General Gauge Mediation Phenomenology

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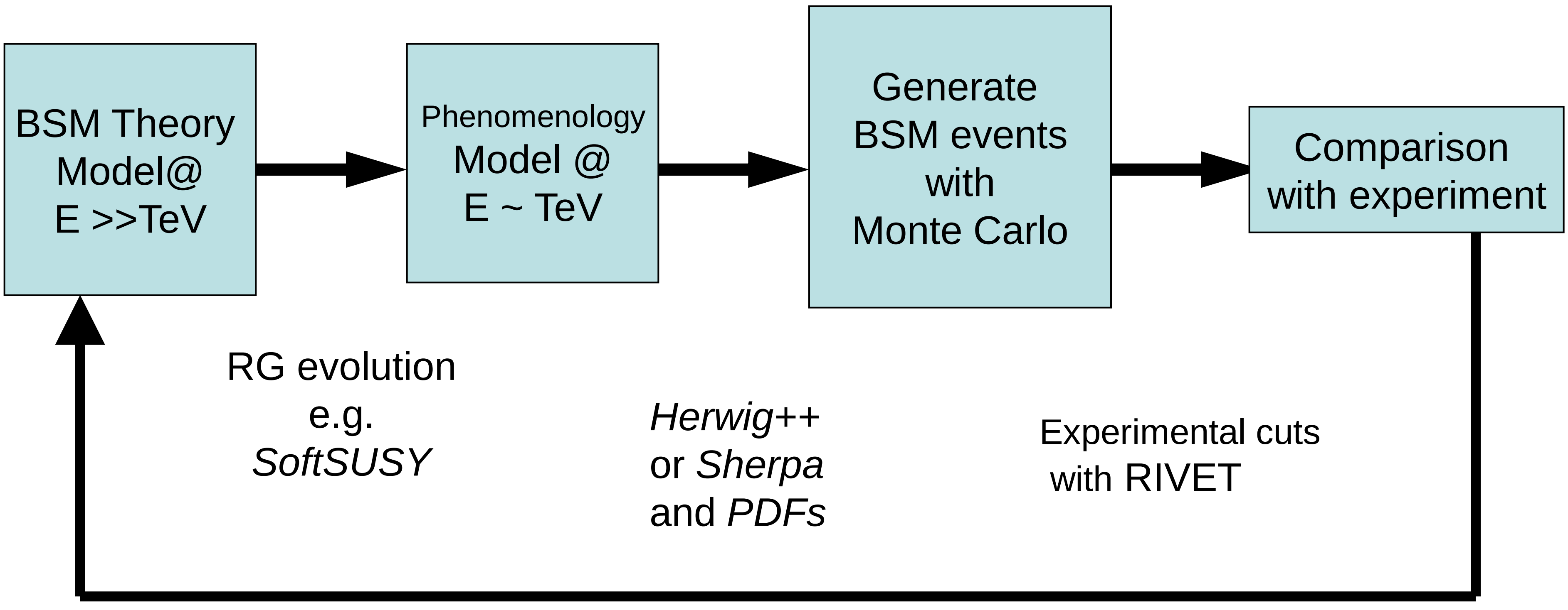
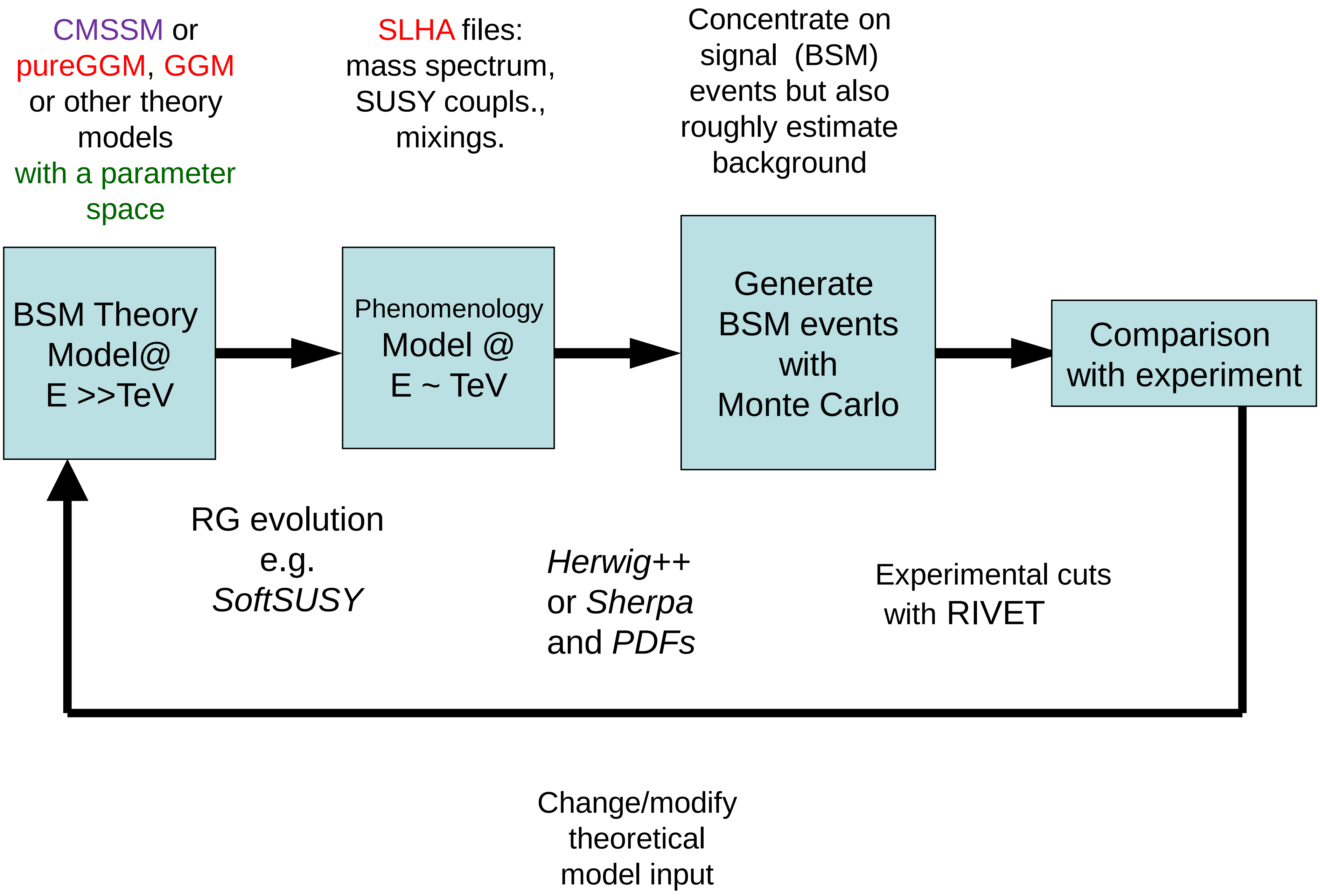
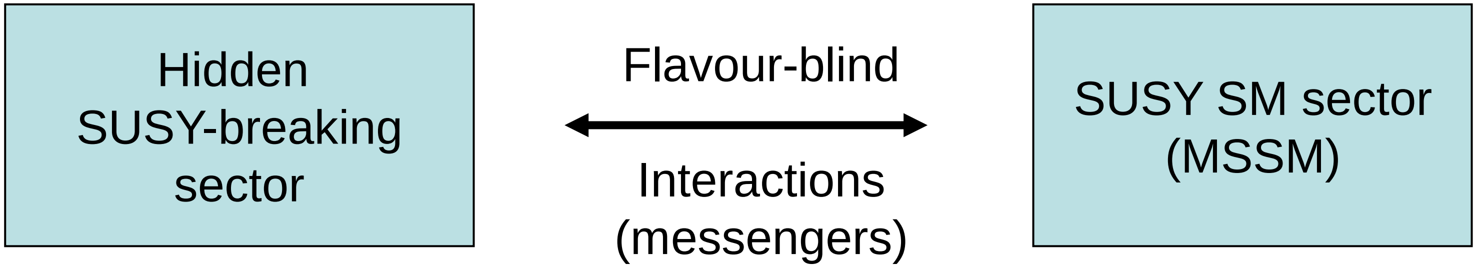


BSM Theory
Model@
E >>TeV
Phenomenology
Model @
E ~ TeV
Generate
BSM events
with
Monte Carlo
Comparison
with experiment
RG evolution
e.g.
SoftSUSY
Herwig++
or *Sherpa*
and *PDFs*
Experimental cuts
with RIVET


CMSSM or
pureGGM, GGM
or other theory
models
with a parameter
space
SLHA files:
mass spectrum,
SUSY coupls.,
mixings.
Concentrate on
signal (BSM)
events but also
roughly estimate
background
BSM Theory
Model@
E >>TeV
Phenomenology
Model @
E ~ TeV
Generate
BSM events
with
Monte Carlo
Comparison
with experiment
RG evolution
e.g.
SoftSUSY
Herwig++
or Sherpa
and PDFs
Experimental cuts
with RIVET
Change/modify
theoretical
model input

SUSY-breaking and mediation

- SUSY is dynamically broken in a Hidden Sector of the full theory and the effects of this SUSY-breaking are mediated to the Visible Sector (MSSM) by some flavour-blind interactions.



- Soft SUSY-breaking terms in the MSSM arise as a result of this mediation. They can be computed from the underlying theory / mediation mechanism (if known).

SUSY-breaking and mediation

- Gravity mediation: SUSY-breaking is communicated to the MSSM only via gravity-strength interactions

  $M_{messenger}=M_P$

- Gauge mediation: Messengers are ordinary matter fields coupled to the Hidden sector and to the SM gauge fields. SM gauge interactions are responsible for the generation of soft terms in MSSM. $M_{messenger}$ is a new scale.

- Extra-dimensional mediation: Gaugino mediation and Anomaly mediation scenarios.

Gravity mediation and CMSSM

Supersymmetry breaking in MSSM arises from M_{Plank}-suppressed terms in the supergravity effective lagrangian.

If one now *assumes* a minimal form with the canonical Kahler potential together with a factorisation between the visible and the hidden sector degrees of freedom one reduces the complicated description of the soft terms to just four parameters

$$m_{1/2} = f\frac{\langle F \rangle}{M_{\rm P}}, \qquad m_0^2 = k\frac{|\langle F \rangle|^2}{M_{\rm P}^2}, \qquad A_0 = \alpha\frac{\langle F \rangle}{M_{\rm P}}, \qquad B_0 = \beta\frac{\langle F \rangle}{M_{\rm P}}.$$

Gravity mediation and CMSSM

At the high scale, M_P (or in unified theories M_{GUT}) all the gaugino masses are given by $m_{1/2}$ and all the scalar masses by m_0. There are only four idependent parameters in the CMSSM.

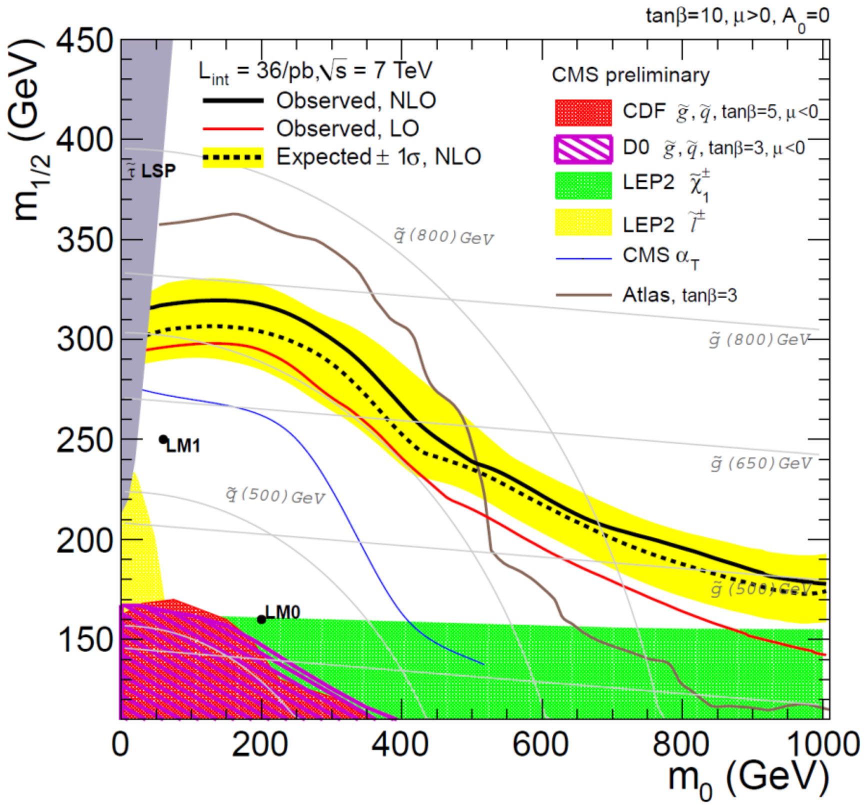
This simple model (and its relatives) is a favourite SUSY realisation of some theorists and most of the experimenters. The entire recent analyses of the CMS and ATLAS collaborations is enterpreted in terms of the CMSSM parameters, m_0 and $m_{1/2}$.

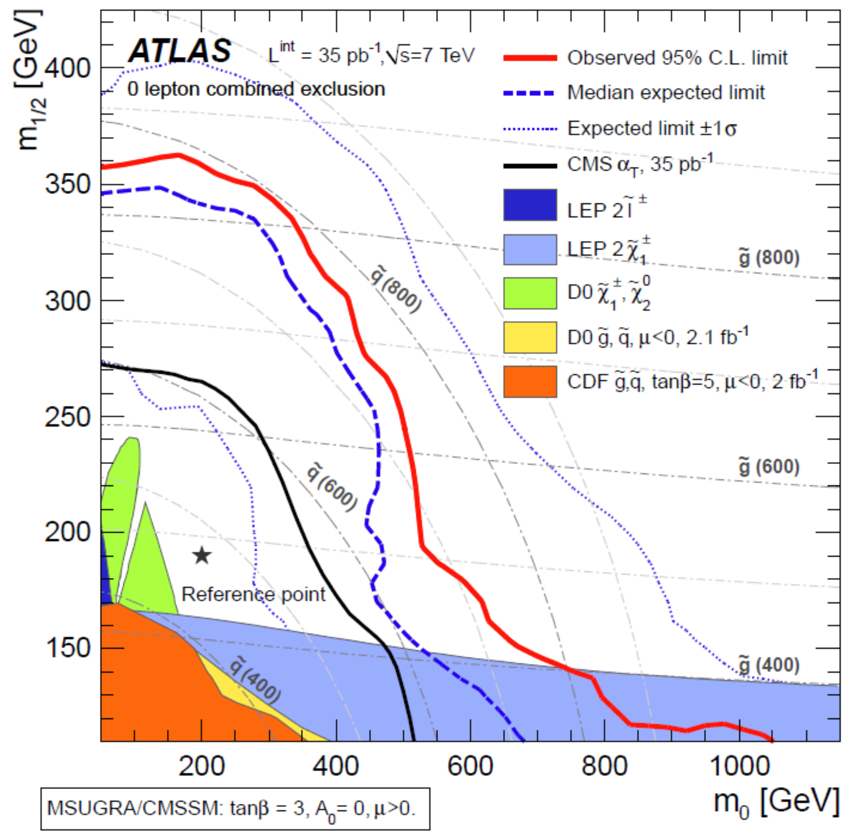
In spite of its universal appeal, the CMSSM is not derived from any theory, it is an assumption within Gravity mediation.

E.G., Gravity mediation in general leads to unsuppressed flavour violation which needs to be explained; in the CMSSM it is set to zero by hand.

CMSSM exclusion plots from CMS and ATLAS

CMS





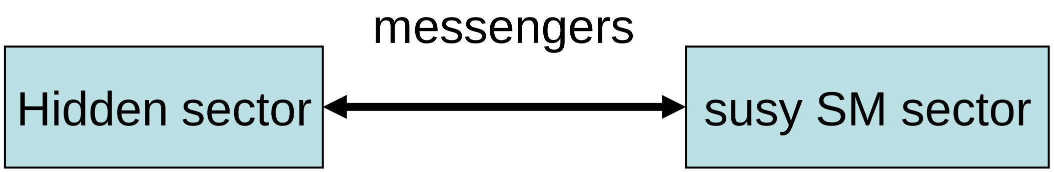
One of our main goals - apply the LHC results and data to SUSY models beyond the CMSSM:

pure General Gauge Mediation

large set of previously proposed benchmark points

(and even CMSSM again)

Gauge mediation



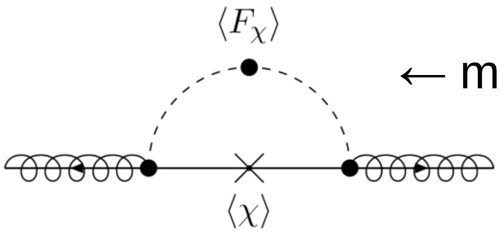
Messenger fields are coupled to the SUSY-breaking sector and to the SM sector. Importantly, in the SM sector they are coupled only to the gauge multiplets, not to the matter fields. => Pure gauge mediation.

Gauge mediation manifestly does not give raise to new flavour changing processes since SM gauge interactions are flavour blind.

LSP of gauge mediation is gravitino. Contrary to gravity mediation the lightest neutralino will always ultimately decay into gravitino and cannot be a dark matter candidate. However this does not rule out a possibility of gravitino dark matter.

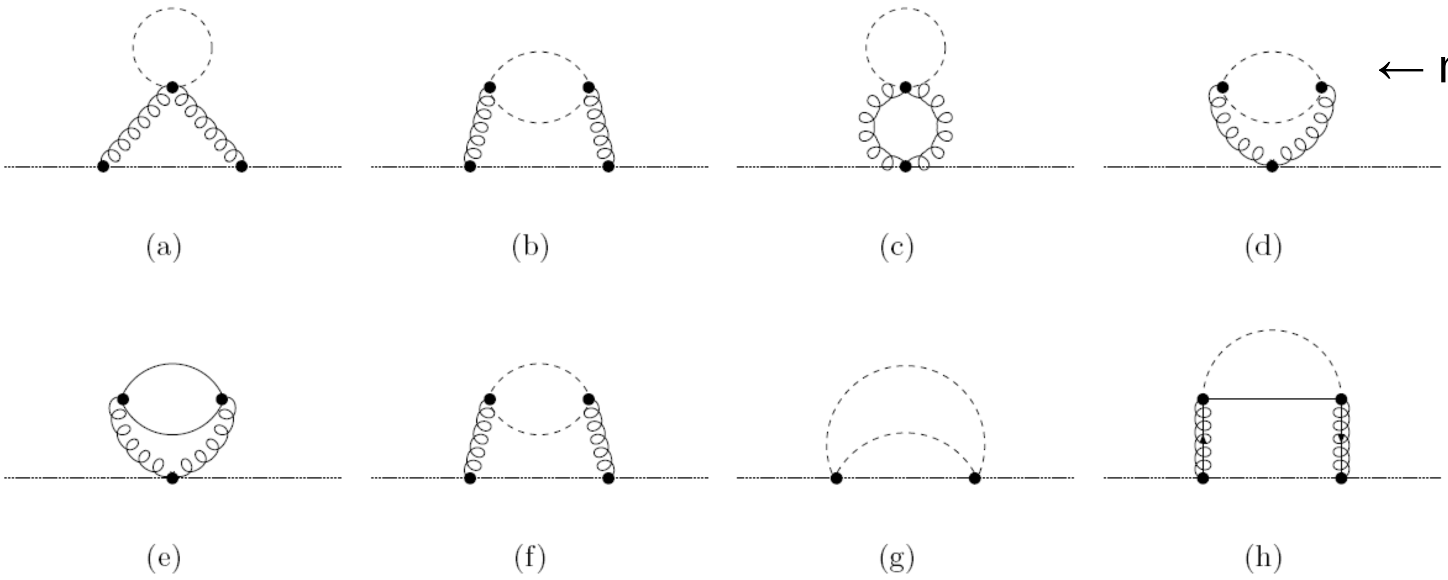
Gauge mediation

- Gaugino masses are generated by:



← messenger loop

- Scalar mass squared are generated by:



← messenger loop

Gauge mediation

These diagrams are computed at the messenger scale (high scale), $1\,\text{TeV} < M_{\text{mess}} < M_{\text{GUT}}$. Gaugino and scalar masses are of the form:

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

where $k_i = (5/3, 1, 1)$, $k_i \alpha_i$ are equal at the GUT scale.

