

# HITTING SBOTTOM IN NATURAL SUSY

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1204.0802



# Natural SUSY: Rough idea

Supersymmetry is a solution to  
the hierarchy problem

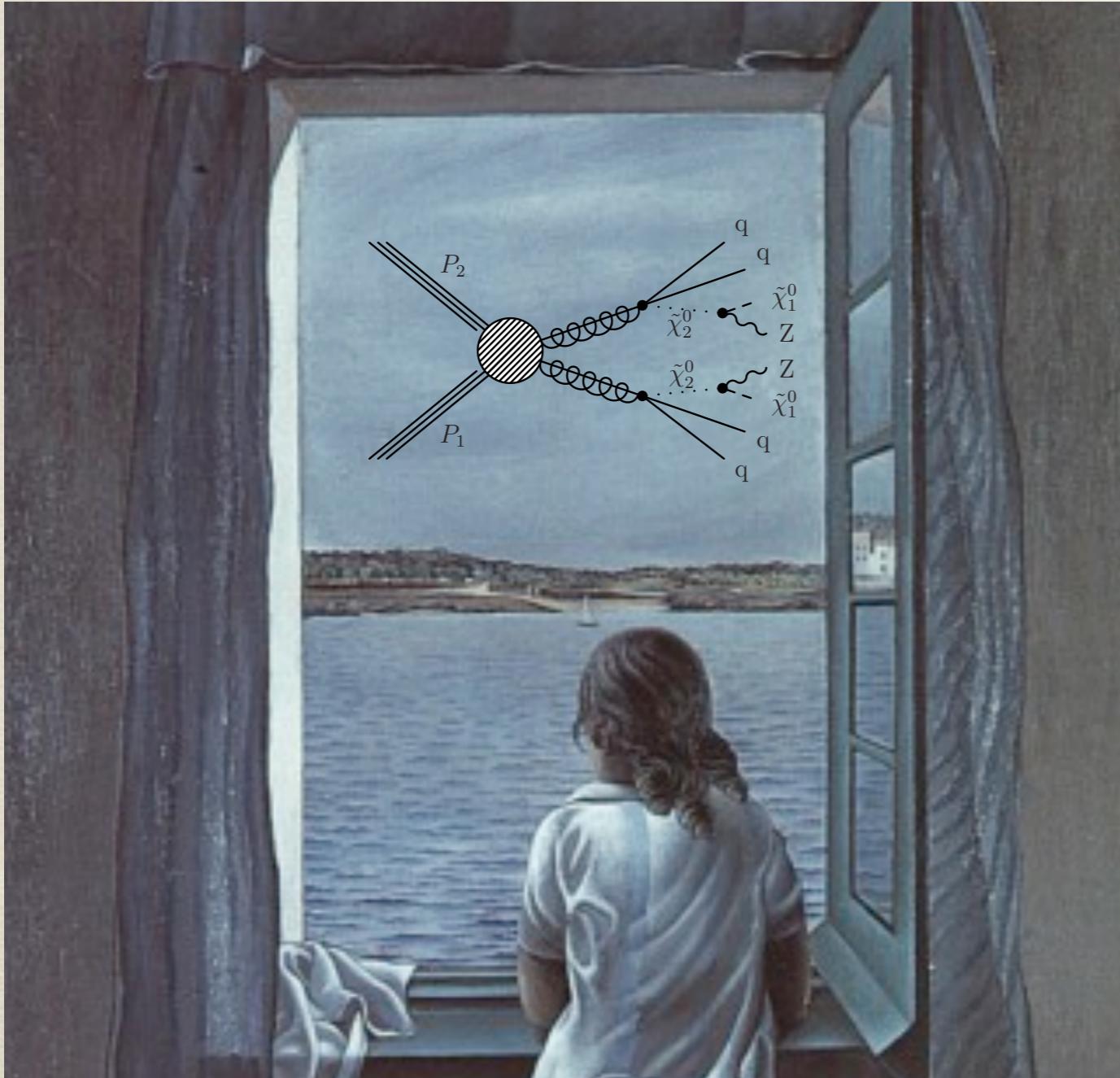
=

stabilization of the EW scale

SUSY (Higgs, Higgsino)  
chiral symmetry fermion: protection scalar

Natural SUSY  
roughly  
SUSY breaking - scale of EWSB

# Natural SUSY: Rough idea



Natural SUSY  
roughly

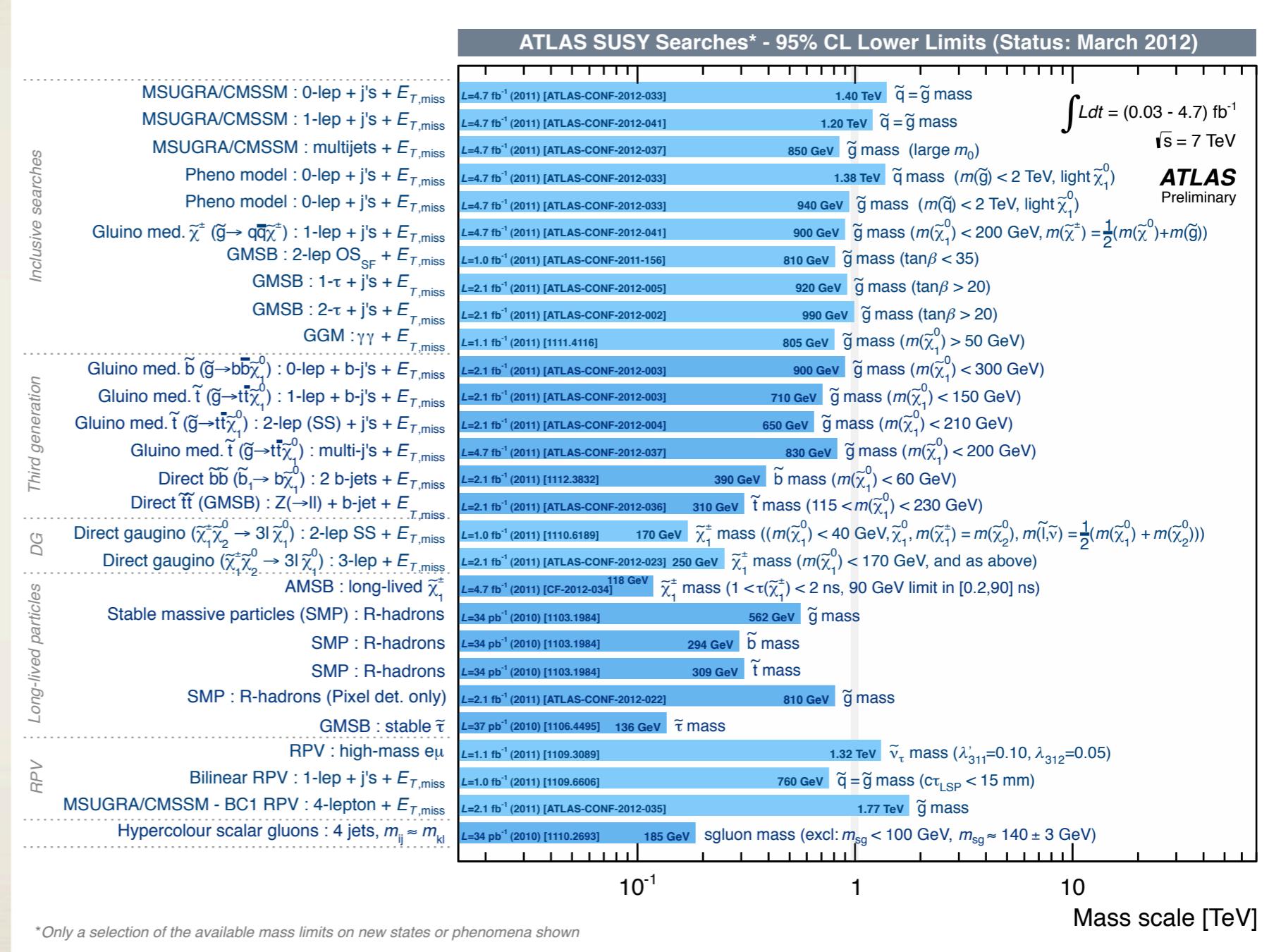
SUSY breaking -  
scale of EWSB

LHC opens the  
window to  
EW scale physics

# Natural SUSY

## confronting experiment

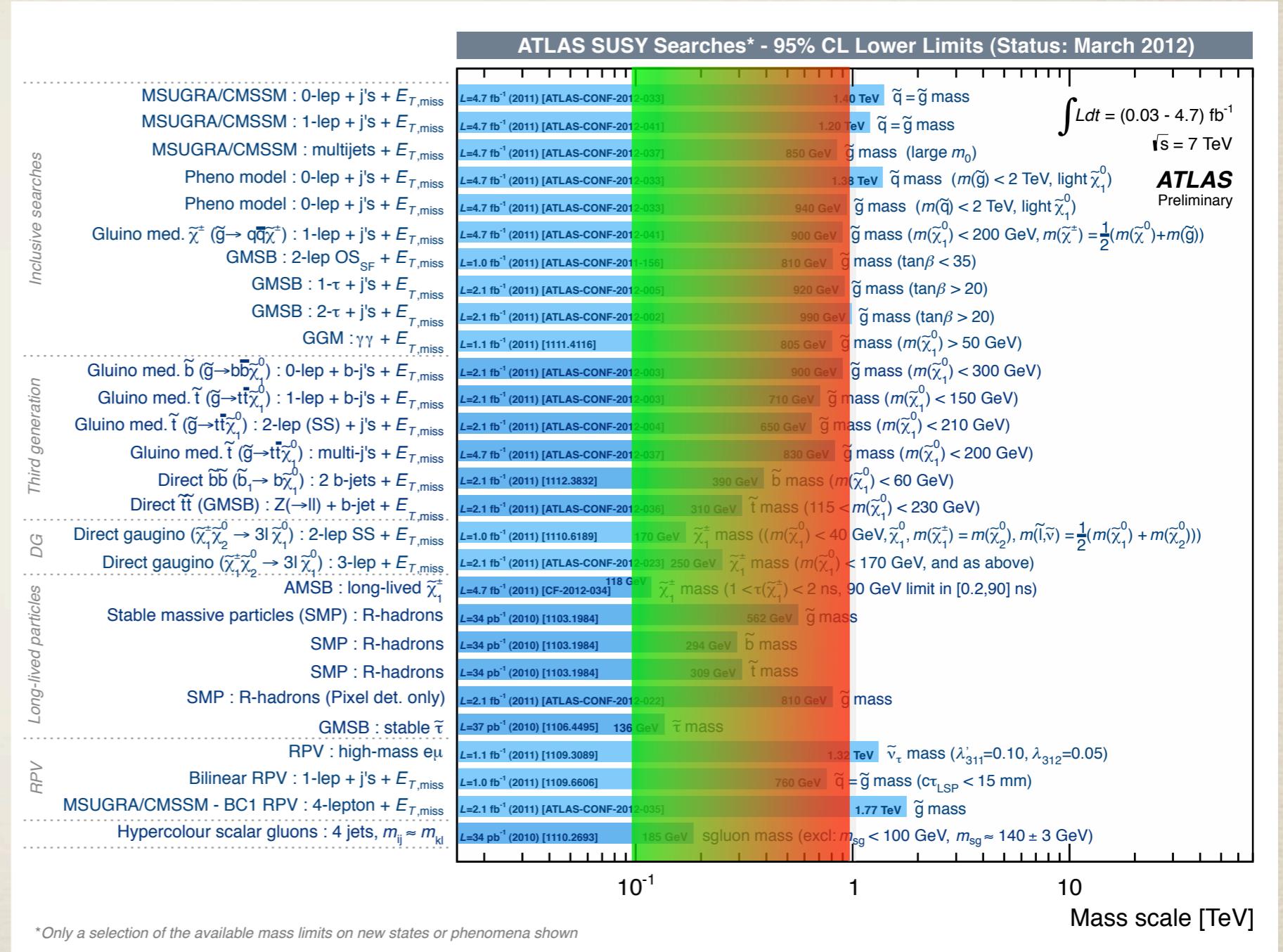
Indeed, the  
window is open



