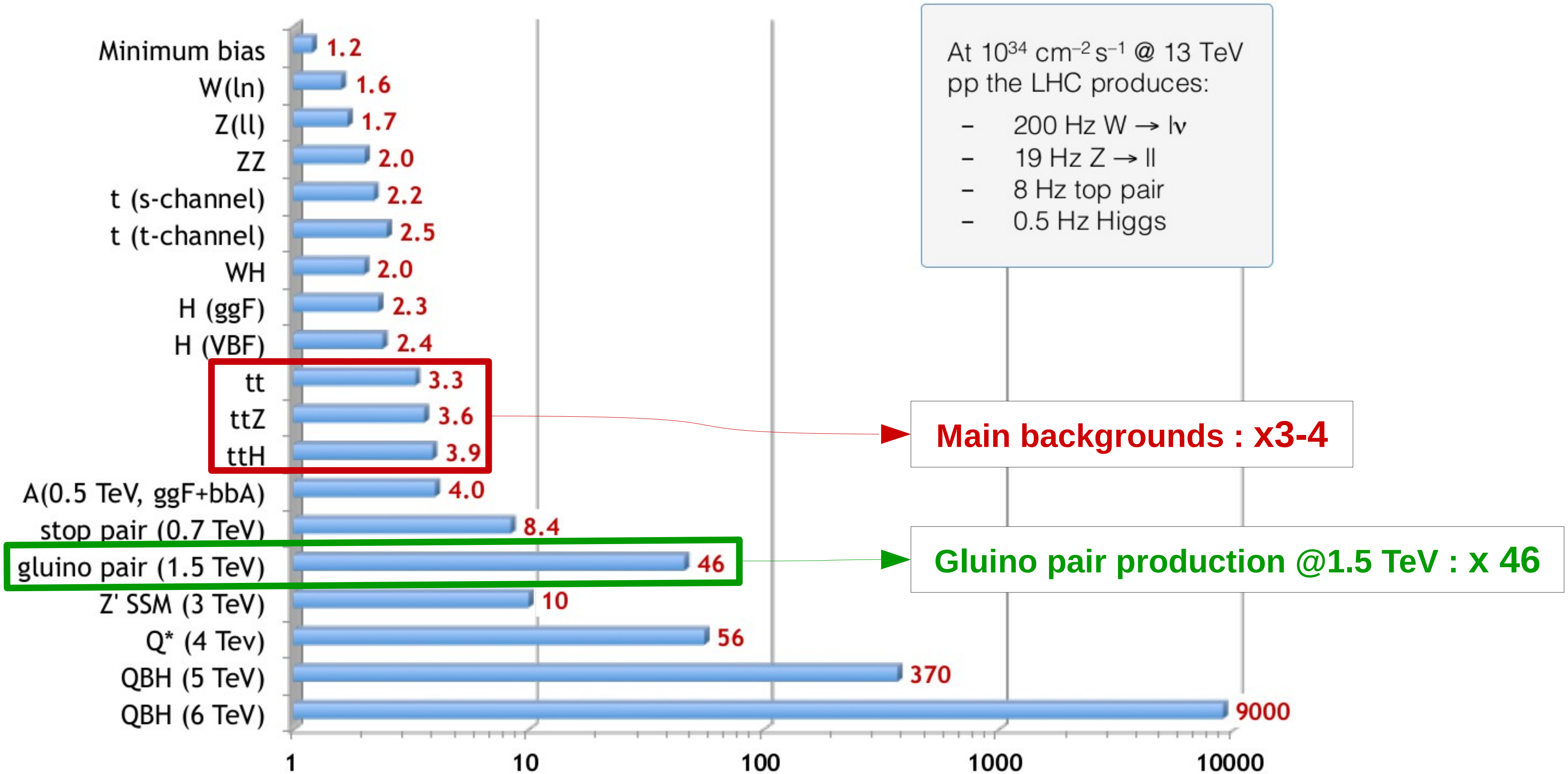
Search for squark and gluino production in leptonic final states with the ATLAS detector

Sebastien Kahn on behalf of the ***ATLAS*** collaboration
CPPM / IN2P3 – Aix-Marseille Université

Workshop on Deep-Inelastic Scattering and related
DIS 2016

SUSY search @13 TeV

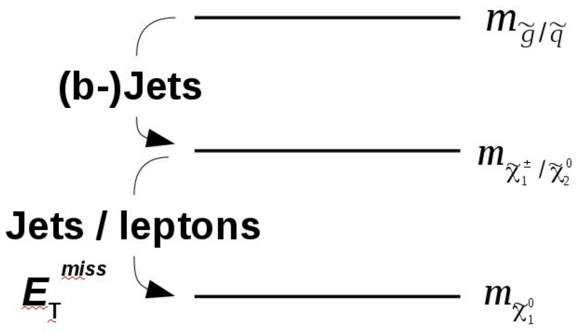
- **8 to 13 TeV cross section increase**



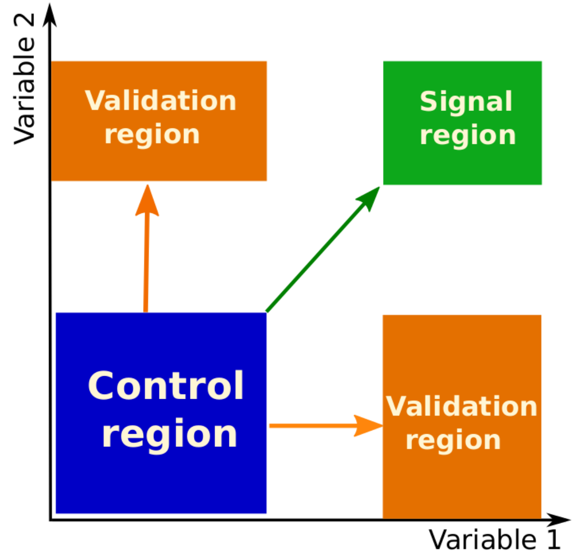
Possible to discover strongly produced SUSY beyond Run-1 limits with the 2015 data (3.2 fb^{-1})

Squarks & gluino searches
General presentation

- **General discriminant variables**
  - **Coloured sparticles**
    → N_{jets} / $N_{\text{b-jets}}$
  - **R-parity conserving models**
    Massive non-interacting particle
    → E_T^{miss}
  - **High gluino / squark masses**
    → $m_{\text{eff}} = \Sigma\, p_T^{\,lep,\,jets} + E_T^{miss}$



- **Background estimates**
  - **Irreducible background :**
    - Predictions checked in **Validation Regions**
    - If dominant, normalized in **Control Regions**
  - **Experimental Background :**
    - Fake lepton / electron charge mis-ID / fake E_T^{miss}
    - **Data driven** estimates



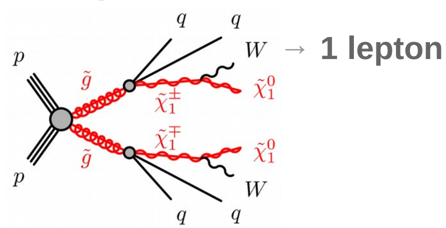
Squarks & gluino searches with leptons

- **0 leptons :** Covered by Geert Jan Besjes (previous talk)

Larger branching ratio ← → **Less SM background**

1 lepton (l) + E_T^{miss} + *jets*

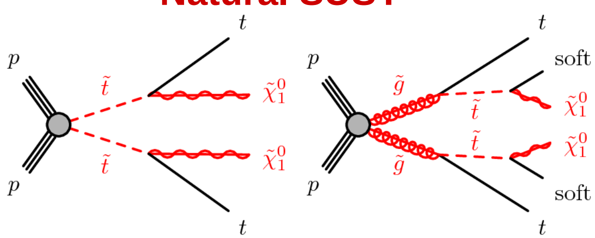
- **Gluino production**



ATLAS-CONF-2015-076

- **Stop production NEW**

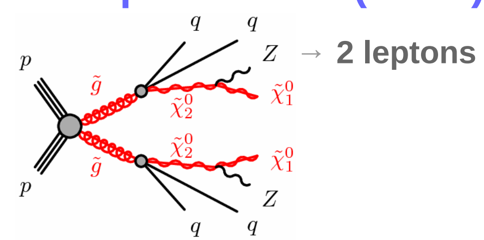
Natural SUSY



ATLAS-CONF-2016-007

2 leptons + E_T^{miss}

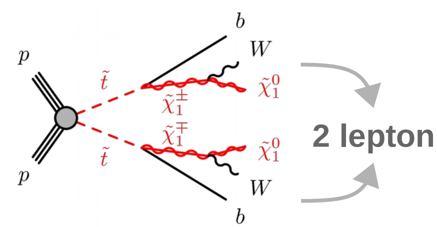
- **Gluino production ($Z \rightarrow ll$)**



ATLAS-CONF-2015-082

- **Stop production NEW**

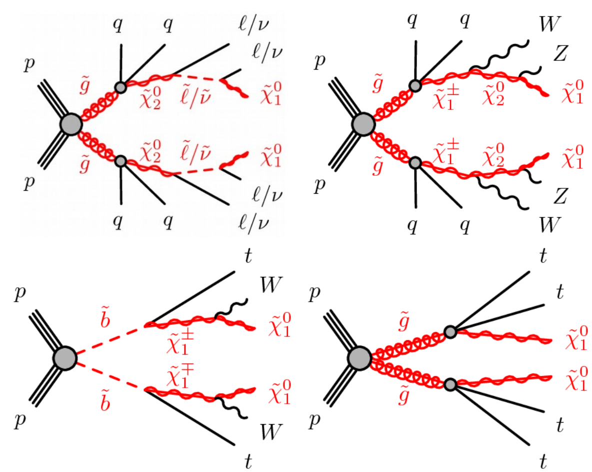
Natural SUSY



ATLAS-CONF-2016-009

2-l same sign or 3-l + *jets*

- **Gluino/sbottom production**



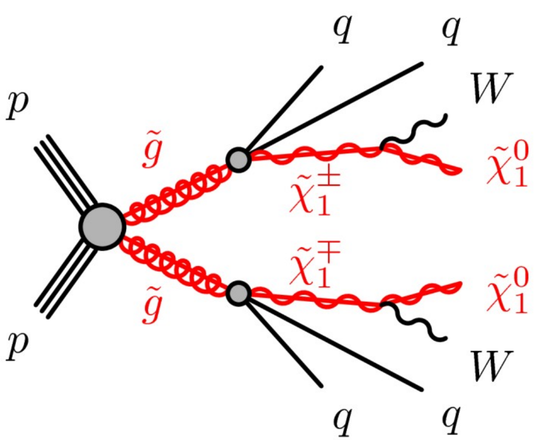
SUSY-2015-09
submitted to EPJ C

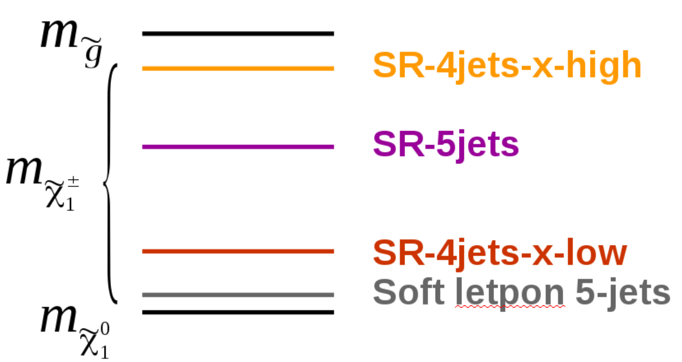
The complementarity of the final states allows to cover a large spectra of SUSY models

1 lepton + E_T^{miss} + jets
Signal regions

- **Two main channels are considered :**
  - **Soft lepton :** 6-7 < p_T^{lep} < 35 GeV
    - **Soft lepton 2-jets**
      → Very small $\Delta m(\tilde{g},\tilde{\chi}^0_1)$
    - **Soft lepton 5-jets**
      → Very small $\Delta m(\tilde{\chi}_1^{\pm},\tilde{\chi}^0_1)$
  - **Hard lepton :** p_T^{lep} > 35 GeV
    - **SR 6-jets**
      → Small $\Delta m(\tilde{g},\tilde{\chi}^0_1)$
    - **SR 4-jets x-low**
    - **SR 5-jets**
    - **SR 4-jets x-high**

    → Large gluino masses
    All $m(\chi_1^{\pm})$ covered
    by the three SR



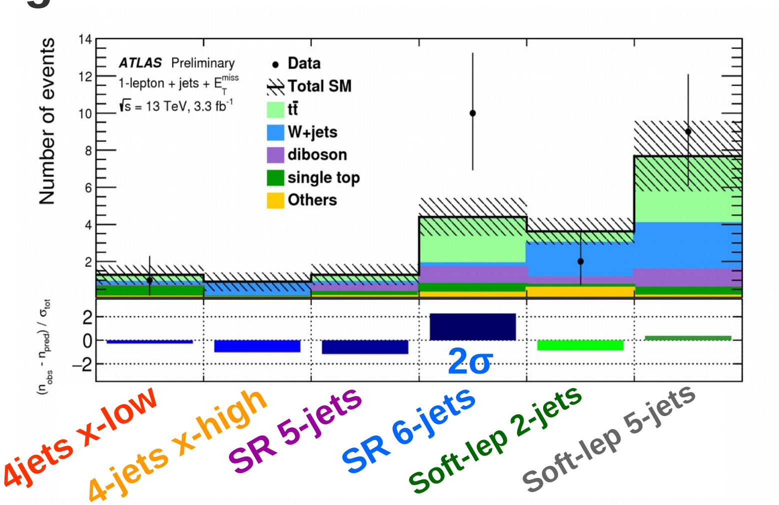


- **Main backgrounds :** $t\bar{t}$, W+jets
  MC normalized with Control Regions

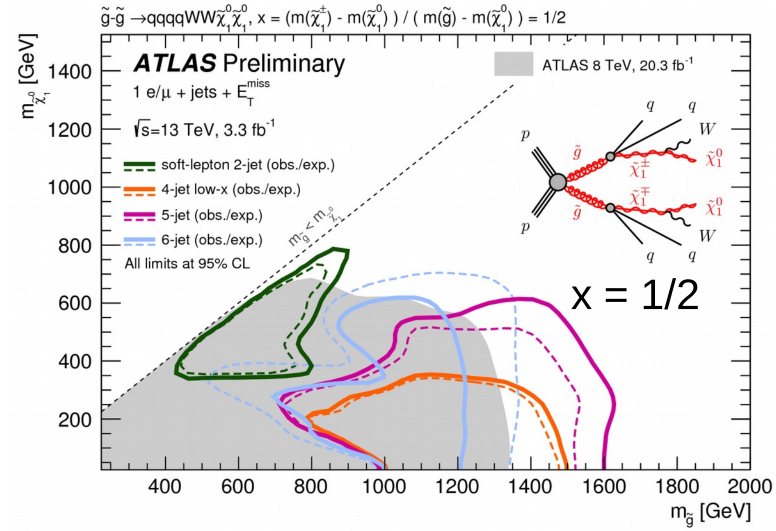
A complete set of six Signal Regions allows to cover all masses configurations

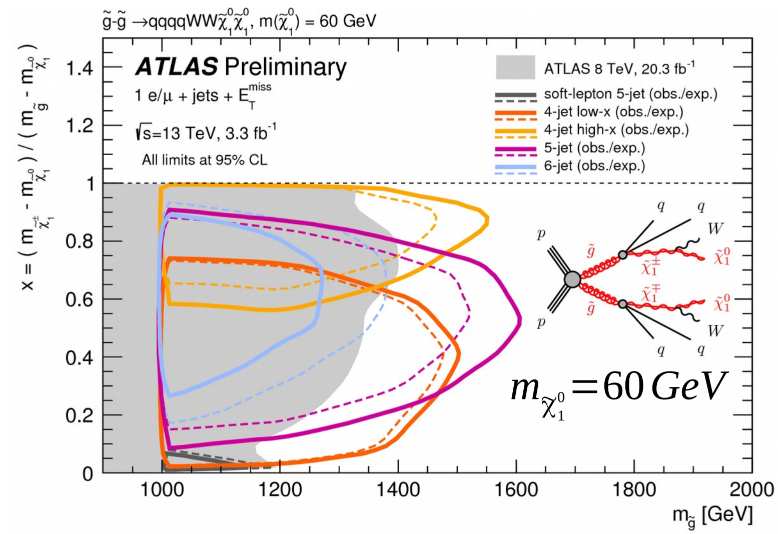
1 lepton + E_T^{miss} + jets Results & Interpretation

