

SUSY after LHC-8

or

“Has Natural SUSY Expired?”

Giovanni Villadoro

ICTP

SUSY as the privileged BSM scenario:

- ✓ Largest space-time symmetry of QFT
- ✓ Natural framework for consistent String Theory

SUSY as the privileged BSM scenario:

- ✓ Largest space-time symmetry of QFT
- ✓ Natural framework for consistent String Theory
- ✓ Elegant solution to the hierarchy problem
- ✓ Successful “prediction” of Gauge Coupling Unification
- ✓ Natural WIMP candidate to Dark Matter

The Hierarchy Problem:

$$\delta v^2 \sim M_{np}^2 \sim \text{SUSY scale}$$

natural \rightarrow *susy scale* \sim *weak scale*

The Hierarchy Problem:

$$\delta v^2 \sim M_{np}^2 \sim \text{SUSY scale}$$

natural \rightarrow *susy scale* \sim *weak scale*

Except Λ_{cc} no real fine-tunings in nature:

$$(m_e \sim \Lambda \sim m_{e^+}, \Delta m_K \sim G_F \Lambda^2 \sim G_F m_c^2, \Delta m_\pi \sim \alpha \Lambda \sim \alpha m_\rho, \dots)$$

The Hierarchy Problem:

$$\delta v^2 \sim M_{np}^2 \sim \text{SUSY scale}$$

natural \rightarrow *susy scale* \sim *weak scale*

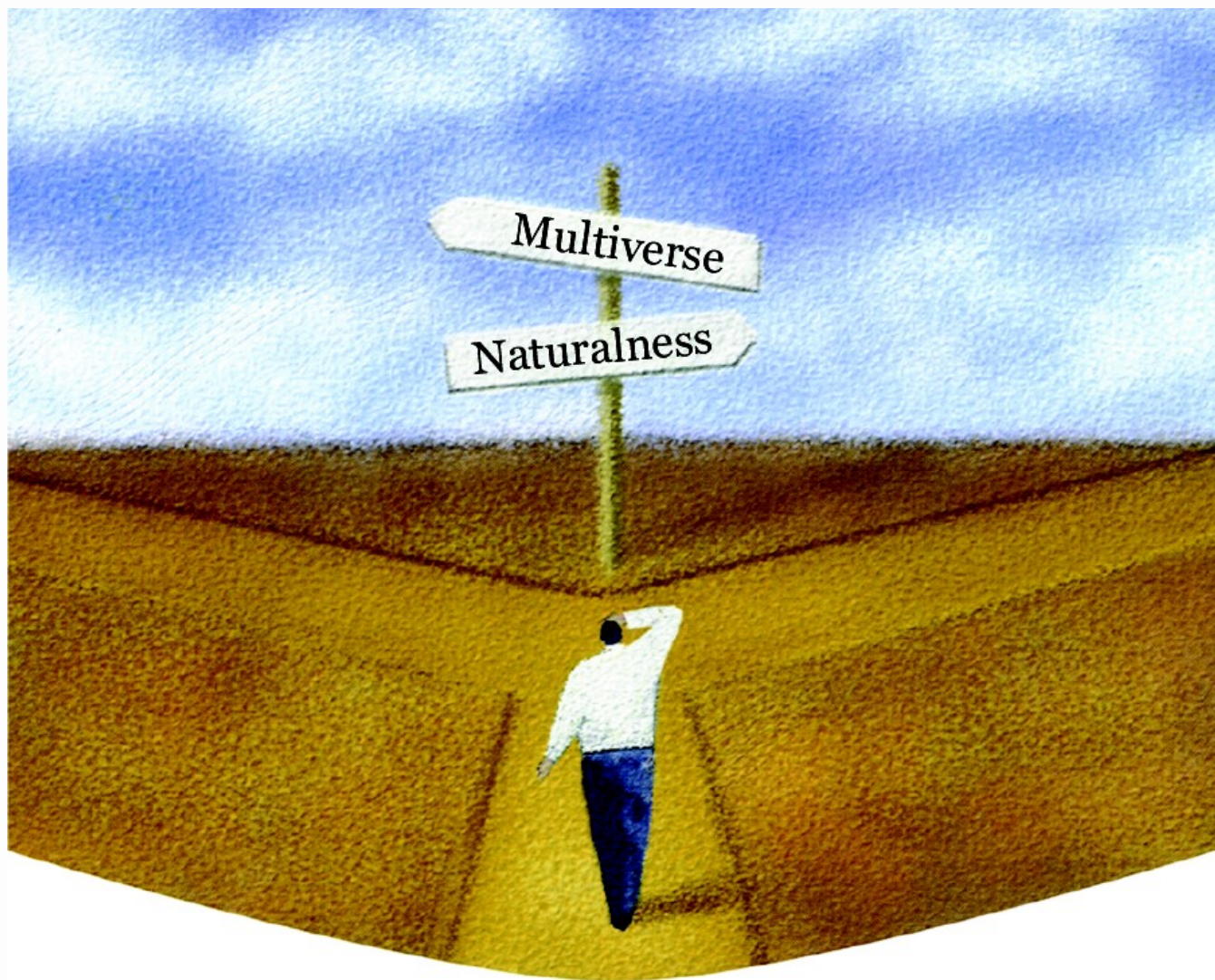
Except Λ_{cc} no real fine-tunings in nature:

$$(m_e \sim \Lambda \sim m_{e^+}, \Delta m_K \sim G_F \Lambda^2 \sim G_F m_c^2, \Delta m_\pi \sim \alpha \Lambda \sim \alpha m_\rho, \dots)$$

First warning signals after LEP

nothing below ~ 100 GeV, $m_h > 114.4$ GeV ...

+ EWPT, + flavor bounds, + EDMs



Fact #1:

The (not that) light Higgs

Fact #1: $m_h \simeq 125 \text{ GeV}$

Higgs mass in MSSM:

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

Fact #1: $m_h \simeq 125 \text{ GeV}$

Higgs mass in MSSM:

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

Fact #1: $m_h \simeq 125 \text{ GeV}$

Higgs mass in MSSM:

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

EW scale in MSSM:

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


Fact #1: $m_h \simeq 125 \text{ GeV}$

Higgs mass in MSSM:

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

EW scale in MSSM:

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


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

Fact #1: $m_h \simeq 125 \text{ GeV}$

in MSSM:

$m_h = 125 \text{ GeV} \Leftrightarrow \text{tuned } \sim 1\% \quad (\sim\text{‰ w/o } a\text{-terms})$

Fact #1: $m_h \simeq 125 \text{ GeV}$

in MSSM:

$$m_h = 125 \text{ GeV} \Leftrightarrow \text{tuned } \sim 1\% \quad (\sim\text{‰ w/o } a\text{-terms})$$

but already after LEP:

$$m_h > 114.4 \text{ GeV} \Leftrightarrow \text{tuned few-}\% \quad (<\% \text{ w/o } a\text{-terms})$$

Fact #1: $m_h \simeq 125 \text{ GeV}$

in MSSM:

$$m_h = 125 \text{ GeV} \Leftrightarrow \text{tuned } \sim 1\% \quad (\sim\% \text{ w/o } a\text{-terms})$$

but already after LEP:

$$m_h > 114.4 \text{ GeV} \Leftrightarrow \text{tuned few-}\% \quad (<\% \text{ w/o } a\text{-terms})$$

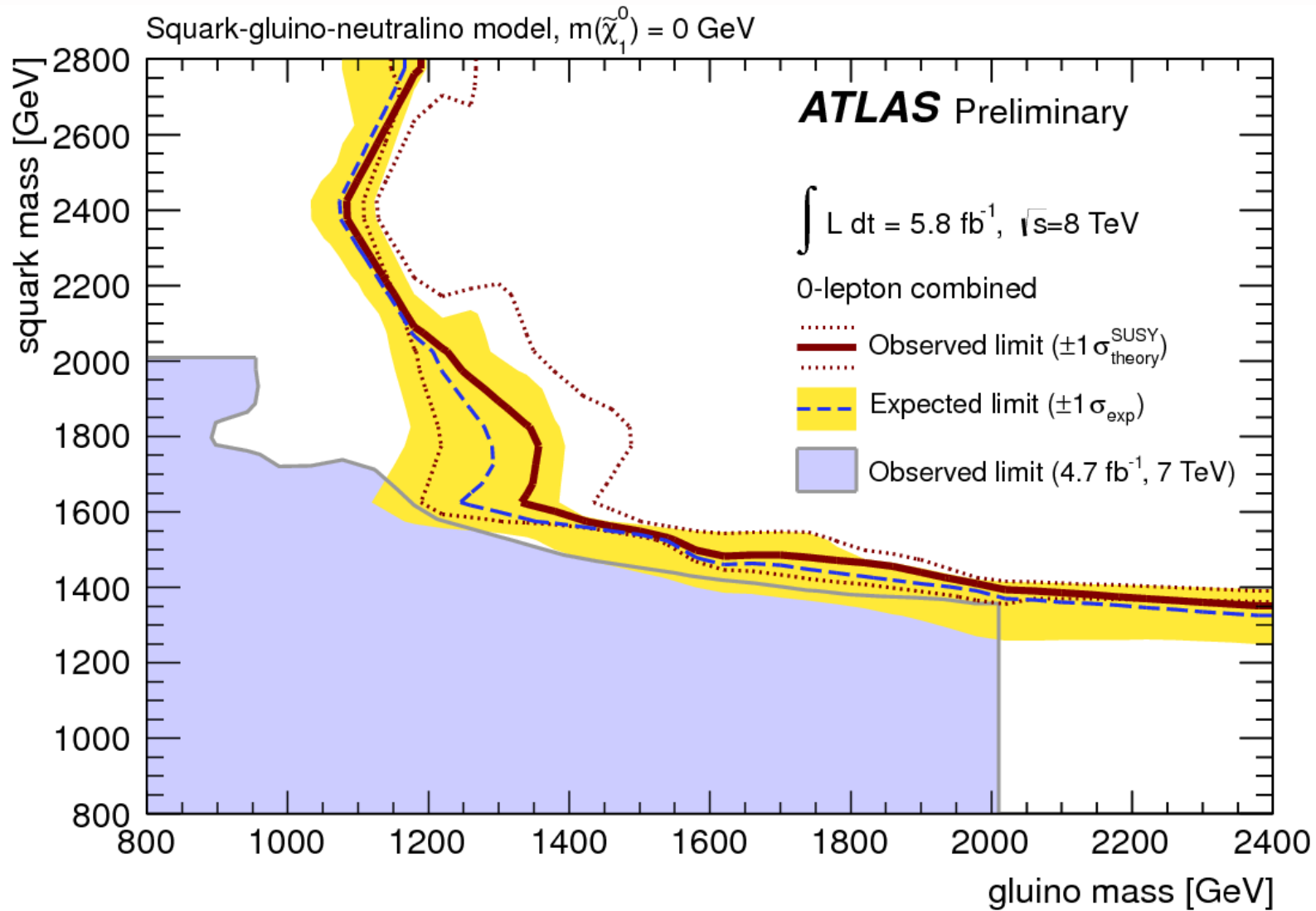
indirect bound on SUSY

$$\lambda_H = \frac{1}{4}(g^2 + g'^2) + \lambda_{extra} \left\{ \begin{array}{l} \text{F-terms: NMSSM / } \lambda\text{SUSY} \\ \text{D-terms: extra gauge groups} \\ \text{loops: extra vector-like gen.} \\ \dots \end{array} \right.$$

Fact #2:

The Missing Superpartner Problem

Fact #2: no 1st gen. squarks



solution #1

“Natural” SUSY

“Natural” SUSY


Dimopoulos-Giudice, Pomarol-Tommasini '95

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

“Natural” SUSY

Dimopoulos-Giudice, Pomarol-Tommasini '95


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



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

“Natural” SUSY

Dimopoulos-Giudice, Pomarol-Tommasini '95

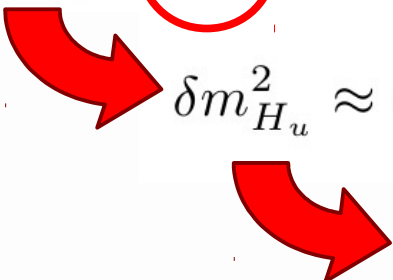
$$m_Z^2 = -2(m_{H_u}^2 + |\mu|^2) + \dots$$


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


$$\delta m_{\tilde{t}}^2 = \frac{8\alpha_s}{3\pi} M_3^2 \log \frac{\Lambda}{M_3}$$

“Natural” SUSY

Dimopoulos-Giudice, Pomarol-Tommasini '95

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

$$\delta m_{H_u}^2 \approx -\frac{3y_t^2 m_{\tilde{t}}^2}{4\pi^2} (1 + a^2/2) \log \frac{\Lambda}{m_{\tilde{t}}}$$
$$\delta m_{\tilde{t}}^2 = \frac{8\alpha_s}{3\pi} M_3^2 \log \frac{\Lambda}{M_3}$$

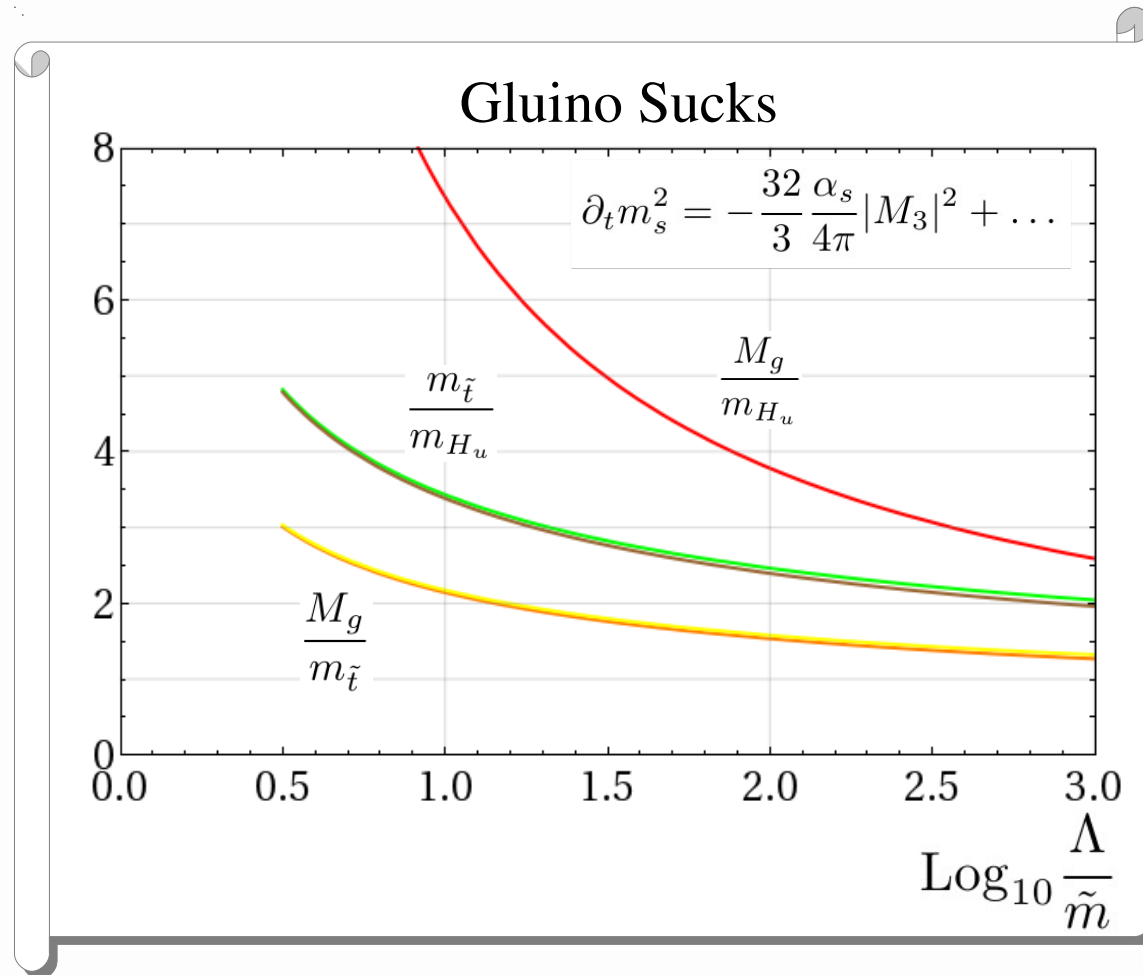
Only need light **higgsinos, stops, gluinos**
(and light mess. scale Λ)

Natural SUSY

Mild cancellation (10% tuning) requires
 $\mu \lesssim 250 \text{ GeV}$, $m_{stop} \lesssim 700 \text{ GeV}$, $M_{gluino} \lesssim 1.4 \text{ TeV}$

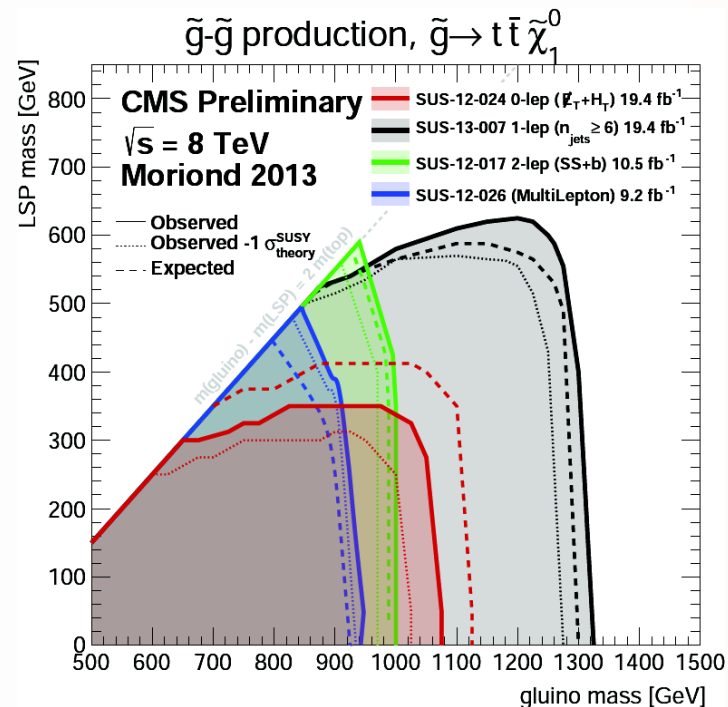
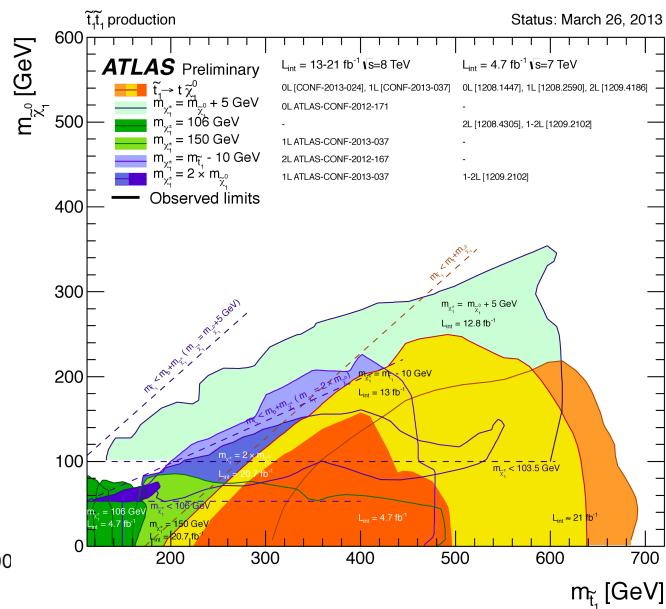
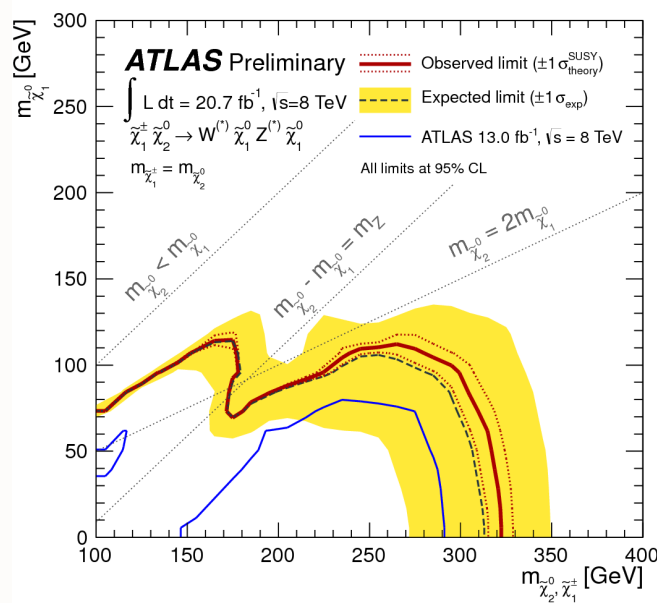
Natural SUSY

Mild cancellation (10% tuning) requires
 $\mu \lesssim 250$ GeV, $m_{stop} \lesssim 700$ GeV, $M_{gluino} \lesssim 1.4$ TeV

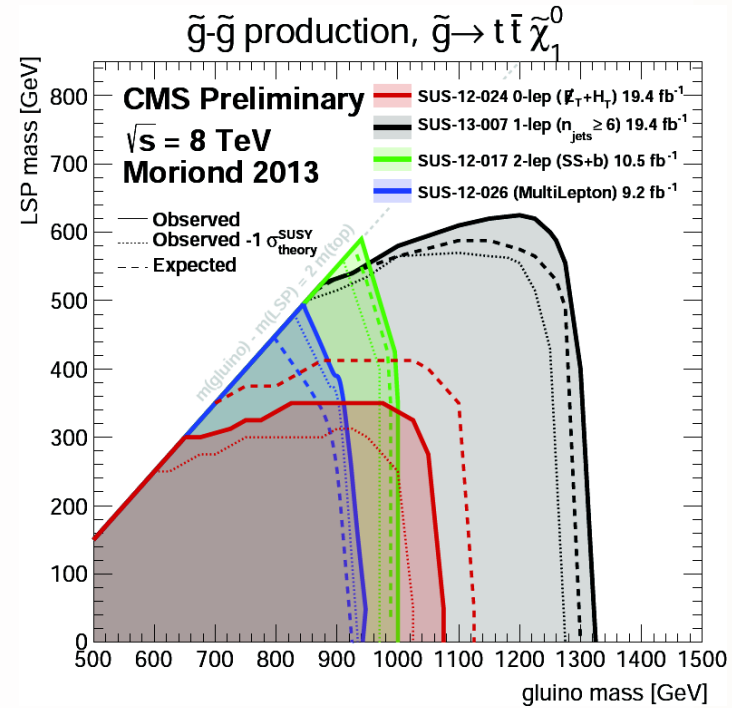
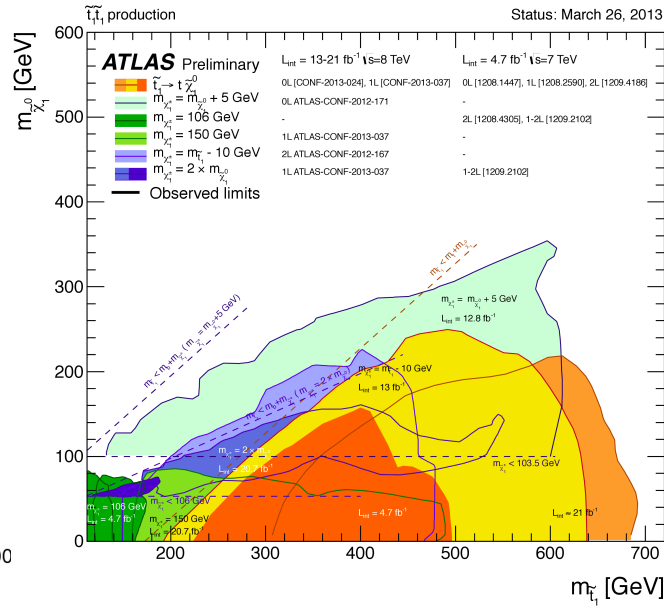
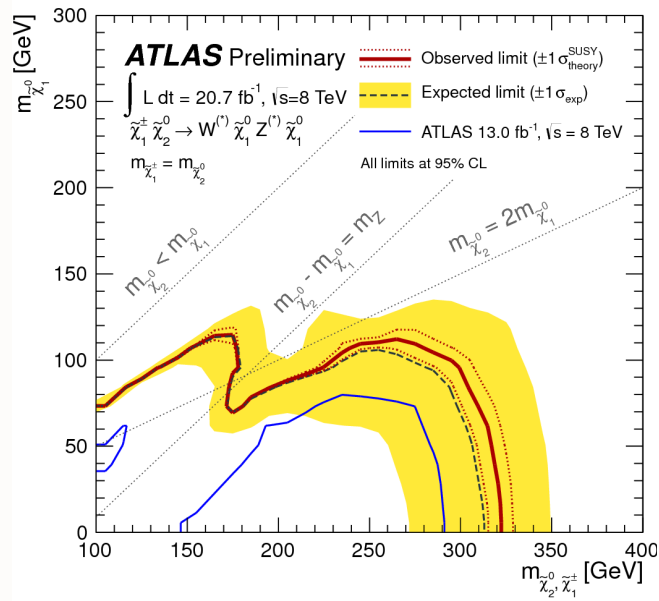


