Phenomenology of General Gauge Mediation

SAA, Matt Dolan, Joerg Jaeckel and Valya Khoze, **JHEP 0912:001,2009**.
e-Print: **arXiv:0910.2674** and to appear

Outline

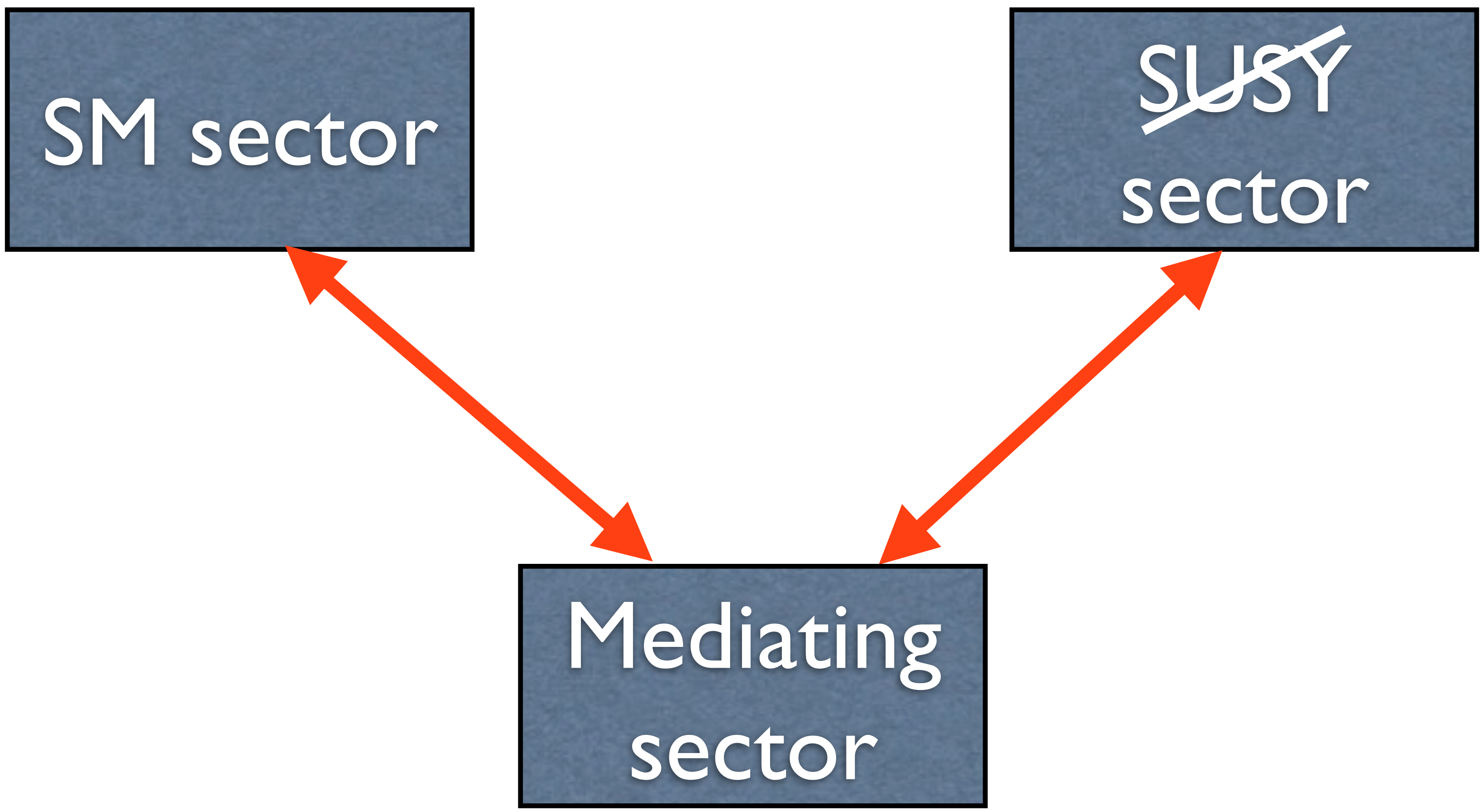
- GGM definition and motivation
- DSB (metastable), two models and two general theorems
- Phenomenology of Pure GGM for LHC @ 7 TeV

Outline

- **GGM definition and motivation**
- DSB (metastable) and two general theorems
- Phenomenology of Pure GGM for LHC @ 7 TeV

“Normal” gauge mediation:

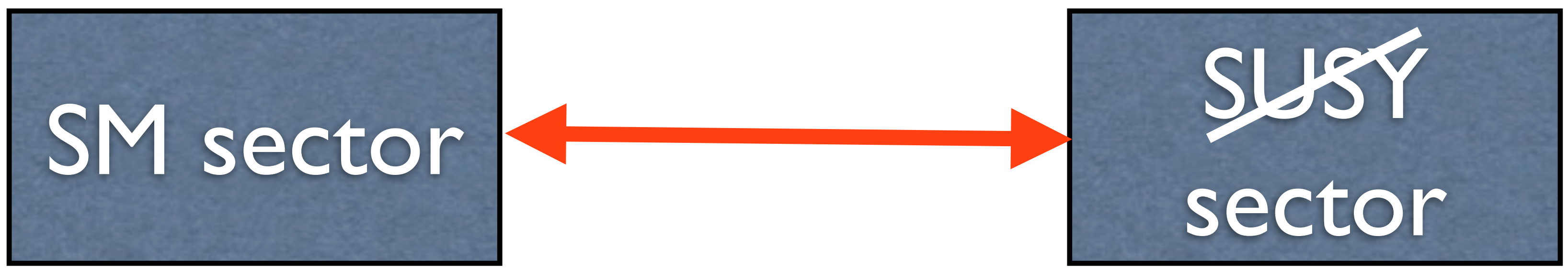
Giudice Rattazzi Phys Rep 1999



$$(f.\tilde{f})\Phi = (f.\tilde{f})(M + \theta^2 F)$$

Universal form for gaugino and sfermion masses - of same order

Direct gauge mediation:



SUSY breaking dynamics now important; can have much smaller gaugino masses

Poppitz Trivedi (1996) ....
Izawa, Momura, Tobe, Yanagida (1997)
Csaki, Shirman, Terning (2006)
Kitano Ooguri Ookouchi (2006)
SAA, Durnford, Jaeckel, Khoze (2007)
SAA, Jaeckel, Khoze, Matos (2008)

General approach:

- Adopt the GGM assumption of Meade, Seiberg and Shih: defined by the requirement that the MSSM becomes decoupled from SUSY breaking sector when $\alpha_1 = \alpha_2 = \alpha_3 = 0$
- They showed that the possible patterns of SUSY breaking (in the MSSM) can be completely determined by 6 combinations of gauge current correlators.
- But what patterns are likely?
- And what underlying physics is associated with each pattern?