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

where the C_i are the quadratic Casimir operators of the gauge groups, $C_i = (Y^2, 3/4, 4/3)$.

Ordinary gauge mediation is a one-scale model $\Lambda_G \simeq \Lambda_S = \frac{F}{M_{\text{mess}}}$.

General Gauge mediation

A simple one-scale model does not capture important dynamics. Scalar soft masses arise when supersymmetry is broken, i.e. $F \neq 0$. But non-vanishing Majorana masses for gauginos requre in addition that a $U(1)$ R-symmetry is broken.

Hence in a generic case, gauginos and scalars are described by *independent* parameters, Λ_G and Λ_S.

Meade, Seiberg and Shih 0801.3278 showed that in most general GGM settings there can be three independent $\Lambda_{G,r}$ scales and three $\Lambda_{S,r}$ scales, one for each gauge group.

However, if one assumes that the theory grand unifies and furthermore that the messengers form unsplit GUT-multiplets, one finds that there is a single Λ_G and a single Λ_S scale.

Jaeckel, VVK, Wymant 1103.1843

General Gauge mediation

Meade, Seiberg and Shih 0801.3278: pure GGM without Unification assumption has at most three independent $\Lambda_{G,r}$ scales and three $\Lambda_{S,r}$ scales:

$$M_{\lambda_r}(M) = k_r \frac{\alpha_r}{4\pi} \Lambda_{G,r} ,$$

$$m^2_{\tilde{f}}(M) = 2 \sum_{r=1}^{3} C_2(f,r) k_r \frac{\alpha_r^2}{(4\pi)^2} \Lambda^2_{S,r}$$

These two constraints give two mass sum rules for each of the three generations

$$Tr\, Y\, m^2 = 0 = Tr\, (B-L)\, m^2 ,$$

or equivalently,

$$m^2_{\tilde{Q}} - 2m^2_{\tilde{U}} + m^2_{\tilde{D}} - m^2_{\tilde{L}} + m^2_{\tilde{E}} = 0 , \quad 2m^2_{\tilde{Q}} - m^2_{\tilde{U}} - m^2_{\tilde{D}} - 2m^2_{\tilde{L}} + m^2_{\tilde{E}} = 0$$

General Gauge mediation

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$$M_{\lambda_r}(M) = k_r \frac{\alpha_r}{4\pi} \Lambda_{G,r} ,$$

$$m^2_{\tilde{f}}(M) = 2 \sum_{r=1}^{3} C_2(f,r) k_r \frac{\alpha_r^2}{(4\pi)^2} \Lambda^2_{S,r}$$

Do these sum rules hold at any scale, e.g. at the low scale?

Do they hold only for the first two generations, or not even that?

Can they be used as a `smoking gun' signature for gauge Mediation?

$$m_Q^2 - 2m_U^2 + m_D^2 - m_L^2 + m_E^2 = 0 , \quad 2m_Q^2 - m_U^2 - m_D^2 - 2m_L^2 + m_E^2 = 0$$

General Gauge mediation

Meade, Seiberg and Shih 0801.3278: pure GGM without Unification assumption has at most three independent $\Lambda_{G,r}$ scales and three $\Lambda_{S,r}$ scales:

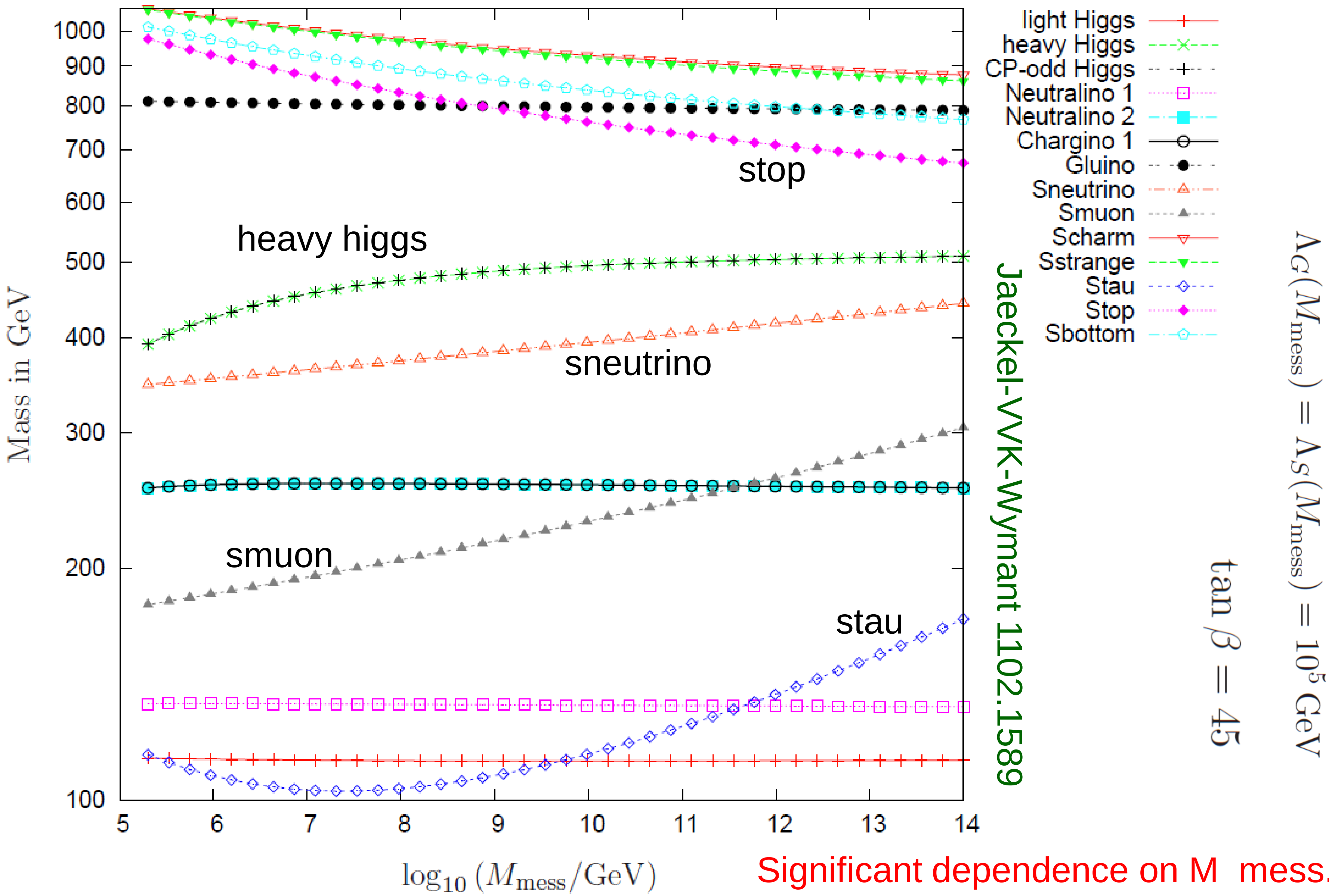
$$M_{\lambda_r}(M) = k_r \frac{\alpha_r}{4\pi} \Lambda_{G,r} ,$$

$$m^2_{\tilde{f}}(M) = 2 \sum_{r=1}^{3} C_2(f,r) k_r \frac{\alpha_r^2}{(4\pi)^2} \Lambda^2_{S,r}$$

If the sum rules were to hold to a good accuracy at any scale M, then the messenger scale would appear to play no role in GGM and would not be a parameter on the GGM model space. (?)

$$m_Q^2 - 2m_U^2 + m_D^2 - m_L^2 + m_E^2 = 0 , \quad 2m_Q^2 - m_U^2 - m_D^2 - 2m_L^2 + m_E^2 = 0$$

Spectrum dependence on the Messenger Scale keeping $\Lambda(M_{mess})$ fixed and varying M_{mess}



Significant dependence on M mess.

Why should one keep Lambda's fixed at M_{mess}? (as on the prev. slide)
Can one keep fixed RG Invariants instead?

-That's what we'll do:

Instead of (or in parallel with) the mass sum rules we will also use

1-loop RG Invariants (RGIs)

$$\frac{d}{dt}(\mathrm{RGI}) = 0 + \mathcal{O}(2\text{-loop})$$

- These RGIs are known analytically and were listed recently in Carena, Draper, Shah, Wagner 1006.4363 for a general MSSM case (see next slide).

- RGIs hold to the first order in alpha SM
- Miss order alpha-squared
- Incorporate effects of the Yukawa coupling of the 3rd generation
- Miss Yukawa effects of the first two generations (set to zero)

- In pure GGM there are six non-trivial RGIs which are in one-to-one correspondence with six Lambdas.

RGI	Definition in terms Soft Masses	GGM value
$D_{B_{13}}$	$2(m^2_{\tilde{Q}_1} - m^2_{\tilde{Q}_3}) - m^2_{\tilde{u}_1} + m^2_{\tilde{u}_3} - m^2_{\tilde{d}_1} + m^2_{\tilde{d}_3}$	0
$D_{L_{13}}$	$2(m^2_{\tilde{L}_1} - m^2_{\tilde{L}_3}) - m^2_{\tilde{e}_1} + m^2_{\tilde{e}_3}$	0
D_{χ_1}	$3(3m^2_{\tilde{d}_1} - 2(m^2_{\tilde{Q}_1} - m^2_{\tilde{L}_1}) - m^2_{\tilde{u}_1}) - m^2_{\tilde{e}_1}$	0
$D_{Y_{13H}}$	$m^2_{\tilde{Q}_1} - 2m^2_{\tilde{u}_1} + m^2_{\tilde{d}_1} - m^2_{\tilde{L}_1} + m^2_{\tilde{e}_1}$ $-\frac{10}{13}\left(m^2_{\tilde{Q}_3} - 2m^2_{\tilde{u}_3} + m^2_{\tilde{d}_3} - m^2_{\tilde{L}_3} + m^2_{\tilde{e}_3} + m^2_{H_u} - m^2_{H_d}\right)$	$-\frac{10}{13}(\delta_u - \delta_d)$
D_Z	$3(m^2_{\tilde{d}_3} - m^2_{\tilde{d}_1}) + 2(m^2_{\tilde{L}_3} - m^2_{H_d})$	$-2\delta_d$
$I_{Y\alpha}$	$\left(m^2_{H_u} - m^2_{H_d} + \sum_{gen}(m^2_{\tilde{Q}} - 2m^2_{\tilde{u}} + m^2_{\tilde{d}} - m^2_{\tilde{L}} + m^2_{\tilde{e}})\right)/g_1^2$	$(\delta_u - \delta_d)/g_1^2$
I_{B_r}	M_r/g_r^2	$\frac{k_r \Lambda_{G,r}}{16\pi^2}$
I_{M_1}	$M_1^2 - \frac{33}{8}(m^2_{\tilde{d}_1} - m^2_{\tilde{u}_1} - m^2_{\tilde{e}_1})$	$\frac{25}{9}\frac{g_1^4(M_{\rm mess})}{(16\pi^2)^2}\left(\Lambda^2_{G,1} + \frac{33}{5}\Lambda^2_{S,1}\right)$
I_{M_2}	$M_2^2 + \frac{1}{24}\left(9(m^2_{\tilde{d}_1} - m^2_{\tilde{u}_1}) + 16m^2_{\tilde{L}_1} - m^2_{\tilde{e}_1}\right)$	$\frac{g_2^4(M_{\rm mess})}{(16\pi^2)^2}\left(\Lambda^2_{G,2} + \Lambda^2_{S,2}\right)$
I_{M_3}	$M_3^2 - \frac{3}{16}(5m^2_{\tilde{d}_1} + m^2_{\tilde{u}_1} - m^2_{\tilde{e}_1})$	$\frac{g_3^4(M_{\rm mess})}{(16\pi^2)^2}\left(\Lambda^2_{G,3} - 3\Lambda^2_{S,3}\right)$

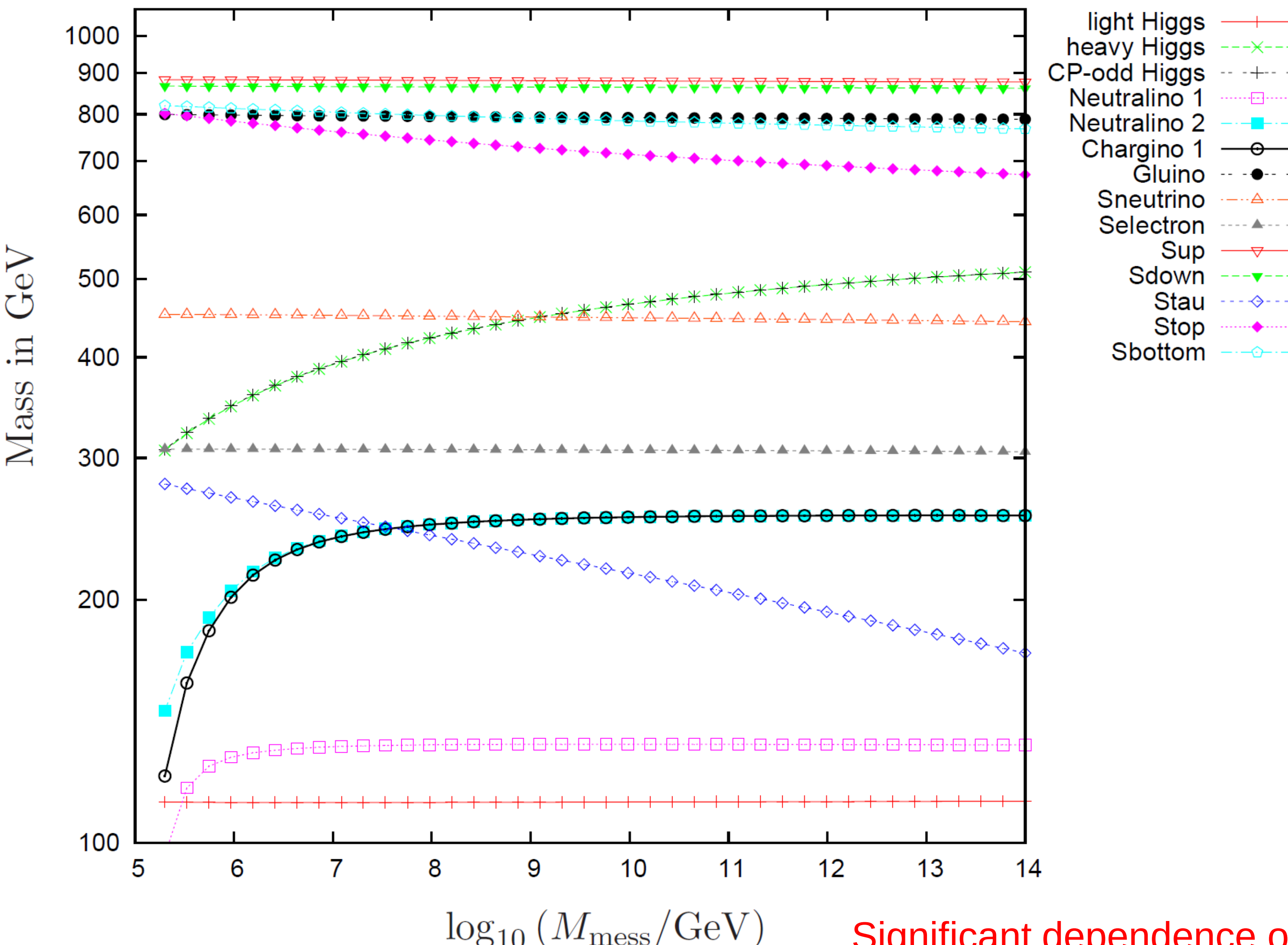
$$m^2_{H_u} = m^2_{\tilde{L}} + \delta_u$$
$$m^2_{H_d} = m^2_{\tilde{L}} + \delta_d$$

6 non-trivial RGIs in GGM

in terms of 6 Lambdas

I_{B_r}	M_r/g_r^2	$\frac{k_r \Lambda_{G,r}}{16\pi^2}$
I_{M_1}	$M_1^2 - \frac{33}{8}(m^2_{\tilde{d}_1} - m^2_{\tilde{u}_1} - m^2_{\tilde{e}_1})$	$\frac{25}{9}\frac{g_1^4(M_{\rm mess})}{(16\pi^2)^2}\left(\Lambda^2_{G,1} + \frac{33}{5}\Lambda^2_{S,1}\right)$
I_{M_2}	$M_2^2 + \frac{1}{24}\left(9(m^2_{\tilde{d}_1} - m^2_{\tilde{u}_1}) + 16 m^2_{\tilde{L}_1} - m^2_{\tilde{e}_1}\right)$	$\frac{g_2^4(M_{\rm mess})}{(16\pi^2)^2}\left(\Lambda^2_{G,2} + \Lambda^2_{S,2}\right)$
I_{M_3}	$M_3^2 - \frac{3}{16}(5m^2_{\tilde{d}_1} + m^2_{\tilde{u}_1} - m^2_{\tilde{e}_1})$	$\frac{g_3^4(M_{\rm mess})}{(16\pi^2)^2}\left(\Lambda^2_{G,3} - 3\Lambda^2_{S,3}\right)$

Spectrum dependence on the Messenger Scale keeping 6 RG-Invariants I_{B_r} and I_{M_r} fixed



Jaeckel-VVK-Wymant 1103.1843

$\tan\beta = 45$

Significant dependence on M mess.

