Supersymmetry overview

from theoretical models to applications at the LHC

Valya Khoze

(IPPP Durham University)

BSM Presentations:

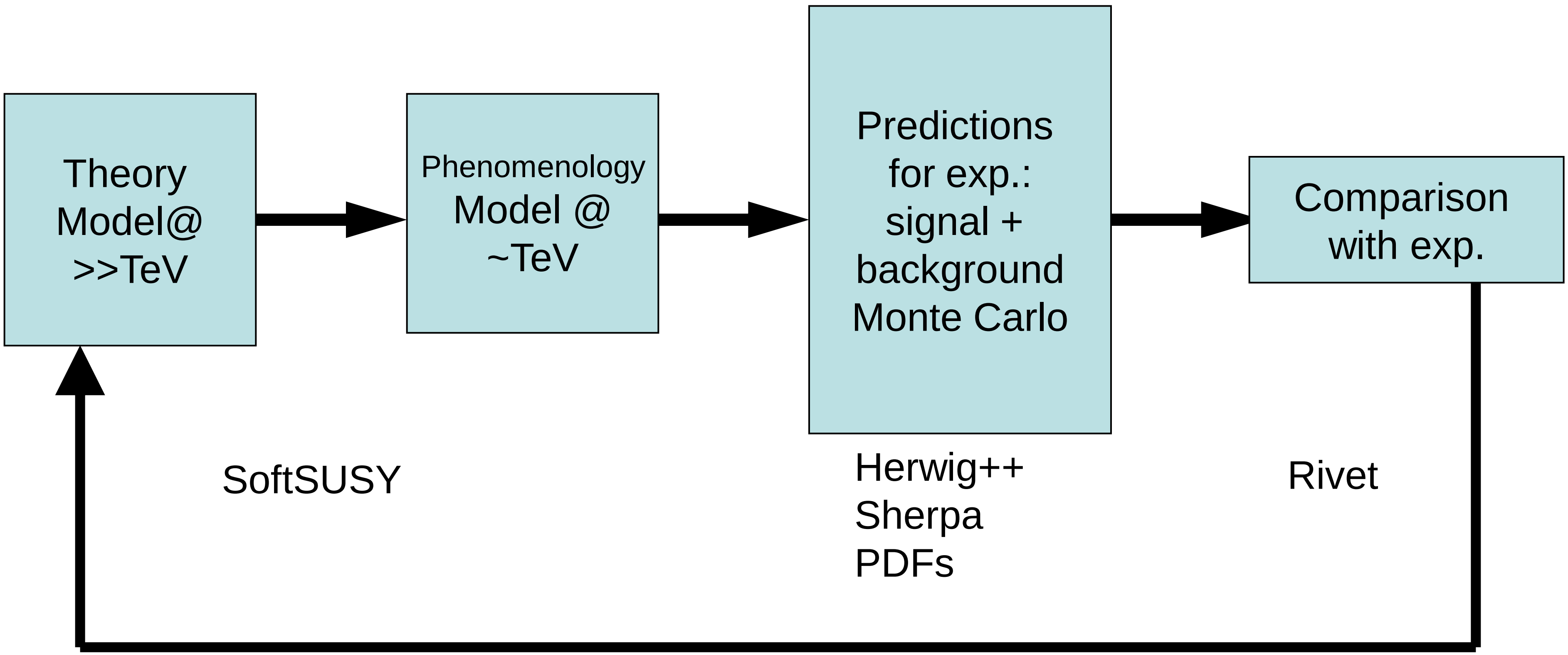
1. Supersymmetry@IPPP overview

   -Valya Khoze

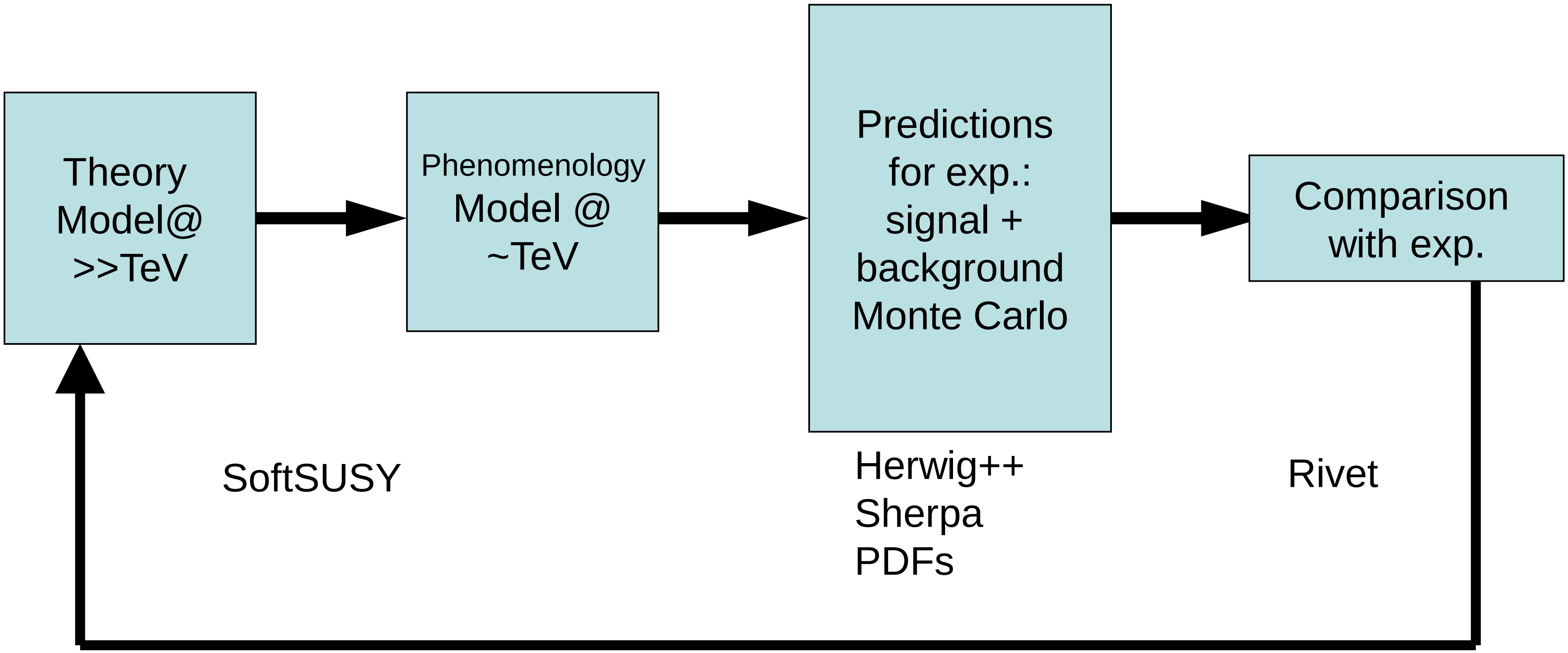
2. Impact of the LHC data on SUSY models -Matt Dolan

3. Beyond the Standard Model at the low energy frontier -Joerg Jaeckel

From models to LHC (and back)@IPPP



From models to LHC (and back)@IPPP



Abel, Brummer, Dolan,
Jaeckel, Khoze

Boehm, Feldmann, Franco,
Pascoli, Lopez-Pavon, Schmidt

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SUSY part - Main Contributors

Steve Abel, James Barnard, Felix Brummer,
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Joerg Jaeckel, Valya Khoze, Luis Matos,
Peter Richardson, Chris Wymant

IPPP academic staff
RA’s
students

2011: Collaboration unique to (and relying upon the existence of) IPPP – synergy of in-house expertise in SUSY-theory, SUSY-phenomenology and Monte Carlo event generation and analysis.

Future plans: further extension and wider collaborations incorporating flavour model building, dark matter, Higgs, string pheno, neutrinos.

Beyond SUSY and BSM topics (covered today) research expertise @IPPP includes:

QCD and Electroweak physics (including higher order calculations,

Higgs physics and top physics)

Parton Distributions (MSTW)

Monte Carlo event generators development and uses

(Herwig and Sherpa)

Scattering amplitudes: on-shell methods and applications

Flavour physics

Neutrino physics

Dark matter and Cosmology

Duality in gauge theory and string theory, non-perturbative dynamics

String phenomenology

Plan of the Talk

1. Why supersymmetry

2. SUSY-breaking and mediation models

3. General gauge mediation (GGM)

4. Gauge Mediation and
   other SUSY models at LHC @ 7 TeV

Why Supersymmetry

SUSY continues to be the most compelling candidate for the theoretical framework describing particle physics beyond the Standard Model. –Why?

1. SUSY (even when softly broken) removes quadratic divergencies previously occurring in the scalar masses.

   $\rightarrow$ *improves consistency of the theory,*

   helps with the hierarchy problem

2. SUSY improves the unification of the Standard Model gauge couplings

   $\rightarrow$ *Grand Unification*

Why Supersymmetry

continued…

3. Supersymmetry breaking triggers electroweak symmetry breaking in the Standard Model by generating a negative mass-squared term for the Higgs H_u

   → *goes towards explaining electroweak symmetry breaking*

4. Supersymmetry with conserved R-parity can explain Dark Matter – neutralino LSPs in gravity mediation; gravitino LSPs in gauge mediation...

   → *Dark Matter and Cosmology applications*

Why Supersymmetry

and finally…

5. Supersymmetry is already required in string theory
   (a UV-complete underlying description unifying with quantum gravity)

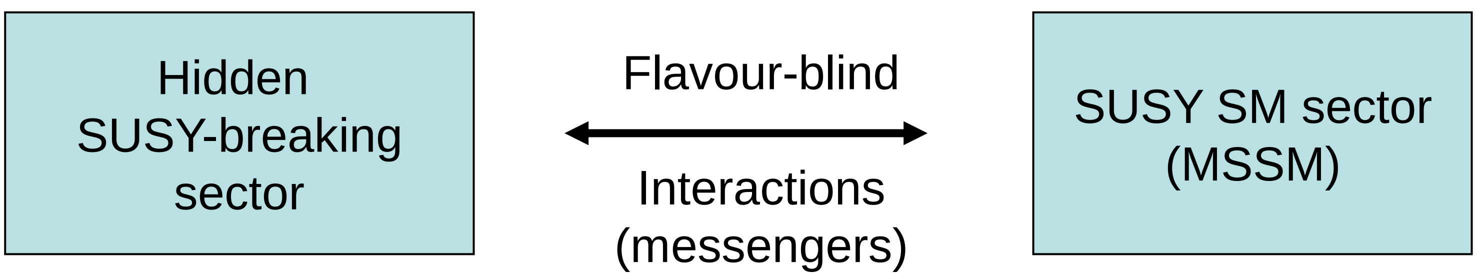
$\rightarrow$ *if SUSY of string theory is not broken at high scales, supersymmetry is not a new addition.*

SUSY-breaking and mediation

- Supersymmetry must be a broken symmetry – no superpartners found so far, clearly mass degeneracy is broken by at least ~100 GeV - 1 TeV effects.
- Supersymmetry is then a spontaneously broken symmetry, but this cannot be phenomenologically realised within just the Standard Model sector.
- Need for a separate SUSY-breaking sector where $\langle F \rangle \neq 0$ are generated.

SUSY-breaking and mediation

- Thus, 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

Two main mediation scenarios:

- 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 free scale.

Also:

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

Gravity mediation and CMSSM

Supersymmetry breaking in MSSM arises from Plank suppressed terms in the supergravity effective lagrangian

$$\begin{aligned}\mathcal{L}_{\rm NR} \;&=\; -\frac{1}{M_{\rm P}}F\left(\frac{1}{2}f_a\lambda^a\lambda^a+\frac{1}{6}y'^{ijk}\phi_i\phi_j\phi_k+\frac{1}{2}\mu'^{ij}\phi_i\phi_j\right)+\text{c.c.}\\ &\quad -\frac{1}{M_{\rm P}^2}FF^*\,k^i_j\phi_i\phi^{*j}\end{aligned}$$

where F is the SUSY-breaking F-term, λ^a and ϕ_i are gauginos and scalars of the MSSM and y'^{ijk}, k^i_j, μ'^{ij} and f^a are dimensionless constants determined by the underlying supergravity theory.

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,

$$f^a = f\;,\qquad k^i_j = k\,\delta^i_j\;,\qquad y'^{ijk} = \alpha\,y^{ijk}\;,\qquad \mu'^{ij} = \beta\,\mu^{ij}$$

Gravity mediation and CMSSM

This simple model is the Constrained MSSM (CMSSM); its soft terms are

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

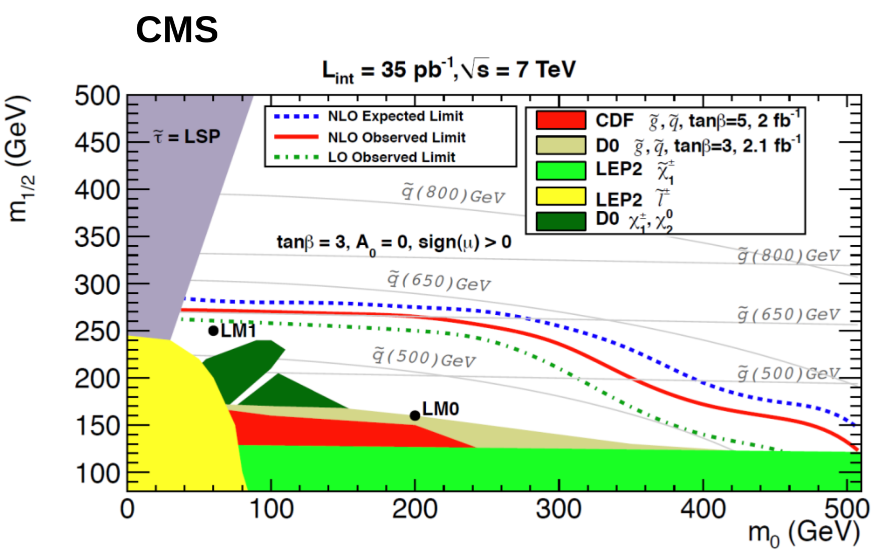
At the high scale, M_P (or in unified theories M_{GUT}) all the gaugino masses are given by $m_{1/2}$ and all the scalar masses by m_0. There are only four idependent parameters in the CMSSM.

