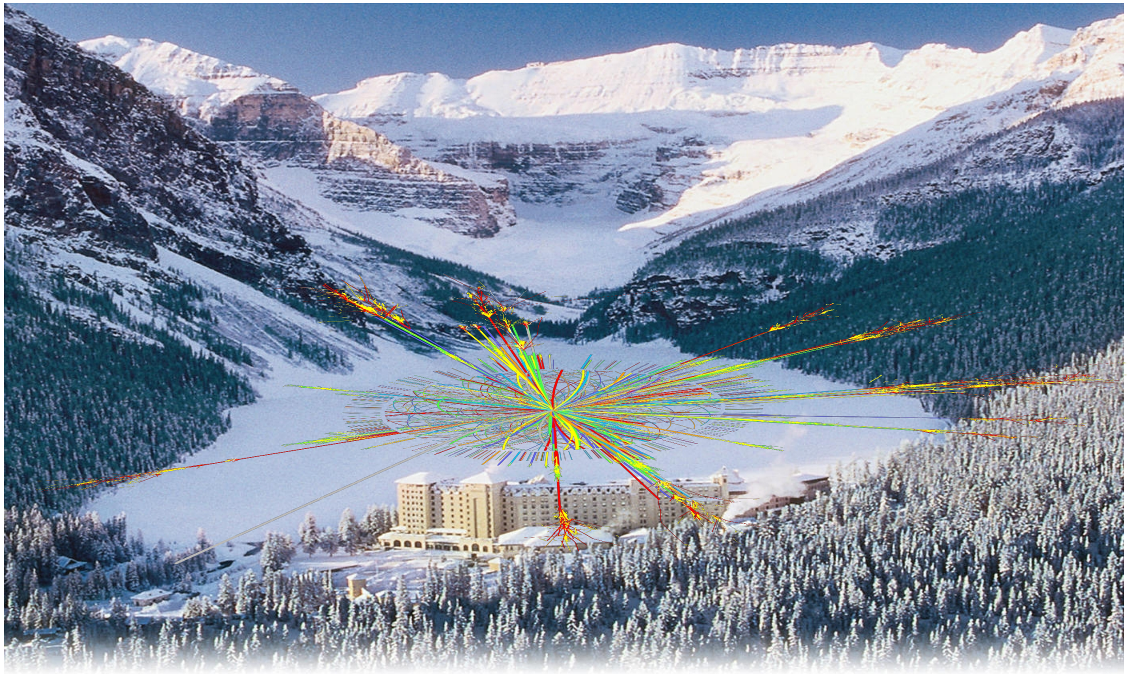
Search for supersymmetry with the ATLAS detector in final states with leptons, jets and missing transverse momentum



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on behalf of the ATLAS Collaboration

University of Victoria

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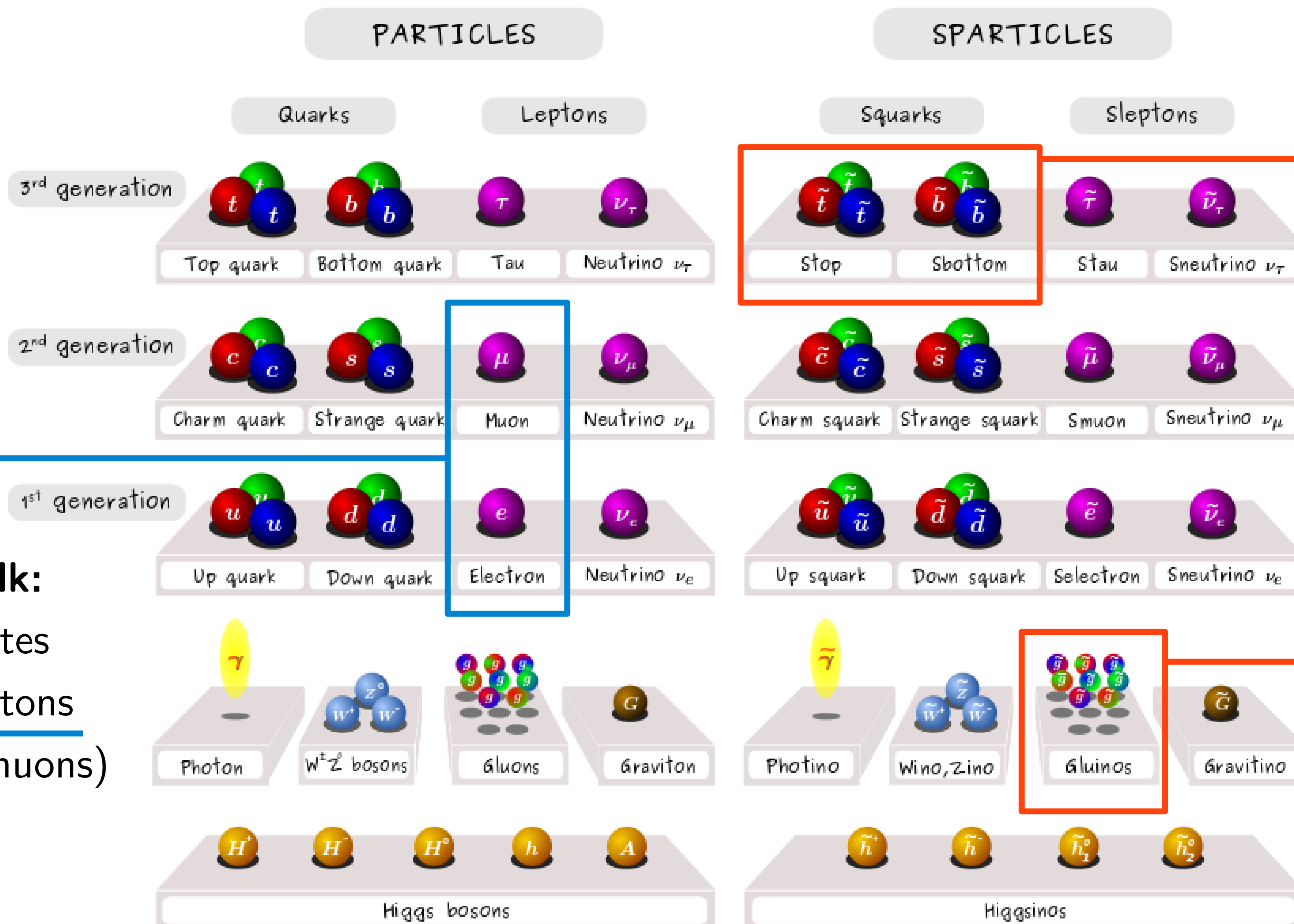
Lake Louise Winter Institute 2016

Searching for supersymmetry with ATLAS

Strong production may be dominant at LHC: gluino-gluino, squark-gluino, squark-squark



This talk:

final states

with leptons

(el. or muons)

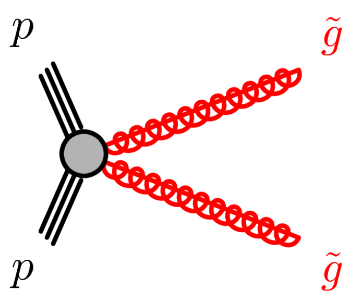
+ jets

+ E_T^{miss}

Analyses with 13 TeV LHC data 3.2 fb^{-1}

- *R*-parity conserved supersymmetry
- Lightest Supersymmetric Particle (LSP) = neutralino $\widetilde{\chi}_1^0$ $\rightarrow$ dark matter candidate

Gluino pair $\rightarrow$ 1 lepton



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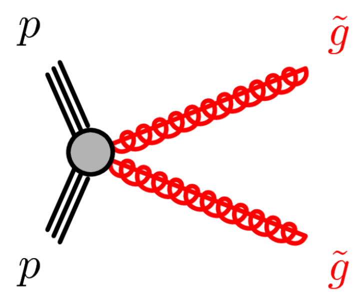
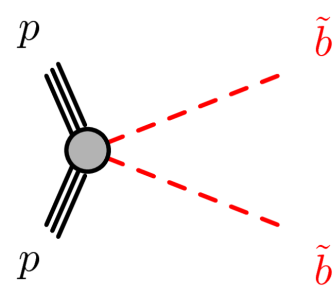
Same-sign 2 leptons + 3 leptons





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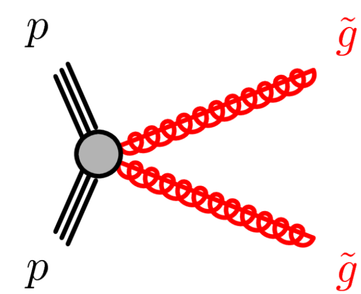
Z + E_T^{miss} $\rightarrow$ 2 leptons



