

SUSY and the Higgs

Giovanni Villadoro

ICTP

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Or

“Where the Higgs is SUSY?”

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The SM is not the complete theory:

Experimentally:

DM, baryogenesis, inflation, strong CP, flavor, ...

Theoretically:

quantum gravity, Landau poles

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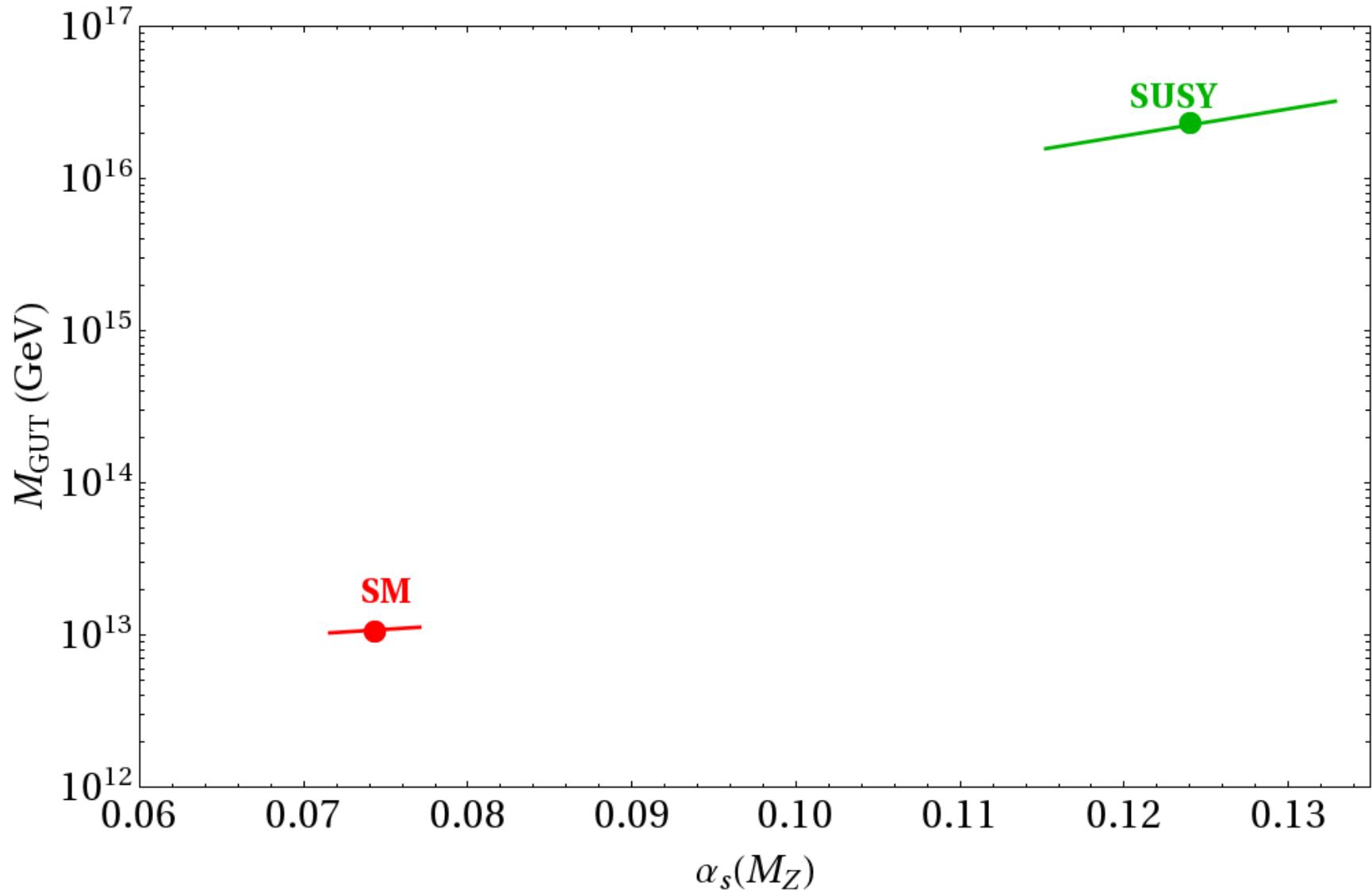
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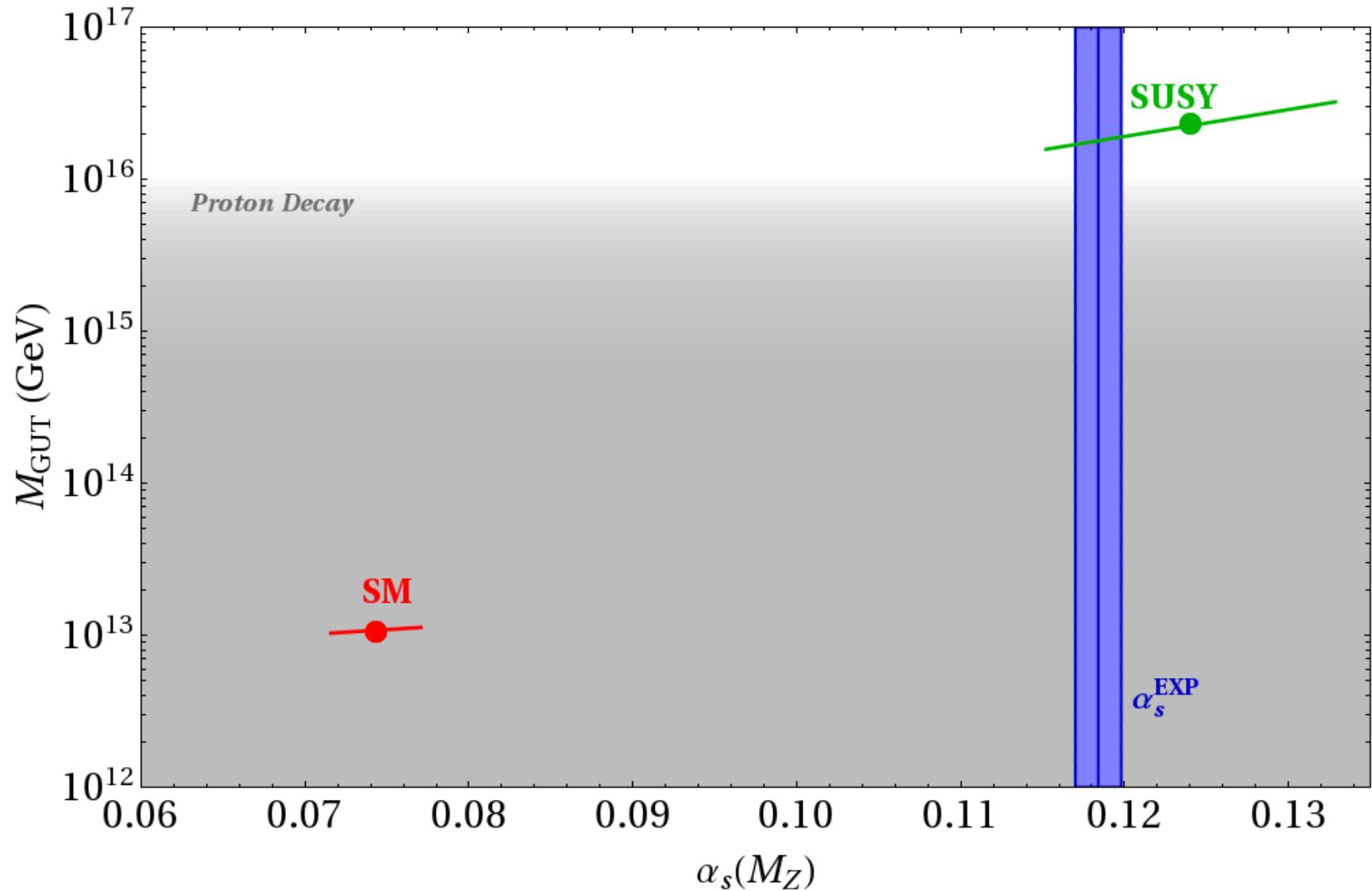
New Physics needed

SUSY is the best motivated theory

A hint from the gut



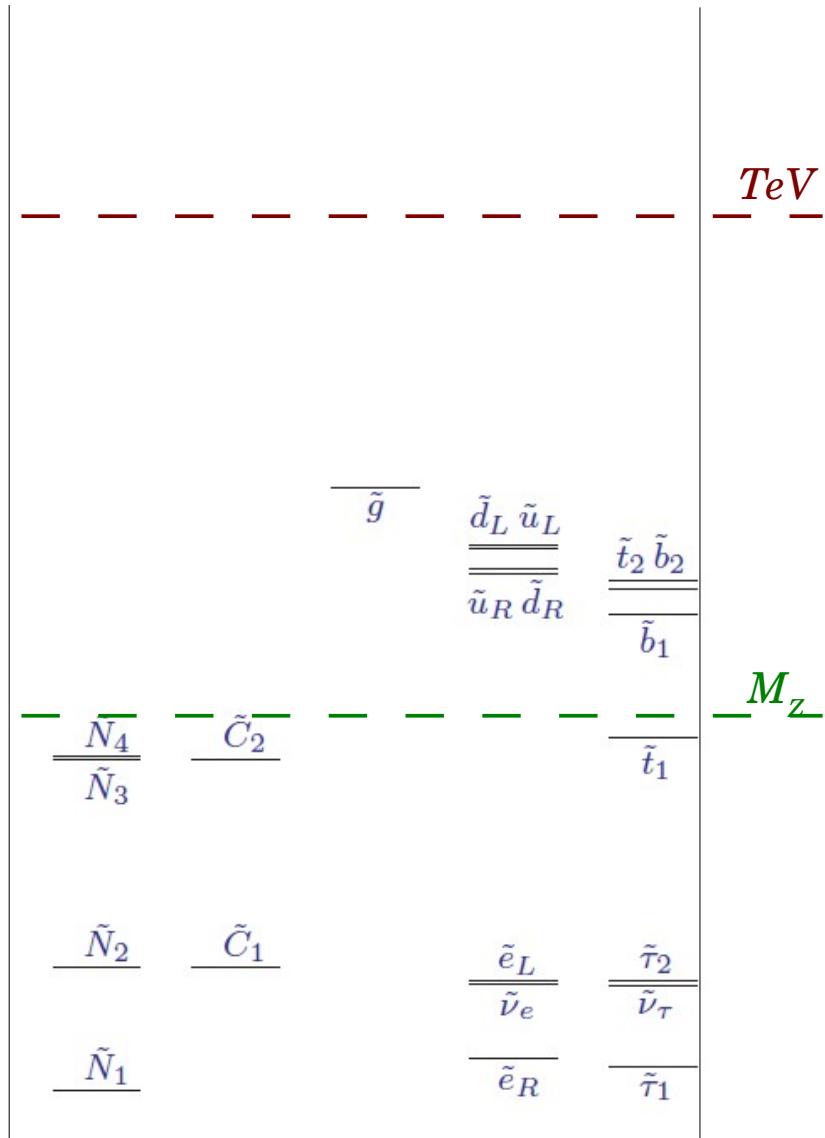
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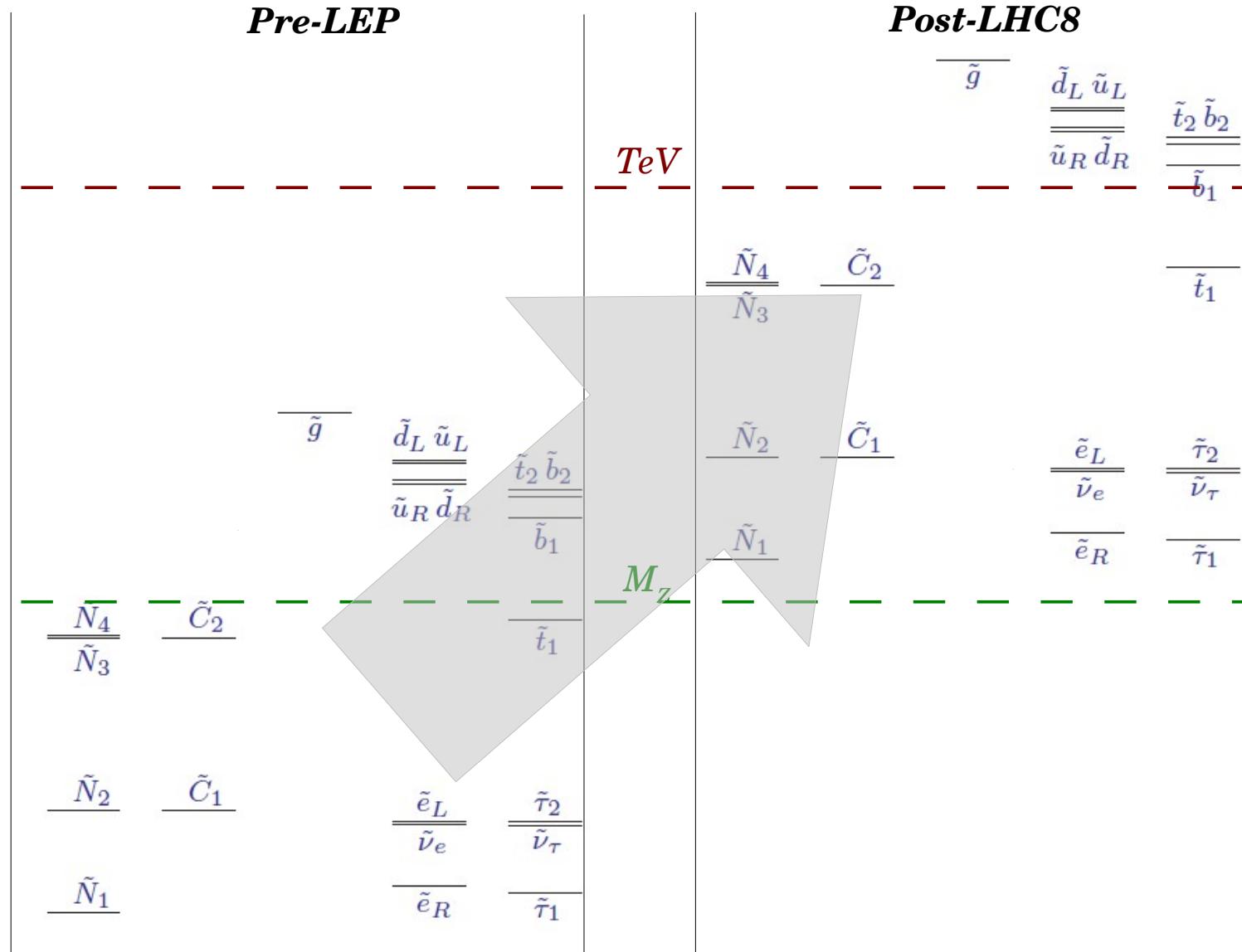
Is SUSY Natural?

