Search for squarks and gluinos in events with one lepton, jets and missing transverse momentum with the ATLAS detector

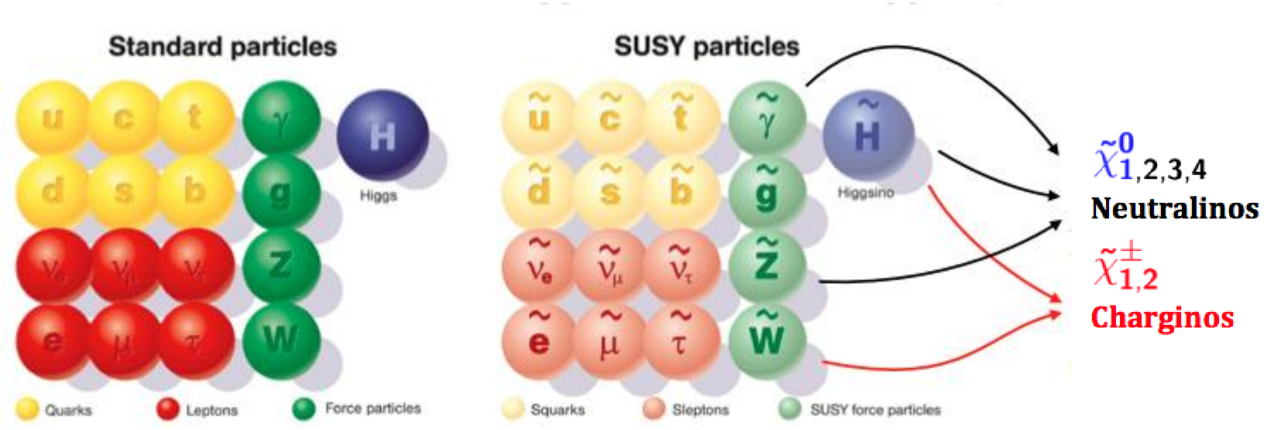
Huajie Cheng, Shan Jin, Yang Liu, Feng Lyu, Huan Ren, Da Xu, Peng Zhang, Xuai Zhuang

(IHEP, CAS)

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

ATLAS EXPERIMENT

Introduction



LHC Run 2: Cross-section for strongly produced signal grows dramatically!

Supersymmetry: one of the most appealing BSM theories.
- Moderates the hierarchy problem.
- Helps with the grand unification of gauge couplings.
- Provides a suitable dark matter candidate.

Strongly produced supersymmetry
- Large cross-section
- Heavy SUSY mass scale
- Generic experimental signatures: multiple jets + leptons + large MET

This talk is to present the latest ICHEP-2016 results (ATLAS-CONF-2016-054) of the ATLAS SUSY inclusive 1-lepton analysis @ 14.8 fb^{-1}.

Targeted SUSY signals

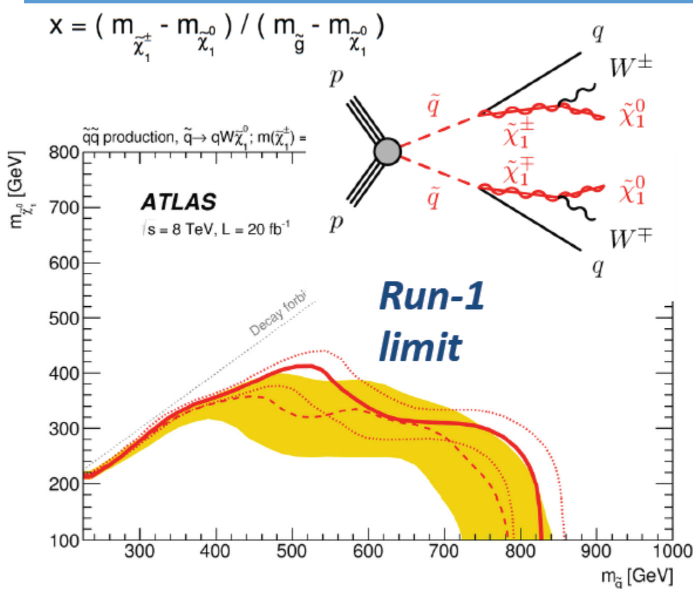
Simplified SUSY models in R-parity conserving scenarios

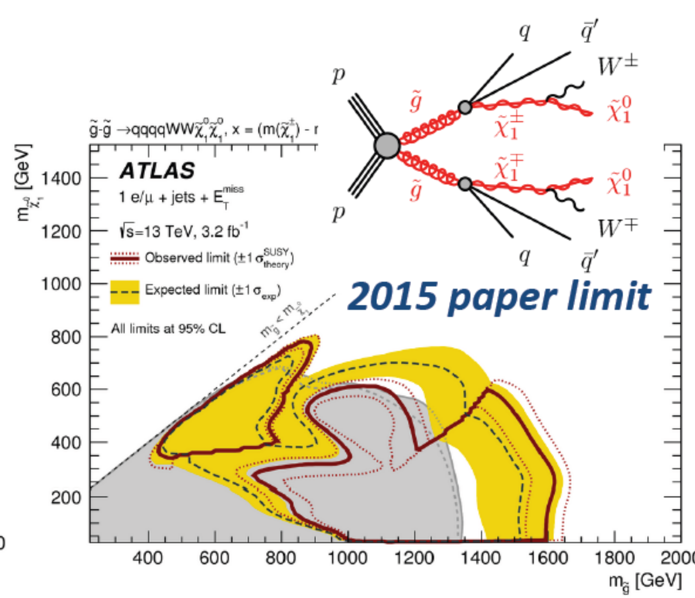
- Lightest neutralino is the LSP and stable
- 100% BR of sparticle decays
- Target the 1lepton + 2-6 jets + MET final state

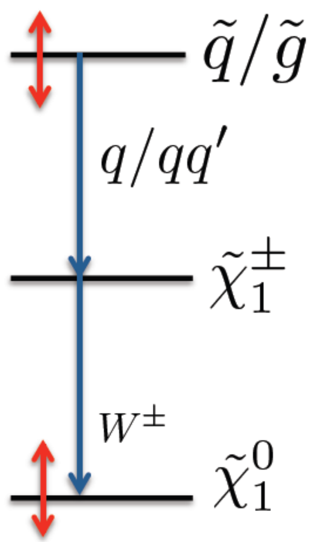
Two parameterizations of the one-step squark/gluino decays

- x=1/2 grid → squark/gluino and LSP masses are allowed to vary
- Variable-x grid → squark/gluino and chargino masses allowed to vary; LSP set to 60 GeV

$$x = (m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}) / (m_{\tilde{g}} - m_{\tilde{\chi}_1^0})$$