Status of Natural SUSY

EWino, Stop, Gluino Bounds



EWino, Stop, Gluino Bounds



$$\mu \gtrsim 320 \text{ GeV}$$

(unless LSP or long-lived NLSP or LSP > 100 GeV)

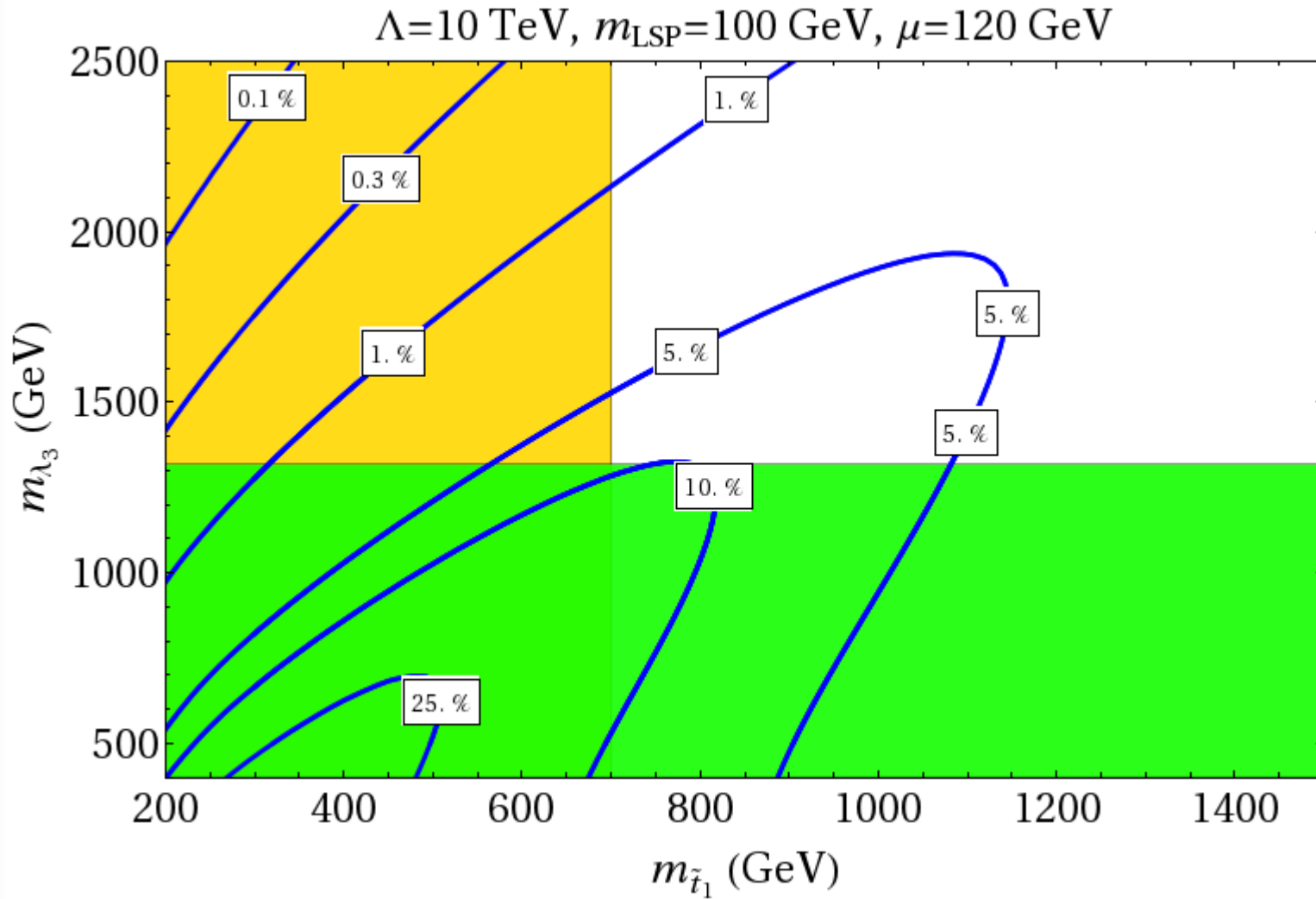
$$m_{\text{stop}} \gtrsim 700 \text{ GeV}$$

(unless heavy LSP or cracks or...)

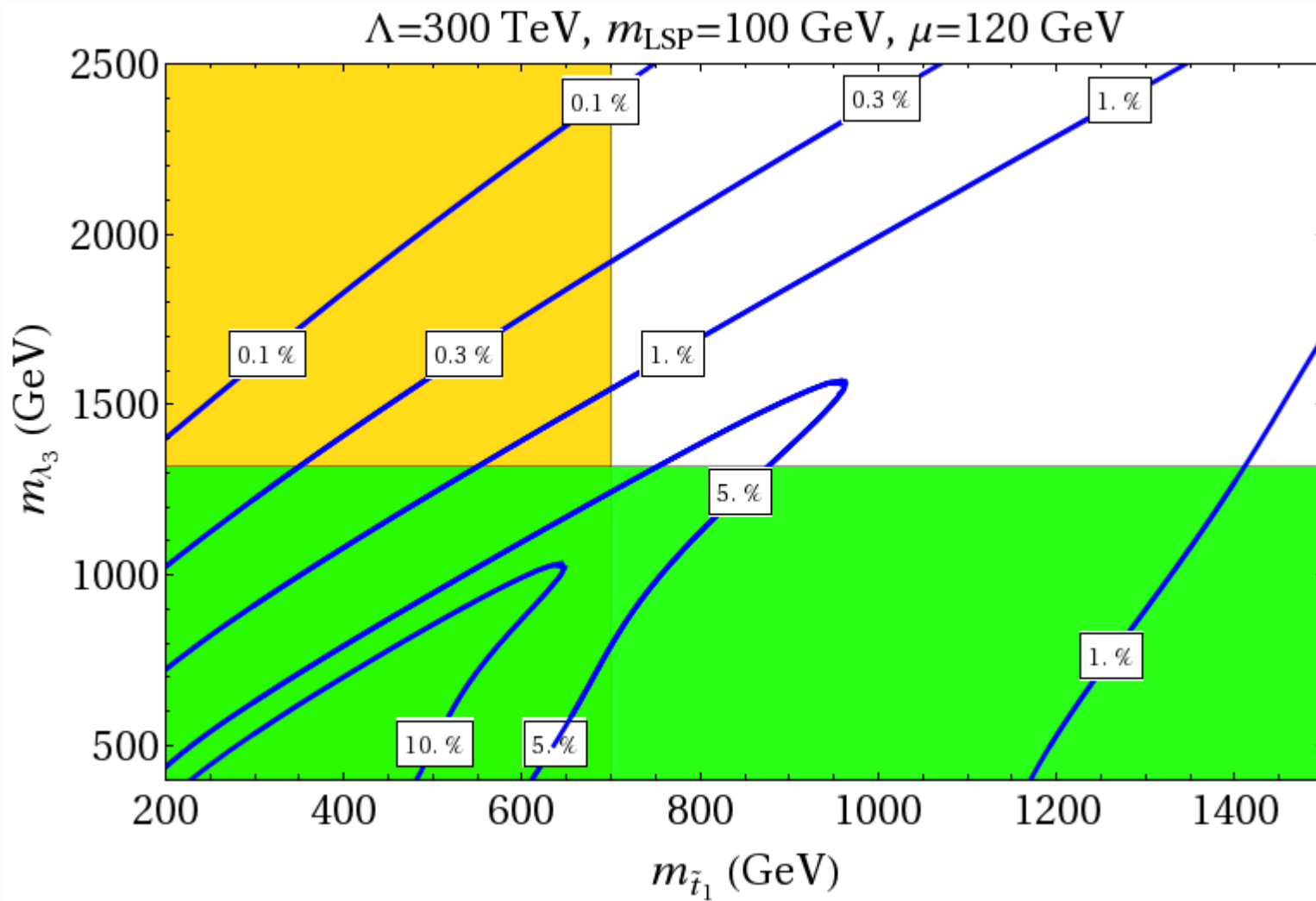
$$M_{\text{gluino}} \gtrsim 1300 \text{ GeV}$$

(unless suppressed BR...)

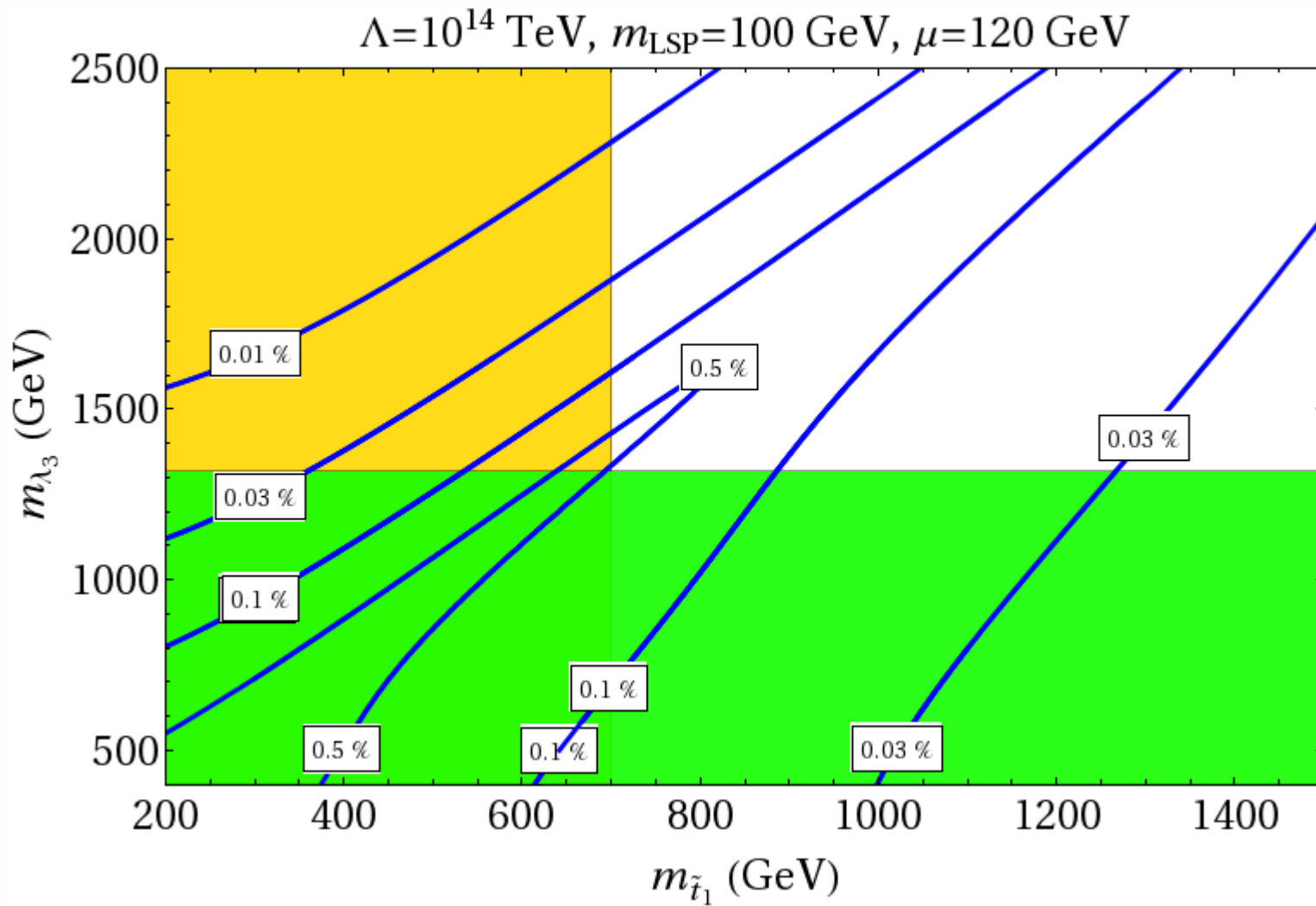
Is “Natural” SUSY Natural?



Is “Natural” SUSY Natural?



Is “Natural” SUSY Natural?



solution #2

No Missing Energy SUSY (RPV)

RPV SUSY

$$W_{RPV} = \mu_i H_u L_i + \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c.$$

RPV SUSY

$$W_{RPV} = \mu_i \tilde{H}_u L_i + \frac{1}{2} \lambda_{ijk} \tilde{L}_i L_j E_k^c + \lambda'_{ijk} \tilde{L}_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c.$$

Leptonic RPV:

many leptons in the final state!

RPV SUSY

$$W_{RPV} = \mu_i \bar{H}_u L_i + \frac{1}{2} \lambda_{ijk} \bar{L}_i L_j E_k^c + \lambda'_{ijk} \bar{L}_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c.$$

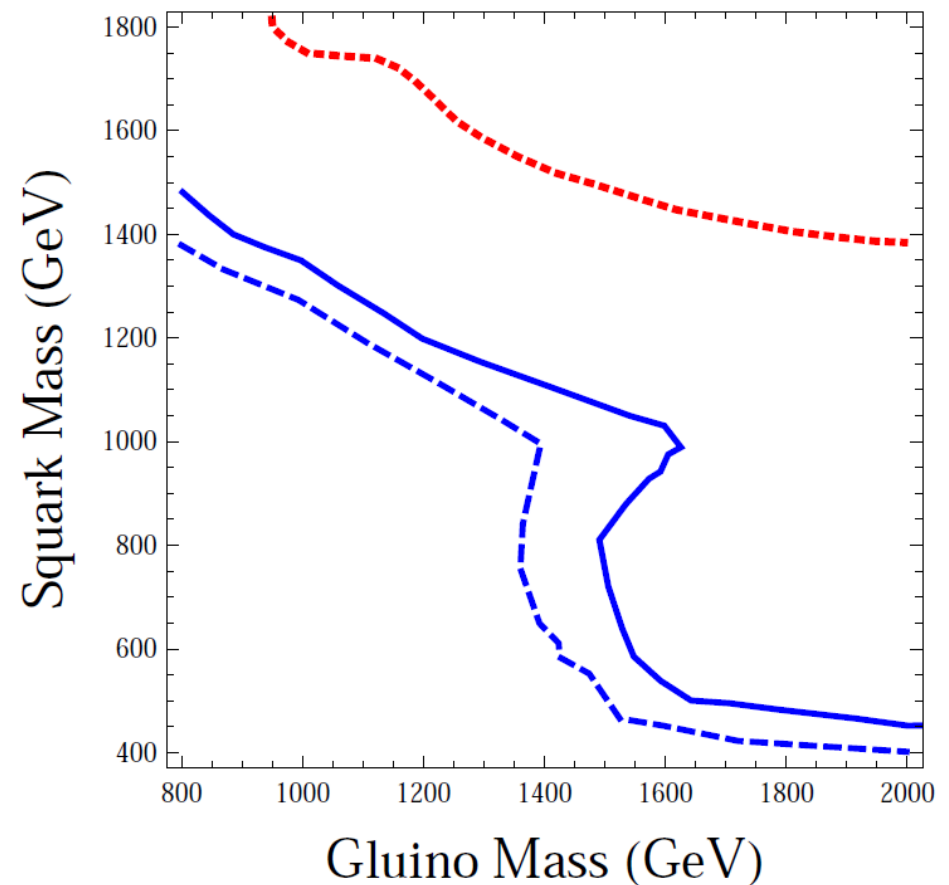
Leptonic RPV:

many leptons in the final state!

or

play dirty: “displaced susy”

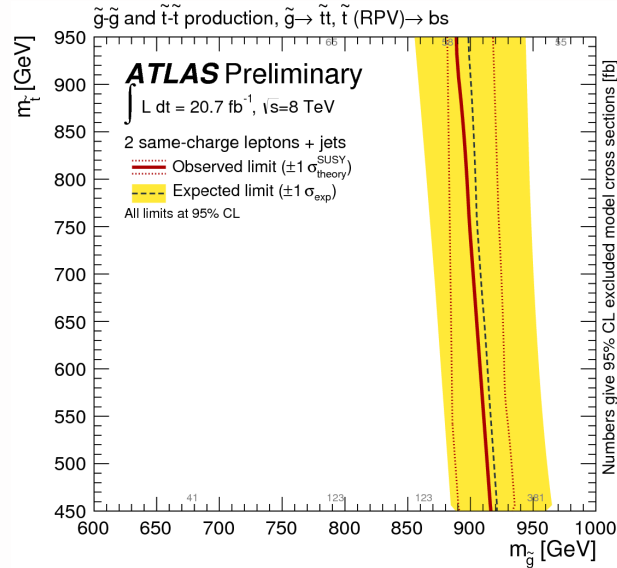
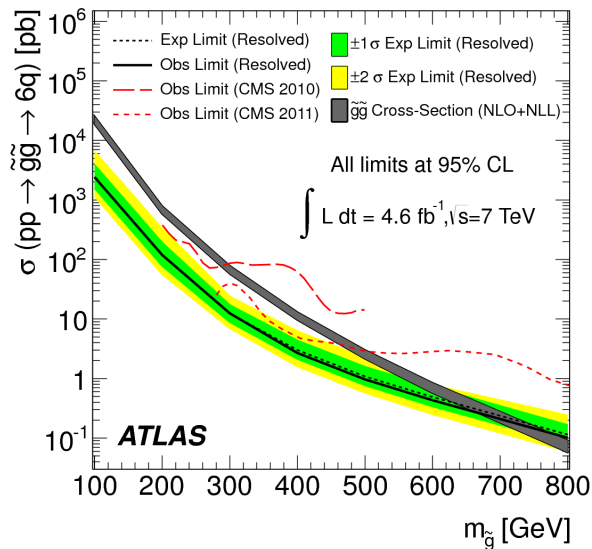
Graham, Kaplan, Rajendran, Saraswat '12



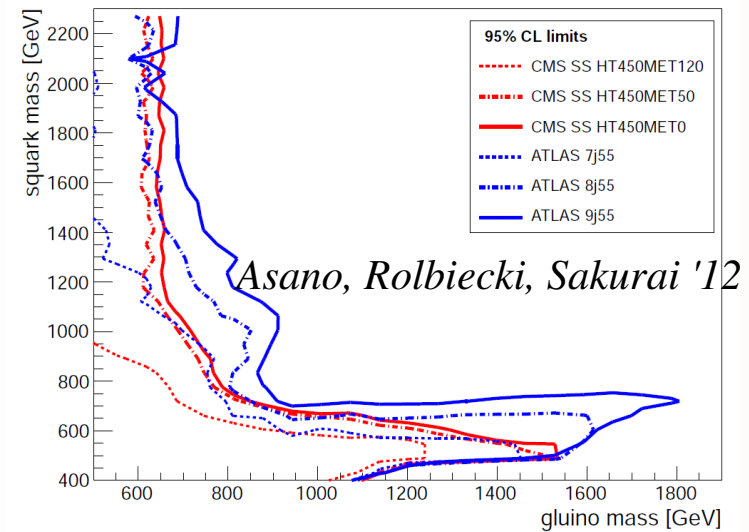
RPV SUSY

$$W_{RPV} = \mu_i H_u L_i + \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c.$$

Baryonic RPV:



simplified model + UDD



RPV SUSY

$$W_{RPV} = \mu_i H_u L_i + \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c.$$

Baryonic RPV:

- $p \rightarrow K^+ G \Rightarrow \lambda'' \lesssim 10^{-8 \div -17} \Rightarrow m_{3/2} > 1 \text{ GeV}$
- n - n , N - N osc. $\Rightarrow \lambda''_{11k} \lesssim 10^{-6}$
- $\tau < \text{detector} \Rightarrow \lambda'' \gtrsim 10^{-6} (\chi^0), \lambda'' \gtrsim 10^{-9} (sq)$
- F_{susy} not too low
- baryon number wash-out...

RPV SUSY

$$W_{RPV} = \mu_i H_u L_i + \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c.$$

- Baryonic RPV:**
- $p \rightarrow K^+ G \Rightarrow \lambda'' \lesssim 10^{-8-17} \Rightarrow m_{3/2} > 1 \text{ GeV}$
 - n - n , N - N osc. $\Rightarrow \lambda''_{llk} \lesssim 10^{-6}$
 - $\tau < \text{detector} \Rightarrow \lambda'' \gtrsim 10^{-6} (\chi^0), \lambda'' \gtrsim 10^{-9} (sq)$
 - F_{susy} not too low
 - baryon number wash-out...

