LHC limits on gluinos and squarks in the minimal Dirac Gaugino model.

arXiv:1812.09293

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work in collaboration with

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Motivation.

- The MSSM, has majorana gauginos described by Weyl fermions as superpartners of the gauge bosons.
- In order to have Dirac gaugino masses, new chiral supermultiplets are added. Suggesting an enriched phenomenology.
  - DGs were proposed by Fayet (1978) to allow massive gluinos and preserving R-symmetry.
  - Dirac gaugino masses only induce a finite shift to sfermin masses, as they appear only in supersoft terms.
- Most of SUSY searches at the LHC are optimised for the MSSM.
- A difference in collider signatures and constraints from currents searches can be expected from the minimal Dirac gaugino model (MDGSSM) as compared to the MSSM.

Particle content of the MDGSSM.

Names		Spin 0	Spin 1/2	Spin 1	$SU(3)$, $SU(2)$, $U(1)_Y$
Quarks	$\mathbf{Q}$	$\tilde{Q} = (\tilde{u}_L, \tilde{d}_L)$	(u_L, d_L)		$(\mathbf{3}, \mathbf{2}, 1/6)$
	$\mathbf{u^c}$	$\tilde{u}^c_L$	u^c_L		$(\bar{\mathbf{3}}, \mathbf{1}, -2/3)$
$(\times 3$ families$)$	$\mathbf{d^c}$	$\tilde{d}^c_L$	u^c_L		$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$
Leptons	$\mathbf{L}$	$(\tilde{\nu}_{eL}, \tilde{e}_L)$	(ν_{eL}, e_L)		$(\mathbf{1}, \mathbf{2}, -1/2)$
$(\times 3$ families$)$	$\mathbf{e^c}$	$\tilde{e}^c_L$	e^c_L		$(\mathbf{1}, \mathbf{1}, 1)$
Higgs	$\mathbf{H_u}$	(H^+_u, H^0_u)	$(\tilde{H}^+_u, \tilde{H}^0_u)$		$(\mathbf{1}, \mathbf{2}, 1/2)$
	$\mathbf{H_d}$	(H^0_d, H^-_d)	$(\tilde{H}^0_d, \tilde{H}^-_d)$		$(\mathbf{1}, \mathbf{2}, -1/2)$
Gluons	$\mathbf{W_{3\alpha}}$		$\tilde{g}_\alpha$	g	$(\mathbf{8}, \mathbf{1}, 0)$
W	$\mathbf{W_{2\alpha}}$		$\tilde{W}^\pm, \tilde{W}^0$	$W^\pm, W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
B	$\mathbf{W_{1\alpha}}$		$\tilde{B}$	B	$(\mathbf{1}, \mathbf{1}, 0)$
DG-octet	$\mathbf{O_g}$	O_g	$\tilde{g}'$		$(\mathbf{8}, \mathbf{1}, 0)$
DG-triplet	$\mathbf{T}$	$\{T^0, T^\pm\}$	$\{\tilde{W}'^\pm, \tilde{W}'^0\}$		$(\mathbf{1},\mathbf{3}, 0)$
DG-singlet	$\mathbf{S}$	S	$\tilde{B}'$		$(\mathbf{1}, \mathbf{1}, 0)$

Chiral and gauge multiplet fields in the model

Additional fields for Dirac gauginos.

Electroweakino mass matrices in the MDGSSM.

- **In the MDGSSM, gauginos are purely Dirac, i.e.** $\mathbf{m_1 = m_1' = m_2 = m_2' = 0}$.
  m_{1D} and m_{2D} are the bino and wino Dirac masses and μ the higgsino mass term.
- λ_S and λ_T are the couplings between the singlet and triplet DG-adjoint fermions, Higgs and higgsino fields:

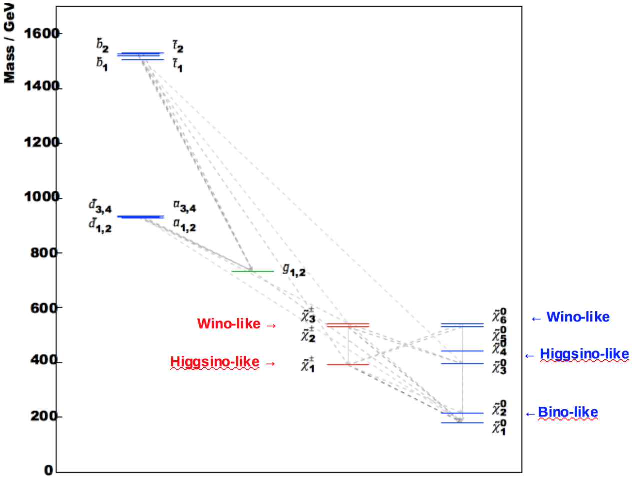
$$W \supset \lambda_S \mathbf{S}\,\mathbf{H_u} \cdot \mathbf{H_d} + 2\lambda_T\, \mathbf{H_d} \cdot \mathbf{T}\mathbf{H_u}\,.$$

