UC Davis – Nov. 19th, 2012

Mini-Split

Giovanni Villadoro

SLAC NATIONAL ACCELERATOR LABORATORY

A.Arvanitaki, N.Craig, S.Dimopoulos – hep-ph/1210.0555

LHC's main target:

understand the physics behind EWSB

(hierarchy problem)

LHC's main target:

understand the physics behind EWSB

(hierarchy problem)

Many possible solutions.

LHC's main target:

understand the physics behind EWSB

(hierarchy problem)

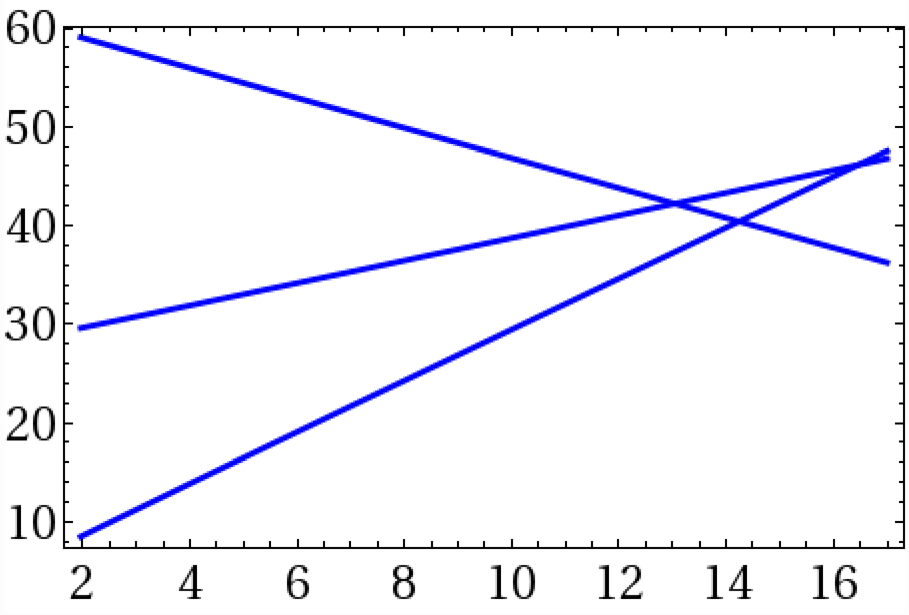
Many possible solutions. One is special: SUSY

LHC's main target:

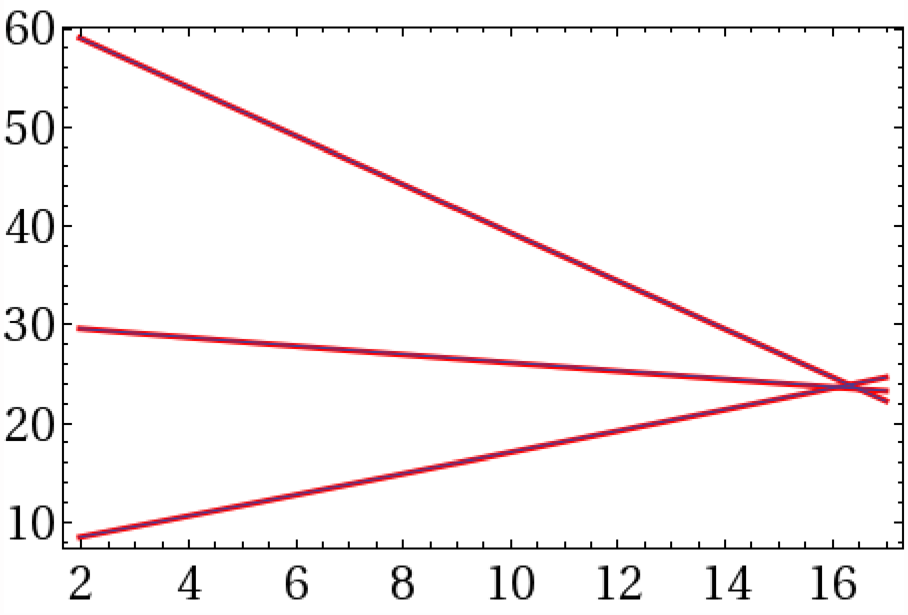
understand the physics behind EWSB
(hierarchy problem)

Many possible solutions. One is special: SUSY

SM



MSSM

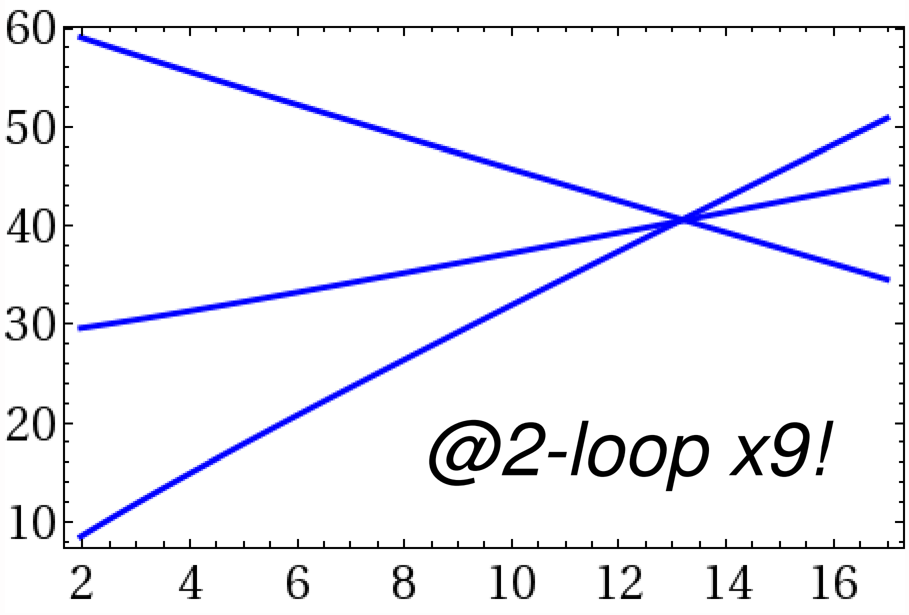


LHC's main target:

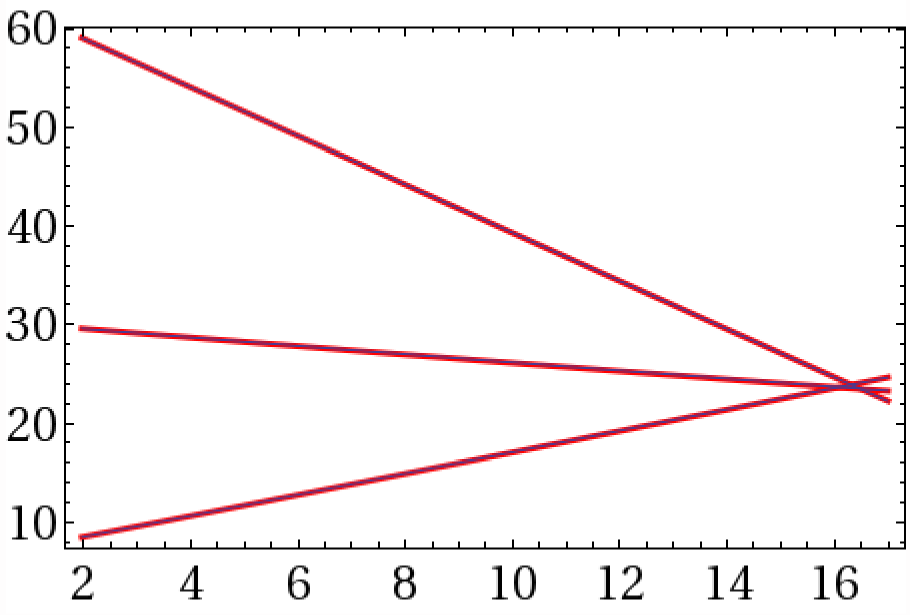
understand the physics behind EWSB
(hierarchy problem)

Many possible solutions. One is special: SUSY

SM

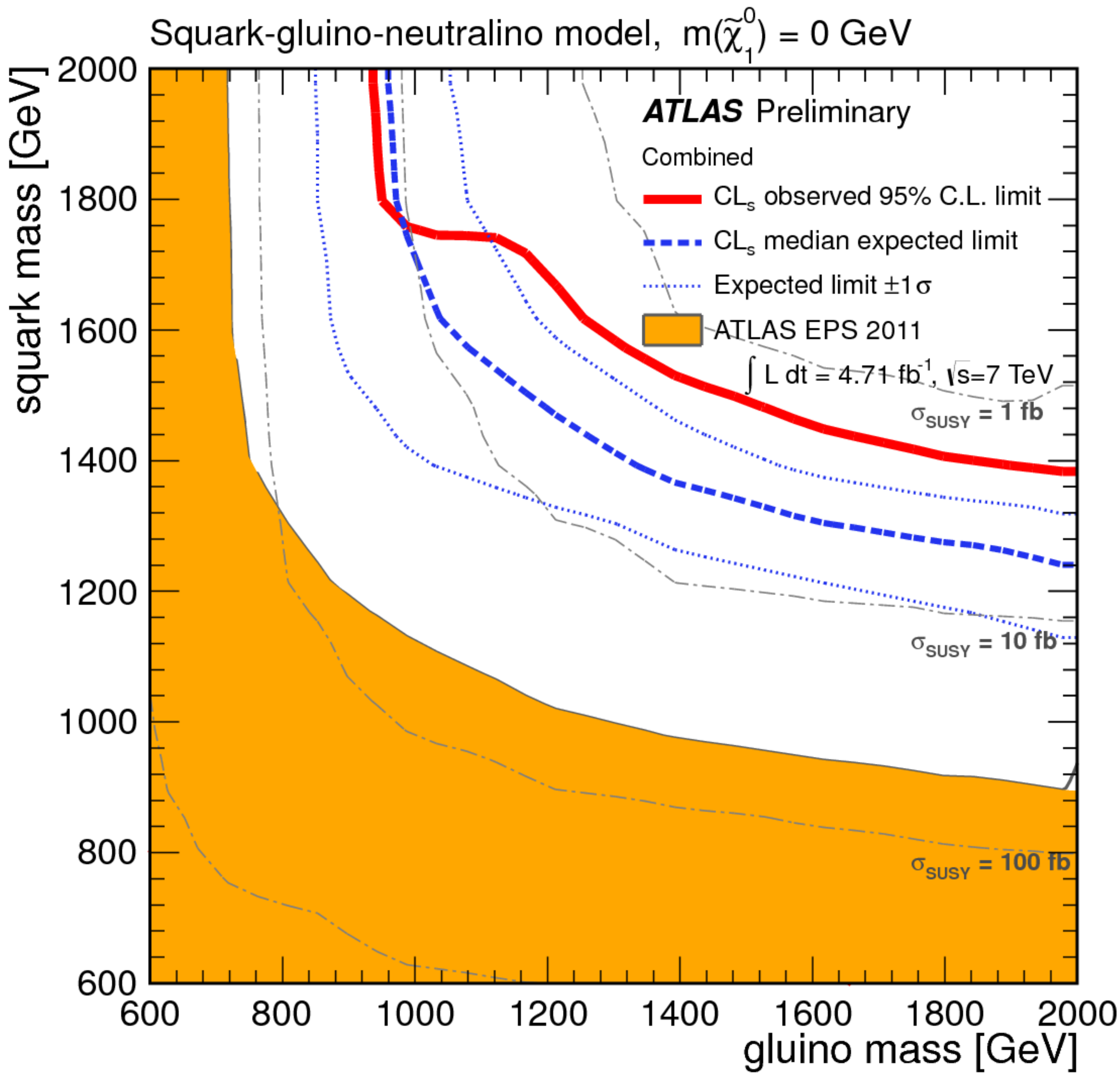


MSSM



The Missing Superpartner Problem

No Vanilla SUSY



Natural SUSY

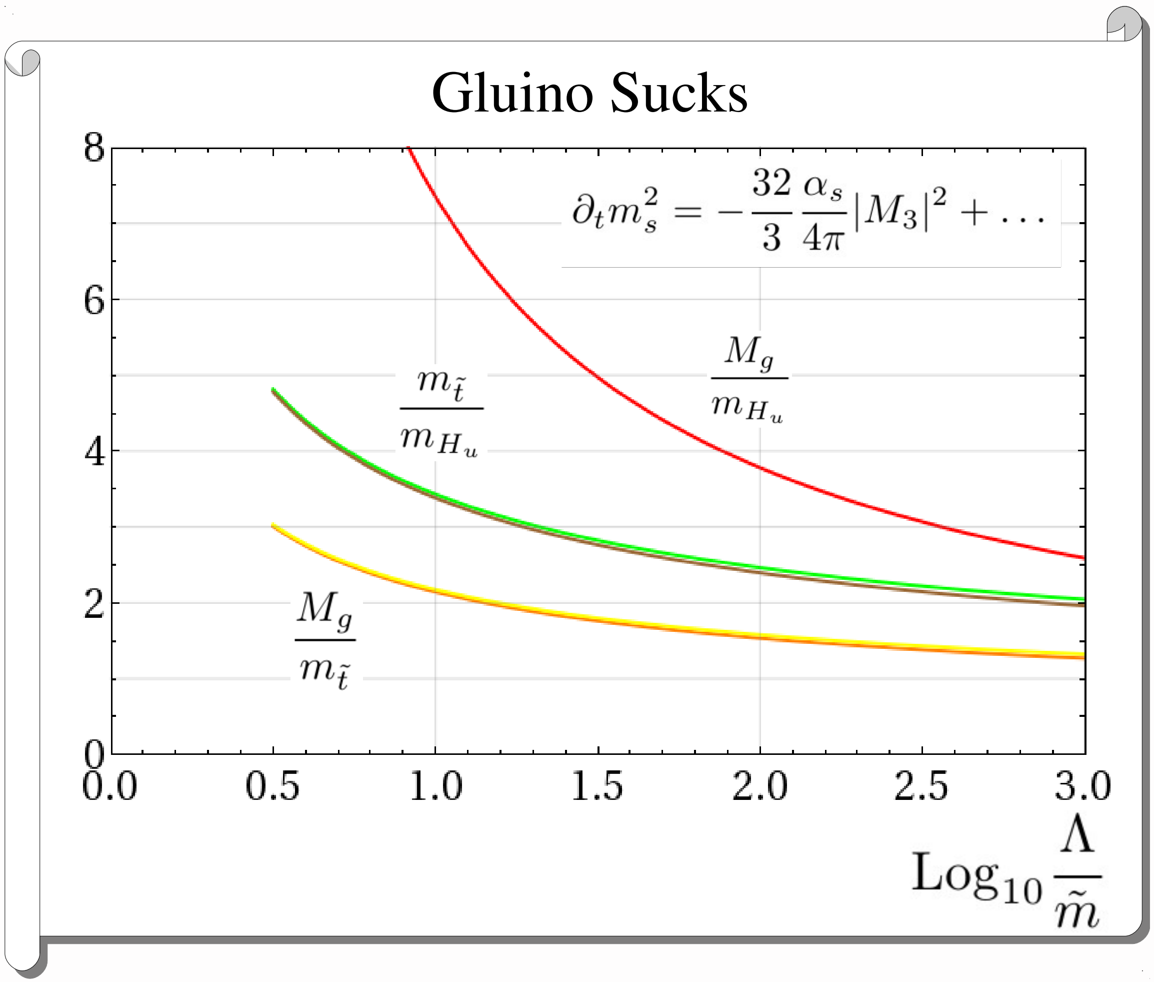
Only main actors of Hierarchy Problem needs to be light:

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

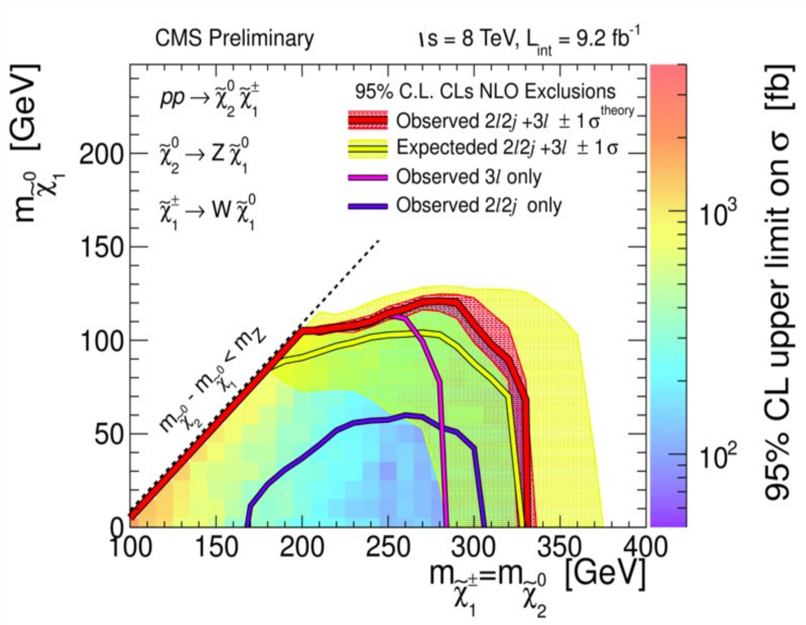
Natural SUSY

Only main actors of Hierarchy Problem needs to be light:

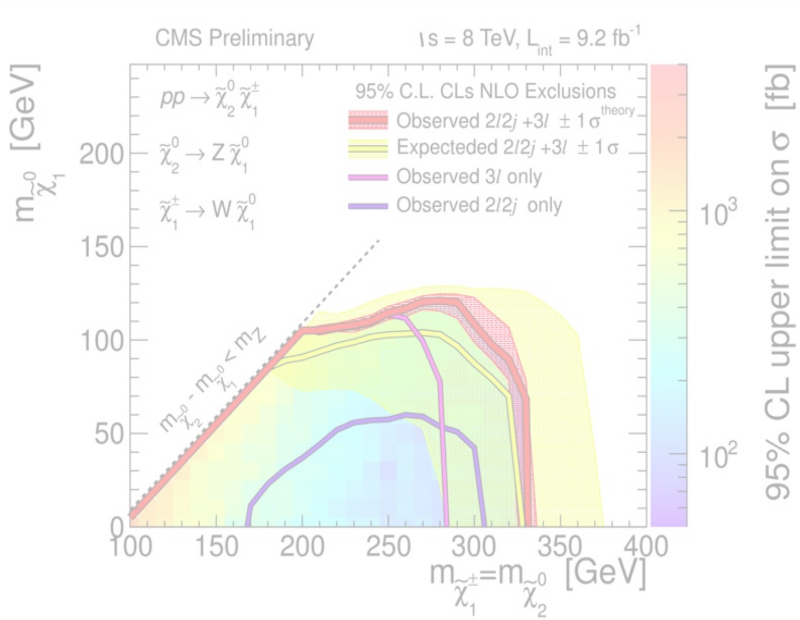
$\mu \lesssim 250$ GeV, $m_{stop} \lesssim 700$ GeV, $M_{gluino} \lesssim 1.4$ TeV

