Is Natural SUSY Expired?

Giovanni Villadoro
ICTP

with Arvanitaki, Baryakhtar, Gherghetta, Huang, Van Tilburg

YES, of course!

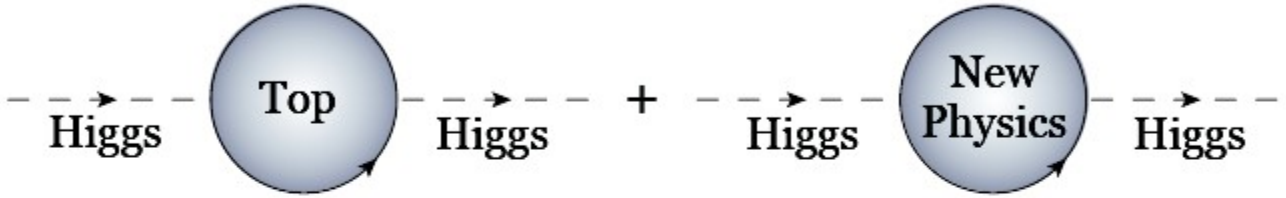
~30 yrs ago!


Tuneland
Λ_{cc}
Naturalness
m_e, Δm_K, Δm_π, ...

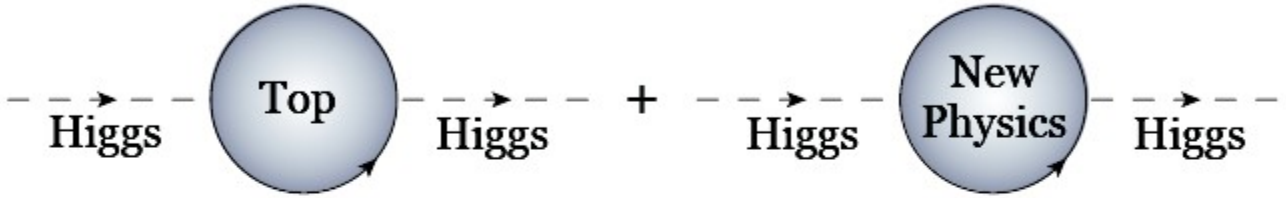

Tuneland
Λ_{cc}
Naturalness
m_e, Δm_K, Δm_π, ...
LIVE
EWPT - LEP
flavor - EDMs
0.40
miles
11:02
11:26
60 mph
TOMTOM

