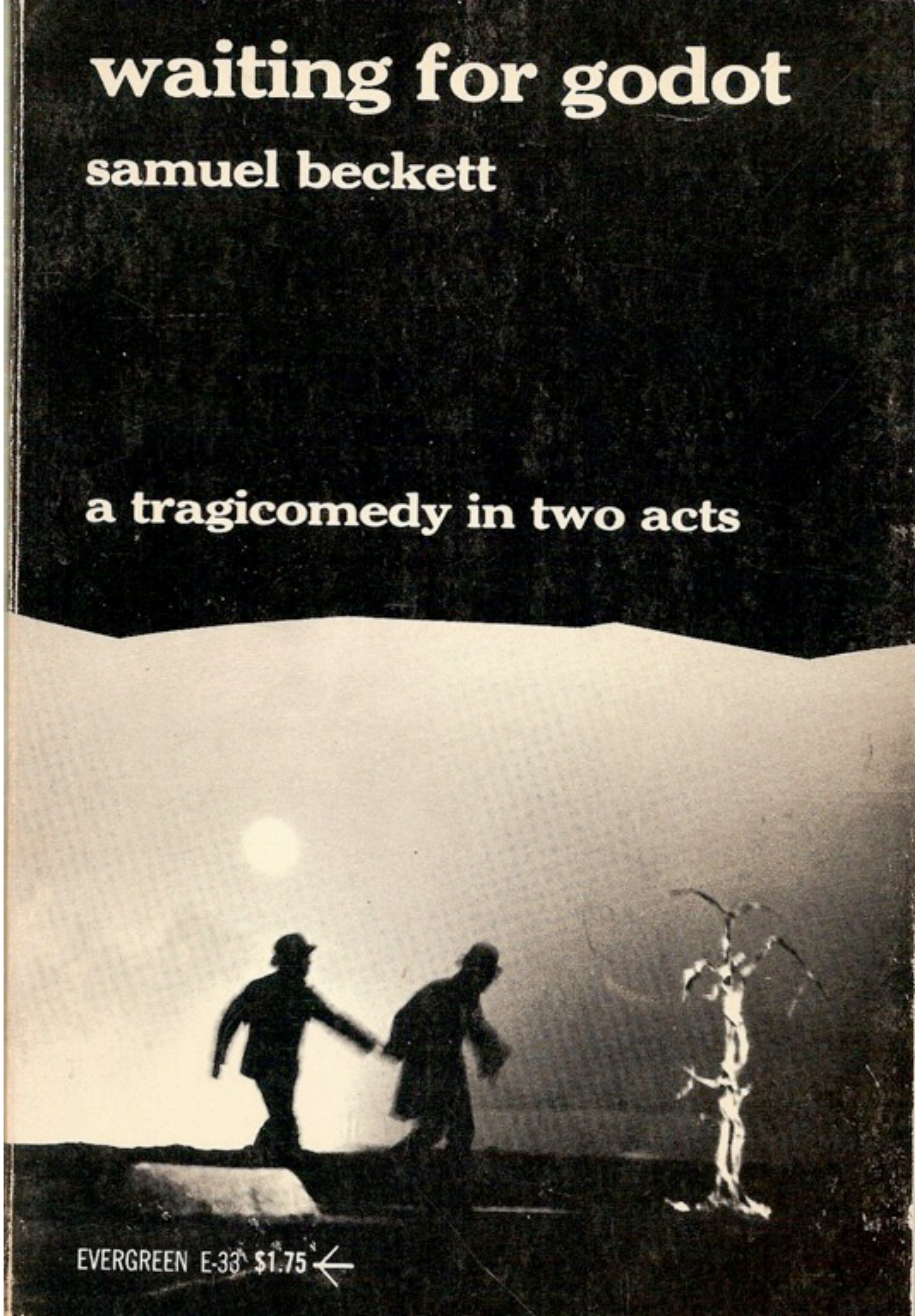
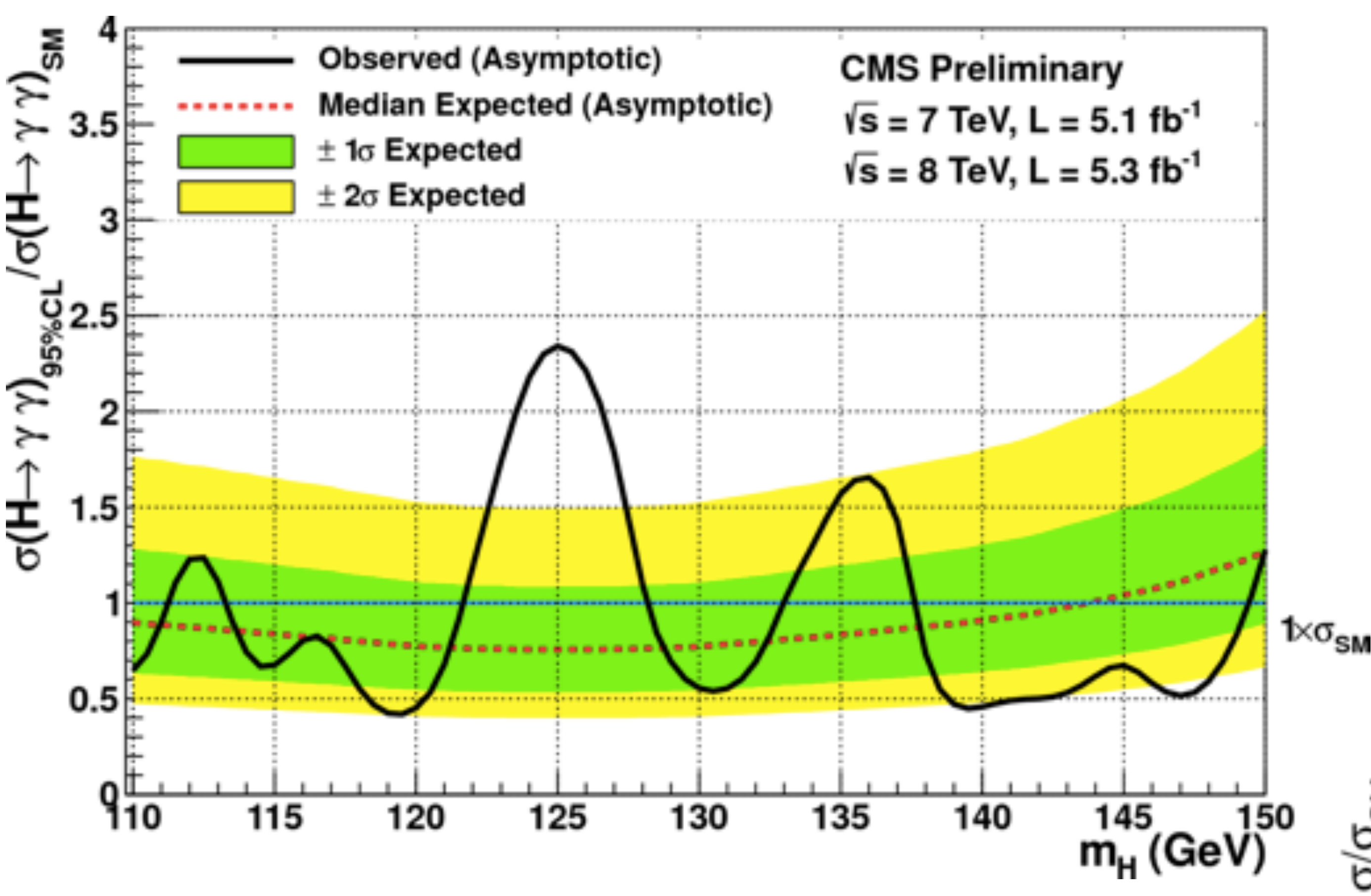
What Has the LHC Done to Theory?

Savas Dimopoulos
Stanford University

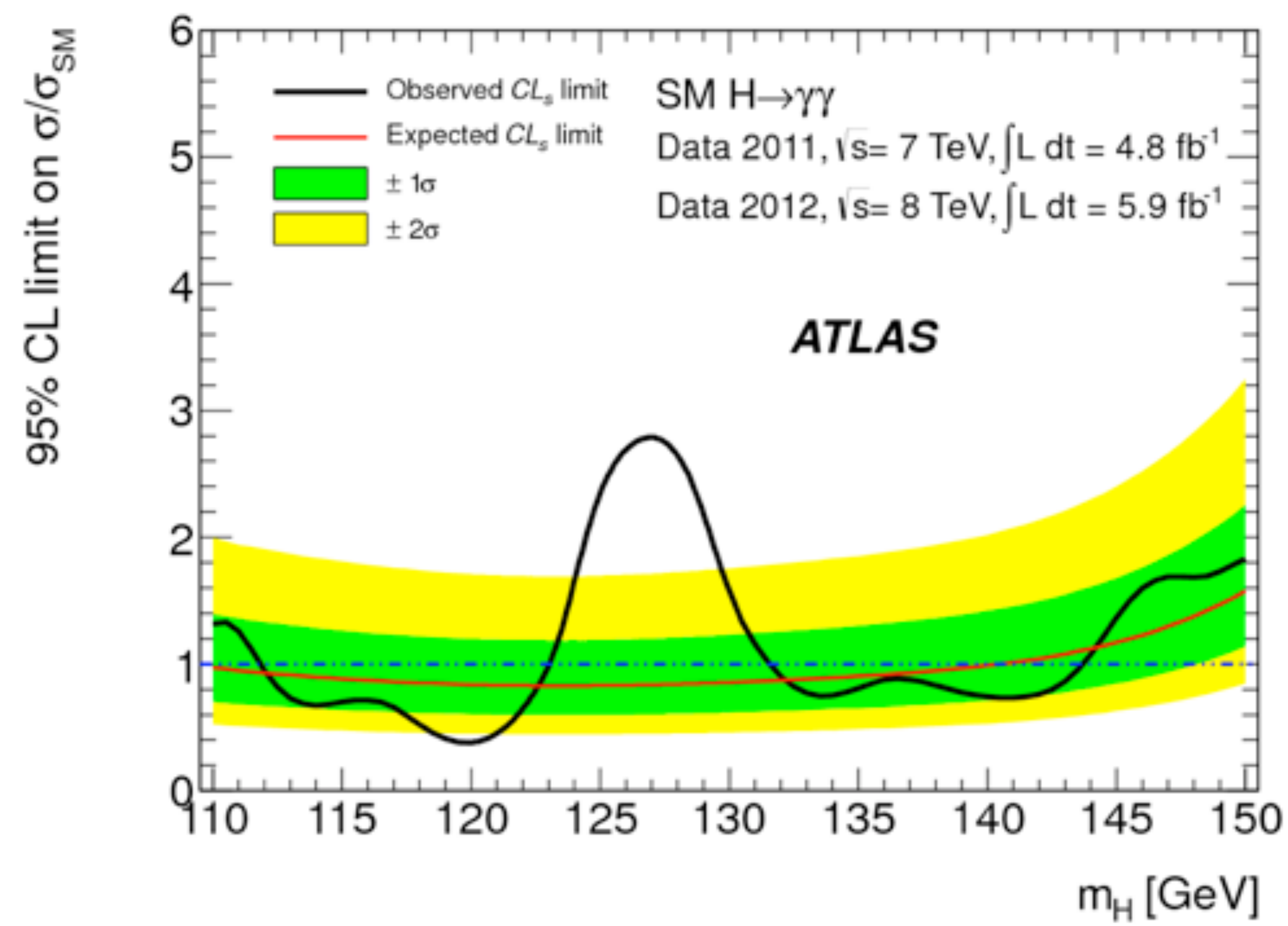


The Higgs at 125 GeV

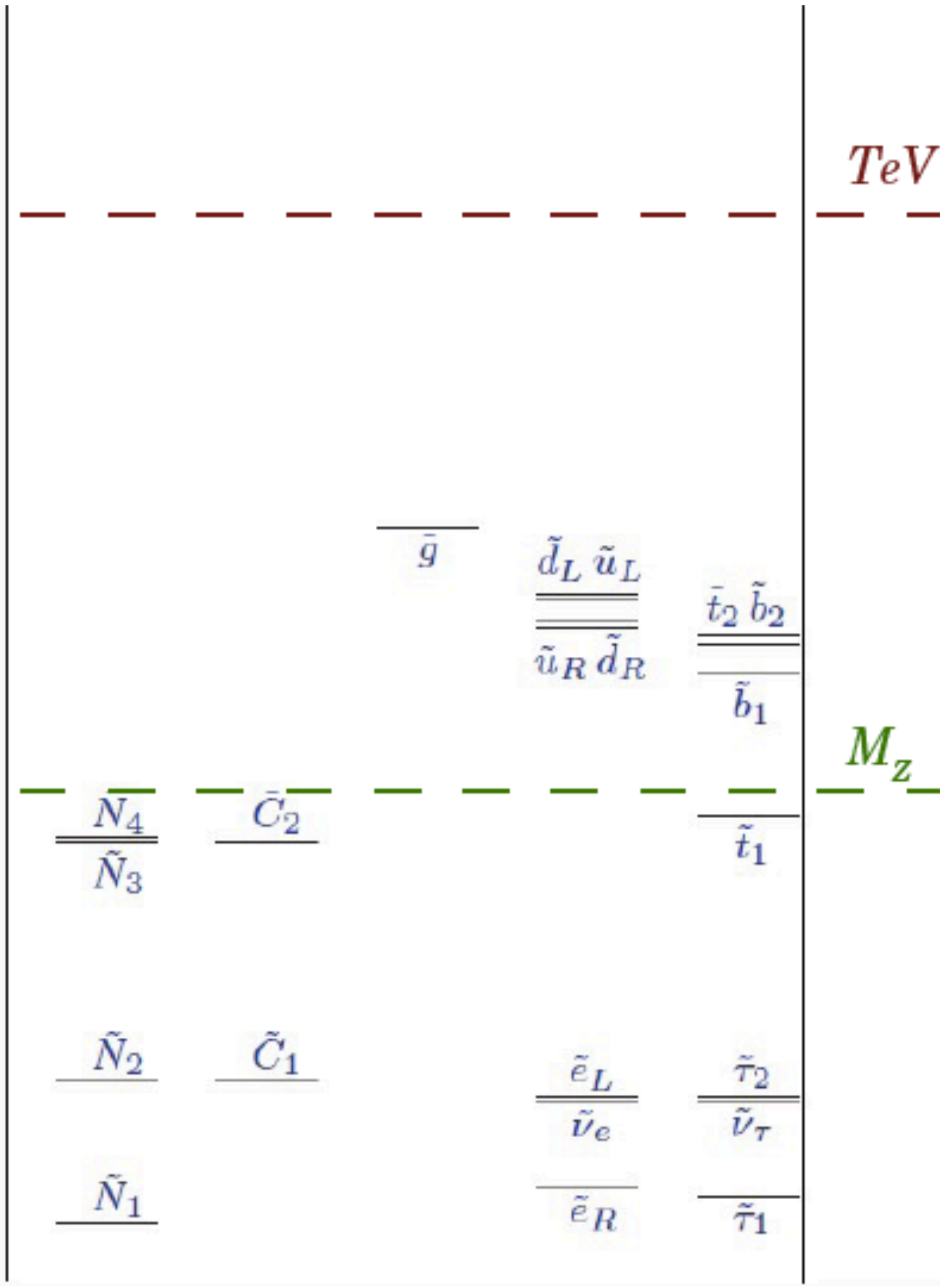


h → γγ in CMS

h → γγ in ATLAS

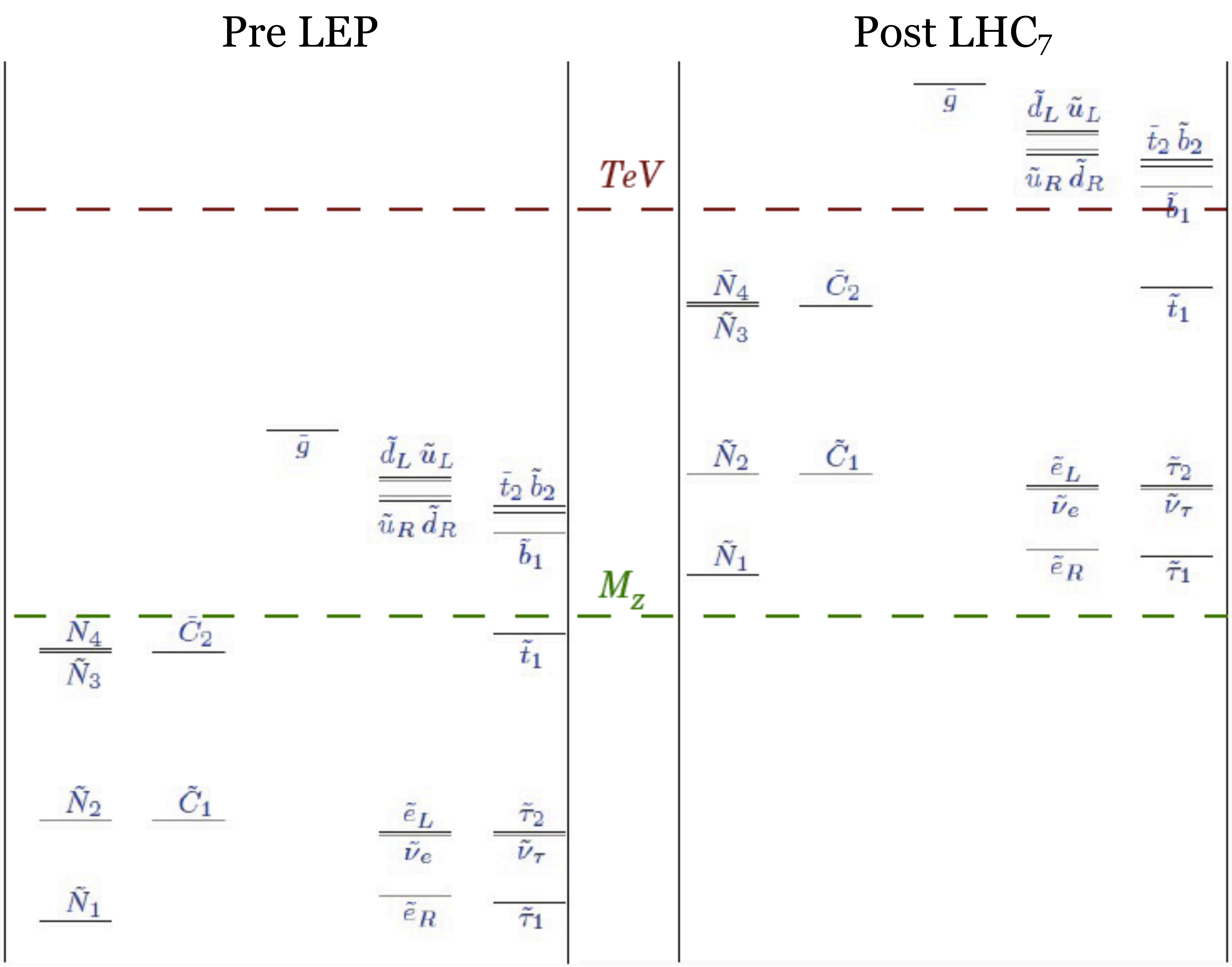


Pre LEP



TeV
M_Z
$\tilde{g}$
$\tilde{d}_L\ \tilde{u}_L$
$\tilde{u}_R\ \tilde{d}_R$
$\tilde{t}_2\ \tilde{b}_2$
$\tilde{b}_1$
$\tilde{N}_4$
$\tilde{N}_3$
$\tilde{C}_2$
$\tilde{t}_1$
$\tilde{N}_2$
$\tilde{C}_1$
$\tilde{e}_L$
$\tilde{\nu}_e$
$\tilde{\tau}_2$
$\tilde{\nu}_\tau$
$\tilde{N}_1$
$\tilde{e}_R$
$\tilde{\tau}_1$