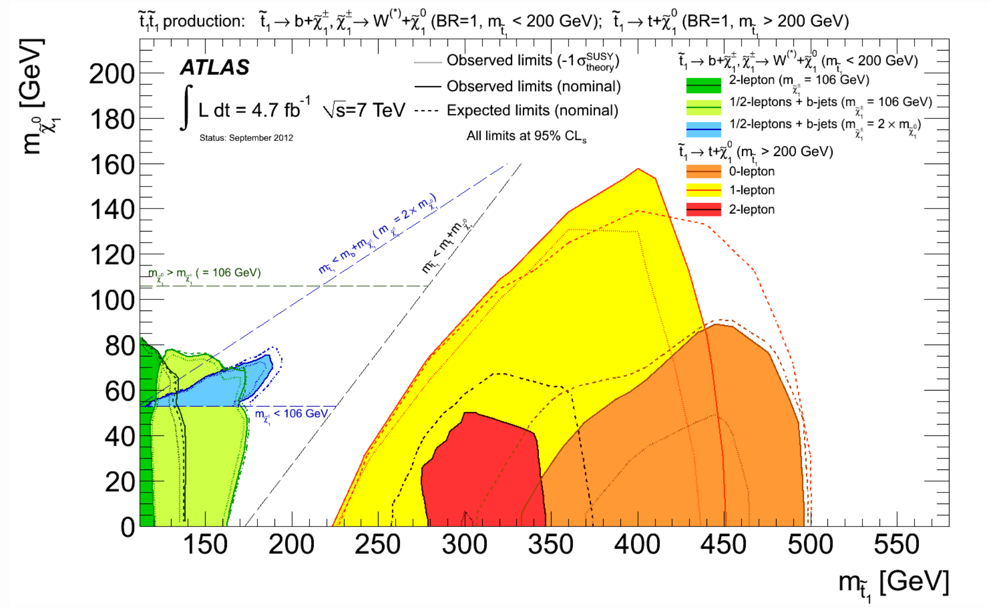


Testing Natural SUSY

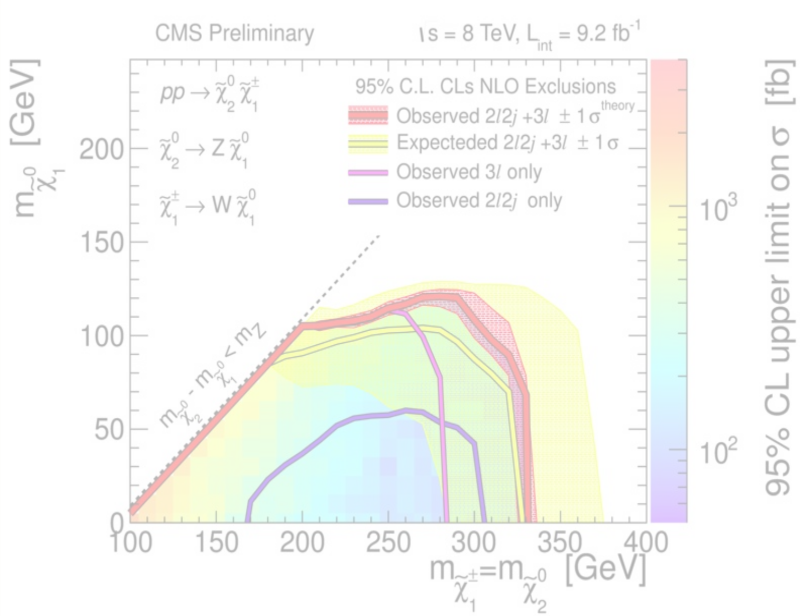


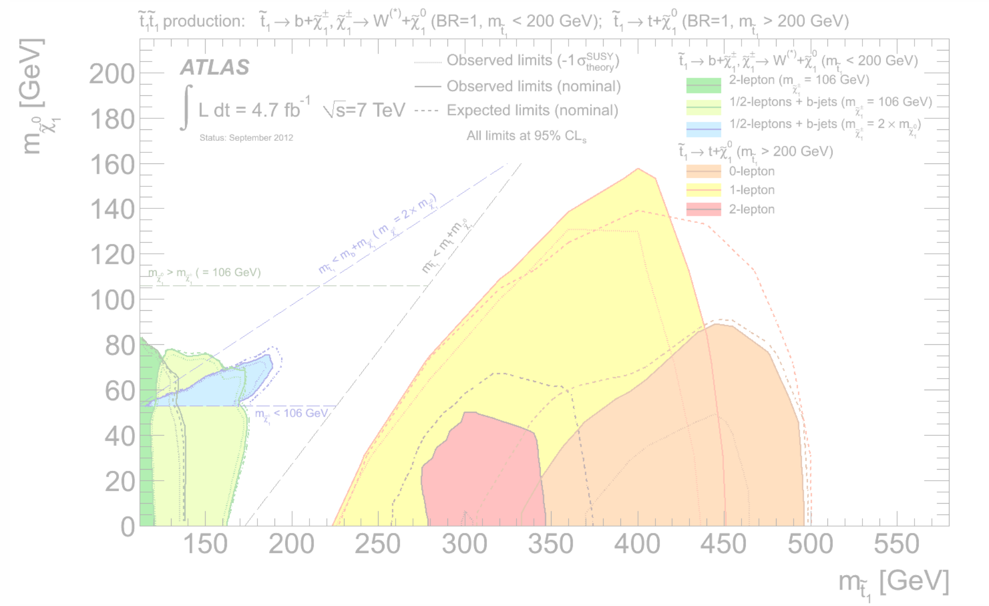
Testing Natural SUSY

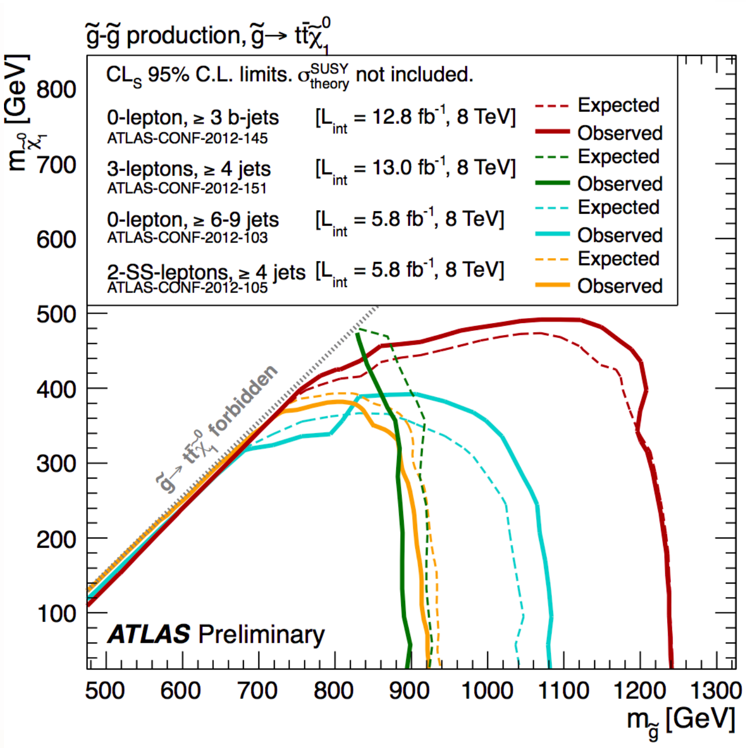


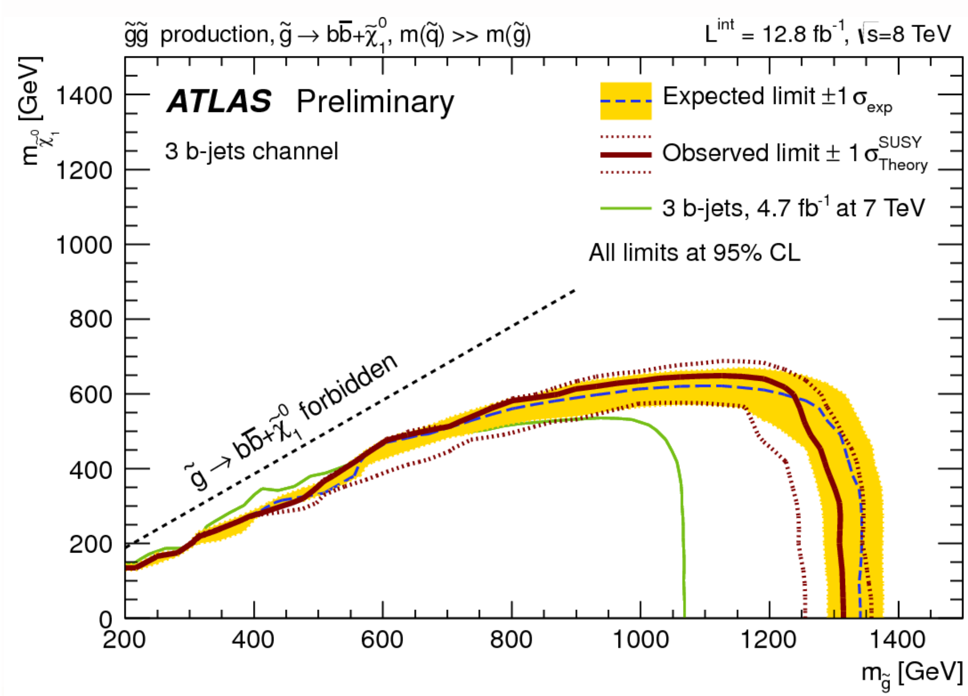


Testing Natural SUSY

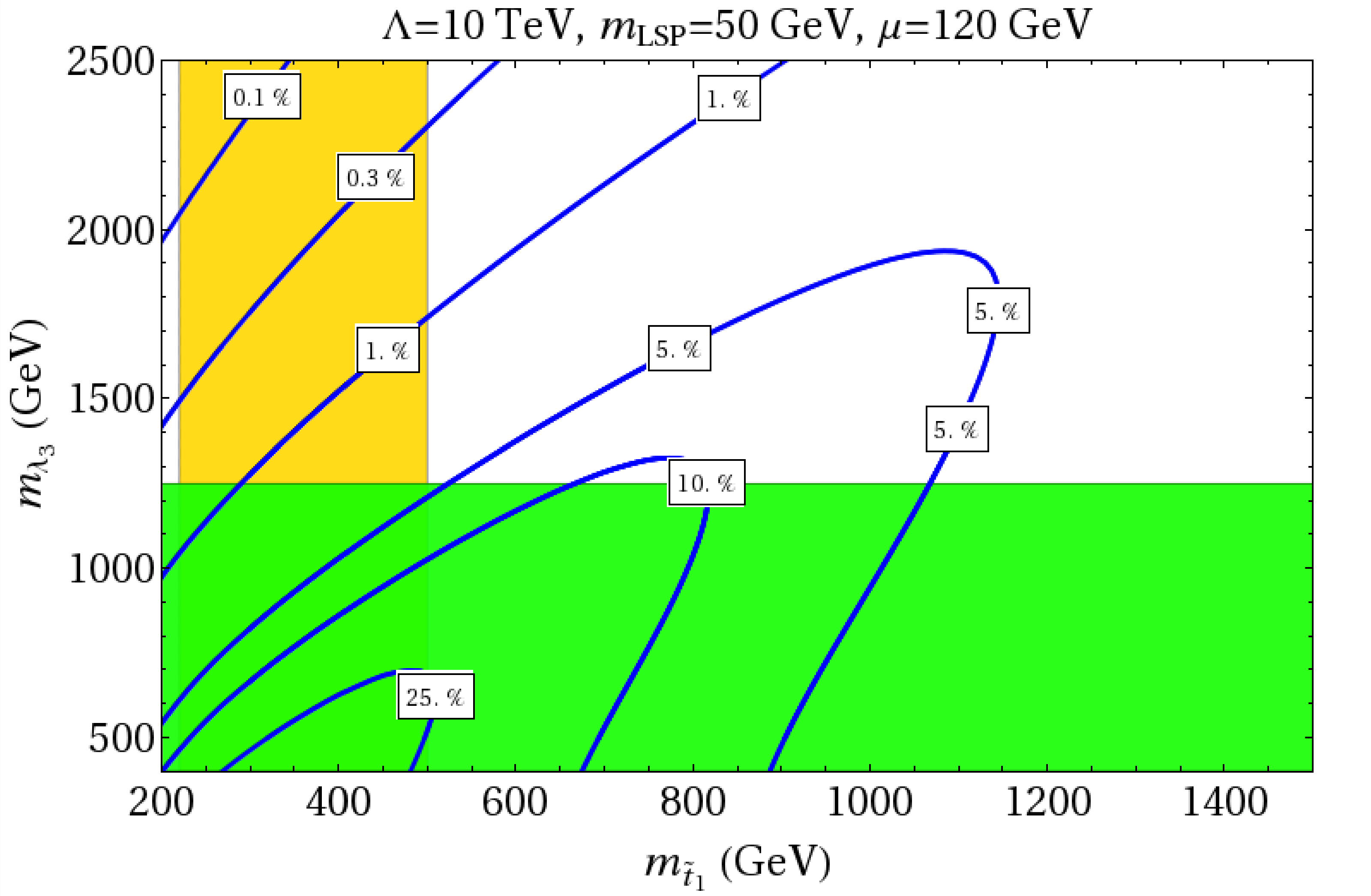




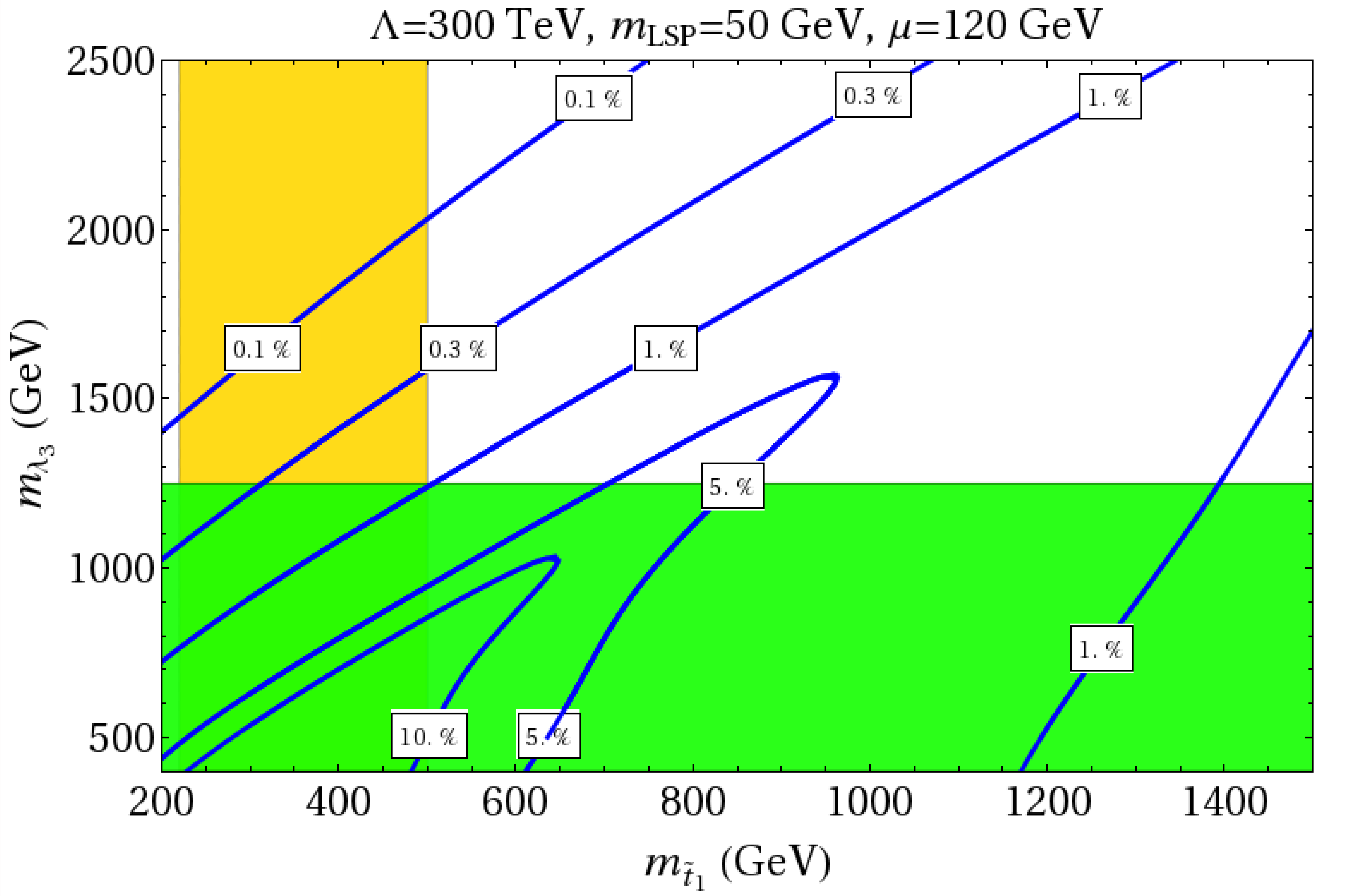




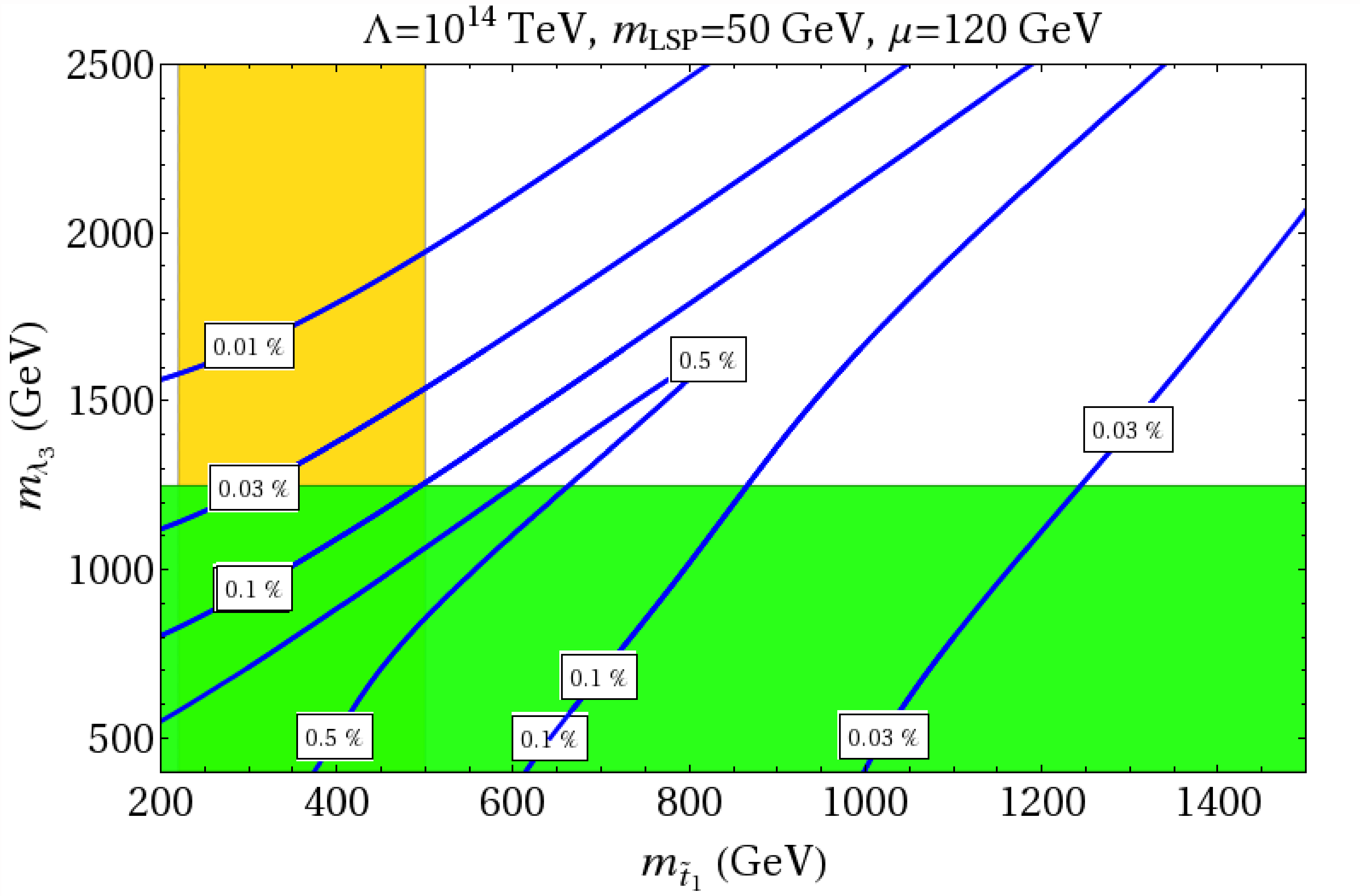
Natural SUSY – How bad it is?



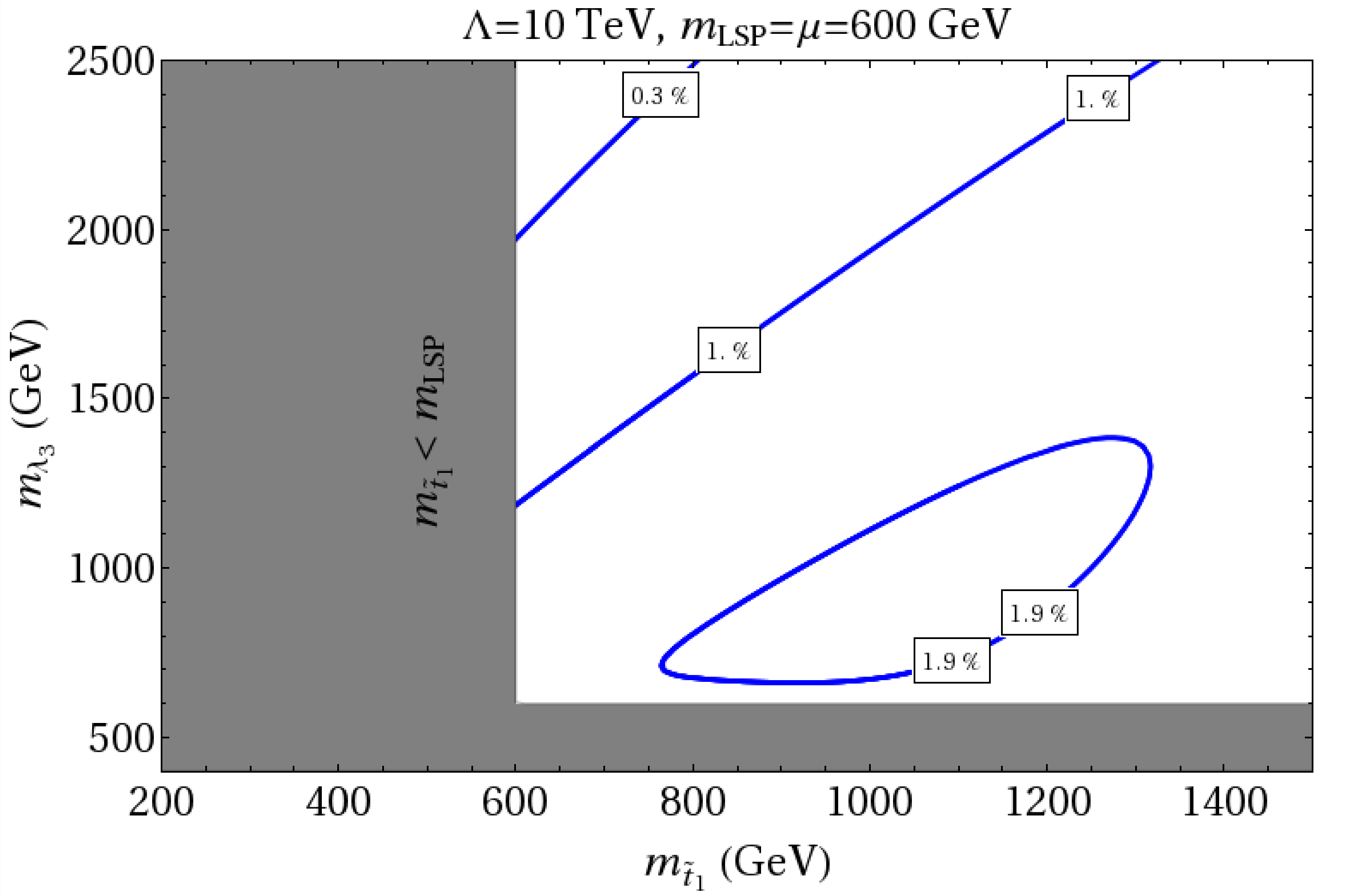
Natural SUSY – How bad it is?



Natural SUSY – How bad it is?



Natural SUSY – How bad it is?



Alternative SUSY models

- leptonic RPV
- Extra neutralinos (singlino, fotini,...)
- Dirac gauginos
- baryonic RPV
- stealth SUSY
- …?

Alternative SUSY models

- leptonic RPV
- Extra neutralinos (singlino, fotini,...)
- Dirac gauginos
- baryonic RPV
- stealth SUSY
- …?

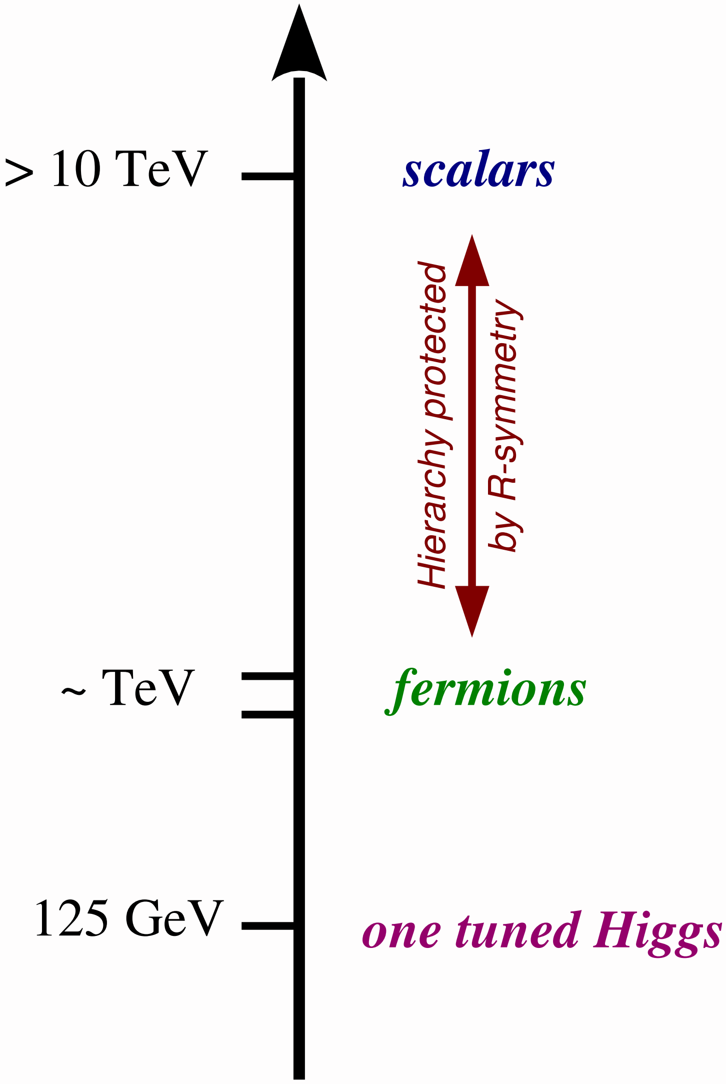
A lot of effort just to hide SUSY, and some degree of tuning often left
is it really worth it?

time to give up?