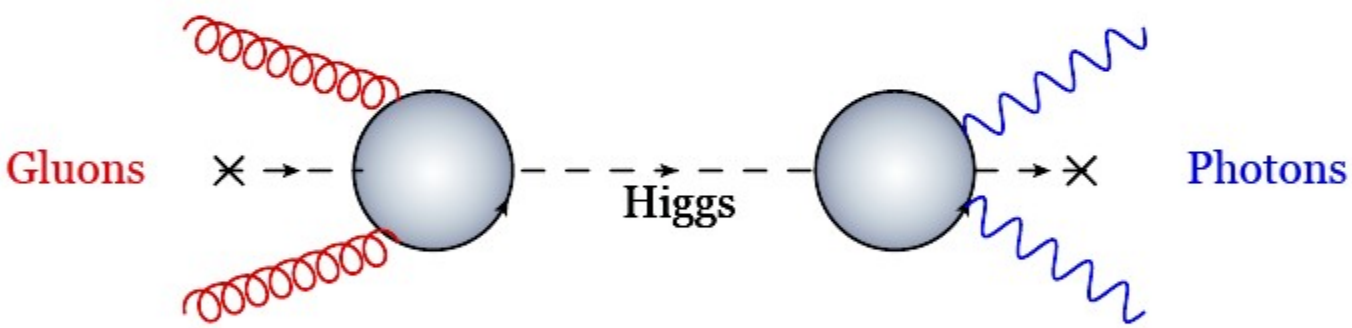
The ~125 GeV Higgs

Naturalness and Higgs Properties



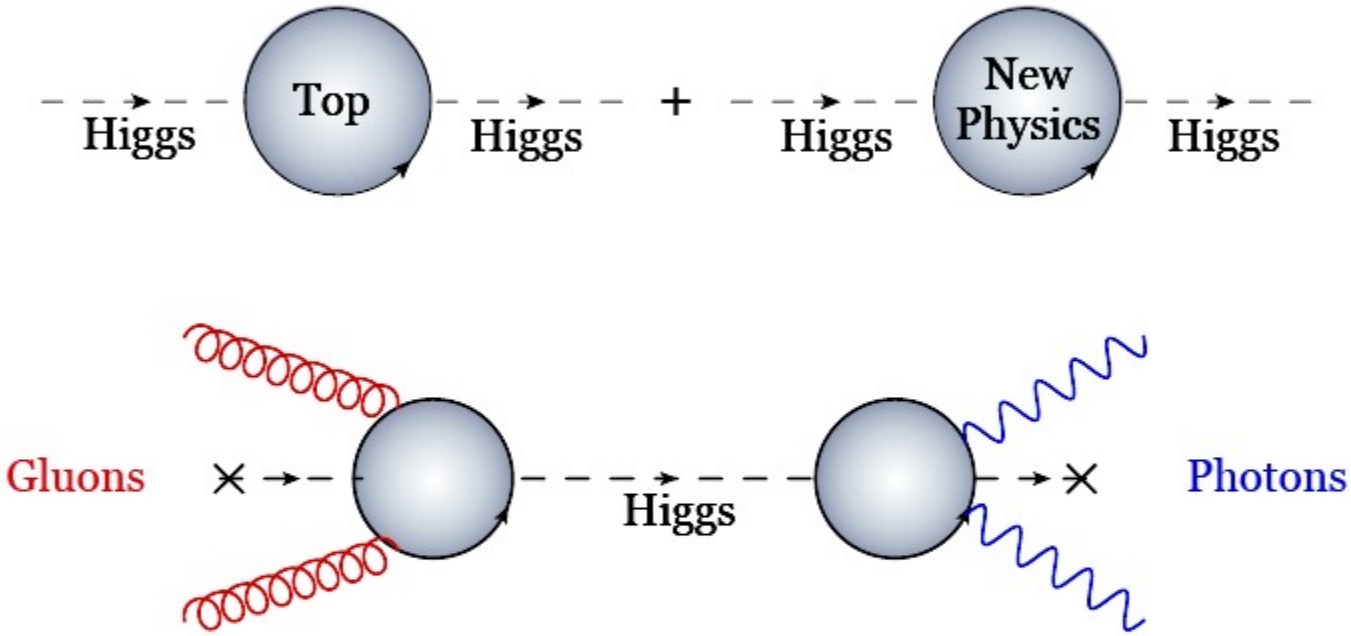
Naturalness and Higgs Properties





A Natural Higgs is not the SM Higgs

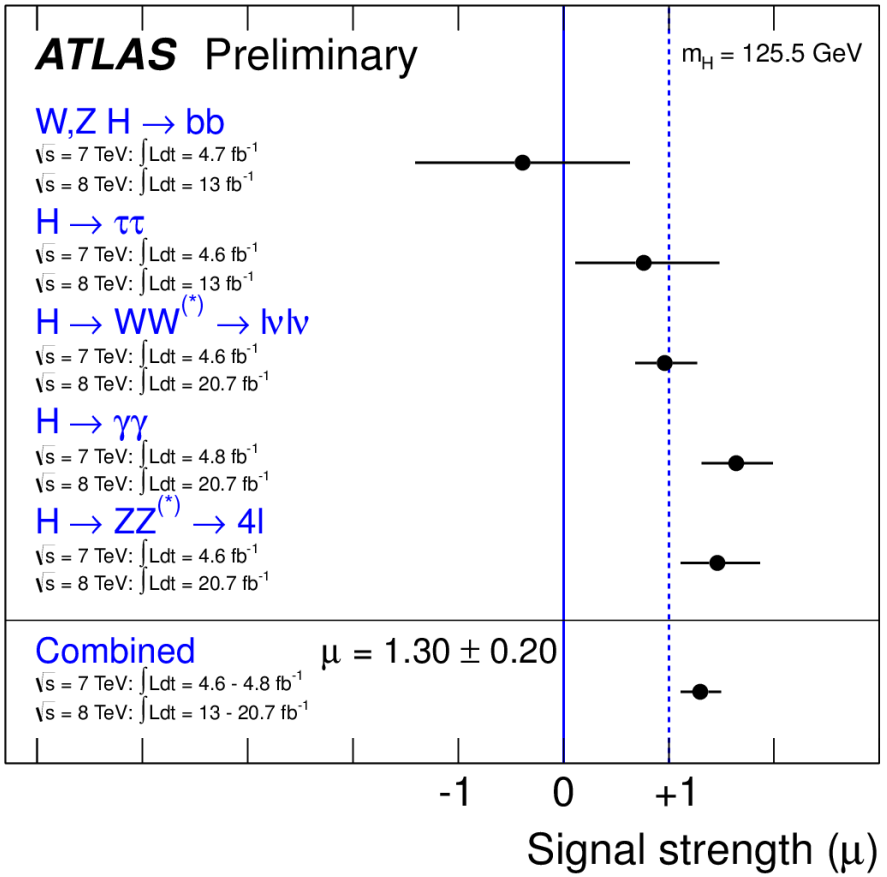
Naturalness and Higgs Properties

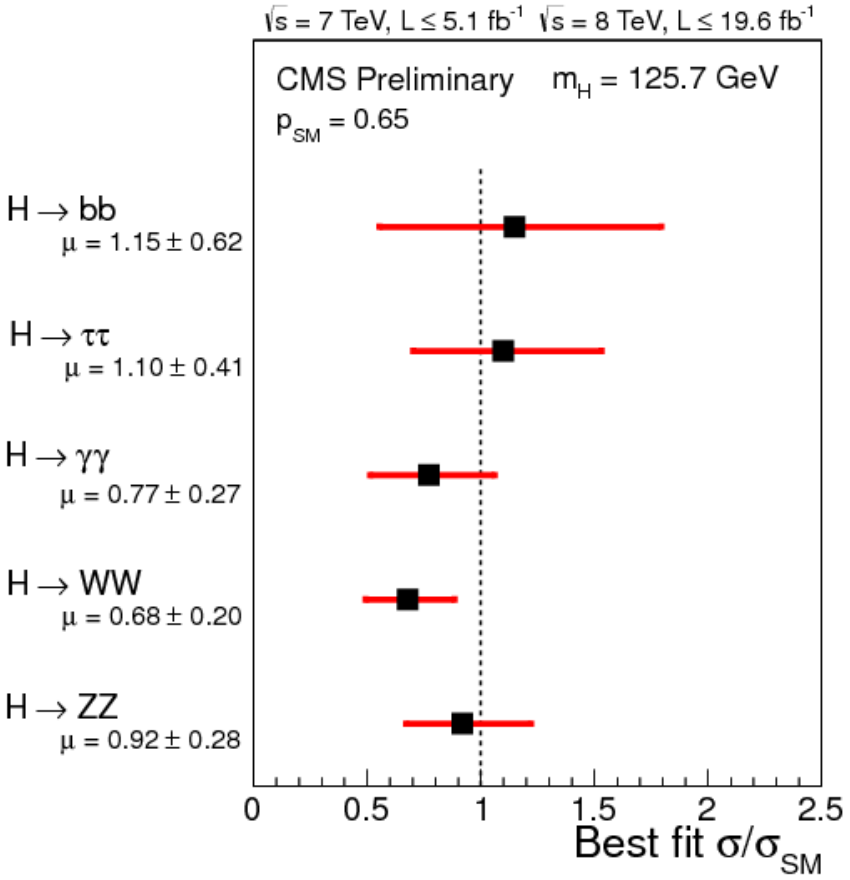


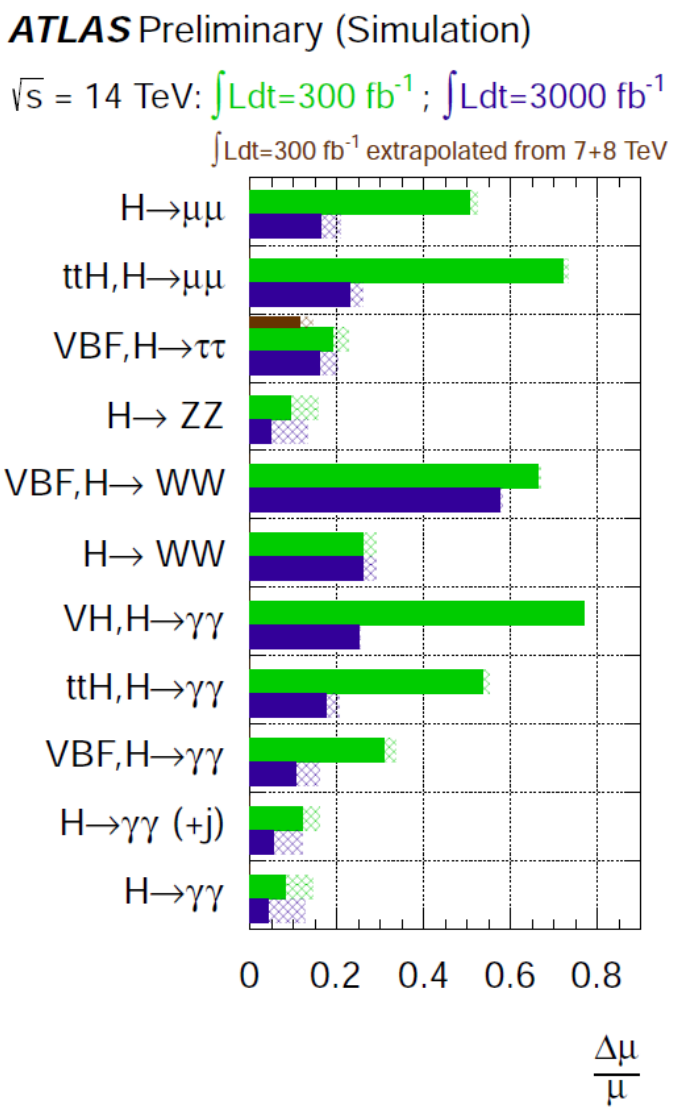
A Natural Higgs is not the SM Higgs

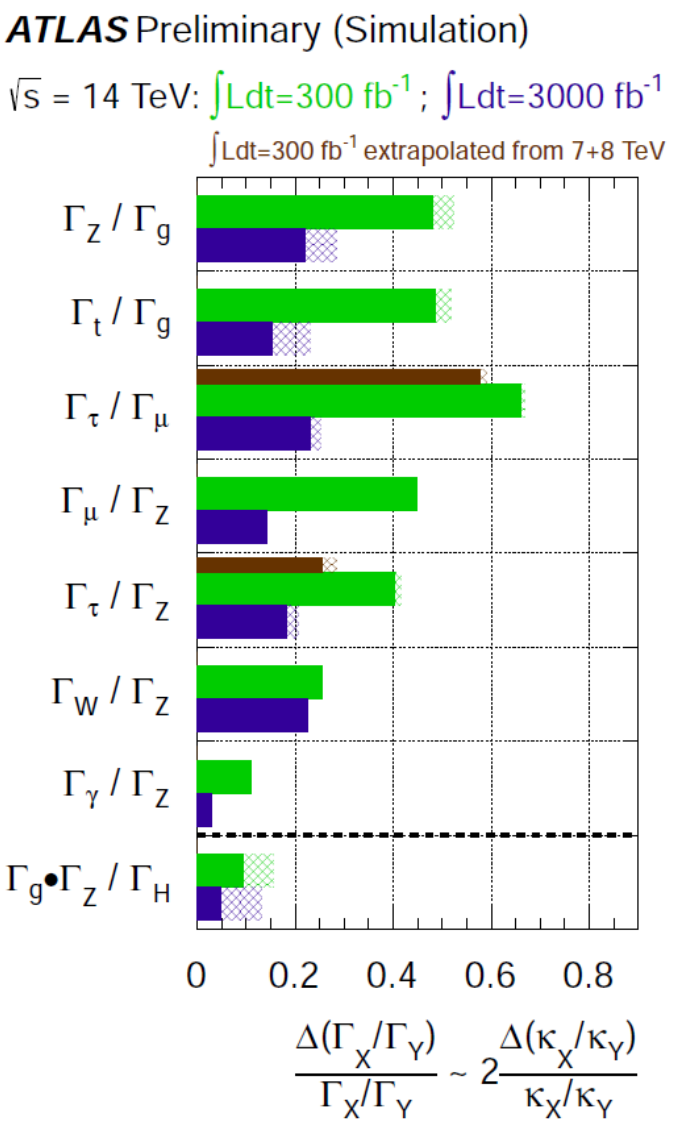
$$\mu_{gg\to h} \approx 1 + \frac{m_t^2}{m_{\tilde{t}}^2} \sim 1 + tuning$$

The very SM-like Higgs



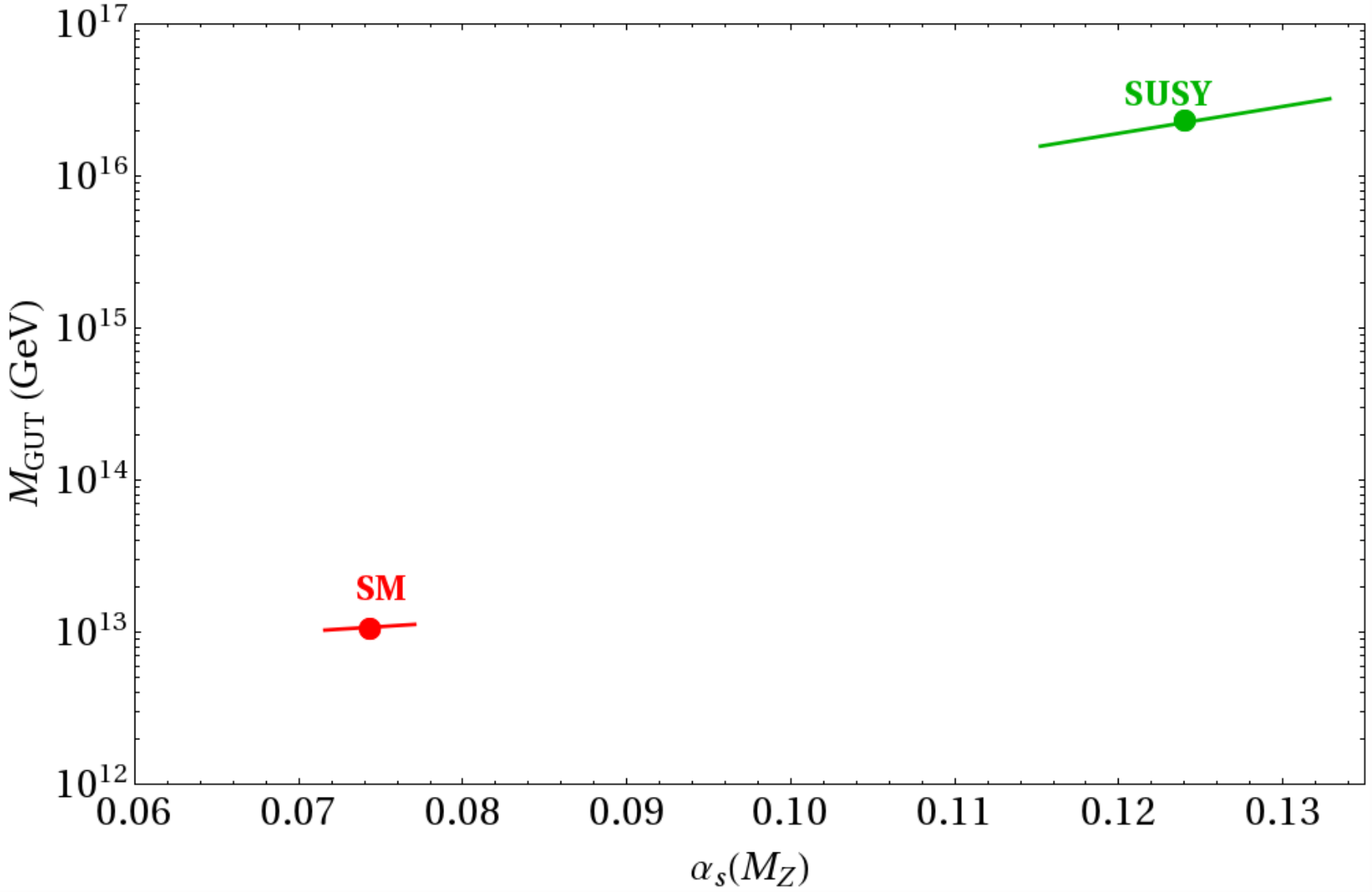



ATLAS Preliminary (Simulation)
√s = 14 TeV: ∫Ldt=300 fb-1 ; ∫Ldt=3000 fb-1
∫Ldt=300 fb-1 extrapolated from 7+8 TeV
H→μμ
ttH,H→μμ
VBF,H→ττ
H→ ZZ
VBF,H→ WW
H→ WW
VH,H→γγ
ttH,H→γγ
VBF,H→γγ
H→γγ (+j)
H→γγ
0
0.2
0.4
0.6
0.8
Δμ/μ

