

Supersymmetry at the Frontiers

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Snowmass on the Pacific, KITP — May 31, 2013

Outline

An Unreasonable Wish List

Supersymmetry in 2013

Wish List for the Frontiers

(Disclaimer: I was asked to have an opinion.)

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Supersymmetry in 2013

Wish List for the Frontiers

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(Disclaimer: Lately, I've been busy running a biology experiment.)



Taking the Broad View

Beyond the SUSY **field content** and **spectrum**...

MSSM, NMSSM, MRSSM, ...

cMSSM, pMSSM, GMSB, ...

Beyond a description in terms of **simplified models**...

$C_8 \rightarrow t t C_0, C_3 \rightarrow t C_0, \dots$

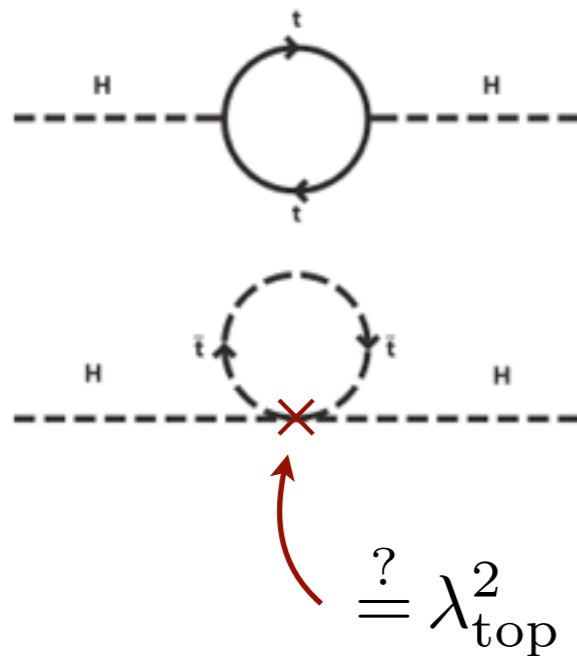
*Want to test SUSY as a (well-motivated)
extension of space-time symmetry*

Ideally: Use superpartners as probes
of structural questions

If SUSY realized in nature...

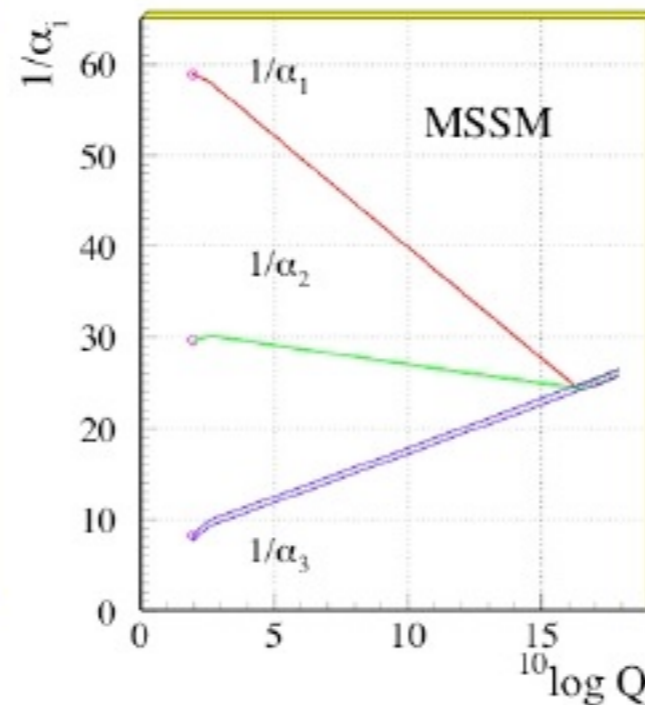
...potentially relevant for understanding the holy trinity

Naturalness



[see e.g. Craig, Englert, McCullough;
Farina, Perelstein, Lorier]

Unification



(already probed?)

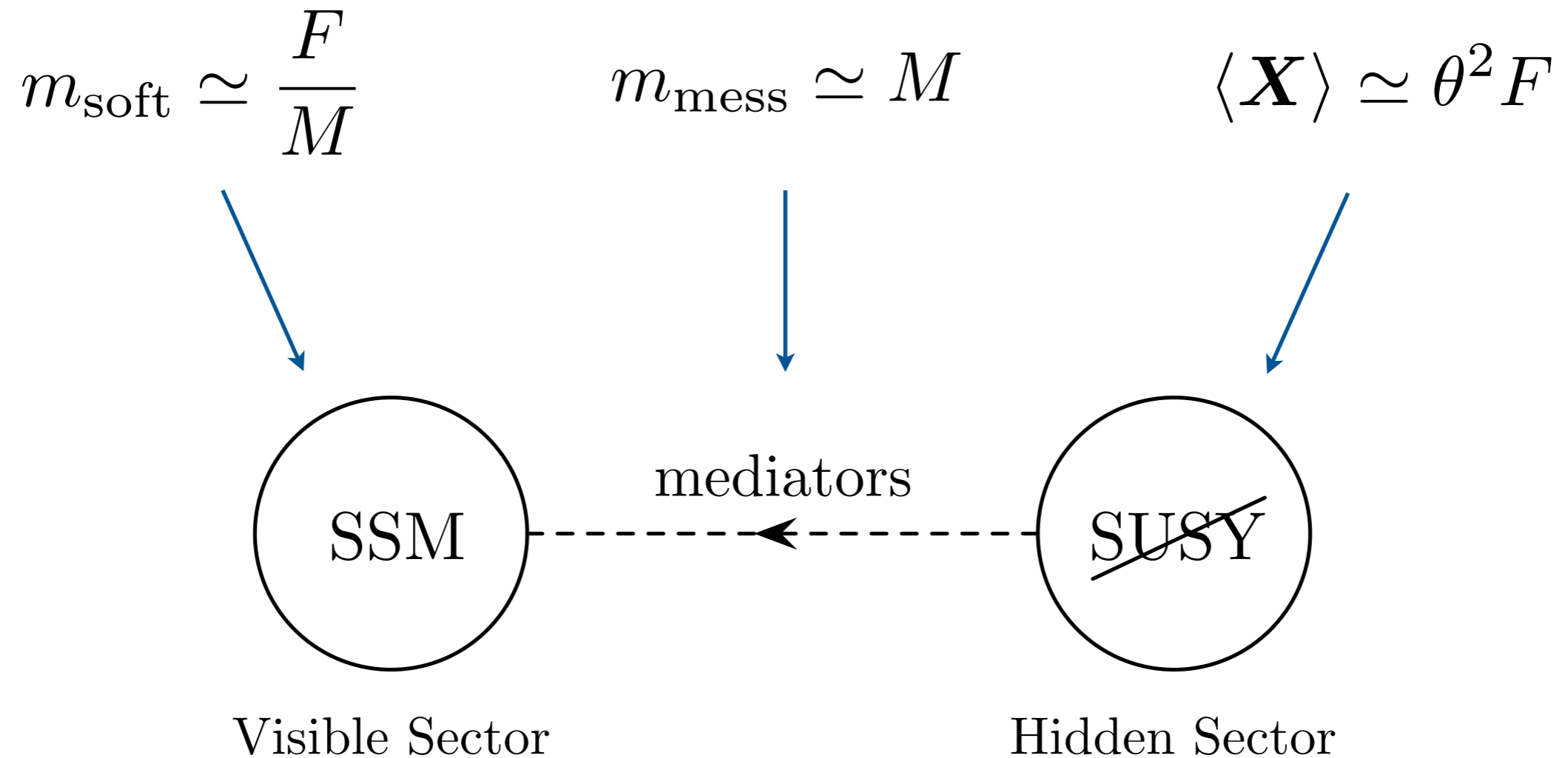
Dark Matter

(more later...)