The 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

"Mini"-Split SUSY

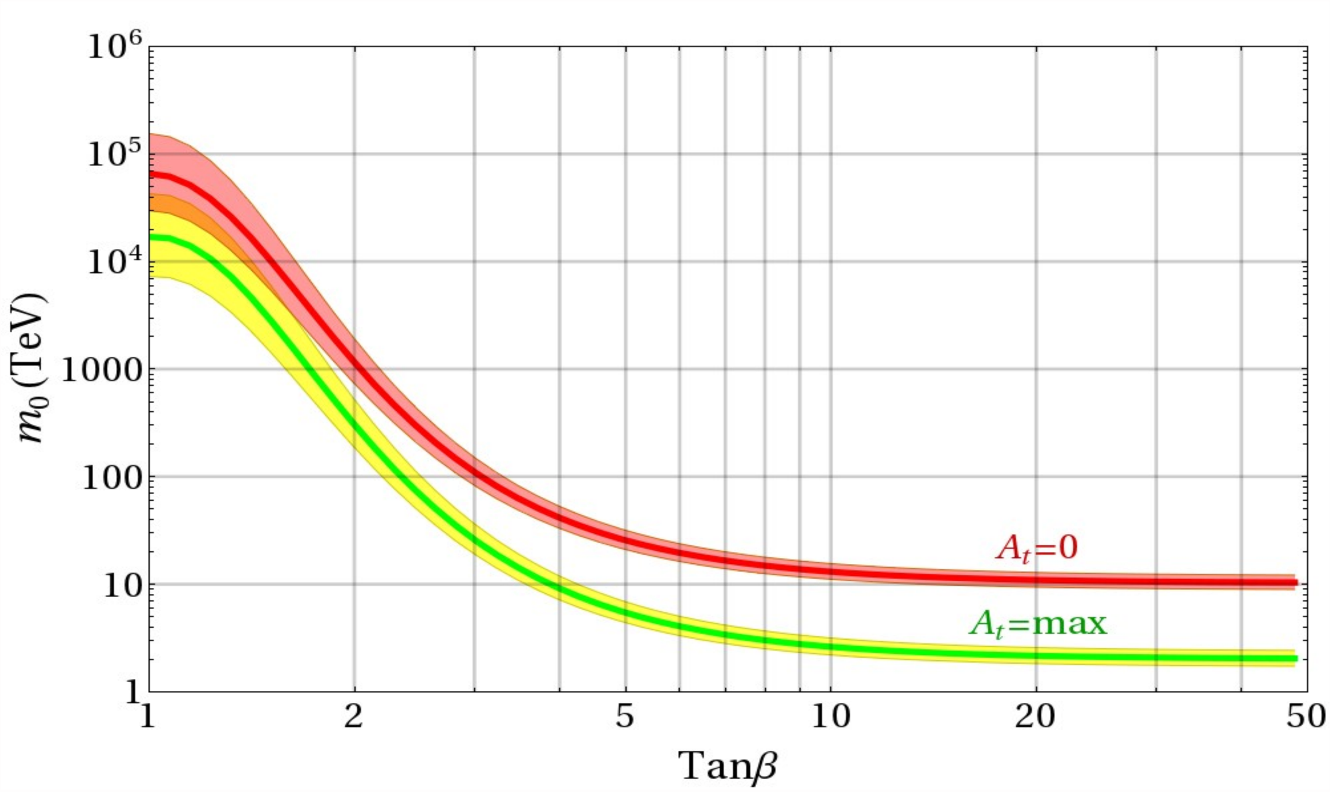
m_H~125.5 GeV fixes $\lambda(m_H)$

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

“Mini”-Split SUSY

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

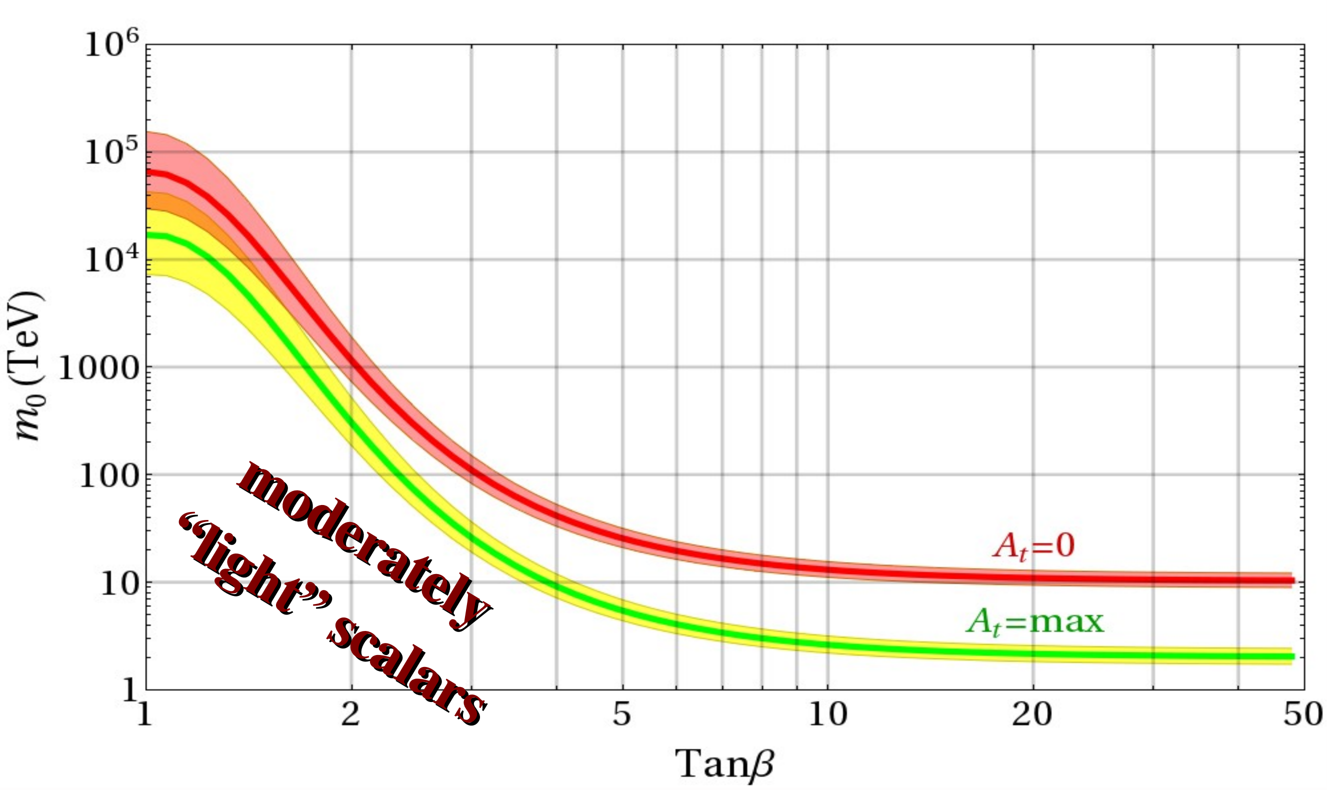
SUSY fixes $$\lambda(\tilde{m}) = \frac{[g^2(\tilde{m}) + g'^2(\tilde{m})]}{4} \cos^2 2\beta$$



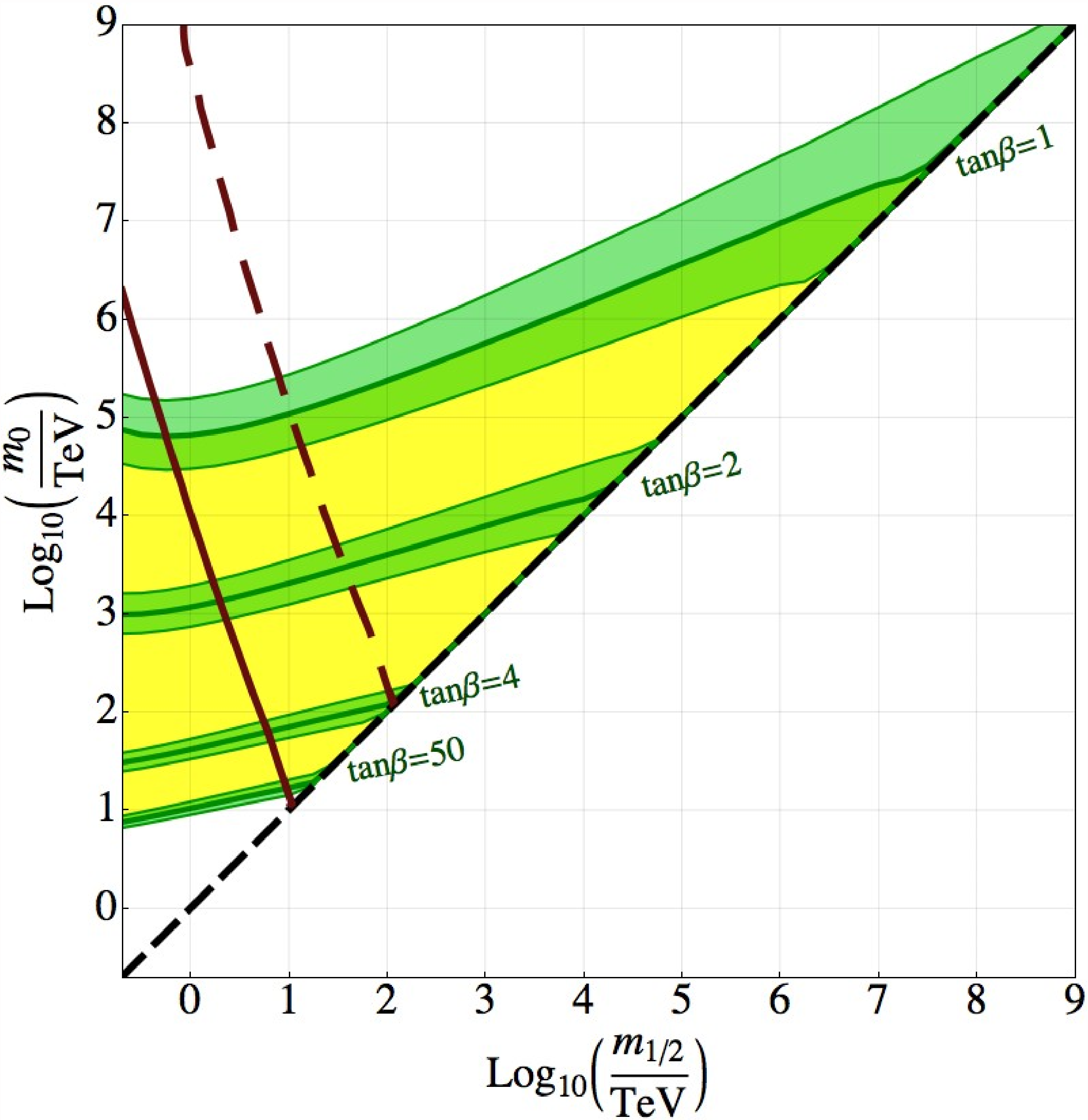
“Mini”-Split SUSY

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

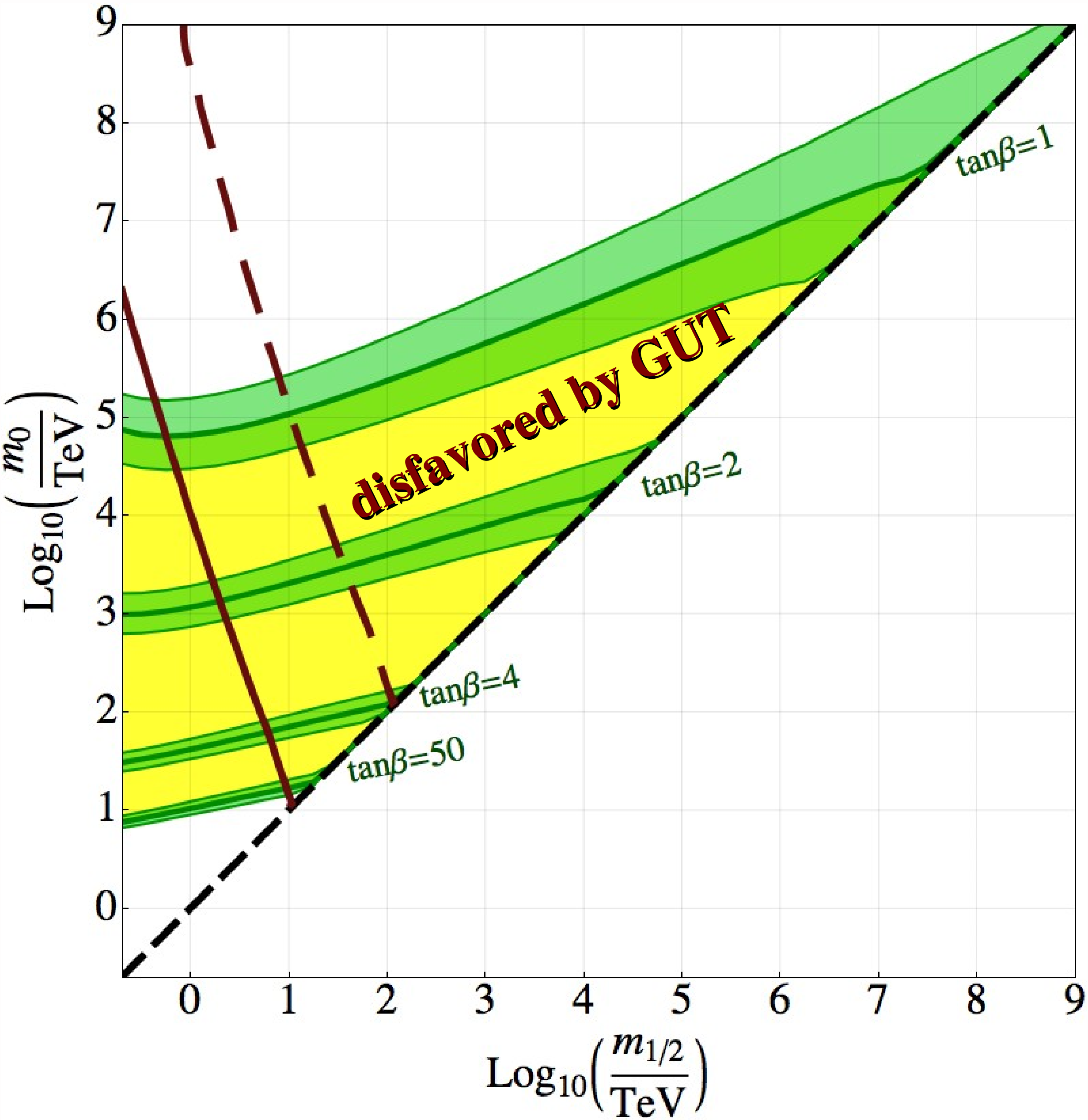
SUSY fixes $$\lambda(\tilde{m}) = \frac{[g^2(\tilde{m}) + g'^2(\tilde{m})]}{4}\cos^2 2\beta$$



more in general



more in general

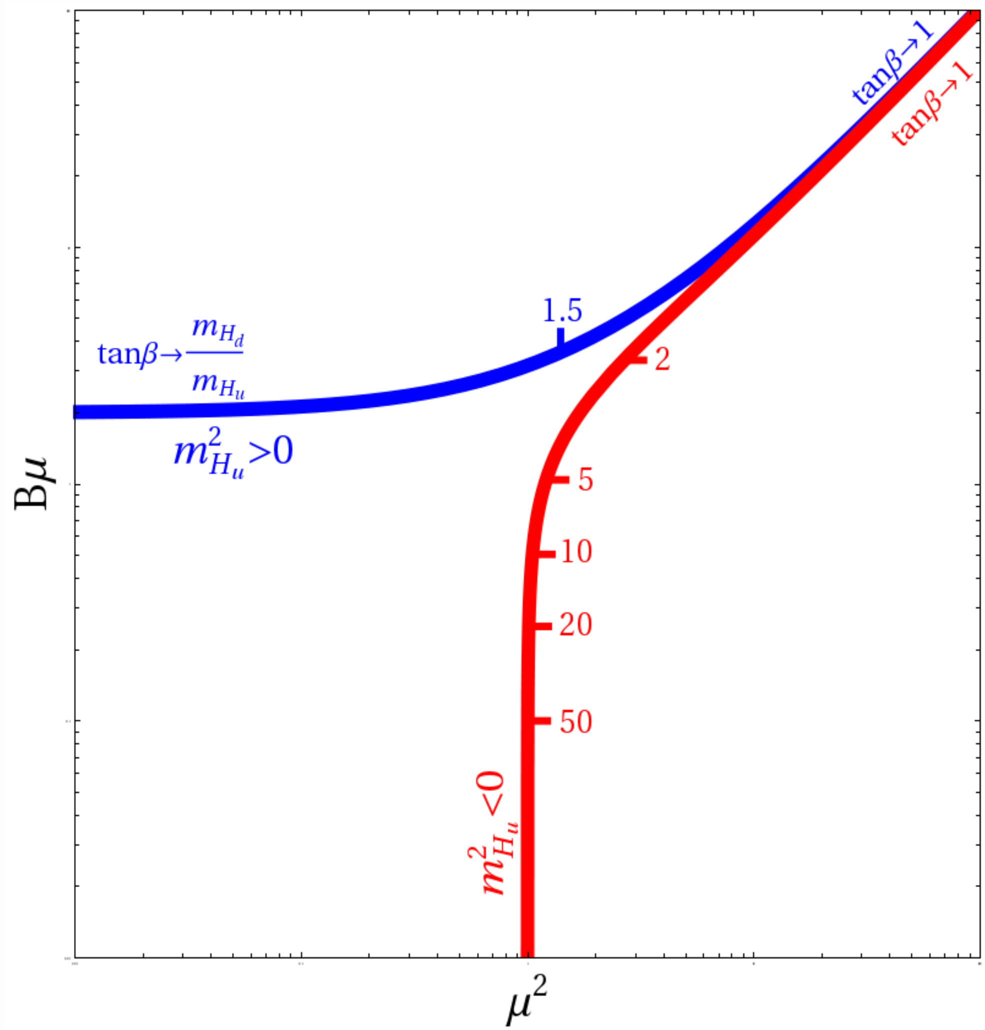


Tuning the EWSB...

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

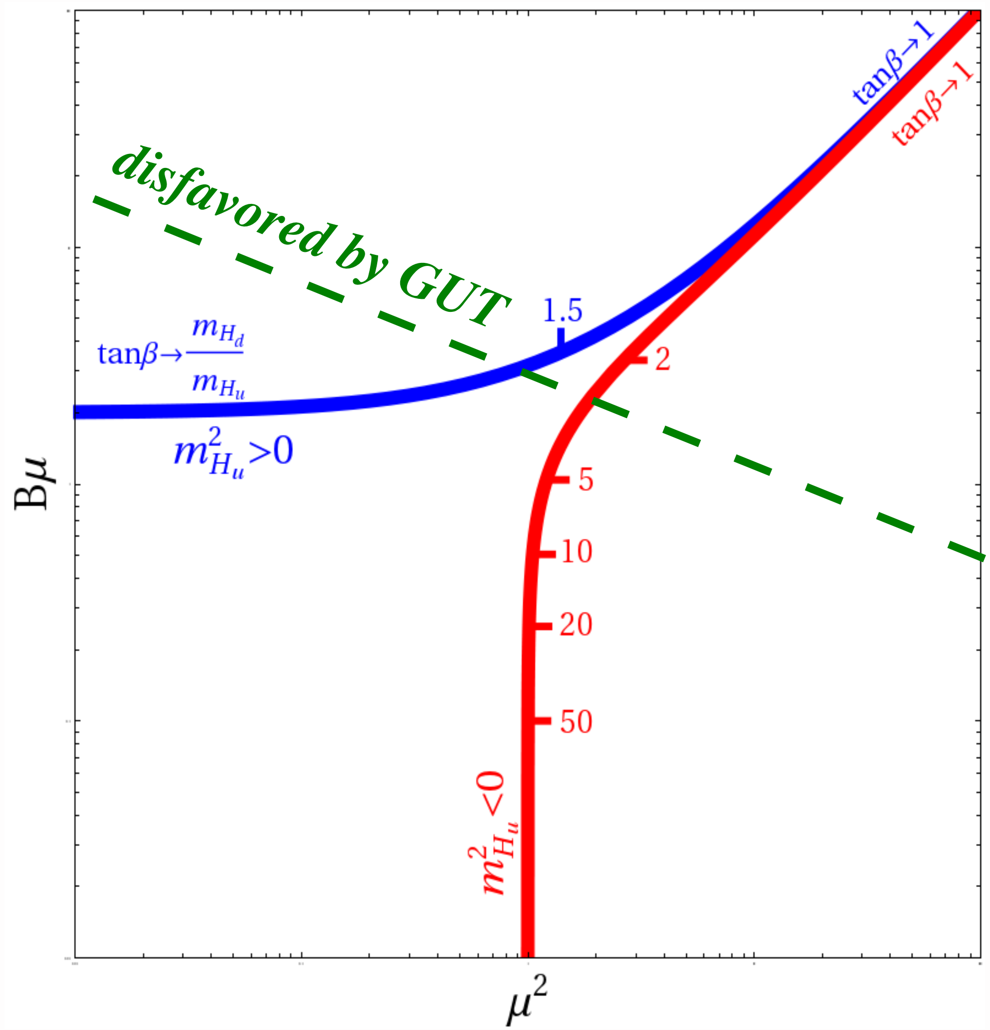
Tuning the EWSB...

