Higgs@125 GeV: Implications for the MSSM and GMSB

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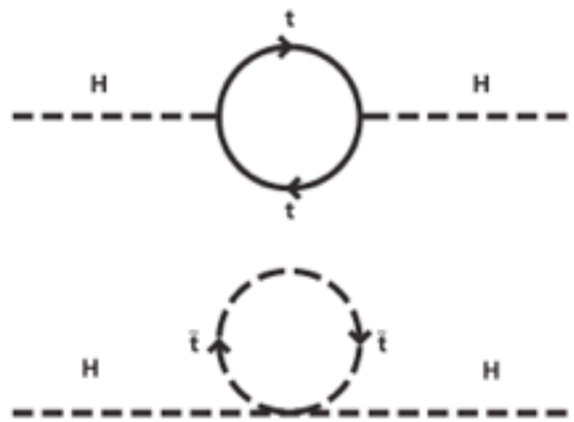
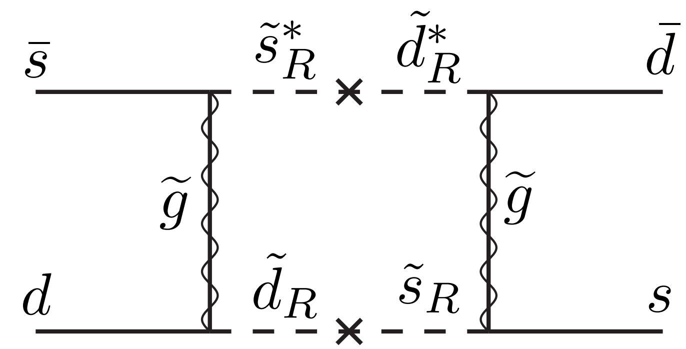
Rutgers University

MCTP Symposium on Higgs Physics
April 17, 2012

Based on:
Draper, Meade, Reece & DS (1112.3068)

Higgs@125 GeV





- A SM-like Higgs at 125 GeV would renew the urgency of the hierarchy problem. What new physics protects the Higgs mass??
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- Precision flavor tests strongly motivate gauge mediated SUSY-breaking (GMSB).

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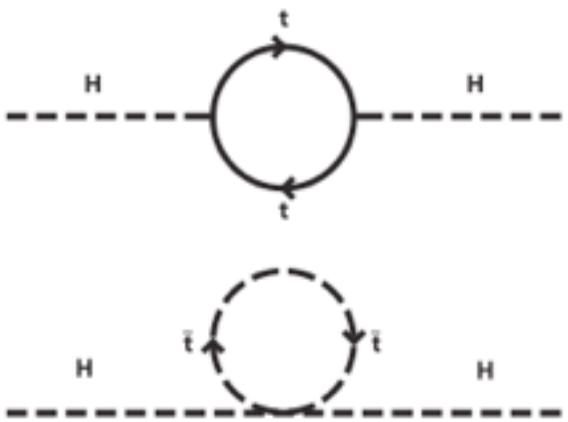

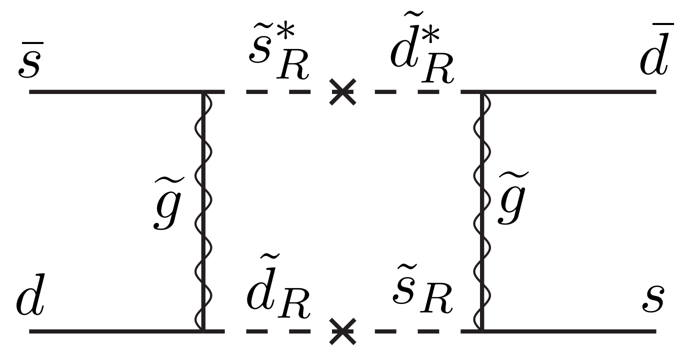

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Question for this talk:

MSSM + GMSB + Higgs@125 GeV $\Rightarrow$???

Implications for the MSSM

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We will set mA=1 TeV in today's talk.

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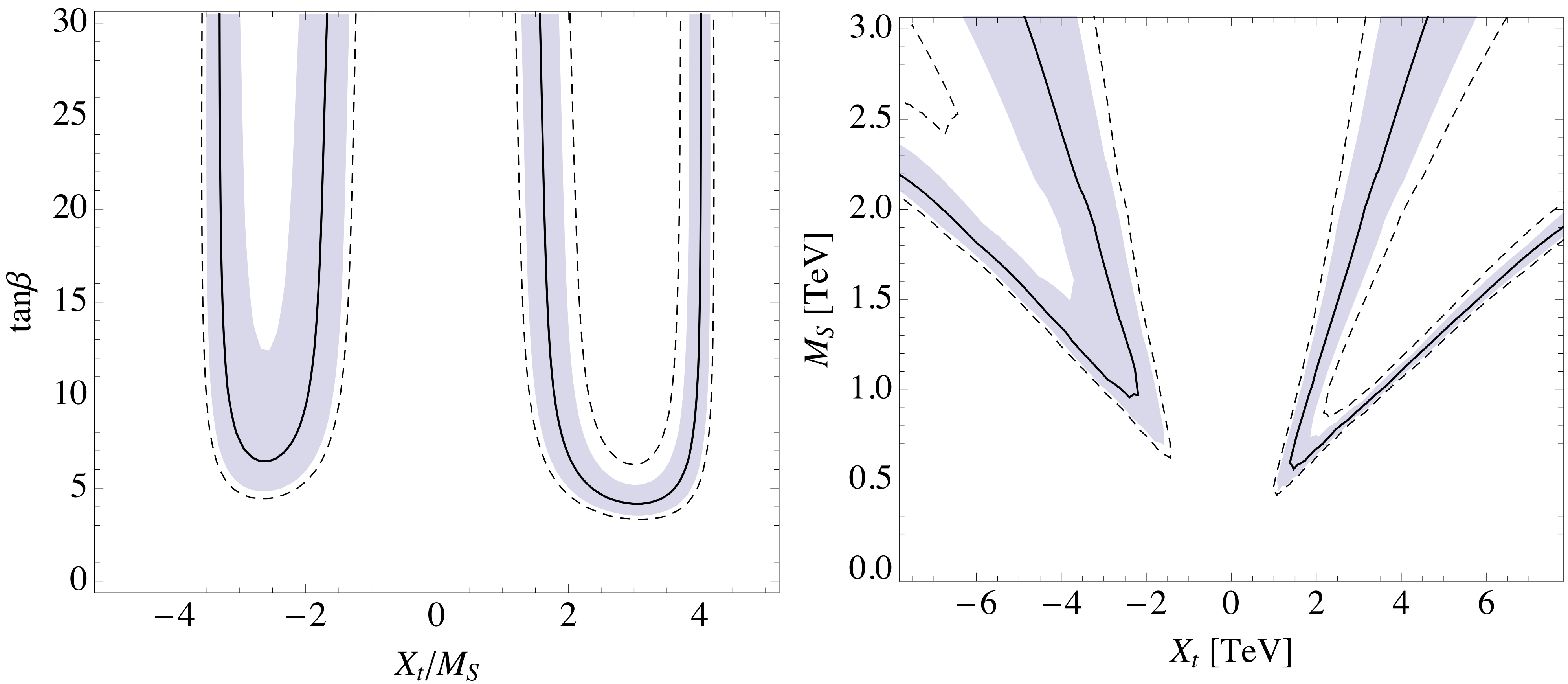

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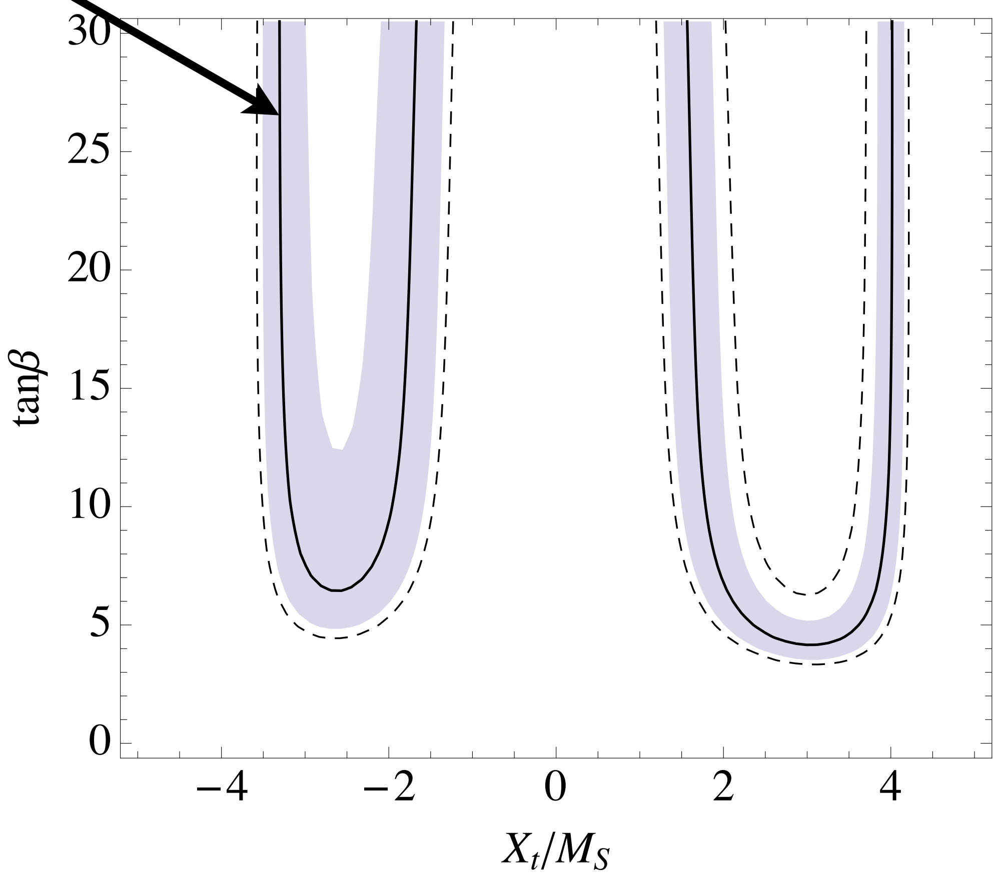

