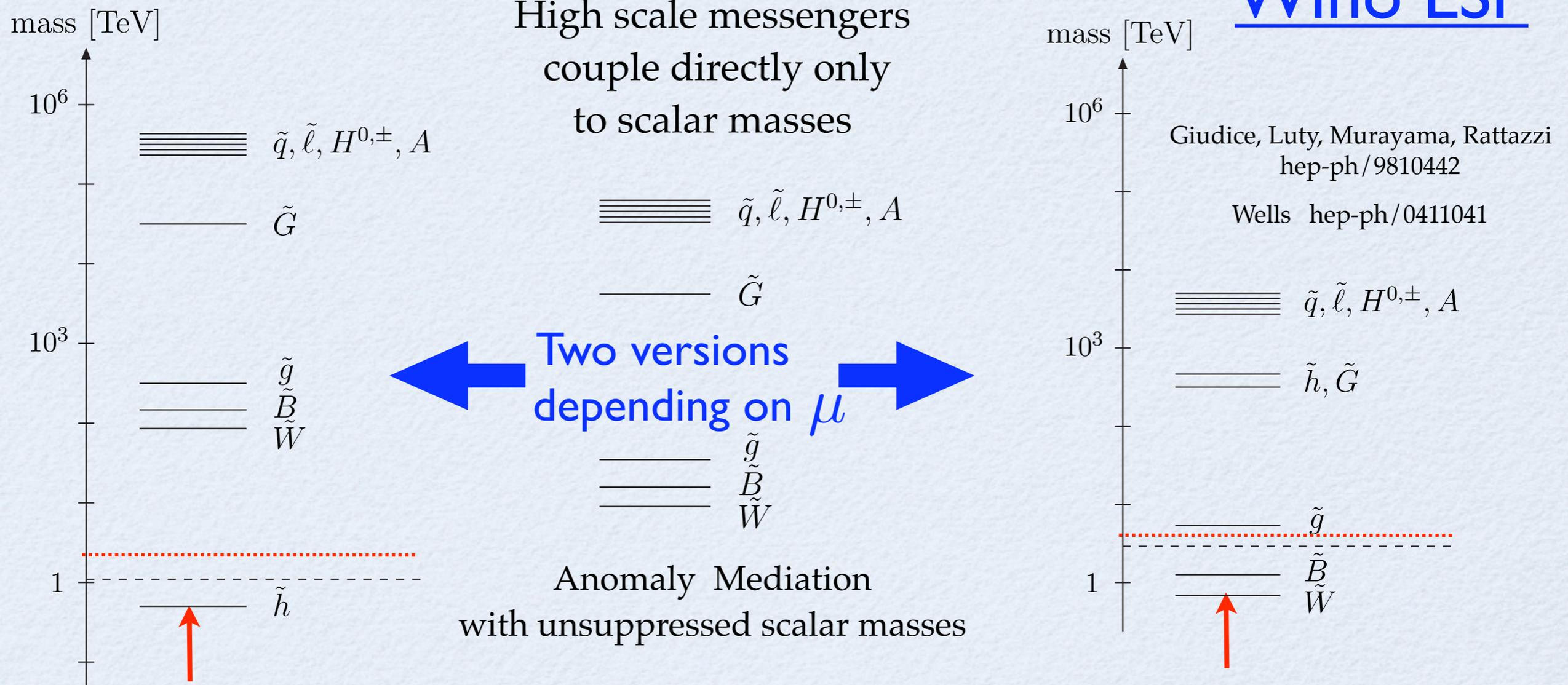
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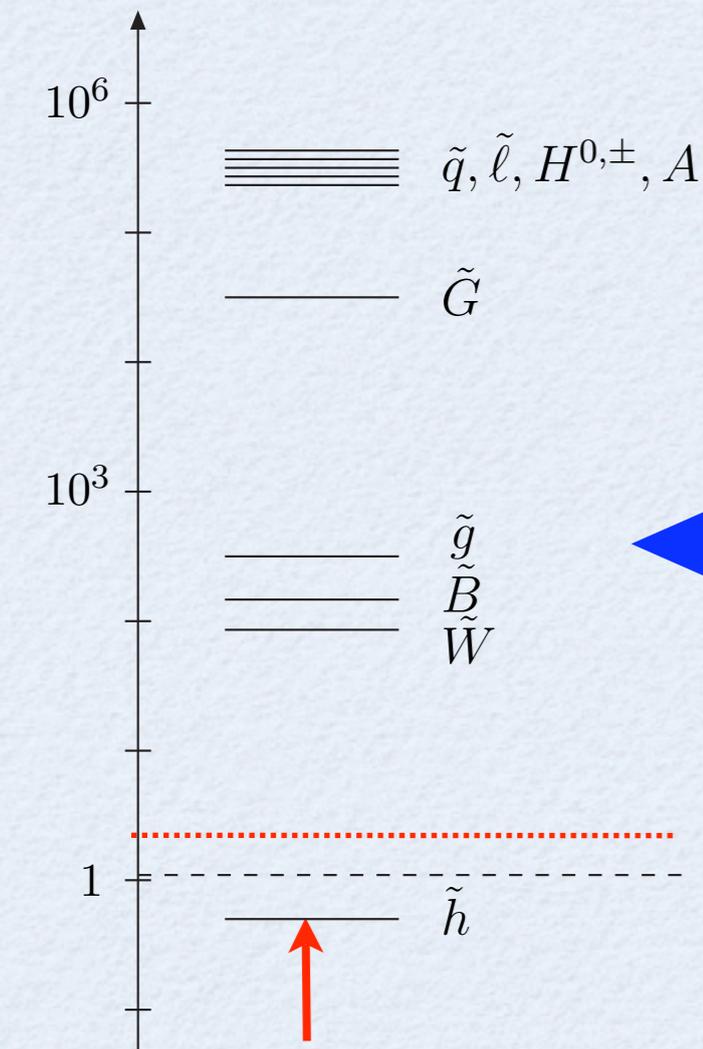
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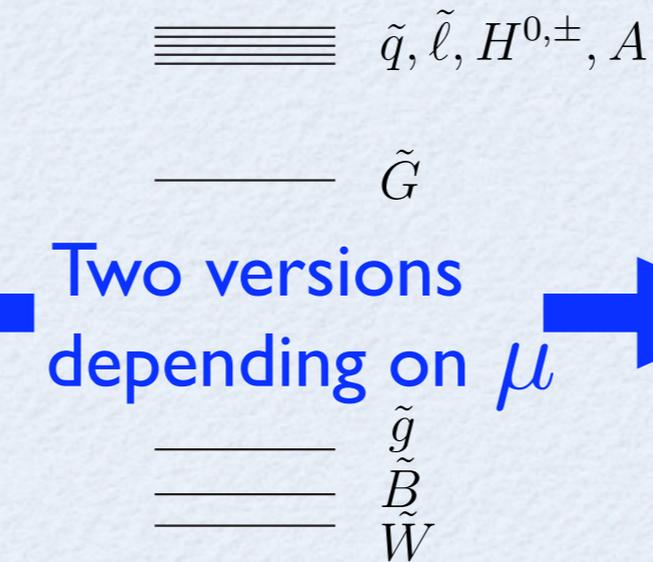
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Wino LSP

mass [TeV]