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



Tuning the EWSB...

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



RGE and tachyons in Split

Yukawa

D-term

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

RGE and tachyons in Split

Yukawa

D-term

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

RGE and tachyons in Split

Yukawa

D-term

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

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

RGE and tachyons in Split

Yukawa

D-term

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

=0 if m_{Hu}=m_{Hd} + 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

Yukawa

D-term

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

=0 if m_{Hu}=m_{Hd} + 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: $X_t \to 0$ $\Rightarrow$ tachyon

RGE and tachyons in Split

Yukawa

D-term

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

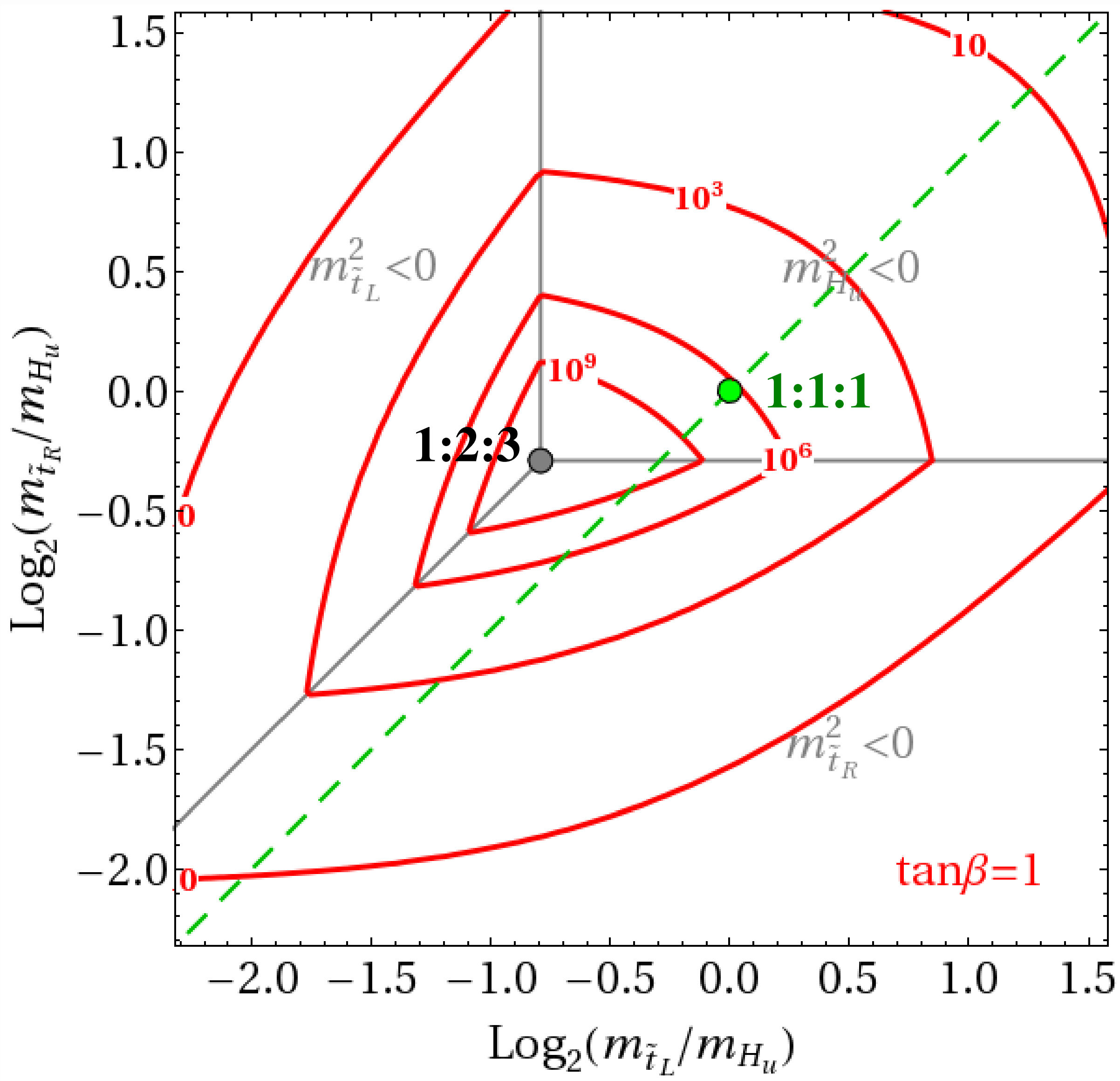
=0 if *m*$_{Hu}$=*m*$_{Hd}$ + GUT B.C.

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

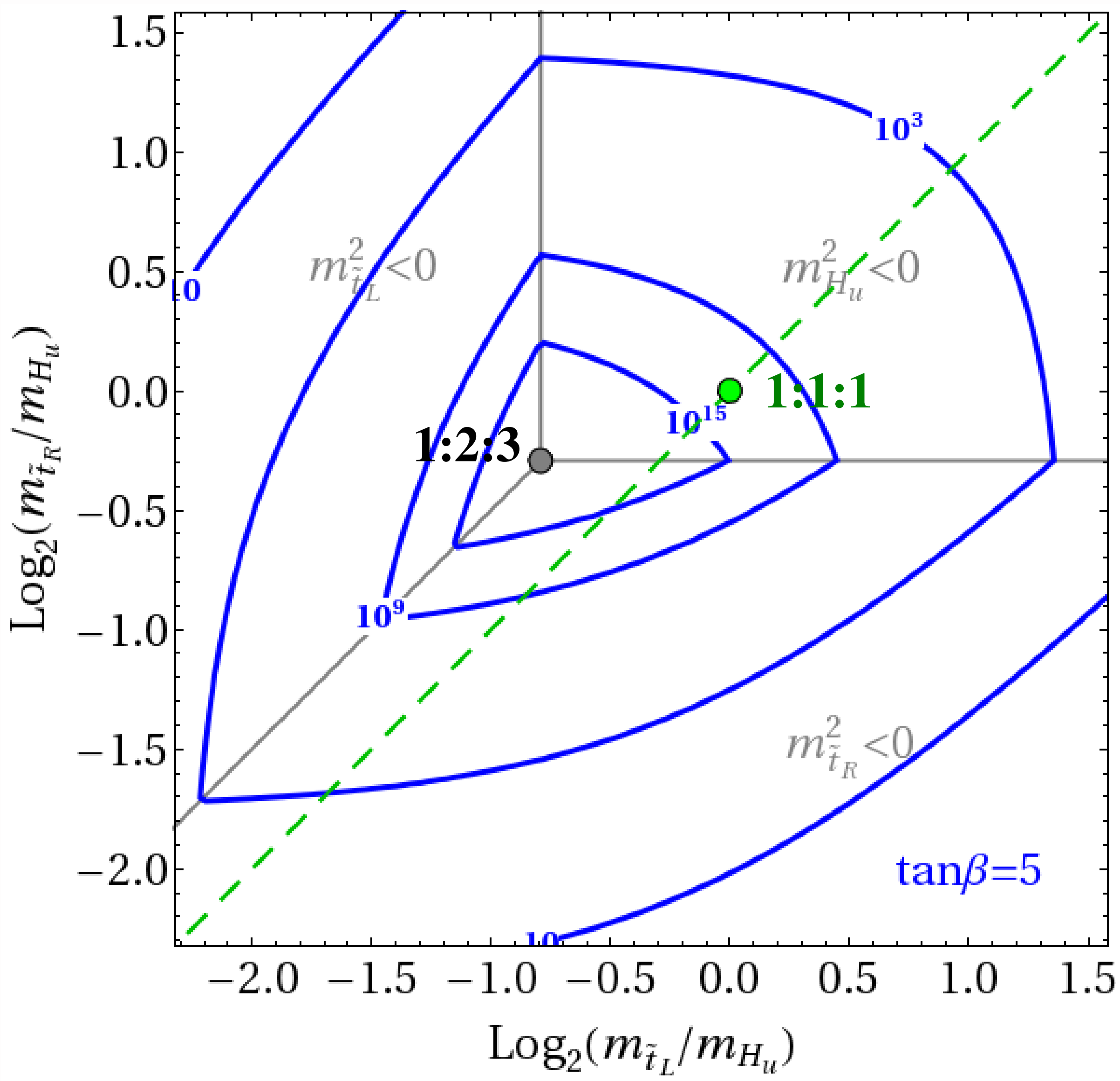
IR fixed point: $X_t \to 0$ $\Rightarrow$ tachyon

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...



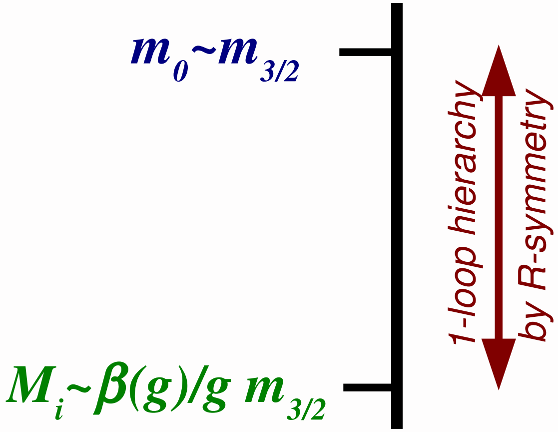
How much you can run...



Examples

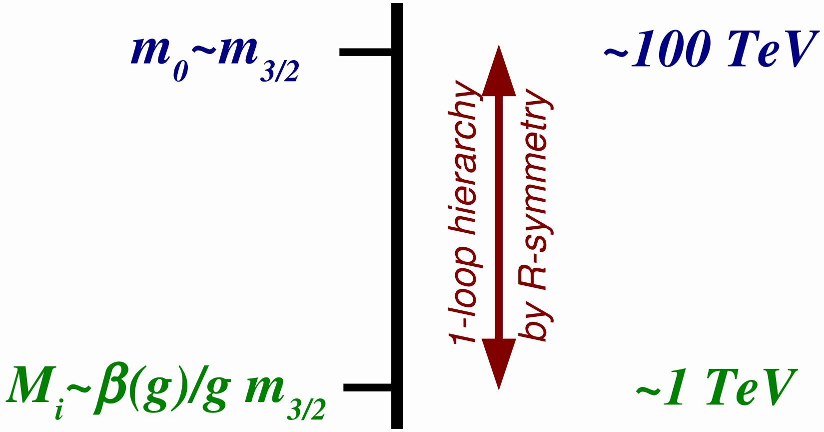
Anomaly Mediation

Giudice, Luty, Murayama, Rattazzi '98



Anomaly Mediation

Giudice, Luty, Murayama, Rattazzi '98



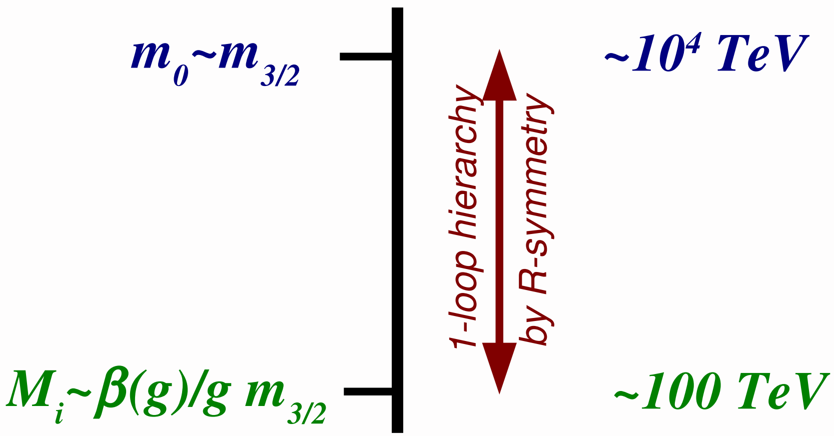
Light AMSB

- $\mu^2 \sim B_\mu \sim m_{3/2}{}^2$

  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

Gauge Mediation

Hidden assumption of natural GM:

Efficient breaking of R-symmetry in SUSY breaking sector

Very easy to get parametrically lighter gauginos:

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

Arkani-Hamed, Giudice, Luty, Rattazzi '98

Gauge Mediation

Hidden assumption of natural GM:

Efficient breaking of R-symmetry in SUSY breaking sector

Very easy to get parametrically lighter gauginos:

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

Arkani-Hamed, Giudice, Luty, Rattazzi '98

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

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

Gauge Mediation

Hidden assumption of natural GM:

Efficient breaking of R-symmetry in SUSY breaking sector

Very easy to get parametrically lighter gauginos:

– by suppresion of R-symmetry breaking in the hidden sector

– by accidental cancellations such as gaugino screening

Arkani-Hamed, Giudice, Luty, Rattazzi '98

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

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

- 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)':

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

SUSY breaking mediated by U(1)'

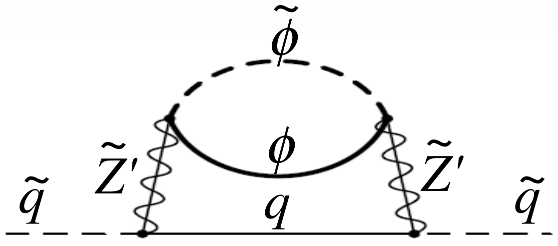
(⇔ mediators only charged under *B*-*L*)

U(1)' Split SUSY

MSSM + U(1)':

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

SUSY breaking mediated by U(1)'
(⇔ mediators only charged under *B*-*L*)



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

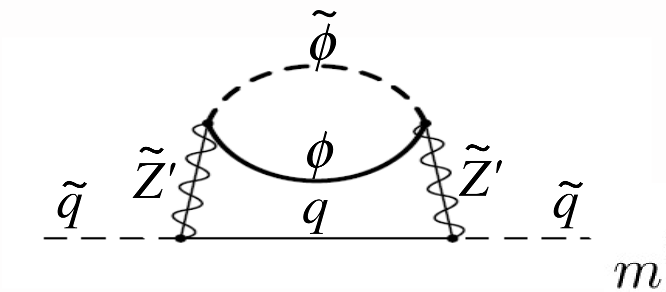
U(1)' Split SUSY

MSSM + U(1)':

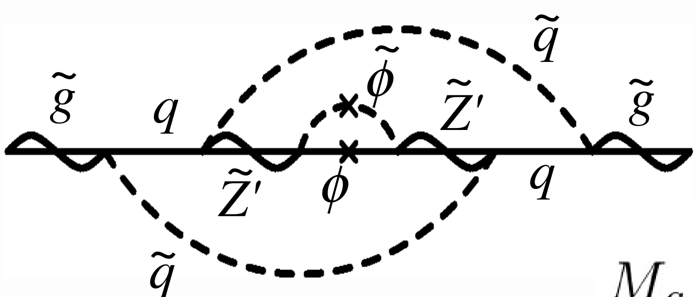
U(1)' = cos(θ) $U(1)_{B\text{-}L}$ + sin(θ) $U(1)_Y$

SUSY breaking mediated by U(1)'

(⇔ mediators only charged under *B*-*L*)



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



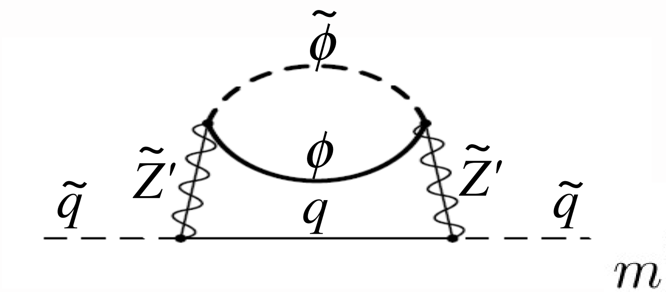
$$M_g \propto \frac{\alpha_g}{4\pi} \left(\frac{\alpha'}{4\pi}\right)^2 \frac{F}{M}$$

U(1)' Split SUSY

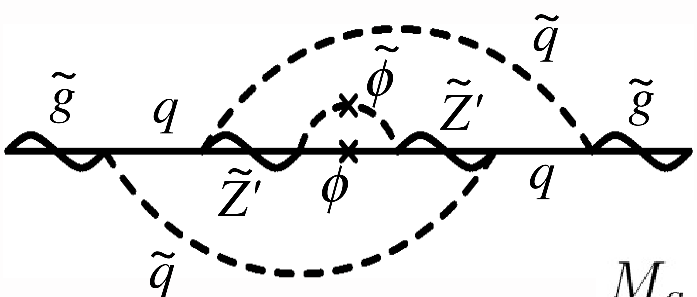
MSSM + U(1)':

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

SUSY breaking mediated by U(1)'
(⇔ mediators only charged under *B*-*L*)