- **No significant excess observed :**



- **Exclusion set using simplified Models**
  - **With** $x = \frac{m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}}{m_{\tilde{g}} - m_{\tilde{\chi}_1^0}} = \frac{1}{2}$
  - **With** $m_{\tilde{\chi}_1^0} = 60\,GeV$



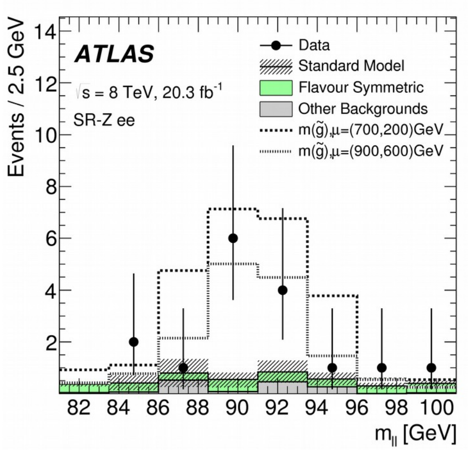


Improvement of the exclusion limits with gluino excluded up to 1.6 TeV

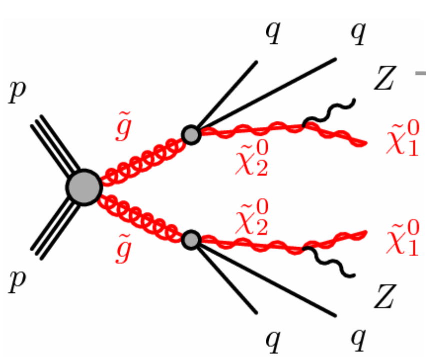
$Z \rightarrow ll + E_T^{miss}$ + *jets*
SR & Bkg estimation

Signal Region

- **Excess in Run-1** SUSY-2014-10
  - 3.0(1.7) σ in the ee(μμ) channel
  - Not observed by CMS



- **Run-2 strategy :** Check the excess using the Run-1 SR



- e^+e^- / $\mu^+\mu^-$ pairs with m_{ll}[81-101] GeV
- E_T^{miss} > 225 GeV
- H_T > 600 GeV
- ≥ 2 jets

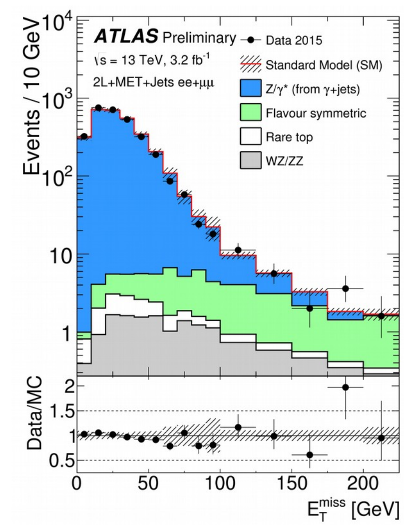
Background estimation

Irreducible

- **Main background (~60%) :** flavour symmetric
  - **Sources :** $t\bar{t}$ (70%), WW (20%), tW, $Z \rightarrow \tau\tau$
  - **Estimated using eμ Control Regions** Same definition as Signal Regions except larger m_{ll} window (more stats)

Detector bkg

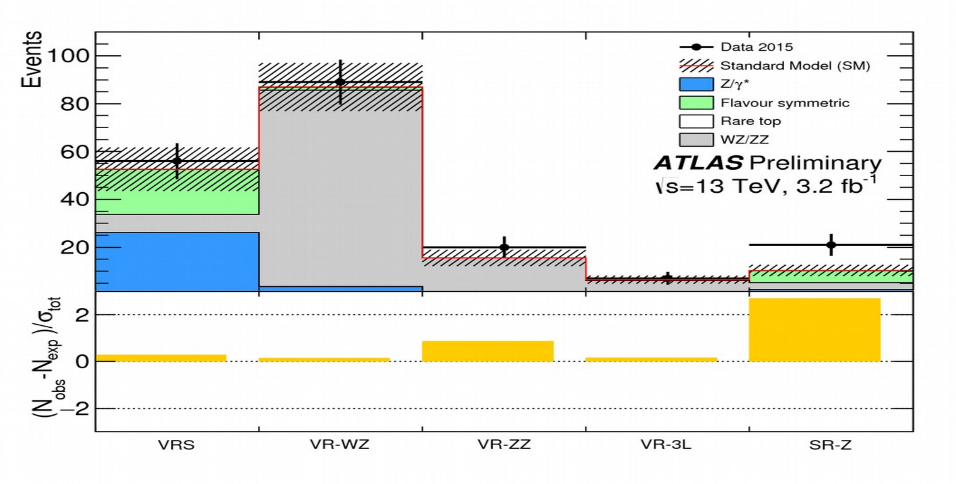
- **Z/γ*+jets bkg (~10%)**
  - **Fake E_T^{miss}** due detector resolution
  - **Data Driven estimate** using E_T^{misss} distribution from γ+jets events

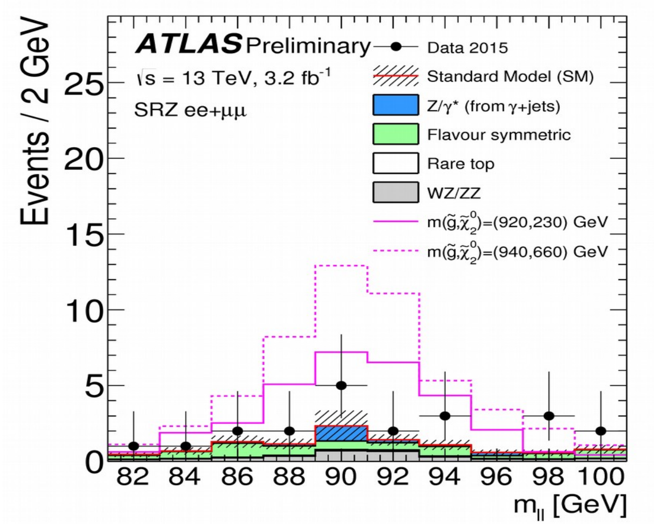


- **Other backgrounds :**
  - MC only (Validation Regions for WZ / ZZ)

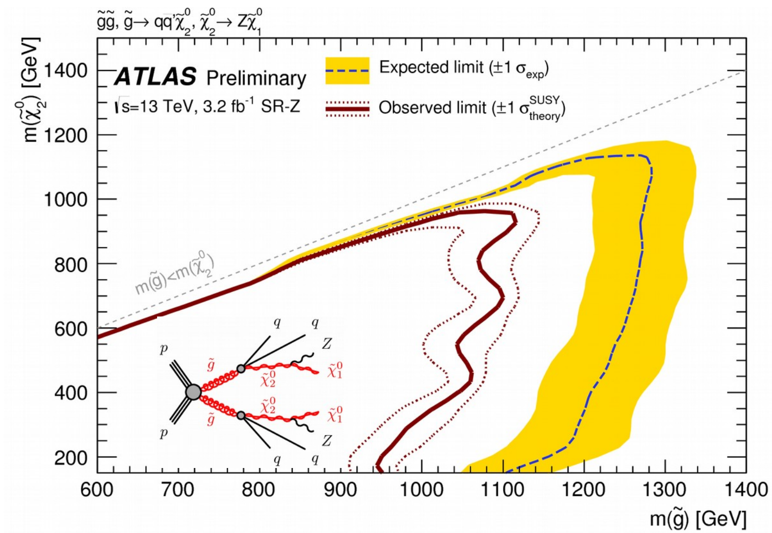
$Z \to ll + E_T^{miss}$ + jets Results & Interpretation

- **Modest 2.2σ deviation** ($N_{ee}/N_{\mu\mu}$ = 10/11)





- **Exclusions set using simplified models**
  - m($\tilde{\chi}^{\circ}_2$) ~ 700 GeV
    → gluino excluded up to 1.1 TeV
  - m($\tilde{\chi}^{\circ}_2$) ~ 200 GeV
    → gluino excluded up to 0.95 TeV
  - Worse limits than expected because of the slight excess



2/ Same sign - 3 leptons
Signal regions

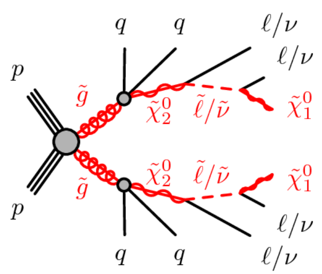
- **Low SM (mostly *VV*, *t$\bar{t}$V*) allow to use loose kinematic requirements**
  - Access to the low $\Delta m(\tilde{\chi}_1^0, \tilde{g})$
  - Sensitivity to a large number of different SUSY processes

Focus on : Cascade decays of light flavour squarks

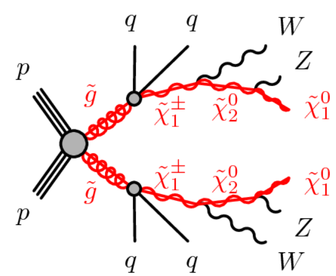
No b-jets

At least 1 b-jet

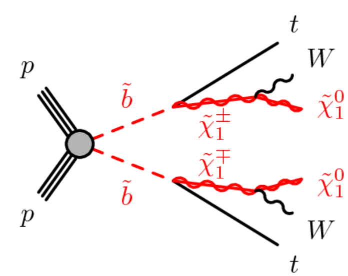
Focus on : Light 3[rd] heavy flavour squarks (natural SUSY)

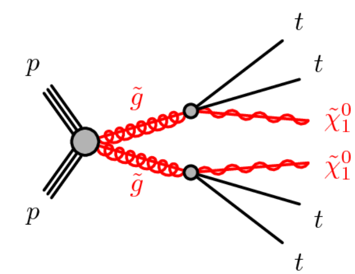


4 leptons



Jets from W/Z





Almost no SM bkg

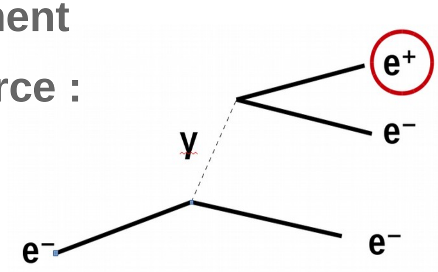
Signal Region	SR0b3j	SR0b5j	SR1b	SR3b
$N_{\mathrm{lep}}^{\mathrm{signal}}$	$\boxed{\geq 3}$	≥ 2	≥ 2	≥ 2
$N_{b-\mathrm{jet}}^{20}$	$= 0$	$= 0$	≥ 1	≥ 3
N_{jet}^{50}	≥ 3	$\boxed{\geq 5}$	≥ 4	$\boxed{-}$
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	≥ 200	≥ 125	≥ 150	$\boxed{\geq 125}$
m_{eff} [GeV]	≥ 550	≥ 650	≥ 550	≥ 650

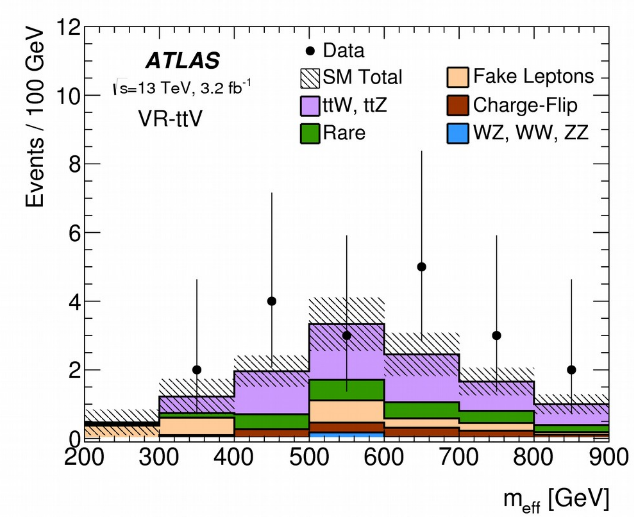
$$m_{\mathrm{eff}} = \sum p_{\mathrm{T}}^{\mathrm{lep}} + p_{\mathrm{T}}^{\mathrm{jets}} + E_{\mathrm{T}}^{\mathrm{miss}}$$

2/ same sign - 3 leptons Background estimation

Detector bkg

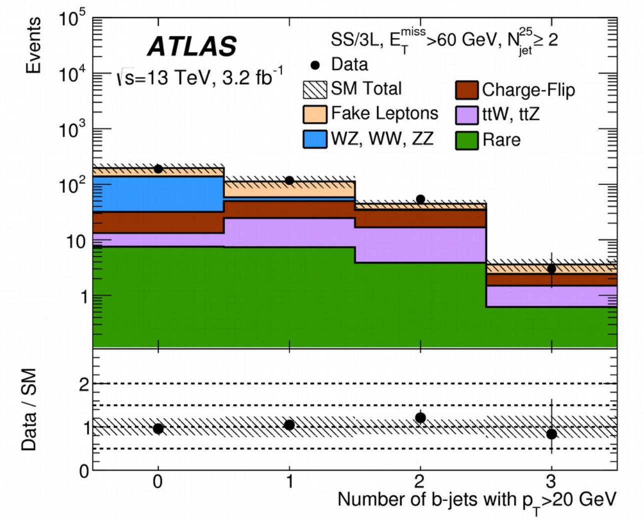
- **Detector background :** Contribution of $t\bar{t}$ events due to
  - **Fake and non-prompt leptons :** light jet mis-ID, b/c quarks decays, γ conversion
    - **Dominant source :** b decays
    - Fully data driven estimate using the dynamic Matrix Method
  - **Electron charge mis-measurement**
    - **Dominant Charge Flip source :** hard brem γ conversion
    - **Data driven estimate :** using Z→ee events





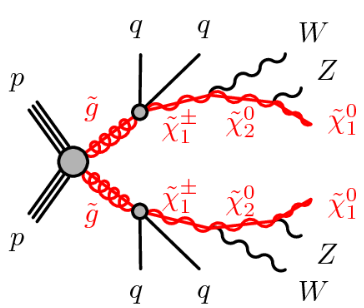
Irreducible

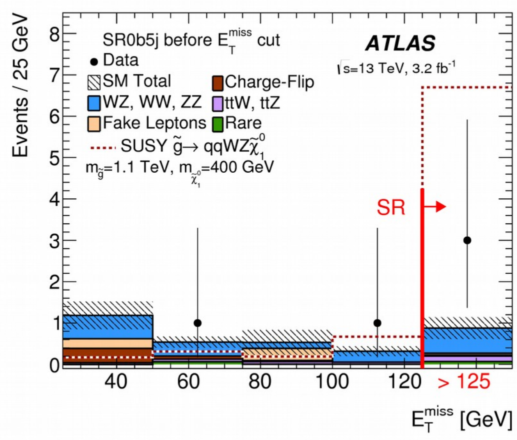
- **Prompt background :** rare processes (*WZ*, $t\bar{t}Z$, $t\bar{t}W$)
  - **MC only**
  - **Validation regions :** dedicated to *WZ*, $t\bar{t}Z$, $t\bar{t}V$



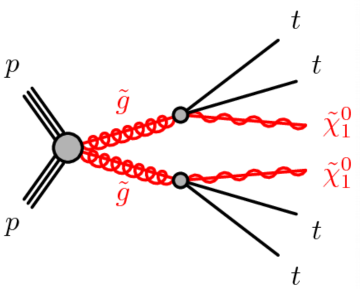
2/ same sign - 3 leptons Results & interpretation