If you have to define a way to measure tuning
then your theory is already tuned.

How Natural SUSY would look like



SUSY is tuned!



The role of the Higgs

$$m_h \simeq 125 \text{ GeV}$$

Higgs mass in MSSM:

$$m_h^2 \simeq m_Z^2 + \frac{3}{\pi^2} \frac{m_t^4}{v^2} \left(\log \frac{m_{\tilde{t}}^2}{m_t^2} + a^2 (1 - a^2/12) \right)$$

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EW scale in MSSM:

$$m_h^2 = -2(m_{H_u}^2 + |\mu|^2) + \dots$$

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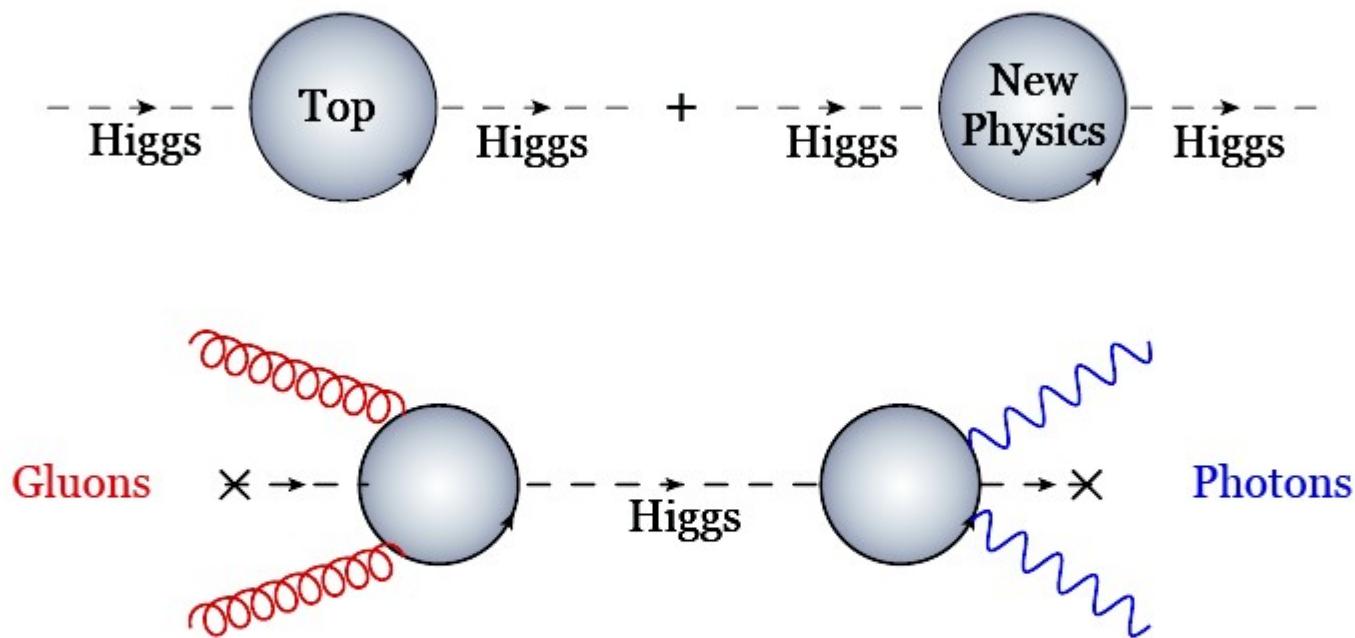
$$m_h^2 = -2(m_{H_u}^2 + |\mu|^2) + \dots$$

$$\delta m_{H_u}^2 \approx -\frac{3y_t^2 m_{\tilde{t}}^2}{4\pi^2} (1 + a^2/2) \log \frac{\Lambda}{m_{\tilde{t}}}$$

Natural SUSY requires a Higgs mass fix

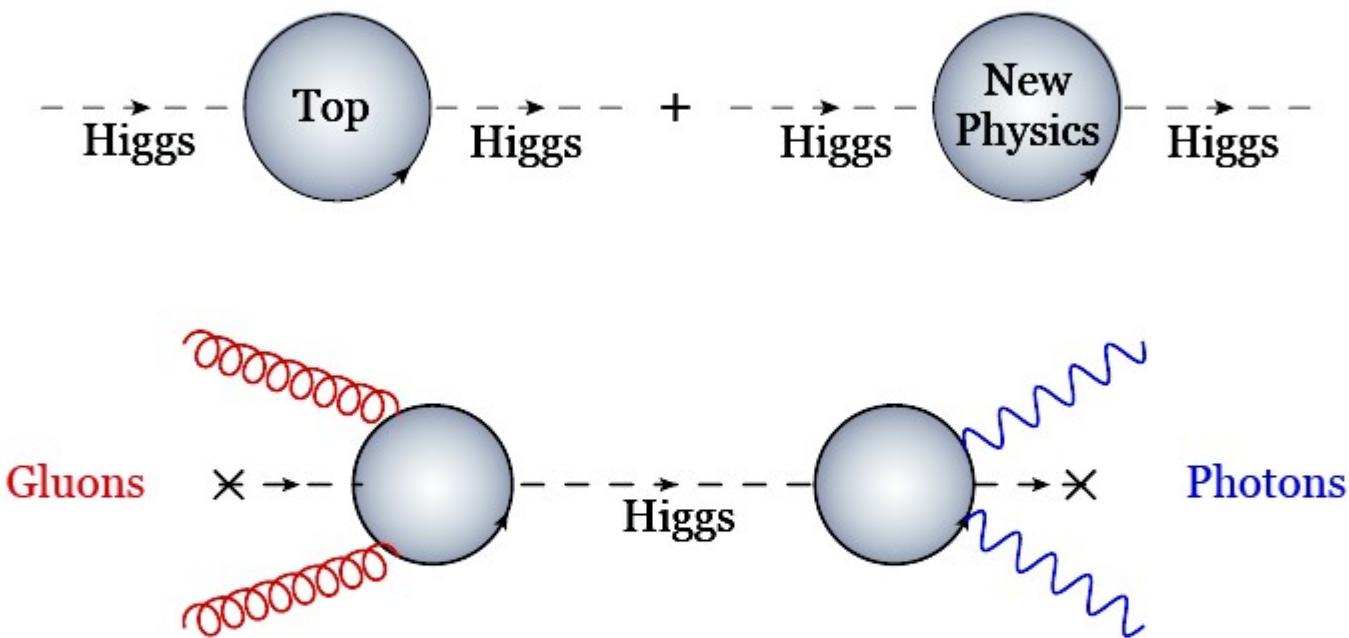
Naturalness and Higgs Properties

Arvanitaki, GV '11



Naturalness and Higgs Properties

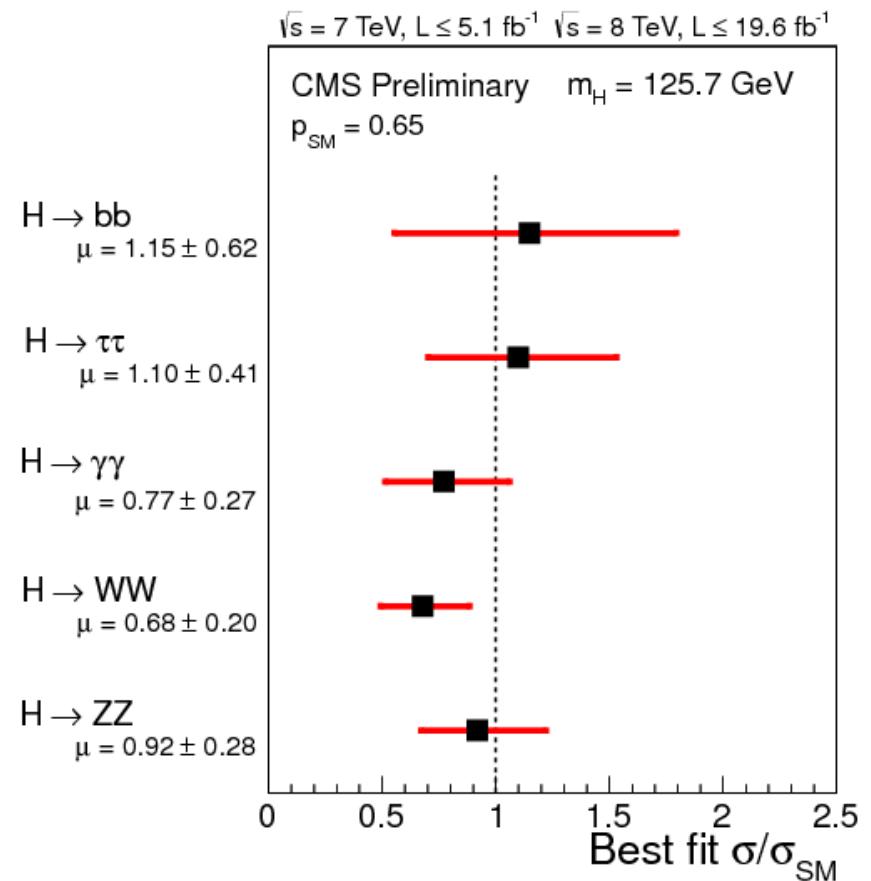
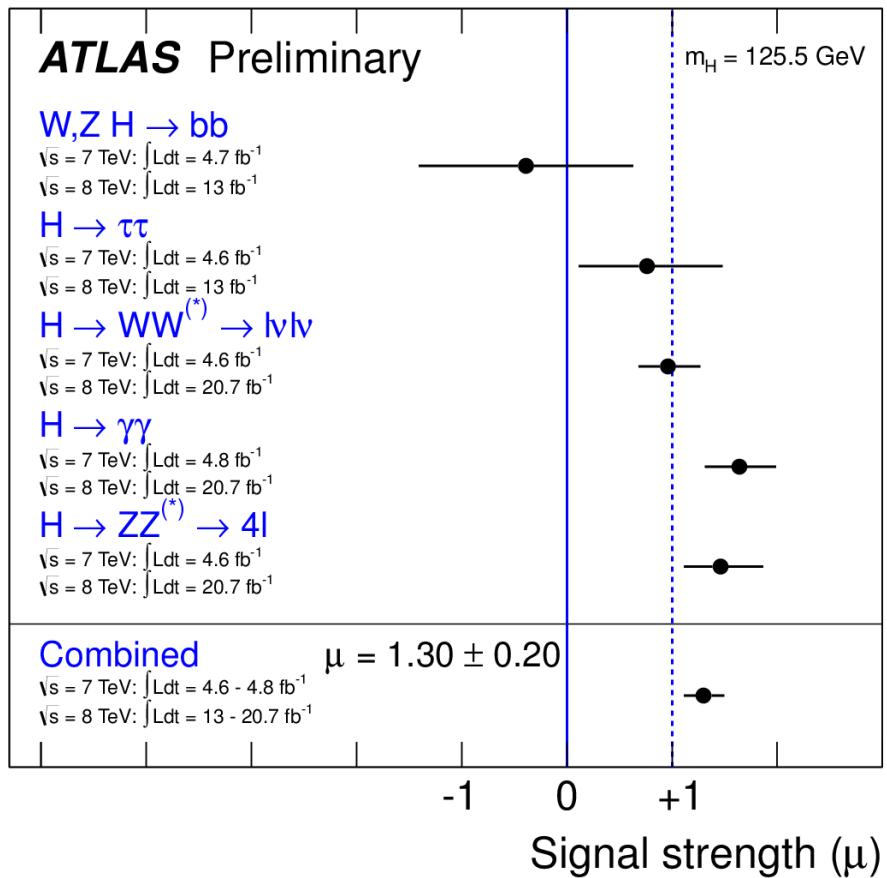
Arvanitaki, GV '11