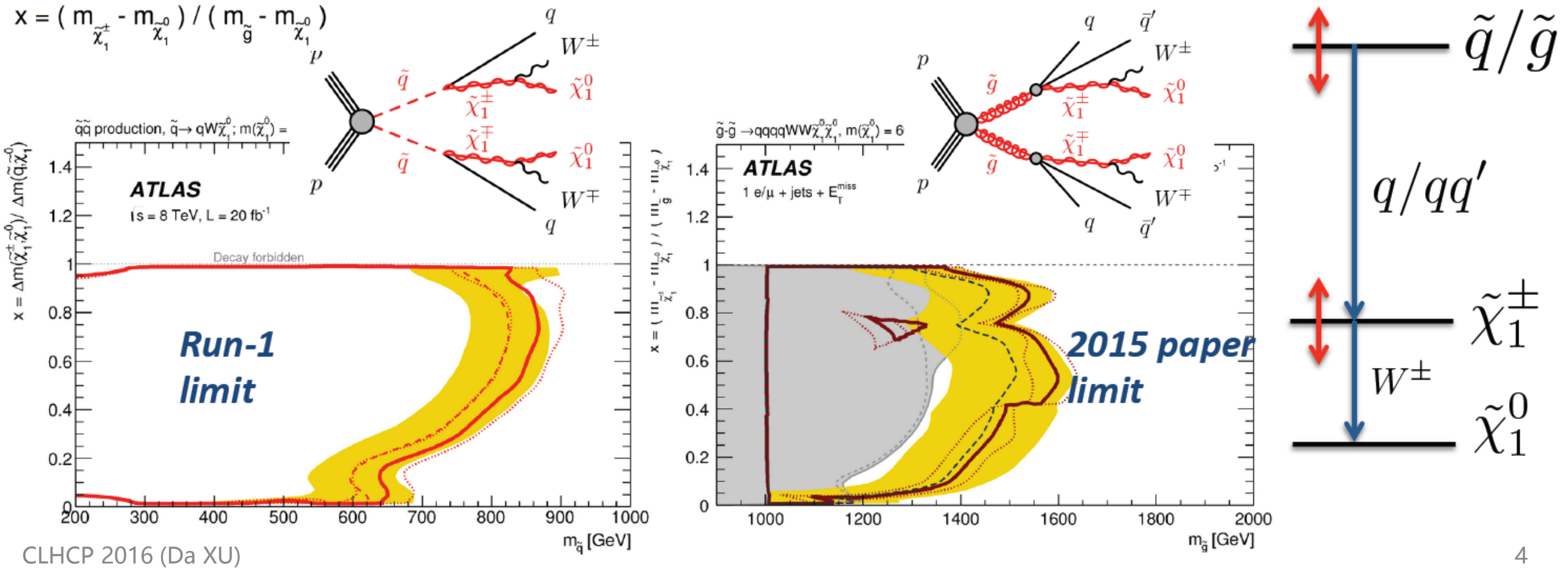
Targeted SUSY signals

Simplified SUSY models in R-parity conserving scenarios

- Lightest neutralino is the LSP and stable
- 100% BR of sparticle decays
- Target the 1lepton + 2-6 jets + MET final state

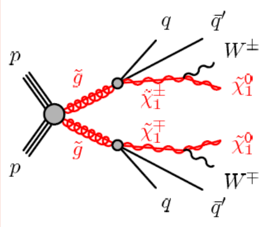
Two parameterizations of the one-step squark/gluino decays

- x=1/2 grid → squark/gluino and LSP masses are allowed to vary
- Variable-x grid → squark/gluino and chargino masses allowed to vary; LSP set to 60 GeV



Signal region design

Different signal regions are designed targeting different signal scenarios.

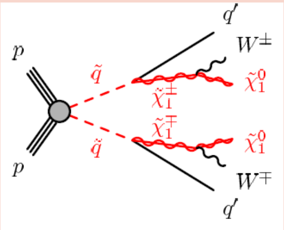


x=1/2 grid: compressed region (soft lepton only)

x=1/2 grid: high gluino mass region

Variable-x grid: high-x

Variable-x grid: low-x



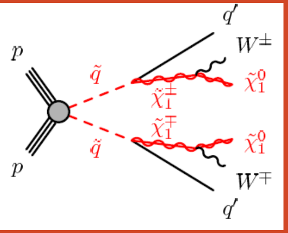
x=1/2 grid: high squark mass region

x=1/2 grid: medium squark mass region

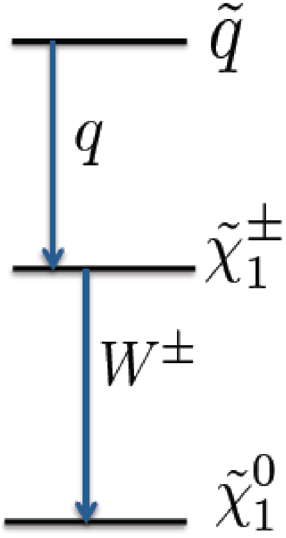
Variable-x grid: high-x

Variable-x grid: low-x

SR @ squark x=1/2 grid



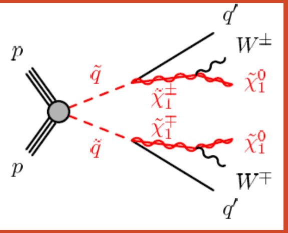
	SS 4J x=1/2	SS 5J x=1/2
N_{lep} (preselected)		$= 1$
p_T^{ℓ}(GeV)		> 35
N_{jet}	≥ 4	≥ 5
$p_T^{\text{jet1,2}}$ (GeV)	> 50	> 50
$p_T^{\text{jet3,4}}$ (GeV)	> 50	> 50
p_T^{jet5} (GeV)	-	> 50
$N_{\text{b-jet}}$		$= 0$
m_T (GeV)	> 175	> 175
E_T^{miss} (GeV)	> 300	> 300
$m_{\text{eff}}^{\text{inc}}$ (GeV)	> 1200	-
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{inc}}$	-	> 0.2
Lepton aplanarity	> 0.08	-

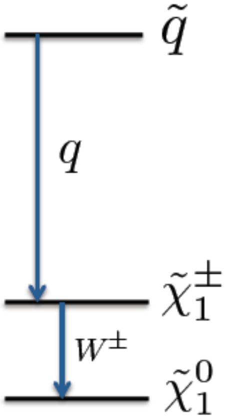


Considerably hard jets

Significant MET and m_T

SR @ squark variable-x grid

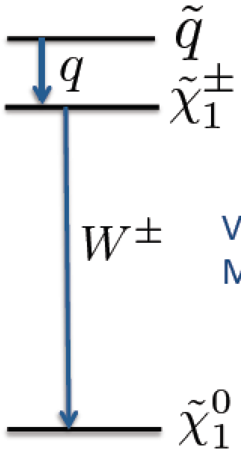




Hard jets from squark decay

'Softer' m_T

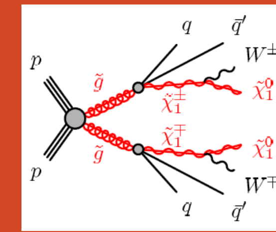
	SS 4J low-x	SS 5J high-x
N_{lep} (preselected)	= 1	
p_T^{ℓ}(GeV)	> 35	
N_{jet}	≥ 4	≥ 5
$p_T^{\text{jet1,2}}$ (GeV)	> 250	> 30
$p_T^{\text{jet3,4}}$ (GeV)	> 30	> 30
p_T^{jet5} (GeV)	-	> 30
$N_{\text{b-jet}}$		
m_T (GeV)	[150, 400]	> 400
E_T^{miss} (GeV)	> 250	> 400
$m_{\text{eff}}^{\text{inc}}$ (GeV)	-	-
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{inc}}$	-	-
Lepton aplanarity	> 0.03	> 0.03



Softer jets

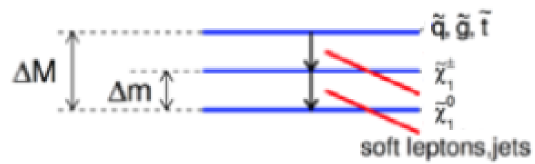
Very hard MET and m_T

SR @ gluino x=1/2 grid & variable-x grid



	GG 2J
N_{lep} (preselected)	= 1
p_{T}^{ℓ} (GeV)	[7(6), 35] for electron (muon)
N_{jet}	≥ 2
$p_{\mathrm{T}}^{\mathrm{jet1}}$ (GeV)	> 200
$p_{\mathrm{T}}^{\mathrm{jet2}}$ (GeV)	> 30
m_{T} (GeV)	> 100
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	> 460
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{\mathrm{inc}}$	> 0.35

"GG2J": soft lepton SR targets extremely compressed scenarios between gluinos and the LSP: *soft lepton; low jet multiplicity*.