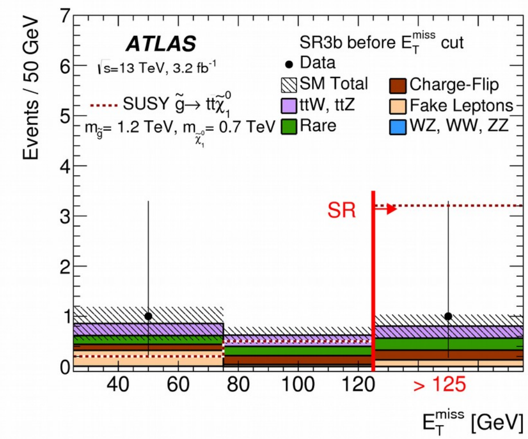
- **0 b-jets / ≥ 5 jets**

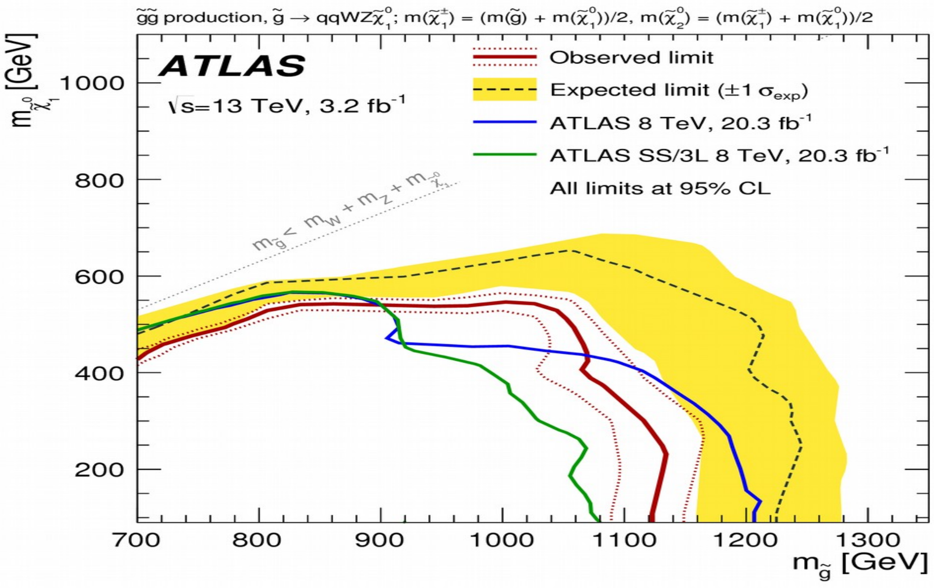


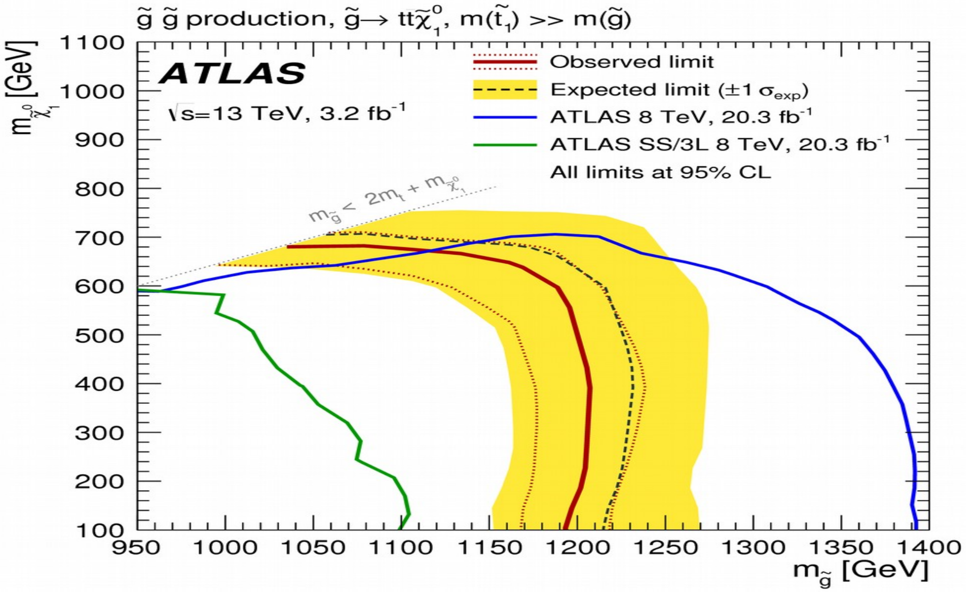


- **At least 3 b-jets**



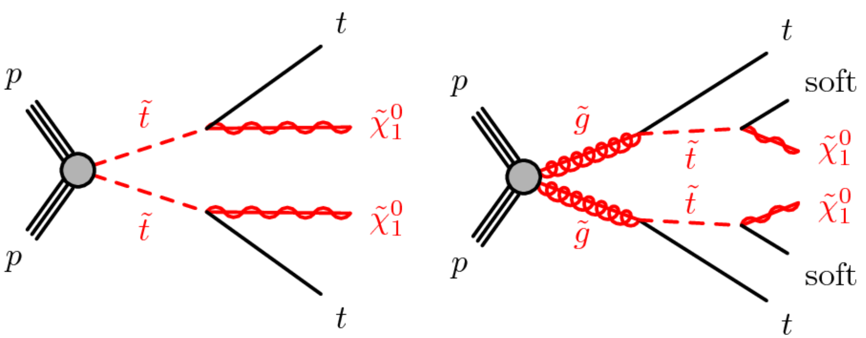




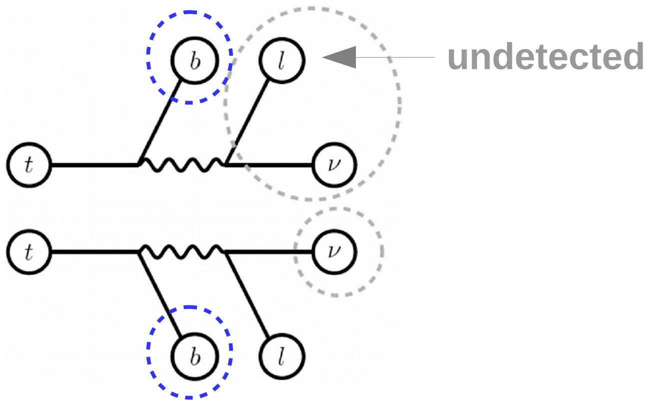


Stop search
1 lepton signal regions

- **Final state close to the one from $t\bar{t}$**
  - **Difficult to extract the signal from bkg**
- **3 Signal Regions with exactly 1 lepton and different E_T^{miss} requirements**
  - **Discrimination against W+jets and $t\bar{t} \rightarrow 1l$**
    - – m_T cut above m_W
    - – At least 1 *b*-jet (for *W*+jet only)
  - **Discrimination against $t\bar{t} \rightarrow 2l$**
    - – At least 4 jets
    - – asymmetric m_{T2}
    - – *topness* based $t\bar{t}$ events χ² fit
  - **Discrimination against multijets**
    - – $H_{T,sig}^{miss}$ based on the sum of the lepton and jet vectors and their resolution
  - **Large radius jets used for boosted W or tops (NEW)**

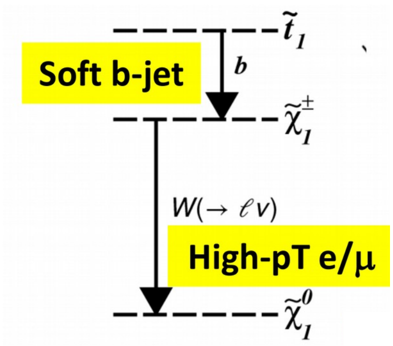


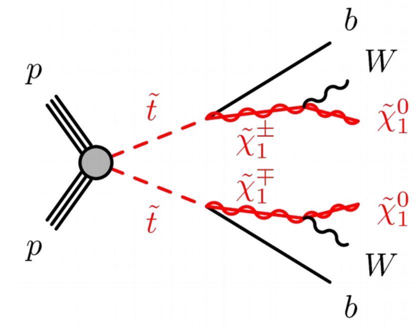
$$am_{T2} = \min_{q_T^{\nu_1+l_1}+q_T^{\nu_2}=p_T^{miss}} \{max[m_T(p_T^{b-jet_1}, q_T^{\nu_1+l_1}), m_T(p_T^{b-jet_2}, q_T^{\nu_2})]\}$$



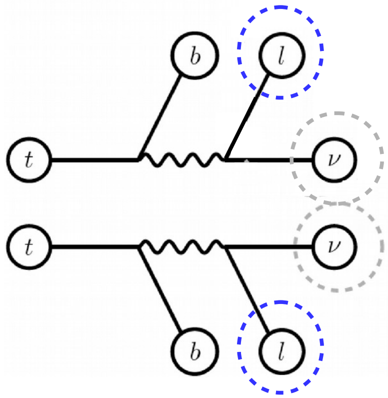
Stop searches
2 leptons Signal regions

- **$\Delta m(\tilde{t}_1,\tilde{\chi}_1^{\pm})$ = 10 GeV**
  → Soft *b*-jets
  - No (b-)jets requirements
- **$\Delta m(\tilde{\chi}_1^{\pm},\tilde{\chi}^0_1)$ >> 1 GeV**
  → 2 boosted leptons & large E_T^{miss}
  - **Discrimination against *WW* and $t\bar{t}$**
    - m_{T2} > 145 GeV
  - **Discrimination against *Z/γ*+jets**
    - $$R1=\frac{E_T^{miss}}{E_T^{miss}+p_T^{l_1}+p_T^{l_2}+p_T^{j_1}+p_T^{j_2}}>0.3$$
  - **Z+jets / ZW background**
    - Z mass veto for same flavour leptons





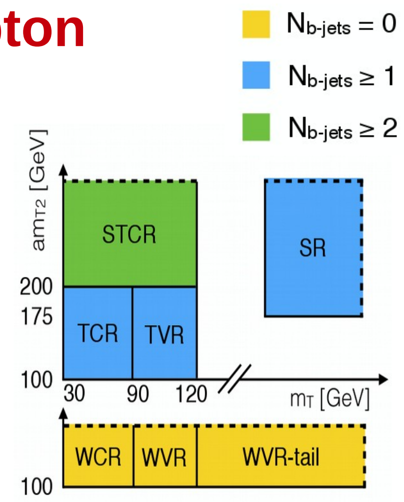
$$m_{T2}=\min_{q_T^{\nu_1}+q_T^{\nu_2}=p_T^{miss}}\{max[m_T(p_T^{l_1},q_T^{\nu_1}),m_T(p_T^{l_2},q_T^{\nu_2})]\}$$



Stop searches background estimation

Stop 1 lepton

- **Main background :** $t\bar{t}$ and W+jets
  - **Estimated using Control Regions** defined reverting the m_T and the am_{T2} cut for different b-jet multiplicities



Irreducible

- **Multijets background**
  - **Due Fake E_T^{miss} and jets mis-identified as leptons**
  - **Data driven estimation :** fake factor Method

Detector bkg

- **Other backgrounds** :
  - MC only

Stop 2 lepton

- **Main background :** VV and $t\bar{t}$
  - **Estimated using Control Regions**
    - **$t\bar{t}$ Control Region :** m_{T2} and R1 (<0.4) on eμ events
    - **VV→$ll\nu\nu$ Control Region :** m_{ll} on ee/μμ events with looser m_{T2}

Irreducible

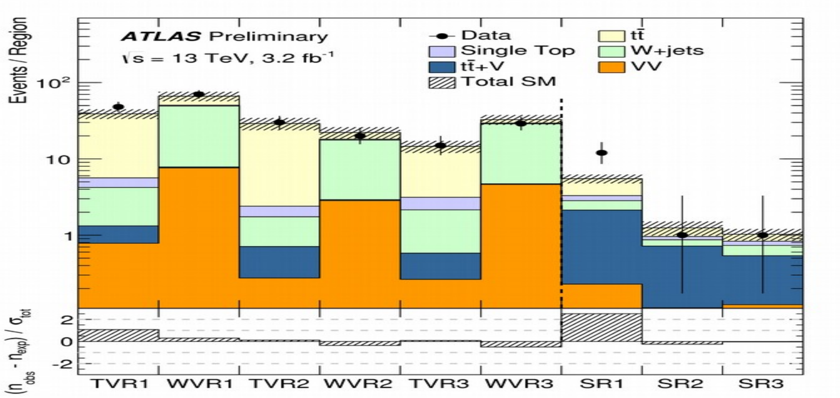
- **Semi-letptonic $t\bar{t}$, single top, W+jets**
  - **Due to fake and non-prompt leptons** light jet mis-ID, b/c quarks decays, γ conversion
  - **Data driven estimate** using the dynamic Matrix Method

Detector bkg

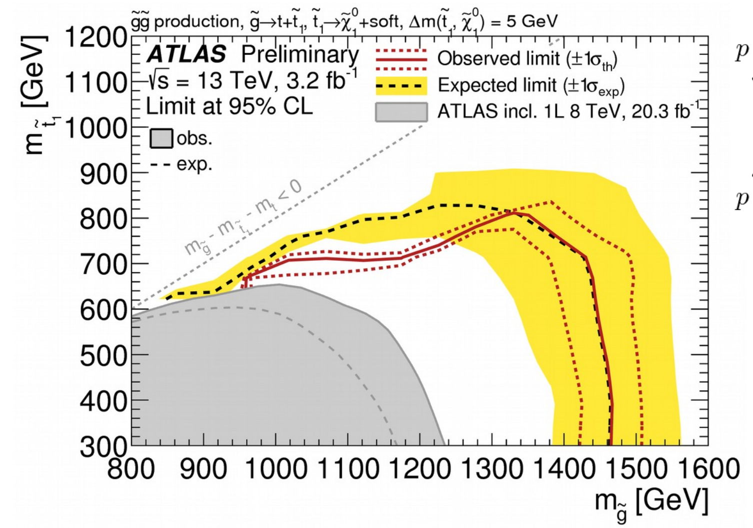
- **Other backgrounds**
  - MC Only

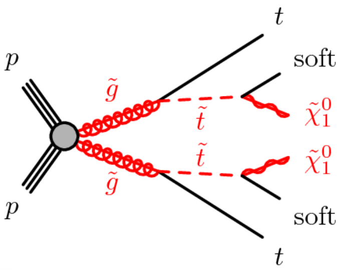
Stop 1 lepton
Results & Interpretation

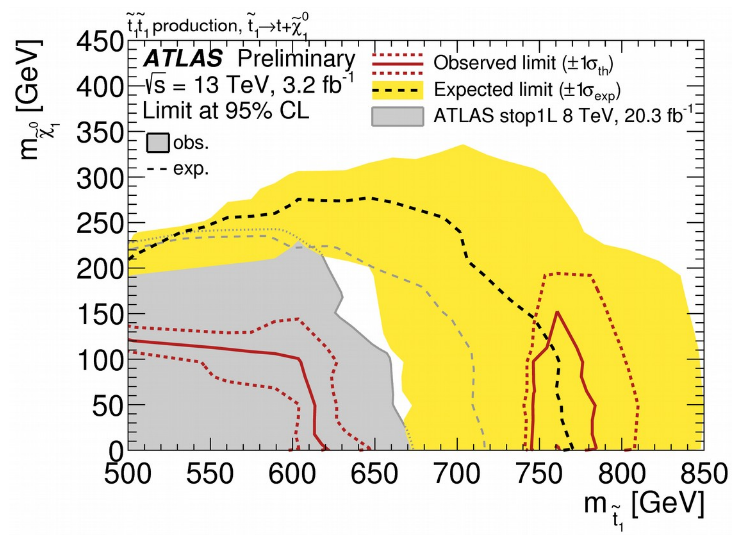
- **No significant excess observed**
  - **Largest deviation : 2.3σ in SR1**

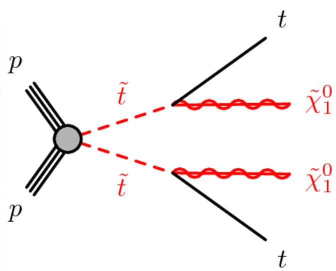


- **Exclusion limits set using simplified models**
  - Gluino decays with small $\Delta m(\tilde{t}_1, \tilde{\chi}^0_1)$
    → **Gluino excluded up to ~1.5 TeV**
  - Stop pair production : excess in SR1
    → **Only exclude a small region at $m(\tilde{t}_1)$ ~ 750 GeV**



