Hitting sbottom in natural SUSY

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With V. Sanz and M. Trott, JHEP 1205 (2012) 139.

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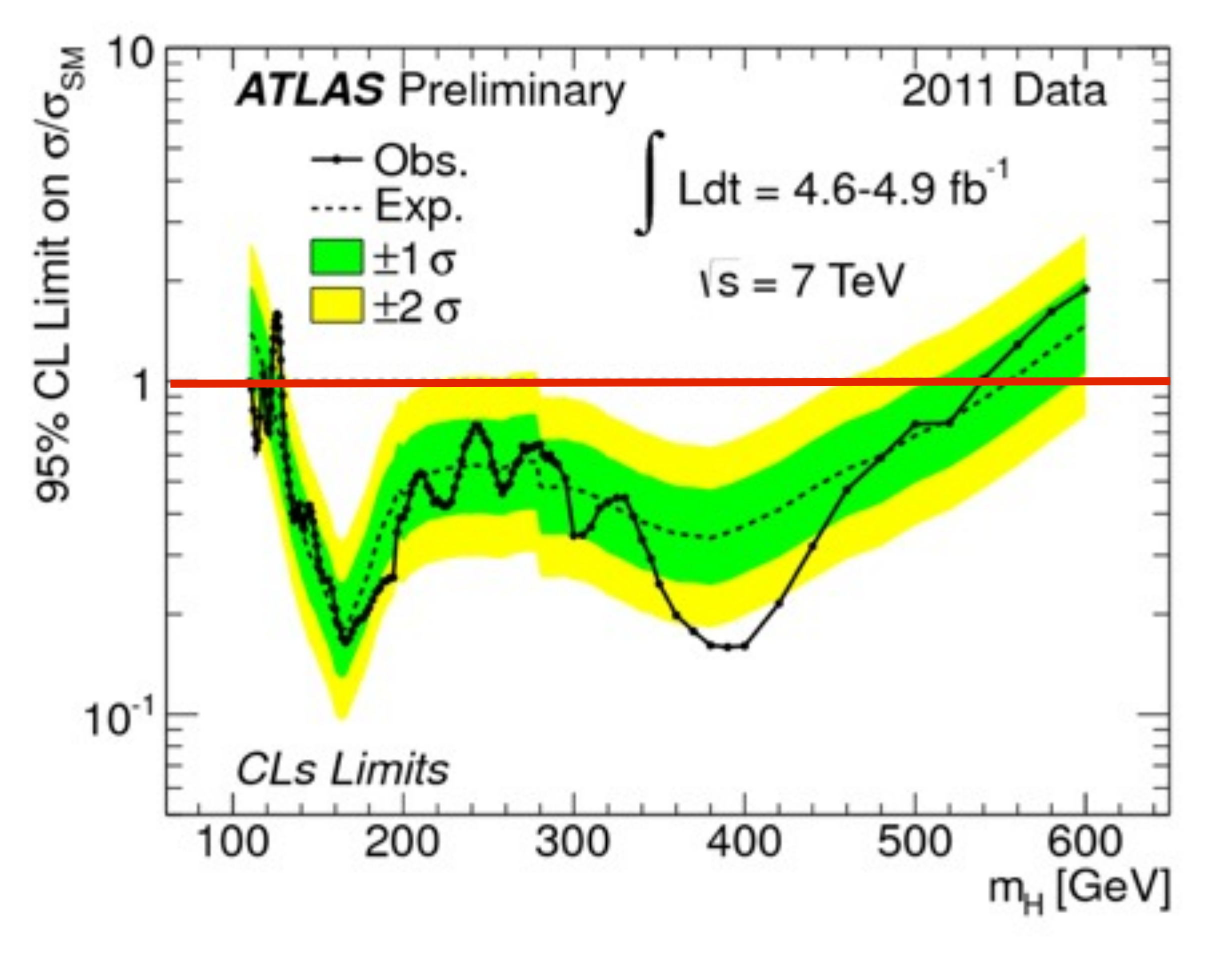
Outline

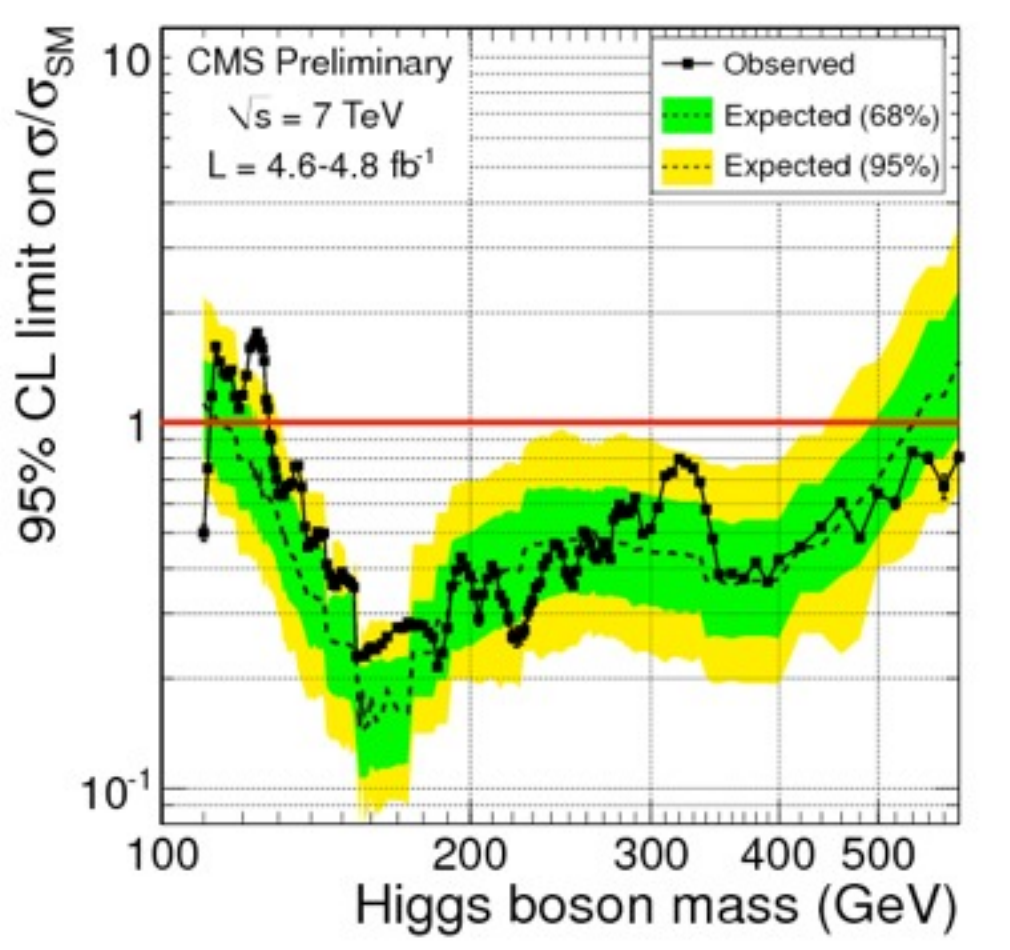
- Motivation
- Higgs boson in MSSM
- Natural SUSY and electroweak precision
- Sbottom search at the LHC

LHC limits on Higgs

- LHC measures $\sigma(pp \to H) \times \mathrm{BR}.$
- 95% CL limits on the SM Higgs mass.



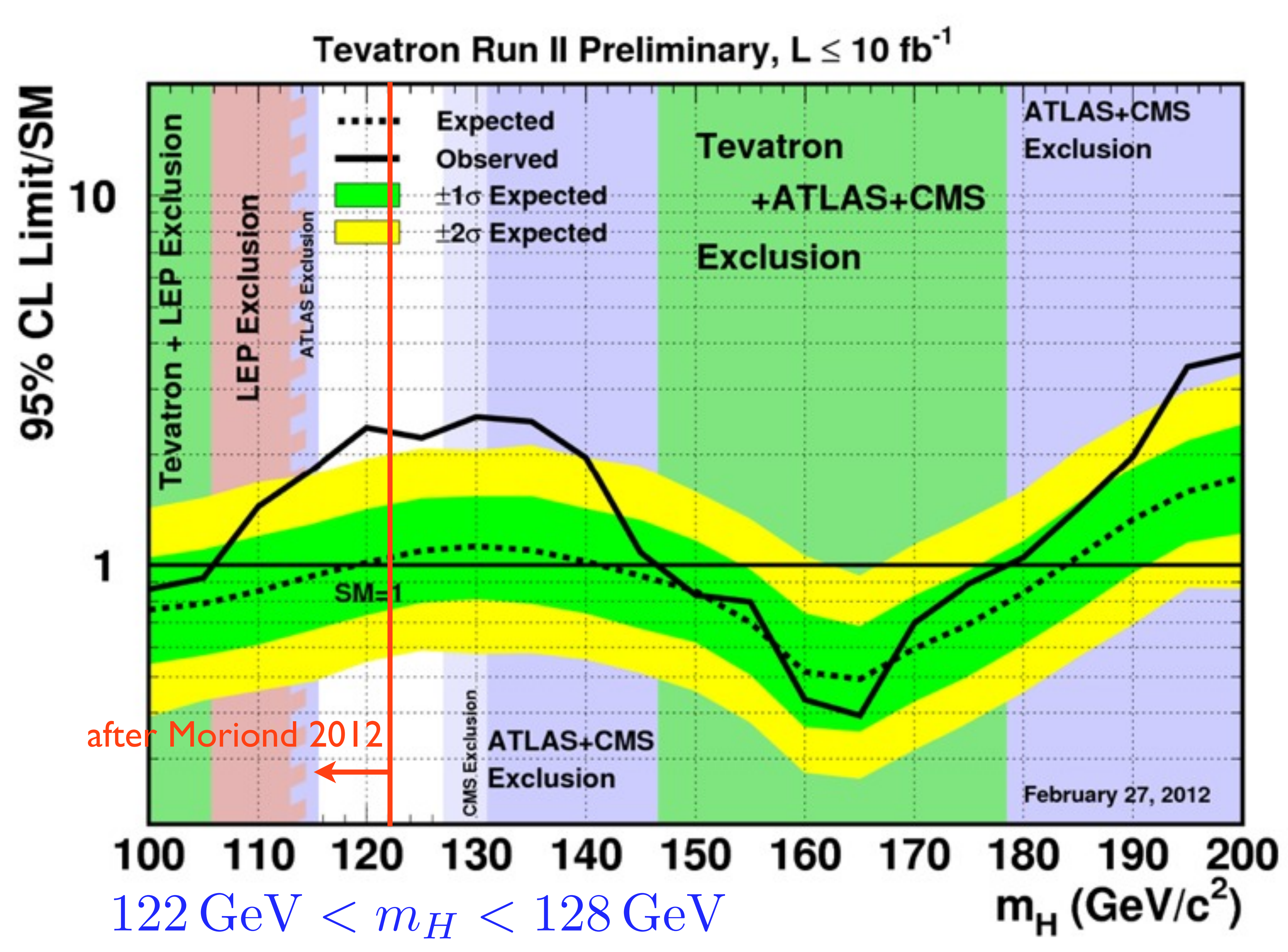
$m_H = 110 - 117.5,\ 118.5 - 122.5,\ 129 - 539\,\mathrm{GeV}$



