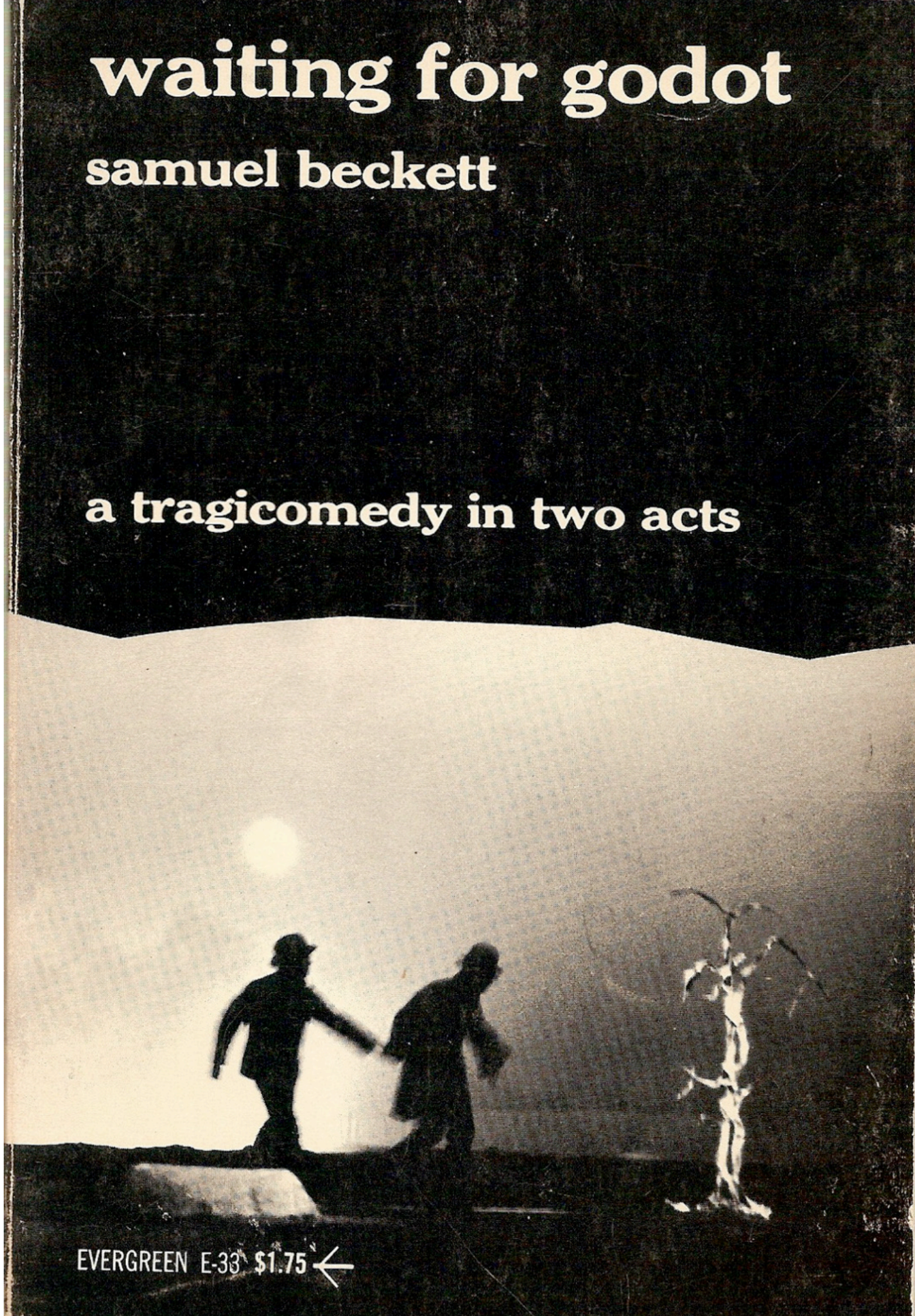
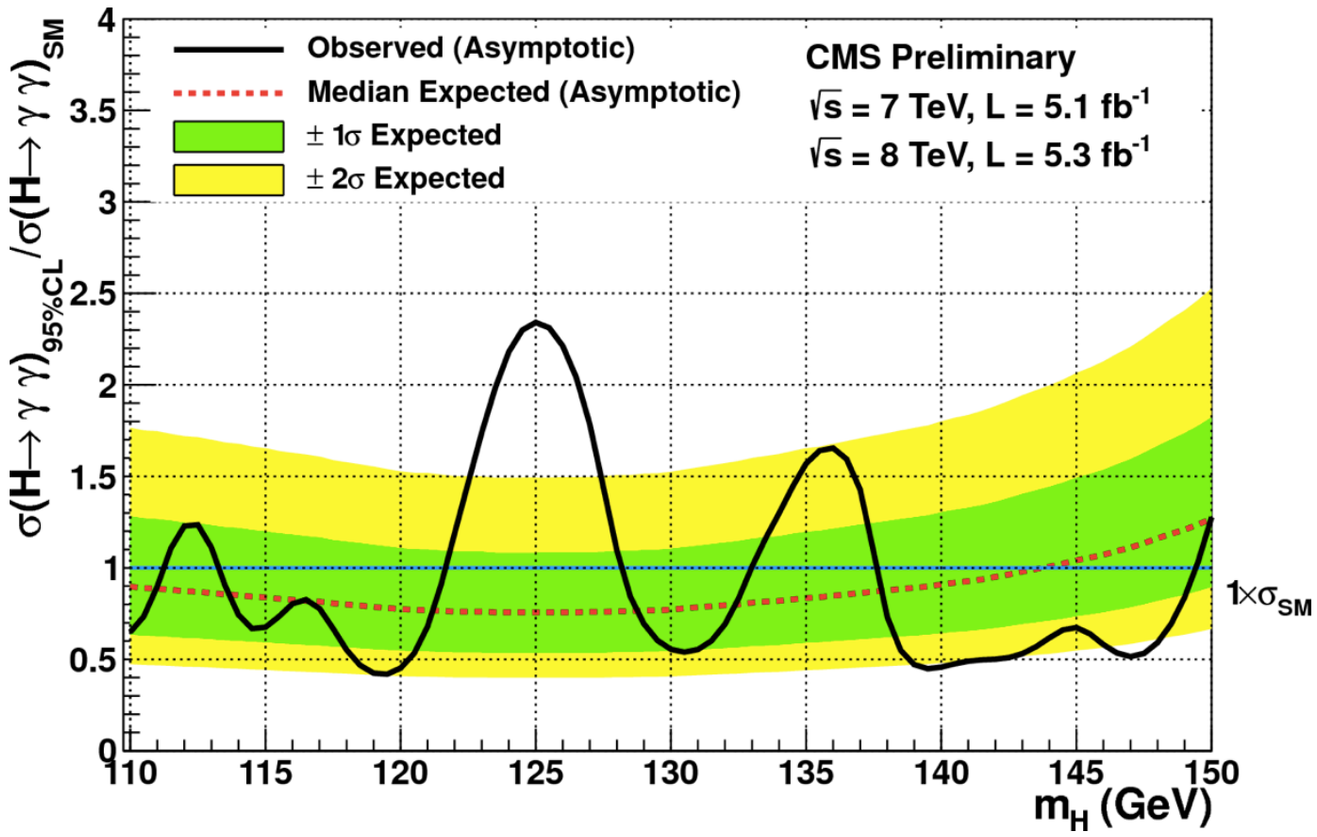
What Has the LHC Done to Theory?