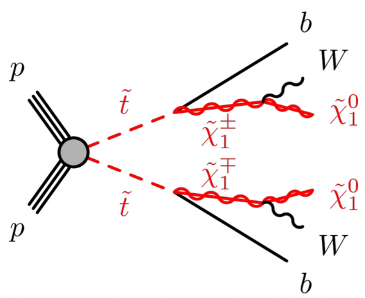


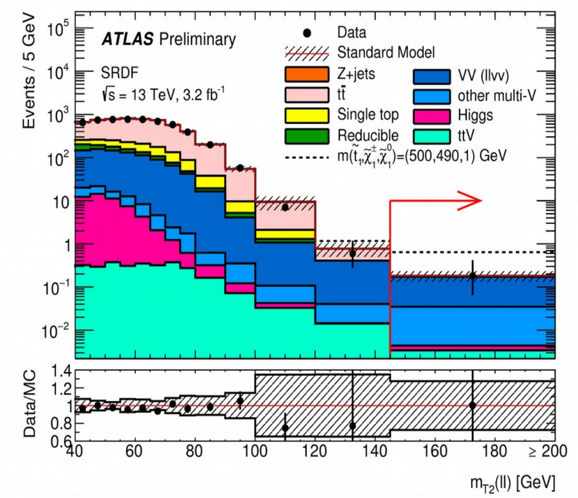


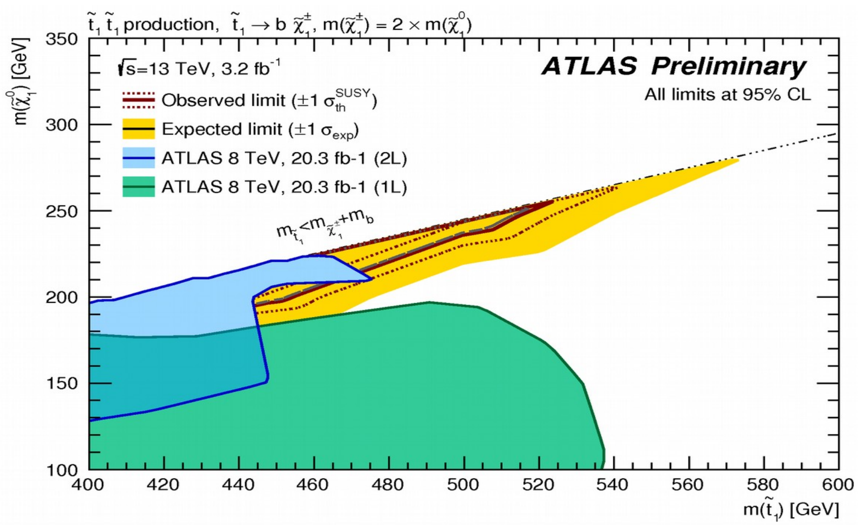


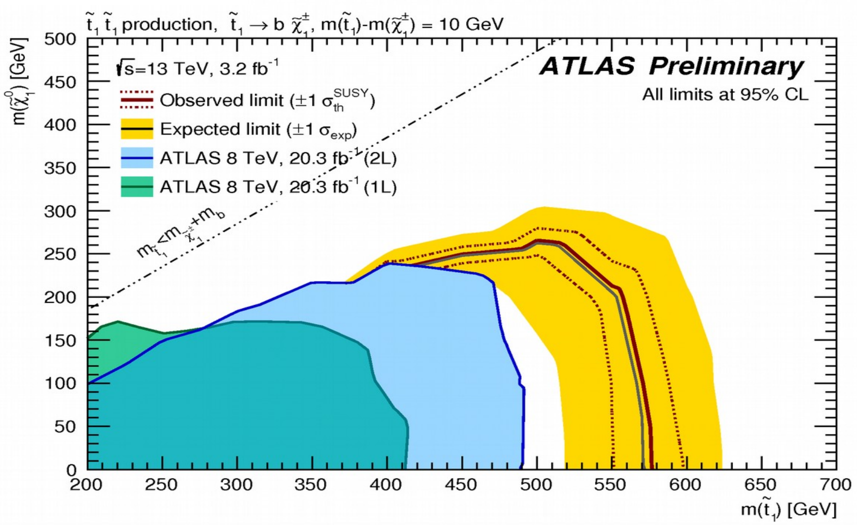
Stop 2 leptons Results & Interpretation

- **No excess in the Signal Regions**
- **Exclusion limits set using simplified models**
  - $\Delta m(\tilde{t}_1,\tilde{\chi}_1^{\pm}) = 10$ GeV
    stop excluded up to 575 GeV
  - $m(\tilde{\chi}_1^{\pm}) = 2 \times m(\tilde{\chi}_1^{0})$
    stop excluded up to 520 GeV at high neutralino masses





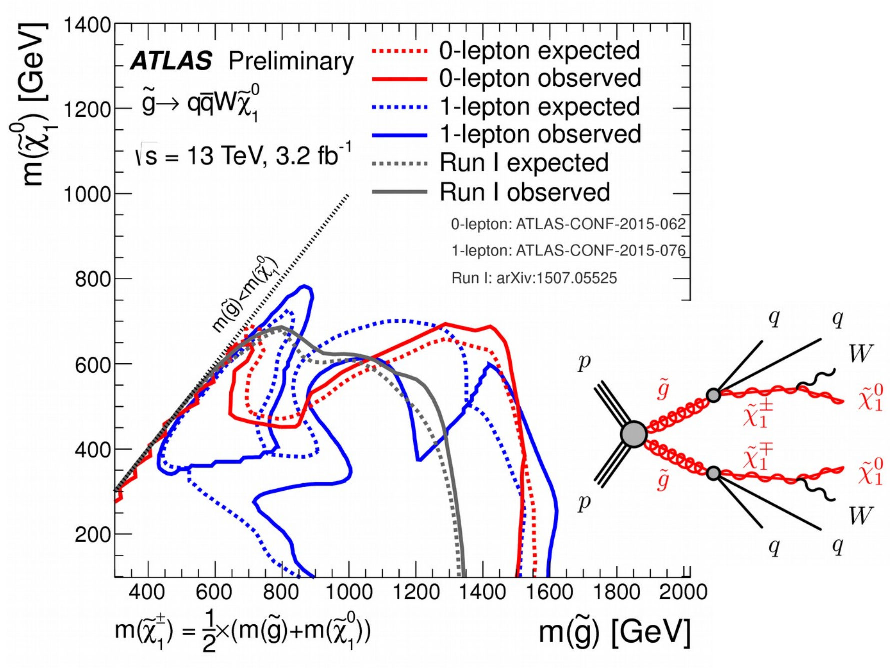


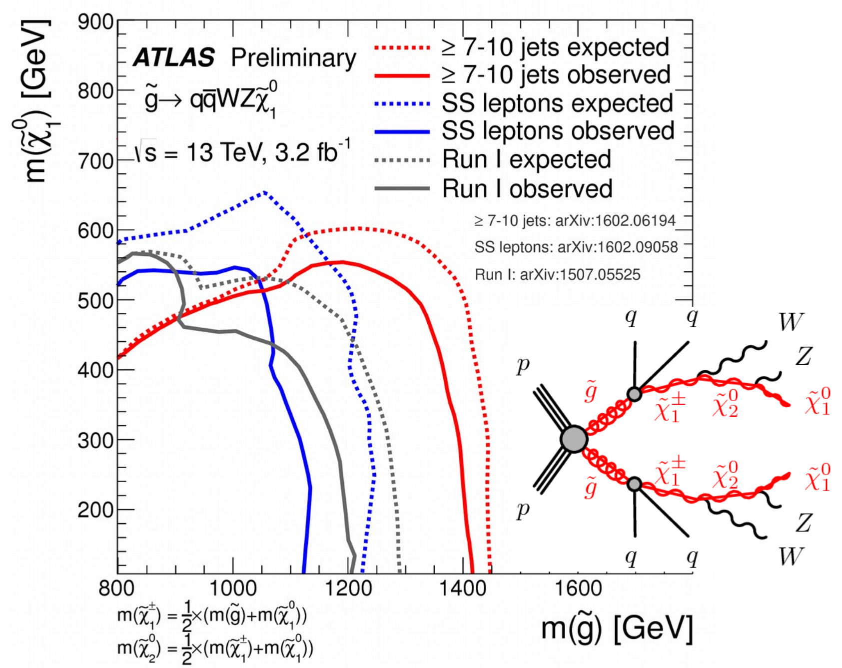


Conclusions

- **No significant excess in search for squarks and gluinos at 13 TeV**
- **Exclusions set beyond Run-1 limits, complementary with the 0 lepton searches**

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults



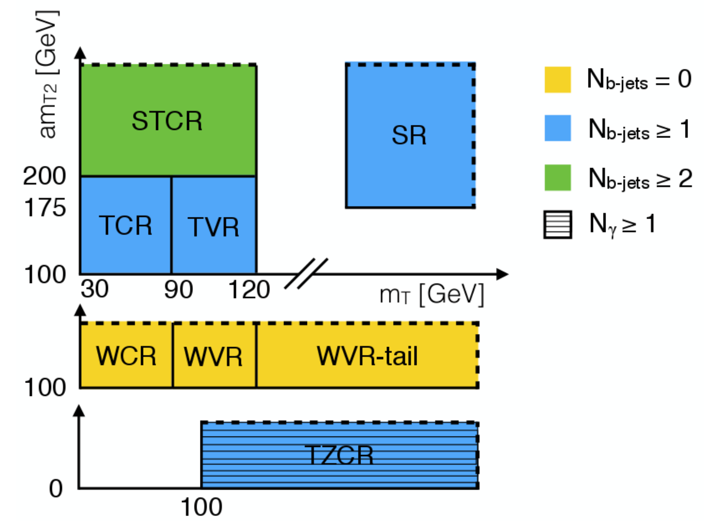


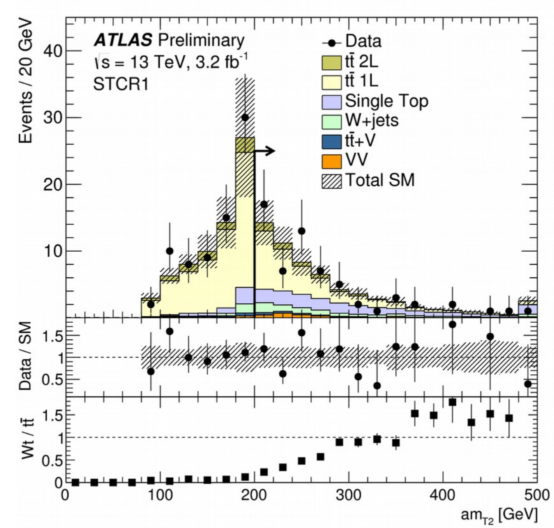
Waiting eagerly for more data!

Auxiliary material

Stop 1L search
Background estimation

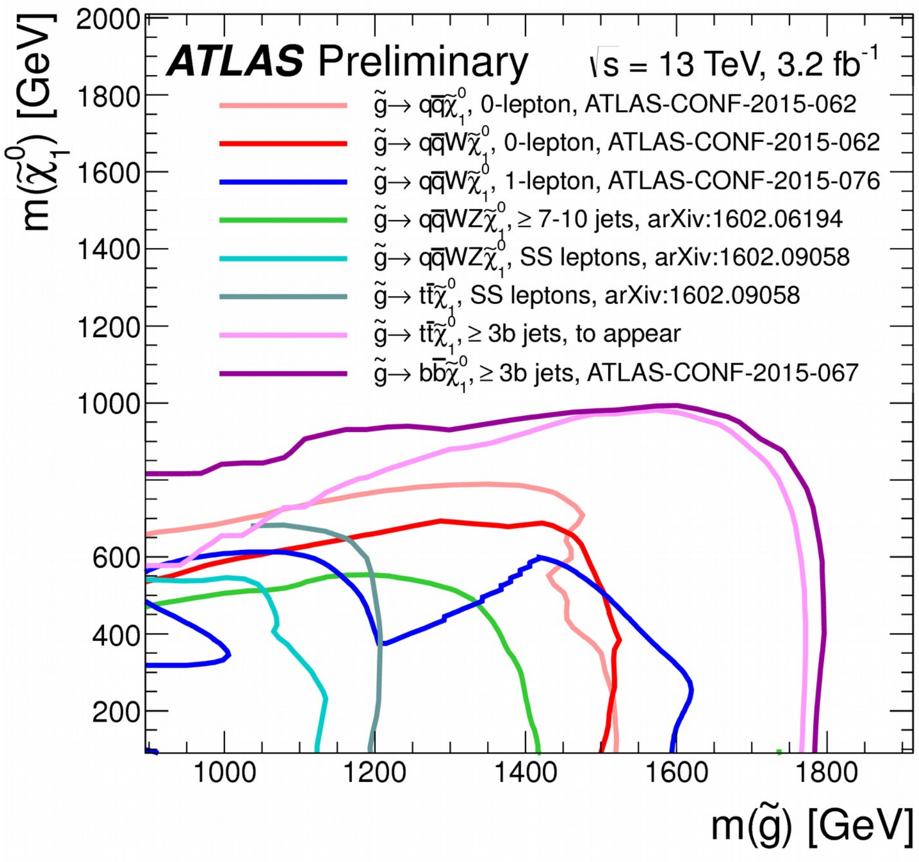
- **Main backgrounds :** single top, $t\bar{t}$, W+jets
  - **Estimated with MC nomalized in Control Regions** defined reverting the m_T and the am_{T2} cut for different b-jet multiplicities
  - **Estimation checked in Validation Regions**
- **Multijets**
  - **Sources :**
    - Fake E_T^{miss}
    - jets mis-identified as leptons
  - **Data driven estimation :** fake factor Method





Back-up
Summary plot

- **All results in the gluino / neutralino plane**
  Different processes considered



Back-up
Stop 1L

- **Signal / Control Regions 1**

Common event selection			
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger		
Lepton	exactly one signal lepton (e, μ), no additional baseline leptons.		
Jets	at least four signal jets, and $|\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})| > 0.4$ for $i \in \{1, 2\}$.		
hadronic τ	veto events with a hadronic τ and $m_{T2}^{\tau} < 80\,\mathrm{GeV}$.		
Variable	SR1	TCR1 / WCR1	STCR1
$\geq$4 jets with $p_{\mathrm{T}} >$ [GeV]	(80 50 40 40)	(80 50 40 40)	(80 50 40 40)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 260	> 200	> 200
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 5	> 5
m_{T} [GeV]	> 170	[30,90]	[30,120]
am_{T2} [GeV]	> 175	[100, 200] / > 100	> 200
topness	> 6.5	> 6.5	> 6.5
m_{top}^{χ} [GeV]	< 270	< 270	< 270
$\Delta R(b, \ell)$	< 3.0	–	–
$\Delta R(b_1, b_2)$	–	–	> 1.2
number of b-tags	≥ 1	≥ 1 / $= 0$	≥ 2

Back-up
Stop 1L

- **Signal / Control Regions 2**

Common event selection			
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger		
Lepton	exactly one signal lepton (e, μ), no additional baseline leptons.		
Jets	at least four signal jets, and $\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert > 0.4$ for $i \in \{1, 2\}$.		
hadronic τ	veto events with a hadronic τ and $m_{T2}^{\tau} < 80\,\mathrm{GeV}$.		