GGM sum rules in terms of observable masses

Sum rules:

$$Tr\,Y\,m^2 = 0 = m_Q^2 - 2m_U^2 + m_D^2 - m_L^2 + m_E^2$$

$$Tr\,(B-L)\,m^2 = 0 = 2m_Q^2 - m_U^2 - m_D^2 - 2m_L^2 + m_E^2$$

and a linear combination

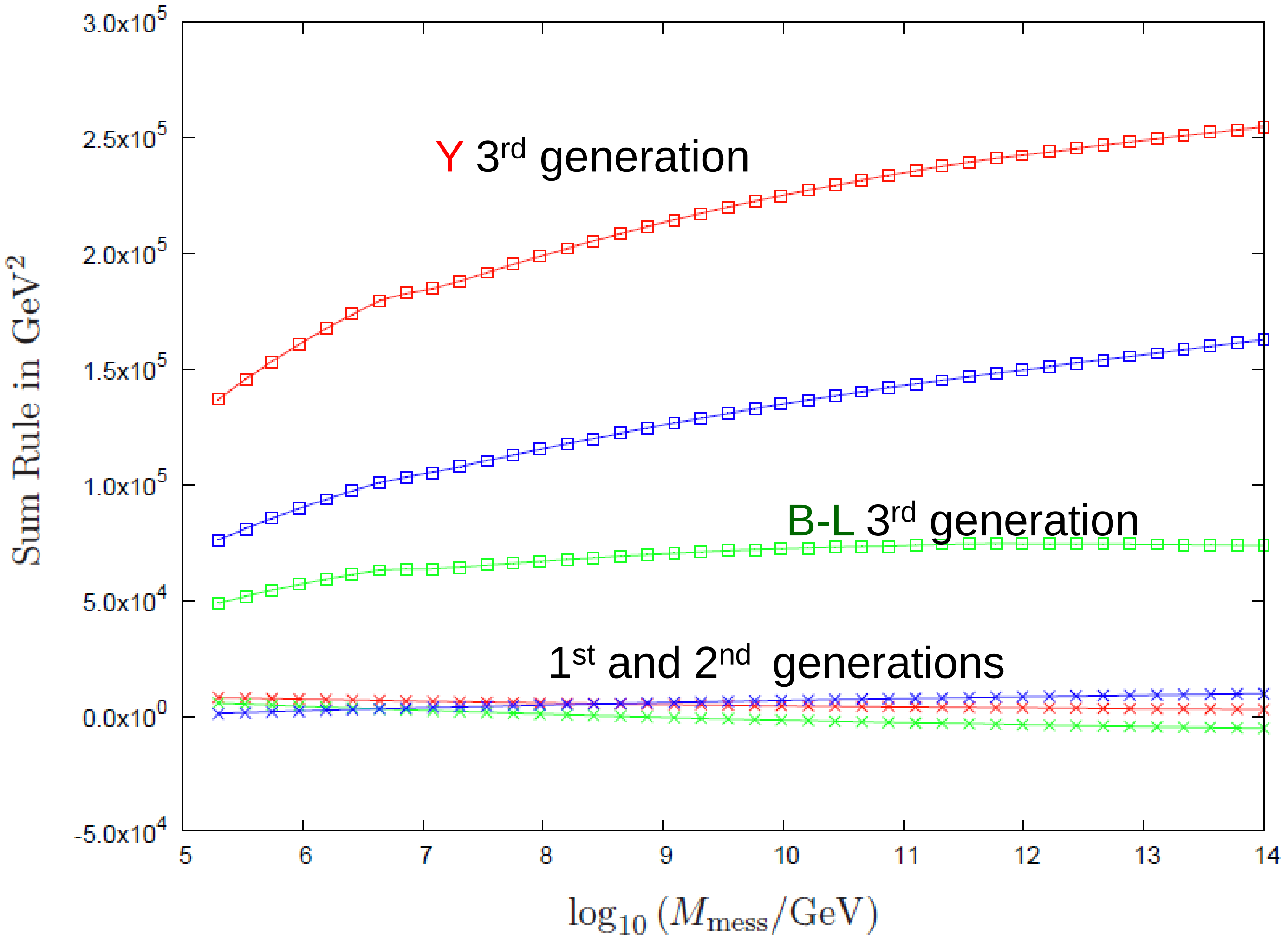
$$Tr\,Y\,m^2 - \frac{5}{4}Tr\,(B-L)\,m^2 = 0$$

express for simplicity first in terms of just the observable masses:

$$\begin{aligned} m_U^2 &= m_{\tilde{t}_1}^2\,, \quad m_D^2 = m_{\tilde{b}_1}^2\,, \quad m_Q^2 = \frac{1}{2}(m_{\tilde{t}_2}^2 + m_{\tilde{b}_2}^2)\,. \\ m_E^2 &= m_{\tilde{\tau}_1}^2\,, \quad m_L^2 = \frac{1}{2}(m_{\tilde{\tau}_2}^2 + m_{\tilde{\nu}_\tau}^2) \end{aligned}$$

GGM sum rules in terms of observable masses

Yukawa effects and 2-loop gauge coupling effects are taken into account



Jaeckel-VVK-Wymant 1102.1589

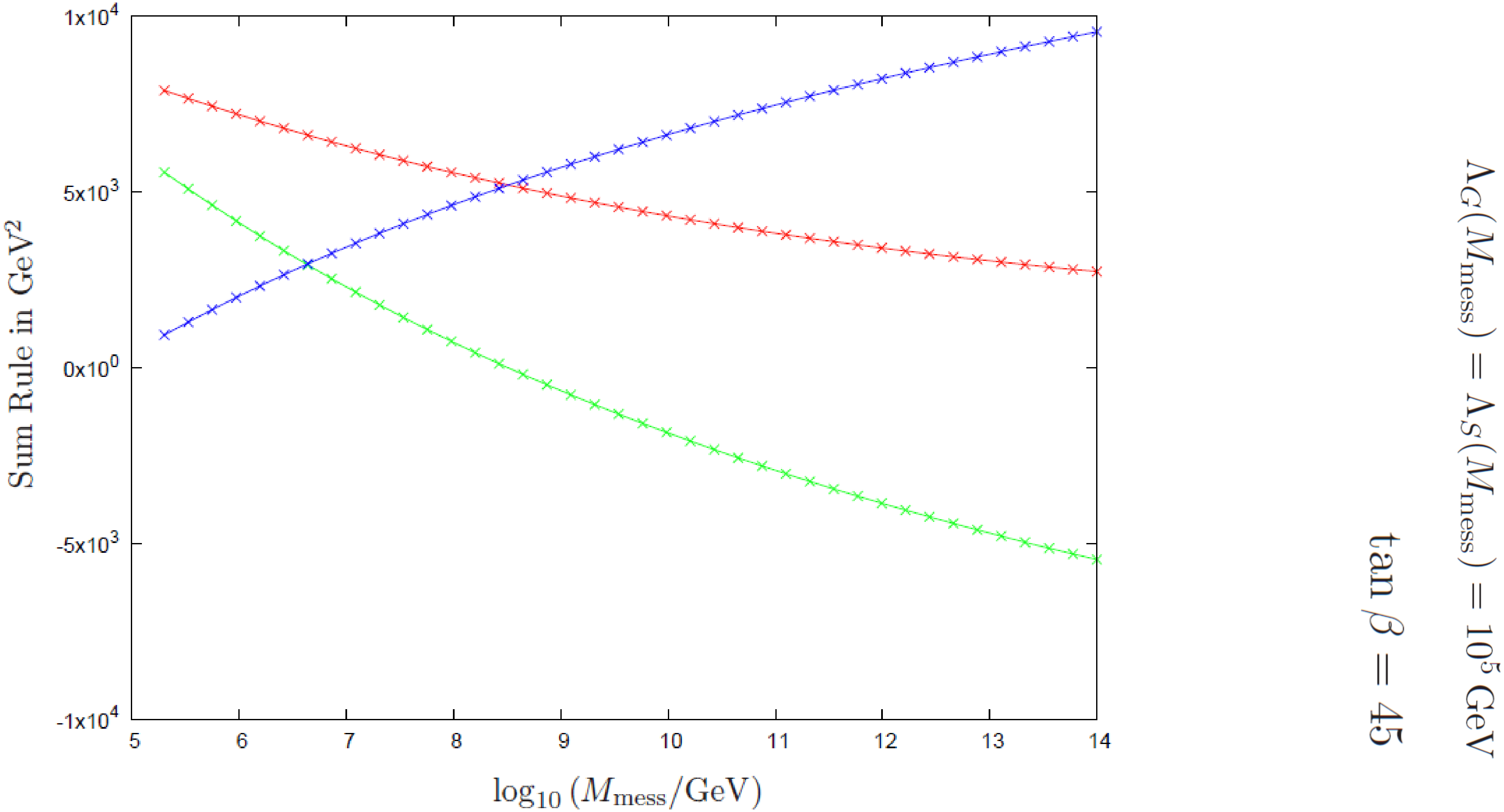
$\tan\beta = 45$

$\Lambda_G(M_{\rm mess}) = \Lambda_S(M_{\rm mess}) = 10^5$ GeV

3rd generation sum rules are non-vanishing and vary with M mess by 15% and 3%.

GGM sum rules in terms of observable masses

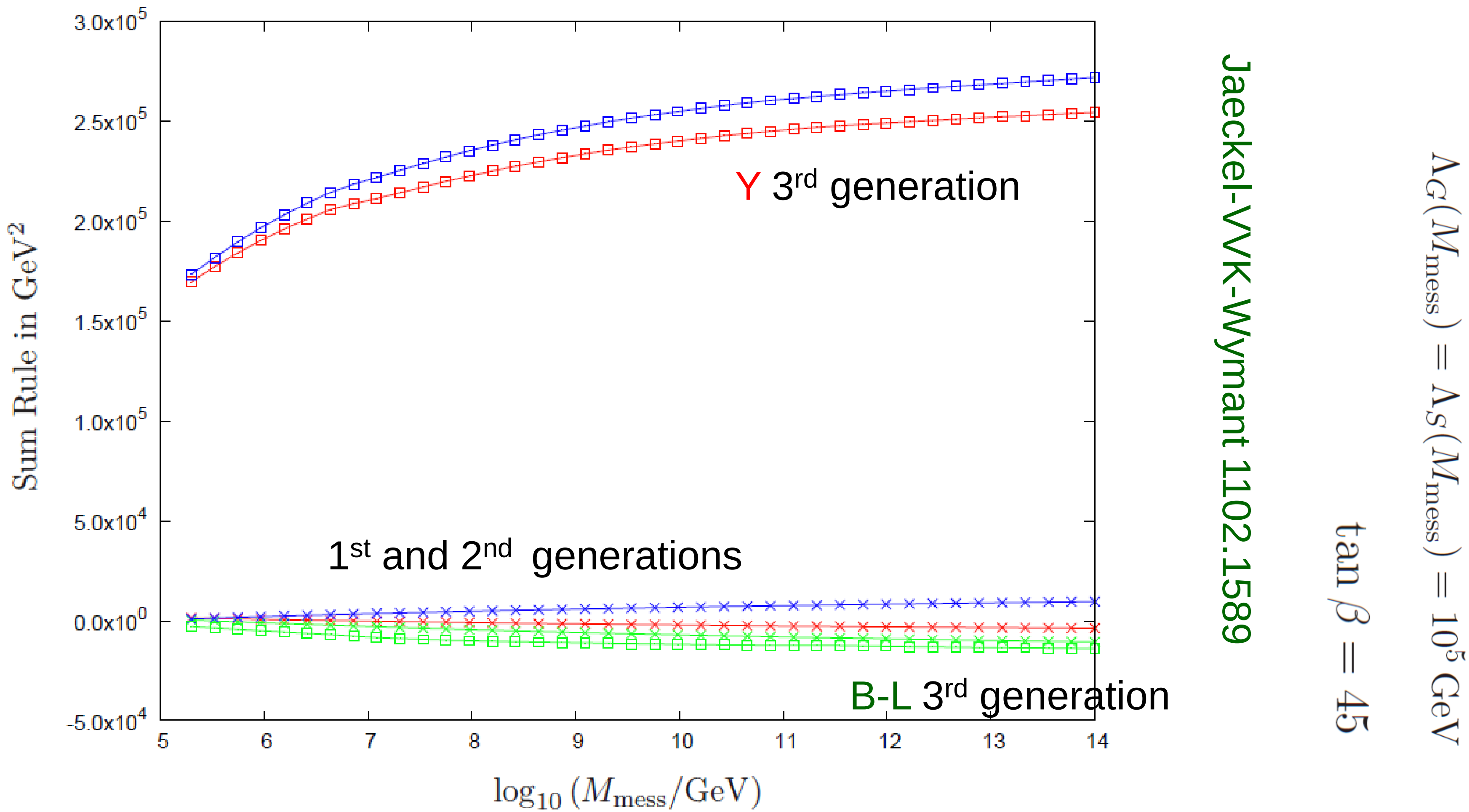
Yukawa effects and 2-loop gauge coupling effects are taken into account



Zoomed on the previous plot for 1st and 2nd generations

GGM sum rules in terms of soft masses

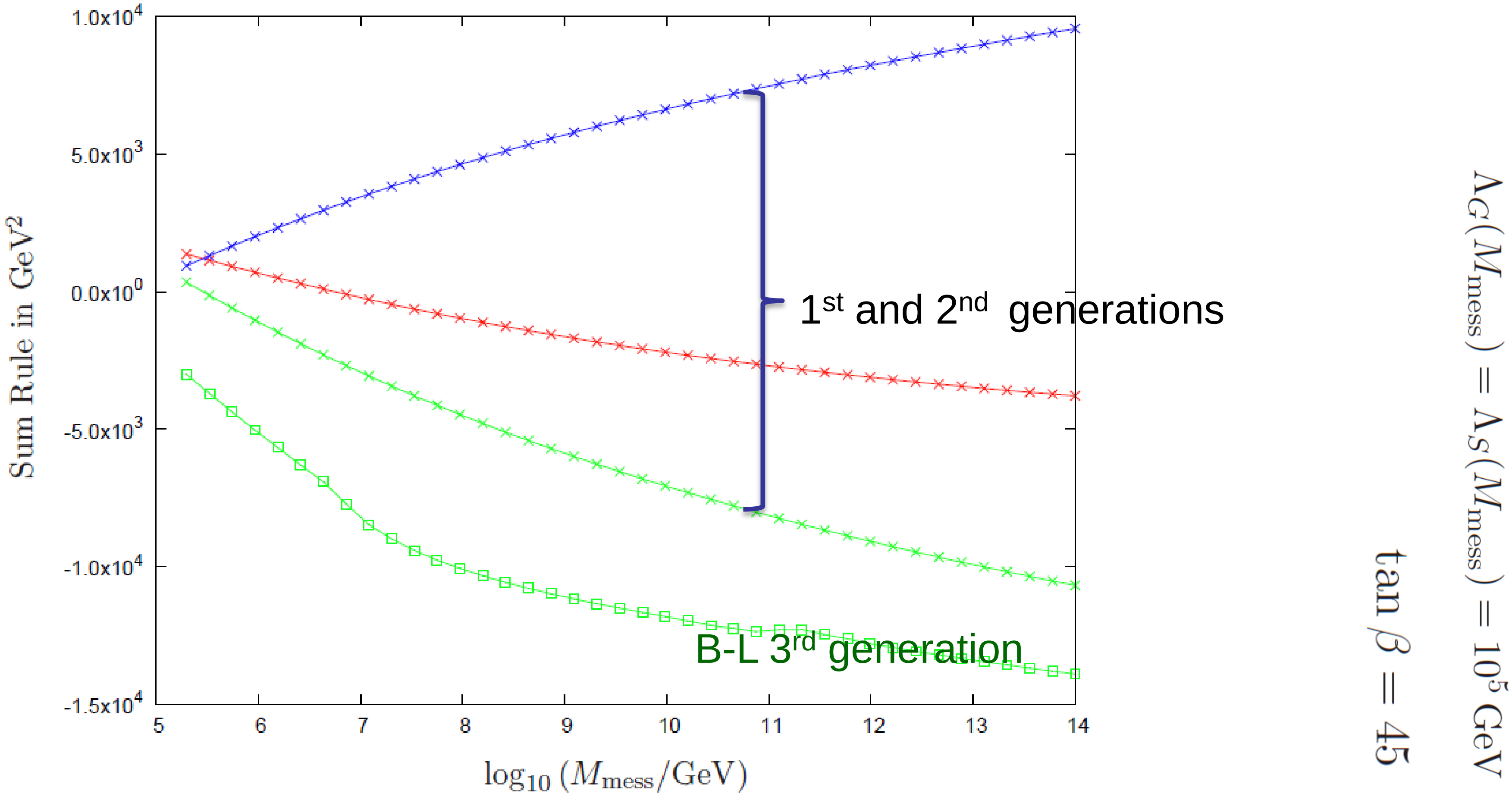
Yukawa effects and 2-loop gauge coupling effects are taken into account



3rd generation Y-sum rule is still broken by 20% (due to large Yukawa) but B-L improves.

GGM sum rules in terms of soft masses

Yukawa effects and 2-loop gauge coupling effects are taken into account



Zoom of the previous slide... Also checked sum rule violations for low tan beta models

General Gauge mediation

Mass sum rules $\neq 0$ and do vary when one changes the high scale, especially the hypercharge sum rule for the third generation

(due to a large Yukawa of the 3rd gen.)