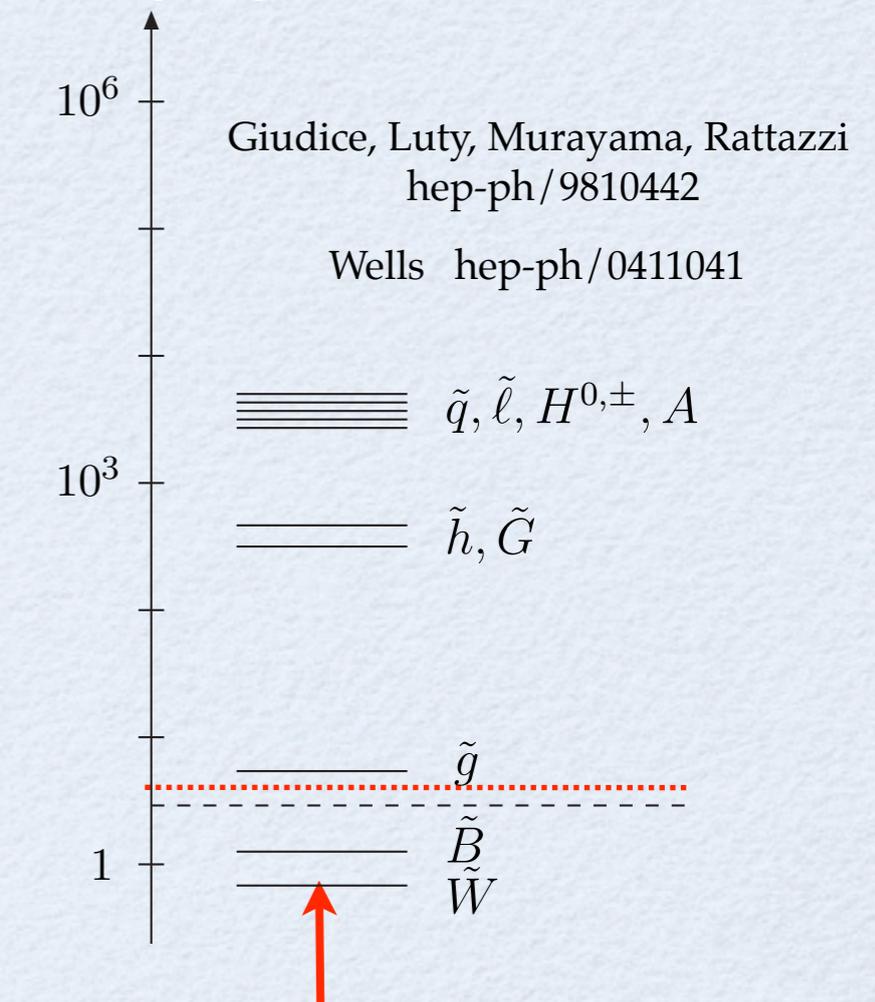
High scale messengers couple directly only to scalar masses



Two versions depending on μ

Anomaly Mediation with unsuppressed scalar masses

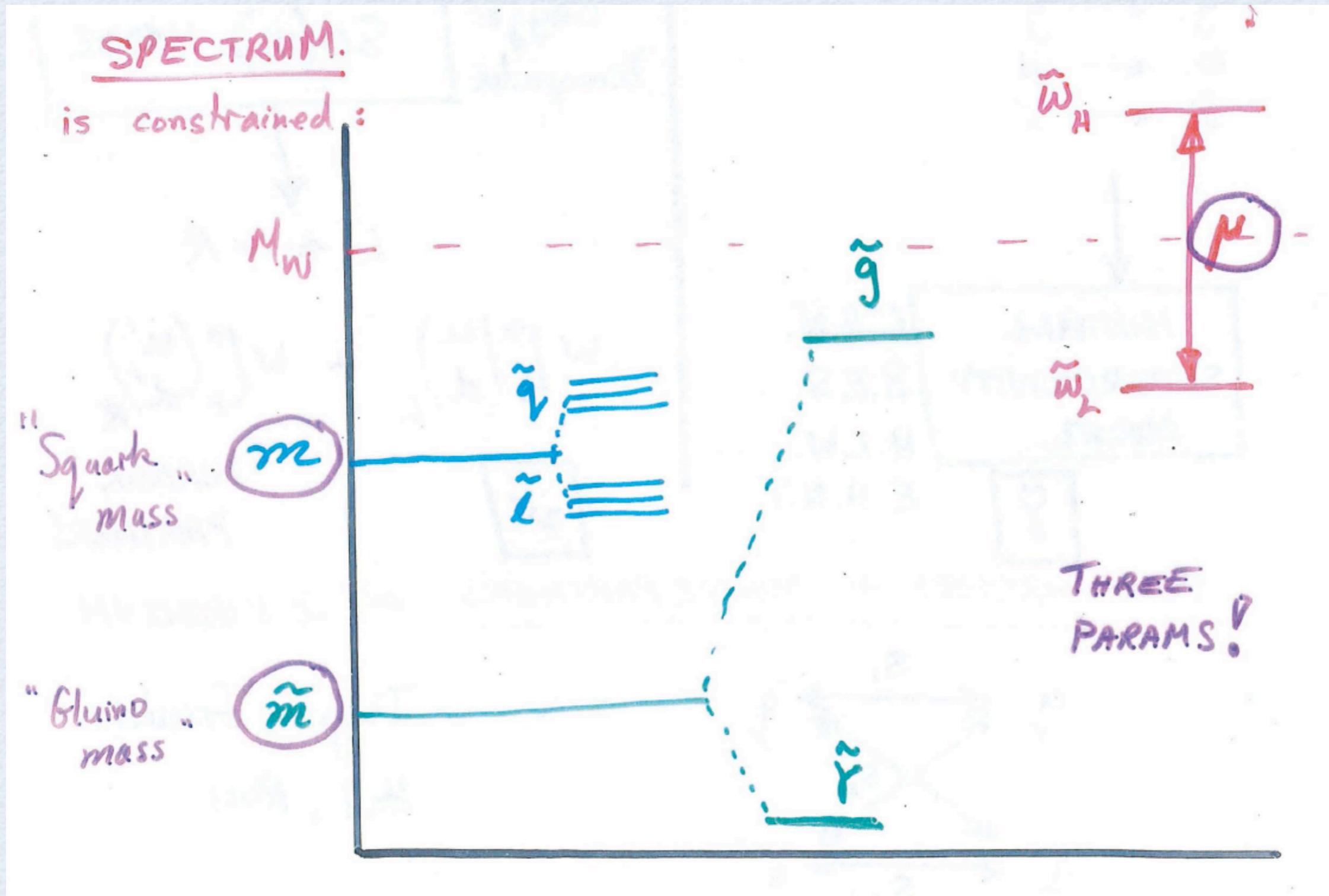
mass [TeV]



Normalization set Environmentally by Dark Matter

A 125 GeV Higgs is good for both

Is SUSY Natural?



Is SUSY Natural?

SUSY at TeV Scale

- MSSM: $\Delta > 100$
- Adding S helps
- ...

SUSY at Higher Scales

Is SUSY Natural?

SUSY at TeV Scale

- MSSM: $\Delta > 100$
- Adding S helps
- ...