	SR2	TCR2 / WCR2	STCR2
$\geq$4 jets with $p_{\mathrm{T}} >$ [GeV]	(120 80 50 25)	(120 80 50 25)	(120 80 50 25)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 350	> 250	> 200
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 20	> 15	> 5
m_{T} [GeV]	> 200	[30,90]	[30,120]
am_{T2} [GeV]	> 175	$[100, 200]$ / > 100	> 200
$\Delta R(b, \ell)$	< 2.5	–	–
$\Delta R(b_1, b_2)$	–	–	> 1.2
number of b-tags	≥ 1	≥ 1 / $= 0$	≥ 2
leading large-R jet p_{T} [GeV]	> 200	> 200	> 200
leading large-R jet mass [GeV]	> 140	> 140	> 0
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, 2^{\mathrm{nd}}$large-R jet)	> 1.0	> 1.0	> 1.0

Back-up
Stop 1L

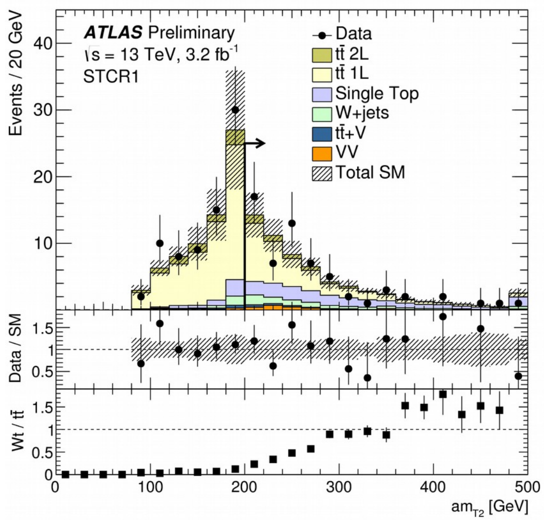
- **Signal / Control Regions 3**

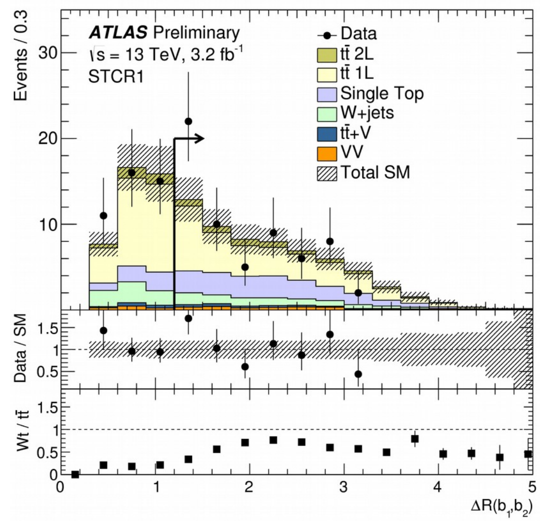
Common event selection	
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
Lepton	exactly one signal lepton (e, μ), no additional baseline leptons.
Jets	at least four signal jets, and $\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert > 0.4$ for $i \in \{1,2\}$.
hadronic τ	veto events with a hadronic τ and $m_{T2}^{\tau} < 80\,\mathrm{GeV}$.

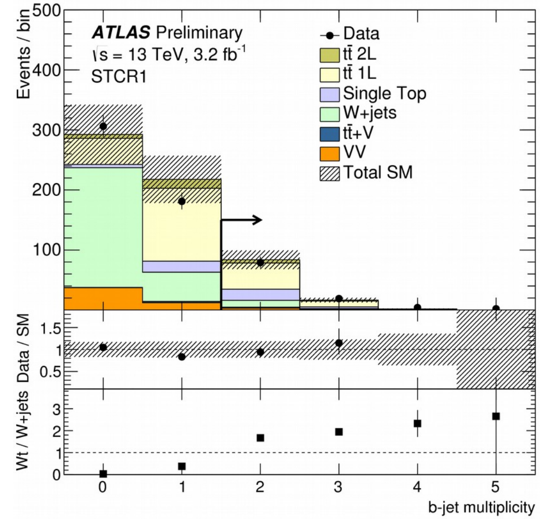
	SR3	TCR3 / WCR3	STCR3
$\geq$4 jets with $p_{\mathrm{T}} >$ [GeV]	(120 80 50 25)	(120 80 50 25)	(120 80 50 25)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 480	> 280	> 200
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 8	> 5
m_{T} [GeV]	> 190	[30,90]	[30,120]
am_{T2} [GeV]	> 175	[100, 200] / > 100	> 200
topness [GeV]	> 9.5	> 0	> 9.5
$\Delta R(b, \ell)$	< 2.8	–	–
$\Delta R(b_1, b_2)$	–	–	> 1.2
number of b-tags	≥ 1	≥ 1 / $= 0$	≥ 2
leading large-R jet p_{T} [GeV]	> 280	> 200	> 200
leading large-R jet mass [GeV]	> 70	> 70	> 70

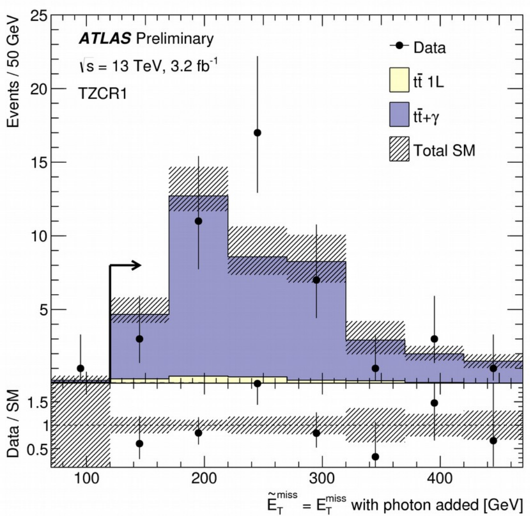
Back-up
Stop 1L

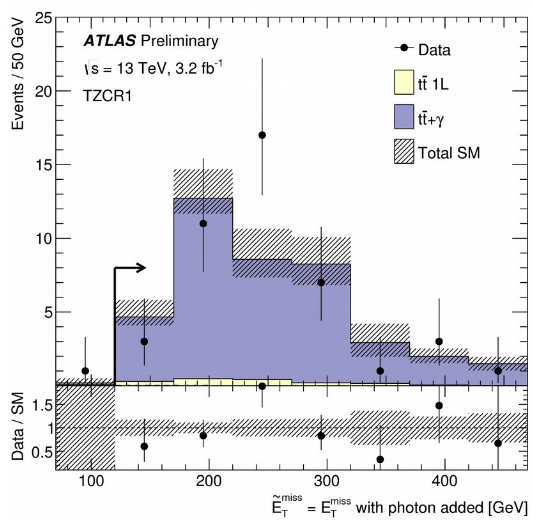
- **Control Region plots (STCR1)**

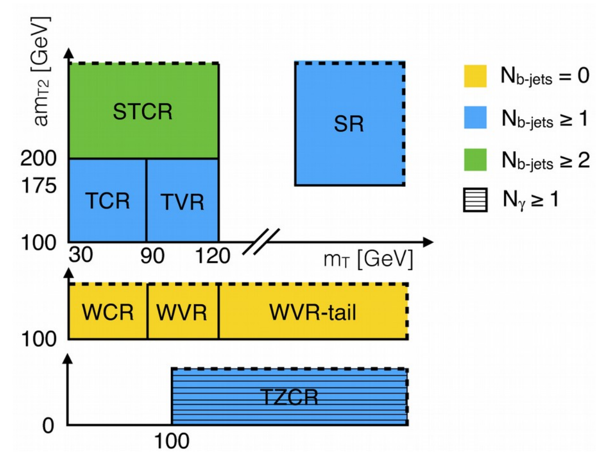










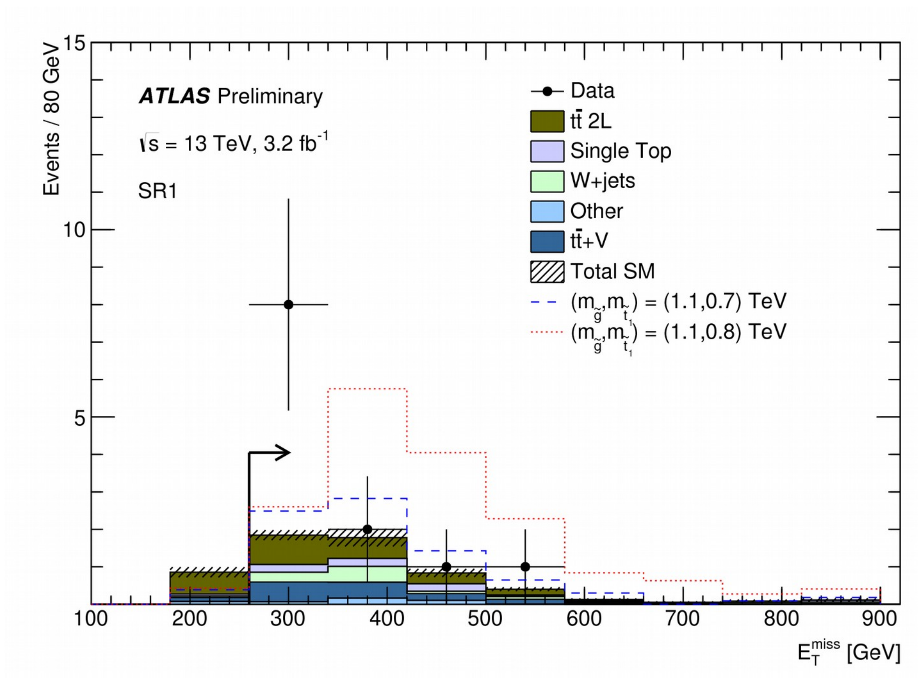


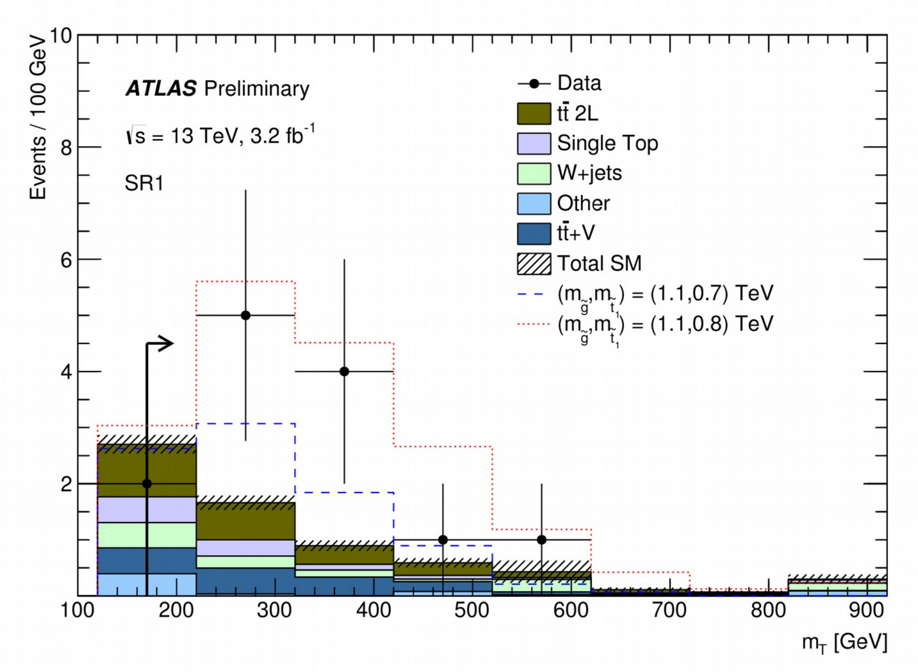
- **SR Yields**

Signal region	SR1	SR2	SR3
Observed	12	1	1
Total bkg	5.50 ± 0.72	1.25 ± 0.26	1.03 ± 0.18
$t\bar{t}$	2.21 ± 0.60	0.29 ± 0.10	0.20 ± 0.07
Single top	0.46 ± 0.39	0.09 ± 0.08	0.10 ± 0.09
W+jets	0.71 ± 0.43	$0.15^{+0.19}_{-0.15}$	0.20 ± 0.09
$t\bar{t} + W/Z$	1.90 ± 0.42	0.61 ± 0.14	0.41 ± 0.10
Diboson	0.23 ± 0.15	0.11 ± 0.07	0.12 ± 0.07
$t\bar{t}$ NF	1.10 ± 0.14	1.06 ± 0.14	0.80 ± 0.13
Single top NF	0.62 ± 0.46	0.65 ± 0.49	0.71 ± 0.42
W+jets NF	0.75 ± 0.12	0.78 ± 0.15	0.93 ± 0.12
$t\bar{t} + W/Z$ NF	1.42 ± 0.24	1.45 ± 0.24	1.46 ± 0.24
p_0	$0.01(2.3\,\sigma)$	$0.50\ (0.0\,\sigma)$	$0.50\ (0.0\,\sigma)$
$N^{\rm limit}_{\rm non-SM}$ exp. (95% CL)	$6.4^{+3.2}_{-2.0}$	$3.6^{+2.3}_{-1.3}$	$3.5^{+2.2}_{-1.2}$
$N^{\rm limit}_{\rm non-SM}$ obs. (95% CL)	13.3	3.4	3.4

Back-up
Stop 1L

- **Signal Region yields**

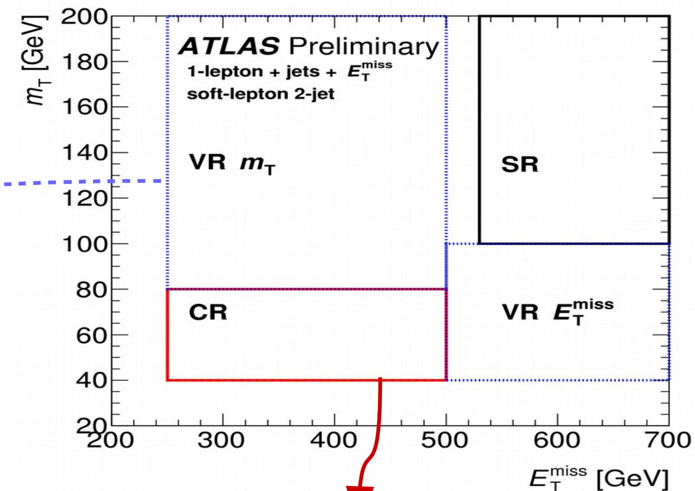


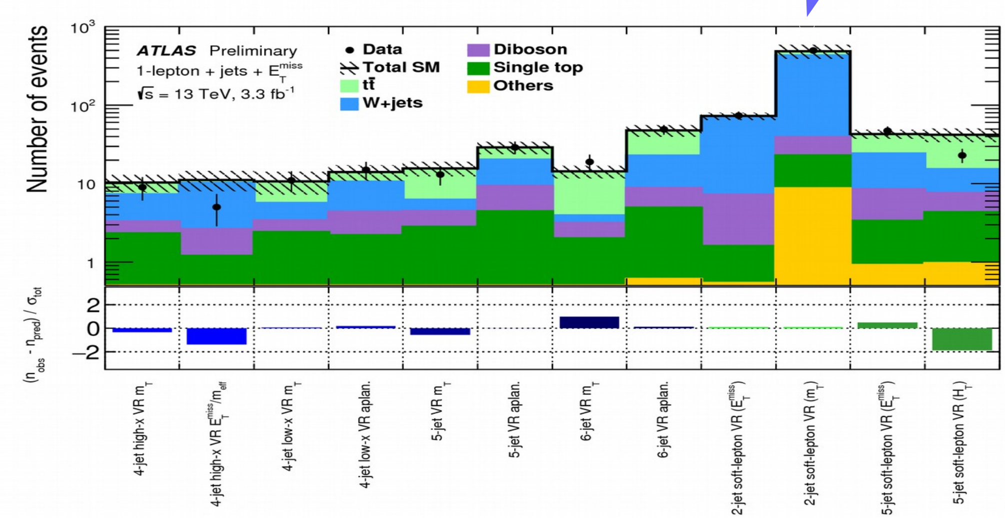


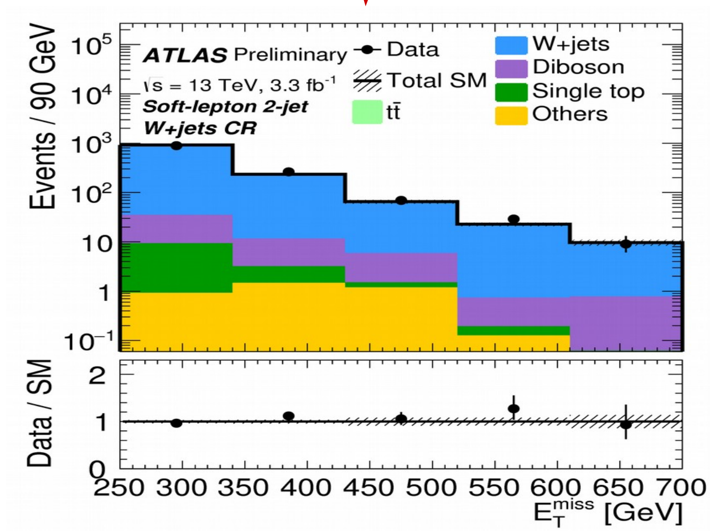
Back-up
1 lepton + E_T^{miss} + jets

- **Main backgrounds :** *tt, W+jets*
  - **MC** normalised with **Data** in **Control Regions (CR)**
  - Extrapolation to SR validated in **Validation Regions (VR)**