Savas Dimopoulos
Stanford University

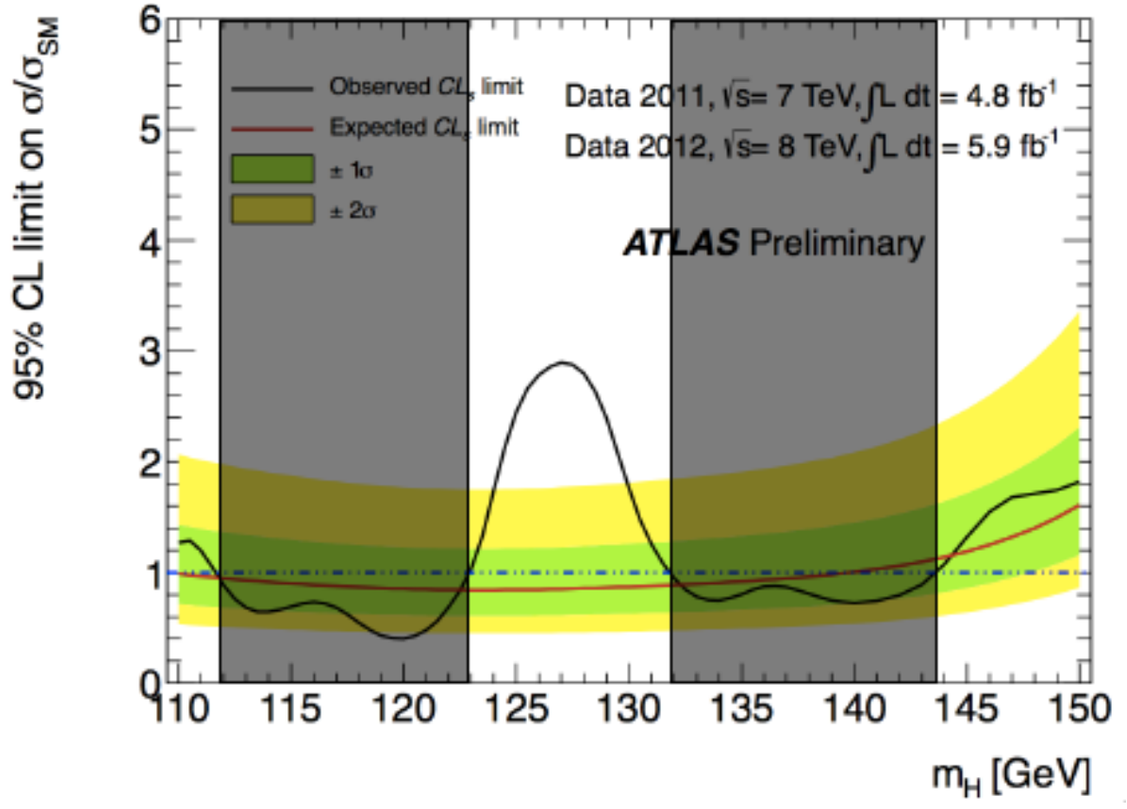


The Higgs at 125 GeV

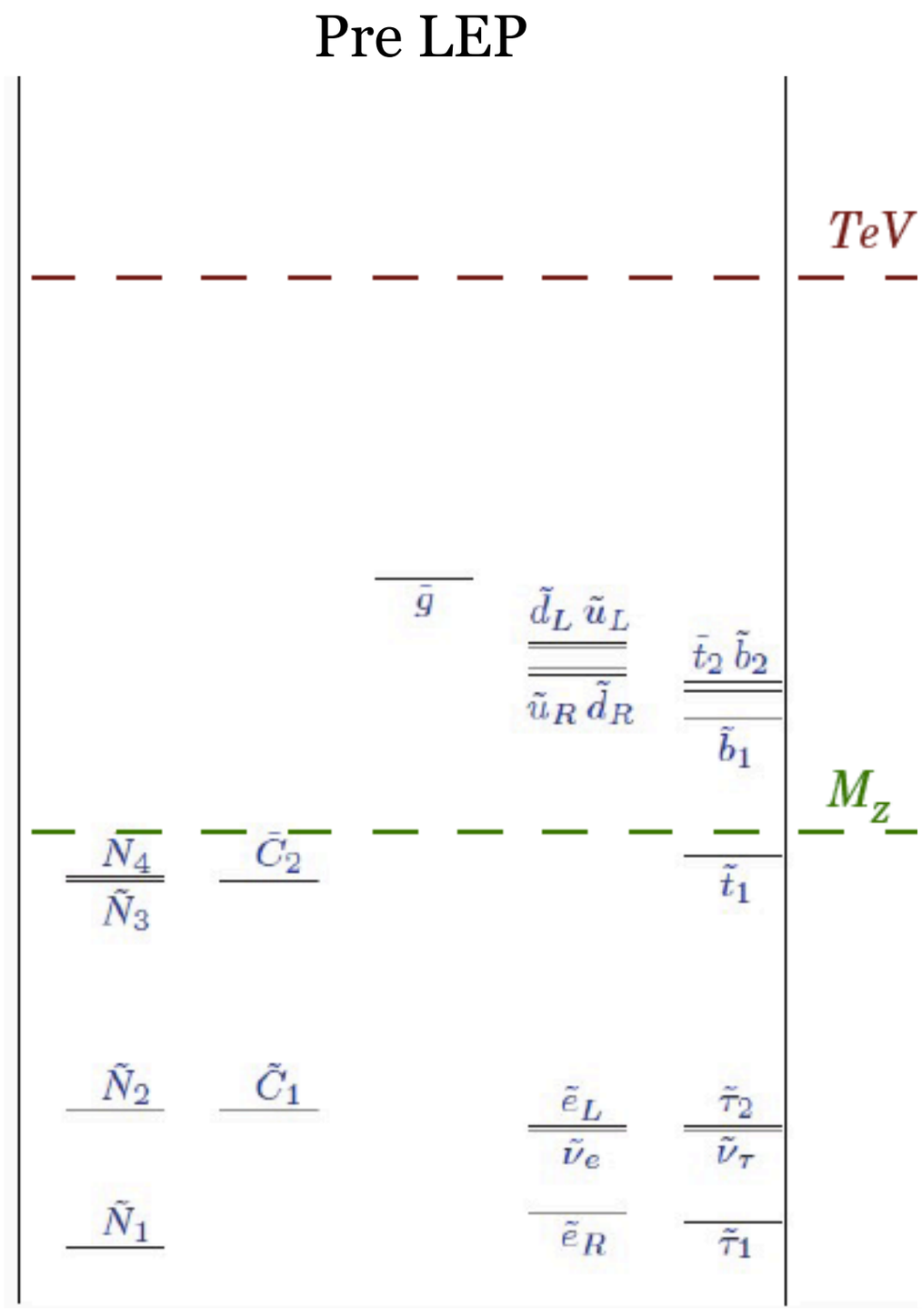


h → γγ in CMS

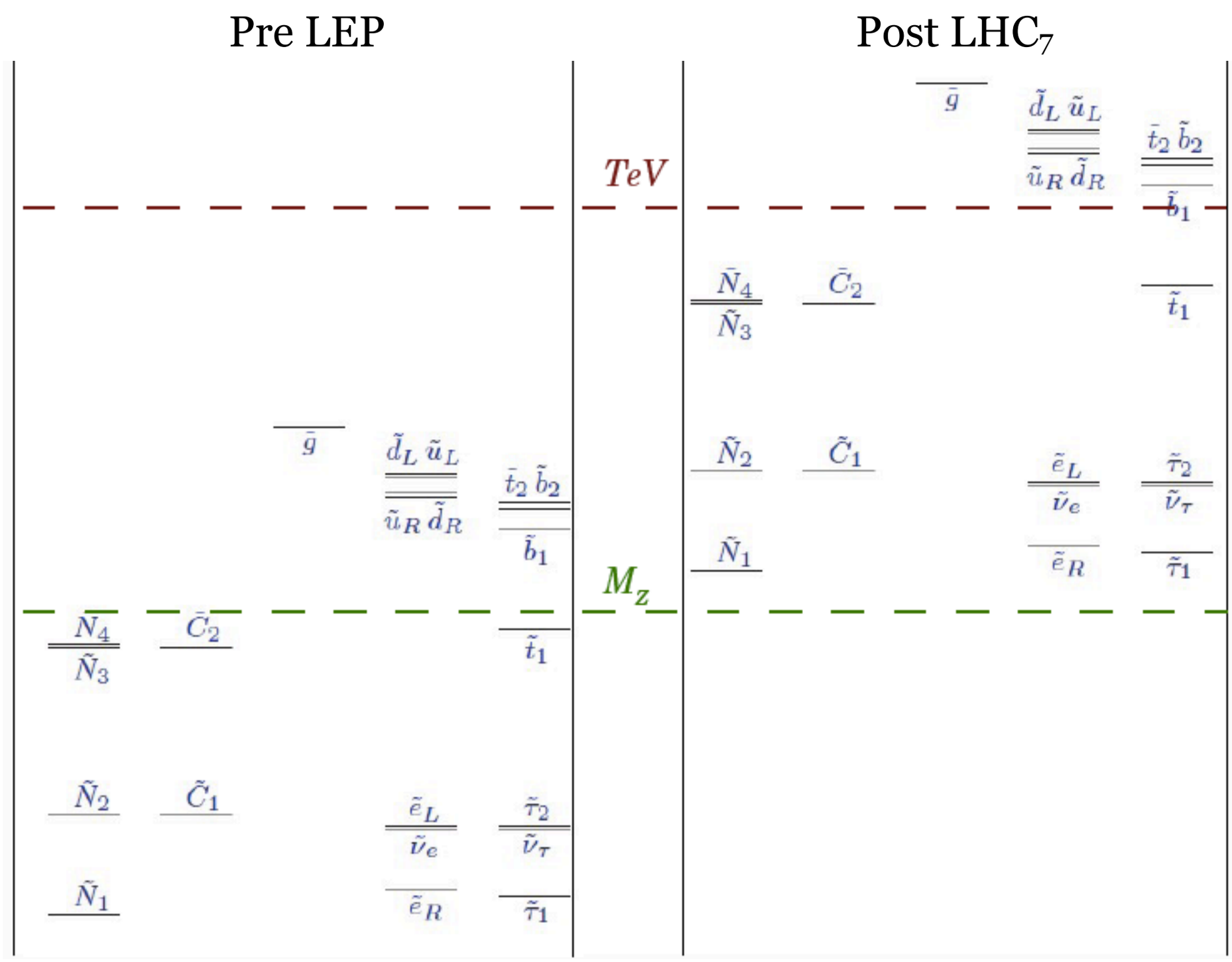
h → γγ in ATLAS



The Hard Facts



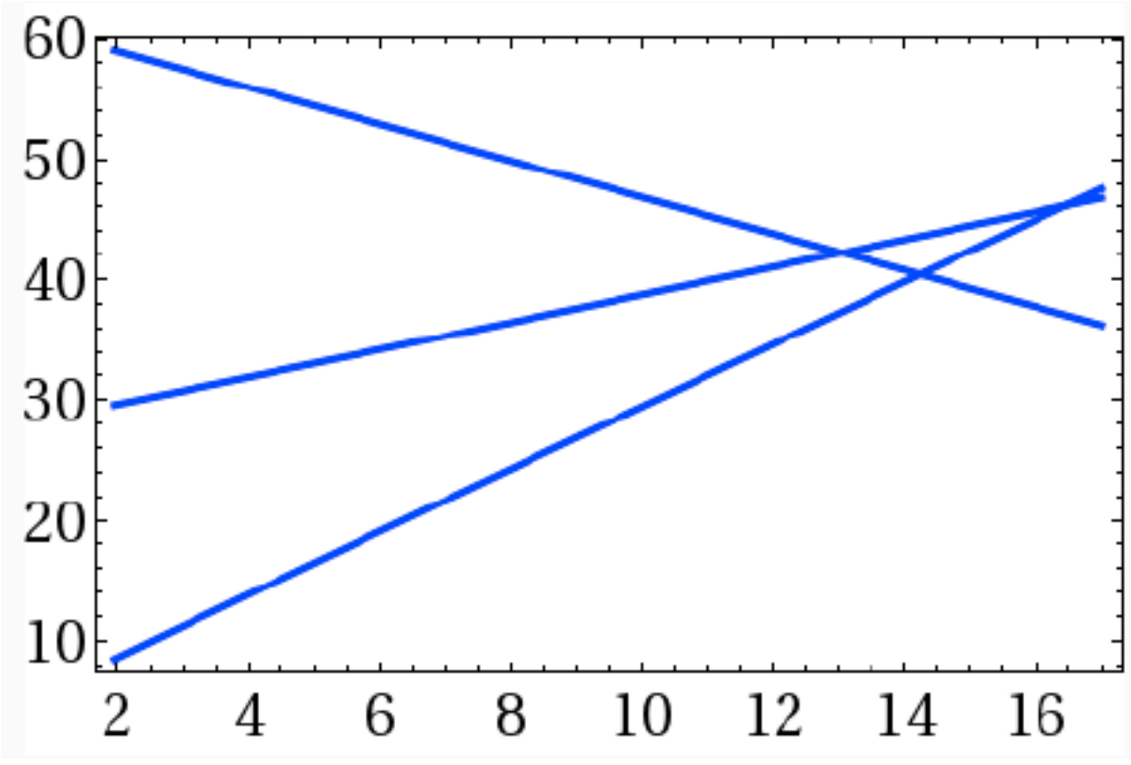
The Hard Facts



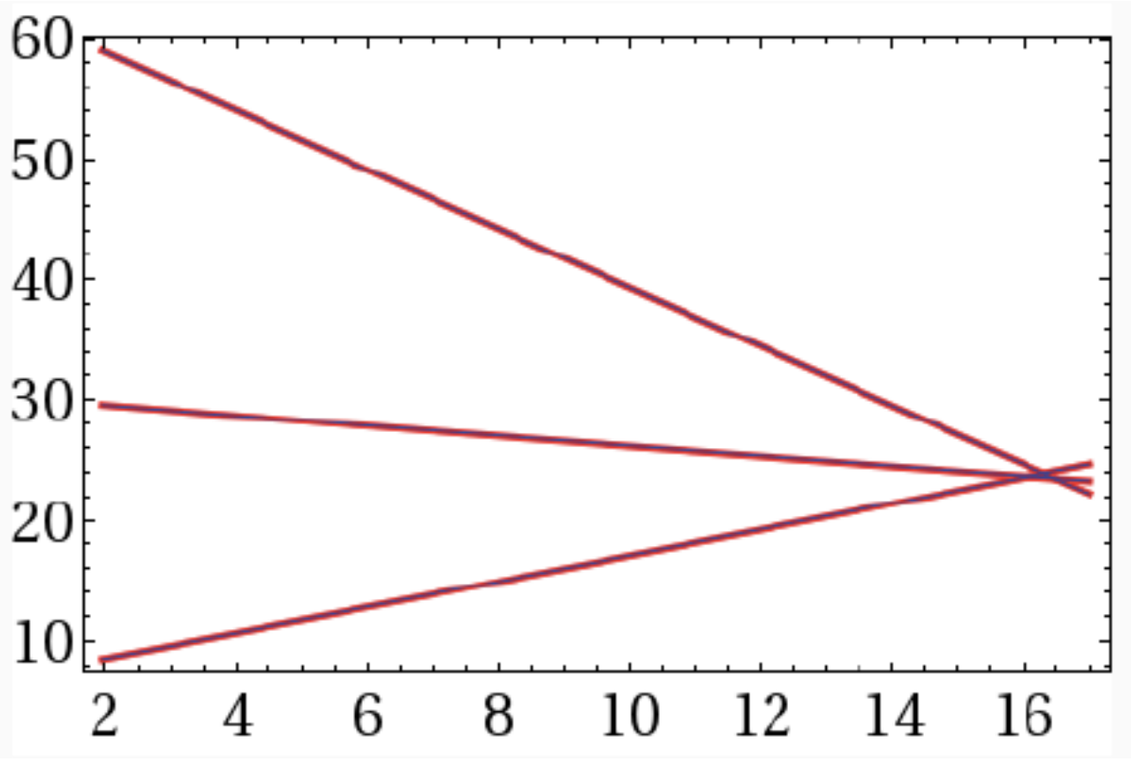
The connection with the hierarchy problem is diminished

Why Supersymmetry?

SM

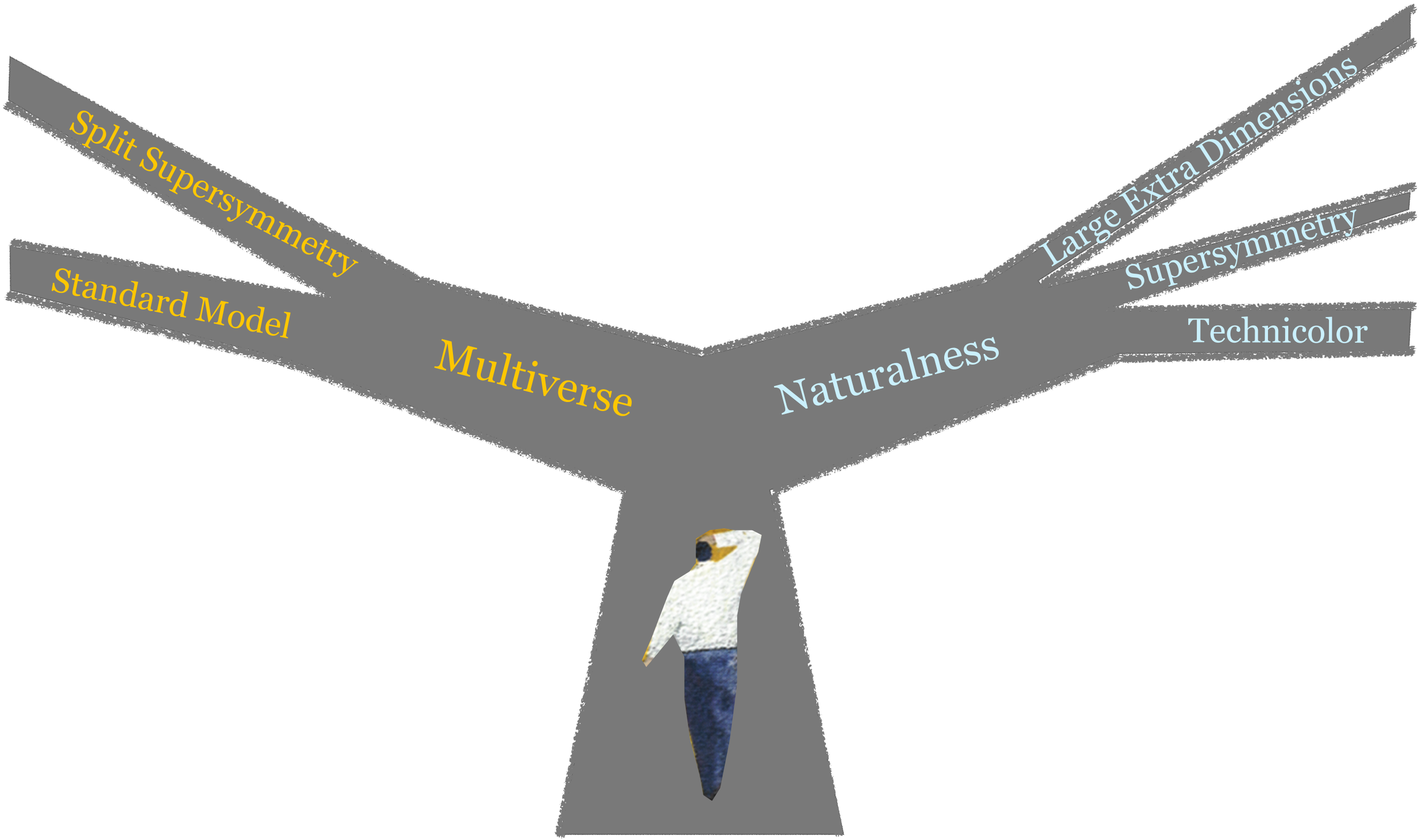


MSSM



Gauge Coupling running at two loops

At the Crossroads



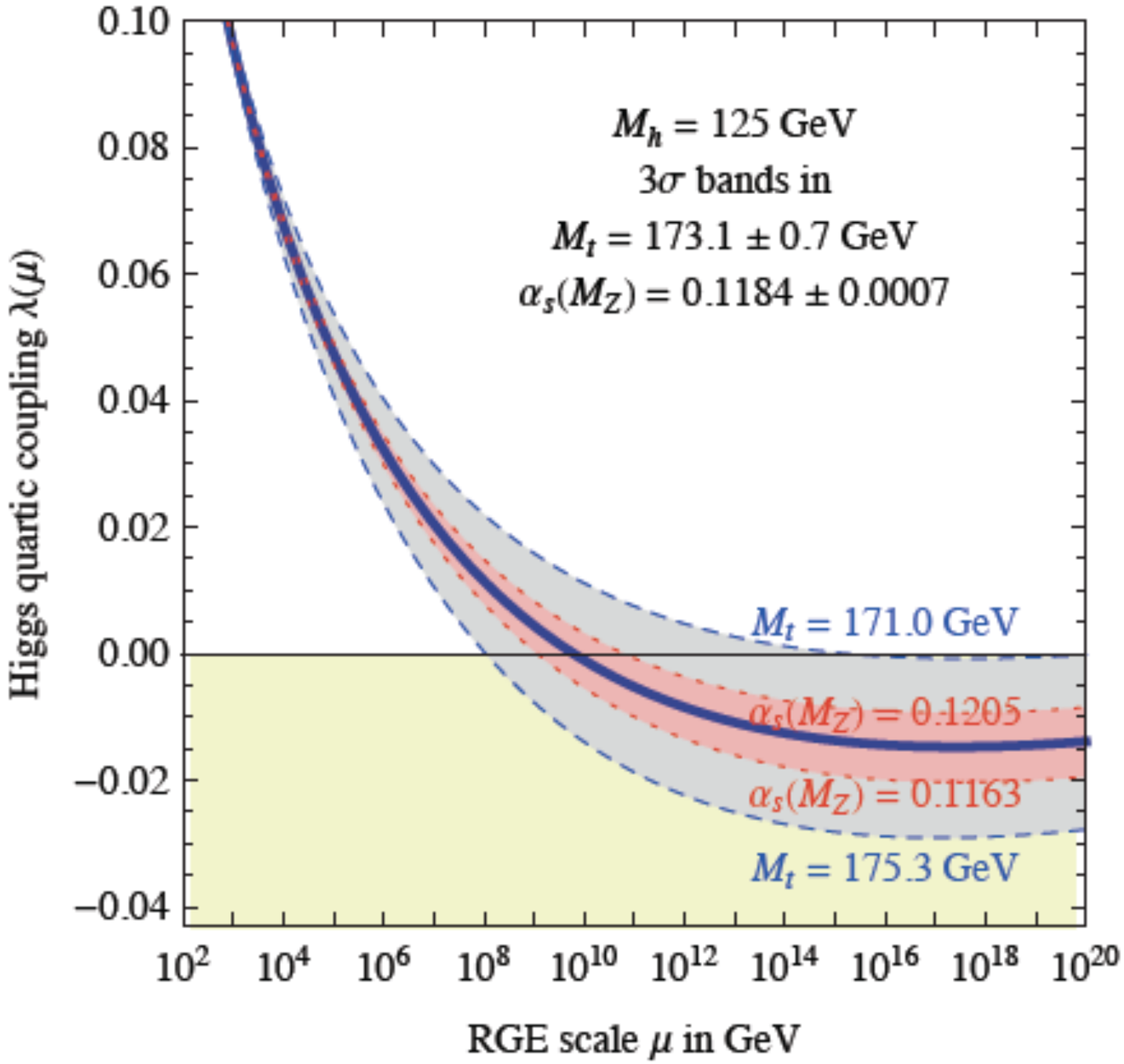
LHC implications for:

- The Standard Model

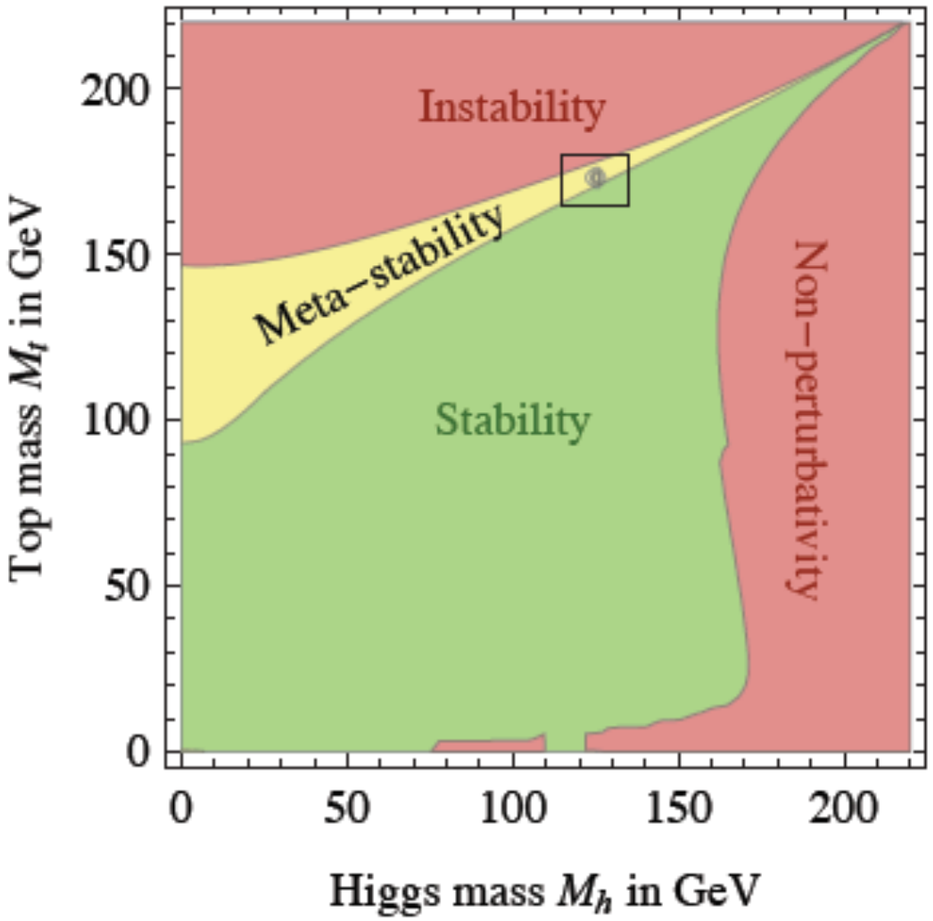
- The Supersymmetric Standard Model

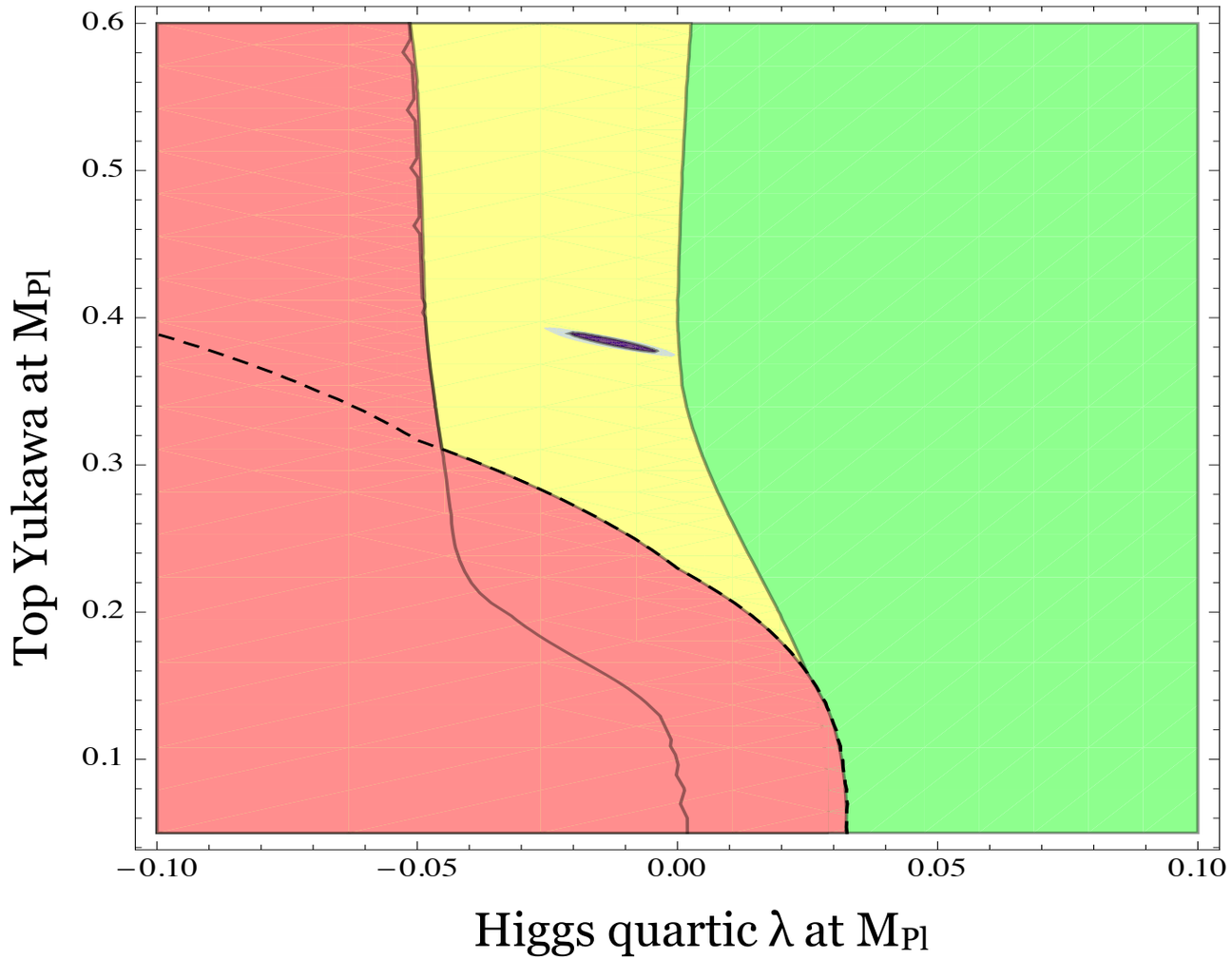
- Split Supersymmetry

The Higgs in the Standard Model

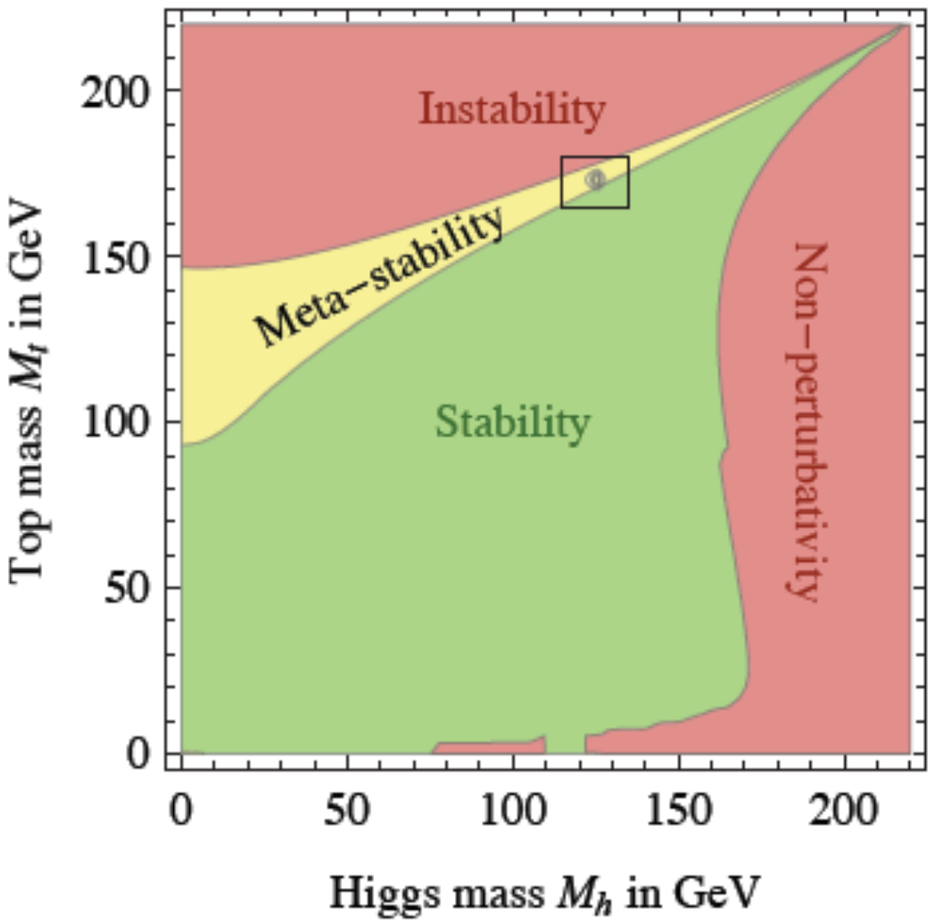


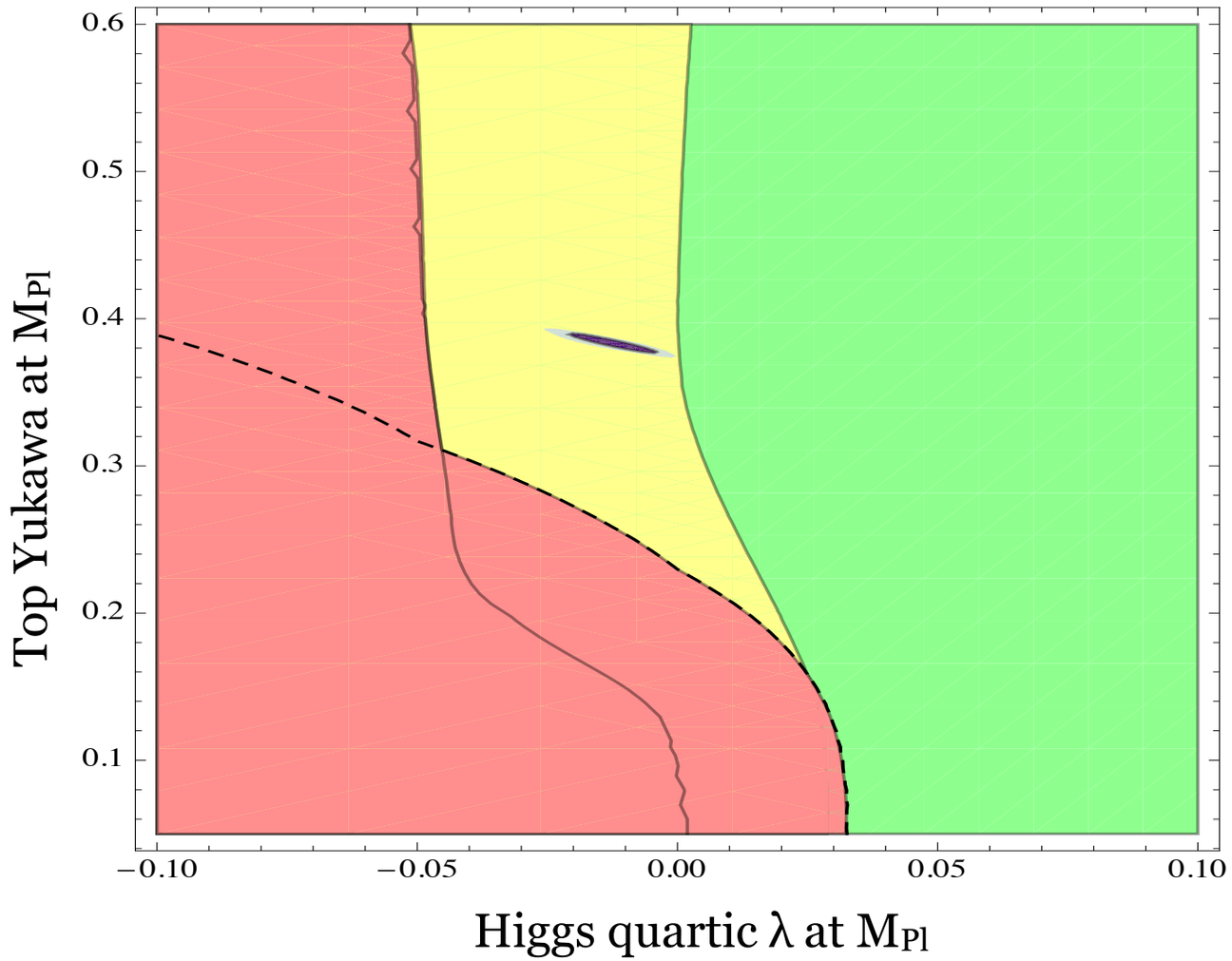
The Higgs in the Standard Model





The Higgs in the Standard Model

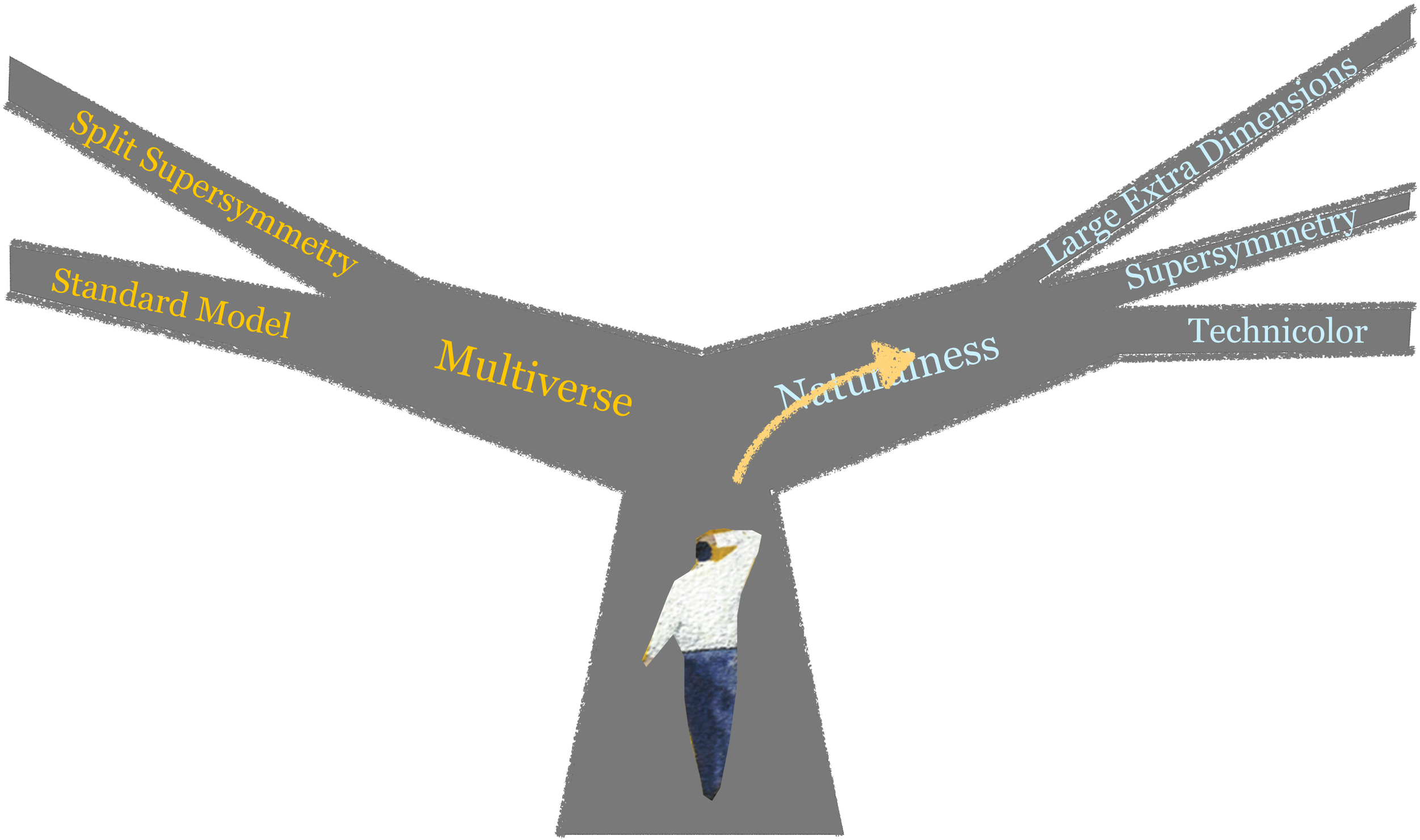




$$\lambda_{\mathrm{SUSY}} = \frac{g^2 + g'^2}{4} \cos^2(2\beta)$$

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

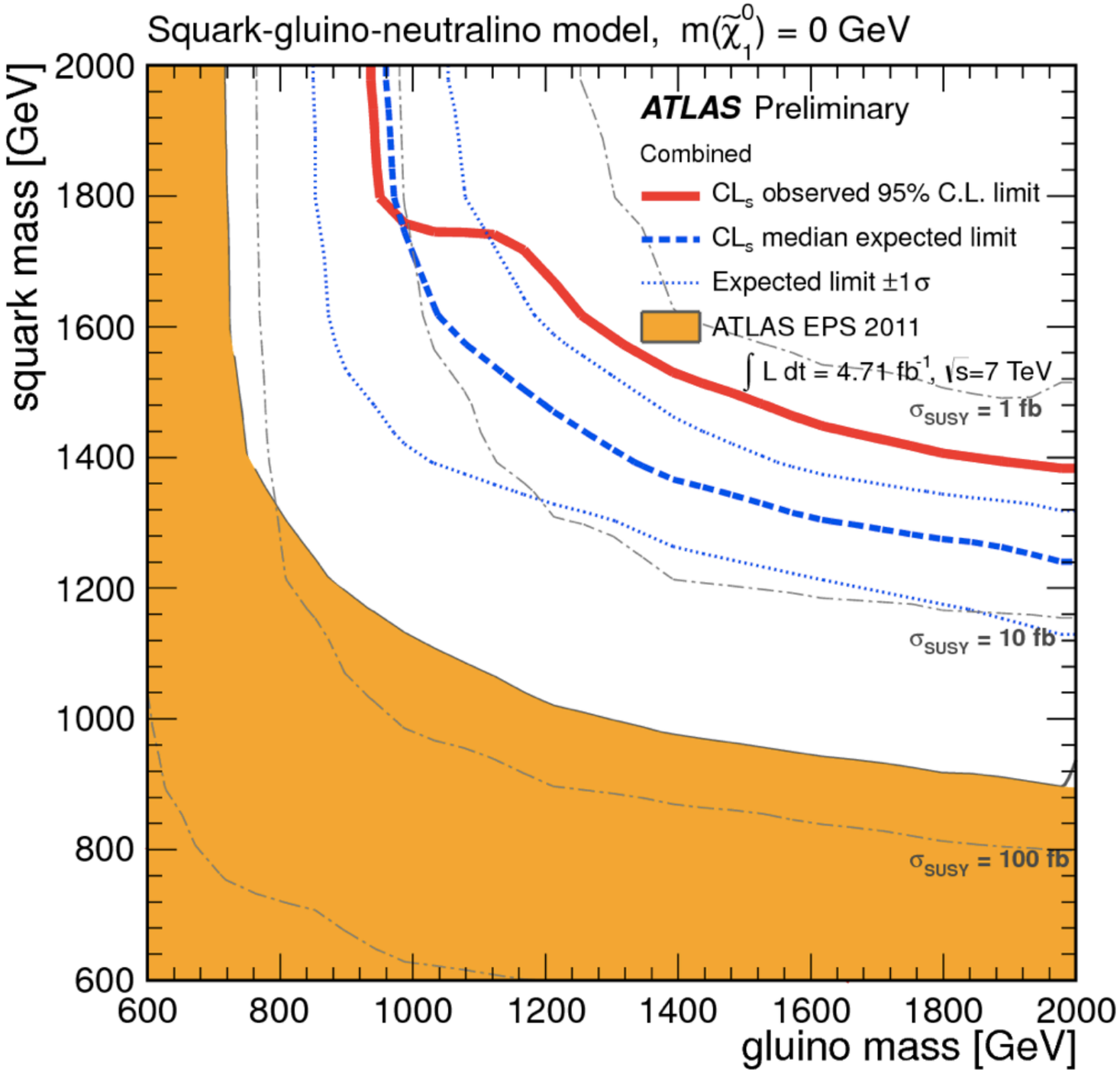
$$W \supset \lambda S H_u H_d$$

or

- New U(1)′ at the TeV scale

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

Squark-Gluino Bounds in the MSSM

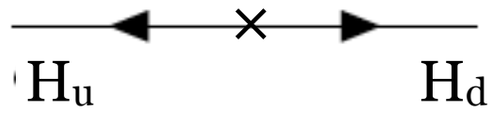


Natural SUSY

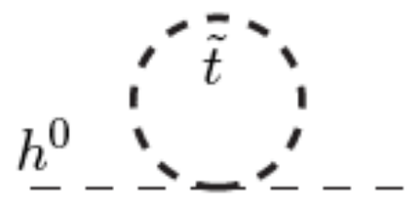
S.D. , Giudice (95)

Bare minimum light spectrum:

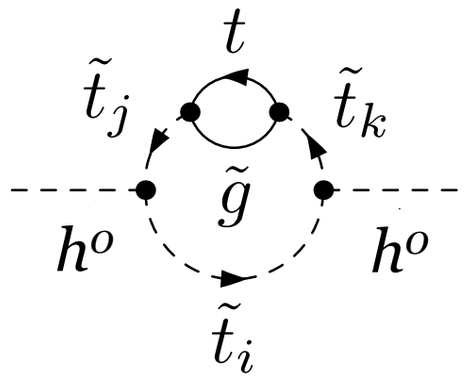
- For less than 10% tuning:
  - At tree-level: Higgsinos < 250 GeV