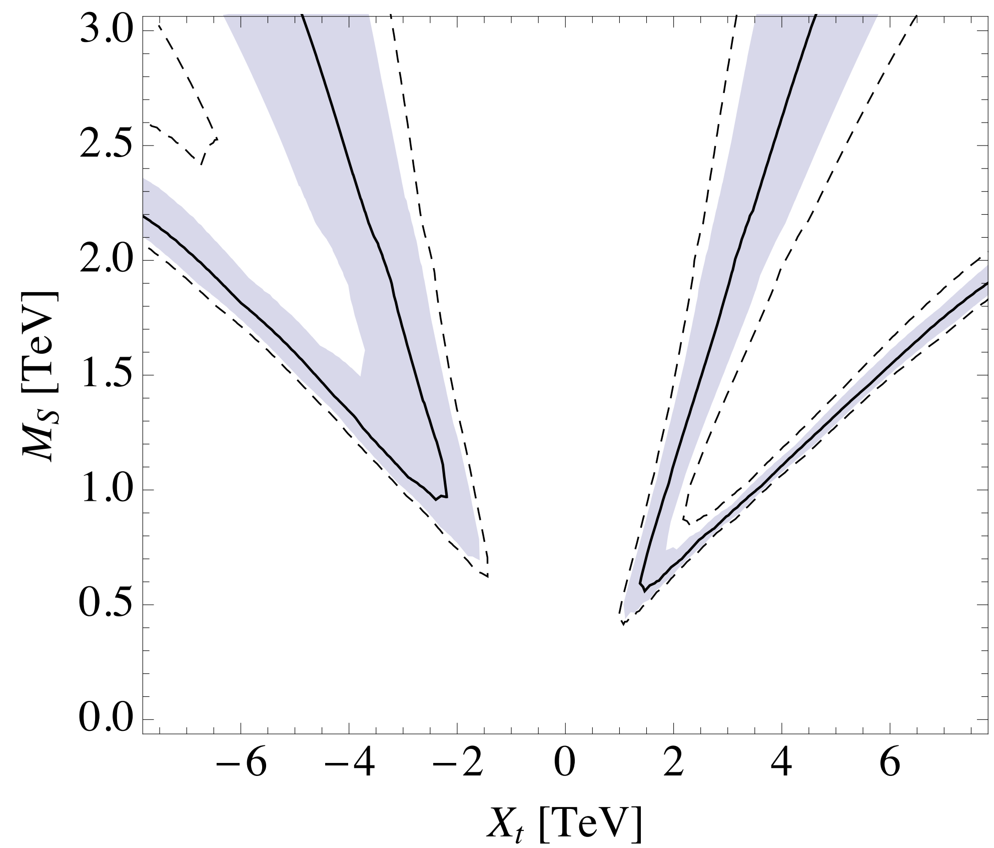

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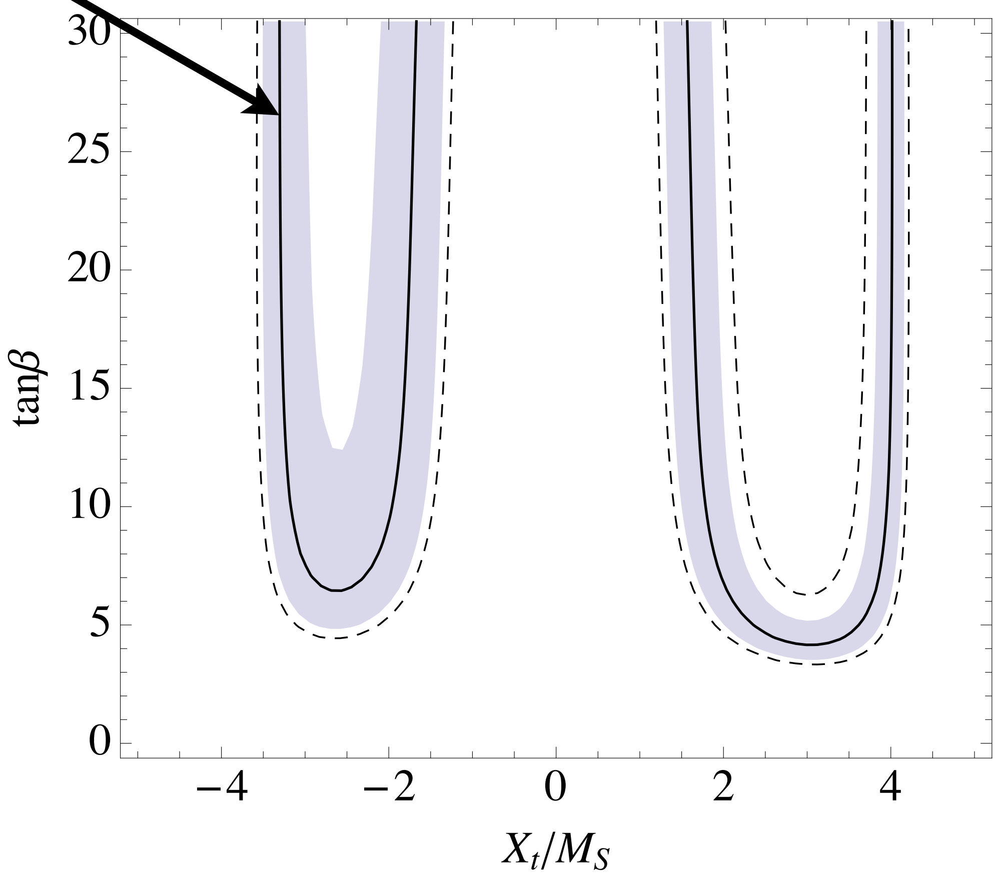

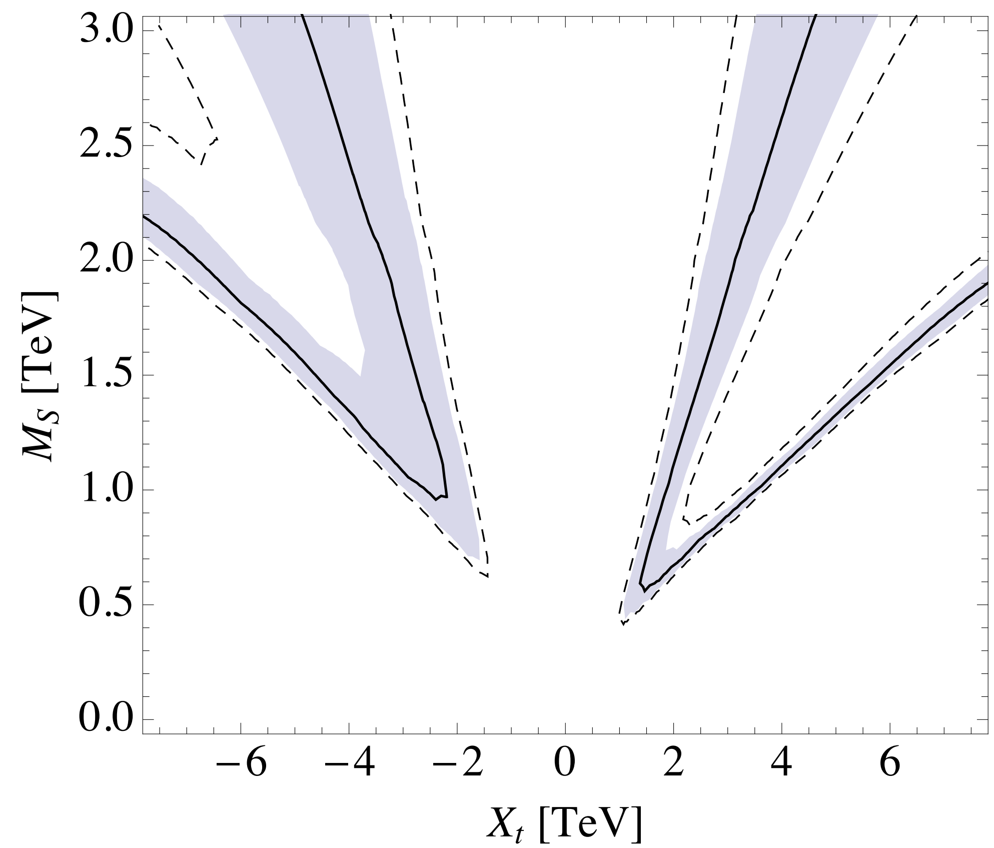

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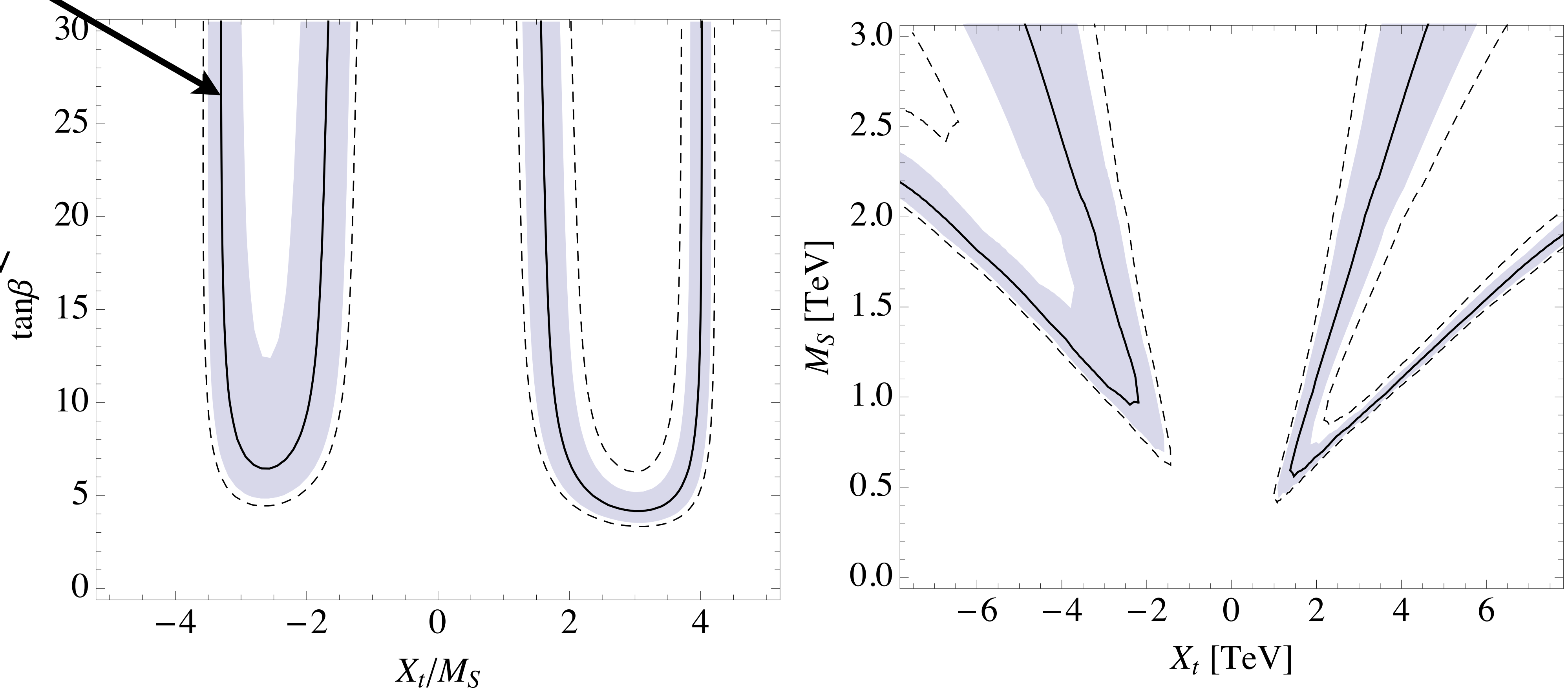