$127.5\,\mathrm{GeV} < m_H < 600\,\mathrm{GeV}$

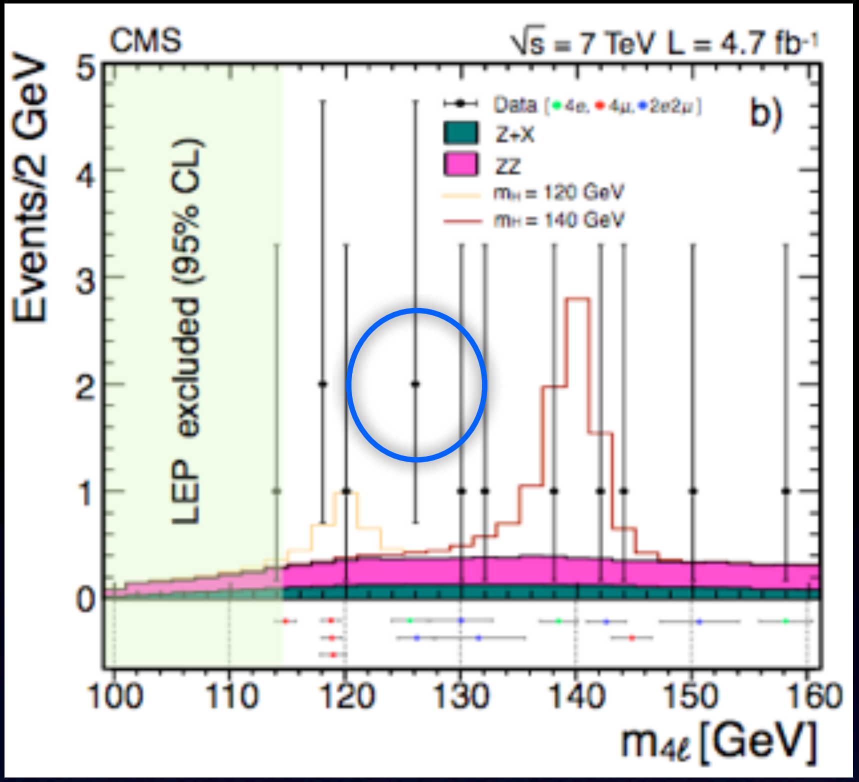
- End of 2012: Entire range could be excluded.

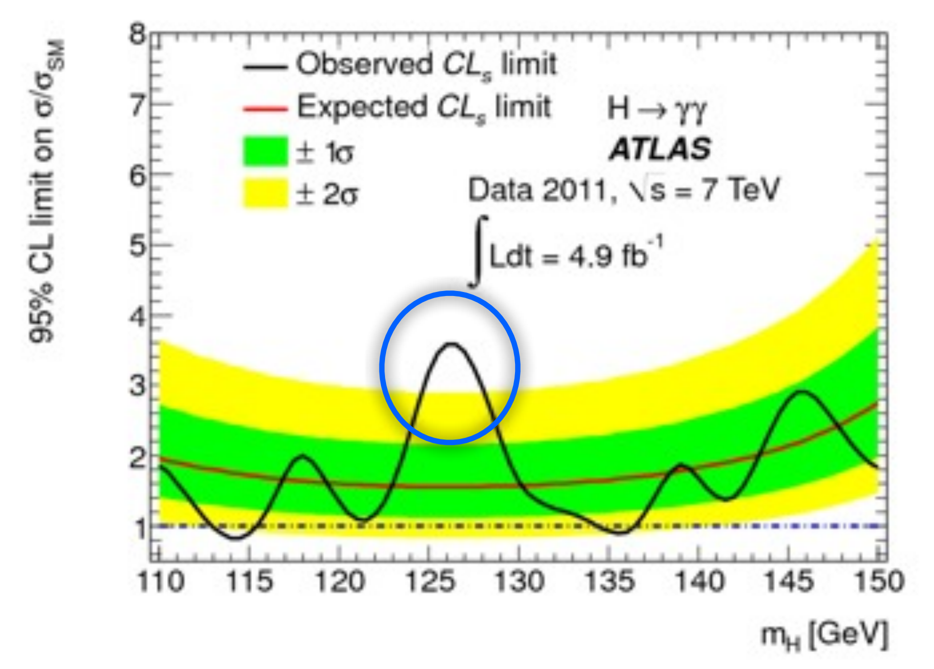
All Combined

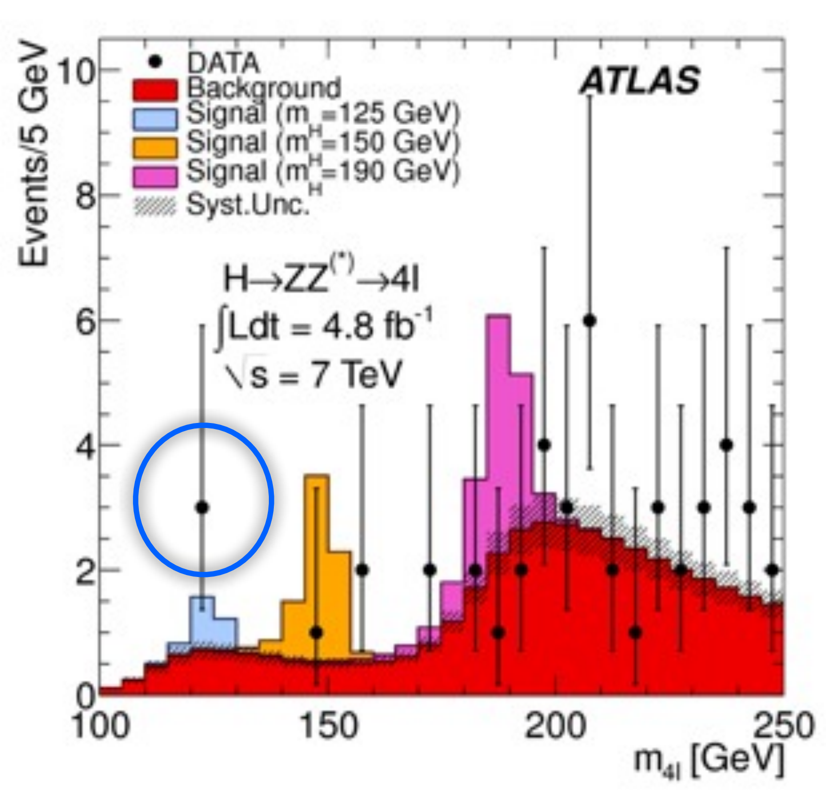


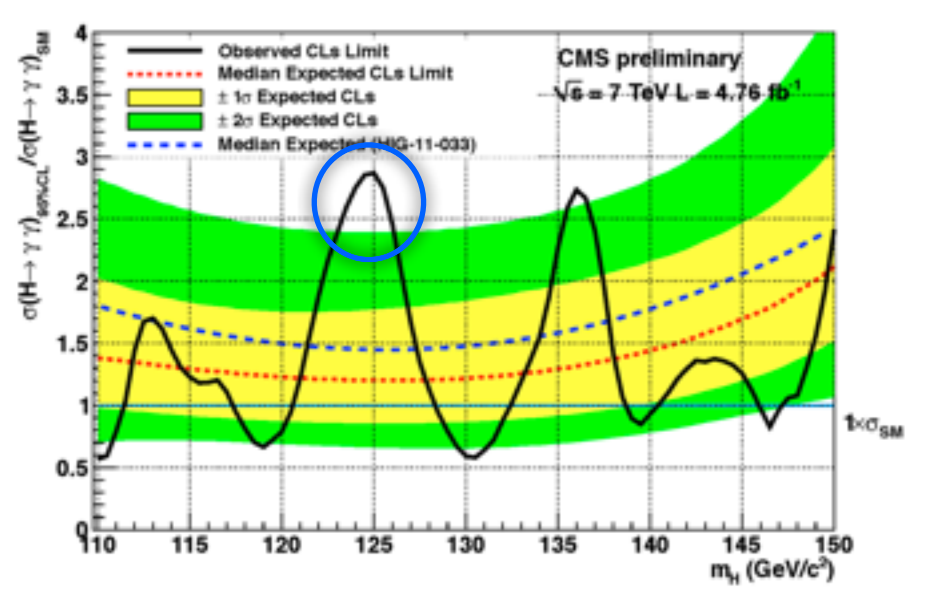
after Moriond 2012

$122\,\mathrm{GeV} < m_H < 128\,\mathrm{GeV}$









125 GeV Higgs

- ZZ (4l), $\gamma\gamma$ ATLAS / CMS $> 2\sigma$ excess.
- Consistent with broad excess $(VH \rightarrow b\bar{b})$ at Tevatron.

What is the meaning of 125 GeV Higgs ?

- Is it the SM Higgs ?
- What if SM Higgs ? New physics at weak scale or high scale ?