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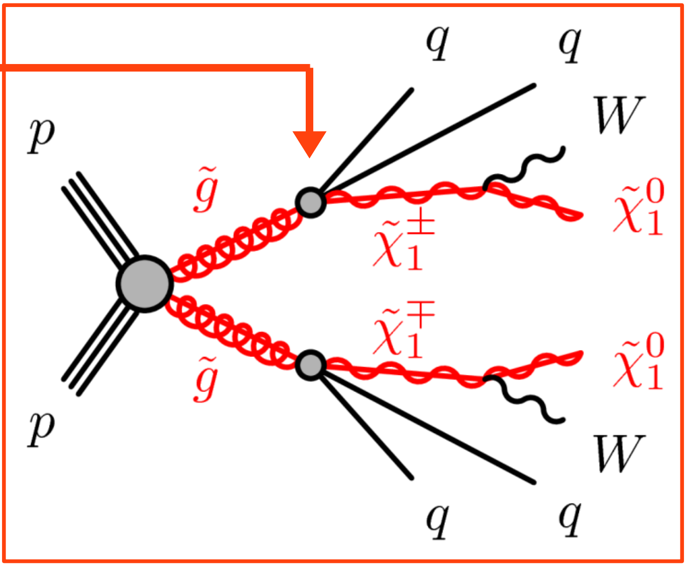
1 lepton + jets + E_T^{miss}

- Direct pair production of gluinos
- Decay: $\tilde{g} \rightarrow q\,\bar{q}'\,\tilde{\chi}_1^{\pm}$
  via virtual squark
  1st and 2nd generations
- BR(SUSY decays) = 1



high jet multiplicity

E_T^{miss}

lepton from W

2 scenarios	
$m_{\tilde{g}}$ free parameter	$m_{\tilde{g}}$ free parameter
$m_{\tilde{\chi}_1^0}$ set to 60 GeV	$m_{\tilde{\chi}_1^0}$ free parameter
$x = \frac{m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}}{m_{\tilde{g}} - m_{\tilde{\chi}_1^0}}$	$m_{\tilde{\chi}_1^{\pm}} = \frac{m_{\tilde{g}} + m_{\tilde{\chi}_1^0}}{2}$

2 channels	
"**Hard**" lepton	"**Soft**" lepton
$p_T > 35$ GeV	$6 \leq p_T < 35$ GeV
Targets **large** mass splittings	Targets **small** mass splittings

1 lepton + jets + E_T^{miss}

- 6 independent signal regions to address the different mass hierarchies
- Best expected signal region used in each point of the parameter space

Hard lepton $p_T > 35$ GeV

⇒ large mass splittings between $\tilde{g}$, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ masses

4jet low x	4jet high x	5jet	6jet
$m_{\tilde{\chi}_1^0} = 60$ GeV		$x = 1/2$	
		$m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$: Large	$m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$: Small
Virtual W ⇓ high p_T jets	Boosted W ⇓ high m_T	m_T & m_{eff}: Tight	m_T & m_{eff}: Relaxed

Soft lepton $6 \leq p_T < 35$ GeV

⇒ compressed spectra

2jet	5jet
Heavy $\tilde{\chi}_1^0$ ⇓ Soft decay objects ⇓ 1 ISR high p_T jet; recoil ↗ kinematics	mass axis m: $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$, $\tilde{g}$ ⇓ High p_T jets; ⇓ Virtual W

Transverse mass: $$m_T = \sqrt{2\, p_T^\ell\, E_T^{miss} - 2\, \vec{p}_T^{\,\ell}\, \vec{p}_T^{\,miss}}$$

Transverse scalar sum: $$H_T = p_T^\ell + \sum_{j=1}^{N_{jet}} p_{T,j}$$

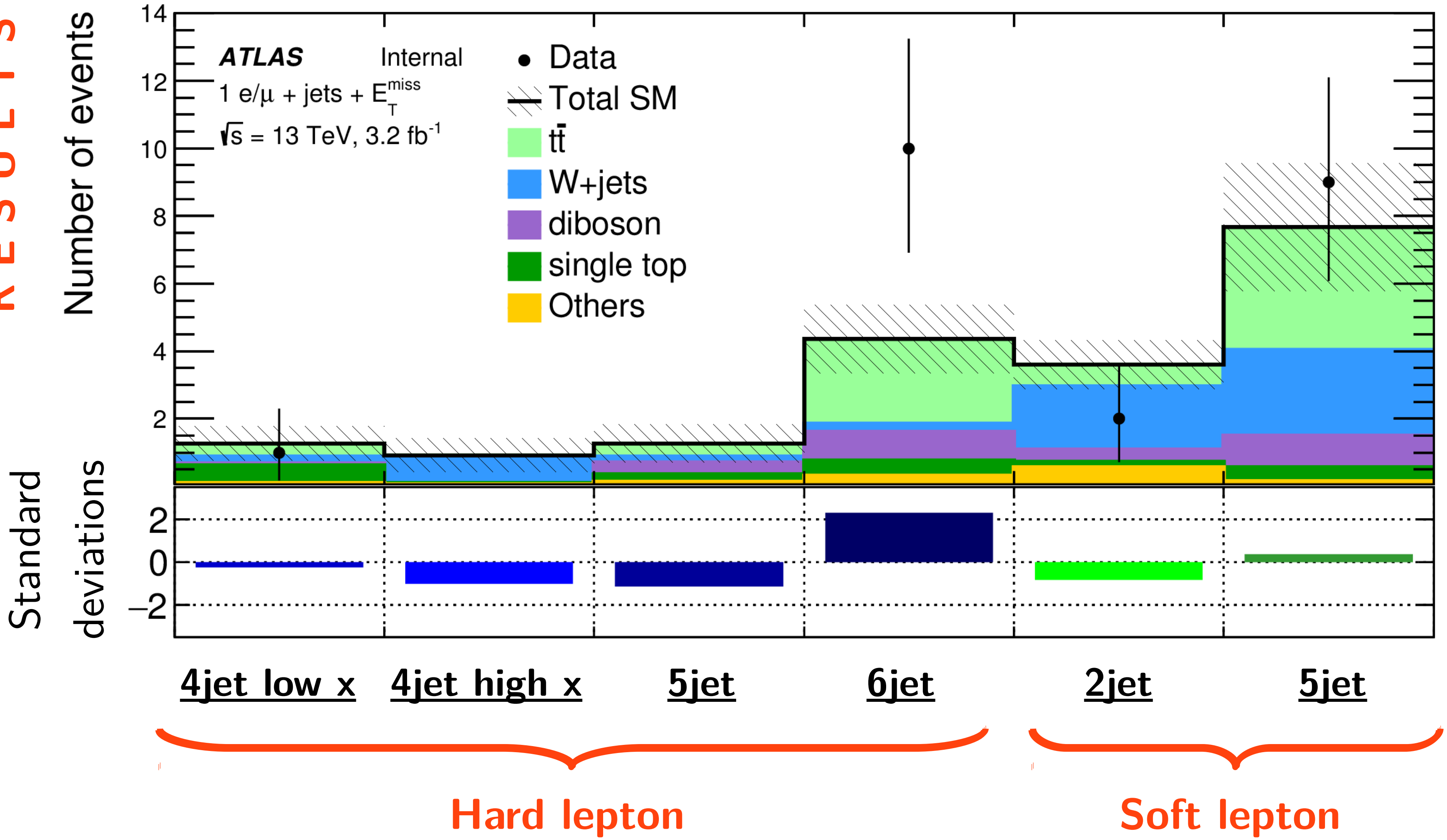
Inclusive eff mass: $$m_{eff}^{inc} = p_T^\ell + \sum_{j=1}^{N_{jet}} p_{T,j} + E_T^{miss}$$

Aplanarity: $$\mathcal{A} = \frac{3}{2}\lambda_3$$ → Smallest eigenvalue of normalised momentum of jets

1 lepton + jets + E_T^{miss}

- Main backgrounds $t\bar{t}$ and W+$jets$, estimated using Monte Carlo
- 2 CRs per SR, where contribution of $t\bar{t}$ and W+$jets$ normalized & extrapolated to SRs