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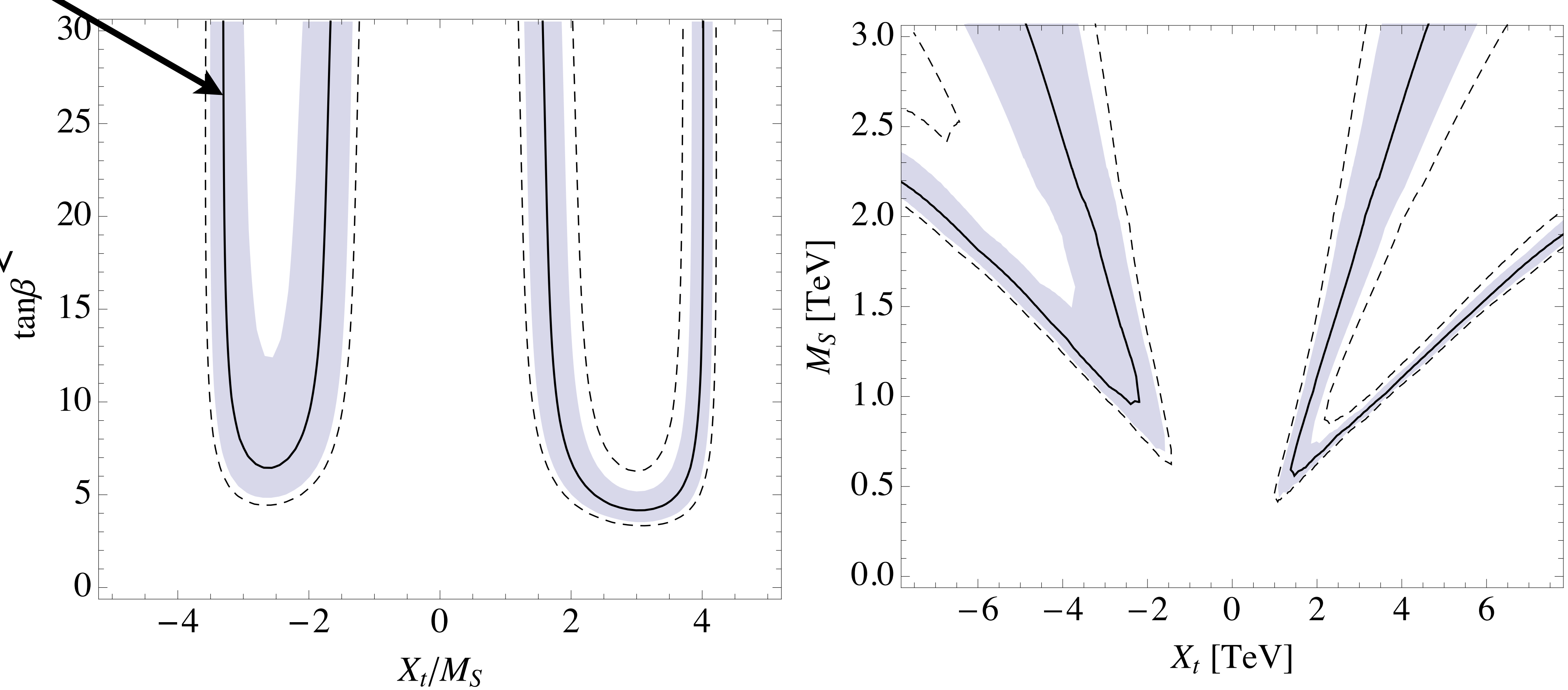

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$$\Rightarrow \boxed{|X_t| \gtrsim 1000 \text{ GeV}}$$

Stop mixing (A-terms) must be large in the MSSM!

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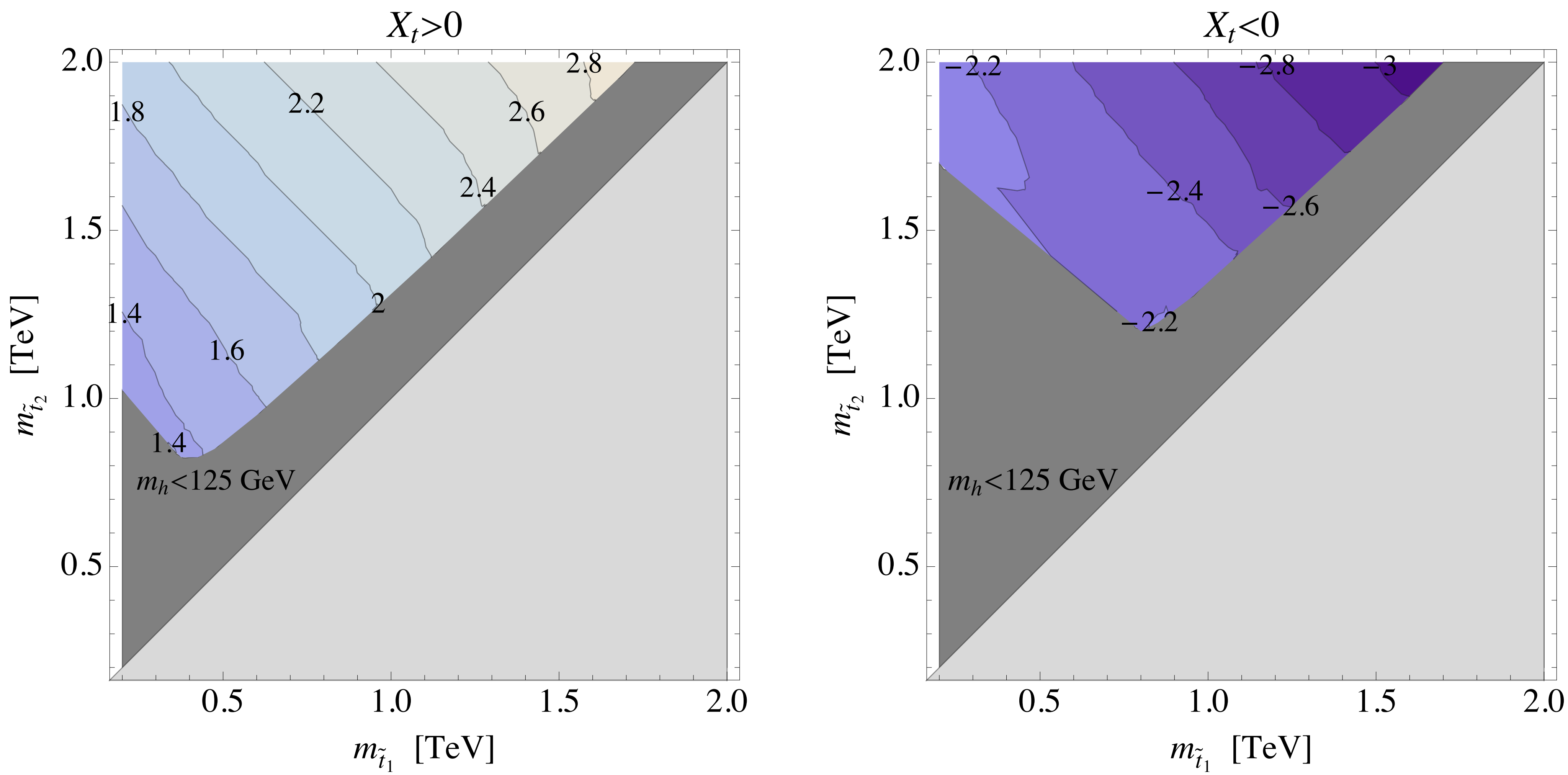
Higgs@125 GeV in the MSSM:

X_t vs (m_{t1}, m_{t2})

Previous plots assumed $m_Q = m_U \approx M_S$ for simplicity. Easy to generalize to split stop masses. For a given $(m_{\tilde{t}_1},\, m_{\tilde{t}_2})$, solve $m_h(m_{\tilde{t}_1},\; m_{\tilde{t}_2},\; X_t) = 125\ \mathrm{GeV}$ for X_t.



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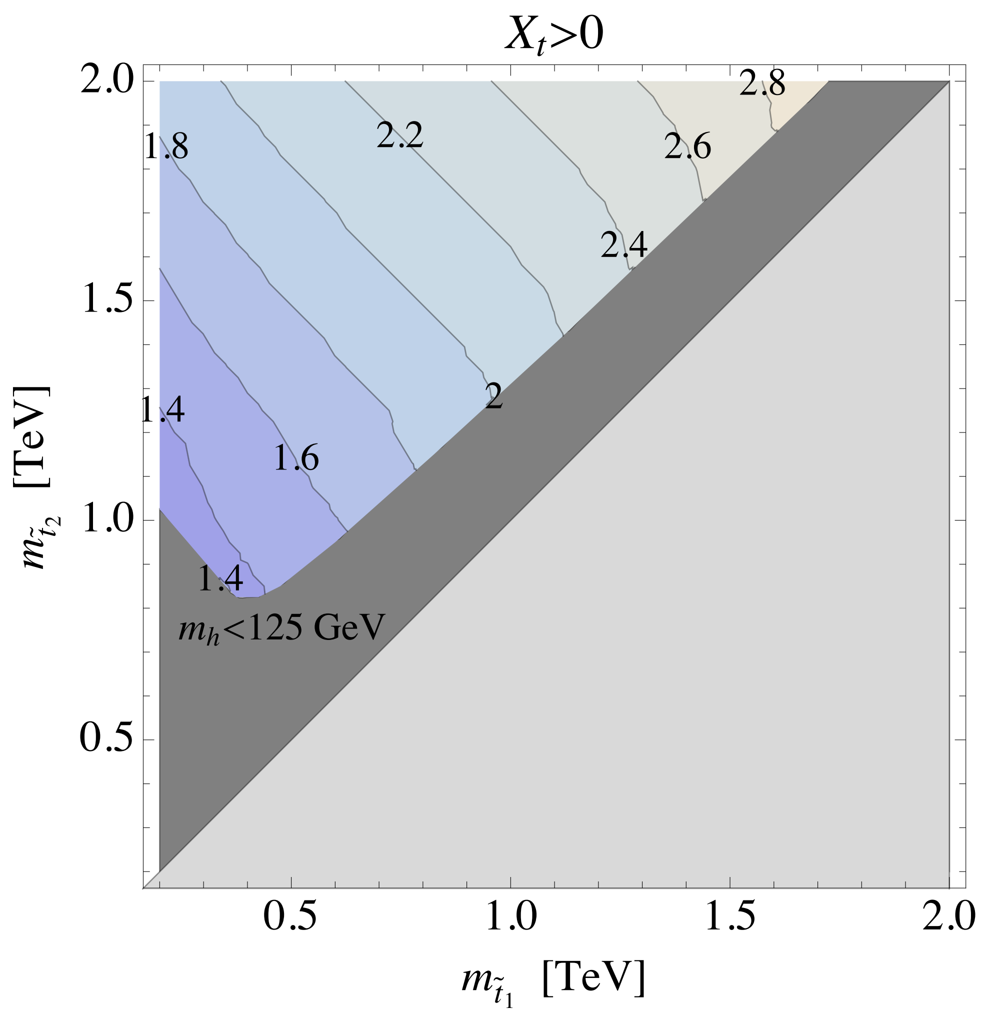