$$\mathcal{M}_N = \begin{pmatrix} 0 & m_{1D} & 0 & 0 & \frac{\sqrt{2}\lambda_S}{g'} m_Z s_W s_\beta & \frac{\sqrt{2}\lambda_S}{g'} m_Z s_W c_\beta \\ m_{1D} & 0 & 0 & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta \\ 0 & 0 & 0 & m_{2D} & -\frac{\sqrt{2}\lambda_T}{g} m_Z c_W s_\beta & -\frac{\sqrt{2}\lambda_T}{g} m_Z c_W c_\beta \\ 0 & 0 & m_{2D} & 0 & m_Z c_W c_\beta & -m_Z c_W s_\beta \\ \frac{\sqrt{2}\lambda_S}{g'} m_Z s_W s_\beta & -m_Z s_W c_\beta & -\frac{\sqrt{2}\lambda_T}{g} m_Z c_W s_\beta & m_Z c_W c_\beta & 0 & -\mu \\ \frac{\sqrt{2}\lambda_S}{g'} m_Z s_W c_\beta & m_Z s_W s_\beta & -\frac{\sqrt{2}\lambda_T}{g} m_Z c_W c_\beta & -m_Z c_W s_\beta & -\mu & 0 \end{pmatrix}$$

$$\mathcal{M}_C = \begin{pmatrix} 0 & m_{2D} & \frac{2\lambda_T}{g} m_W c_\beta \\ m_{2D} & 0 & \sqrt{2} m_W s_\beta \\ -\frac{2\lambda_T}{g} m_W s_\beta & \sqrt{2} m_W c_\beta & \mu \end{pmatrix}$$

Binos, Winos, Higgsinos.

Example benchmark point.

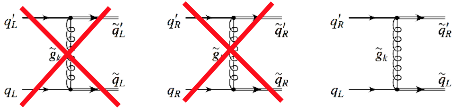


In all our scenarios, electroweakinos respect the same mass hierarchy:

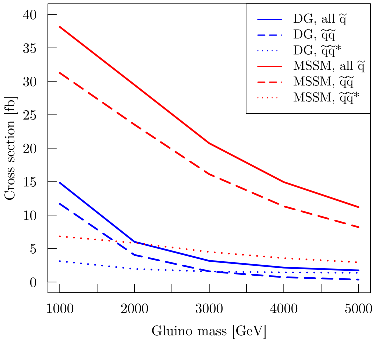
$$m_{winos} > m_{higgsinos} > m_{binos}.$$

Gluino and squark production (comparison with MSSM).

- **Squark pair production.** t-channel exchange of the Dirac gluino forbids final states with squarks of the same helicity, reducing squark production cross section. $\longrightarrow$
- **Gluino pair production.** Cross section enhanced because there are more gluino-degrees of freedom.
- **Gluino-squark production.** This is identical to the Majorana case.

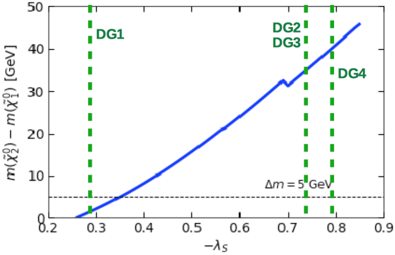


Squark production, LHC 13 TeV, $m_{\tilde{q}}$=1.5 TeV.

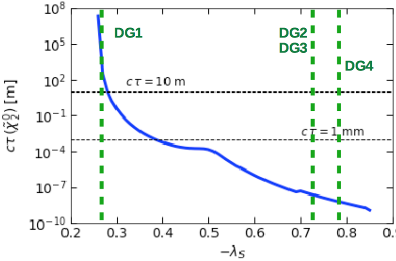


arXiv:1111.4322

Mass splitting/Lifetime of bino-like neutralinos.



Mass splitting between $\tilde{\chi}^0_{1,2}$.



The lifetime of $\tilde{\chi}^0_2$.