Required ingredients:

- Higgs fix
- low scale mediation (but not too low)
- extra susy breaking sector ($m_p < m_{3/2} < 5 \text{ GeV}$)
- non-universal gaugino masses
- avoid vanilla spectra: leptons, W , Z ...
- hierarchical λ''

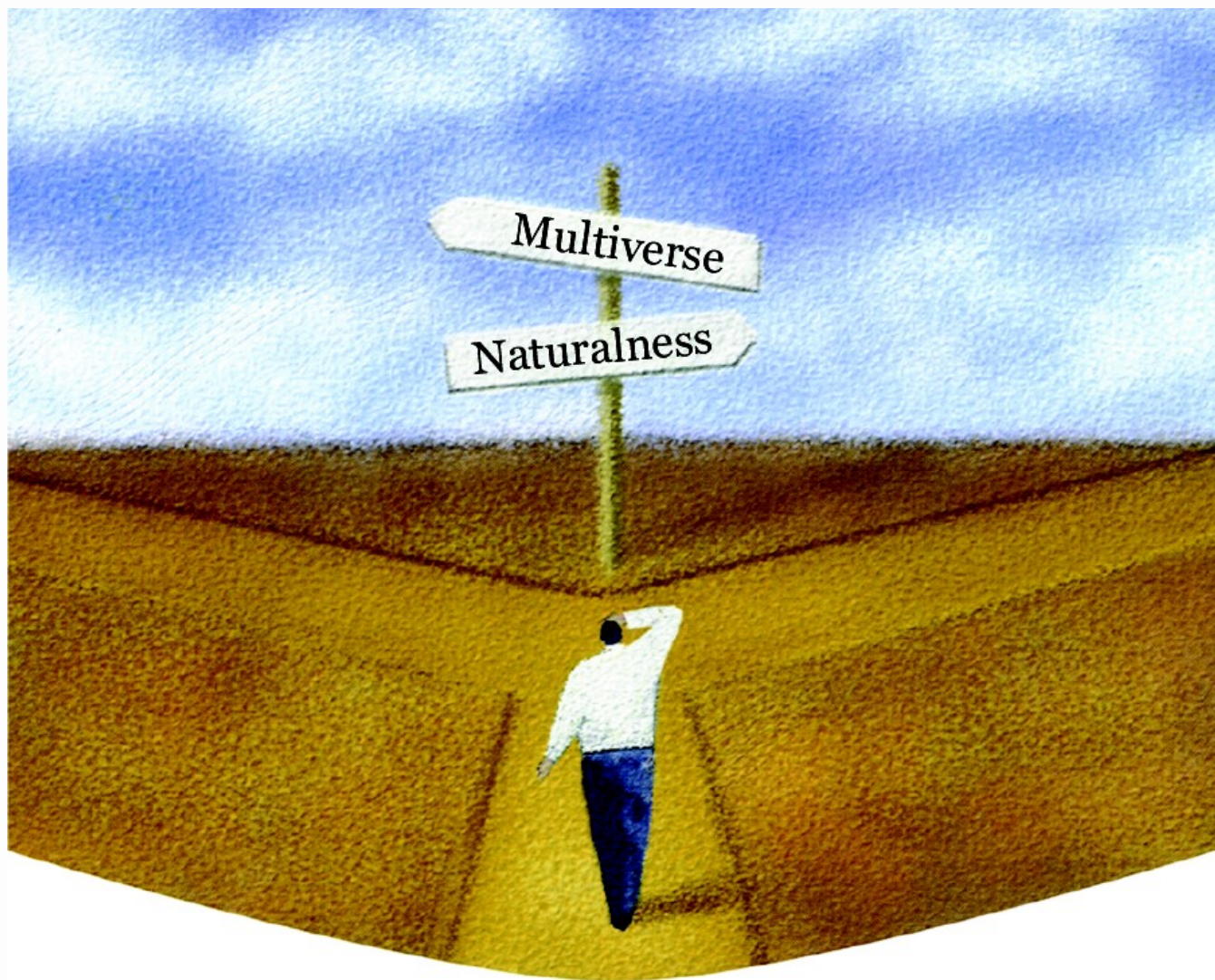
Less “canonical” tuning?

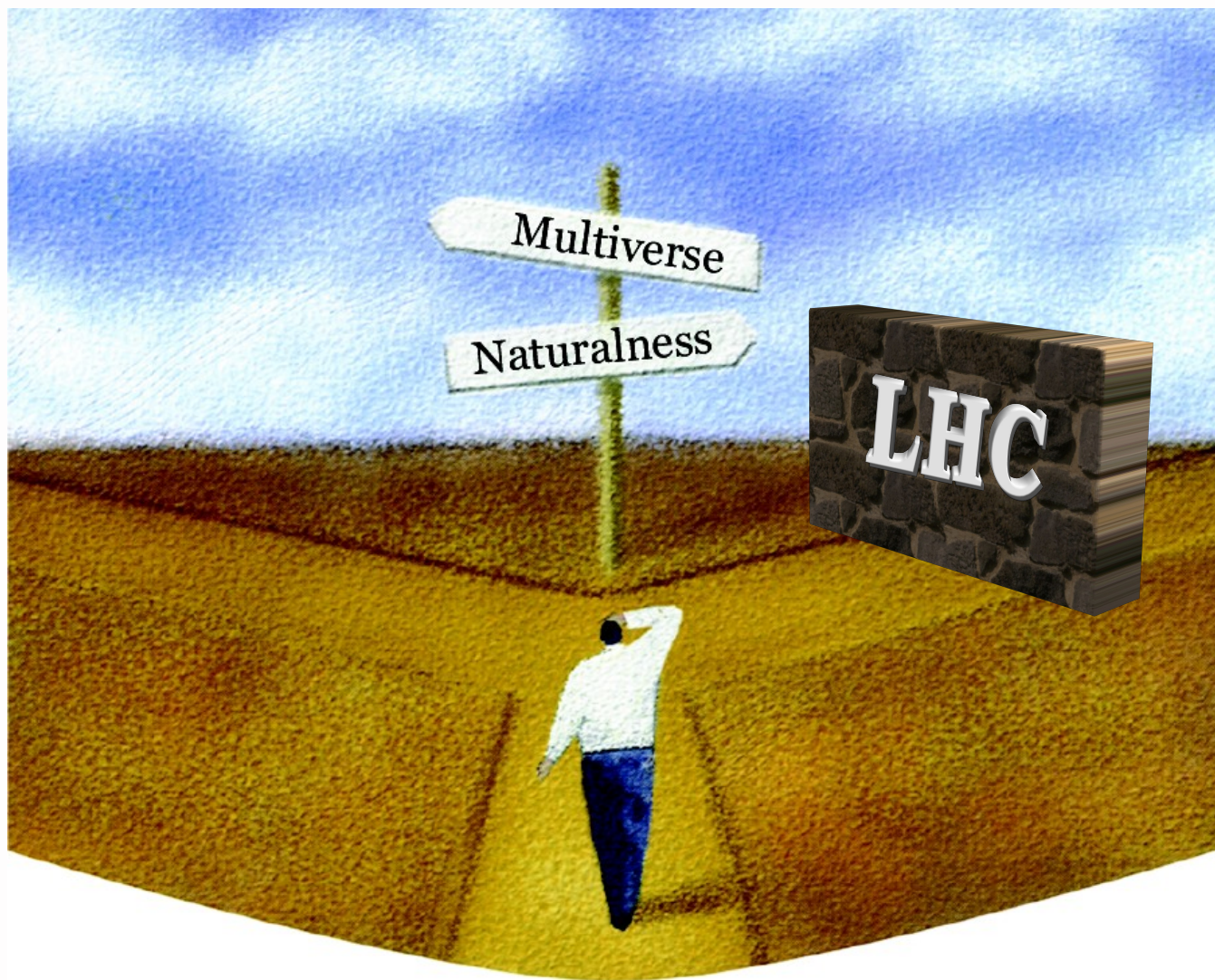
More “hidden” tunings?

what about combining more mechanisms?

not really an option if the goal is naturalness...

...tuning in theory space!

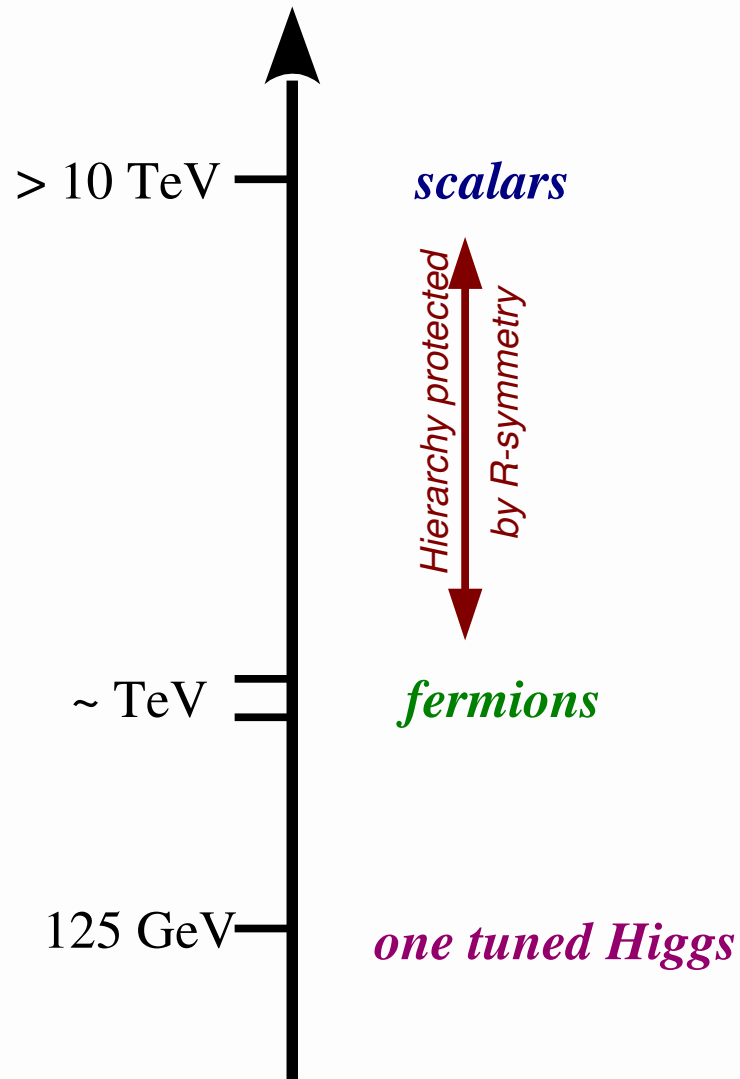




The “unnatural” alternative:
(Mini) Split SUSY

Split SUSY spectrum

Arkani-Hamed and Dimopoulos '04

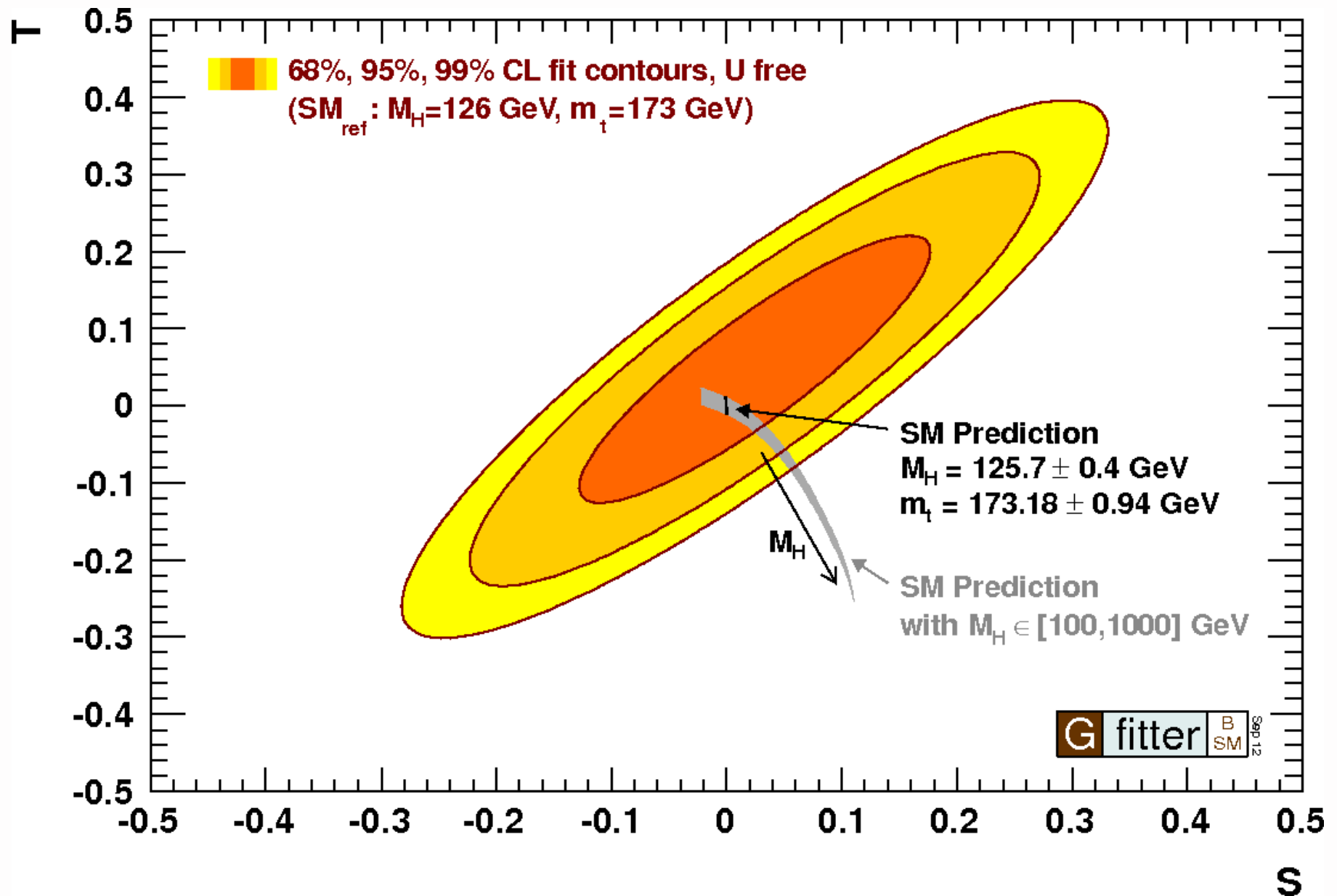


*Avoids problems with flavor,
EDM and collider bounds*

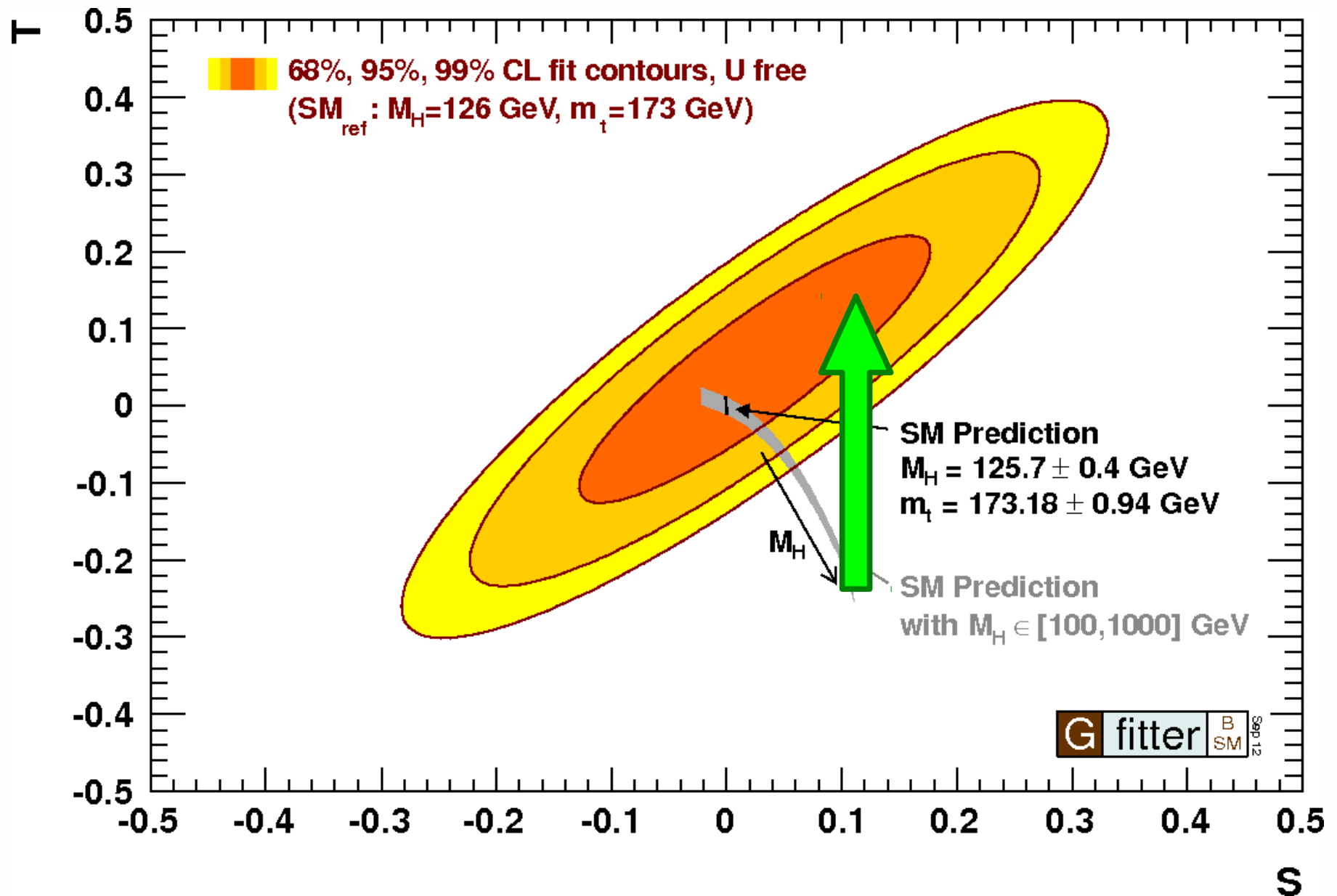
*Preserves successful
Gauge Coupling Unification
and Dark Matter*

Why to insist on SUSY?