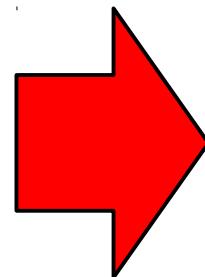
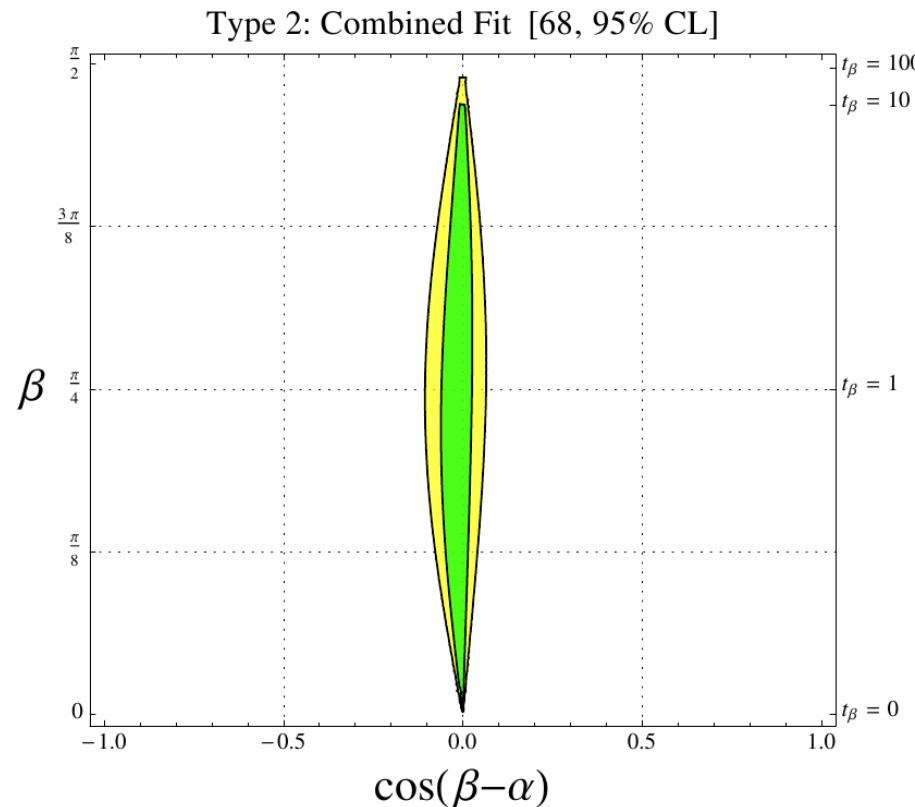
A Natural Higgs is not the SM Higgs

$$\mu_{gg \rightarrow h} \approx 1 + \frac{m_t^2}{m_{\tilde{t}}^2} \sim 1 + \text{tuning}$$

The very SM-like Higgs



Implications for Higgs Models



generically
small mixing (<10%)
between the Higgses

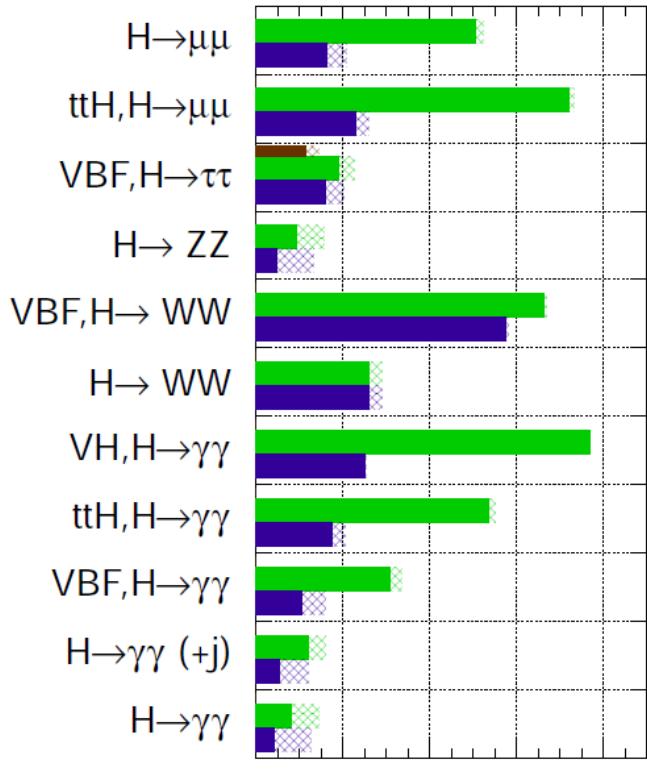
125 GeV Higgs is
pretty SM-like

from Craig, Galloway, Thomas '13

Future of couplings at LHC

ATLAS Preliminary (Simulation)

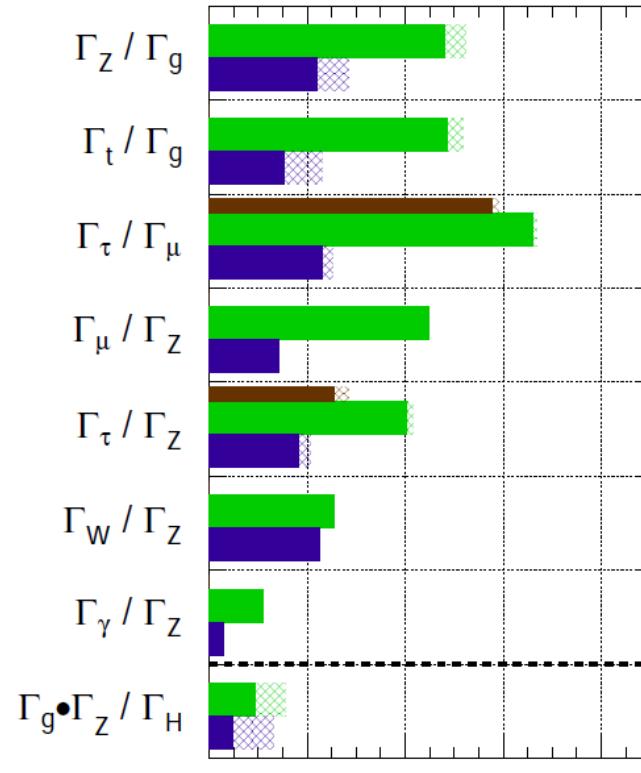
$\sqrt{s} = 14 \text{ TeV}$: $\int L dt = 300 \text{ fb}^{-1}$; $\int L dt = 3000 \text{ fb}^{-1}$
 $\int L dt = 300 \text{ fb}^{-1}$ extrapolated from 7+8 TeV



$$\frac{\Delta\mu}{\mu}$$

ATLAS Preliminary (Simulation)

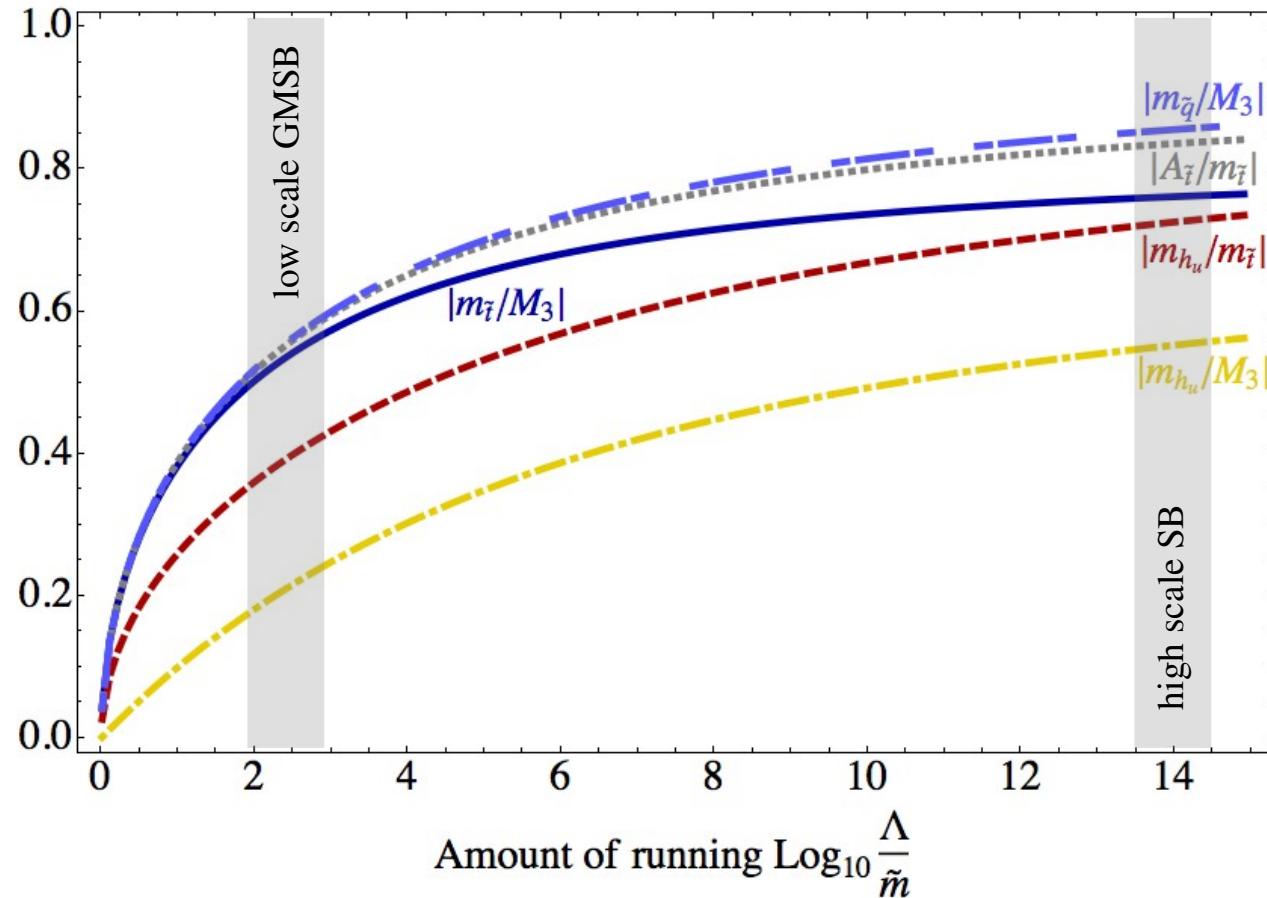
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$$\frac{\Delta(\Gamma_X/\Gamma_Y)}{\Gamma_X/\Gamma_Y} \sim 2 \frac{\Delta(\kappa_X/\kappa_Y)}{\kappa_X/\kappa_Y}$$

How bad is the tuning?