SUSY at Higher Scales

- b/τ suggests SUSY at 1-10 TeV
- High Scale SUSY -- a worry
- Moderately Split Spectra like 125 GeV

Thresholds for b/τ

Susy thresholds: δ_b, δ_3

Unified threshold: ϵ

Precision b/τ : $\epsilon = \epsilon(\delta_b, \delta_3, \tan \beta)$

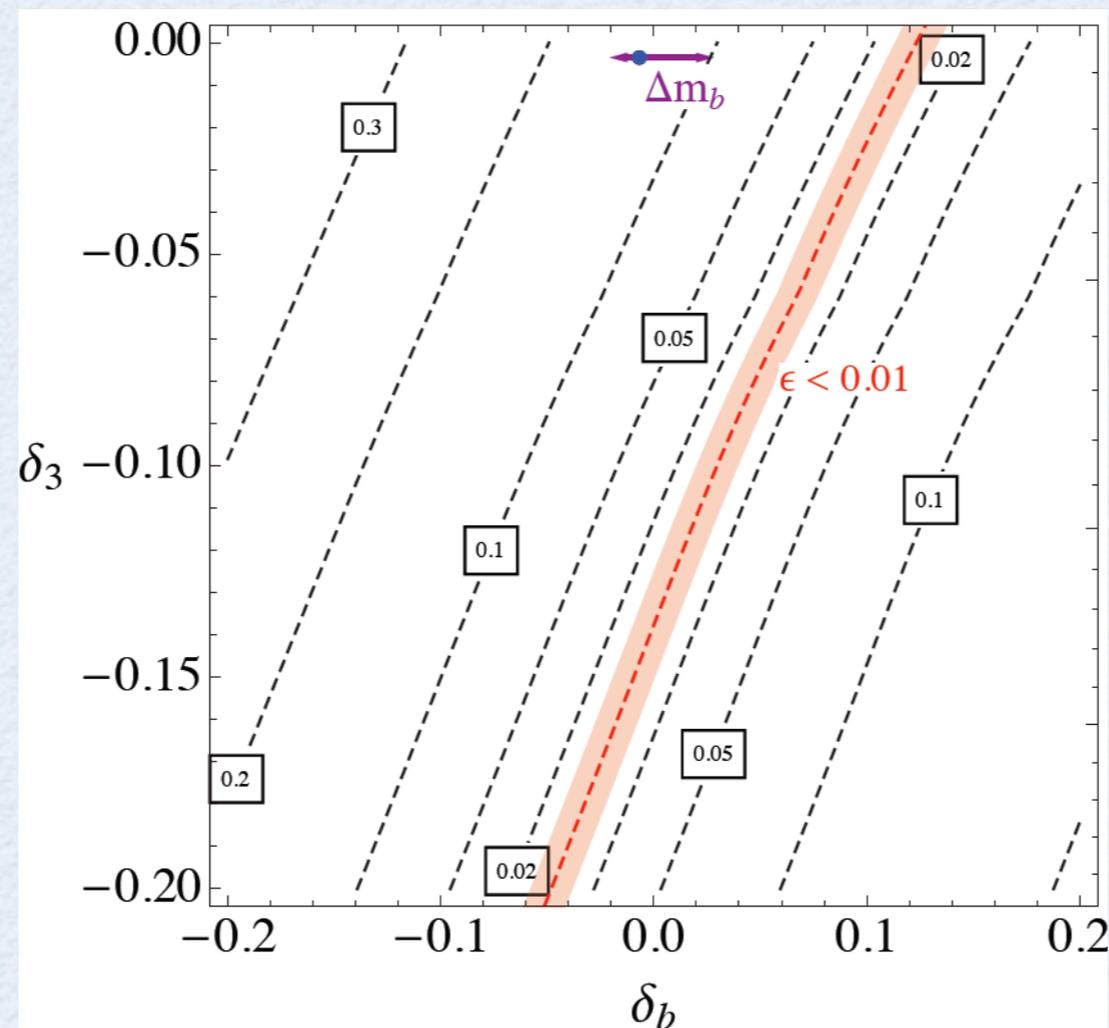
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$\tan \beta = 50$



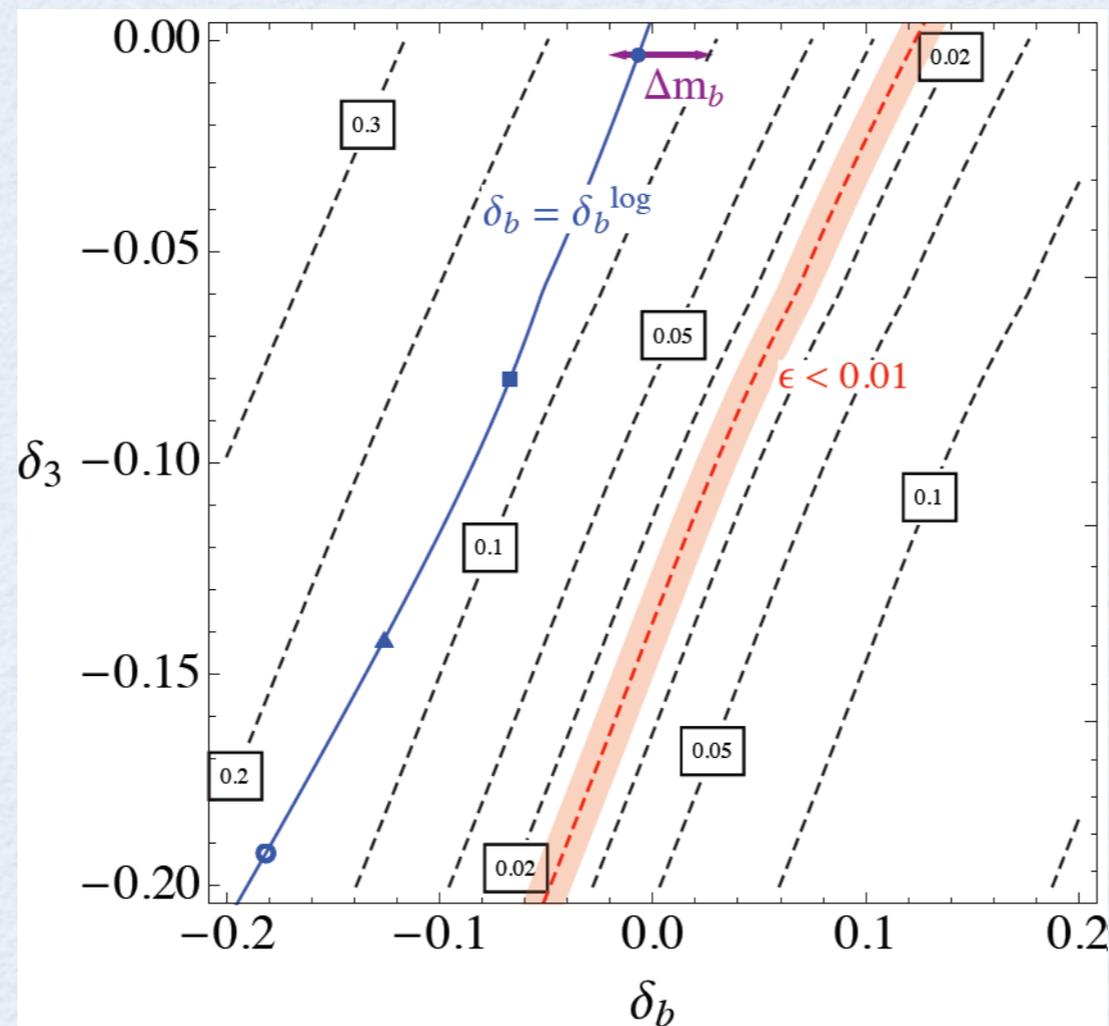
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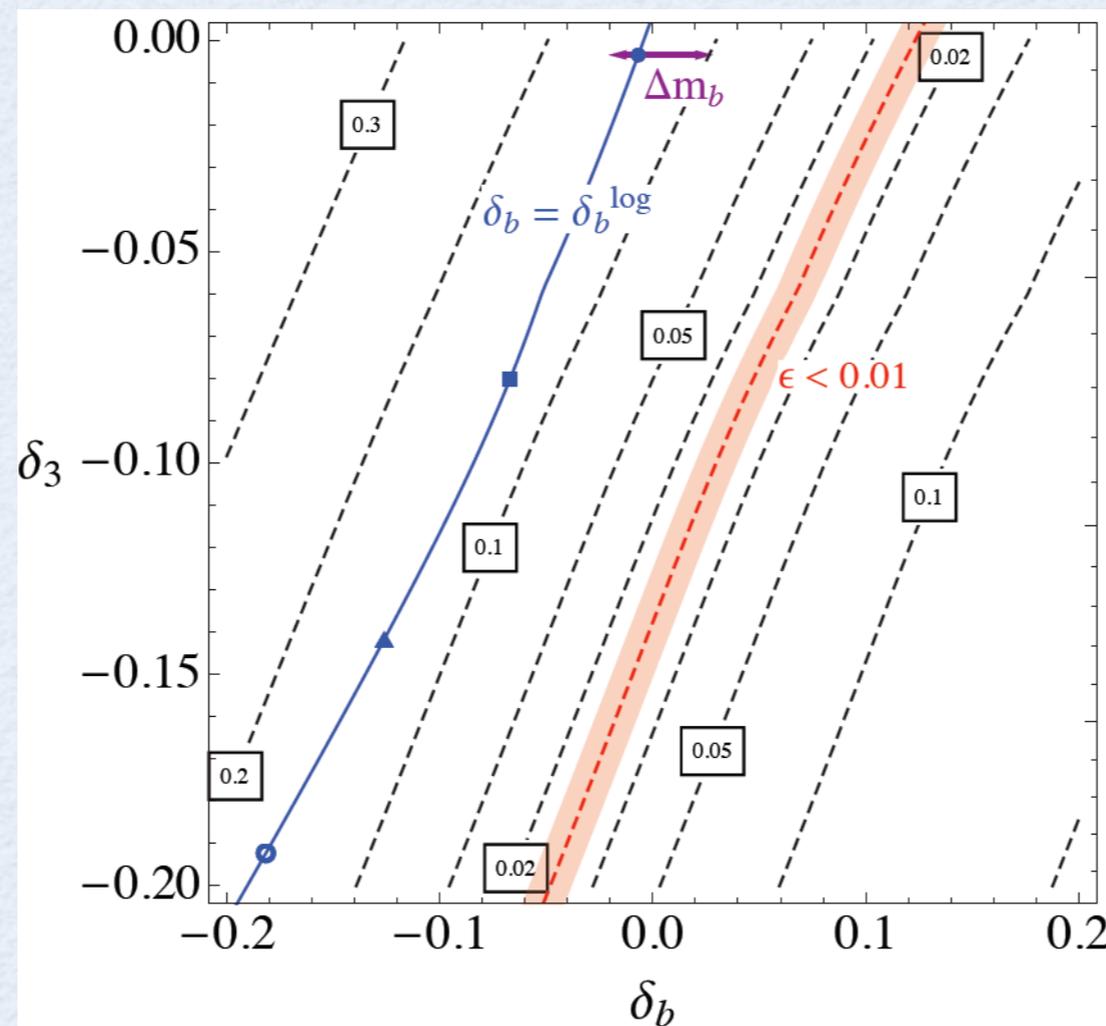
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✿ Varying $\tan \beta$