Ideally: want direct experimental probes of this

If SUSY realized in nature...

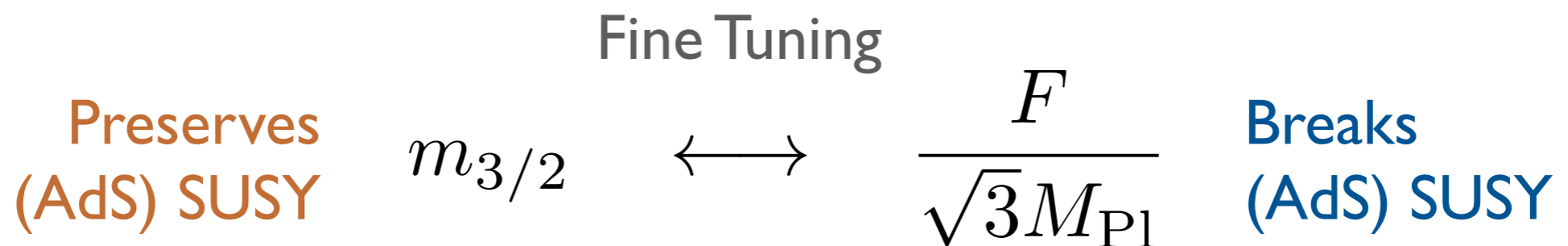
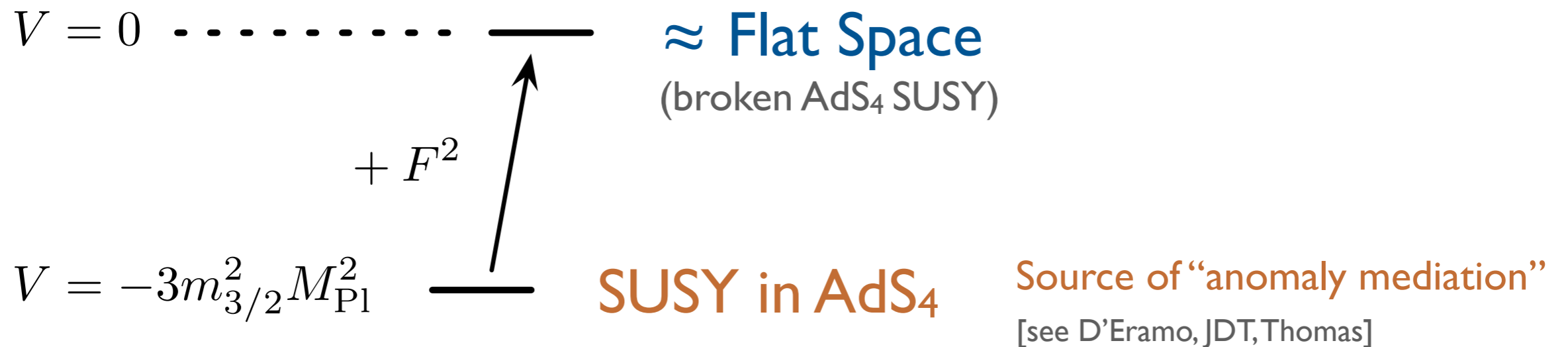
...likely to involve standard SUSY paradigm



Ideally: want direct experimental probes of this

If SUSY realized in nature...

...we'll all have to learn about SUSY in AdS space



Ideally: want direct experimental probes of this

An Unreasonable Wish List

(Save for Snowmass 2013+N)

Find superpartners of all standard model fields

Verify cancellation of quadratic divergences in Higgs sector

Verify SUSY (and unification) coupling relations

Verify fine-tuning of AdS curvature against SUSY breaking

Measure $m_{3/2}$ (and abundance $\Omega_{3/2}$)

Extract messenger quantum numbers

Extract hidden sector dynamics

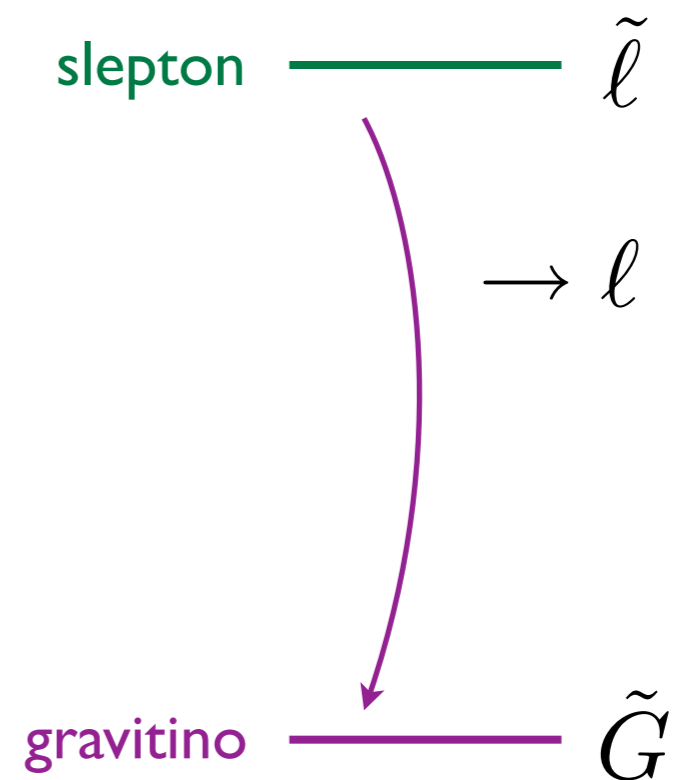
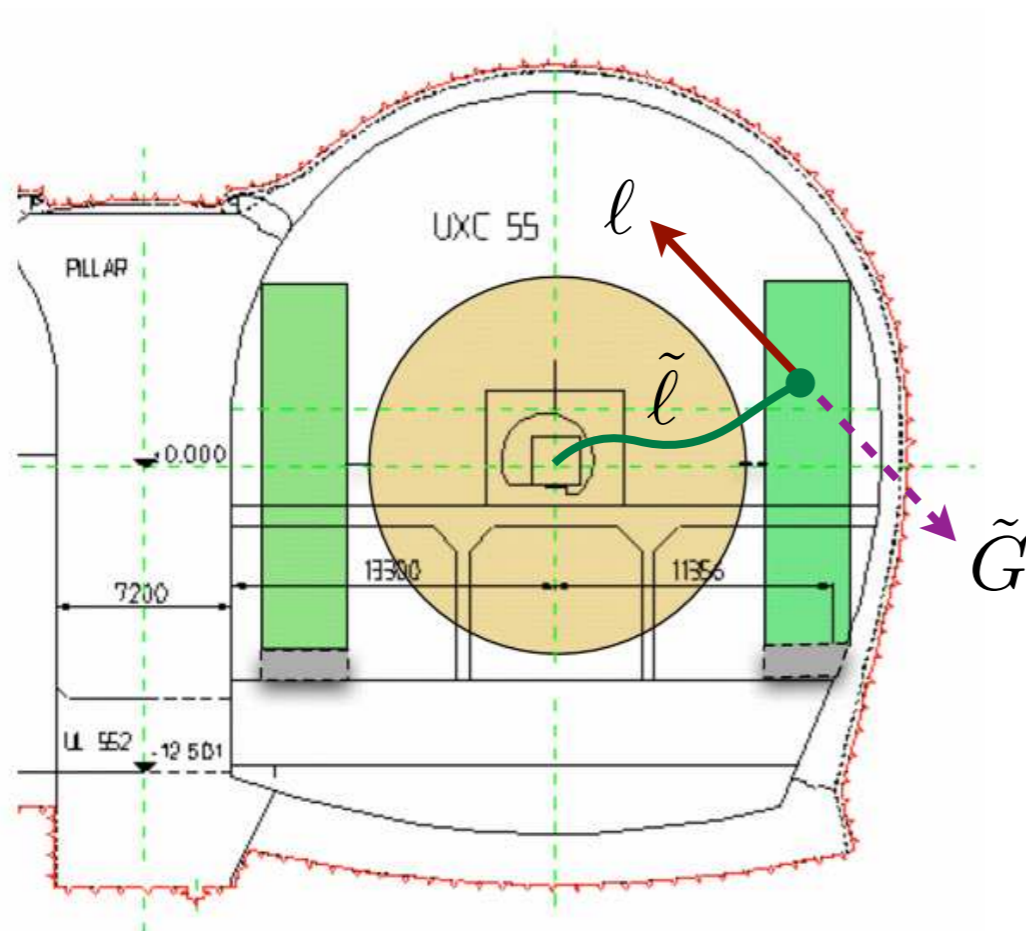
Test whether moduli are stabilized supersymmetrically