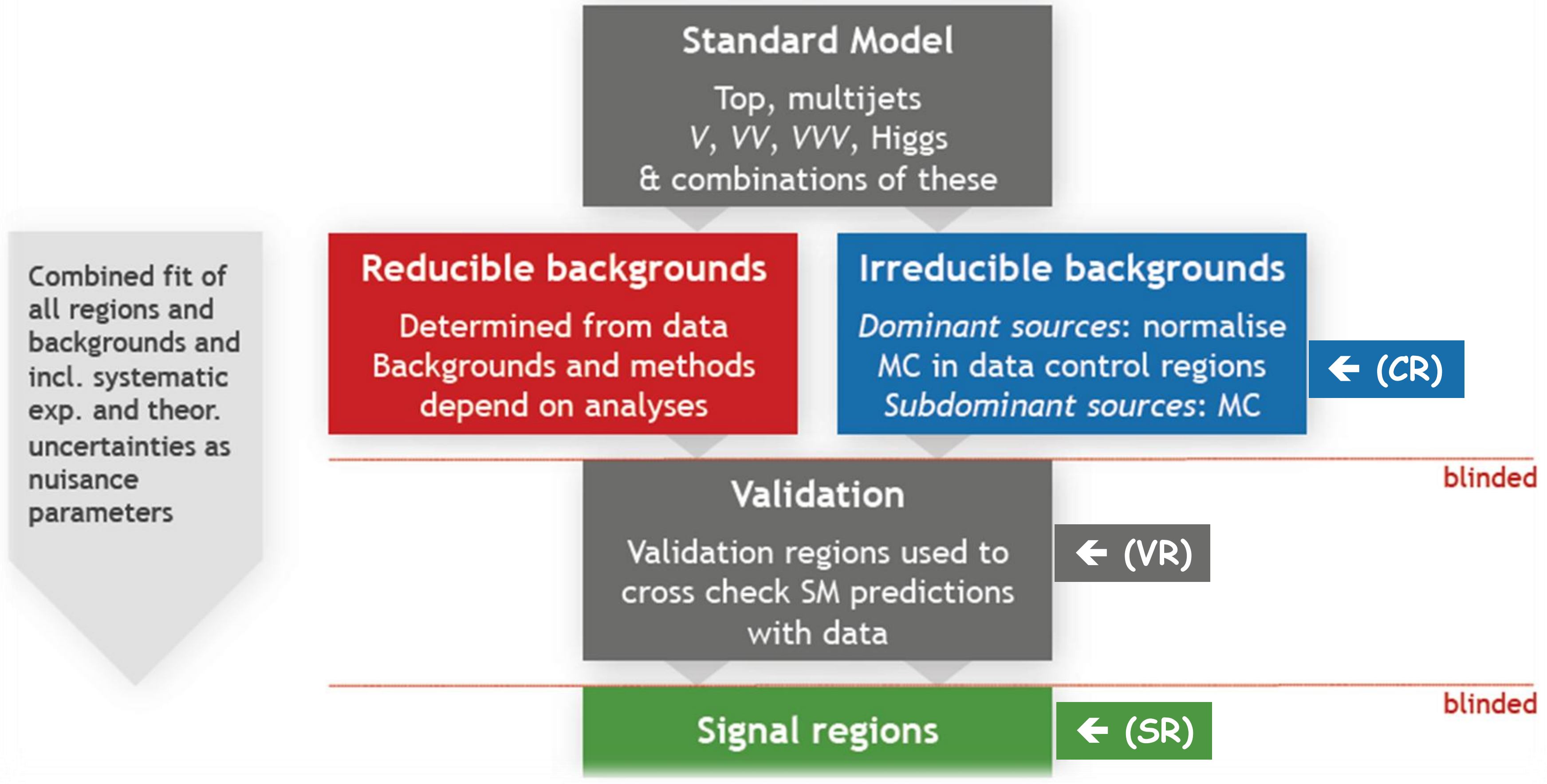


	GG 6J bulk	GG 6J high-mass	GG 4J low-x	GG 4J low-x b-veto	GG 4J high-x
N_{lep} (preselected)	2015 paper		= 1		
p_{T}^{ℓ} (GeV)	> 35	> 35	$> 7(6)$ for electron (muon)	$> 7(6)$ for electron (muon)	> 35
N_{jet}	≥ 6	≥ 6	≥ 4	≥ 4	≥ 4
$p_{\mathrm{T}}^{\mathrm{jet1}}$ (GeV)	> 125	> 125	> 100	> 100	> 400
$p_{\mathrm{T}}^{\mathrm{jet2,3}}$ (GeV)	> 30	> 30	> 100	> 100	> 30
$p_{\mathrm{T}}^{\mathrm{jet4}}$ (GeV)	> 30	> 30	> 100	> 100	[30, 100]
$p_{\mathrm{T}}^{\mathrm{jet5,6}}$ (GeV)	> 30	> 30	-	-	-
$N_{b-\mathrm{jet}}$	-	-	-	= 0	-
m_{T} (GeV)	> 225	> 225	> 125	> 125	> 475
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	> 250	> 250	> 250	> 250	> 250
$m_{\mathrm{eff}}^{\mathrm{inc}}$ (GeV)	> 1000	> 2000	> 2000	> 2000	> 1600
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{\mathrm{inc}}$	> 0.2	> 0.1	-	-	> 0.3
Jet aplanarity	> 0.04	> 0.04	> 0.06	> 0.03	-

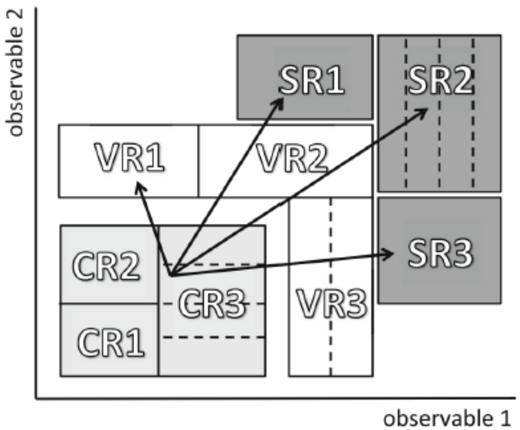
"GG 6J bulk": kinematically identical to 2015-paper-SR (~2σ excess): confirm or deny the excess quickly!