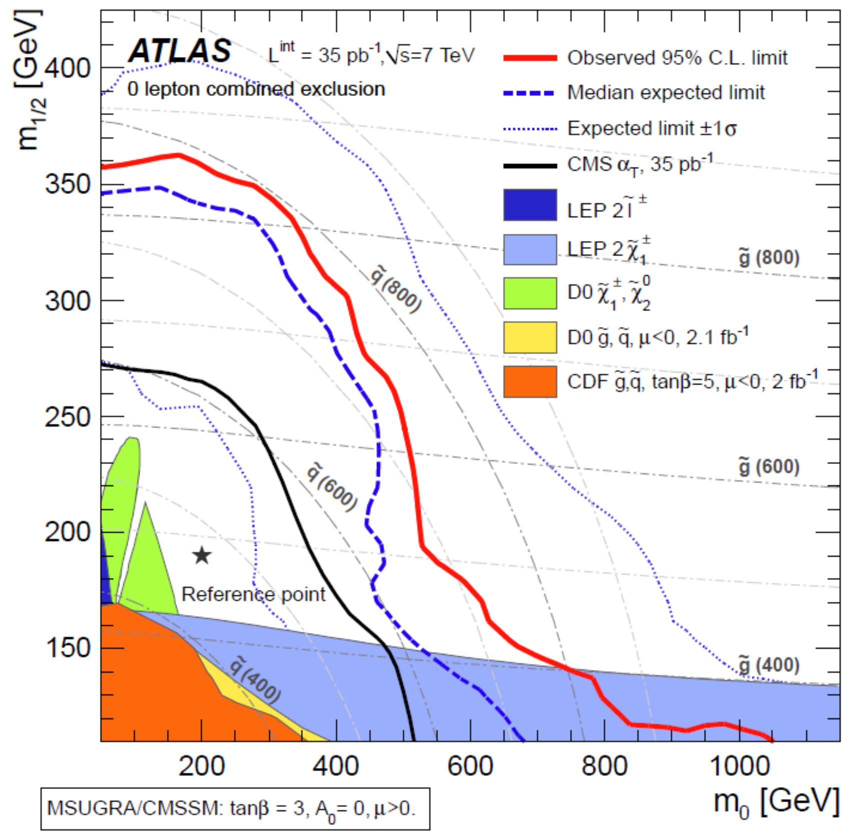
This simple model (and its relatives) is a favourite SUSY realisation of some theorists and most of the experimenters. The entire recent analyses of the CMS and ATLAS collaborations is enterpreted in terms of the CMSSM parameters, m_0 and $m_{1/2}$.

It is important to stress that inspite 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



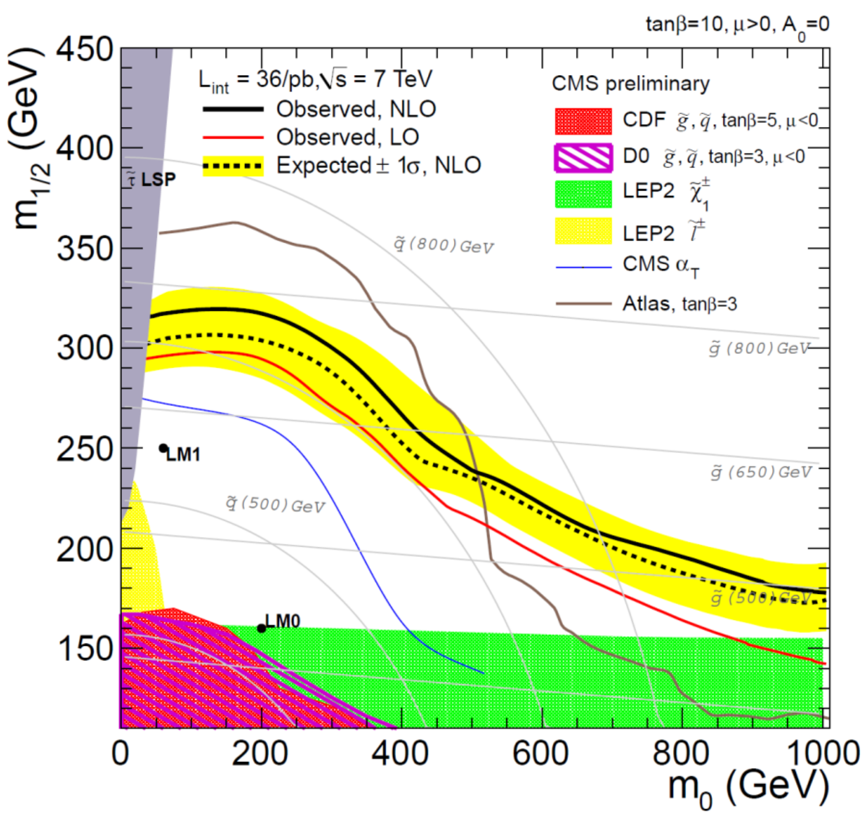


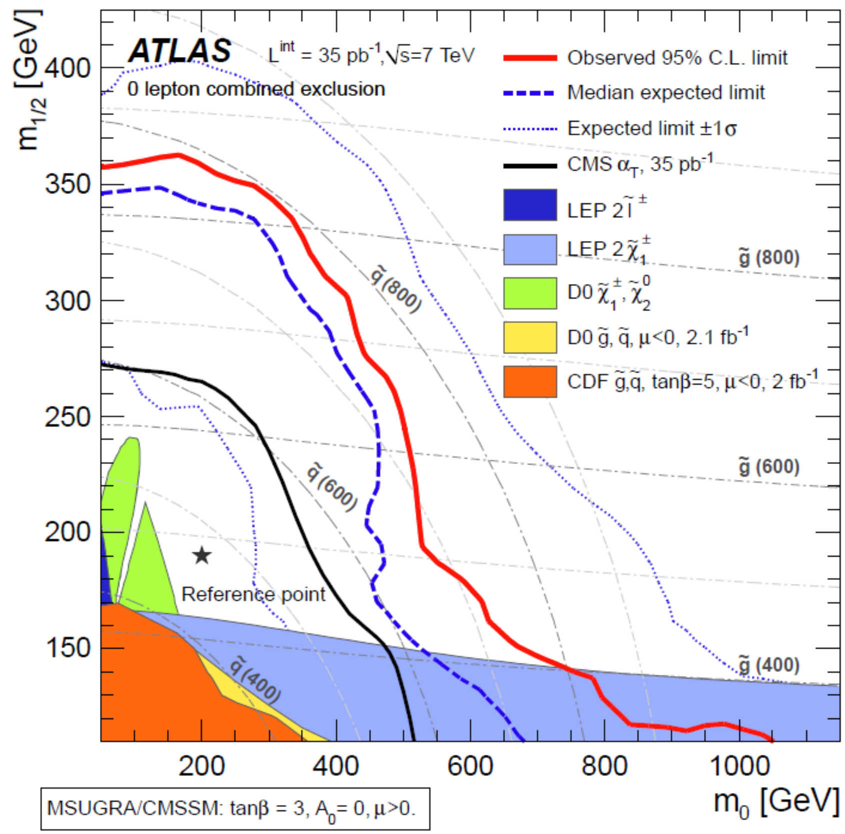
One of our main goals - apply the LHC results and data to SUSY models beyond the CMSSM:

General Gauge Mediation
large set of previously proposed benchmark points
(and even CMSSM again)

CMSSM exclusion plots from CMS and ATLAS

CMS





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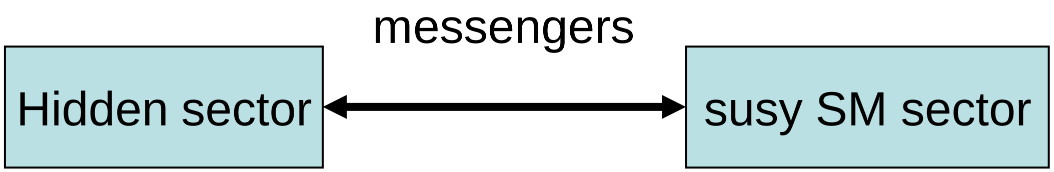
Gauge mediation



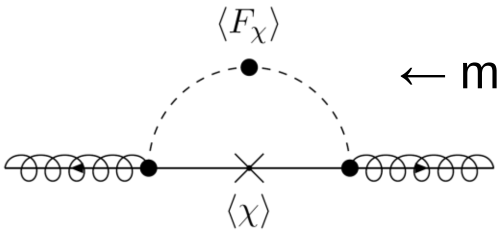
Messenger fields are coupled to the SUSY-breaking sector and to the SM sector. Importantly, in the SM sector they are coupled only to the gauge multiplets, not to the matter fields. => Pure gauge mediation.

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.

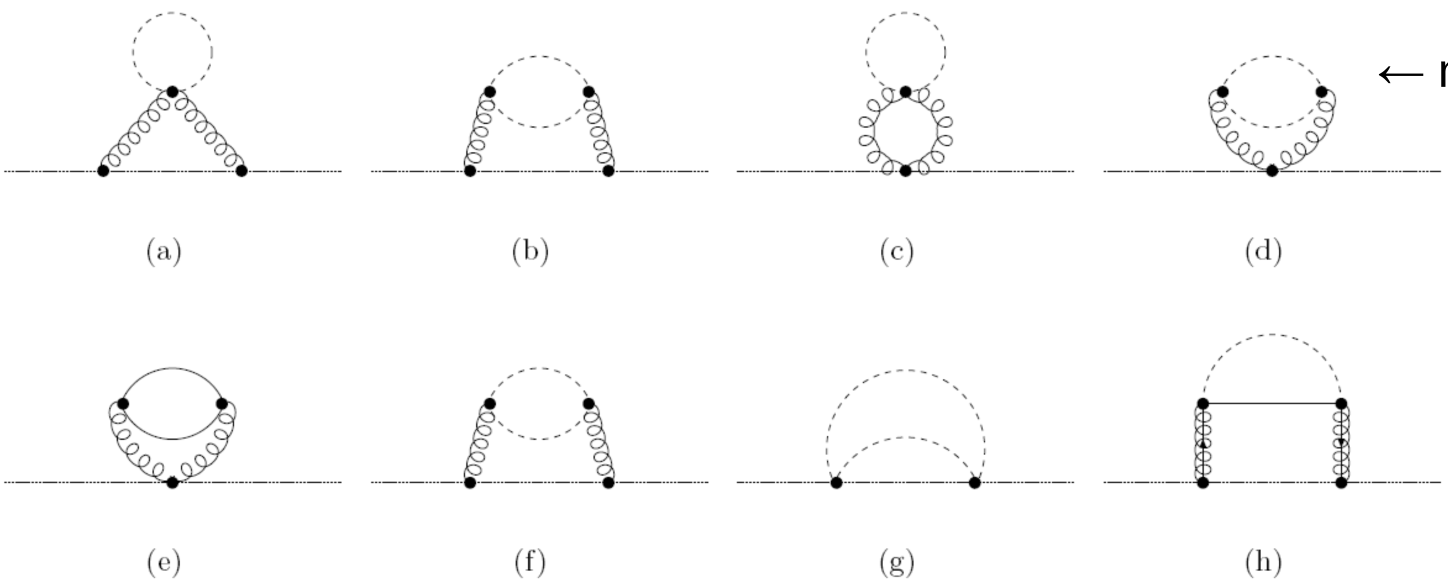
Gauge mediation

- 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 $\Lambda_G \simeq \Lambda_S = \frac{F}{M_{\text{mess}}}$.

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 $\Lambda_{G,i}$ scales and three $\Lambda_{S,i}$ 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.