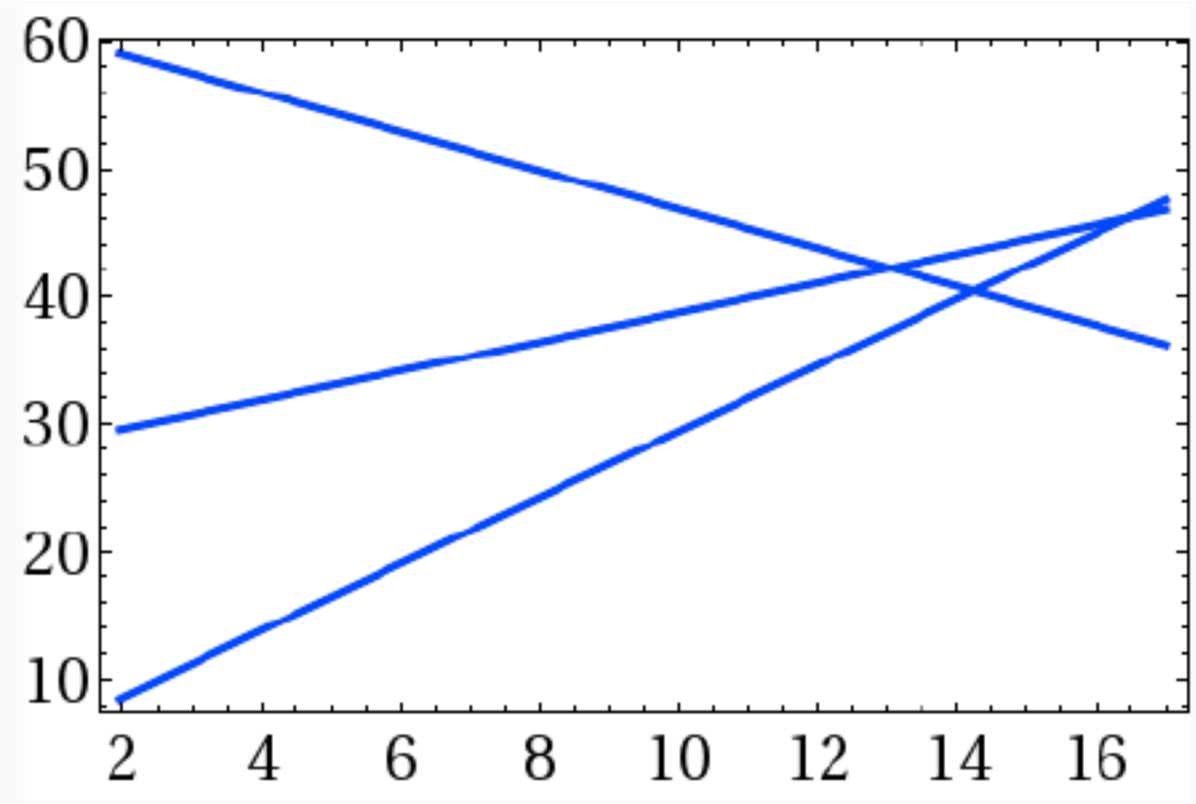
The Missing Superpartner Problem



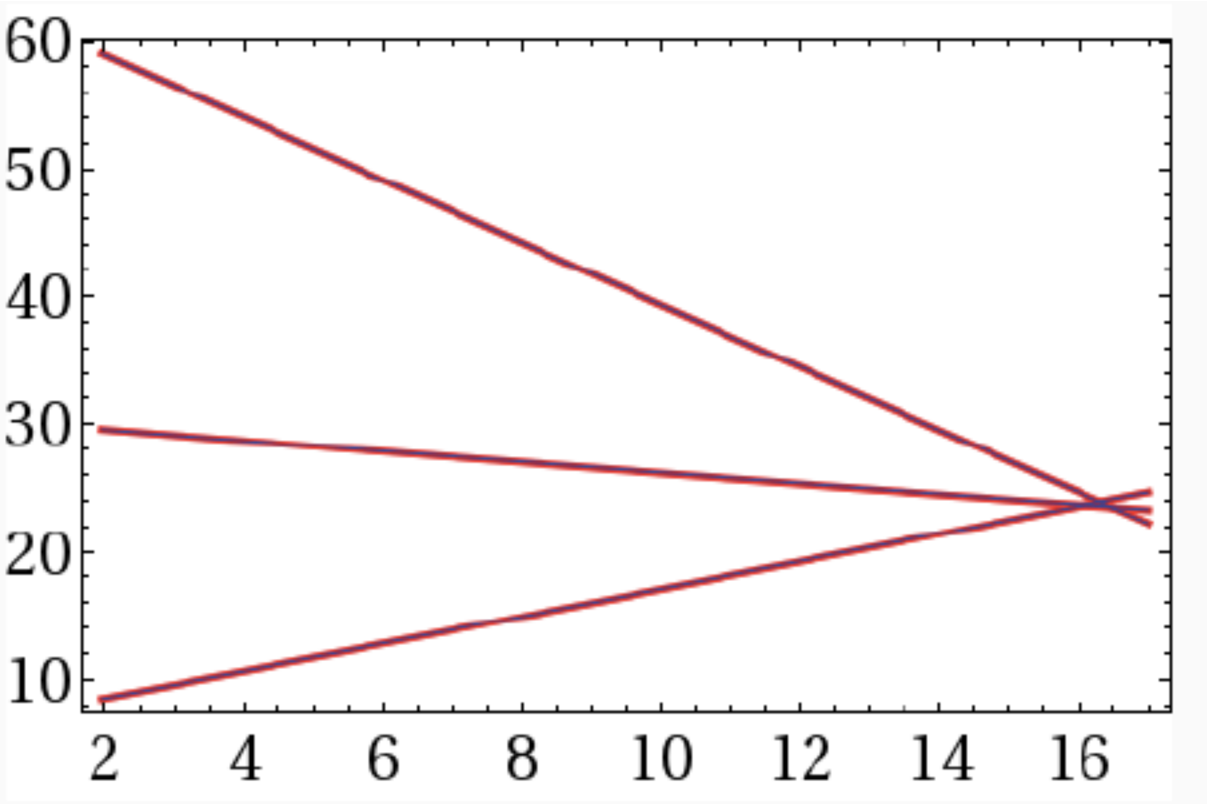
The connection with the hierarchy problem is diminished

Why Supersymmetry?

SM

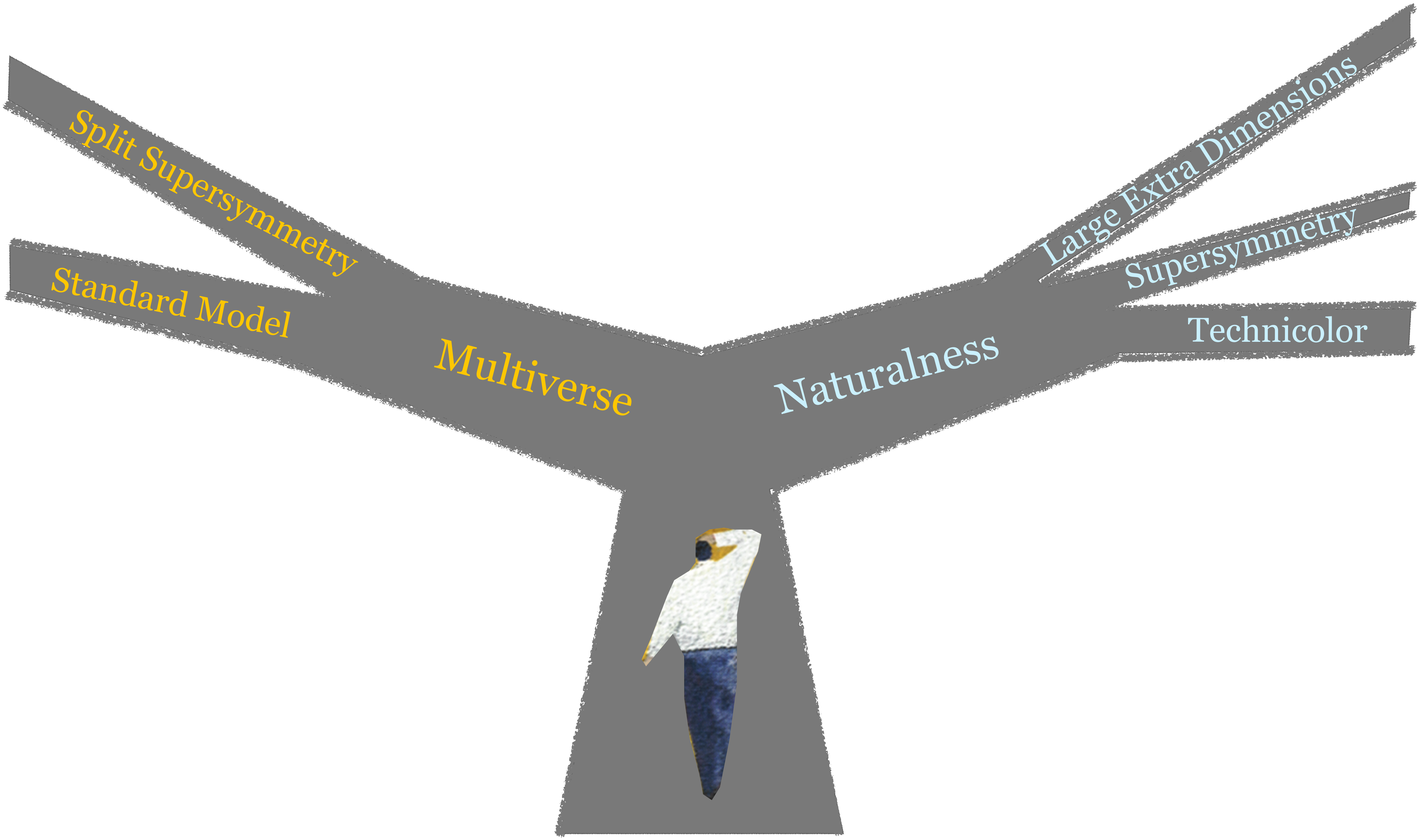


MSSM



Gauge Coupling running at two loops

At a Crossroad



LHC implications for:

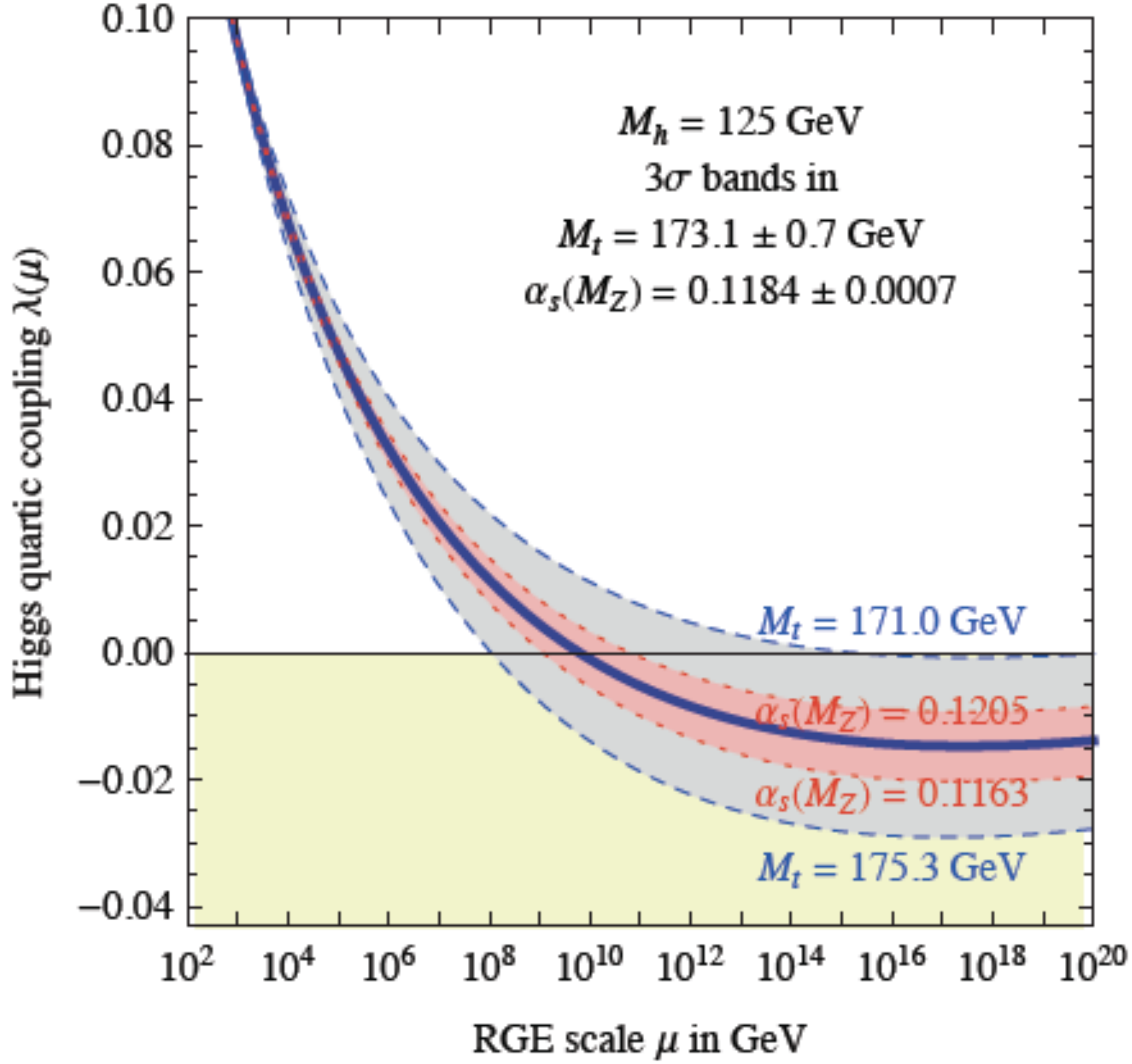
- The Standard Model

- The Supersymmetric Standard Model

- Split Supersymmetry

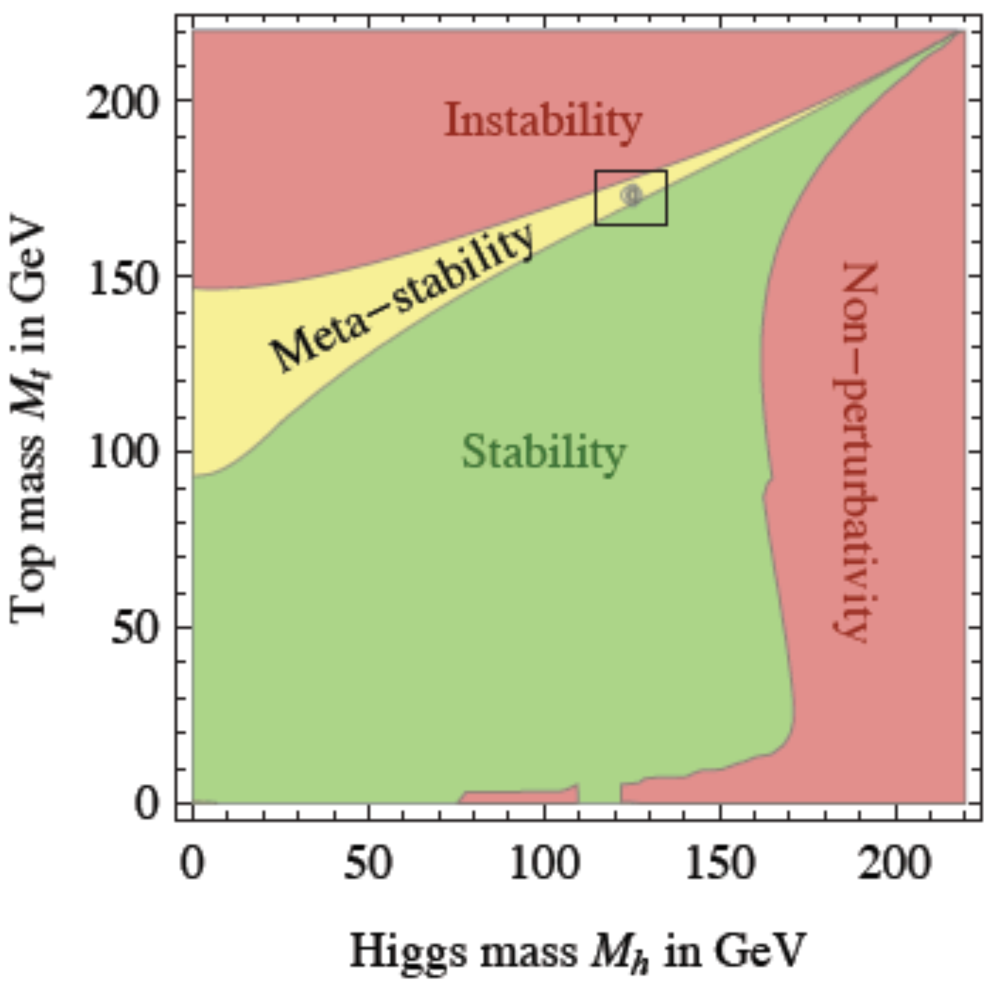
- Higgs and Naturalness

The Higgs in the Standard Model

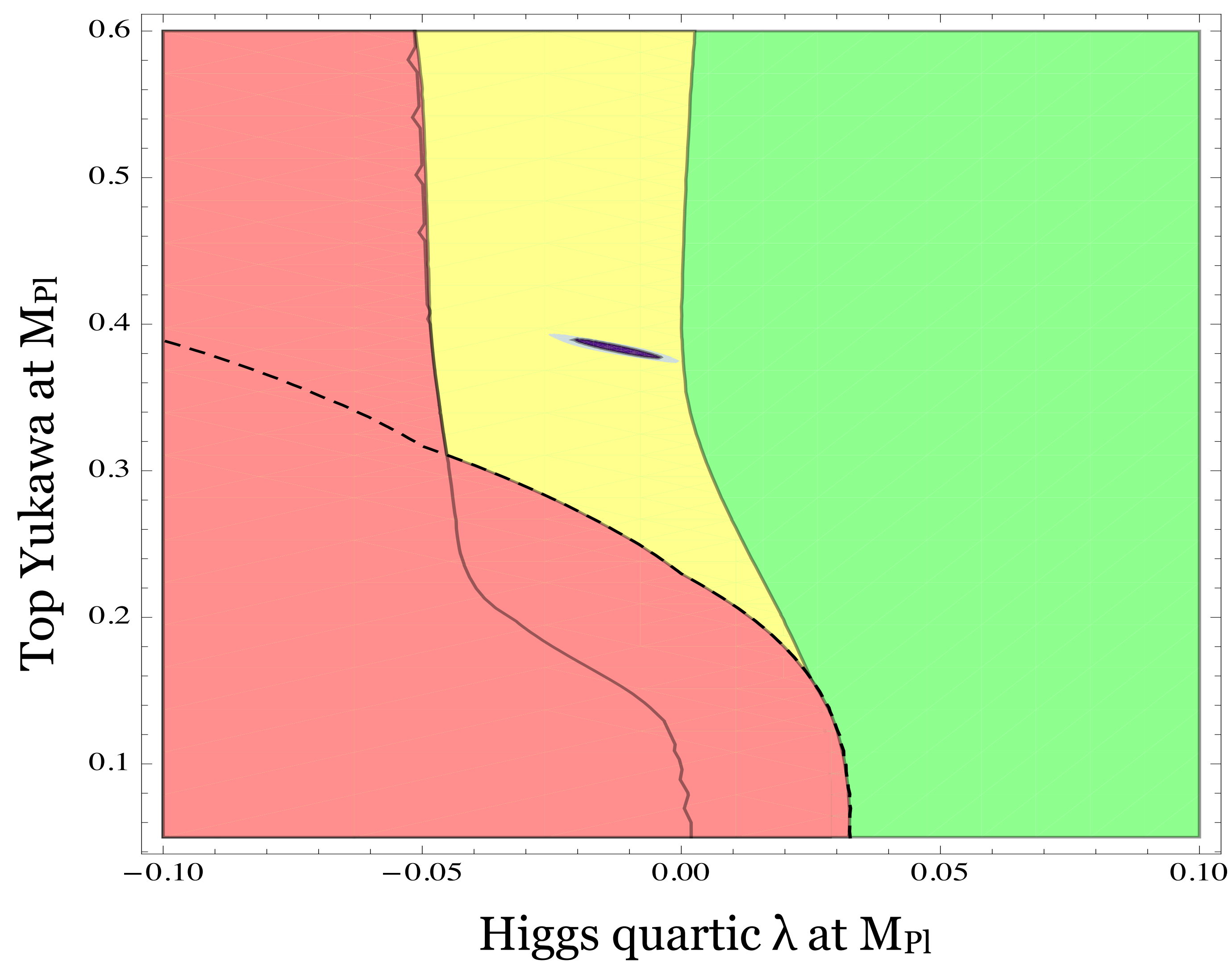


Degrassi-Di Vita-Elias Miro ´-Espinosa-Giudice-Isidori-Strumia ’12

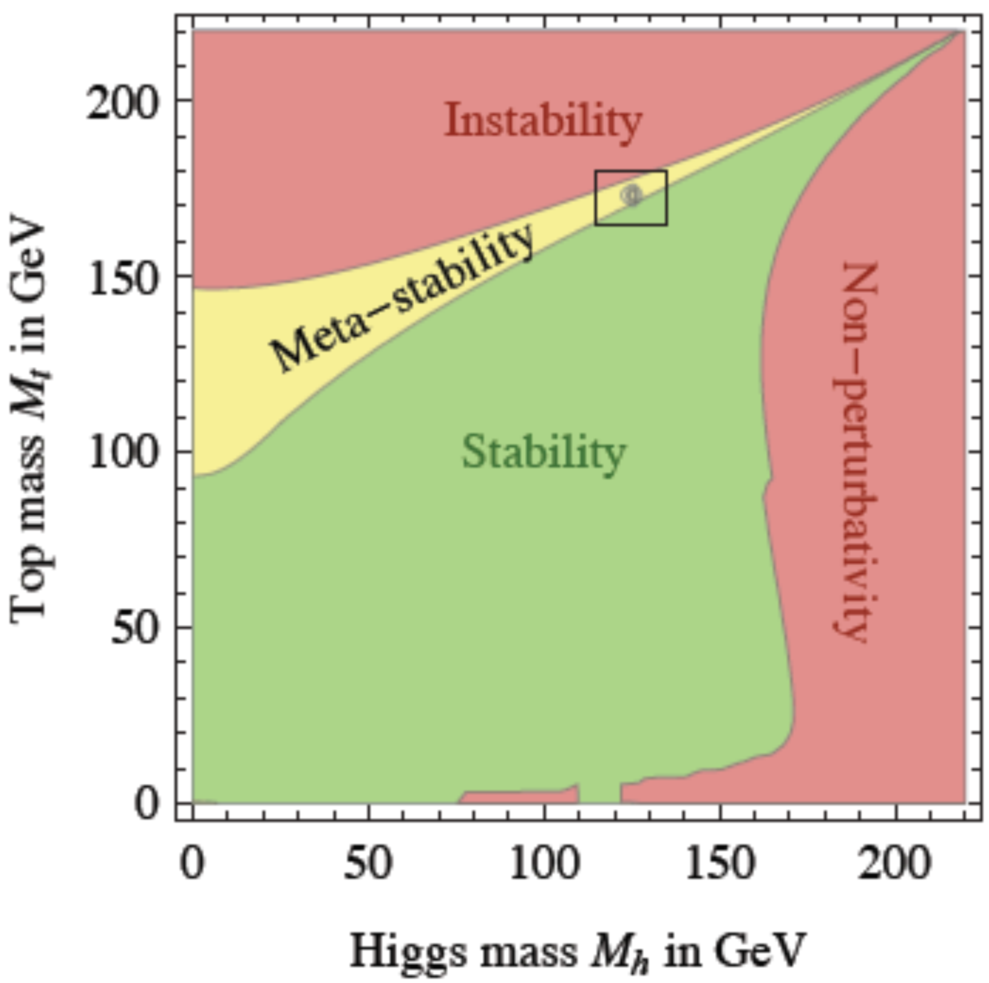
The Higgs in the Standard Model



Giudice
and
Strumia
(2011)



The Higgs in the Standard Model



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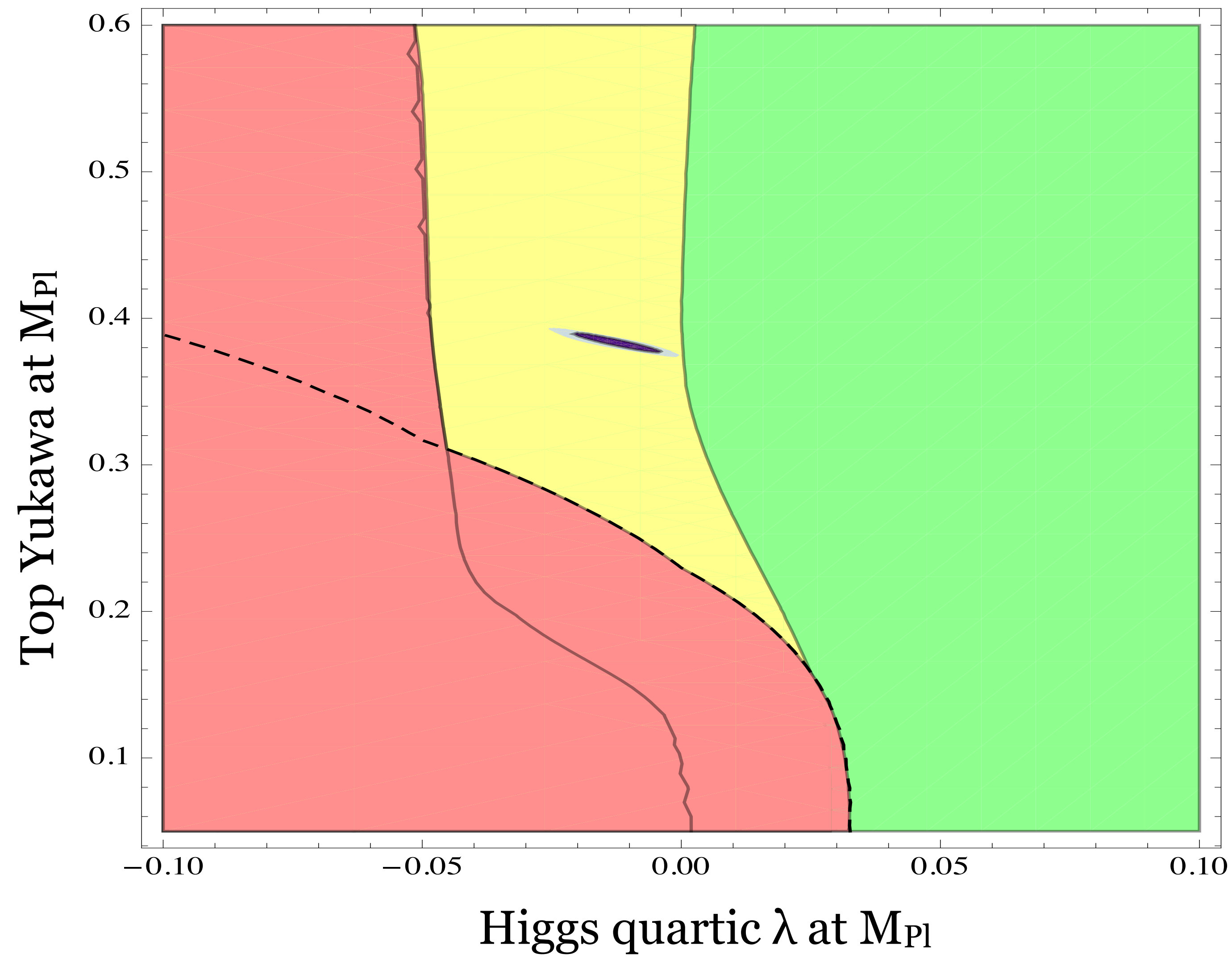
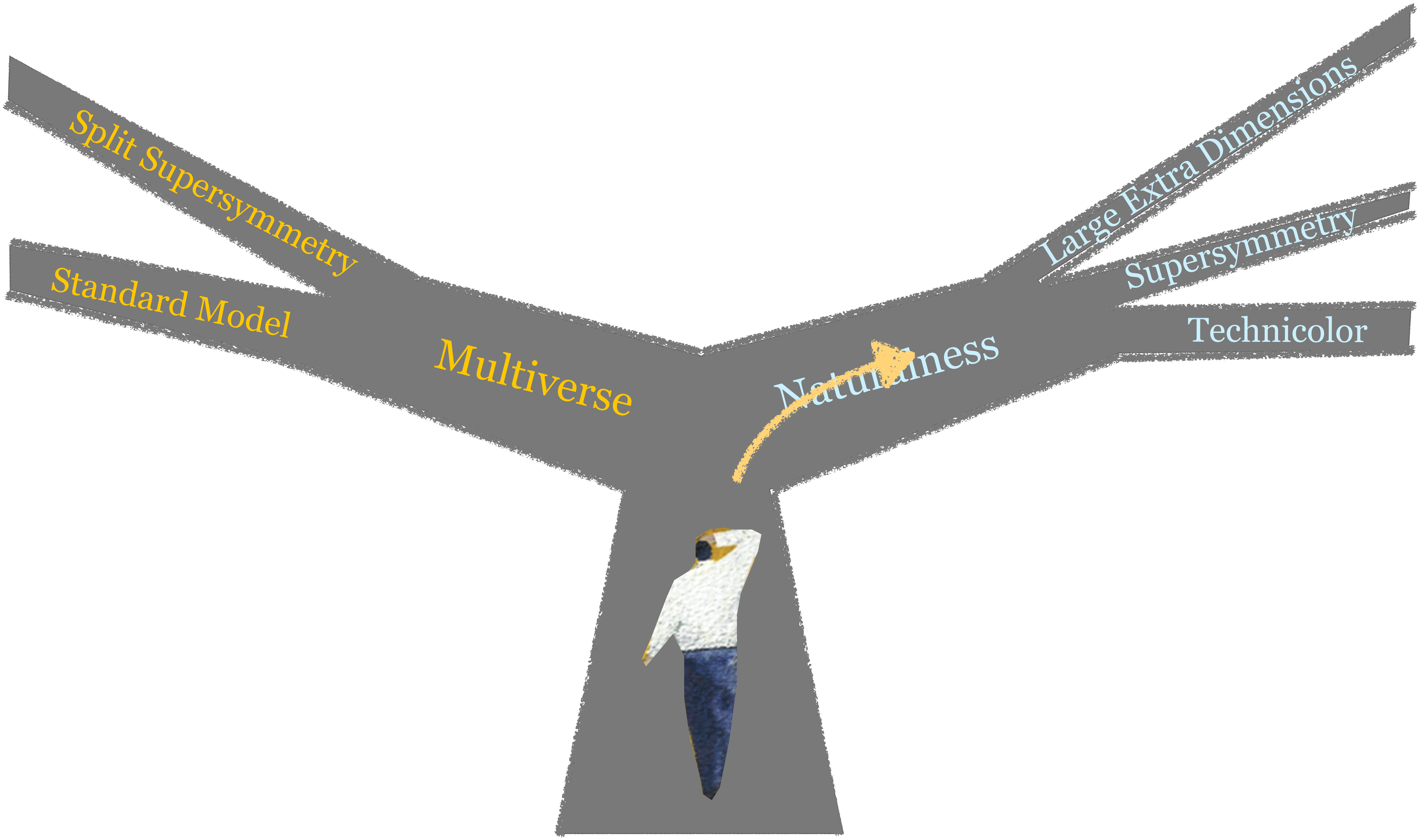


$$\lambda_{\rm SUSY} = \frac{g^2 + g'^2}{4}\cos^2(2\beta)$$

Hint for high scale SUSY?

At the Crossroads



“Why it's very natural, very natural.
I myself in your situation, ...
I'd wait till it was black night before
I gave up.”

Samuel Beckett, “Waiting for Godot”

SSM and the Higgs mass

- If minimal particle content

$$m_h^2 \leq m_Z^2 + \text{stop corrections}$$

  - Needs heavy stop, tuned

- Need to increase the tree level Higgs mass

  - New singlet - NMSSM

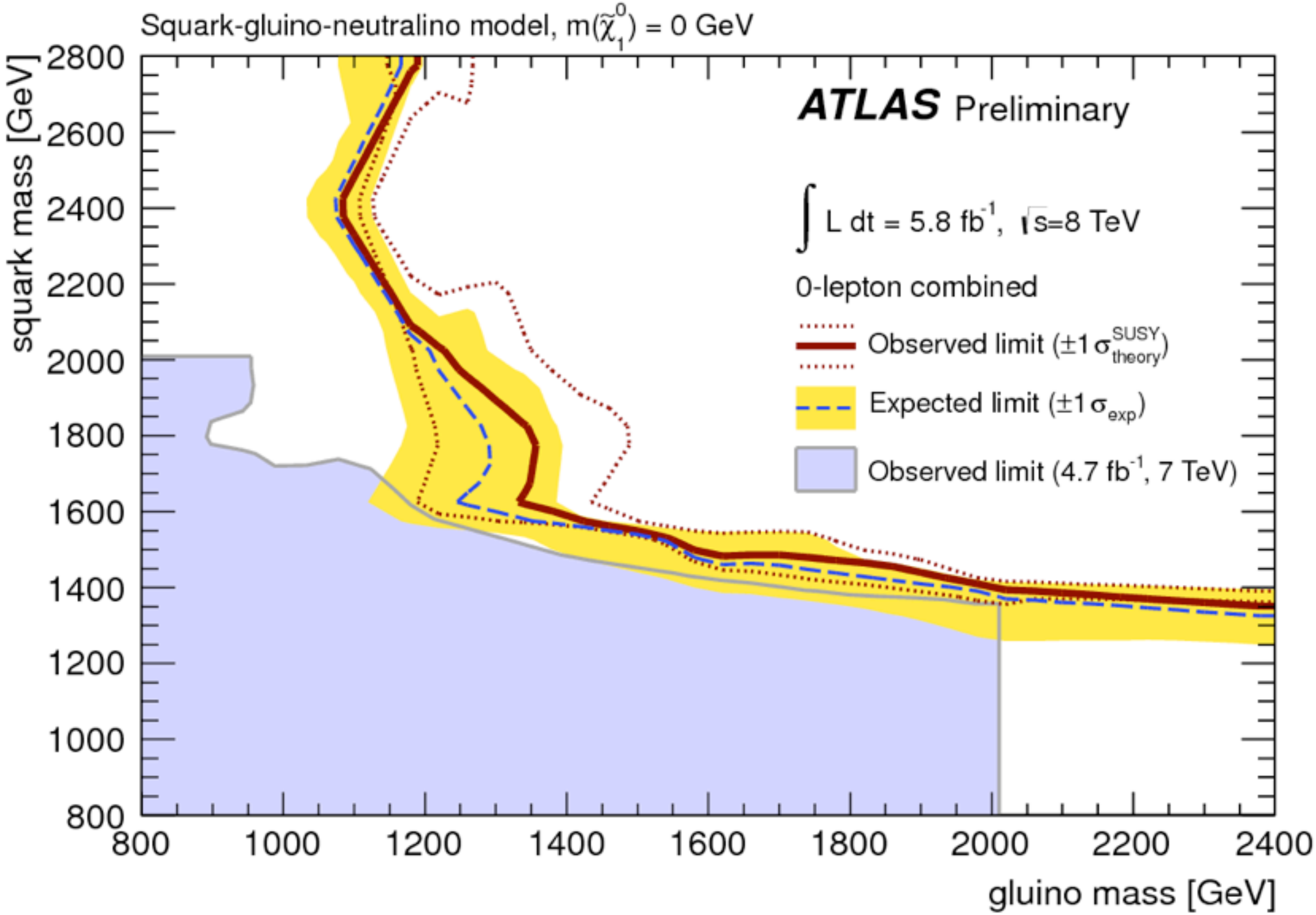
$$W \supset \lambda S H_u H_d$$

or

  - New U(1)′ at the TeV scale

$$m^2_{h-tree} \leq \left(m_Z^2 + g'^2 v^2\right)$$

Squark-Gluino Bounds in the MSSM

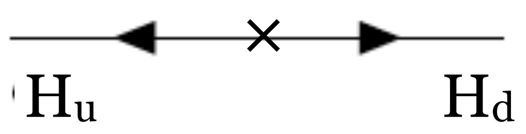


Natural SUSY

S.D. , Giudice (95)