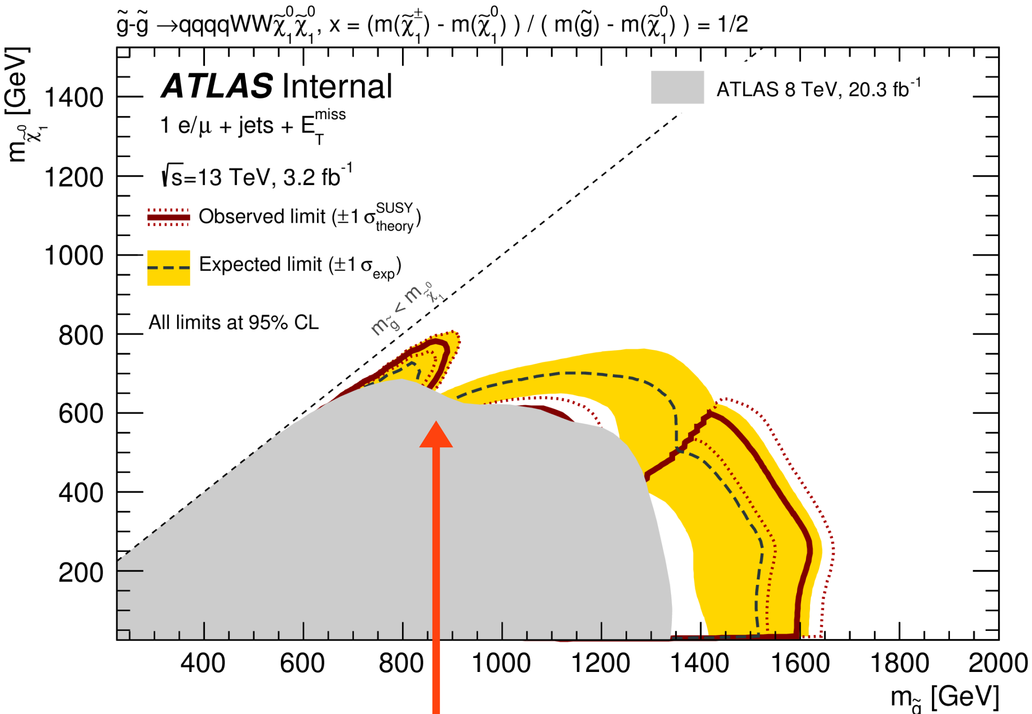
RESULTS

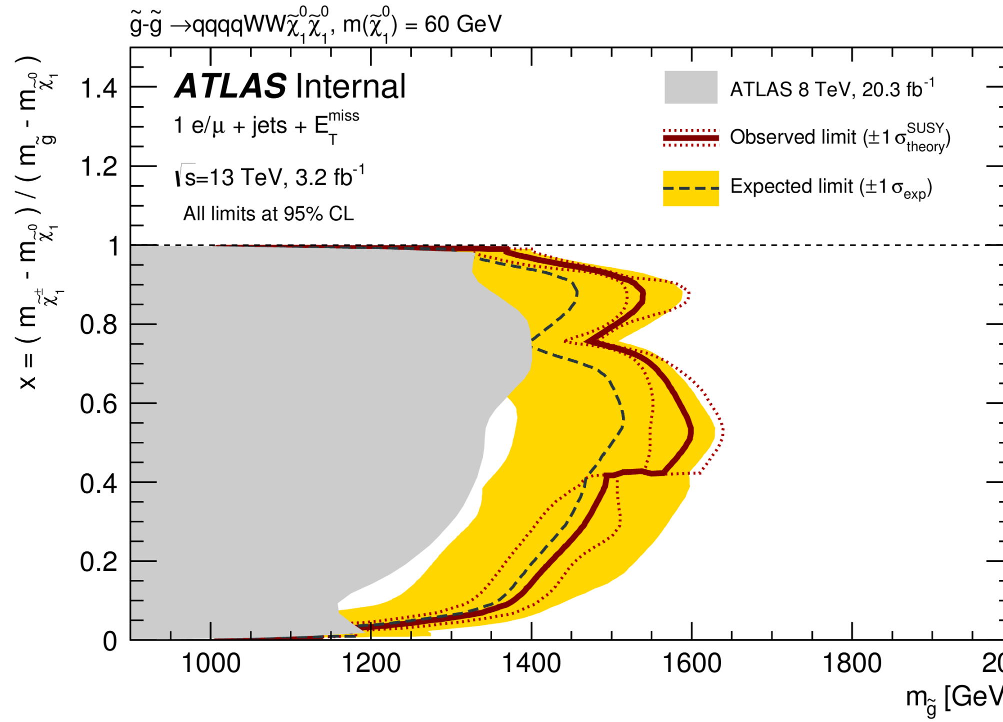


- Excess in 6jet: in muon channel, 8 observed events, 2.5 ± 0.8 predicted, local significance = 2.5 σ

1 lepton + jets + E_T^{miss}

- Model-dependent limits (limits for each SR shown in backup-slide)





For compressed spectra models and with $x = 1/2$, neutralino 1 masses excluded up to 870 GeV

For large $m_{\tilde{g}}$ - $m_{\tilde{\chi}_1^0}$, gluino masses excluded up to 1.6 TeV

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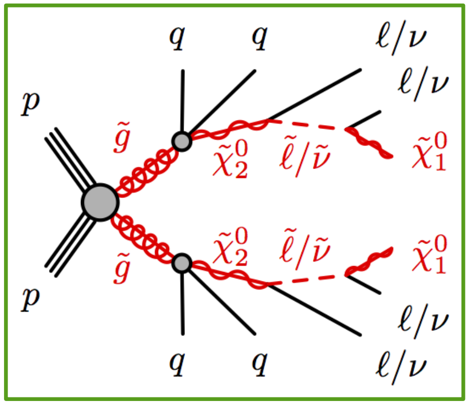
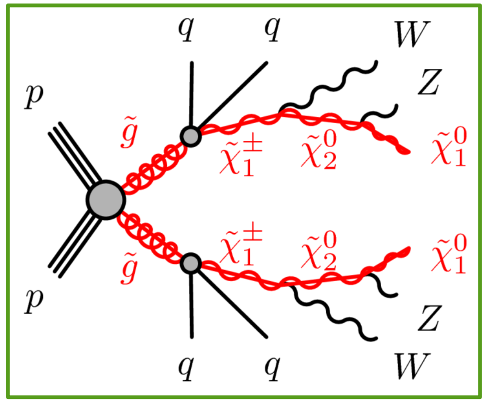
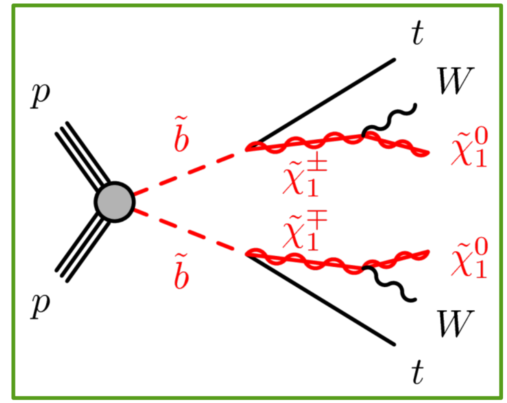
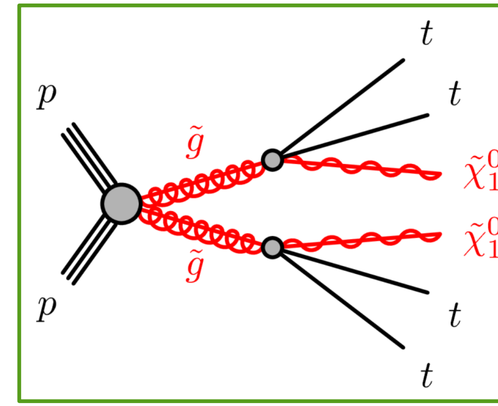
Same sign dileptons + 3 leptons + E_T^{miss}

- Events selection: 2 leptons same-sign ($e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$) or 3 leptons
- Same sign leptons: occurs in many BSM scenarios, in SM → very small cross sections