Objective: strategy for GMSB pheno at early LHC

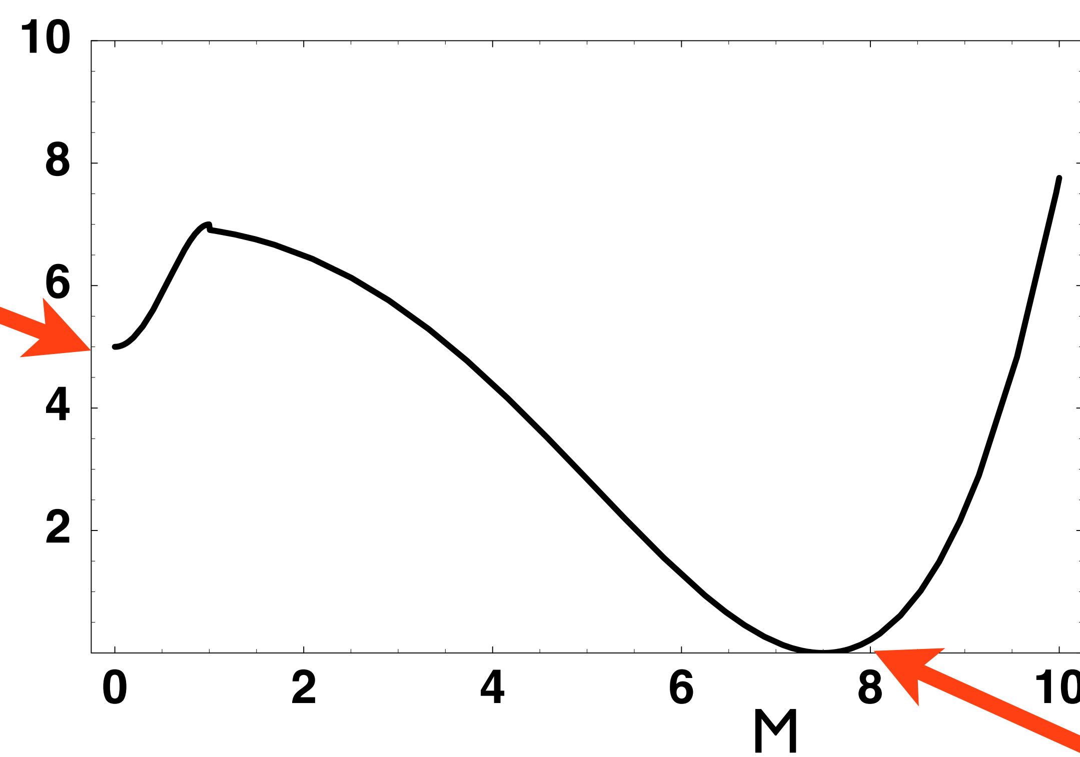
Outline

- GGM definition and motivation
- **DSB (metastable) and two general theorems**
- Phenomenology of Pure GGM for LHC @ 7 TeV

DSB (metastable)

ISS model (2006) inspired much of the current interest (Intriligator Seiberg Shih)

Universe sits here



vacuum is supersymmetric

Nelson-Seiberg Th'm

The origin is metastable because of an *anomalous* R-symmetry

$$W^{ISS} = W_{cl} + W_{dyn}$$

In a generic theory SUSY breaking requires an R-symmetry (Nelson, Seiberg)

But: gaugino mass terms $M_\lambda \lambda^\alpha \lambda_\alpha$ always have non-zero R-charge

So: non-zero gaugino masses require both R-symmetry
and SUSY breaking -> R-symmetry breaking!

Nelson-Seiberg Th'm

Two possible options (NB - the anomalous R-breaking can't give gaugino masses):

1) Explicit R-breaking

$$W = W_{R-sym} + \varepsilon \, W_{R-breaking}$$

a global SUSY minimum develops $\mathcal{O}(1/\varepsilon^{\text{power}})$ away in field space

$$M_\lambda \propto \varepsilon^{\text{power}'}$$

2) Spontaneous R-breaking (or a combination of explicit + spontaneous)

Explicit Breaking example

Murayama and Nomura 2007

How to break an R-breaking gaugino mass without destabilising vacuum? ISS is based on electric/magnetic Seiberg duals - suppose the messenger sector breaks R-symmetry maximally in the electric theory:

$$W_{cl} = W_{cl}^{ISS} + \frac{\lambda}{M_{Pl}} Q\tilde{Q} f \tilde{f} + M f \tilde{f}$$

$$\Downarrow$$

$$W_{cl} = W_{cl}^{ISS} + \frac{\lambda\Lambda}{M_{Pl}} \Phi f \tilde{f} + M f \tilde{f}$$

Explicit Breaking example

Murayama and Nomura 2007

How to break an R-breaking gaugino mass without destabilising vacuum? ISS is based on electric/magnetic Seiberg duals - suppose the messenger sector breaks R-symmetry maximally in the electric theory:

$$W_{cl} = W_{cl}^{ISS} + \frac{\lambda}{M_{Pl}} Q\tilde{Q} f \tilde{f} + M f \tilde{f}$$

$$\Downarrow$$

$$W_{cl} = W_{cl}^{ISS} + \boxed{\frac{\lambda\Lambda}{M_{Pl}}} \Phi f \tilde{f} + M f \tilde{f}$$

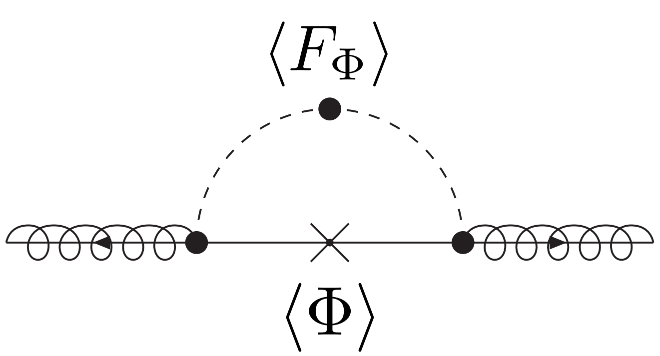
$$:= \varepsilon$$

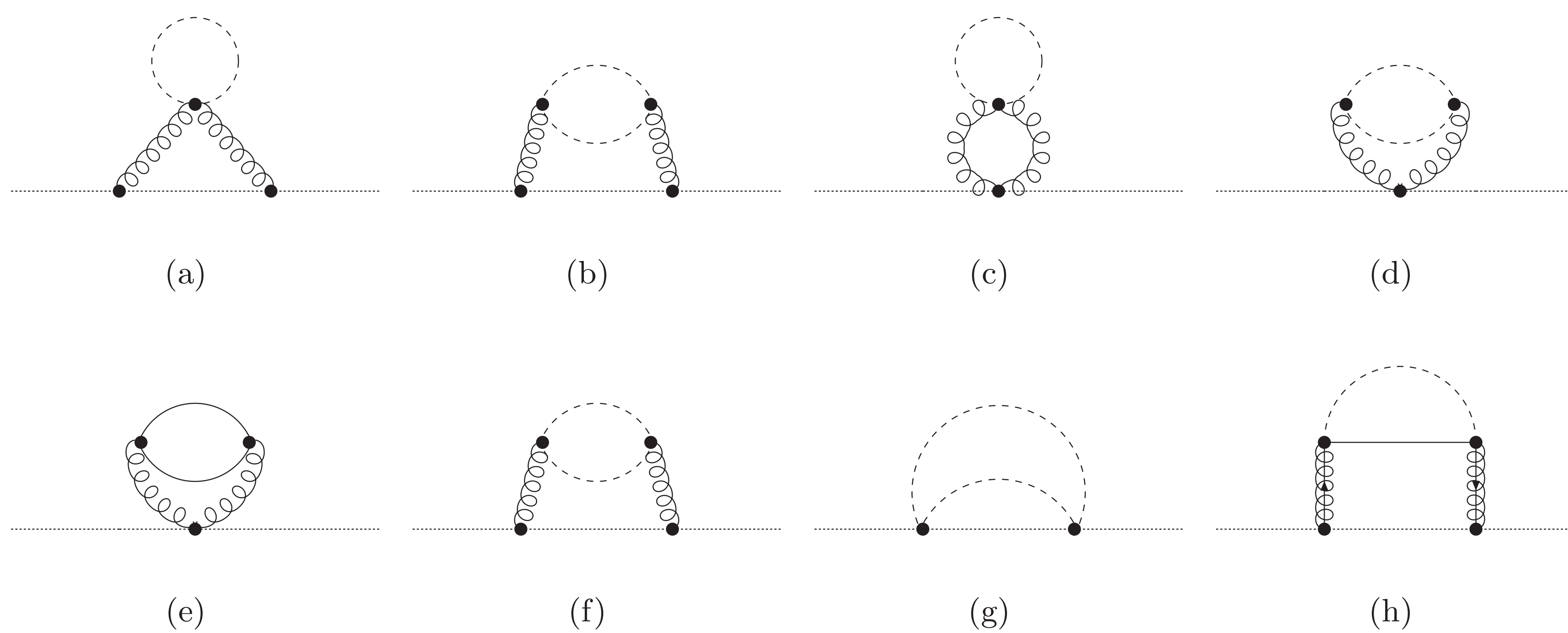
Explicit Breaking example

Murayama and Nomura 2007

Thanks to Nelson-Seiberg, a new lower vacuum appears but far away ...

The model generates gaugino and scalar masses of the same order - but you have to be reasonably careful to avoid vacuum decay





Spontaneous Breaking example

Can simply “deform” ISS for direct gauge mediation (SAA, Durnford, Jaeckel, Khoze)

$$W_{cl} = W_{cl}^{ISS} + m\varepsilon_{ab}\varepsilon^{rs} q_r^a q_s^b$$

where $r, s = 1, 2$ are the 1st and 2nd “flavour” numbers.

and $a, b = 1, 2$ are gauge indices.