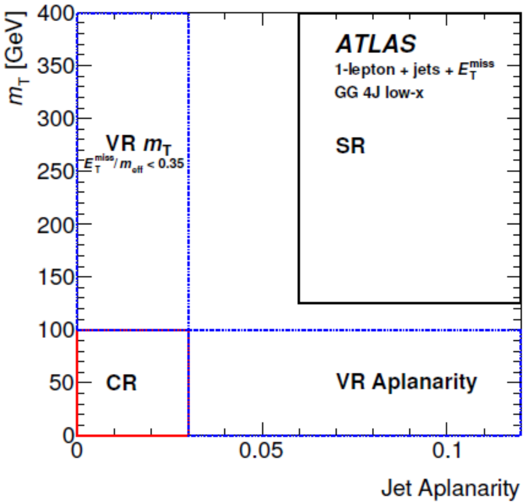
Background strategy

- **Control regions are used to constrain normalization of dominant backgrounds (i.e. ttbar, W+jets).**

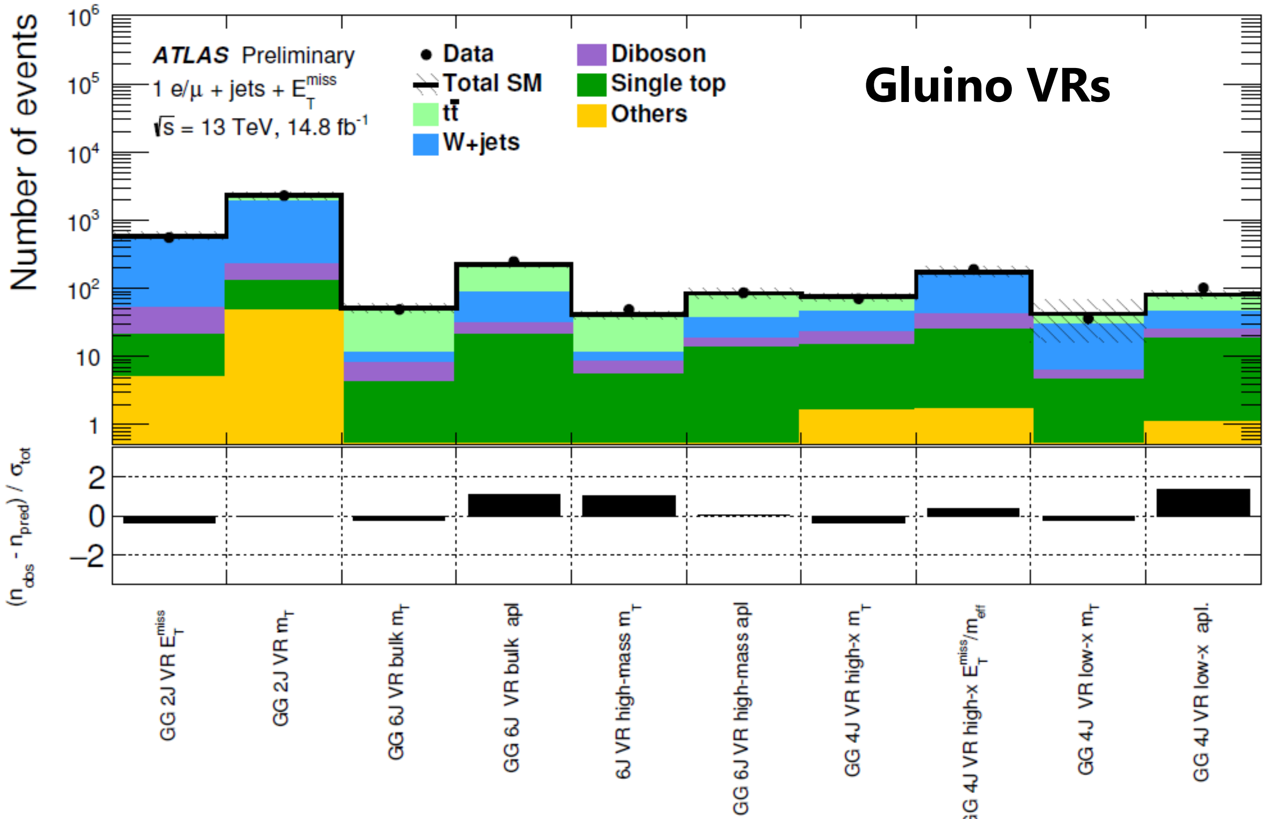


Background estimation



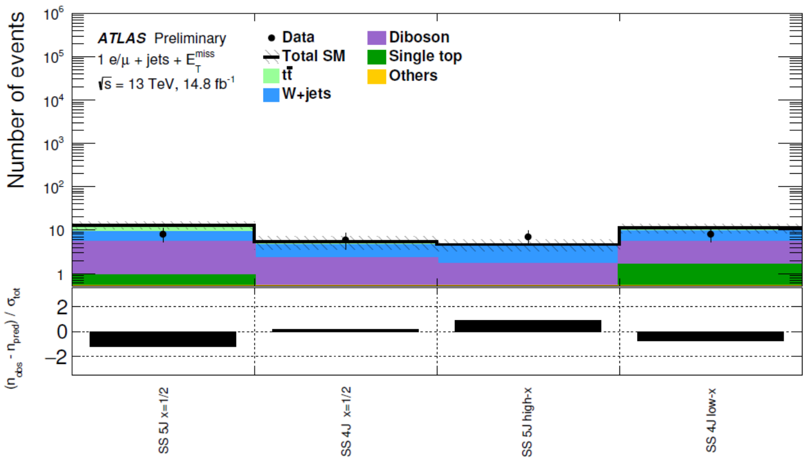


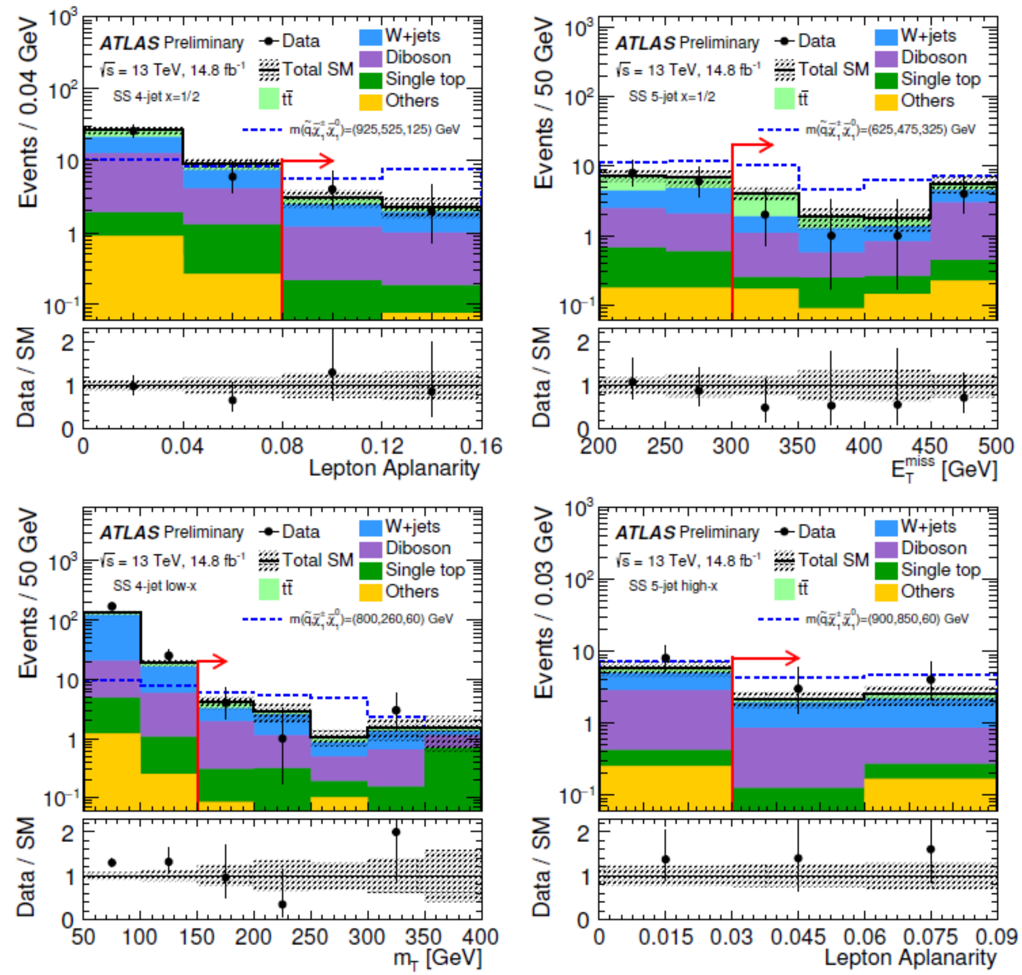
- Validation regions provide a statistically independent cross-check of CR-SR extrapolation.
- Background estimates agree well in all VRs.