...

Determine which string vacuum we occupy

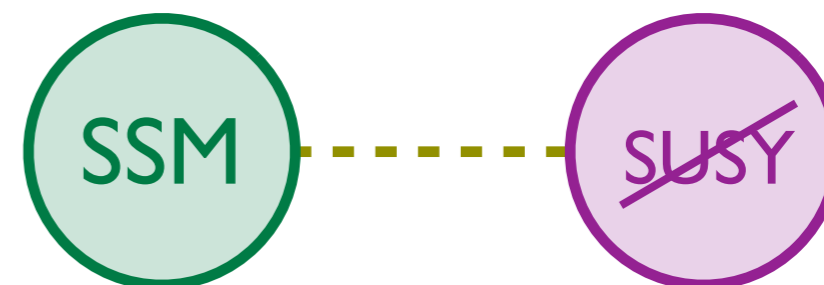
Not entirely pie-in-the-sky!

Decays of *meta-stable charged particles* to *gravitinos*



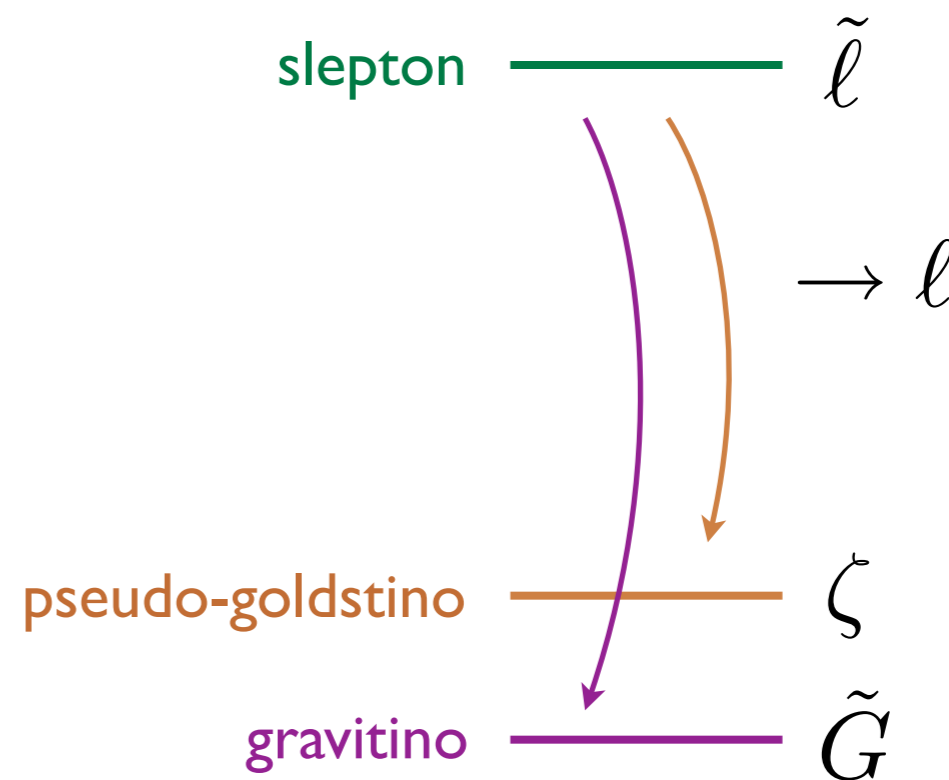
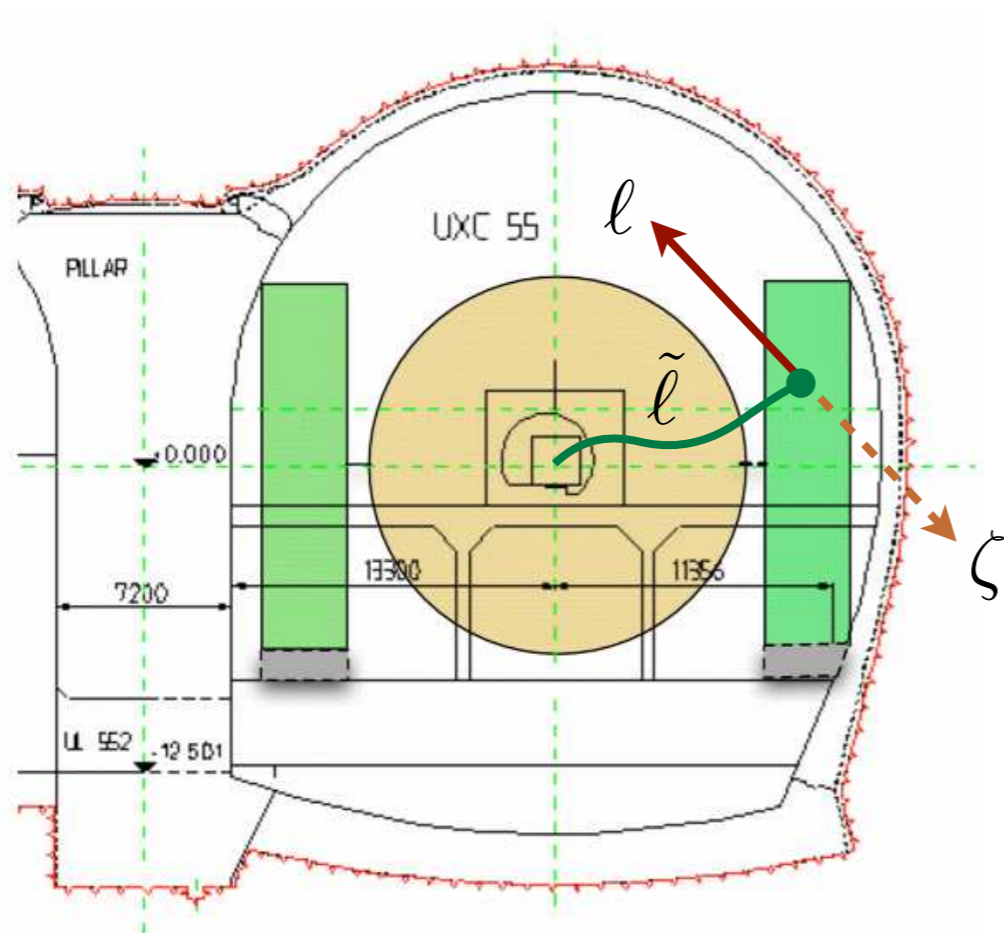
$$m_{3/2}^2 \simeq \frac{m_{\tilde{l}}^5}{48\pi\Gamma_{\tilde{l} \rightarrow l\tilde{G}} M_{\text{Pl}}^2}$$

[Hamaguchi, Kuno, Nakaya, Nojiri;
Feng, Smith; Hamaguchi, Nojiri, de Rooek; ...]