→ Two problems of naturalness

Hierarchy problem

- Why is Gravity so weaker than Weak force ?

$$\frac{G_F \hbar^2}{G_N c^2} \sim 10^{33}$$

- How is the Higgs mass so small ?

$$G_F \sim \frac{1}{m_H^2},\ G_N \sim \frac{1}{M_P^2} \ \Rightarrow\ m_H \ll M_P ?$$

- SM particles induce large Higgs mass by loops.

$$\Rightarrow\ \delta m_H^2 = \kappa \Lambda^2 .$$

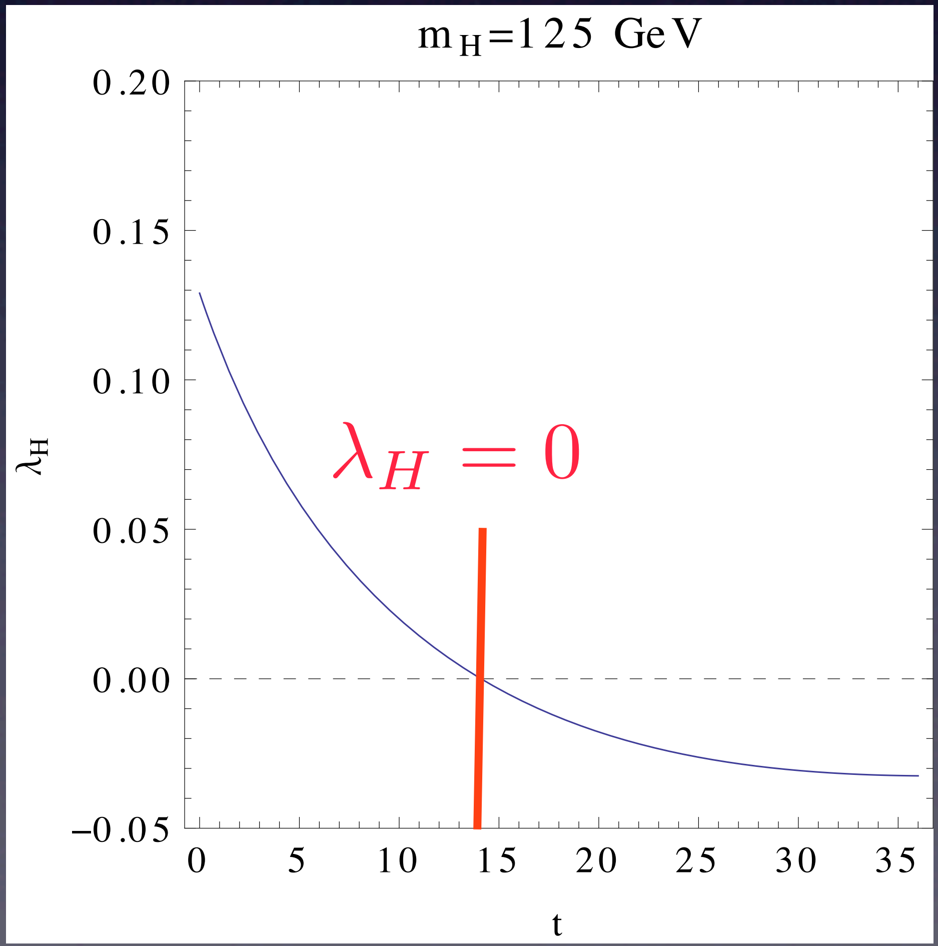
New physics at TeV scale must cancel the large Higgs mass.

Vacuum instability

- Higgs quartic coupling can turn negative at high scale.

→ EW vacuum becomes unstable.

- No symmetry enhancement at $\lambda_H = 0$.



$t \equiv \ln(\mu/M_t)$

Stability until Planck scale:

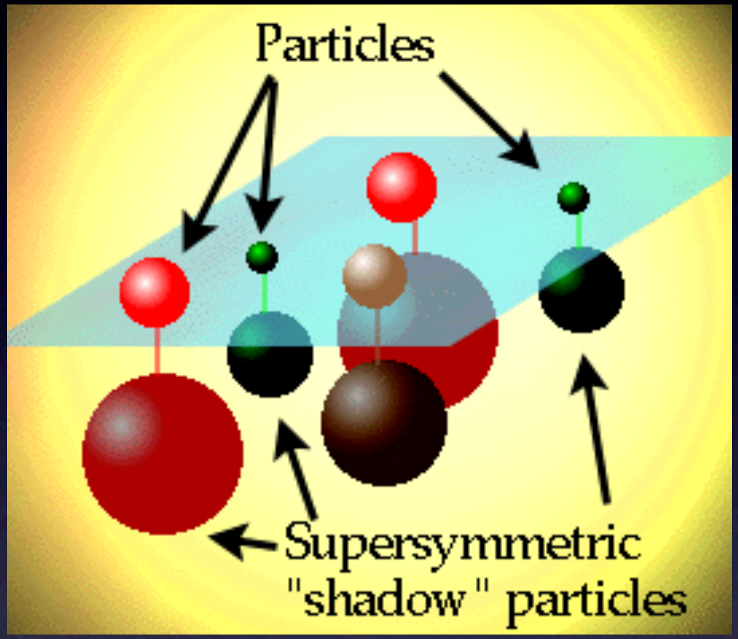
$$m_H > 129.4 + 1.4\left(\frac{m_t(\mathrm{GeV}) - 173.1}{0.7}\right)$$

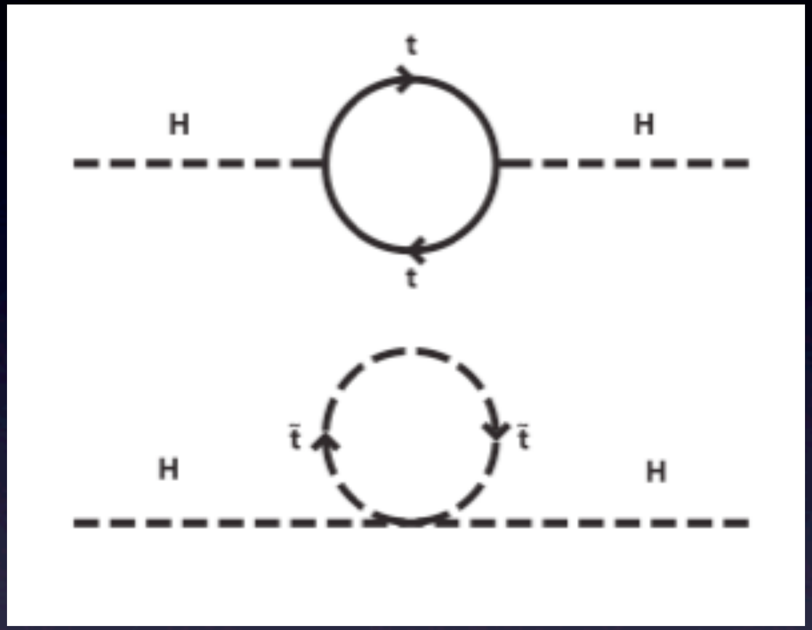
$$-0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0\,[\mathrm{GeV}]$$

[Degrassi et al, 2012]

Naturalness problems in SUSY

- Superparticles cancel large Higgs mass.





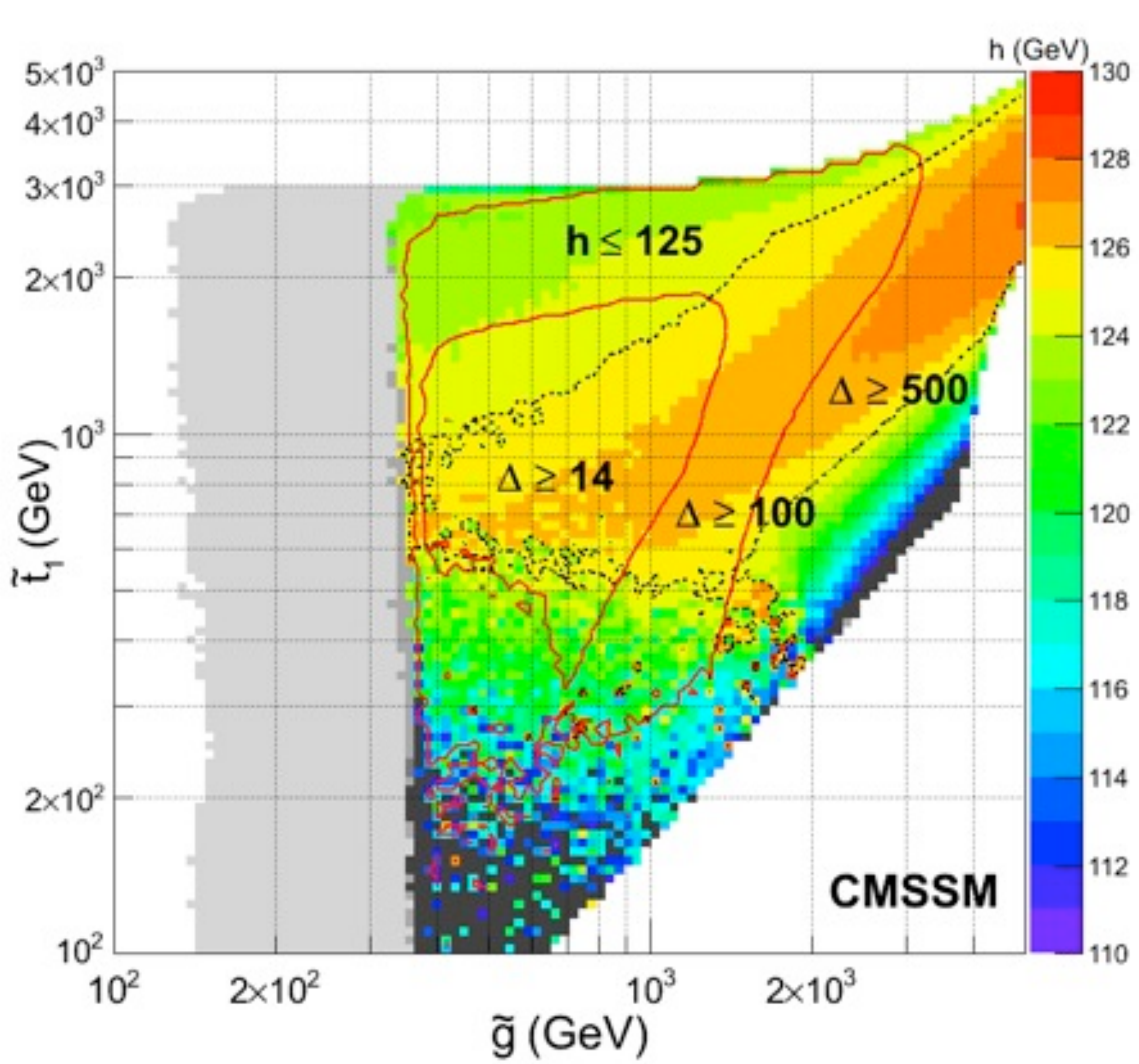
- Higgs quartic terms are positive definite,