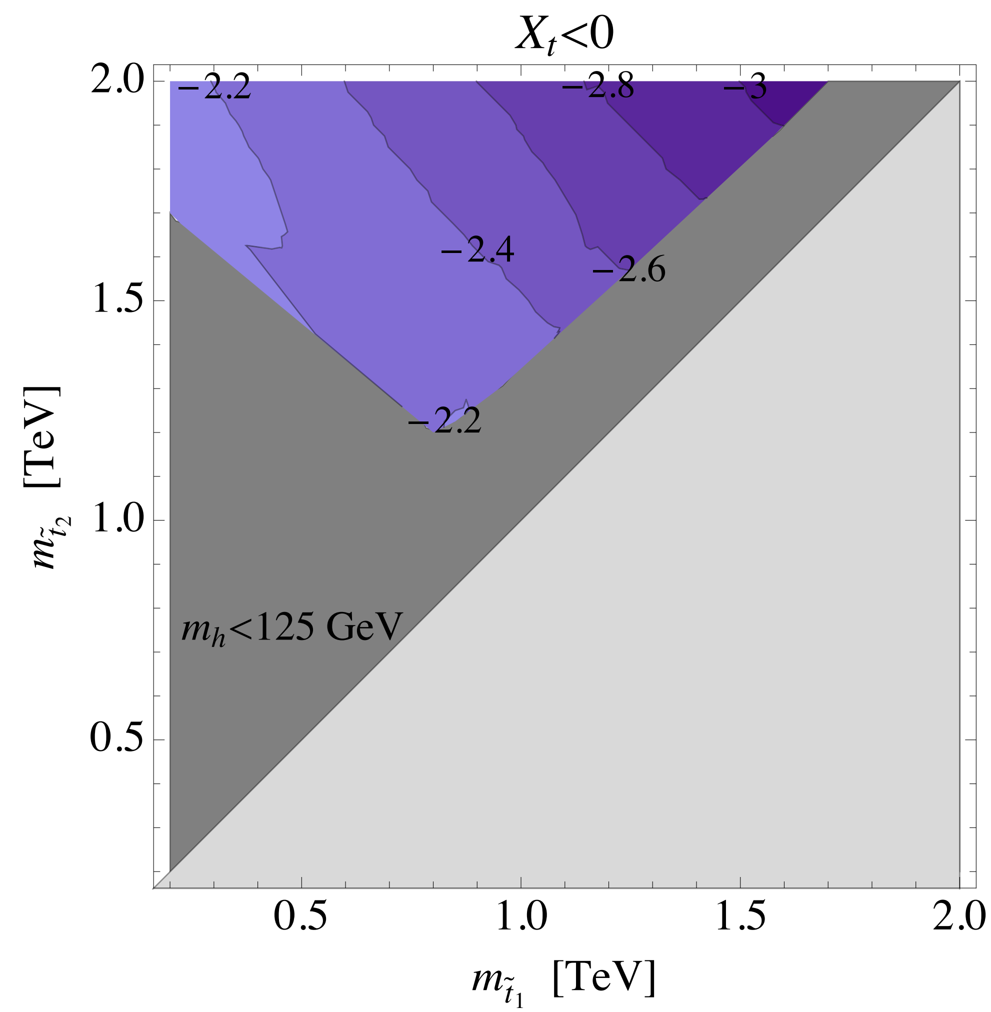

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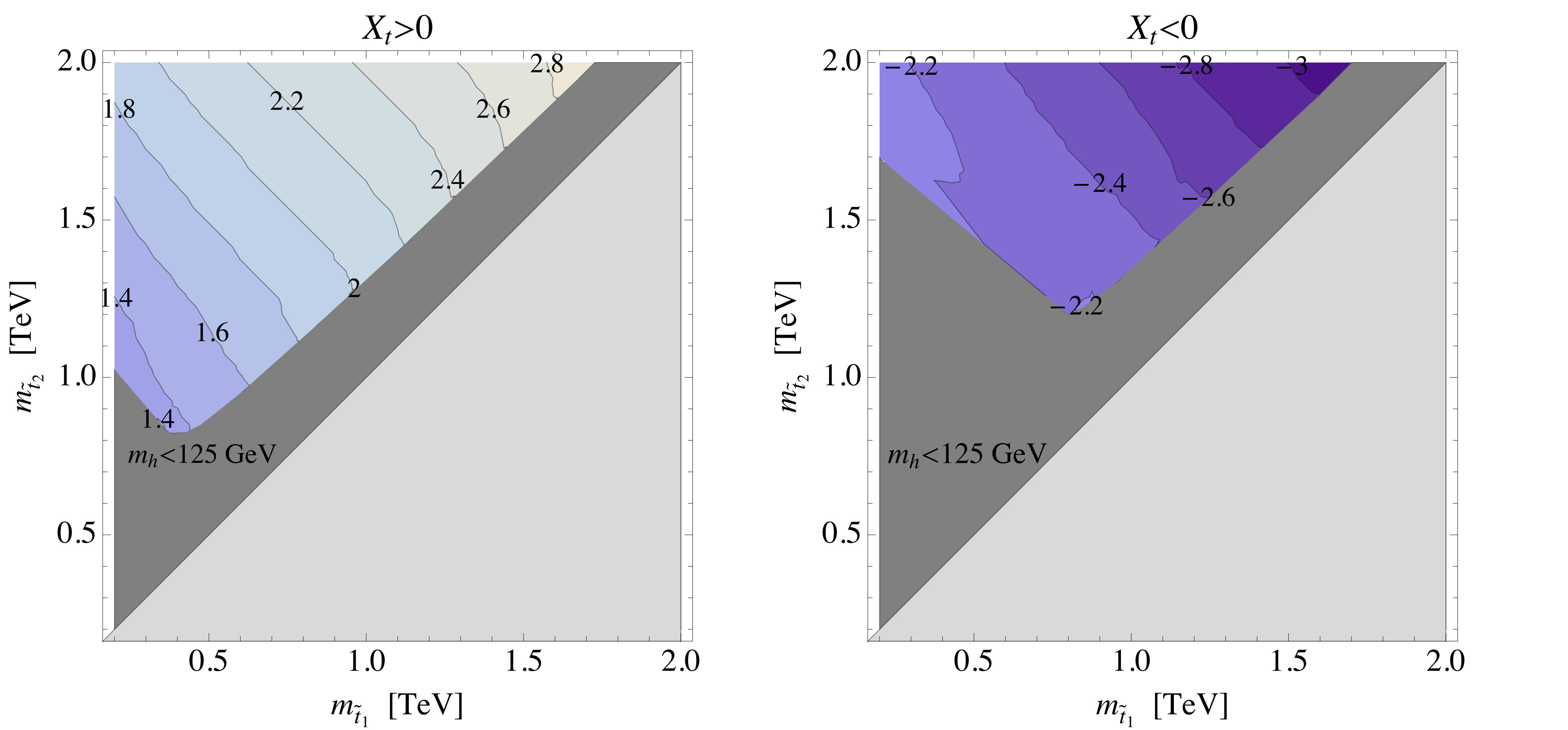

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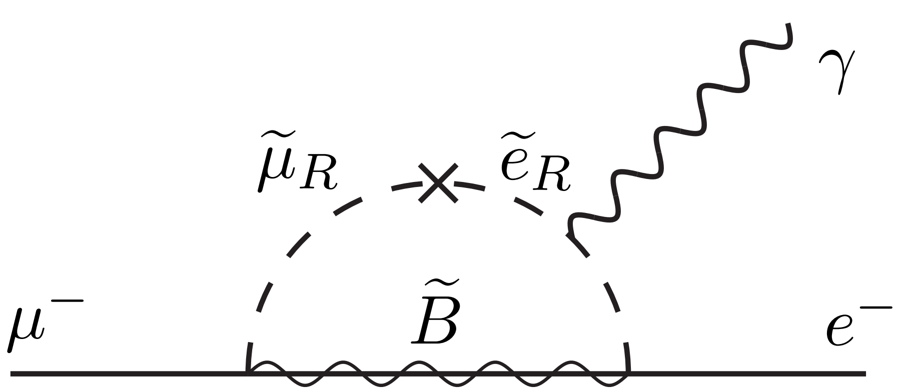
Stop1 can be light, provided stop2 is sufficiently heavy.

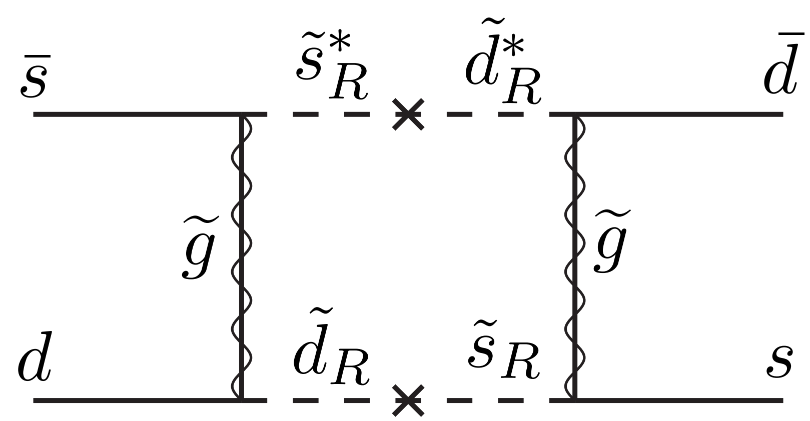
Implications for GMSB

MSSM Flavor Problem

- The ~120 soft SUSY-breaking parameters of the MSSM must arise from a simpler underlying source.
- A generic soft Lagrangian suffers from a severe flavor problem.
- The mediation of SUSY-breaking must be flavor universal to a very high degree of accuracy.