Constraints for four benchmark scenarios will be shown:

- One with small $\tilde{\chi}^0_{1,2}$ mass spliting/long $\tilde{\chi}^0_2$ lifetime: DG1 where λ_S=-0.27 .
- Three with a large $\tilde{\chi}^0_{1,2}$ mass spliting/short $\tilde{\chi}^0_2$ lifetime: DG2,DG3 with λ_S =-0.74 and DG4 with λ_S =-0.79.

Benchmark scenarios.

Parameters				
	DG1	DG2	DG3	DG4
m_{1D}	200	200	200	200
m_{2D}	500	500	500	1175
μ	400	400	400	400
$\tan\beta$	2	2	2	2
$-\lambda_S$	0.27	0.74	0.74	0.79
$\sqrt{2}\,\lambda_T$	0.14	0.14	0.14	-0.26
$m^2_{\tilde{Q}_3}$	1.25e7	6.5e6	2.26e6	8.26e6
$m^2_{\tilde{Q}_1}$	6.25e6	6.25e6	6.25e6	6.25e6
m_{3D}	1750	1750	1750	1750

Masses				
	DG1	DG2	DG3	DG4
$\tilde{\chi}^0_1$	201.35	182.1	181.8	182.4
$\tilde{\chi}^0_2$	201.72	218.0	216.6	213.2
$\tilde{\chi}^0_3$	403	400	396	408
$\tilde{\chi}^0_4$	419	445	441	437
$\tilde{\chi}^0_5$	537	536	535	1226
$\tilde{\chi}^0_6$	548	548	546	1227
$\tilde{\chi}^\pm_1$	400	395	391	398
$\tilde{\chi}^\pm_2$	536	536	534	1224
$\tilde{\chi}^\pm_3$	549	548	547	1229
$\tilde{t}_1$	3604	2607	1590	2894
$\tilde{t}_2$	3613	2637	1613	2927
h_1	124.0	125.0	125.3	125.2

Parameters and masses of the four benchmark scenarios; m_{1D}, m_{2D}, μ, $\tan\beta$, λ_S, λ_T and the soft masses of the third generation ($m^2_{\tilde{Q}_3} = m^2_{\tilde{U}_3} = m^2_{\tilde{D}_3}$) are fixed for each benchmark, while m_{3D} and $m^2_{\tilde{Q}_1} = m^2_{\tilde{U}_1} = m^2_{\tilde{Q}_1}$ will be varied to scan over gluino and squark masses.

Large vs small bino mass spliting.

Large mass splitting, but heavier winos.

Constraining with two approaches: SMS and Recasting.

Simplified Model Results.

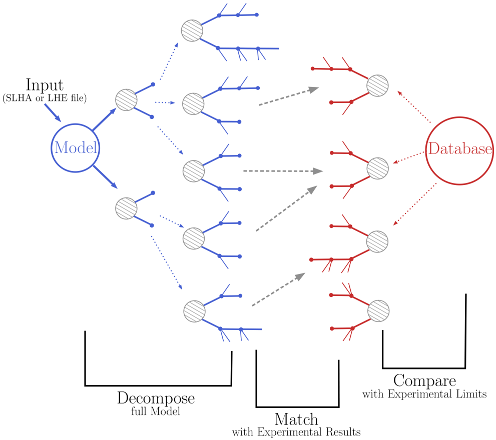
- SModelS: based on a general procedure to decompose BSM collider signatures presenting a Z_2 symmetry into Simplified Model Spectrum (SMS) topologies. arXiv:1811.10624

Recasting.

- Recasting based on MC event simulation, using MadAnalysis arXiv:1808.00480.
- Event simulation performed with the MadGraph5_aMC@NLO framework. arXiv:1804.10017

See Sabine Kraml's talk in the next session, for more.

Simplified Model Spectrum (SMS) approach.

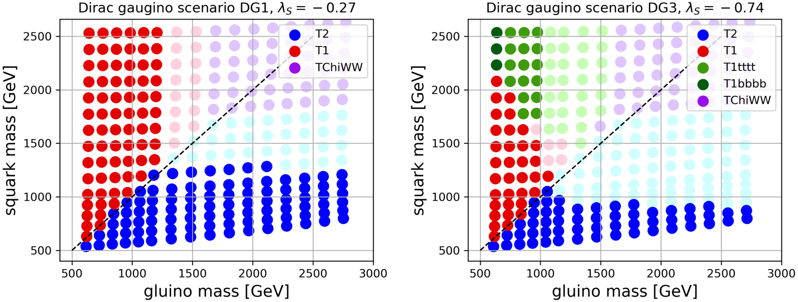


from: https://smodels.github.io

- Decomposition of BSM into SMS topologies
- Database of experimental results for different SMS topologies.
- Interface between Decompositon and experimental results. (Compare xsections of SMS topologies with experimental limits...)