Example : soft lepton 2-jets



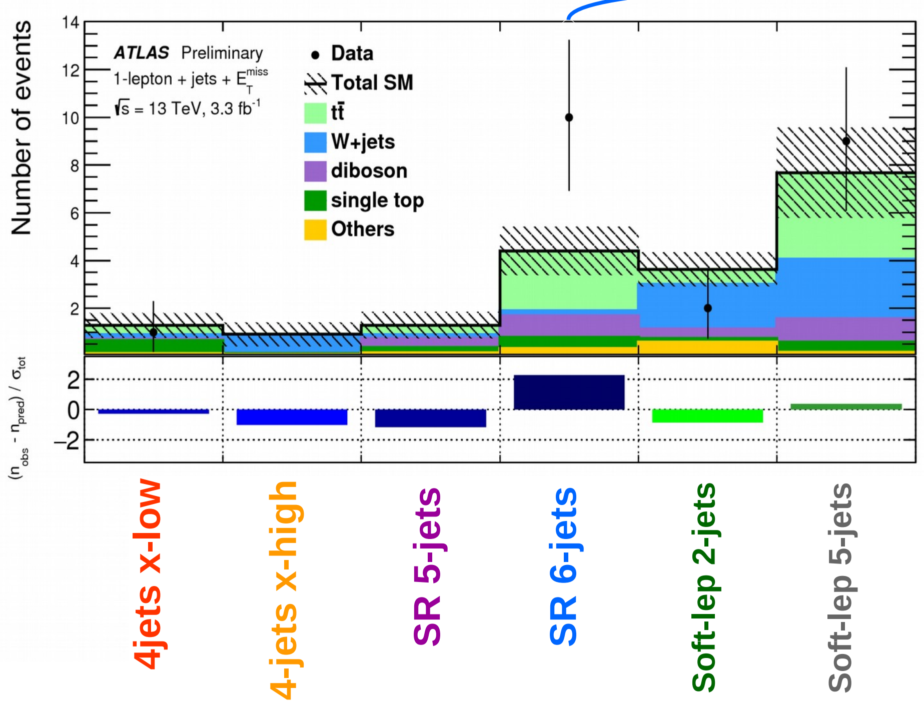


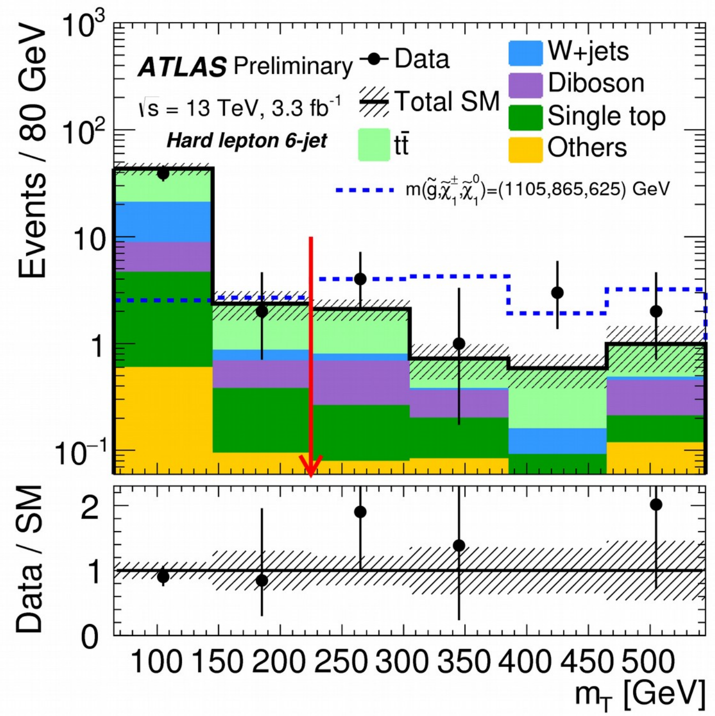


- **Sub-dominant backgrounds :** *Z+jets, VV, single top*
  - **MC** only

Back-up
1 lepton + E_T^{miss} + jets

- **Overall good data/MC agreement**
- **Largest deviation (~ 2σ)** : SR 6-jets
  - Electron : $N_{obs}(N_{exp}) = 2\ (1.9 \pm 0.6)$
  - Muon : $N_{obs}(N_{exp}) = 8\ (2.5 \pm 0.8)$



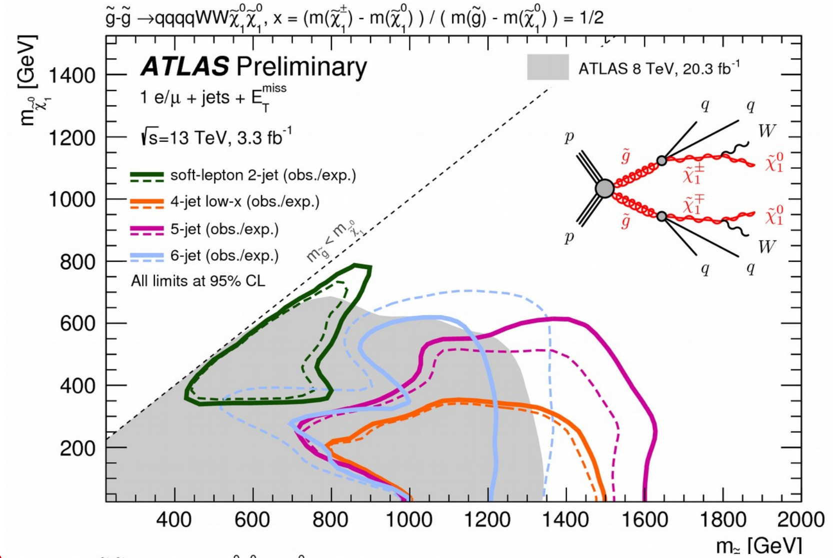


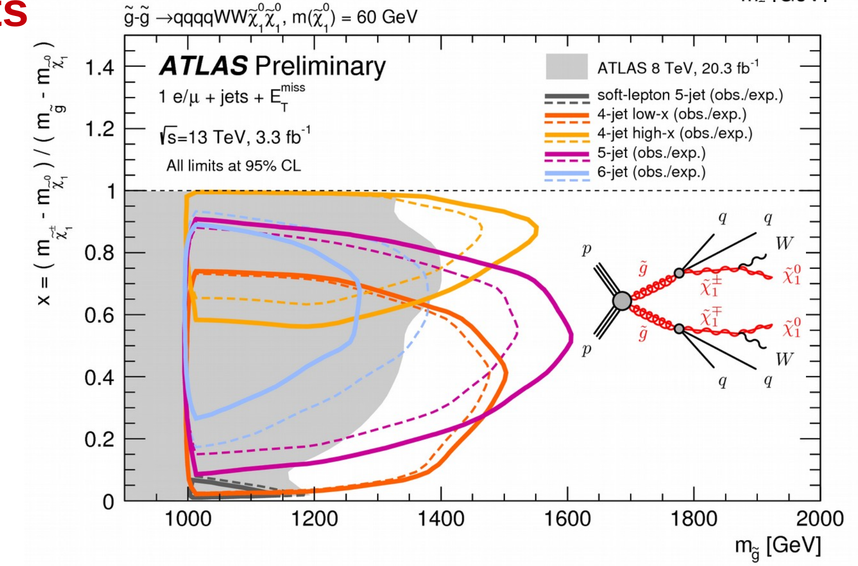
No significant deviation from SM
→ Results used to sets limits
on simplified SUSY models

Back-up
1 lepton + E_T^{miss} + jets

- **Exclusion set using simplified Models**
  - With $x = \dfrac{m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}}{m_{\tilde{g}} - m_{\tilde{\chi}_1^0}} = \dfrac{1}{2}$
    - **Soft leptons 2-jets :** small $\Delta m(\tilde{g},\tilde{\chi}_1^0)$
    - **SR 5-jets :** large $\Delta m(\tilde{g},\tilde{\chi}_1^0)$
    - **SR 6-jets :** 2σ excess
      → No improvements wrt Run-1
  - With $m_{\tilde{\chi}_1^0} = 60\,GeV$
    - **SR 4-jets x-high :** x [0.8-1]
    - **SR 5-jets :** x [0.3-0.8]
    - **SR 4-jets x-low :** x [0.05-0.5]

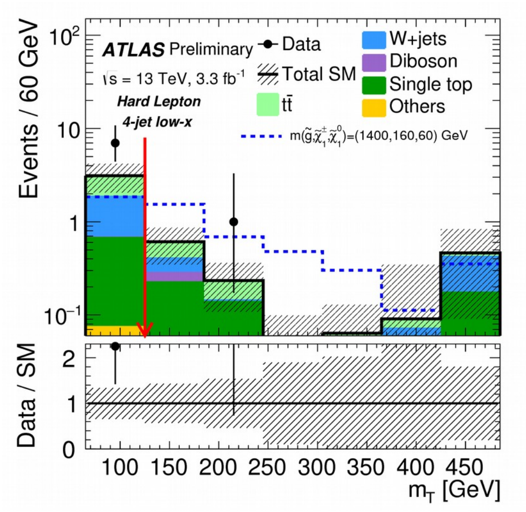
Beyond Run-1 limits

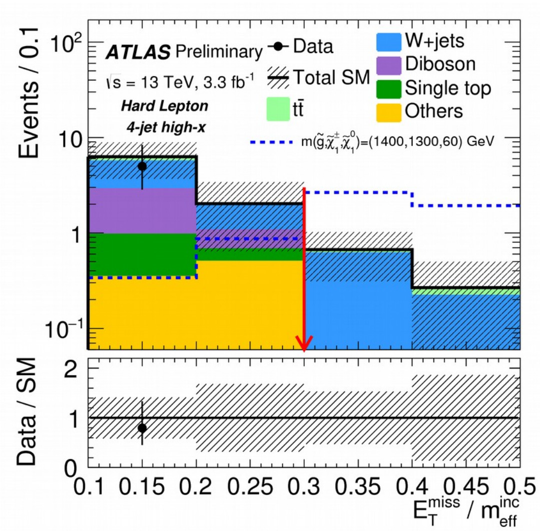


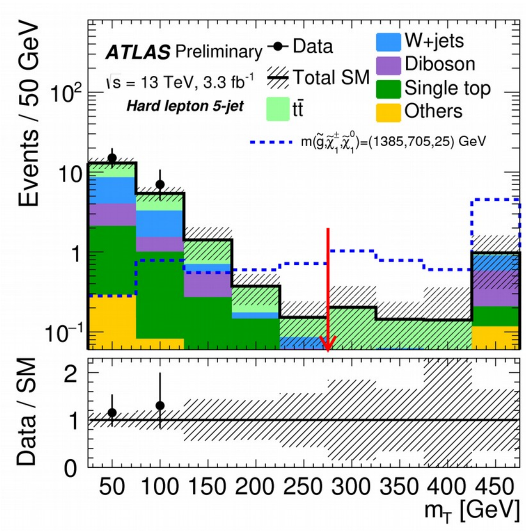


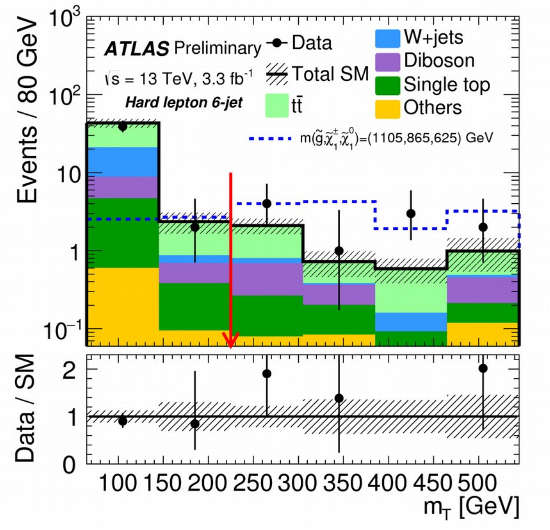
Improvement of the exclusion in almost all the possible configurations with gluino excluded up to 1.6 TeV

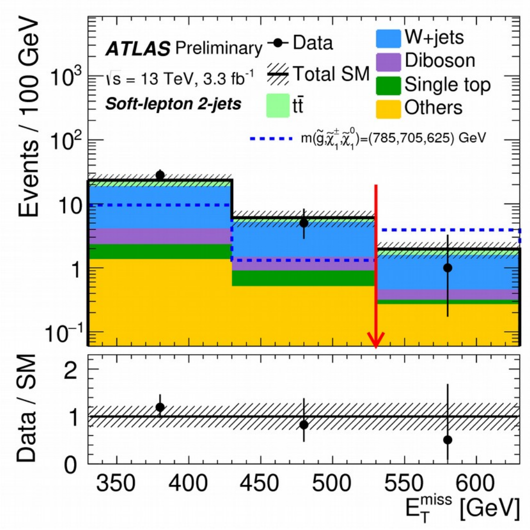
Back-up
1 leptons results

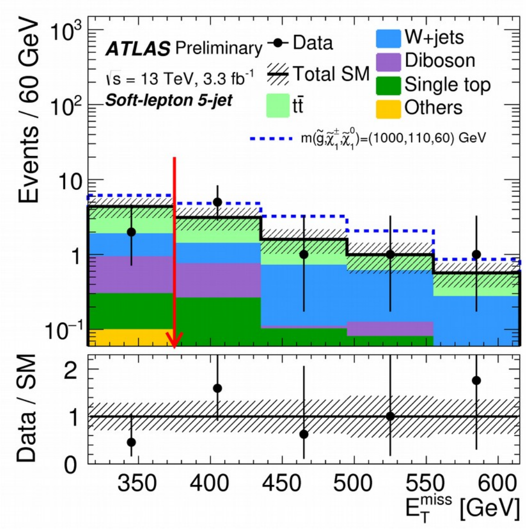












Back-up
1 lepton SR definitions

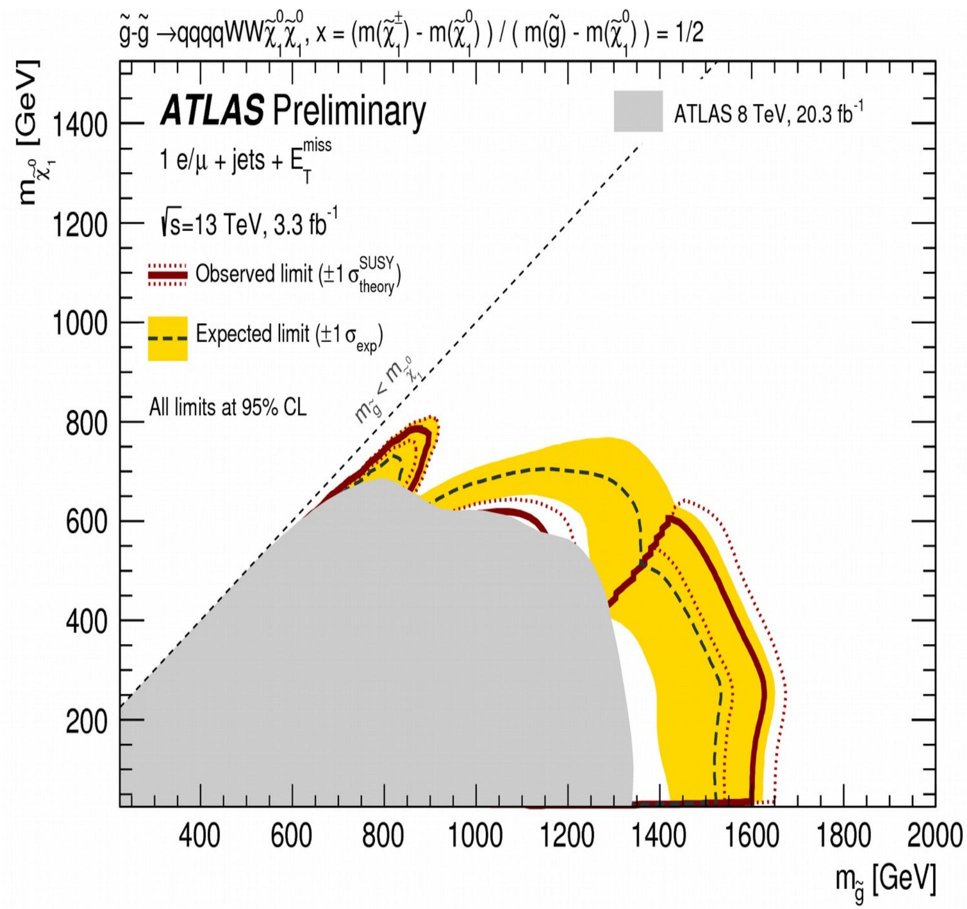
	2-jet soft-lepton SR	5-jet soft-lepton SR
N_{lep}	$= 1$	$= 1$
$p_{\mathrm{T}}^{\ell\, e(\mu)}$ (GeV)	7(6) - 35	7(6) - 35
$p_{\mathrm{T}}^{\ell_2\, e(\mu)}$ (GeV)	$< 7(6)$	$< 7(6)$
N_{jet}	≥ 2	≥ 5
$p_{\mathrm{T}}{}^{\mathrm{jet}}$ (GeV)	$> 180, 30$	$> \boxed{200, 200, 200}, 30, 30$
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	$\boxed{> 530}$	$\boxed{> 375}$
m_{T} (GeV)	$\boxed{> 100}$	-
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{\mathrm{incl}}$	$\boxed{> 0.38}$	-
H_{T} (GeV)	-	$\boxed{> 1100}$
Jet aplanarity	-	> 0.02