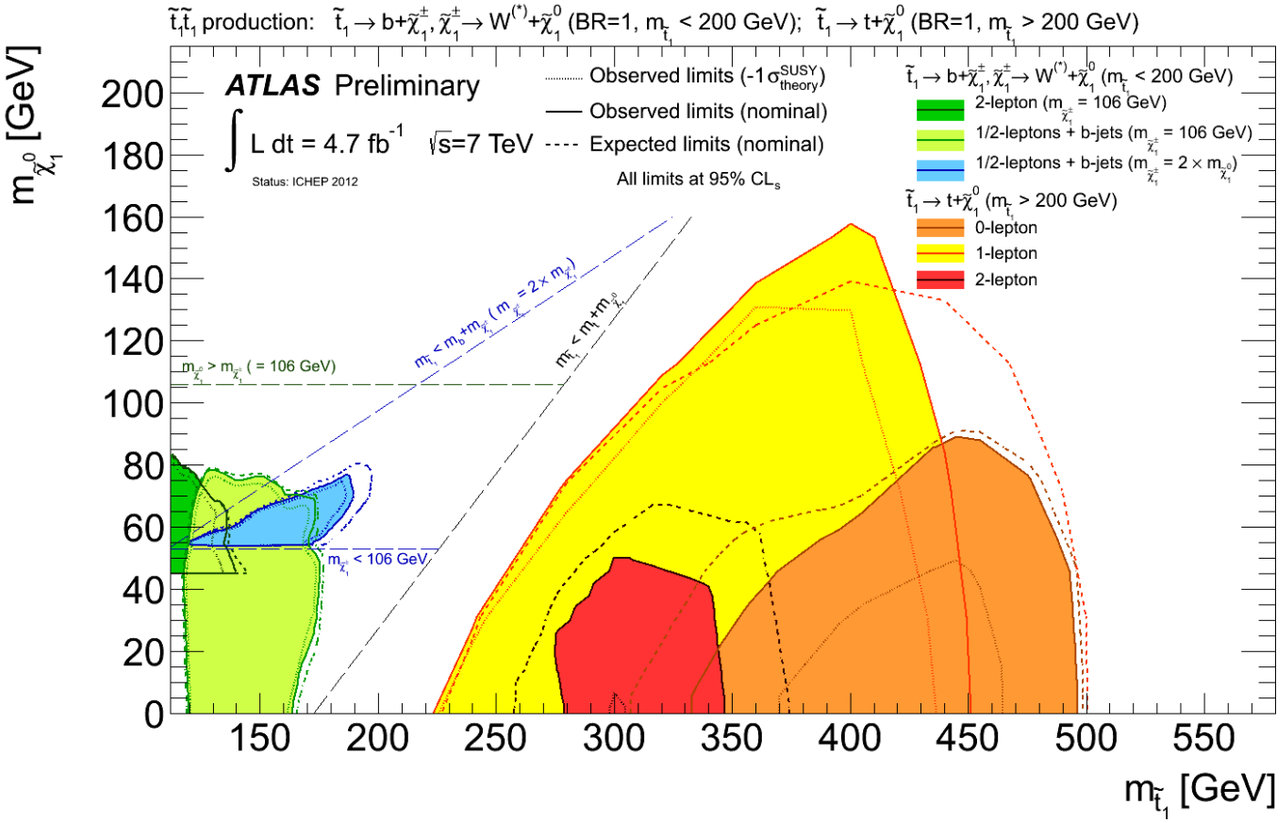
  - At one loop: Stops < 600 GeV

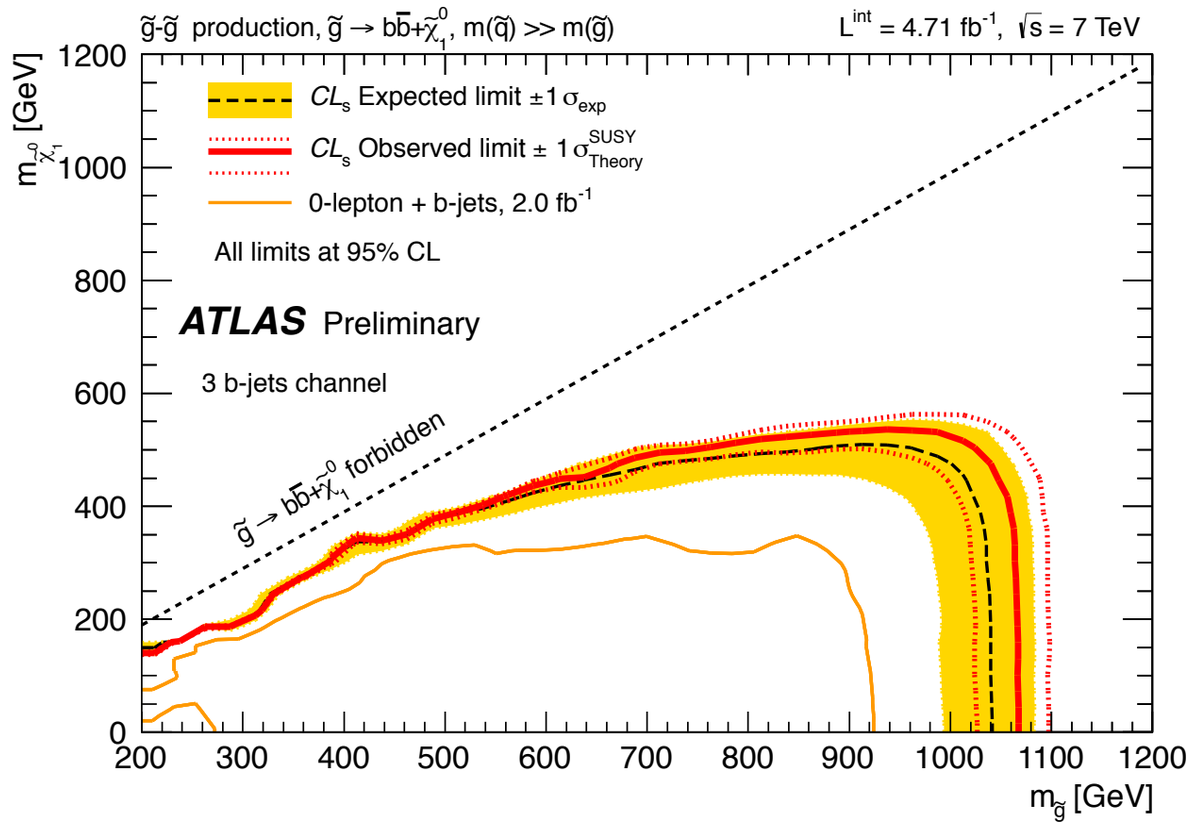


  - At two loops: Gluinos < 1.4 TeV



Bounds on Natural Supersymmetry

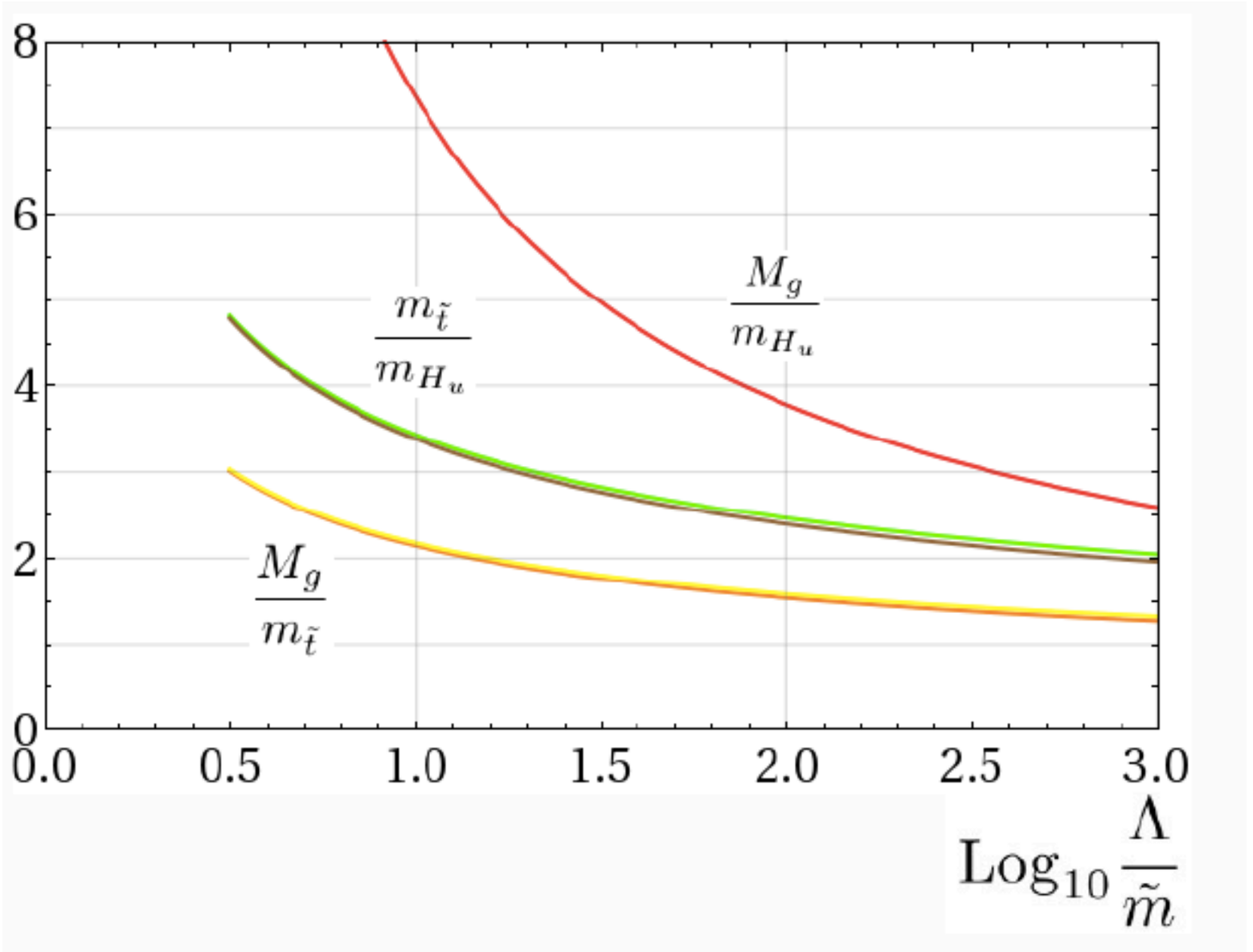




- Gluino up to ~ 1 TeV

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

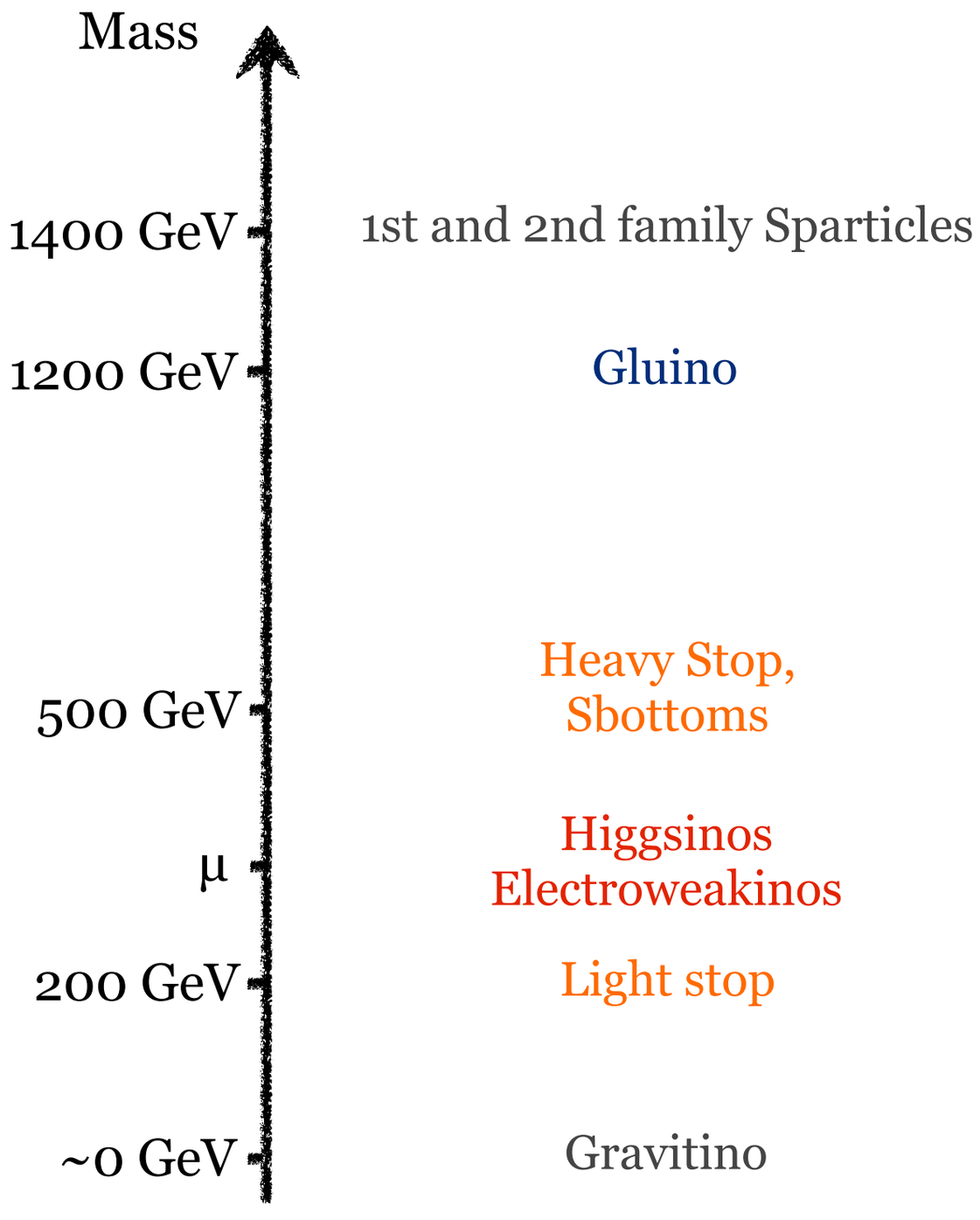
The Gluino Sucks



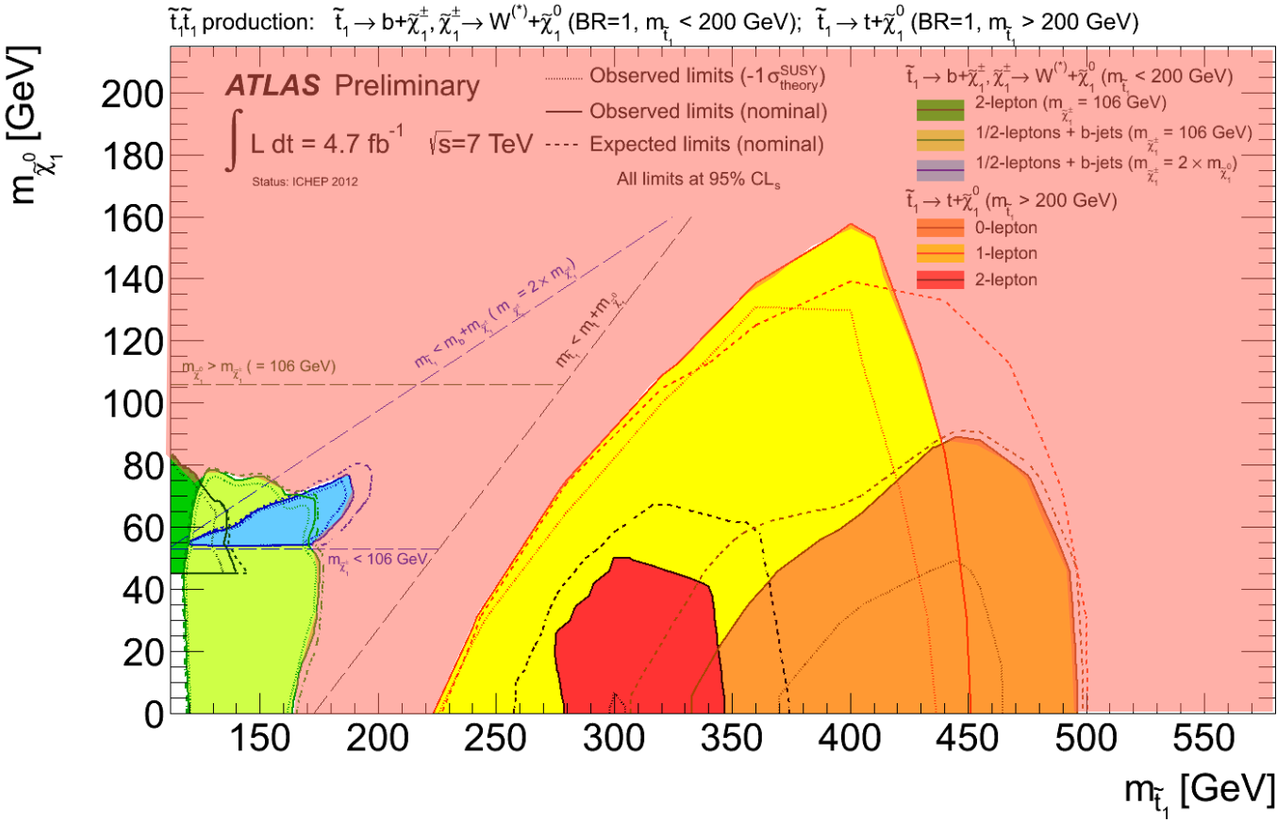
Gluino Bounds constrain all Low Energy Supersymmetry scenarios

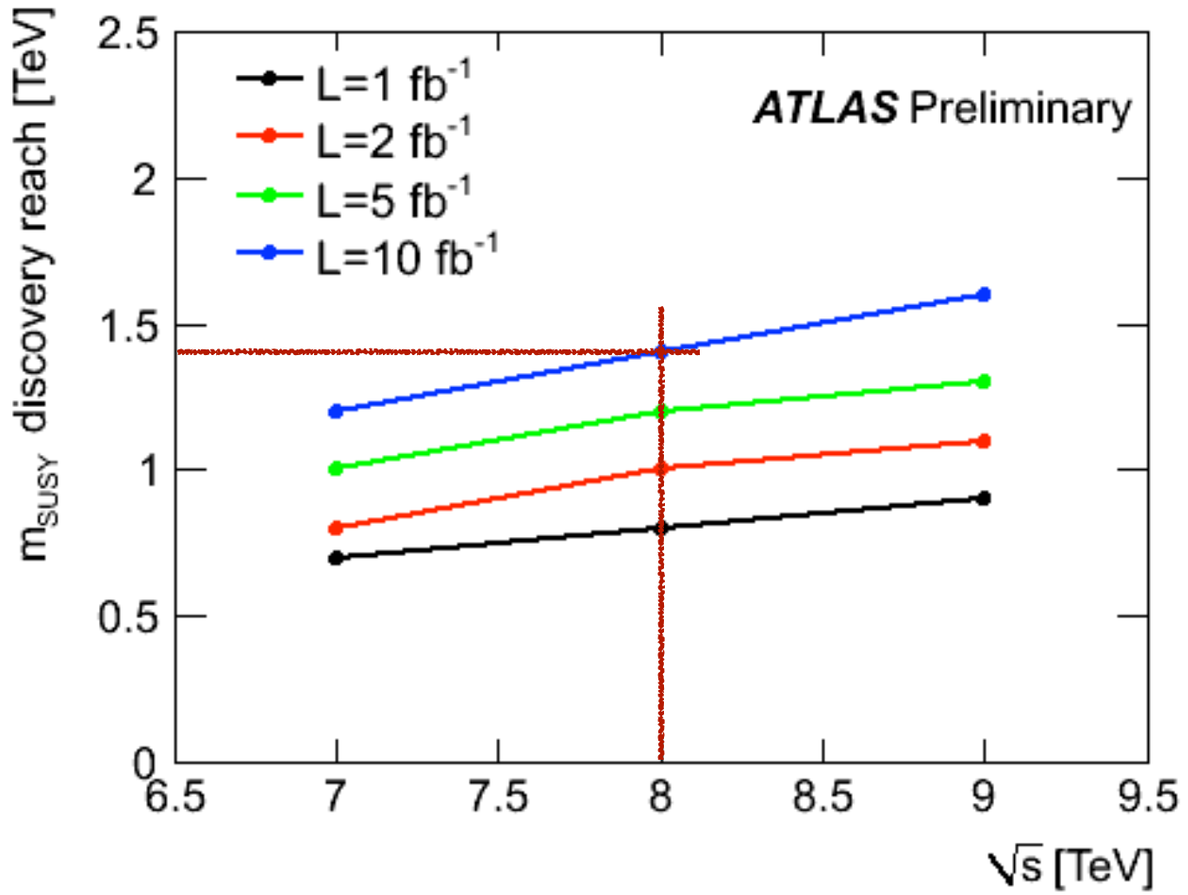
A Natural SUSY Spectrum

- Involves one additional singlet for the Higgs mass
- Requires low scale gauge mediation to minimize gluino running