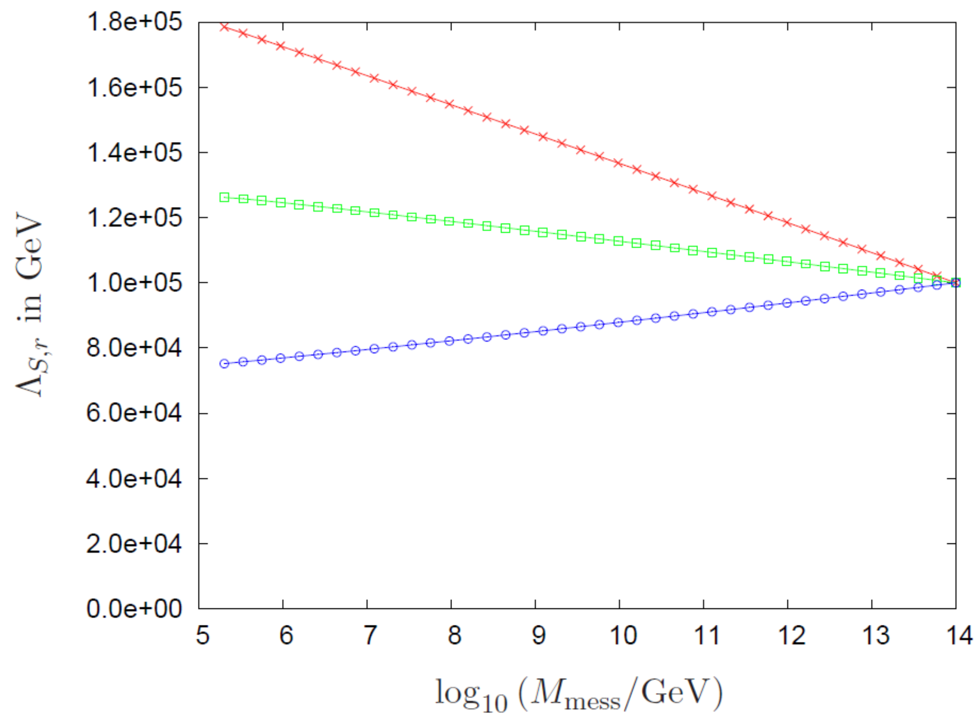
Jaeckel, VVK, Wymant 1103.1843

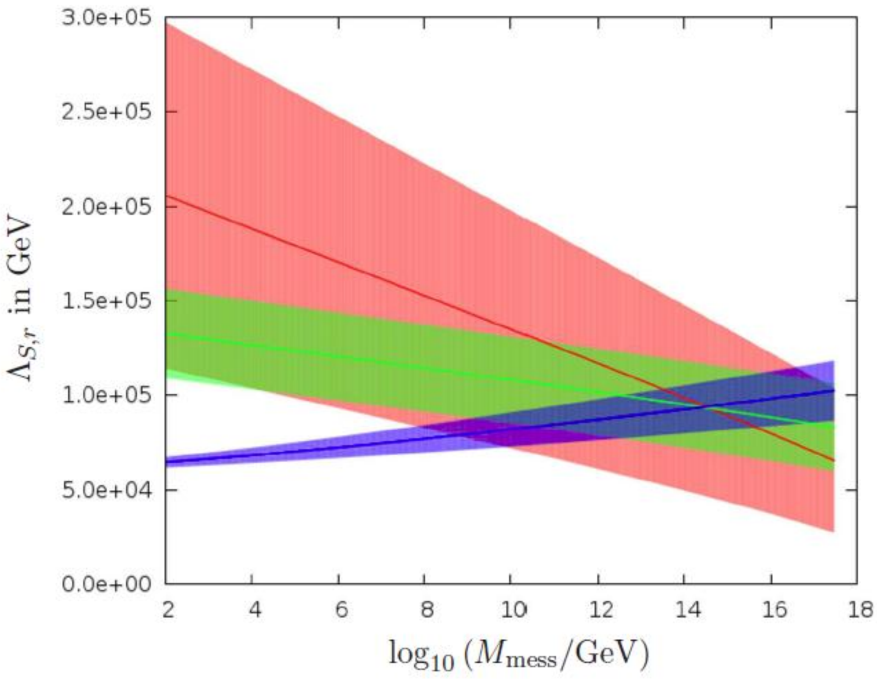
Gauge mediation

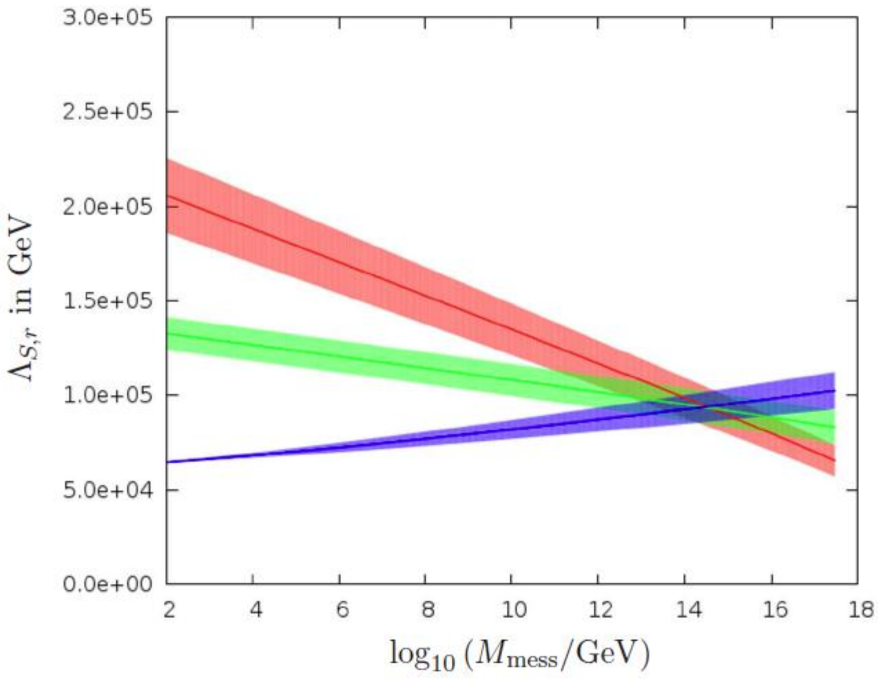
Jaeckel, VVK, Wymant 1103.1843 and 1102.1589

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:







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 a criterium independent of the 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} .

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 GGM Phenomenology: B and mu

Pure GGM on its own does not generate the μ-parameter appearing in the effective Lagrangian,

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

The phenomenologically required value of μ is roughly of the order of the electroweak scale and is determined from the requirements of electroweak symmetry breaking.

The Higgs-sector effective Lagrangian also includes soft supersymmetry-breaking terms generated by the SUSY-breaking sector

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

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

Pure GGM Phenomenology: B and mu

In a strict interpretation of GGM we have no direct couplings of the SUSY-breaking sector to the Higgs sector, we have $B_\mu \approx 0$ at the messenger scale.

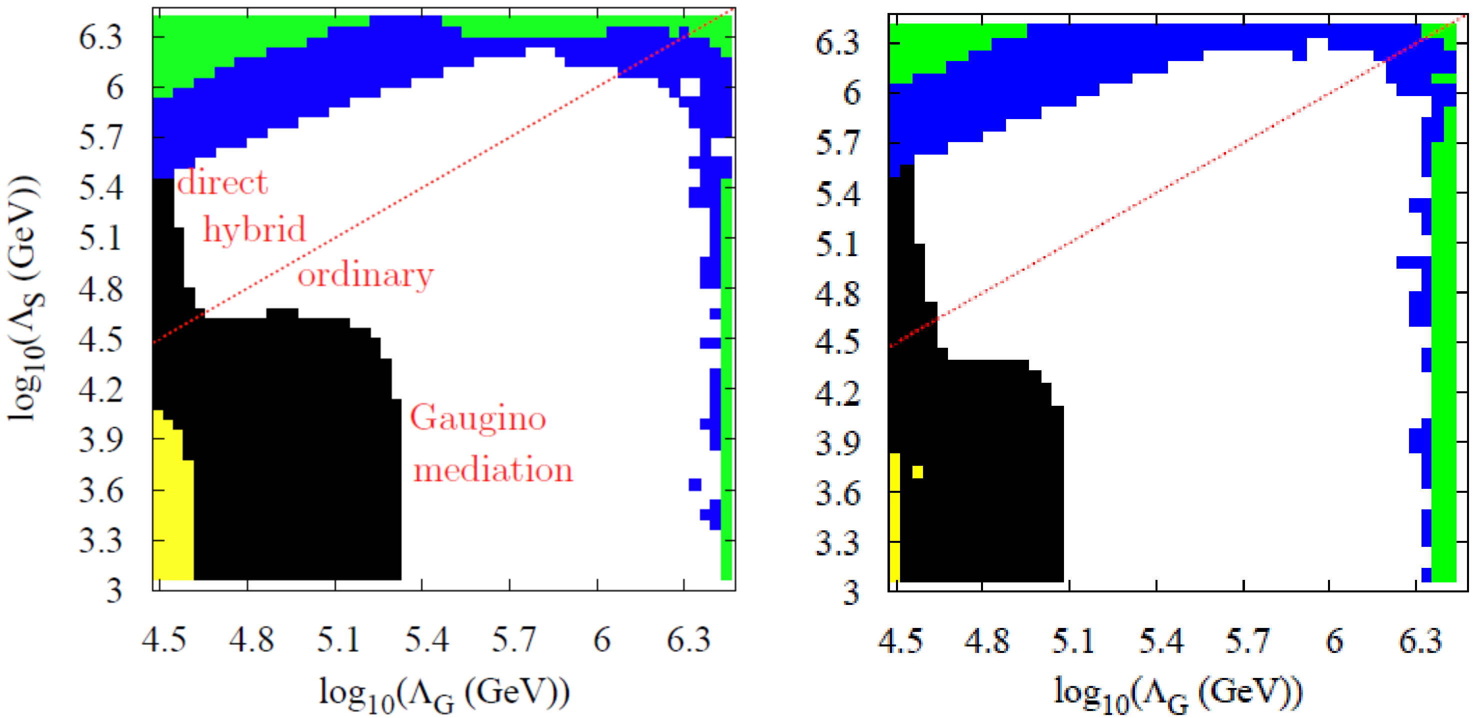
From this a quite small but perfectly viable value of B_μ is then generated radiatively at the electroweak scale.

We then use the measured value of the mass of the Z-boson to predict values of $\tan\beta$ and μ from the requirement of electroweak symmetry breaking.

Since it is B_μ which is responsible for communicating the vev of H_u to H_d, this implies that the ratio of these two vevs, $\tan\beta$, will be large (between 15 and 65).

This is in contrast to the common approach where $\tan\beta$ is taken as an arbitrary input and B_μ at the high scale is obtained from it. For us B_μ(rather than $\tan\beta$) is the fundamental quantity.

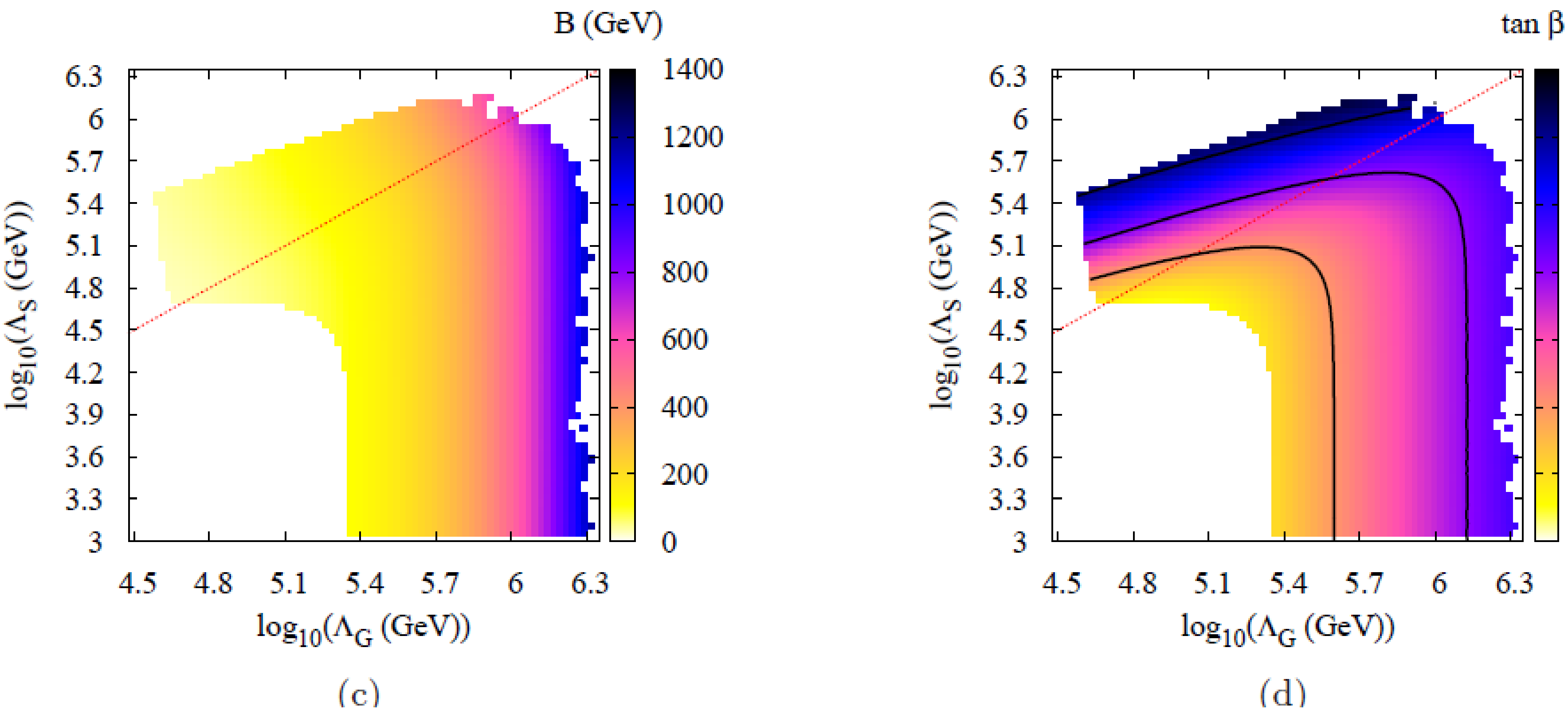
Pure GGM: finding the Parameter Space



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

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

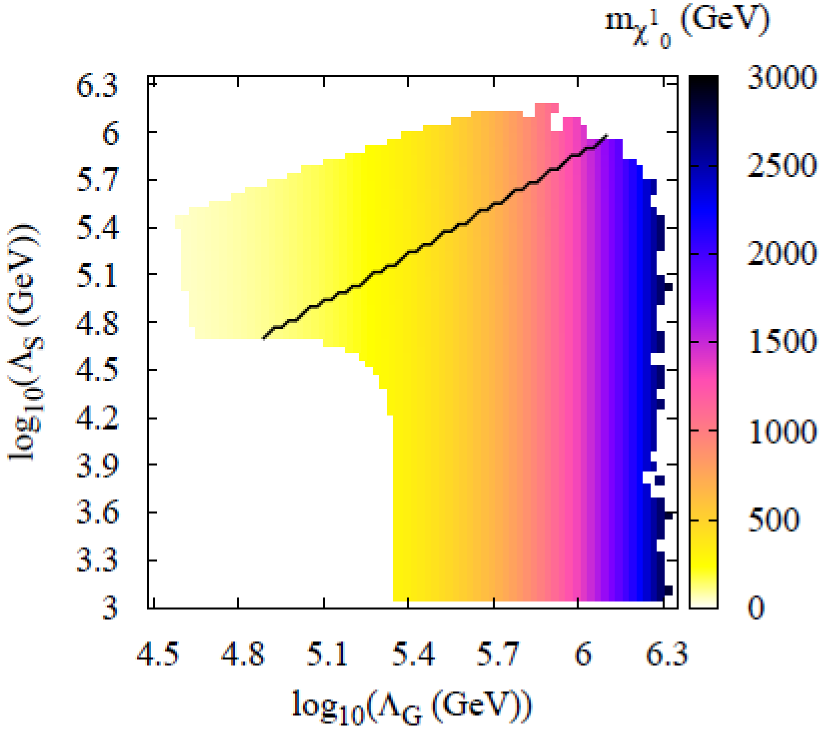
Pure GGM: B and tan(beta) at low energies



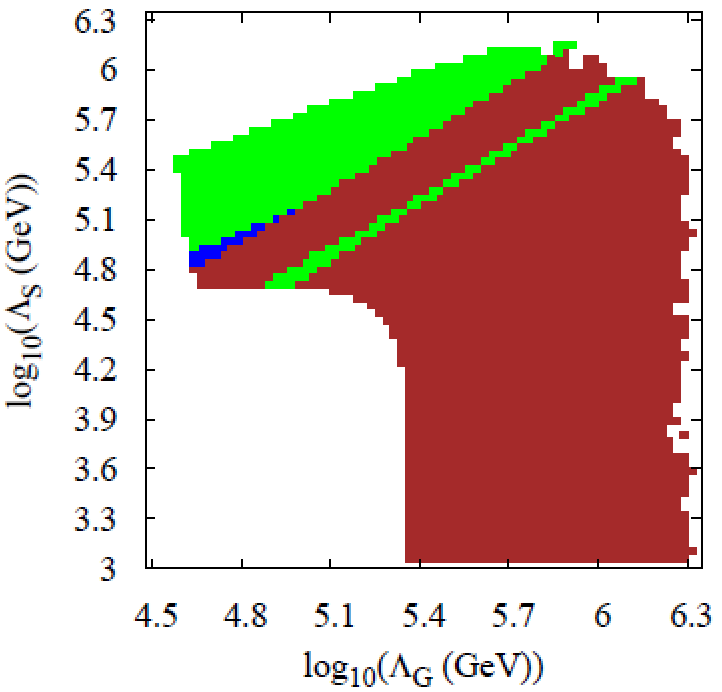
(c) B parameter for $M_{mess} = 10^{10}$ GeV .