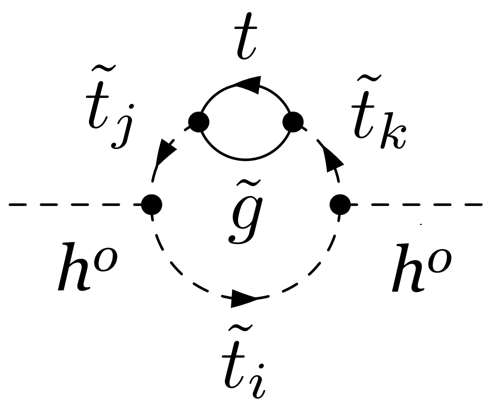
Bare minimum light spectrum:

- For less than 10% tuning:
  - At tree-level: Higgsinos < 250 GeV



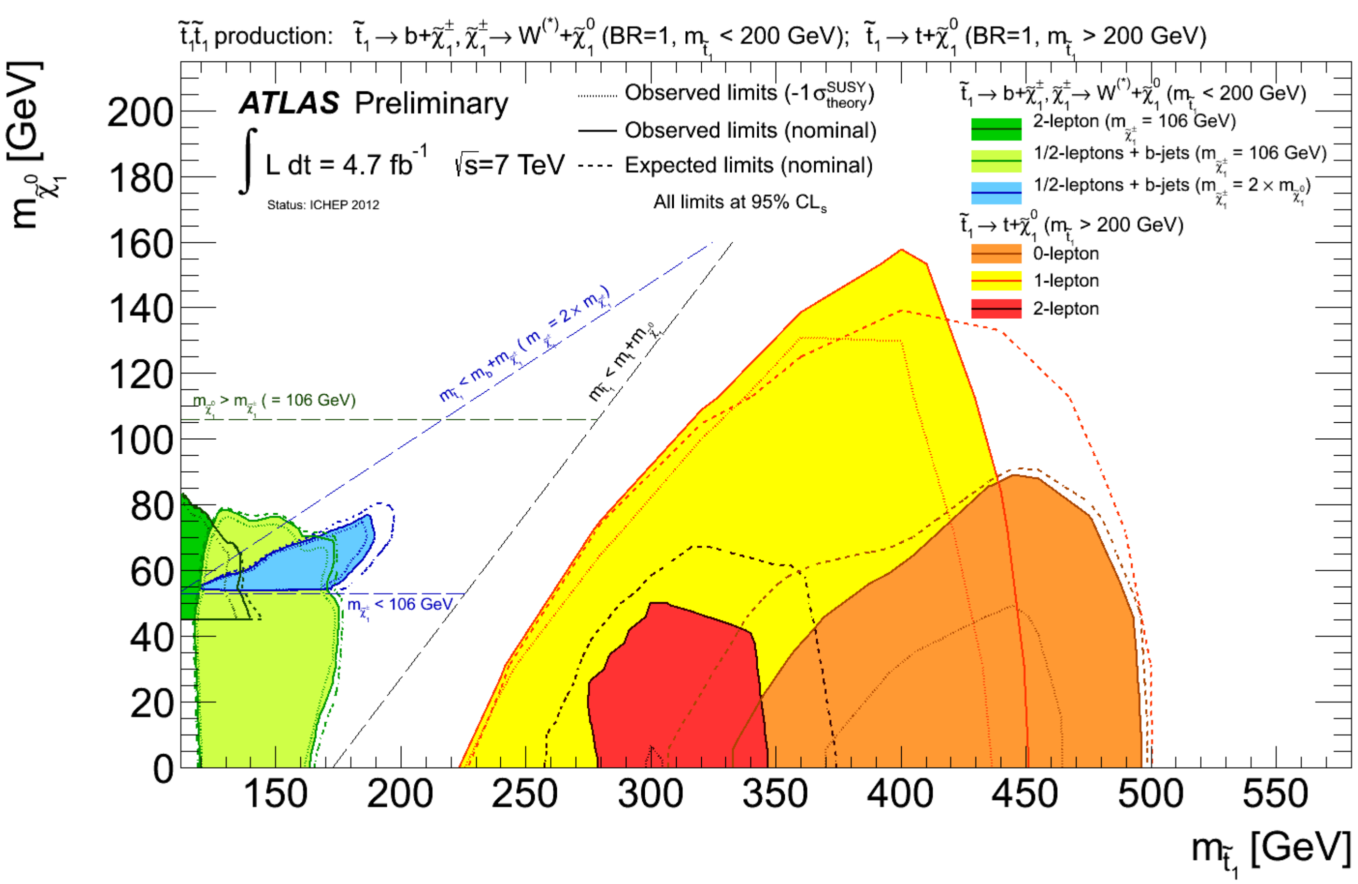
  - At one loop: Stops < 600 GeV

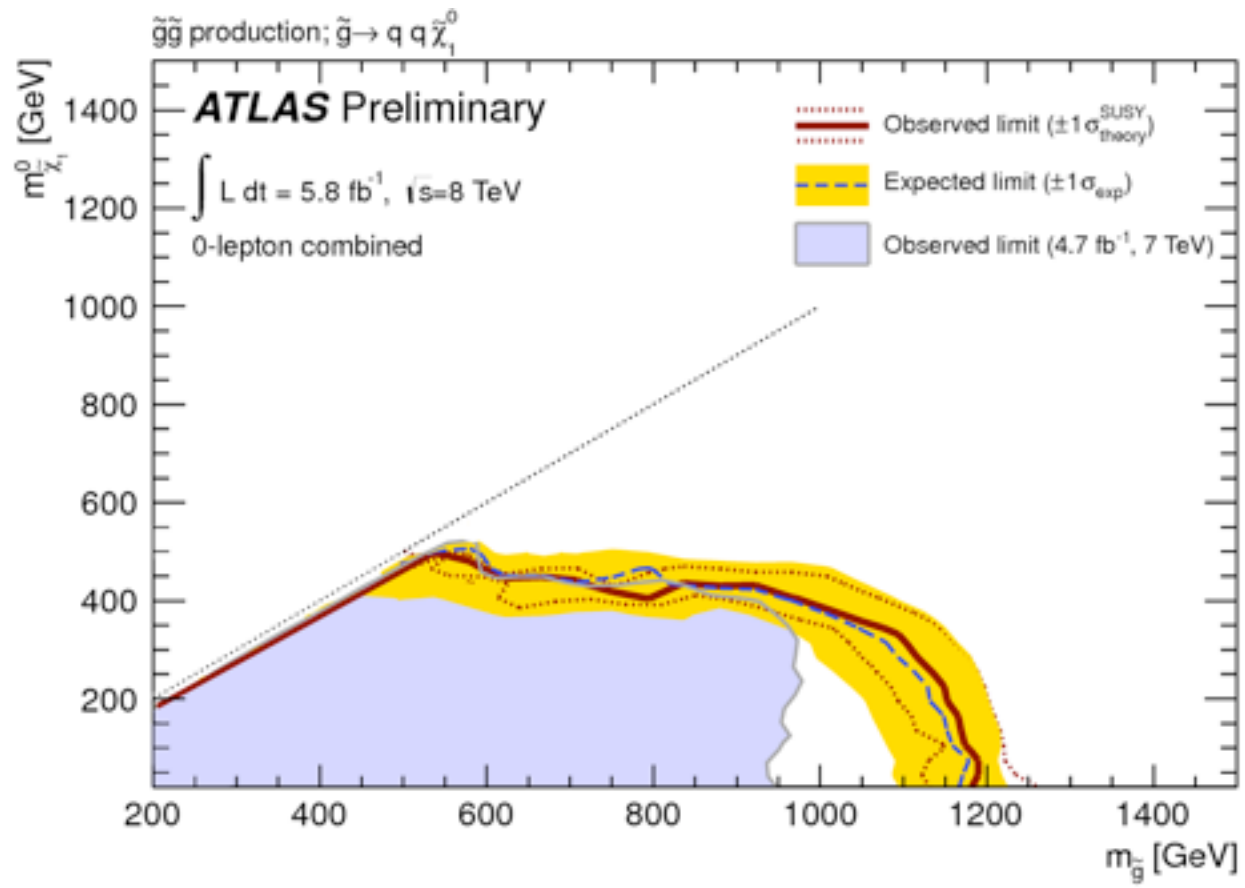
  - At two loops: Gluinos < 1.4 TeV



The other sparticles can be heavier

Bounds on Natural Supersymmetry

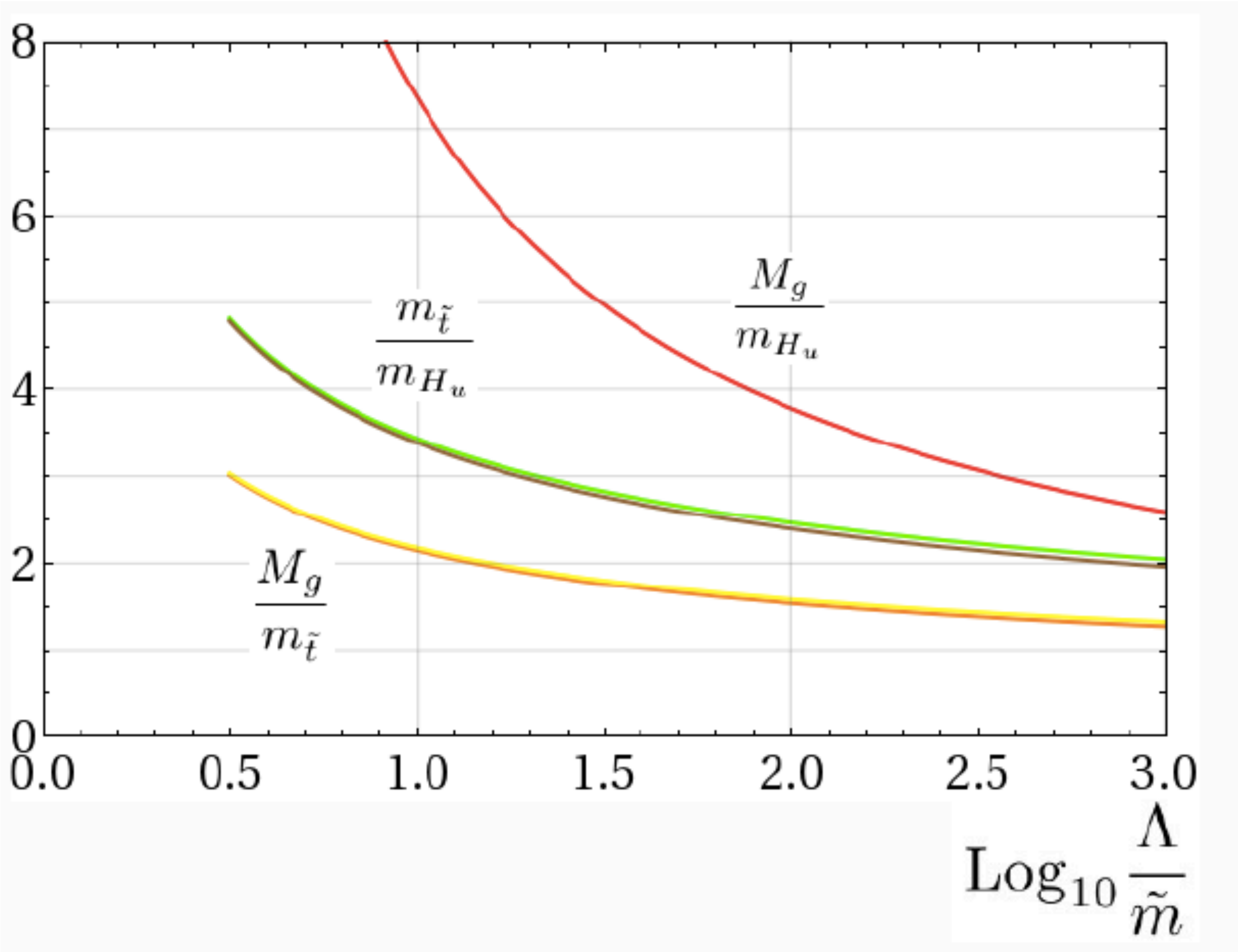




- Stop up to ~500 GeV (except region around top)