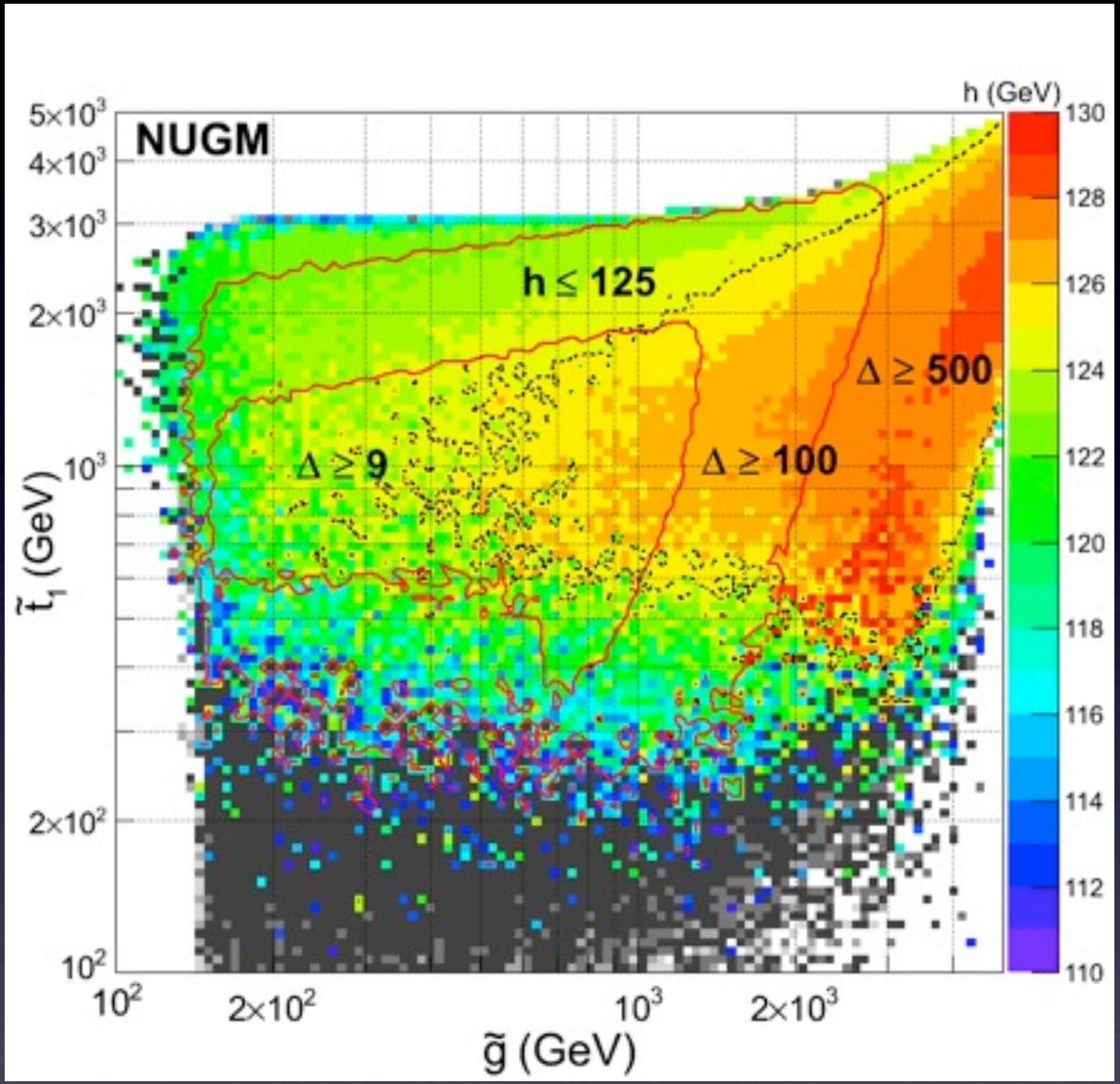
$$V_D = \frac{1}{8}(g^2 + g'^2)(|H_u|^2 - |H_d|^2)^2 = \frac{1}{8}(g^2 + g'^2)h^2\cos^2(2\beta) + \cdots .$$

- Relation above sparticle mass: $\lambda_H \sim g^2$

⇒ Vacuum stability is automatic until GUT scale.

125 GeV Higgs mass in MSSM



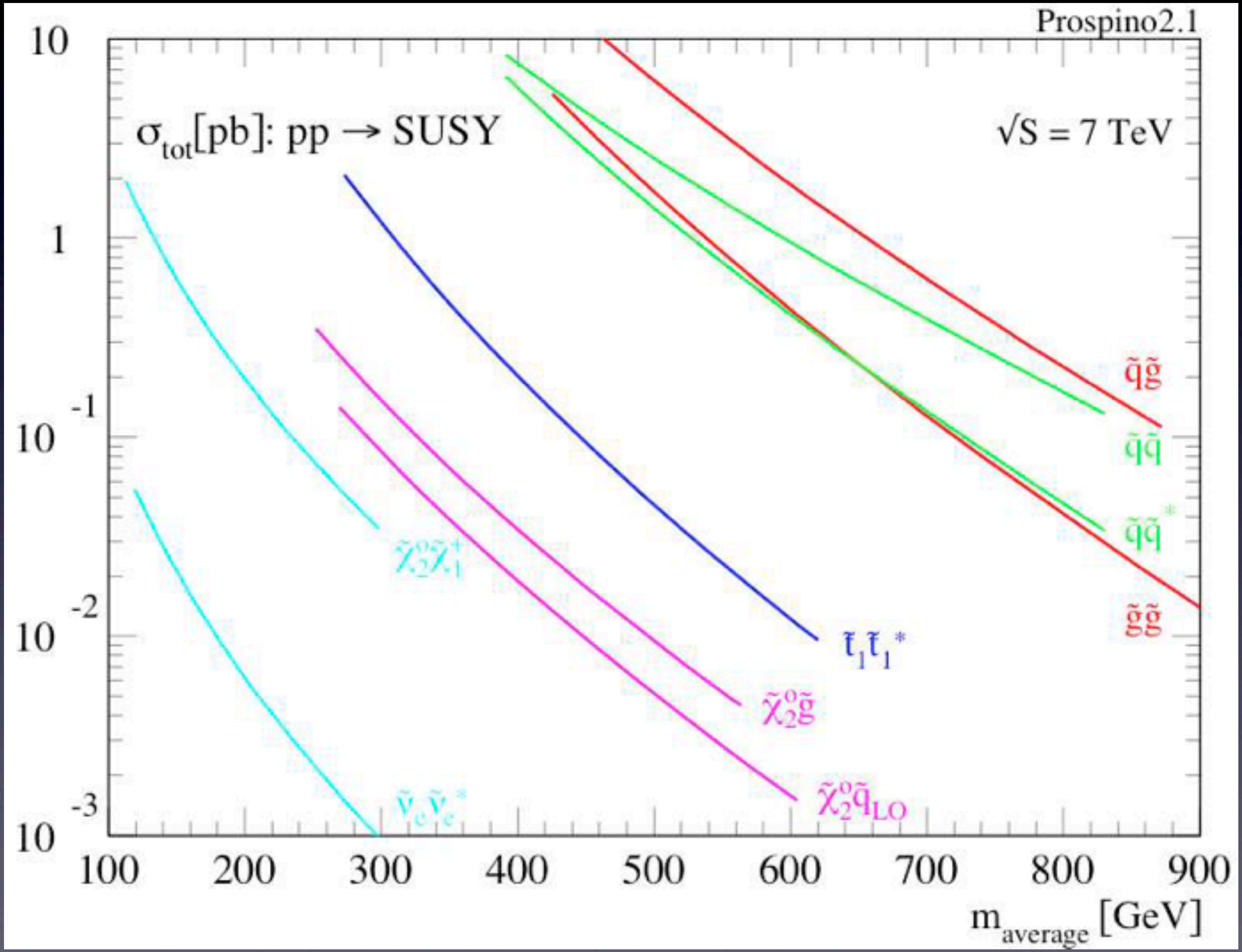


- 125 GeV Higgs mass implies: [Ghilencea, HML, Park (2012)]

$$m_{\tilde{t}} \gtrsim 600\,\mathrm{GeV},\;\; m_{\tilde{g}} \gtrsim 1\,\mathrm{TeV} \qquad \Delta \simeq 500-1000.$$

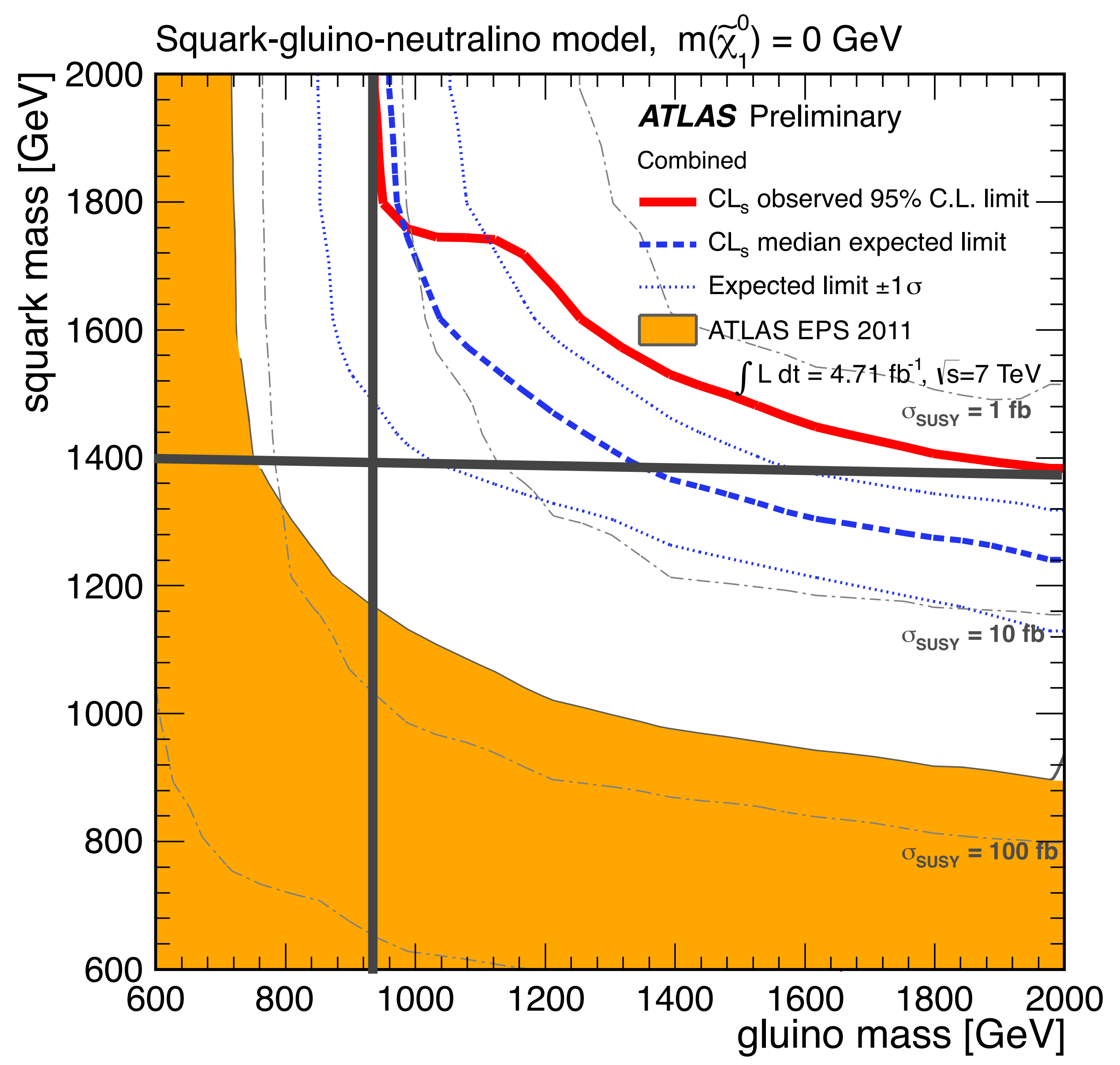
Fine-tuning: 0.1-0.2% level in all GUT-based MSSM