(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



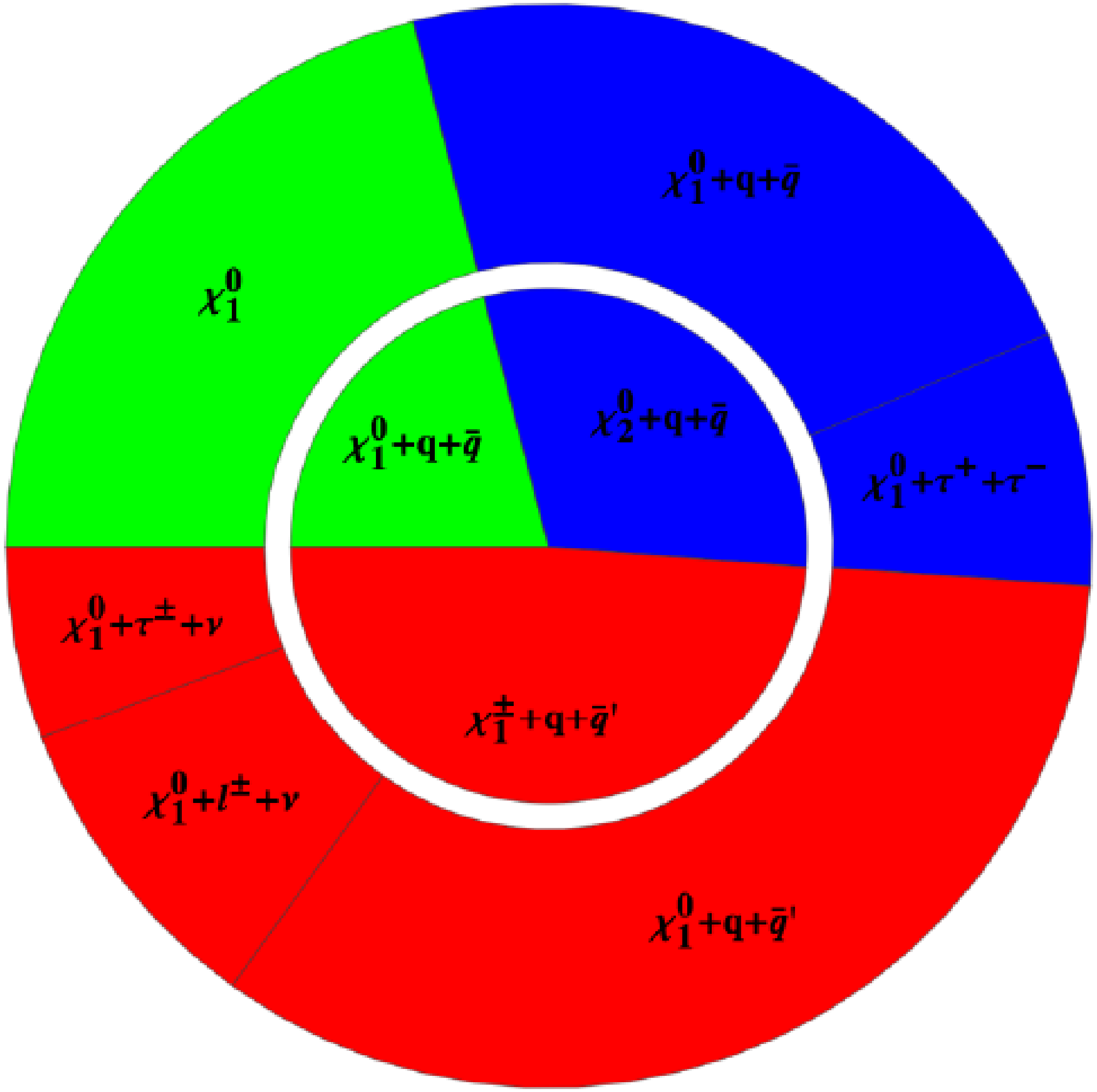
(c)



(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.

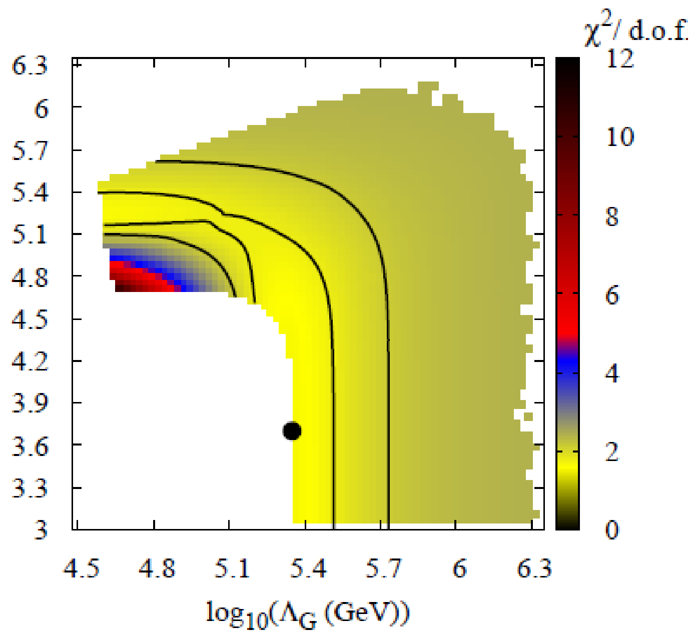
Example of gluino decay cascades for a characteristic point with a relatively light gluino (and neutralino NLSP).



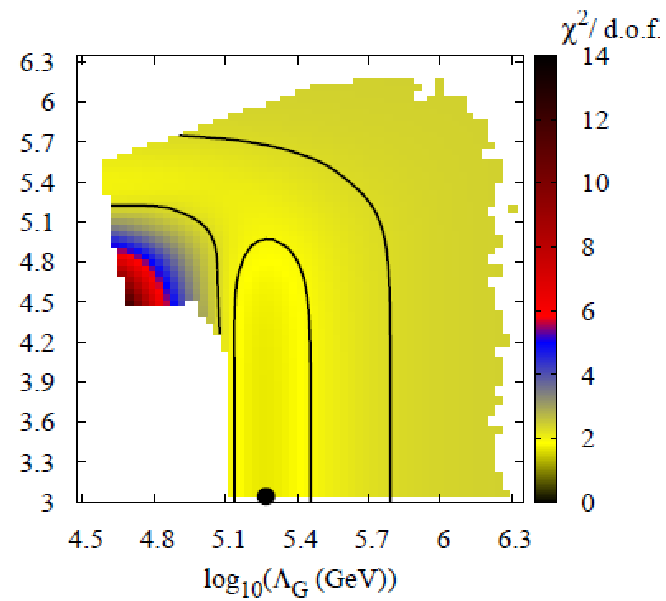
Pure GGM: experimental constraints

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

$$\chi_i^2 = \frac{(p_i - c_i)^2}{\sigma_i^2}$$



(c)

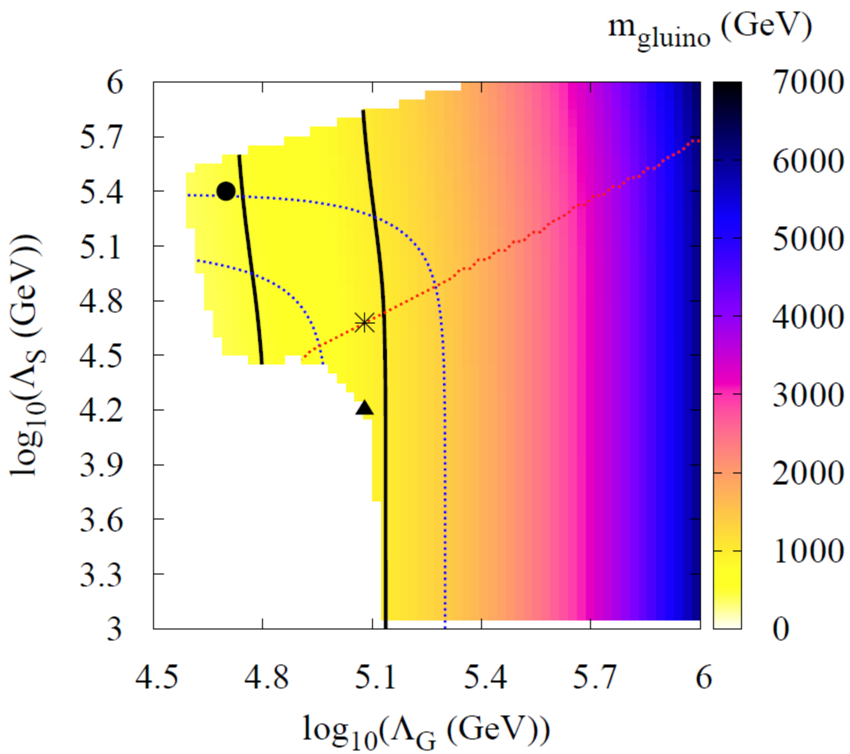


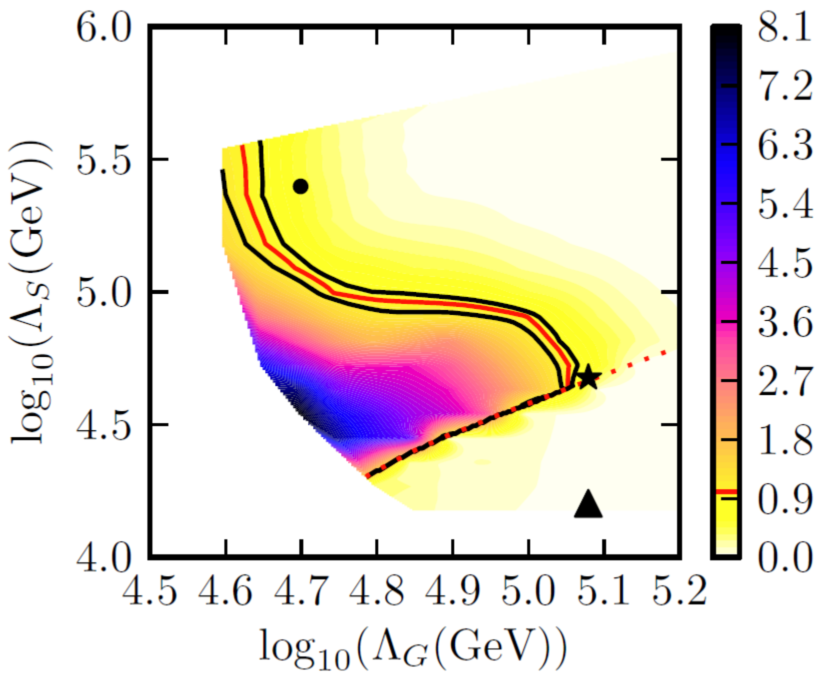
(e)

χ^2 distribution in the Λ_G-Λ_S plane for $M_{\text{mess}} = 10^{10}$ and 10^{14} GeV. Black lines denote the boundaries of the 68% and 95% confidence regions. The black spots mark the best-fit points

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

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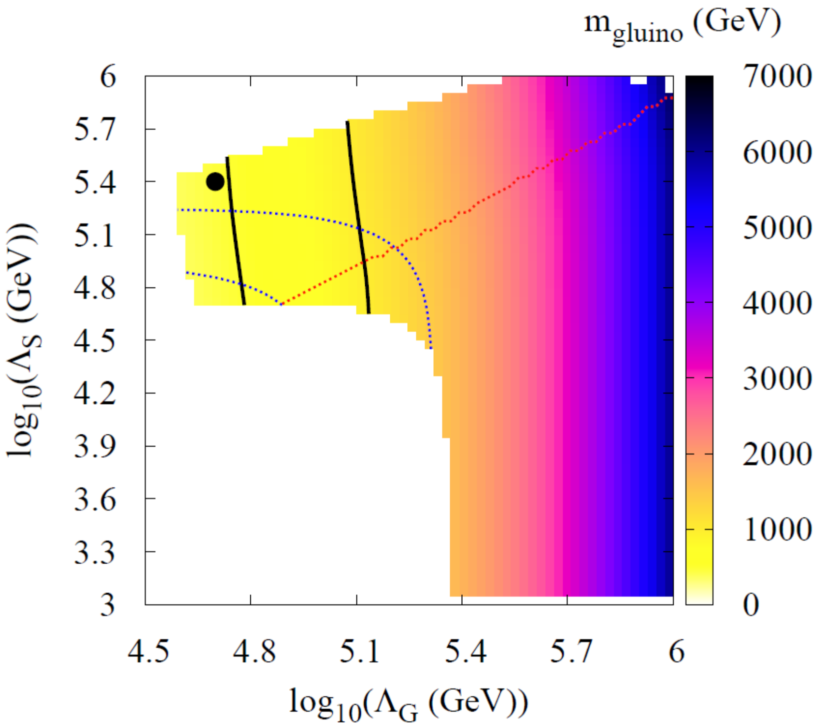
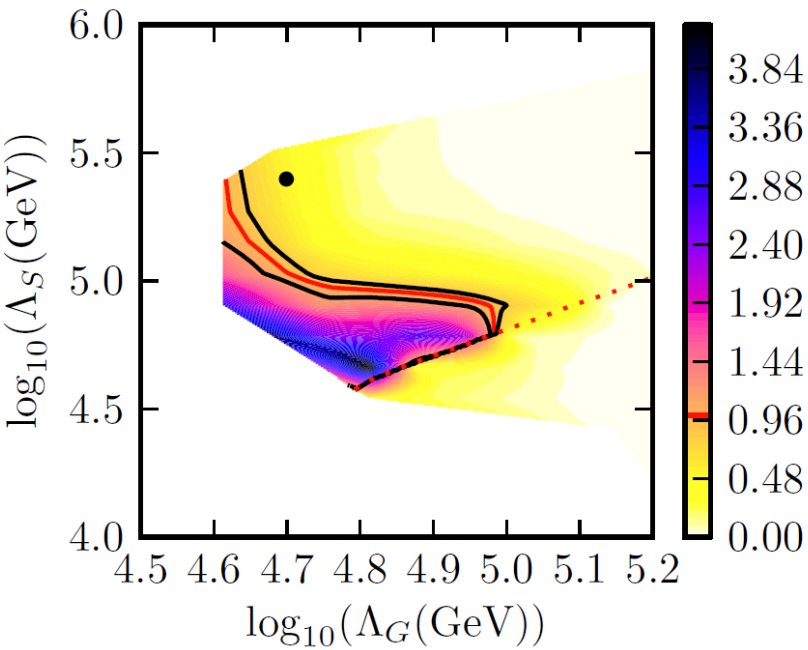