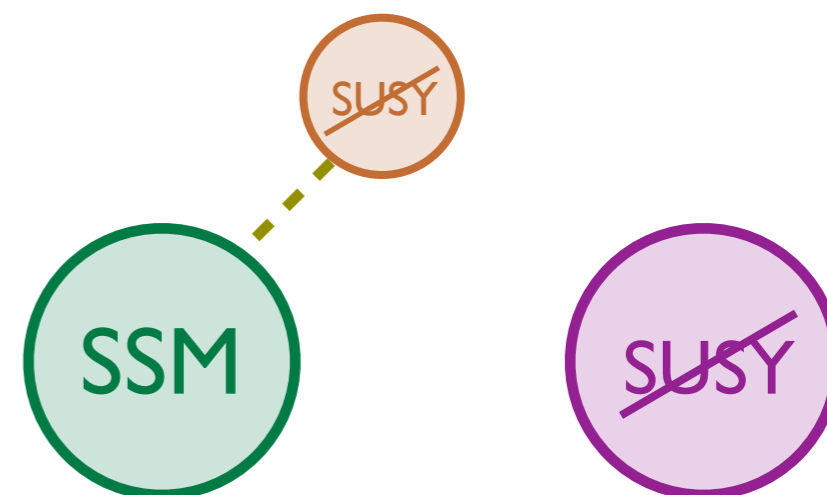
Not entirely pie-in-the-sky!

Decays of *meta-stable charged particles* to “goldstini”



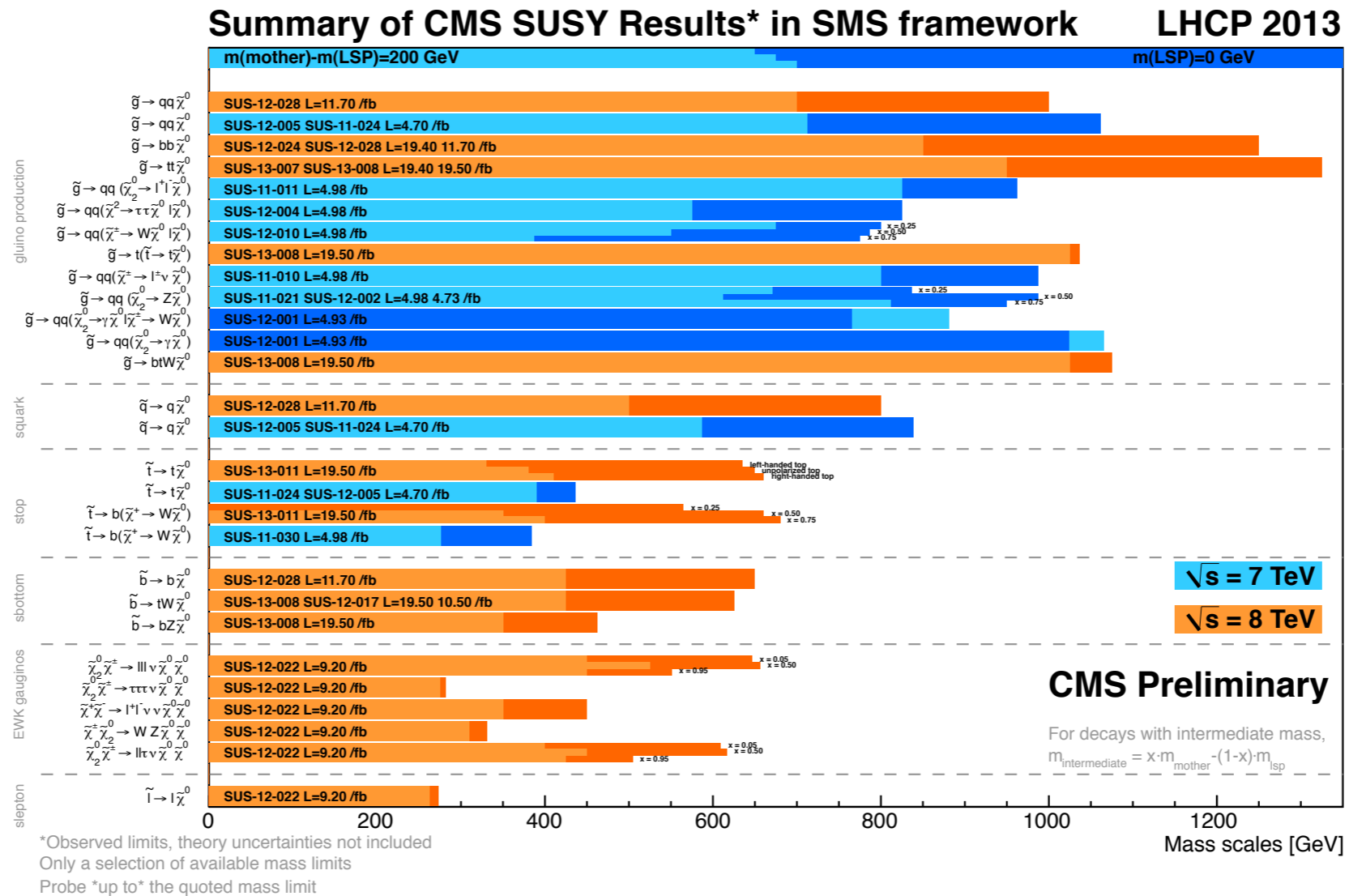
$$m_\zeta \simeq 2m_{3/2} \quad \frac{\Gamma_{\tilde{l} \rightarrow l\zeta}}{\Gamma_{\tilde{l} \rightarrow l\tilde{G}}} \simeq \left(\frac{F_{\text{us}}}{F_{\text{total}}} \right)^2$$

[Cheung, Nomura, JDT;
[Cheung, Mardon, Nomura, JDT; ...]