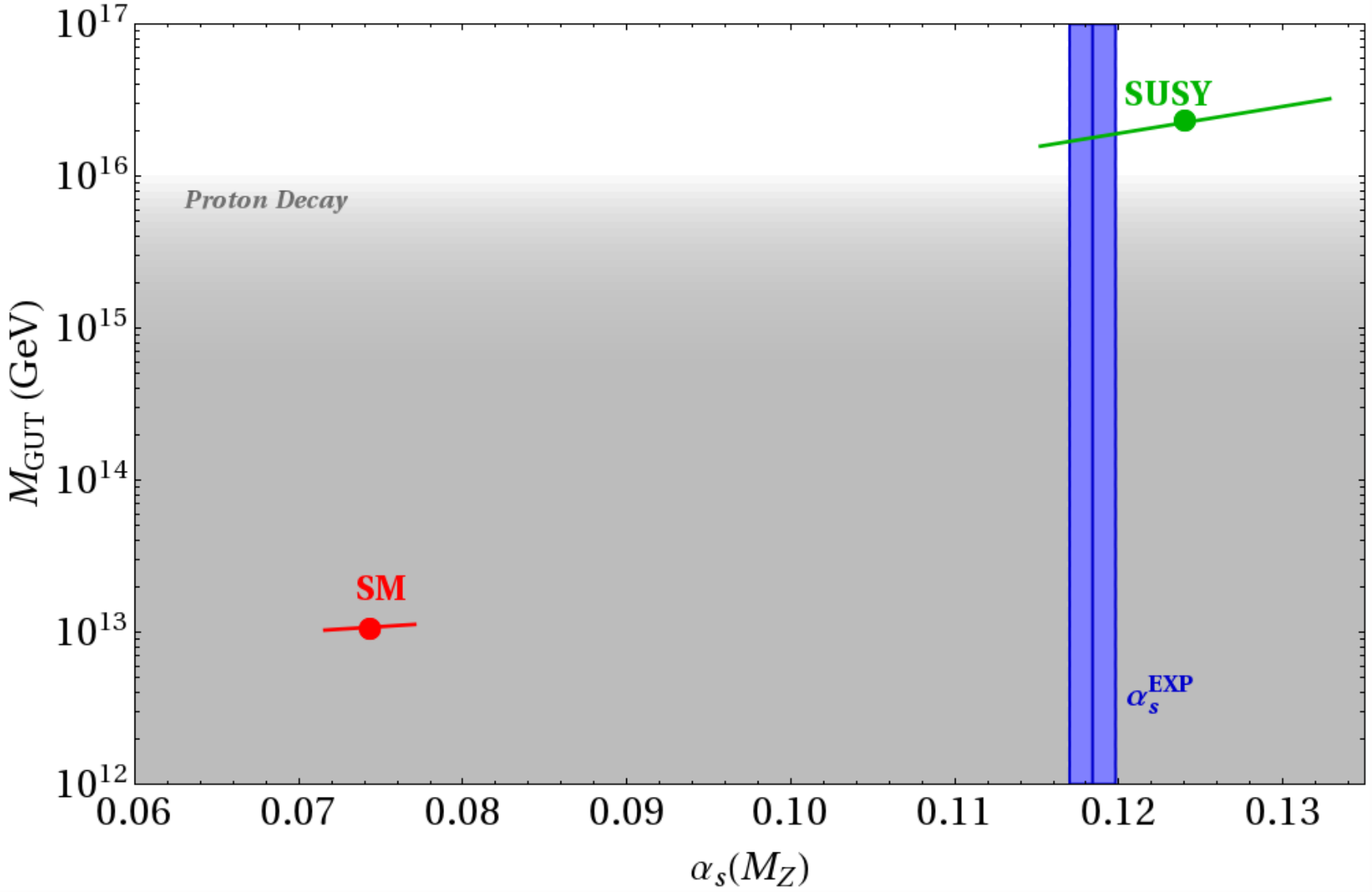

ATLAS Preliminary (Simulation)
√s = 14 TeV: ∫Ldt=300 fb-1 ; ∫Ldt=3000 fb-1
∫Ldt=300 fb-1 extrapolated from 7+8 TeV
Γ_Z / Γ_g
Γ_t / Γ_g
Γ_τ / Γ_μ
Γ_μ / Γ_Z
Γ_τ / Γ_Z
Γ_W / Γ_Z
Γ_γ / Γ_Z
Γ_g•Γ_Z / Γ_H
0
0.2
0.4
0.6
0.8
Δ(Γ_X/Γ_Y)/(Γ_X/Γ_Y) ~ 2 Δ(κ_X/κ_Y)/(κ_X/κ_Y)

Why SUSY

Why SUSY

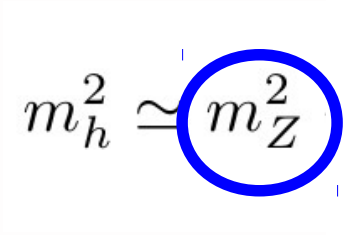

10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
M_{GUT} (GeV)
SUSY
SM
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
$\alpha_s(M_Z)$

Why SUSY


10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
M_{GUT} (GeV)
Proton Decay
SUSY
SM
α_s^{EXP}
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
$\alpha_s(M_Z)$

SUSY and the Higgs

SUSY and the 125 GeV Higgs



SUSY and the 125 GeV Higgs

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

SUSY and the 125 GeV Higgs

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SUSY and the 125 GeV Higgs

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

The Missing Superpartner Problem

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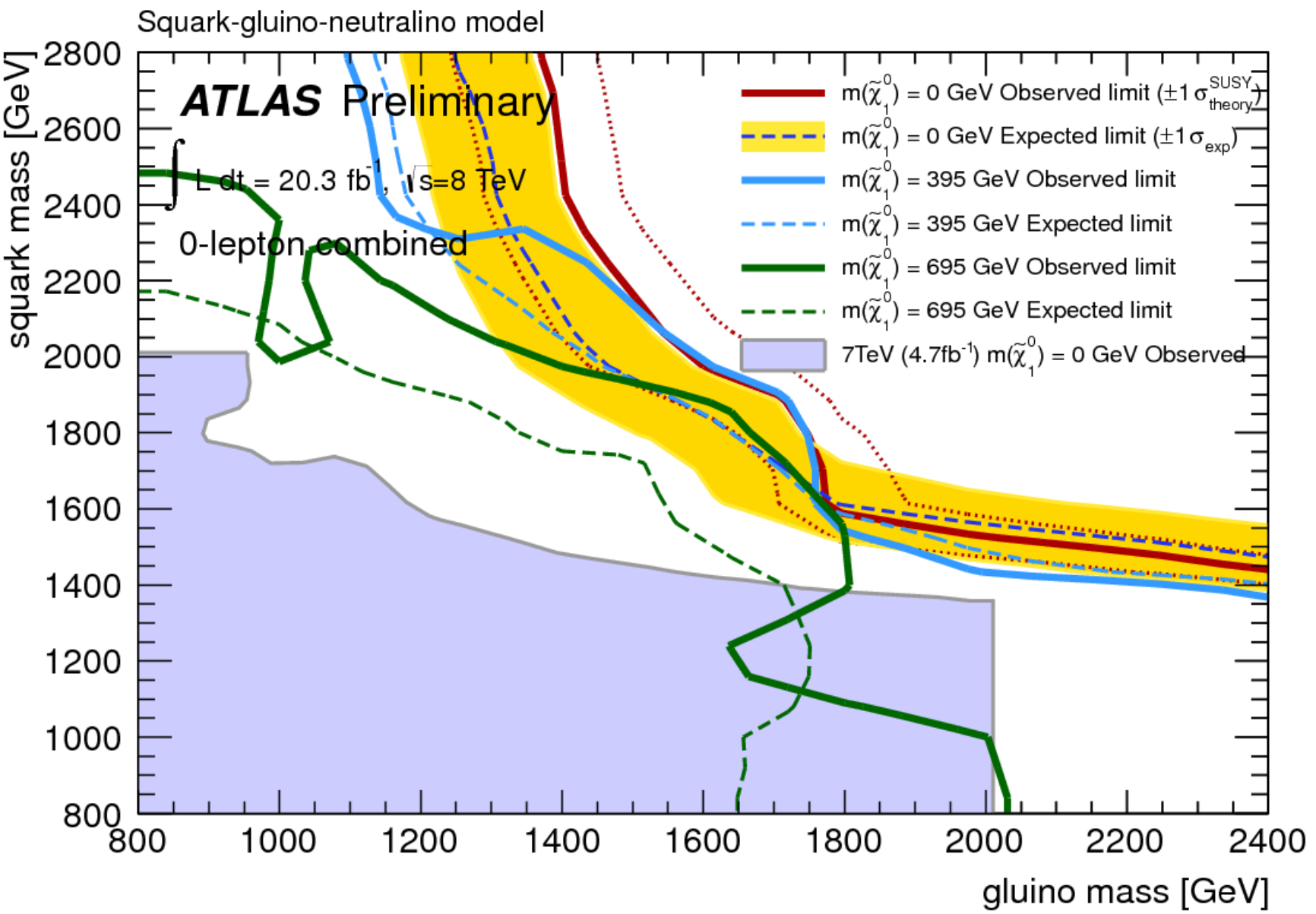
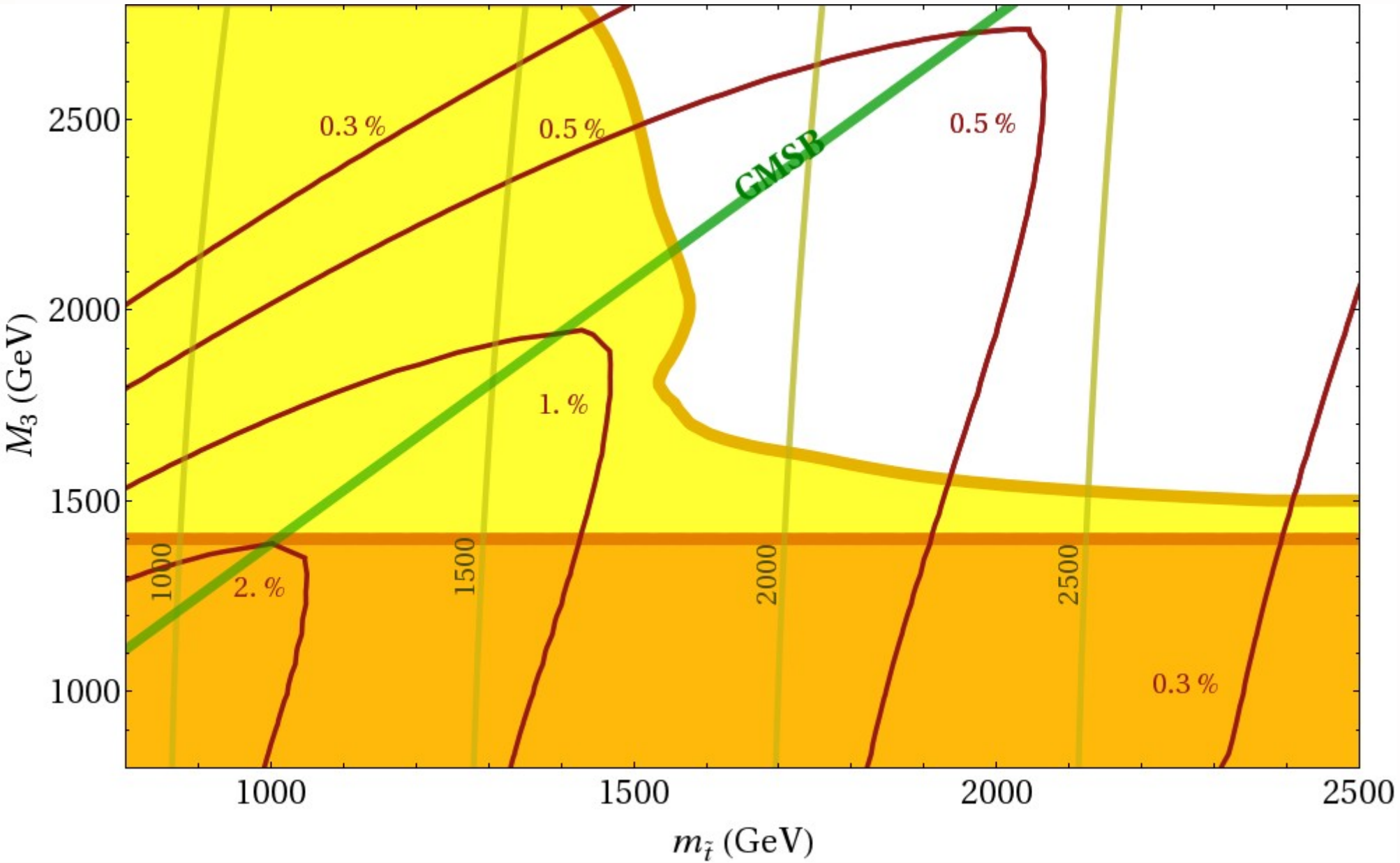