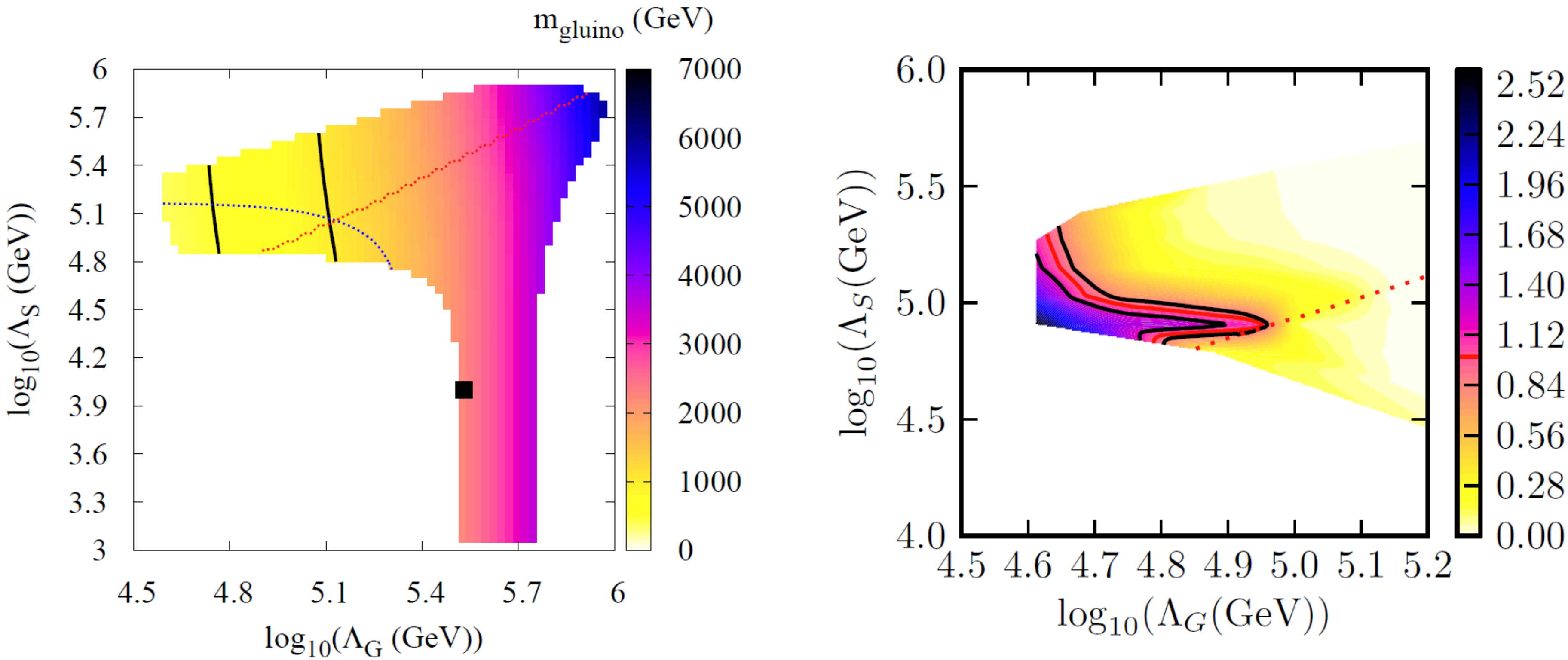


Left panel is the parameter space @ $M_{mess}=10^{10}$ GeV before the LHC data.

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

• To compare the predictions of a particular BSM model with the ATLAS results we need to calculate the expected number of signal events passing the cuts in each of the four regions (A,B,C,D) defined by ATLAS.

A,B,C,D are designed to target light $\tilde{q}\tilde{q}$, heavy $\tilde{q}\tilde{q}$, $\tilde{g}\tilde{g}$ and $\tilde{g}\tilde{q}$ production respectively by imposing different selection criteria on the number of jets (≥ 2 in A and B and ≥ 3 in C and D) as well as on the kinematics (E_T^{miss}, m_{eff} and m_{T2}))

• Each SUSY model is a point in the MSSM parameter space which is specified by the mass spectrum, SUSY couplings and mixing angles at the electroweak scale. All these are contained in SLHA files produced by SoftSUSY starting from the high-scale input from GGM or any other model.

ATLAS Constraints on pGGM parameter space

Dolan-Grellscheid-Jaeckel-VVK-Richardson 1104.0585

- The calculation of the number of signal events was carried out with Herwig++ and the experimental event selection was implemented using the RIVET.

- The fraction of BSM events computed with Herwig++ which passed the experimental cuts in A,B,C,D was then used together with the next-to-leading order 2 to 2 cross-section calculated using Prospino to obtain the final number of signal events passing the cuts for each of the four signal regions.

- The number of events and the 95% confidence level exclusion limit was obtained from the maximum non-SM cross sections of 1.3, 0.35, 1.1 and 0.11 pb, for regions A,B,C and D, respectively given by ATLAS

ATLAS Constraints on pGGM parameter space

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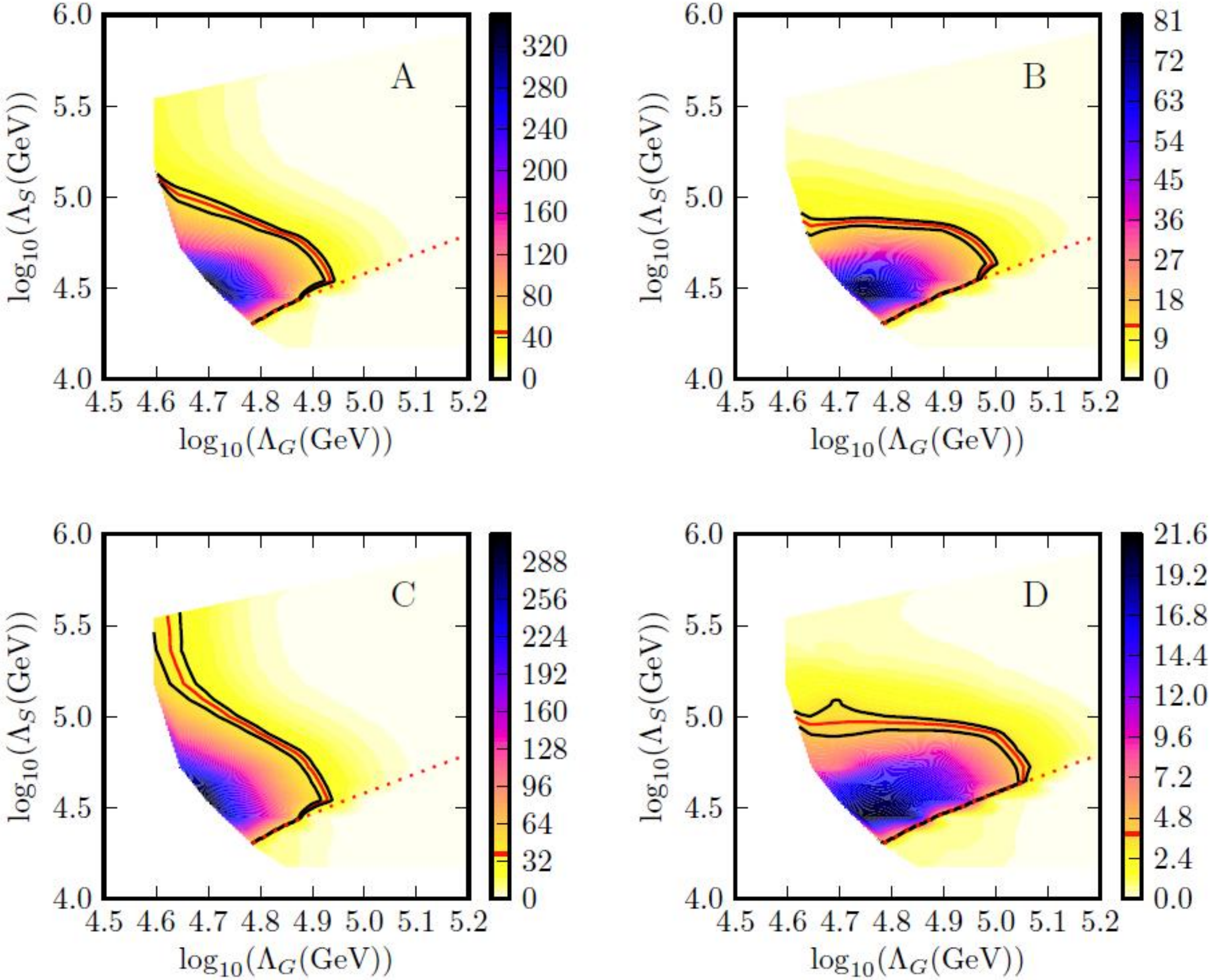

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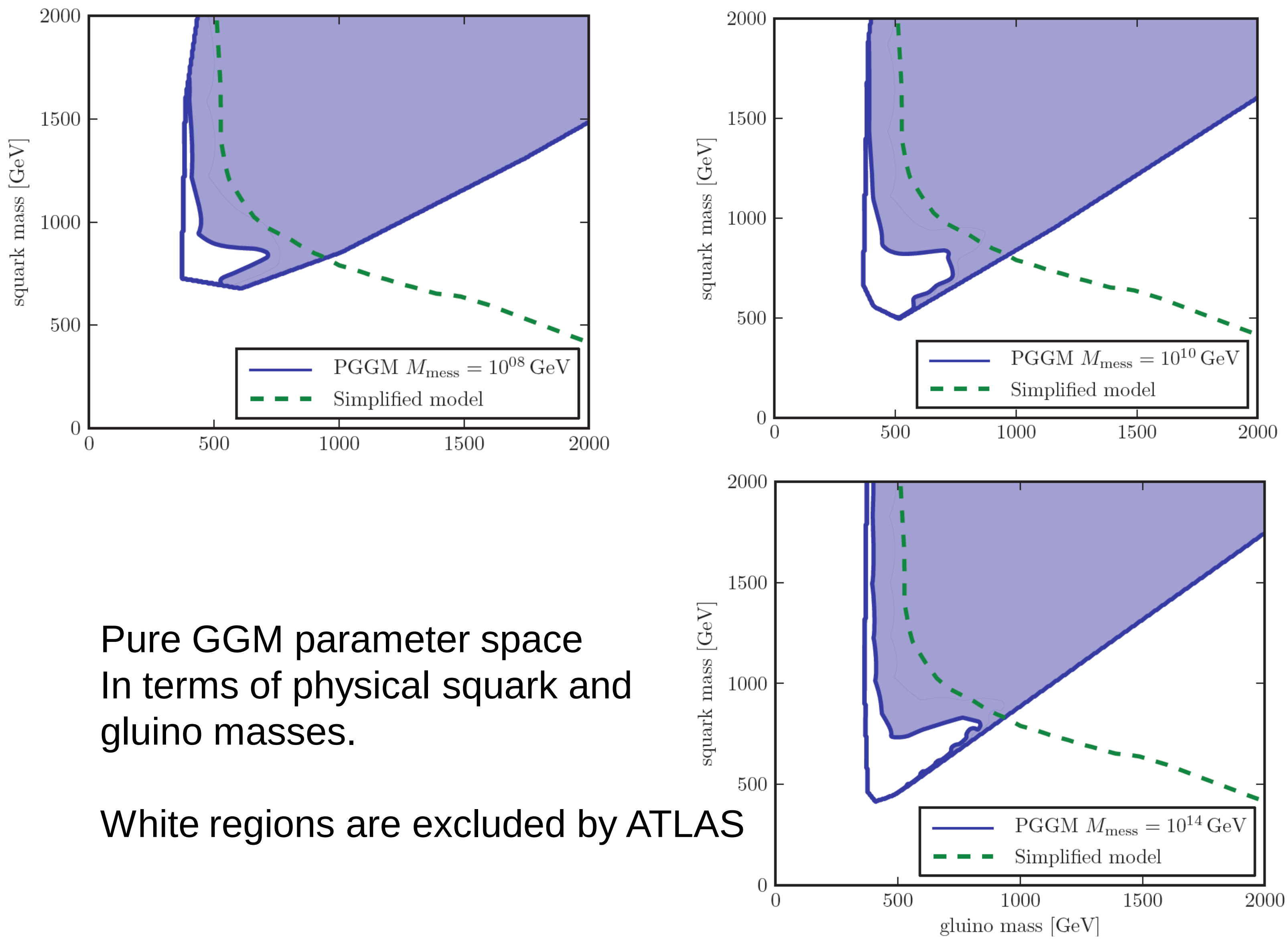
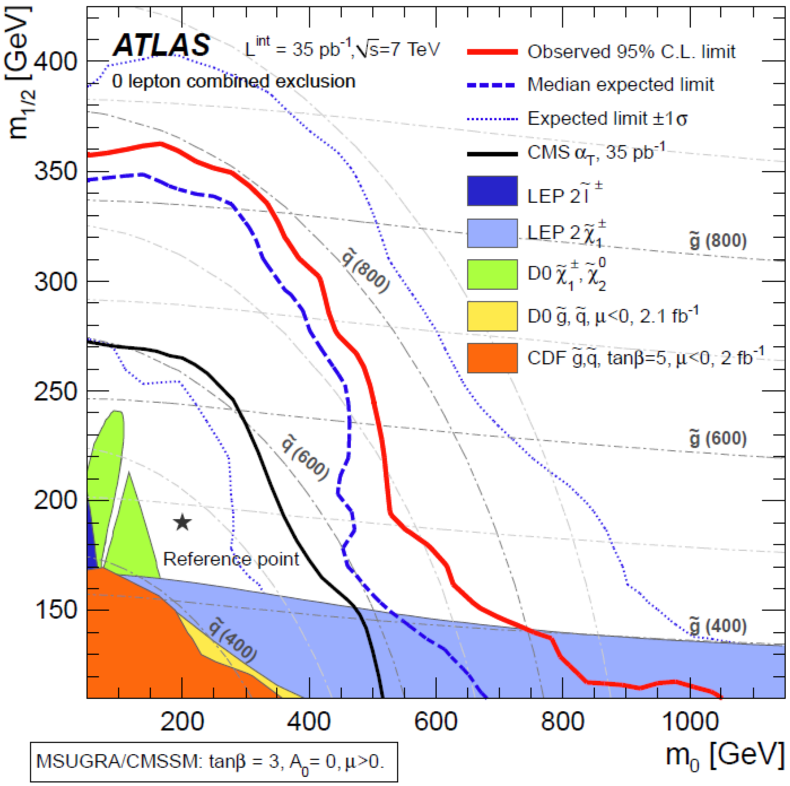
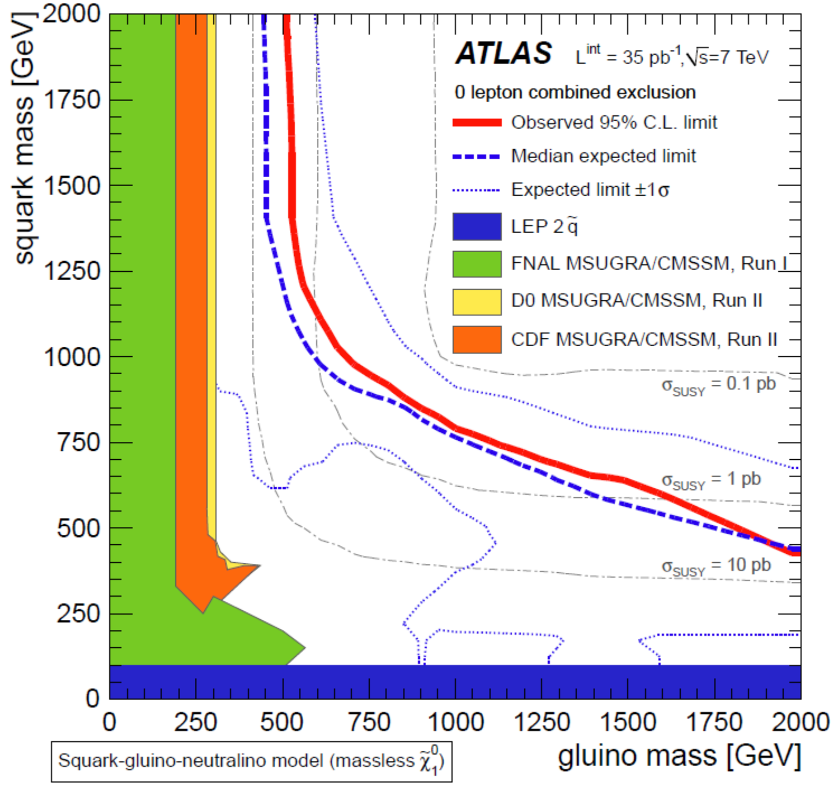