See Sabine Kraml's talk in the next session, for more.

Exclusion by SModelS.

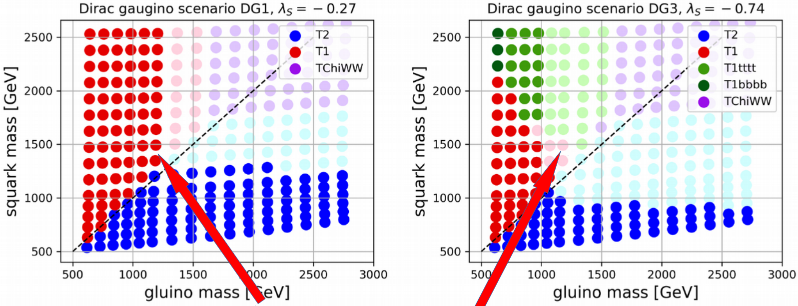


Gluino vs squark masses map of the SModelS limits. Hard coloured points means exclusion.

T1: $pp \to \tilde{g}\tilde{g},\ \tilde{g} \to q\bar{q}\tilde{\chi}_1^0$; T1tttt: $pp \to \tilde{g}\tilde{g},\ t\bar{t}\tilde{\chi}_1^0$; T2: $pp \to \tilde{q}\tilde{q}^{(*)}, \tilde{q} \to q\tilde{\chi}_1^0$; TChiWW: $pp \to \tilde{\chi}_i^{\pm}\tilde{\chi}_i^{\pm},\ \tilde{\chi}_i^{\pm} \to W^{\pm}\tilde{\chi}_1^0$

Due to the complexity of the model, constraints from SMS are weaker. E.g. The effective cross section from the T1 topology above is roughly 1% of the total.

Exclusion by SModelS.



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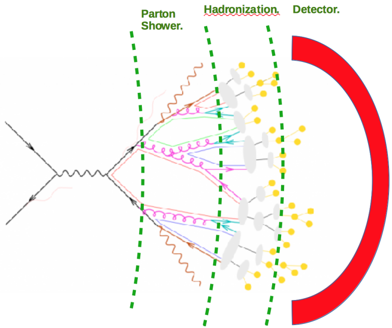
The difference comes mainly from the fact that in DG3, the $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 f\bar{f}$ decay goes via an off-shell Z which is considered as a different topology in SMS.

$pp \to \tilde{q}\tilde{q}^{(*)}, \tilde{q} \to q\tilde{\chi}_1^0$; TChiWW: $pp \to \tilde{\chi}_i^{\pm}\tilde{\chi}_i^{\pm},\ \tilde{\chi}_i^{\pm} \to W^{\pm}\tilde{\chi}_1^0$

Due to the complexity of the model, constraints from SMS are weaker. E.g. The effective cross section from the T1 topology above is roughly 1% of the total.

Recasting.

- Involves full chain event simulation: parton level events, showering, hadronization, detector simulation and signal selection. In this work MadGraph, Pythia8, Delphes and MadAnalysis was used.
- A constantly growing database of implented (and validated) analyses.
- Comparison between simulated events of a certain model with adequate analyses in the database.



See Sabine Kraml's talk in the next session, for more.

ATLAS SUSY 2016-07 Implementation

Search for squarks and gluinos in final states with jets and missing transverse momentum using 36 fb^{-1} of $\sqrt{s}$ =13 TeV *pp* collision data with the ATLAS detector

madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase

Rechercher

http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase

Available Analyses

!! please properly cite all the re-implementation codes you are using; here are a BibTeX file and a file with plain LaTeX format for this purpose !!