Supersymmetry in 2013

No superpartners under the lamppost

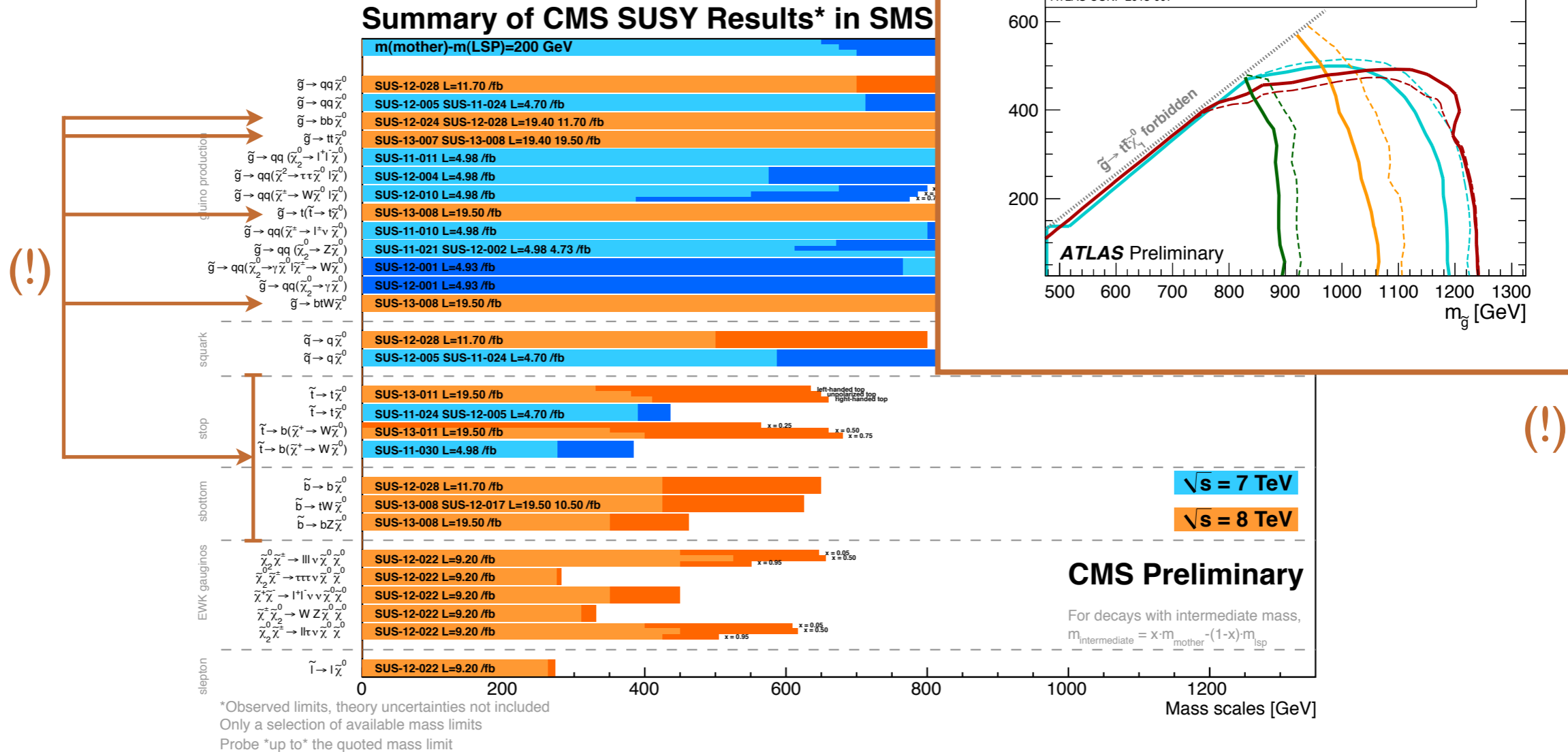


Current task: Find any evidence for superpartners

Squeezed Spectra? R-parity Violation? Third-Generation Rich? Other Blind Spots?

Supersymmetry in 2013

No superpartners under the lamppost



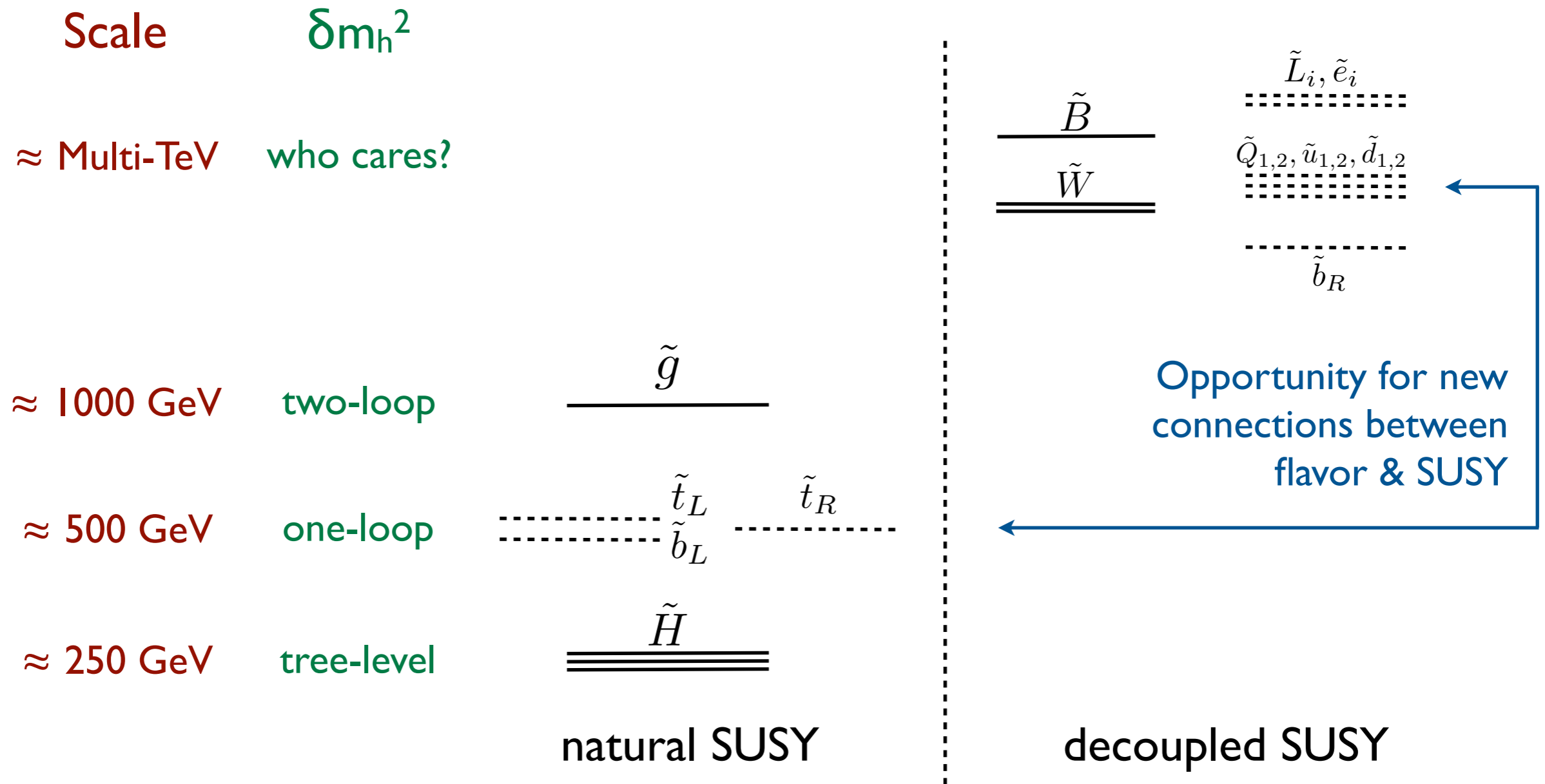
Current task: Find any evidence for superpartners

Squeezed Spectra? R-parity Violation? Third-Generation Rich? Other Blind Spots?