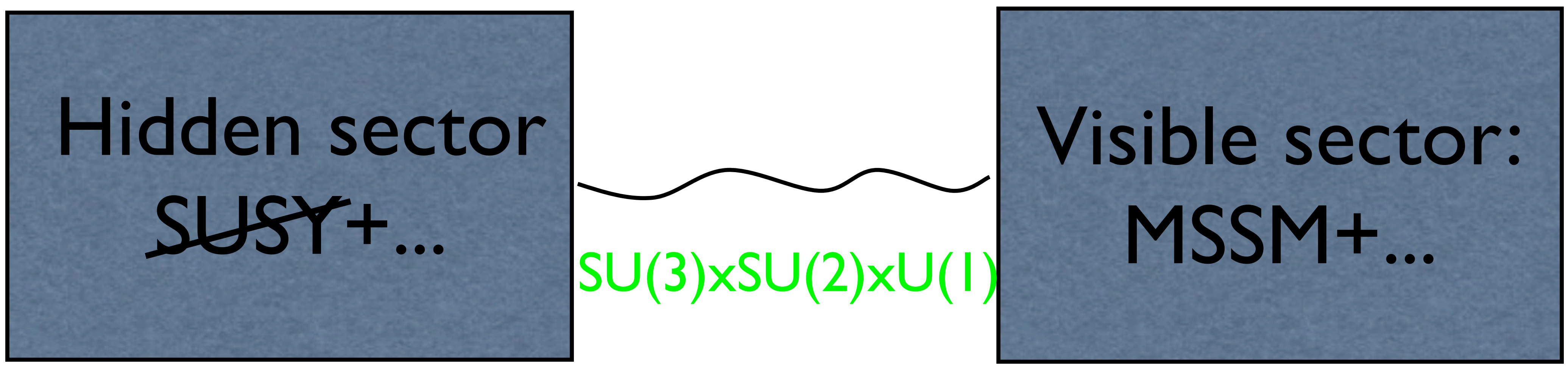


$\mathrm{Br}(\mu \to e\gamma)_{exp} < 1.2 \times 10^{-11}$



$(\Delta m_K)_{exp} = (3.483 \pm 0.006) \times 10^{-12}\ \mathrm{MeV}$

Gauge Mediation



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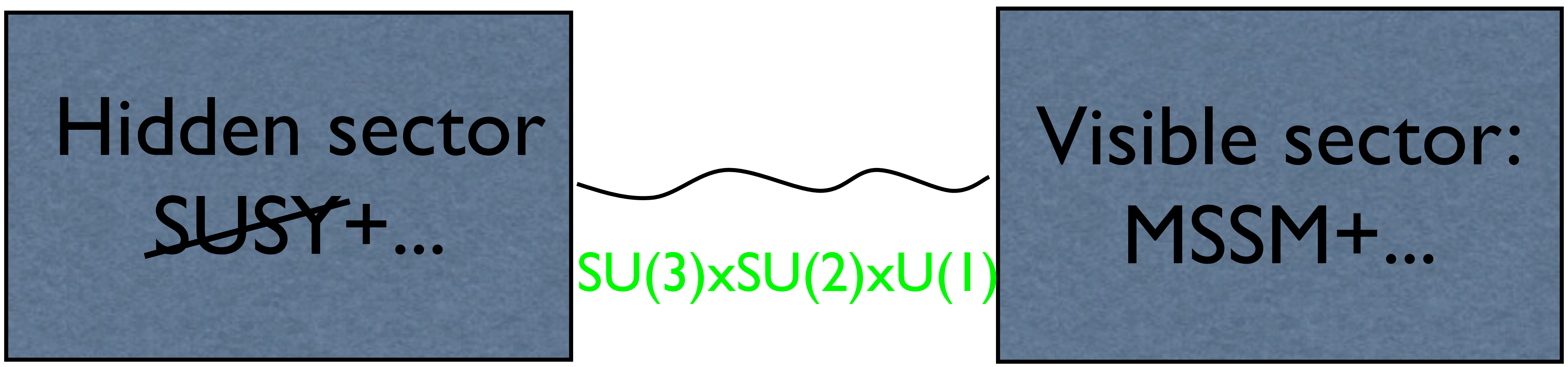

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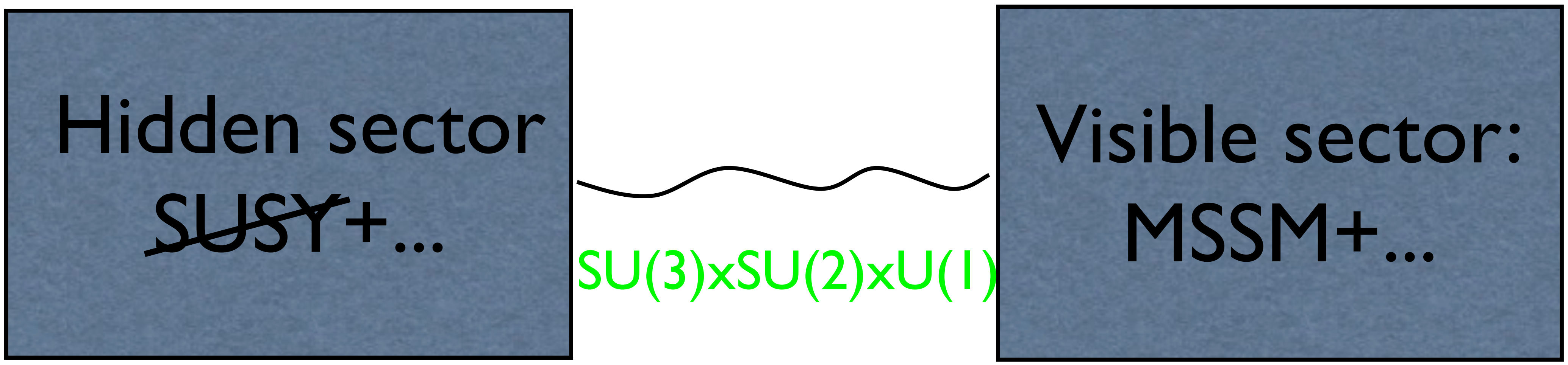
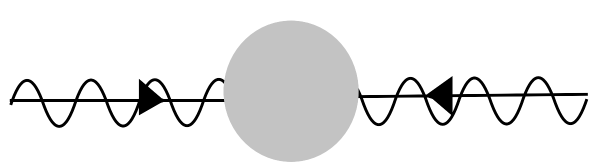
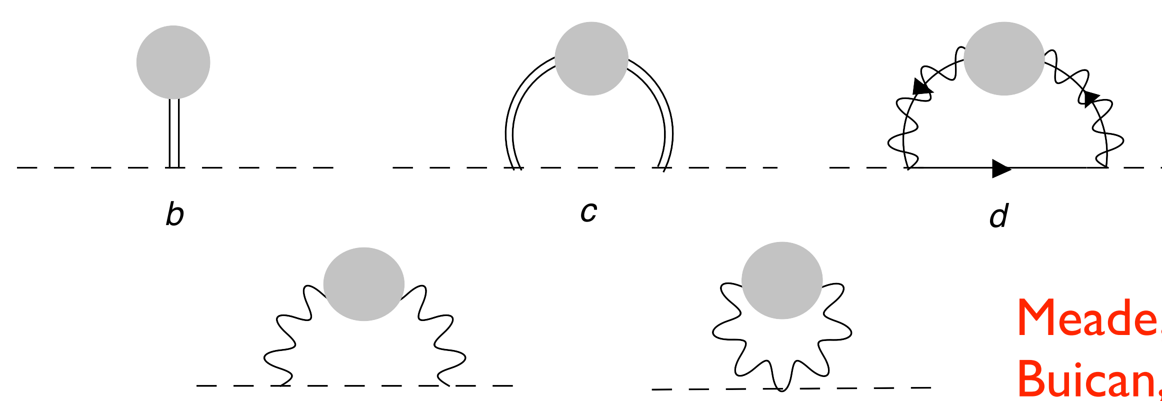


- Gauge mediation offers the best (only?) explanation for the required flavor universality of the soft Lagrangian.

- In 2008, my collaborators and I invented a model-independent framework for GMSB: "General Gauge Mediation"





Meade, Seiberg & DS;
Buican, Meade, Seiberg, DS

Idea: express soft masses in terms of currents and their correlation functions

GGM: Higgs Mass

- Using this, we derived the most general predictions of gauge mediation:
  - Parameter space: $(A_1, A_2, A_3) \to m^2_{Q,u,d,L,e}$
    $(B_1, B_2, B_3) \to M_{1,2,3}$
  - Sum rules: $\mathrm{Tr}\,(B-L)m^2_{\tilde{f}} = \mathrm{Tr}\,Y m^2_{\tilde{f}} = 0$
  - A-terms ≈ 0