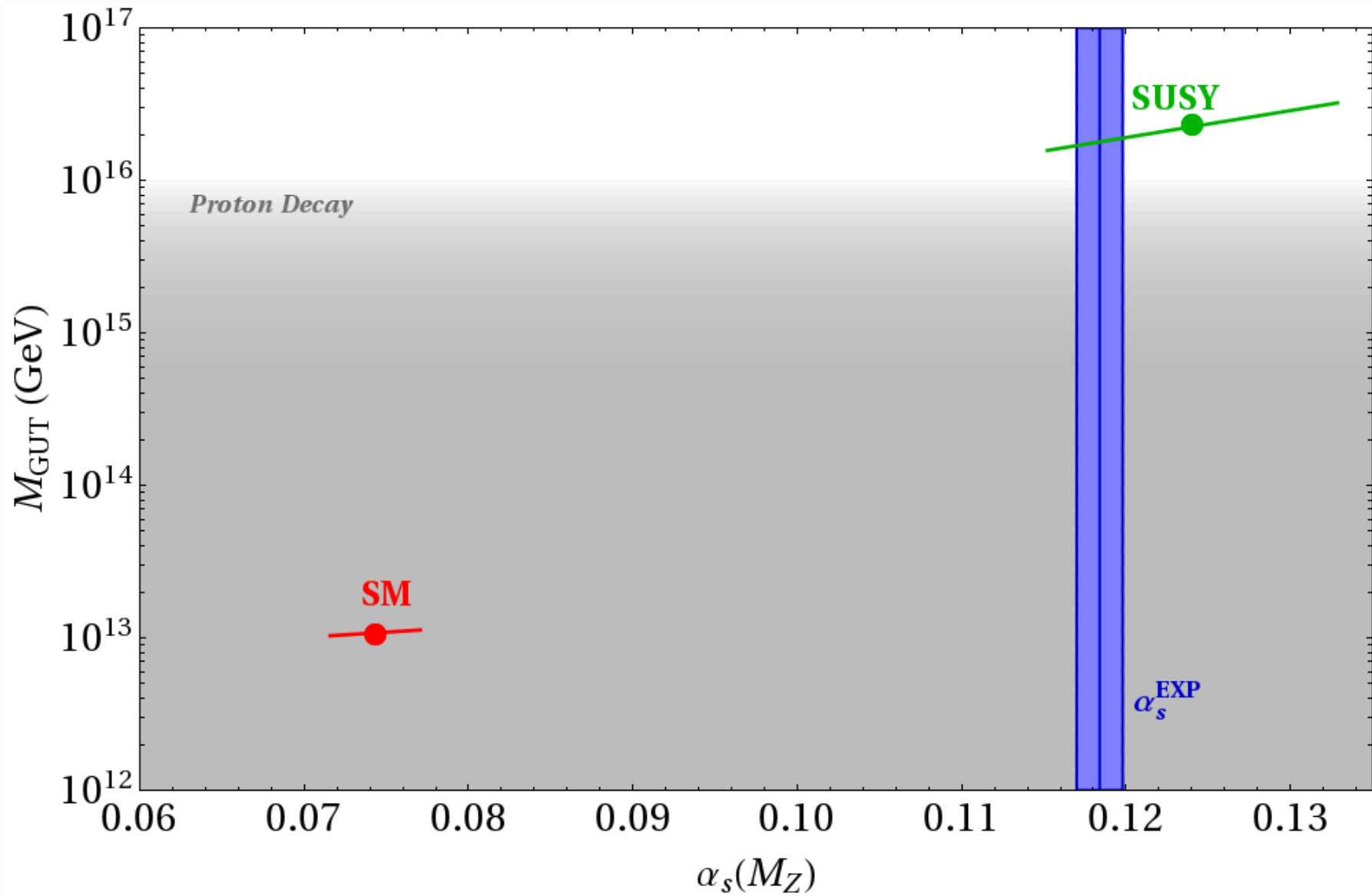
An analogy



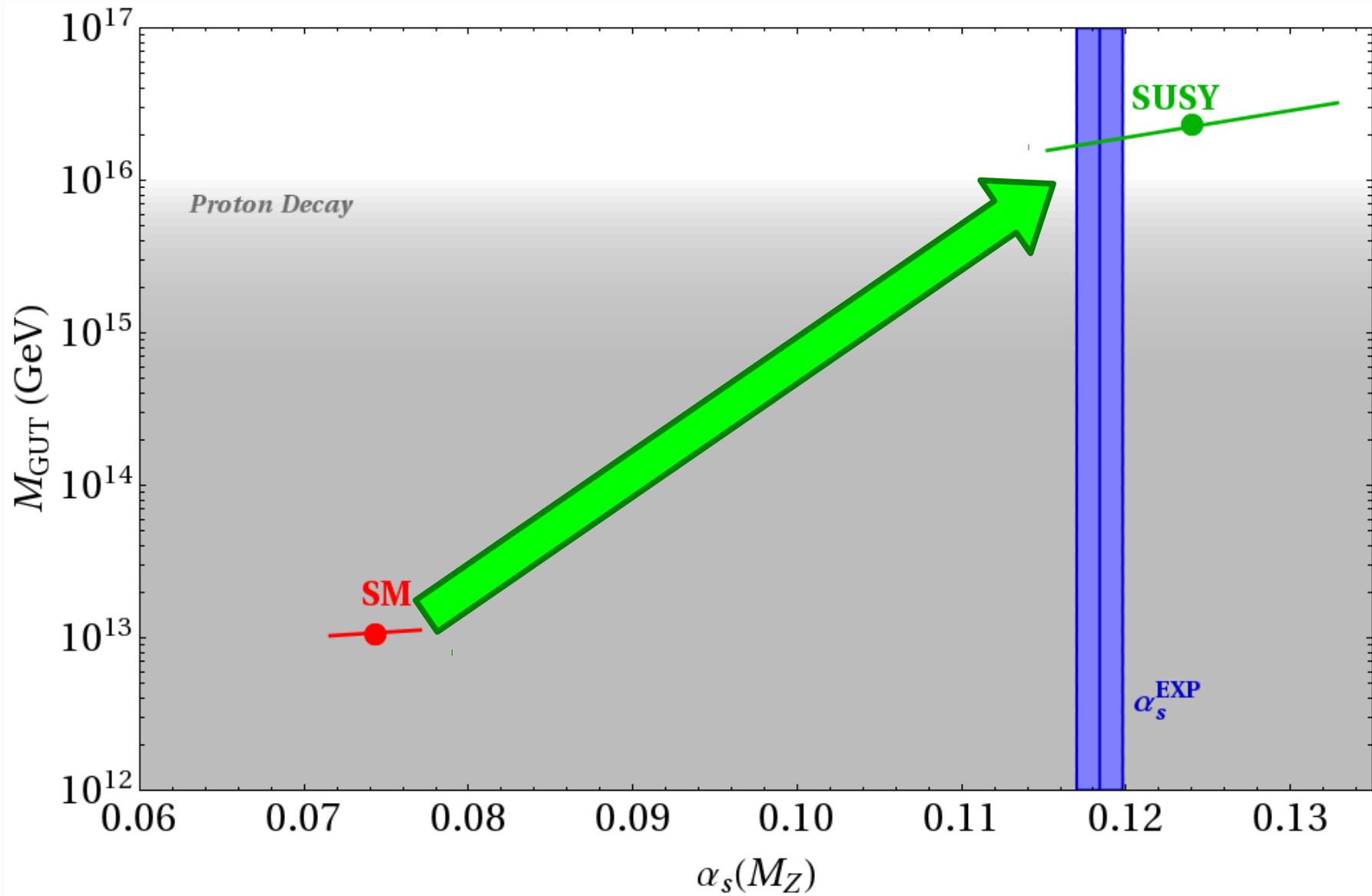
An analogy



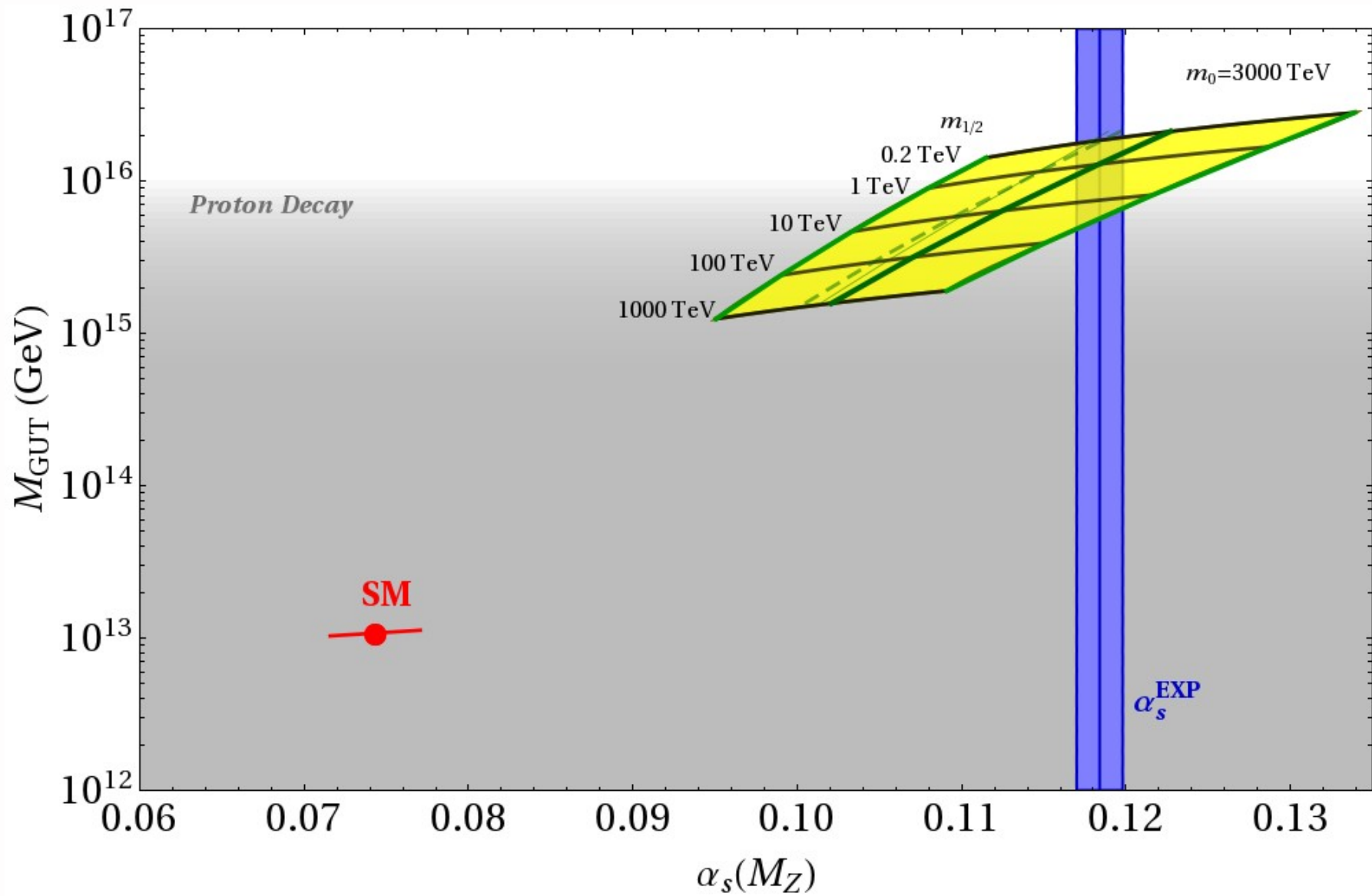
An analogy



An analogy



An analogy



“Mini”-Split SUSY

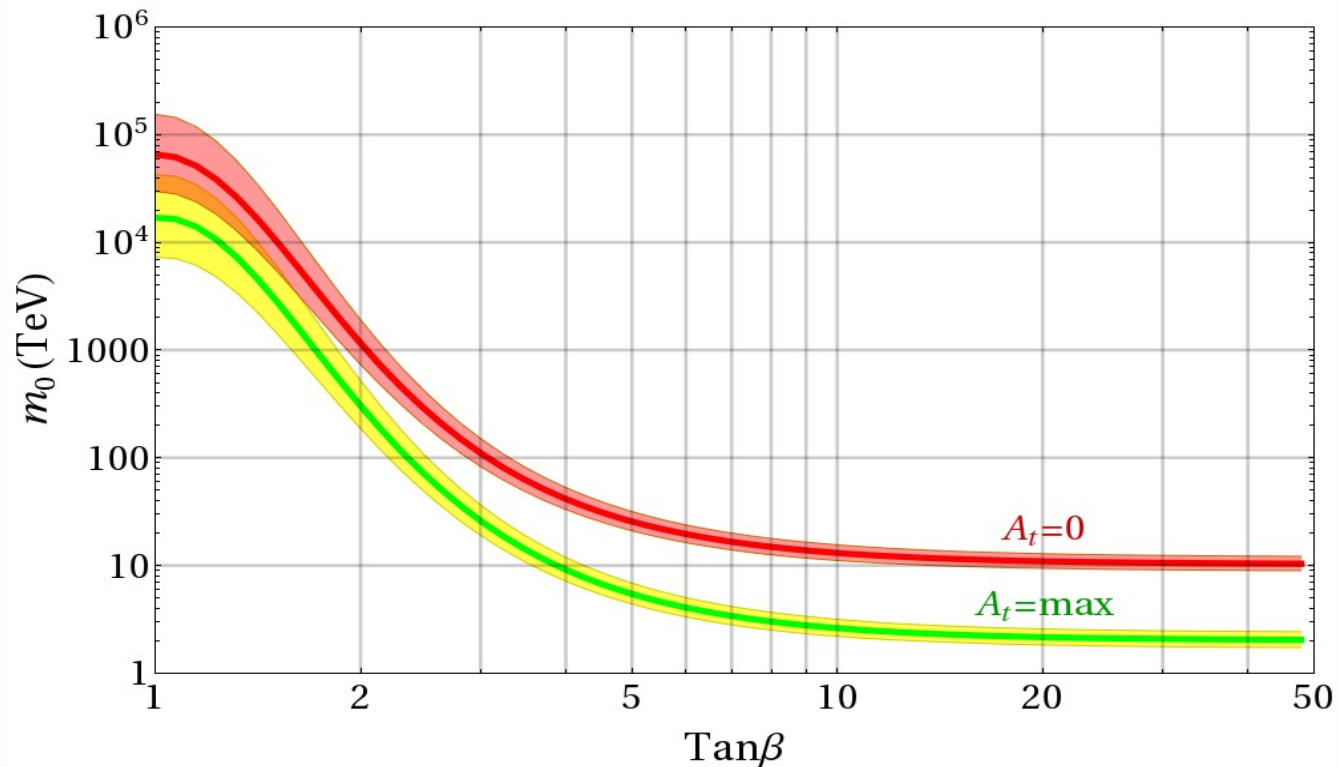
$m_H \sim 125.5$ GeV fixes $\lambda(m_H)$

SUSY fixes $\lambda(\tilde{m}) = \frac{[g^2(\tilde{m}) + g'^2(\tilde{m})]}{4} \cos^2 2\beta$

“Mini”-Split SUSY

$m_H \sim 125.5$ GeV fixes $\lambda(m_H)$

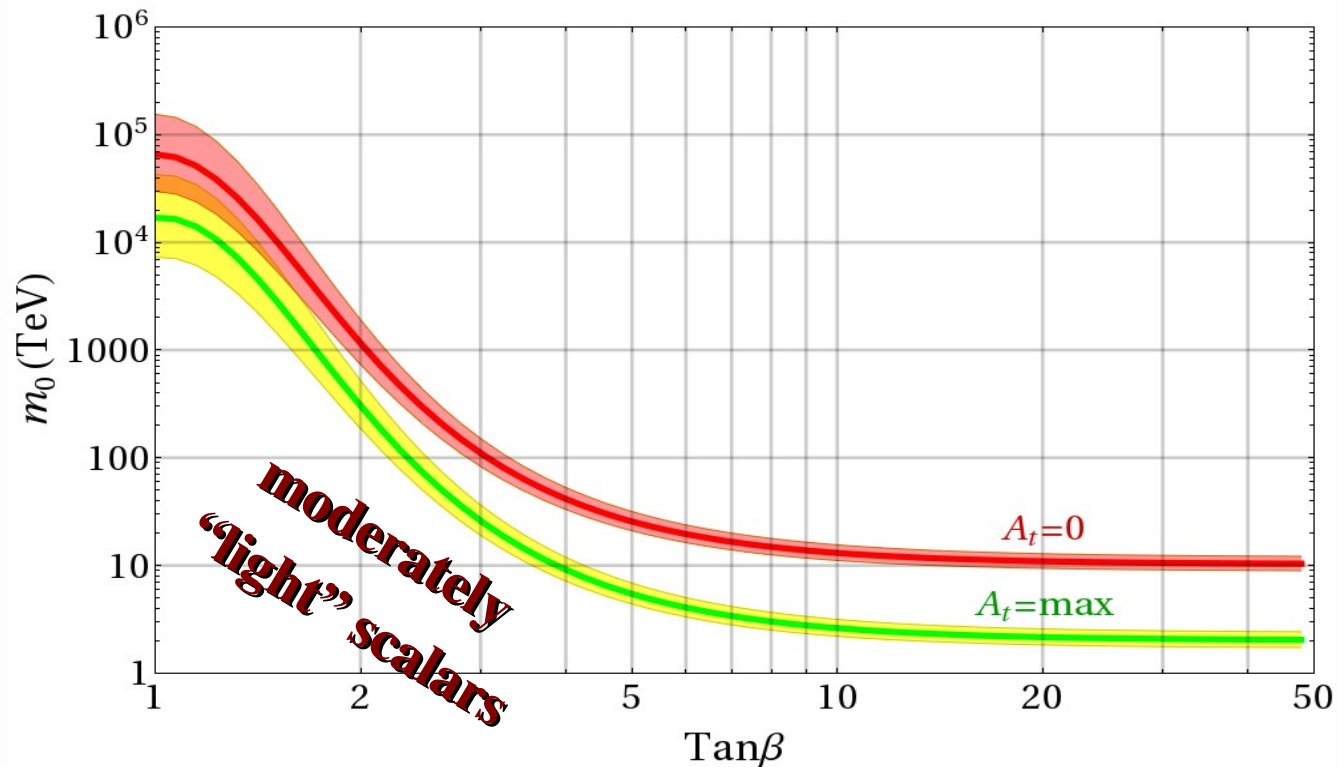
SUSY fixes $\lambda(\tilde{m}) = \frac{[g^2(\tilde{m}) + g'^2(\tilde{m})]}{4} \cos^2 2\beta$



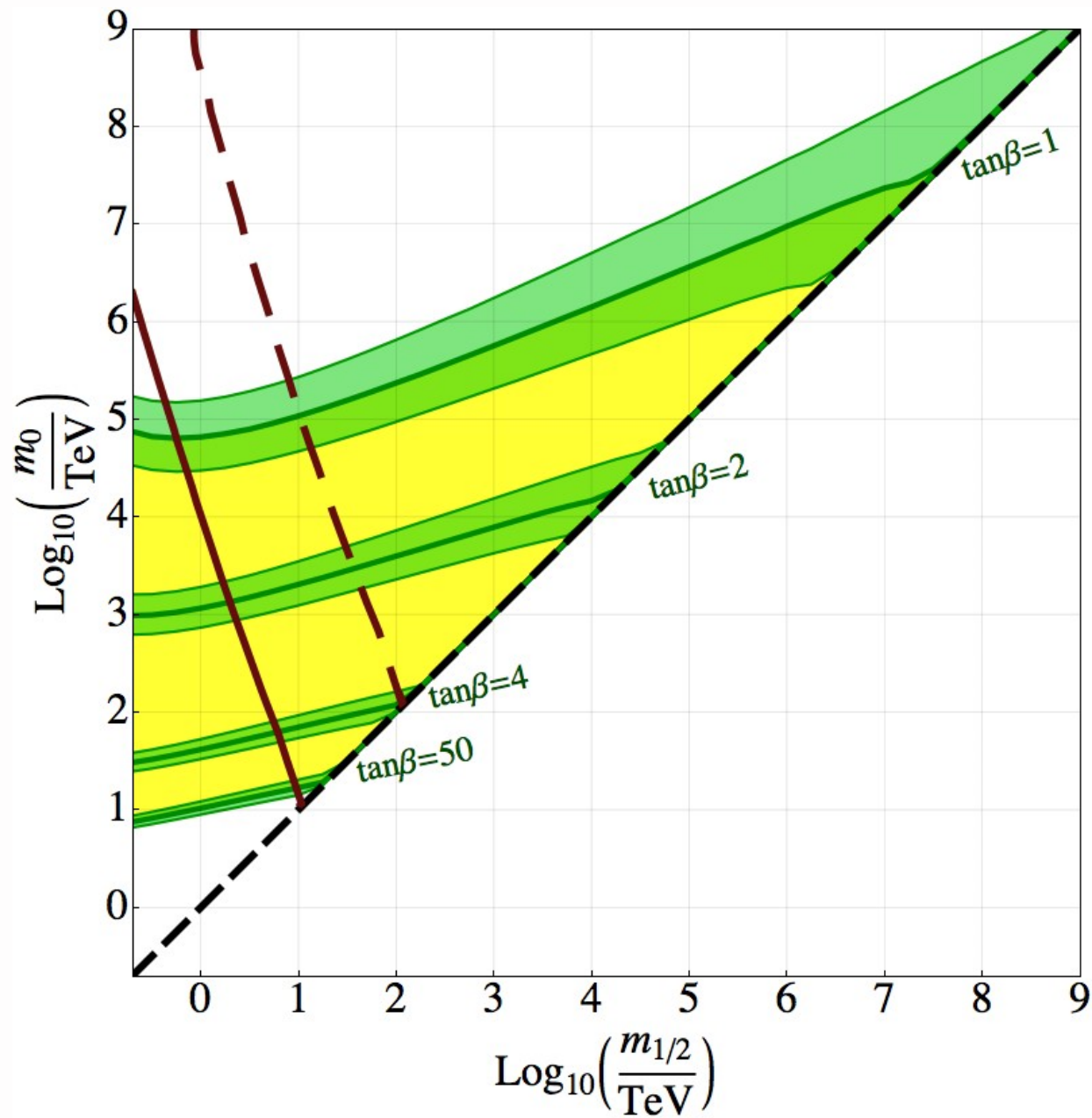
“Mini”-Split SUSY

$m_H \sim 125.5$ GeV fixes $\lambda(m_H)$

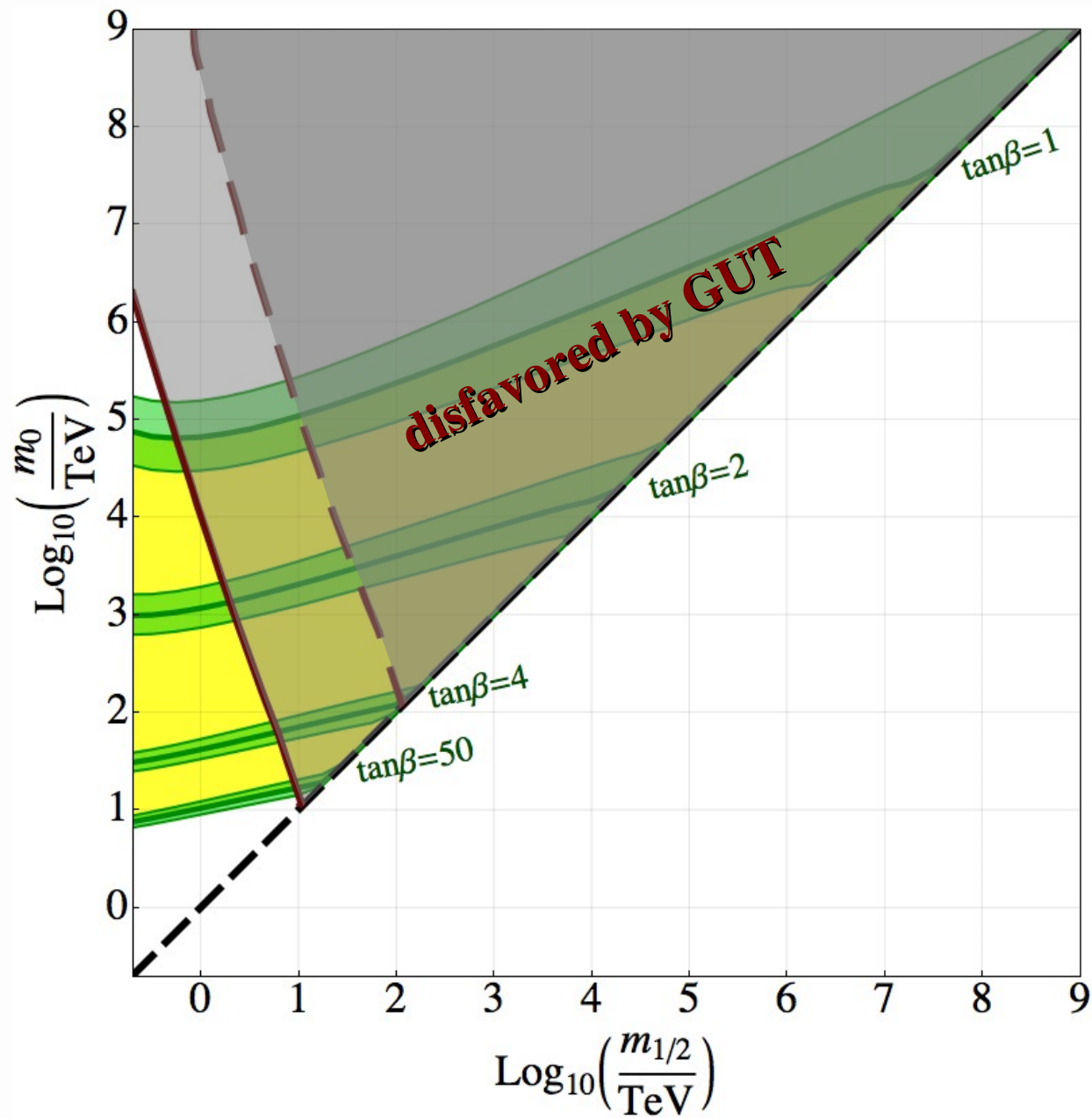
SUSY fixes $\lambda(\tilde{m}) = \frac{[g^2(\tilde{m}) + g'^2(\tilde{m})]}{4} \cos^2 2\beta$