Gauge the remaining 5 flavours: $SU(5)_f \supset G_{SM}$

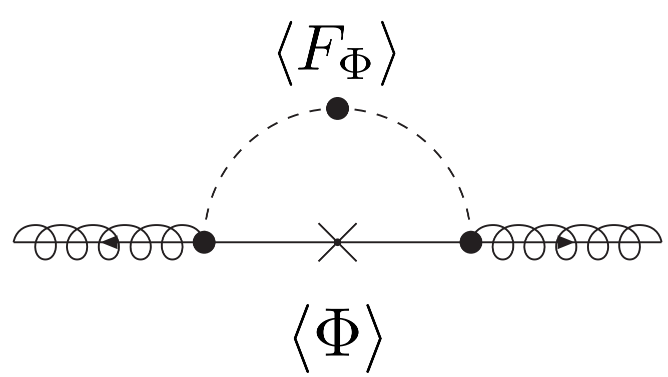
Because of the deformation Φ develops a VEV, and R-is broken.

Spontaneous Breaking example

The mediators are $q^a_{i=1..5}$ and $\tilde{q}^{i=1..5}_a$ and the typical scalar mass is

$$m_{scalar} \sim \frac{g_A^2}{16\pi^2}\mu_2$$

But ... this is a model of ‘slightly split SUSY‘ - gaugino masses are zero at tree-level. Typically suppressed by a factor of a few * 10 (similar to the effect found by Izawa, Momura, Tobe, Yanagida in 1997)



$$= 0$$

Why? Komargodski and Shih Th'm

If there is a non-zero gaugino mass at leading order then there will be some value of pseudo-Goldstone mode (i.e.$\langle\Phi\rangle$*) with tachyonic messengers.*

Non-zero gaugino masses require a lower lying vacuum at some point in moduli space, *at tree-level* (note that the basic ISS model does not have this).

Hybrid model

(SAA, Jaeckel, Khoze)

Simplest way to see this in action: bring in a lower lying vacuum from infinity by having explicit R-breaking messenger:

$$W_{cl} = W_{cl}^{ISS} + W^{deform} + W^{MN}$$

Hybrid model

(SAA, Jaeckel, Khoze)

At leading order gaugino masses from explicit f-messengers only, but scalars from both q and f-messengers.

$$\frac{M^2_{gaugino}}{m^2_{scalar}} \sim N_f . \frac{1}{1 + \frac{N_q}{N_f}\left(\frac{M_f}{\lambda\mu_5}\right)^2}$$

The distance away in field space of the lower vacuum is $\Phi \sim M_f/\lambda$

As this is brought in from infinity, the SUSY breaking goes from being infinitely split to standard ~ 1.

Outline

- GGM definition and motivation
- DSB (metastable), two models and two general theorems
- **Phenomenology of Pure GGM for LHC @ 7 TeV**

"Pure" means no additional generation of Higgs "B term".
This must be generated radiatively -> large tan beta (Rattazzi, Sarid; Gabrielli Sarid)

General set-up for phenomenological study

Take Pure GGM parameter space and restrict to single effective scale for the gaugino masses and for the scalar masses

- includes any scenario with preserved GUT structure in mediation
- captures the main effects of R-symmetry and metastability
- is equivalent to $m_0,\ m_{1/2}$ in CMSSM
- in contrast with other work (e.g. Carpenter; Rajaraman, Shirman, Smidt, Yu)

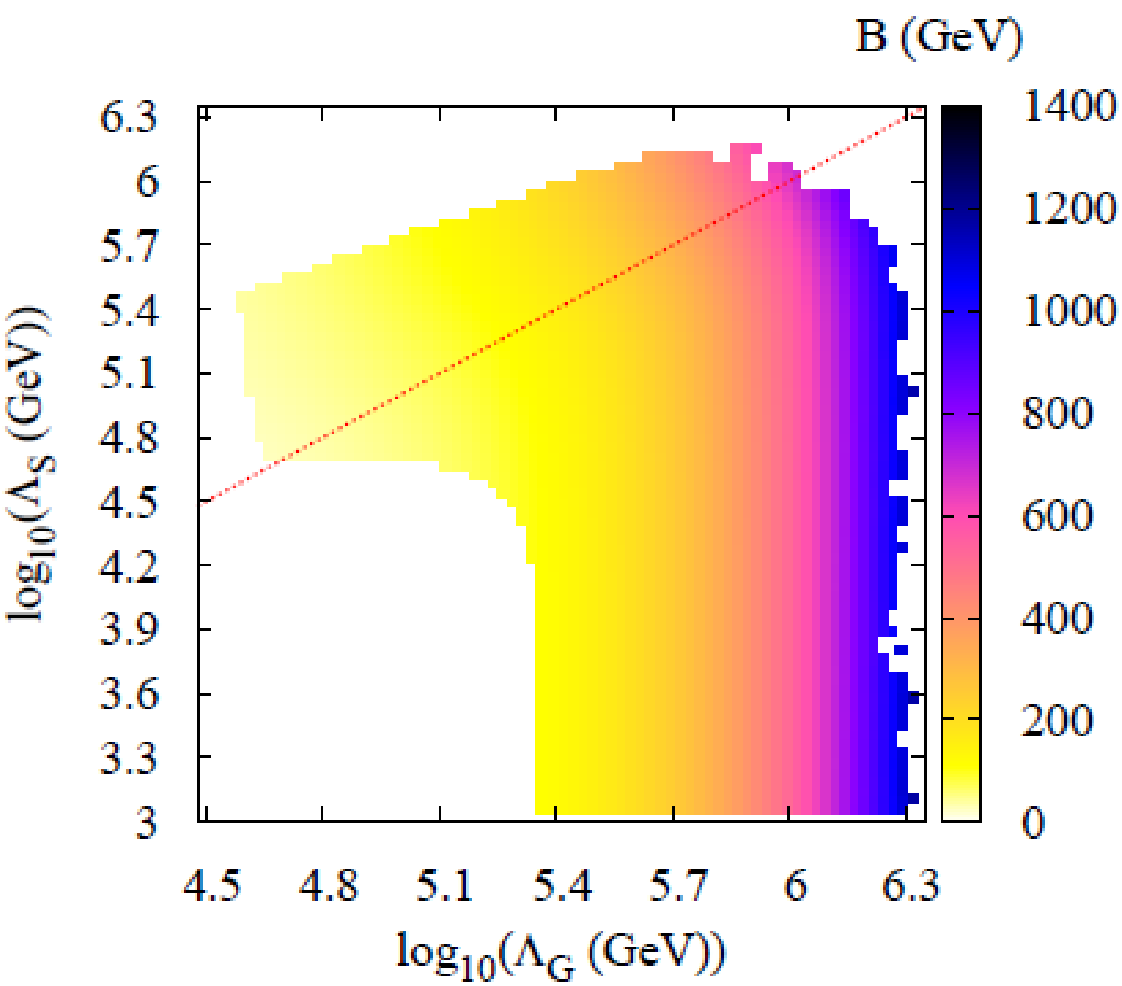
$$M_{\tilde{\lambda}_i}(M_{mess}) = k_i \frac{\alpha_i(M_{mess})}{4\pi} \Lambda_G$$