ATLAS@7TeV

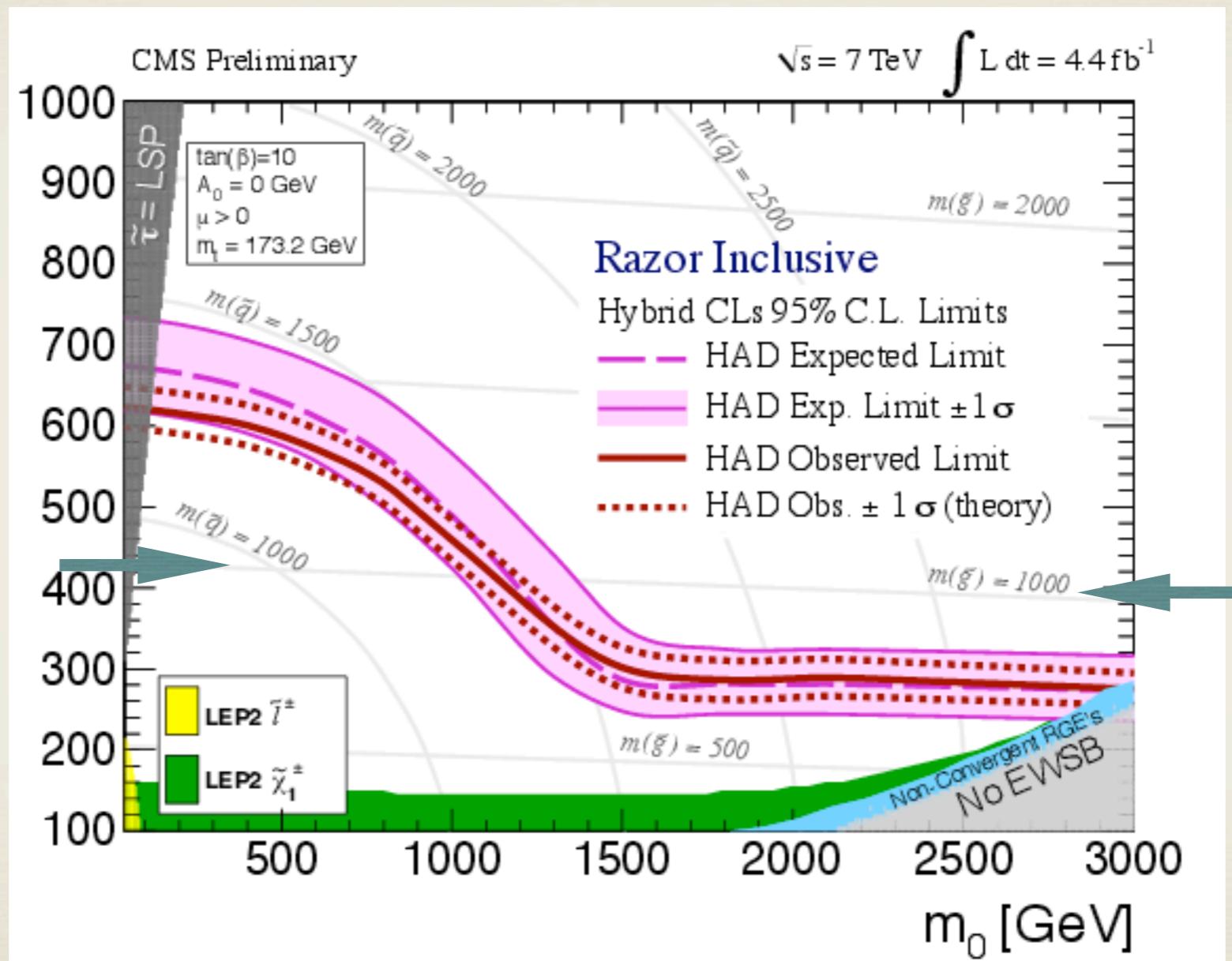
# Natural SUSY

## confronting experiment



ATLAS@7TeV

# Natural SUSY confronting experiment

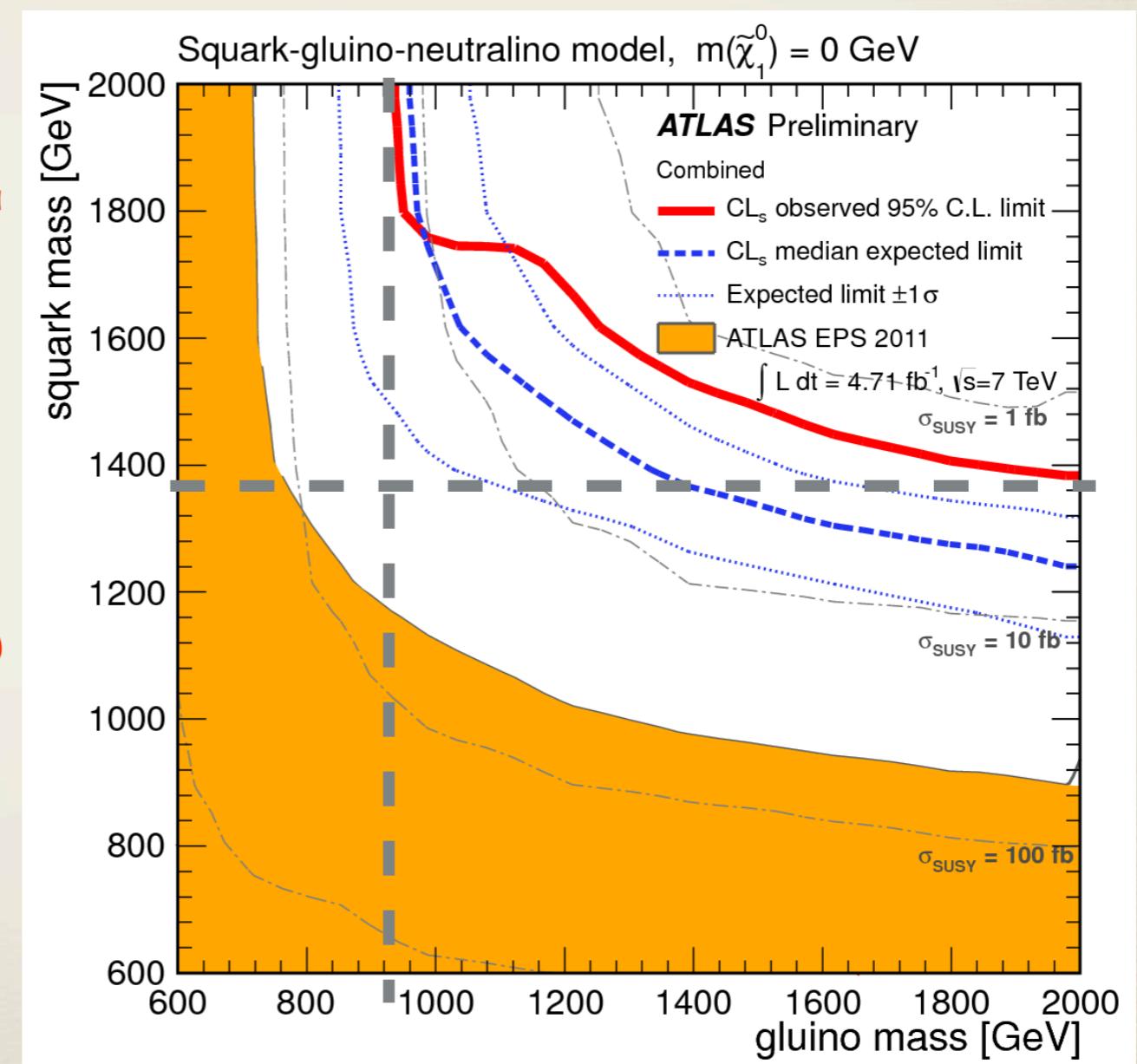


# Natural SUSY confronting experiment

ATLAS-CONF-2012-033

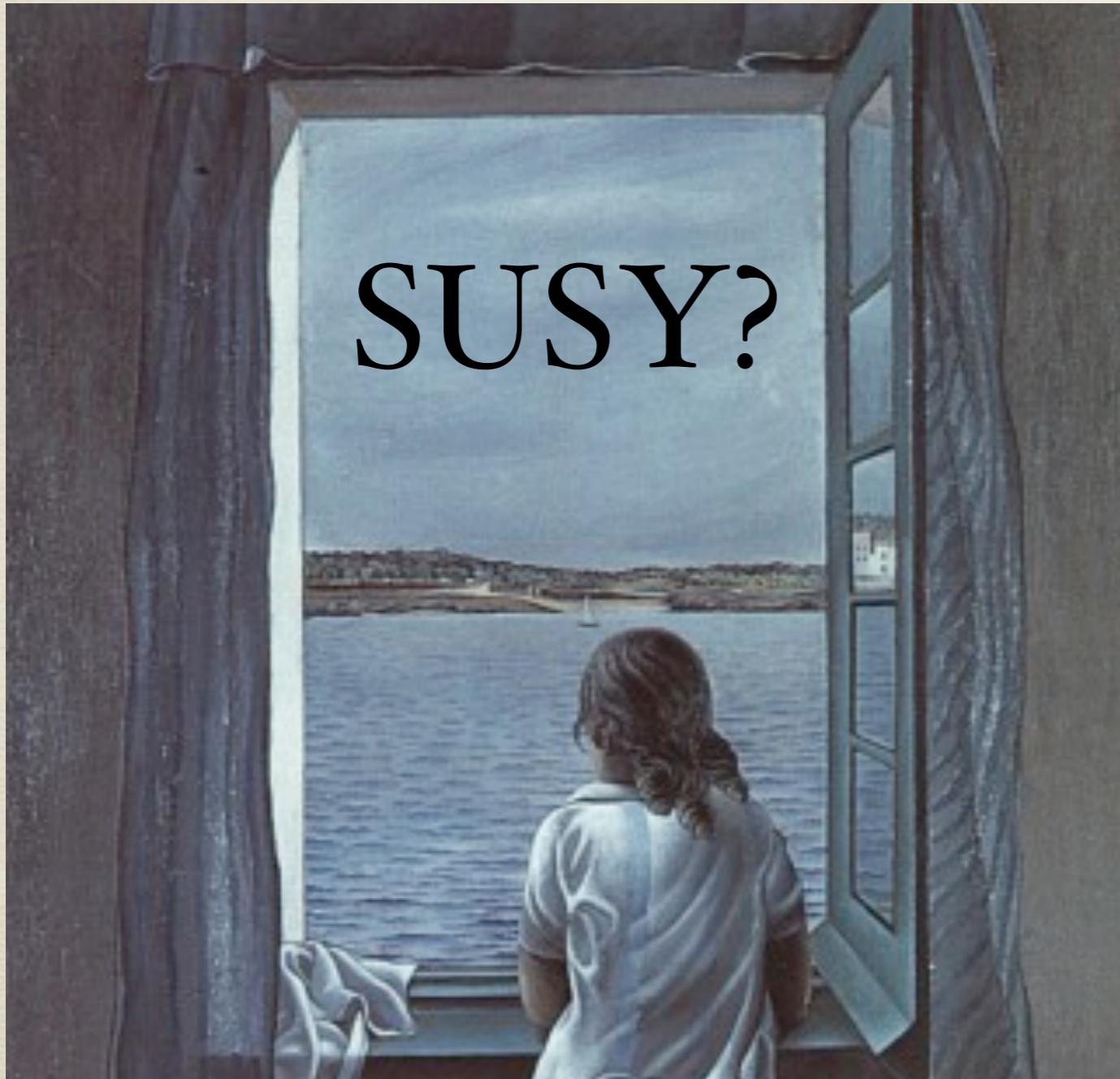
Simplified  
model

1st and 2nd generation squarks



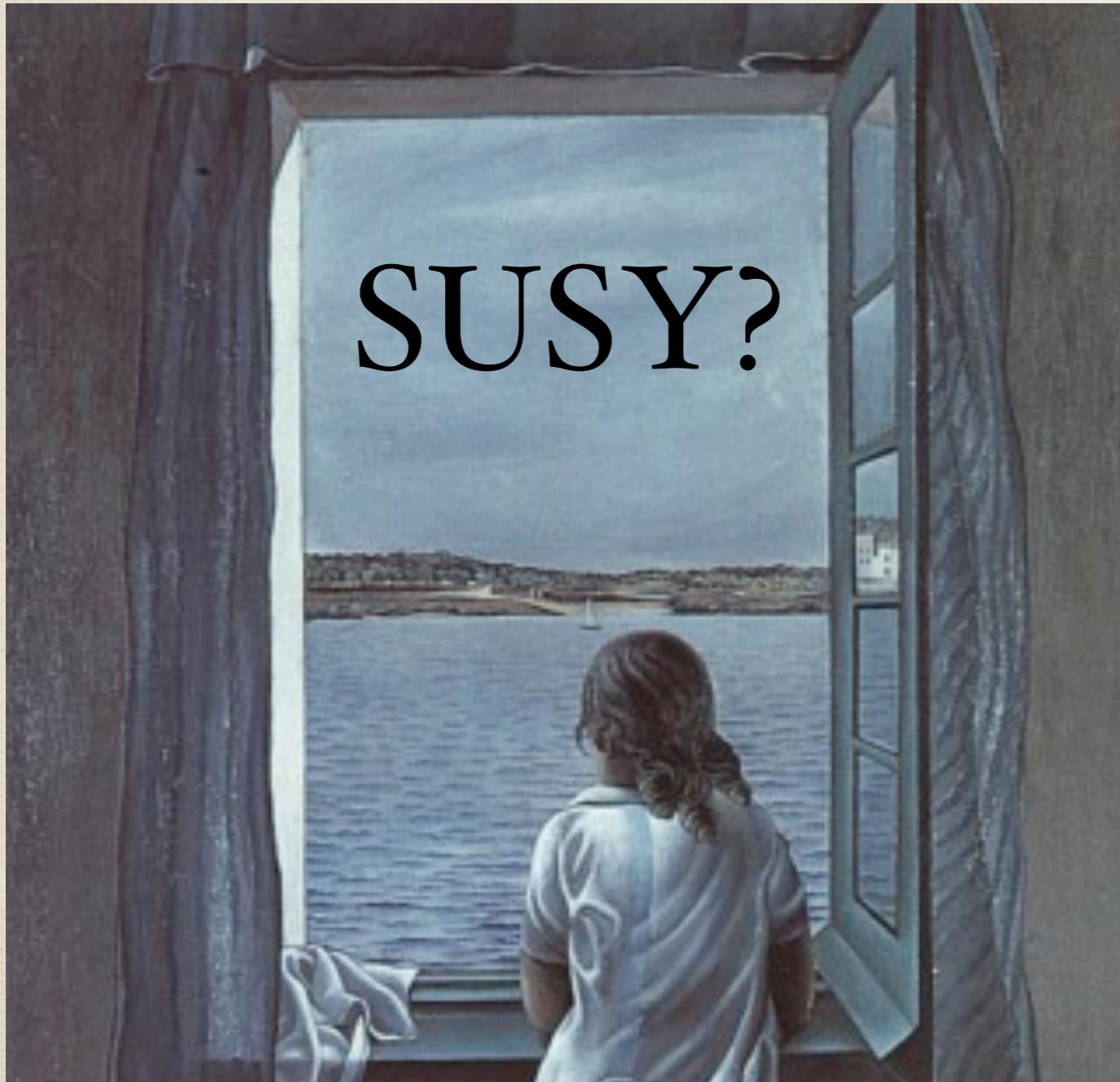
gluino

# Natural SUSY?



SUSY?

# Natural SUSY?

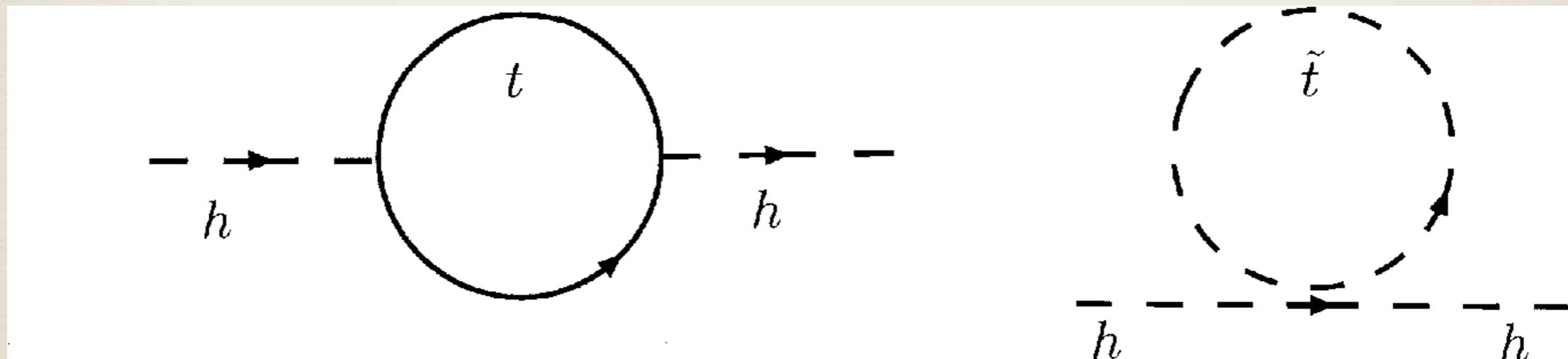


BUT

**Natural SUSY**  
=corrections from SUSY  
breaking to EWSB shouldn't  
de-stabilize the EW scale

# Natural SUSY more precisely

EWSB mostly talks to SUSY sparticles with large Yukawas