<u>Gluino pair production → light quarks</u>

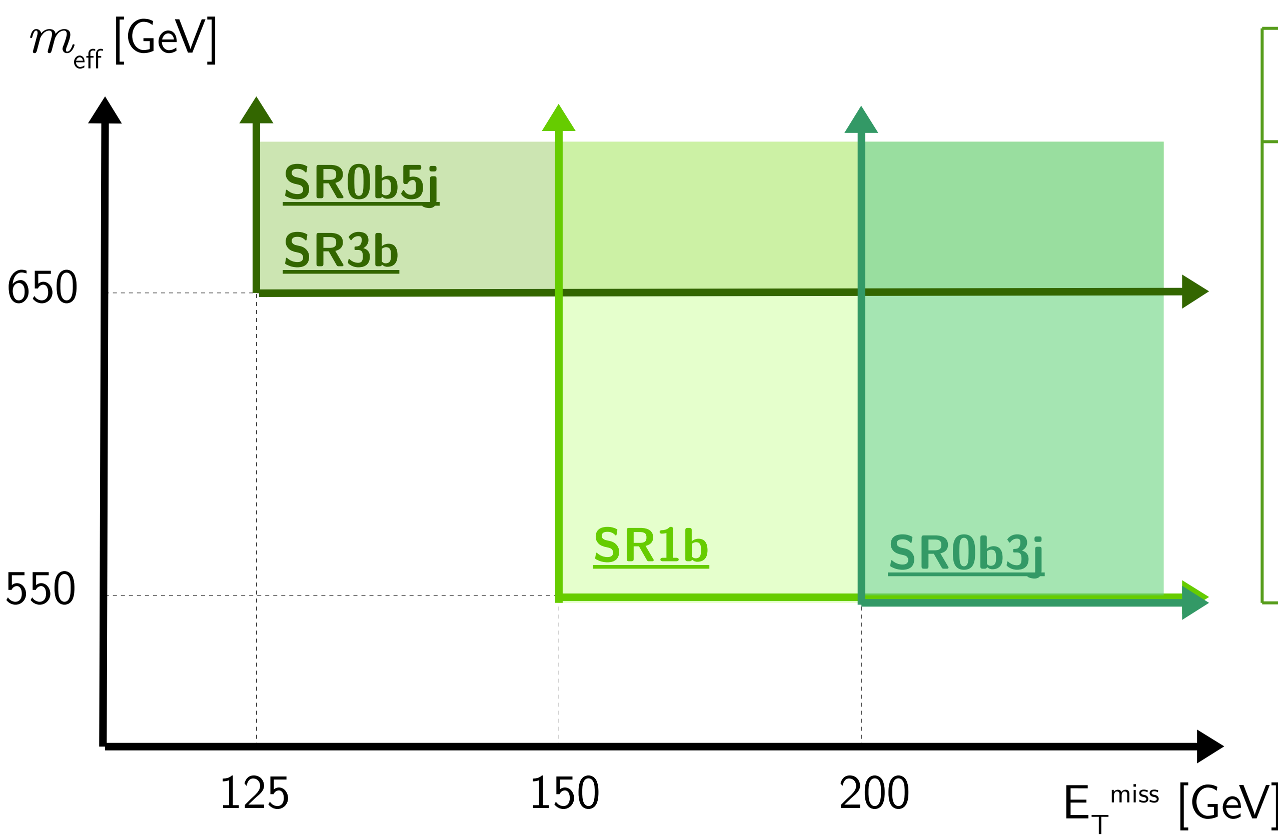
via light sleptons	via $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$
⇩	⇩
Final states rich in leptons	Final states rich in light jets
⇩	⇩
<u>SR0b3j</u>	**<u>SR0b5j</u>**

<u>3[rd] generation squarks assumed lighter</u>

Direct $\tilde{b}_1\tilde{b}_1^*$ production	Gluino → off-shell stop
⇩	⇩
2 b-jets (MV2c20) in final states	4 b-jets in final states
⇩	⇩
<u>SR1b</u>	**<u>SR3b</u>**

Same sign dileptons + 3 leptons + E_T^{miss}

- 4 overlapping signal regions to maximize sensitivity



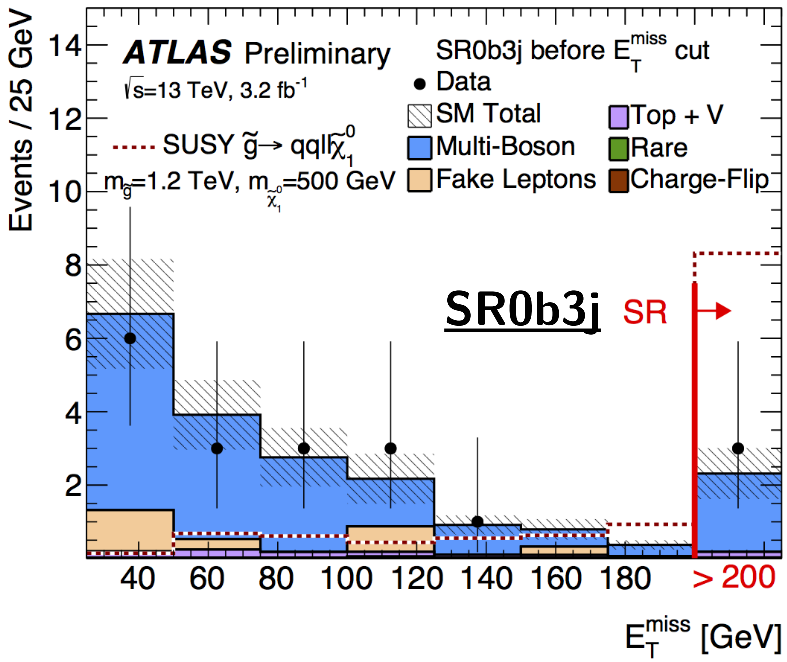
signal lepton: $p_T > 20$ GeV

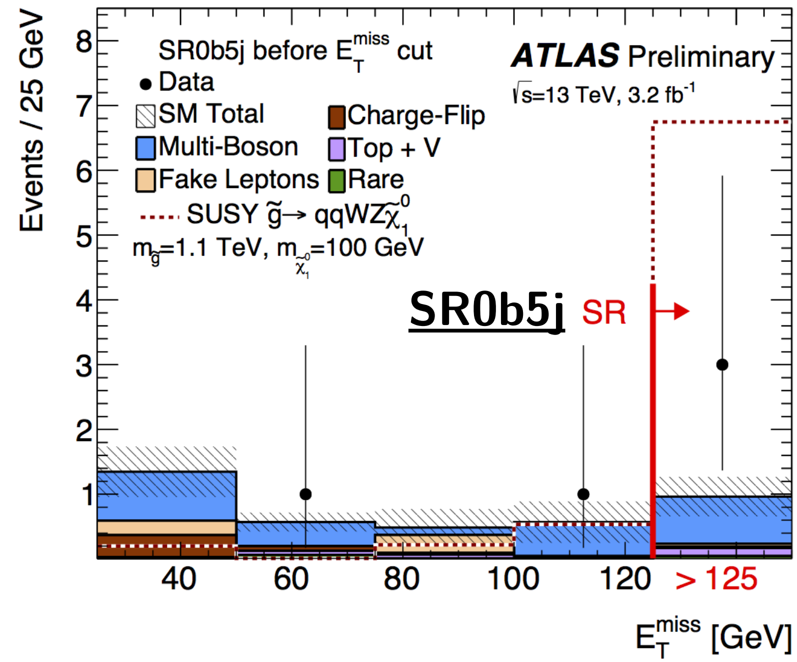
SR0b3j	**SR0b5j**	**SR1b**	**SR3b**
$\geq 3\,\ell$	$\geq 2\,\ell$	$\geq 2\,\ell$	$\geq 2\,\ell$
≥ 3 jets	≥ 5 jets	≥ 4 jets	–
0 b-jet	0 b-jet	≥ 1 b-jet	≥ 3 b-jets

Backgrounds

- SS prompt $\geq 2\ell$: $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}h$, tZ , diboson, triboson → Monte Carlo
- Electron mismeasurement "charge flip" → weight OS data (small bkg)
- Fake or non-prompt leptons: data-driven "matrix method"

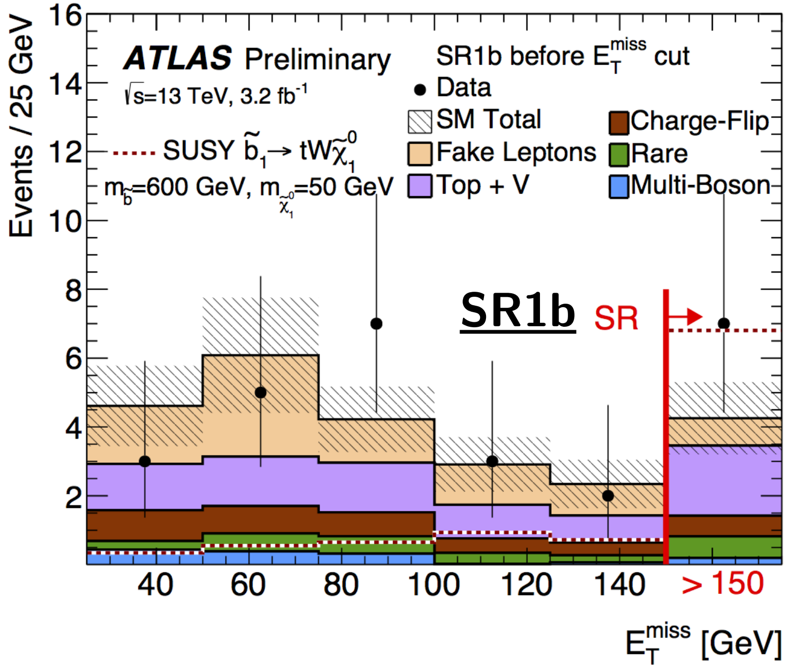
Same sign dileptons + 3 leptons + E_T^{miss}