Results: squark regions

No excess beyond SM.

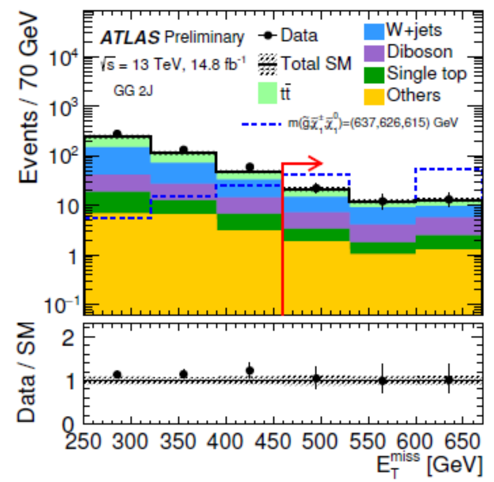


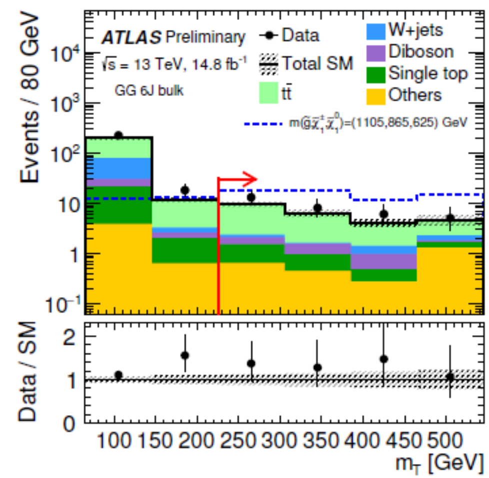


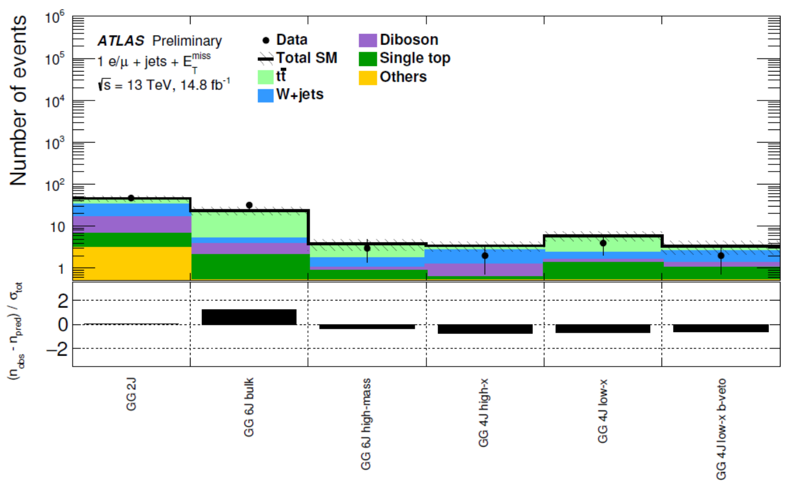
Results: gluino regions

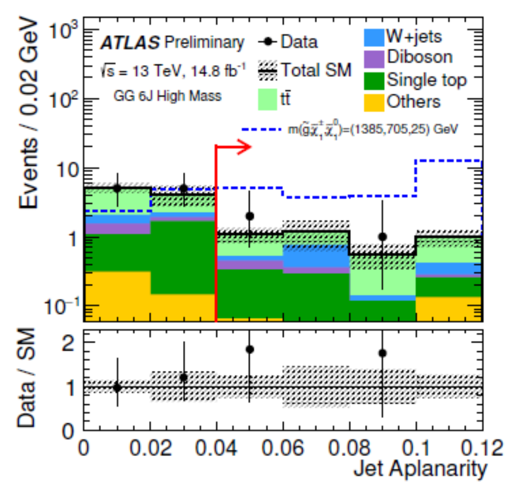
"GG 6Jbulk": w/ the combined data 2015-2016, data are compatible with the prediction at 1.2sigma.

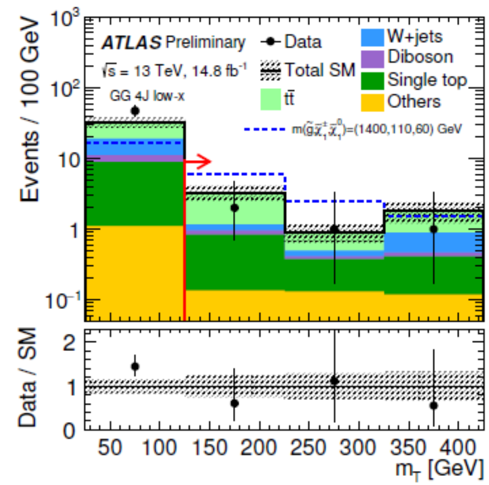
In general, good obs/pre agreement.