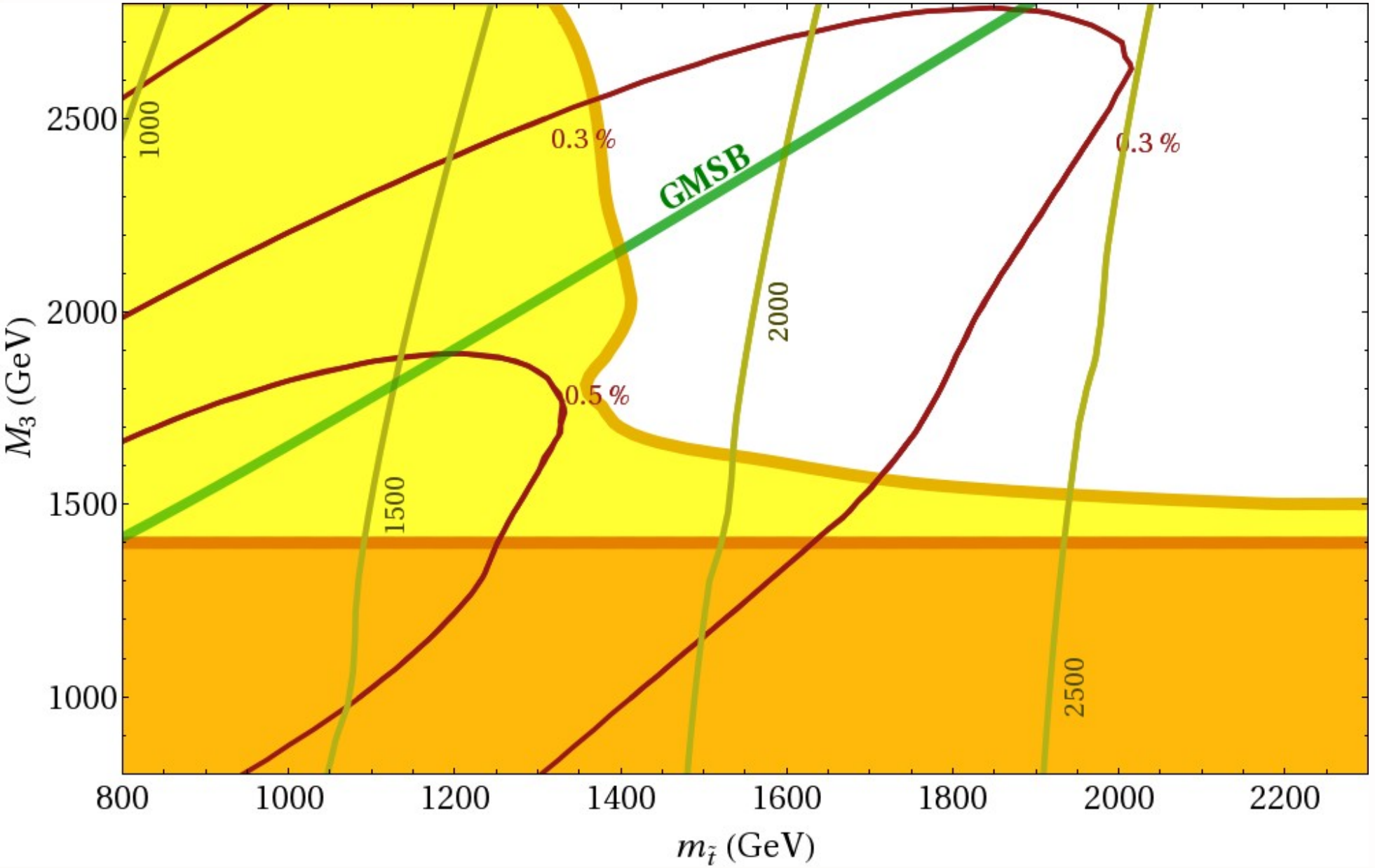
NMSSM

(low scale GM M_{mess} = 300 TeV)

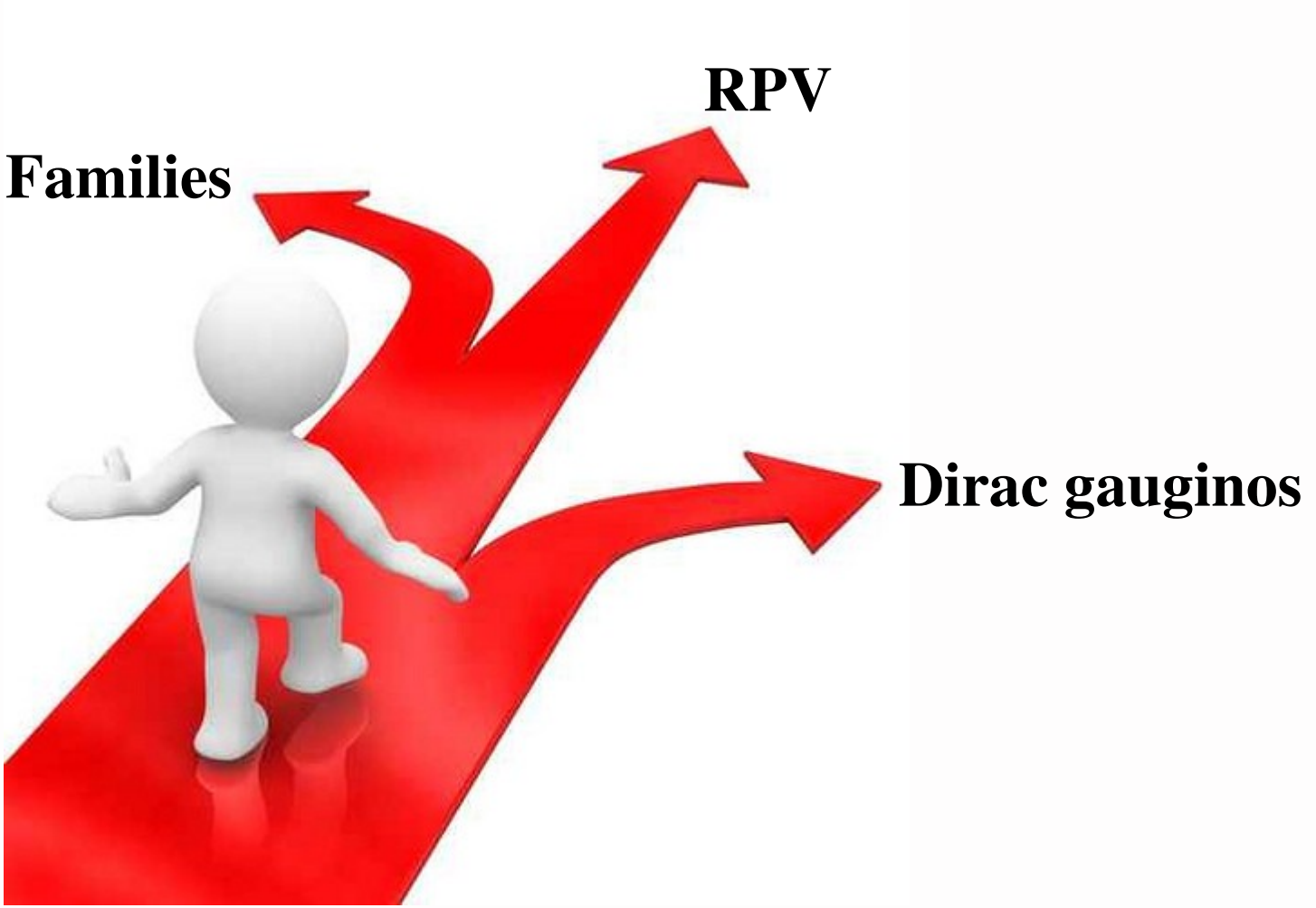


Push-Up Model

(low scale GM + large A-terms M_{mess} = 300 TeV)