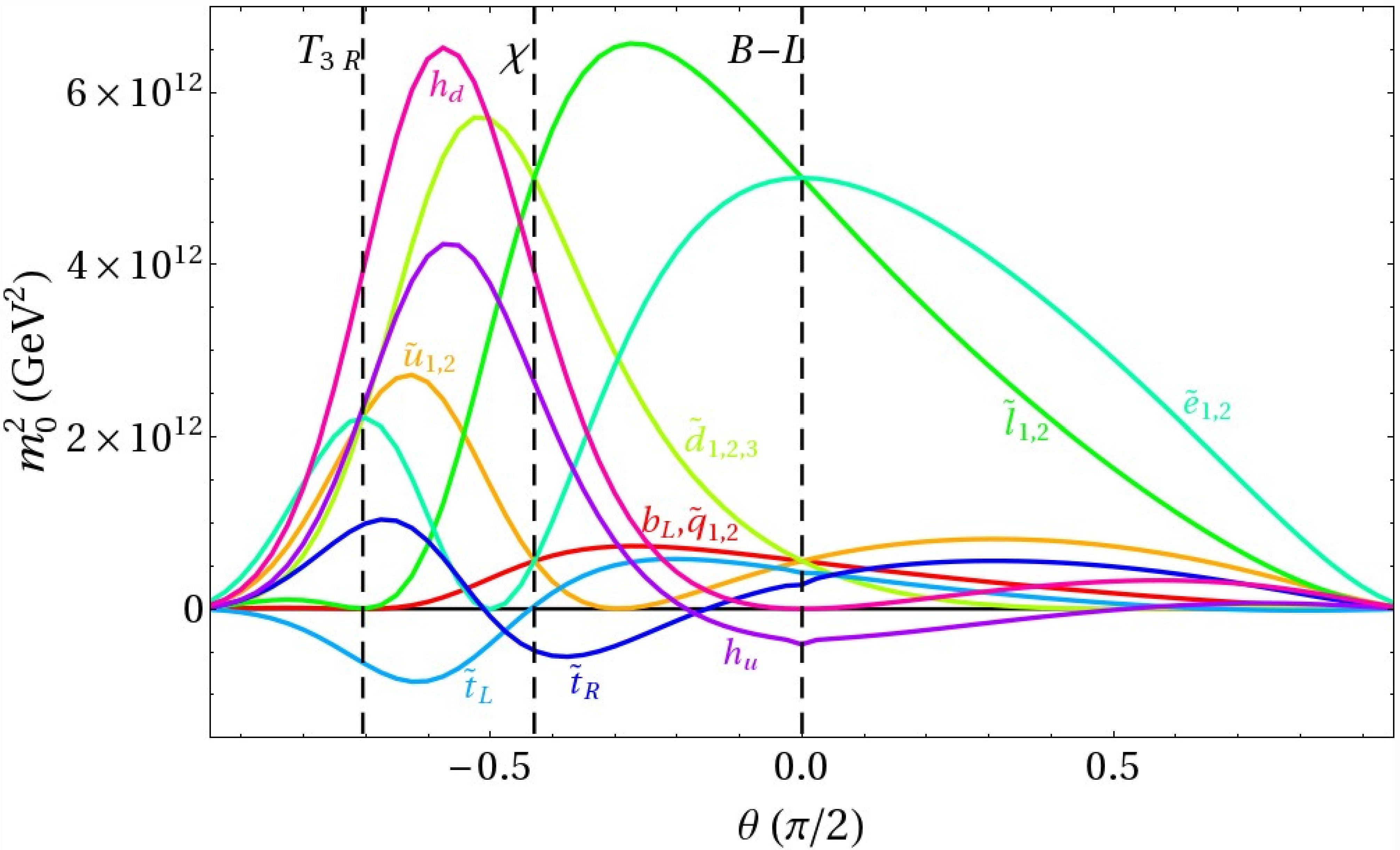
$$m_s^2 \propto \left(\frac{\alpha'}{4\pi}\right)^2 \left(\frac{F}{M}\right)^2$$



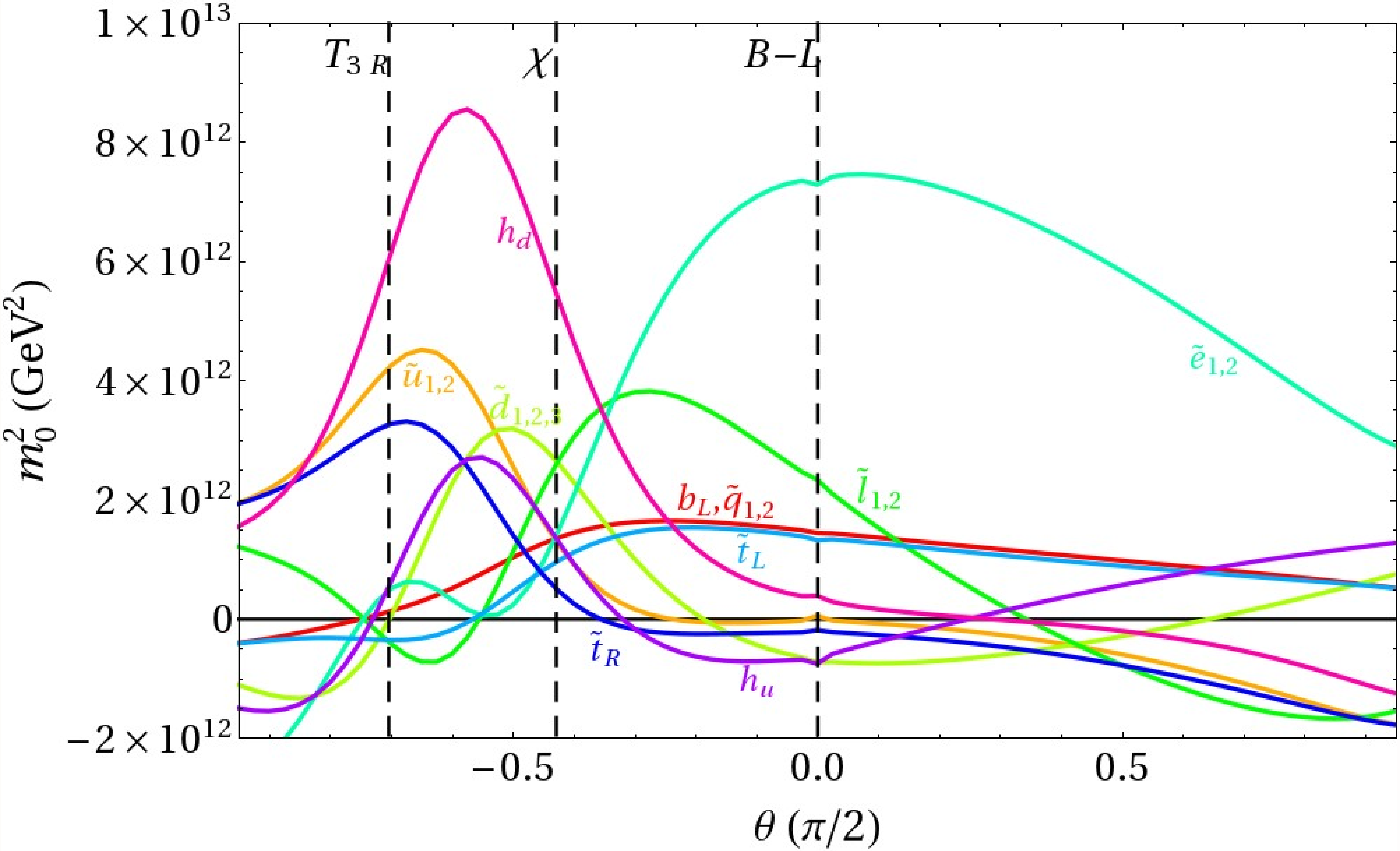
$$M_g \propto \frac{\alpha_g}{4\pi} \left(\frac{\alpha'}{4\pi}\right)^2 \frac{F}{M}$$