Pure GGM parameter space
In terms of physical squark and
gluino masses.

White regions are excluded by ATLAS

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





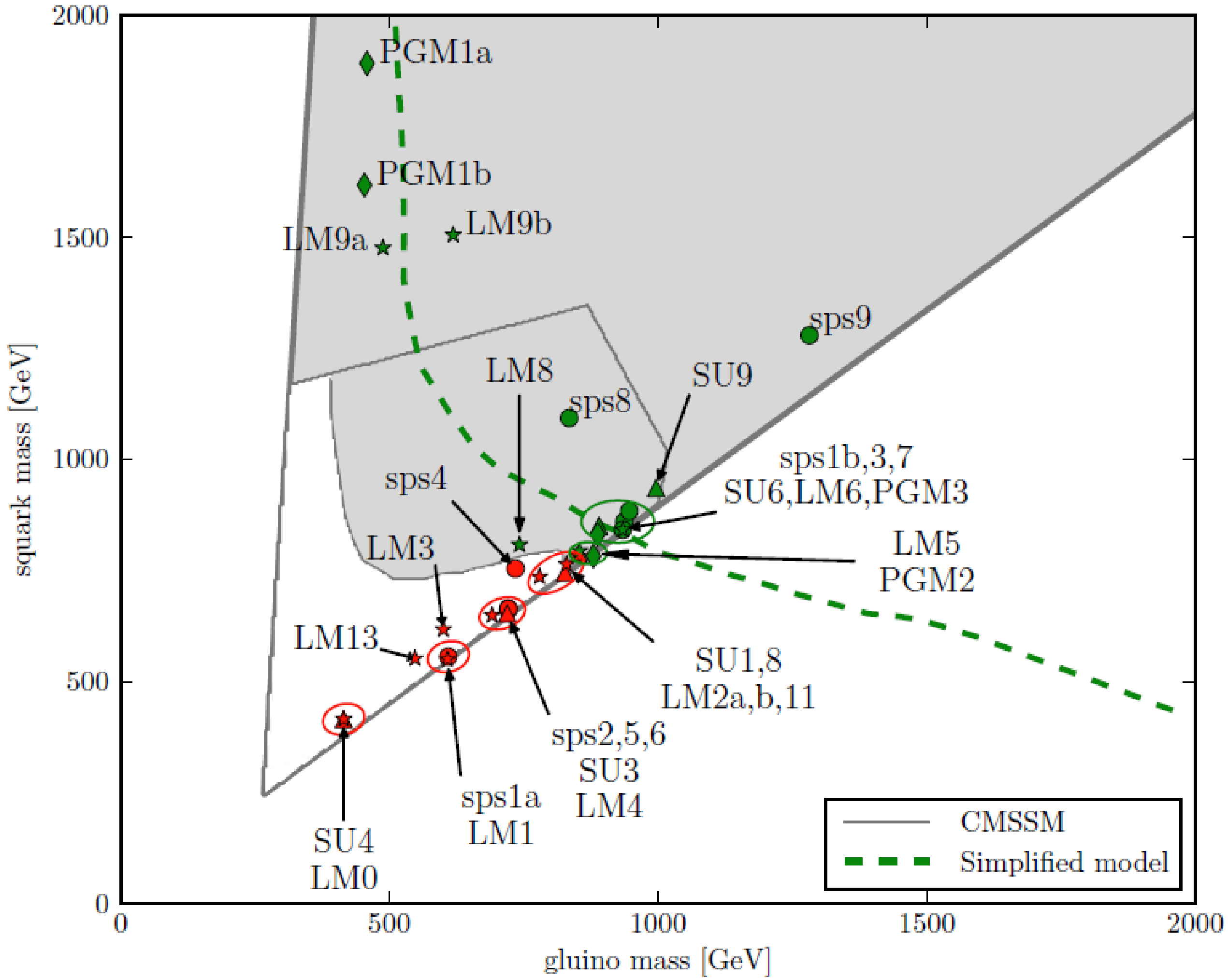
CMSSM exclusion contour on $m_{1/2}$ - m_0 plane

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

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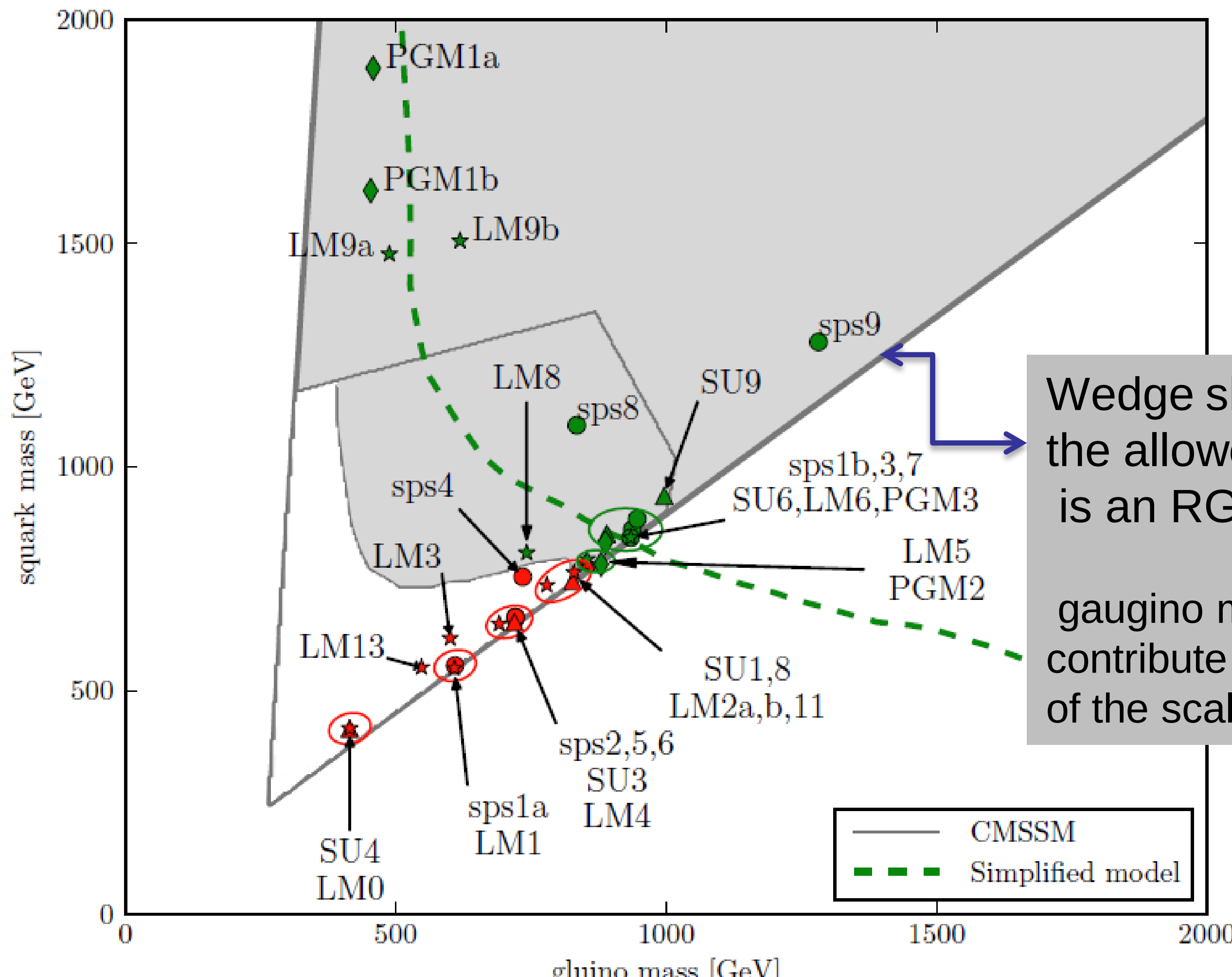

Wedge shape of the allowed region is an RG effect:

gaugino masses contribute to running of the scalar masses

Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

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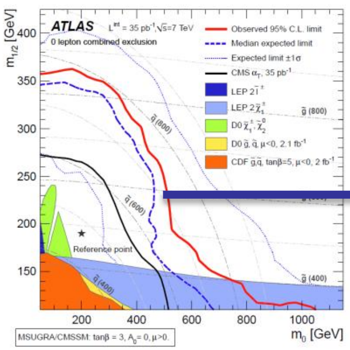
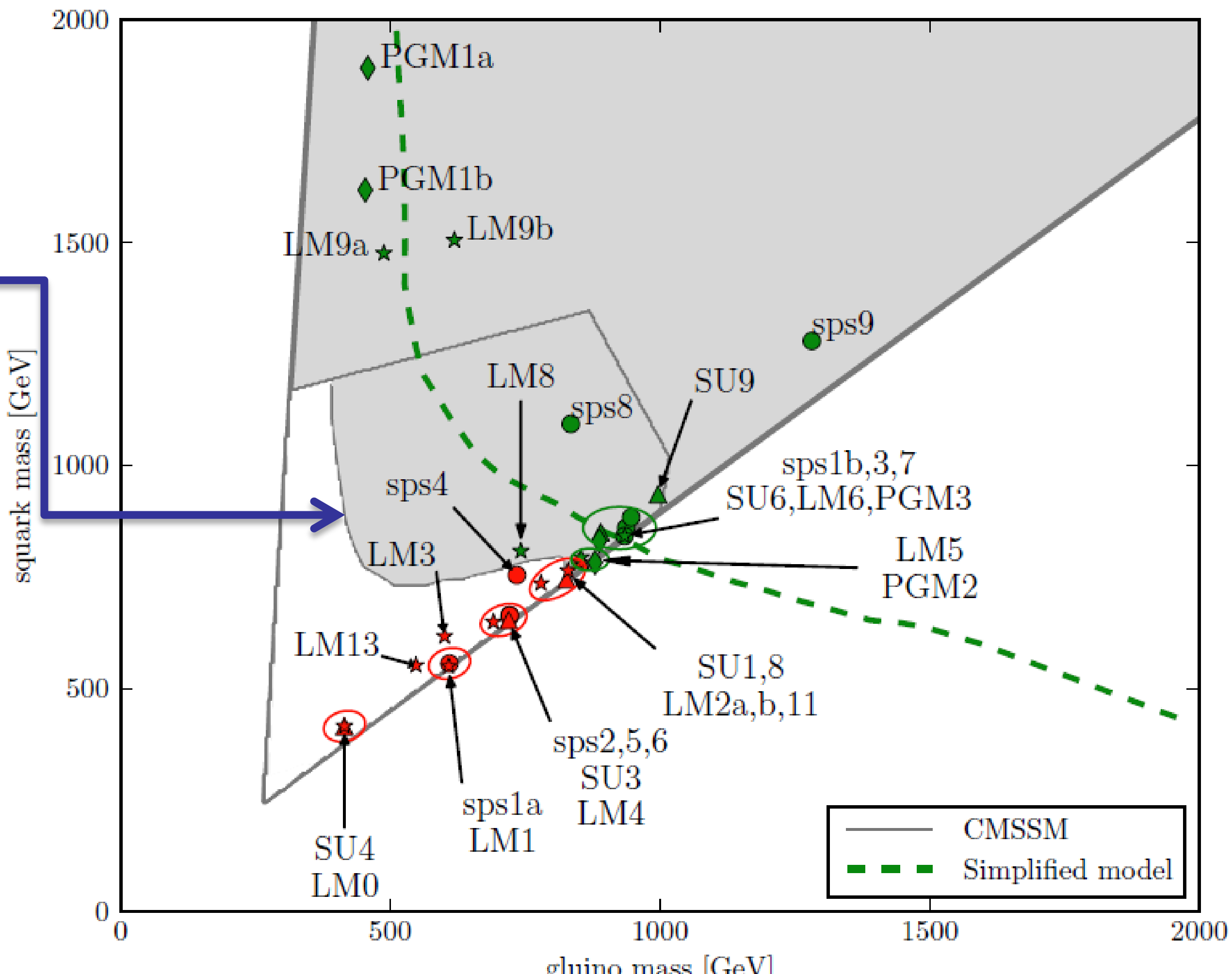