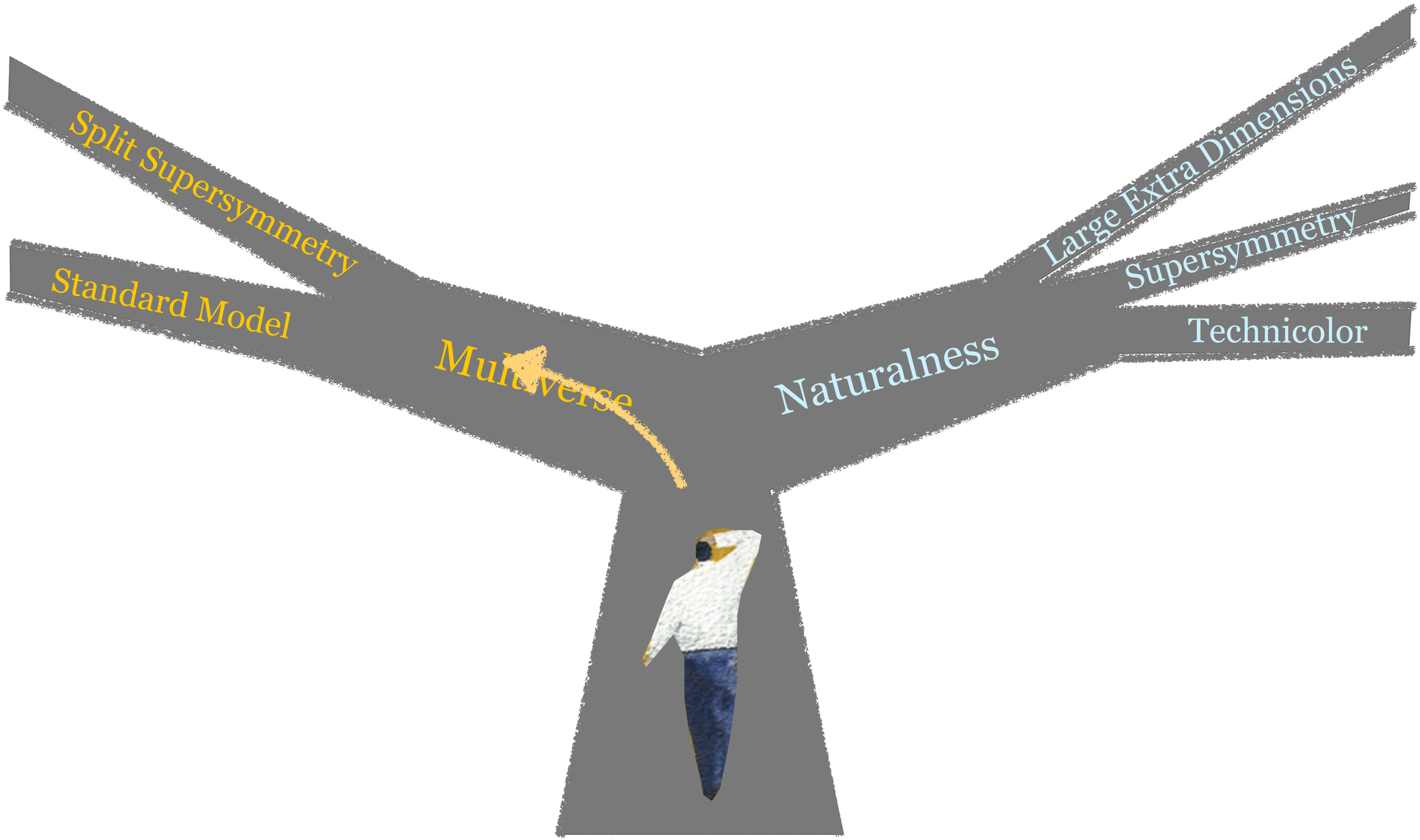
Prospects for Natural SUSY by December





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

At the Crossroads



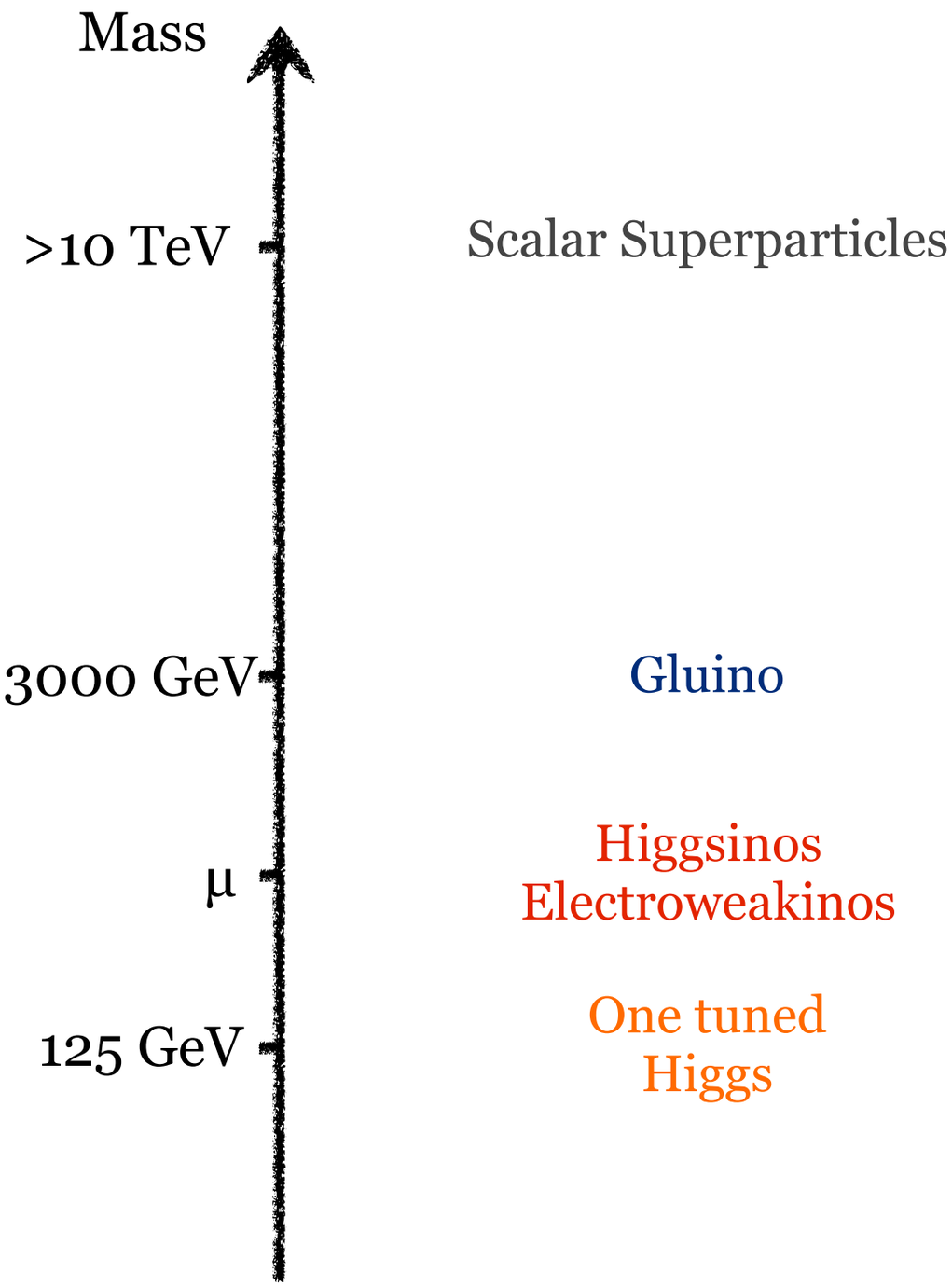
You and your landscapes!

Tell me about the worms!

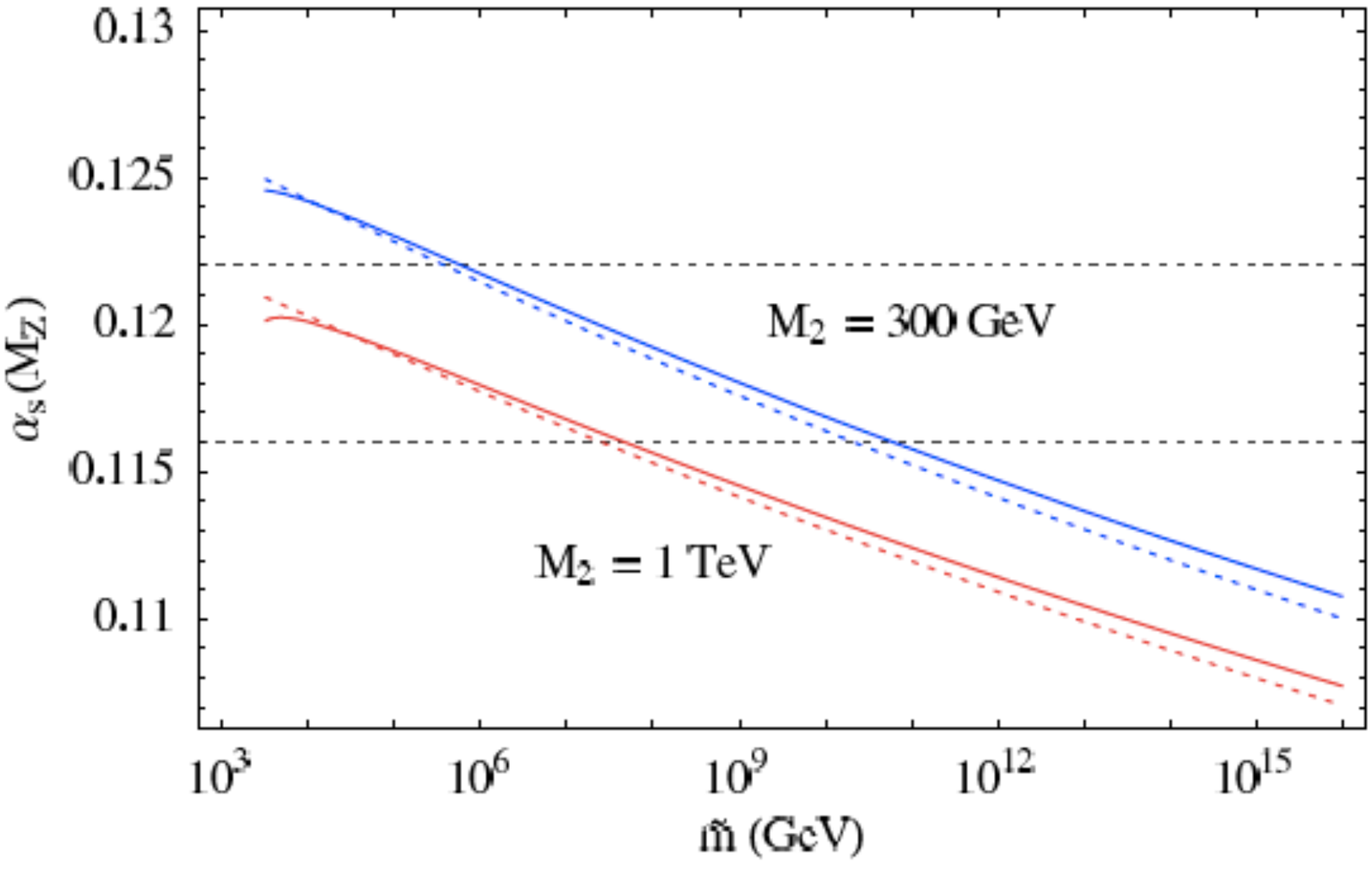
Samuel Beckett, “Waiting for Godot”

Split Supersymmetry

- Solves flavor and CP problems
- Preserves successes of Dark Matter and gauge coupling unification



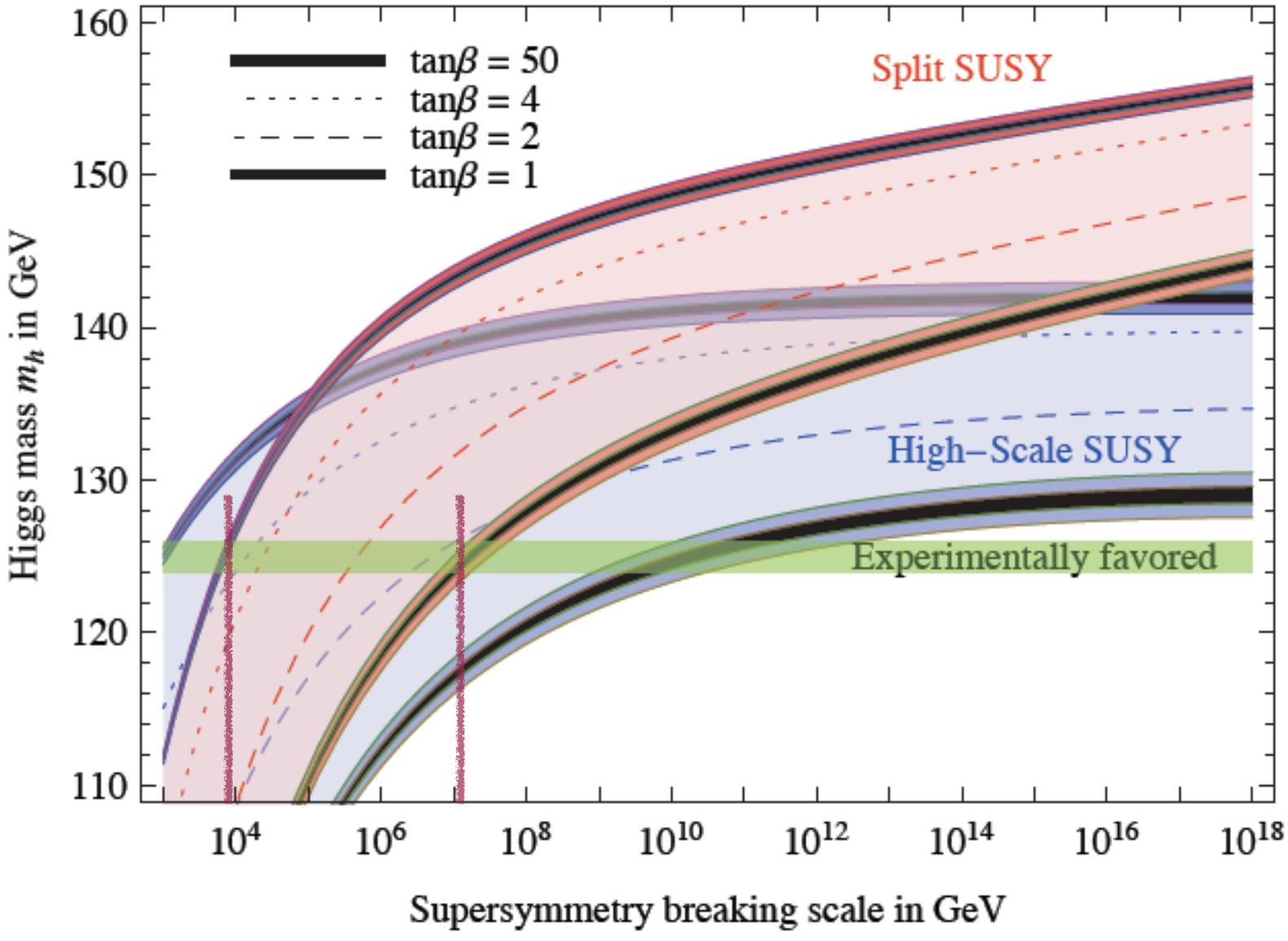
Unification in Split Supersymmetry



Prediction for α_s at M_Z at two loops

Works as well as ordinary Supersymmetry

125 GeV Higgs in Split Supersymmetry

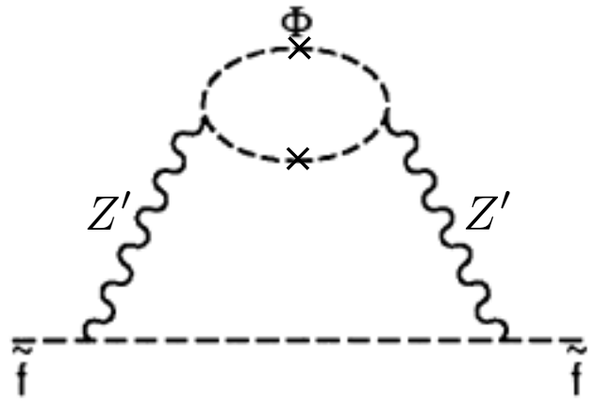


Giudice and Strumia (2011)

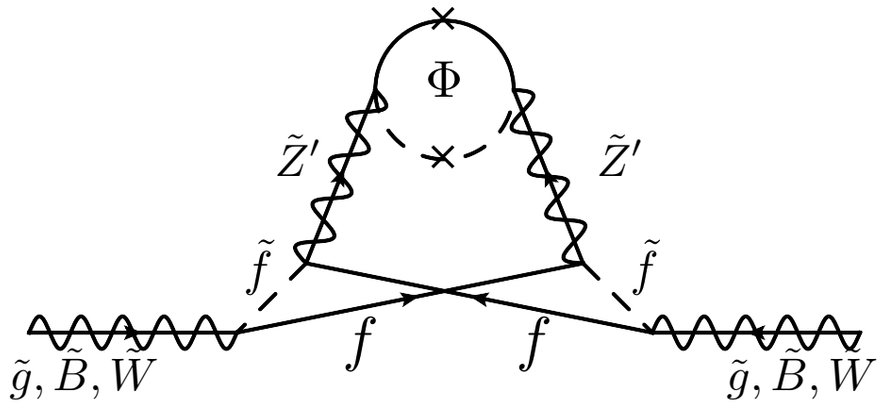
- Scalars separated from fermions by loop factor(s)
- Possible mechanism: Anomaly mediation

Mini-Split Spectrum

- U(1)′ gauge mediation with Arvanitaki, Craig, Villadoro
  - Scalar masses (squared) at two loops



  - SM Gaugino masses at three loops



- Two loop hierarchy between scalars and fermions

$$\frac{m_{\text{gaugino}}}{m_{\text{scalar}}} \sim \frac{\alpha'}{4\pi}\frac{\alpha_{\text{SM}}}{4\pi}$$