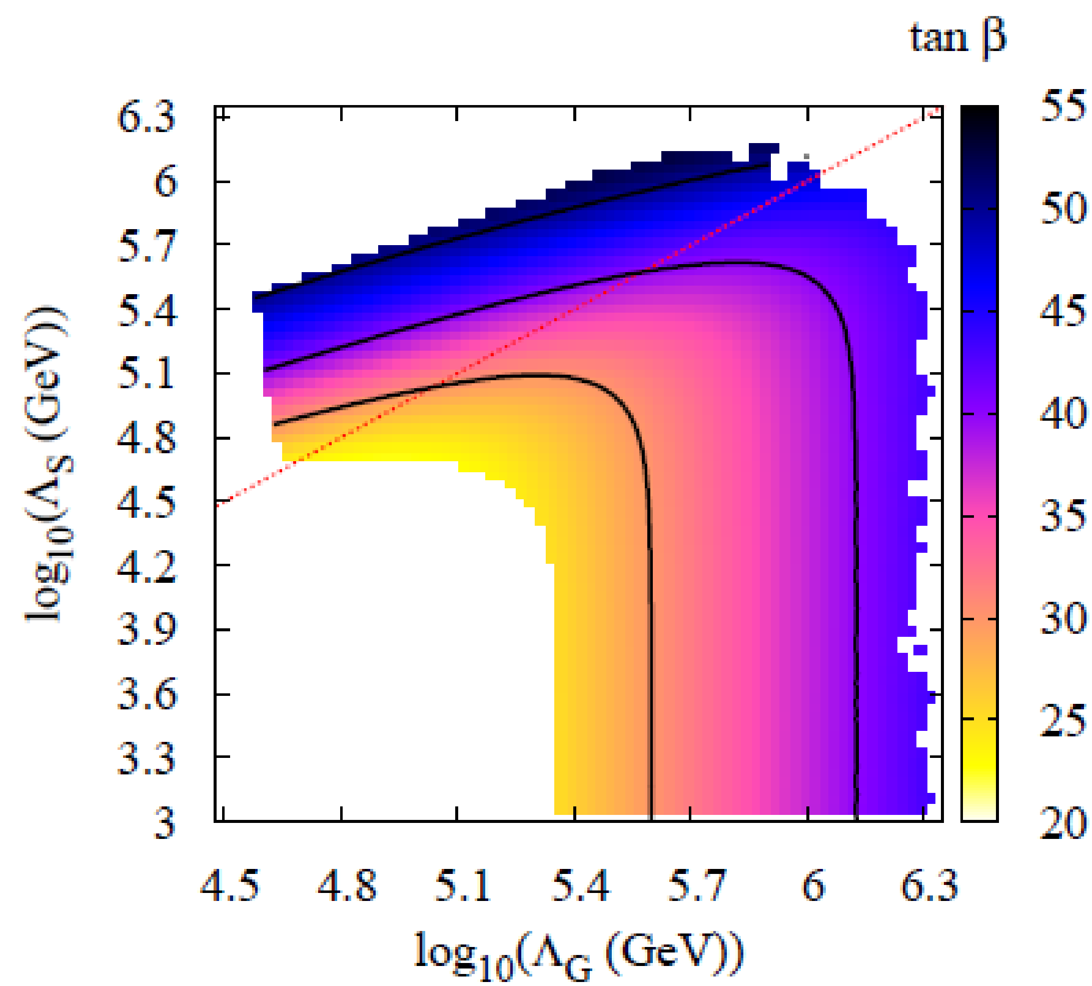
$$m^2_{\tilde{f}}(M_{mess}) = 2 \sum_{i=1}^{3} C_i k_i \frac{\alpha_i^2(M_{mess})}{(4\pi)^2} \Lambda_S^2$$

where C's are quadratic Casimir operators of gauge groups, $k_i = (5/3, 1, 1)$ and $k_i \alpha_i$ are equal at the GUT scale.

B and tan beta at low energy

e.g. take intermediate messenger scale: $M_{mess} = 10^{10}$ GeV ***(SoftSUSY***: Allanach)