SUSY 3rd generation particles close to EW scale

# Natural SUSY more precisely

even more precisely  
define FINE-TUNING

Ellis et al '86  
Barbieri et al '88

shift in mZ due to SUSY loops

one-loop stop contribution

$$\boxed{\delta_t m_Z^2} = \frac{3}{16\pi^2} \left( y_t^2 (m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2 - 2m_t^2) + \frac{(m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2)^2}{4v^2 \sin^2 \beta} 4 c_{\tilde{t}}^2 s_{\tilde{t}}^2 \right) \log \left( \frac{2\Lambda^2}{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2} \right)$$

EW

Yukawa

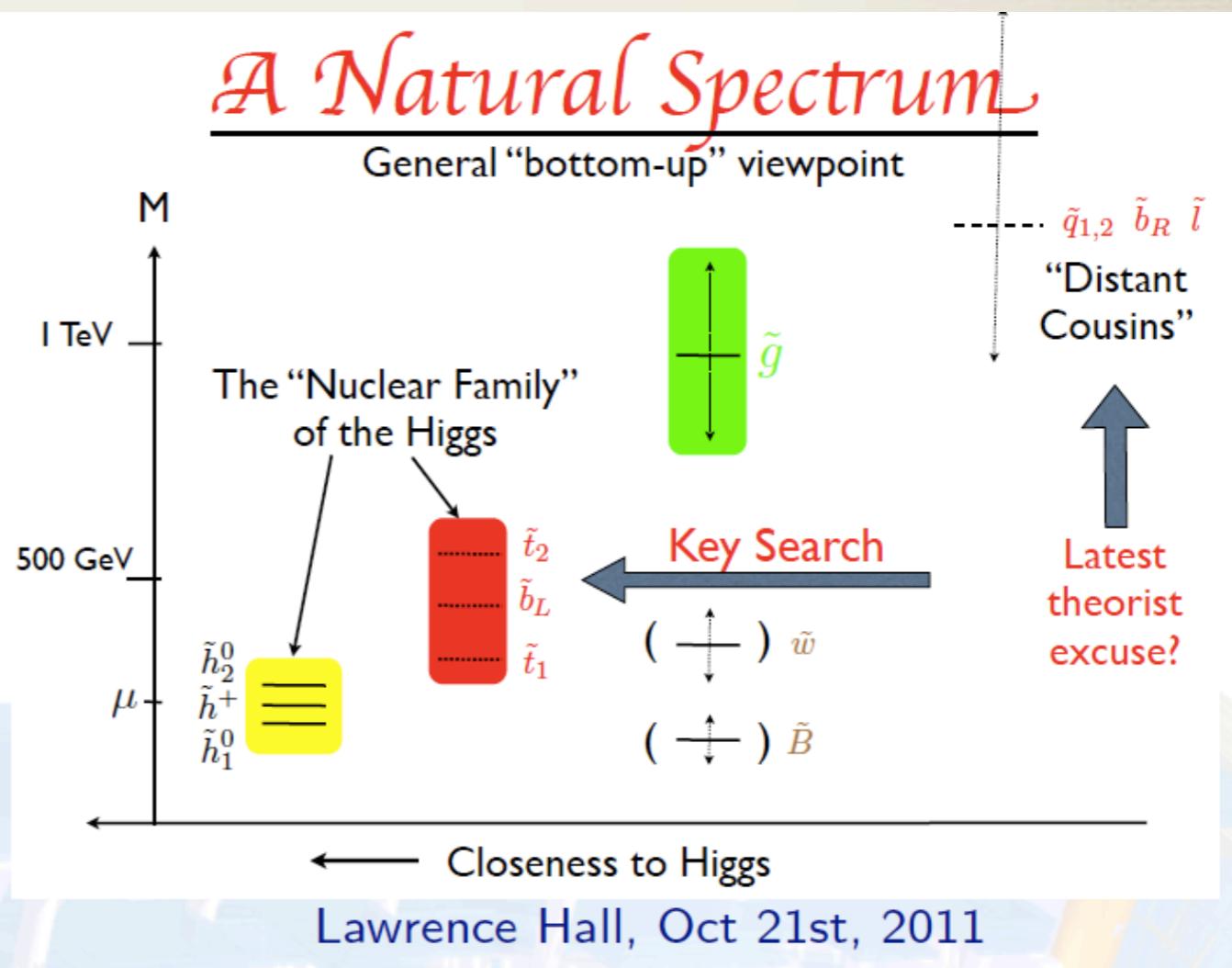
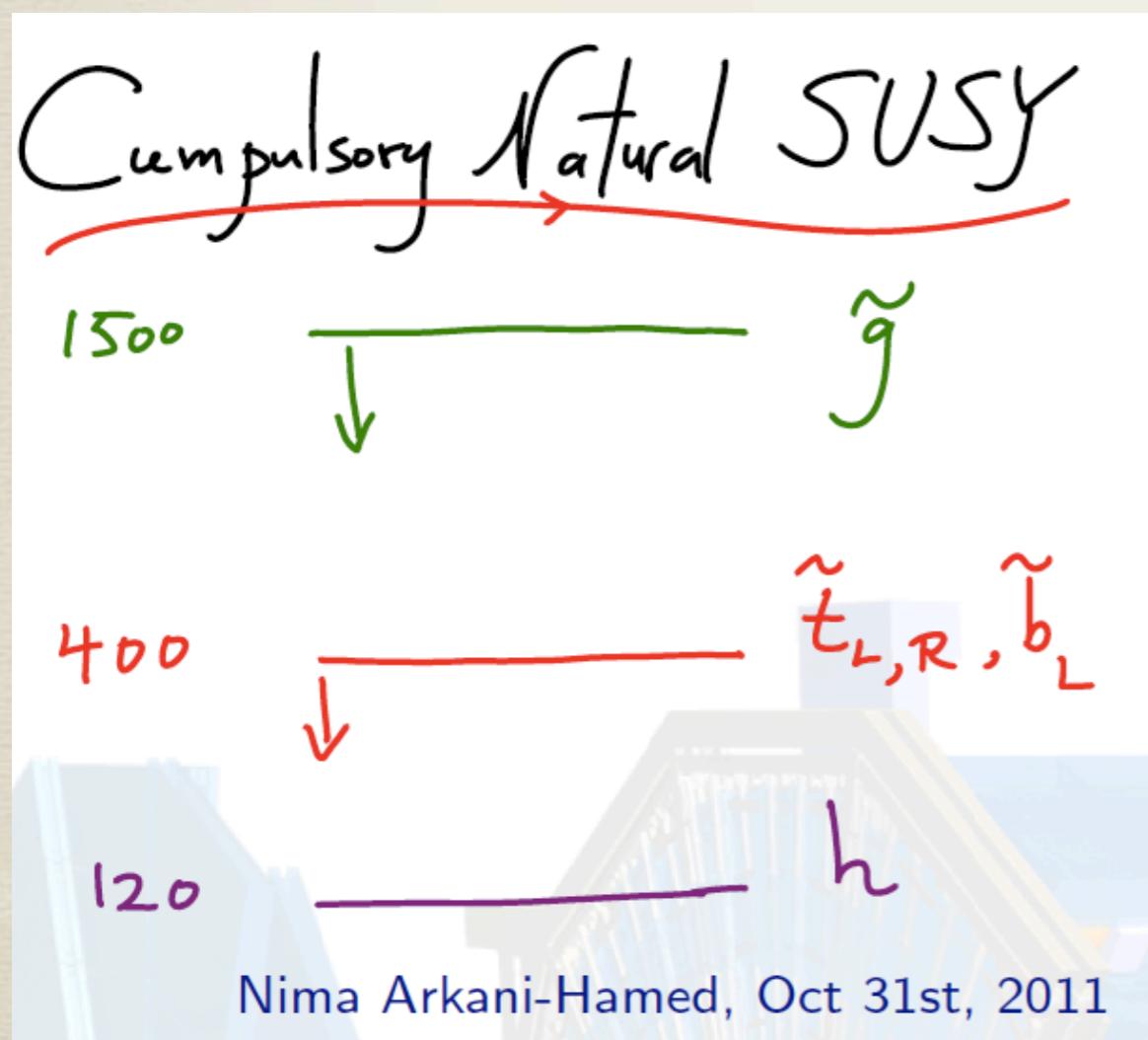
SUSY