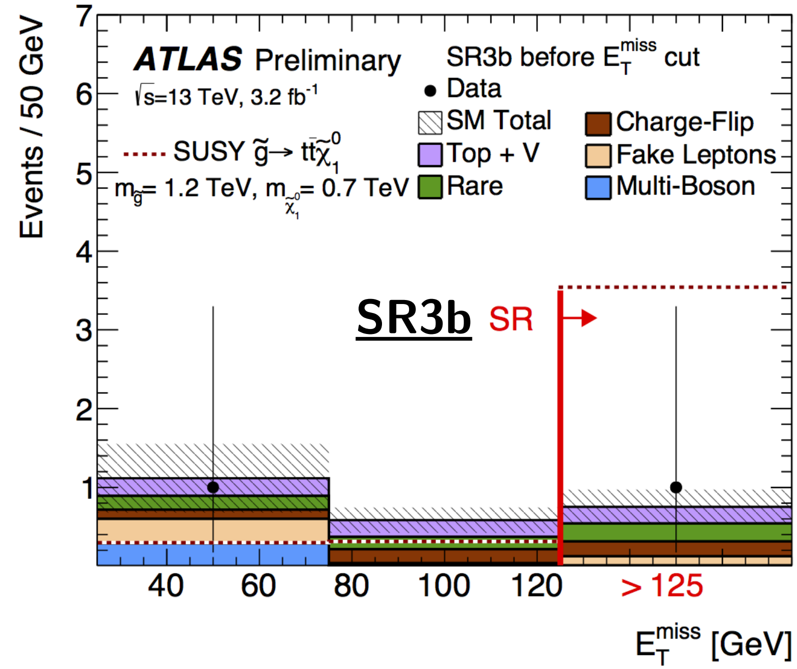




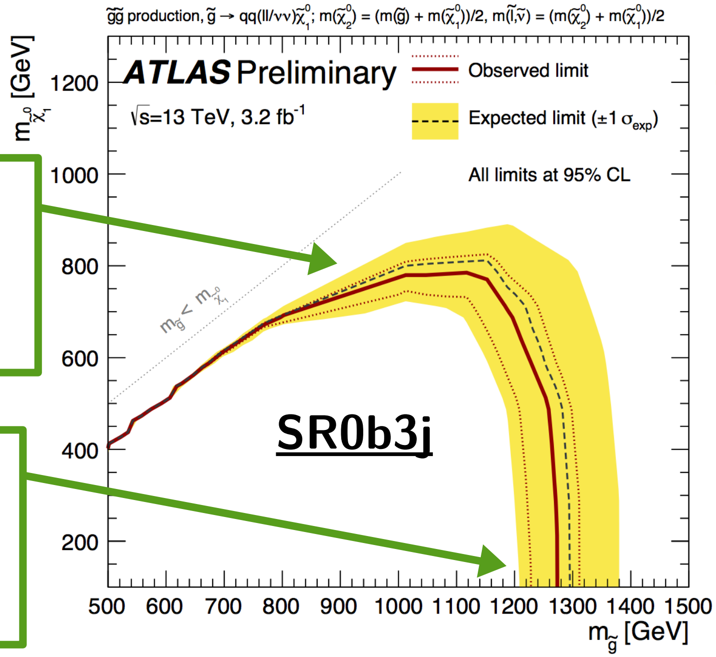
p-value $= 0.06$

3 events in SR0b3j + 2 events in SR1b contain 3 leptons



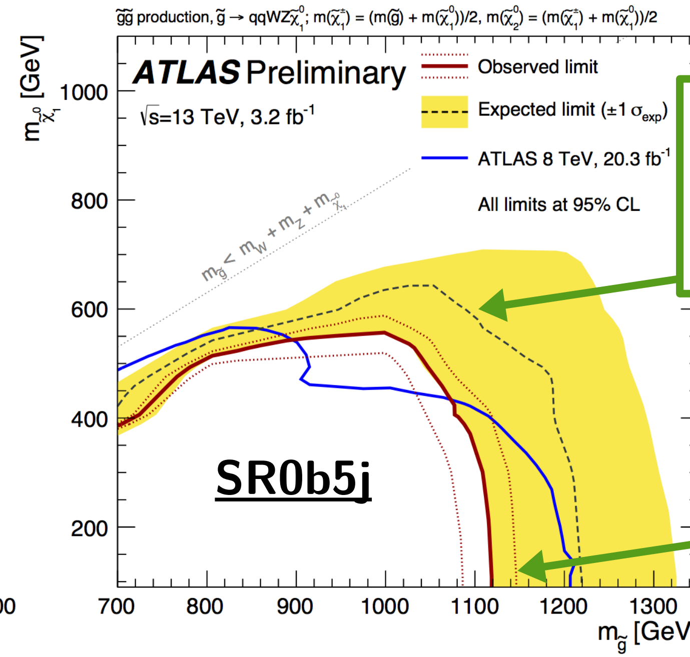


Same sign dileptons + 3 leptons + E_T^{miss}



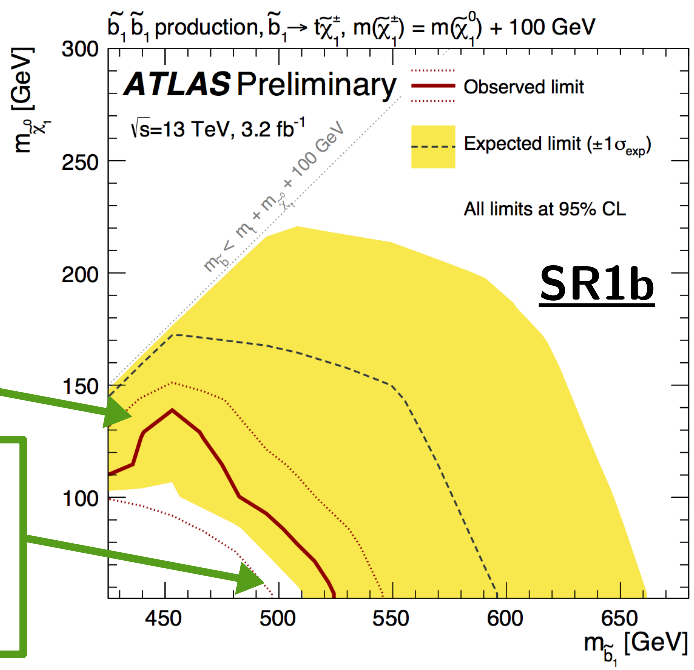
$m(\widetilde{\chi}_1^0)$ excluded up to 775 GeV if $m(\widetilde{g}) \approx 1$ TeV

$m(\widetilde{g})$ excluded up to 1.6 TeV for light LSP



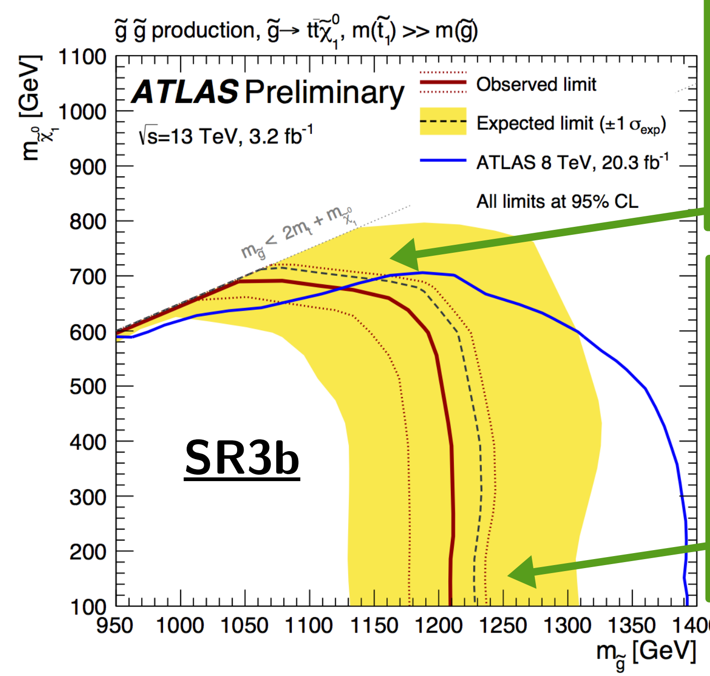
$m(\widetilde{\chi}_1^0)$ excluded up to 550 GeV for $m(\widetilde{g}) \approx 1$ TeV

$m(\widetilde{g})$ excluded up to 1.1 TeV for light LSP



$m(\widetilde{\chi}_1^0)$ excluded up to 135 GeV for $m(\widetilde{b}_1) \approx 450$ GeV