Reason for Optimism: Natural SUSY


(though quite constrained by top-rich searches)



[many papers since mid-90s; figure adapted from Papucci, Ruderman, Weiler]


Flavor Mediation Delivers Natural SUSY


(anomaly-free) gauged $SU(3)_F$ as mediator of SUSY breaking

$SU(3)/SU(2)$ 

$SU(2)$ 

Broken $SU(3)_F$ Gauge Group
(Cartan Rank 2)

$\tilde{q}_{1,2}, \tilde{\ell}_{1,2}$ 

$\tilde{t}, \tilde{b}, \tilde{\tau}, \tilde{\nu}_3$ 

t 

c 

u 

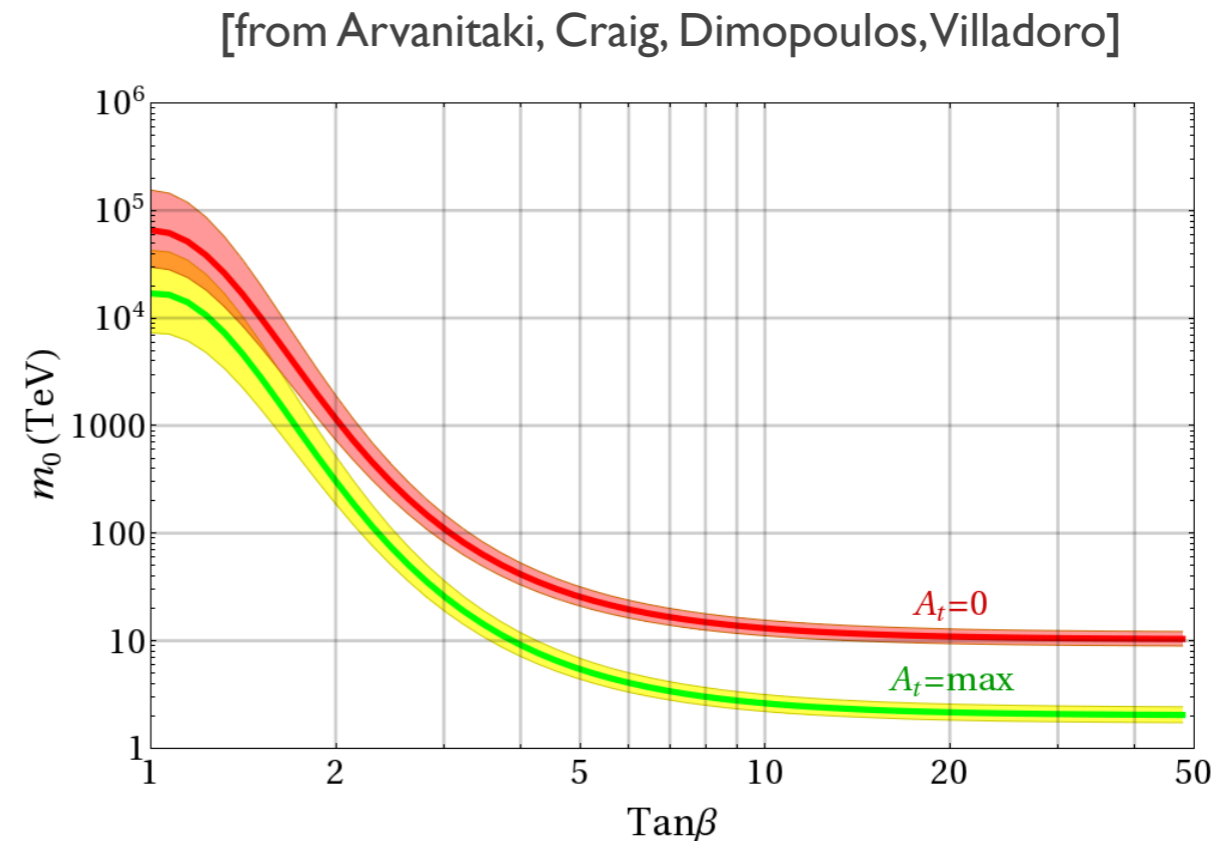
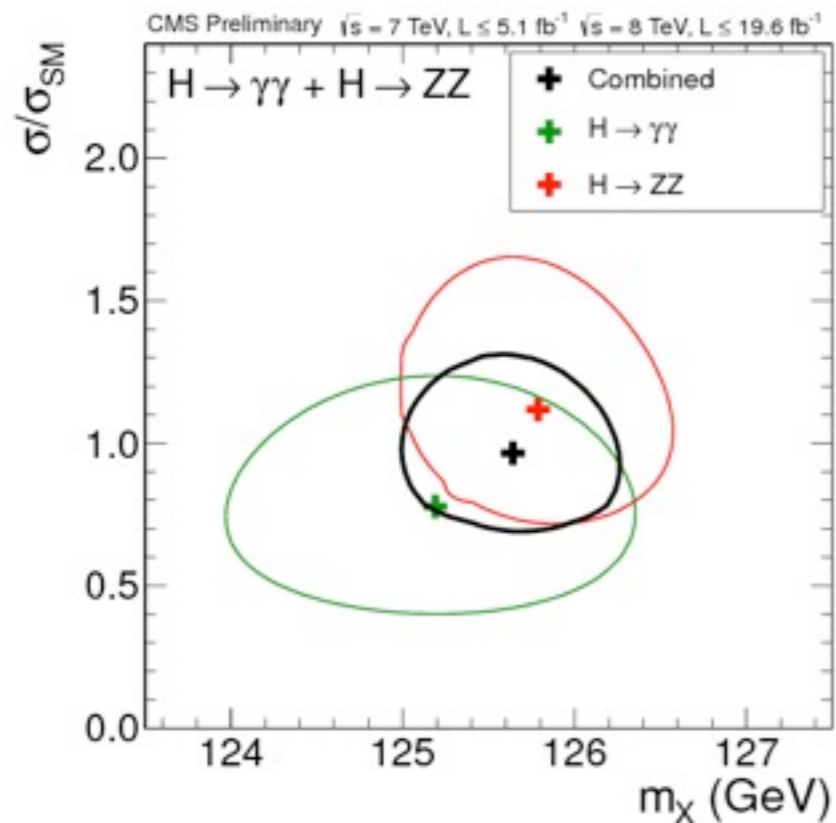
Standard Model
Quark Hierarchy

Desired Natural
Superpartner Hierarchy

If true, expect flavor signals,
e.g. B-meson mixing

[Craig, McCullough, JDT]

Reason for Pessimism: SM-ish Higgs at 126 GeV



*If MSSM, then at least we know
where to look for stops*

Circumstantial evidence for a mini-desert

(Of course, could be NMSSM, λ SUSY, non-decoupling D-terms, ...
split-ish spectrum of heavy sfermions but light gauginos, ...)