“Hiding” SUSY



solution #1:

“Natural” SUSY

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Dimopoulos-Giudice, Pomarol-Tommasini '95

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

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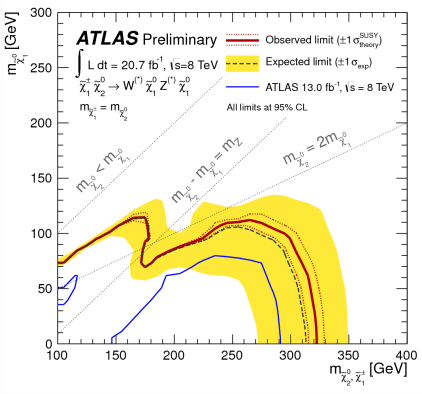
Only need light higgsinos, stops, gluinos
(and light mess. scale Λ)

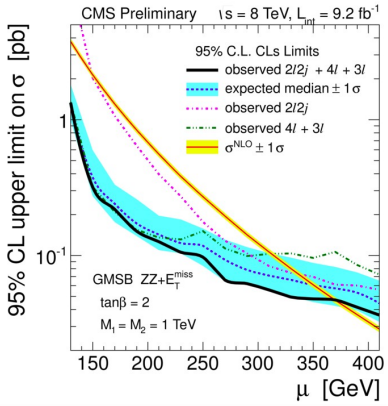
10% tuning $\Rightarrow$ $\mu \lesssim 250$ GeV, $m_{stop} \lesssim 700$ GeV, $M_{gluino} \lesssim 1.4$ TeV

(assuming ultra-low med-scale and $m_{stop}(\Lambda)=0$)

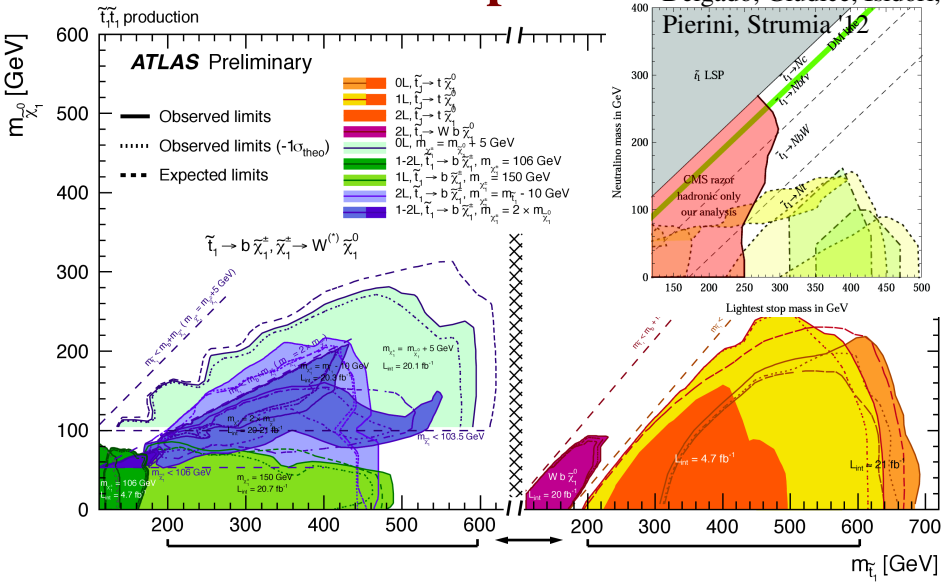
Status of Natural SUSY

EWinos

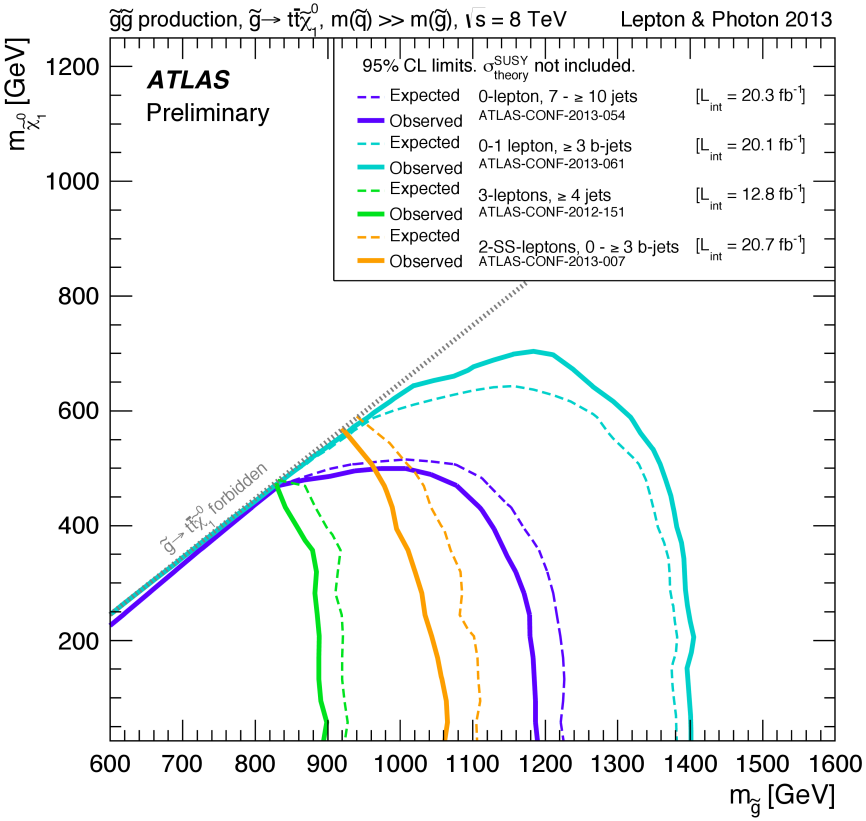




stops

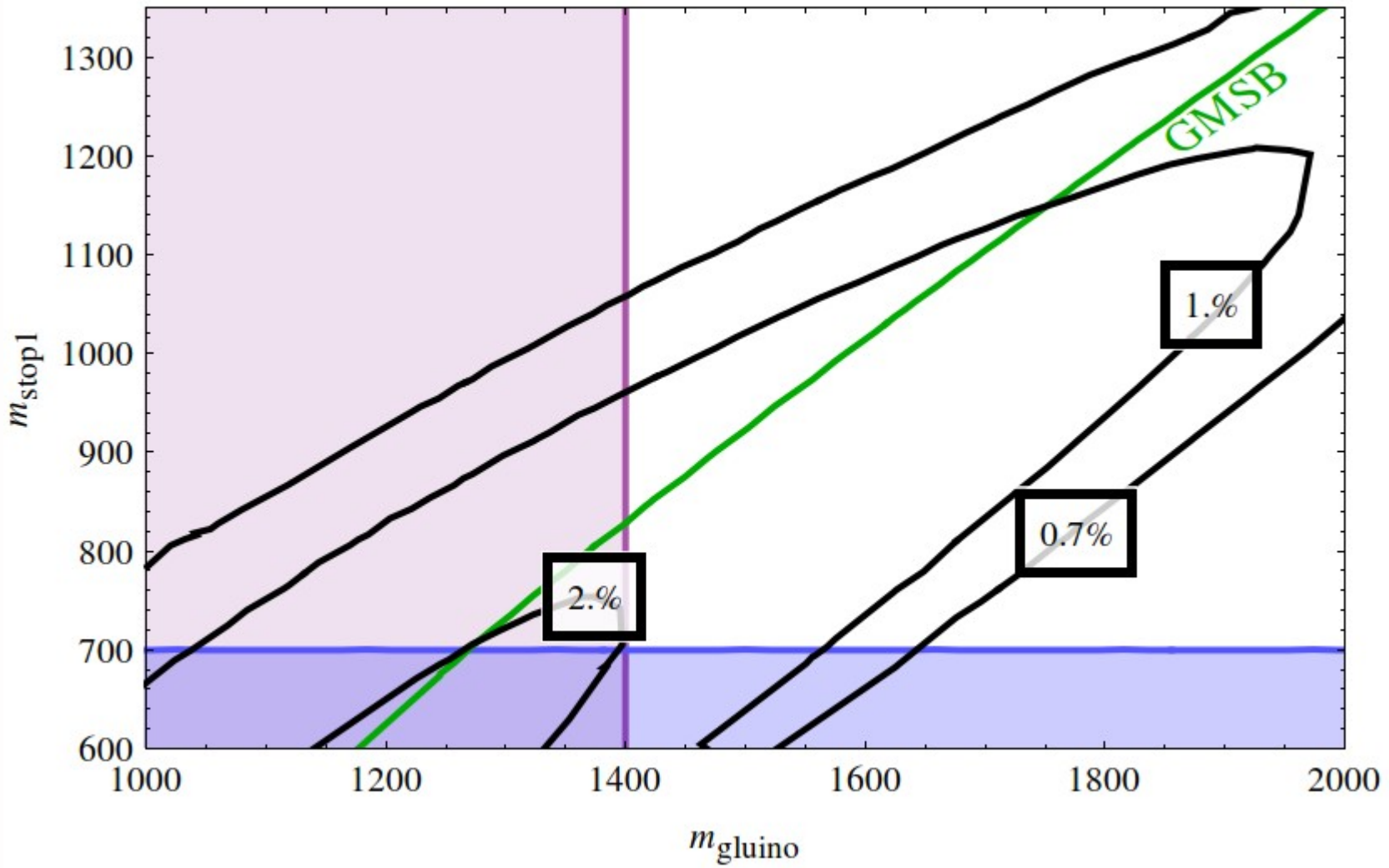


gluino



U(1)' – Split Families

(low scale GM M_{mess} = 1000 TeV)



solution #2:

RPV

RPV SUSY

$$W_{RPV} = \mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k.$$

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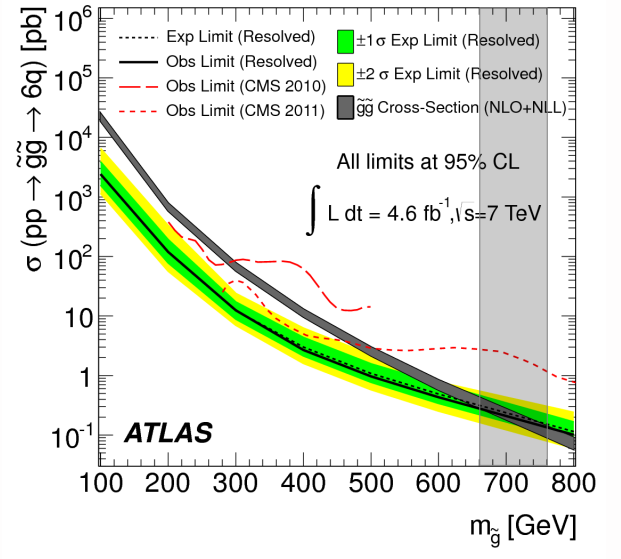
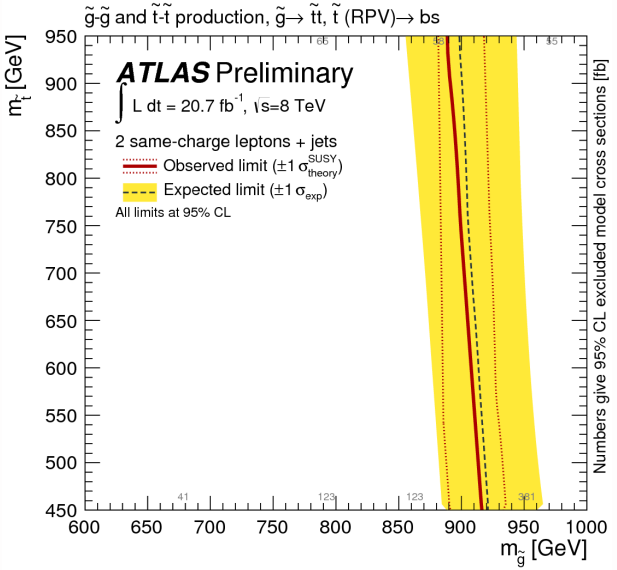
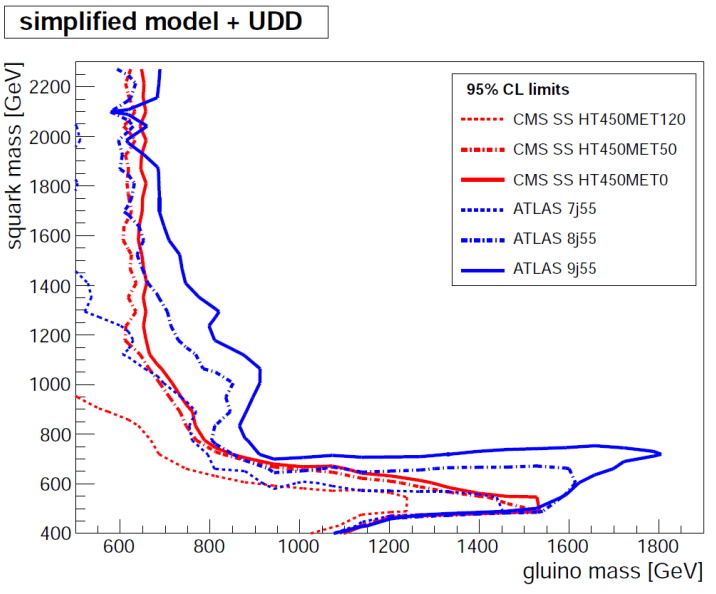
Baryonic RPV:







Asano, Rolbiecki, Sakurai '12

RPV SUSY

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Baryonic RPV:

- $p \to K^+ G$

$$\lambda''_{ijk} \lesssim 10^{-6} \frac{m_{\tilde{G}}}{\text{keV}} \left(\frac{m_{\tilde{s}_R}}{500\,\text{GeV}}\right)^3 \quad \lambda''_{112} \lesssim 10^{-12} \frac{m_G}{\text{keV}} \left(\frac{m_{\tilde{s}_R}}{500\,\text{GeV}}\right)^2$$

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$$F \gtrsim (10^5\,\mathrm{GeV})^2 \left(\frac{m_{\tilde{q}}}{500\,\mathrm{GeV}}\right)^2 \left(\frac{\lambda''_{max}}{10^{-2}}\right)^{-1}$$

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- $\tau <$ *detector*

$\lambda'' \gtrsim 10^{-6}$ *(3-body)* $\quad \lambda'' \gtrsim 10^{-9}$ *(2-body)*

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- $\tau <$ *detector* $\quad \lambda'' \gtrsim 10^{-6}$ *(3-body)* $\quad \lambda'' \gtrsim 10^{-9}$ *(2-body)*
- *n-n, N-N osc.* $\quad \lambda''_{11k} \lesssim 10^{-5}$

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- *n-n, N-N osc.* $\quad \lambda''_{11k} \lesssim 10^{-5}$
- *baryon number wash-out...* $\quad |\lambda''_{ijk}| \lesssim 10^{-7}$

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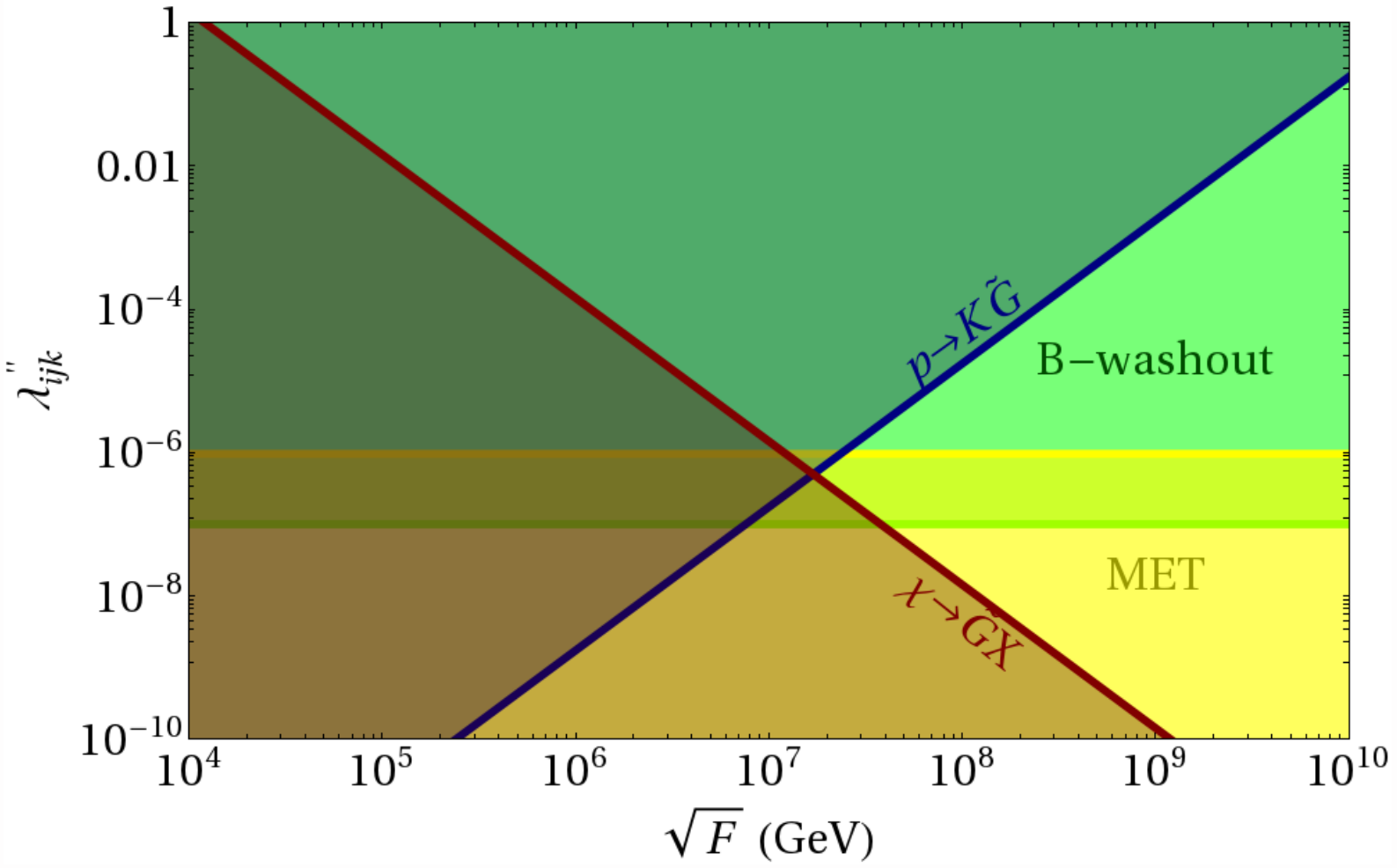