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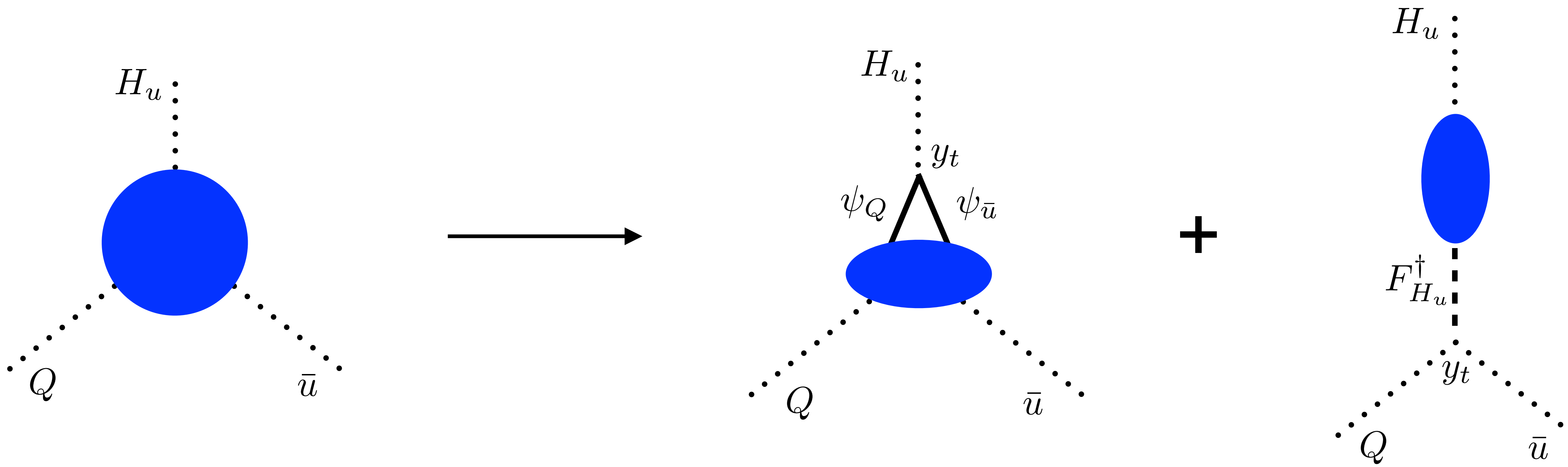
Higgs mass primarily relates to this

A-terms in GGM

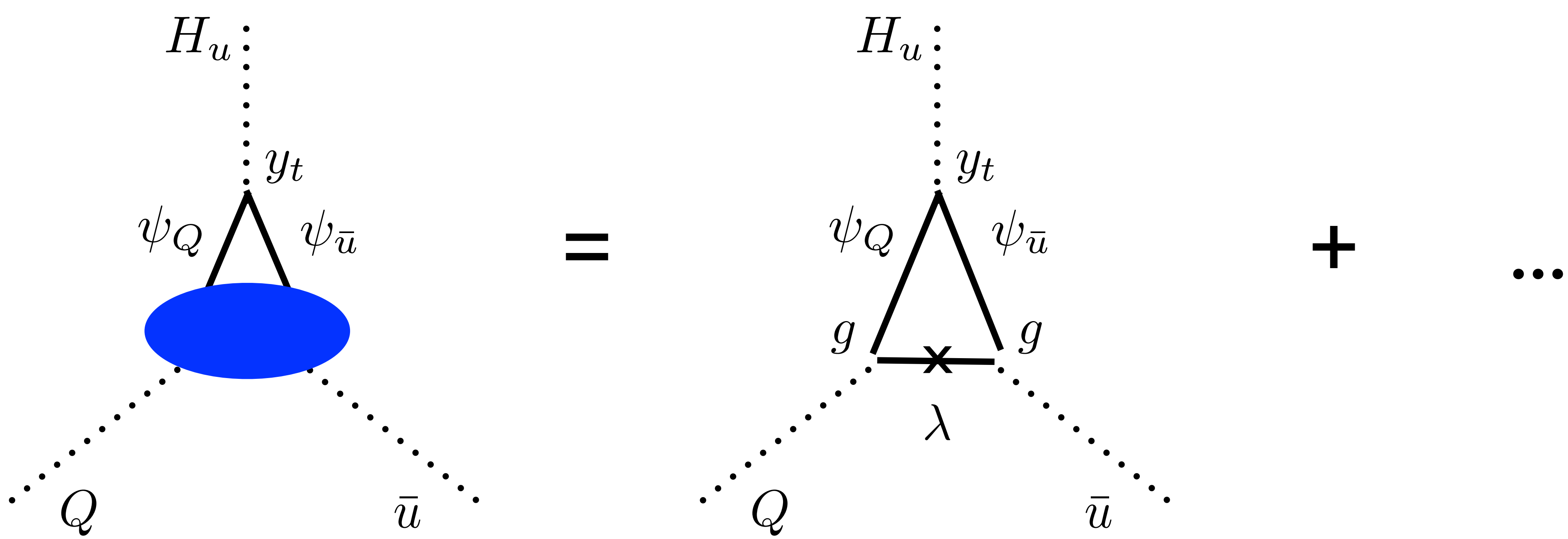
$$\mathcal{L} \supset A_t Q \bar{u} H_u + c.c.$$

- With gauge interactions alone, A terms are not generated at all -- they are protected by phase rotations of the squark fields.
- Need to involve Yukawa couplings.



A-terms in GGM

- Leading order effect in Yukawa+GGM comes at two loops O(g^4)



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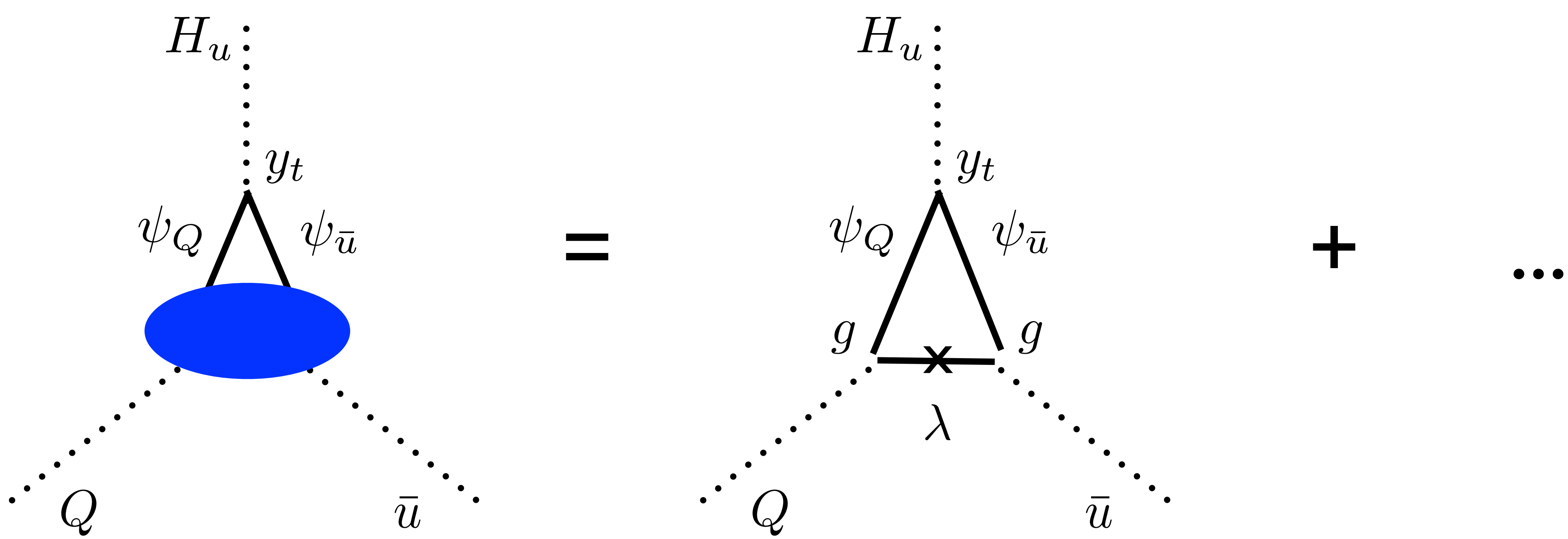

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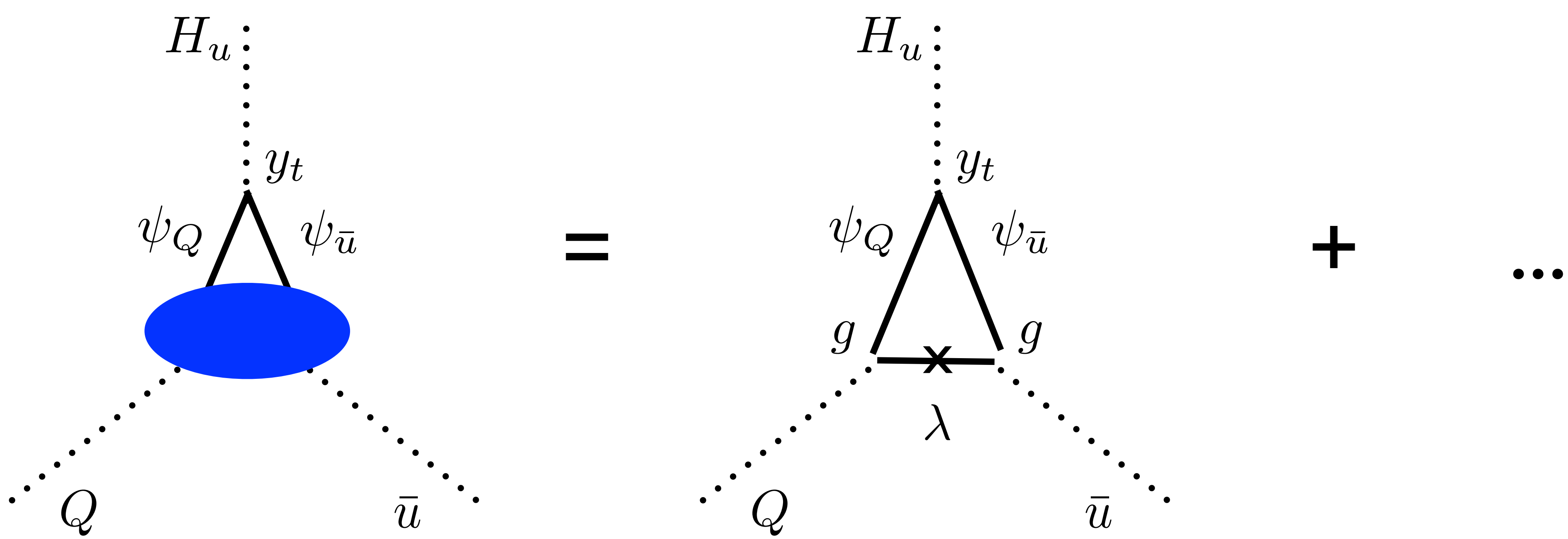

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This is the standard MSSM contribution to A terms!