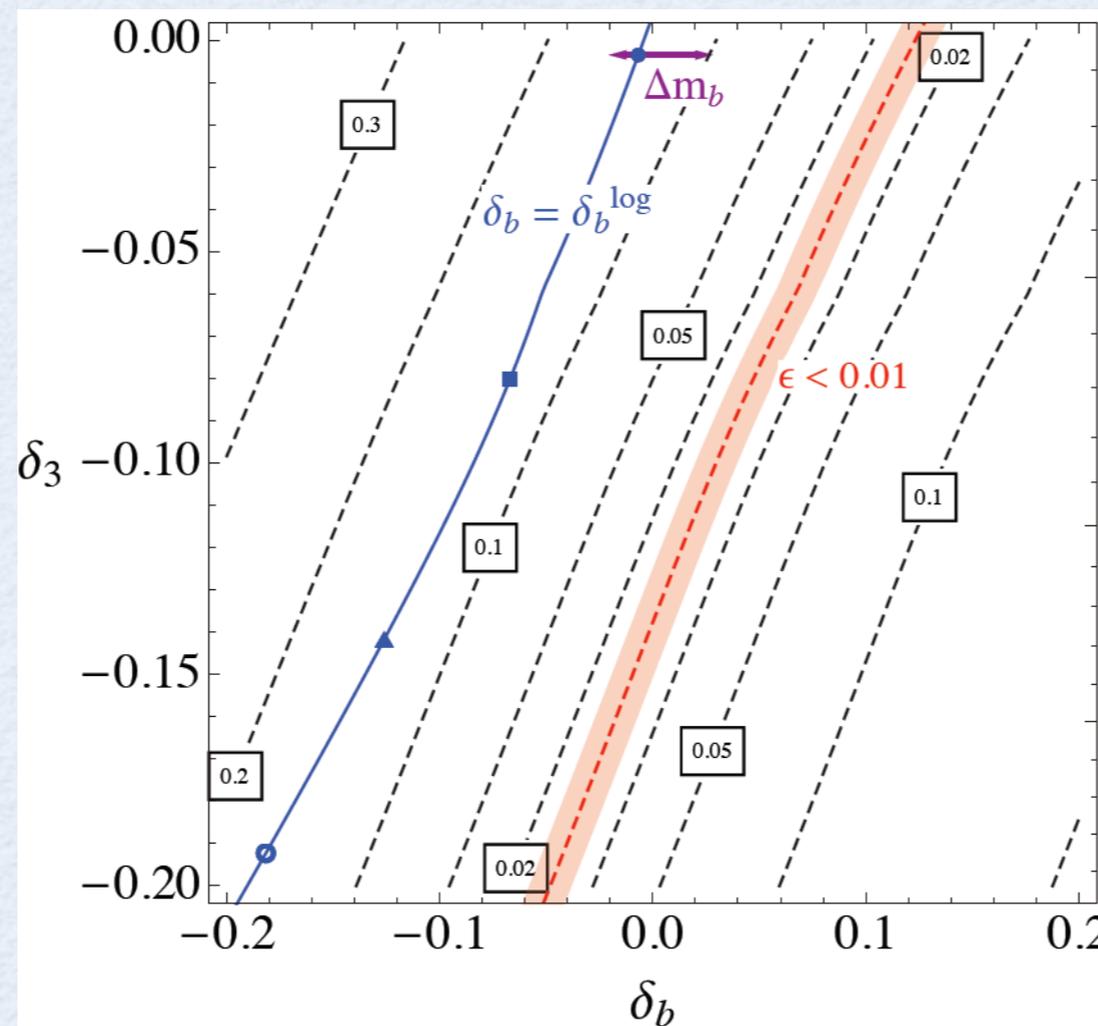
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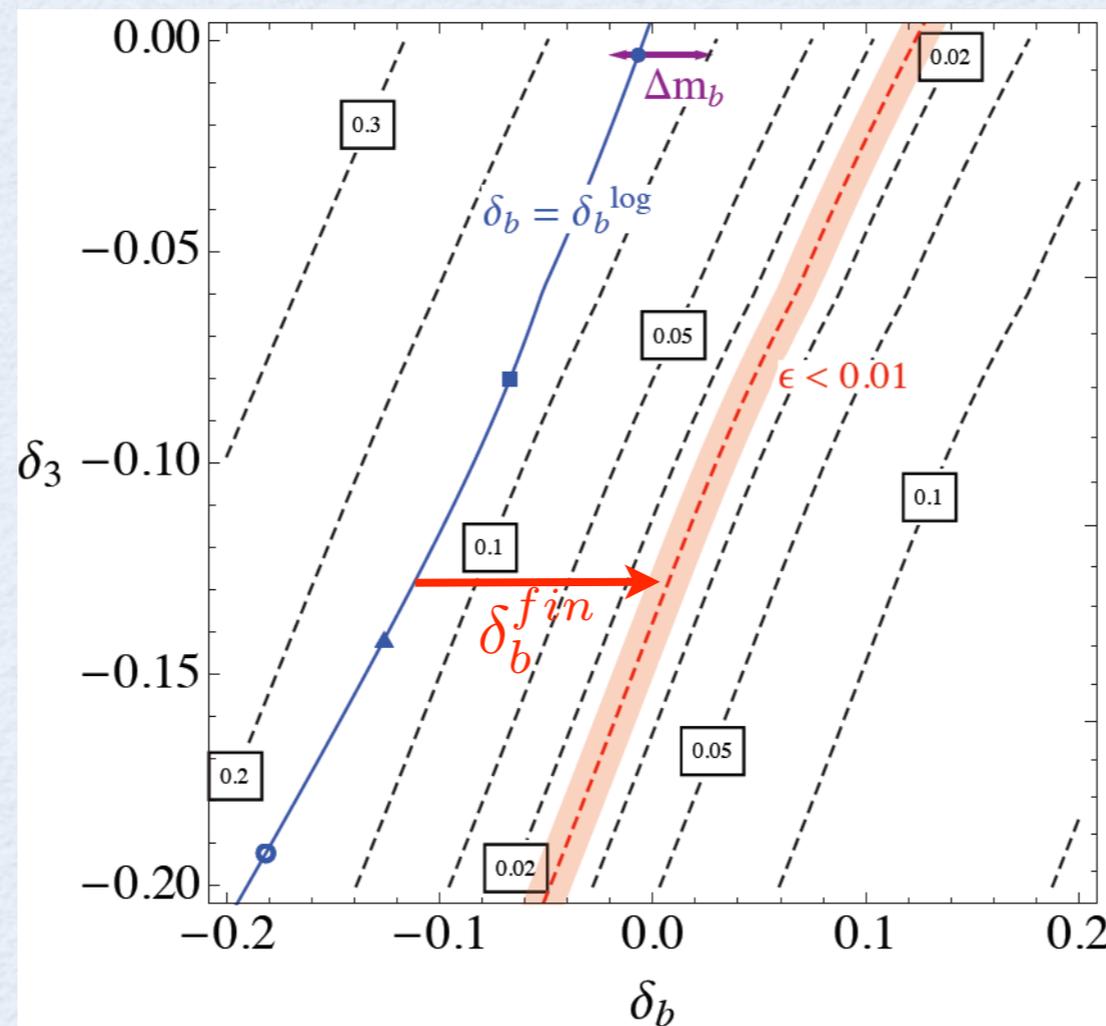
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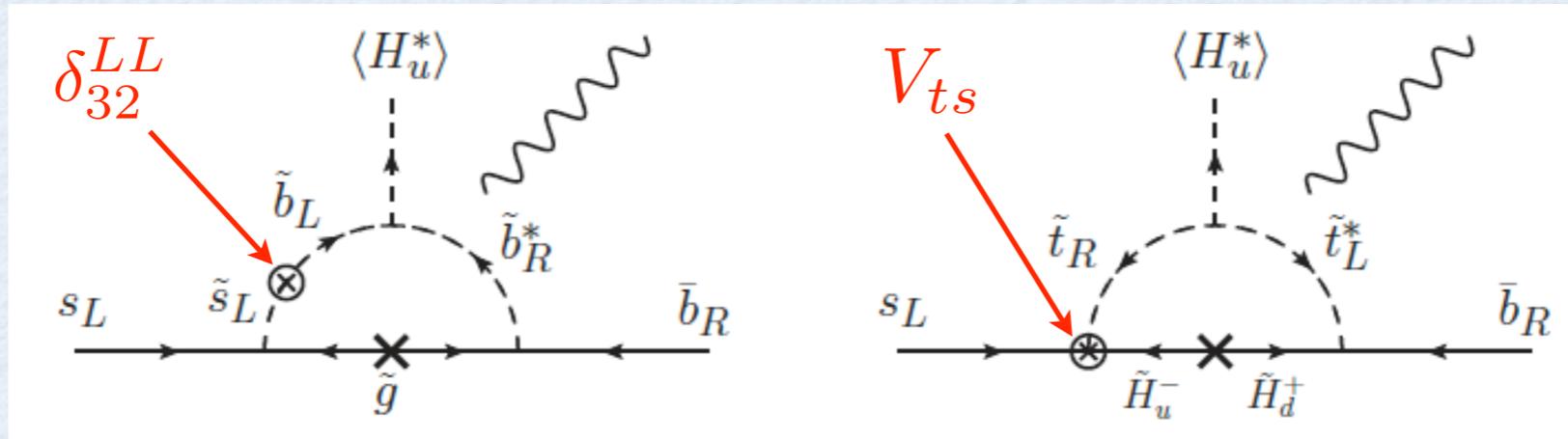