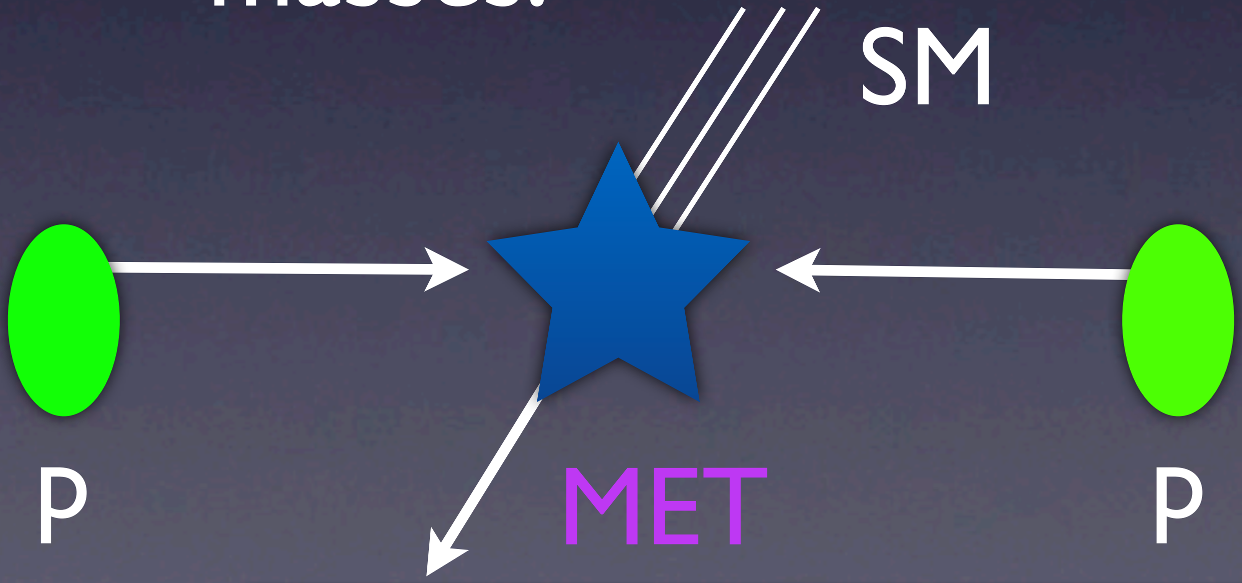
Sparticle production



LHC limits on sparticles

- $m_{\tilde{q}_1} \approx m_{\tilde{q}_2} \approx m_{\tilde{q}_3}$:
  all squarks are equally constrained.
- Jets + large MET:
  strong limits on 1st/2nd generation squark masses.





SM

P

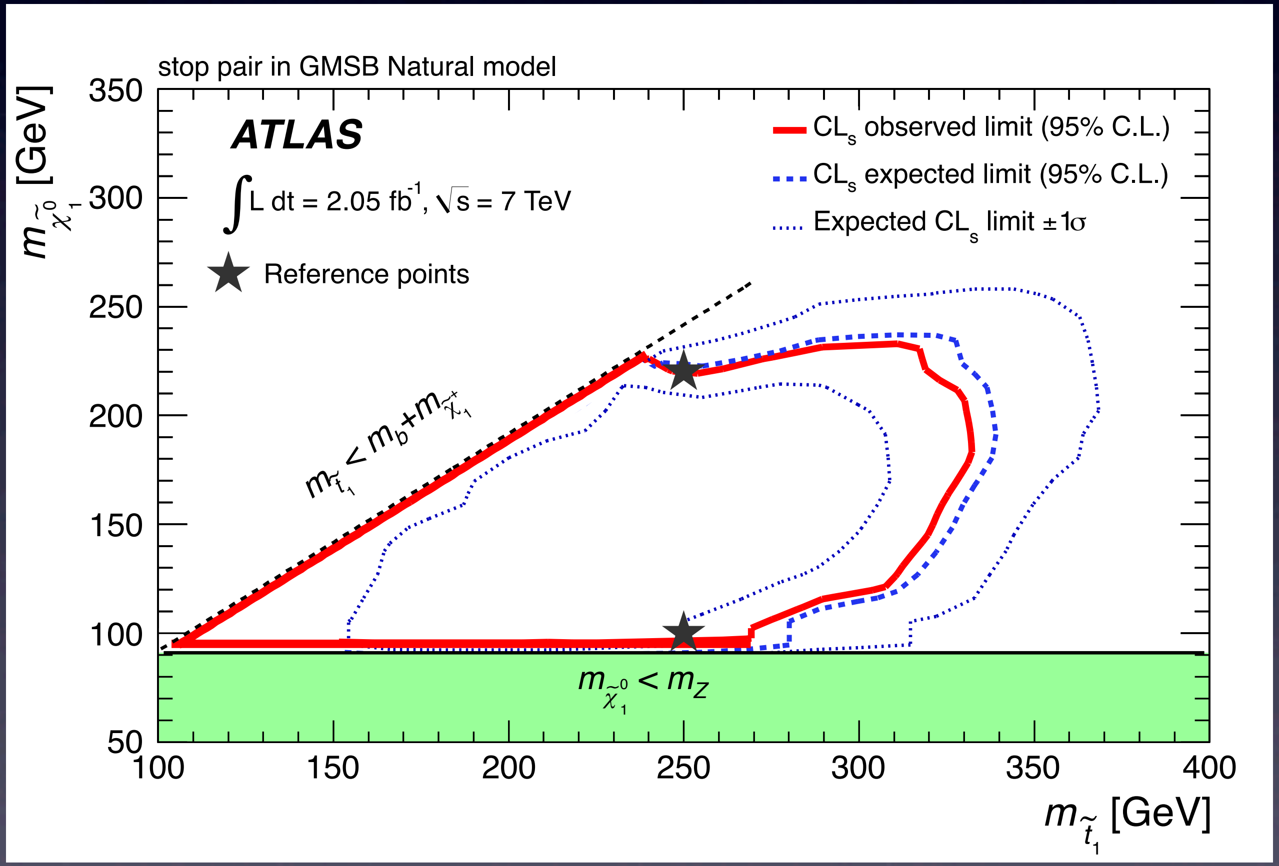
MET

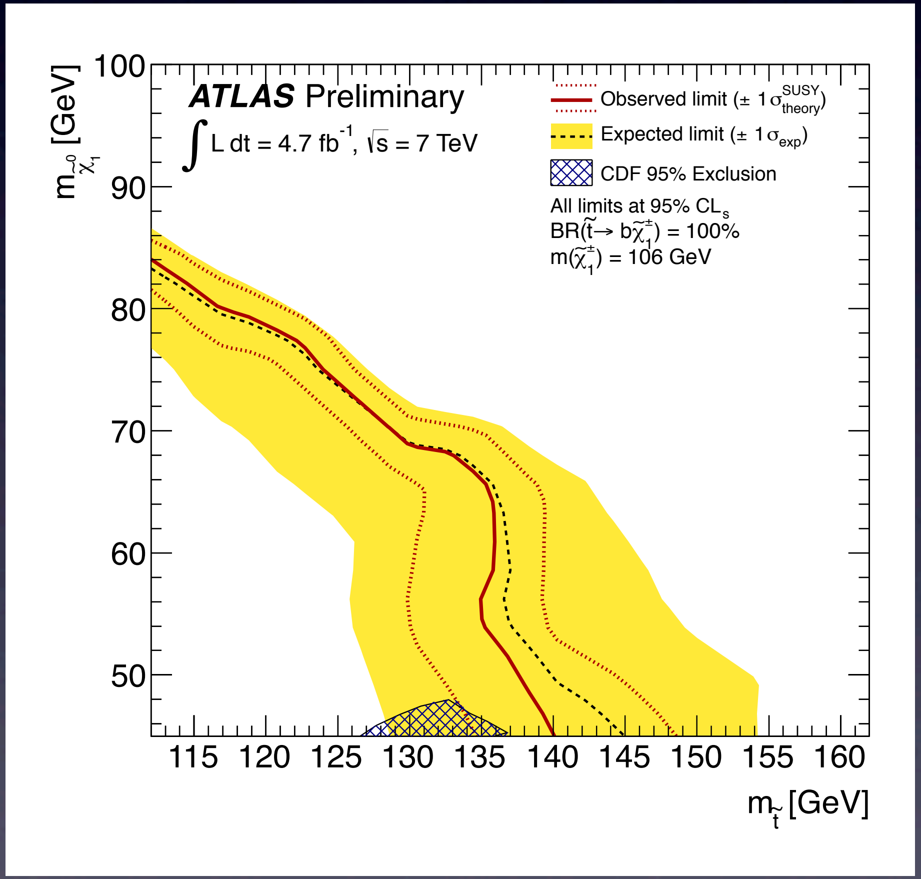
P

$$m_{\tilde{g}} > 930\,\mathrm{GeV}, \qquad m_{\tilde{q}} > 1400\,\mathrm{GeV}.$$

3rd generation squarks

- Weaker limits due to small direct production cross section (pdf-suppressed gluino-channel).
- Most stop searches model-dependent. (e.g. tt bkg).





$\mathrm{bjets} + \mathrm{MET} + Z(\to ll)$

stop mass: 330 GeV for

$115\,\mathrm{GeV} < m_{\chi^0} < 230\,\mathrm{GeV}.$

$\mathrm{OS\ leptons} + \mathrm{MET} + \geq 1\,\mathrm{jets}$

stop mass: 130 GeV for

$m_{\chi^0} < 65\,\mathrm{GeV}$

More minimal SUSY models

10 TeV — 1st/2nd generation squarks (Little correction to EWSB)

<1TeV — Gluino (EWSB at 2-loop)

a few 100 GeV — 3rd generation squarks (Large correction to EWSB)

125GeV — Higgs

LSP

→ "Natural SUSY"

Likely to endure stop search in 2012 LHC.