more in general

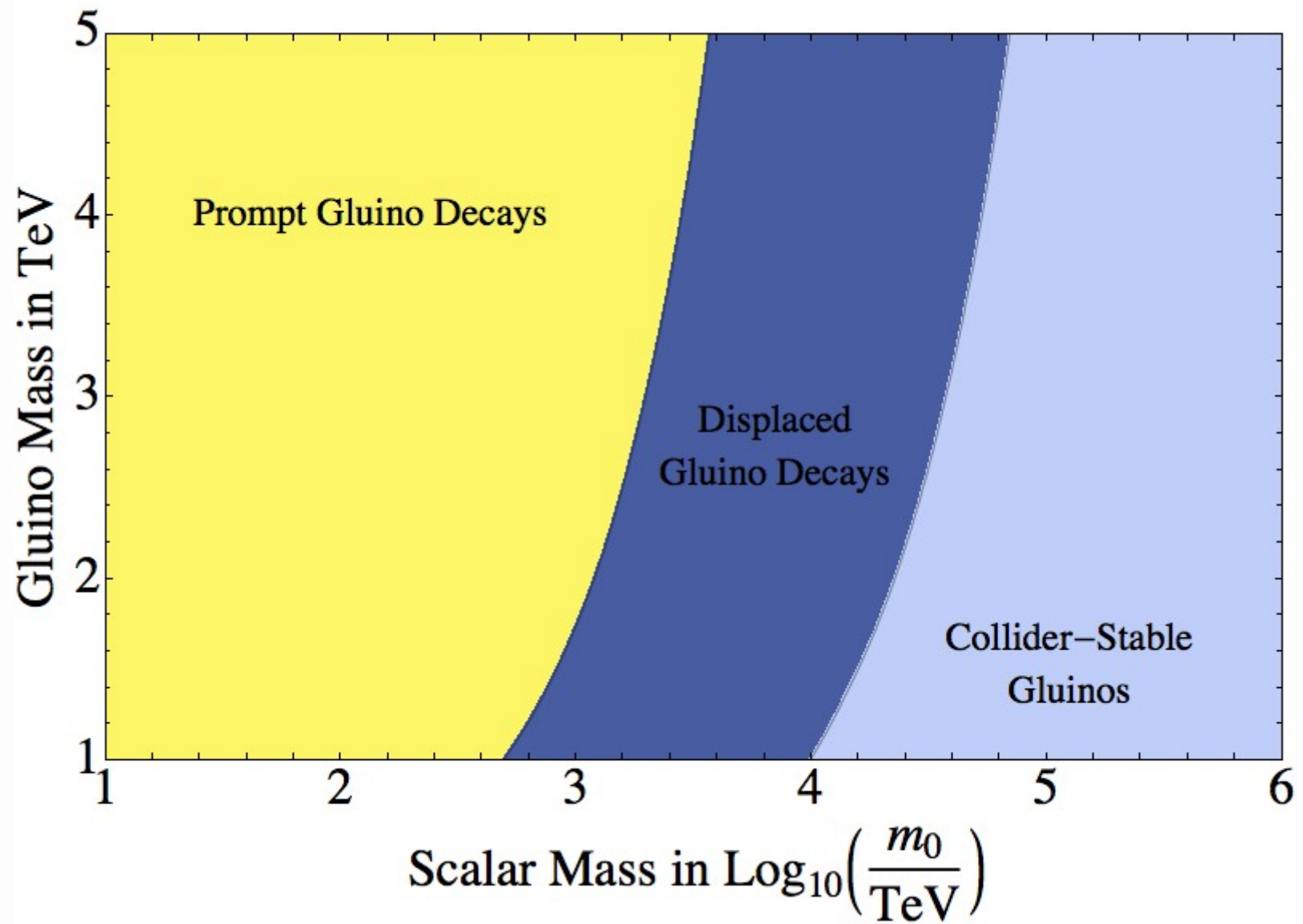


more in general

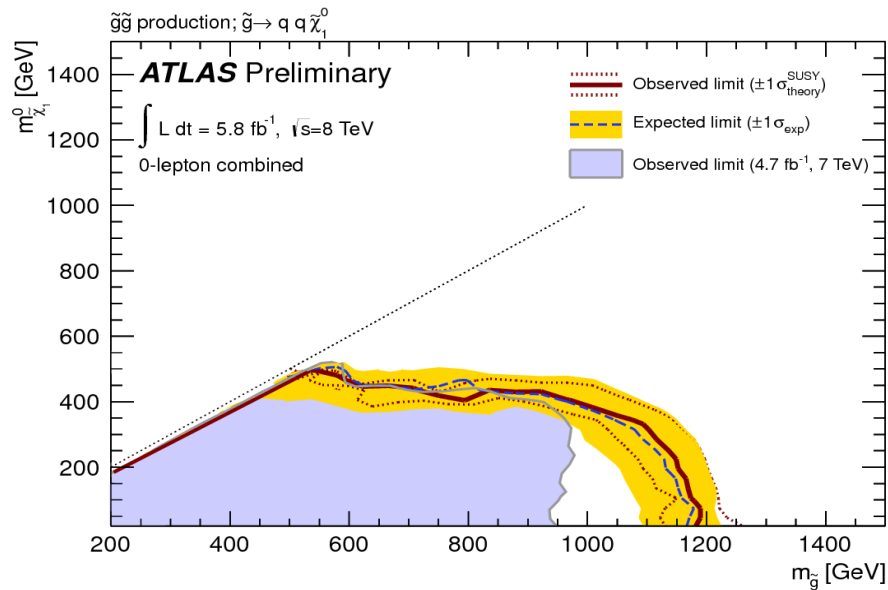


Phenomenology

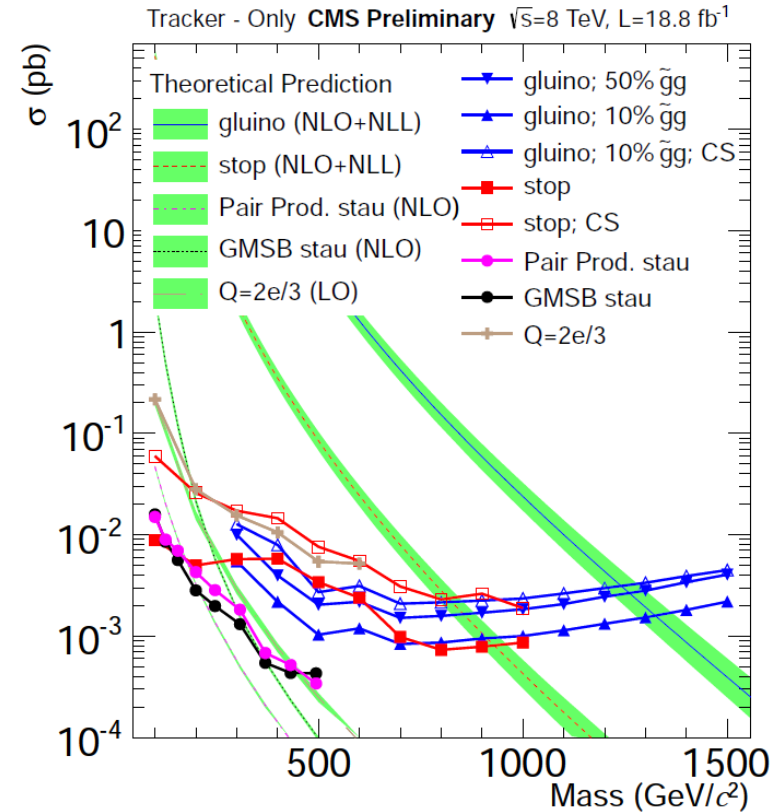
Phenomenology: Gluino



Glauino Bounds from the LHC



For prompt or slightly displaced gluinos



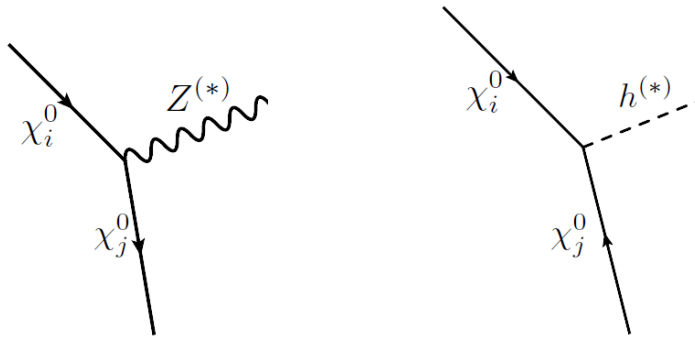
For collider "stable" gluinos

$M_{\text{gluino}} > 1.3 \text{ TeV}$ for split gluino

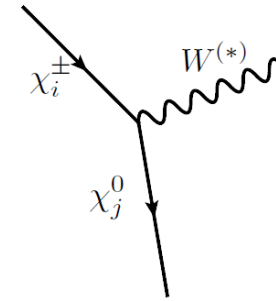
2.5 TeV to 3 TeV ultimate reach for split gluino

Phenomenology: EWinos

Neutralino decays

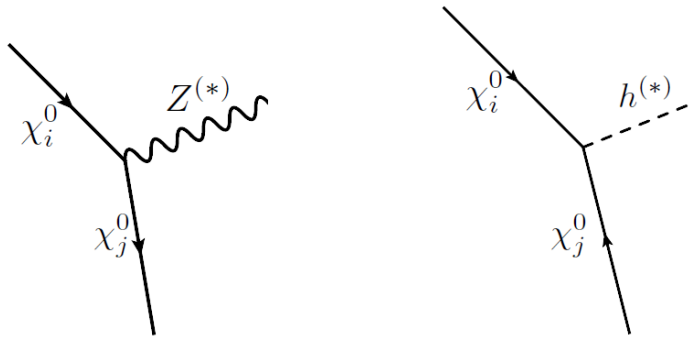


Chargino decays

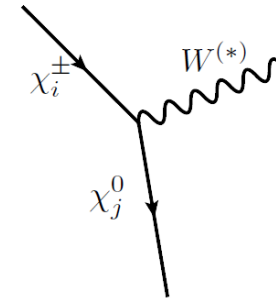


Phenomenology: EWinos

Neutralino decays



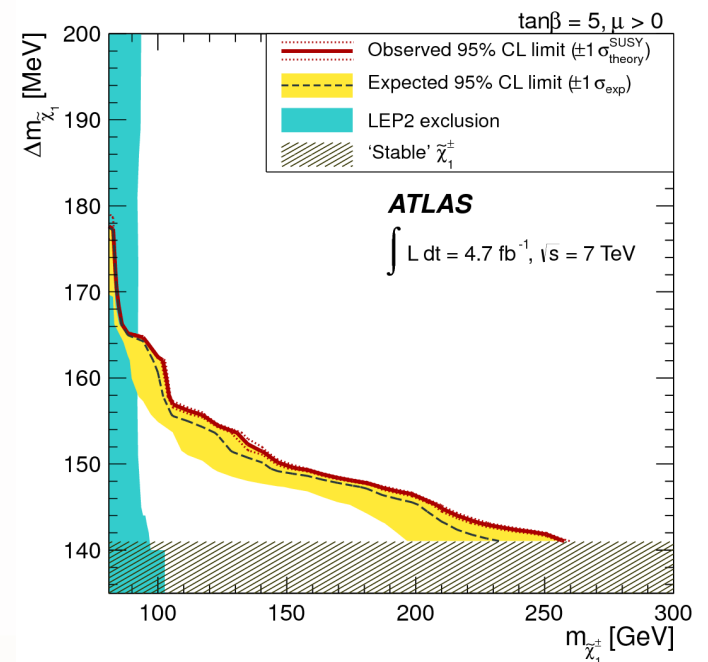
Chargino decays



Heavy Higgsinos:

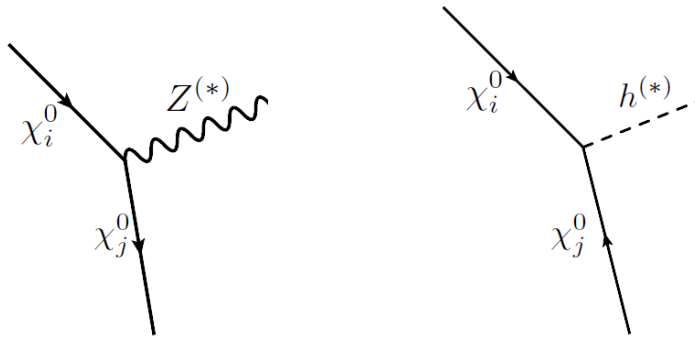
Bino LSP : $\chi^\pm \chi^0 \rightarrow Wh + \text{MET}$ $\chi^+ \chi^- \rightarrow WW + \text{MET}$

Wino LSP: $\Delta m \sim 170 \text{ MeV} \rightarrow 10 \text{ cm stubs (trig. on ISR + MET)}$

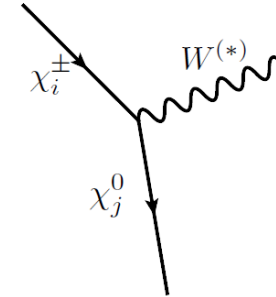


Phenomenology: EWinos

Neutralino decays



Chargino decays



Heavy Higgsinos:

Bino LSP : $\chi^\pm \chi^0 \rightarrow Wh + \text{MET}$ $\chi^+ \chi^- \rightarrow WW + \text{MET}$

Wino LSP: $\Delta m \sim 170 \text{ MeV} \rightarrow 10 \text{ cm stubs (trig. on ISR + MET)}$

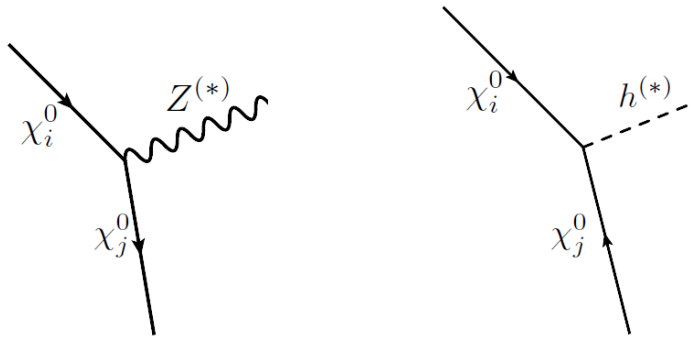
Light Higgsinos:

Usual EWino searches

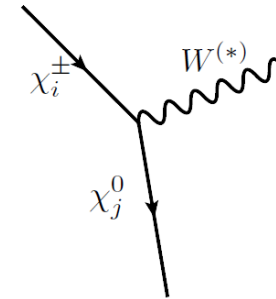
Possibility of testing all couplings and measuring $\tan\beta$ at LC

Phenomenology: EWinos

Neutralino decays



Chargino decays



Heavy Higgsinos:

Bino LSP : $\chi^\pm \chi^0 \rightarrow Wh + \text{MET}$ $\chi^+ \chi^- \rightarrow WW + \text{MET}$

Wino LSP: $\Delta m \sim 170 \text{ MeV} \rightarrow 10 \text{ cm stubs (trig. on ISR + MET)}$

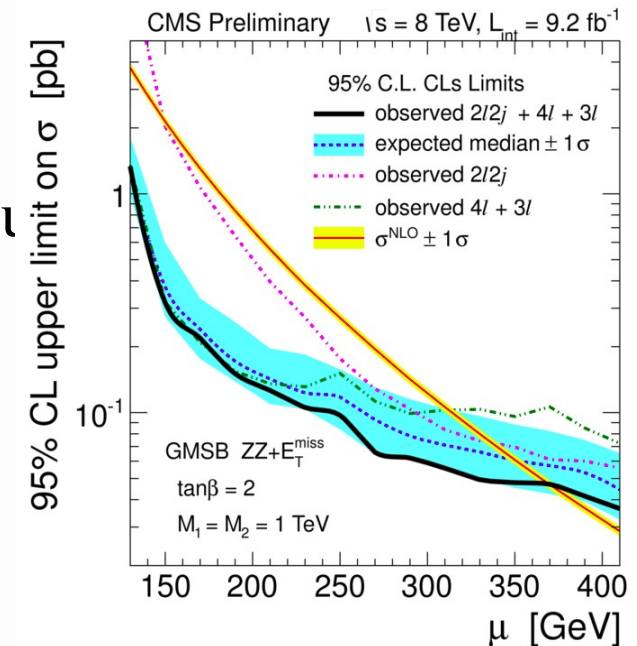
Light Higgsinos:

Usual EWino searches

Possibility of testing all couplings and measu

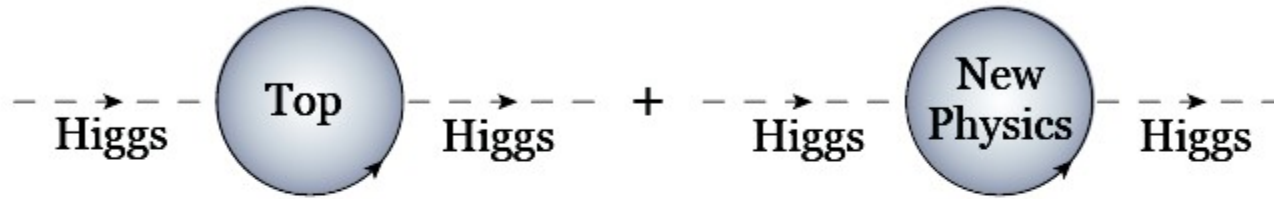
Only Higgsinos:

$\Delta m \sim 355 \text{ MeV} \rightarrow < 1 \text{ cm stubs harder to see}$
if light gravitino $h/Z + G$ decay

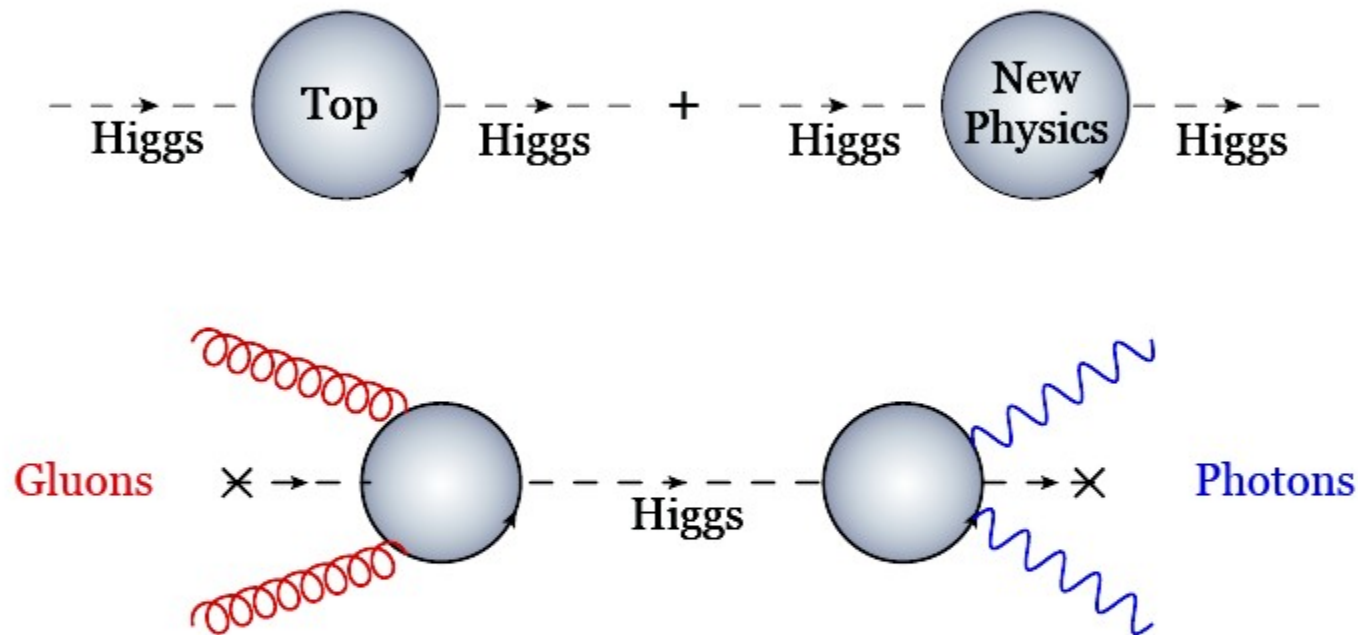


Learning from the Higgs

Naturalness and Higgs Properties

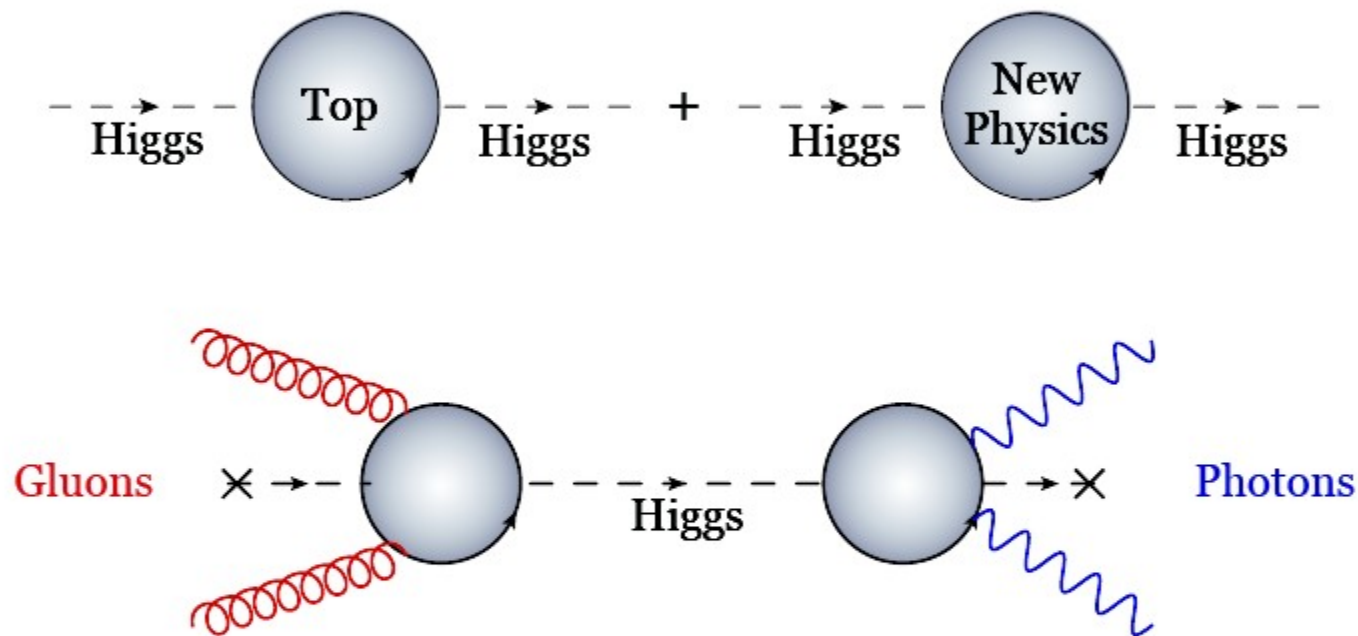


Naturalness and Higgs Properties



A Natural Higgs is not the SM Higgs

Naturalness and Higgs Properties



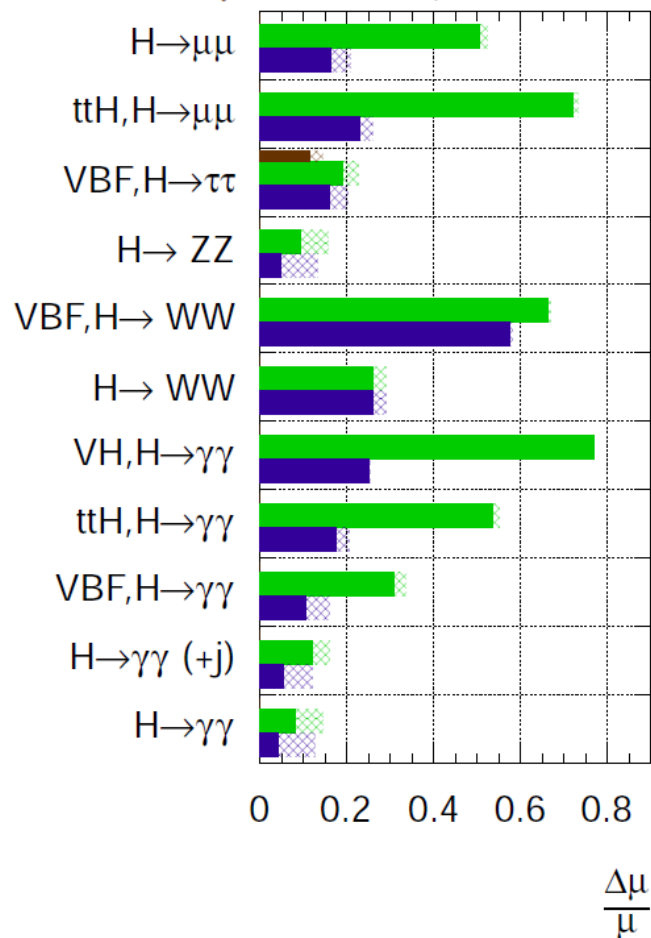
A Natural Higgs is not the SM Higgs

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

ATLAS Preliminary (Simulation)

$\sqrt{s} = 14$ TeV: $\int Ldt=300 \text{ fb}^{-1}$; $\int Ldt=3000 \text{ fb}^{-1}$