cutoff: messenger scale

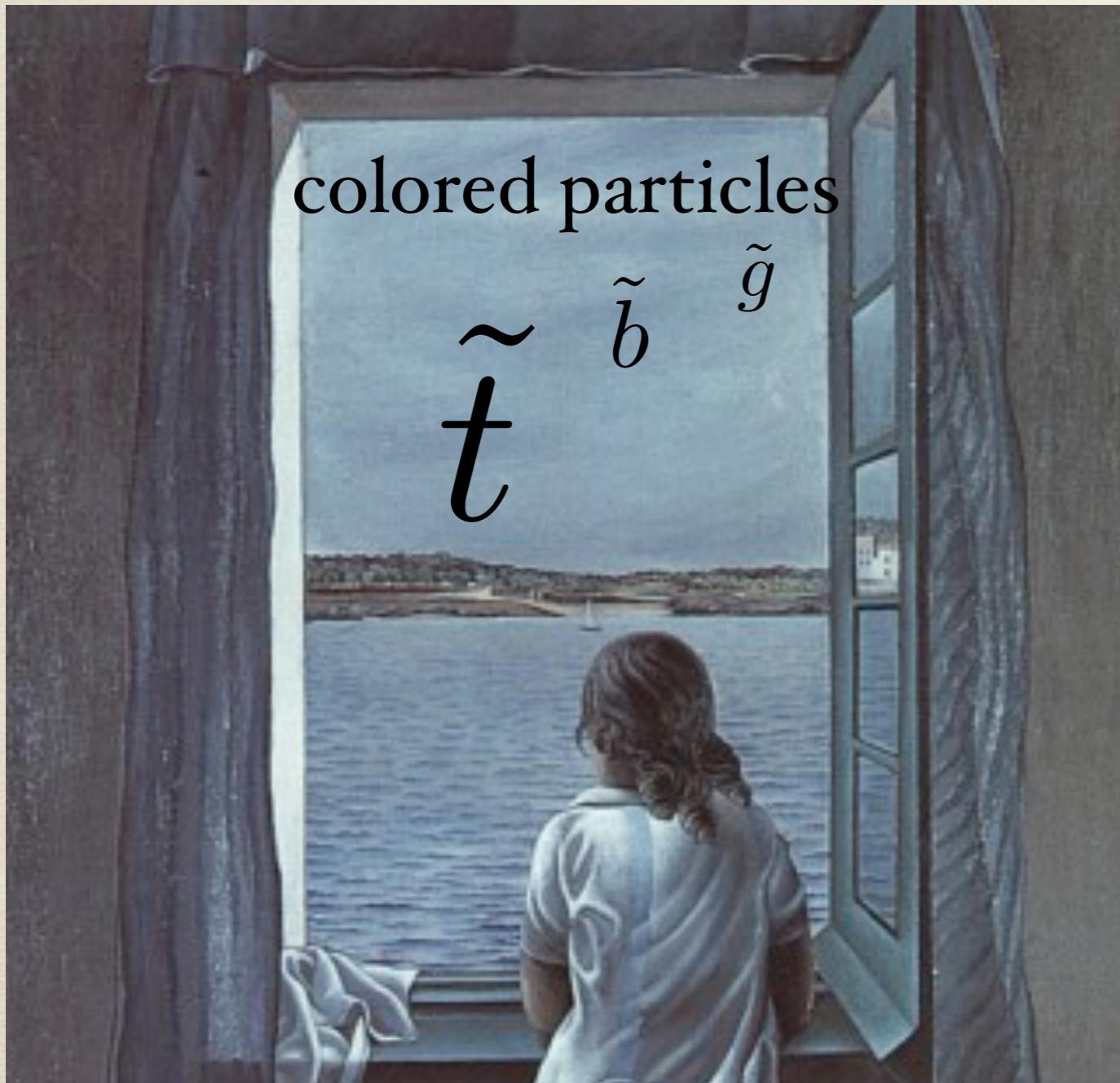
more contributions:  
Higgsinos, two-loop gluino, etc

# Natural SUSY more precisely

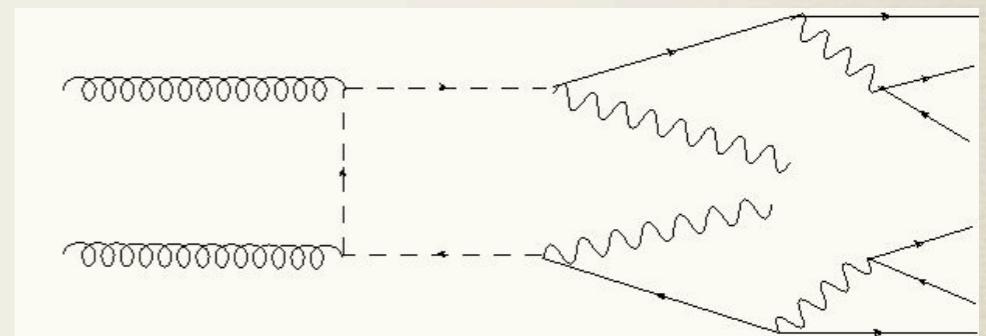
# Heard about it a lot...



# Natural SUSY and stops



stop searches are tough  
leptonic  $t\bar{t} + \text{MET}$

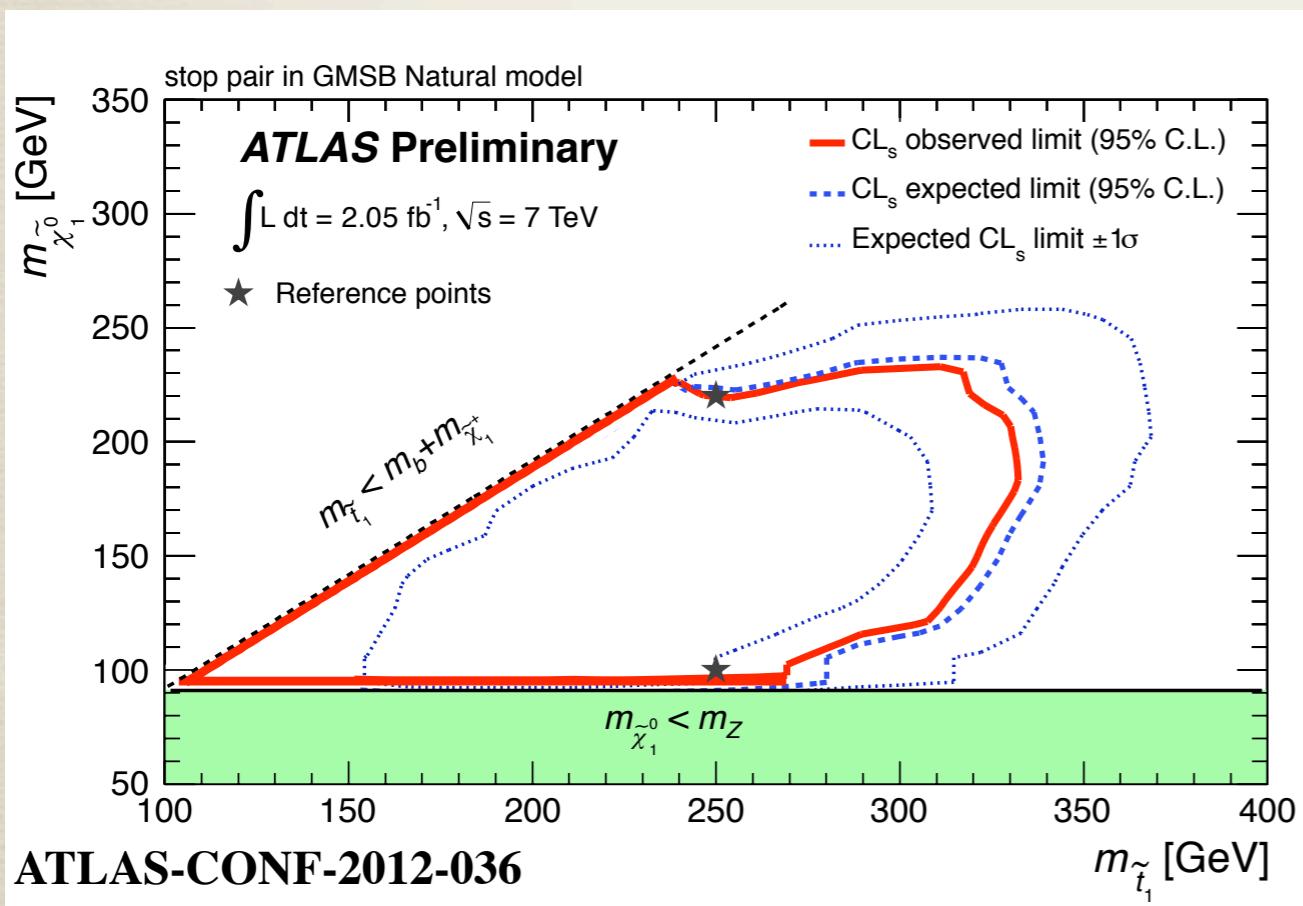


looks a lot like  
leptonic  $t\bar{t}$

# Natural SUSY and stops

No stop direct production limits  
searches on their way

Instead, gluino-assisted, leptonic-Z+MET...



ATLAS-CONF-2011-130  
ATLAS-CONF-2011-098  
ATLAS-CONF-2012-003  
ATLAS-CONF-2012-036

# Stop/Sbottom

Stop and sbottom sectors are related by  
constraints on violations of custodial symmetry  
and origin of SUSY breaking terms

$$\Delta\rho_0^{SUSY} \approx \frac{3 G_F \cos^2 \theta_{\tilde{t}}}{8 \sqrt{2} \pi^2} \left\{ -\sin^2 \theta_{\tilde{t}} F_0[m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2] + F_0[m_{\tilde{t}_1}^2, m_{\tilde{b}_1}^2] + \tan^2 \theta_{\tilde{t}} F_0[m_{\tilde{t}_2}^2, m_{\tilde{b}_1}^2] \right\}.$$

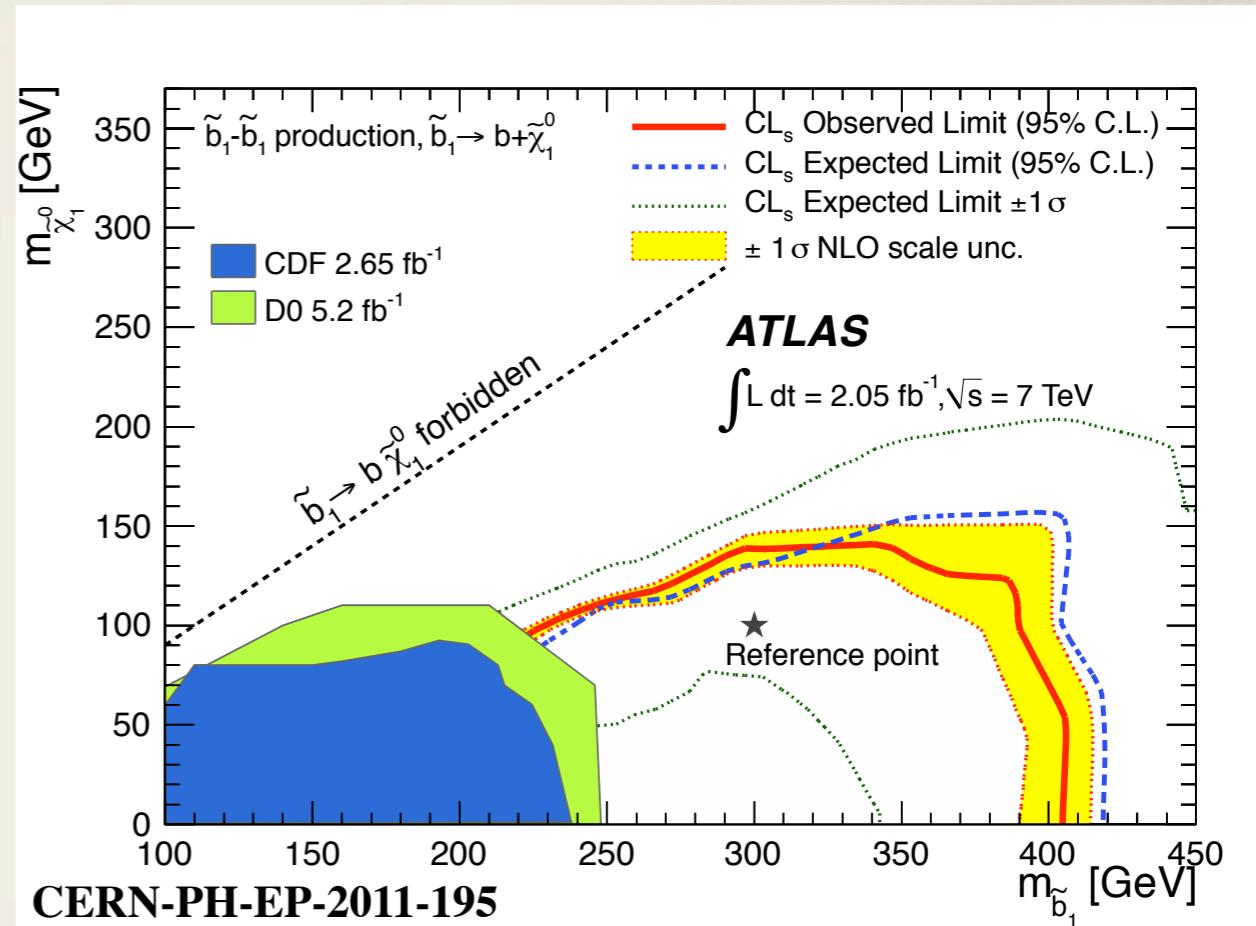
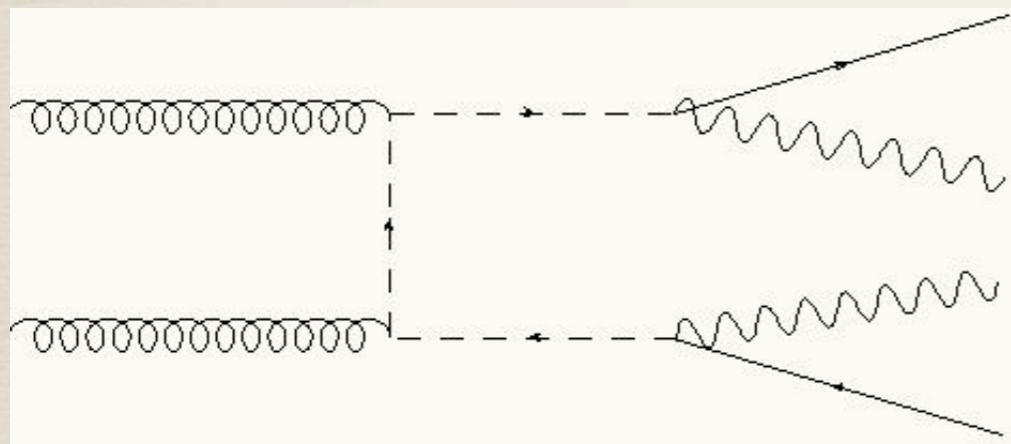
SUSY breaking