The Gluino Sucks (effect)

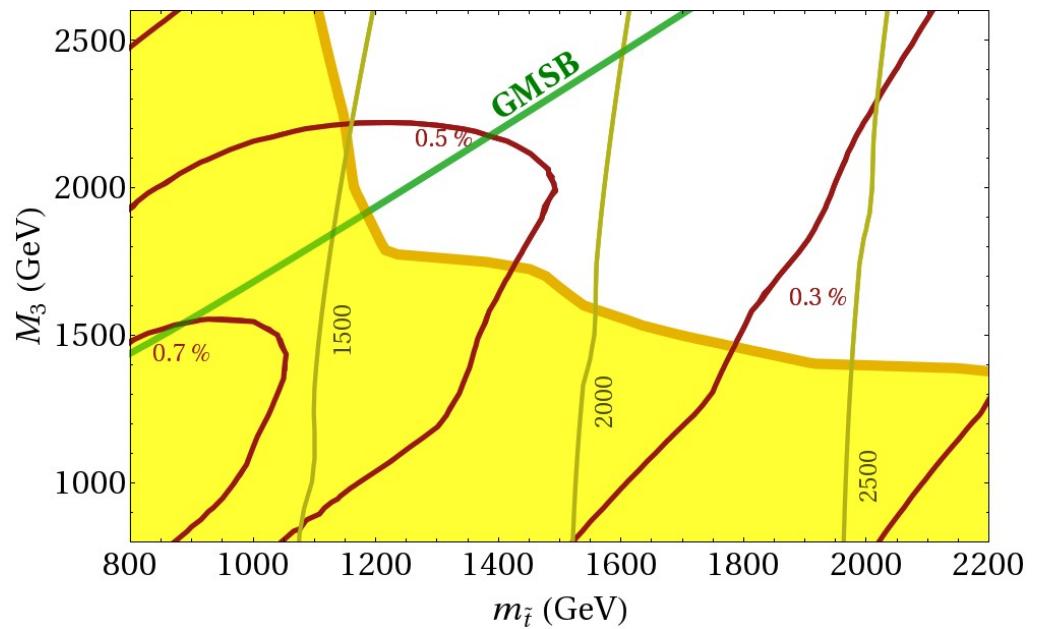


Arvanitaki, Craig, Dimopoulos, GV '12
Arvanitaki, Baryakhtar, Huang, Van Tilburg, GV '13

The benchmark models:

The **push-up** model:

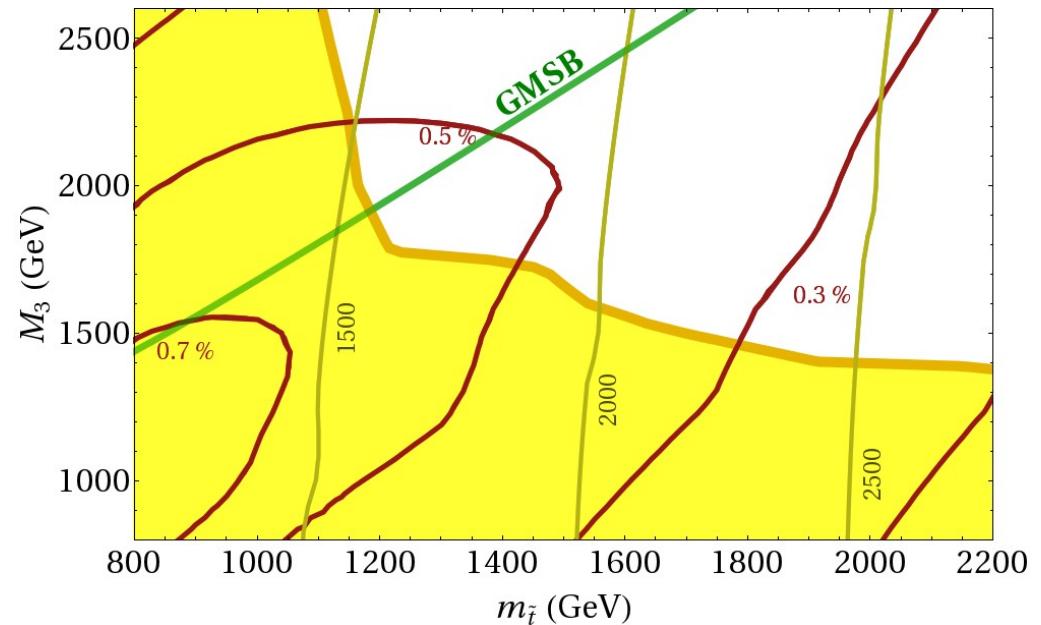
MSSM (low-scale GMSB)
w/ A-terms



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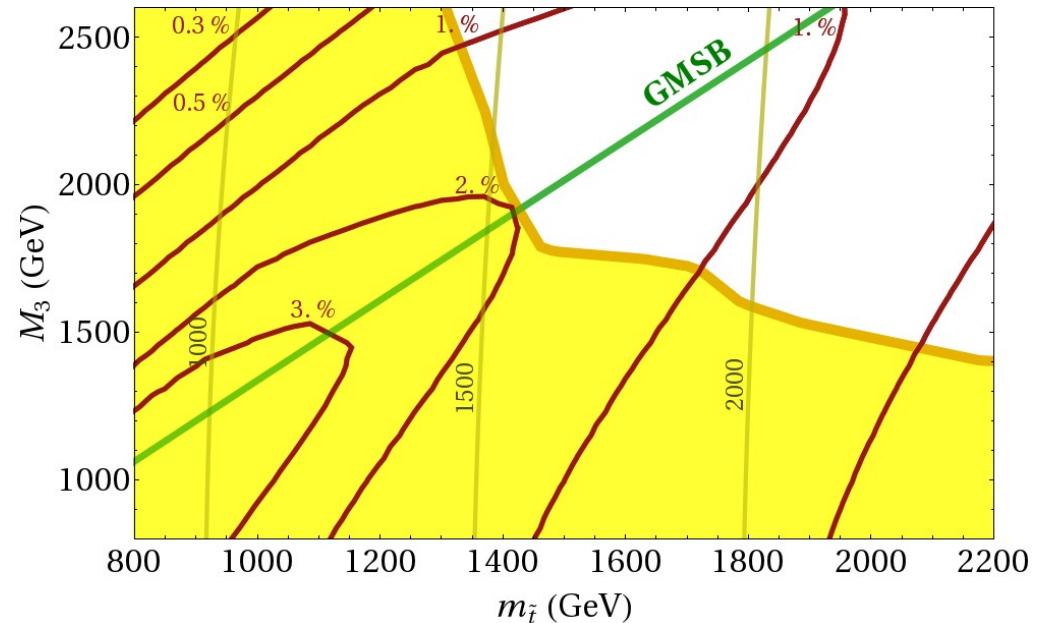
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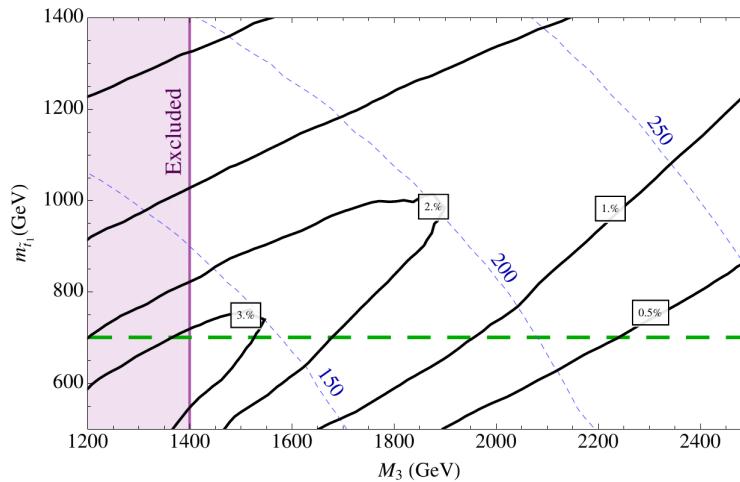
NMSSM-like models:

(w/ low-scale GMSB)



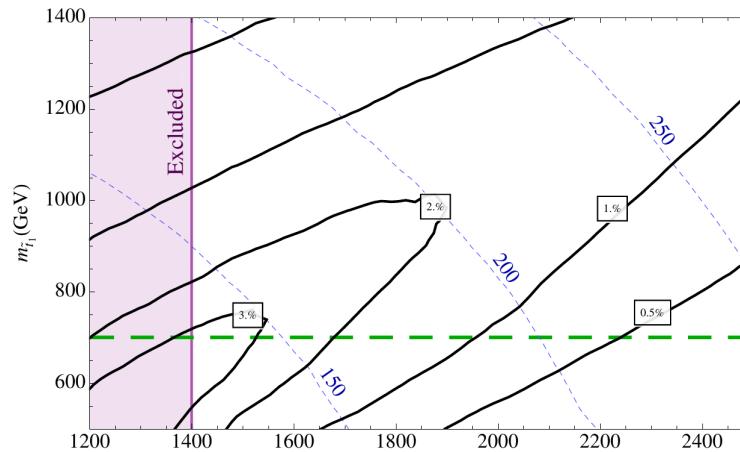
3 examples to “hide” SUSY

Split Families
aka
“Natural” SUSY

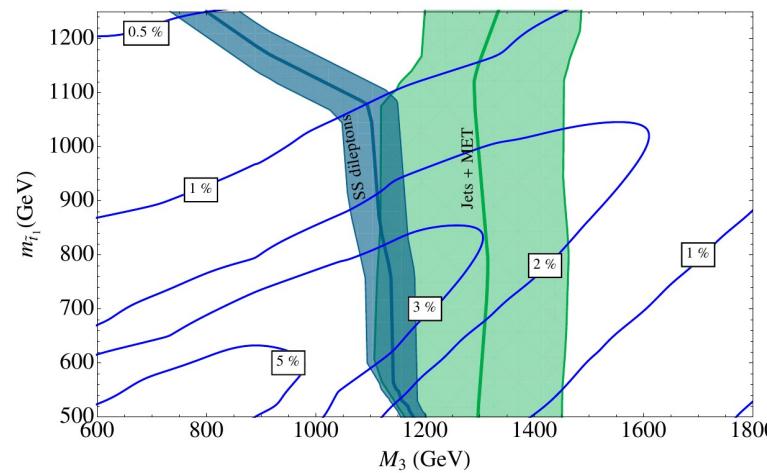


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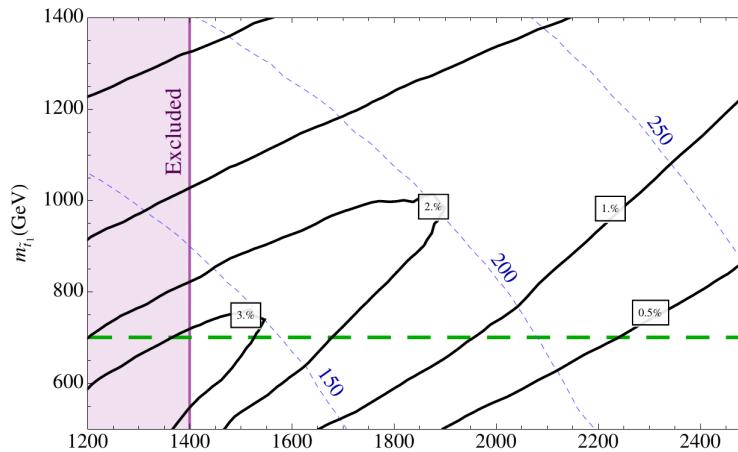