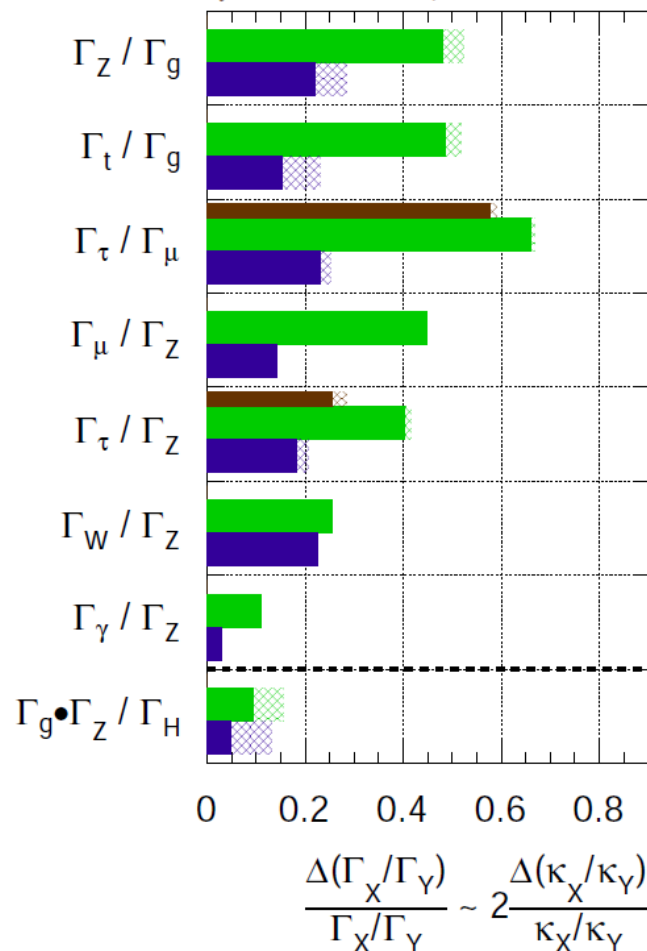
$\int Ldt=300 \text{ fb}^{-1}$ extrapolated from 7+8 TeV



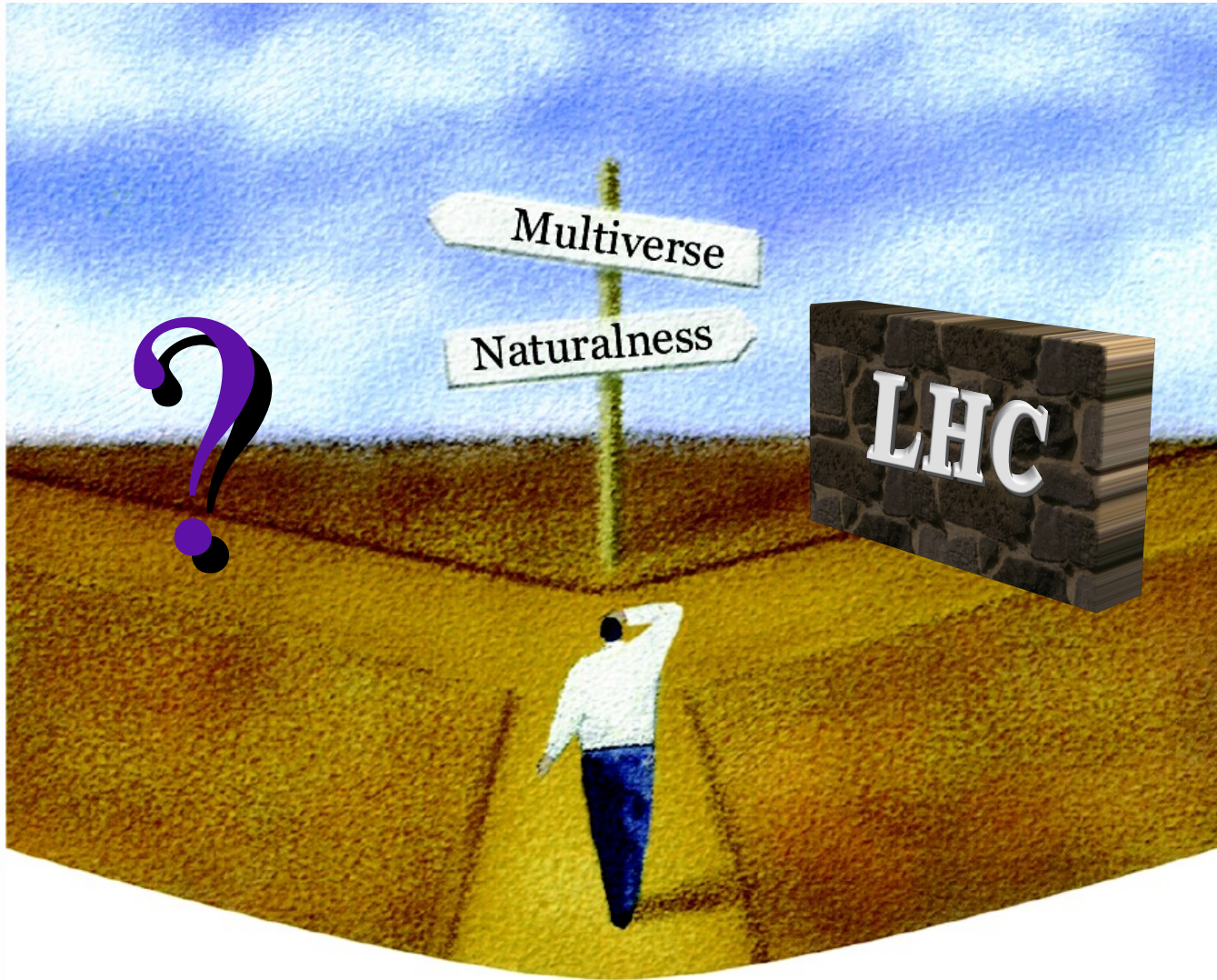
ATLAS Preliminary (Simulation)

$\sqrt{s} = 14$ TeV: $\int Ldt=300 \text{ fb}^{-1}$; $\int Ldt=3000 \text{ fb}^{-1}$

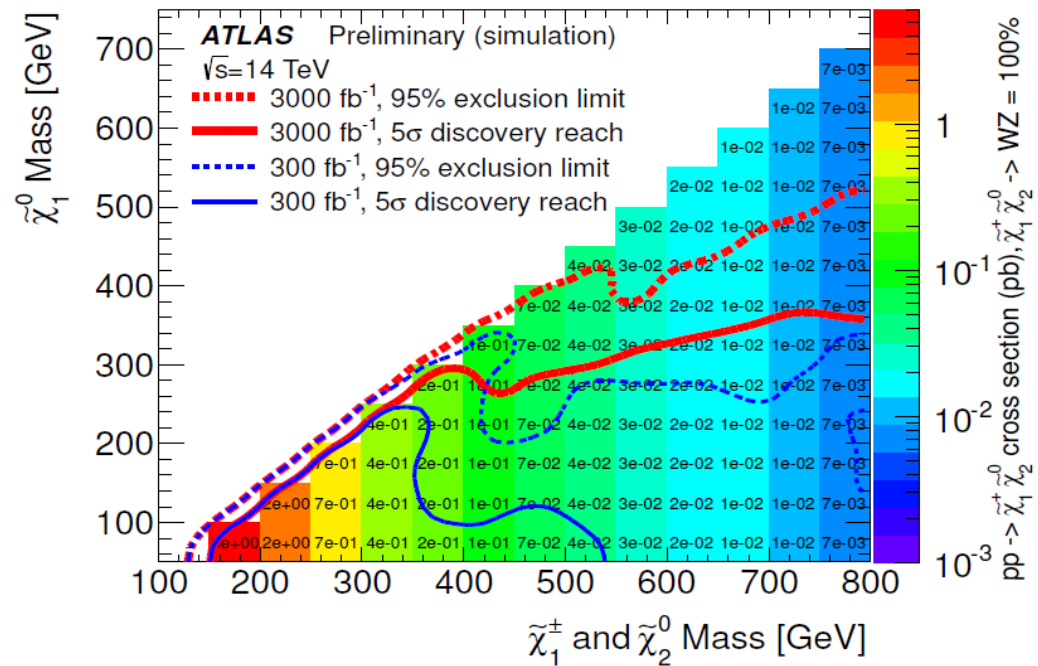
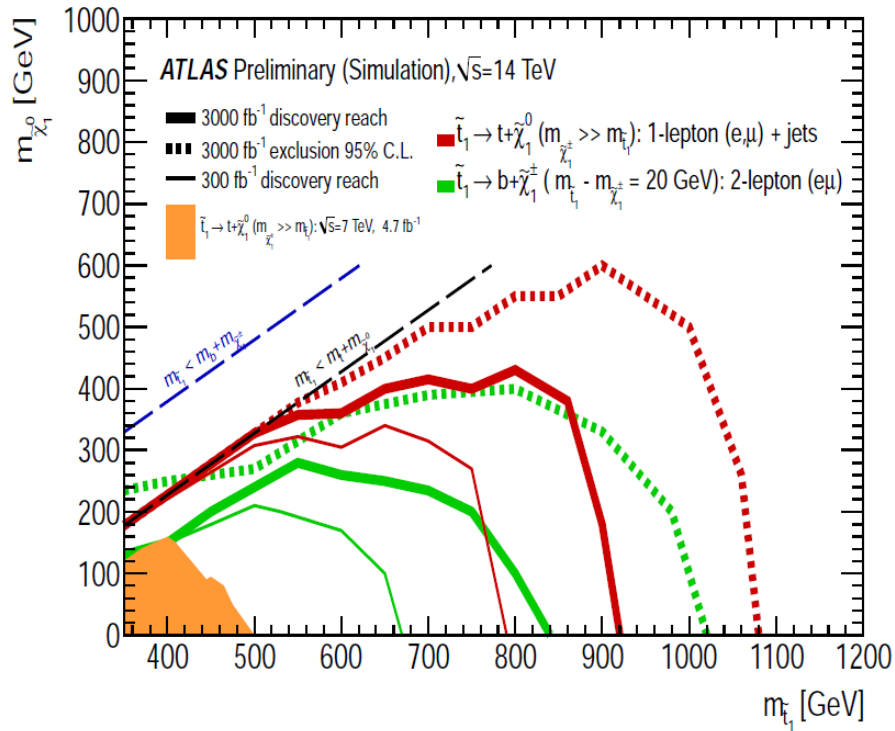
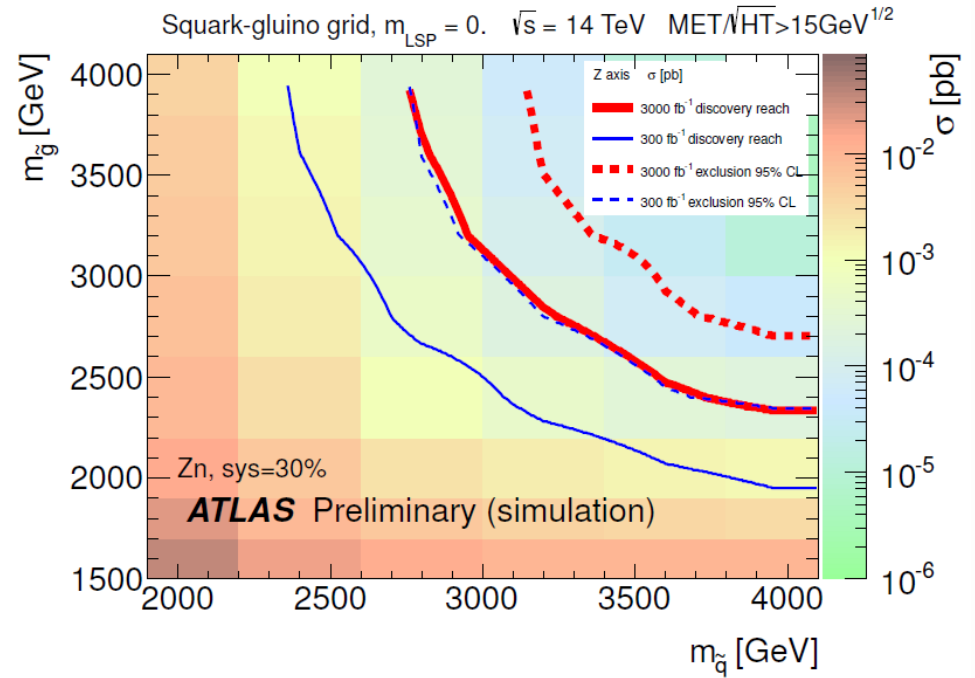
$\int Ldt=300 \text{ fb}^{-1}$ extrapolated from 7+8 TeV



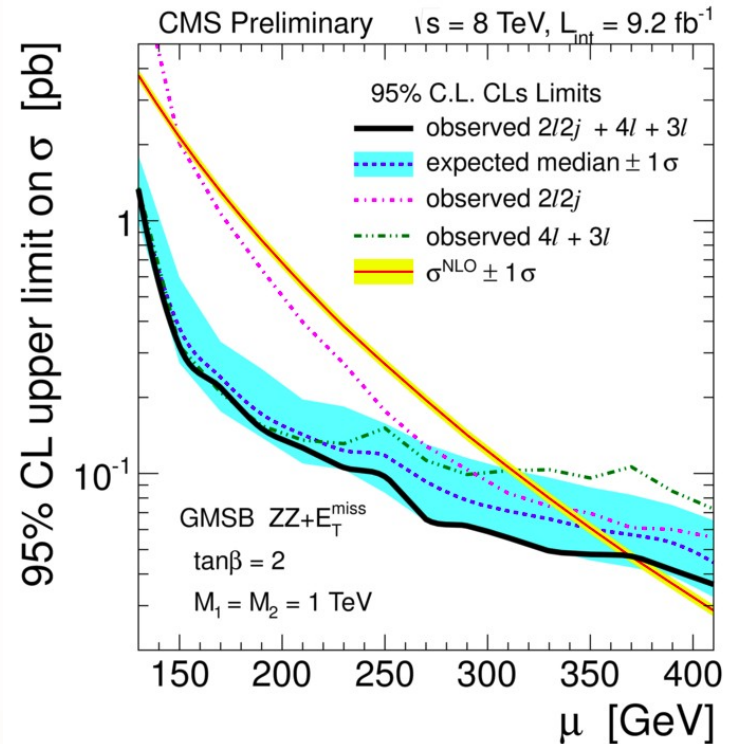
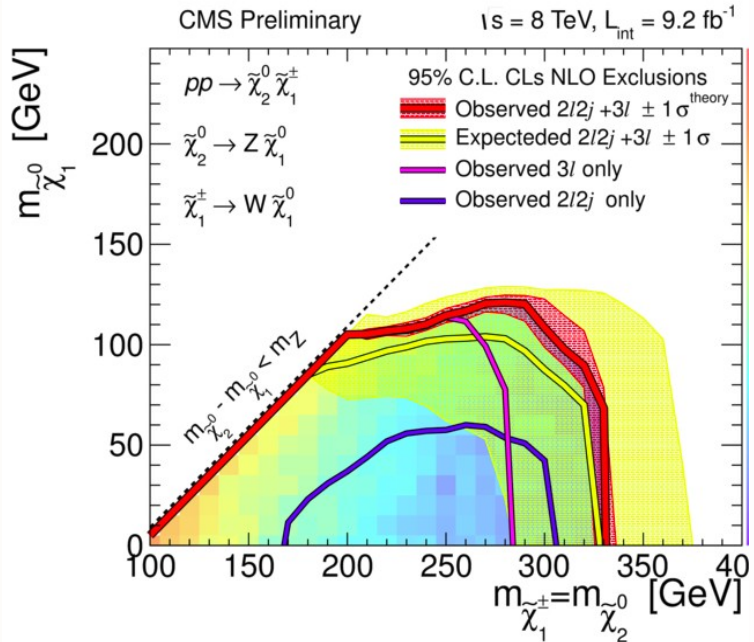
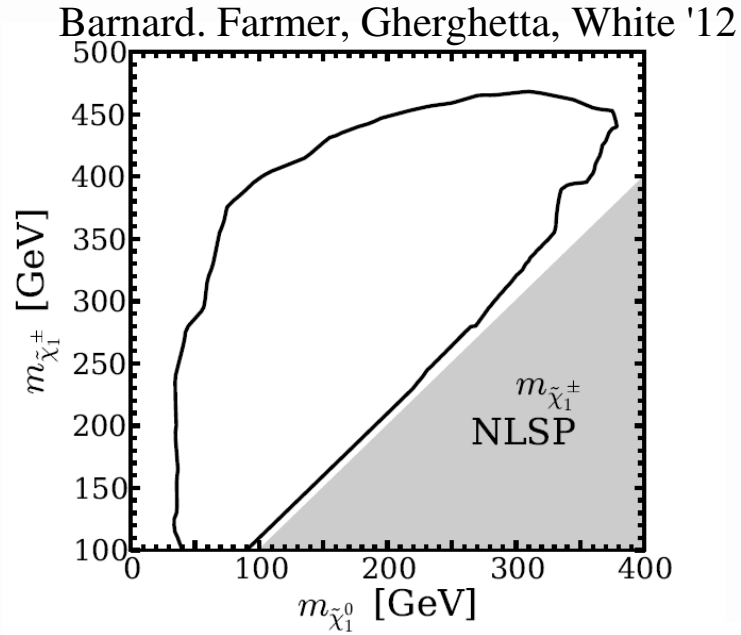
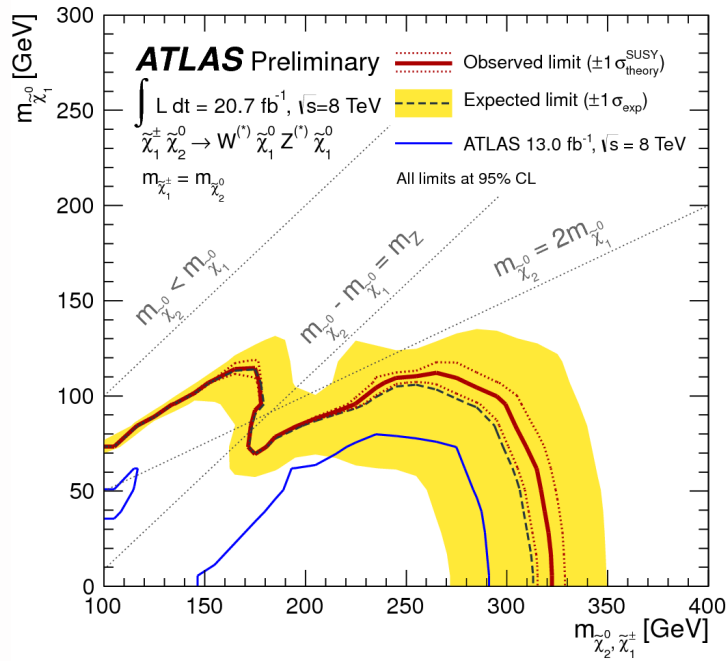
Conclusions



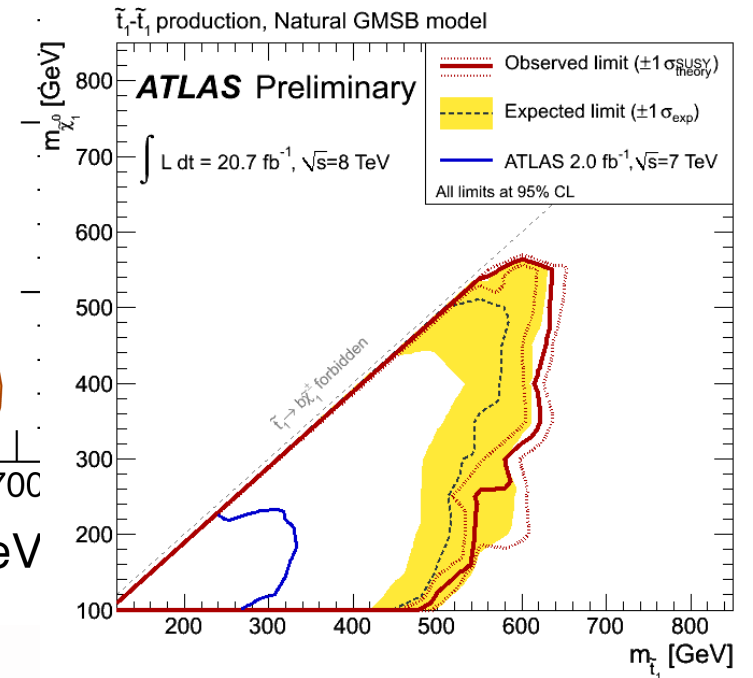
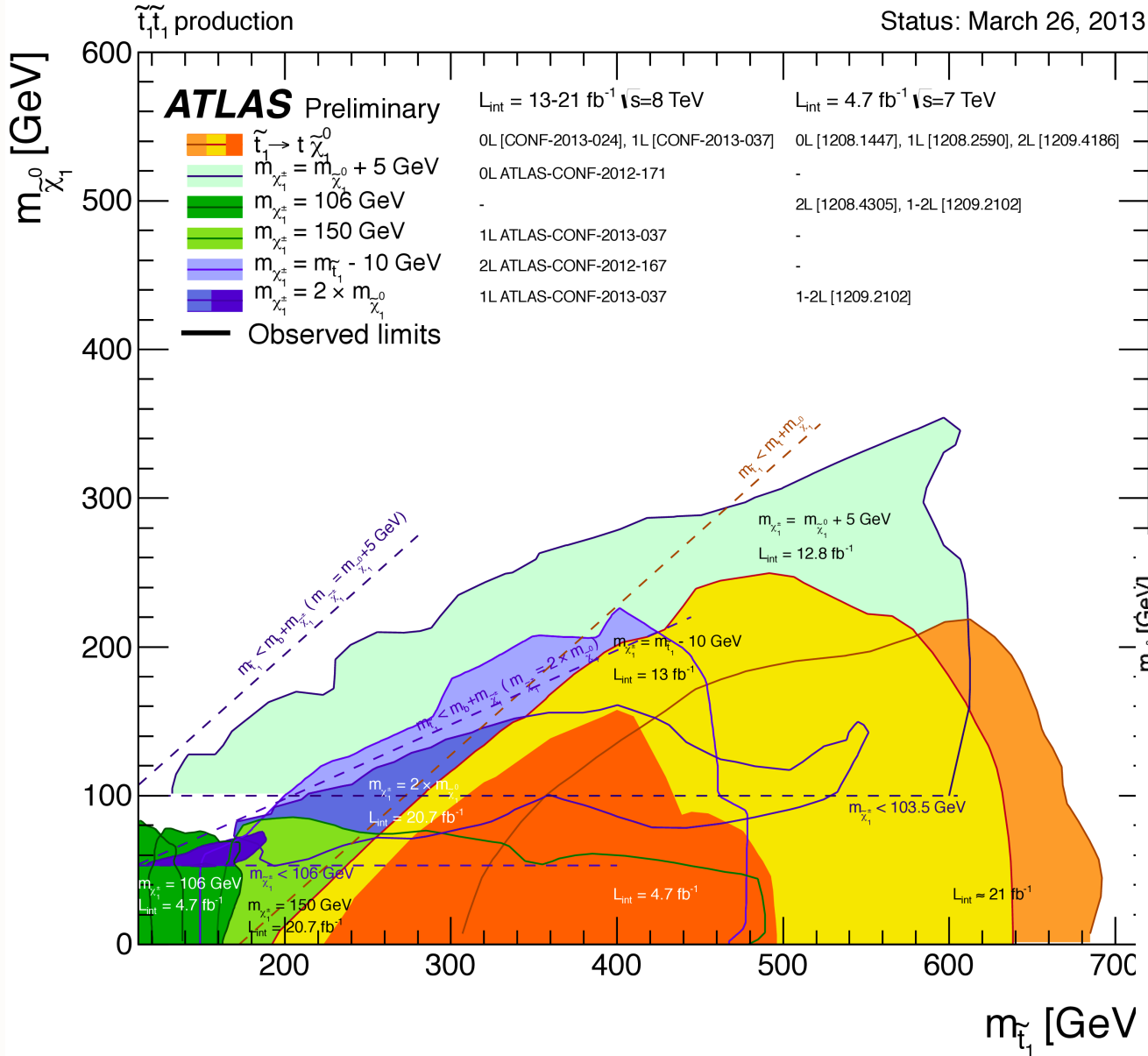
Back-up Slides