$$\frac{dA_t}{dt} \sim y_t^2 A_t + g_3^2 M_3$$

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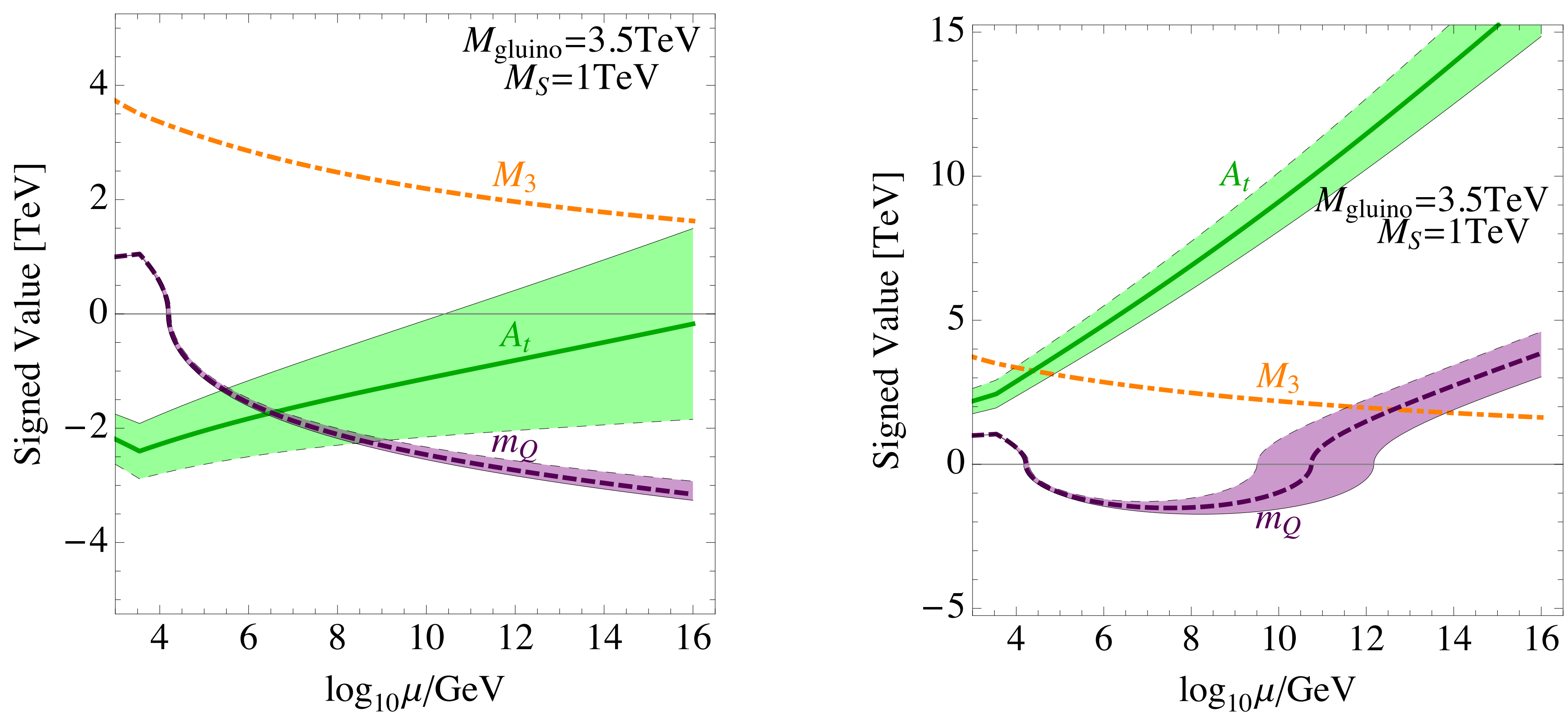
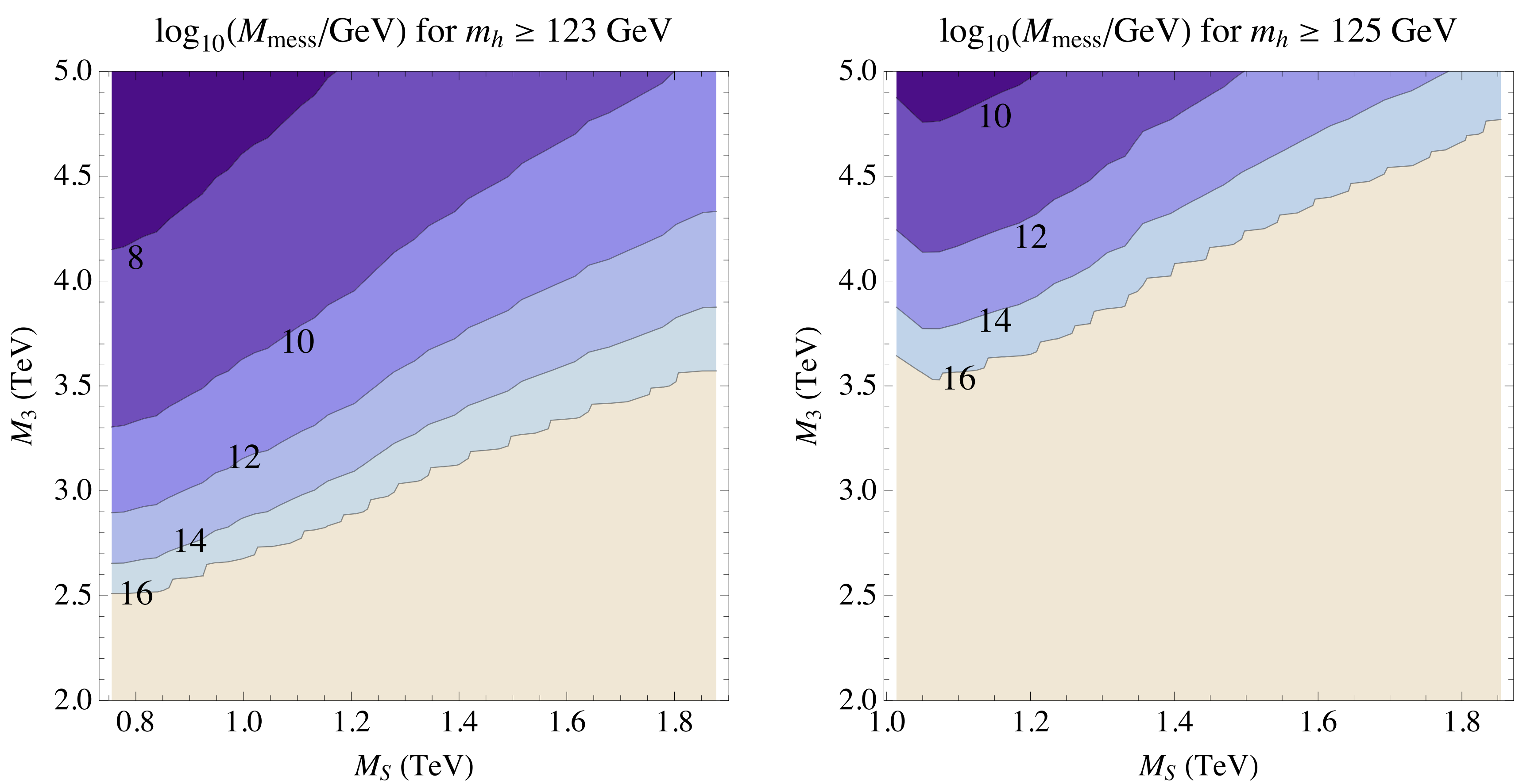


Higgs@125 GeV in the MSSM +GMSB

- $A_t > 0$ not possible in vanilla GMSB.
- $A_t < 0$ possible, but requires large M_3 and M_{mess}.