Mass spectrum varies as well either when $\Lambda(M_{mess})$ is fixed or when RG Invariants are fixed at M_{mess}

The messenger scale is a true parameter of GGM

and at the same time mass sum rules cannot be used at low scales as the smoking gun signature of gauge mediation

....so forget the sum rules from now on... but keep M_{mess}

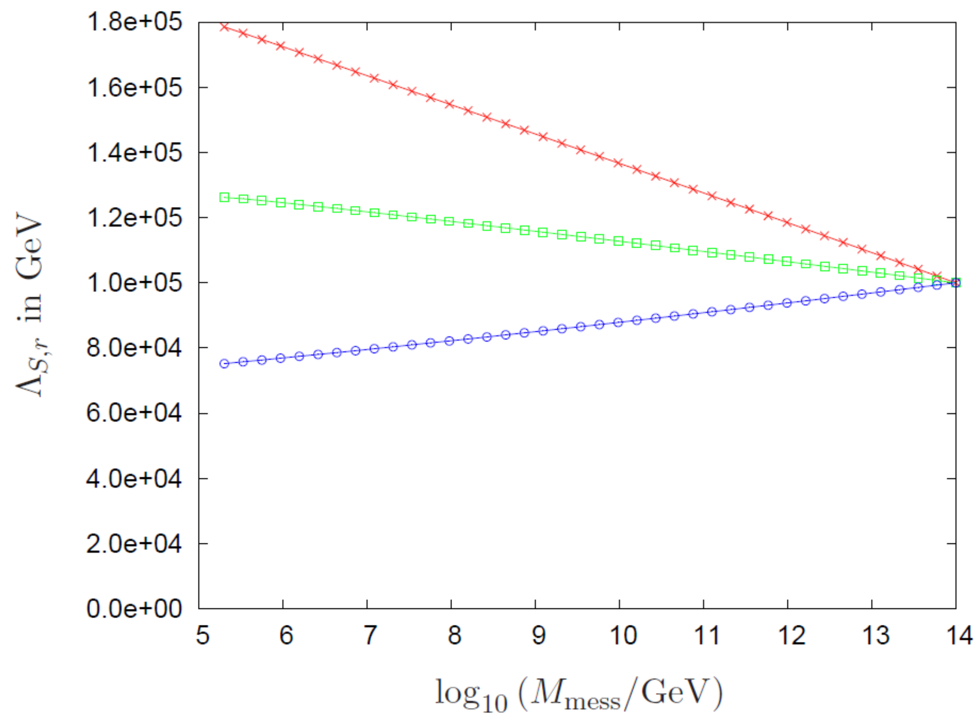
GGM with Unification

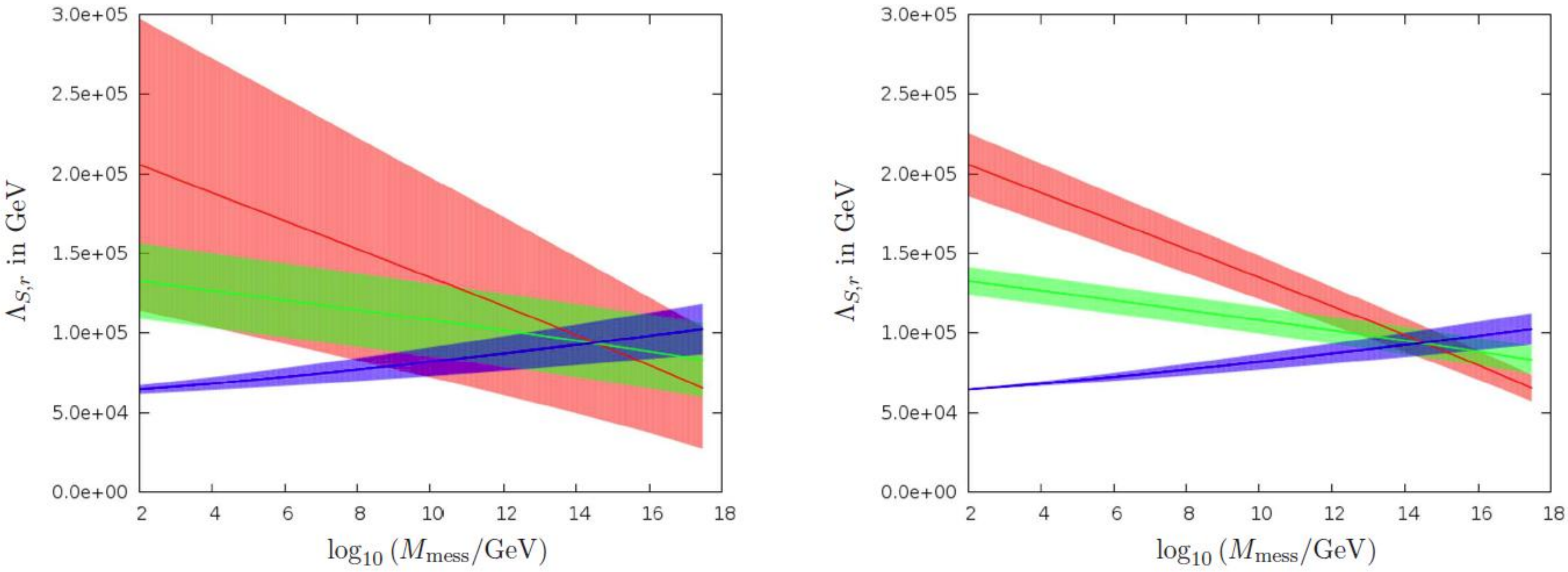
Jaeckel, VVK, Wymant 1103.1843 and 1102.1589

In these unified GGM settings there are three input parameters, M_{mess} and Λ_G, Λ_S (at M_{mess}). In addition there is $\tan\beta$.

Below the messenger scale, Λ_G scales remain constant, but the Λ_S scales split due to RG evolution:

Here RGIs are kept fixed at M_{mess} and Λ_S are reconstructed from them.





If supersymmetry is discovered, and if (in remote future) all squark and slepton masses of the first two generations will be measured, depending on the accuracy of these measurements, one can in principle reconstruct the running Λ_S parameters and check if Unification and Gauge Mediation take place.

This is more than the usual unification of gauge couplings.

Pure General Gauge Mediation

Abel, Dolan, Jaeckel, VVK 0910.2674 and 1009.1164

Studied GGM models defined in terms of three input parameters, Λ_G, Λ_S and M_{mess} . The value of B at the high scale is small in pure GGM.

This is the gauge mediation analogue to the canonical CMSSM $(m_{1/2}, m_0)$.

Important to determine if any region in this parameter space is favoured or excluded by experimental data in order to provide direction for model building and investigate current and expected LHC signals.

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

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

Pure General Gauge Mediation

- ➔ We have a simple setup with three parameters, Λ_G, Λ_S, M_{mess}

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

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

What about a-terms?

- Soft terms include:

$$a_u^{ij} H_u Q^i \overline{u}^j + a_d^{ij} H_d Q^i \overline{d}^j + a_L^{ij} H_d L^i \overline{E}^j \;,$$

➡ **Are predicted in GGM to be small at M_{mess}**

The (soft)Higgs sector and B_μ

$$m_u^2|H_u|^2 + m_d^2|H_d|^2 + (B_\mu H_u H_d + c.c.) \ ,$$

$= m_L^2$

$= 0$ @$\mathbf{M_{mess}}$

In pure gauge mediation

Slepton mass-squared

The (soft)Higgs sector and B_μ

$$m_u^2|H_u|^2 + m_d^2|H_d|^2 + (B_\mu H_u H_d + c.c.) \ ,$$

$$m_u^2,\ m_d^2 = m_L^2 \qquad B_\mu = 0 \qquad @M_{mess}$$

m_u^2 is driven negative by stop loops due to large top Ykawa => gives vev to H_u

then B_μ needed to give vev to H_d (and masses to down-type particles)???

The (soft)Higgs sector and B_μ

$$m_u^2|H_u|^2 + m_d^2|H_d|^2 + (B_\mu H_u H_d + c.c.) \ ,$$

$$< 0 \qquad\qquad \neq 0 \qquad \text{@}M_{EW}$$

$B_\mu \neq 0$ generated by RG evolution to M_{EW}

B_μ typically remains small ➔ Large tanβ

Pure General Gauge Mediation set-up

What about μ?

- SUSY Higgs term:

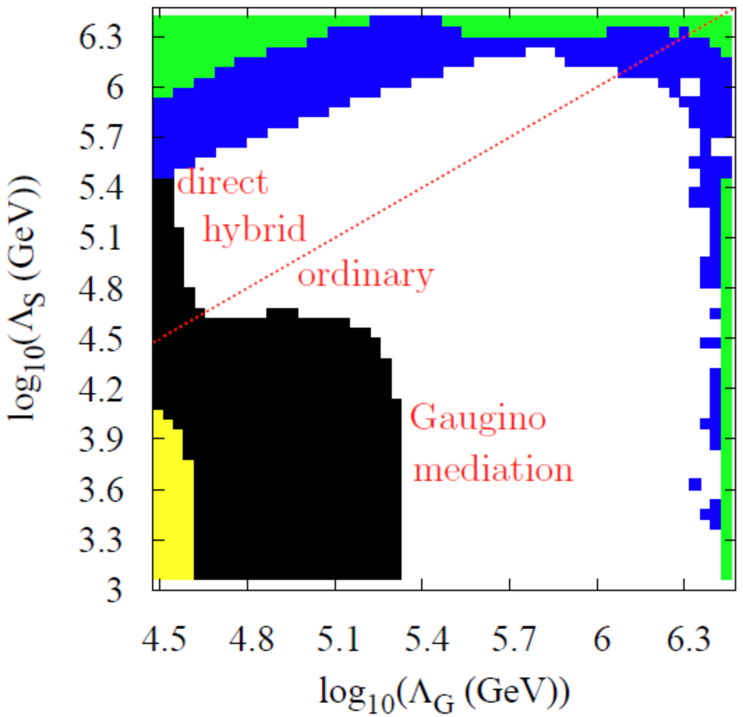
$$\mathcal{L}_{eff} \supset \int d^2\theta \ \mu \, H_u H_d$$

➔SUSY preserving term, not necessarily connected to SUSY breaking

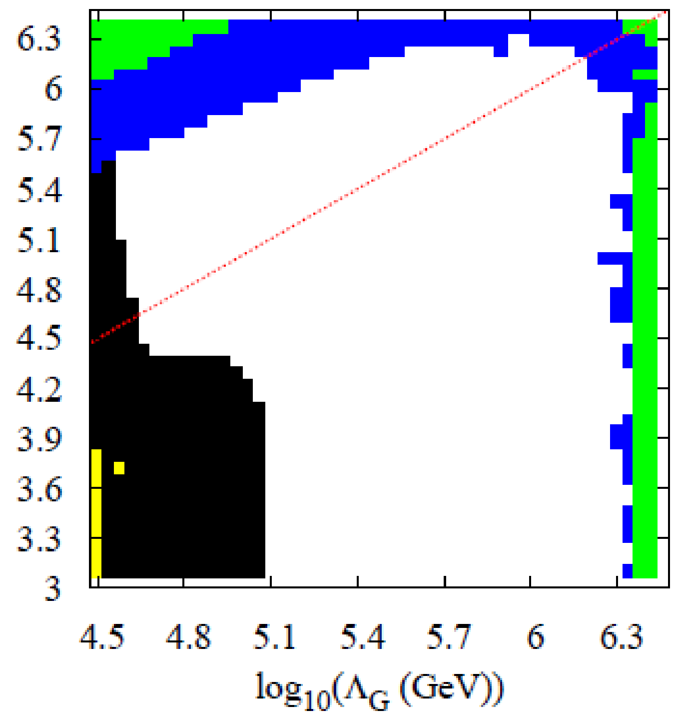
➔Determine from EW symmetry breaking

➔Accept fine-tuning

Pure GGM: finding the Parameter Space



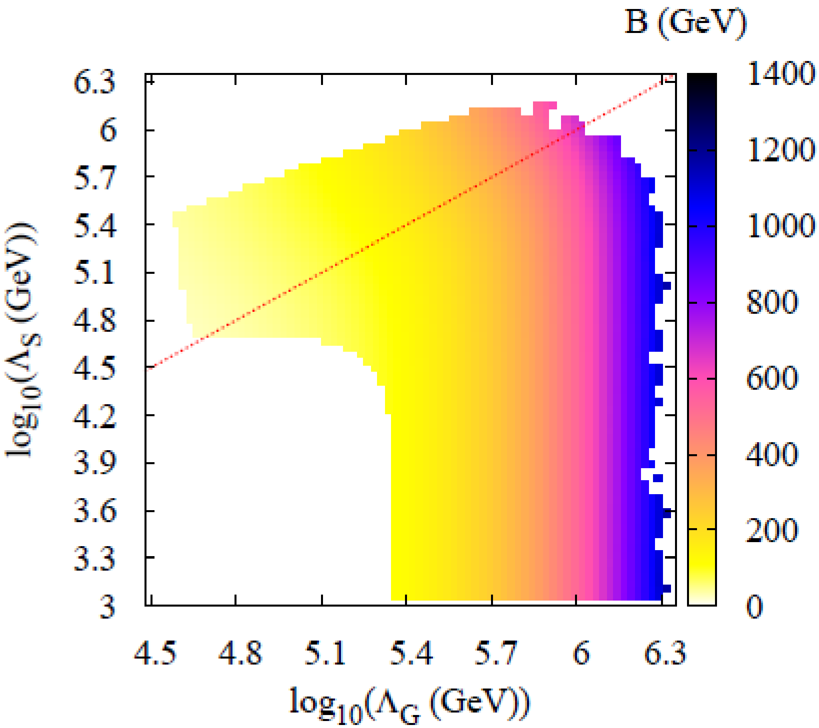
$M_{\text{mess}} = 10^{10}$ GeV



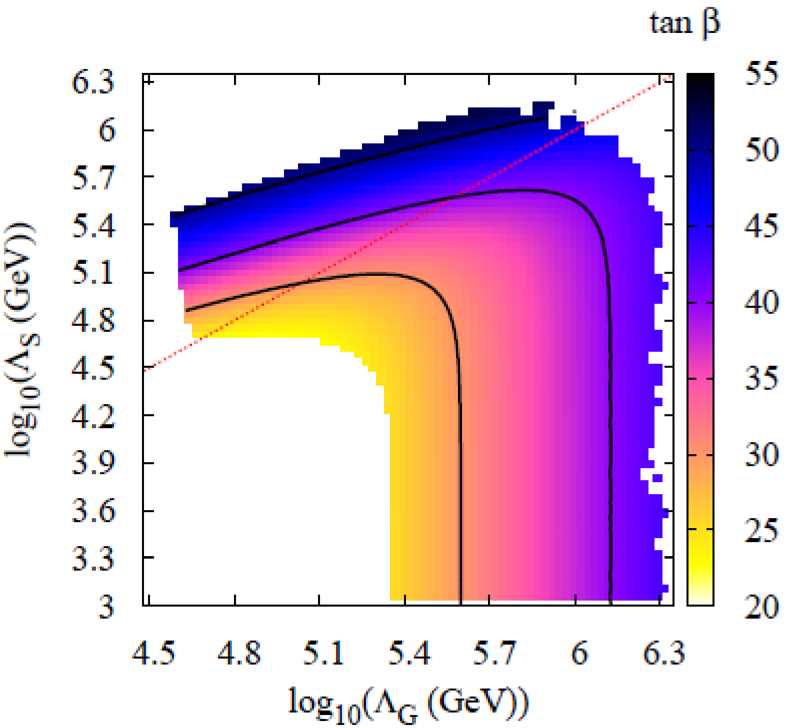
$M_{\text{mess}} = 10^{14}$ GeV.

Yellow is excluded by the presence of tachyons in the spectrum; black is excluded by the direct search limits. In the blue region Soft-SUSY has not converged and in the green region one of Yukawas reaches a Landau pole during RG evolution. The red dotted line indicates the ordinary gauge mediation scenario where $\Lambda_G = \Lambda_S$.

Pure GGM: B and tan(beta) at low energies



(c)

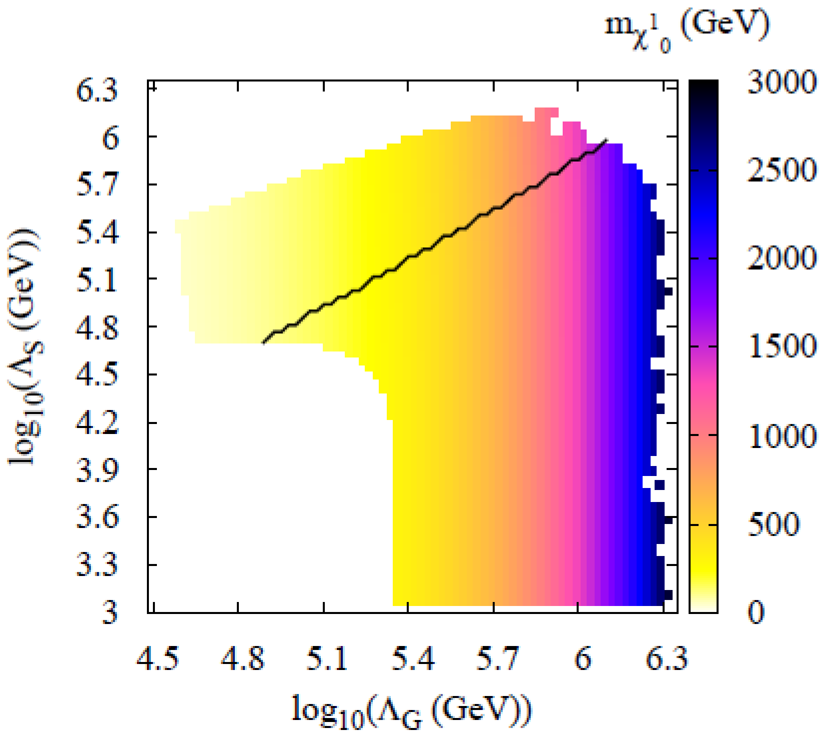


(d)

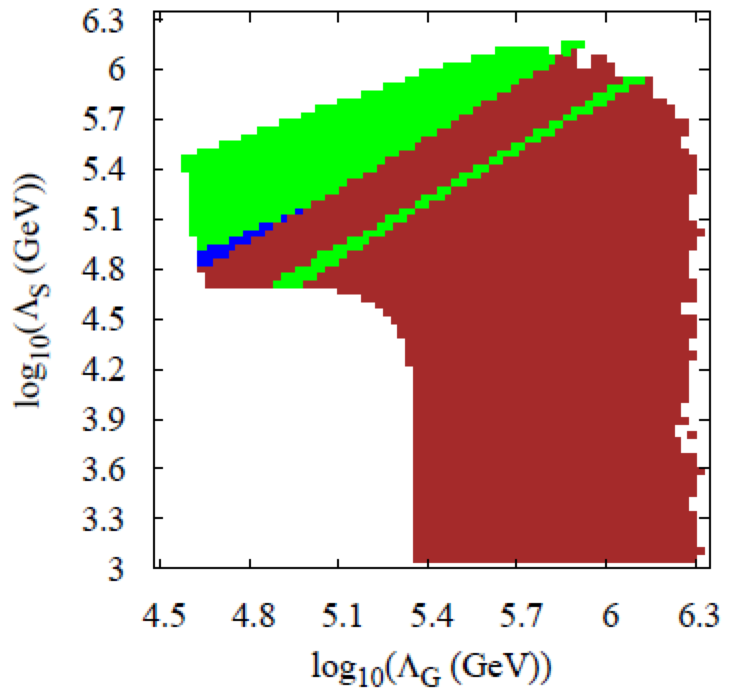
(c) B parameter for $M_{mess} = 10^{10}$ GeV .

(d) shows $\tan\beta$ obtained from the electroweak breaking along with contours of $\tan\beta = 20, 30, 40, 50, 60$.