EW precision constraint

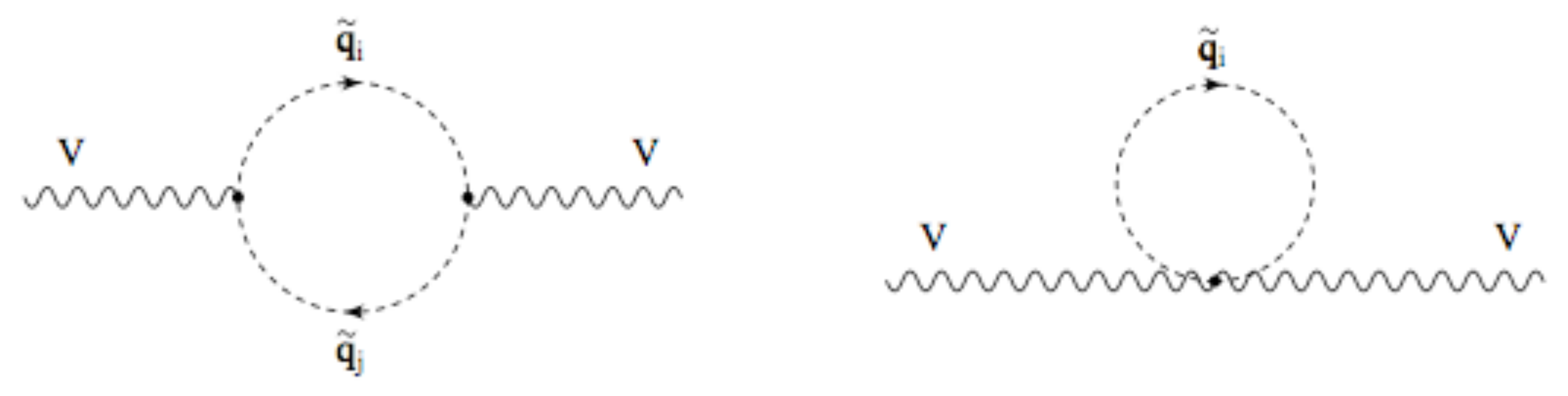
- Electroweak precision data:

[HML, Sanz, Trott (2012)]

$$\delta\rho \equiv \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = (4.2 \pm 2.7) \times 10^{-4}$$

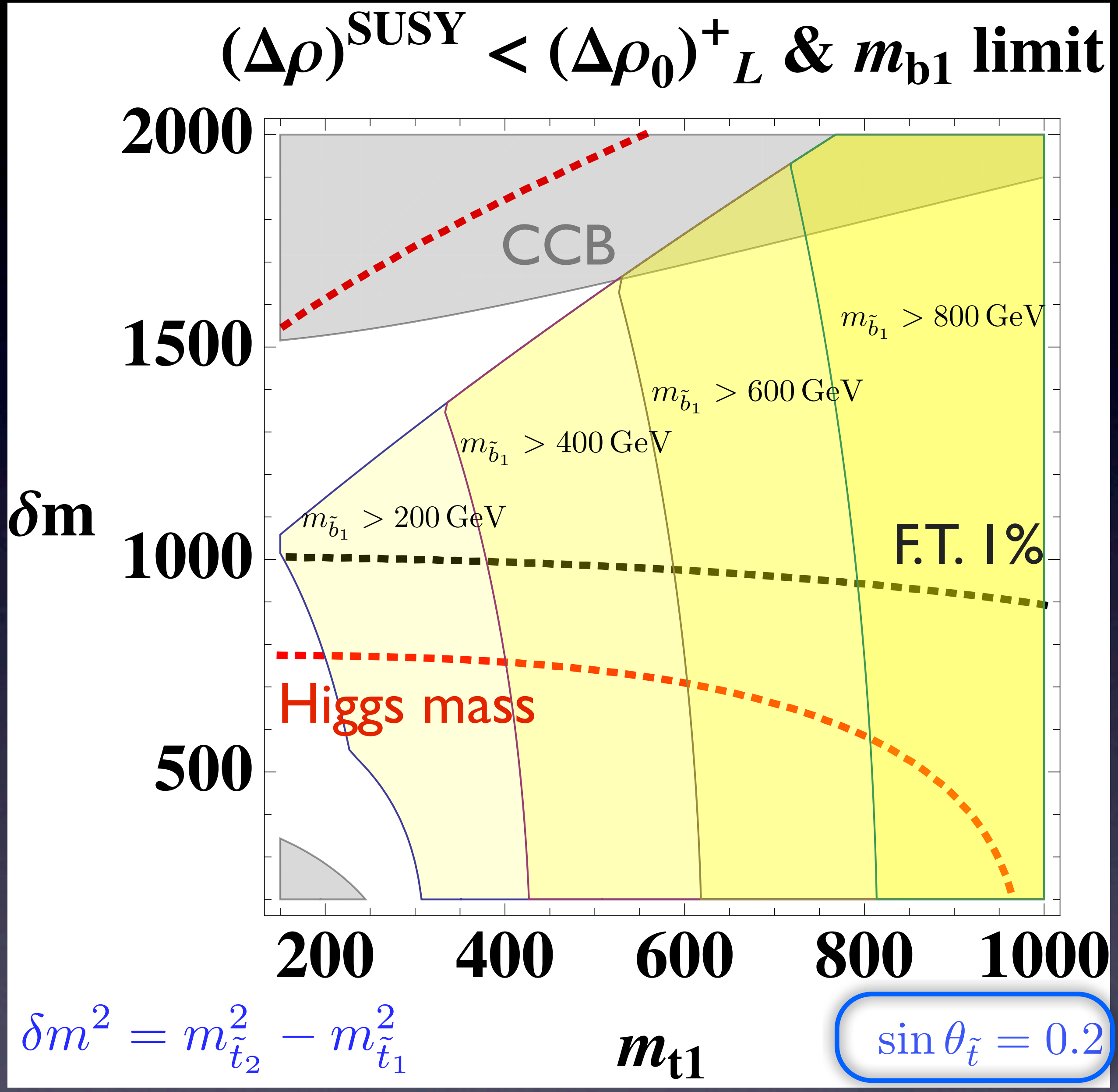
[STU best fit with recent W-boson mass + 125 GeV Higgs]

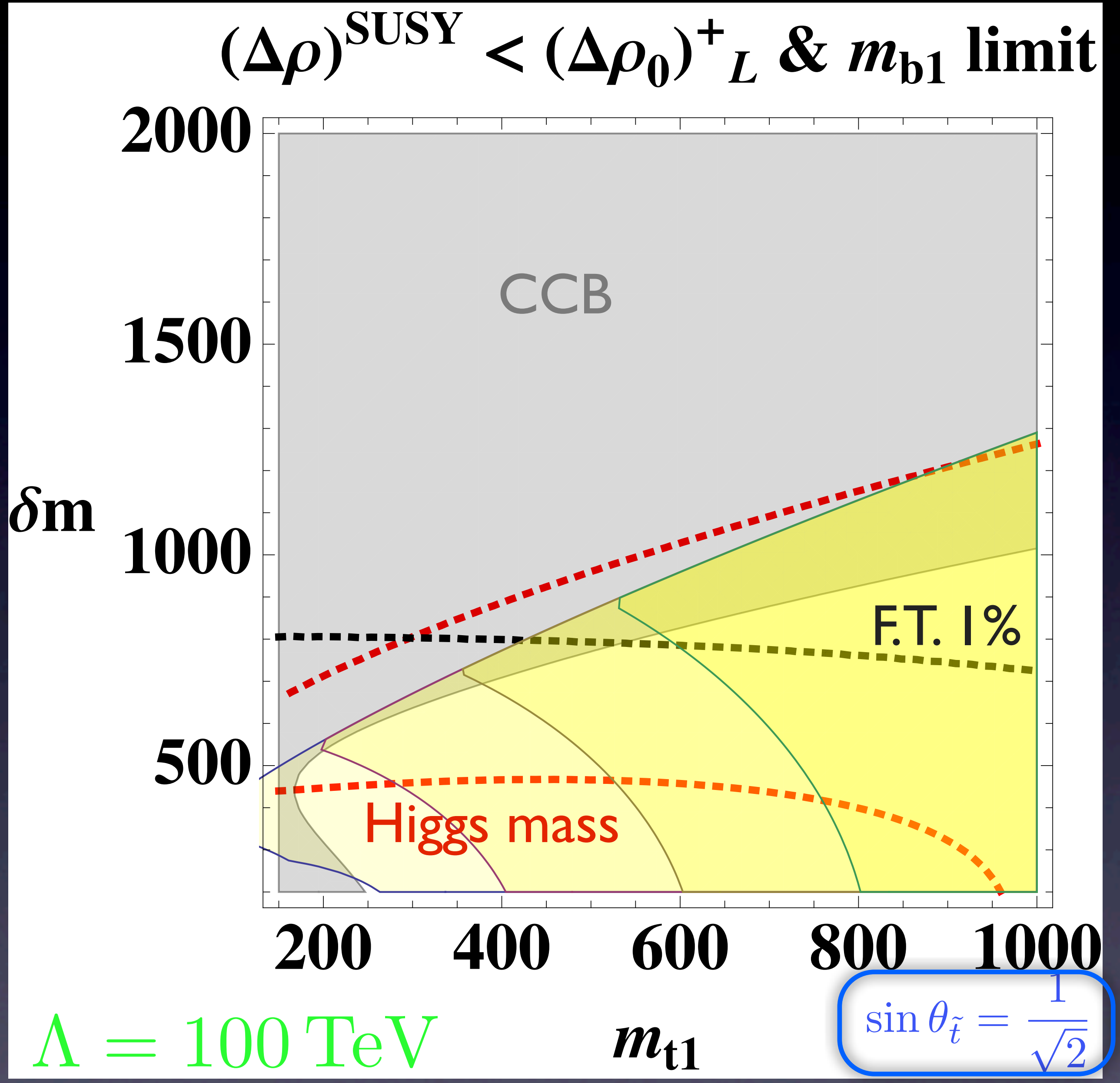
$$\delta\rho = 0 : \; SU(2) \text{ custodial symmetry}$$



SU(2) relation: $m^2_{\tilde{b}_L} \approx m^2_{\tilde{t}_L} - m_t^2 - m_W^2 \cos(2\beta)$

EWPD + Higgs + F.T.