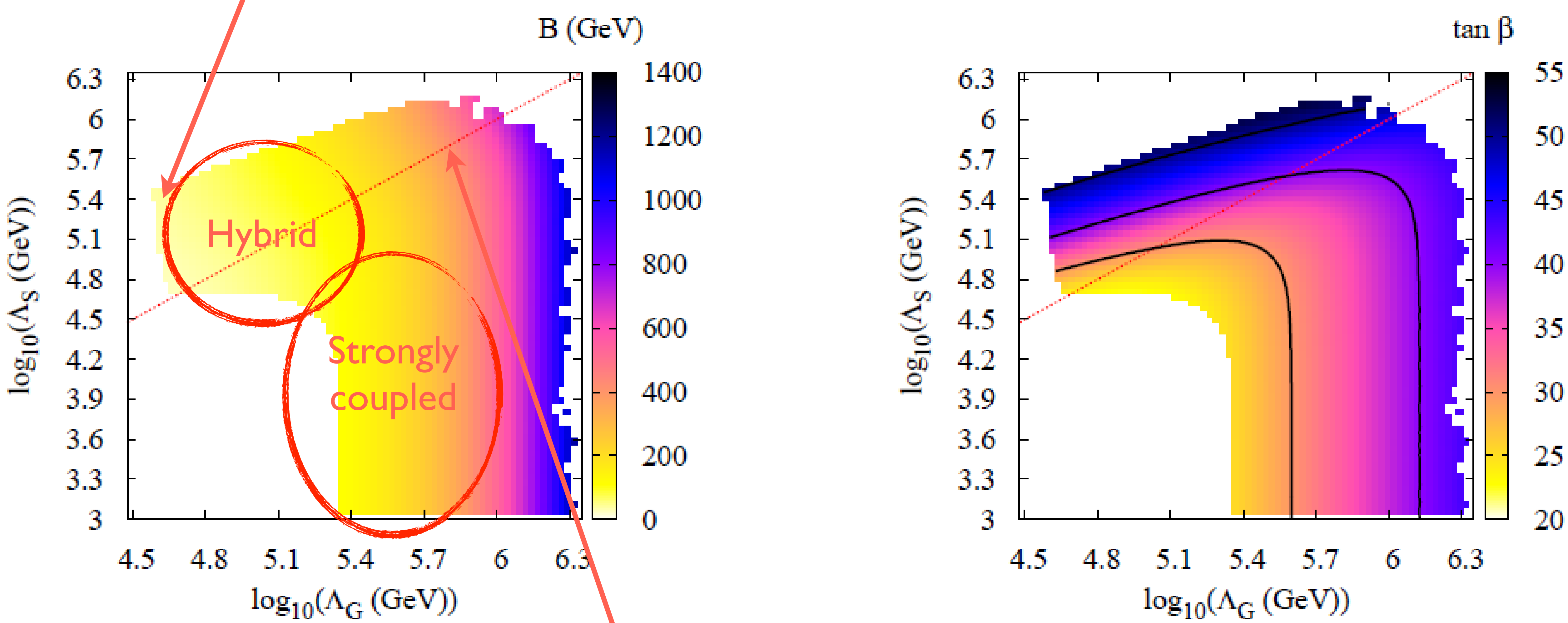




B and tan beta at low energy

Direct mediation with spontaneous R-breaking

e.g. take intermediate messenger scale: $M_{mess} = 10^{10}$ GeV



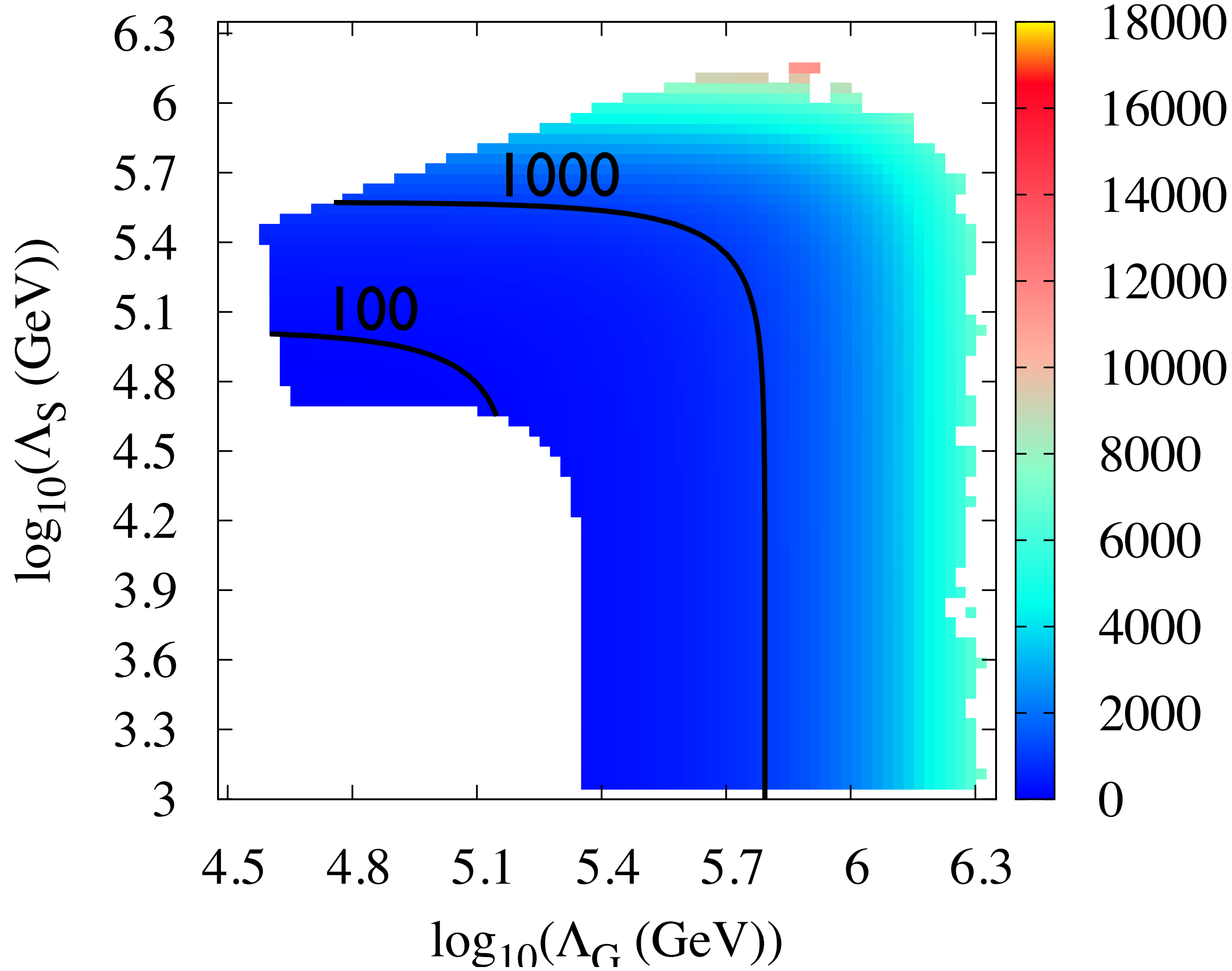
Standard gauge mediation line

Fine tuning

Dominated by scalar masses which decrease when either Λ_G or Λ_S decrease.
So starting at the line of standard gauge mediation and going to the split scenario by decreasing Λ_G does not increase tuning

$$c_a \equiv \left| \frac{\partial \ln M_Z^2}{\partial \ln a} \right|$$

(Barbieri, Strumia; de Carlos, Casas)



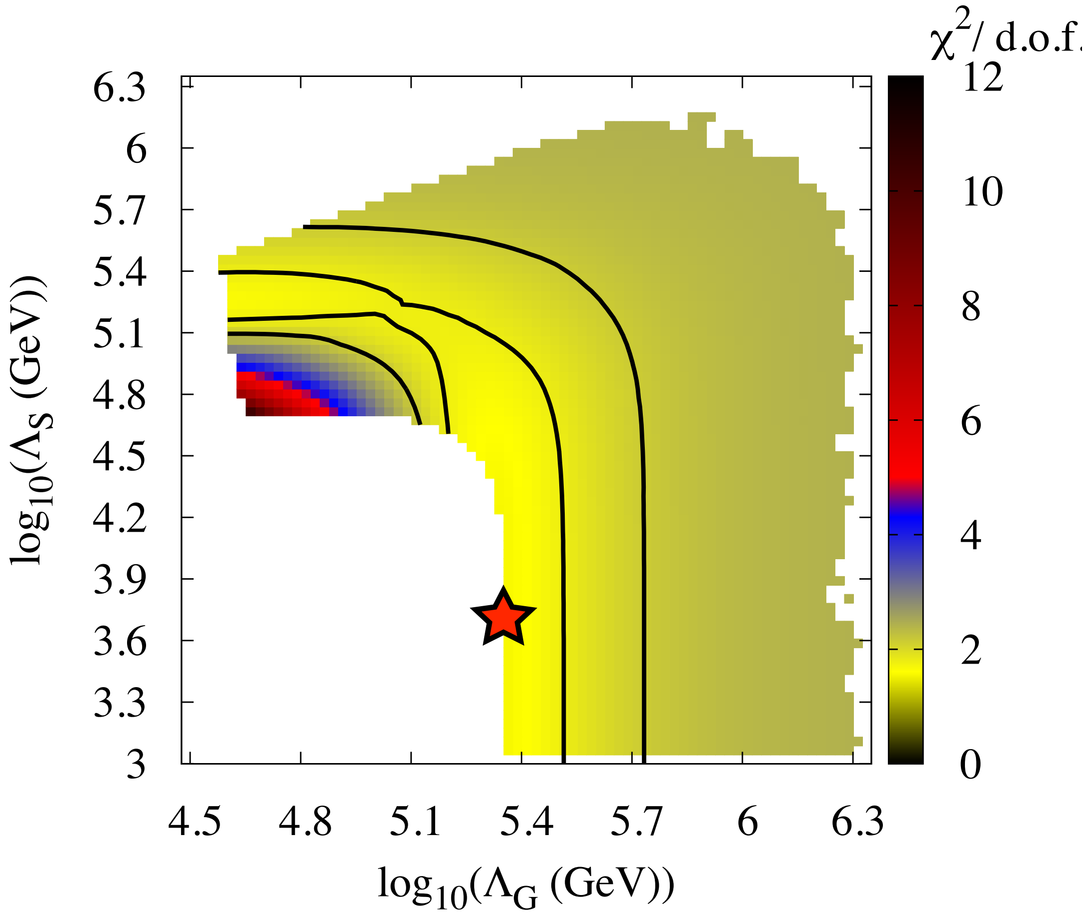
Experimental constraints

To compare with Normal Gauge mediation, look at general scalar and gaugino masses in gauge mediation and apply experimental bounds ...

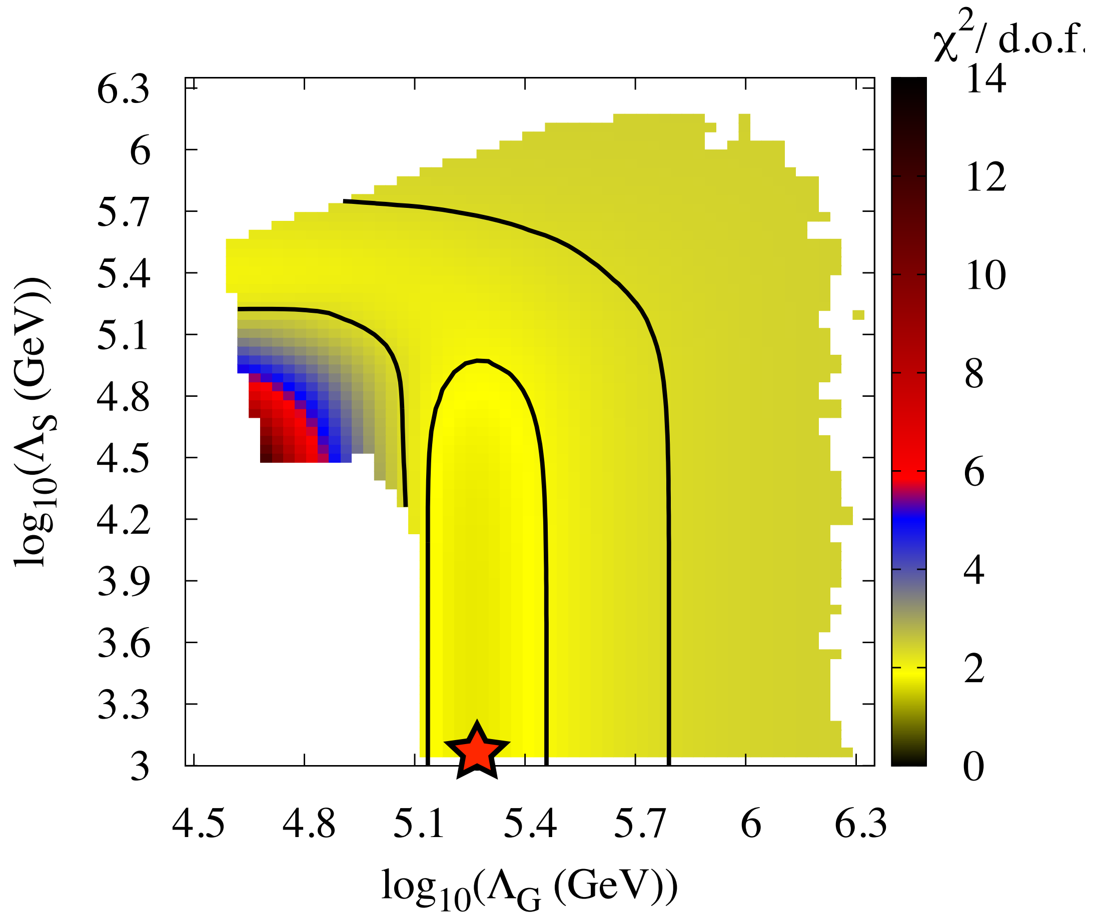
Observable	Constraint
$\delta a_\mu \times 10^{10}$	29.5 ± 8.8
$m_h[\mathrm{GeV}]$	> 114.4 GeV
$BR(B \to X_s \gamma) \times 10^4$	3.28 ± 0.29
$BR(B_s \to \mu^+ \mu^-)$	$< 5.8 \times 10^{-8}$
$BR(B \to D \tau \nu)$	0.416 ± 0.138
$BR(D_s \to \tau \nu)$	$5.7 \pm 0.5 \times 10^{-2}$
$BR(D_s \to \mu \nu)$	$5.7 \pm 0.5 \times 10^{-3}$
$R_{B\tau\nu}$	1.9 ± 0.60
Δ_{0-}	$0.031^{+0.03}_{-0.025}$
R_{l23}	1.004 ± 0.007