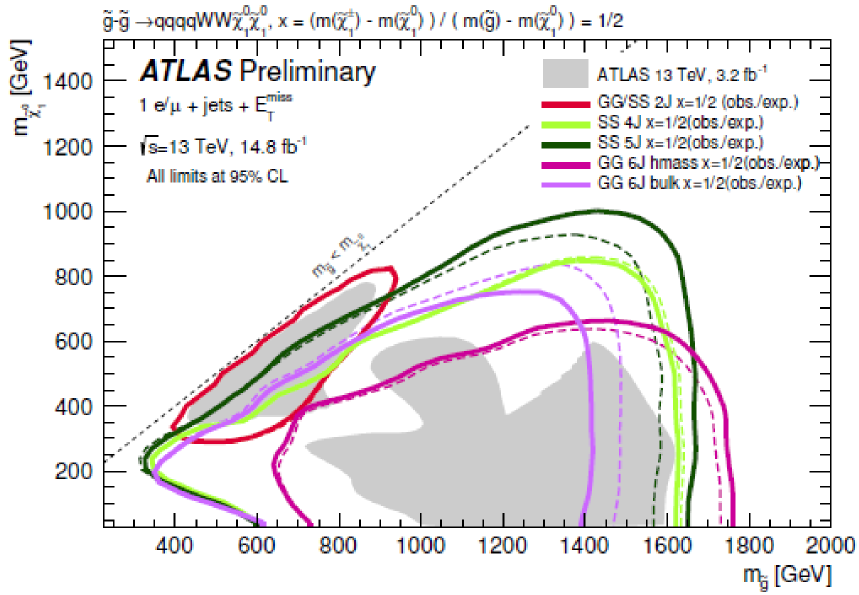


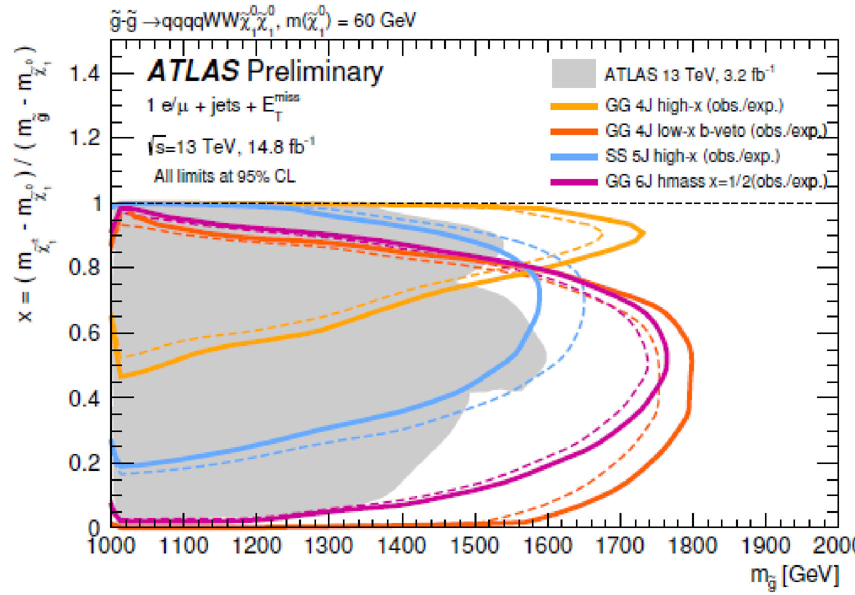
Model independent limit

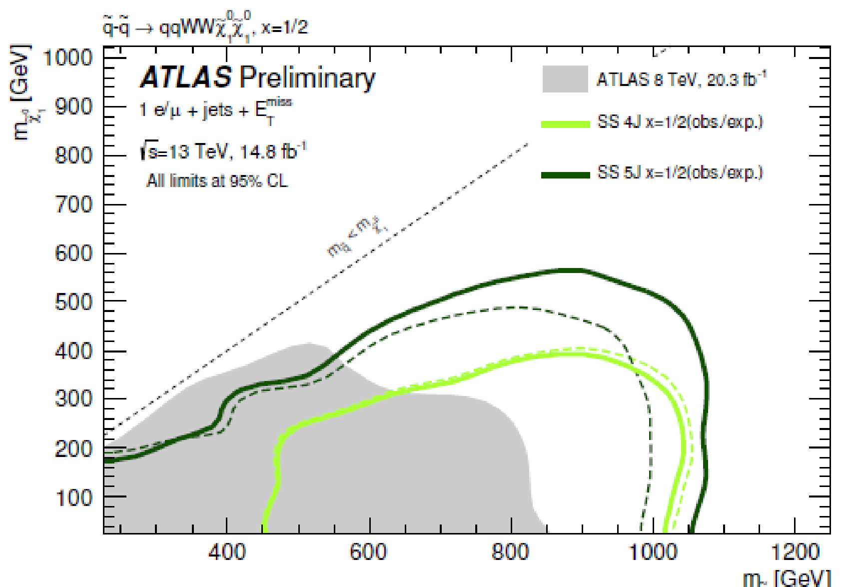
Region	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B	$p(s=0)$
GG 2J	1.44	21.3	$20.2^{+6.8}_{-5.1}$	0.56	0.41
GG 6J bulk	1.49	22.1	$14.7^{+6.3}_{-4.2}$	0.89	0.11
GG 6J high-mass	0.35	5.1	$5.5^{+2.2}_{-1.4}$	0.40	0.90
GG 4J high-x	0.28	4.2	$5.2^{+2.2}_{-1.2}$	0.26	0.77
GG 4J low-x	0.37	5.5	$6.6^{+2.7}_{-1.7}$	0.28	0.83
SS 4J x=1/2	0.51	7.5	$6.9^{+2.8}_{-1.7}$	0.62	0.40
SS 5J x=1/2	0.43	6.3	$9.1^{+3.4}_{-2.4}$	0.13	0.88
SS 4J low-x	0.59	8.8	$6.6^{+2.5}_{-1.6}$	0.83	0.18
SS 5J high-x	0.49	7.2	$8.8^{+3.5}_{-2.1}$	0.26	0.91

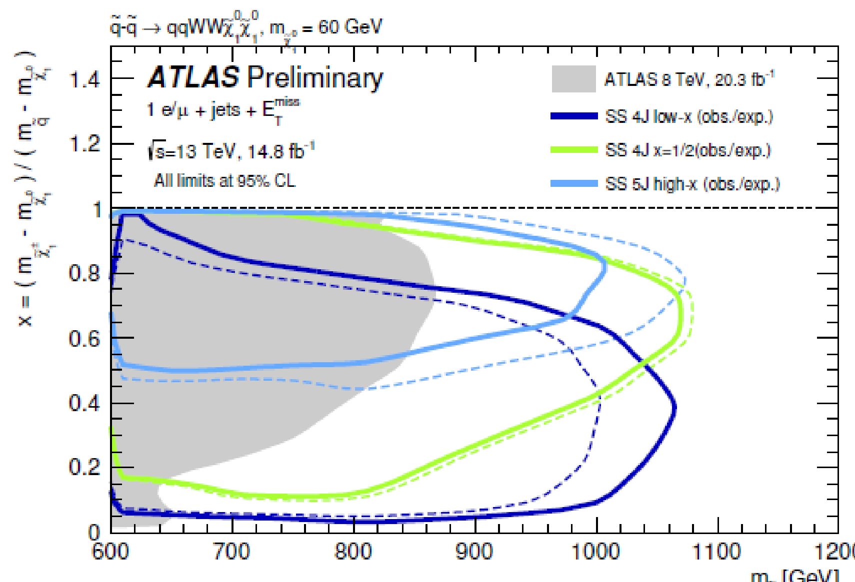
ATLAS-CONF-2016-054

95% CL exclusion limit (summary)