baryonic RPV

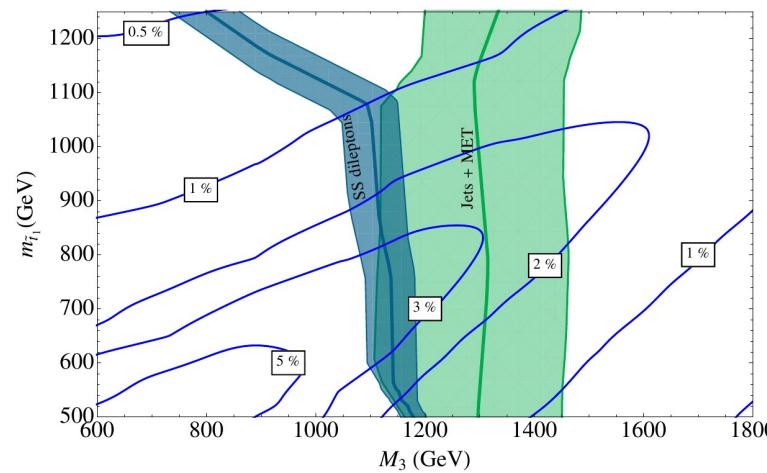


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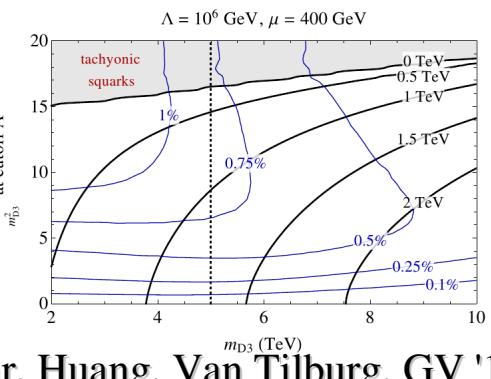
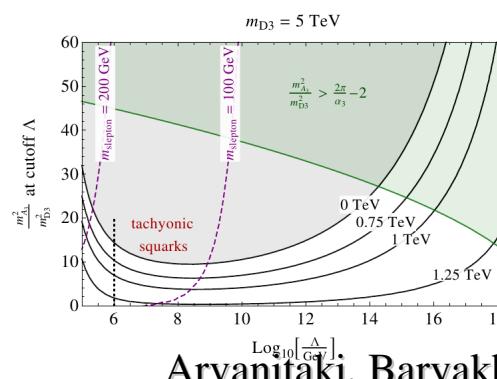
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baryonic RPV



Dirac gauginos



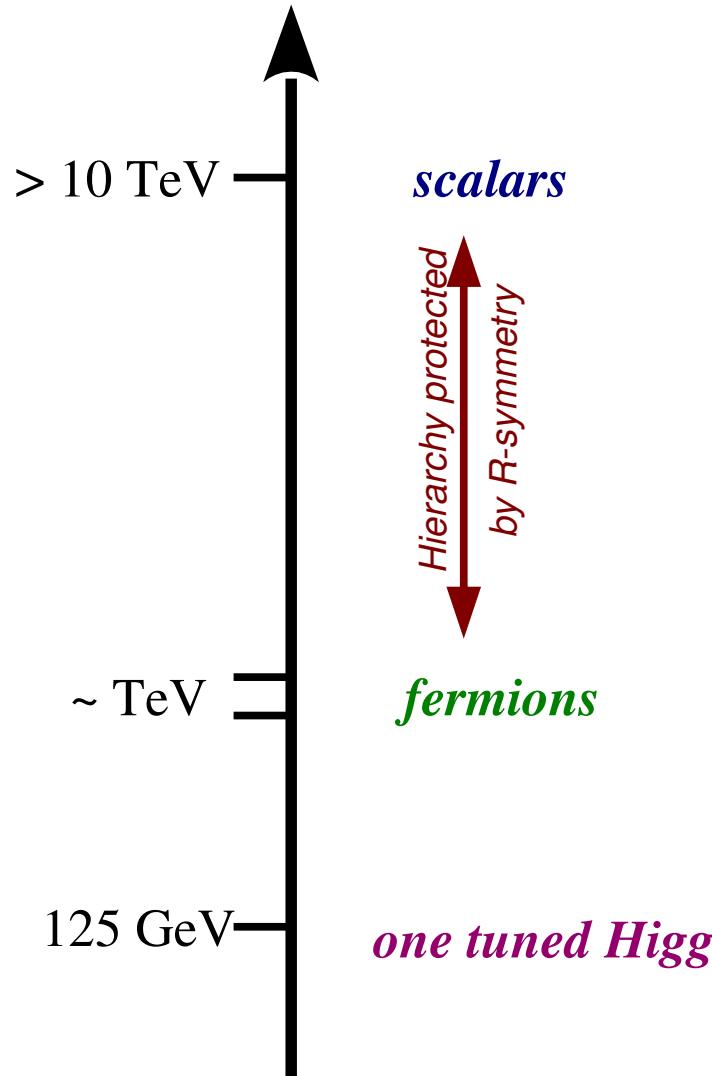
To summarize:

Minimal SUSY at best 1% tuned

few % after model building
(plus FT in model space...)

Split SUSY spectrum

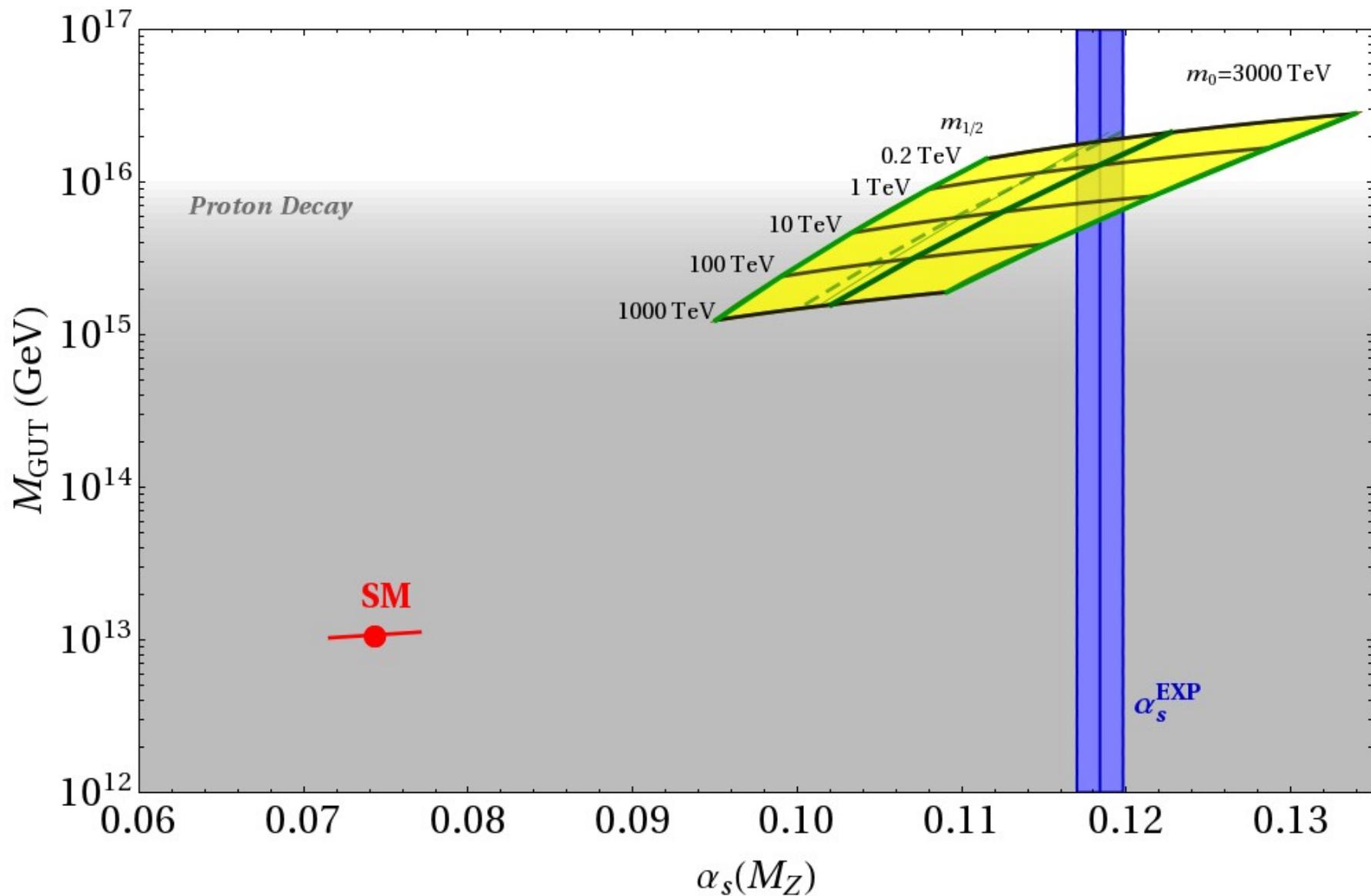
Arkani-Hamed and Dimopoulos '04



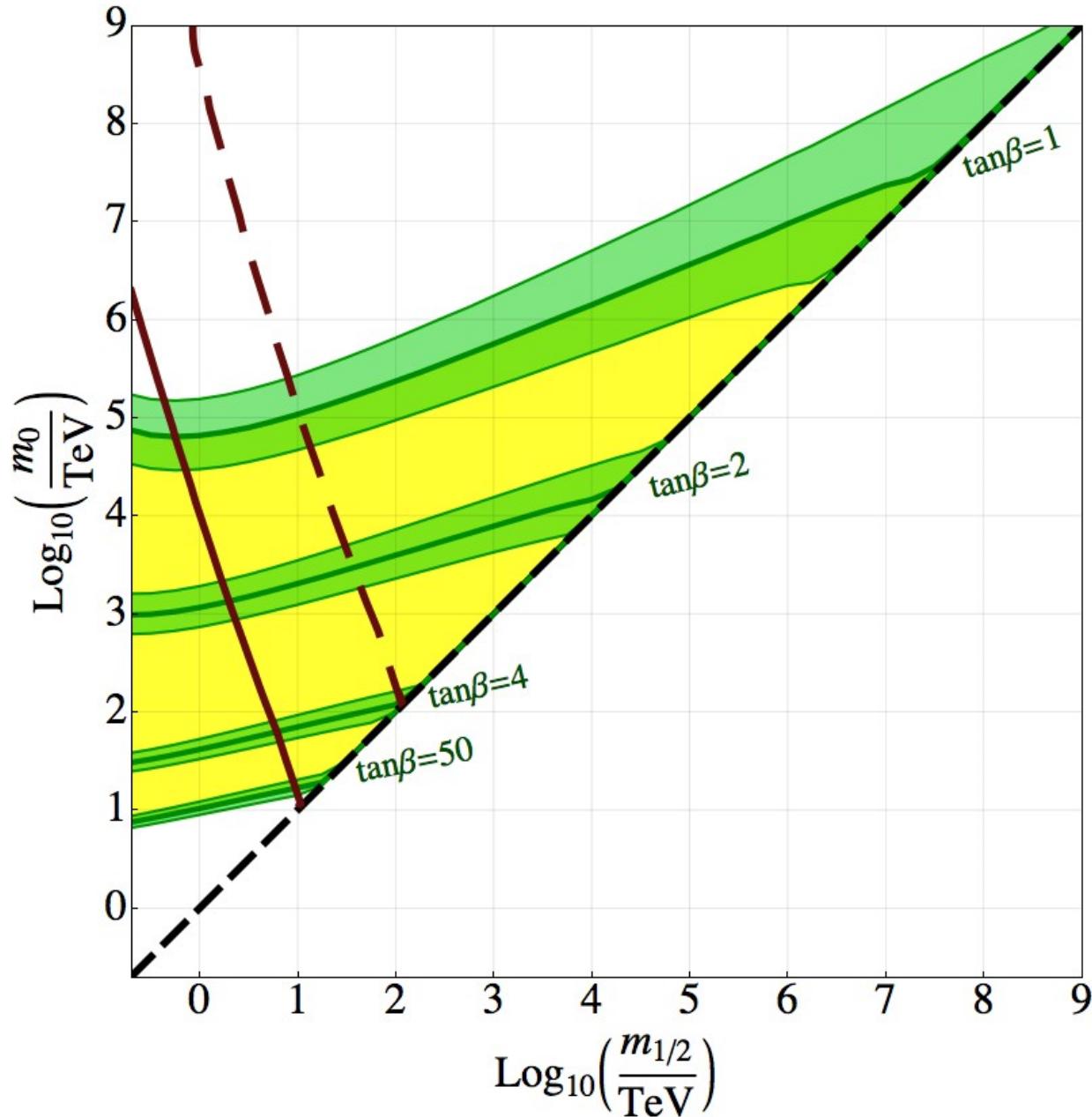
*Avoids problems with flavor,
EDM and collider bounds*