Experimental constraints

Fit doesn't favour degenerate SUSY breaking for scalars and gauginos



messenger scale = 10^{10}



messenger scale = 10^{14}

NLSP

The NLSP can eventually decay to the LSP (the gravitino)

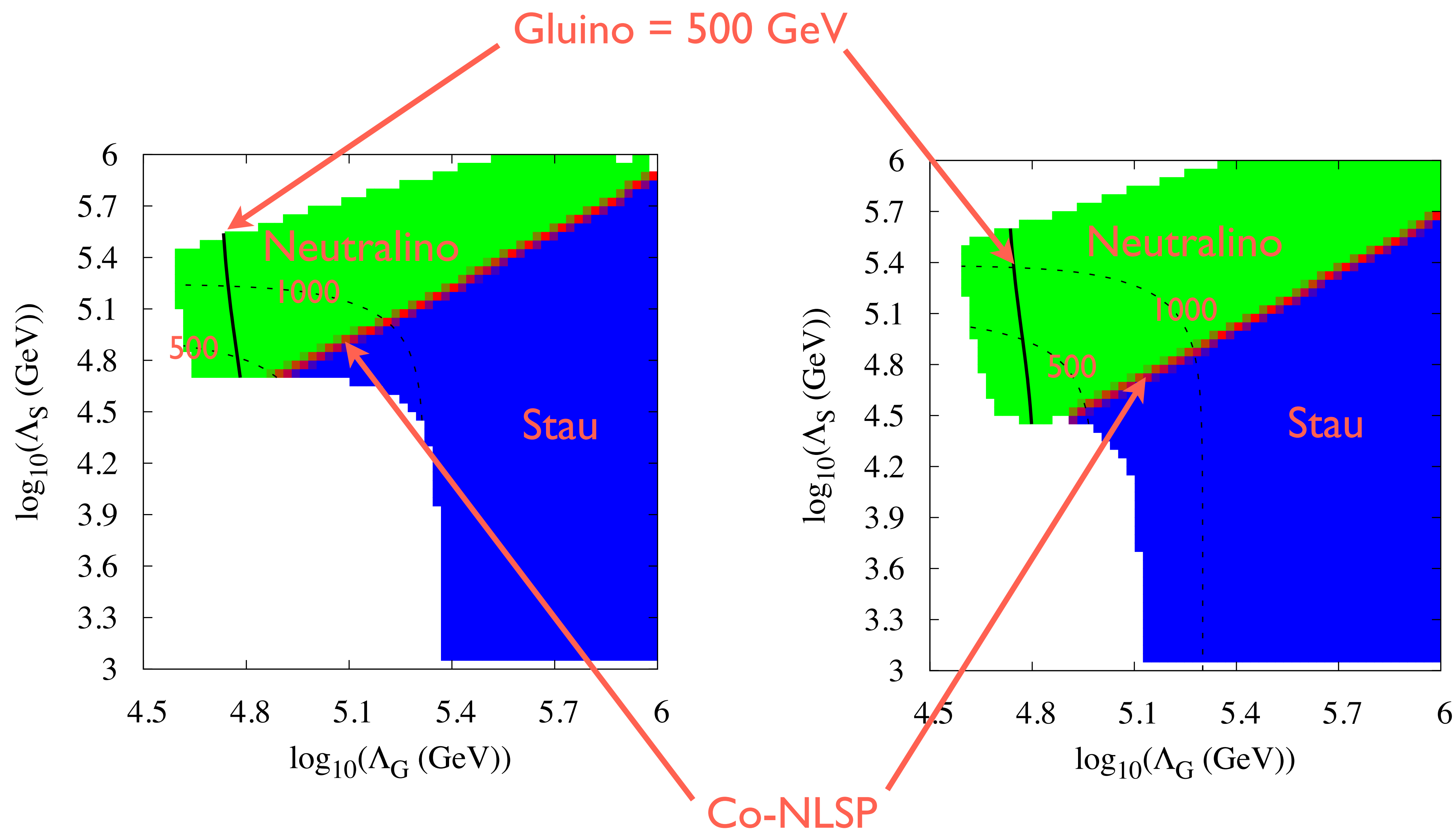
•Neutralino: displaced vertex with decay to photon $(\chi_1^0 \to \tilde{G}\gamma)$
or jet/lepton pairs $(\chi_1^0 \to \tilde{G}Z \to \tilde{G} + jets/l\bar{l})$

•Stau: displaced vertex with ionization track and decay
predominantly to jets $(\tilde{\tau}_R \to \tilde{G}\tau \to \tilde{G}\nu_\tau + jets/l'\bar{l})$