This is the ATLAS exclusion contour



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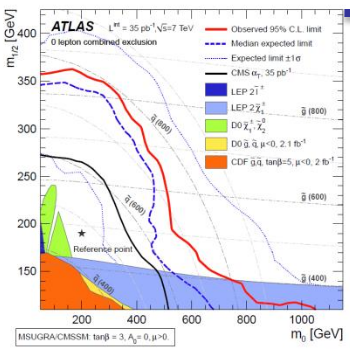
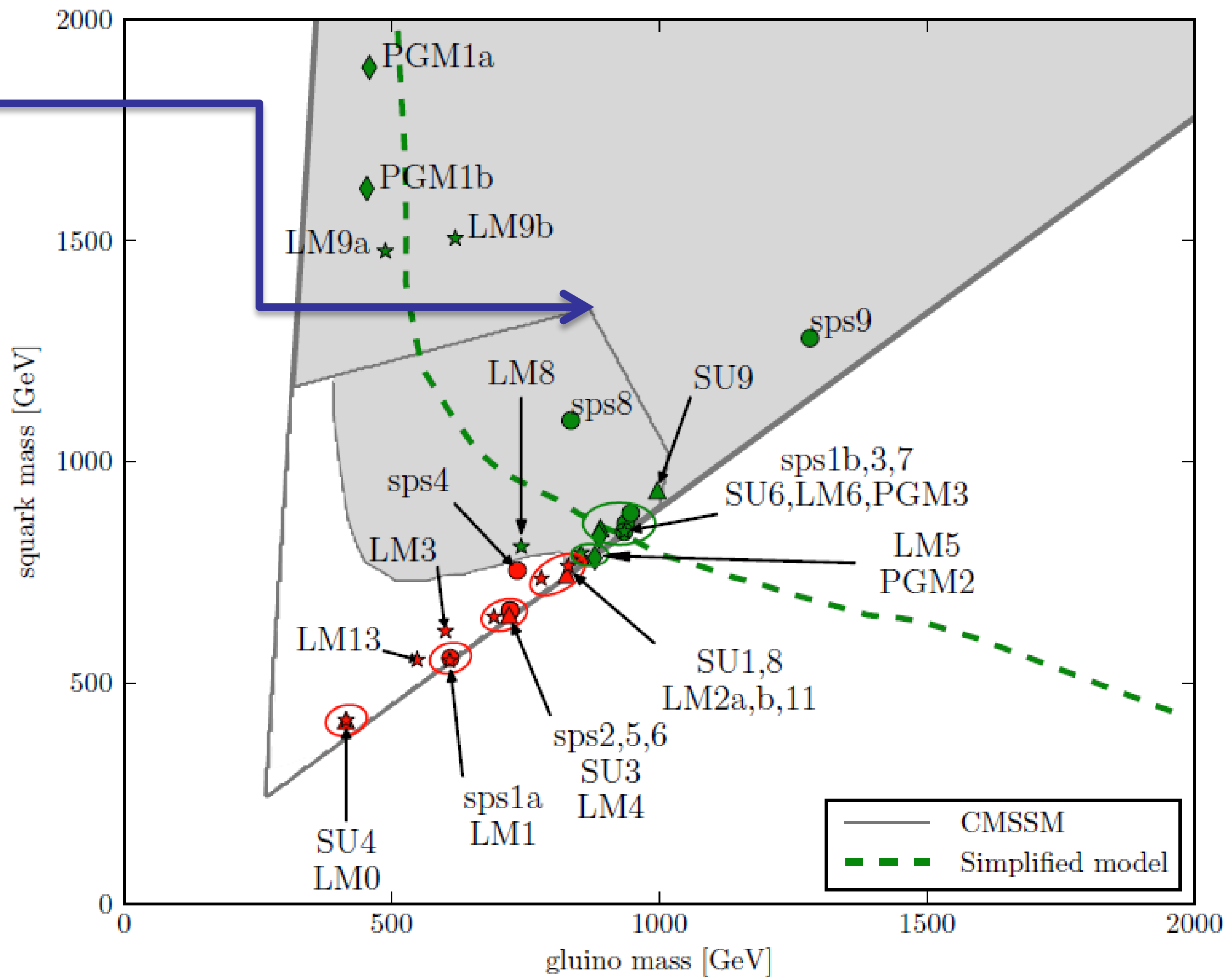


This is an upper boundary of the $m_{1/2}$-m_0 plot



Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

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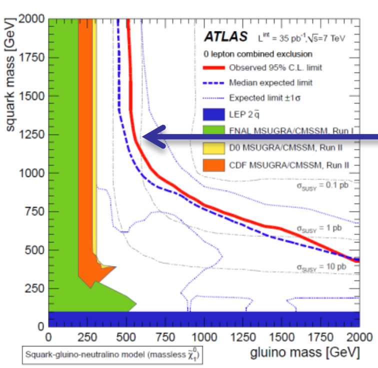
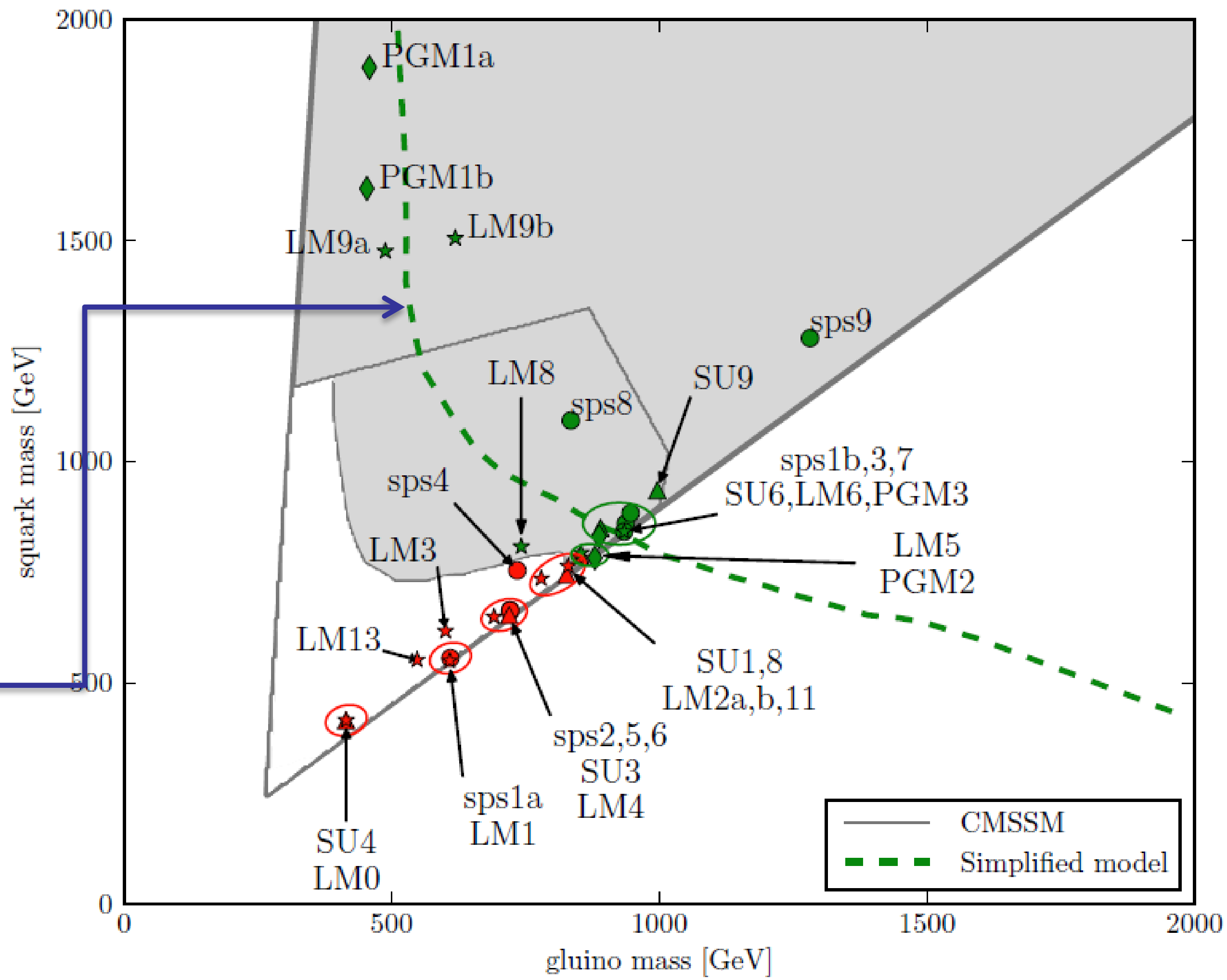
This is the exclusion contour for a simplified model (χ_1^0,squark, gluino)





Implementation of ATLAS exclusion on CMSSM and the standard benchmark points

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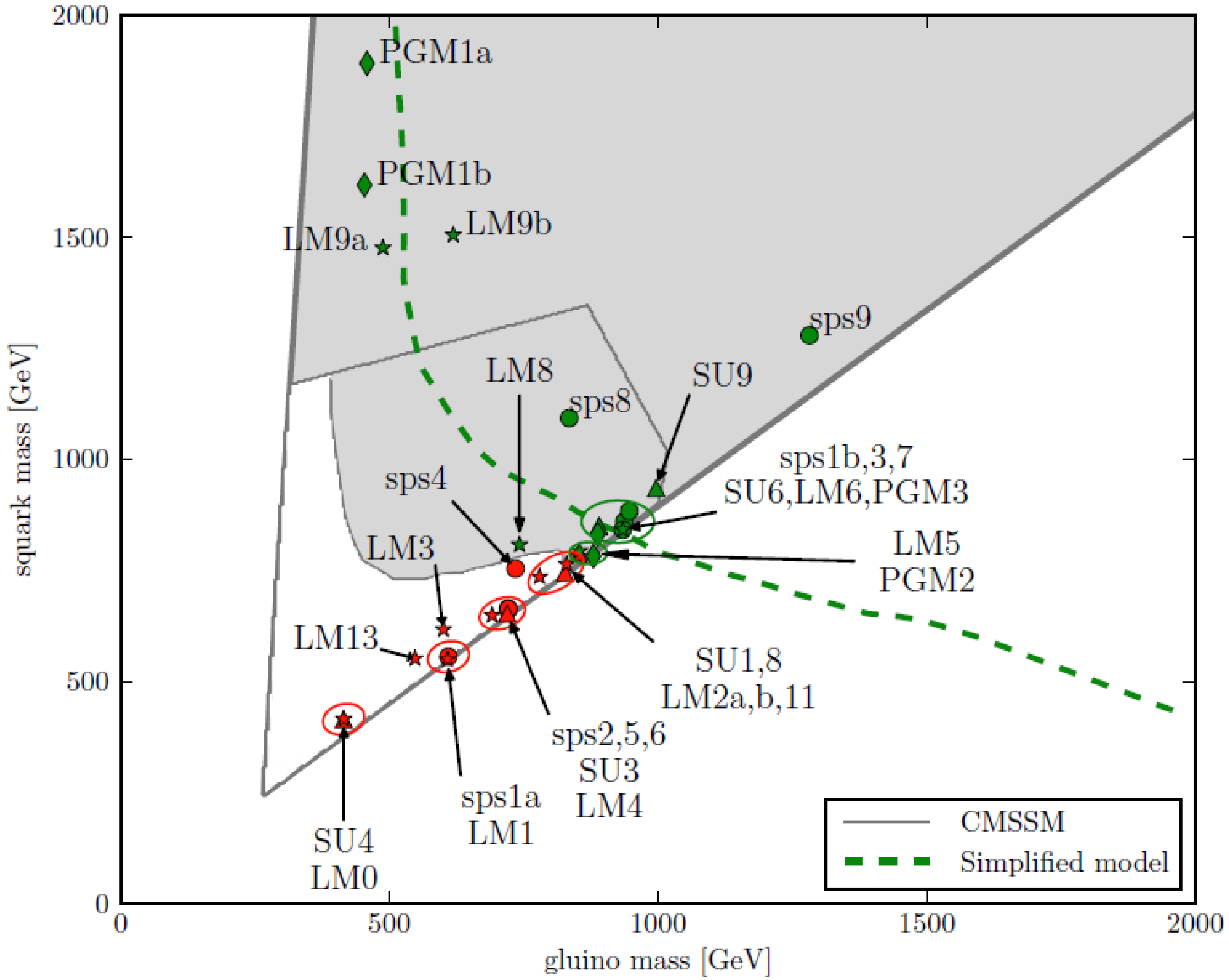
Excluded and still allowed benchmark points