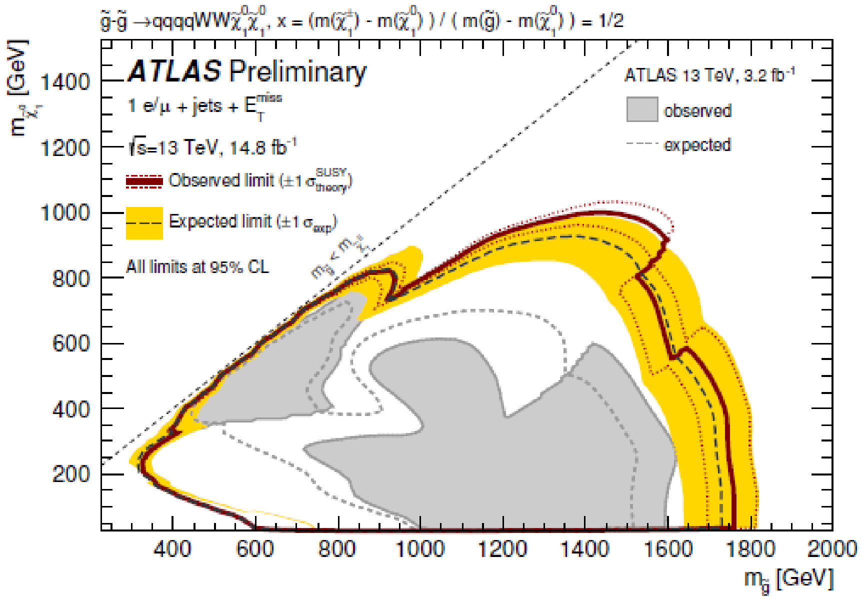


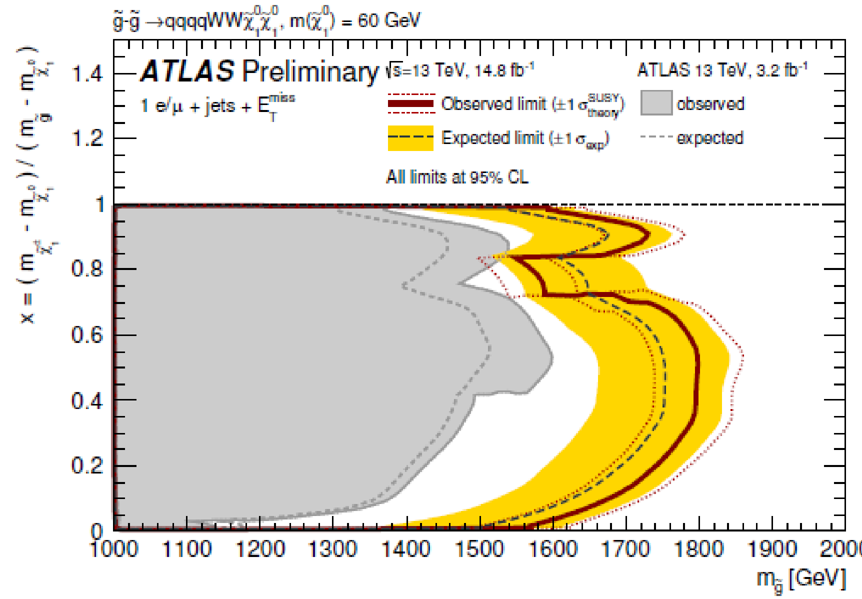


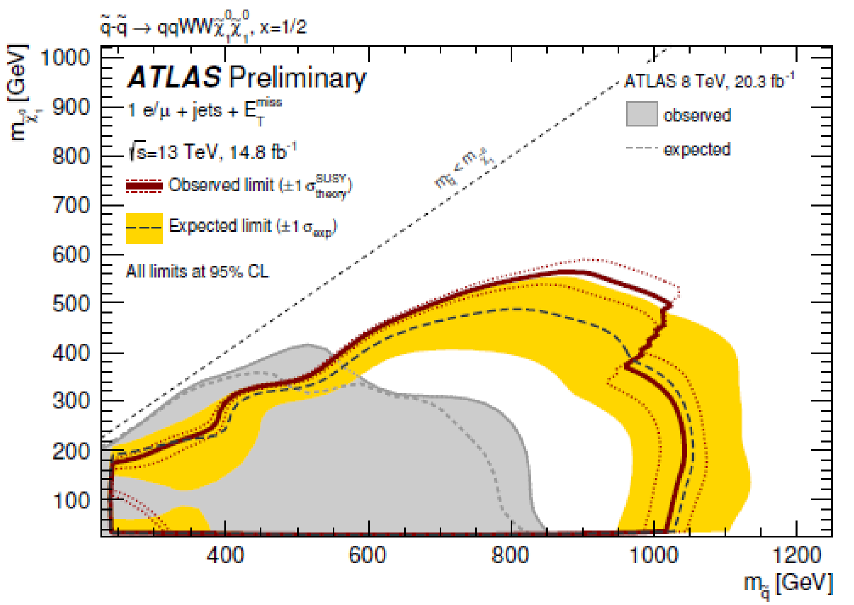


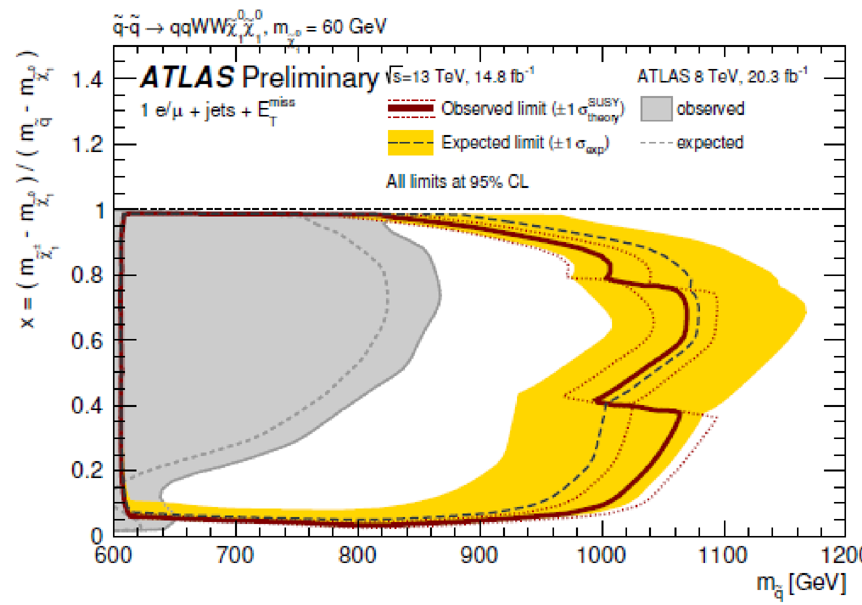


95% CL exclusion limit (combined)









Summary

- Search for squarks and gluinos with one lepton final state is performed with 2015+2016 pre-summer data.
- No excesses above the SM observation in any of the 10 SRs. The 2.1sigma excess in the 2015 6J SR has now decreased to 1.2sigma.
- Limits on squarks/gluinos significantly extended beyond Run-1/2015 results.
- Future plan: the paper using all 2015+2016 data is under preparation targeting Moriond 2017.