Spectrum in U(1)′ mediated Split SUSY

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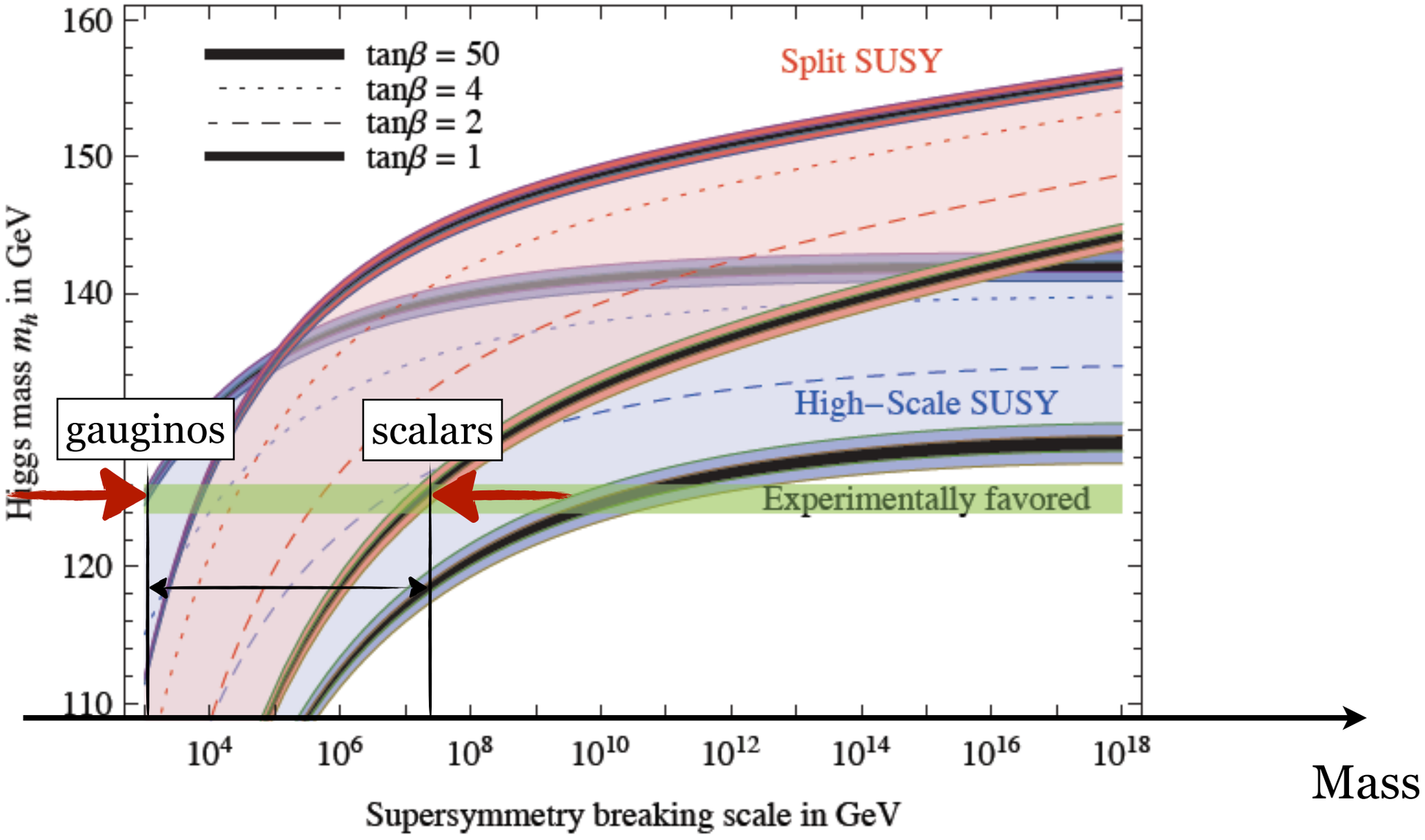
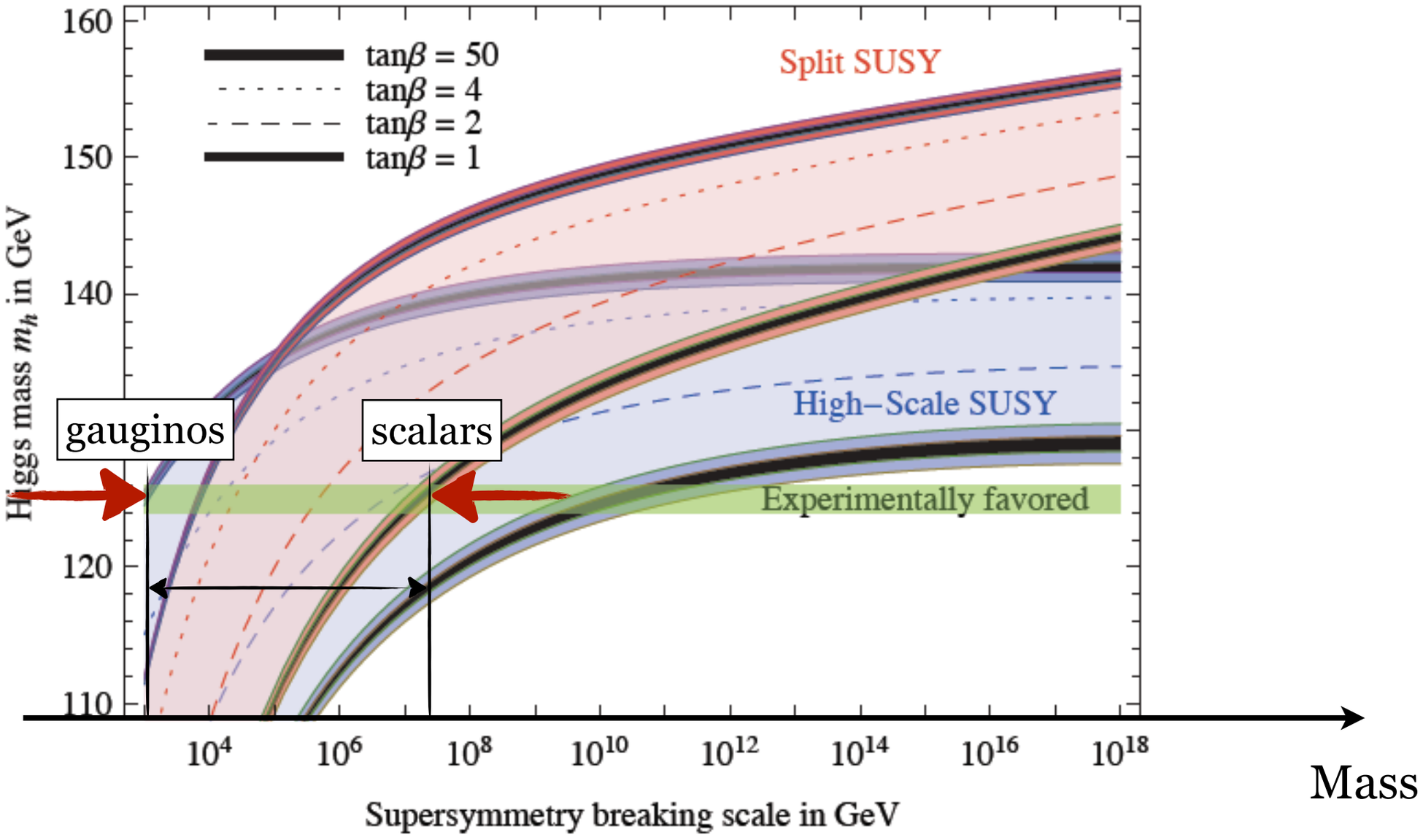
- Gauginos pushed heavier by experimental bounds

Spectrum in U(1)′ mediated Split SUSY



- Gauginos pushed heavier by experimental bounds
- Scalar mass upper bound from the Higgs Mass

Spectrum in U(1)′ mediated Split SUSY

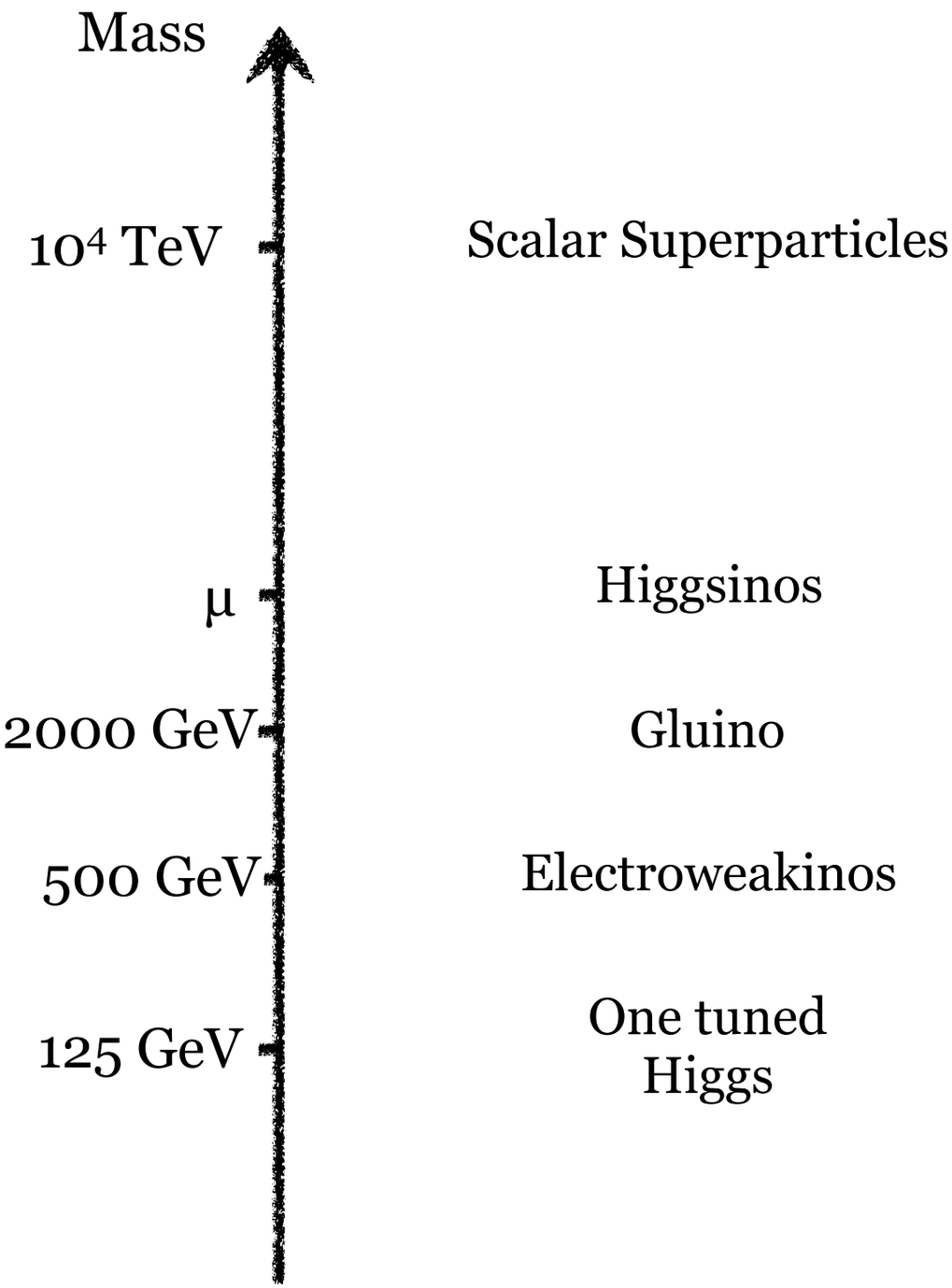


- Gauginos pushed heavier by experimental bounds
- Scalar mass upper bound from the Higgs Mass
- Fixed hierarchy between gauginos and scalars makes gauginos LHC accessible

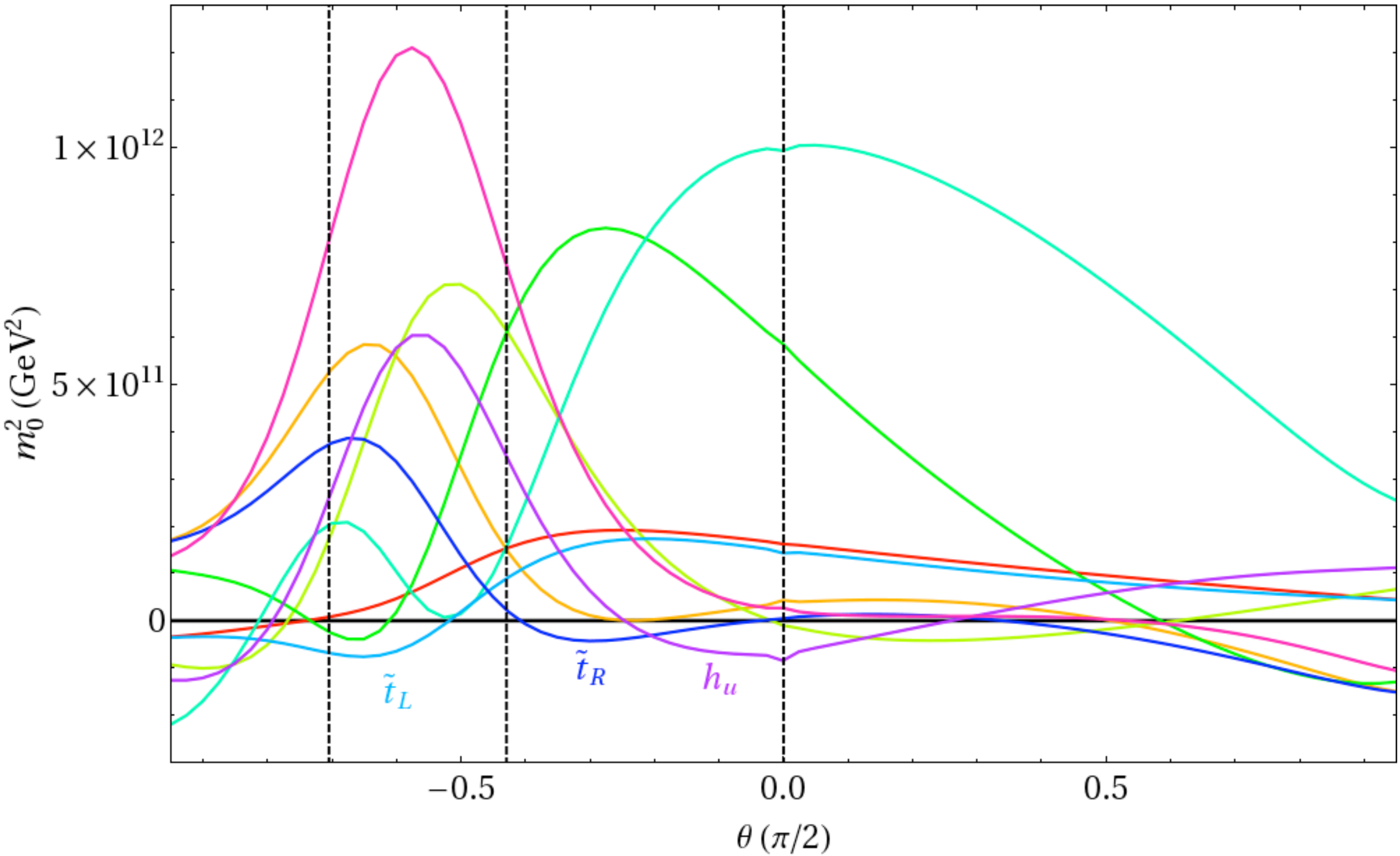
Mini-Split Spectrum

with Arvanitaki, Craig, Villadoro

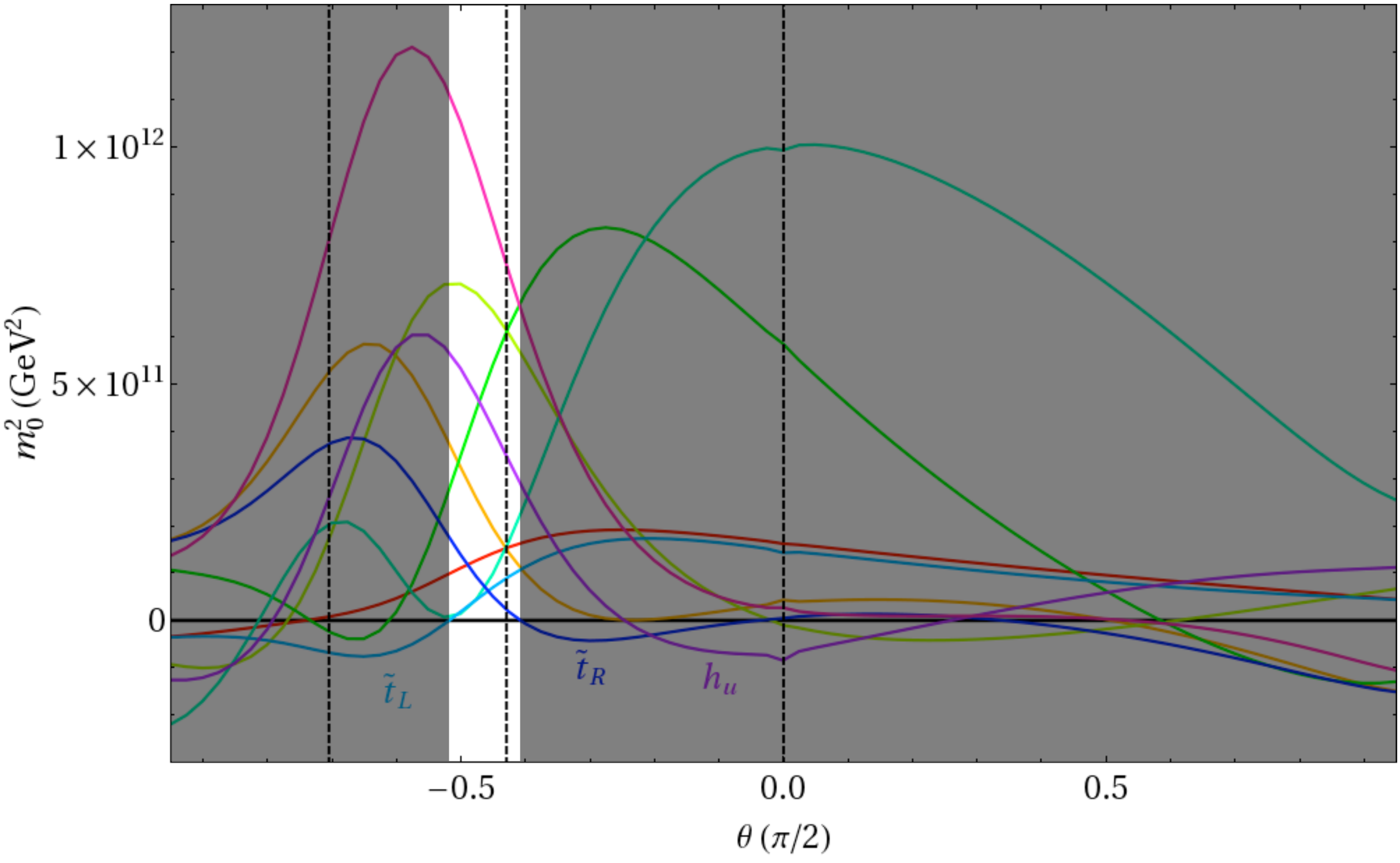
- For $U(1)' = \cos\theta\ U(1)_{B-L} + \sin\theta\ U(1)_Y$
- μ determined by $B\mu$ requirement
- Lightest Supersymmetric Particle Bino