$$m_{\tilde{b}_1}^2 \approx \cos^2 \theta_{\tilde{t}} m_{\tilde{t}_1}^2 + \sin^2 \theta_{\tilde{t}} m_{\tilde{t}_2}^2 - m_t^2 - m_W^2 \cos(2\beta)$$

$$m_{\tilde{b}_1} \rightarrow (\theta_{\tilde{t}} , m_{\tilde{t}_1} , m_{\tilde{t}_2})$$

# Sbottom searches

$$m_{\tilde{b}_1} \rightarrow (\theta_{\tilde{t}}, m_{\tilde{t}_1}, m_{\tilde{t}_2})$$

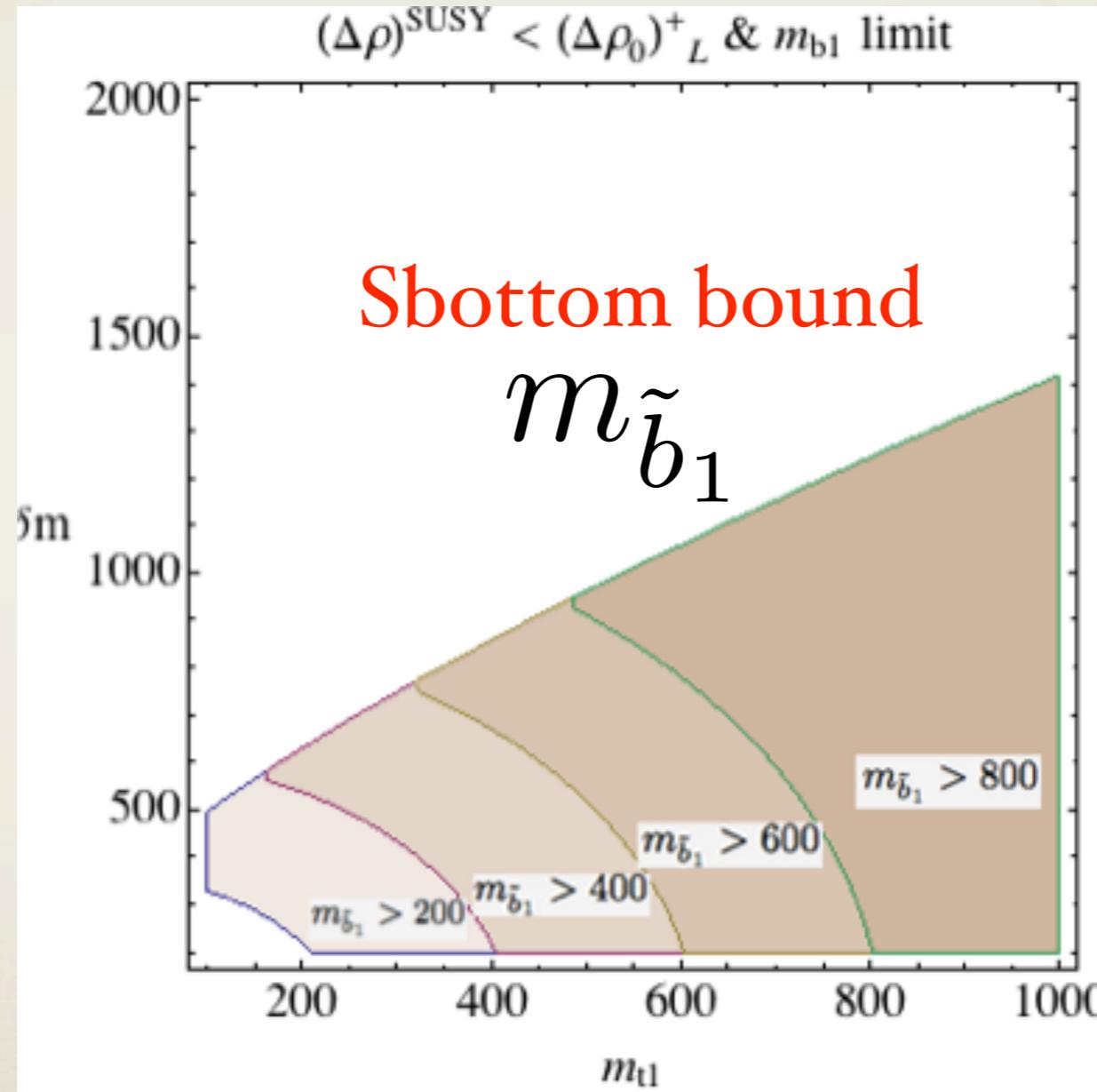


ATLAS arXiv:1112.3832  
accepted PRL

veto on leptons, no veto on extra-jets

# Sbottom/Stop searches

$$\delta m = m_{\tilde{t}_2} - m_{\tilde{t}_1}$$



$$m_{\tilde{t}_1}$$

From the  
sbottom/stop  
relations before

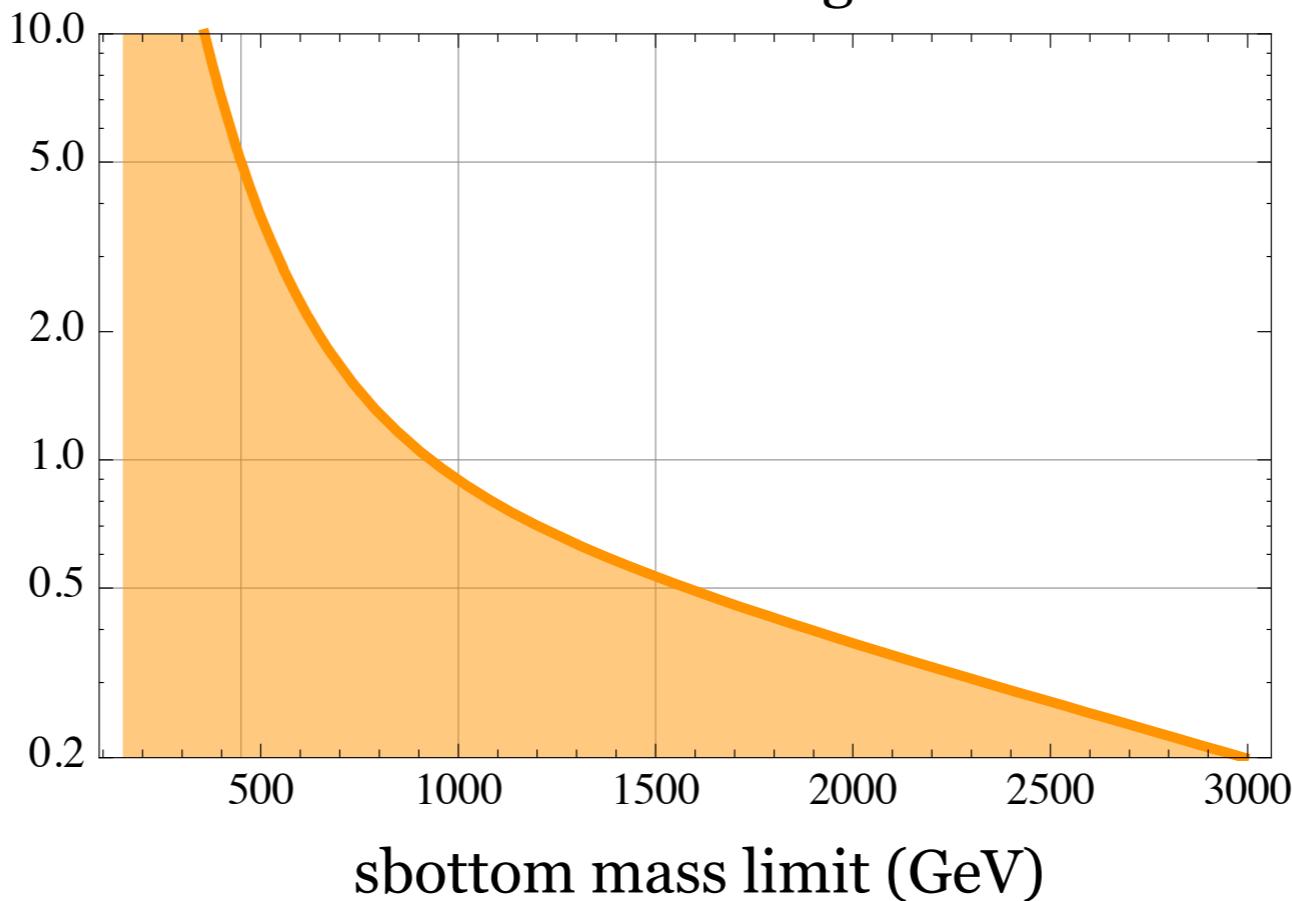
maximal mixing case

# Back to natural SUSY

$$\delta_t m_Z^2 = \frac{3}{16\pi^2} \left( y_t^2 (m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2 - 2m_t^2) + \frac{(m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2)^2}{4v^2 \sin^2 \beta} 4 c_t^2 s_t^2 \right) \log \left( \frac{2\Lambda^2}{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2} \right)$$