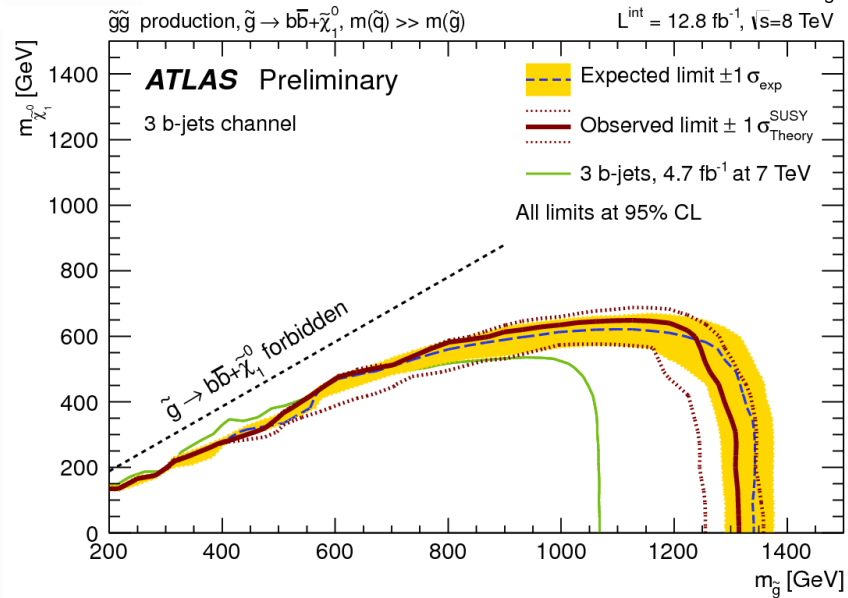
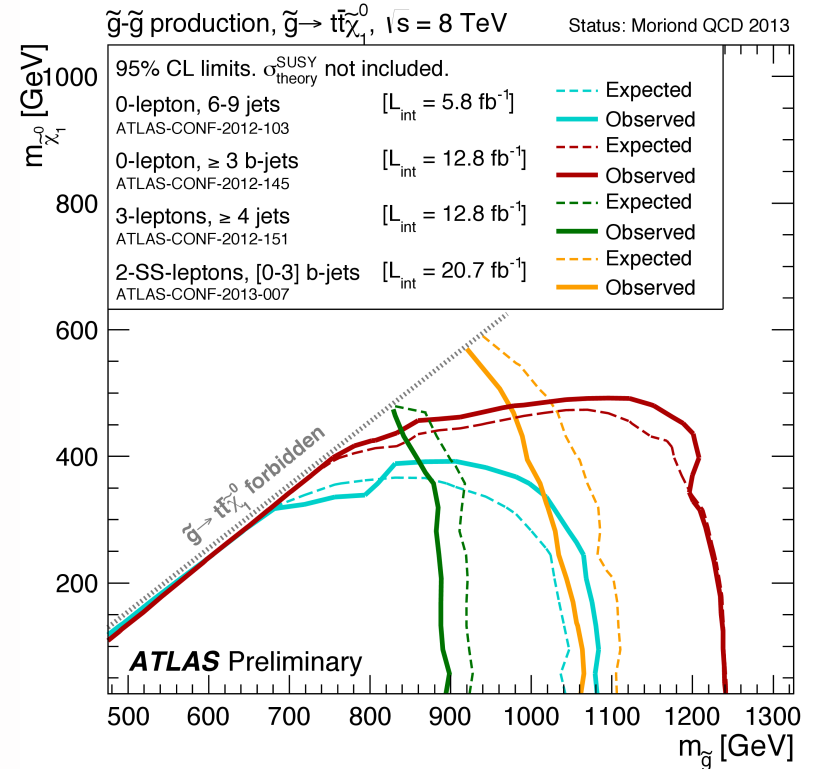
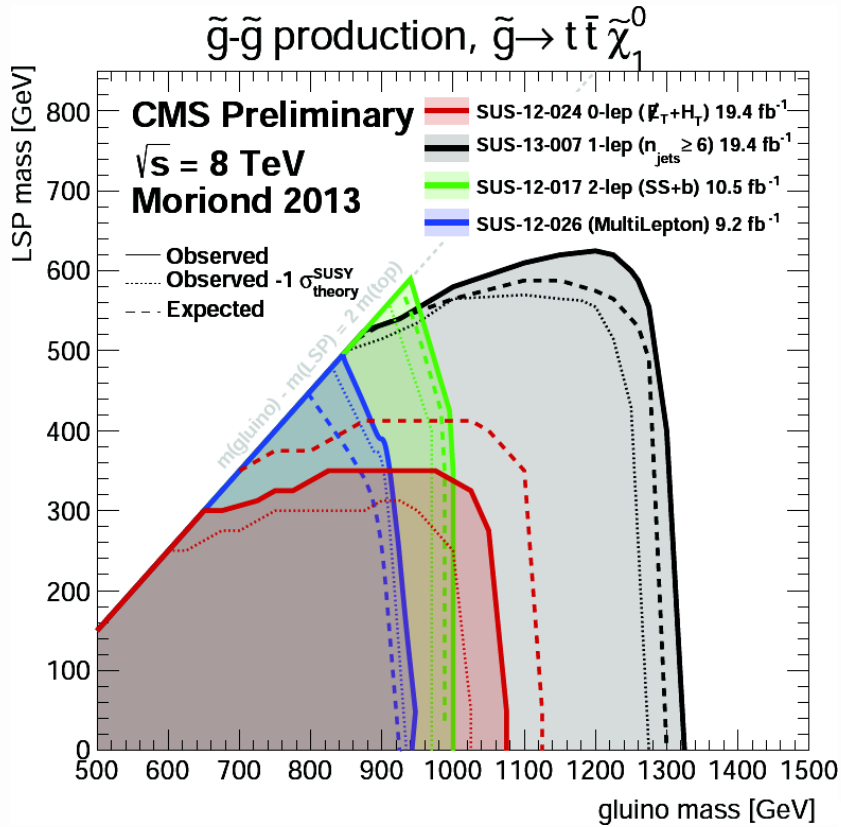
EWino Bounds



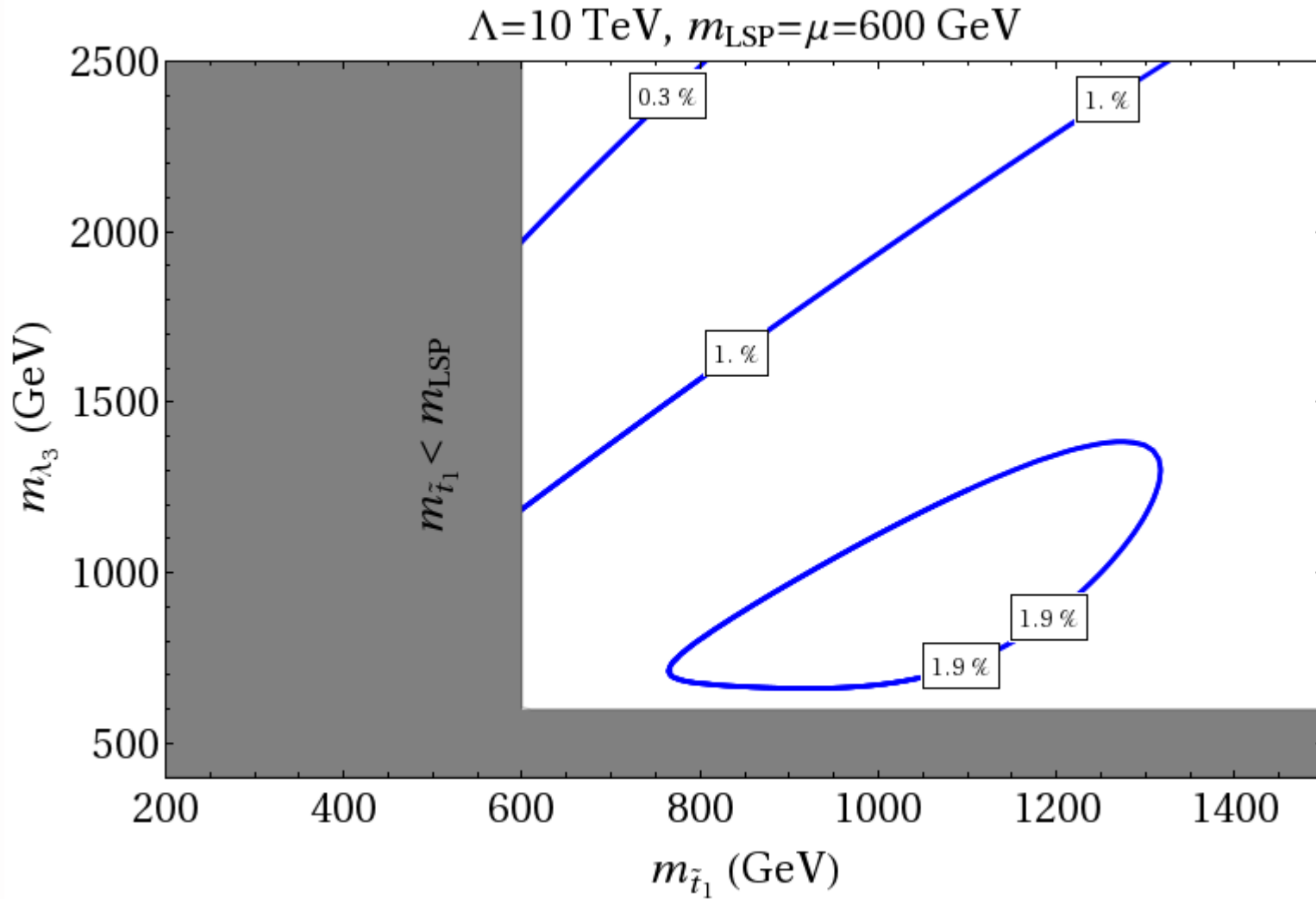
Stop Bounds



Glino Bounds



Is “Natural” SUSY Natural?



Is “Natural” SUSY Natural?

in progress with:
Arvanitaki, Baryakhtar, Gherghetta, Huang, Van Tilburg

$$\frac{5+\bar{5}}{1+\bar{1}} M_D$$

$$\frac{M_N}{F^{1/2}}$$

$U(1)'_{B-L}$ for the first two generations

Gauge Mediation (+ some Higgs mass fix)

$$m_{1,2}$$

$$m_3, \mu, m_H, M_{123}$$

$$\text{CKM mixing from: } \lambda_i Q_i H_d D_3 \frac{\Phi}{X_D}$$

$$\varepsilon_K \text{ constraints} \rightarrow m_{1,2} \gtrsim \text{few TeV}$$

$$\Rightarrow M_D > 10^7 \text{ GeV} \Rightarrow \text{few \% tuning}$$

Dirac gauginos:

the good:

- $N=2$ symm. \rightarrow no large log corrections to scalars
- suppressed t -channel squark production
- suppressed flavor effects

$$\int d^2\theta \sqrt{2} \frac{W'_\alpha W_j^\alpha A_j}{M}$$
$$\int d^2\theta \frac{W'_\alpha W'^\alpha}{M^2} A_j^2$$
$$m^2 = \frac{C_i(r) \alpha_i m_i^2}{\pi} \log \left(\frac{\delta^2}{m_i^2} \right)$$

the bad:

- in general left with a finite $\sim \log(\text{loop})$ factor
- at best $\log(\text{few})$ expected (extra model building)
- larger prod. cross section for gauginos
- unification in trouble
- extra model building for Higgs quartic
- tachyons?
- ...

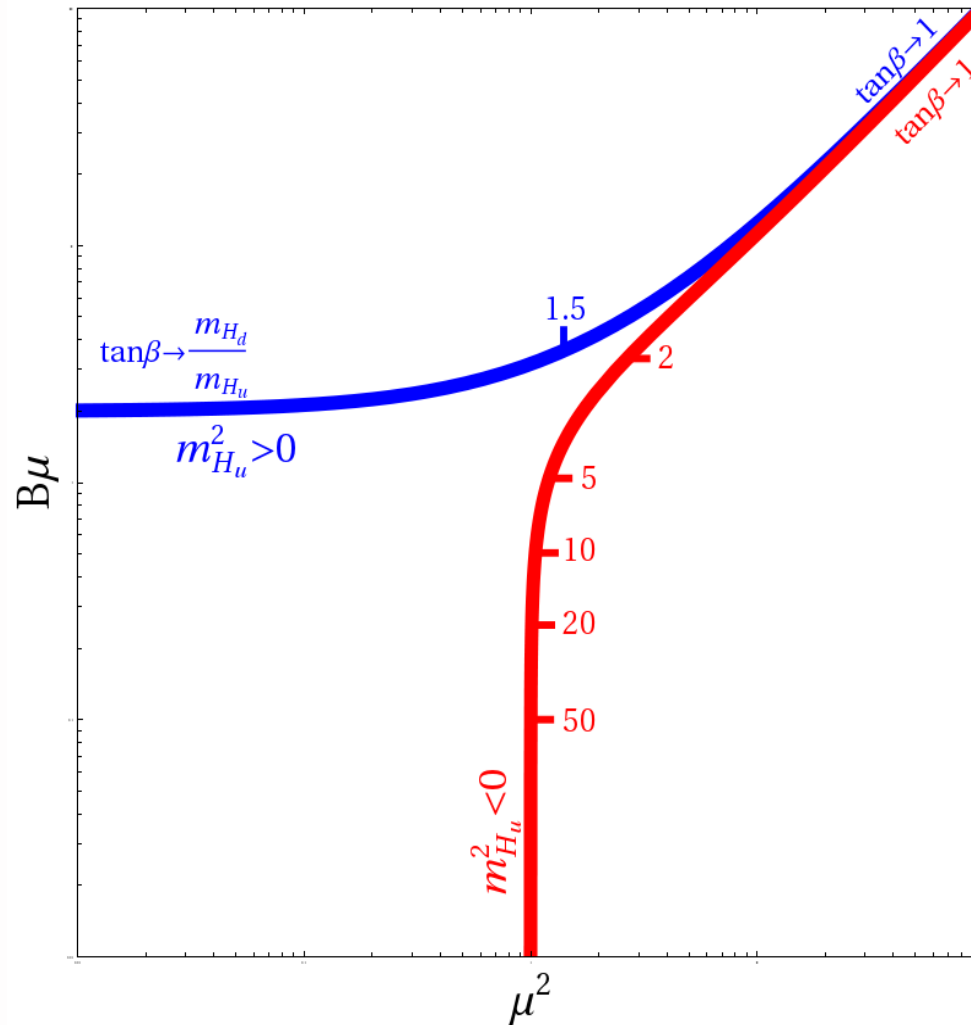
any improvement?

Tuning the EWSB...

$$\det \begin{pmatrix} |\mu|^2 + m_{H_u}^2 & -B_\mu \\ -B_\mu^* & |\mu|^2 + m_{H_d}^2 \end{pmatrix} \approx 0, \quad \tan \beta = \sqrt{\frac{m_{H_d}^2 + |\mu|^2}{m_{H_u}^2 + |\mu|^2}}$$

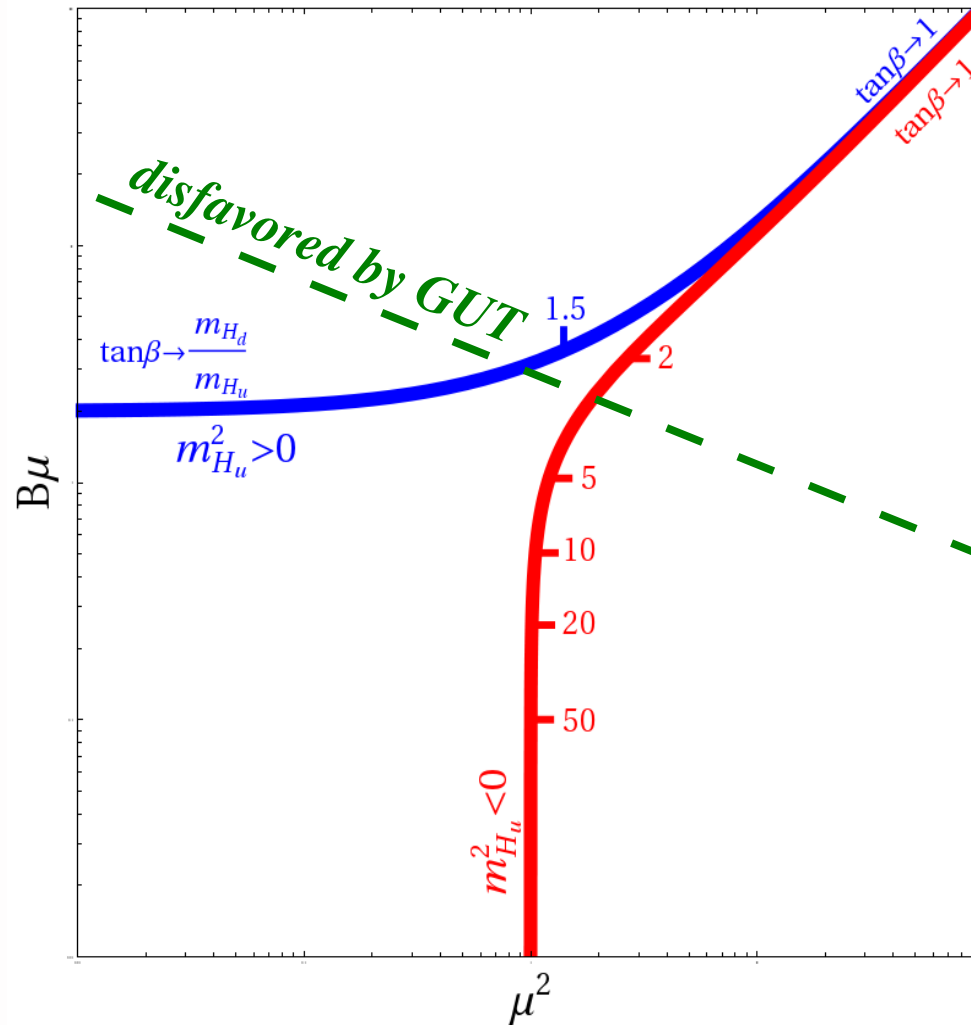
Tuning the EWSB...

$$\det \begin{pmatrix} |\mu|^2 + m_{H_u}^2 & -B_\mu \\ -B_\mu^* & |\mu|^2 + m_{H_d}^2 \end{pmatrix} \approx 0, \quad \tan \beta = \sqrt{\frac{m_{H_d}^2 + |\mu|^2}{m_{H_u}^2 + |\mu|^2}}$$



Tuning the EWSB...

$$\det \begin{pmatrix} |\mu|^2 + m_{H_u}^2 & -B_\mu \\ -B_\mu^* & |\mu|^2 + m_{H_d}^2 \end{pmatrix} \approx 0, \quad \tan \beta = \sqrt{\frac{m_{H_d}^2 + |\mu|^2}{m_{H_u}^2 + |\mu|^2}}$$



RGE and tachyons in Split

$$\frac{dm_i^2}{dt} = c_i X_t + \frac{6}{5} Y_i \frac{\alpha_Y}{4\pi} \text{Tr}(Y m^2) - (\text{gauginos})$$

Yukawa *D-term*

RGE and tachyons in Split

$$\frac{dm_i^2}{dt} = c_i X_t + \frac{6}{5} Y_i \frac{\alpha_Y}{4\pi} \text{Tr}(Y m^2) - \text{gauginos}$$

The equation is annotated with a blue box labeled "Yukawa" pointing to the $c_i X_t$ term, a green box labeled "D-term" pointing to the $\frac{6}{5} Y_i \frac{\alpha_Y}{4\pi} \text{Tr}(Y m^2)$ term, and a red 'X' over the gauginos term.

RGE and tachyons in Split

$$\frac{dm_i^2}{dt} = c_i X_t + \frac{6}{5} Y_i \frac{\alpha_Y}{4\pi} \text{Tr}(Y m^2) - \text{gauginos}$$

Yukawa *D-term*



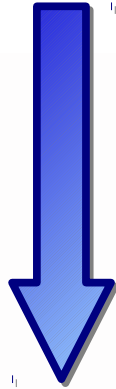
=0 if $m_{Hu} = m_{Hd}$ + GUT B.C.