•Co-NLSP: neutralino/stau mass difference less than tau-mass - mix of two

NLSP

The NLSP is either neutralino or stau or co-NLSP



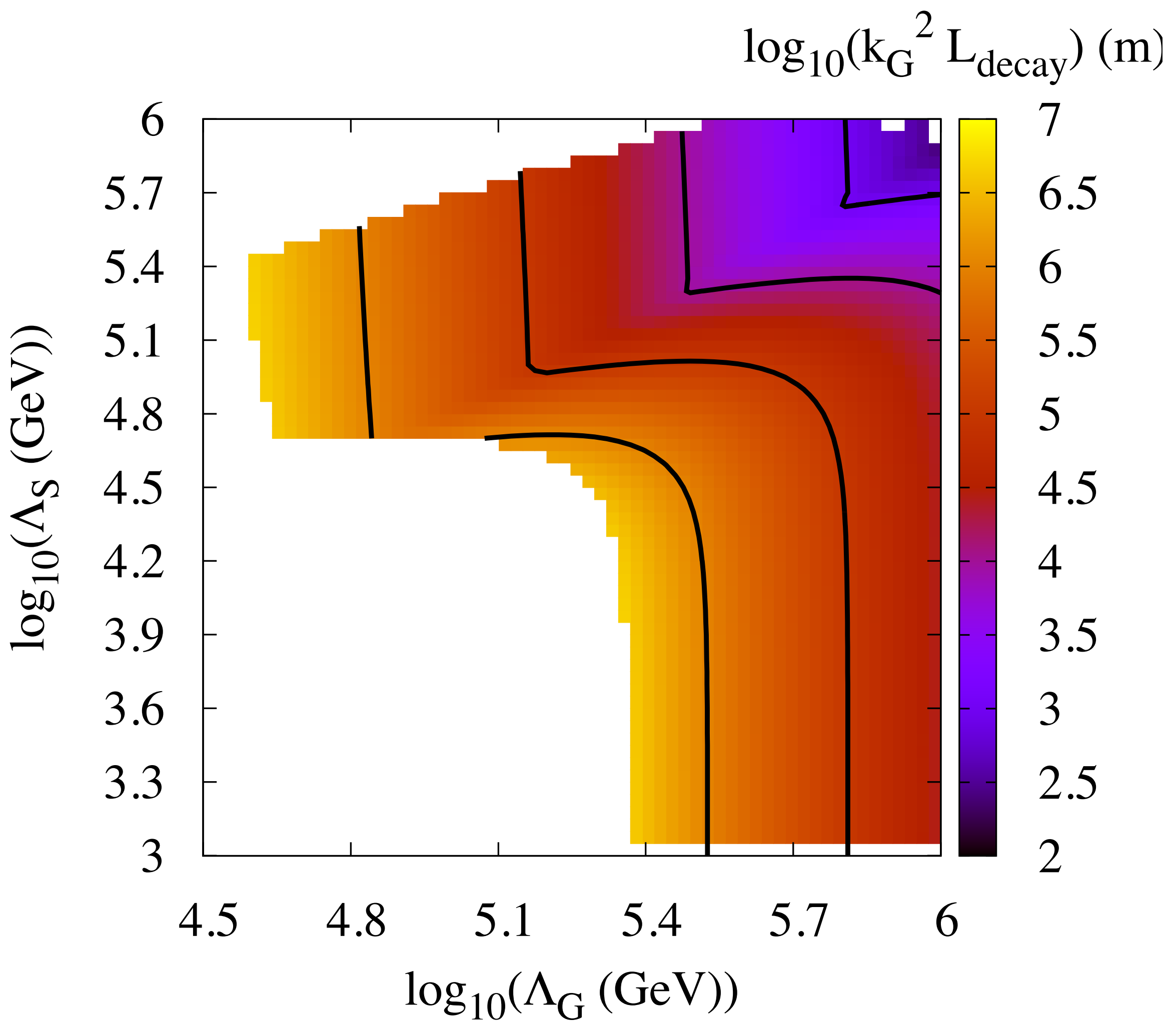
NLSP

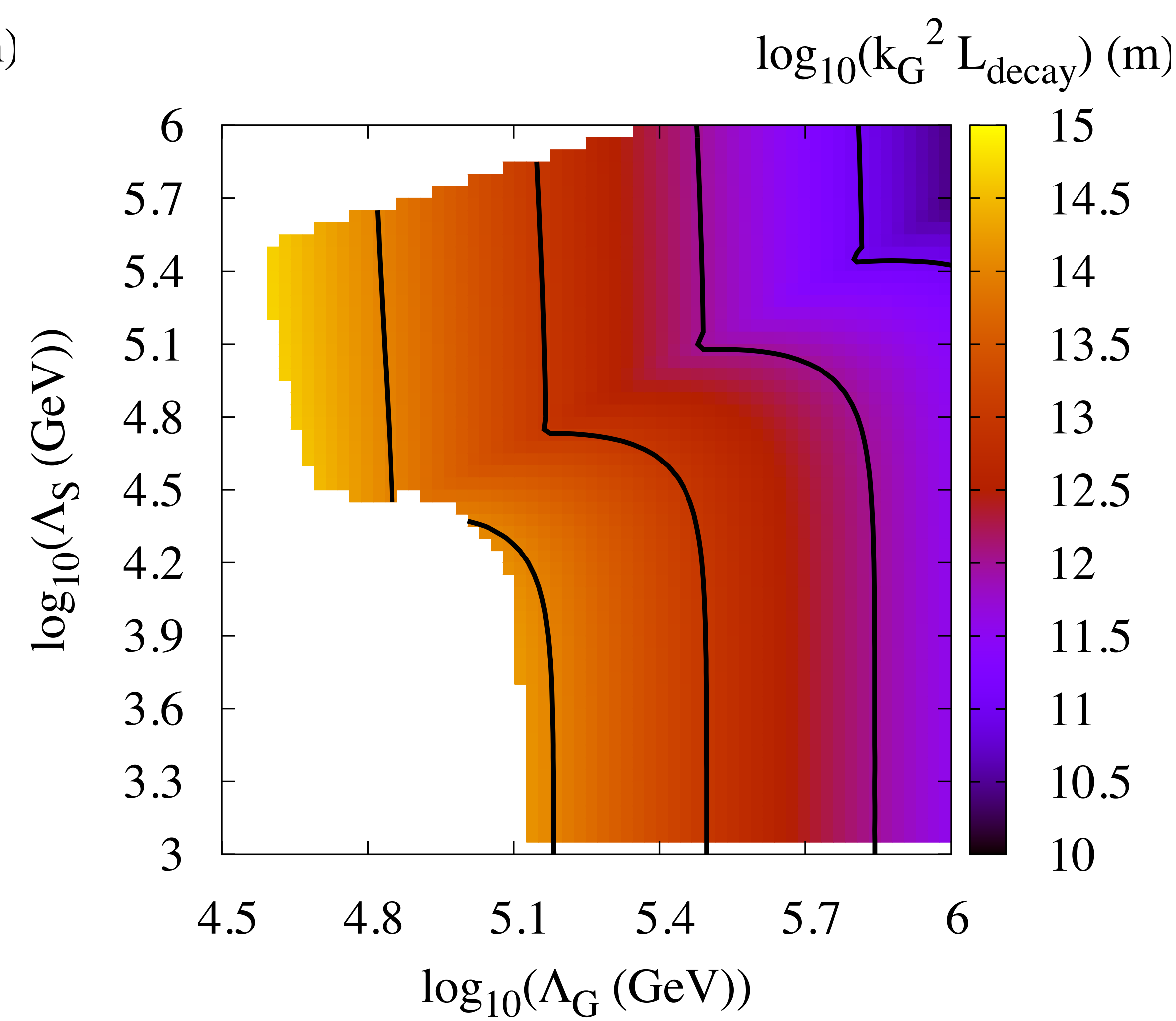
Decay inside detector?

(Bagger Matchev Pierce Zhang)

$$k_G^2 L_{decay} = \frac{1}{\kappa}\left(\frac{100\,\mathrm{GeV}}{m_{NLSP}}\right)^5\left(\frac{\sqrt{\Lambda_G M_{mess}}}{100\,\mathrm{TeV}}\right)^4 0.1\,\mathrm{mm}$$

where κ is of order one (mixing in NLSP) and k_G is the effective number of messengers to the gaugino ($\Lambda_G = k_G F_0/M_{mess}$)