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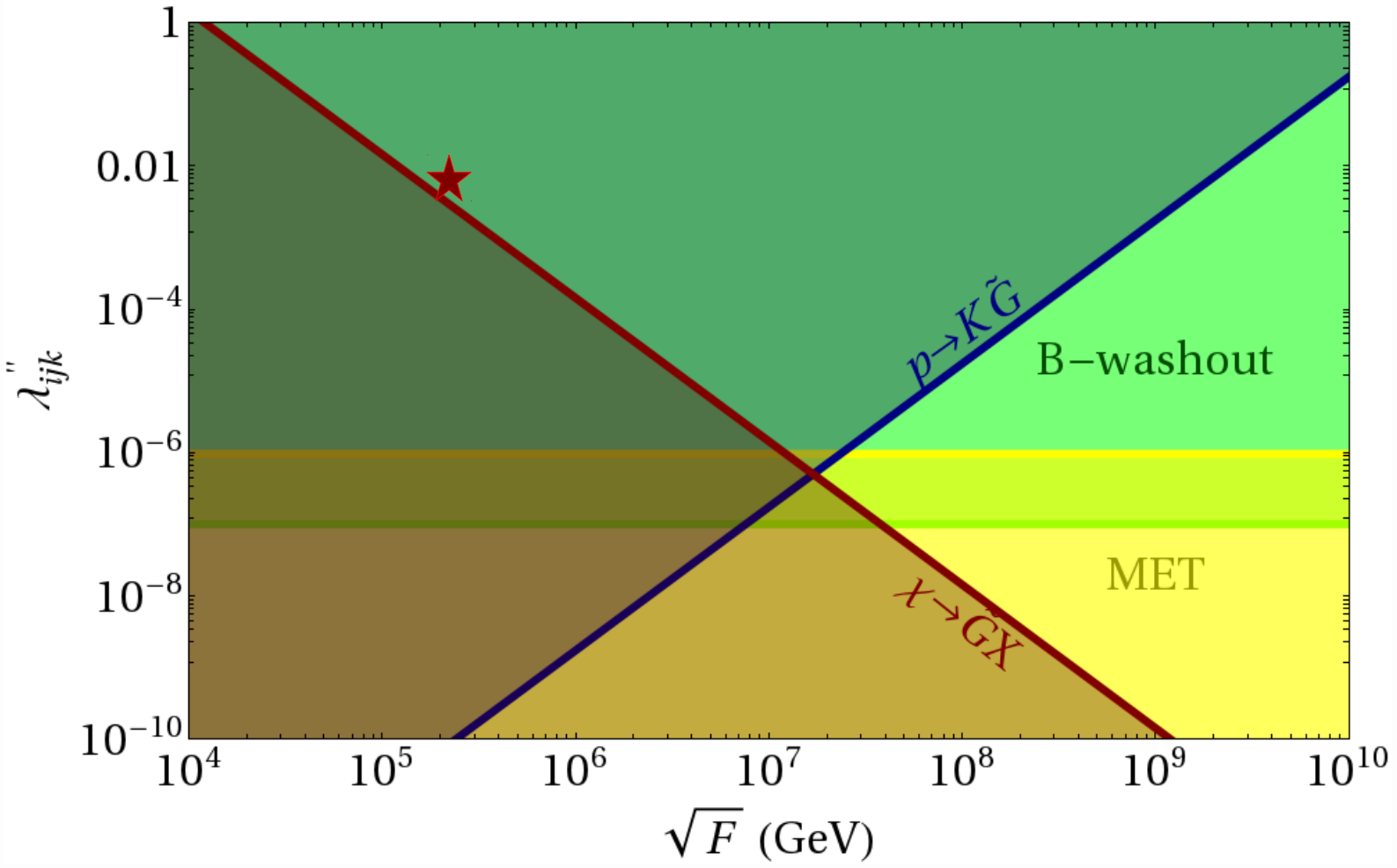

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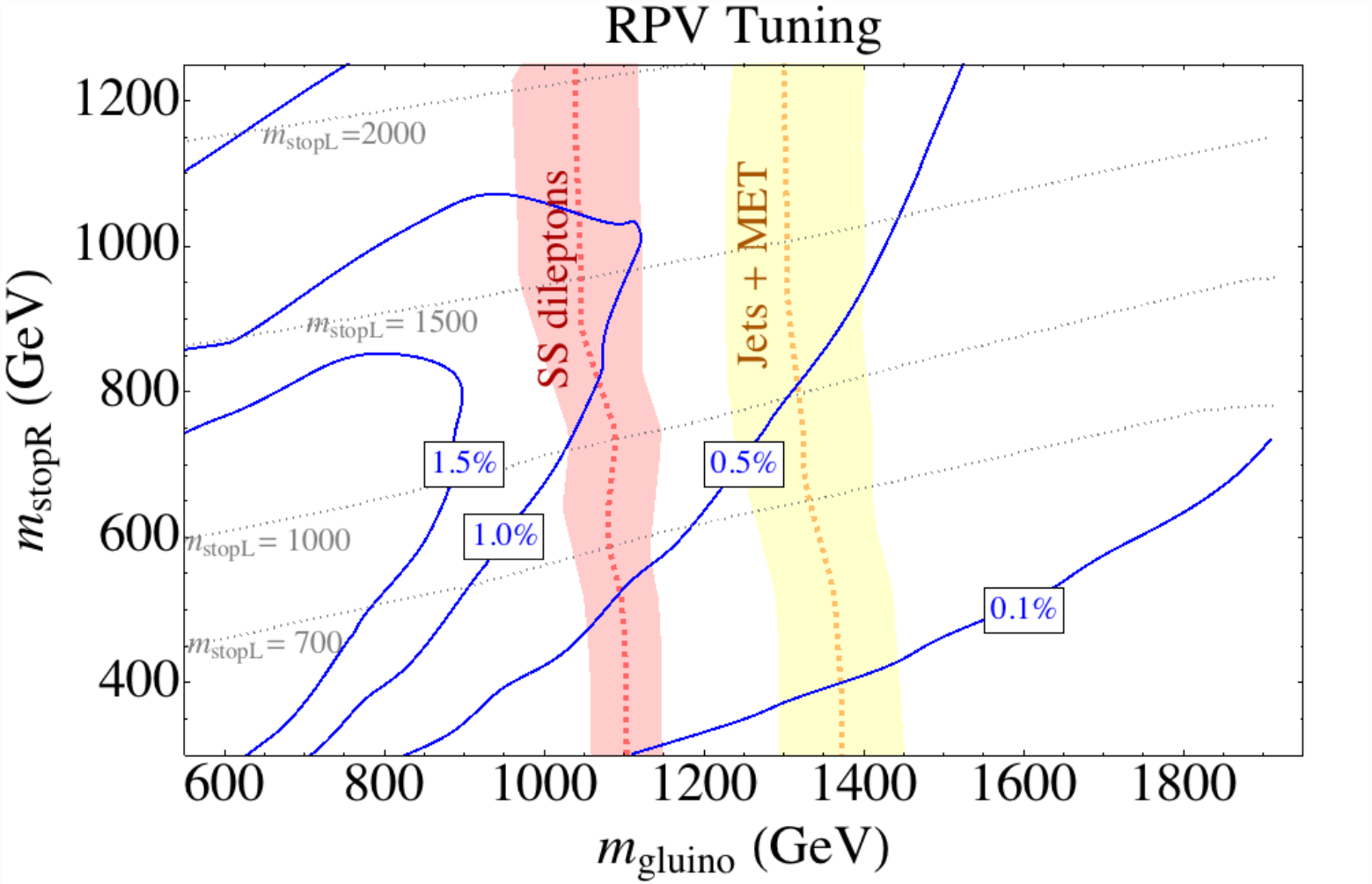
Baryonic RPV: (after model building)



“solution” #3:

Dirac gauginos

Dirac gauginos

$$m^2_{\mathrm{Re}(A_i)} = 4m^2_{Di} + m^2_{A_i} + B_{A_i} \qquad m^2_{\mathrm{Im}(A_i)} = m^2_{A_i} - B_{A_i}$$

$$\Delta_{\mathrm{finite}} m^2_{\tilde{f}} = \sum_i \frac{C_i(f)\alpha_i m^2_{Di}}{\pi} \log \frac{m^2_{\mathrm{Re}(A_i)}}{m^2_{Di}}$$