- Gluino up to ~ 1.2 TeV

The Gluino Sucks

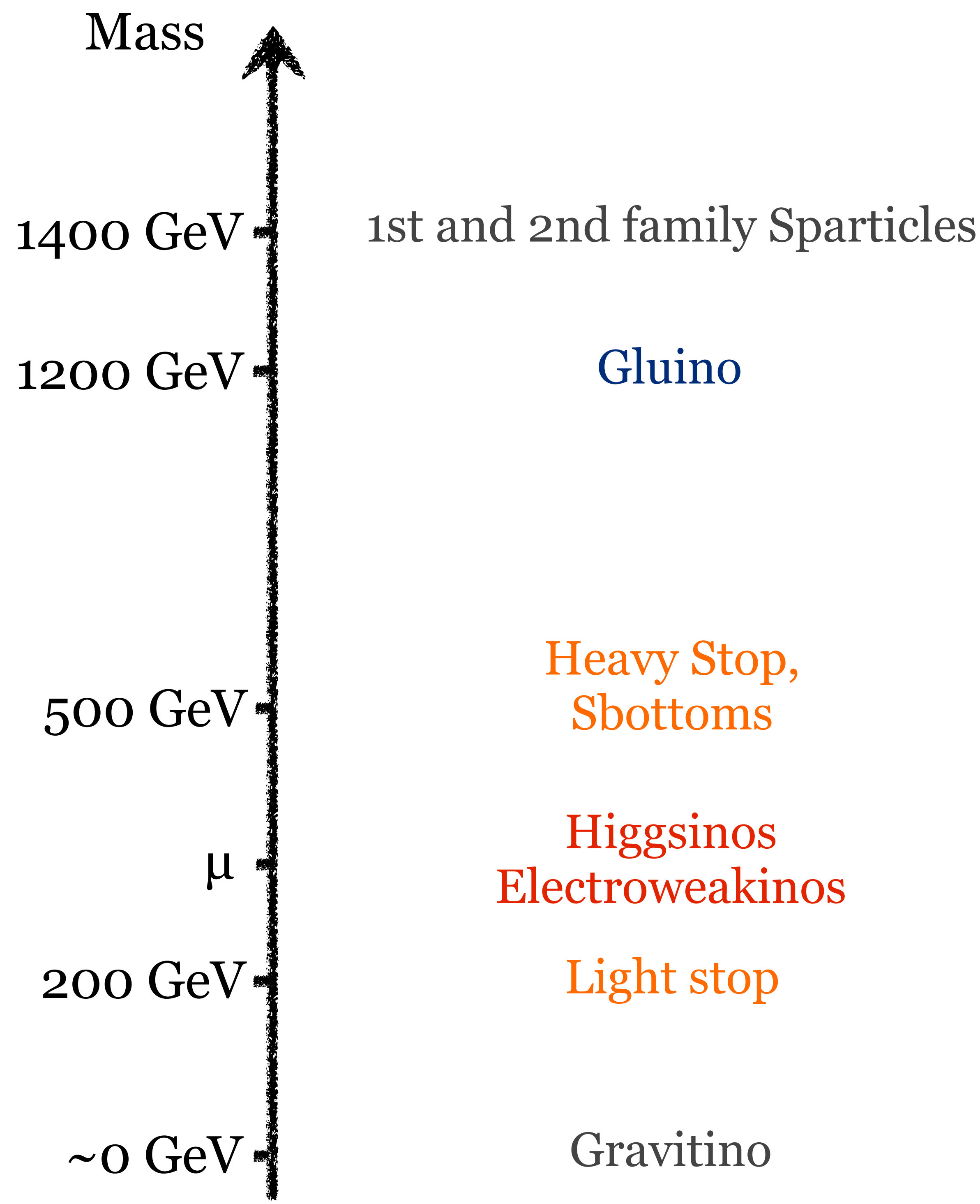


Gluino Bounds constrain all Low Energy Supersymmetry scenarios

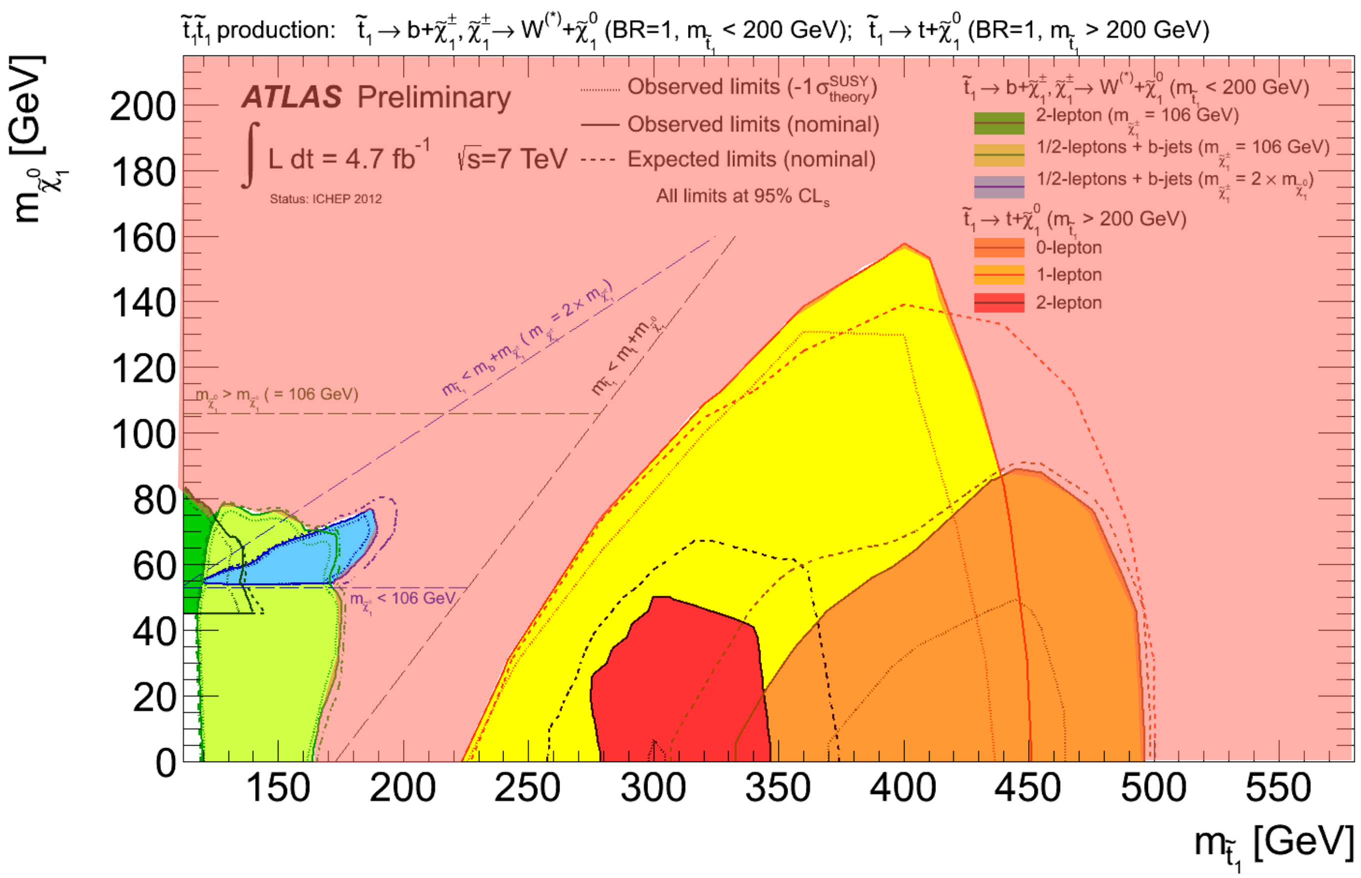
A Natural SUSY Spectrum

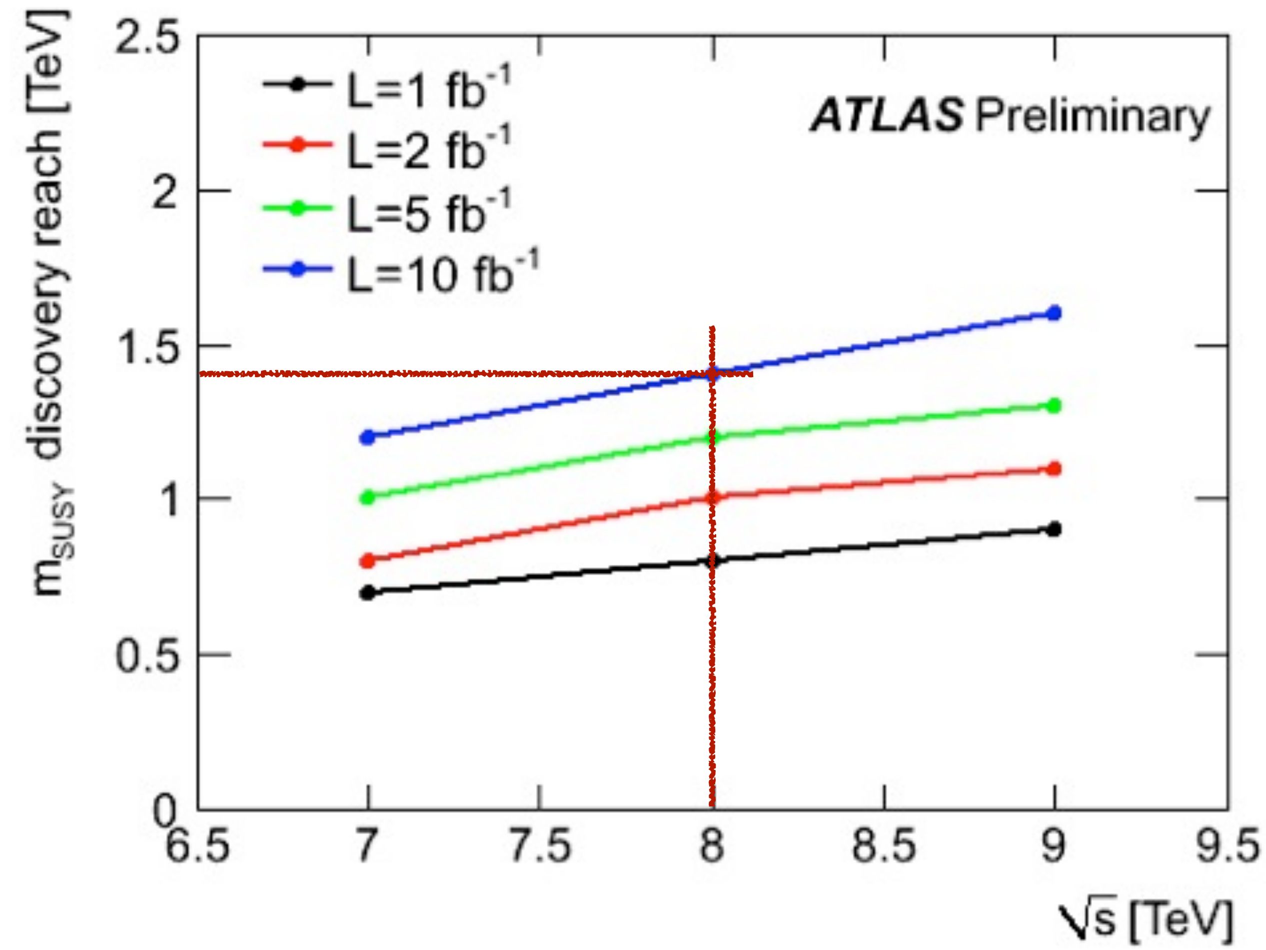
- Involves one additional singlet for the Higgs mass

- Requires low scale gauge mediation to minimize gluino running



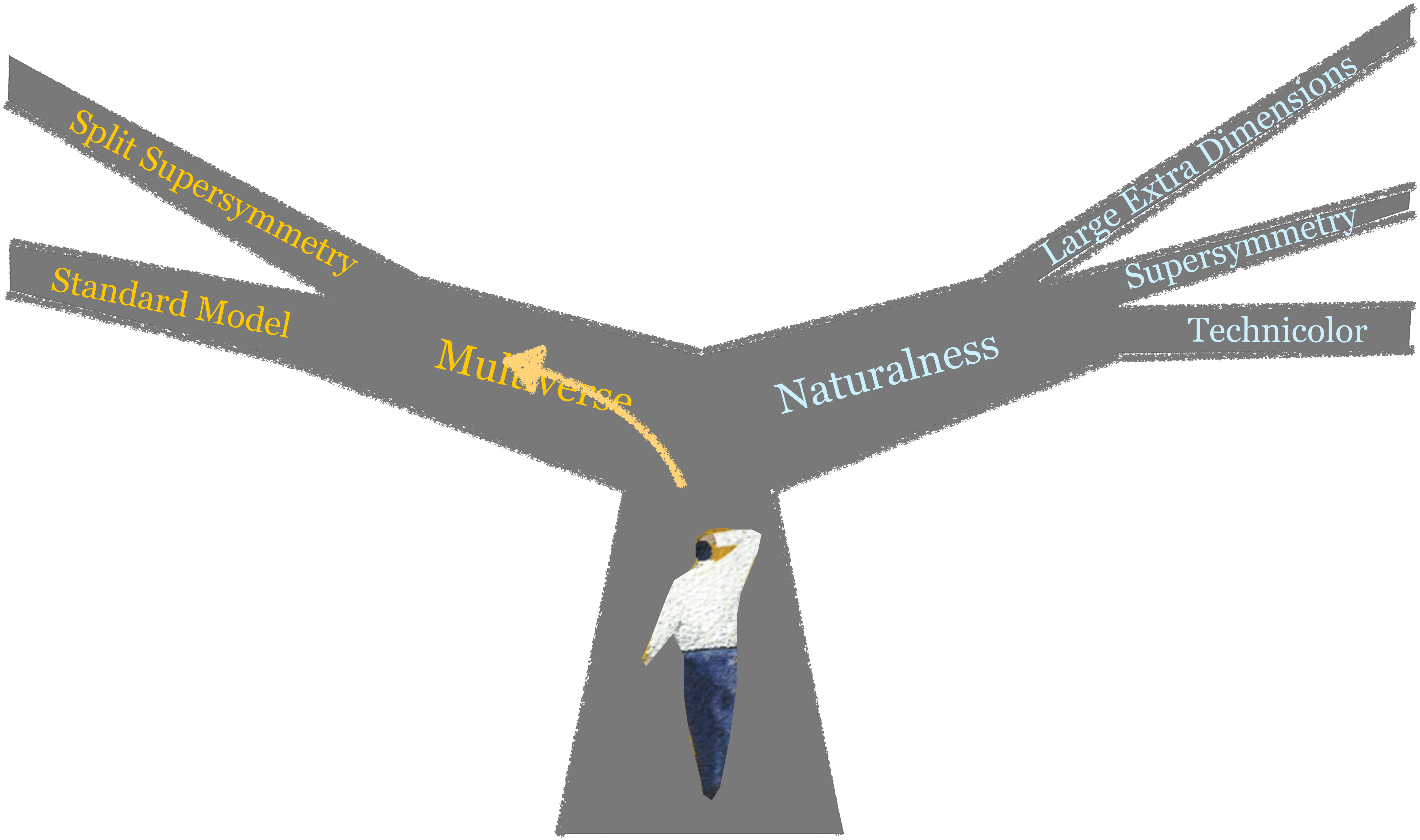
Prospects for Natural SUSY by December





- Gluino probed up to 1.5-1.8 TeV
- Stop probed to more than 500 GeV
- Natural SUSY further tested by the end of 2012

At the Crossroads



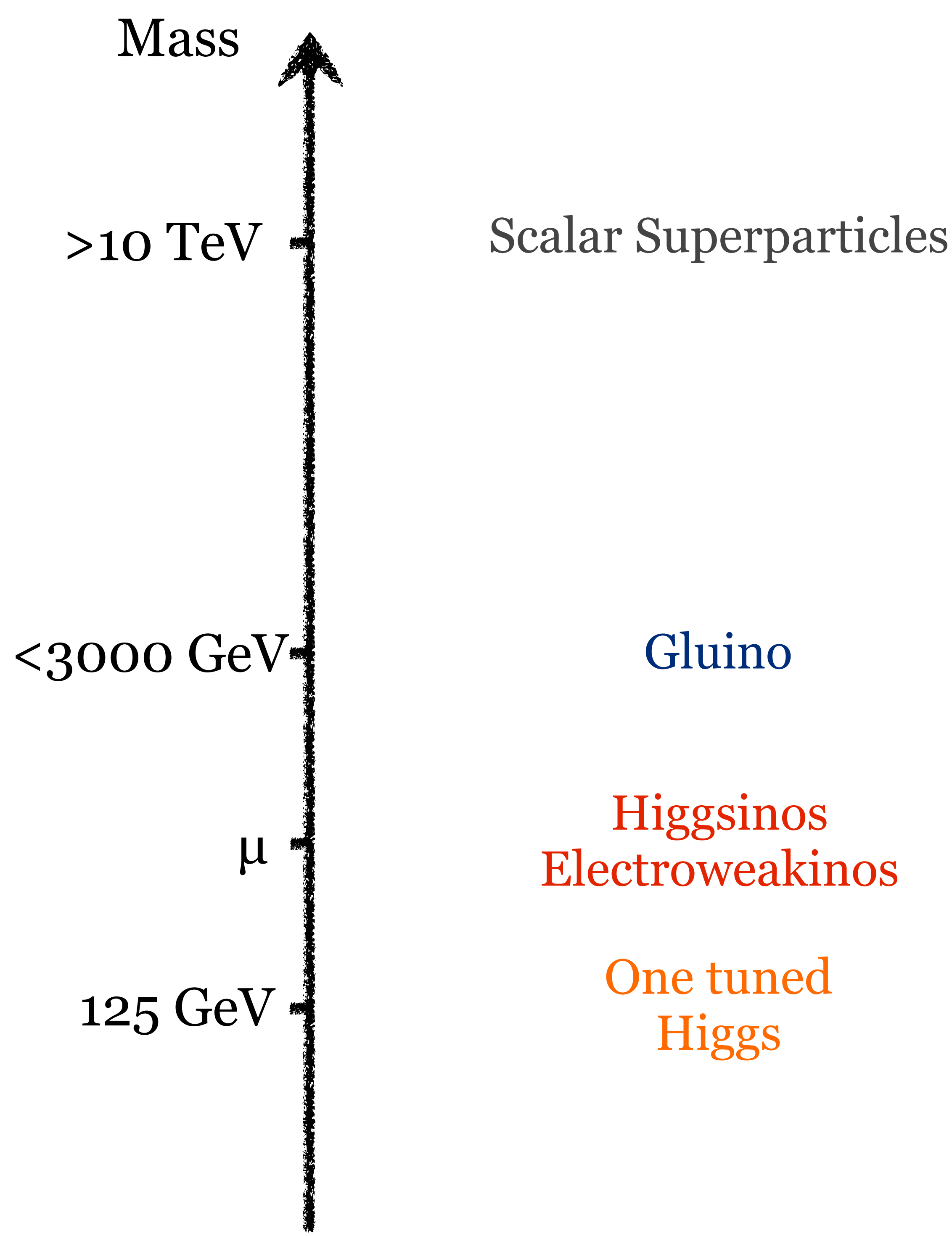
You and your landscapes!
Tell me about the worms!

Samuel Beckett, “Waiting for Godot”