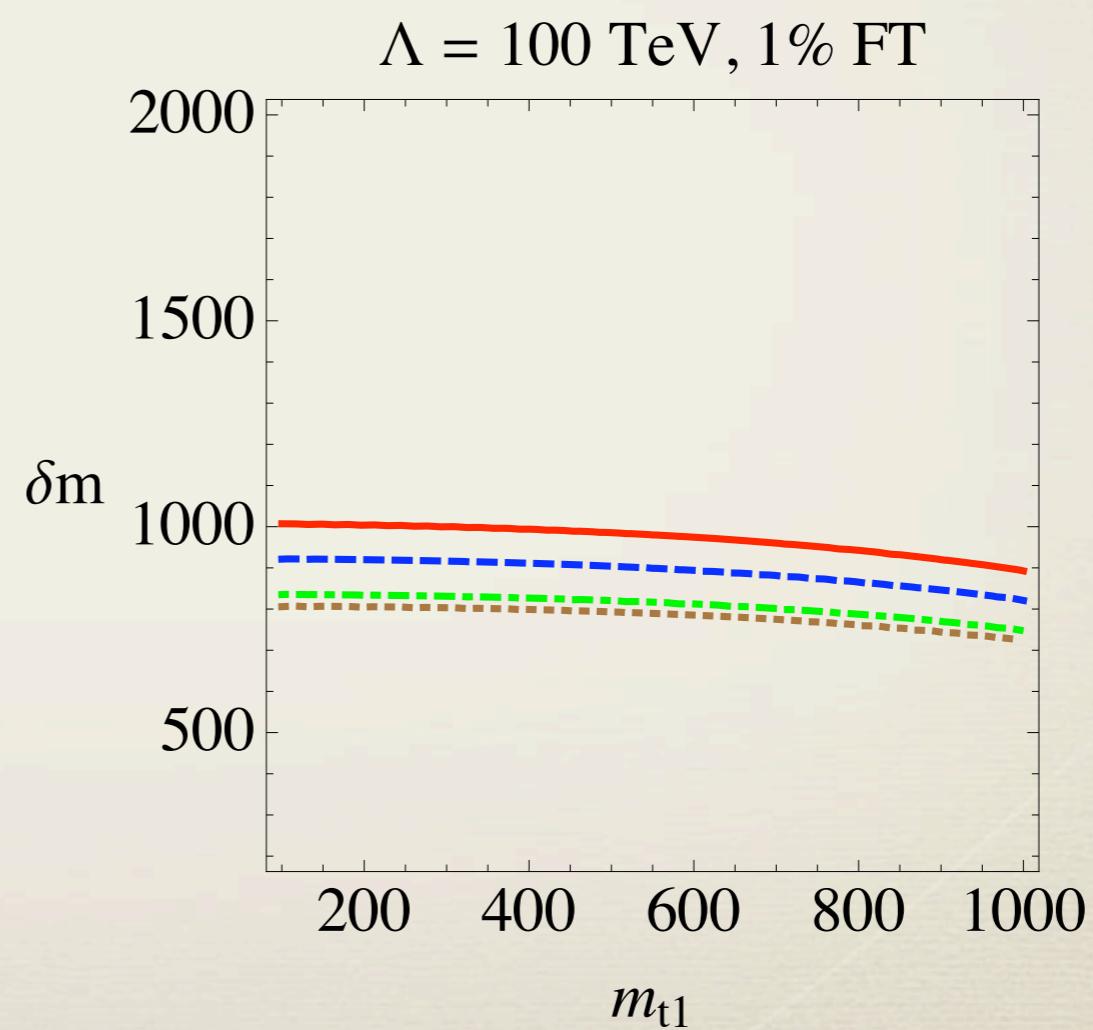
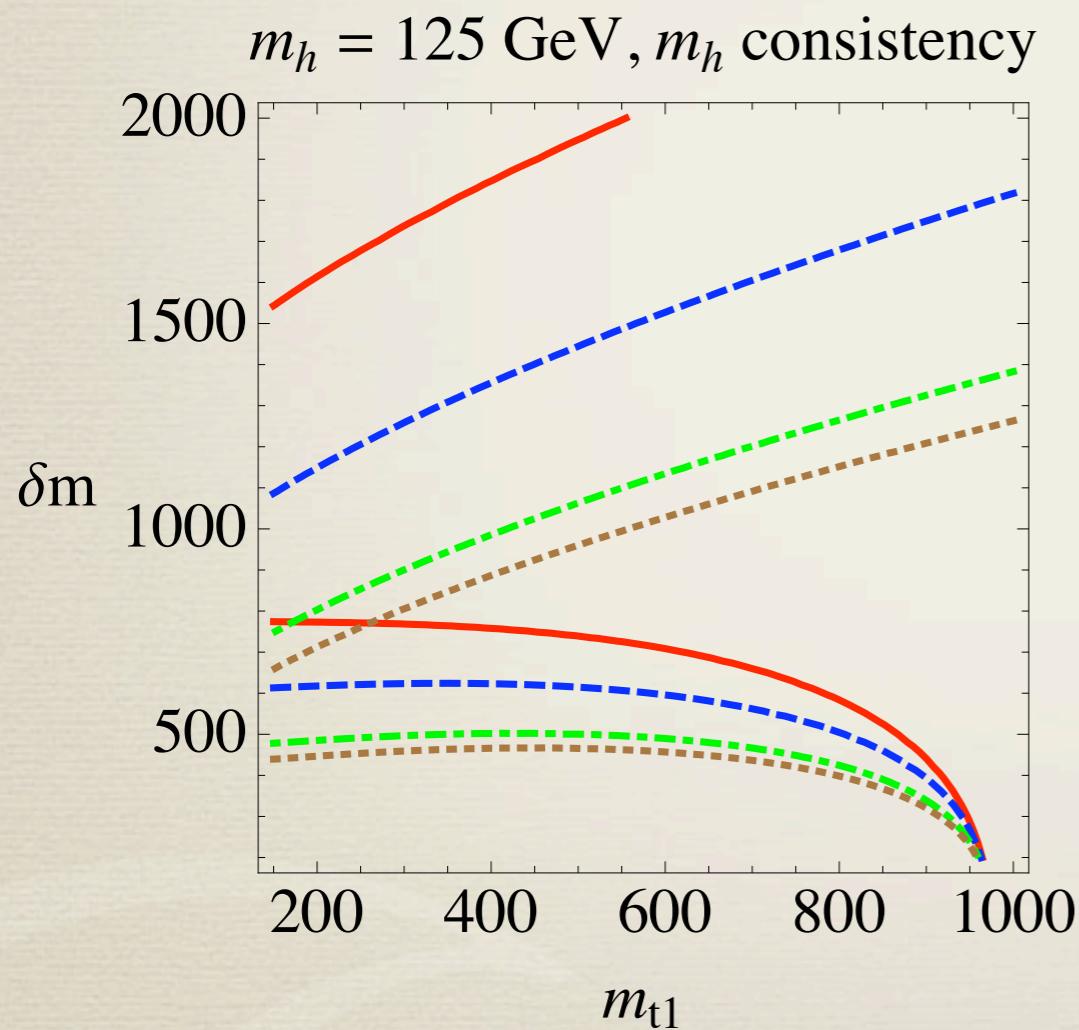
just stops

Minimum amount of fine-tuning  
maximal mixing case



# Beyond Natural SUSY: MSSM Higgs

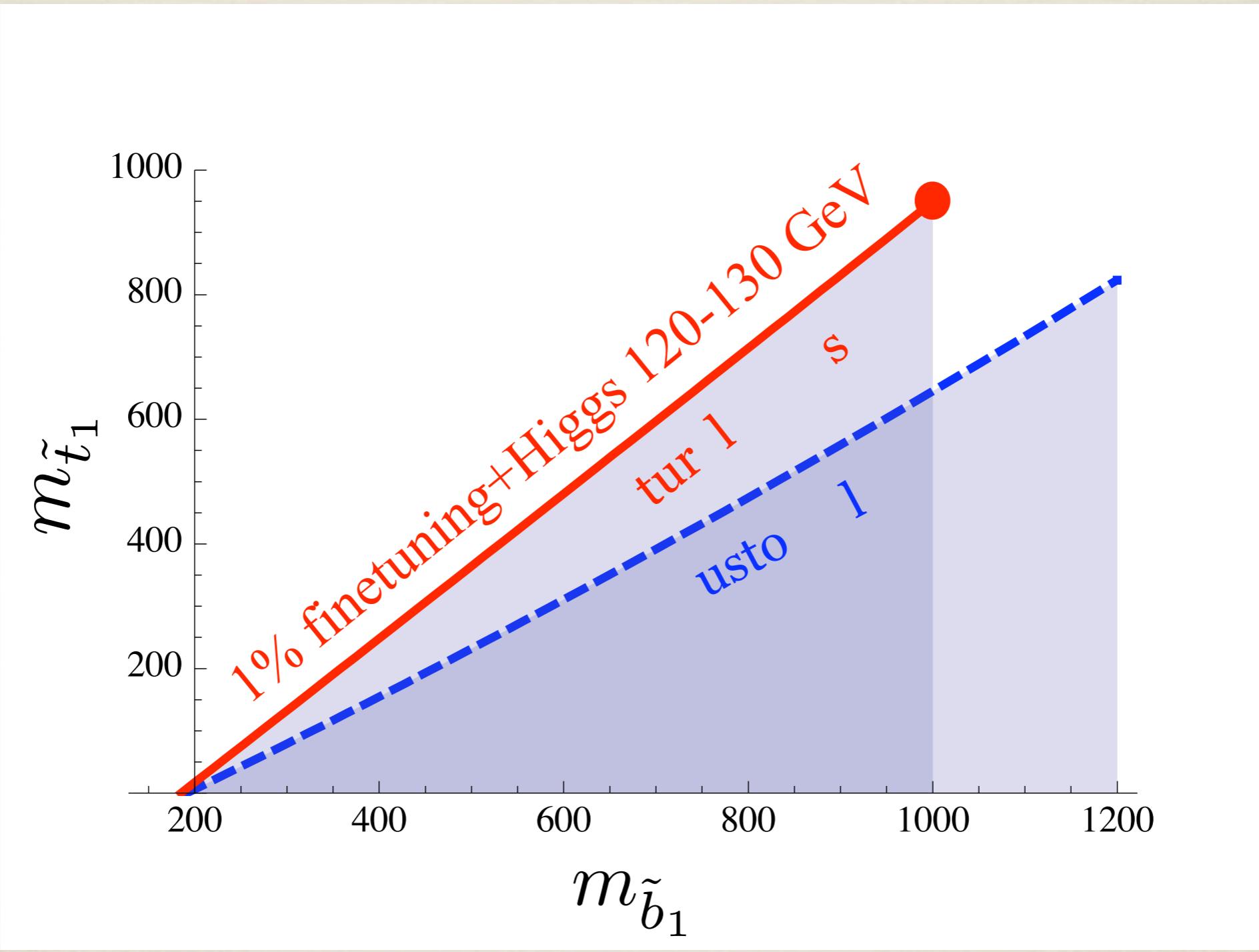
$$\begin{aligned}
m_h^2 = m_Z^2 \cos^2(2\beta) + \frac{3}{4\pi^2} \sin^2 \beta y_t^2 & \left[ m_t^2 \log \left( \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} \right) + c_{\tilde{t}}^2 s_{\tilde{t}}^2 (m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2) \log \left( m_{\tilde{t}_2}^2 / m_{\tilde{t}_1}^2 \right) \right. \\
& \left. + \frac{c_{\tilde{t}}^4 s_{\tilde{t}}^4}{m_t^2} \left( (m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2)^2 - \frac{1}{2} (m_{\tilde{t}_2}^4 - m_{\tilde{t}_1}^4) \log \left( m_{\tilde{t}_2}^2 / m_{\tilde{t}_1}^2 \right) \right) \right].
\end{aligned}$$