Pure GGM: NLSP and NNLSP



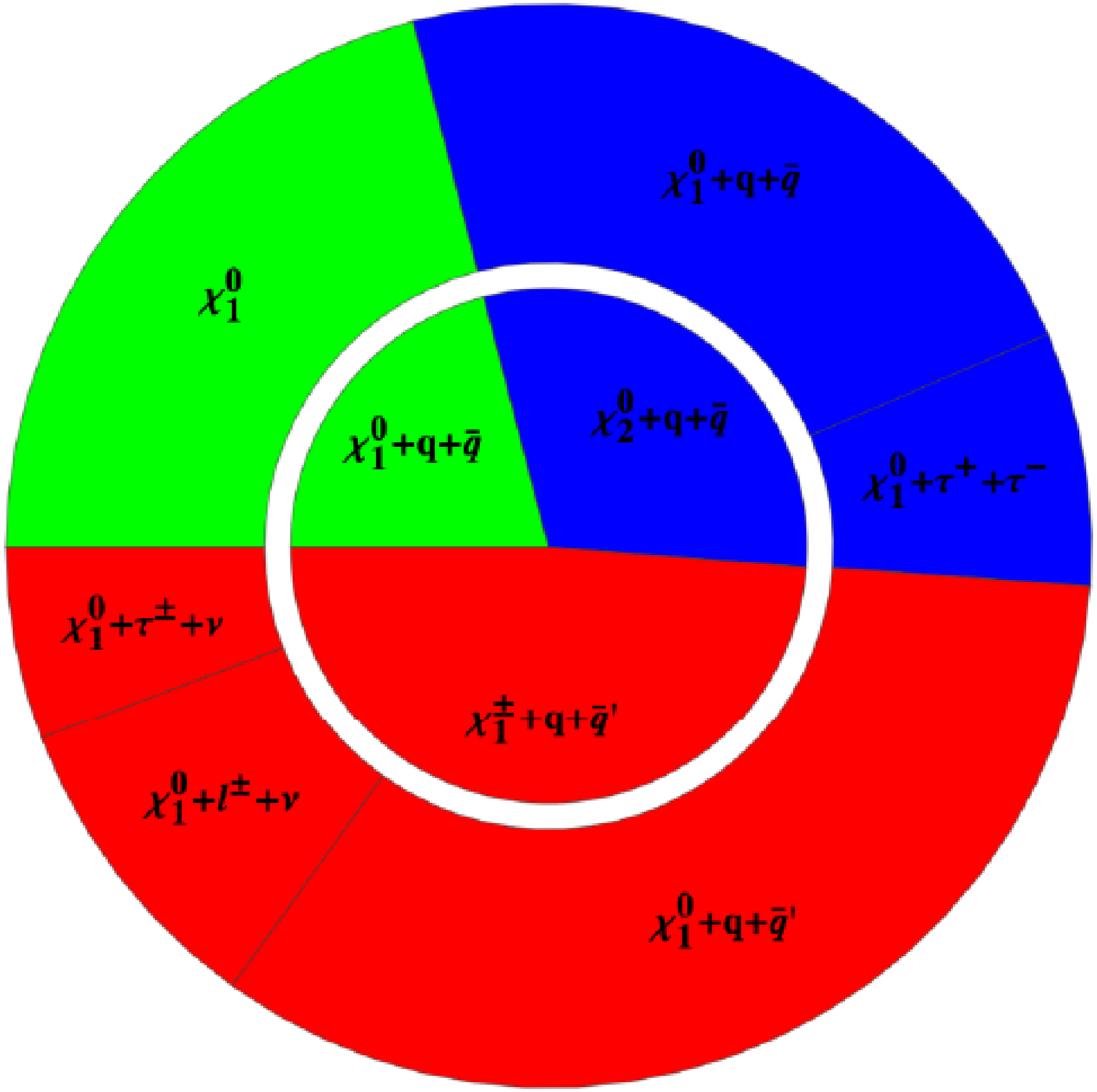
(c)



(d)

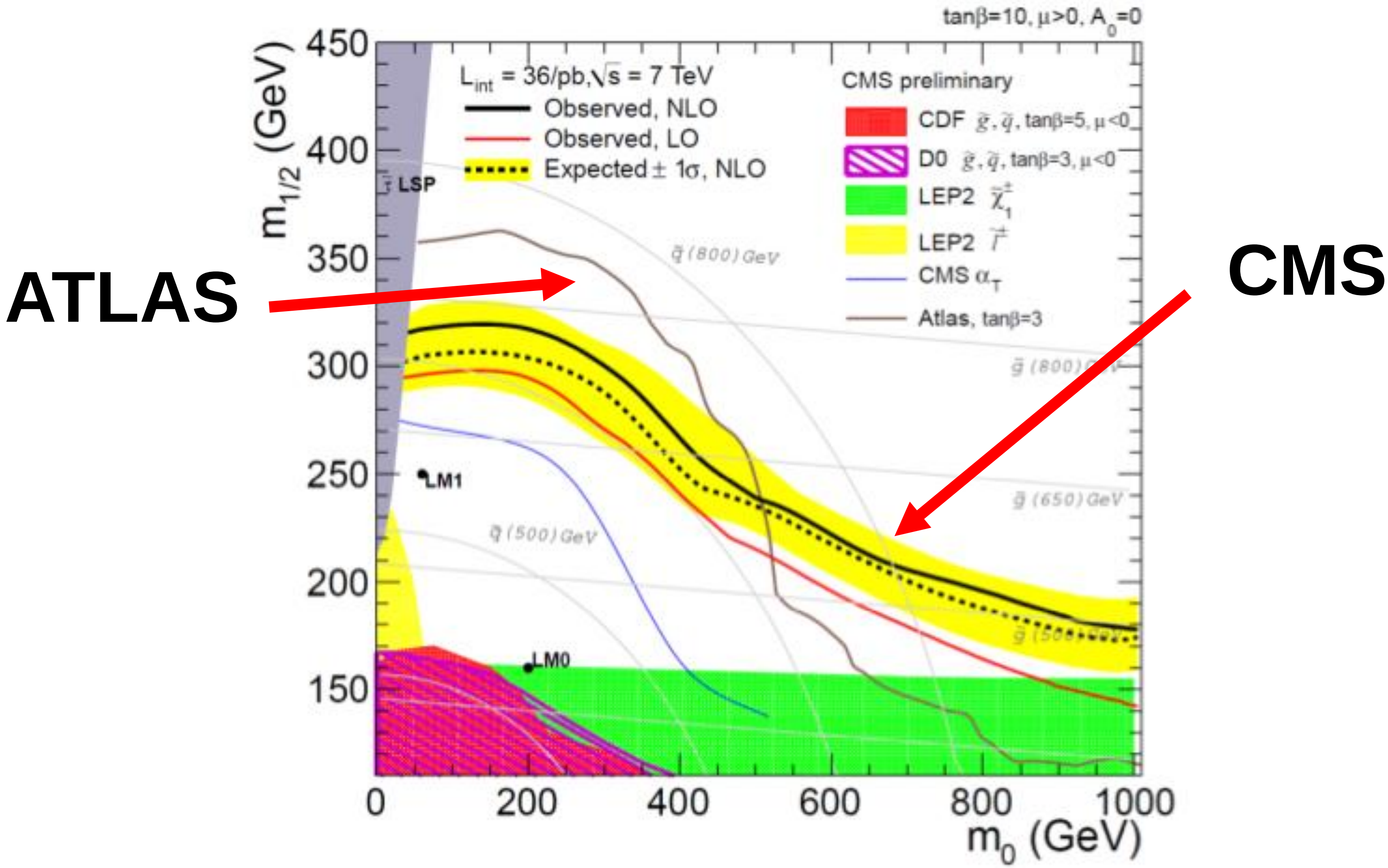
Details of the spectrum for $M_{mess} = 10^{10} GeV$.
(c) shows the lightest neutralino mass. Above the black line the NLSP is neutralino, below it is the stau, sometimes the smuon.
(d) shows the NNLSP species. Green is neutralino, brown is a slepton and blue is the lightest chargino.

Example of gluino decay cascades for a characteristic point with a relatively light gluino (and neutralino NLSP).



CMS + ATLAS

Have searched for jets + missing energy



CMS + ATLAS

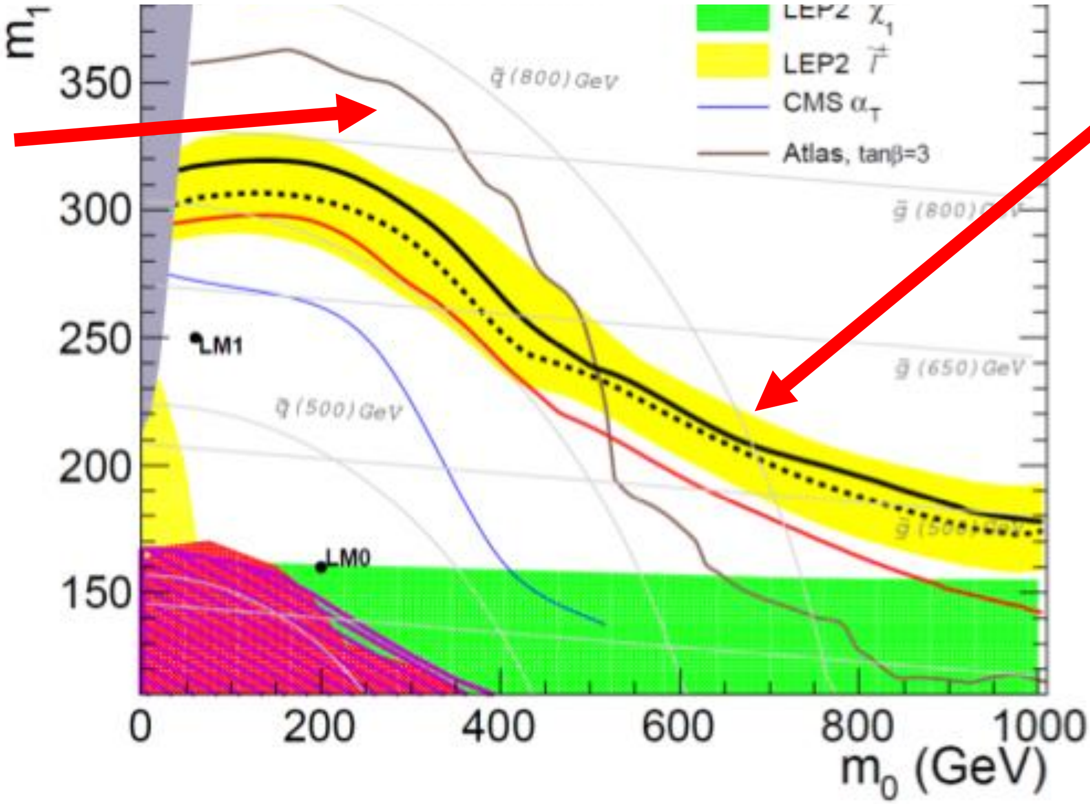
Have searched for jets + missing energy

Interpretation in CMSSM…

Now: check other SUSY models!

ATLAS

CMS



ATLAS: What is measured?

Maximal cross section after cuts are applied

		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–

$$\sigma(\text{after cuts}) \leq \quad 1.3 \quad 0.35 \quad 1.1 \quad 0.11 \ \text{pb}$$

designed for $\quad \tilde{q}\tilde{q} \quad \tilde{q}\tilde{q} \quad \tilde{g}\tilde{g} \quad \tilde{q}\tilde{g}$

heavy

ATLAS Constraints on pGGM parameter space

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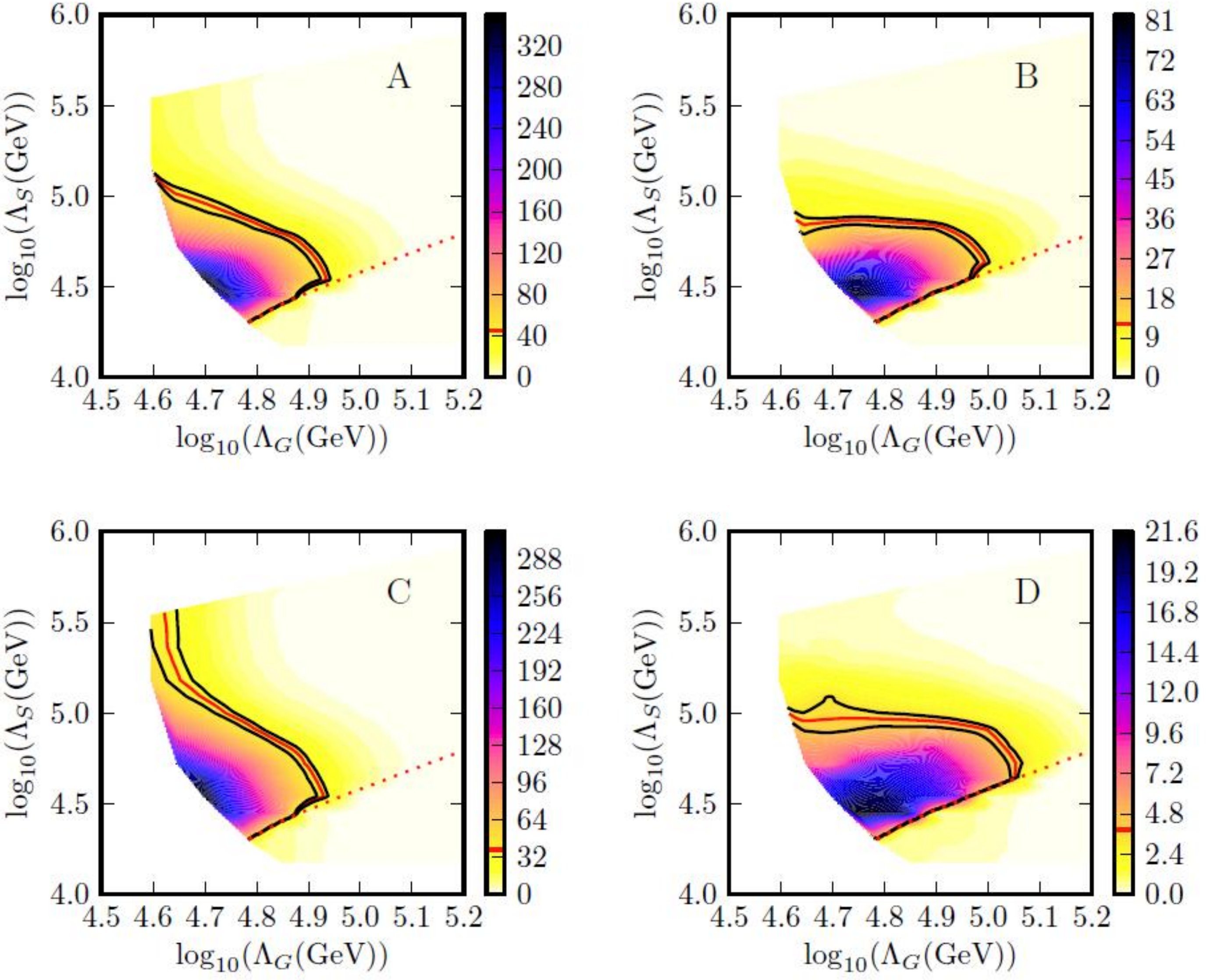
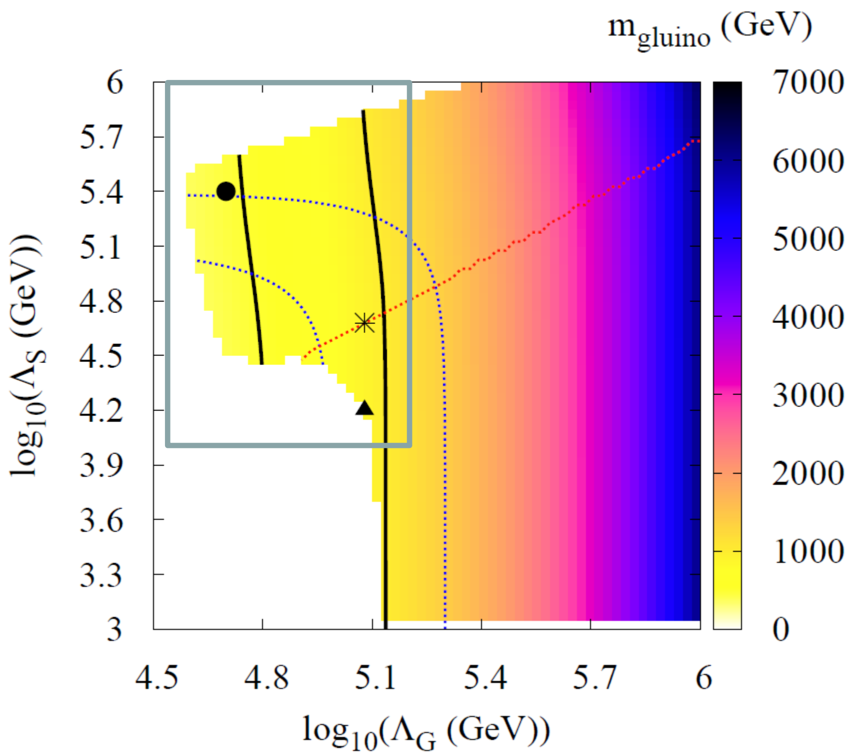
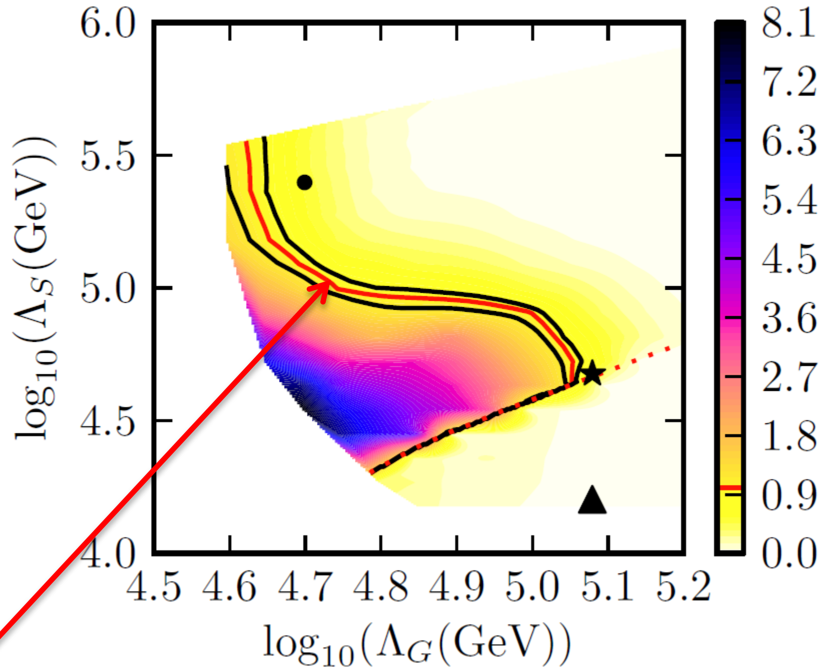