$m(\widetilde{b}_1)$ excluded up to 525 GeV for light LSP



Excl. $m(\widetilde{\chi}_1^0) \rightarrow 700$ GeV in compressed scenarios

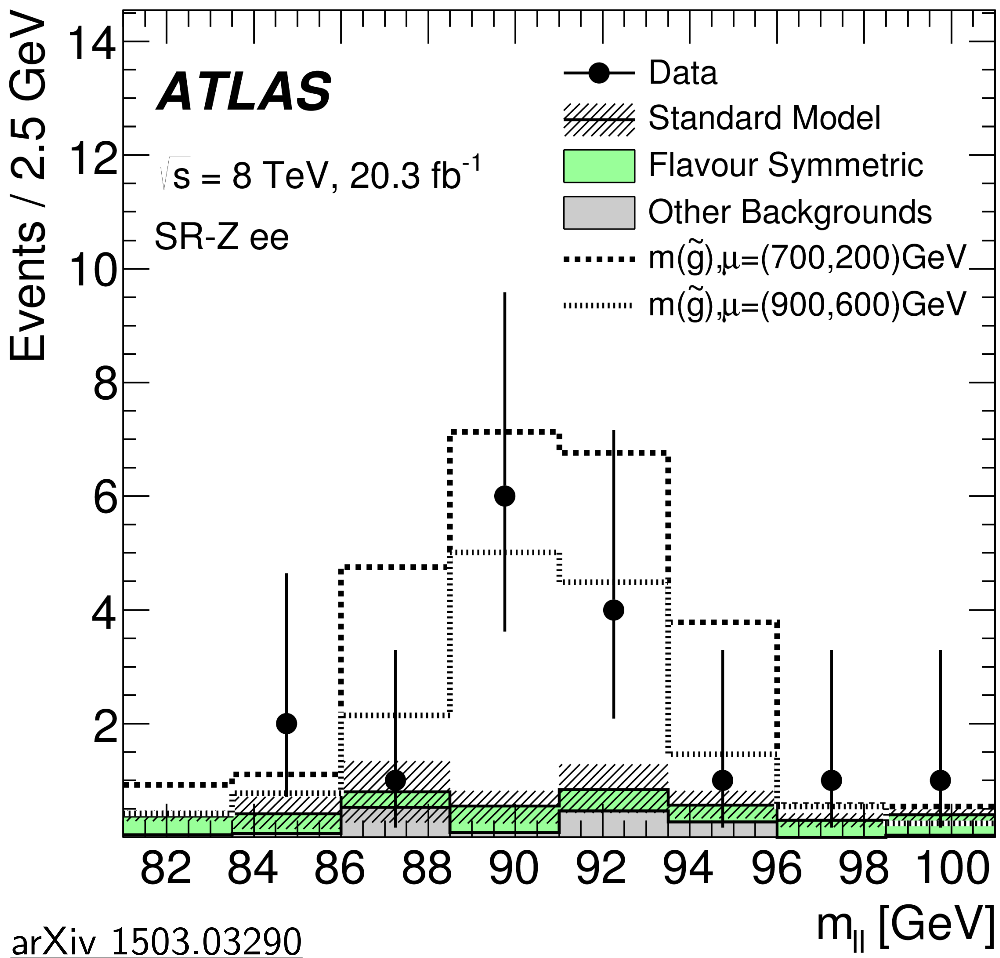
$m(\widetilde{g})$ excluded up to 1.2 TeV for $m(\widetilde{\chi}_1^0) < 600$ GeV

Z + E_T^{miss} → 2 leptons

- Z boson produced in SUSY cascade → decaying leptonically (electron / muon)

8 TeV Run 1

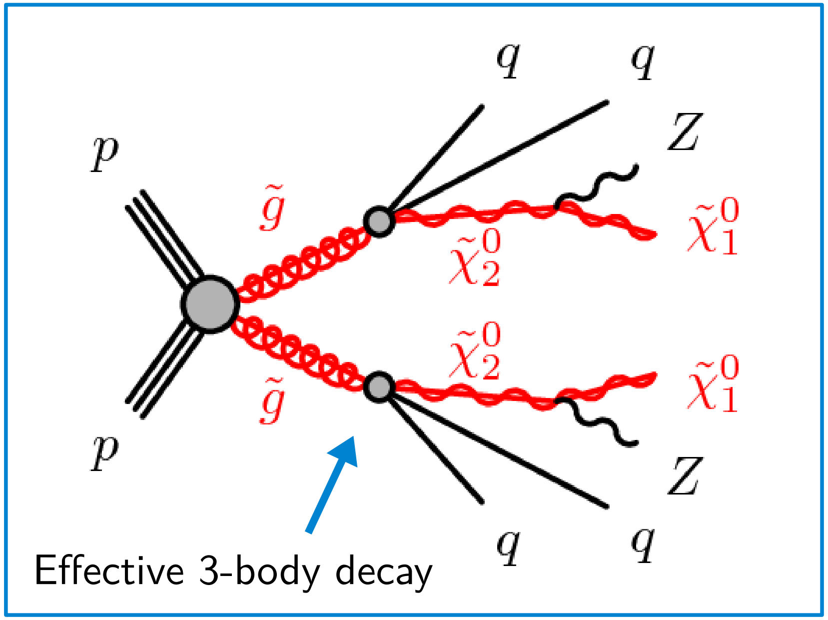
- 3.0 (1.7) σ excess in the ee (μμ) channel



arXiv 1503.03290

13 TeV Run 2

- Decay $\tilde{g} \rightarrow \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0$
- All other sparticles decoupled

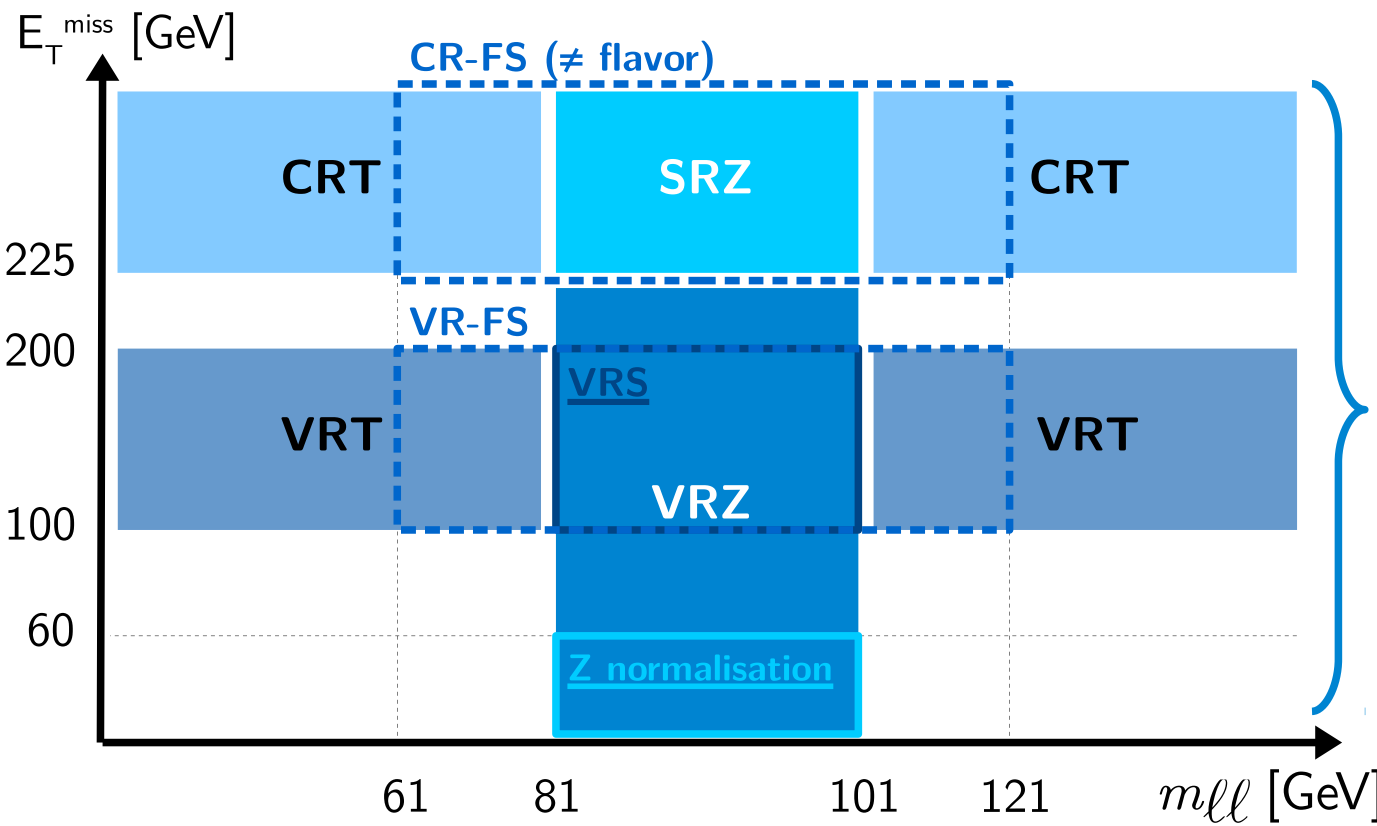


- Different object definitions Run 2

(new tracking layer, new muon overlap removal)

$Z + E_T^{miss} \rightarrow$ 2 leptons

- Events in SR ≥ 2 leptons, leading pair = same flavor opposite sign (SFOS): $e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$



- leading e/μ: p_T > 50 GeV
- subleading e/μ: p_T > 25 GeV
- ≥ 2 jets
- High transverse sum H_T
- Azimutal angle either jets $\Delta\phi(\mathrm{jet}_{1,2}, \boldsymbol{p}_T^{\mathrm{miss}})$ > 0.04