Dirac gauginos

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Dirac gauginos

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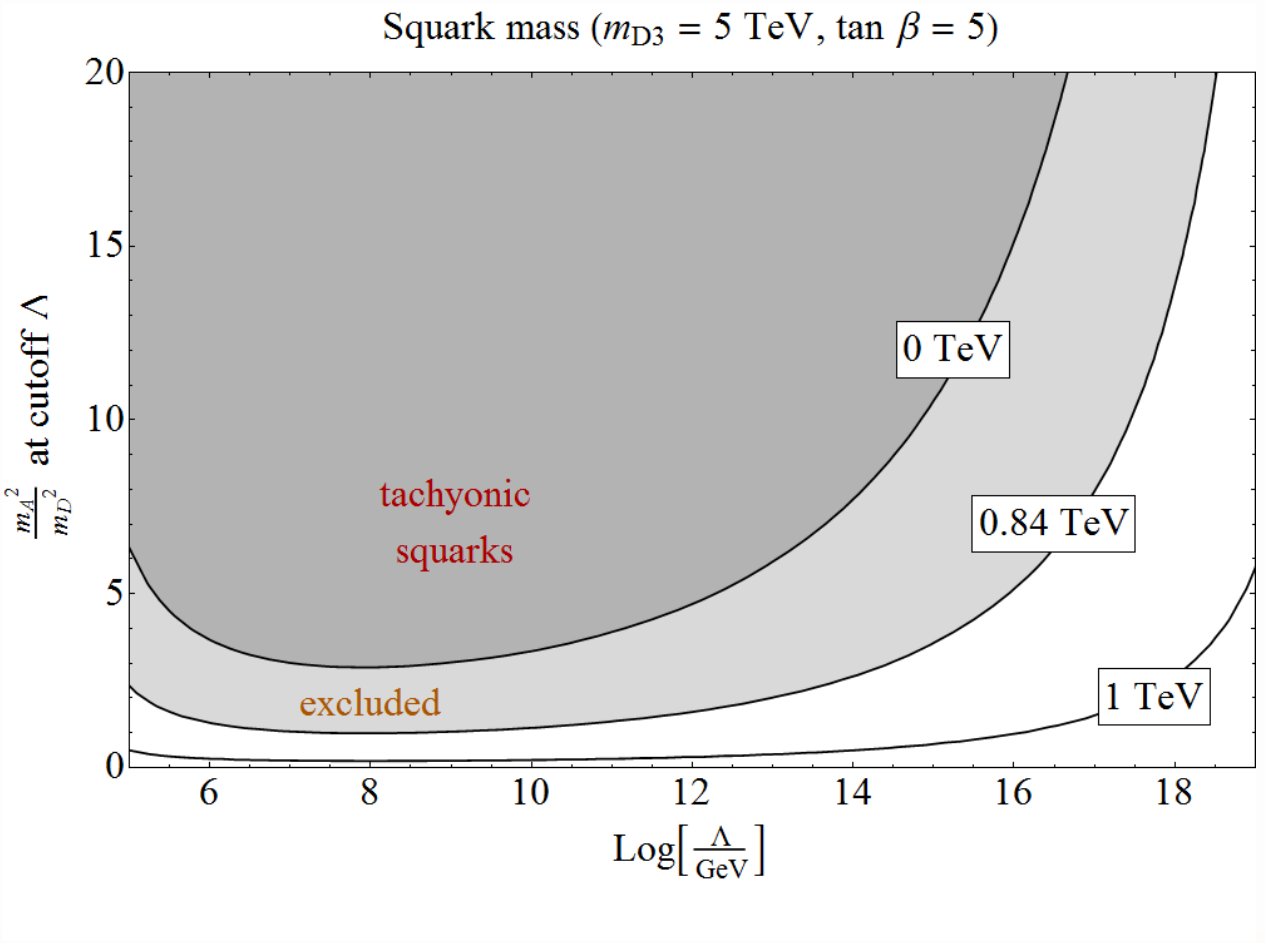
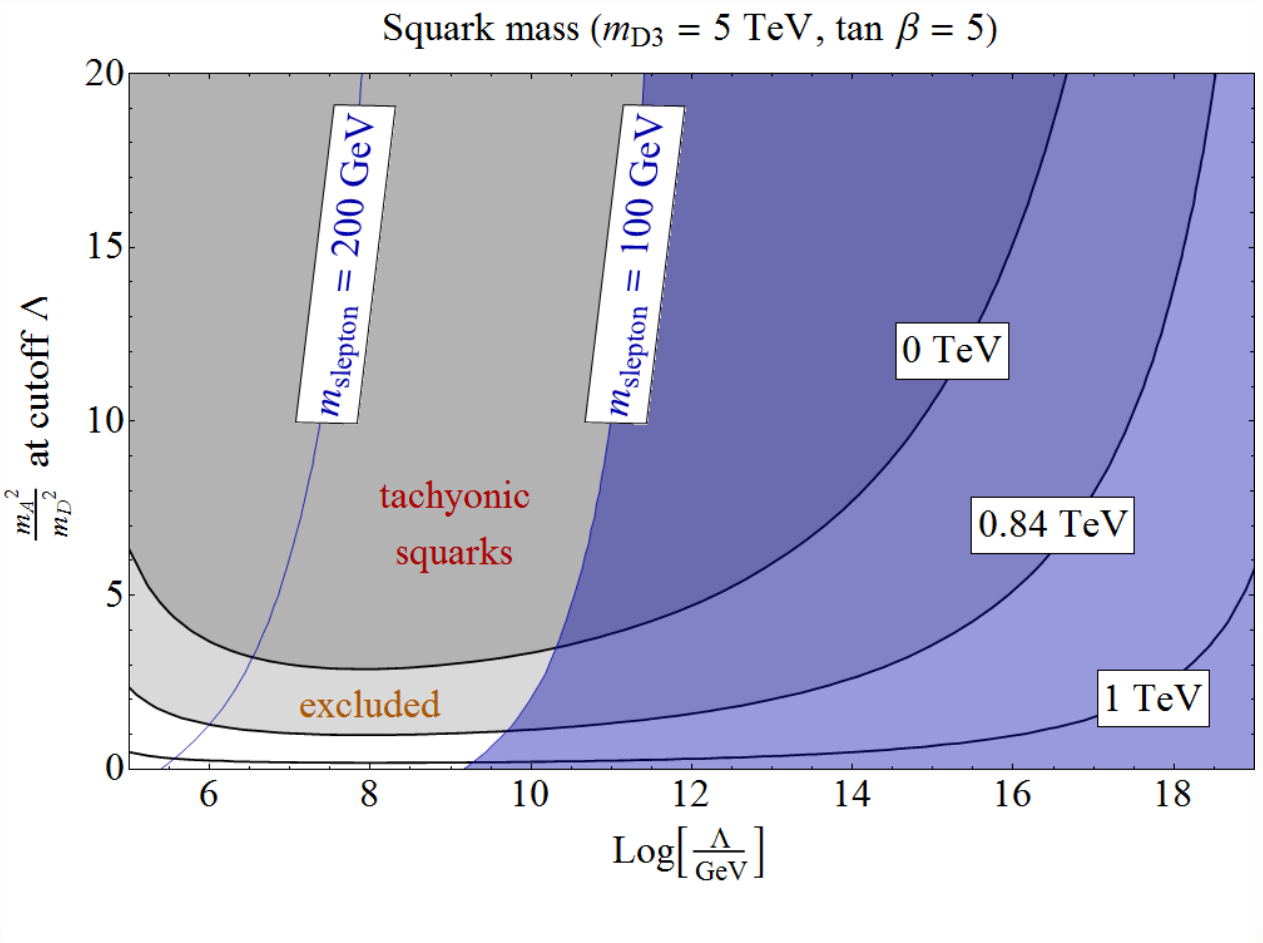


Dirac gauginos

$$m^2_{\mathrm{Re}(A_i)} = 4m^2_{Di} + m^2_{A_i} + B_{A_i} \qquad m^2_{\mathrm{Im}(A_i)} = m^2_{A_i} - B_{A_i}$$

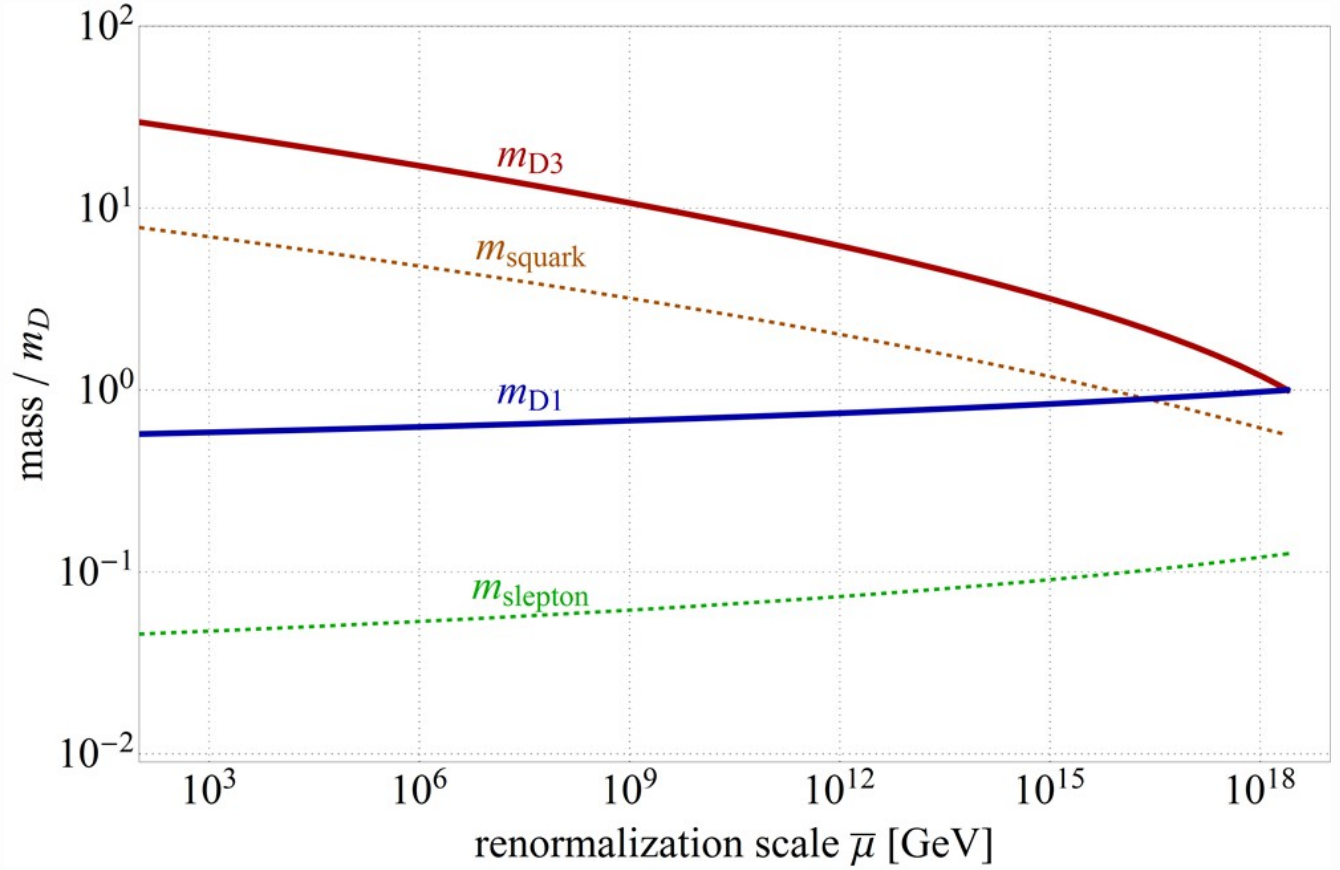
$$\Delta_{\mathrm{finite}} m^2_{\tilde{f}} = \sum_i \frac{C_i(f)\alpha_i m^2_{Di}}{\pi} \log \frac{m^2_{\mathrm{Re}(A_i)}}{m^2_{Di}} \qquad \partial_t m^2_{\tilde{q}} \simeq \frac{1}{(4\pi)^2} \frac{256}{3} \alpha_3^2 m^2_{A_3}$$



Dirac gauginos

$$m^2_{\mathrm{Re}(A_i)} = 4m^2_{Di} + m^2_{A_i} + B_{A_i} \qquad m^2_{\mathrm{Im}(A_i)} = m^2_{A_i} - B_{A_i}$$

$$\Delta_{\mathrm{finite}} m^2_{\tilde{f}} = \sum_i \frac{C_i(f)\alpha_i m^2_{Di}}{\pi} \log \frac{m^2_{\mathrm{Re}(A_i)}}{m^2_{Di}} \qquad \partial_t m^2_{\tilde{q}} \simeq \frac{1}{(4\pi)^2} \frac{256}{3} \alpha_3^2 m^2_{A_3}$$



Summary

	Before Model Building	After Model Building	After #$@#!&
Push-Up	0.5%	0.5%	
NMSSM	1%	1%	
Split Families	2%	<2%	
RPV	few %?	<1%	
Dirac	ND	ND	~0.1%


Tuneland
Λ_{cc}
Naturalness
m_e, Δm_K, Δm_π, ...


Tuneland
Λ_{cc} , EW?
Naturalness
m_e, Δm_K, Δm_π, ...
LHC

Principle of Naturalness

LHC

Phenomenologist