ATLAS Constraints on pGGM parameter space

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

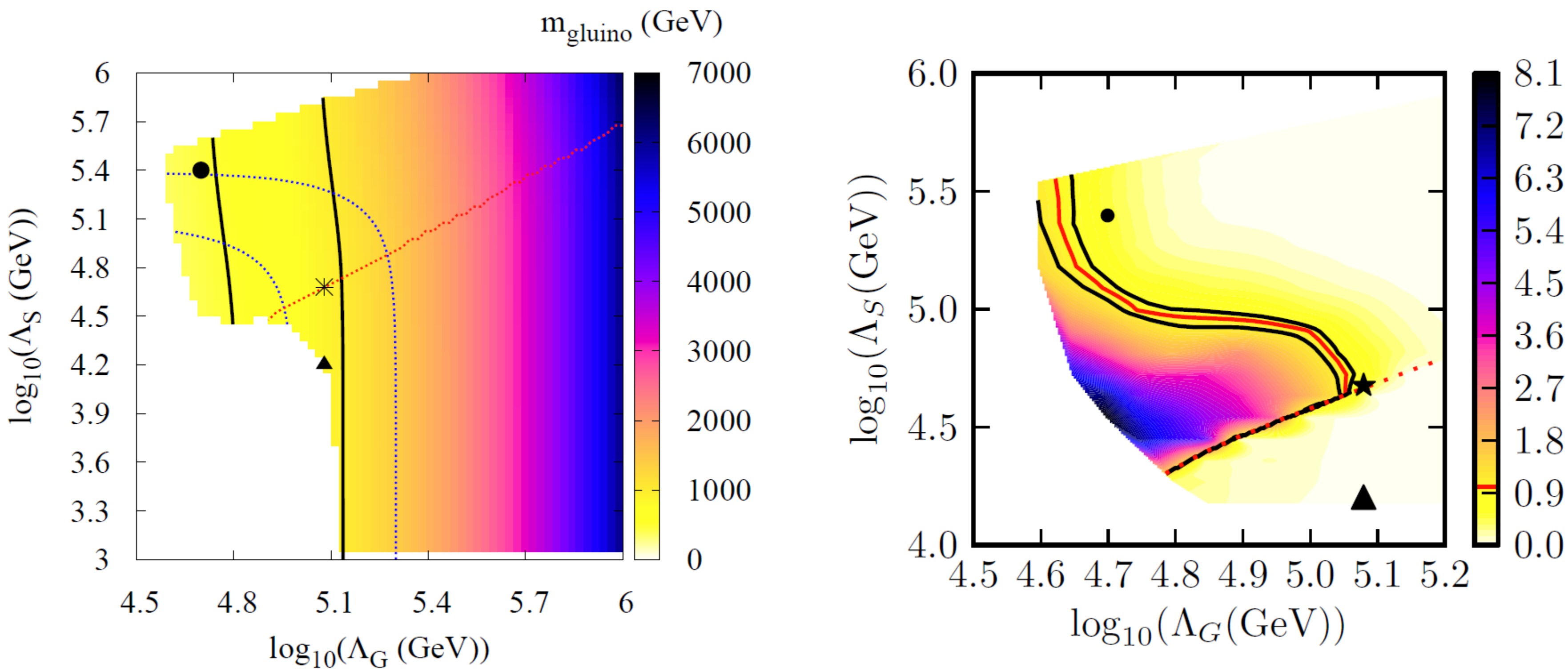




95% CL EXCLUSION Contour from the ATLAS data

ATLAS Constraints on pGGM parameter space

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

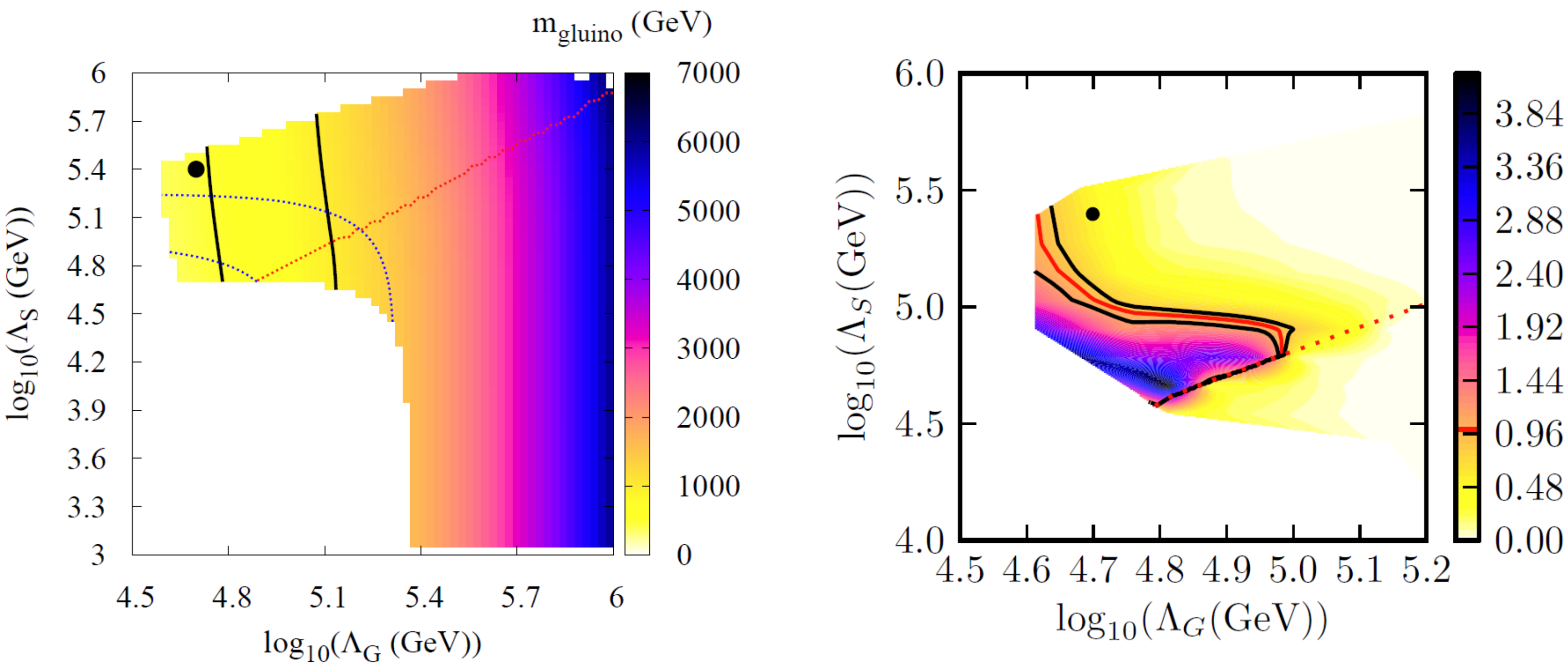


Left panel is the parameter space @ $M_{mess}=10^{14}$ GeV before the LHC data. Stop mass contours (500 GeV and 1 TeV) are dotted lines and solid lines are gluinos (500 GeV and 1 TeV) . NLSP is neutralino above the diagonal and stau below.

Right panel shows 95% exclusion contour in red derived from ATLAS data. Colour scale shows the expected number of signal events normalised to the exclusion limit, i.e. 1.

ATLAS Constraints on pGGM parameter space

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

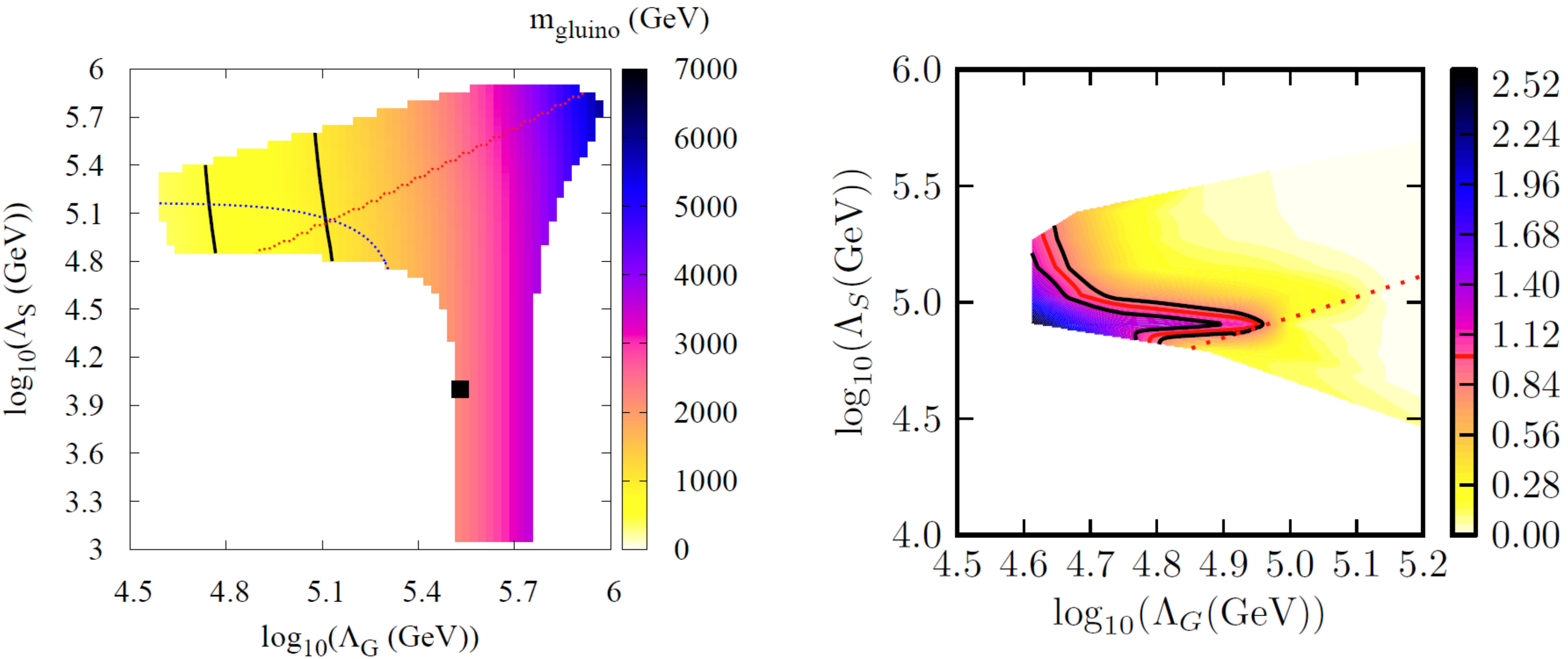


Left panel is the parameter space @ $M_{mess}=10^{10}$ GeV before the LHC data.

Right panel shows 95% exclusion contour in red derived from ATLAS data. Colour scale shows the expected number of signal events normalised to the exclusion limit, i.e. 1.

ATLAS Constraints on pGGM parameter space

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

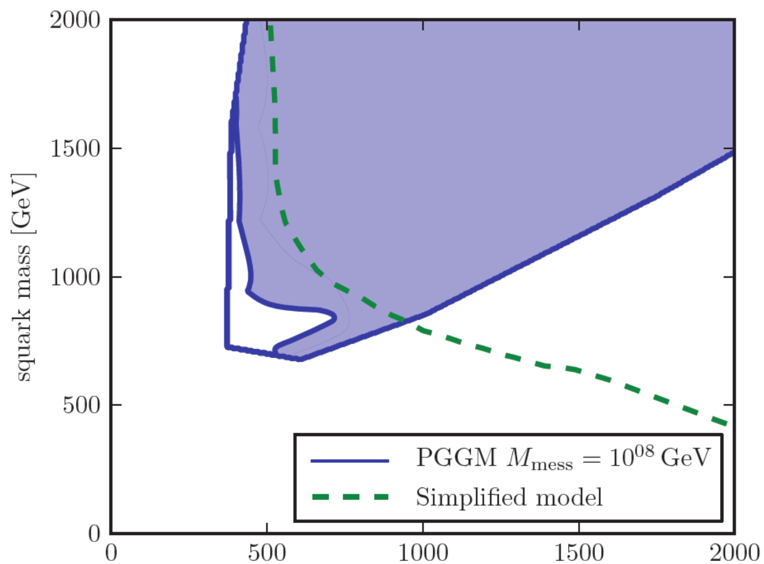


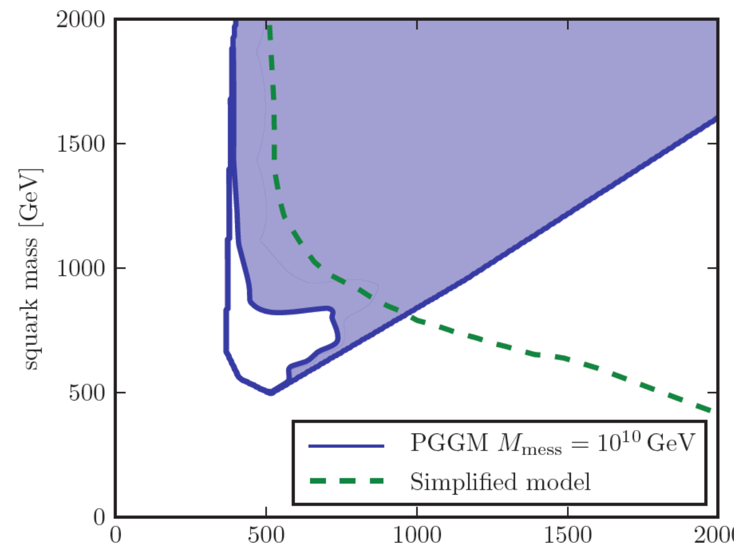
Left panel is the parameter space @ $M_{mess}=10^8$ GeV before the LHC data.

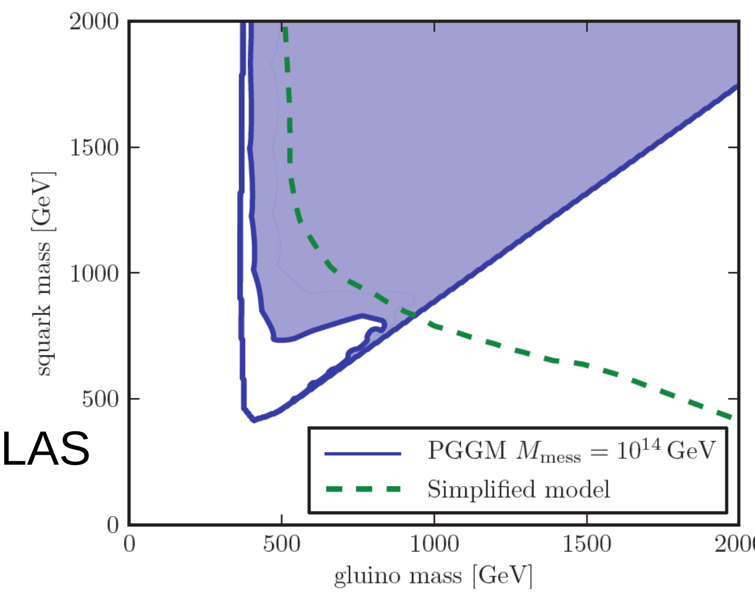
Right panel shows 95% exclusion contour in red derived from ATLAS data. Colour scale shows the expected number of signal events normalised to the exclusion limit, i.e. 1.

ATLAS Constraints on pGGM parameter space

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585



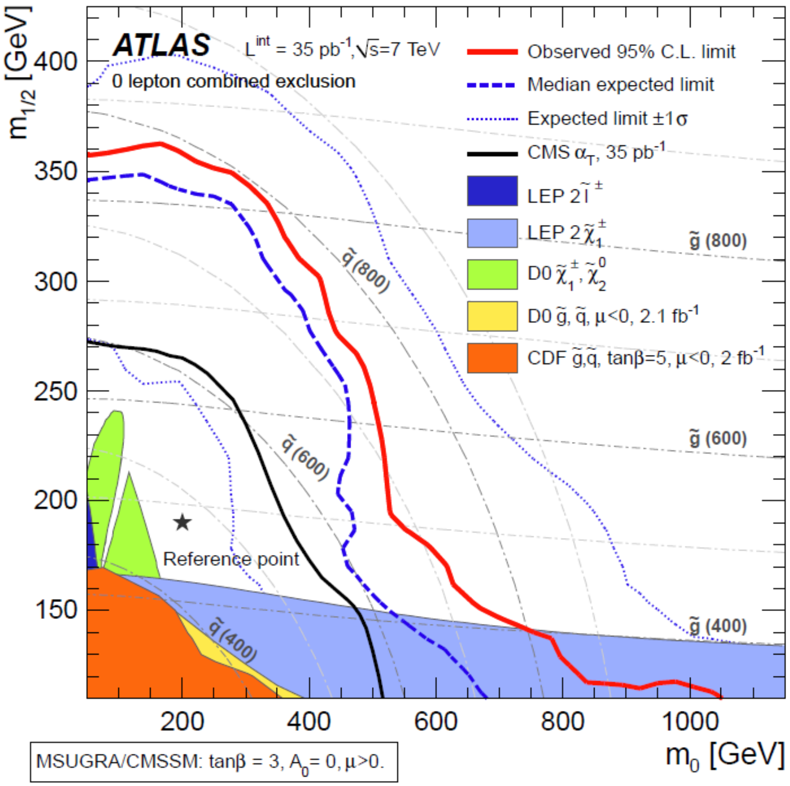


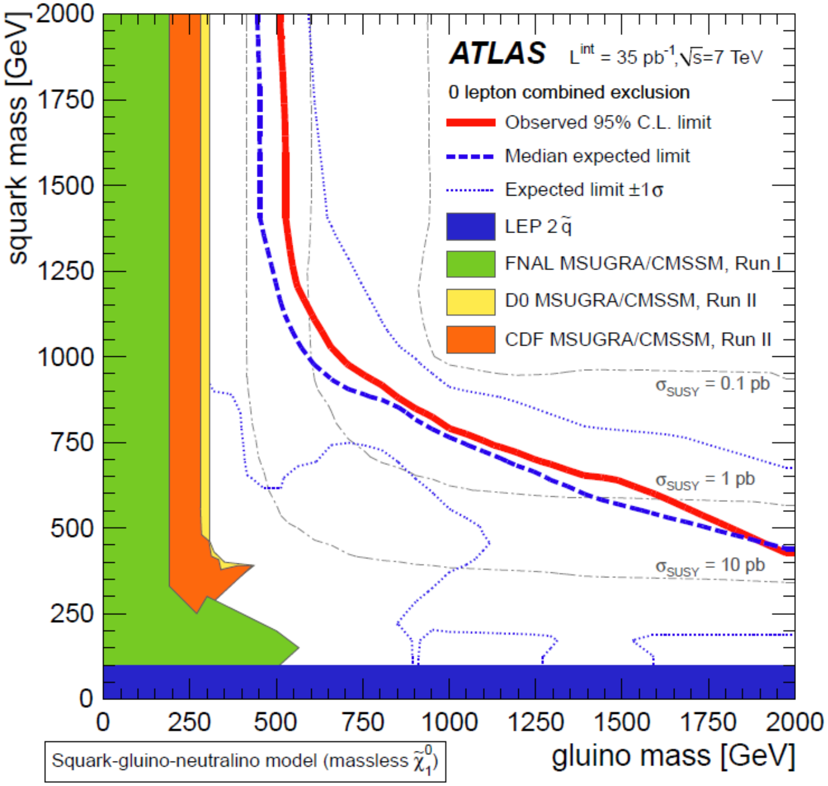


Pure GGM parameter space
In terms of physical squark and gluino masses.