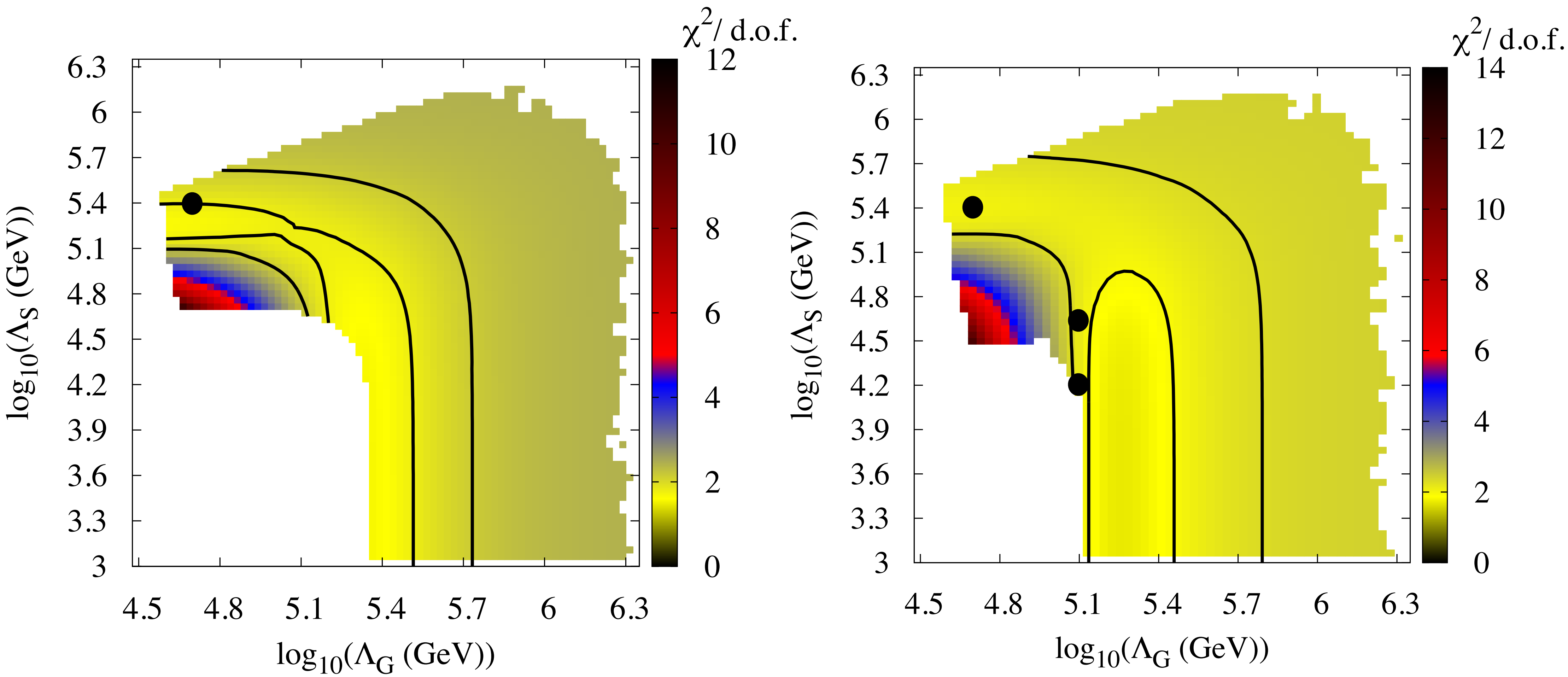




Benchmark points

http://www.ippp.dur.ac.uk/~SUSY

Two light gluino points (direct mediation), a stau NLSP point (many messengers/ strong coupling) and a co-NLSP point (close to ordinary GM)



messenger scale = 10^{10} messenger scale = 10^{14}

Benchmark point	PGM1a	PGM1b
M_{mess} (GeV)	10^{10}	10^{14}
Λ_G (GeV)	5×10^4	5×10^4
Λ_S (GeV)	2.5×10^5	2.5×10^5
$\tan\beta$	46.6	41.2
χ_1^0	**67**	**67**
χ_2^0	136	133
χ_3^0	1038	936
χ_4^0	1039	938
$\chi_1^\pm$	136	134
$\chi_2^\pm$	1039	937
$\tilde{g}$	**458**	**453**
$\tilde{e}_L, \tilde{\mu}_L$	927	1013
$\tilde{e}_R, \tilde{\mu}_R$	540	712
$\tilde{\tau}_1$	392	544
$\tilde{\tau}_2$	898	964
$\tilde{\nu}_{1,2}$	925	1011
$\tilde{\nu}_3$	889	958
$\tilde{t}_1$	1418	1050
$\tilde{t}_2$	1729	1471
$\tilde{b}_1$	1578	1287
$\tilde{b}_2$	1731	1471
$\tilde{u}_L, \tilde{c}_L$	2011	1760
$\tilde{u}_R, \tilde{c}_R$	1803	1520
$\tilde{d}_L, \tilde{s}_L$	1983	1734
$\tilde{d}_R, \tilde{s}_R$	1774	1460
h_0	116.9	115.3
A_0, H_0	944	1032
$H^\pm$	947	1035

Benchmark points

http://www.ippp.dur.ac.uk/~SUSY

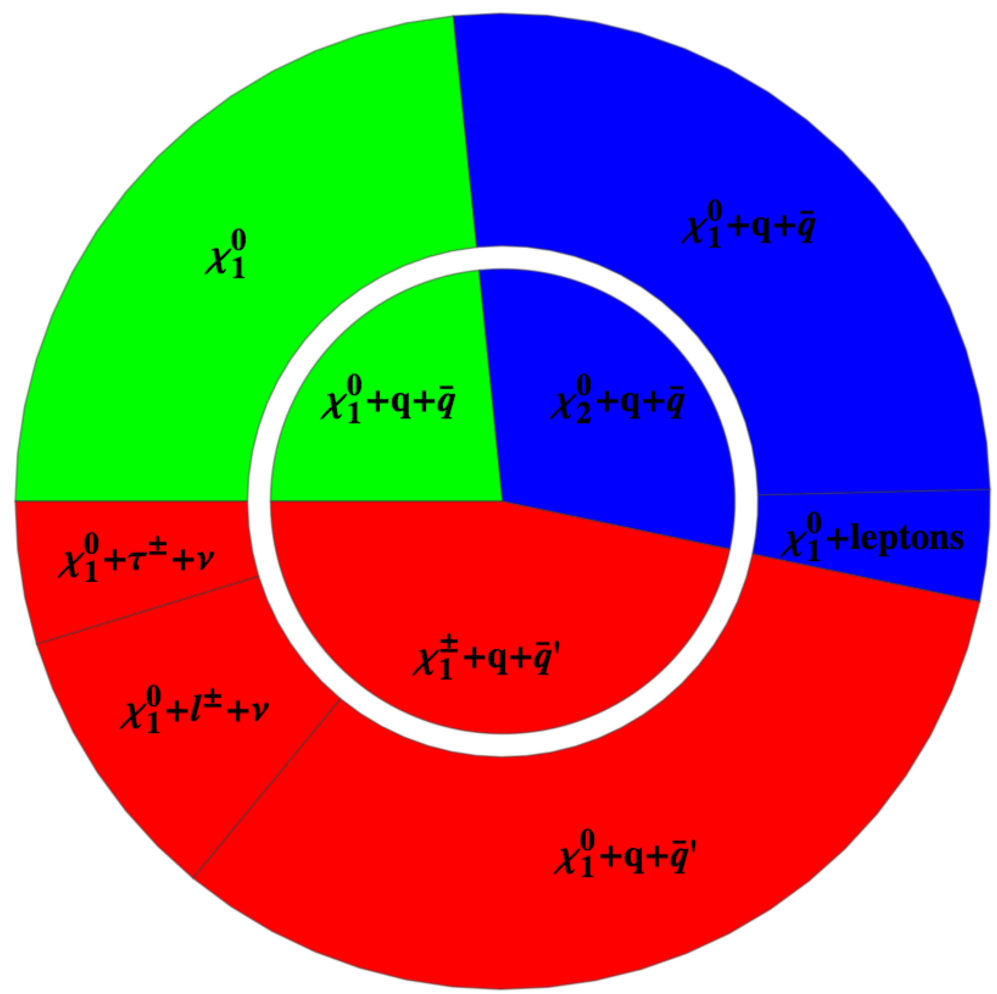
Production at 7TeV: most important processes (***Prospino2.1***:Beenakker, Hopker Spira Plehn)

Benchmark Point	$\sigma_{pp\to\tilde{g}\tilde{g}}$	$\sigma_{pp\to\chi_2^0\chi_1^\pm}$	$\sigma_{pp\to\chi_1^+\chi_1^-}$	$\sigma_{pp\to\tilde{g}\tilde{q}}$
PGM1a	4090	2682	1320	18.9
PGM1a	4340	2835	1390	58.7

Benchmark Point	$\sigma_{pp\to\tilde{g}\tilde{g}}$	$\sigma_{pp\to\tilde{q}\tilde{q}}$	$\sigma_{pp\to\tilde{g}\tilde{q}}$	$\sigma_{pp\to\tilde{q}\bar{\tilde{q}}}$	$\sigma_{pp\to\tilde{\tau}_i\tilde{\tau}_j}$	$\sigma_{pp\to\chi_2^0\chi_1^\pm}$
Stau	17	190	164	54	91	49
Co-NLSP	16	133	128	34	17	50

Decays of gluino:

(***SUSY-HIT***:Djouadi Muehlleitner Spira)



Summary

- Direct, indirect and hybrid scenarios can cover much of available gauge mediation parameter space - including ordinary and mildly split
- A strategy for phenomenology that captures the effects of the vacuum structure is to analyse in Λ_S, Λ_G parameter space.
- Pure General Gauge Mediation phenomenology is accessible at 7TeV in a number of interesting scenarios
- Light gluino (with neutralino NLSP), stau-NLSP and co-NLSP phenomenology
- SLHA data for benchmark points at http://www.ippp.dur.ac.uk/~SUSY