*Preserves successful
Gauge Coupling Unification
and Dark Matter*

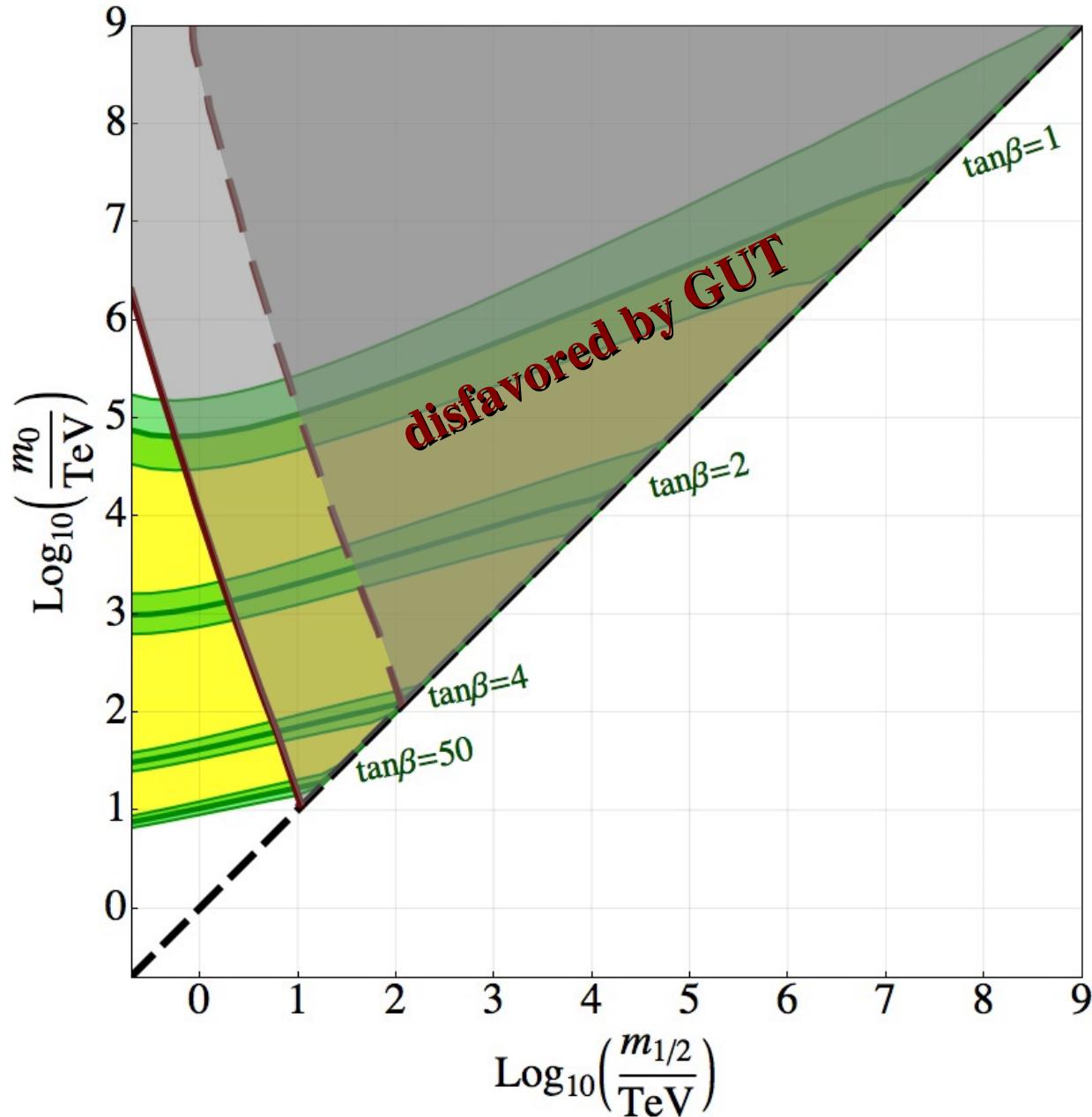
GUT in split



Implications of 125 GeV Higgs



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Just because you can tune...

RGE prefer $m_{Hu}^2 < 0$

EWSB: if $m_{Hu}^2 < 0 \Rightarrow \mu \sim m_{soft}$
if $\mu \ll m_{soft} \Rightarrow$ small running

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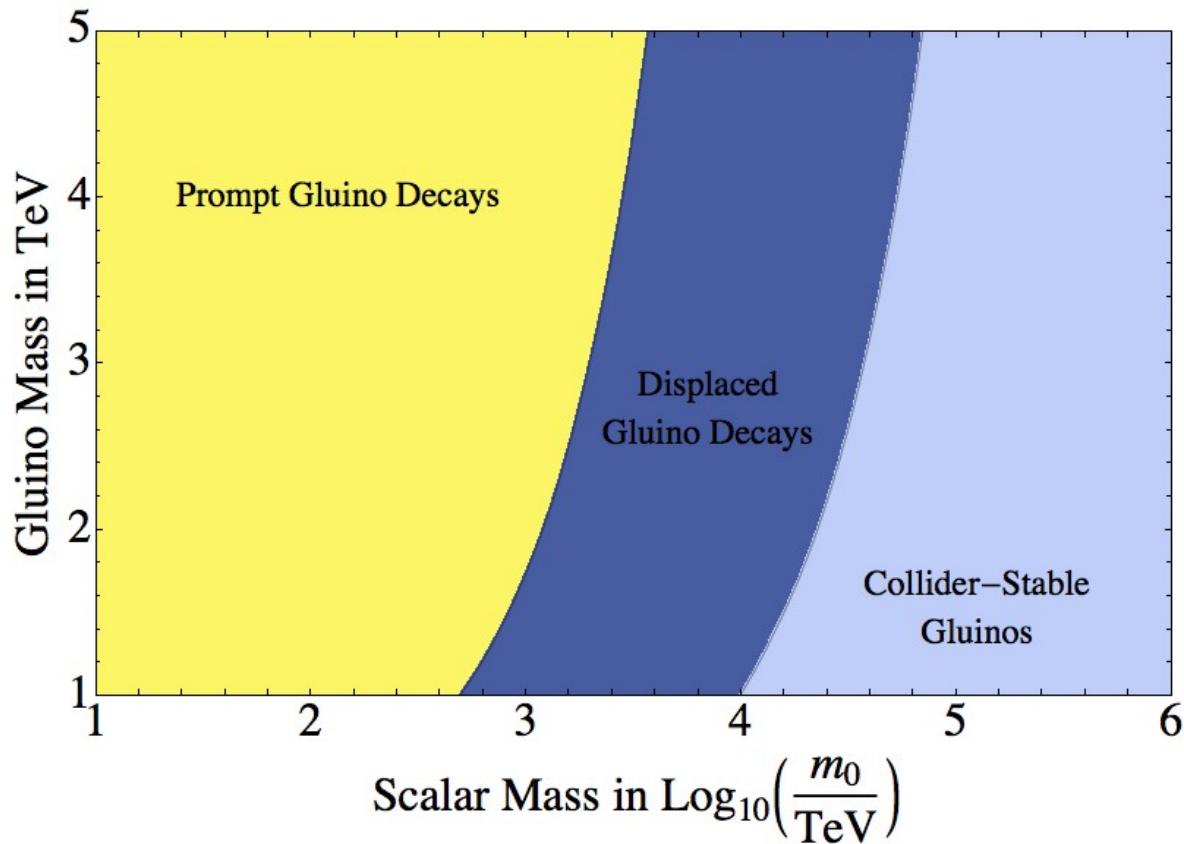
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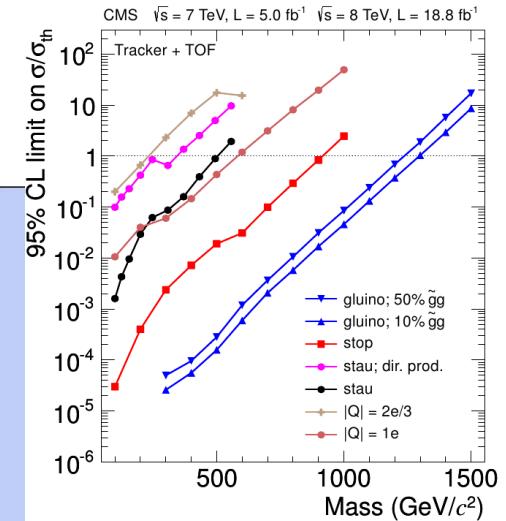
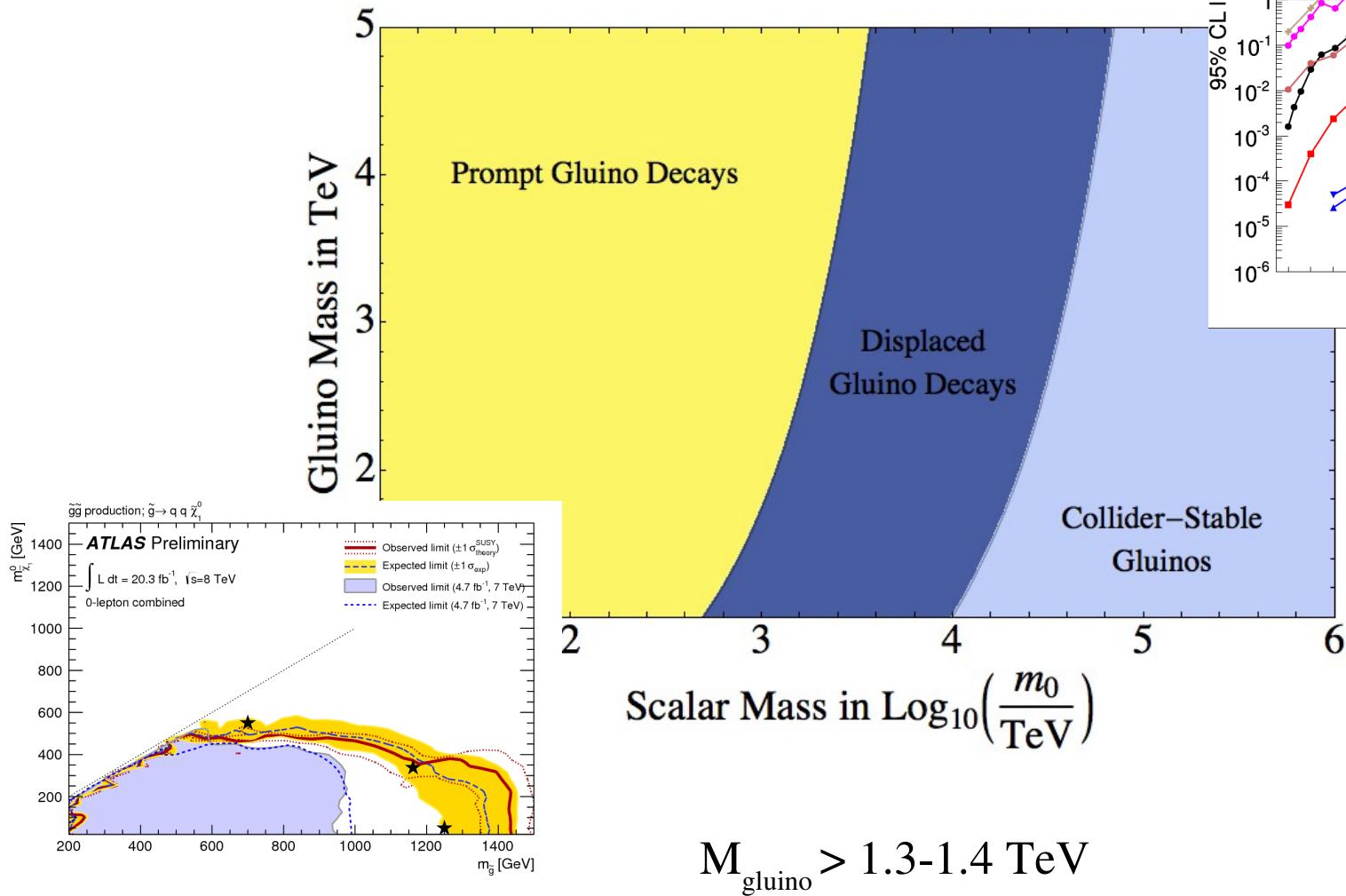
Many ways to get a Mini-Split spectrum:

- Gauge Mediation (R -symm. parameter+gaugino screening)
- Anomaly mediation (1-loop),
- $U(1)'$ mediation (2-loops)
- . . .

Split Gluinos



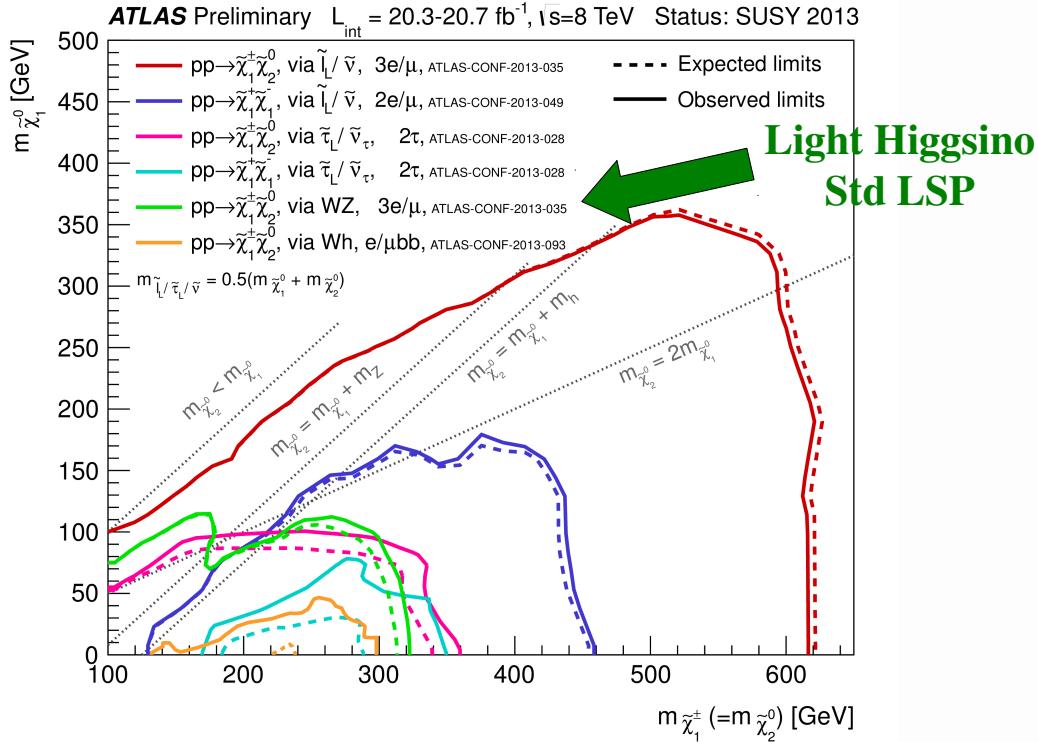
Split Gluinos



$M_{\text{gluino}} > 1.3\text{--}1.4 \text{ TeV}$

2.5 to 3 TeV ultimate LHC reach

Split EWino

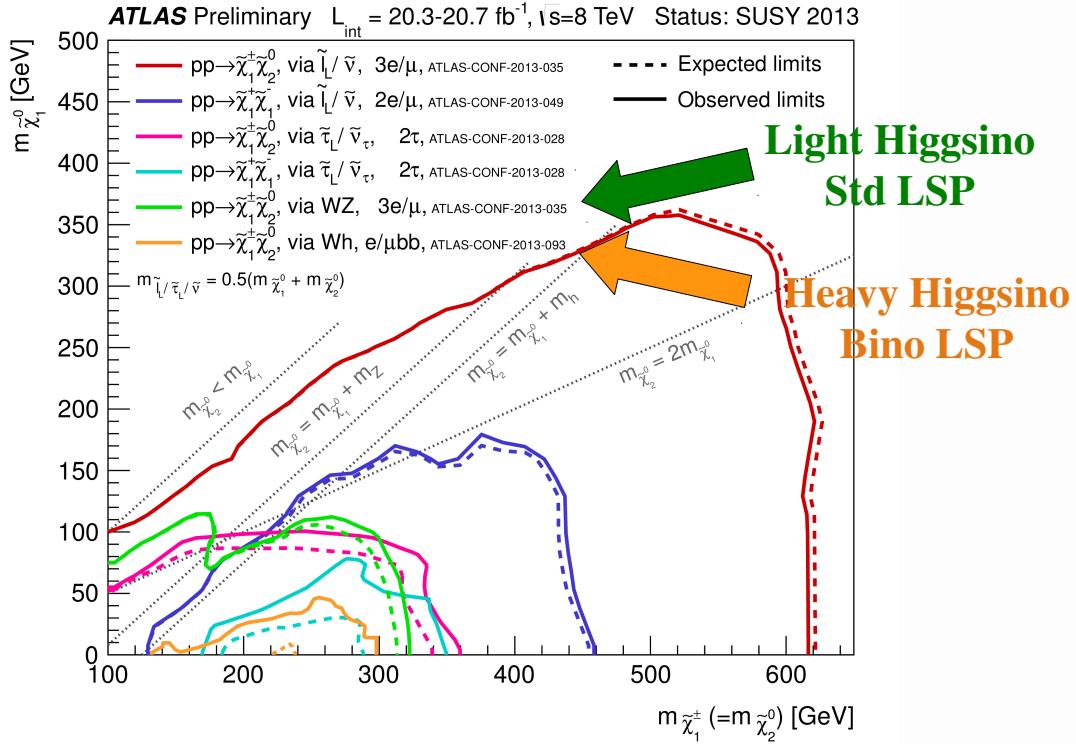


Golden scenario:

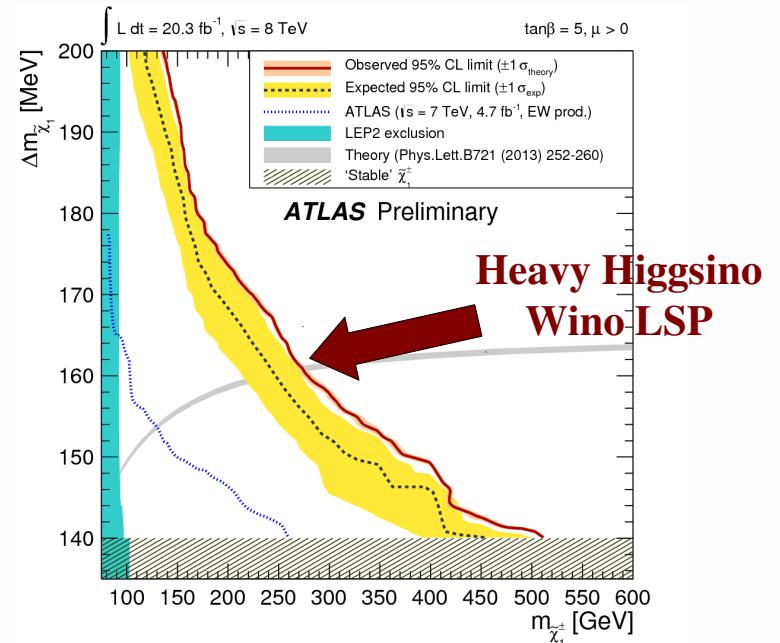
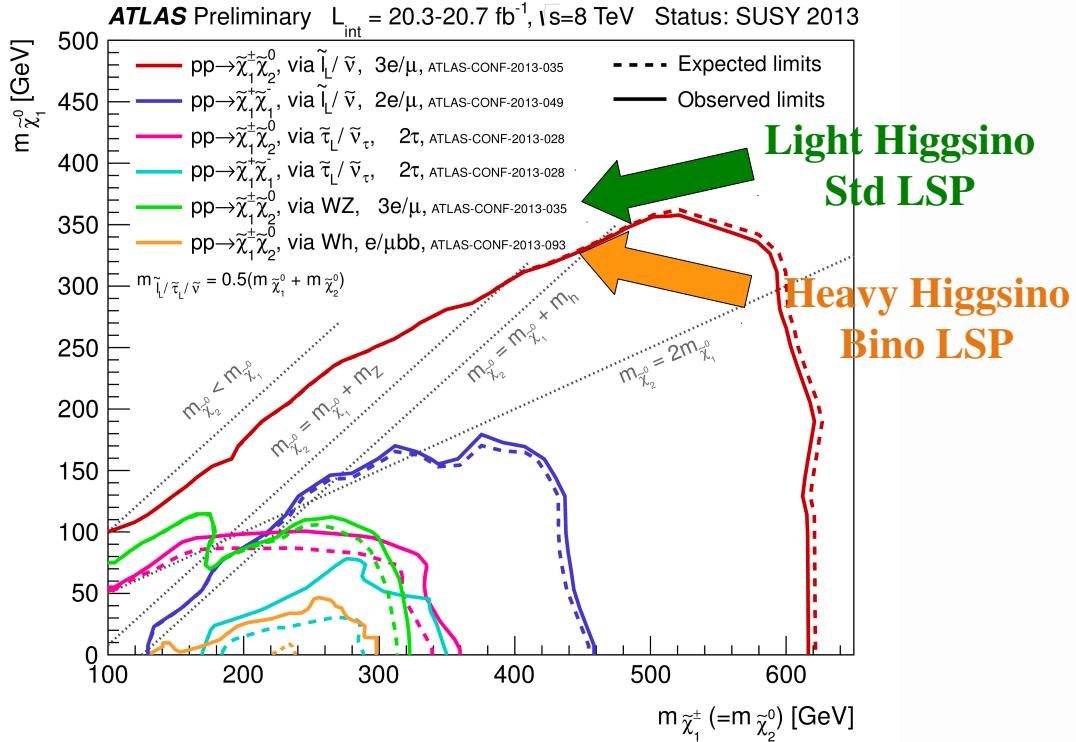
All EWino within LHC reach