White regions are excluded by ATLAS

Let us pause and compare with the CMSSM results (ATLAS)





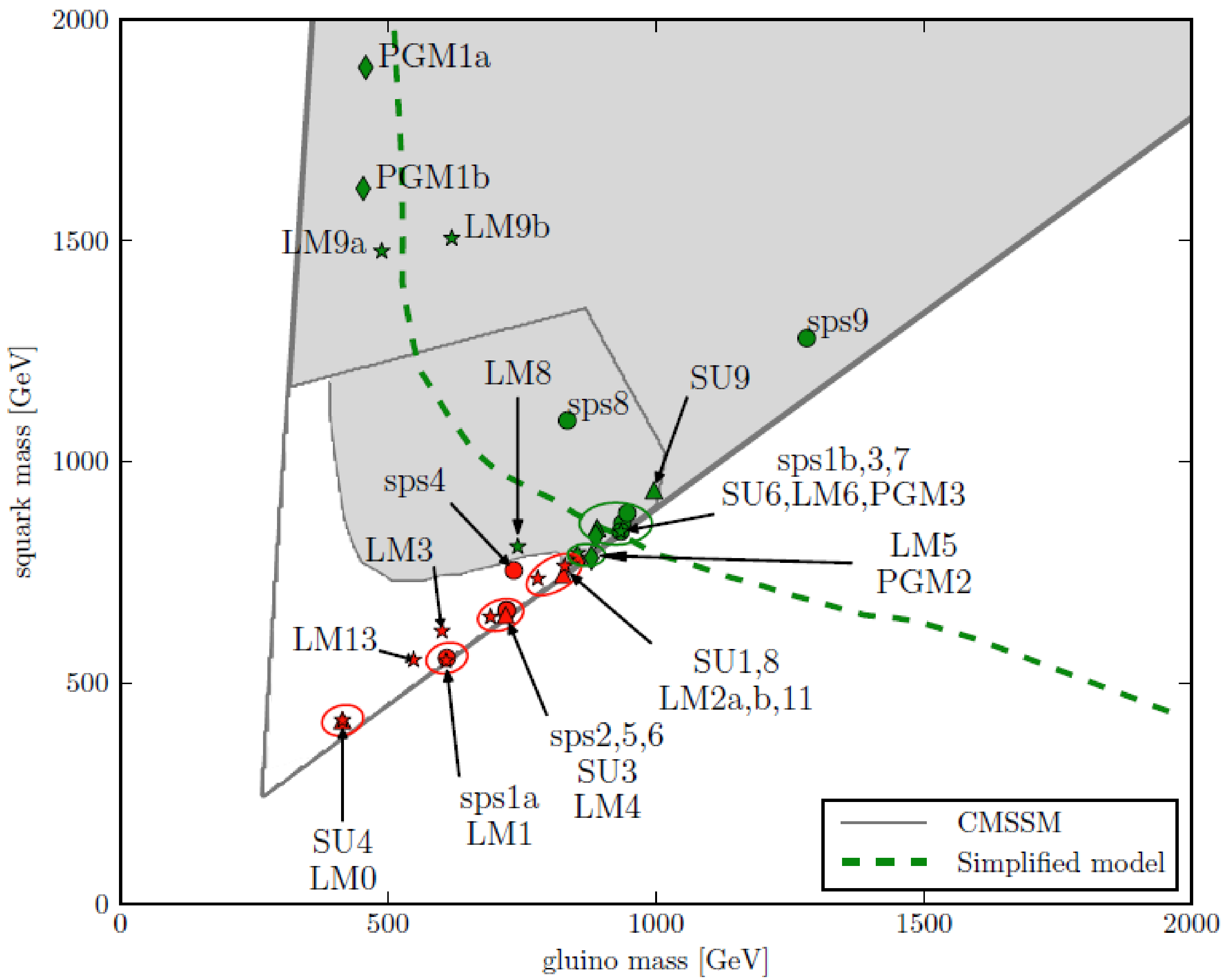
CMSSM exclusion contour on $m_{1/2}$ - m_0 plane

Exclusion contour for a simplified model on the physical squark-gluino mass plane

Our implementation of ATLAS exclusion on CMSSM and the standard benchmark points

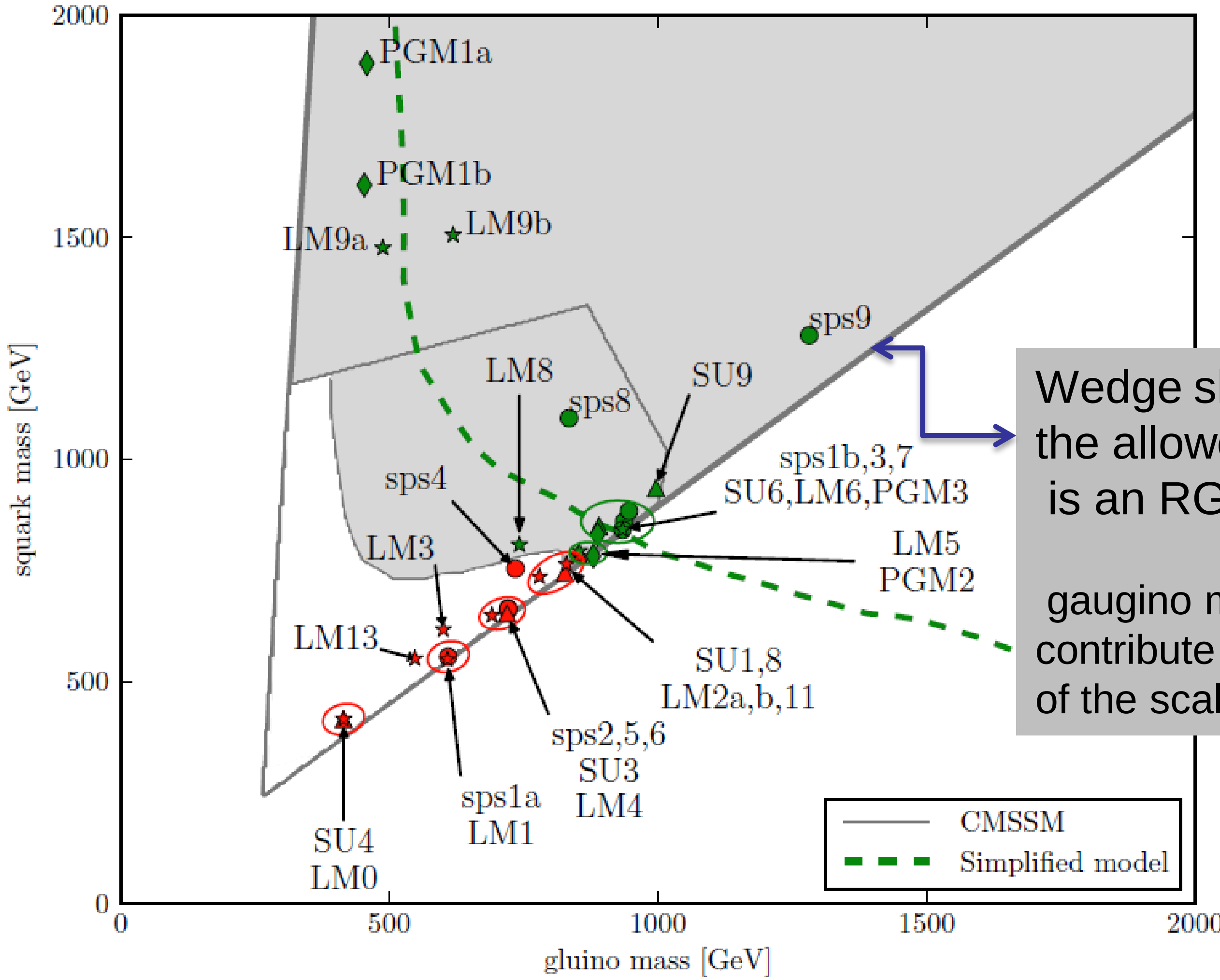
Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

squark-gluino physical mass plane



Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

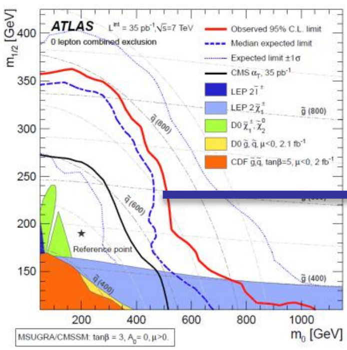


Wedge shape of the allowed region is an RG effect:

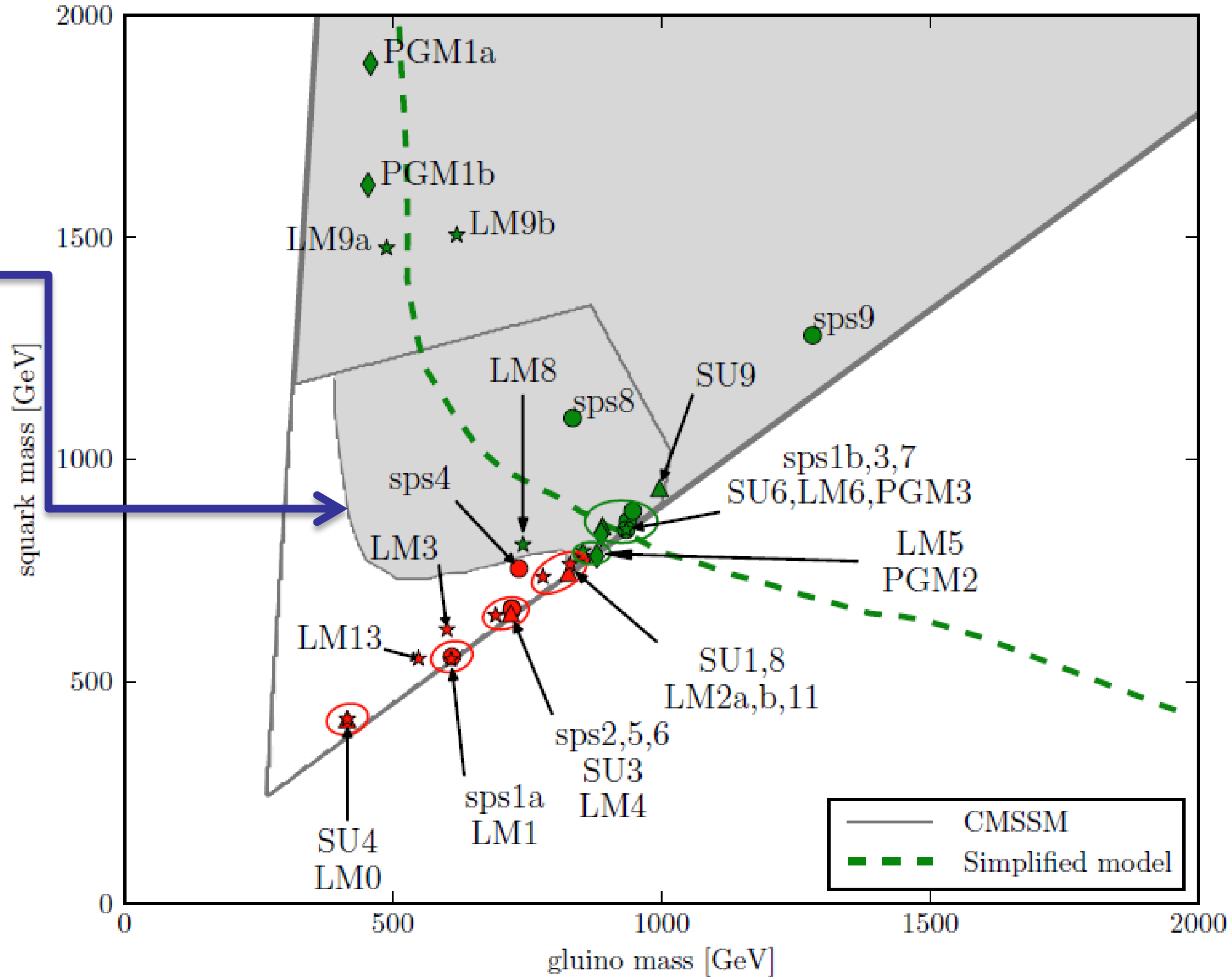
gaugino masses contribute to running of the scalar masses

Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

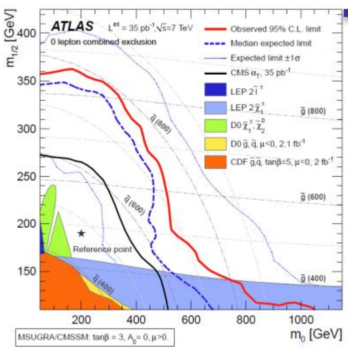


This is the ATLAS exclusion contour

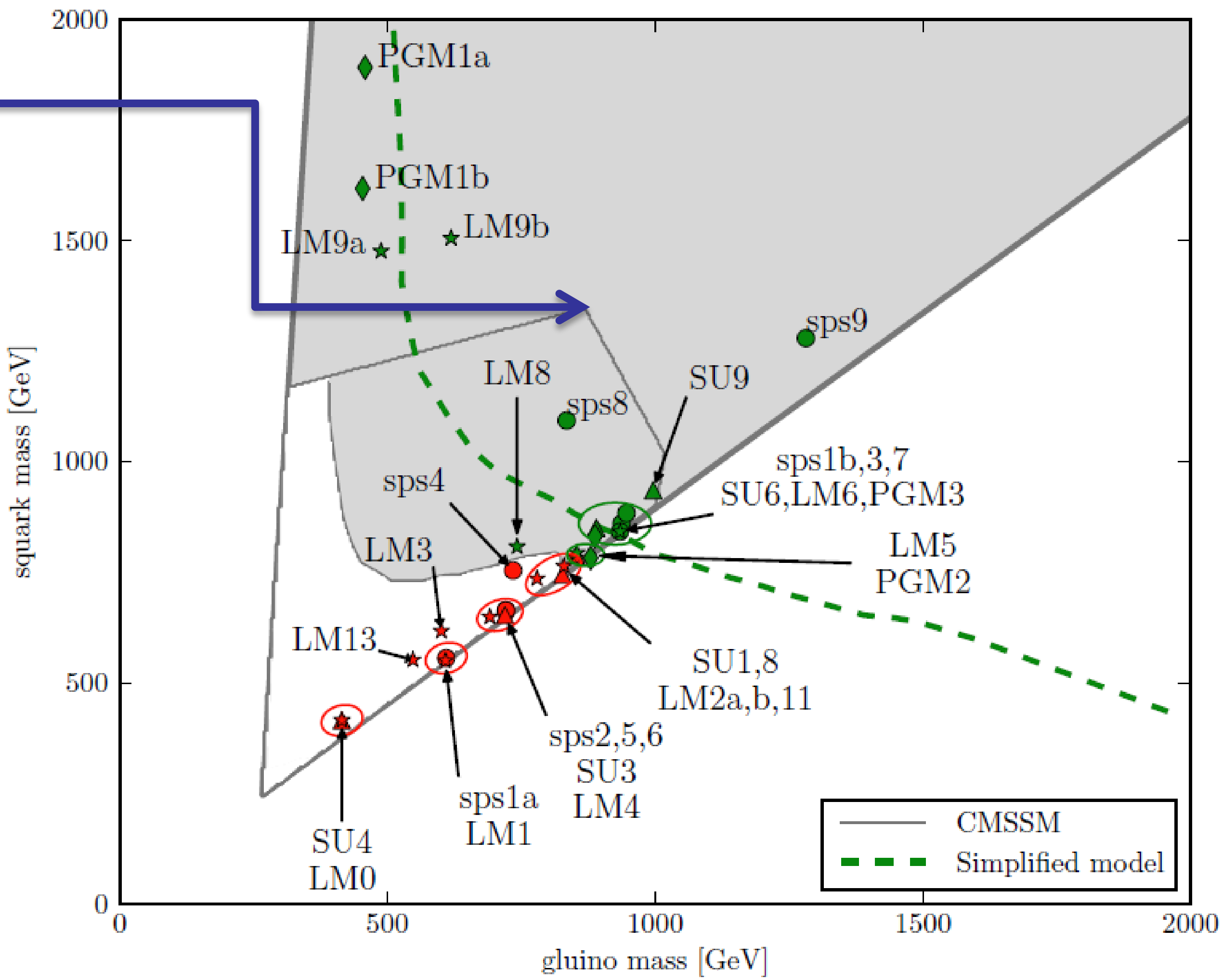


Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585



This is an upper boundary of the $m_{1/2}$-m_0 plot



Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

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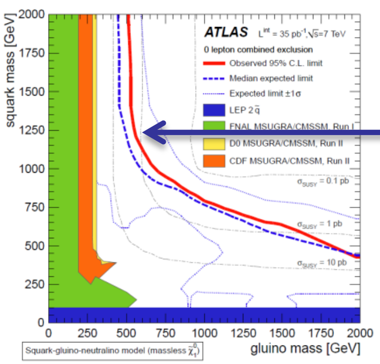
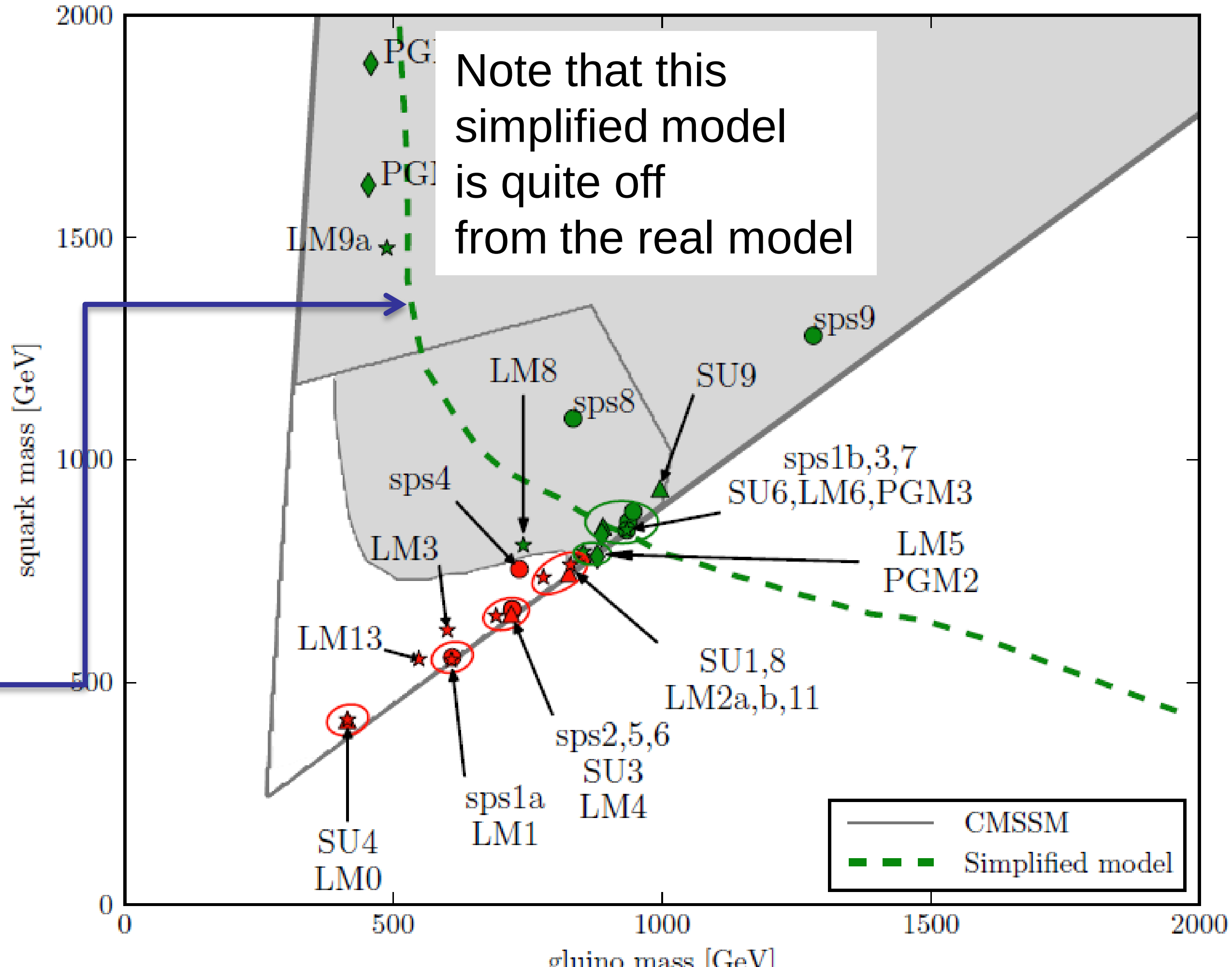
This is the exclusion contour for a simplified model (χ_1^0,squark, gluino)





Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

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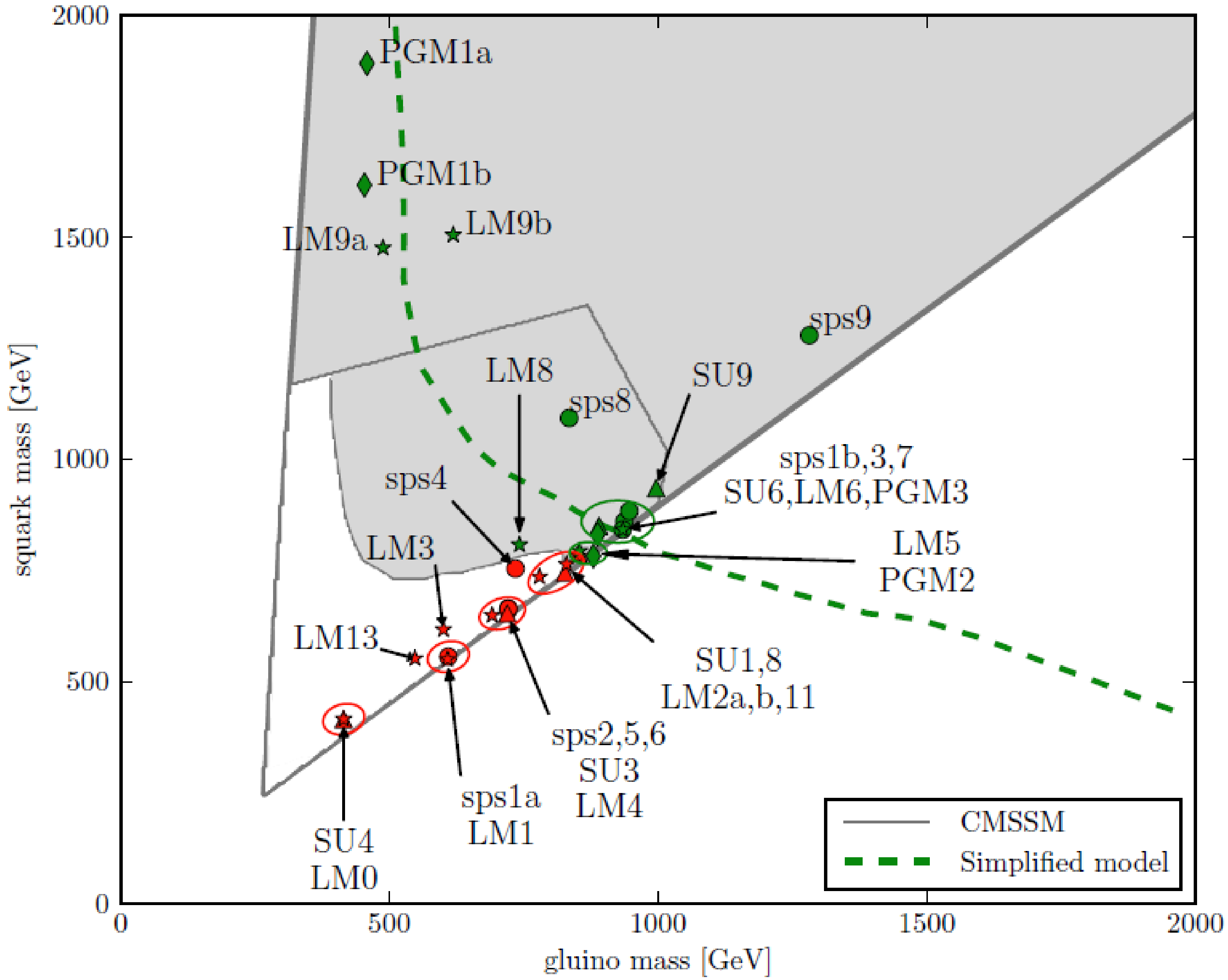
Excluded and still allowed benchmark points



Benchmark point	mediation scenario	σ/pb				status
		A	B	C	D	ATLAS 35pb^{-1}
ATLAS Limits		1.3	0.35	1.1	0.11	
sps1a [13]	CMSSM	2.031	0.933	1.731	0.418	A,B,C,D
sps1b [13]	CMSSM	0.120	0.089	0.098	0.067	allowed
sps2 [13]	CMSSM	0.674	0.388	0.584	0.243	B,D
sps3 [13]	CMSSM	0.123	0.093	0.097	0.067	allowed
sps4 [13]	CMSSM	0.334	0.199	0.309	0.144	D
sps5 [13]	CMSSM	0.606	0.328	0.541	0.190	D
sps6 [13]	CMSSM (non-universal $m_{\frac{1}{2}}$)	0.721	0.416	0.584	0.226	B,D
sps7 [13]	GMSB ($\tilde{\tau}_1$ NLSP)	0.022	0.016	0.023	0.015	allowed
sps8 [13]	GMSB ($\tilde{\chi}_1^0$ NLSP)	0.021	0.011	0.022	0.009	allowed
sps9 [13]	AMSB	0.019*	0.004*	0.006*	0.002*	A,B,C,D
SU1 [14]	CMSSM	0.311	0.212	0.246	0.143	D
SU2 [14]	CMSSM	0.009	0.002	0.010	0.001	allowed
SU3 [14]	CMSSM	0.787	0.440	0.637	0.258	B,D
SU4 [14]	CMSSM	6.723	1.174	7.064	0.406	A,B,C,D
SU6 [14]	CMSSM	0.140	0.101	0.115	0.074	allowed
SU8a [14]	CMSSM	0.251	0.174	0.197	0.120	D
SU9 [14]	CMSSM	0.060	0.046	0.053	0.040	allowed
LM0 [15]	CMSSM	6.723	1.174	7.064	0.406	A,B,C,D
LM1 [15]	CMSSM	2.307	1.108	1.808	0.458	A,B,C,D
LM2a [15]	CMSSM	0.303	0.201	0.241	0.139	D
LM2b [15]	CMSSM	0.260	0.180	0.205	0.123	D
LM3 [15]	CMSSM	1.155	0.504	1.113	0.270	B,C,D
LM4 [15]	CMSSM	0.783	0.432	0.699	0.260	B,D
LM5 [15]	CMSSM	0.202	0.138	0.179	0.109	allowed
LM6 [15]	CMSSM	0.127	0.094	0.099	0.068	allowed
LM7 [15]	CMSSM	0.062	0.013	0.072	0.006	allowed
LM8 [15]	CMSSM	0.189	0.099	0.194	0.082	allowed
LM9a [15]	CMSSM	0.238	0.029	0.358	0.015	allowed
LM9b [15]	CMSSM	0.075	0.017	0.088	0.009	allowed
LM10 [15]	CMSSM	0.003	0.000	0.003	0.000	allowed
LM11 [15]	CMSSM	0.358	0.223	0.311	0.166	D
LM12 [15]	CMSSM	0.037	0.008	0.043	0.004	allowed
LM13 [15]	CMSSM	2.523	0.904	2.289	0.331	A,B,C,D
PGM1a [12]	pure GGM ($\tilde{\chi}_1^0$ NLSP)	0.351	0.030	0.570	0.009	allowed
PGM1b [12]	pure GGM ($\tilde{\chi}_1^0$ NLSP)	0.373	0.032	0.625	0.014	allowed
PGM2 [12]	pure GGM ($\tilde{\tau}_1$ NLSP)	0.008*	0.005*	0.009*	0.003*	allowed
PGM3 [12]	pure GGM ($\tilde{\tau}_1, \tilde{\chi}_1^0$ co-NLSP)	0.140	0.103	0.121	0.086	allowed
PGM4 [12]	pure GGM ($\tilde{\tau}_1$ NLSP)	0.000	0.000	0.000	0.000	allowed

[13] Snowmass
[14] ATLAS
[15] CMS
[12] pure GGM

Implementation of ATLAS constraints on the CMSSM overlaid with pGGM and benchmarks

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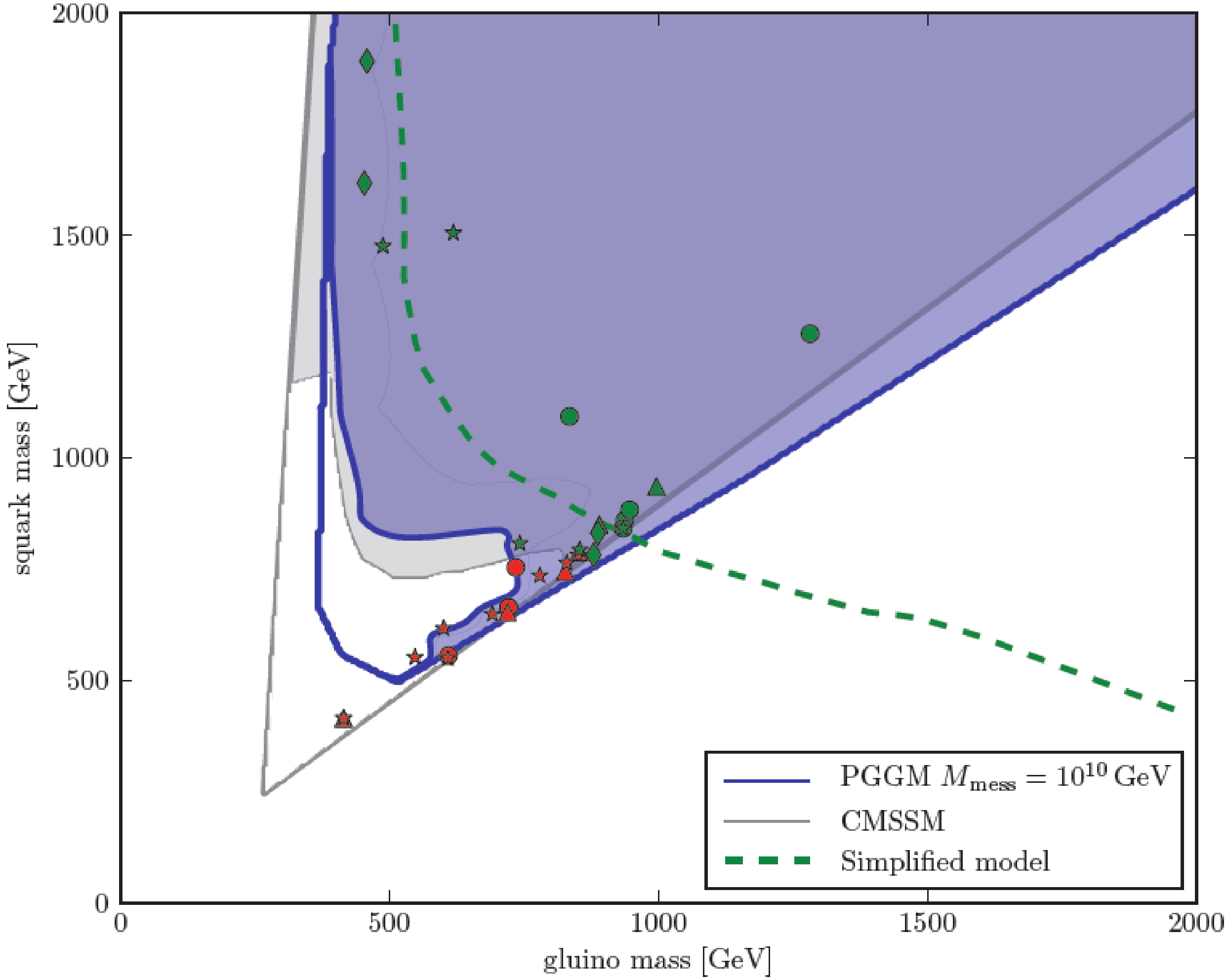

Implementation of ATLAS constraints on the CMSSM overlaid with pGGM and benchmarks

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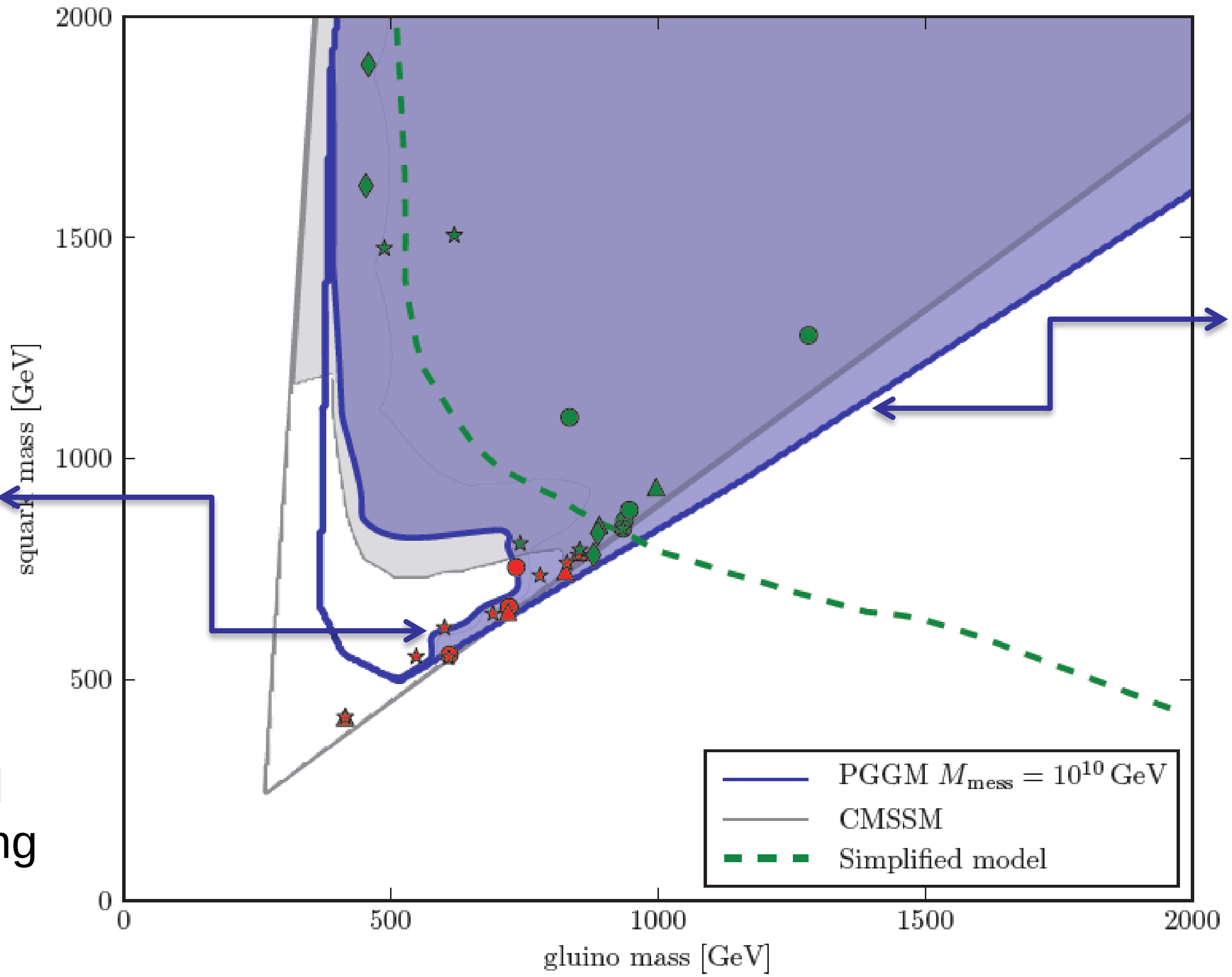
The allowed \`tongue' region corresponds to stau-NLSP region in GGM

not constrained Jets with missing E_T searches



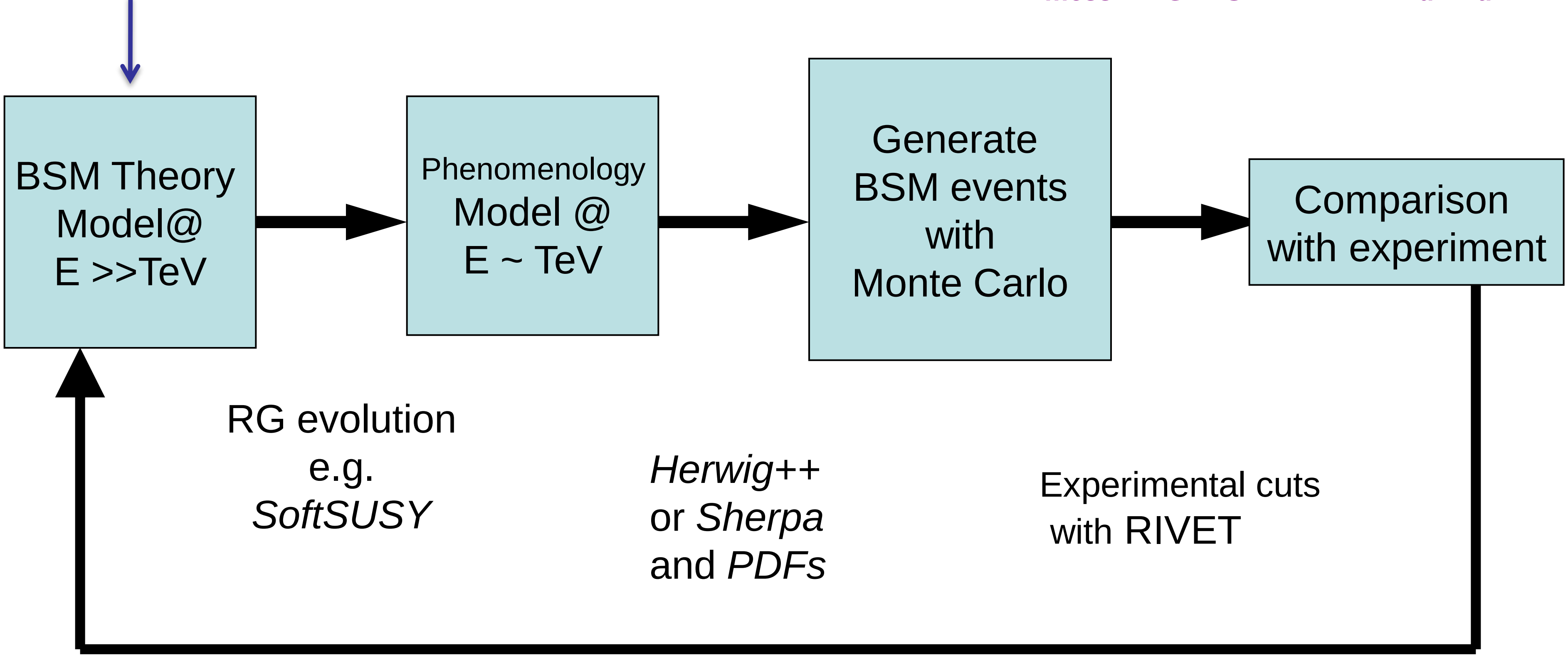
Opening angle of the wedge is wider in Gauge mediation since its susy-breaking scale is lower

BSM theory input needs a parameter space

pureGGM:=(M_{mess}, Λ_G,Λ_S)

In progress:

Extended GGM=(M_{mess}, Λ_G,Λ_S , tan β, δ_u, δ_d)



Summary

Why SUSY

SUSY Breaking and
different Mediation scenarios

Phenomenology of pure General
Gauge mediation

Constraints on Gauge mediation and
other models from the LHC data.