Scalar Spectrum as a Function of θ

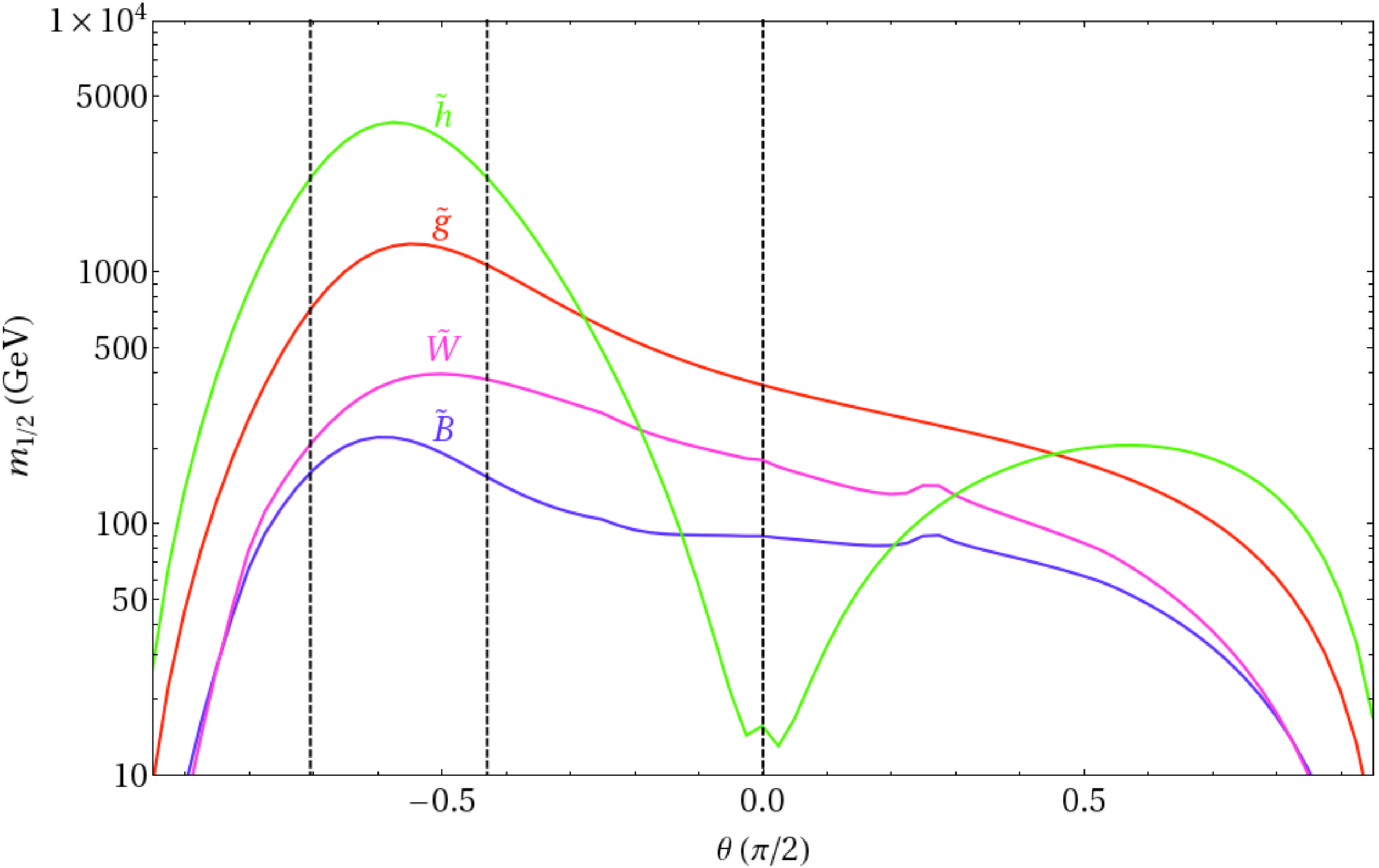


Scalar Spectrum as a Function of θ

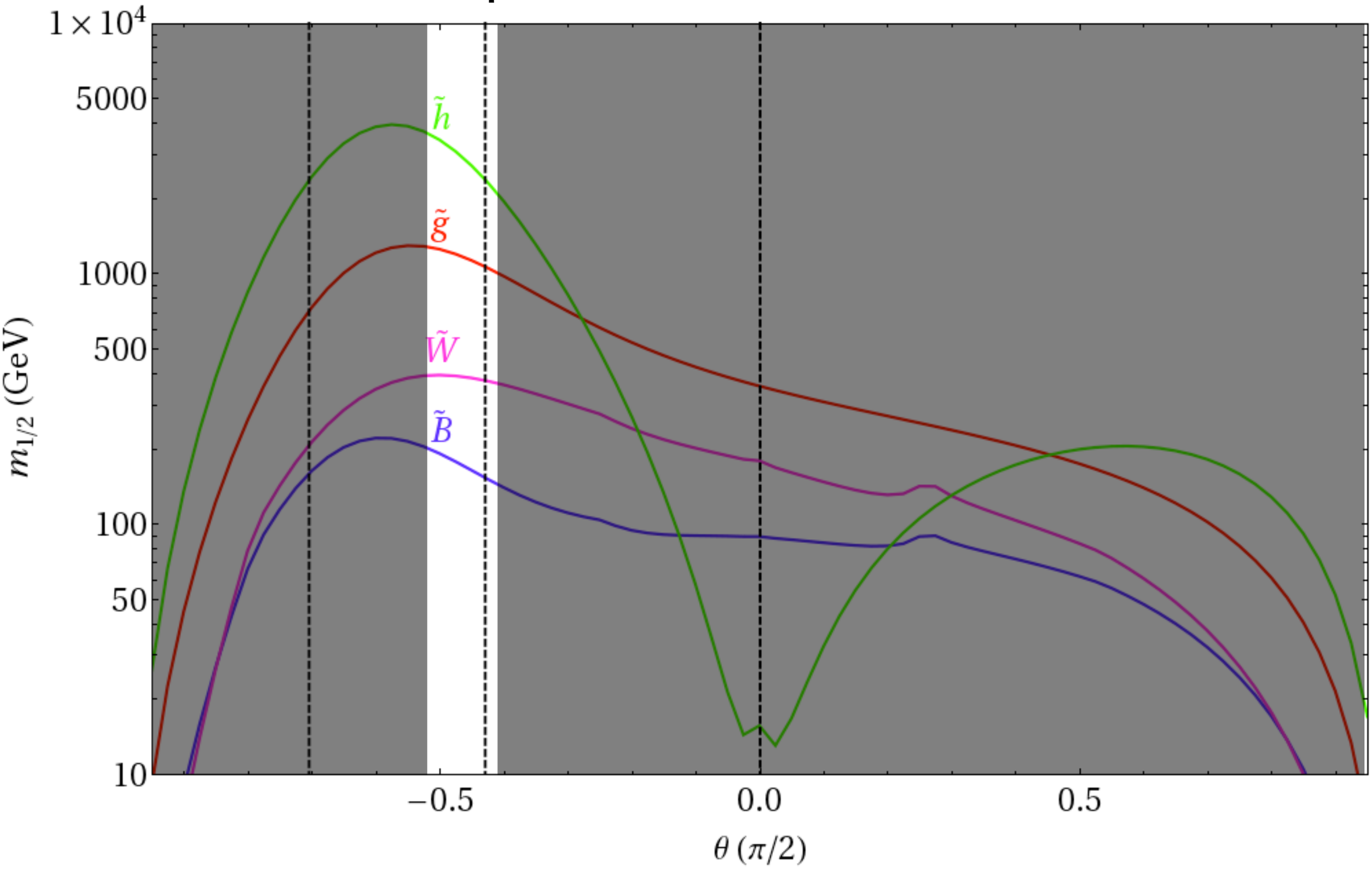


Excluded by color or (wrong) electroweak breaking

Fermion Spectrum as a function of θ



Fermion Spectrum as a function of θ



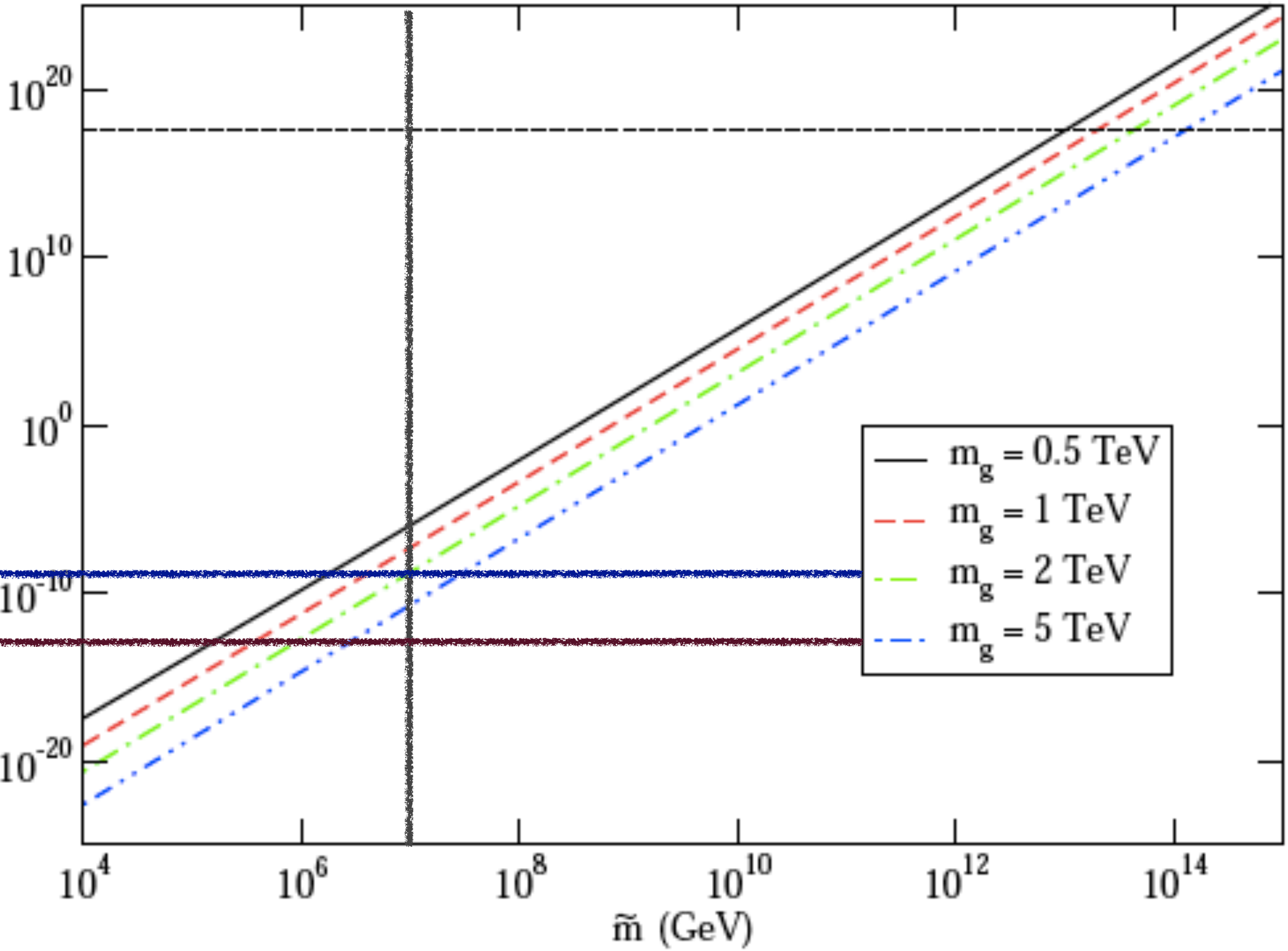
Excluded by negative scalar mass²

Long-lived Gluinos at the LHC

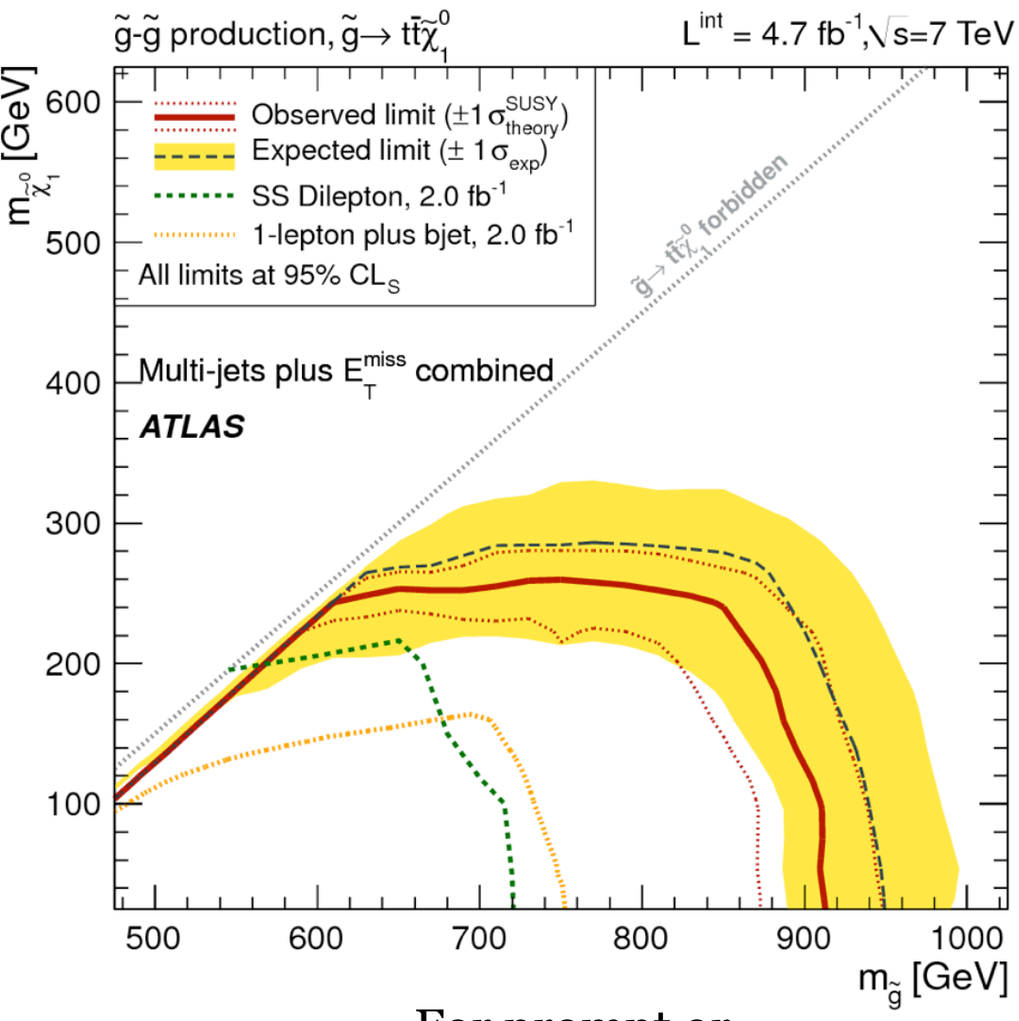
Collider "Stable" Gluinos

Displaced Gluinos

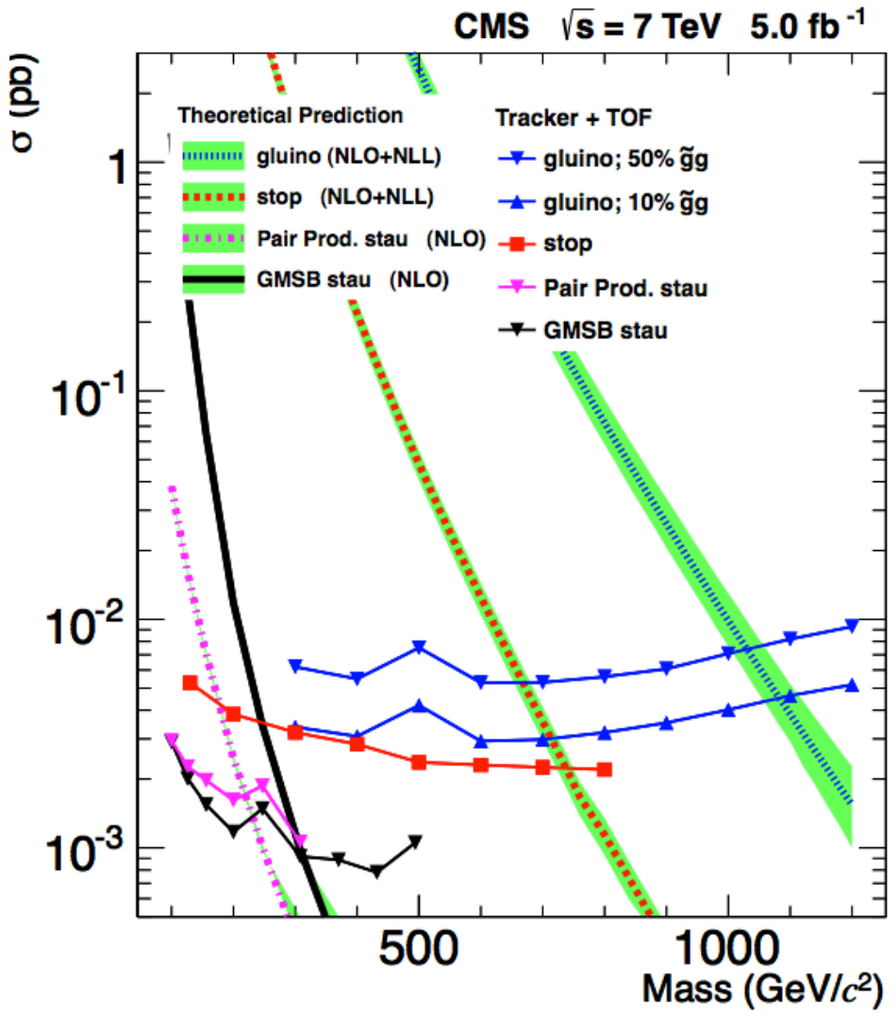
Prompt Gluinos



Gluino Bounds from the LHC



For prompt or
slightly displaced gluinos



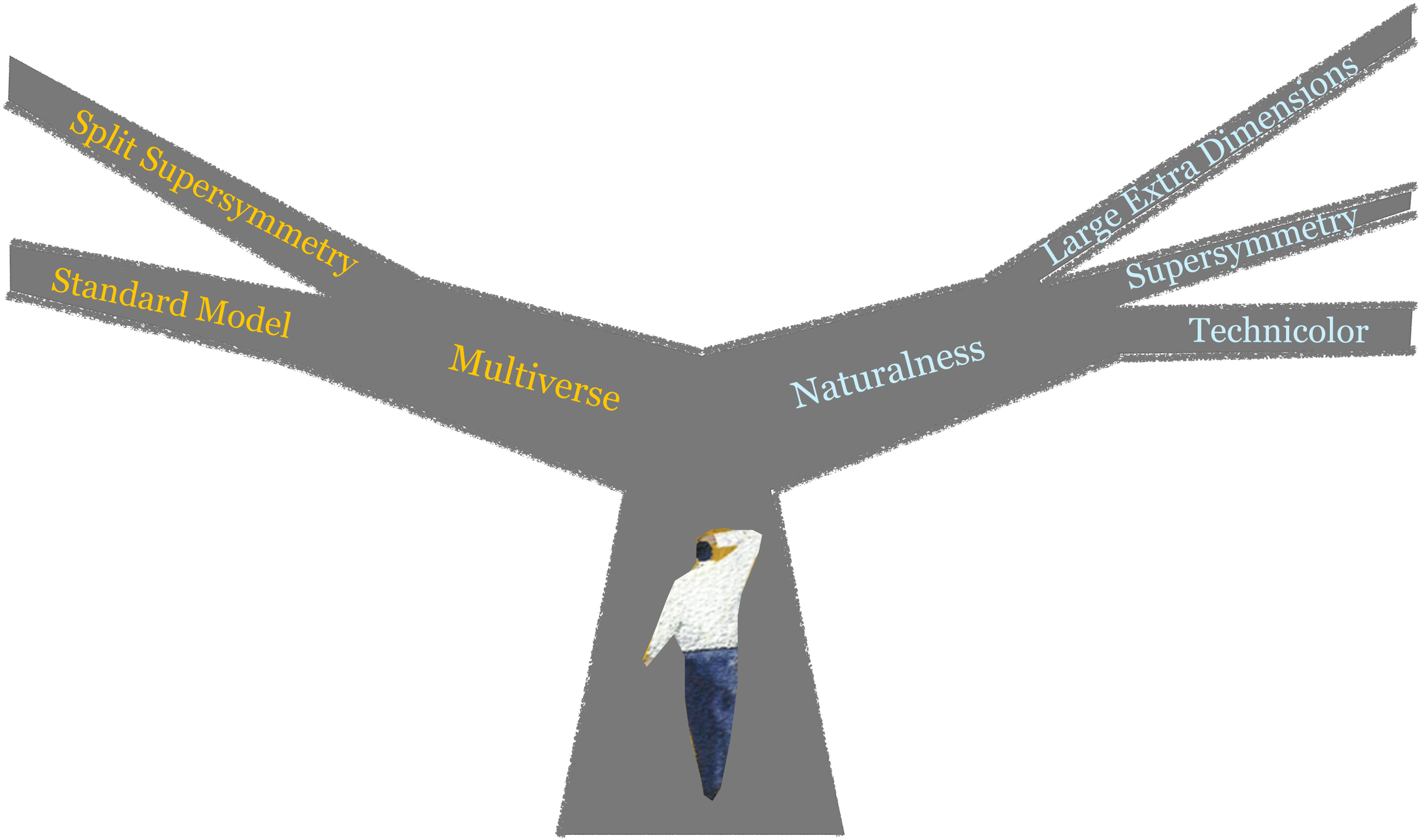
For collider “stable” gluinos

M_{gluino} > 1 TeV for split gluino

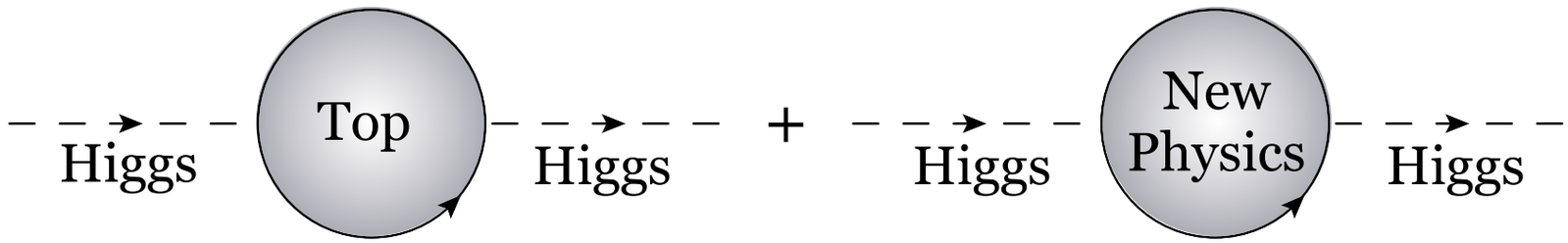
2.5 TeV to 3 TeV ultimate reach for split gluino

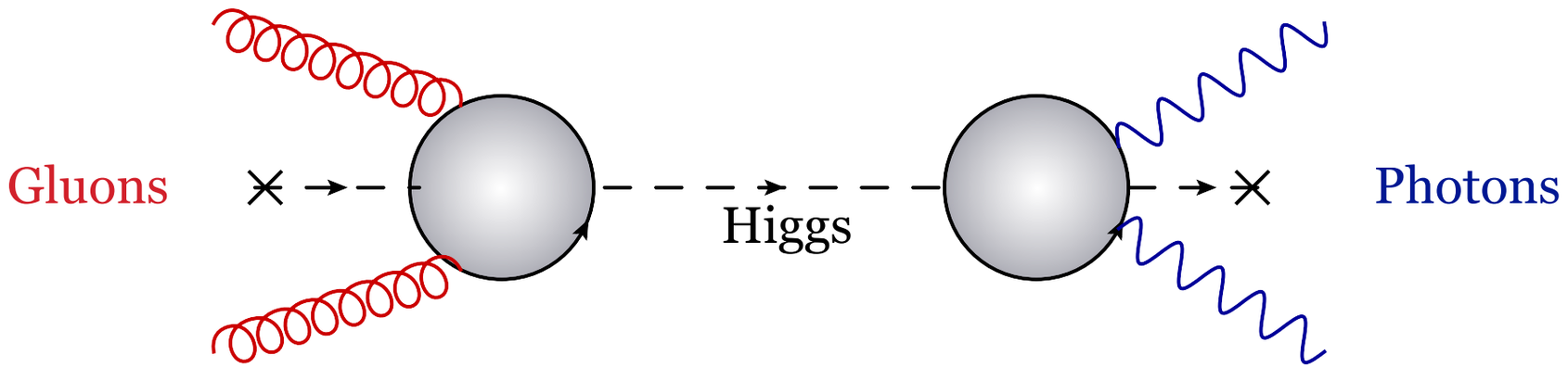