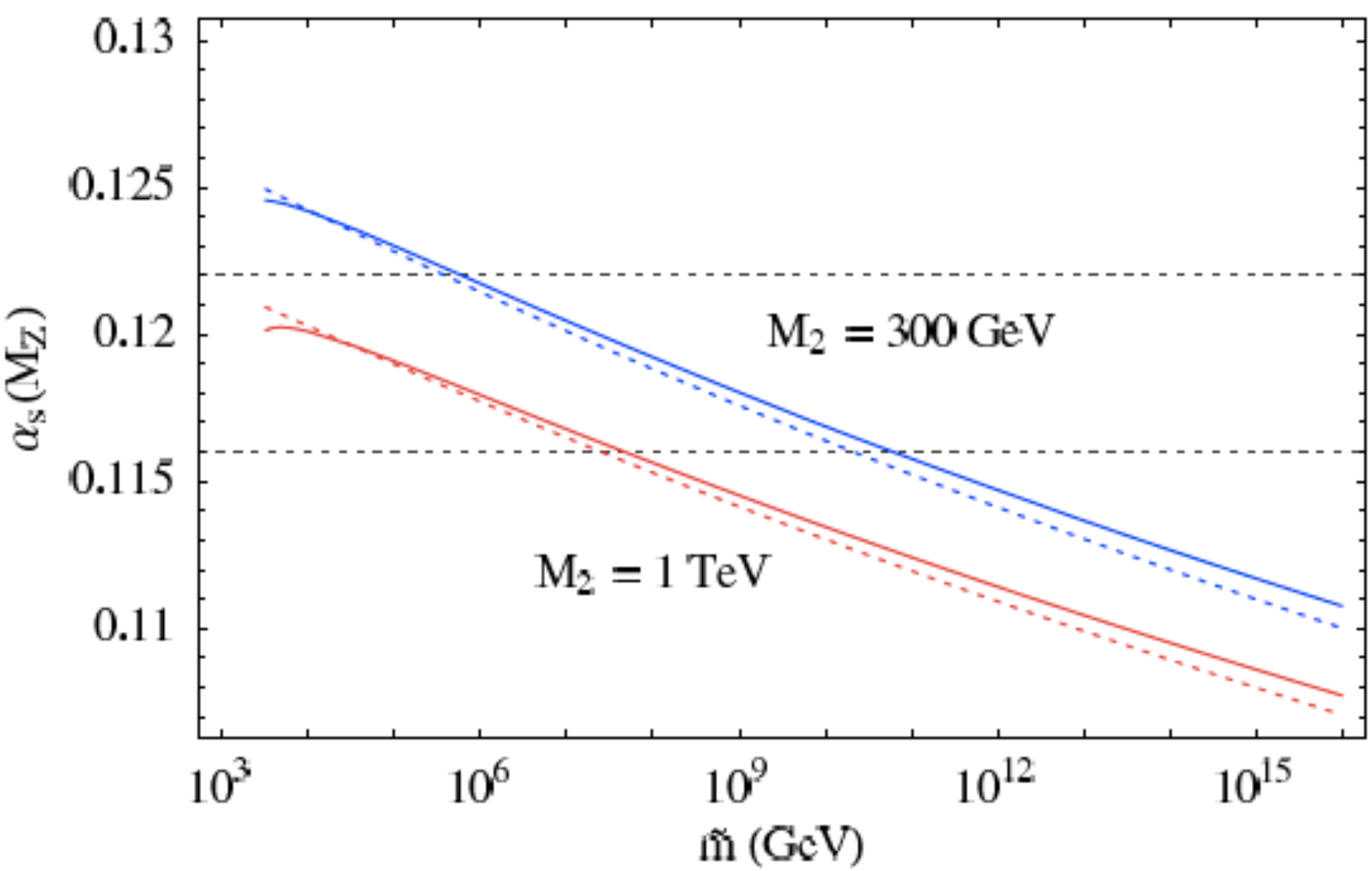
Split Supersymmetry

- Solves flavor and CP problems

- Preserves successes of Dark Matter and gauge coupling unification



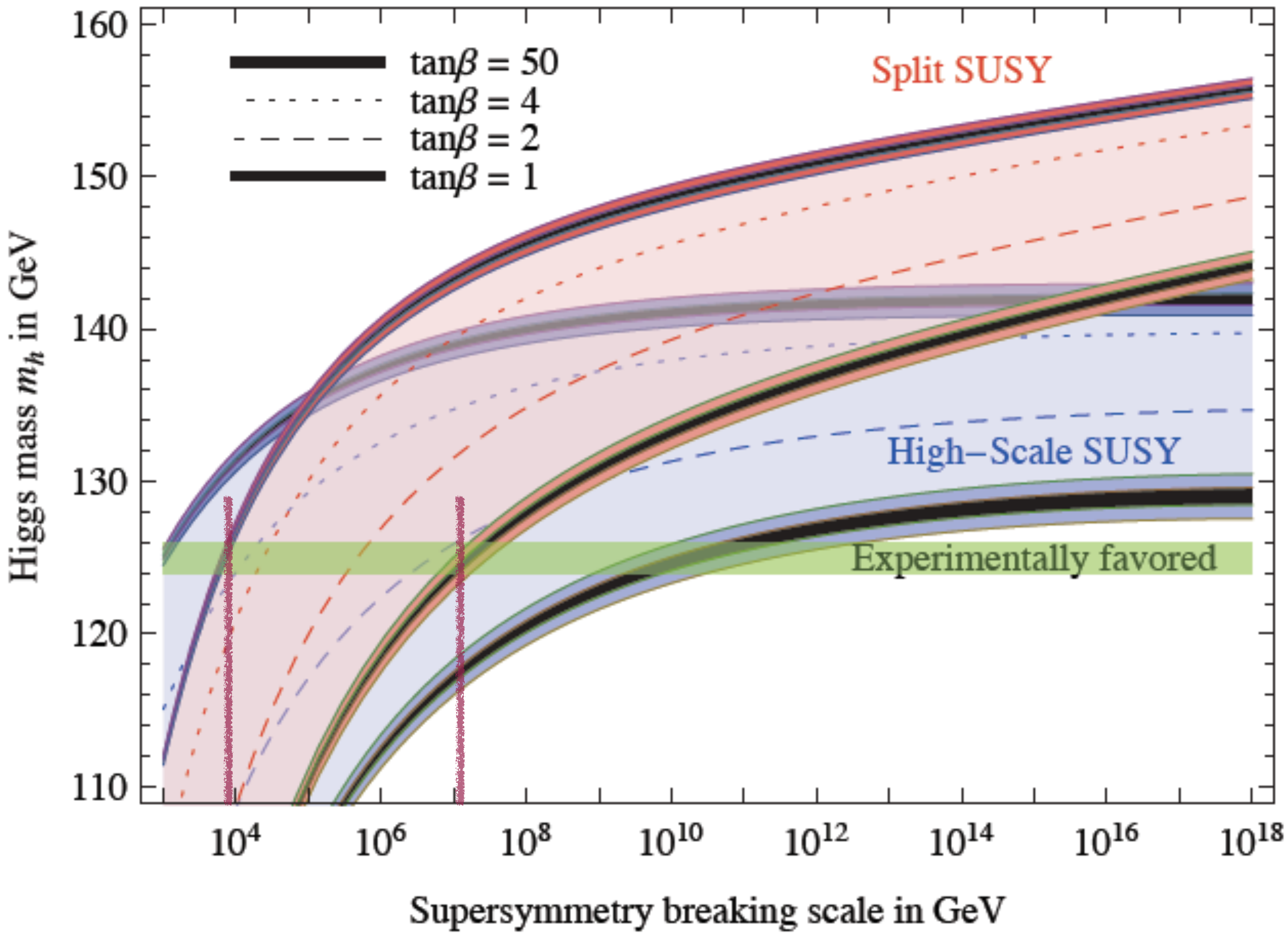
Unification in Split Supersymmetry



Prediction for α_s at M_Z at two loops

Works as well as ordinary Supersymmetry

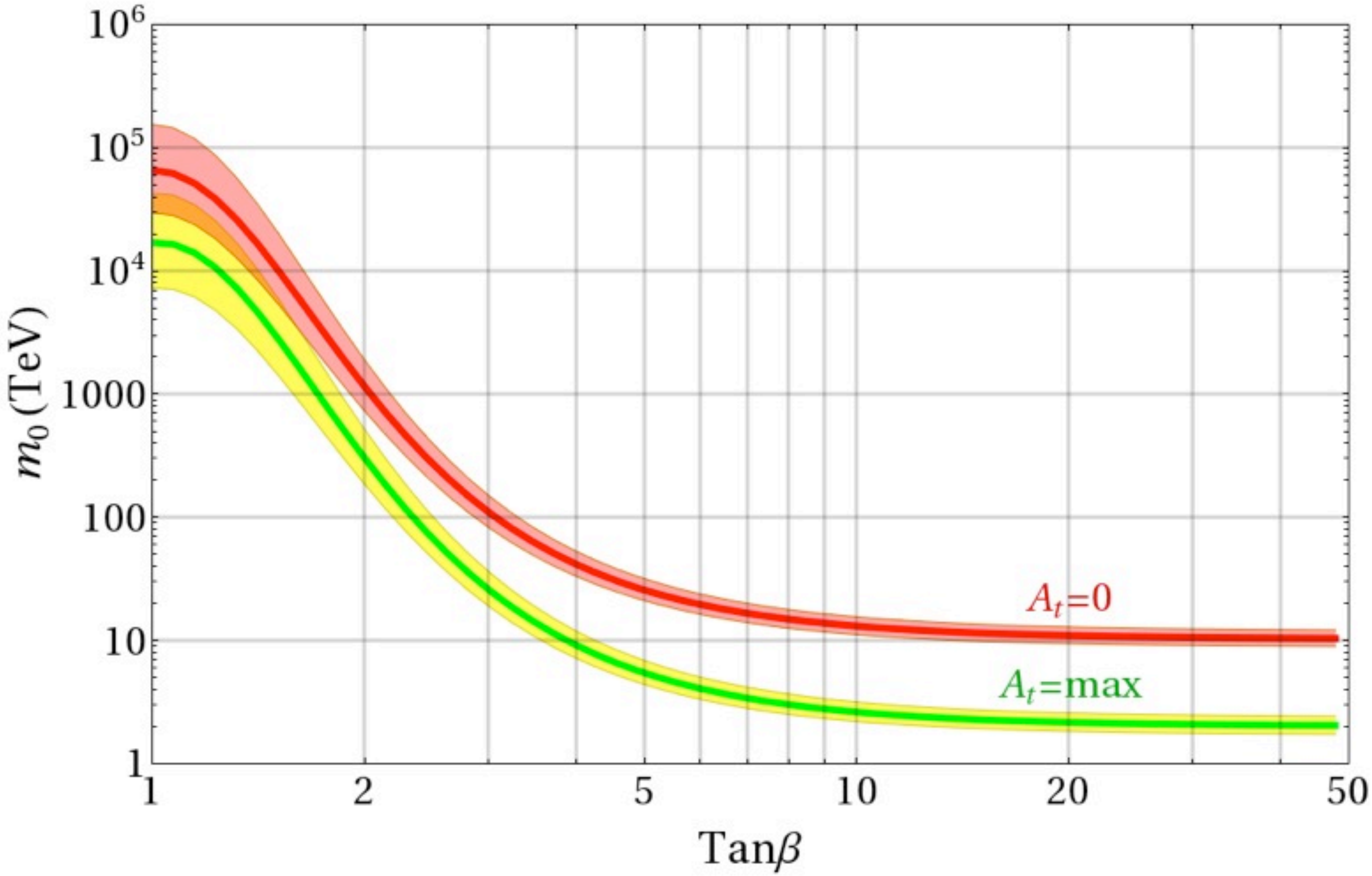
125 GeV Higgs in Split Supersymmetry



Giudice and Strumia (2011)

125 GeV Higgs in Split Supersymmetry

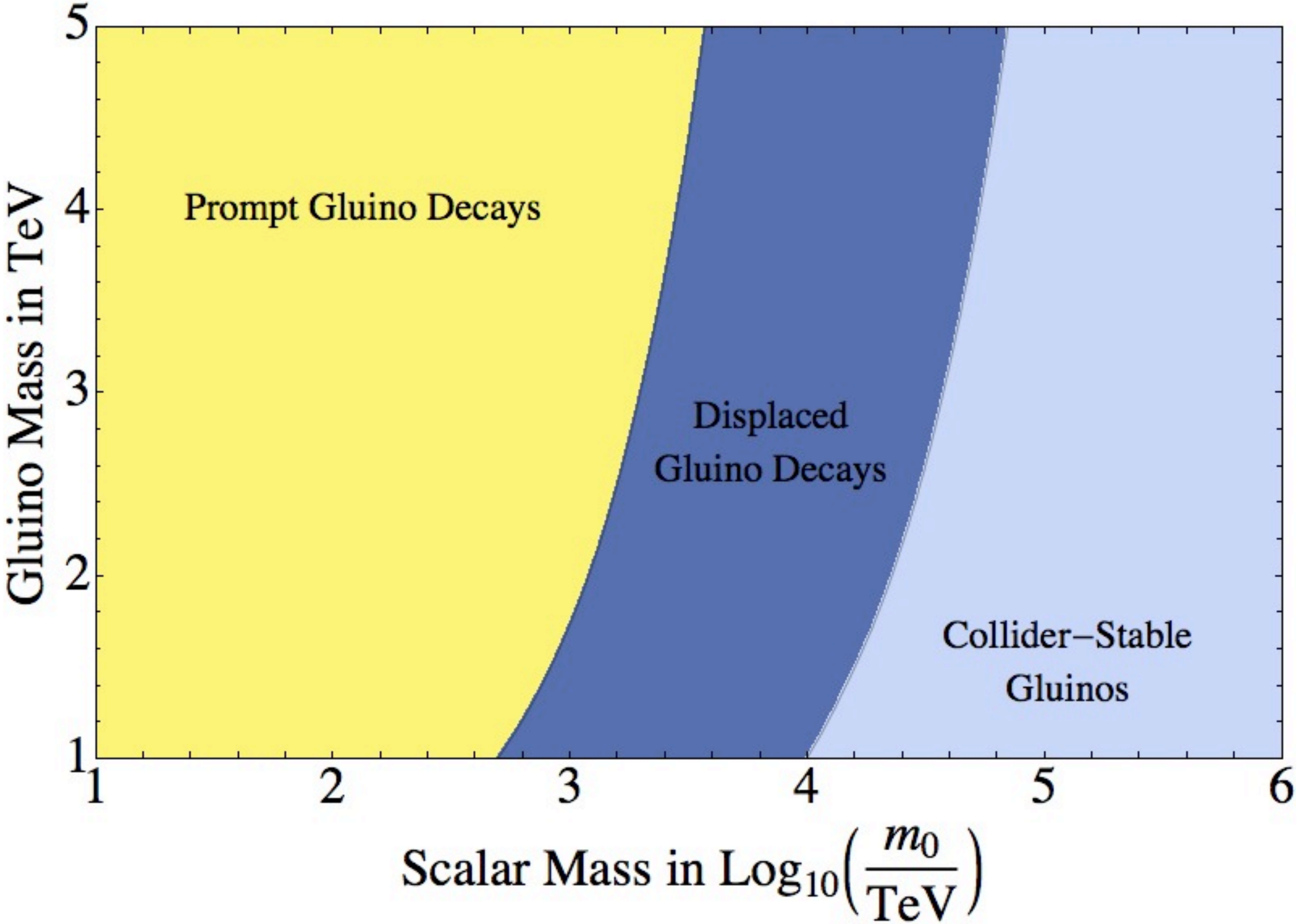
Arvanitaki, Craig, SD, Villadoro (to appear)



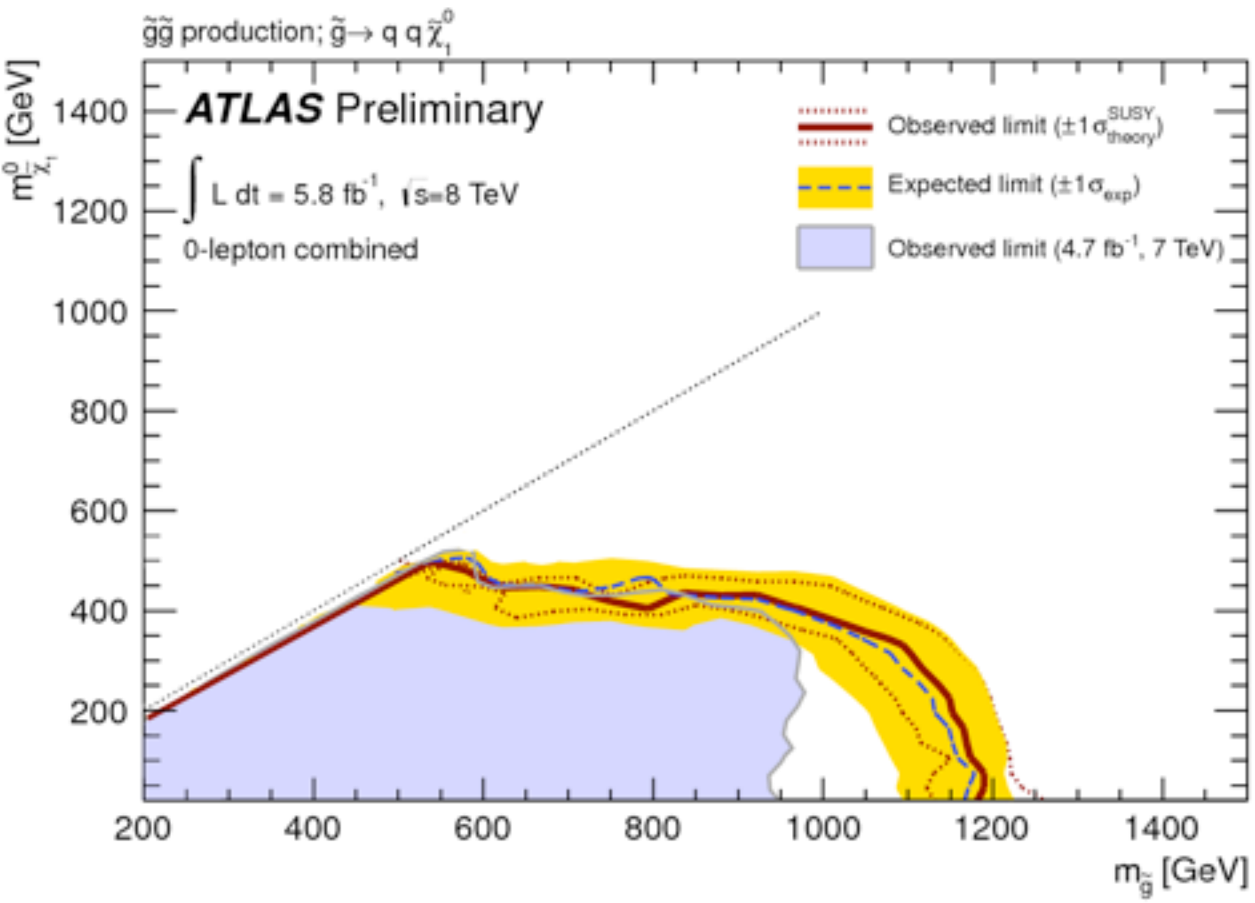
- When tanβ > 3 the scalars are lighter than 100 TeV
- Gauginos and higgsinos one or more loops below

Long-lived Gluinos at the LHC

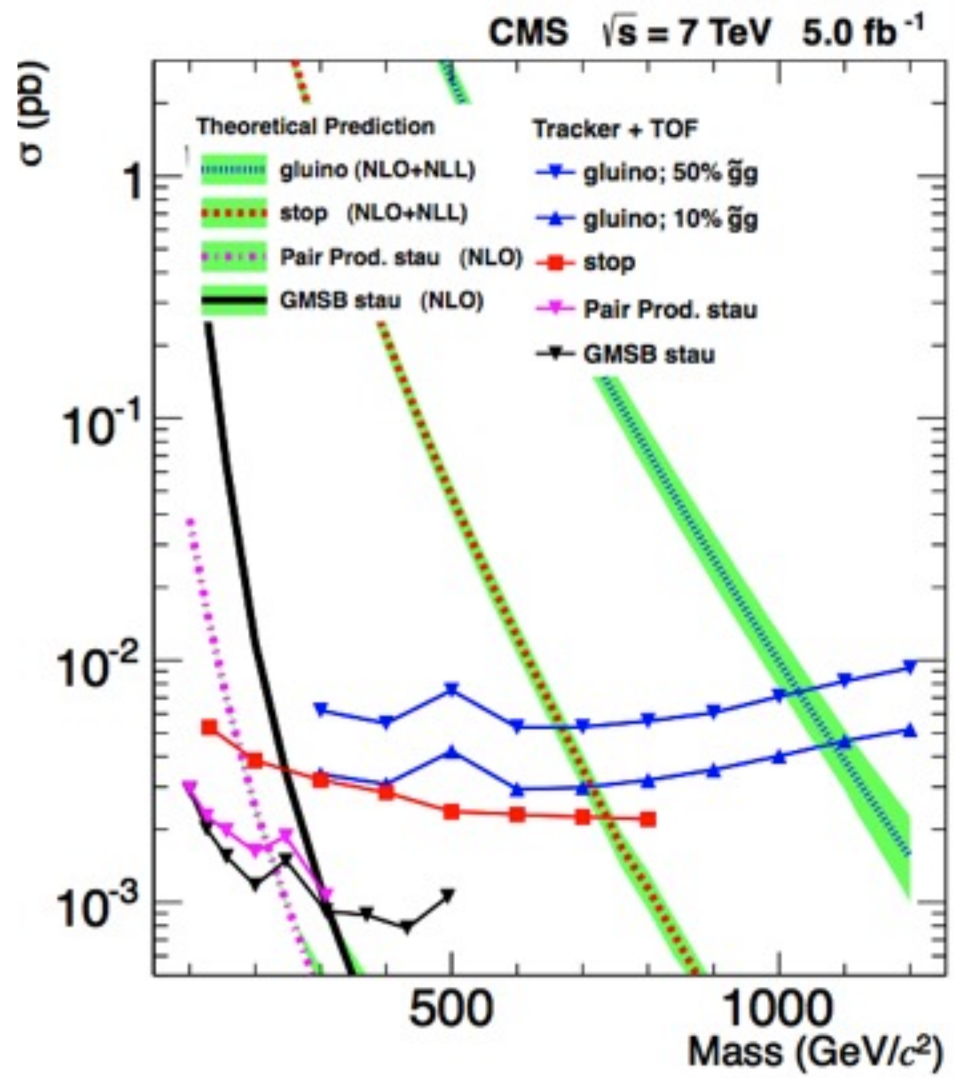
Arvanitaki, Craig, SD, Villadoro (to appear)