mixing angle: 0.2–0.5

# Natural MSSM Higgs

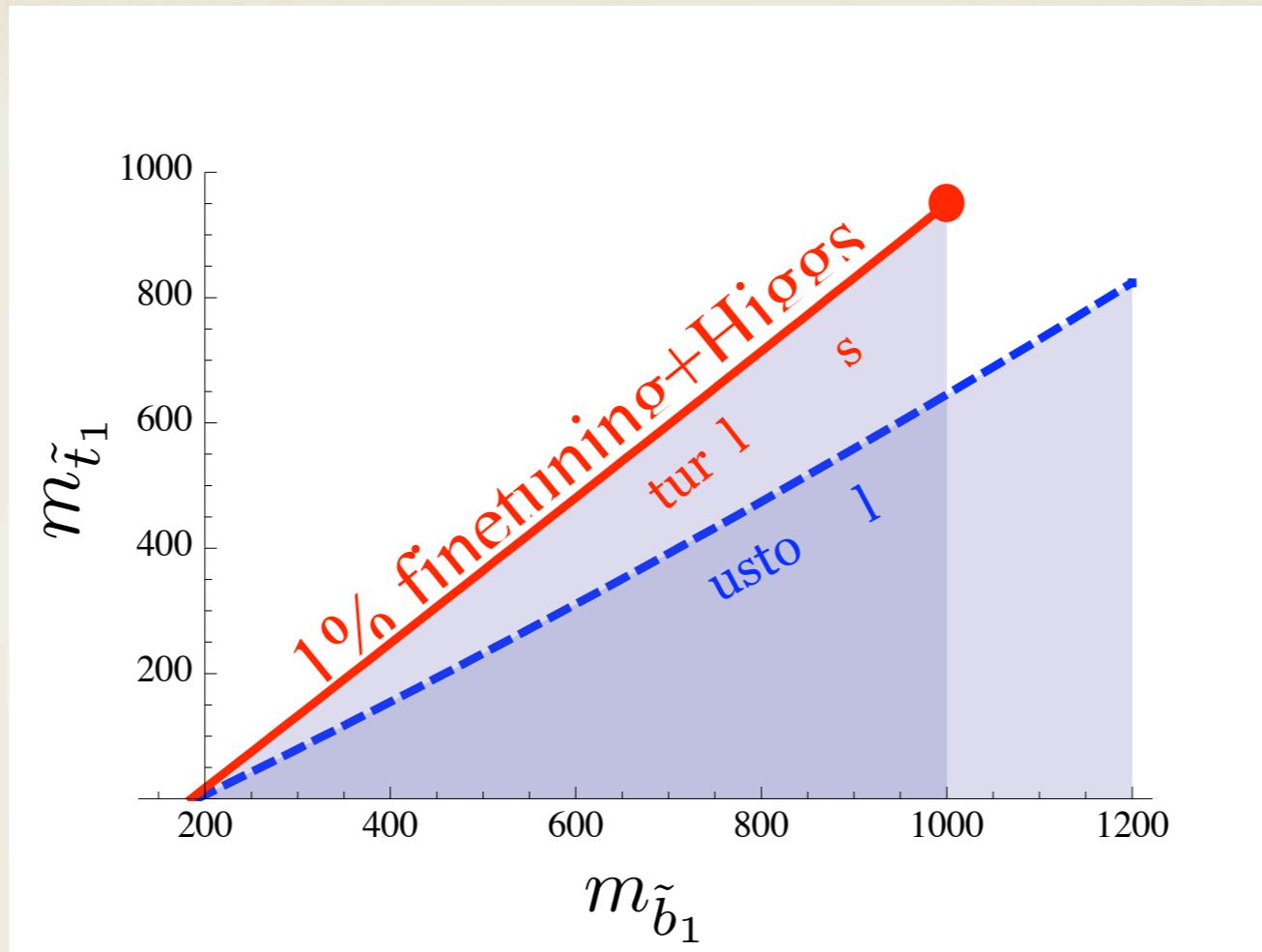
derived limit on stop



limit on sbottom

# So...

Sbottom searches are a way to access to the stop sector

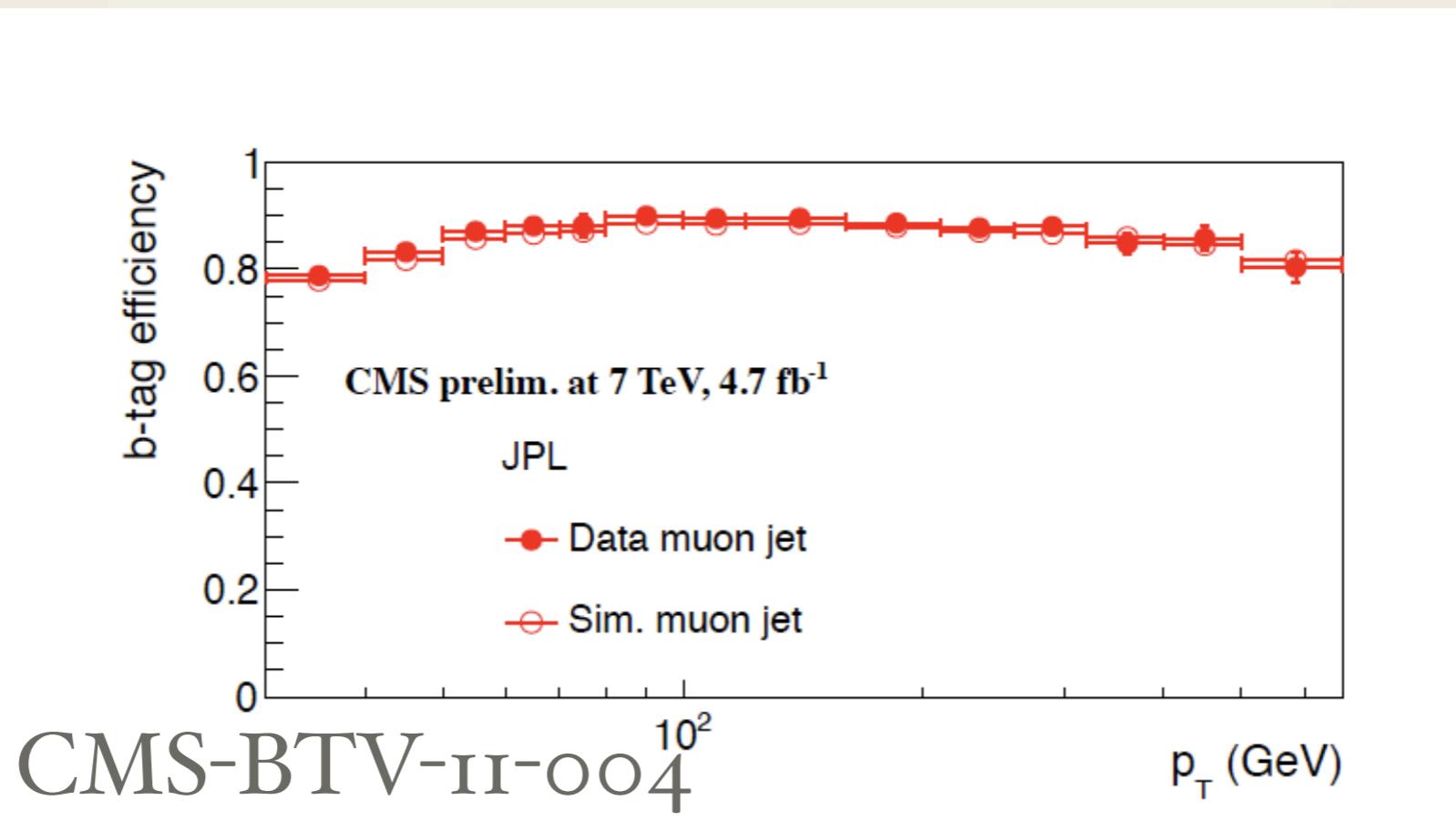


more assumptions:  
natural, MSSM...  
stronger limits

# LHC@8 TeV: Sbottom searches

sbottom searches depend on b-tagging: pretty stable

7 TeV data up to 670 GeV  
8 TeV commissioning  
not available

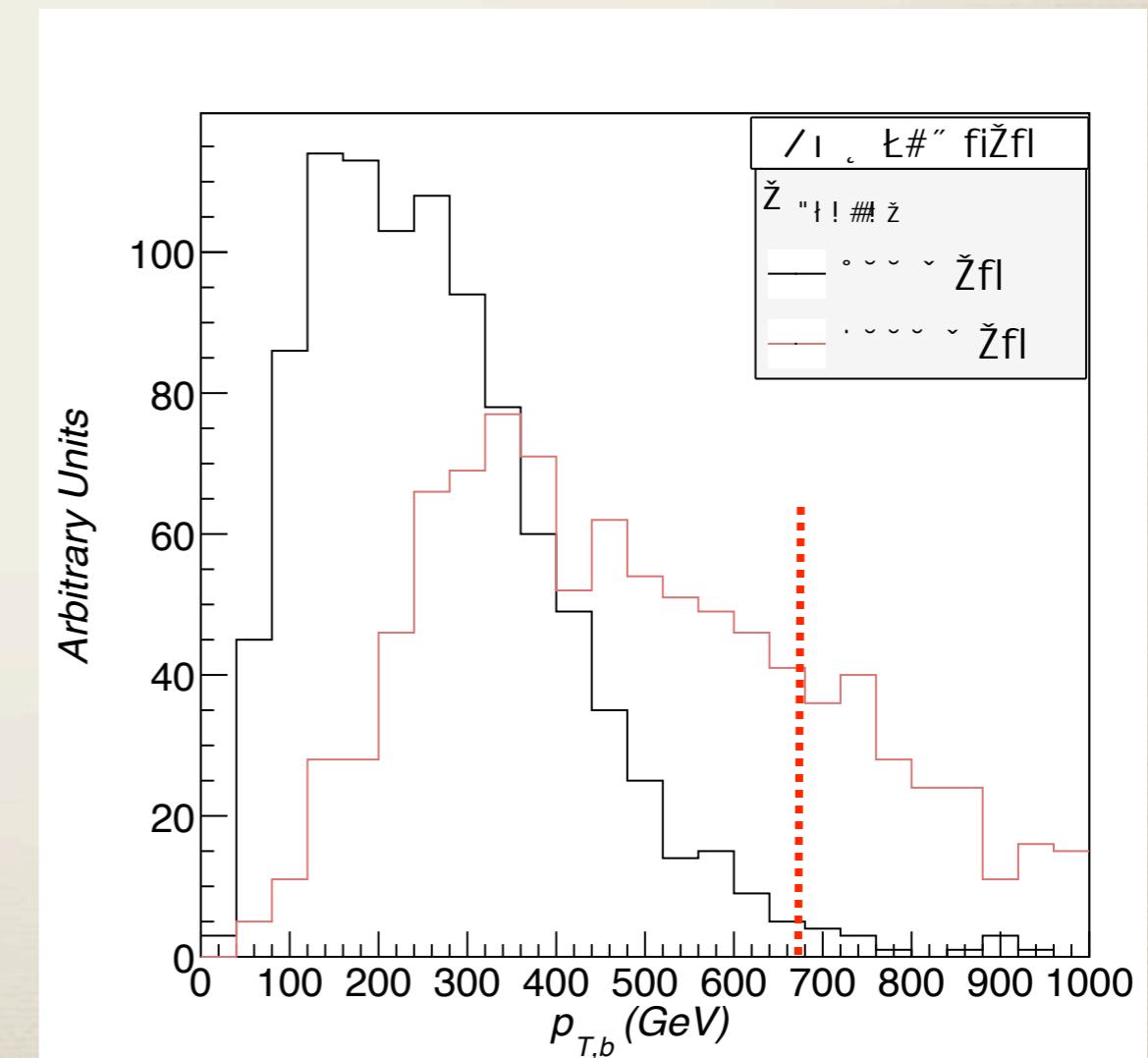
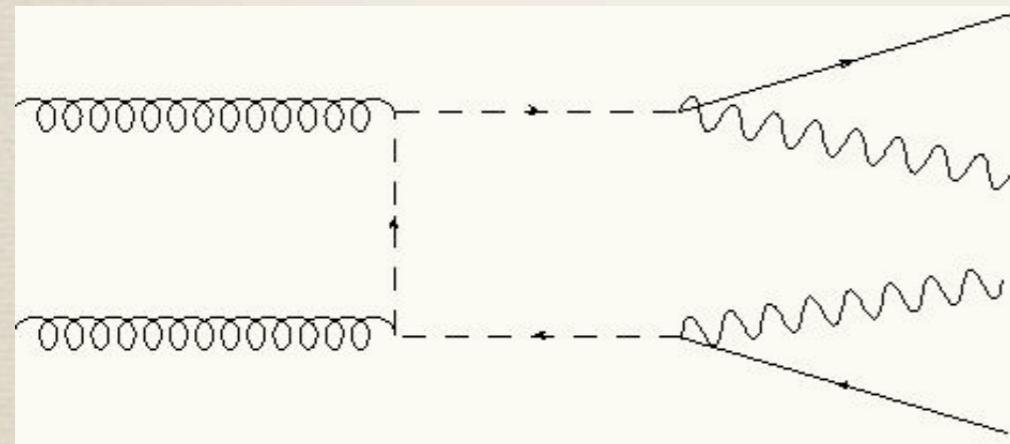


# LHC@8 TeV: Sbottom searches

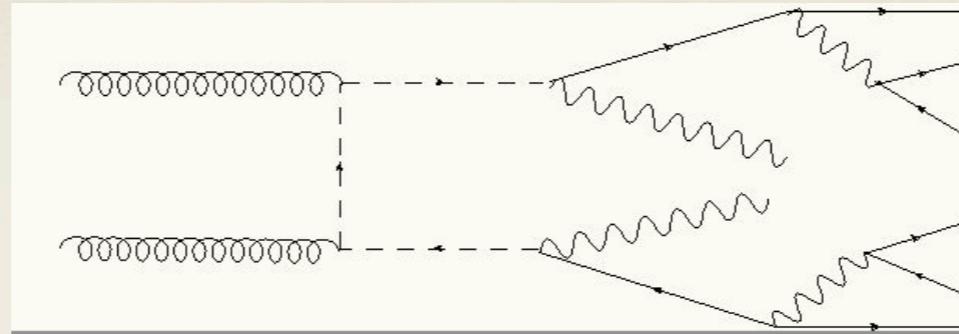
sbottom searches depend on b-tagging: pretty stable