ATLAS analyses, 13 TeV

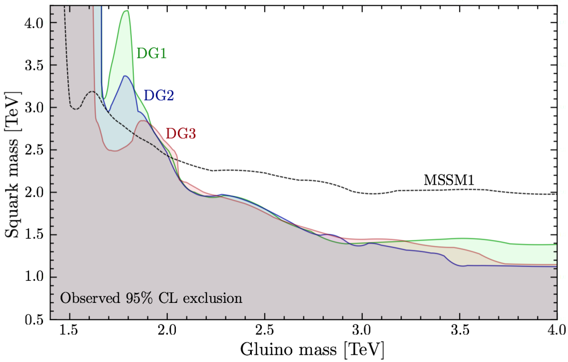
Analysis	Short Description	Implemented by	Code	Validation note	Version
ATLAS-SUSY-2015-06	Multijet + missing transverse momentum	S. Banerjee, B. Fuks, B. Zaldivar	Inspire	PDF	v1.3/Delphes3
ATLAS-SUSY-2016-07	Multijet + missing transverse momentum (36.1 fb-1)	G. Chalons, H. Reyes-Gonzalez	Inspire	PDF Pythia files	v1.7/Delphes3
ATLAS-EXOT-2015-03	Monojet (3.2 fb-1)	D. Sengupta	Inspire	PDF	v1.3/Delphes3
ATLAS-EXOT-2016-25	Mono-Higgs (36.1 fb-1)	S. Jeon, Y. Kang, G. Lee, C. Yu	Inspire	PDF	v1.6/Delphes3
ATLAS-EXOT-2016-27	Monojet (36.2 fb-1)	D. Sengupta	Inspire	PDF	v1.6/Delphes3
ATLAS-EXOT-2016-32	Monophoton (36.1 fb-1)	S. Baek, T.H. Jung	Inspire	PDF	v1.6/Delphes3
ATLAS-CONF-2016-086	b-pair + missing transverse momentum	B. Fuks & M. Zumbihl	Inspire	PDF	v1.6/Delphes3

Delphes card for ATLAS-CONF-2016-086
Delphes card for ATLAS-EXOT-2015-03, ATLAS-SUSY-2015-06 and ATLAS-SUSY-2016-07
Delphes card for ATLAS-EXOT-2016-25
Delphes card for ATLAS-EXOT-2016-27
Delphes card for ATLAS-EXOT-2016-32

Light wino cases: DG1, DG2, DG3 vs MSSM1.

DG1 : λ_S = -0.27; $m_{\tilde{t}} \backsim m_{\tilde{b}} \backsim$3.6TeV, DG2 : λ_S = -0.74; $m_{\tilde{t}} \backsim m_{\tilde{b}} \backsim$2.6TeV

DG3 : λ_S = -0.74; $m_{\tilde{t}} \backsim m_{\tilde{b}} \backsim$1.6TeV MSSM1: M_1 = 200 GeV, M_2 = 500 GeV $m_{\tilde{t}} \backsim m_{\tilde{b}} \backsim$3.6TeV.

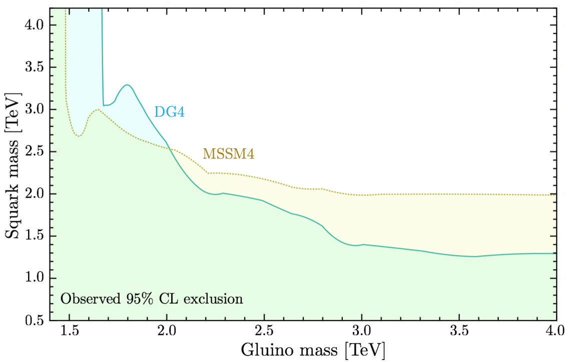


Gluino vs squark mass map of the 95% CL exclusion limit (at LO) of DG1, DG2,DG3 and MSSM1 from the recasting of the ATLAS-SUSY-2016-07 analysis, using only the best signal region.

Heavy wino case: DG4 vs MSSM4.

DG4 : λ_S = -0.79; λ_T =-0.37 $m_{\tilde{t}} \backsim m_{\tilde{b}} \backsim$3 TeV,

MSSM1: M_1 = 200 GeV, M_2 = 1200 GeV $m_{\tilde{t}} \backsim m_{\tilde{b}} \backsim$3 TeV.



Gluino vs squark mass map of the 95% CL exclusion limits (at LO) of DG4 and MSSM4 from the recasting of the ATLAS-SUSY-2016-07 analysis, using only the best signal region.