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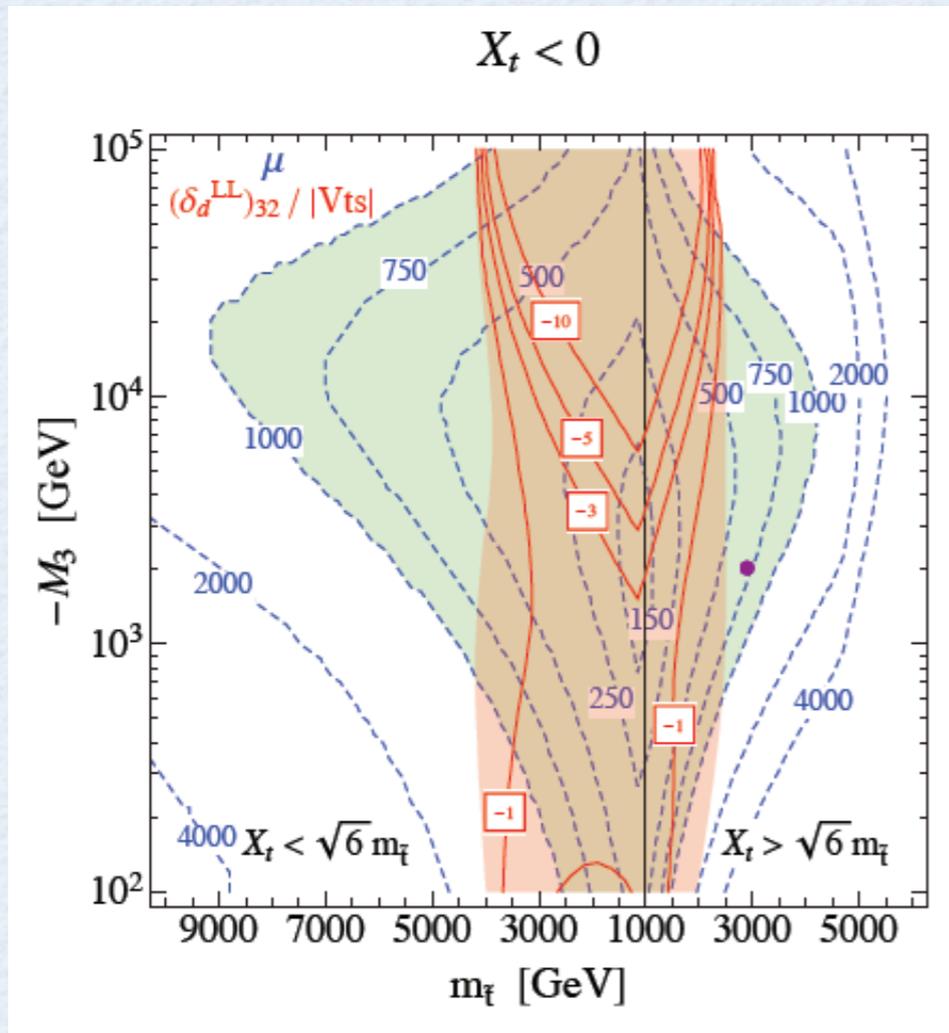
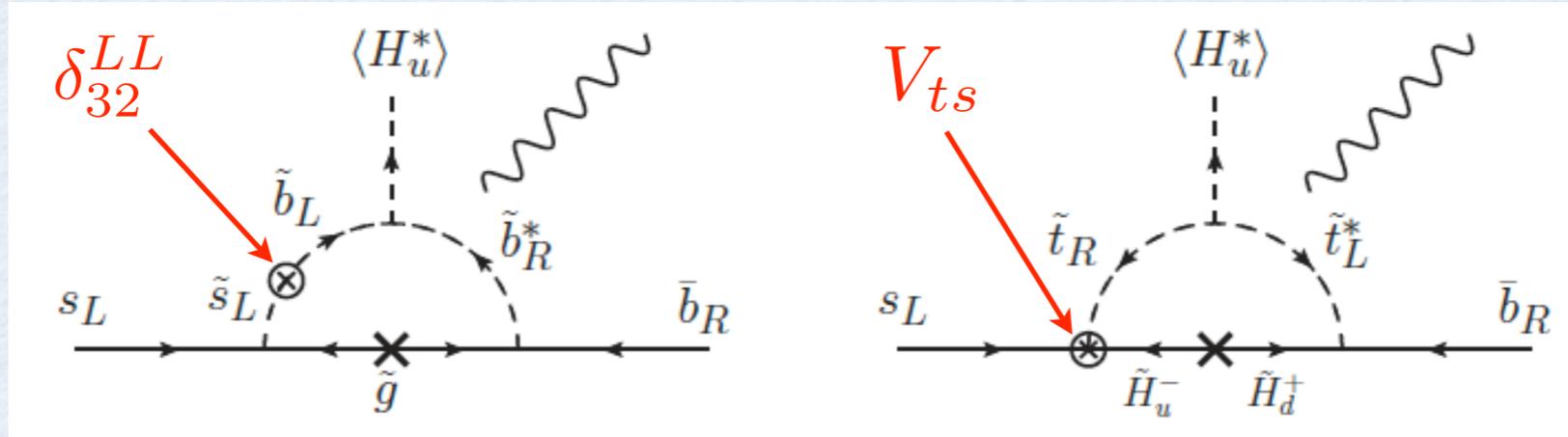
✿ ϵ