+ 2 VRs with 3ℓ

+ 1 VR with 4ℓ

Backgrounds in SR

- 60% "flavor-symmetric" [$t\bar{t}$, WW, Wt, $Z \rightarrow \tau\tau$]: "flavor-symmetry" method
  → $N_{ee/\mu\mu}$ estimated from data events in eμ control sample (≠ flavor) CR-FS
- 30% WZ/ZZ + rare top processes → MC estimated
- Z/γ*+jets: peaks in Z window → data driven method using γ+jets events

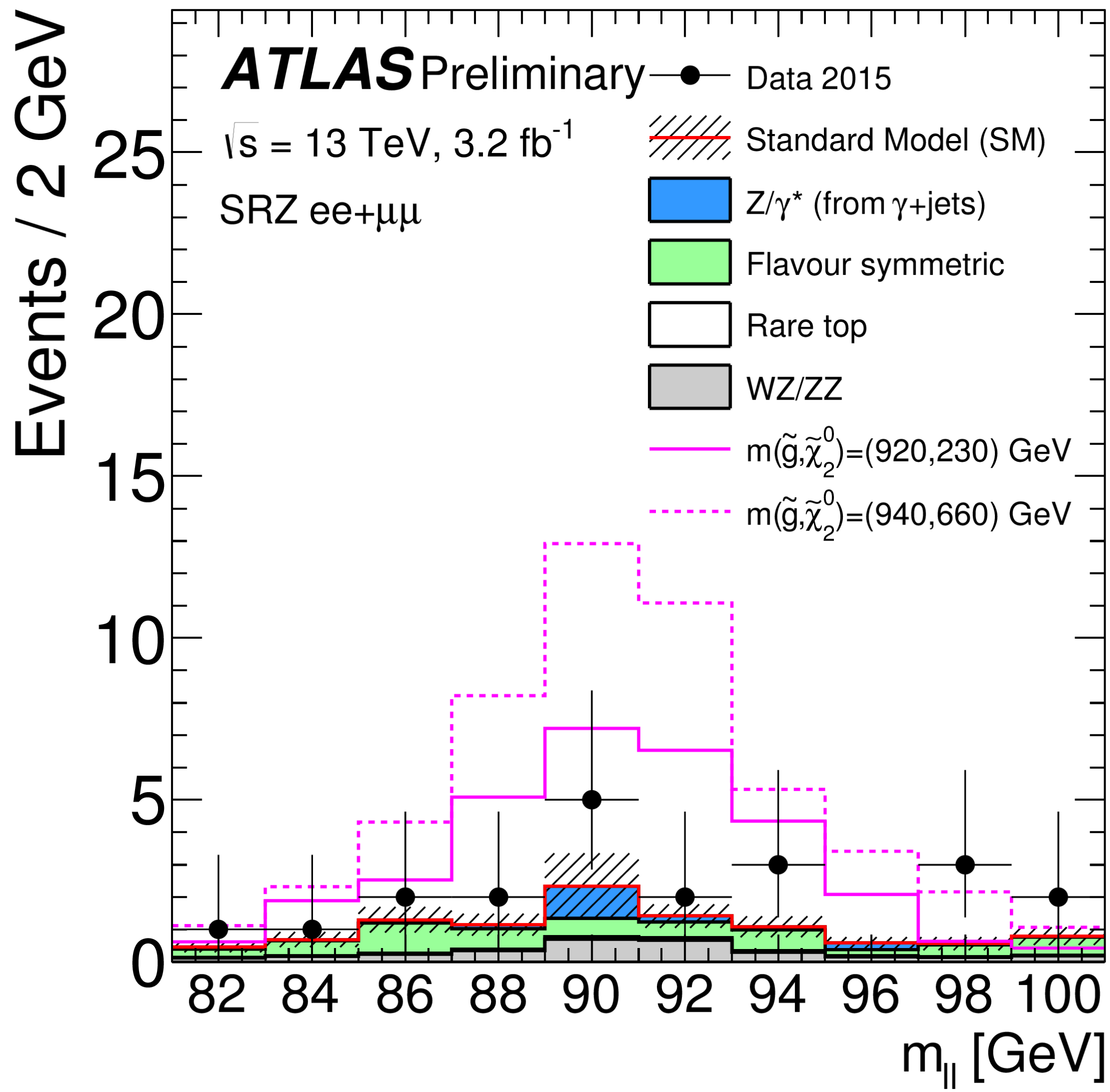
$Z + E_T^{miss} \rightarrow 2$ leptons

Results with 3.2 fb^{-1}

	SRZ
Observed events	21
Total expected background events	10.3 ± 2.3
Flavour symmetric ($t\bar{t}$, Wt, WW and $Z \rightarrow \tau\tau$)	5.1 ± 2.0
WZ/ZZ events	2.9 ± 0.8
Z/γ^* + jets events	1.9 ± 0.8
Rare top events	0.4 ± 0.1
p-value	0.013
Significance	2.2
Observed (Expected) S^{95}	$20.0\ (10.2^{+4.4}_{-3.0})$

- Predicted background = 10.3 ± 2.3
- Observed 21 events:
  - 10 data events in ee channel
  - 11 data events in $\mu\mu$ channel

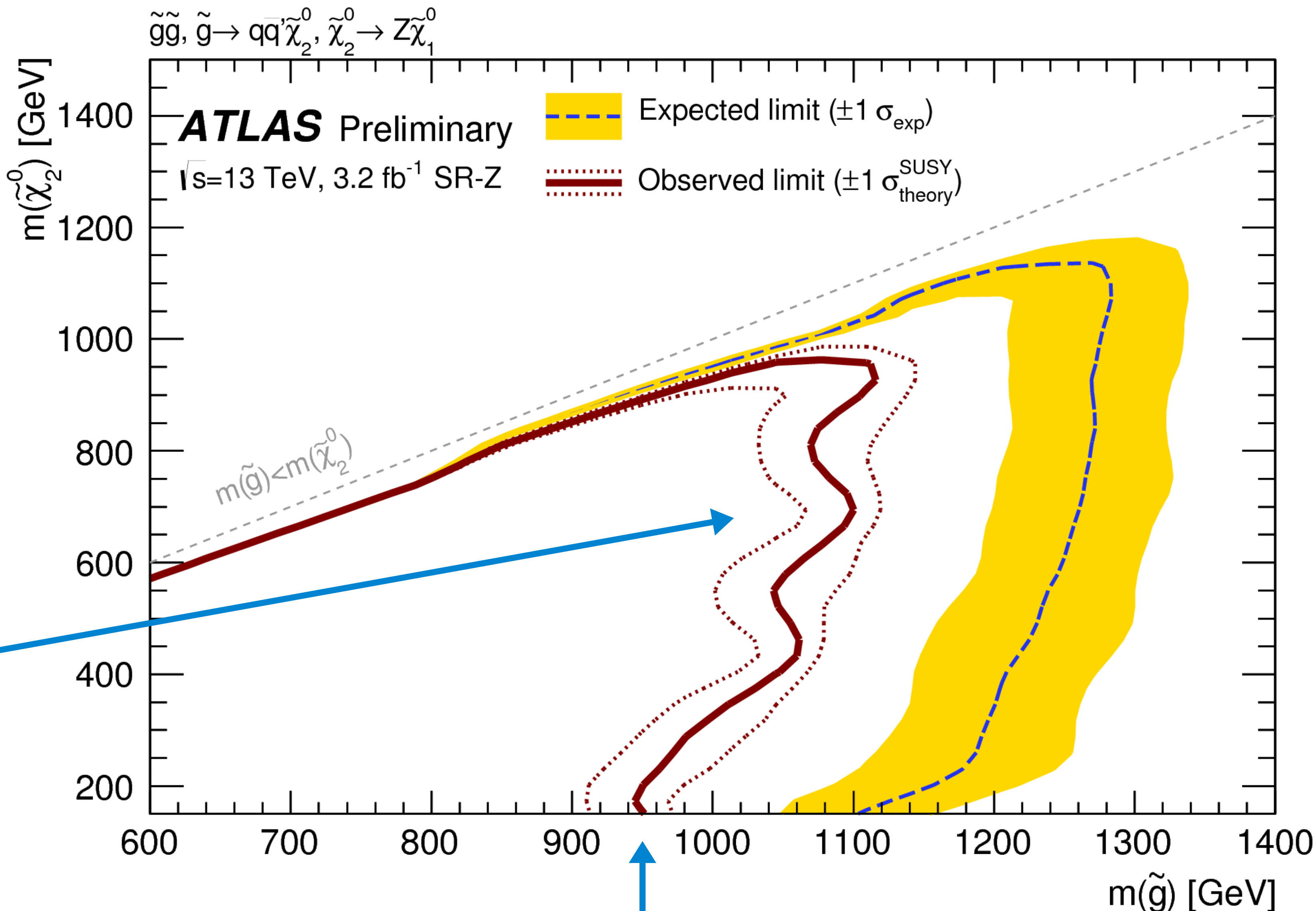
- Local significance in SRZ = $2.2\ \sigma$



More data needed!