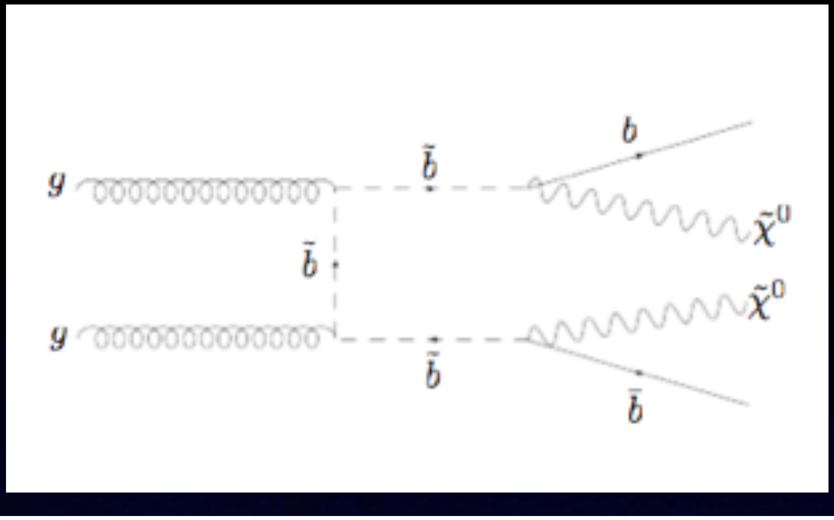


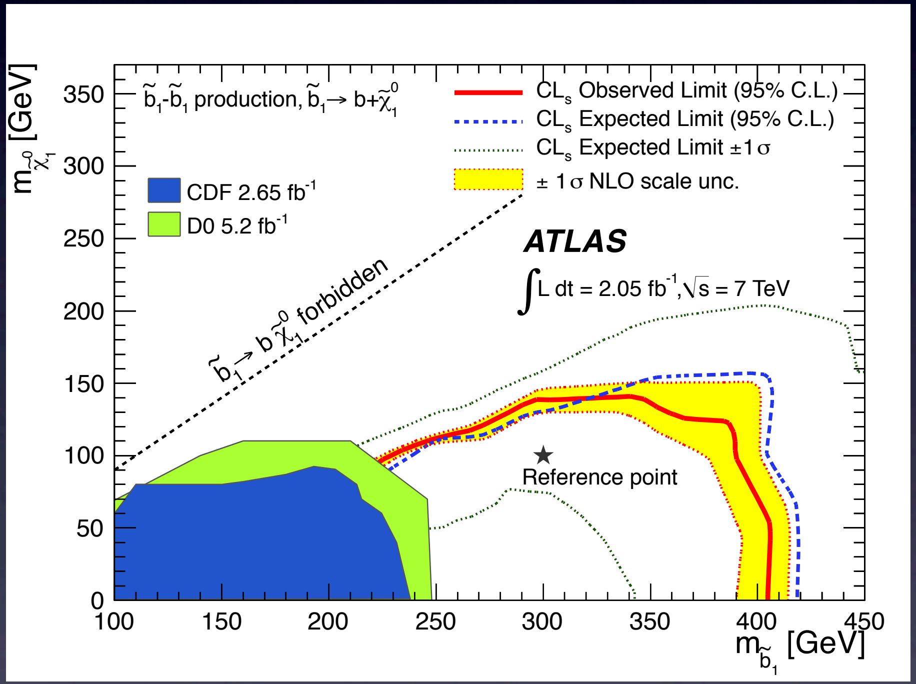


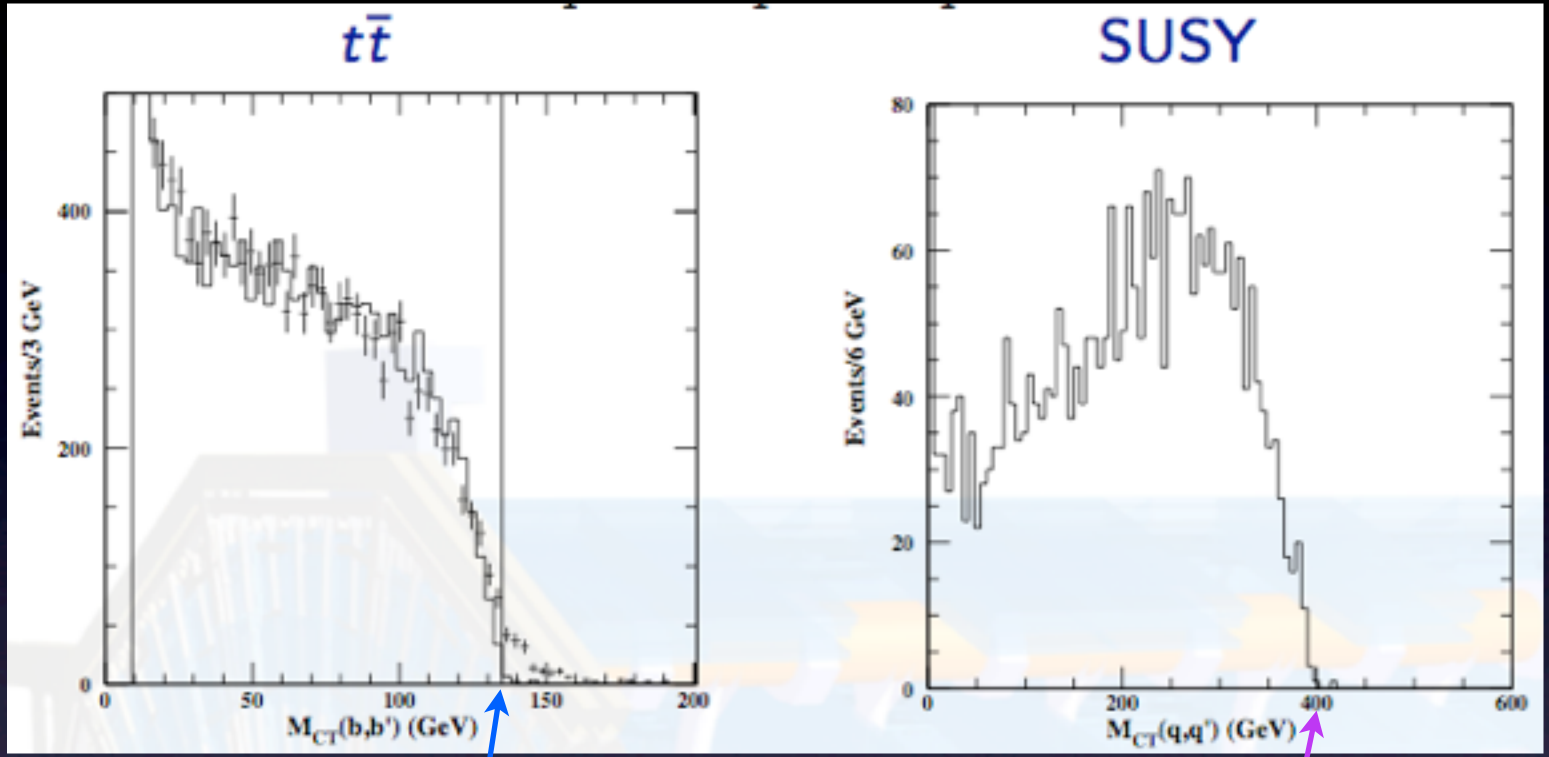
Maximal mixing, small mass splitting between stops is favored.

Stop masses “scale up” with sbottom limit.

LHC limit on sbottom







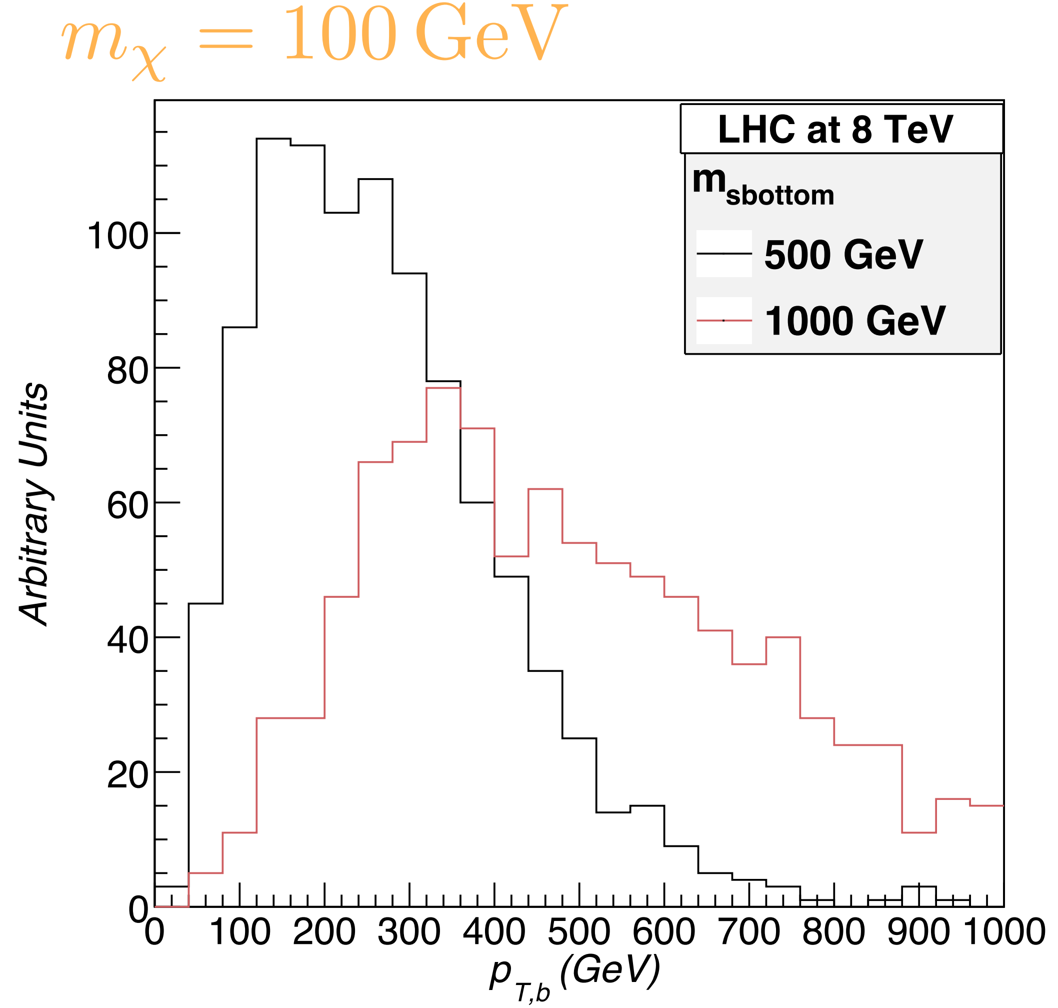
135 GeV

$$\frac{m_{\tilde{b}}^2 - m_{\chi^0}^2}{m_{\tilde{b}}}$$

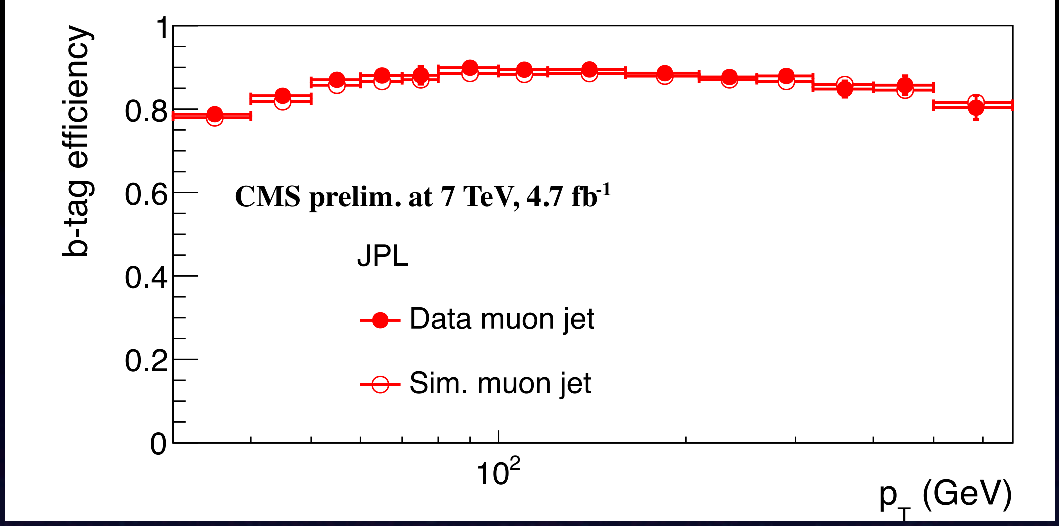
- Most sensitive for $m_{\tilde{b}} - m_{\chi^0} > 130\,\mathrm{GeV};$ two jets b-tagged.
- Contranverse mass: $m_{CT} = [E_T(b_1) + E_T(b_2)]^2 - [\vec{p}_T(b_1) - \vec{p}_T(b_2)]^2.$
- Limit varies 200 to 400 GeV for $\mathrm{Br}(\tilde{b}_1 \rightarrow b\chi^0) > 0.13.$