RGE and tachyons in Split

$$\frac{dm_i^2}{dt} = c_i X_t + \frac{6}{5} Y_i \frac{\alpha_Y}{4\pi} \text{Tr}(Y m^2) - \text{(gauginos)}$$

Yukawa

D-term

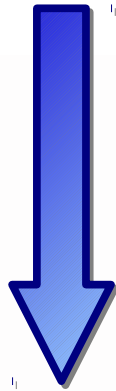


=0 if $m_{H_u} = m_{H_d}$ + GUT B.C.

$$X_t = \frac{|y_t|^2}{8\pi^2} (m_{H_u}^2 + m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2)$$

RGE and tachyons in Split

$$\frac{dm_i^2}{dt} = \overset{\text{Yukawa}}{c_i X_t} + \overset{\text{D-term}}{\frac{6}{5} Y_i \frac{\alpha_Y}{4\pi} \text{Tr}(Y m^2)} - \text{(gauginos)}$$



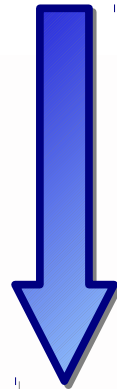
=0 if $m_{Hu} = m_{Hd}$ + GUT B.C.

$$X_t = \frac{|y_t|^2}{8\pi^2} (m_{Hu}^2 + m_{tL}^2 + m_{tR}^2)$$

IR fixed point: $X_t \rightarrow 0 \Rightarrow$ tachyon

RGE and tachyons in Split

$$\frac{dm_i^2}{dt} = \overset{\text{Yukawa}}{c_i X_t} + \overset{\text{D-term}}{\frac{6}{5} Y_i \frac{\alpha_Y}{4\pi} \text{Tr}(Y m^2)} - \text{(gauge bosons)}$$



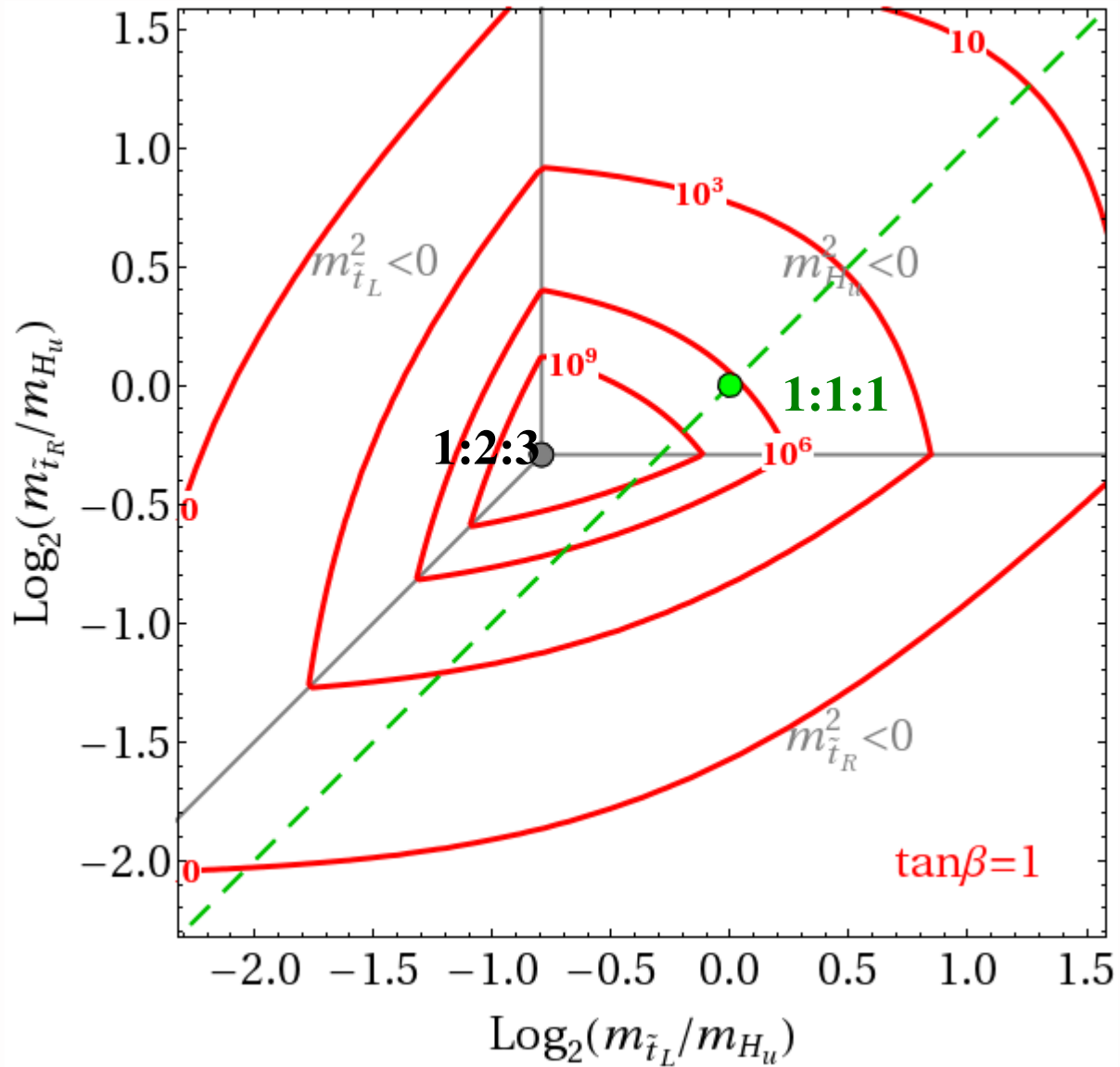
=0 if $m_{H_u} = m_{H_d}$ + GUT B.C.

$$X_t = \frac{|y_t|^2}{8\pi^2} (m_{H_u}^2 + m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2)$$

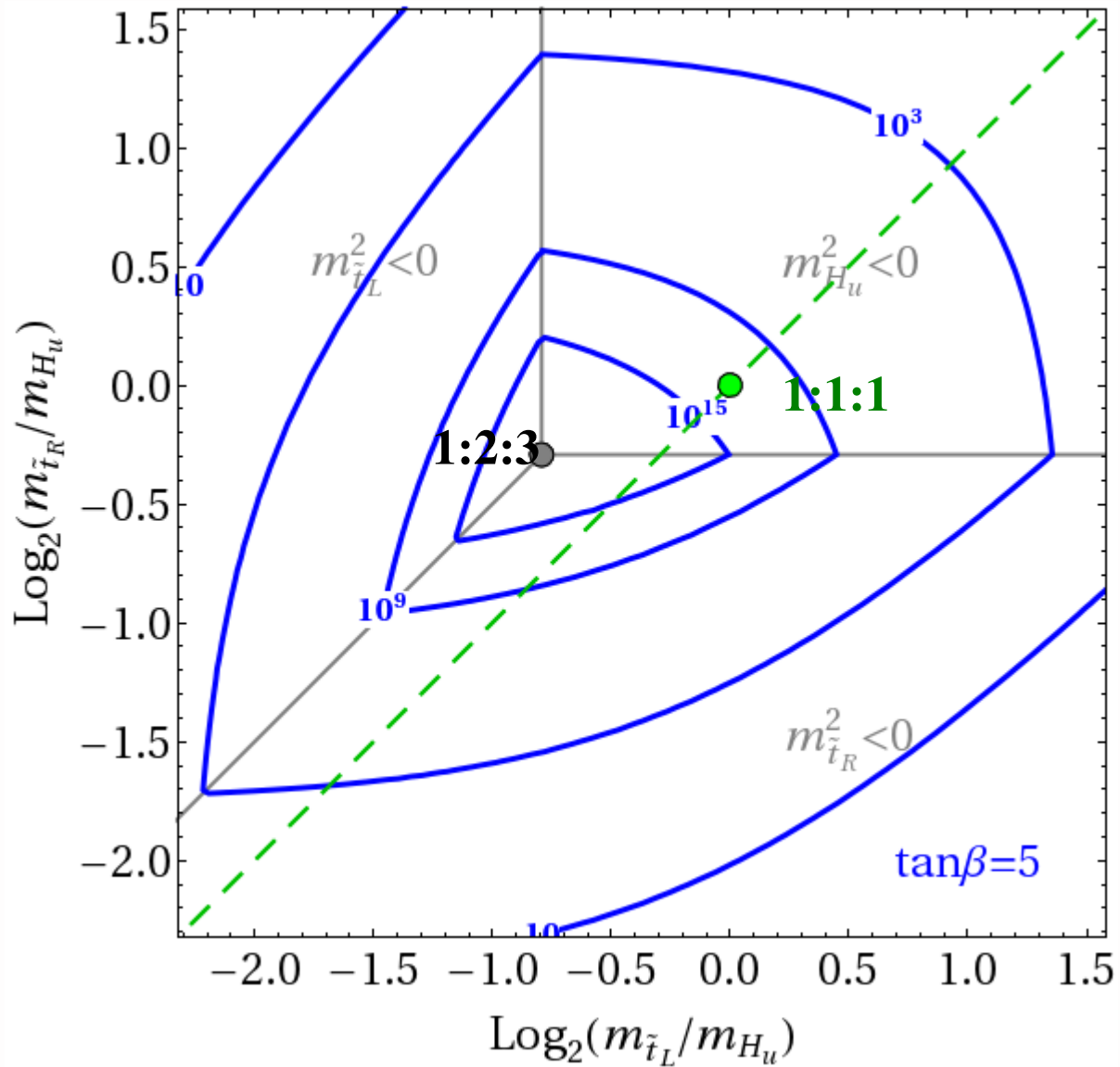
IR fixed point: $X_t \rightarrow 0 \Rightarrow$ tachyon

UV fixed point $m_{\tilde{t}_L}^2 : m_{\tilde{t}_R}^2 : m_{H_u}^2 = 1 : 2 : 3$

How much you can run...

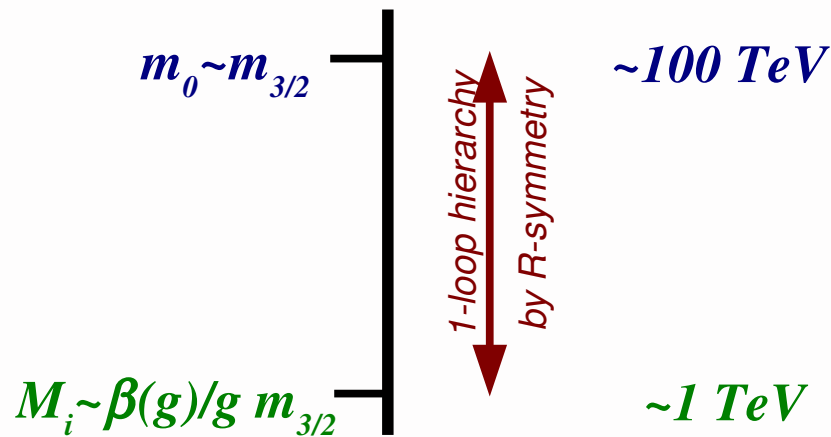


How much you can run...



Anomaly Mediation

Giudice, Luty, Murayama, Rattazzi '98

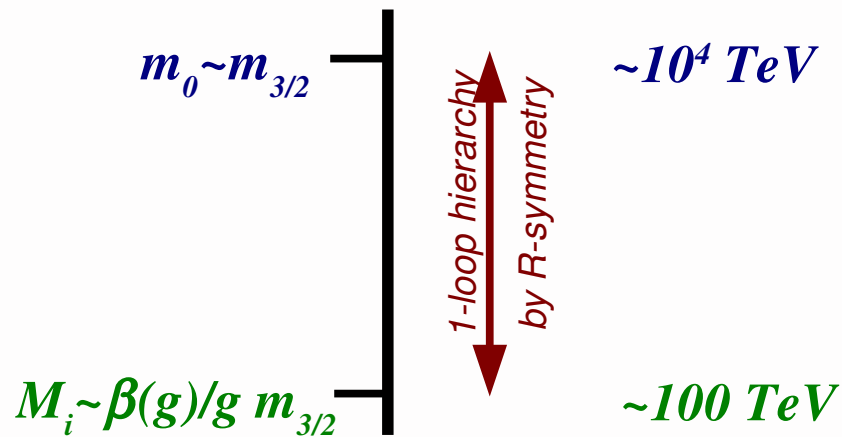


Light AMSB

- $\mu^2 \sim B_\mu \sim m_{3/2}^2$
Giudice-Masiero or explicit μ -term
- $\tan\beta \sim 4$
- m_{Hu}^2 can run negative
- Light gauginos (W - or B -ino LSP)
- GUT still OK
- Flavor Problem

Anomaly Mediation

Giudice, Luty, Murayama, Rattazzi '98



Heavy AMSB

- $B_\mu \sim m_{3/2}^2 \gg \mu^2$
Giudice-Masiero-ish
- $\tan\beta \sim 1$
- $m_{Hu}^2 > 0$
- Heavy gauginos
(higgsinos can be light)
- GUT OK
- No Flavor Problem

Gauge Mediation

Hidden assumption of natural GM:

Efficient breaking of R-symmetry in SUSY breaking sector

Very easy to get parametrically lighter gauginos:

- by **suppression of R-symmetry** breaking in the hidden sector
- by accidental cancellations such as **gaugino screening**

Arkani-Hamed, Giudice, Luty, Rattazzi '98

Example: $W = M_R (\Phi_1 \bar{\Phi}_1 + \Phi_2 \bar{\Phi}_2) + X \Phi_1 \bar{\Phi}_2$ $X = M + F\theta^2$

$$m_{\lambda_i} = \frac{\alpha_i}{6\pi} \frac{M}{M_R} \frac{F^3}{M_R^5} + \mathcal{O} \left(\frac{M^3}{M_R^3} \frac{F^3}{M_R^5}, \frac{F^5}{M_R^9} \right)$$

- Advantage over AMGB: no flavor problem
- Advantages over natural GM:
 - gravitino can be heavier than LSP → thermal dark matter
 - μ - $B\mu$ no longer a problem

U(1)' Split SUSY

MSSM + U(1)':

$$U(1)' = \cos(\theta) U(1)_{B-L} + \sin(\theta) U(1)_Y$$

SUSY breaking mediated by U(1)'

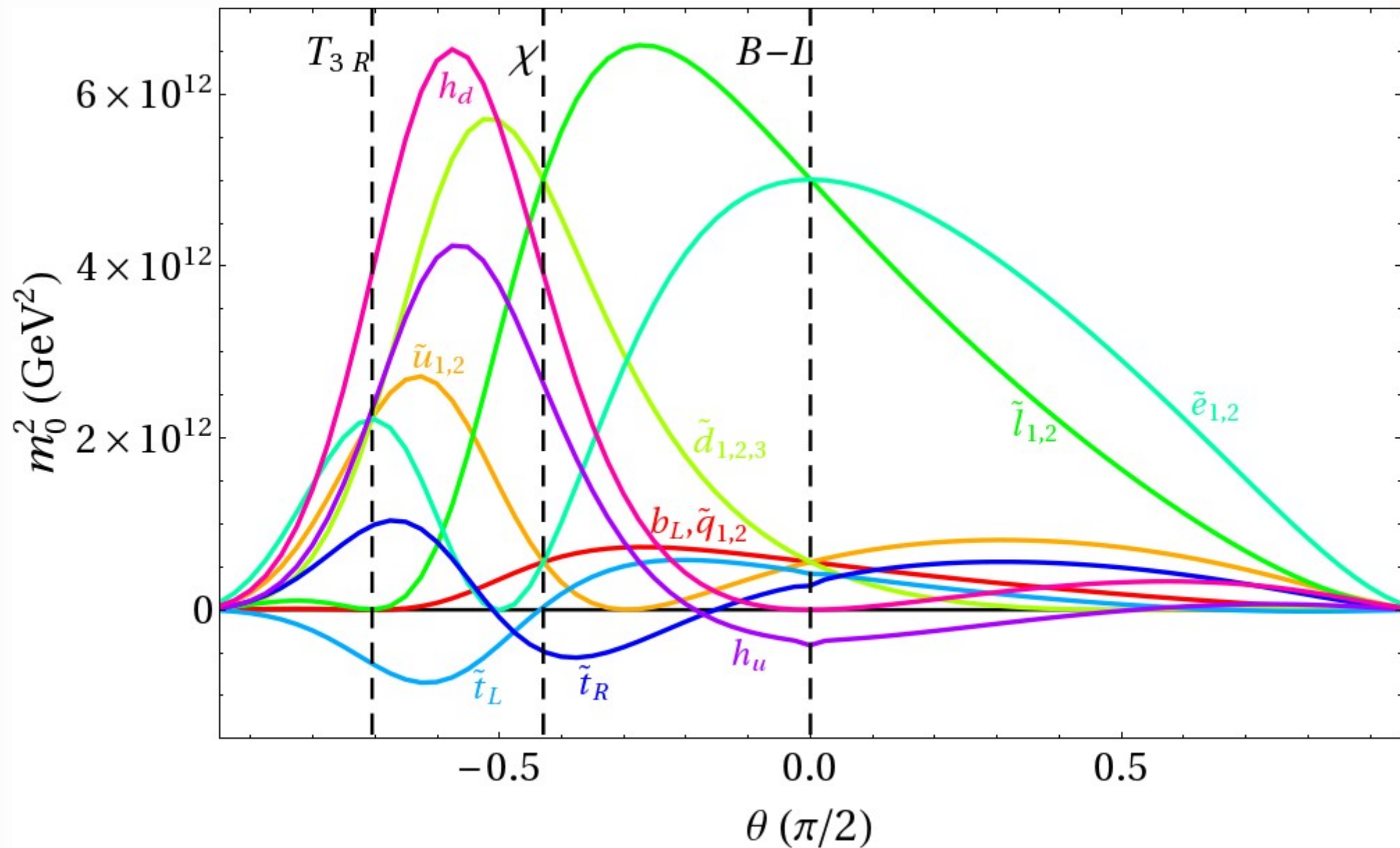
(\Leftrightarrow mediators only charged under $B-L$)

$m_s^2 \propto \left(\frac{\alpha'}{4\pi}\right)^2 \left(\frac{F}{M}\right)^2$

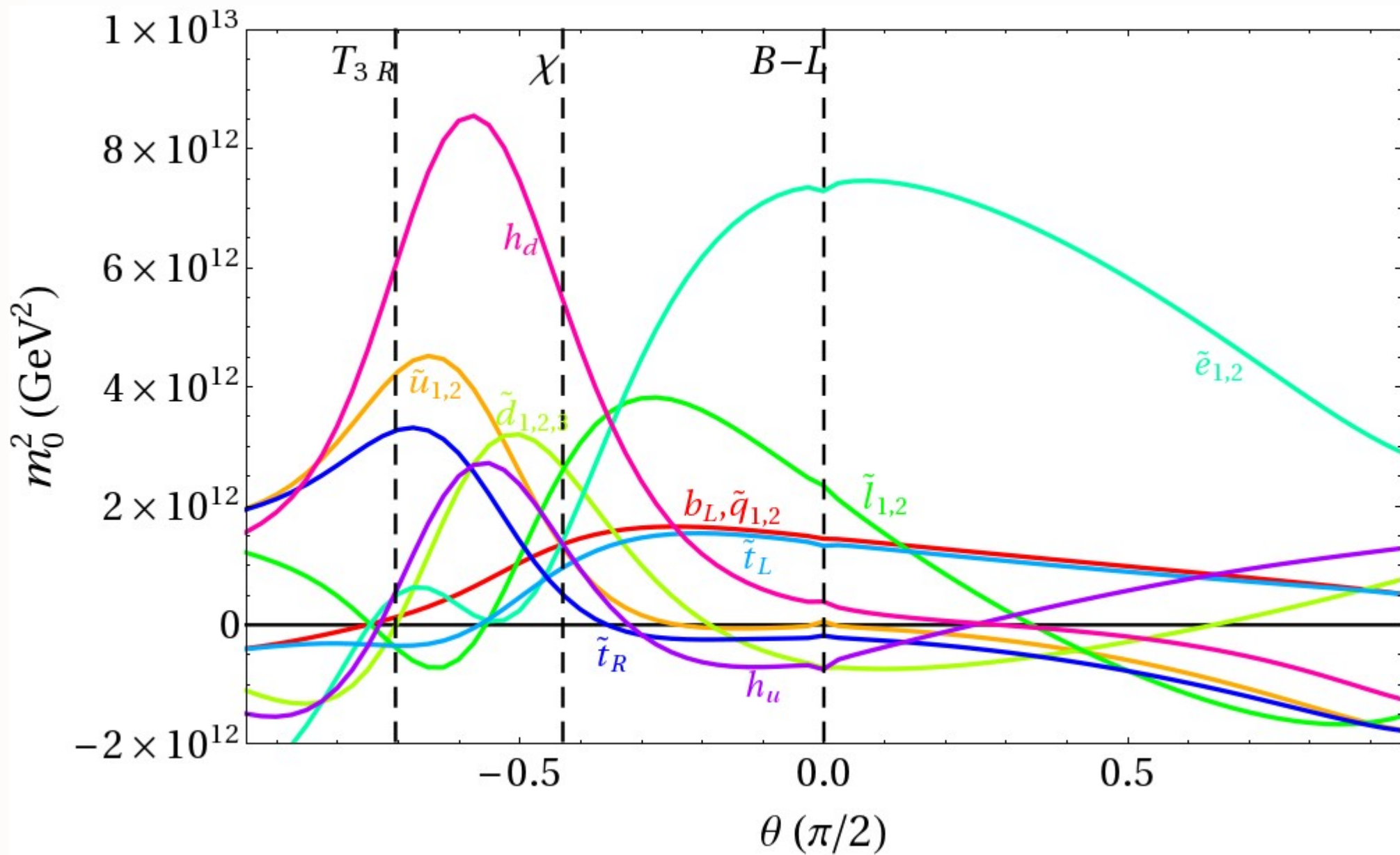
$M_g \propto \frac{\alpha_g}{4\pi} \left(\frac{\alpha'}{4\pi}\right)^2 \frac{F}{M}$

$$\frac{M_g}{m_s} \sim \frac{\alpha_g}{4\pi} \frac{\alpha'}{4\pi}$$

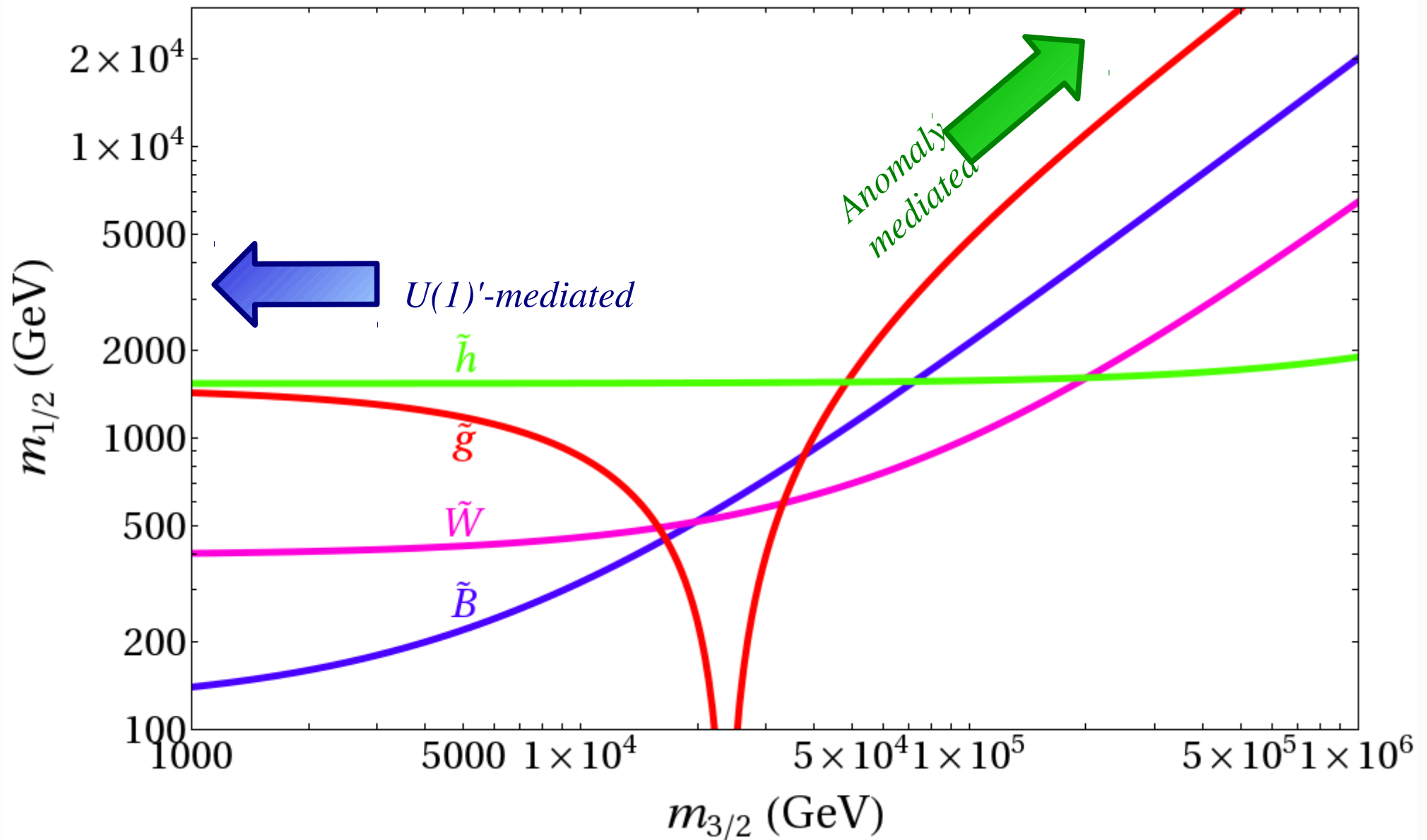
U(1)' spectrum with no D-terms



U(1)' spectrum with D-terms



U(1)' fermion spectrum



Higgs couplings in Split

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