LC could test mini-split unambiguously

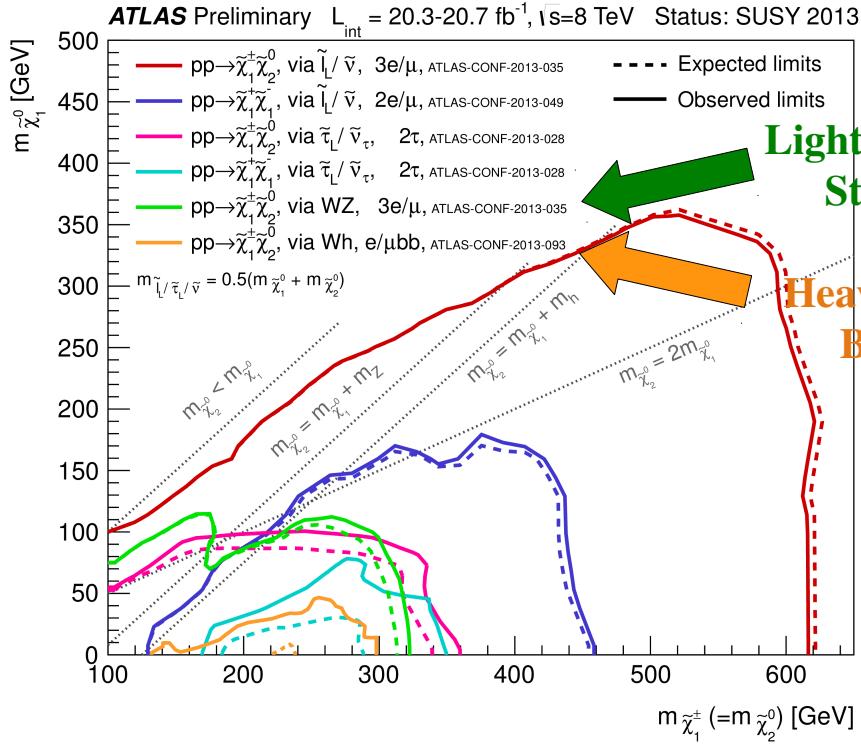
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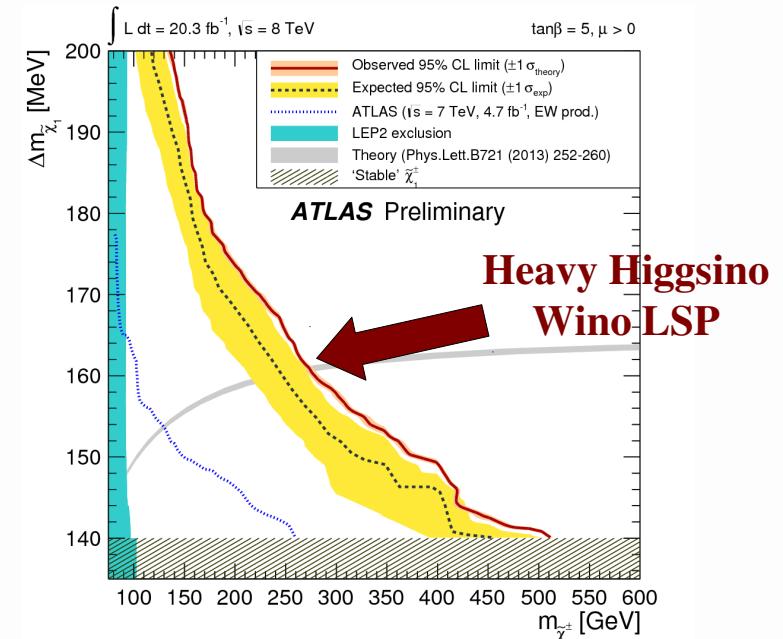


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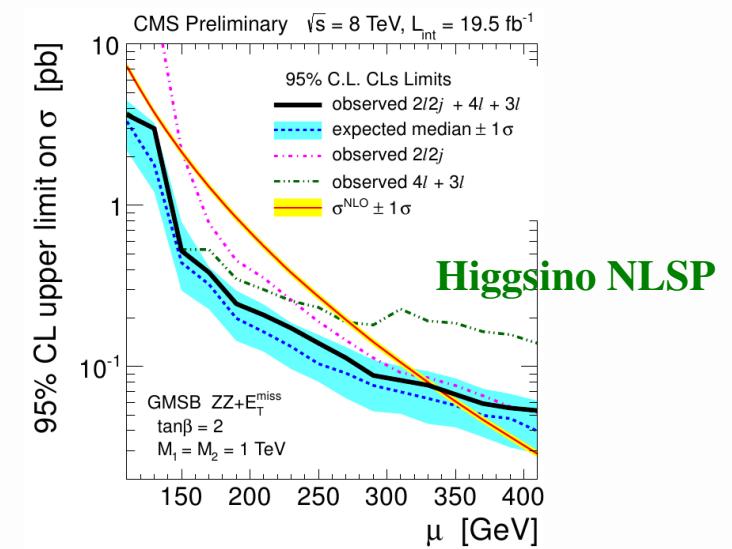


Light Higgsino
Std LSP

Heavy Higgsino
Bino LSP

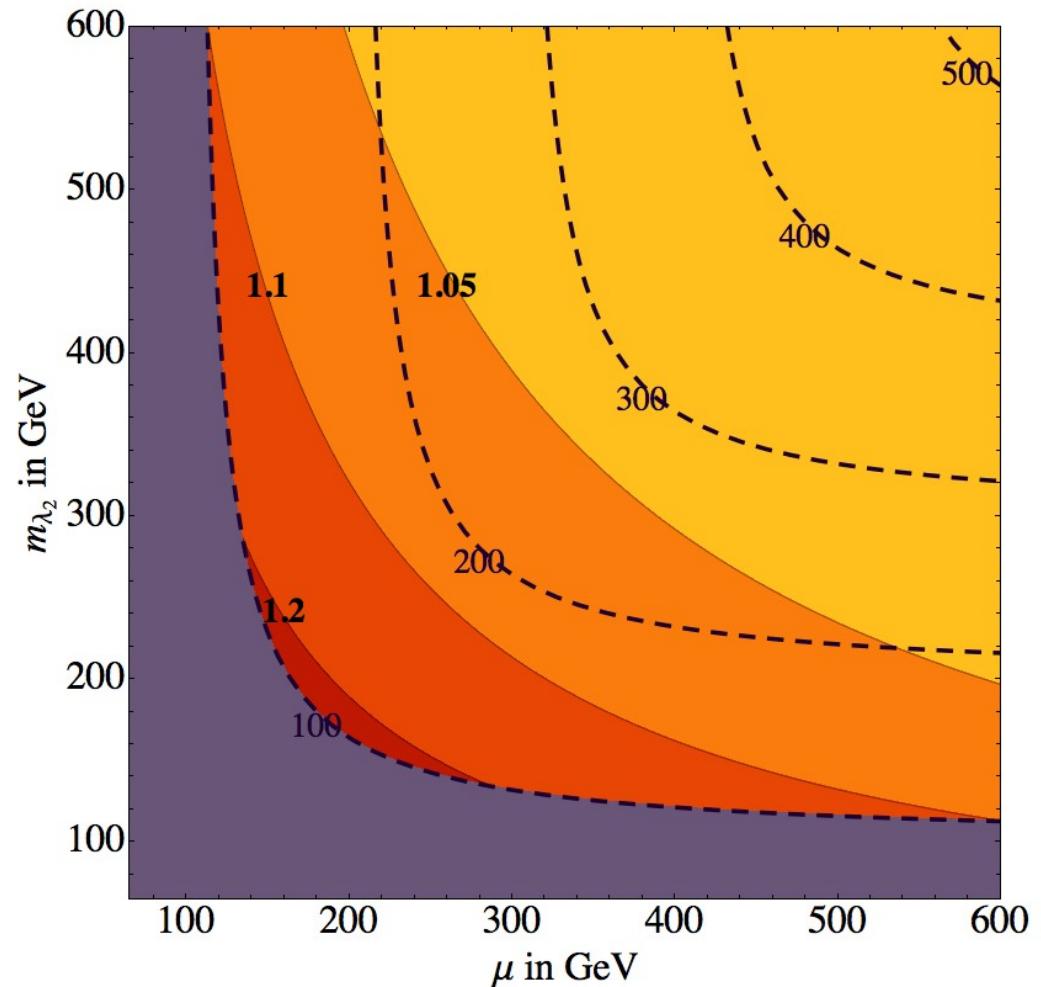
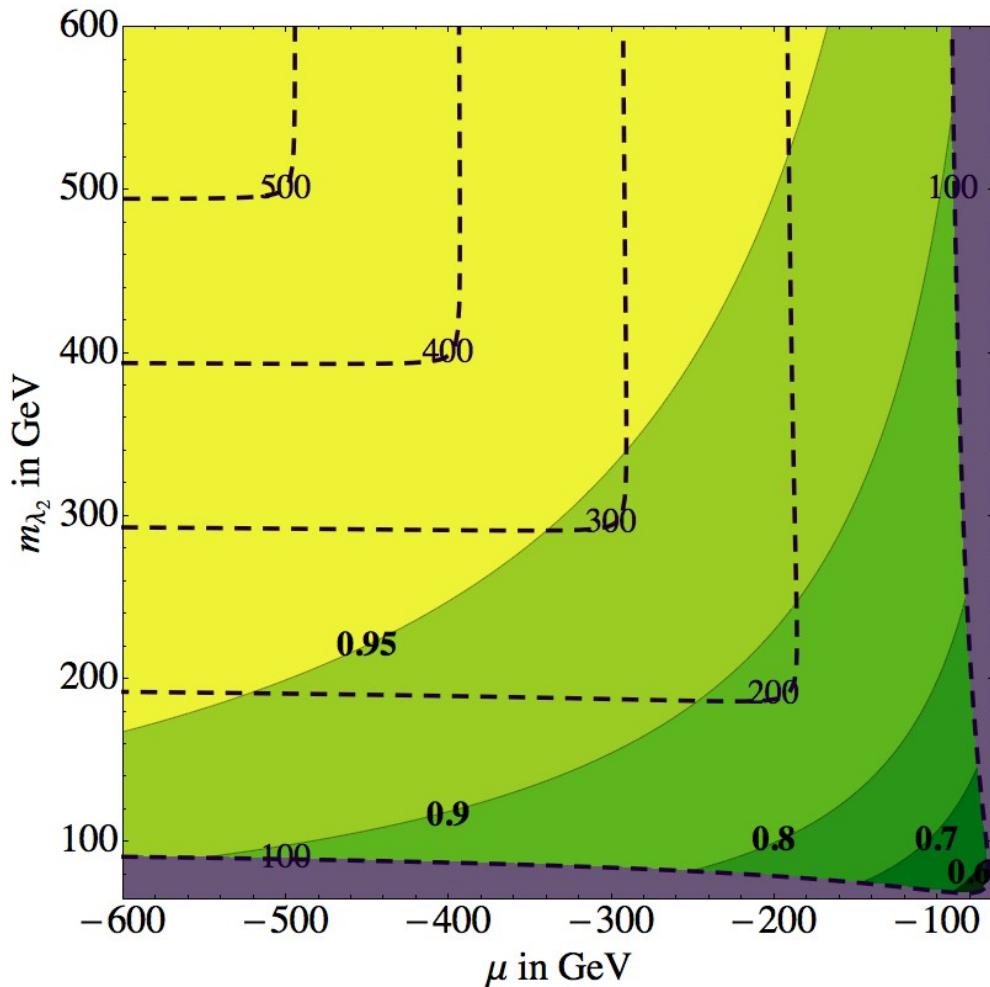


Heavy Higgsino
Wino LSP



Higgs couplings in Split

$$\frac{\Gamma_{h \rightarrow \gamma\gamma}}{\Gamma_{h \rightarrow \gamma\gamma}^{SM}} \simeq 1 + \frac{12}{17} \frac{m_W^2 \sin 2\beta}{\mu m_{\lambda_2} - m_W^2 \sin 2\beta}$$



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the Dreamer:

*« ... because SUSY is around the corner, $M_3 \sim m_{squark} \sim 2$ TeV
the world is 1% tuned and we have just been (quite) unlucky. »*

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+ dirac gaugino + non-universal gaugino masses + extra-dimensions
+ blablabla and SUSY is Natural !!! »

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the Heretic:

« ... because the vacua with 1-2 loop hierarchy in the SUSY spectrum
are more “probable” than those with a “natural” EW scale »