$p_T(\text{bjet})$  vs sbottom mass

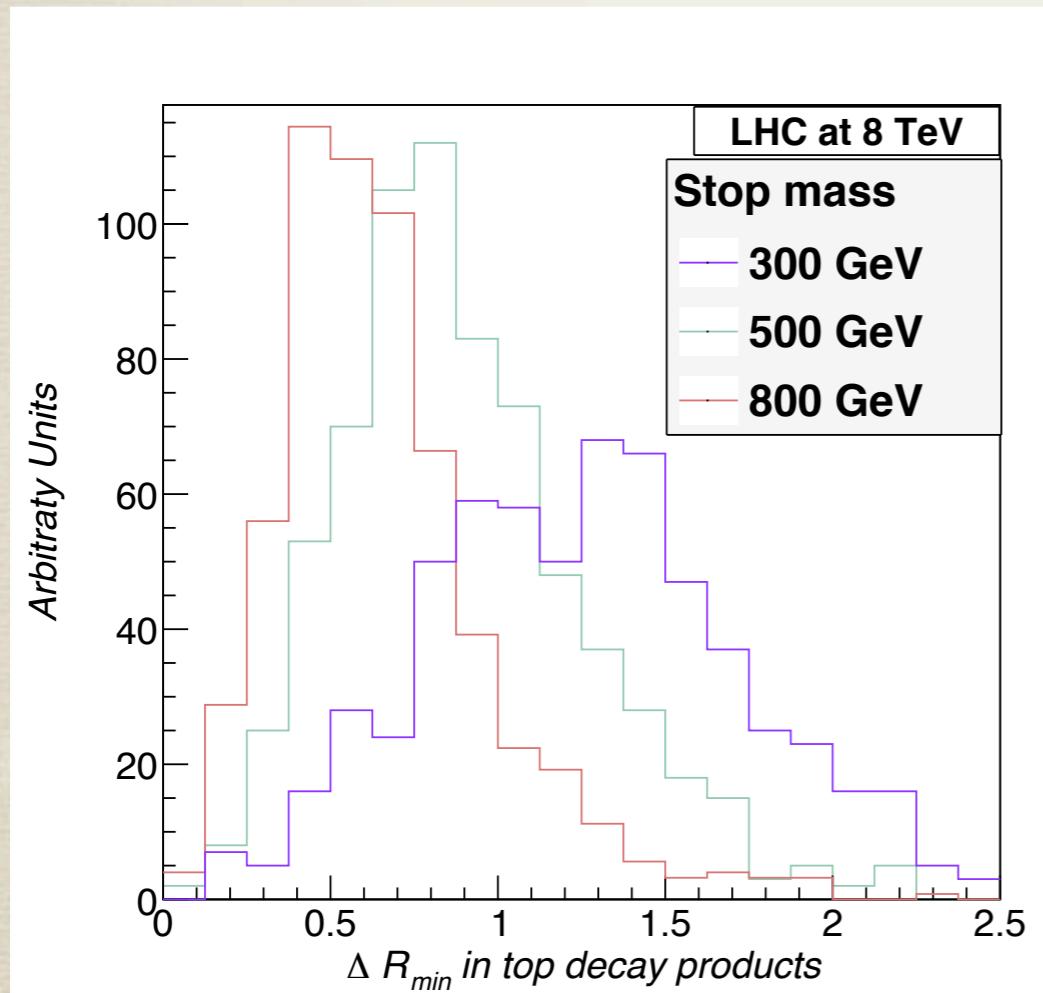
7 TeV data up to 670 GeV



# LHC@8 TeV: Stop searches



stop searches don't scale-up so nicely



isolation degrades with  
stop mass  
enter in boosted top techniques  
but < 1 TeV is in-between

# LHC@8 TeV: Stop-Sbottom comparison

|              | <b>Sbottom</b><br>For $p_T^b < 670$ GeV<br>$\epsilon_{b,tag} \simeq 60 - 80\%$ [52]<br>$\epsilon_{mistag} \simeq 1 - 10\%$ [52]. | <b>Stop, non boosted</b><br>SM $t\bar{t}$ similar.<br>Considering only lepton isolation criteria $\Delta R > 0.7$ . | <b>Stop, boosted</b><br>Top-tagging eff. $\gtrsim 40\%$<br>if $p_T^t \in [600, 1600]$ GeV [51] |
|--------------|--|---|--|
|              | $\epsilon_{p_T^b < 670}$   | $\epsilon_{\Delta R > 0.7}$   | $\epsilon_{p_T^{top} > 600}$   |
| < 300 GeV    | 1  | > 0.50  | < 0.01   |
| 300-700 GeV  | $\simeq 1$   | 0.50-0.25   | 0.01-0.1   |
| 700-1000 GeV | >0.78  | <0.25   | 0.1-0.3  |

# Conclusions

Natural SUSY: stop sector  
Custodial symmetry relates sbottom and stop

Sbottom searches underway, scale-up nicely

Stop searches harder, in-between two regimes  
(boosted/non-boosted)

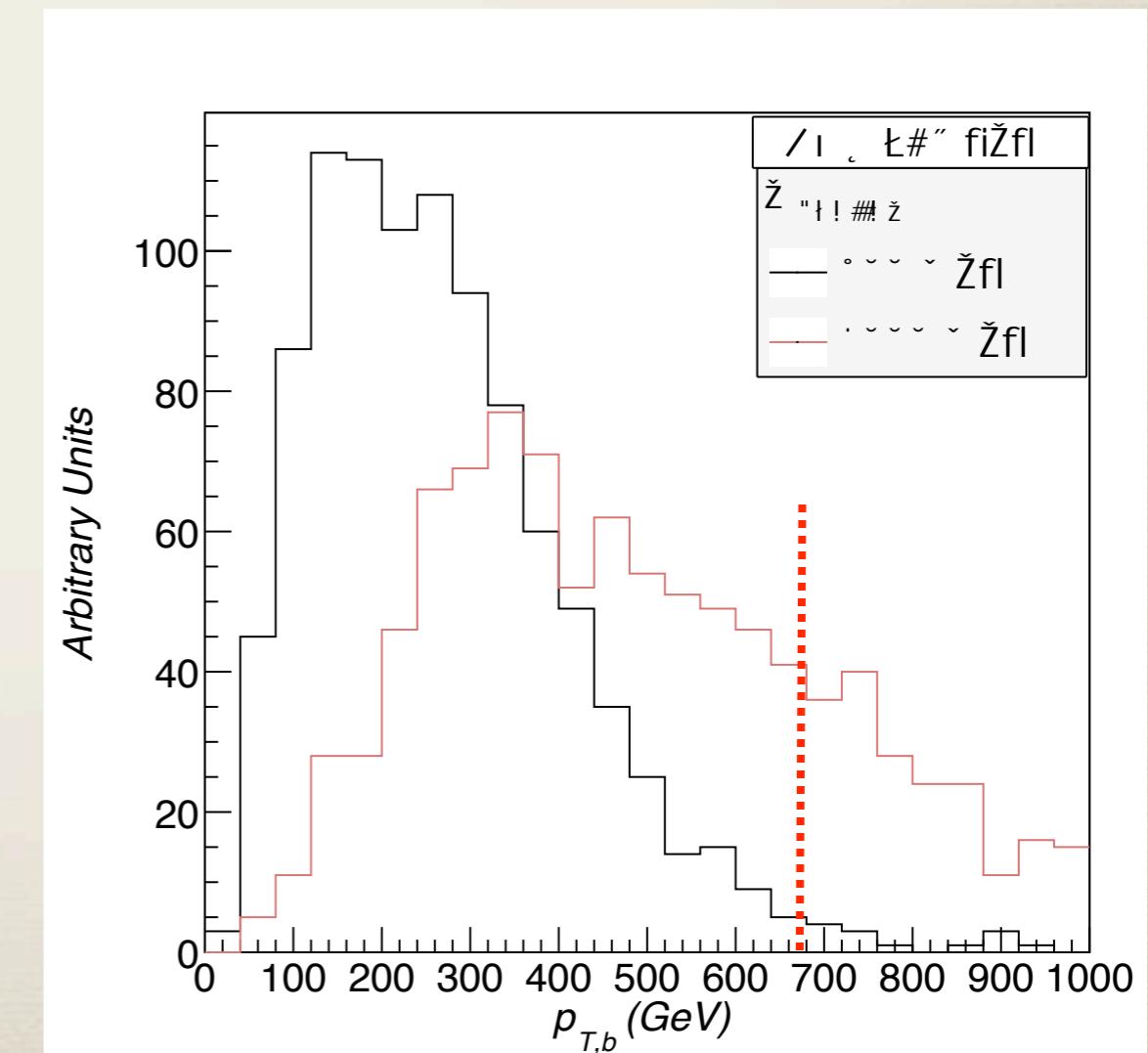
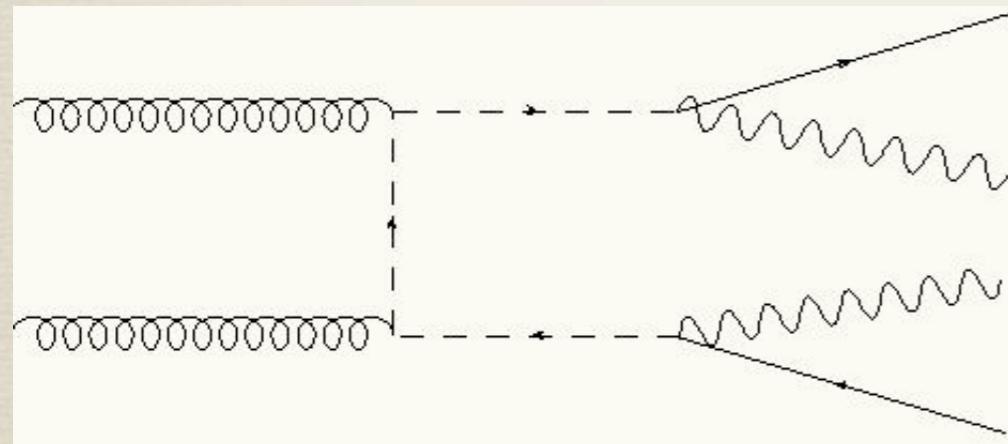
sbottom limits: stop limits  
AND  
discovery would go through sbottom searches

# LHC@8 TeV: Sbottom searches

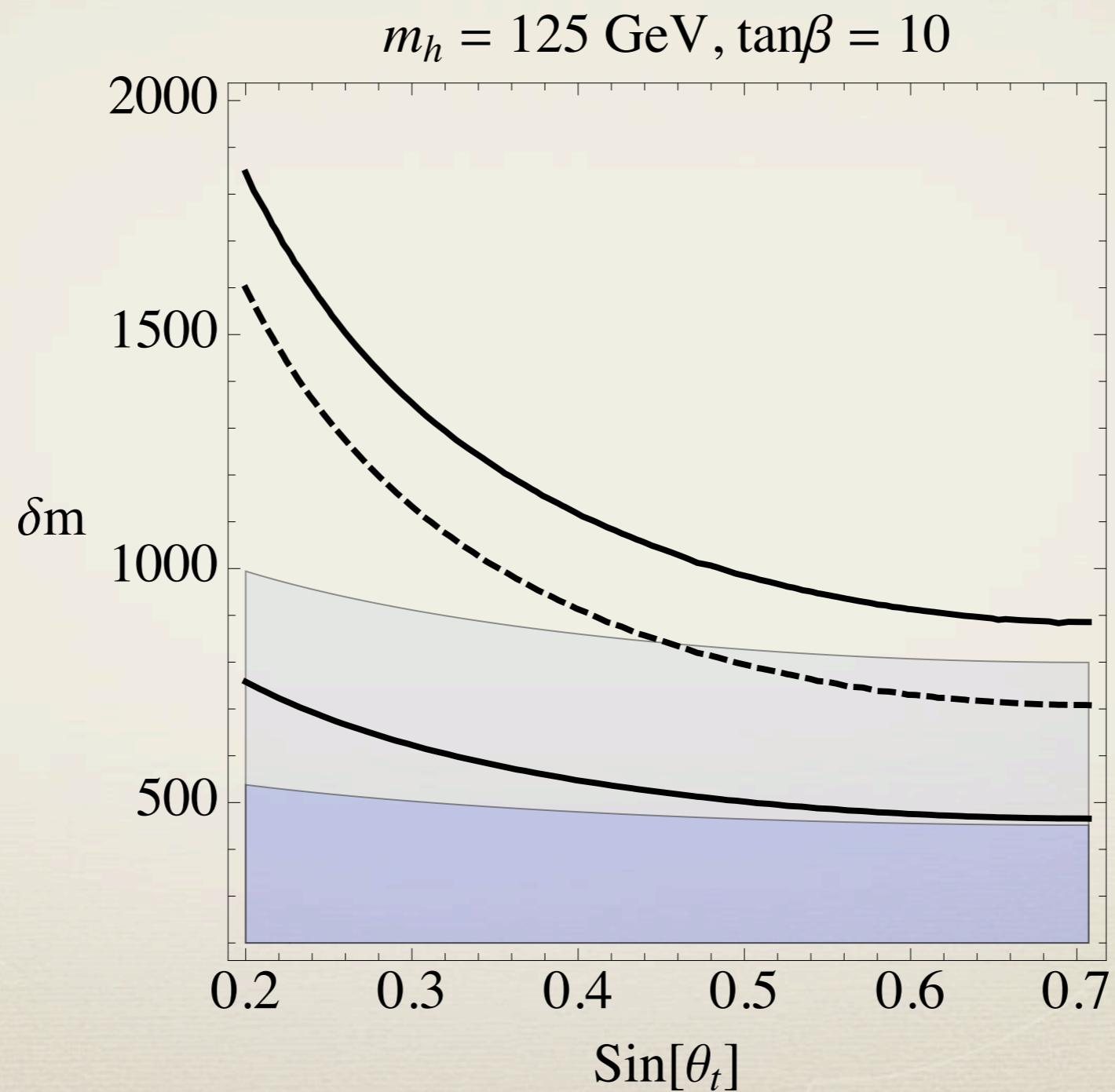
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$p_T(\text{bjet})$  vs sbottom mass

7 TeV data up to 670 GeV



# Beyond Natural SUSY: MSSM Higgs



# Natural SUSY and stops