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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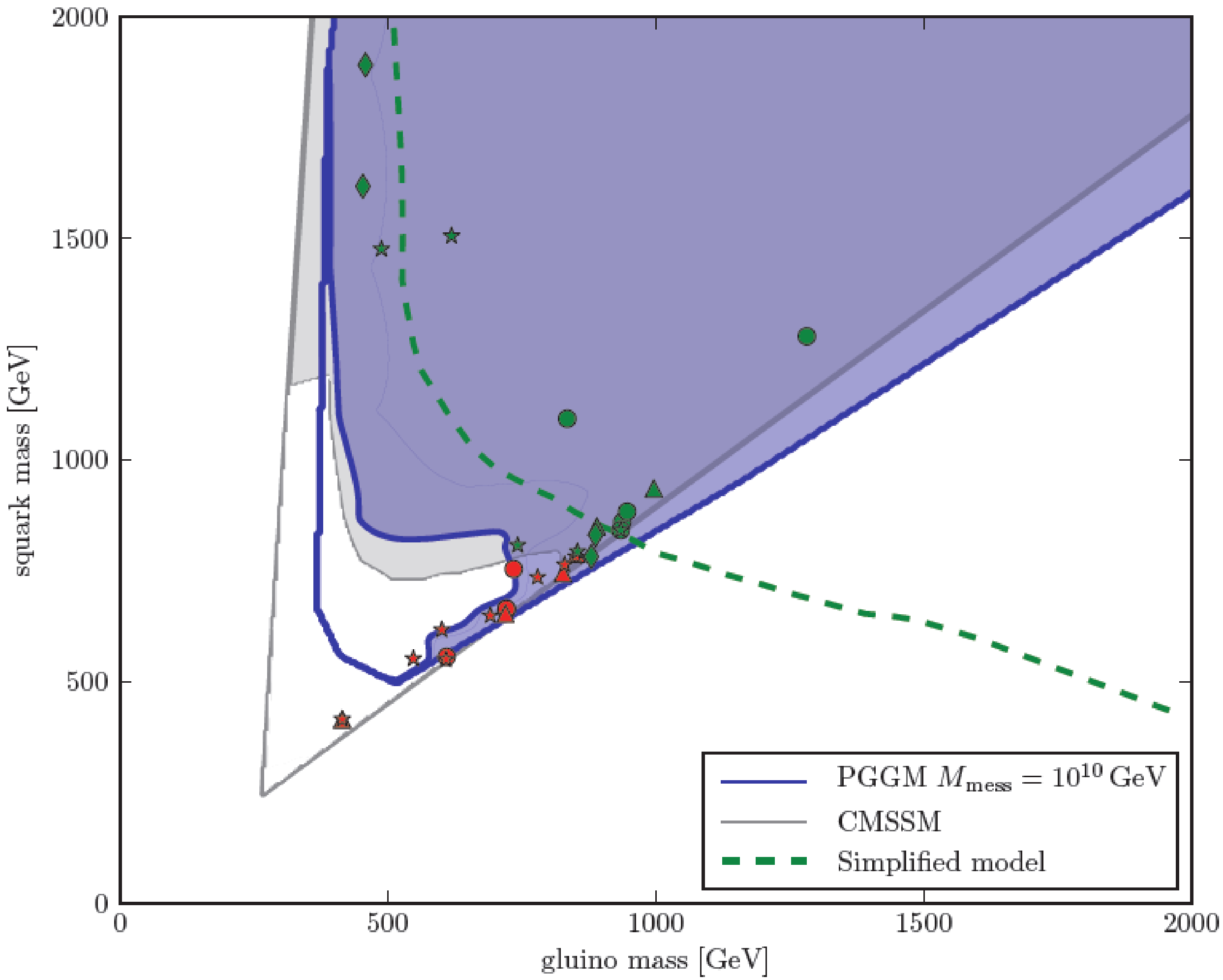

Implementation of ATLAS constraints on the CMSSM overlaid with pGGM and benchmarks

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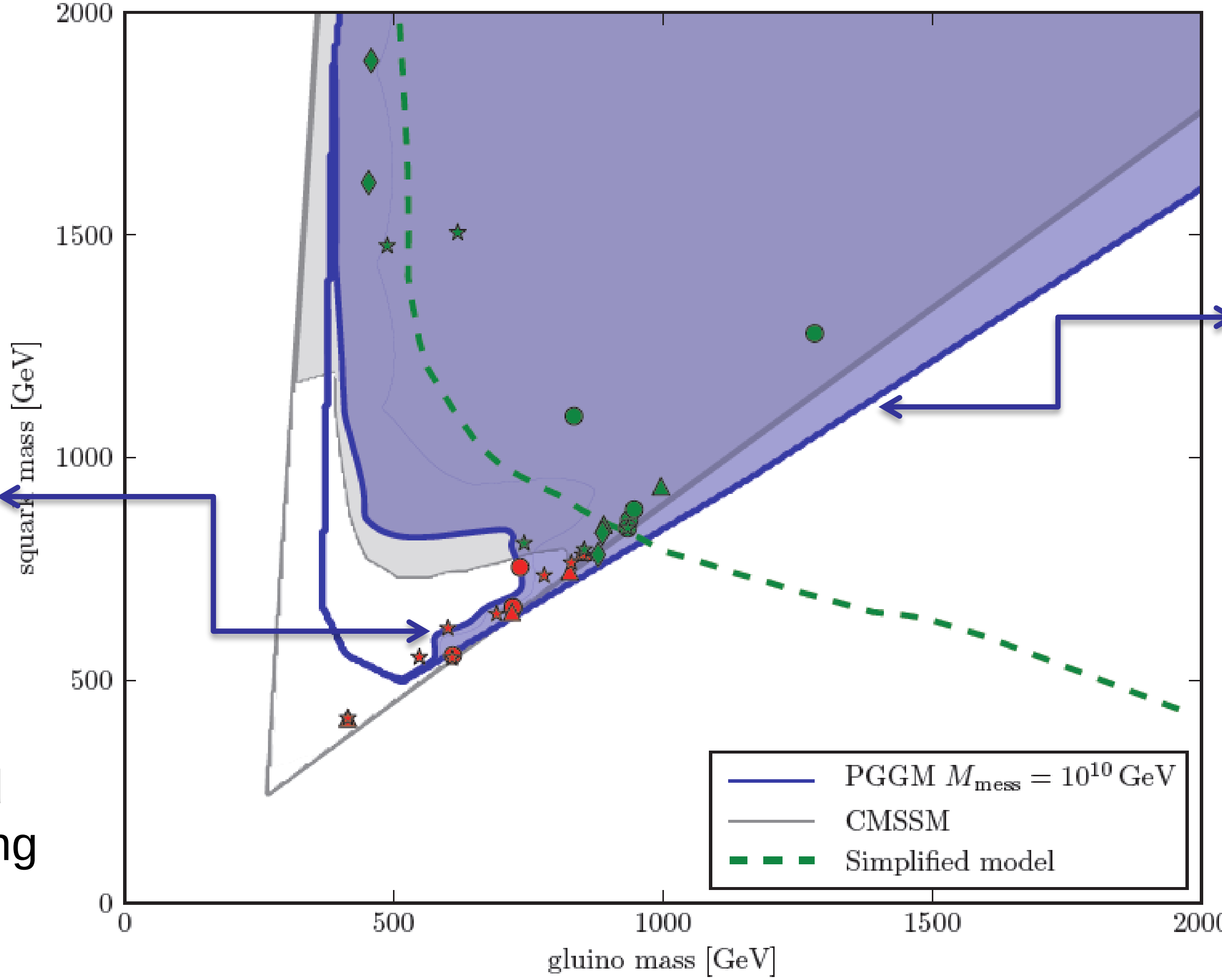
The allowed `tongue' region corresponds to stau-NLSP region in GGM

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

Summary

1. Why SUSY

2. SUSY Breaking and different Mediation scenarios

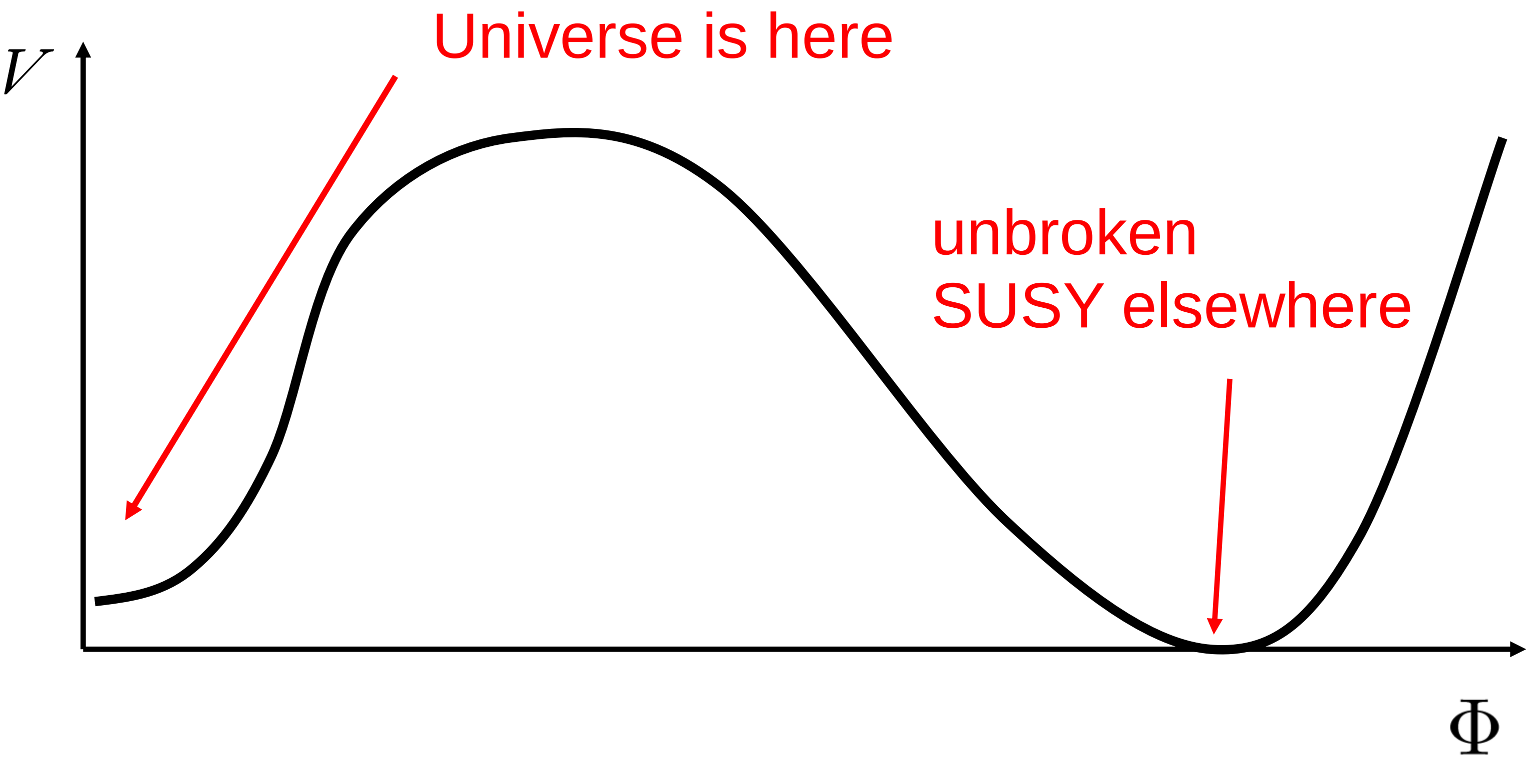
3. Phenomenology of pure General Gauge mediation

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

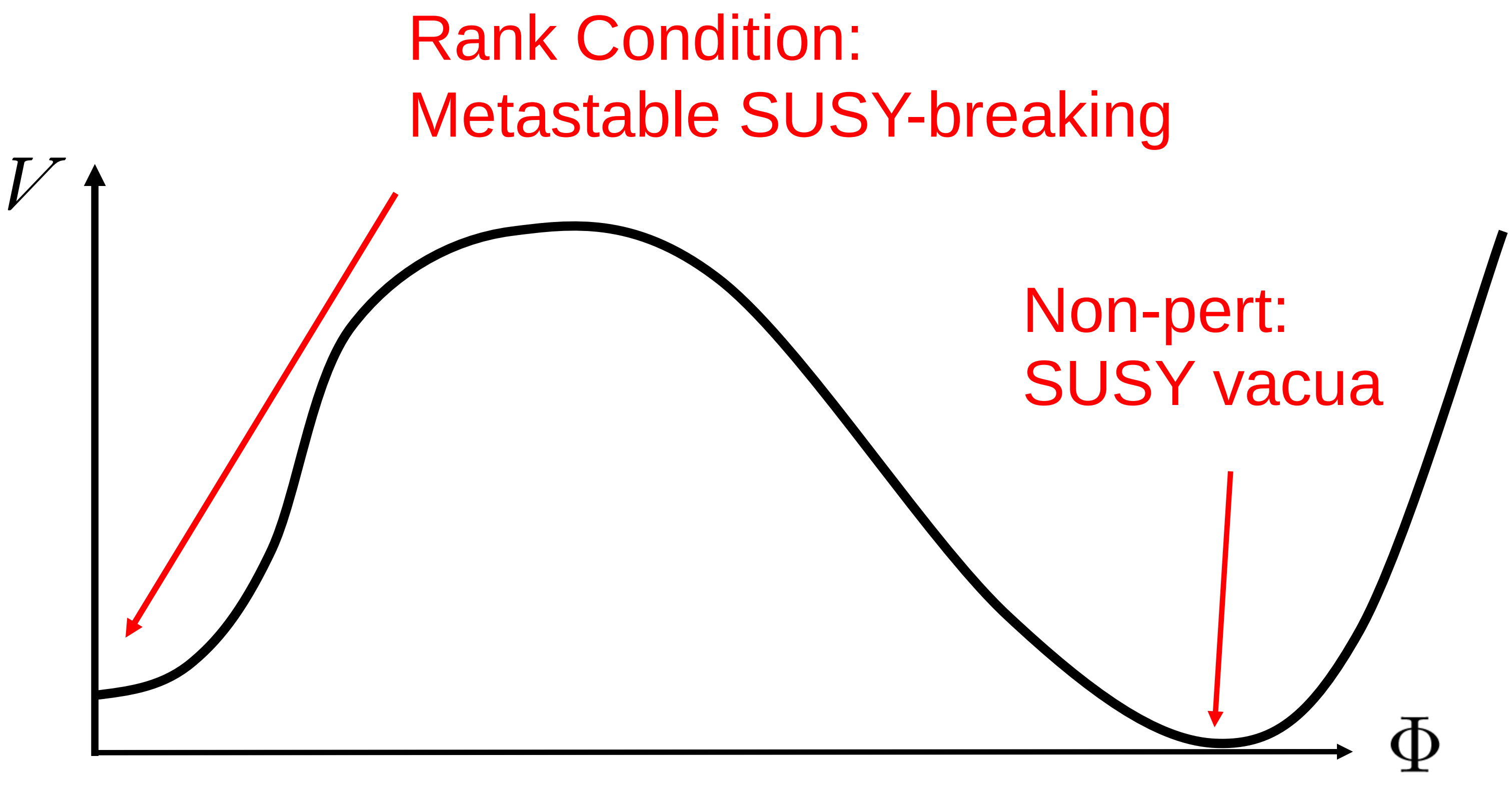
EXTRA SLIDES

K Intriligator, N Seiberg, D Shih JHEP 0604 (2006) 021

ISS picture of meta-stable SUSY breaking



ISS (Hidden SUSY-Breaking) Sector



Cosmological Implications

Why did the Universe start from the non-supersymmetric vacuum in the first place ?

S Abel, C-S Chu, J Jaeckel, V V Khoze JHEP 0701 (2007) 089
S Abel, J Jaeckel, V V Khoze JHEP 0701 (2007) 015

=> Thermal effects drive the Universe to the susy-breaking vacuum even if it starts after inflation in the susy-preserving one.

see also N Craig, P Fox, J Wacker '07
W Fischler *et al* '07

J Ellis, C Llewellyn Smith, G Ross PLB 114 (1982) 227