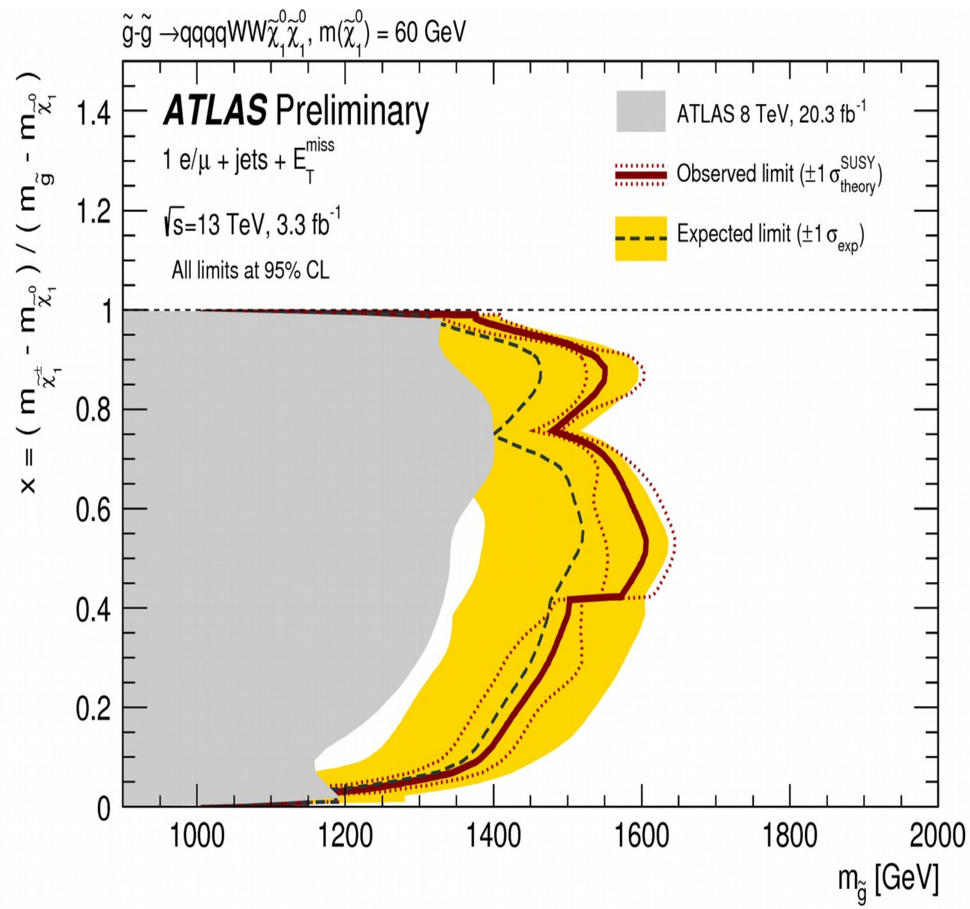
	4-jet high-x SR	4-jet low-x SR	5-jet SR	6-jet SR
N_{lep}	$= 1$	$= 1$	$= 1$	$= 1$
p_{T}^{ℓ} (GeV)	> 35	> 35	> 35	> 35
$p_{\mathrm{T}}^{\ell_2}$ (GeV)	< 10	< 10	< 10	< 10
N_{jet}	≥ 4	≥ 4	≥ 5	≥ 6
$p_{\mathrm{T}}{}^{\mathrm{jet}}$ (GeV)	$> 325, 30, \ldots, 30$	$> \boxed{325, 150, \ldots, 150}$	$> 225, 50, \ldots, 50$	$> 125, 30, \ldots, 30$
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	> 200	> 200	> 250	> 250
m_{T} (GeV)	$\boxed{> 425}$	> 125	> 275	> 225
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{\mathrm{incl}}$	$\boxed{> 0.3}$	-	> 0.1	$\boxed{> 0.2}$
$m_{\mathrm{eff}}^{\mathrm{incl}}$ (GeV)	$\boxed{> 1800}$	$\boxed{> 2000}$	$\boxed{> 1800}$	$\boxed{> 1000}$
Jet aplanarity	-	> 0.04	> 0.04	> 0.04

Back-up
1 lepton SR yields

	Hard-lepton				Soft-lepton	
	4-jet low x	4-jet high x	5-jet	6-jet	2-jet	5-jet
Observed events	1	0	0	$\boxed{10}$	2	9
Fitted background events	1.3 ± 0.5	0.9 ± 0.5	1.3 ± 0.6	$\boxed{4.4 \pm 1.0}$	3.6 ± 0.7	7.7 ± 1.9
$t\bar{t}$	0.40 ± 0.31	0.08 ± 0.07	0.39 ± 0.24	2.5 ± 0.9	0.64 ± 0.33	3.6 ± 1.2
W+jets	0.19 ± 0.12	0.7 ± 0.5	0.16 ± 0.12	0.22 ± 0.15	1.9 ± 0.5	2.5 ± 1.3
Z+jets	0.046 ± 0.024	0.029 ± 0.028	0.08 ± 0.04	0.08 ± 0.08	0.49 ± 0.13	0.09 ± 0.05
Single-Top	0.5 ± 0.5	$0.04^{+0.10}_{-0.04}$	$0.22^{+0.23}_{-0.22}$	0.5 ± 0.4	0.16 ± 0.14	0.43 ± 0.34
Diboson	$0.06^{+0.20}_{-0.06}$	$0.002^{+0.014}_{-0.002}$	0.38 ± 0.24	0.9 ± 0.5	0.39 ± 0.17	1.0 ± 0.7
$t\bar{t}$ +V	0.050 ± 0.022	0.025 ± 0.013	0.060 ± 0.030	0.24 ± 0.08	0.088 ± 0.029	0.067 ± 0.025
Background yield from simulation	1.7	1.1	1.6	5.2	4.0	9.4
$t\bar{t}$	0.80	0.26	0.63	3.2	0.93	4.1
W+jets	0.20	0.7	0.22	0.32	1.9	3.8
Z+jets	0.046	0.029	0.08	0.08	0.49	0.09
Single-t	0.5	0.04	0.22	0.5	0.16	0.43
Diboson	0.06	0.002	0.38	0.9	0.39	1.0
$t\bar{t}$ +V	0.050	0.025	0.060	0.24	0.088	0.067

Back-up
1 lepton Exclusions

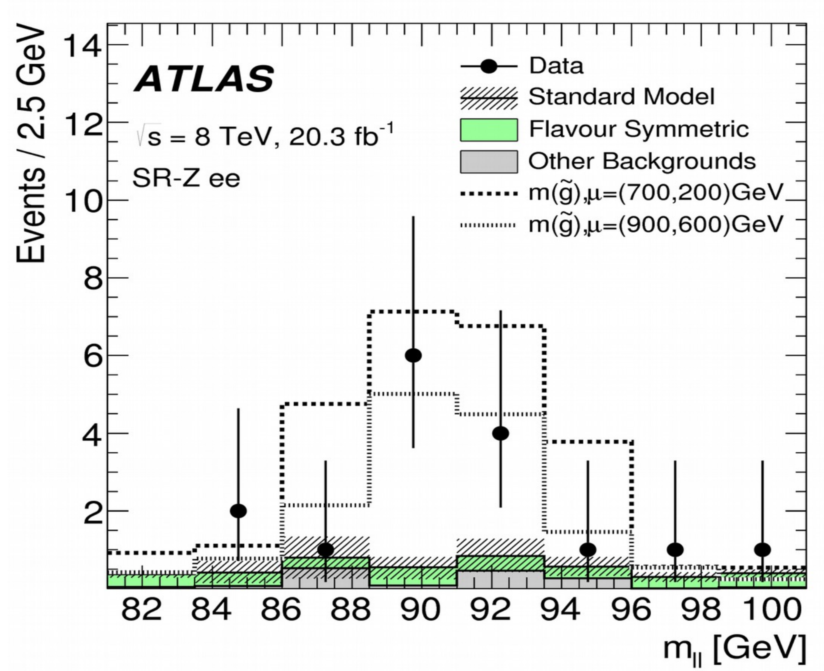


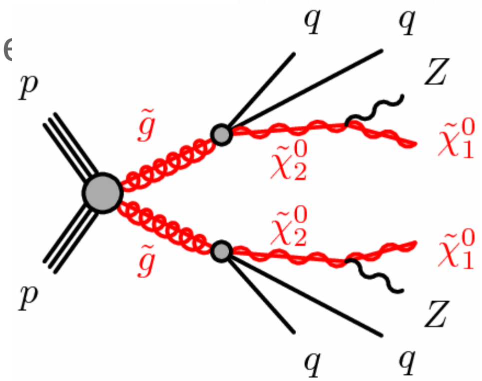


Back-up

Z → *ll* + E_T^{miss} + jets

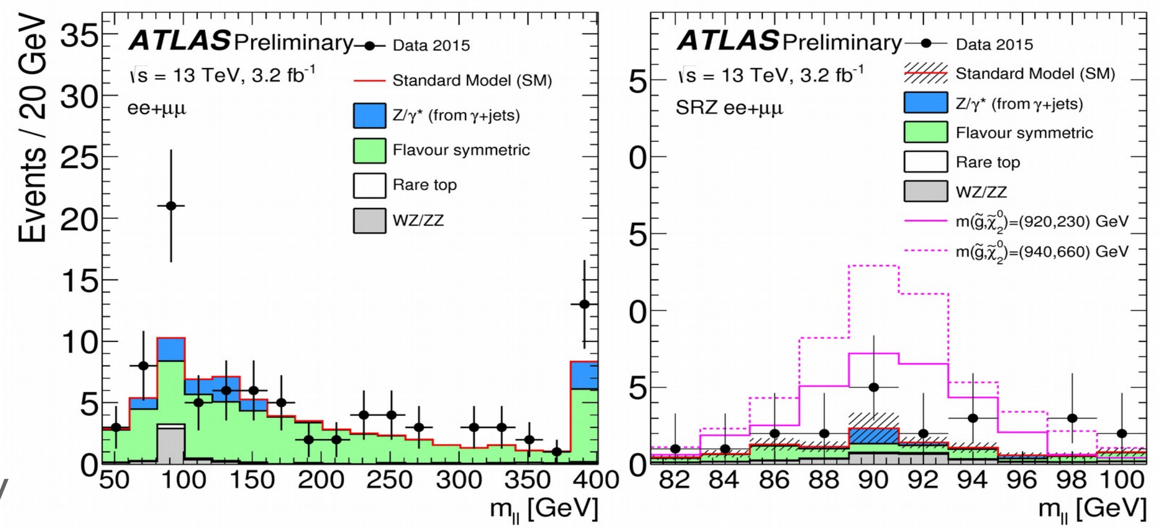
- **Excess in Run-1 :** SUSY-2014-10
  - 3.0(1.7) σ in the ee(μμ) channel
  - Not observed by CMS
- **Run 2 strategy :** Check the excess reproducing the same SR
  - e^+e^- / $\mu^+\mu^-$ pair with :
    - P_T > 50 / 25 GeV
    - m_{ll}[81- 101] GeV
  - ≥ 2 jets with $\Delta\Phi_{min}(E_T^{miss}, \text{jets}) > 0.4$
  - E_T^{miss} > 225 GeV and H_T > 600 Ge

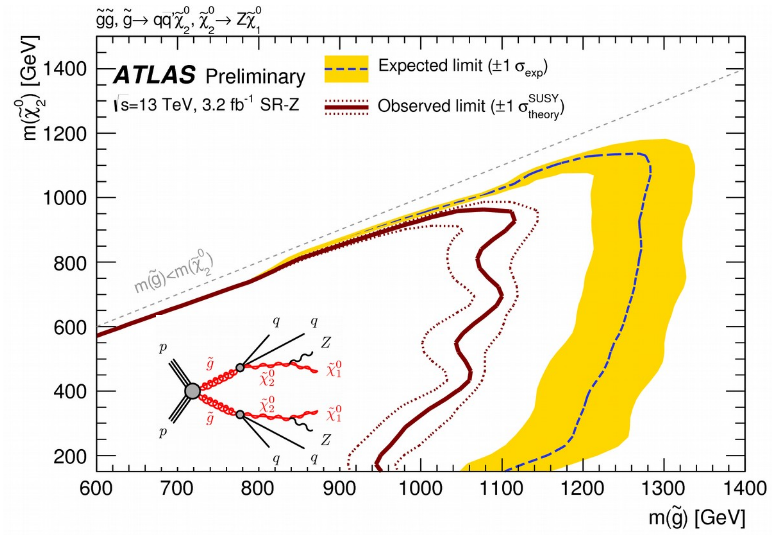




Back-up
Z→*ll* + E_T^{miss} + jets

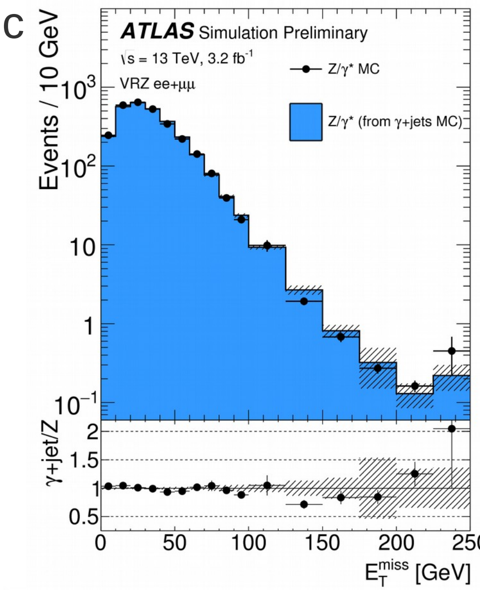
- **SR Yields :**
  - N_{obs} (N_{exp}) = 21 (10.3 +/- 2.3)
  - N_{ee} / $N_{\mu\mu}$ = 10 / 11
  - Significance : 2.2σ
- **Interpretation**
  - m($\tilde{\chi}^{\circ}_2$) ~ 700 GeV
    → gluino excluded up to 1.1 TeV
  - m($\tilde{\chi}^{\circ}_2$) ~ 200 GeV
    → gluino excluded up to 0.95 TeV
  - Worse limits than expected because of the slight excess