Z + E_T^{miss} → 2 leptons

Exclusion limits at 95% CL



Gluino masses excluded up to **1.1 TeV** for $m(\widetilde{\chi}_2^0) \approx 700$ GeV

in simplified model $\widetilde{g} \rightarrow \widetilde{\chi}_2^0 \rightarrow \widetilde{\chi}_1^0$

impact of systematic uncertainties on signal cross section on observed limit ≈ 40 GeV

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Summary

- 3 searches for **supersymmetry** with the **ATLAS** detector using **13 TeV data , 3.2 fb^{-1}**

Gluino pair $\rightarrow$ 1 lepton

- Direct gluino pair production
- $\neq$ mass splittings $\rightarrow$ 6 SRs
- Local 2.5 σ excess in 1 SR
- Large mass splitting:

Gluinos excluded $\rightarrow$ 1.6 TeV

- Compressed spectra:

LSP excluded $\rightarrow$ 870 GeV

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Same-sign $2\ell + 3\ell$

- Direct pair production of gluino & sbottom
- 4 overlapping SRs
- For light LSP:

Gluinos excl. $\rightarrow$ 1.1 – 1.6 TeV

Sbottom excl. $\rightarrow$ 525 GeV

- For gluino $\approx$ 1 TeV:

LSP excl. $\rightarrow$ 550 – 775 GeV

- For sbottom $\approx$ 540 GeV:

LSP excl. $\rightarrow$ 135 GeV

ATLAS-CONF-2015-078

Z + E_T^{miss} $\rightarrow$ 2 leptons

- Z boson produced through $\tilde{g} \rightarrow \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0$
- Data-driven methods cross-checked with MC
- Excess of 2.2 σ in SR
- Simplified model:

Gluinos excl. $\rightarrow$ 1.1 TeV

For $\tilde{\chi}_2^0$ masses $\approx$ 700 GeV

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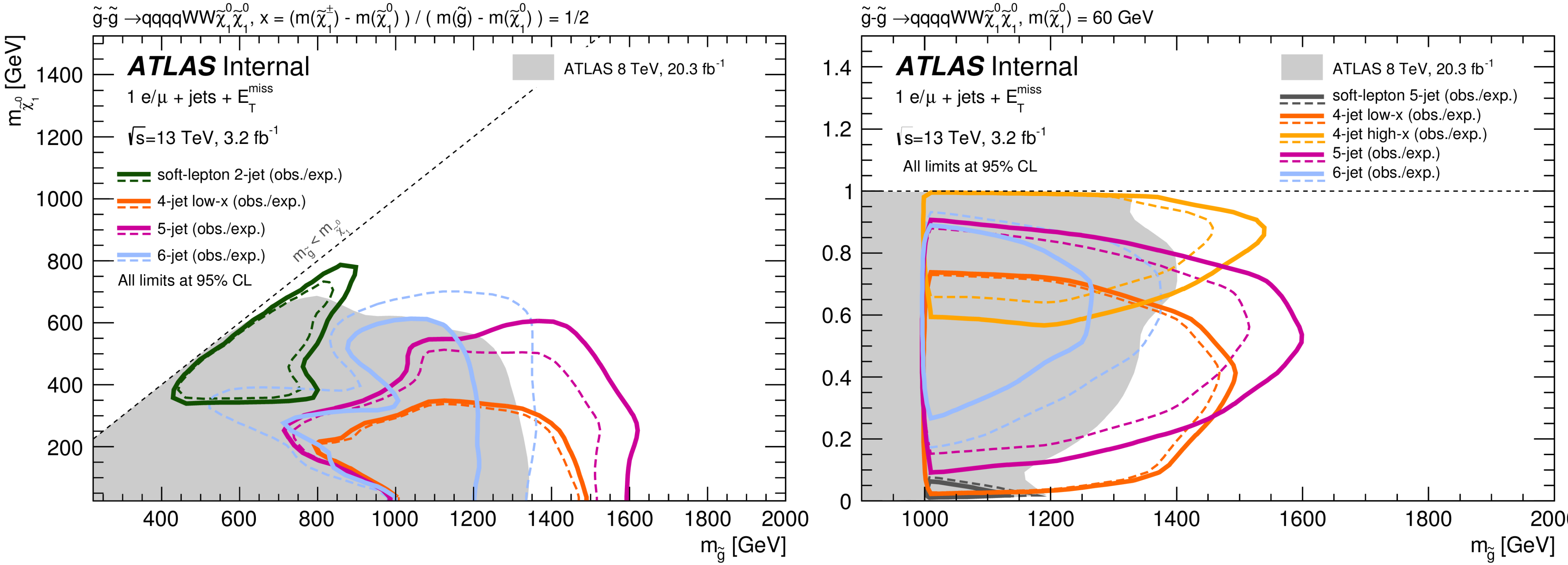
To be continued with thicker data...

BACKUP SLIDES

1 lepton + jets + E_T^{miss}



Signal region	$\langle\epsilon\sigma\rangle_{obs}^{95}$[fb]	S_{obs}^{95}	S_{exp}^{95}	CL_b	$p(s=0)$
Hard-lepton					
4-jet low-x	1.18	3.9	$4.1^{+1.6}_{-1.0}$	0.45	0.50
4-jet high-x	0.83	2.8	$3.0^{+1.4}_{-0.2}$	0.27	0.50
5-jet	0.84	2.8	$3.5^{+1.4}_{-0.7}$	0.18	0.50
6-jet	3.84	12.7	$6.5^{+2.6}_{-1.5}$	0.97	0.02
Soft-lepton					
2-jet	1.27	4.2	$5.4^{+2.1}_{-1.5}$	0.22	0.50
5-jet	2.78	9.2	$8.1^{+3.1}_{-2.0}$	0.67	0.34

Same sign dileptons + 3 leptons + E_T^{miss}

Table 5: The number of observed data events and expected background contributions in the signal regions. The p-value of the observed events for the background-only hypothesis is denoted by $p(s = 0)$. The "Rare" category contains the contributions from $t\bar{t}t\bar{t}$, $t\bar{t}t$ and $t\bar{t}WW$ production. Background categories shown as "–" denote that they cannot contribute to a given region (charge flips or $W^{\pm}W^{\pm}jj$ in 3-lepton regions). The individual uncertainties can be correlated and therefore do not necessarily add up in quadrature to the total systematic uncertainty.

	SR0b3j	SR0b5j	SR1b	SR3b
Observed events	3	3	7	1
Total bkg events	2.4 ± 0.7	0.98 ± 0.32	4.3 ± 1.0	0.78 ± 0.24
$p(s = 0)$	0.33	0.06	0.12	0.36
Fake/non-prompt leptons	< 0.2	$0.04^{+0.17}_{-0.04}$	0.8 ± 0.8	0.12 ± 0.16
Charge flip	–	0.02 ± 0.01	0.60 ± 0.12	0.19 ± 0.06
$t\bar{t}W$, $t\bar{t}Z$	0.13 ± 0.06	0.11 ± 0.06	2.0 ± 0.7	0.21 ± 0.09
WZ	1.5 ± 0.5	0.61 ± 0.25	0.17 ± 0.09	< 0.02
$W^{\pm}W^{\pm}jj$	–	0.11 ± 0.05	0.03 ± 0.01	< 0.01
ZZ	0.6 ± 0.4	< 0.14	< 0.03	< 0.03
Triboson	0.09 ± 0.05	0.02 ± 0.01	0.02 ± 0.01	< 0.01
Rare	0.05 ± 0.04	0.05 ± 0.04	0.7 ± 0.4	0.26 ± 0.14

Table 6: Signal model-independent upper limits on the visible signal cross-section ($\sigma_{\mathrm{vis}} = \sigma_{\mathrm{prod}} \times A \times \epsilon$) and on the number of BSM events (N_{BSM}) in the four SRs. The numbers (in parentheses) give the observed (expected) 95% CL upper limits. Calculations are performed with pseudo-experiments. The $\pm 1\sigma$ variations on the expected limit due to the statistical and systematic uncertainties on the background prediction are also shown.

	SR0b3j	SR0b5j	SR1b	SR3b
$\sigma_{\mathrm{vis}}^{\mathrm{obs}}$ [fb]	1.7	2.0	2.8	1.2
$N_{\mathrm{BSM}}^{\mathrm{obs}}$ ($N_{\mathrm{BSM}}^{\mathrm{exp}}$)	5.5 ($4.6^{+2.1}_{-0.8}$)	6.3 ($3.6^{+1.4}_{-1.1}$)	8.9 ($5.8^{+2.6}_{-1.5}$)	3.7 ($3.5^{+1.3}_{-0.3}$)