Gluino Bounds from the LHC



For prompt or
slightly displaced gluinos



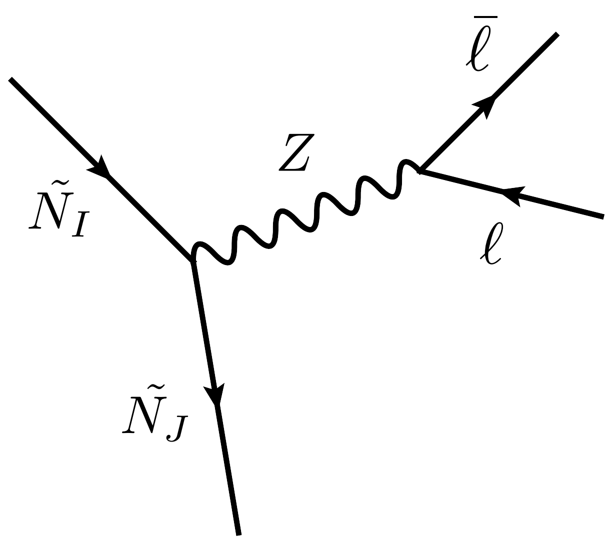
For collider "stable" gluinos

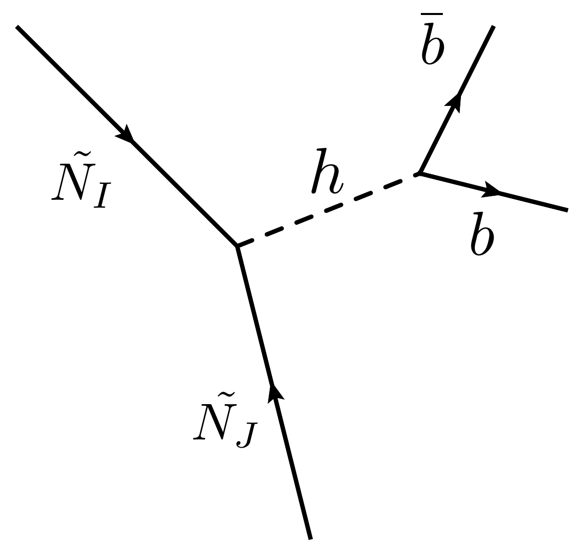
$M_{gluino} > 1$ TeV for split gluino

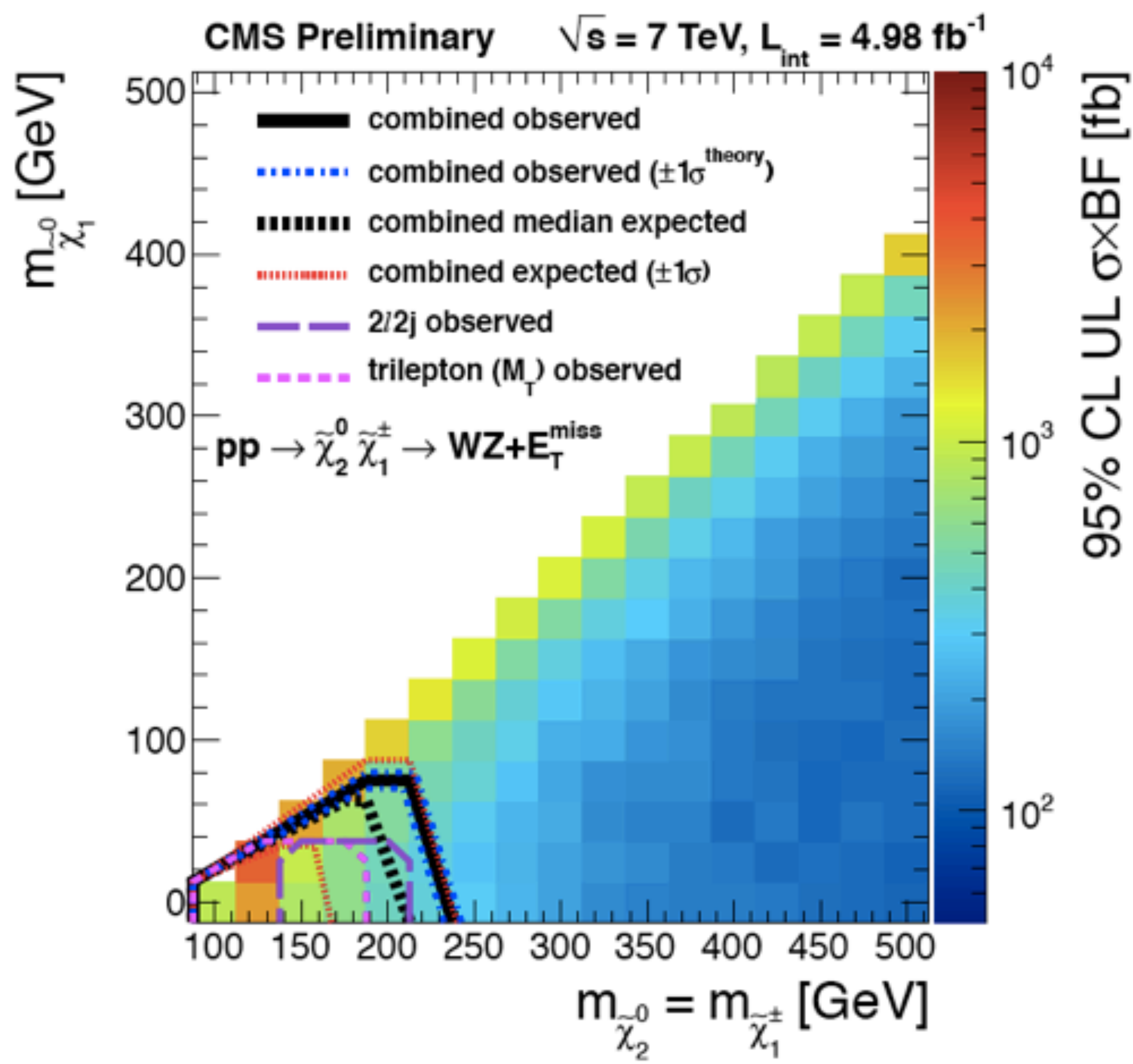
2.5 TeV to 3 TeV ultimate reach for split gluino

Split Signatures beyond the Gluino: Electroweakinos and Higgsinos

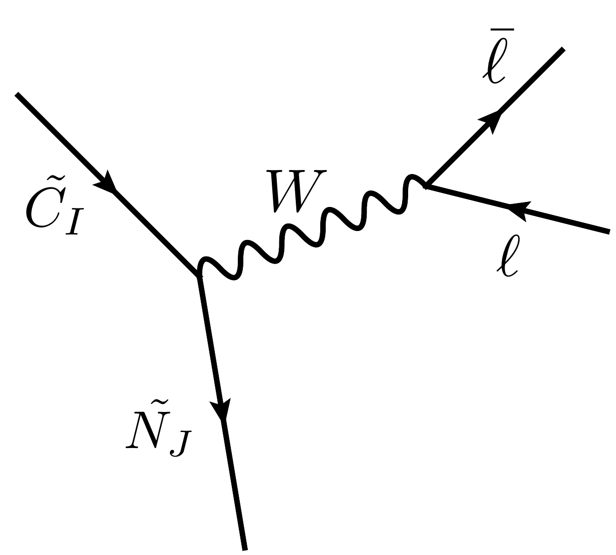
Neutralino decays



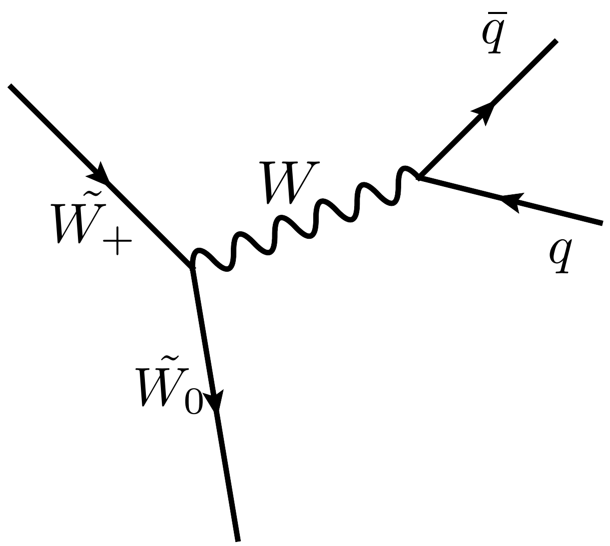


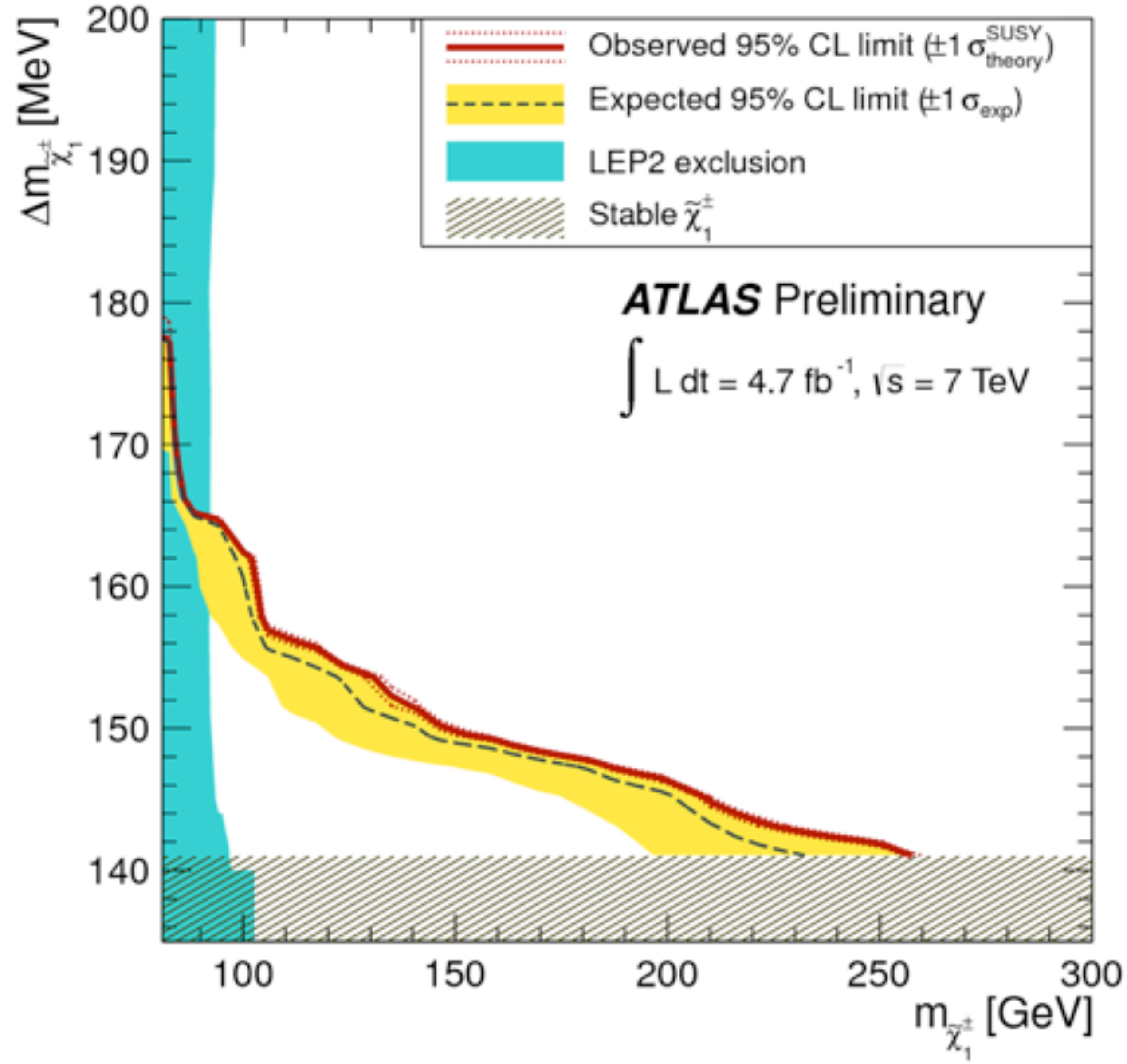


Chargino decays



Pure Wino LSP phenomenology

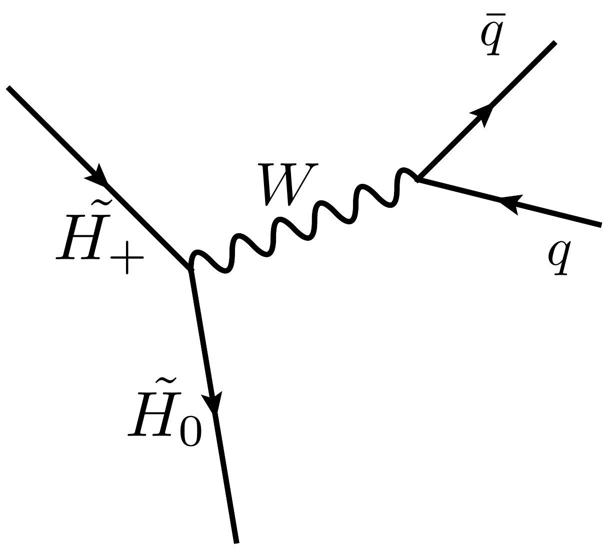




$$\Delta m \approx 155 - 175 \text{ MeV}$$

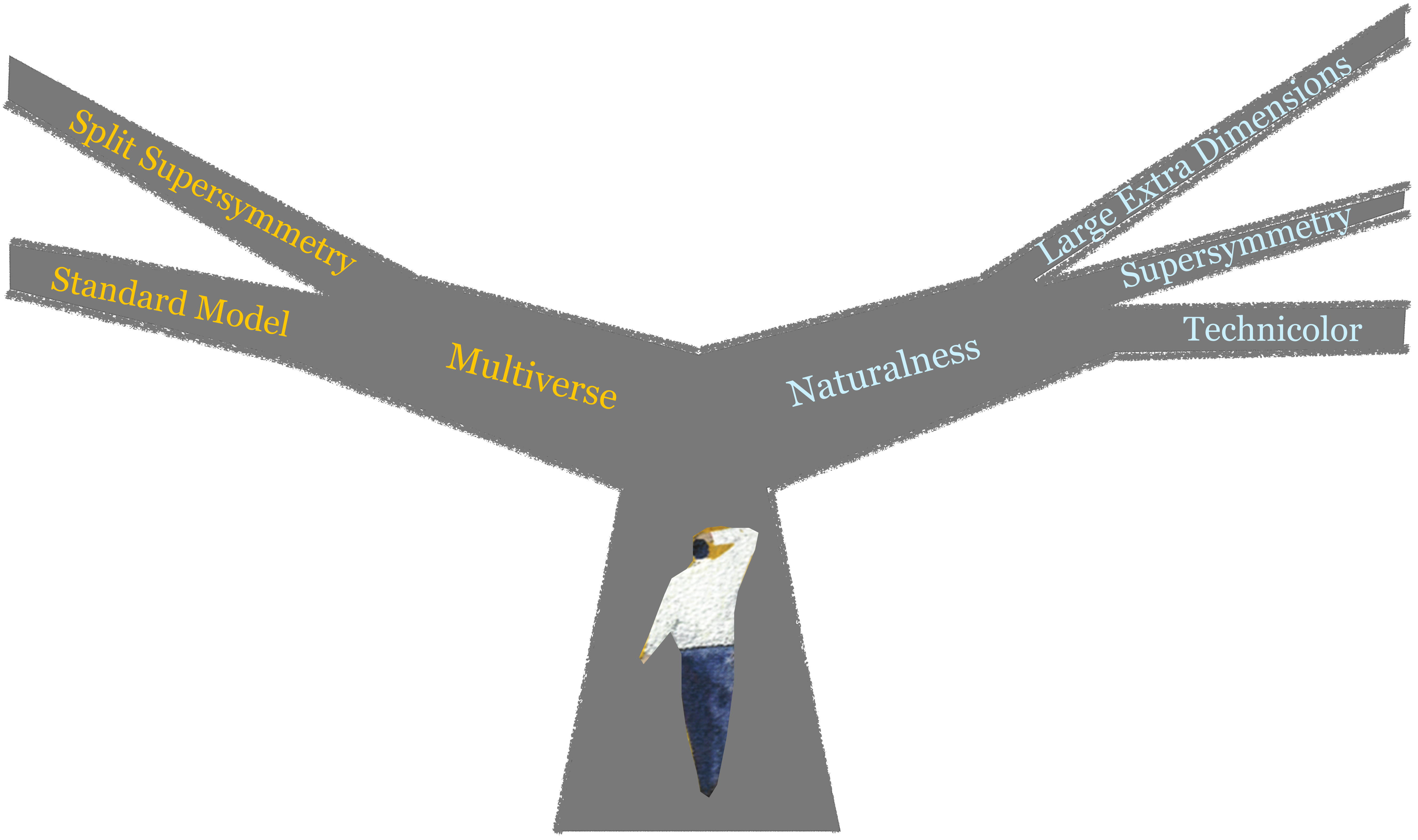
- Soft Pions
- Charged track length of order cm