✿ δ_b^{fin}

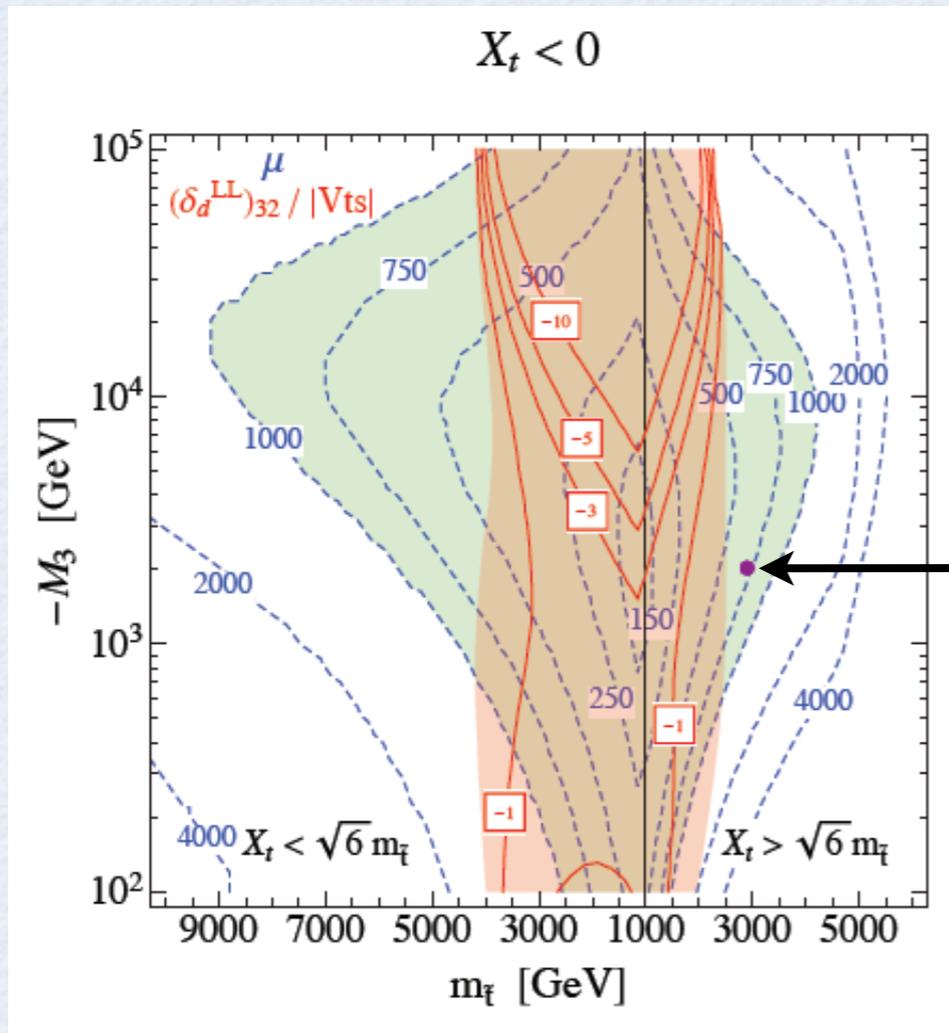
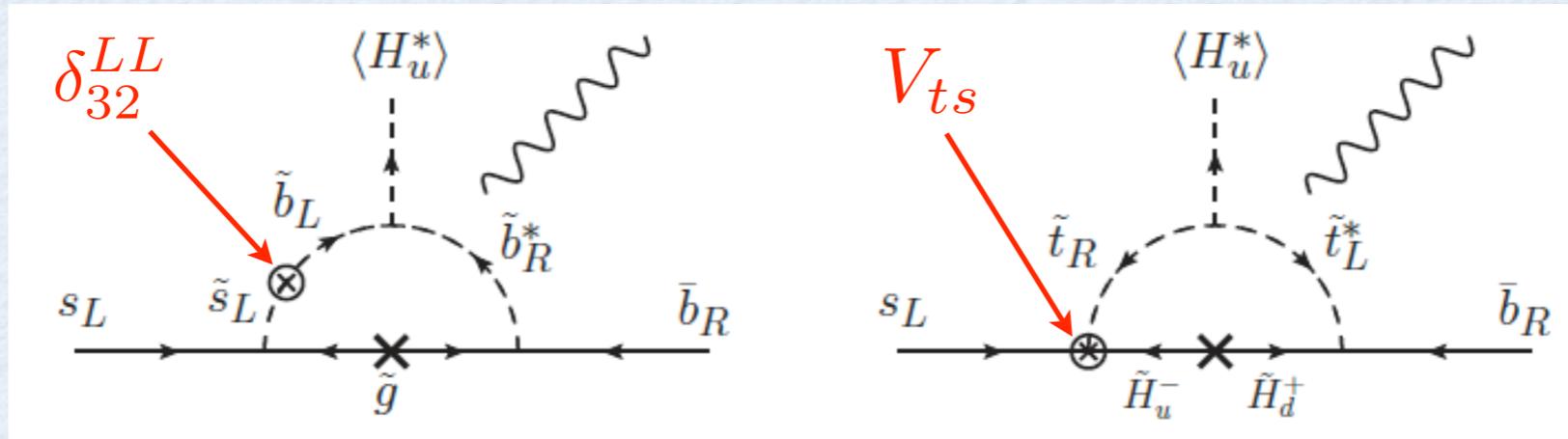
Rare B decays