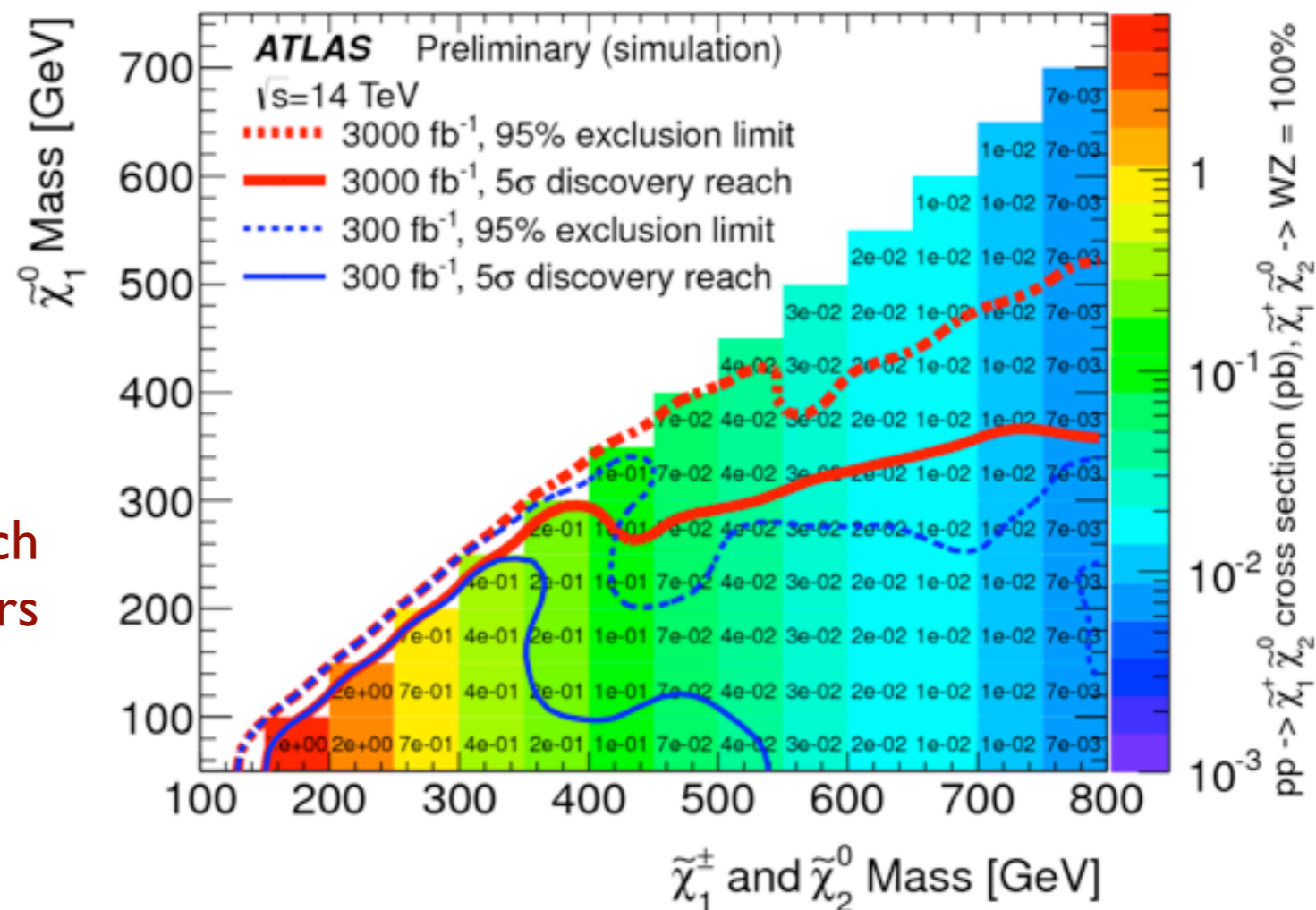
SUSY right around the corner?



Find evidence for superpartners

- ✓ Upgrade LHC to 13/14 TeV
- ✓ Confront challenging kinematics/final states
- ✓ High Luminosity LHC, esp. for background-limited searches

trilepton search
for electroweakino pairs



SUSY right around the corner?



Find evidence for superpartners



Upgrade LHC to 13/14 TeV



Confront challenging kinematics/final states



High Luminosity LHC, esp. for background-limited searches

SUSY right around the *next* corner?



Search for (colored) superpartners



Build a 100 TeV proton-proton machine



Invest longterm in advanced accelerator technology



Consider less direct probes of SUSY



??



(Hope we can check more than one box...)

(I was asked to have an opinion. You should have one as well.)

Wish List for the Frontiers

a.k.a. three oases in the mini-desert?

If sfermions are quasi-decoupled...

Focus on **ubiquitous elements** of SUSY models that are accessible in near-term frontier experiments

Two Higgs Doublet (+ Singlet) Sectors

High-Scale Symmetry Violation (esp. CP)

(Thermal-Relic) Neutralino Dark Matter

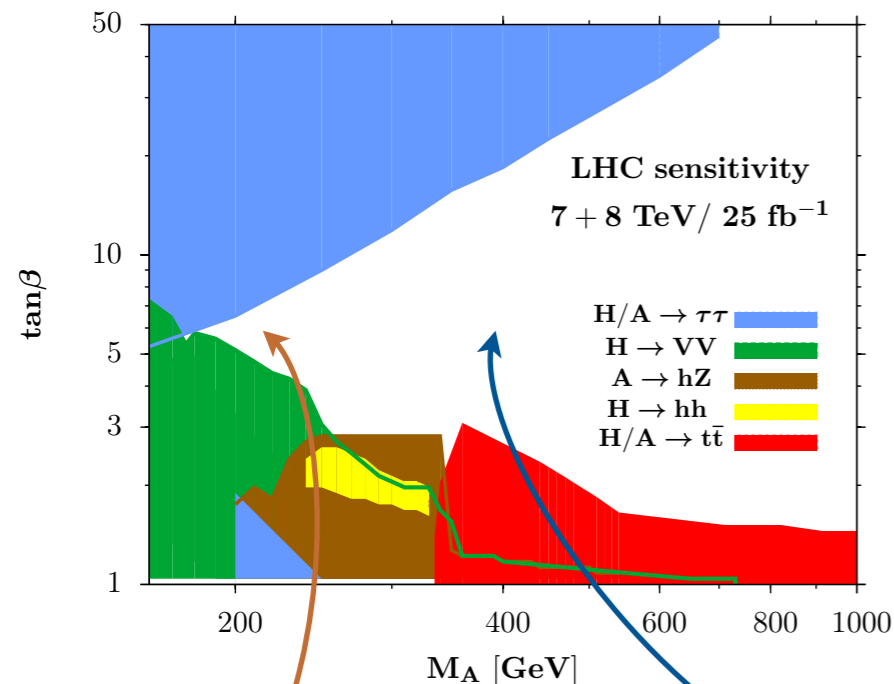
Two Higgs Doublet (+ Singlet) Sectors

$$W = \mu H_u H_d + \lambda S H_u H_d + \dots \quad (\text{apologies to the wrong-Higgs/ inert-Higgs literature})$$

Logical Possibility:

Sfermions are quasi-decoupled
Extra Higgs/singlets still at weak scale

[in MSSM, from Djouadi, Quevillon]



Constrained by h^0 couplings?

The infamous “wedge”

Questions:

- ▶ Direct searches for $H^0/A^0/H^\pm/S^0$ vs. Indirect tests through h^0 properties? [e.g. Craig, Galloway, Thomas; ...]
- ▶ How fast do we hit decoupling regime (from e^+e^- perspective)?
- ▶ Model building? (i.e. alignment without decoupling, RG stability?)

Symmetry-Violating Terms (esp. CP)

$$W = LH_u + QD^c L + U^c D^c D^c + LLE^c + QQQQL + \dots$$

Logical Possibility:

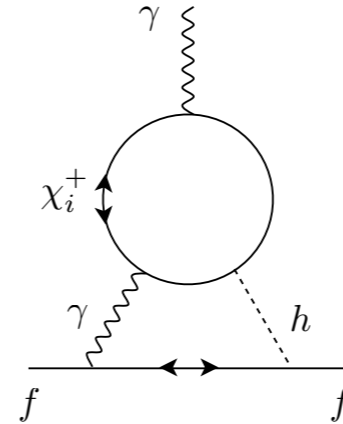
Sfermions are quasi-decoupled
Still remnant symmetry-violation

(B, L, lepton flavor, quark flavor, CP, ...)