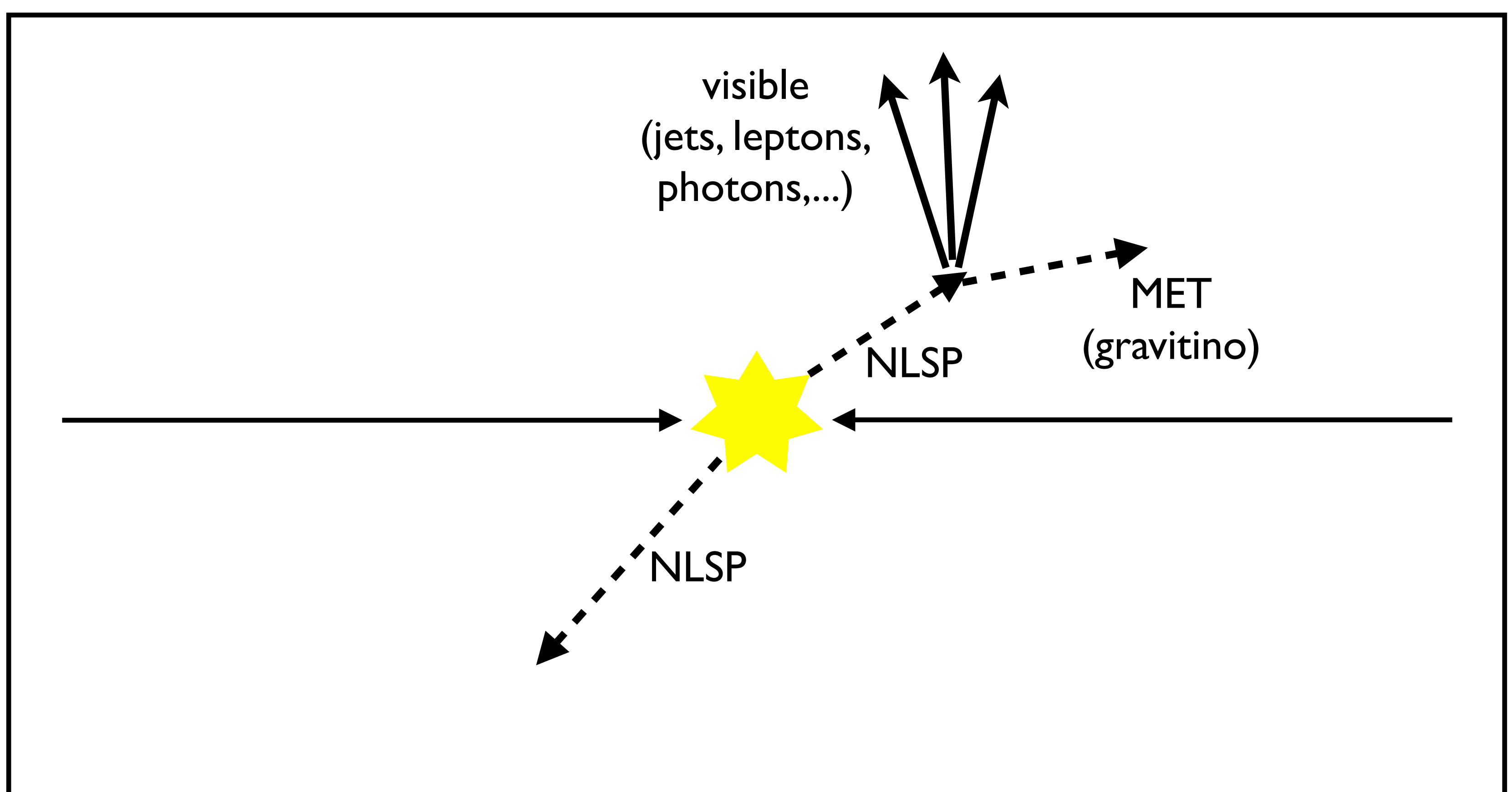


$$M_3 \gtrsim 3 \text{ TeV}, \qquad M_{mess} \gtrsim 10^8 \text{ GeV}$$

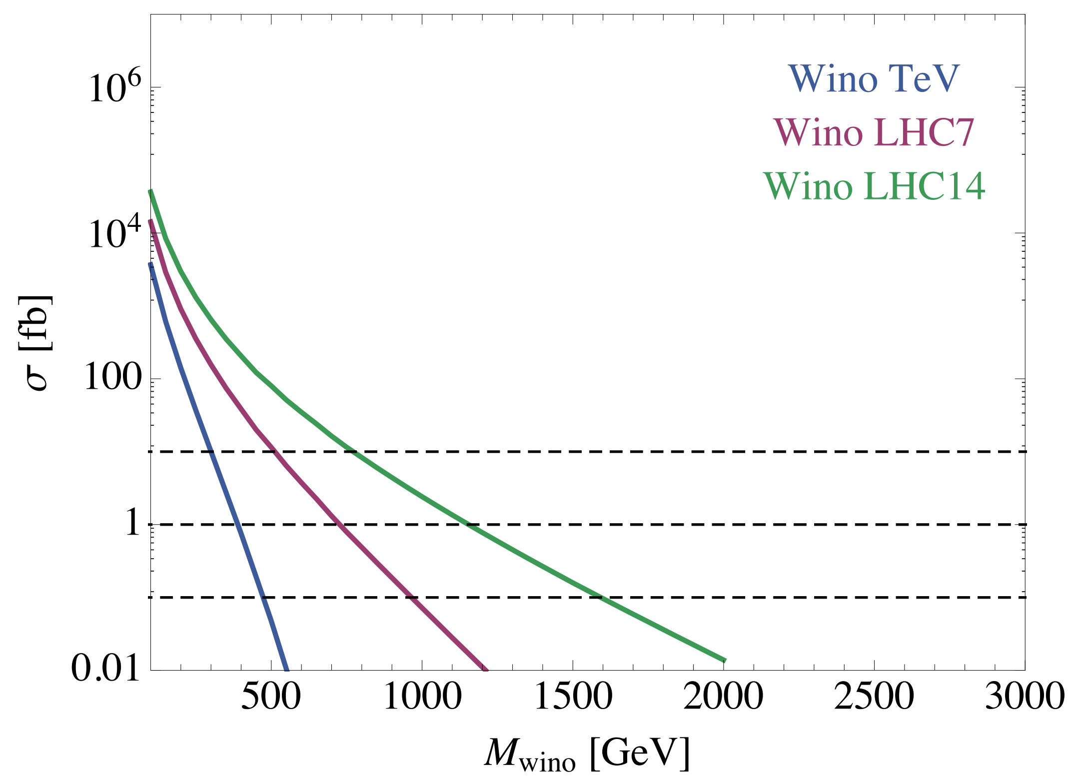
Consequences for Collider Signatures

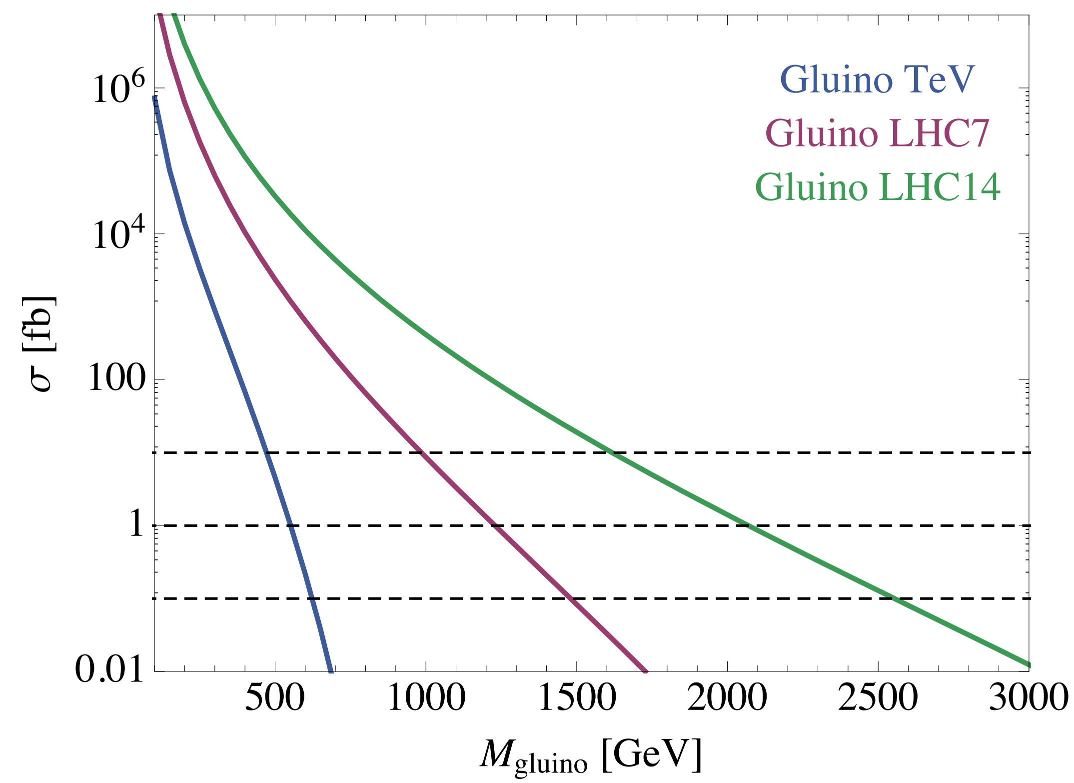
$$c\tau_{NLSP} \sim 1 \text{ m } \left(\frac{M_{mess}}{10^7 \text{ GeV}}\right)^2 \left(\frac{100 \text{ GeV}}{m_{NLSP}}\right)^5$$

For m_{NLSP} <~ 1 TeV and M_{mess} >~ 10^8 GeV, NLSP decay is always at least measurably displaced inside the detector.



Consequences for Collider Signatures





For M_3 >~ 3 TeV, gluinos are basically out of reach of the LHC!

Other superpartners (squarks, sleptons, EW-inos) can still be light and accessible.

Summary so far

- “Theorem”: MSSM + GMSB + Higgs@125 => 
- Highly constrained. Huge parts of parameter space ruled out.
  - Messenger scale must be intermediate to high. Displaced or long-lived NLSPs.
  - Gluinos must be heavy.
- Could be the way things are!
- Motivates searches for displaced vertices, CHAMPs, R-hadrons. Also, searches for squark and EW production.
- To evade these conclusions, we must modify one of the starting points.

Evading the constraints

MSSM + GMSB + Higgs@125 => 

Options for evading  :

1. The Higgs is not at 125 GeV. The recent hints are just fluctuations.

2. Modify GMSB to achieve large A-terms at the messenger scale.

3. Modify the MSSM to boost the Higgs mass, allowing for small A-terms at the weak scale.

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But the SM Higgs is now excluded everywhere except around 125 GeV! Option 1 would require "hiding" the Higgs in the MSSM -- not an easy task!

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Appealing approach: need to extend GGM anyway for mu and Bmu:

$$\delta W = \lambda \mathcal{O}_\mu H_u H_d + \lambda_u \mathcal{O}_d H_u + \lambda_d \mathcal{O}_u H_d$$

Meade, Seiberg & DS
Komargodski & Seiberg

A-terms beyond GGM

- Many problems with this approach...
  - One-loop A-term typically implies one-loop mHu^2

$$A_t \sim \int d^4\theta\, X^\dagger H_u^\dagger H_u \quad m_{H_u}^2 \sim \int d^4\theta\, X^\dagger X H_u^\dagger H_u$$

    Very analogous to the mu/Bmu problem!

$$\mu \sim \int d^4\theta\, X^\dagger H_u H_d \quad B_\mu \sim \int d^4\theta\, X^\dagger X H_u H_d$$

  - Successful solution to mu/Bmu generally implies small A-terms (Komargodski & Seiberg)
  - Currently investigating this in more detail (Craig, Knapen, DS, ... in progress).

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Higgs beyond the MSSM

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

- In NMSSM, can have $m_{\rm higgs}$ = 125 GeV without requiring large A-terms.
- Many well-known problems with the NMSSM (Singlet tadpoles, domain walls...) (cf N. Weiner's talk)
- NMSSM+GMSB has even more problems:
  - A-terms for singlet are small for the same reasons as before.
  - Need these A-terms together with negative singlet mass-squared for successful EWSB and extended Higgs spectrum. Generally near-impossible to achieve. (Dine & Nelson '93; de Gouvea, Friedland, Murayama '97; Morrissey & Pierce '08;....)

Higgs beyond the MSSM

- Other extensions of the MSSM?
  - compositeness, "fat Higgs", non-decoupling D-terms, extra vector-like matter....
  - Luty, Terning, Grant '00; Harnik, Kribs, Larson, Murayama '03; Chang, Kilic, Mahbubani '04; Birkedal, Chacko & Nomura '04; Delgado & Tait '05; Craig, Stolarski, Thaler '11; Csaki, Randall, Terning '12, ...
  - Generally, unification is problematic in these approaches...

Conclusions

- 125 GeV Higgs in the MSSM+GMSB is highly constrained. Requires high messenger scale and heavy gluinos.
- This motivates the following avenues for exploration:
  - extensions of the MSSM + GMSB
  - MSSM + extensions to GMSB
- Cosmological consequences?
  - High messenger scale -> gravitino problem?
  - Long-lived NLSPs -> constraints from BBN?
  - Negative squark mass-squareds in RGEs -> meta-stable vacuum?

IMPORTANT DISCLAIMER

- Questions I've heard from people:
  - Is GMSB ruled out by the 125 GeV Higgs?
  - Are standard collider signatures of GMSB such as $\gamma\gamma$+MET suddenly irrelevant?
  - Should I work on something else?
- We can imagine that some modification of the Higgs sector of the MSSM+GMSB boosts the Higgs mass to 125 GeV while preserving all the usual collider signatures.
- Much too early to say! Sensible experimentalists should ignore these theoretical struggles and continue looking for new physics!!

The End