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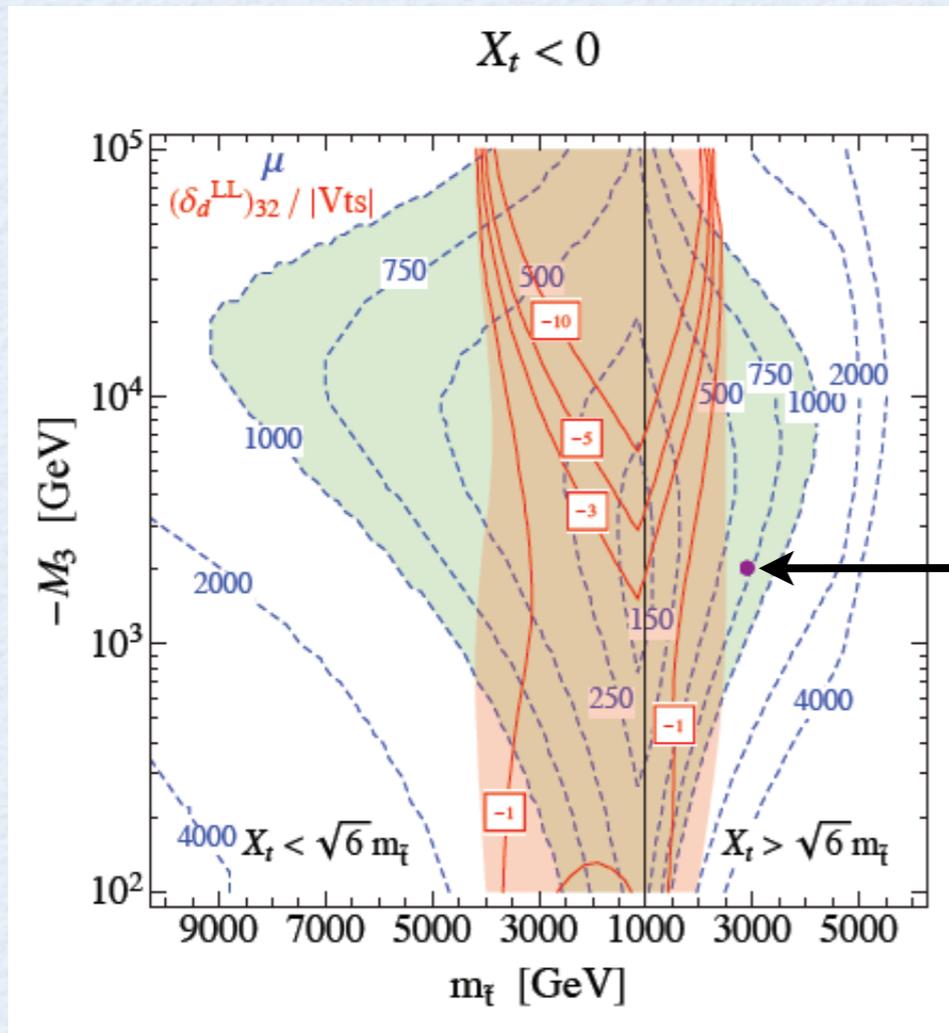
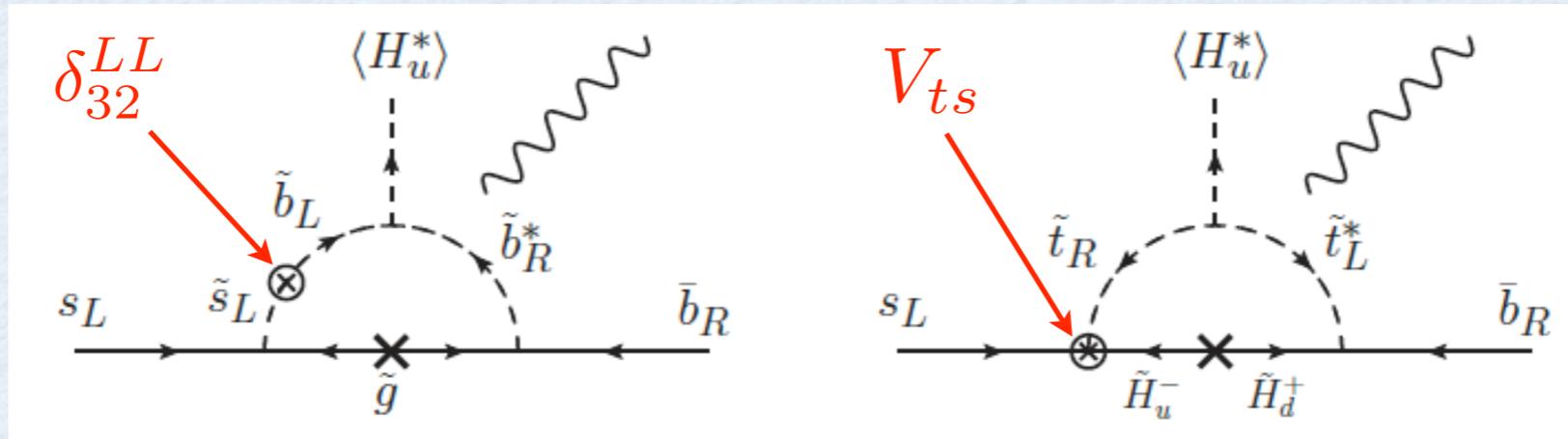
Rare B decays