Extra slides

Thanks ☺

The aplanarity, $\mathcal{A}$ is a variable designed to allow more global information about the full momentum tensor of the event, M_{xyz}, via its eigenvalues λ_1, λ_2 and λ_3:

$$\sum_{i\ jet} \begin{pmatrix} P_x^2 & P_x P_y & P_x P_z \\ P_y P_x & P_y^2 & P_y P_z \\ P_z P_x & P_z P_y & P_z^2 \end{pmatrix}$$

Find the eigenvalues → $Av = \lambda v$

Ordered: $\lambda 1 > \lambda 2 > \lambda 3$

Normalised: $\sum_i \lambda_i = 1$

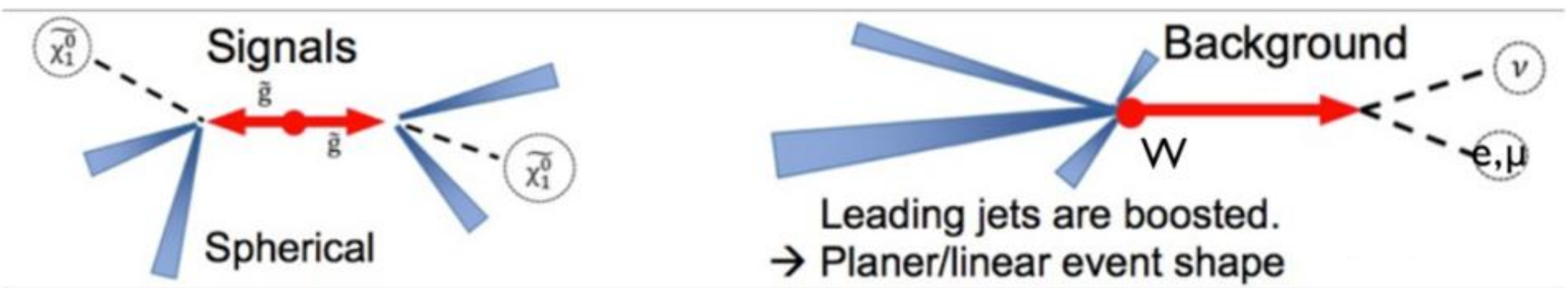
- Three categories of events:

$\lambda 1 >> \lambda 2, \lambda 3$ ‣ **Linear** event: most of momentum concentrated along 1 line

$\lambda 1 \gtrsim \lambda 2 >> \lambda 3$ ‣ **Planar** event: most of momentum concentrated in a plane

$\lambda 1 \gtrsim \lambda 2 \gtrsim \lambda 3$ ‣ **Aplanar** event: momentum activity in all 3 directions

- **Aplanarity** = $\frac{3}{2}\lambda_3$



Discriminating variables

The transverse mass (m_{T}) of the lepton (ℓ) and $\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}$ is defined as

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell}E_{\mathrm{T}}^{\mathrm{miss}}(1 - \cos[\Delta\phi(\vec{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})])}, \quad (1)$$

where $\Delta\phi(\vec{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})$ is the azimuthal angle between the lepton and the missing transverse momentum. This is used in the soft-lepton 2-jet signal region and all hard-lepton signal regions to reject W+jets and semileptonic $t\bar{t}$ events.

The inclusive effective mass ($m_{\mathrm{eff}}^{\mathrm{inc}}$) is the scalar sum of the p_{T} of the lepton, the jets and $E_{\mathrm{T}}^{\mathrm{miss}}$:

$$m_{\mathrm{eff}}^{\mathrm{inc}} = p_{\mathrm{T}}^{\ell} + \sum_{j=1}^{N_{\mathrm{jet}}} p_{\mathrm{T},j} + E_{\mathrm{T}}^{\mathrm{miss}}, \quad (2)$$

where the index j runs over all the signal jets in the event with $\mathrm{p_T} > 30$ GeV. The inclusive effective mass provides good discrimination against SM backgrounds, without being too sensitive to the details of the SUSY cascade decay chain.

The transverse scalar sum (H_{T}) is defined as

$$H_{\mathrm{T}} = p_{\mathrm{T}}^{\ell} + \sum_{j=1}^{N_{\mathrm{jet}}} p_{\mathrm{T},j},$$

Systematic strategy

<u>Theory uncertainties: the procedure will be similar to 2015 analysis and follow closely to the PMG recommendations.</u>

- Uncertainties on ttbar and W+jets (scale variations; ISR/FSR; Hadronization/fragmentation; Hard scattering generation)
- Uncertainties on Z+jets, single-top, diboson and ttV
- Uncertainties on signal cross-section, variations of Madgraph and Pythia parameters (renormalization/factorization scales, ISR/FSR scales, Madgraph jet matching scale)

<u>Experimental uncertainties following recommendations of CP/SUSY groups.</u>

- Jet energy scale (reduced set), resolution
- Lepton scale, resolution and efficiency
- MET scale, resolution
- B-tagging uncertainties
- Pile-up uncertainty

SR yields

Region (GG)	2J	6J bulk	6J high-mass	4J low-x	4J low-x b-veto	4J high-x
Observed events	47	32	3	4	2	2
Fitted background events	46 ± 7	24 ± 5	3.8 ± 1.2	6.0 ± 1.6	3.3 ± 1.2	3.4 ± 0.9
Fitted $t\bar{t}$ events	12.4 ± 3.5	17 ± 5	2.0 ± 0.9	3.4 ± 1.6	0.8 ± 0.4	0.7 ± 0.4
Fitted W+jets events	16.7 ± 3.2	1.2 ± 0.5	0.6 ± 0.4	0.7 ± 0.4	1.2 ± 0.7	1.4 ± 0.4
Fitted Z+jets events	2.9 ± 1.7	$0.04^{+0.07}_{-0.04}$	0.11 ± 0.09	0.11 ± 0.08	0.030 ± 0.030	0.040 ± 0.030
Fitted single top events	3.4 ± 2.8	2.0 ± 1.6	0.7 ± 0.6	1.2 ± 1.0	1.0 ± 0.9	0.6 ± 0.5
Fitted diboson events	9 ± 5	1.8 ± 1.5	$0.20^{+0.33}_{-0.20}$	$0.21^{+0.32}_{-0.21}$	$0.31^{+0.33}_{-0.31}$	0.6 ± 0.6
Fitted $t\bar{t}$+V events	1.27 ± 0.12	1.72 ± 0.32	0.18 ± 0.06	0.27 ± 0.05	0.04 ± 0.010	0.18 ± 0.04

Region (SS)	4J x=1/2	5J x=1/2	4J low-x	5J high-x
Observed events	6	8	8	7
Fitted background events	5.4 ± 1.7	13.2 ± 2.5	11.1 ± 2.7	4.6 ± 1.4
Fitted $t\bar{t}$ events	1.0 ± 0.5	4.2 ± 1.5	1.8 ± 1.0	0.51 ± 0.20
Fitted W+jets events	2.2 ± 0.6	3.6 ± 0.9	4.0 ± 1.1	2.4 ± 0.8
Fitted Z+jets events	0.08 ± 0.06	0.29 ± 0.19	0.16 ± 0.09	0.11 ± 0.08
Fitted single top events	0.27 ± 0.24	0.6 ± 0.5	1.4 ± 1.2	0.18 ± 0.17
Fitted diboson events	1.8 ± 1.5	4.3 ± 2.5	3.7 ± 2.1	0.6 ± 0.6
Fitted $t\bar{t}$+V events	0.059 ± 0.022	0.34 ± 0.08	0.13 ± 0.04	0.104 ± 0.031