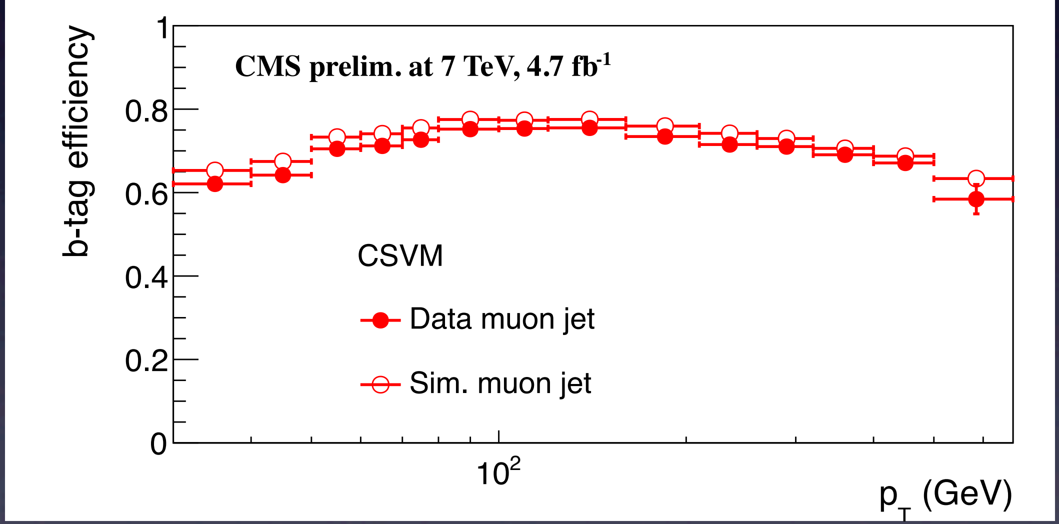
$[\tilde{b}_1 = \tilde{b}_R,\ \mathrm{Br} = 1]$

Efficiency for sbottom



(produced by Madgraph5)





b-jet tagging efficiency: $\epsilon_{btag} \simeq 60 - 80\%$ for $p_T^b < 670\,\mathrm{GeV}$

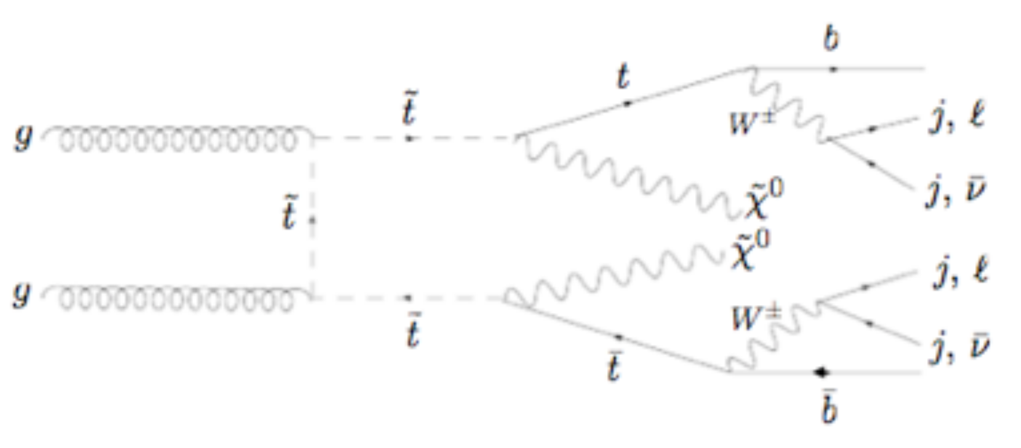
(@ LHC 7 TeV)

b-jet mistag rate: 1-10%

Large portion of events below 670 GeV

Stop search

- Stop pair has a large background from the SM top pair.



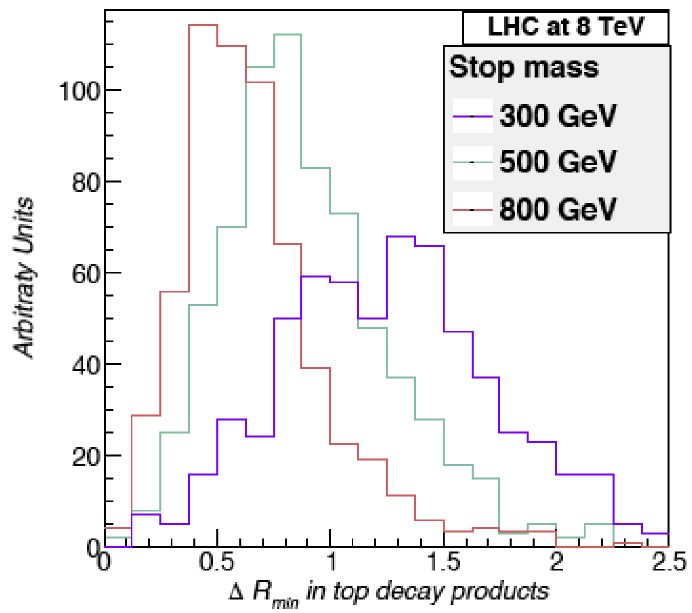
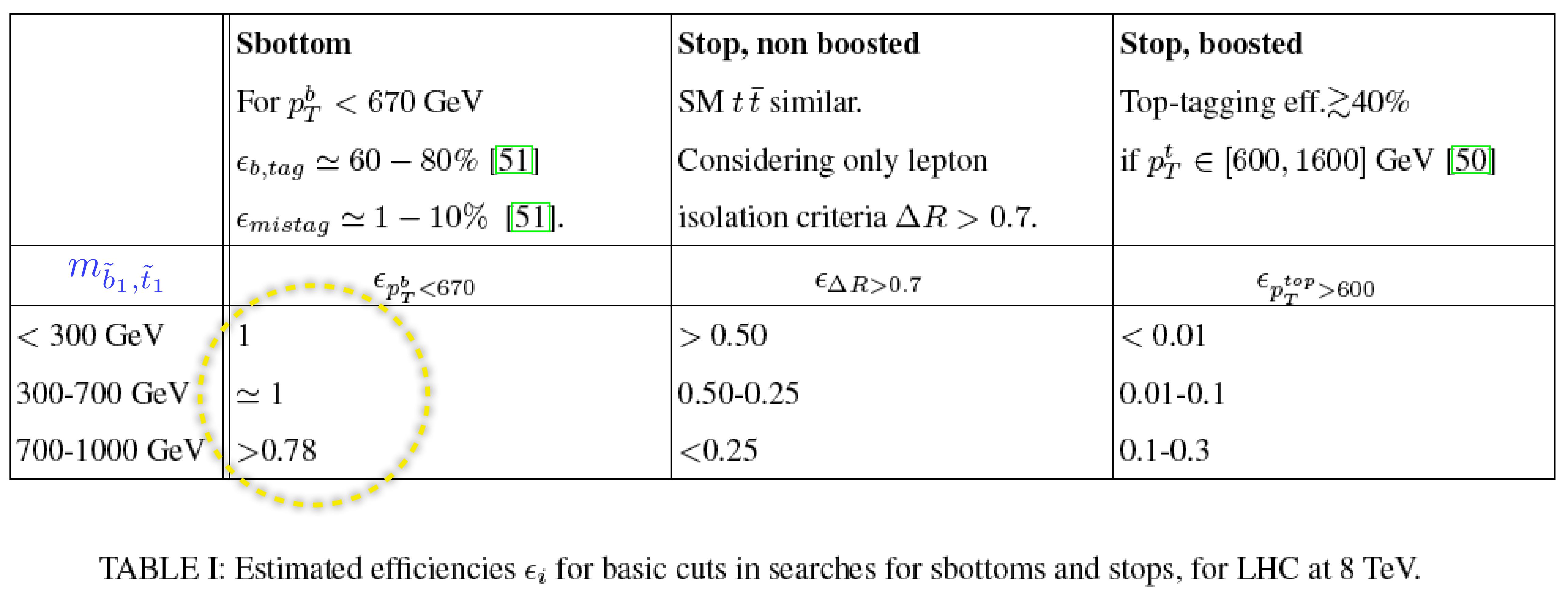


FIG. 6: Minimum separation in R space between two jets of the top decay coming from a stop.

- The heavier stop, the harder to satisfy either b-tagging (“W-hadronic”) or lepton isolation criteria (“W-leptonic”): $\Delta R > 0.7$.
- Ways-out: boosted “top-tagging”; pt-scaled isolation cut.

Efficiency comparison



	Sbottom For $p_T^b < 670$ GeV $\epsilon_{b,tag} \simeq 60-80\%$ [51] $\epsilon_{mistag} \simeq 1-10\%$ [51].	**Stop, non boosted** SM $t\,\bar{t}$ similar. Considering only lepton isolation criteria $\Delta R > 0.7$.	**Stop, boosted** Top-tagging eff.$\gtrsim 40\%$ if $p_T^t \in [600, 1600]$ GeV [50]
$m_{\tilde{b}_1,\tilde{t}_1}$	$\epsilon_{p_T^b<670}$	$\epsilon_{\Delta R>0.7}$	$\epsilon_{p_T^{top}>600}$
< 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

TABLE I: Estimated efficiencies ϵ_i for basic cuts in searches for sbottoms and stops, for LHC at 8 TeV.

Sbottom search has a stable b-jet tag efficiency.

- 2012 reach: $m_{\tilde{b}_1} \sim 800\,\mathrm{GeV}$ at $20\,\mathrm{fb}^{-1}$ $8\,\mathrm{TeV}$.

Conclusions

- MSSM ensures both vacuum stability and small Higgs mass, but at the cost of a fine-tuning at 0.1-0.2% level.
- We should wait for "natural SUSY" with the split spectrum to be discovered soon.
- Sbottom direct search is efficient, constraining a lot of parameter space in "natural SUSY".