Look at

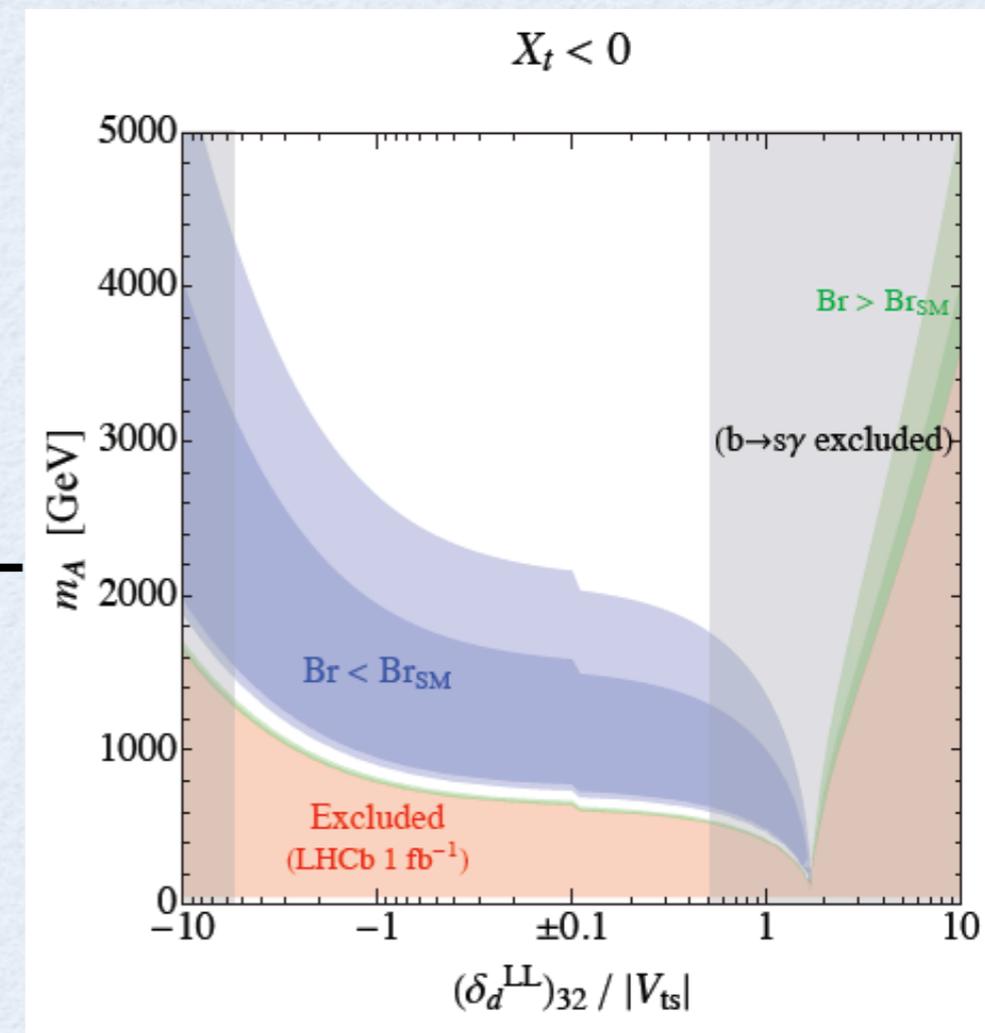
$$B_s \rightarrow \mu^+ \mu^-$$

Rare B decays

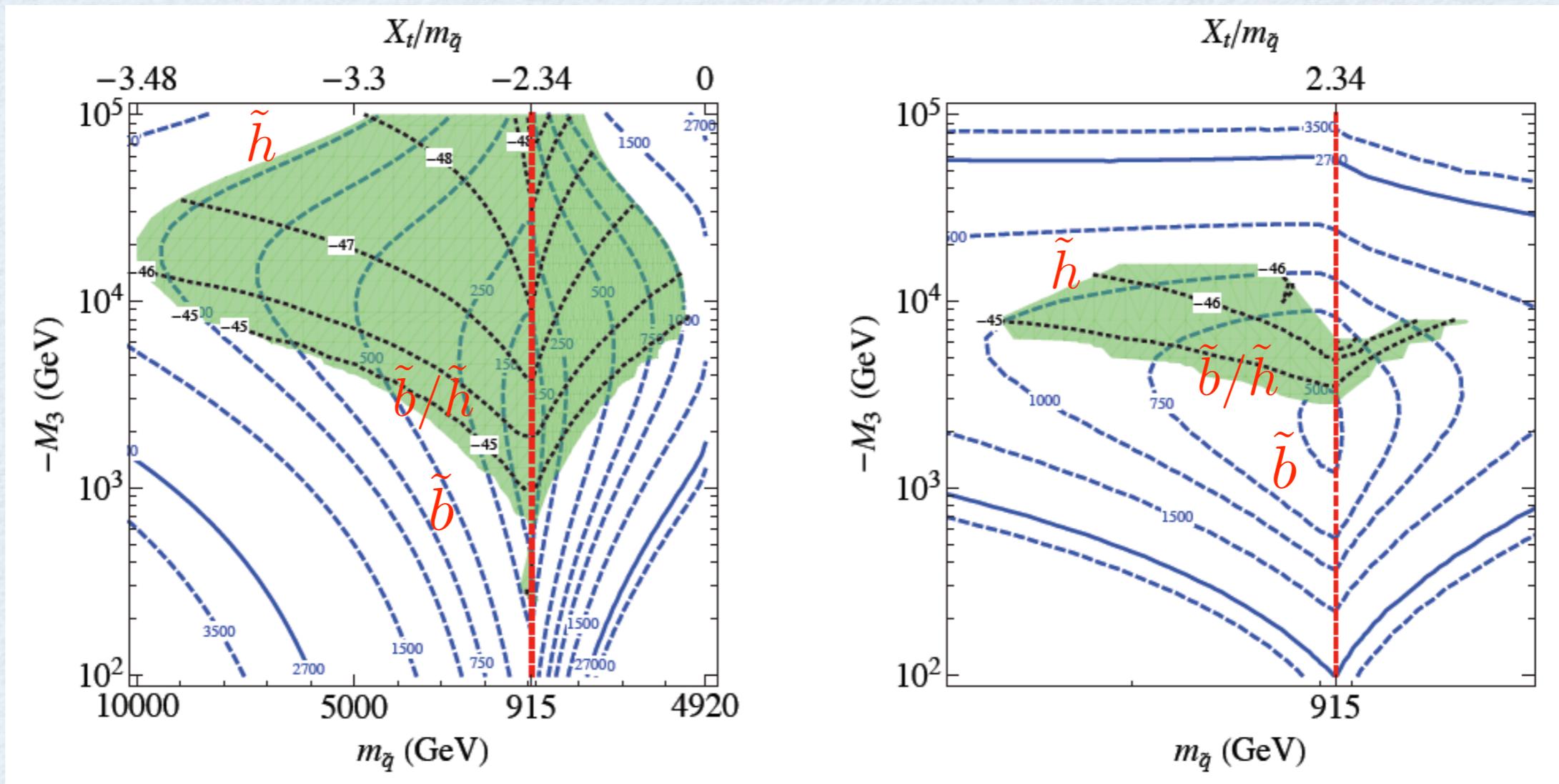


Look at

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Dark Matter Direct Detection



Green: $\Omega h^2 \leq 0.1$

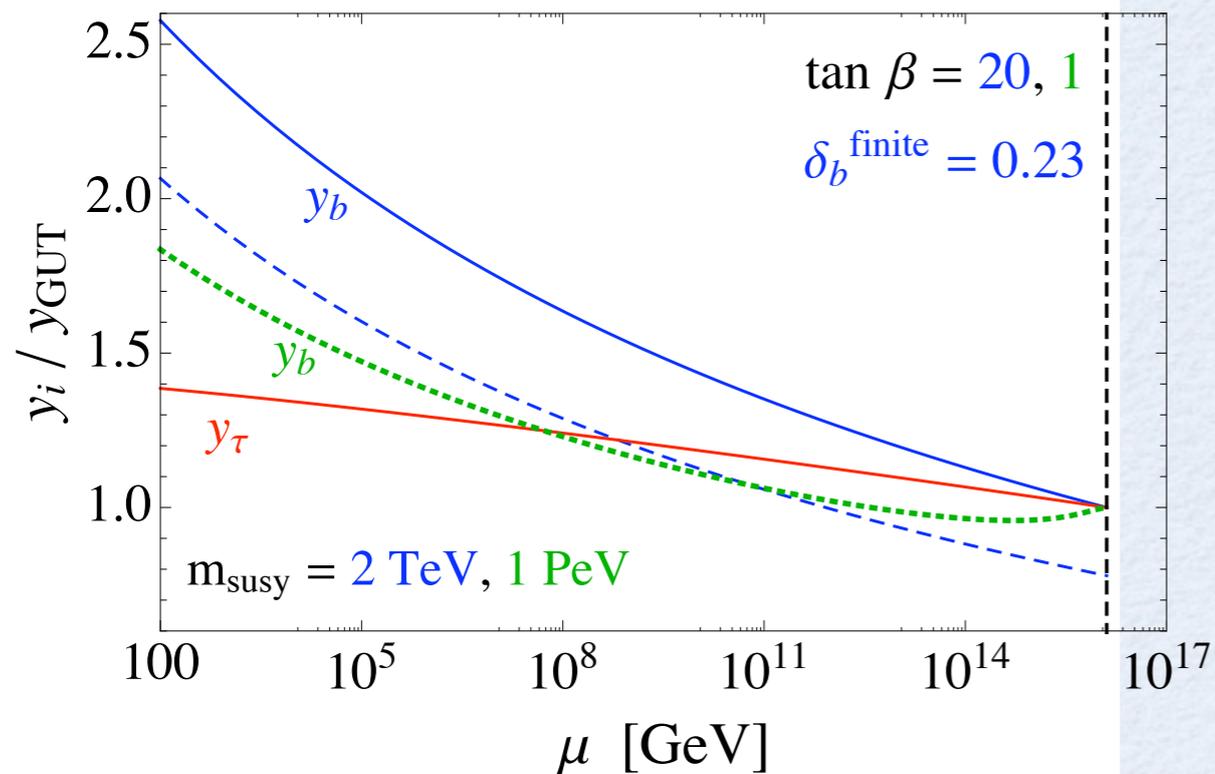
..... $\log_{10}(\sigma_{DD}/\text{cm}^2)$

$\tan \beta = 50$

Gauginos mass unification

b/τ at low $\tan \beta$

sample running



low $\tan \beta$