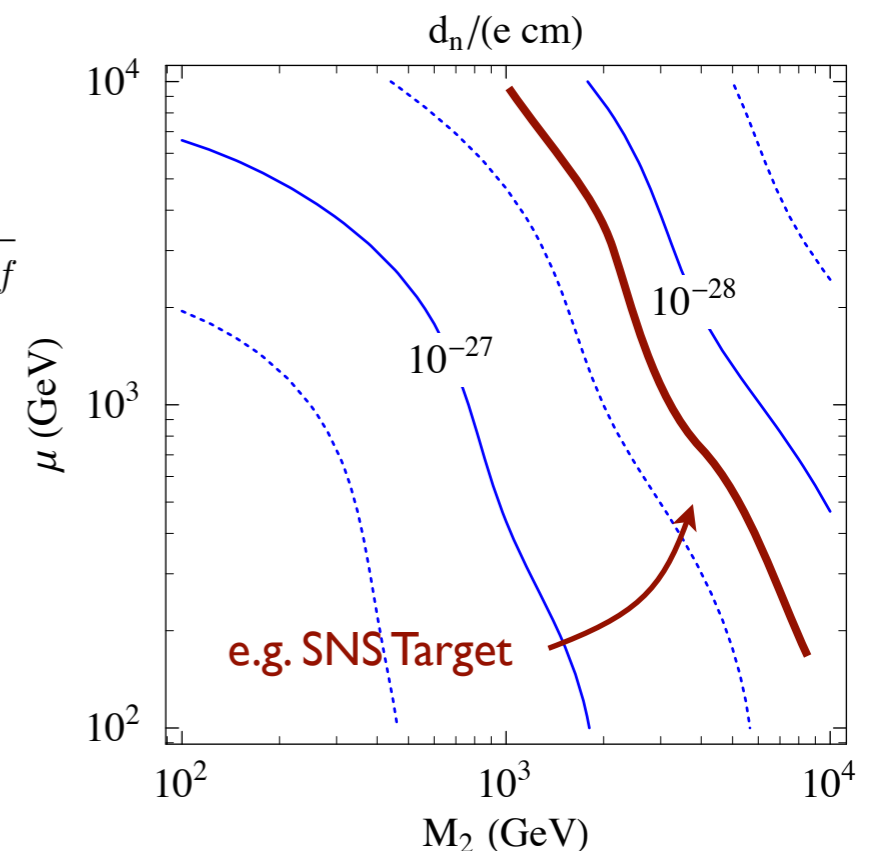
Key Target: EDMs from SUSY CP

e.g. $\phi = \arg(M_i \mu)$

↑ ↑
model-building challenge to make aligned!



[from split SUSY study of two-loop EDMs: Giudice, Romanino]



Question:

- ▶ Motivated targets for B/L/flavor-violation for e.g. 10 TeV sfermions?

(Thermal-Relic) Neutralino Dark Matter

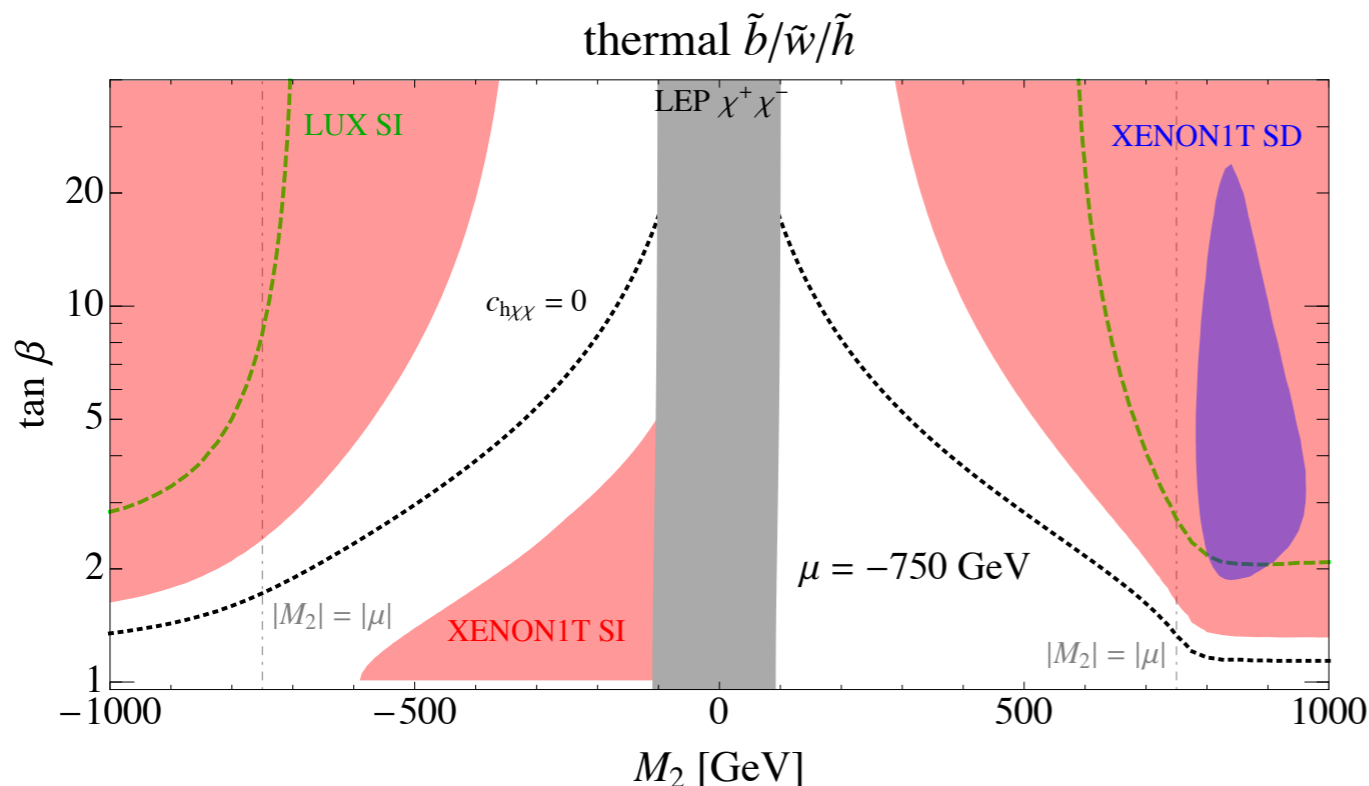
$$\chi_0 = \alpha_1 \tilde{B} + \alpha_2 \tilde{W}_3 + \alpha_3 \tilde{H}_u + \alpha_4 \tilde{H}_d + \alpha_5 \tilde{S} \leftarrow \text{plausible}$$

Logical Possibility:

Sfermions are quasi-decoupled
Still WIMP miracle for neutralinos

(of course, non-thermal/under-abundant also attractive)

[from comprehensive study in Cheung, Hall, Pinner, Ruderman]



Questions:

- ▶ Can indirect detection cover blind spots in direct detection?
- ▶ Ultimate LHC reach of mono-anything searches with decoupled sfermions?

Key Benchmark Dark Matter Scenarios

Plausible thermal relics

(Nearly) Pure Higgsino: 1.0 TeV

(Nearly) Pure Wino: 2.7 TeV

(including Sommerfeld effect)

Direct Detection: Z^0 coupling absent (inelastic for Higgsino)
 h^0 coupling suppressed by purity
Loop-induced couplings suppressed by accident
[$\sigma < 10^{-47}$ cm²; see e.g. Hisano, Ishiwata, Nagata, Takesako]

Indirect Detection: Stringent FERMI/HESS bound for non-thermal winos
Prospects for thermal winos/higgsinos?
CTA? Neutrino Telescopes?

Colliders: Can (futuristic) machine test 2.7 TeV winos?
Even if tiny neutralino/chargino mass splittings?

Summary

An Unreasonable Wish List

Ideally, superpartners could be used as probes to answer structural questions

Supersymmetry in 2013

We are not in that ideal world; Higgs at 126 GeV suggestive of mini-desert

Wish List for the Frontiers

My high priority targets, given ubiquitous elements of SUSY:

Two Higgs Doublet (+ Singlet) Sectors
Symmetry-Violating Terms (esp. CP)
(Thermal-Relic) Neutralino Dark Matter

- + *High Luminosity LHC, esp. for background-limited processes*
- + *Ambitious next-generation energy frontier machine (100 TeV pp?)*