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

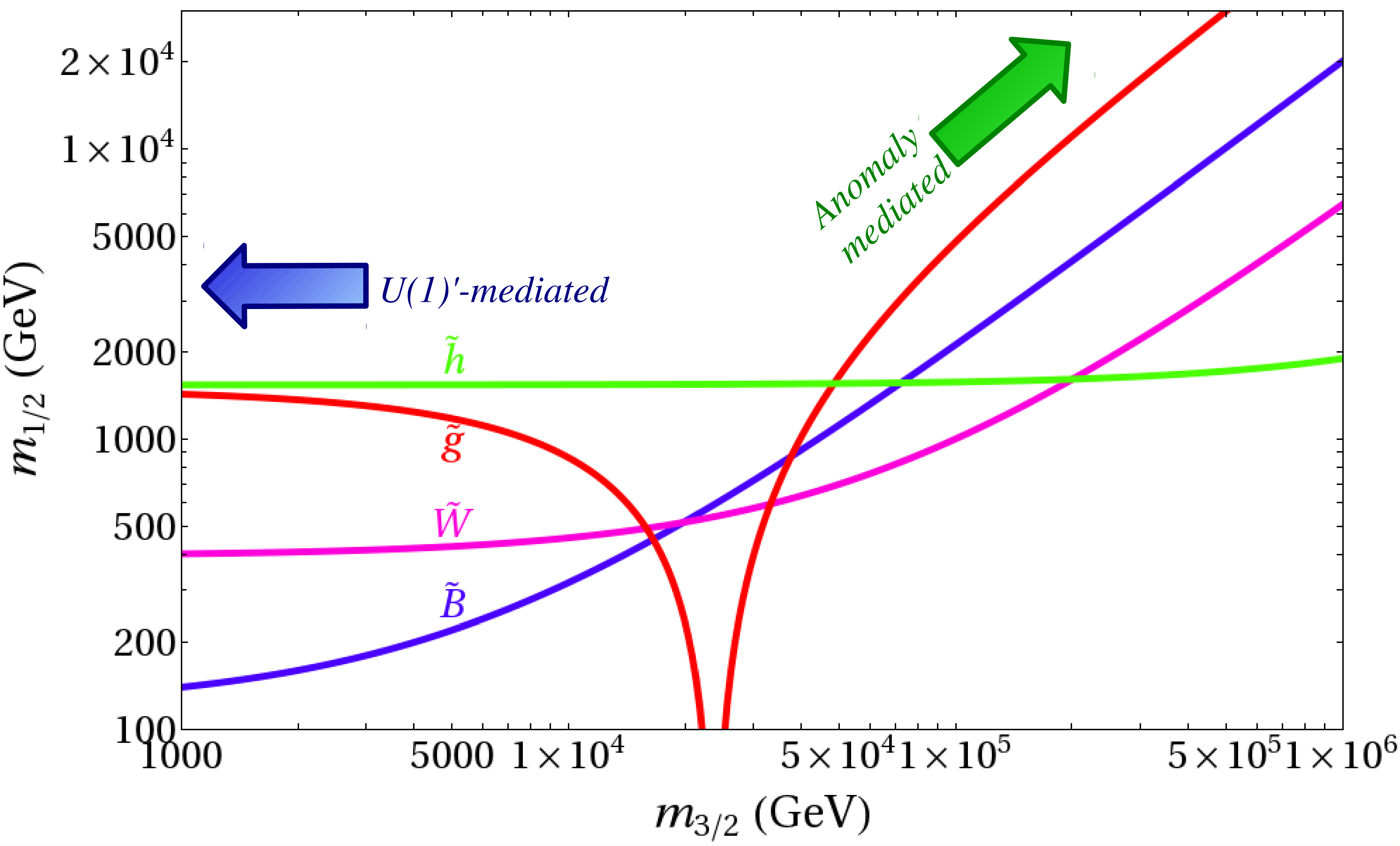
U(1)' spectrum with no D-terms



U(1)' spectrum with D-terms

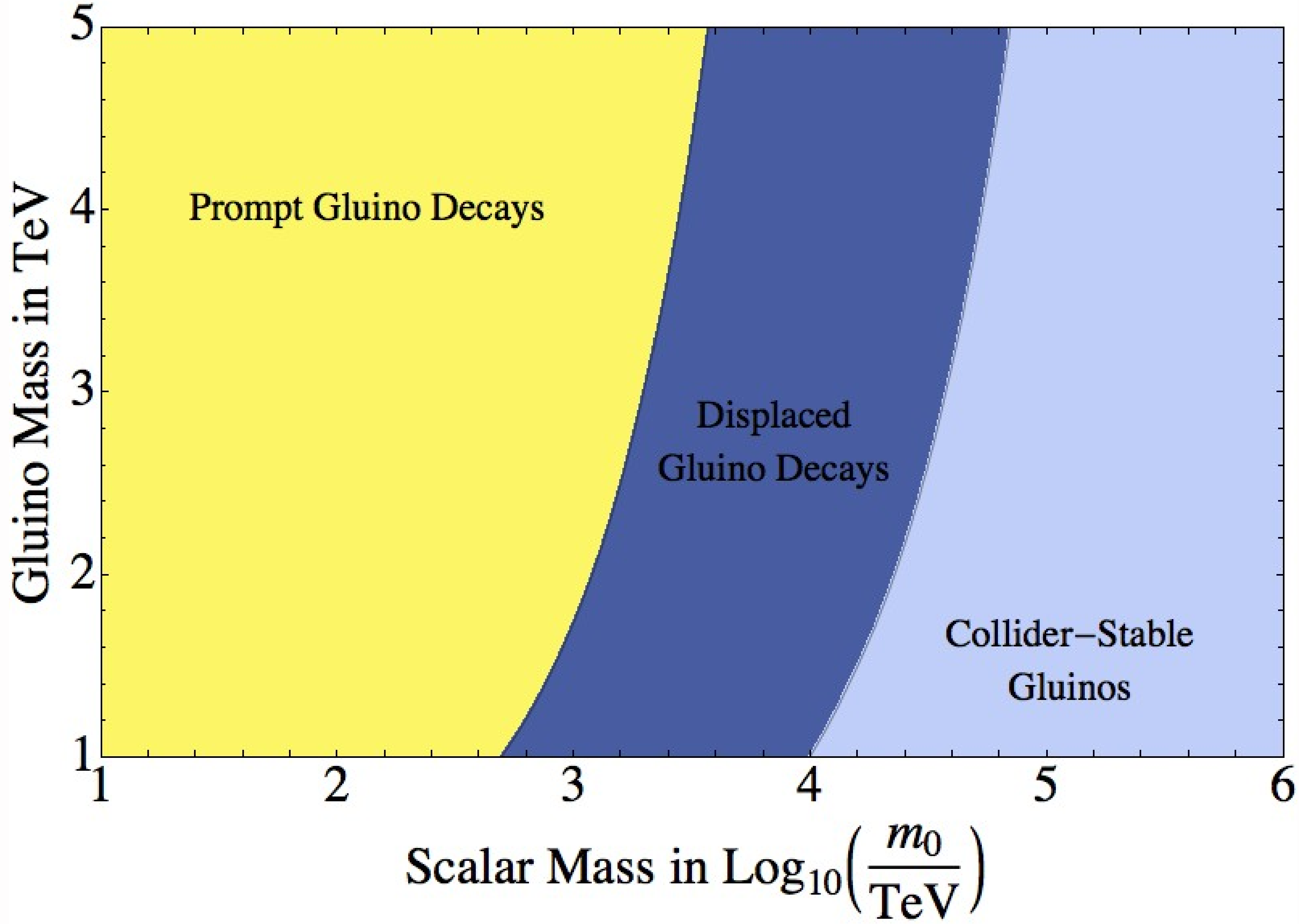


U(1)' fermion spectrum

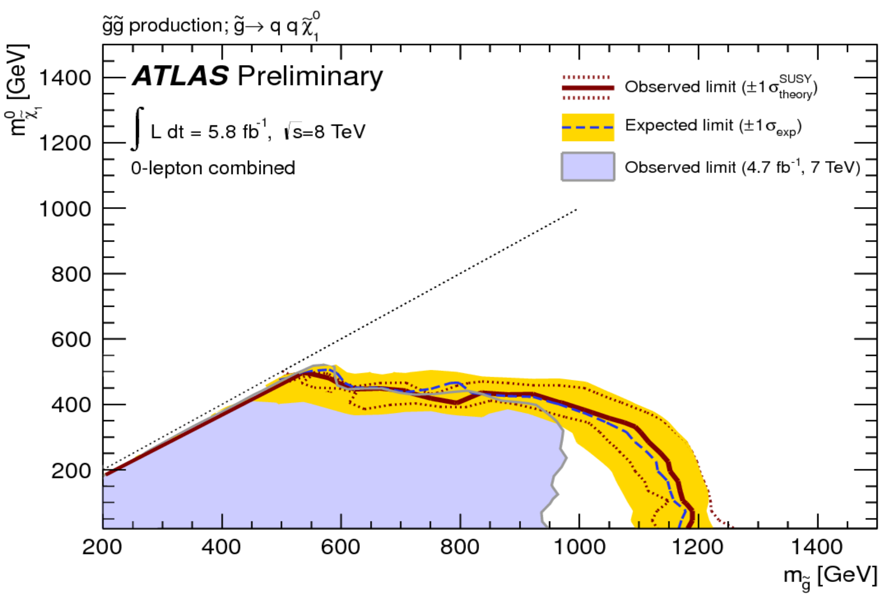


Phenomenology

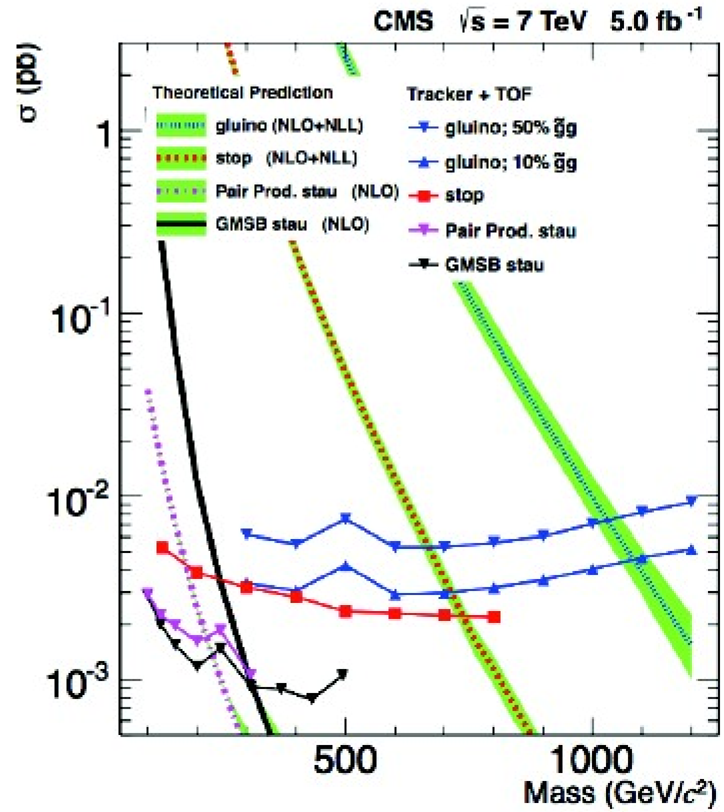
Phenomenology: Gluino



Gluino Bounds from the LHC



For prompt or
slightly displaced gluinos

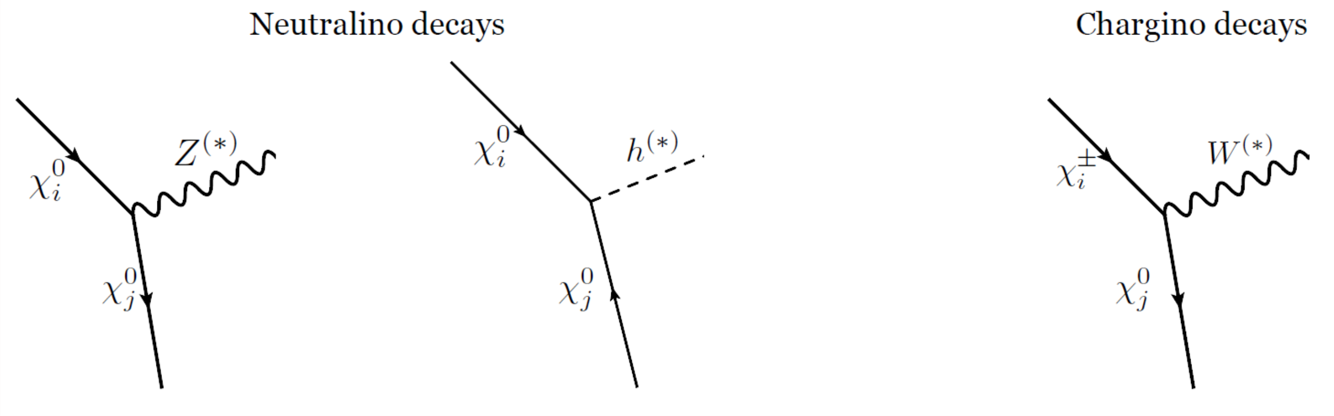


For collider "stable" gluinos

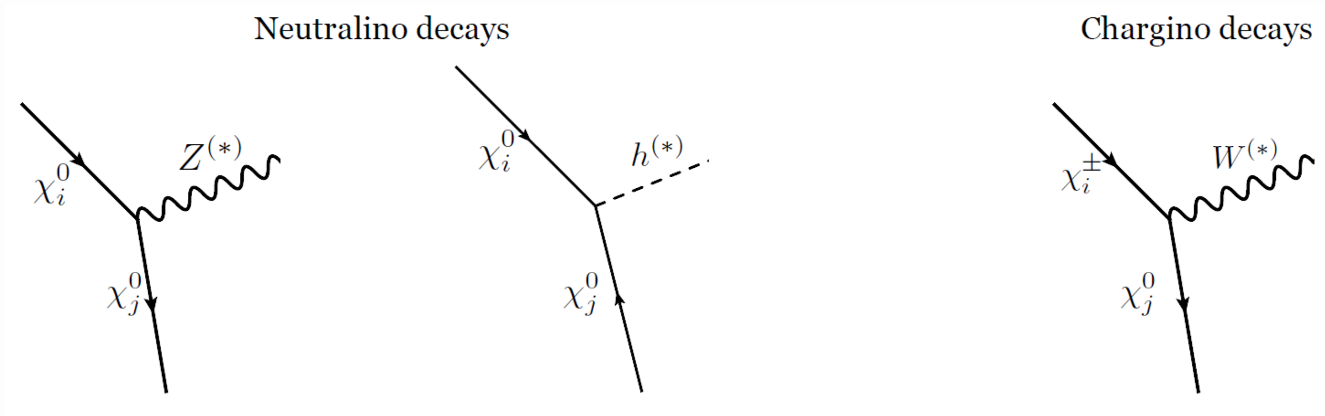
$M_{\text{gluino}} > 1$ TeV for split gluino

2.5 TeV to 3 TeV ultimate reach for split gluino

Phenomenology: EWinos



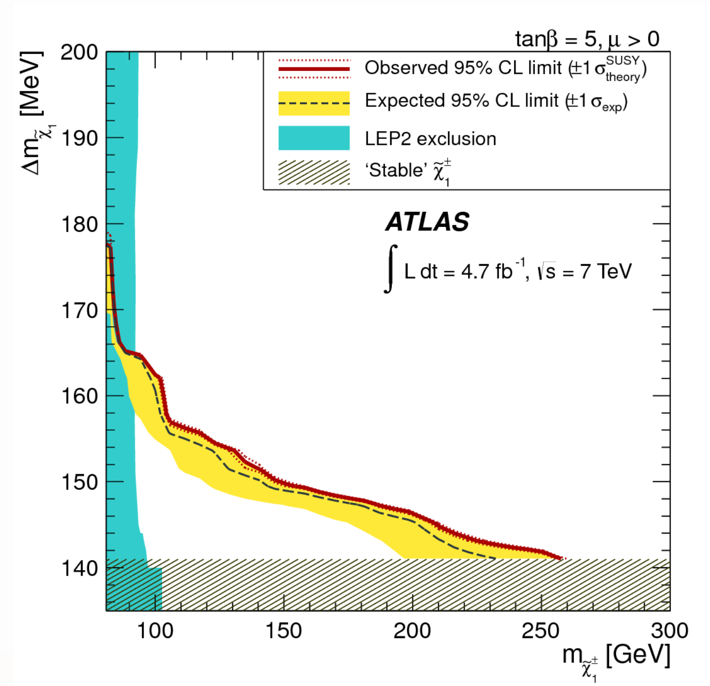
Phenomenology: EWinos



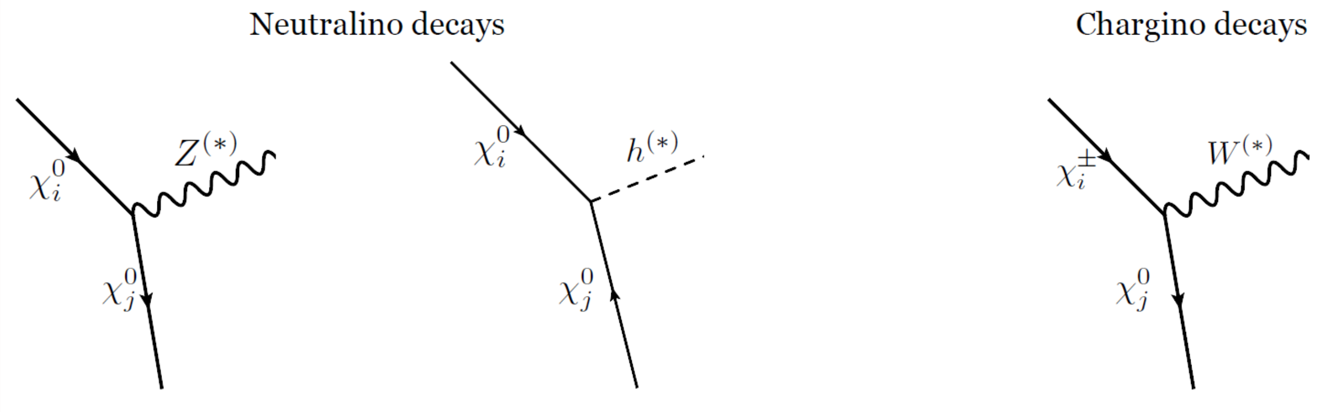
Heavy Higgsinos:

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

Wino LSP: Δm~170 MeV → 10cm stubs (trig. on ISR+MET)



Phenomenology: EWinos



Heavy Higgsinos:

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

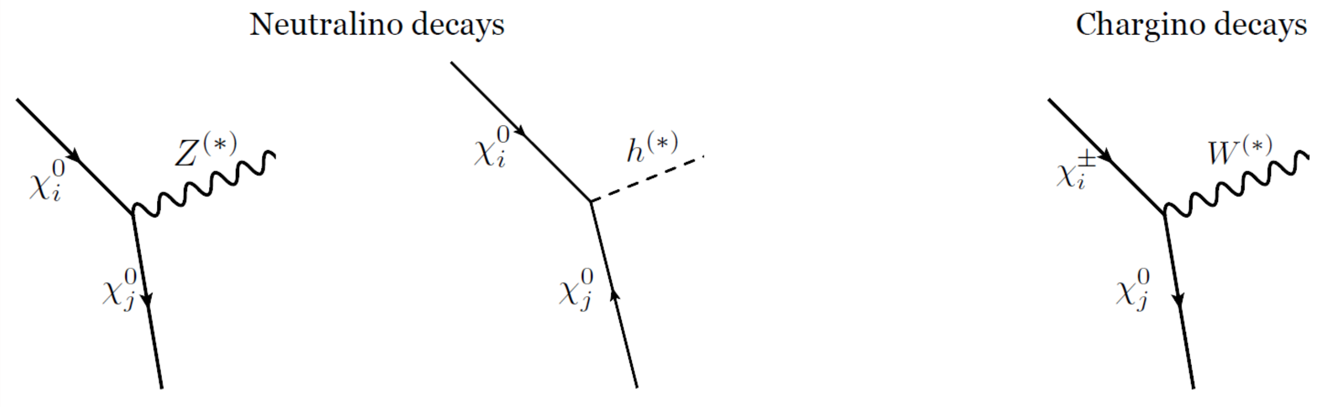
Wino LSP: Δm~170 MeV → 10cm stubs (trig. on ISR+MET)

Light Higgsinos:

Usual EWino searches

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

Phenomenology: EWinos



Heavy Higgsinos:

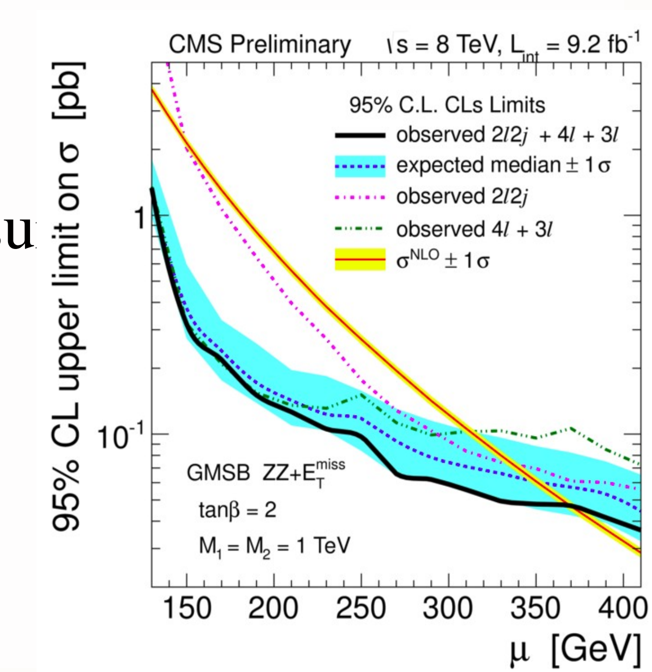
Bino LSP : $\chi^\pm\chi^0 \rightarrow Wh$+MET $\chi^+\chi^- \rightarrow WW$+MET

Wino LSP: Δm~170 MeV → 10cm stubs (trig. on ISR+MET)

Light Higgsinos:

Usual EWino searches

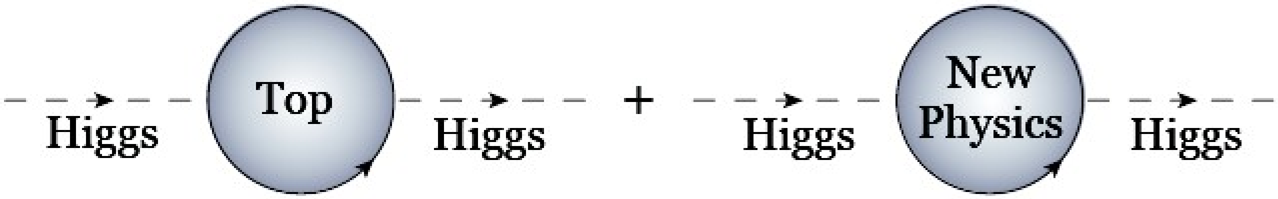
Possibility of testing all couplings and measu



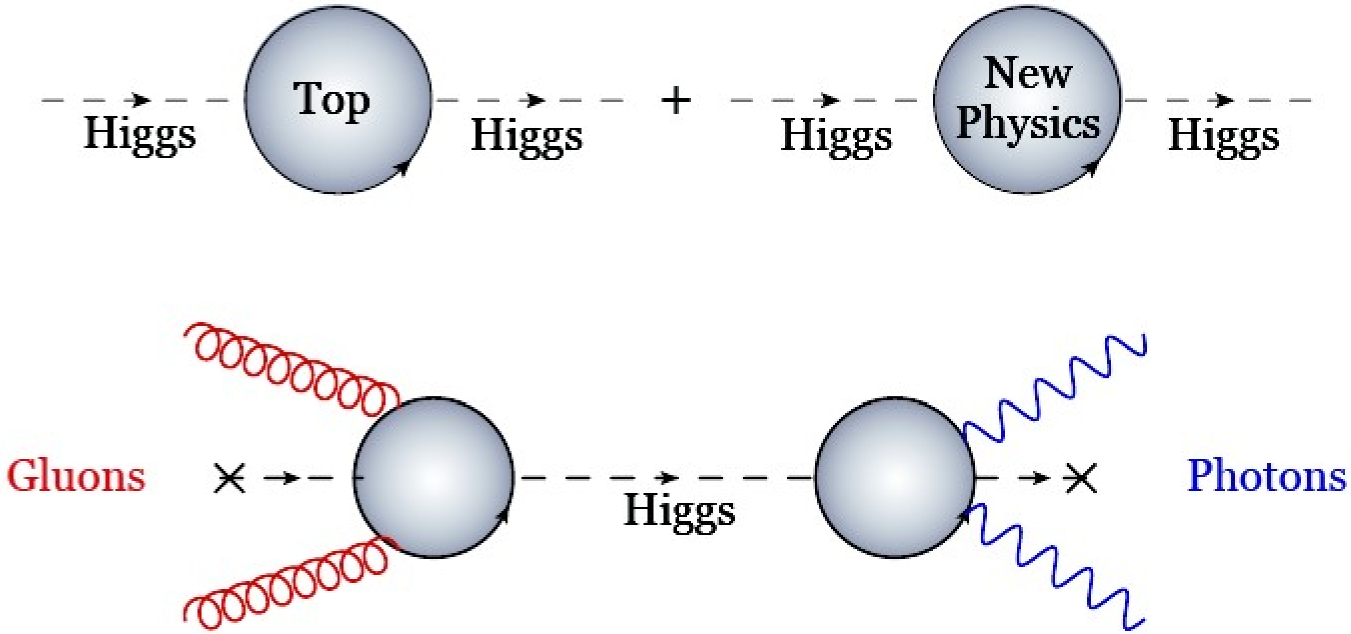
Only Higgsinos:

Δm~355 MeV → <1cm stubs harder to see
if light gravitino h/Z+G decay

Naturalness and Higgs Properties

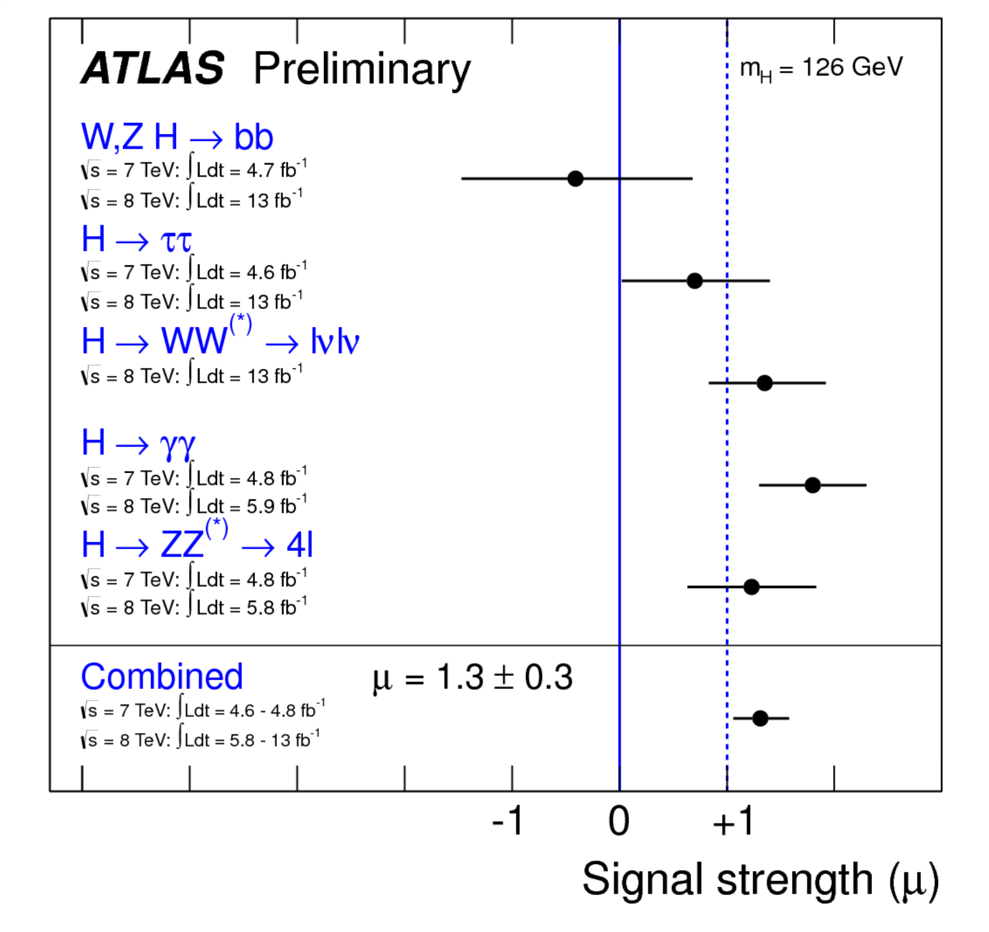


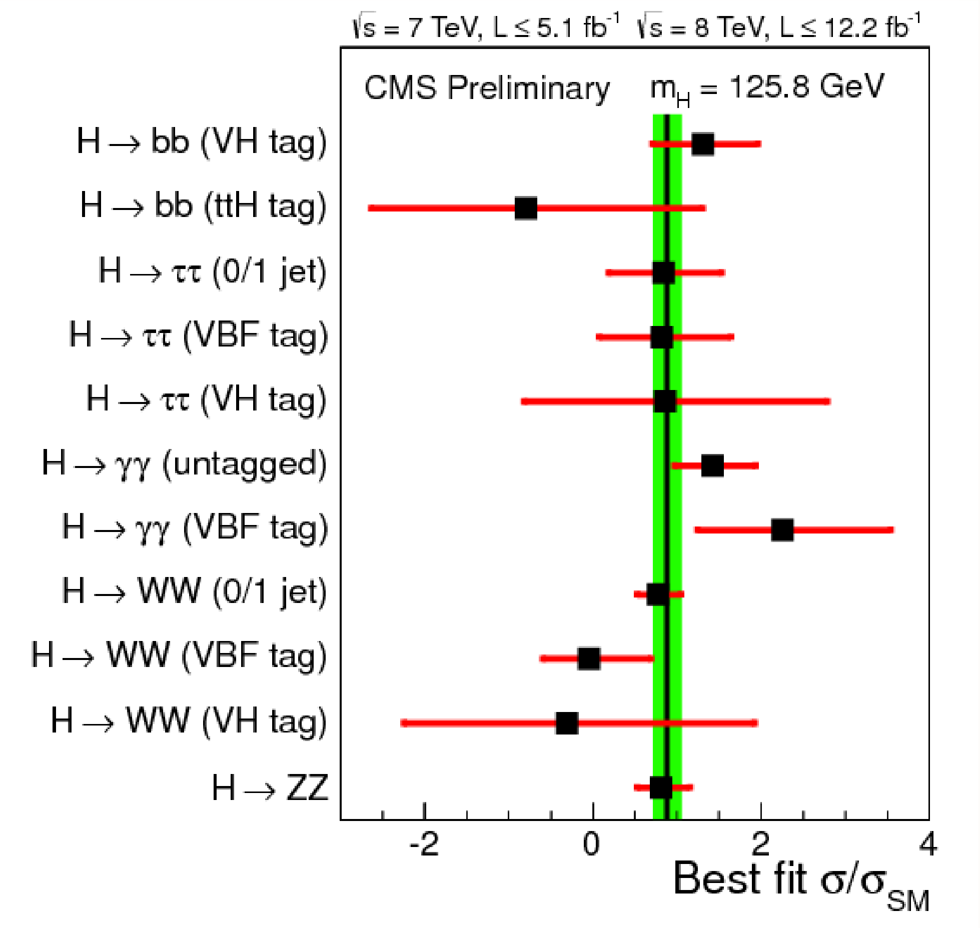
Naturalness and Higgs Properties



A Natural Higgs is not the SM Higgs

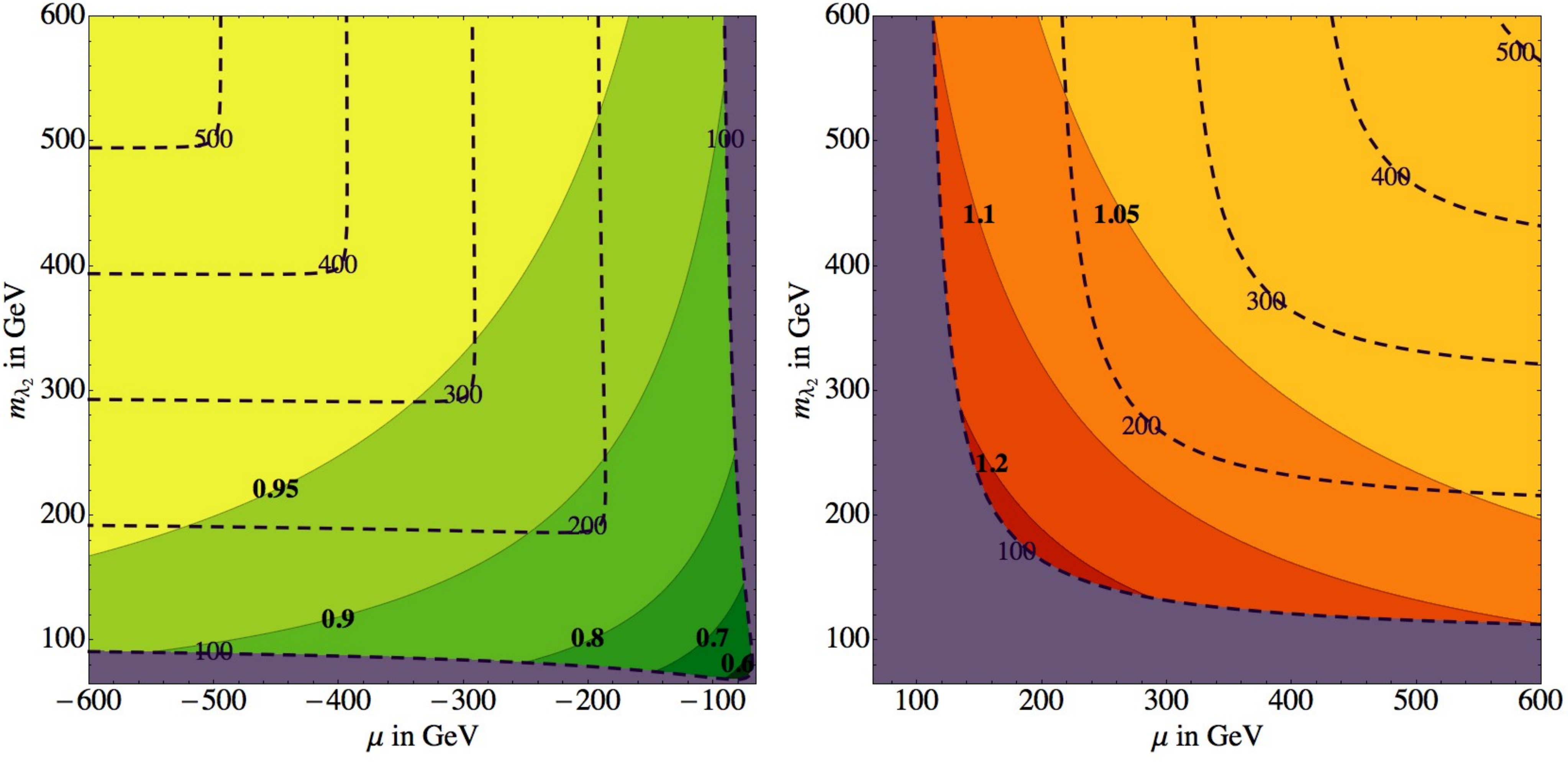
Higgs couplings



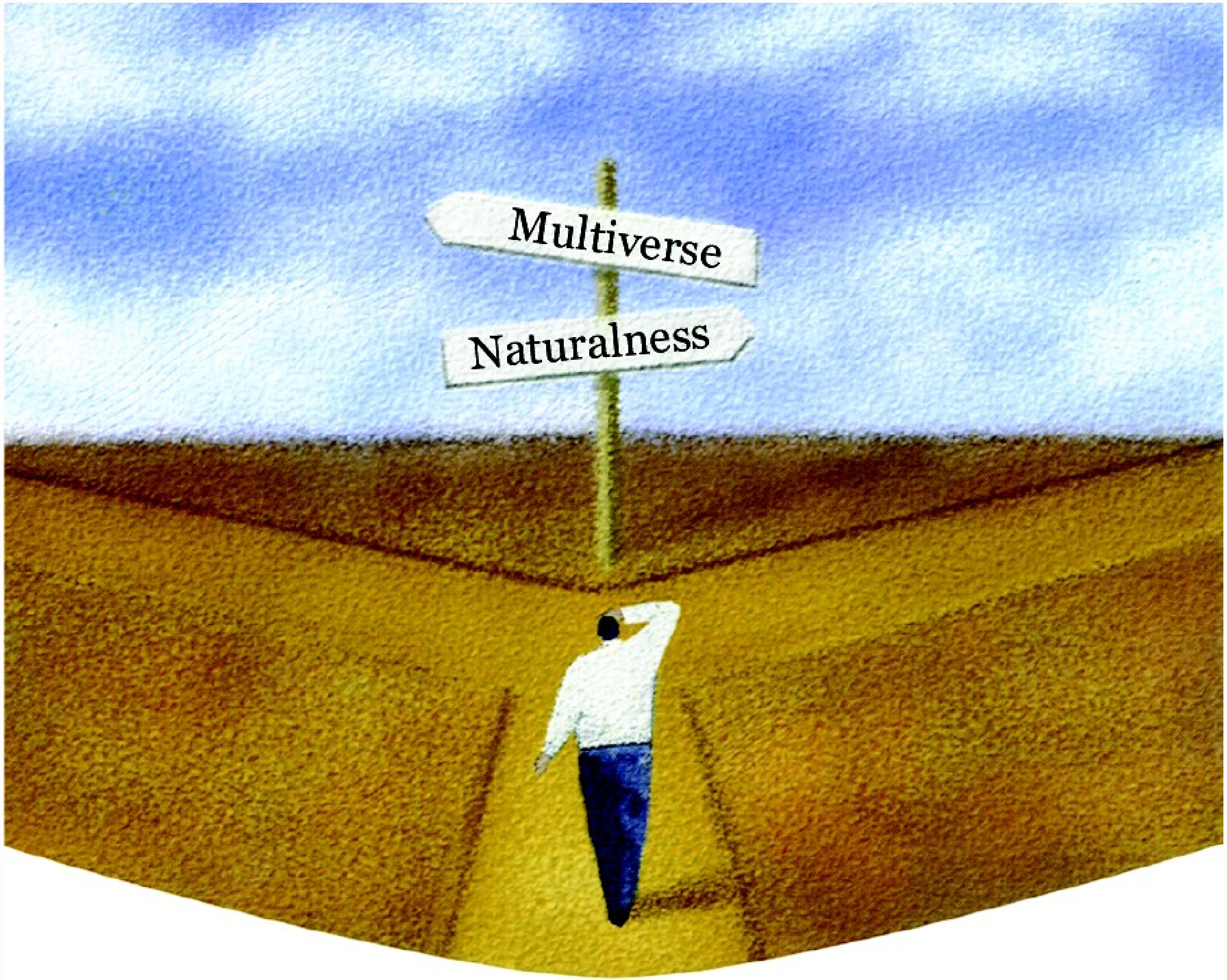


Higgs couplings in Split

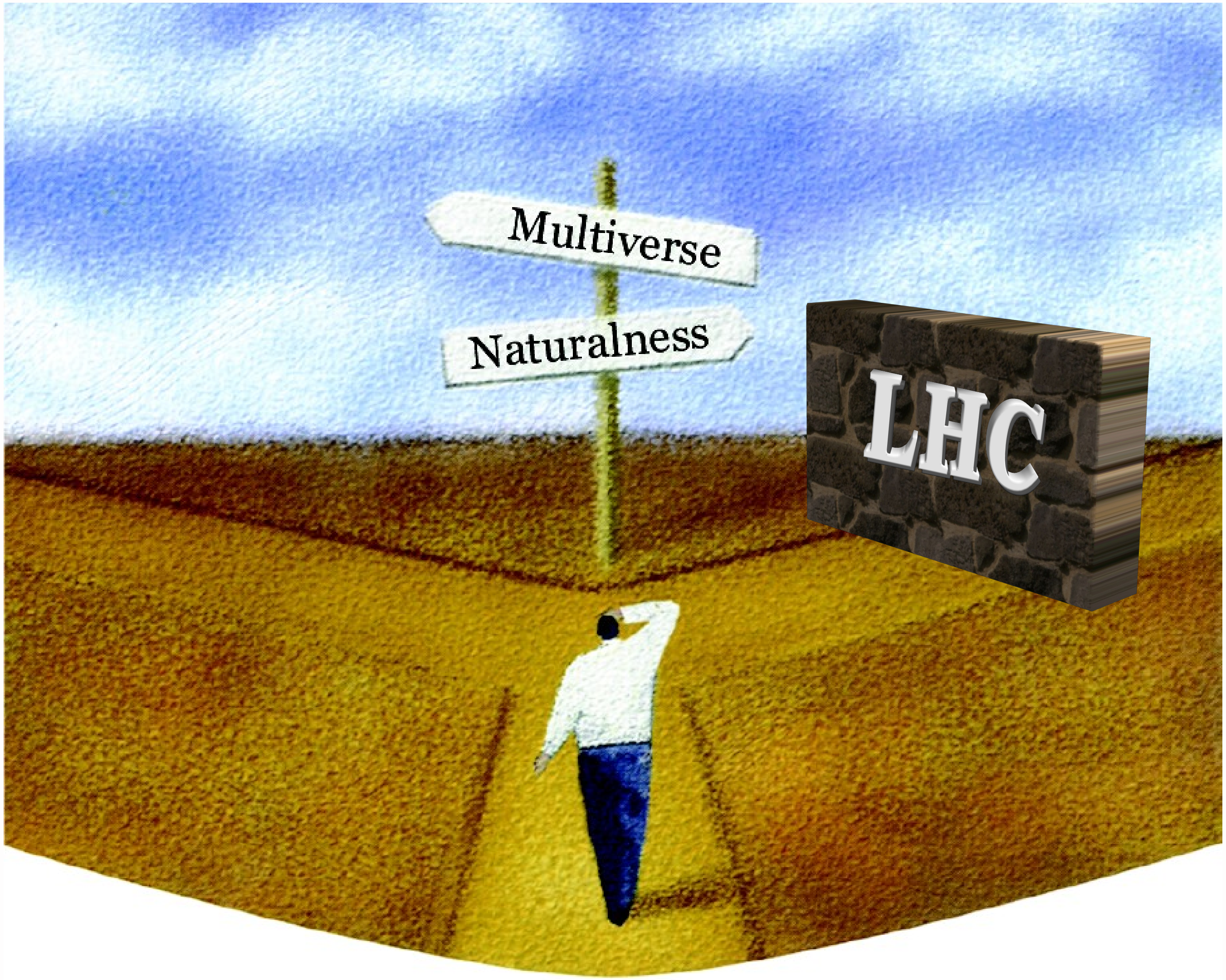
$$\frac{\Gamma_{h\to\gamma\gamma}}{\Gamma^{SM}_{h\to\gamma\gamma}} \simeq 1 + \frac{12}{17}\frac{m_W^2 \sin 2\beta}{\mu\, m_{\lambda_2} - m_W^2 \sin 2\beta}$$



Conclusions



Conclusions



Conclusions