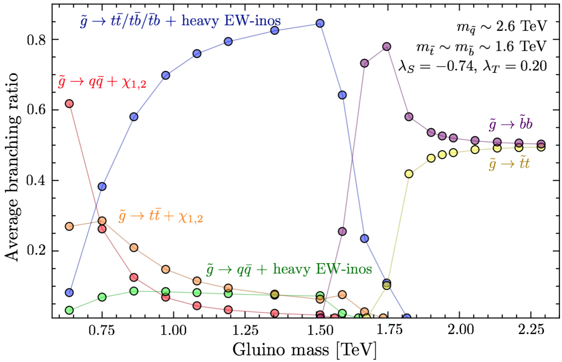
Summary

- Summary
  - A phenomenological study of the MDGSSM has been performed, using two aproaches: Simplified Model Results and Recasting.
  - Bounds on squarks and gluinos were found for 4 benchmark scenarios of the MDGSSM and compared with equivalent MSSM scenarios.
  - SModelS provides fast preliminary limits (≈3hours per benchmark scenario vs ≈1week with full recast.) saving a considerable amount of computing time; Due to the complexity of the model this constraints are not very strong so we turn to MC event simulation for stronger constrains.
- Outlook
  - Study limits in the electroweak sector.
  - Study the scenario with small mass bino splitting on the light of LLP searches.

Thank you!

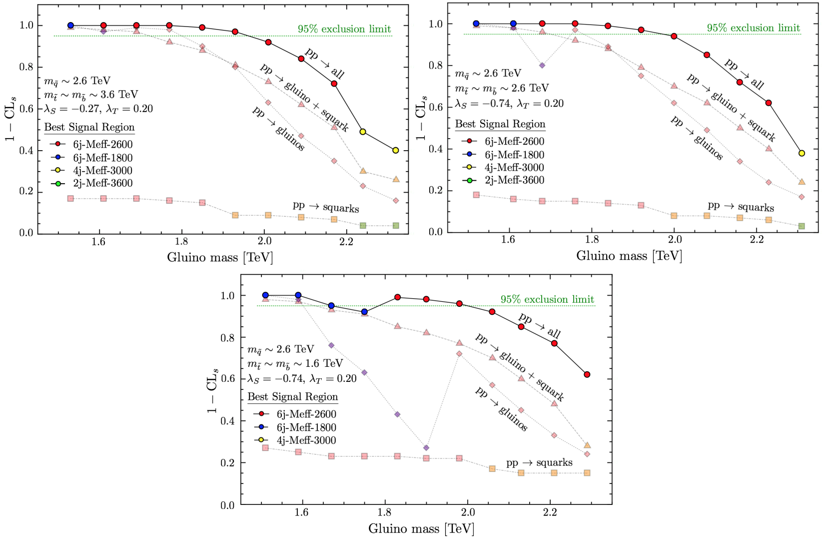
Back-up slides.

BRs DG3.



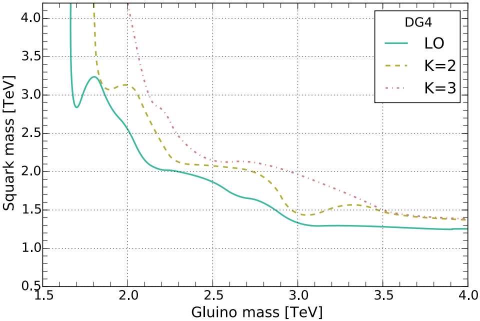
Branching ratios of gluino decays for DG3 as function of the gluino mass, $m_{\tilde{q}} \approx 2.6$ TeV.

Best signal regions.



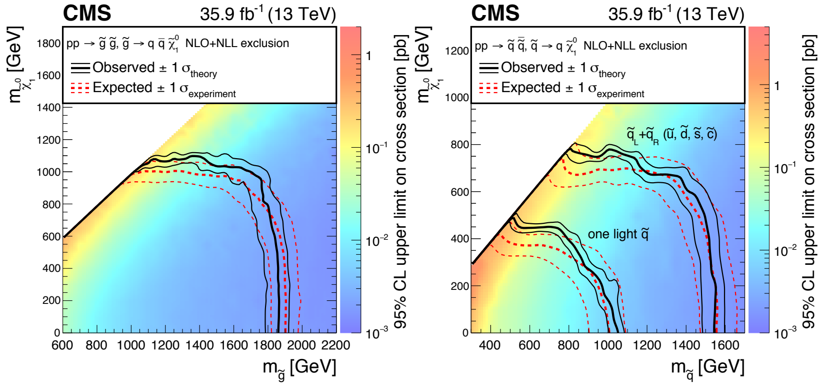
1-CLs values in the best signal regions vs squark mass for DG1, DG2 and

CLs exclusion limits for DG4 with K-factors.



95% CL exclusion limits in the gluino vs. squark mass plane for benchmark DG4 with K-factors 1 (LO), 2 and 3.

CMS-SUS-16-03 exclusion limits*.



Squark and gluino mass constraints from the CMS-SUS-16-036 analysis.

*To compare with SModelS and recasting results.