Higgsino LSP:
The Minimal Model for Unification

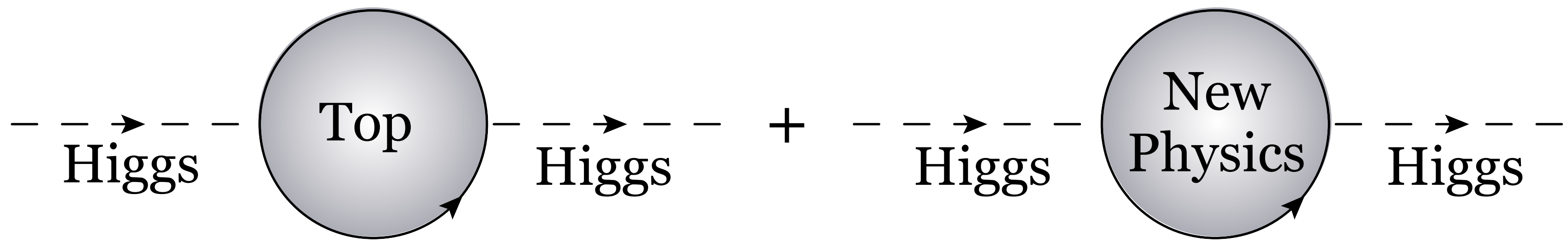


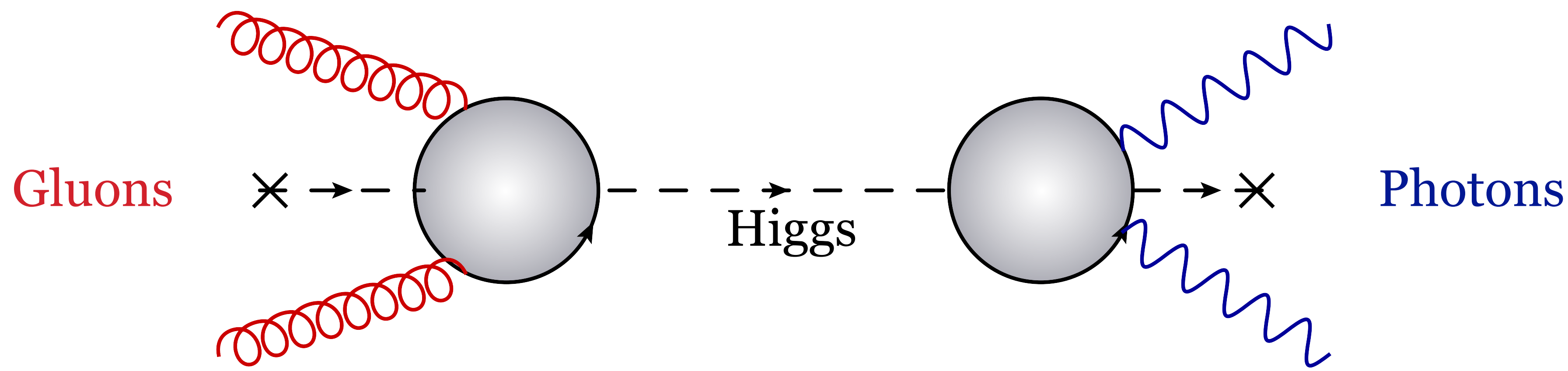
- Only light Higgsinos in the Spectrum
- Mass splitting ~355 MeV
- Soft pions with sub-cm charged tracks
- Working search strategy ?

What can the Higgs tell us?



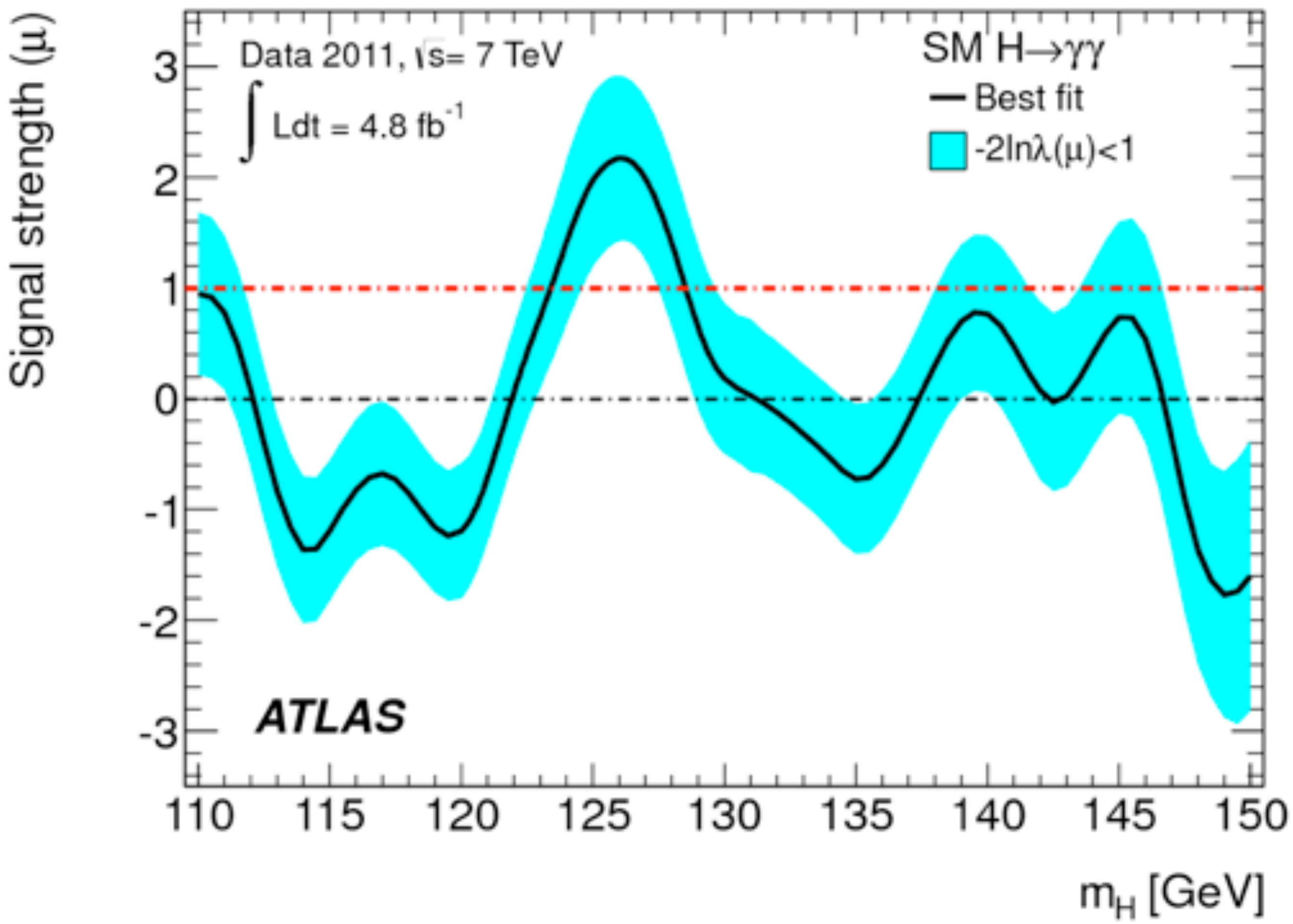
Naturalness and Higgs Properties





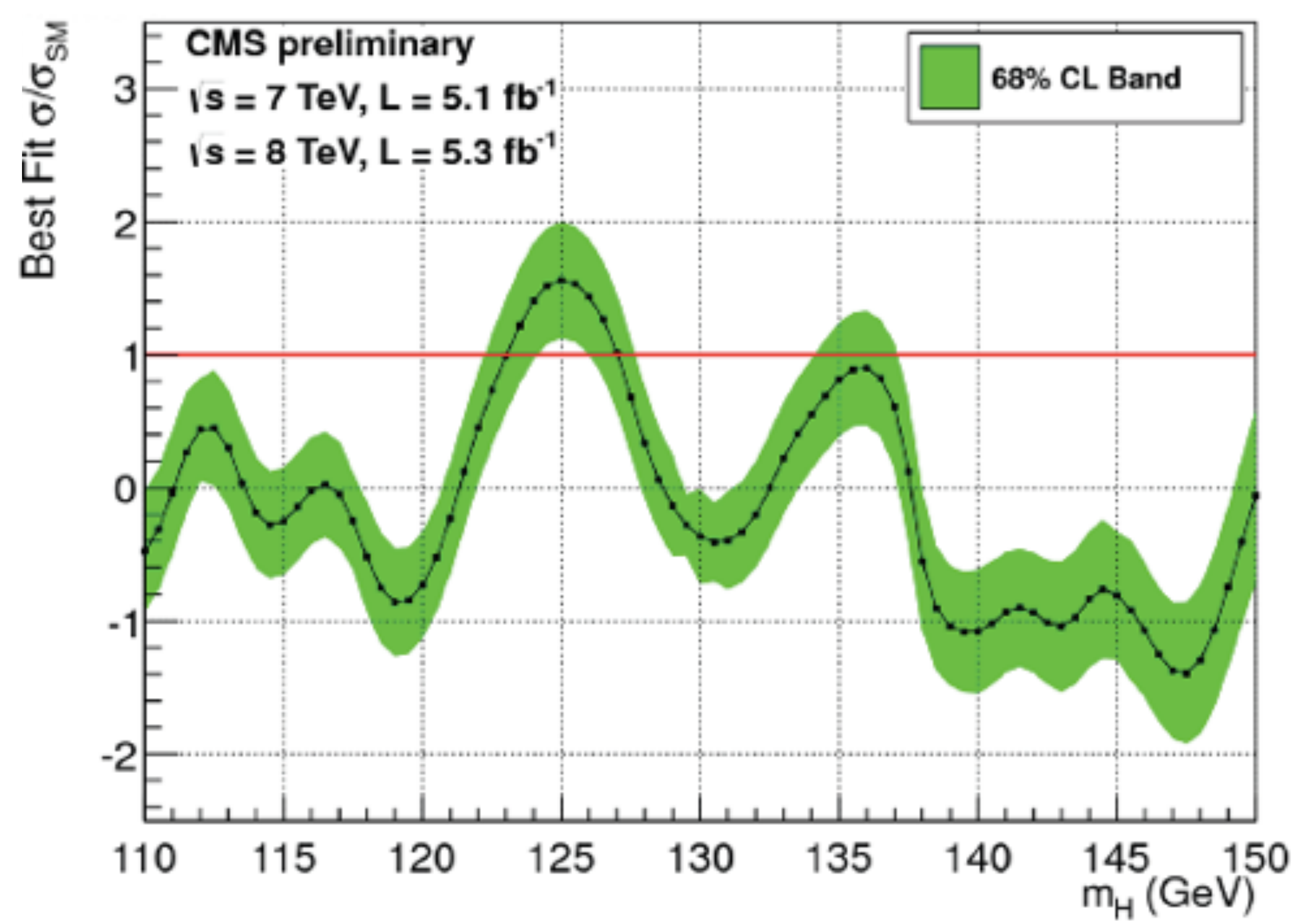
A Natural Higgs is not the SM Higgs

The hints for a BSM 125 GeV Higgs



$2 \times \sigma_{SM}$
in $h \to \gamma\gamma$ from ATLAS

$1.5 \times \sigma_{SM}$
in $h \to \gamma\gamma$ from CMS

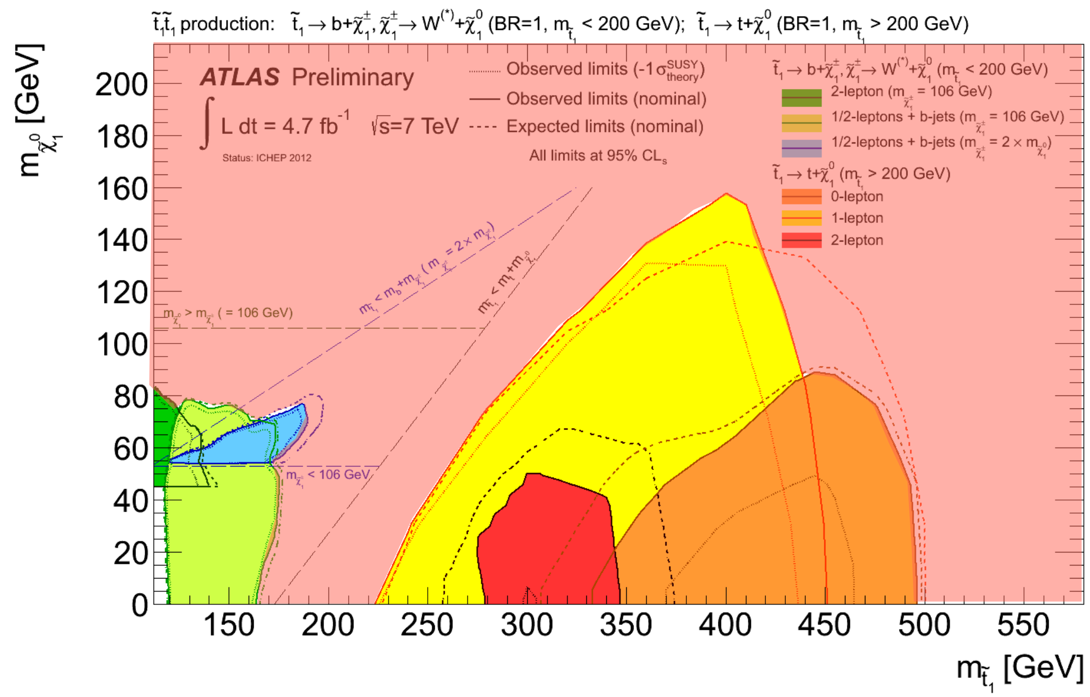


Conclusions

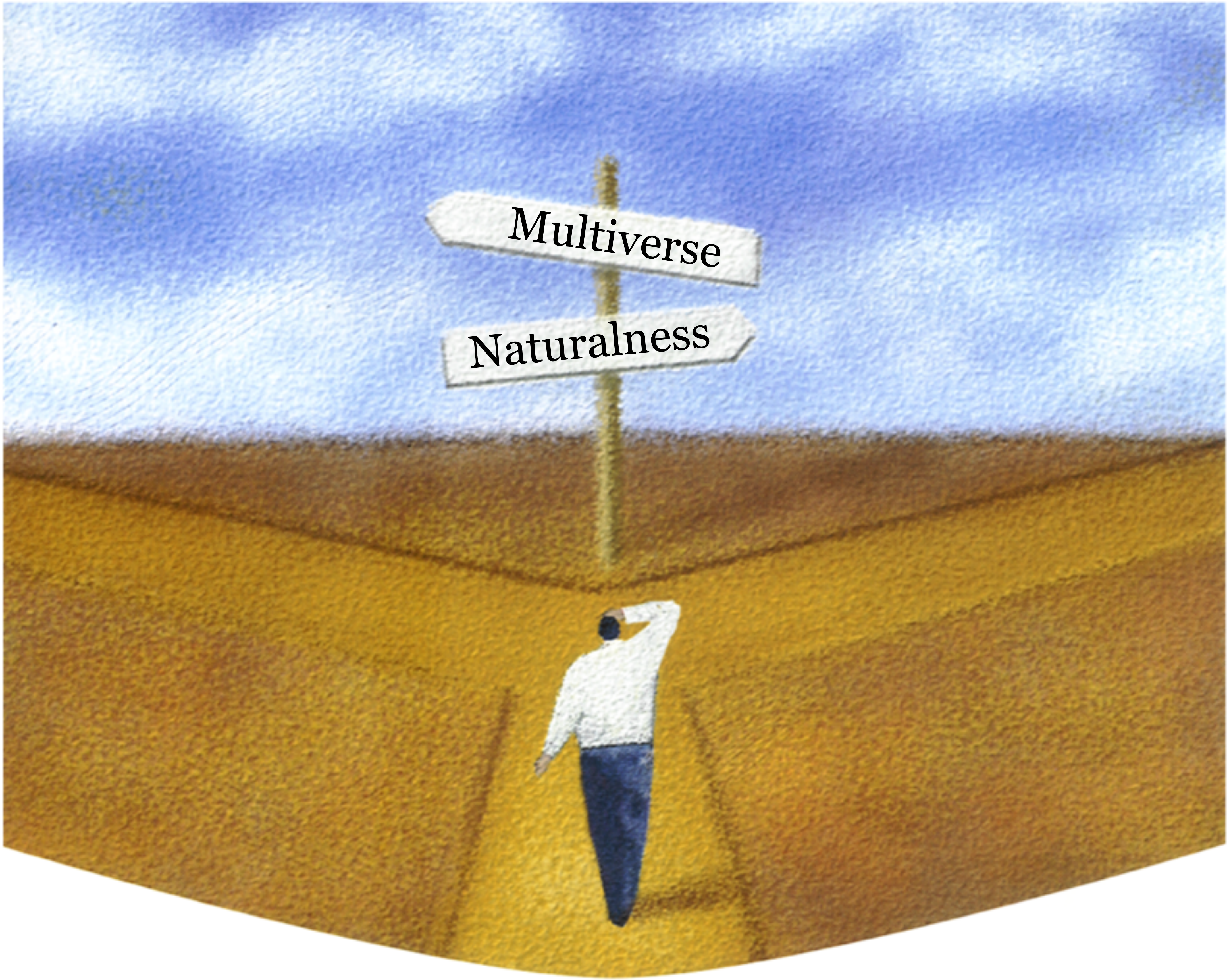
- Natural Supersymmetry
  - Requires new ingredient in the MSSM for the Higgs
  - Gluino mass constraints push natural SUSY to the corner
  - LHC will further test Natural SUSY by the end of 2012
- Split Supersymmetry
  - Higgs Mass points to Mini Split
- Higgs Mass and Properties
  - A non SM higgs favors naturalness

What is Next Experimentally?

- This year
  - Fill the stop gap
  - Probe Gluino up to 1.8 TeV
  - Study h → γγ



- Next 5 years
  - Study Higgs couplings
  - Continue looking for sparticles



The Large Hadron Collider will tell us!