Electroweakinos also LHC accessible

What can the Higgs tell us?



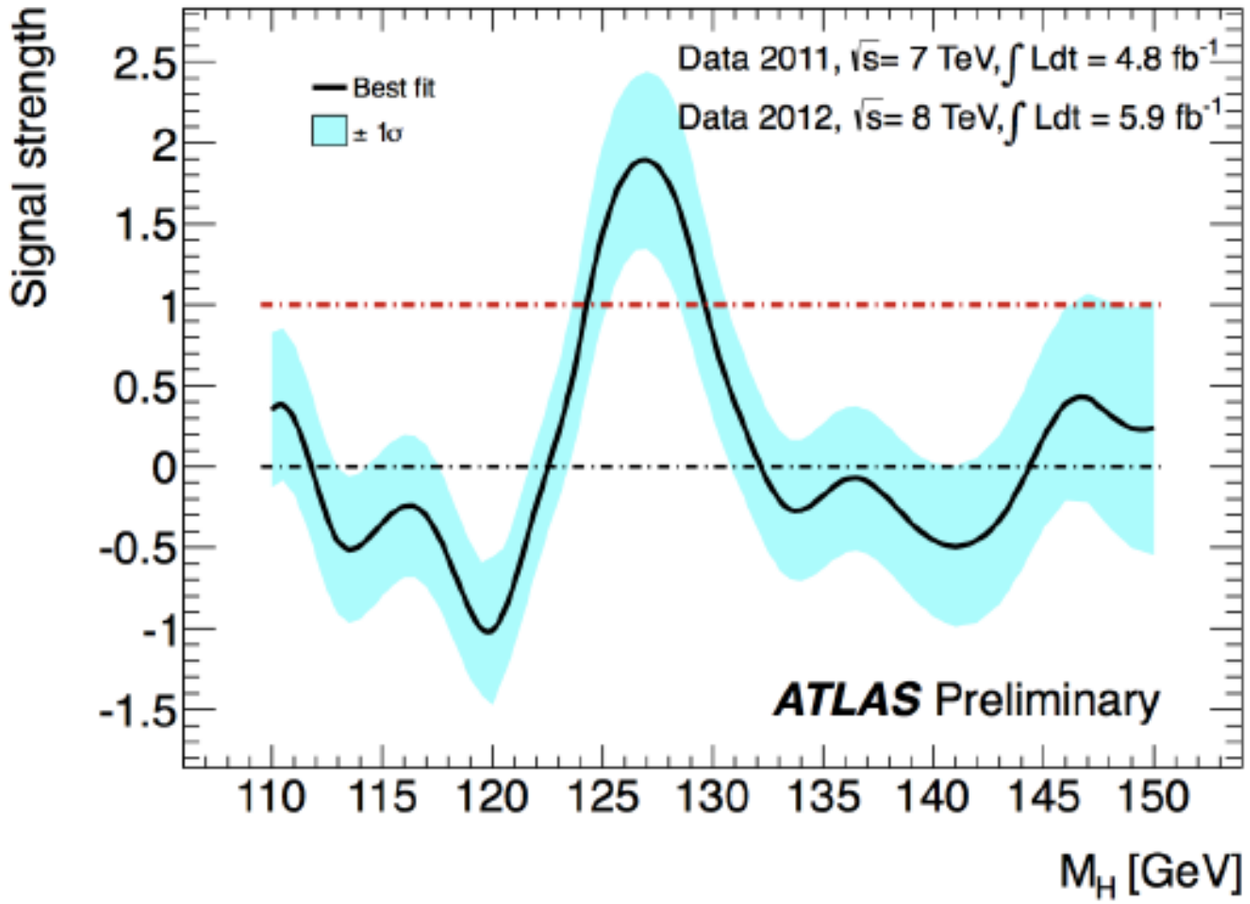
Naturalness and Higgs Properties





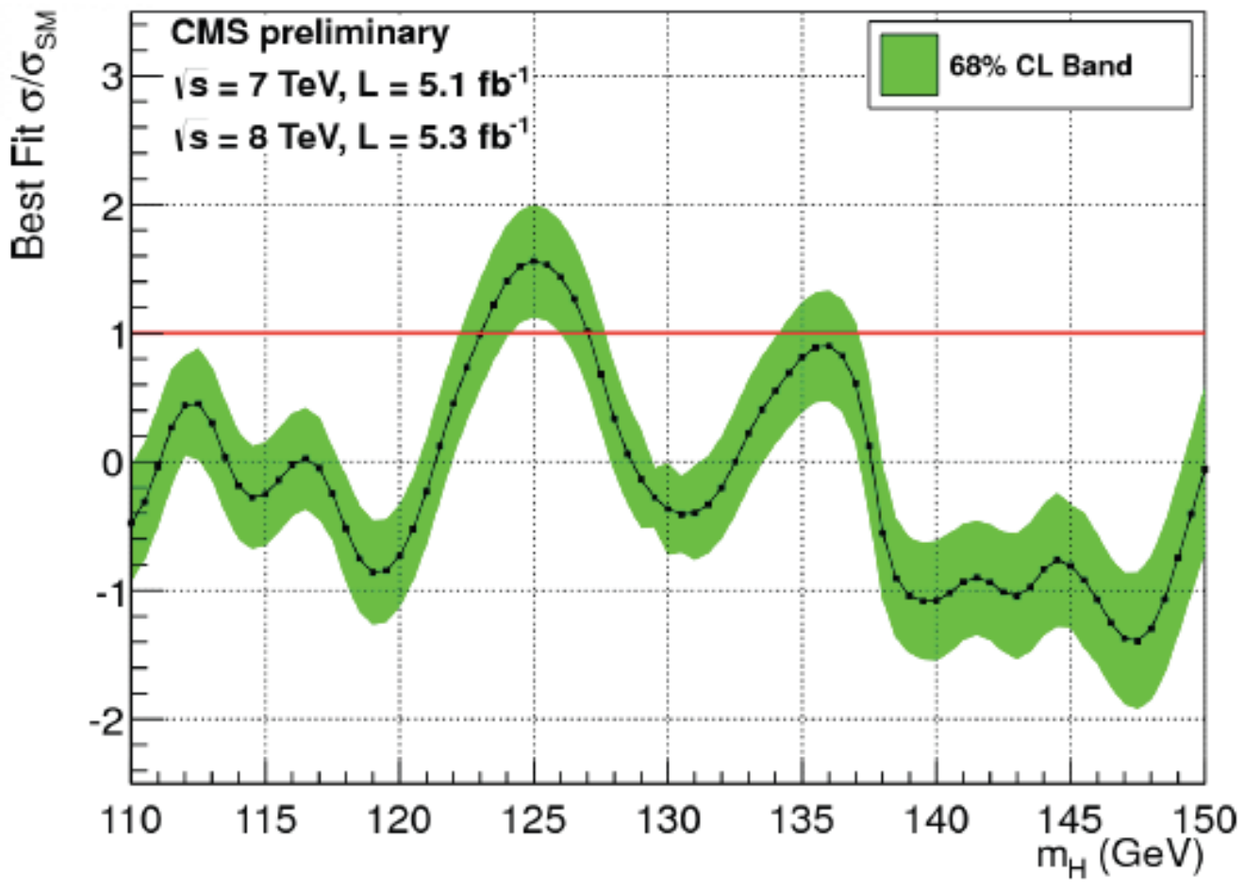
A Natural Higgs is not the SM Higgs

The hints for a 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

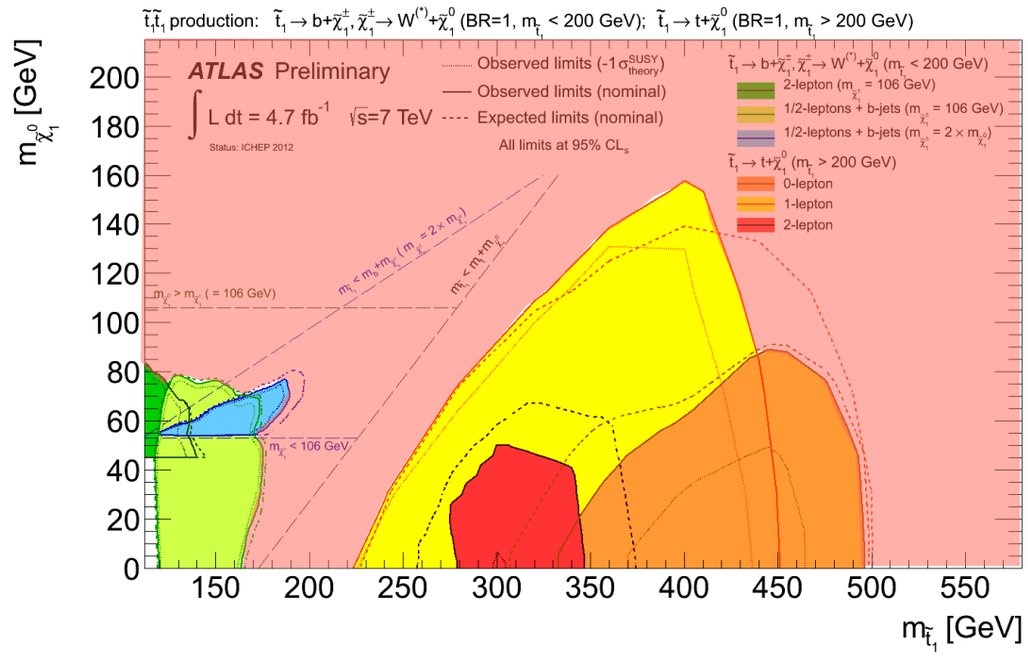
- Natural Supersymmetry
  - Requires new ingredient in the MSSM for the Higgs
  - Gluino mass constraints push natural SUSY to the corner
  - LHC may “exclude” Natural SUSY by the end of 2012

- Split Supersymmetry
  - Higgs Mass points to Mini Split

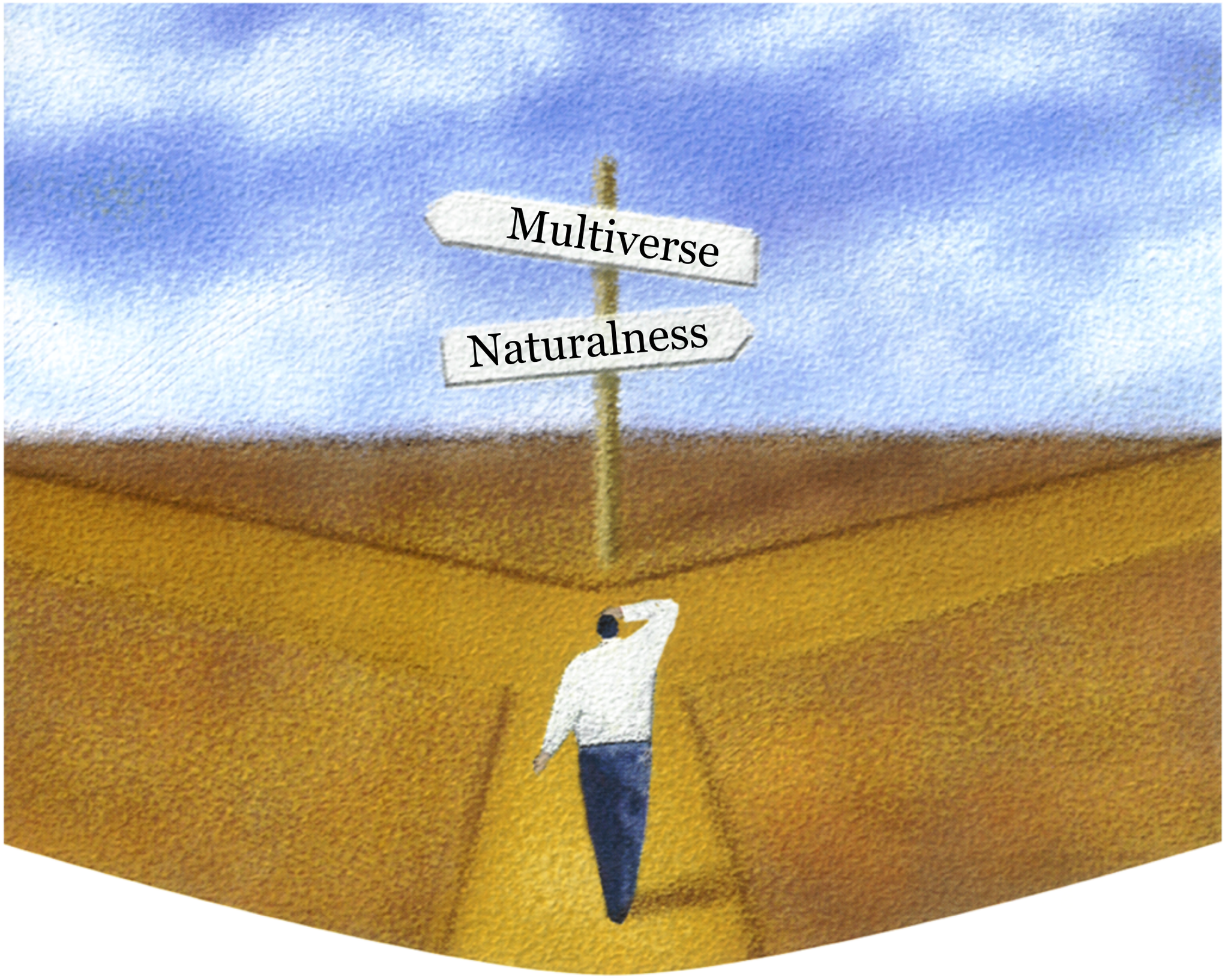
- Higgs Mass and Properties
  - Traditional SUSY scenaria account for up to 30% of change in σ×Br
  - A non SM higgs favors naturalness

What is Next Experimentally?

- Next 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!