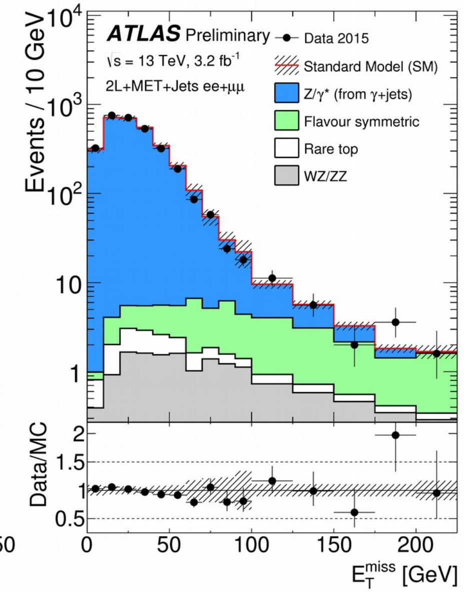


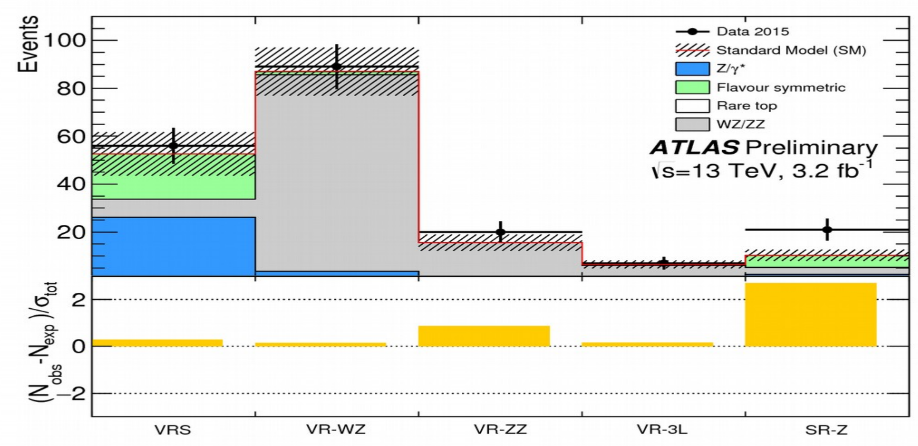


Back-up
$Z \rightarrow ll + E_T^{miss}$ + jets

- **Dominant background (~60%) :** flavour symmetric
  - Sources : tt (70%), WW (20%), tW (8%), $Z \rightarrow \tau\tau$
  - Estimated using eμ Data Control Regions
    - Same kinematics as Signal Regions except larger m_{ll} window (more stats)
- ***Z/γ*+jets background (~10%) :***
  - Fake E_T^{misss} due detector resolution
  - Estimated using E_T^{misss} distribution from γ+jets
    - Selection : $N_\gamma \geq 1$, $N_{Jets} \geq 2$
    - γ reweighted to Z p_T
    - Normalised dedicated CR
      - E_T^{miss} < 60 GeV
      - All other kinematic SR requirements
- **Other Backgrounds (~30%) :** WZ, ZZ, ttV etc ...
  - MC Only + dedicated WZ and ZZ validation in Data







Back-up
Z+MET SR/VR definitions

Region	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	H_{T} [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	SF/DF	$\Delta\phi(\mathrm{jet}_{12}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})$	$m_{\mathrm{T}}(\ell_3, E_{\mathrm{T}}^{\mathrm{miss}})$ [GeV]	$n_{\text{b-jets}}$
Signal regions								
SRZ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
Control regions								
Z normalisation	< 60	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
CR-FS	> 225	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4	-	-
CRT	> 225	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4	-	-
Validation regions								
VRZ	< 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
VRT	100–200	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4	-	-
VRS	100–200	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
VR-FS	100–200	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4	-	-
VR-WZ	100–200	-	-	-	3ℓ	-	< 100	0
VR-ZZ	< 100	-	-	-	4ℓ	-	-	0
VR-3L	60–100	> 200	≥ 2	$81 < m_{\ell\ell} < 101$	3ℓ	> 0.4	-	-

Back-up
Z+Met SR/VR Yields

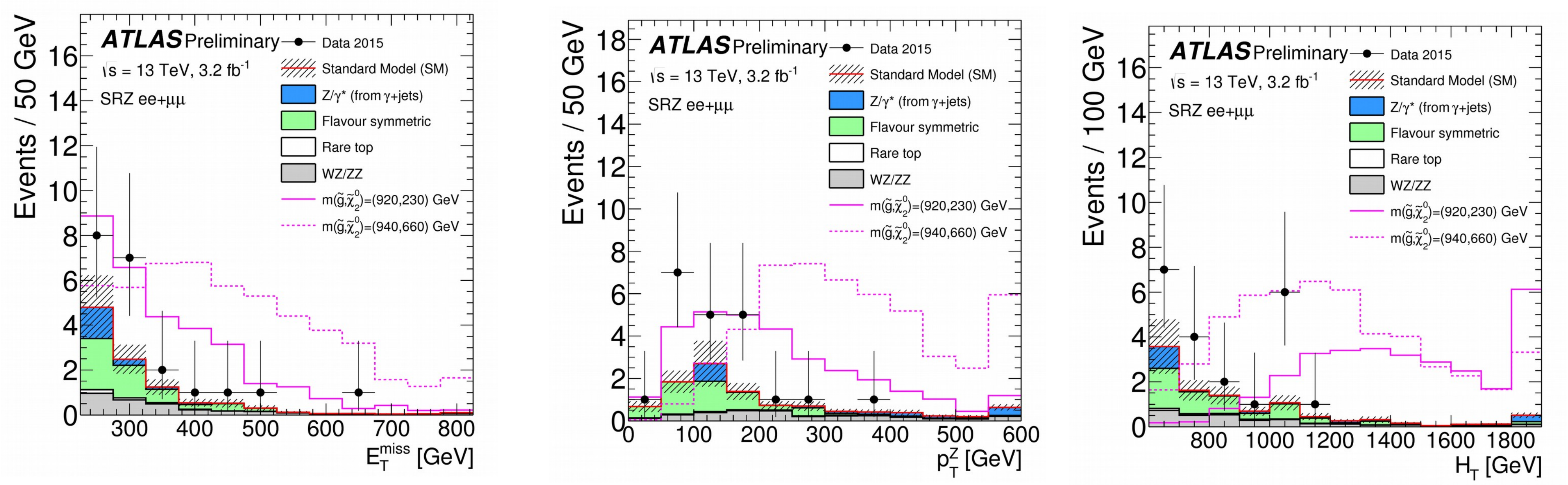
SR / VR Yields

	SRZ	VRS	VR-WZ	VR-ZZ	VR-3L
Observed events	21	56	89	20	7
Total expected background events	10.3 ± 2.3	52.6 ± 9.1	87 ± 10	15.5 ± 3.4	6.5 ± 1.6
Flavour symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	5.1 ± 2.0	18.9 ± 4.8	1.3 ± 0.4	0	0.3 ± 0.2
WZ/ZZ events	2.9 ± 0.8	7.5 ± 1.7	82 ± 10	15.5 ± 3.4	4.9 ± 1.6
$Z/\gamma^* +$ jets events	1.9 ± 0.8	24.8 ± 7.6	2.7 ± 2.8	0	0.2 ± 0.2
Rare top events	0.4 ± 0.1	1.4 ± 0.2	0.9 ± 0.4	0.04 ± 0.02	1.0 ± 0.1
p-value	0.013				
Significance	2.2				
Observed (Expected) S^{95}	$20.0\ (10.2^{+4.4}_{-3.0})$				

Systematics

VRS	VR-WZ	VR-ZZ	VR-3L
56	89	20	7
52.6 ± 9.1	87 ± 10	15.5 ± 3.4	6.5 ± 1.6
18.9 ± 4.8	1.3 ± 0.4	0	0.3 ± 0.2
7.5 ± 1.7	82 ± 10	15.5 ± 3.4	4.9 ± 1.6
24.8 ± 7.6	2.7 ± 2.8	0	0.2 ± 0.2
1.4 ± 0.2	0.9 ± 0.4	0.04 ± 0.02	1.0 ± 0.1

Back-up
Z+MET Kinematic plots



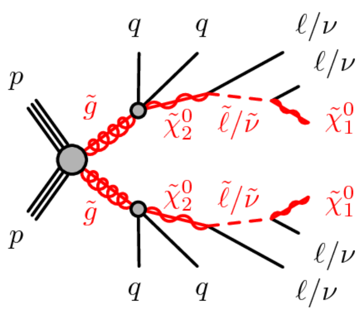
No data driven shape corrections

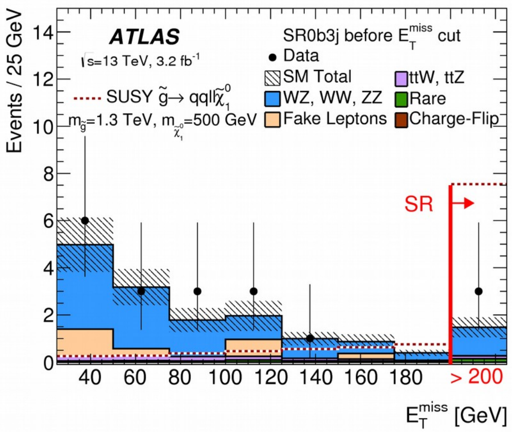
Back-up
Stop 2L

- **Control Region**

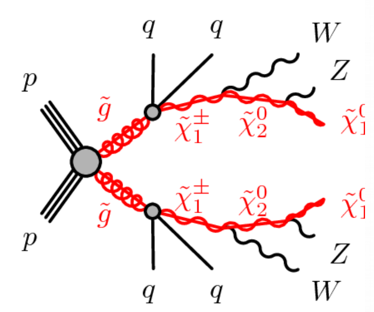
Back-up
2l same sign - 3 leptons

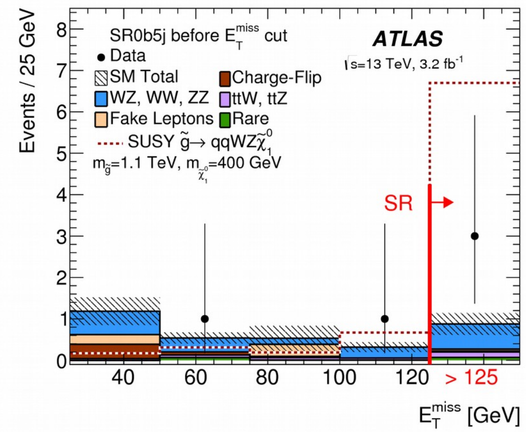
- **0 b-jets / ≥ 3 jets**

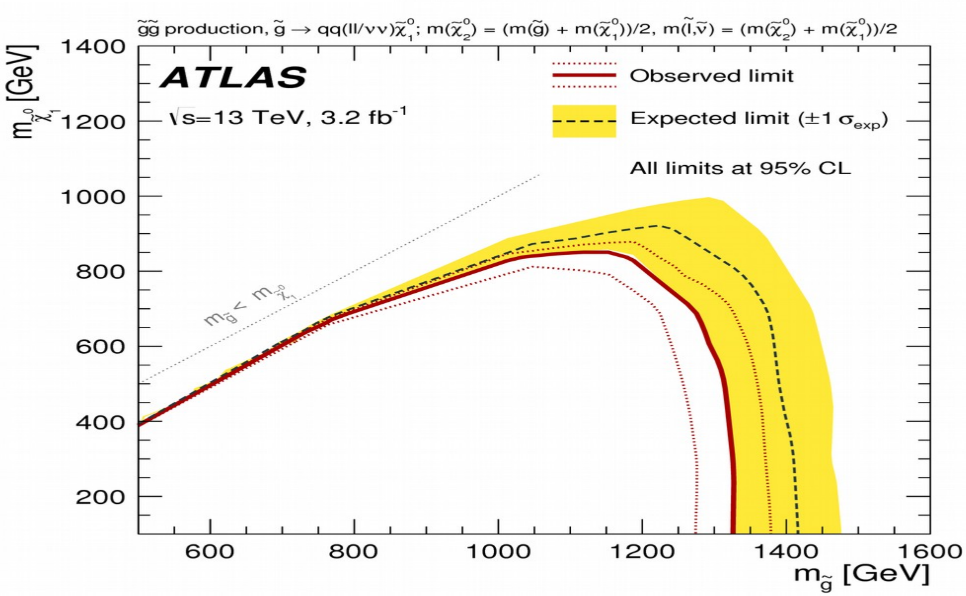


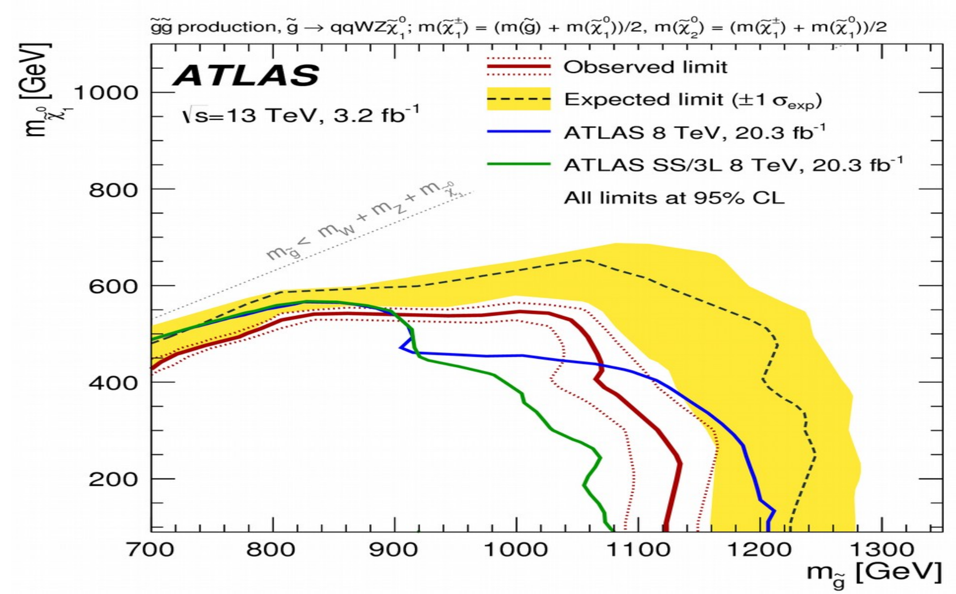


- **0 b-jets / ≥ 5 jets**



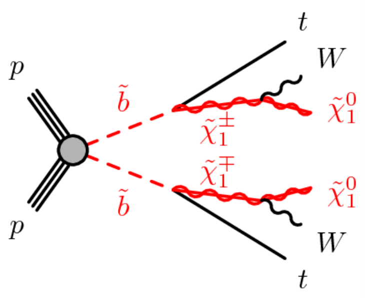


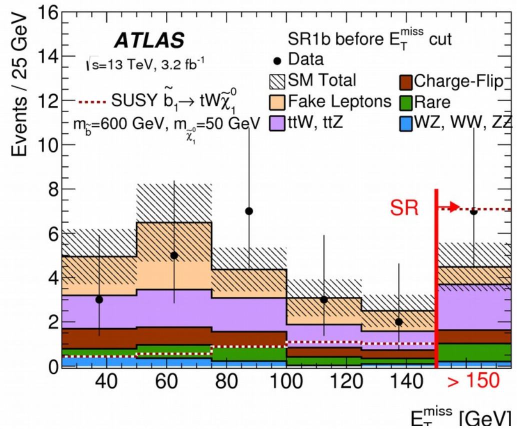




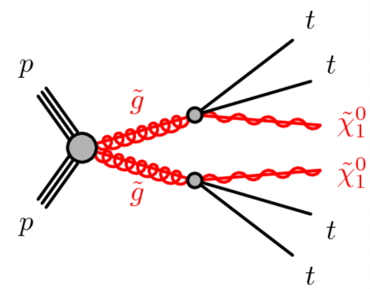
Back-up
2/ same sign - 3 leptons

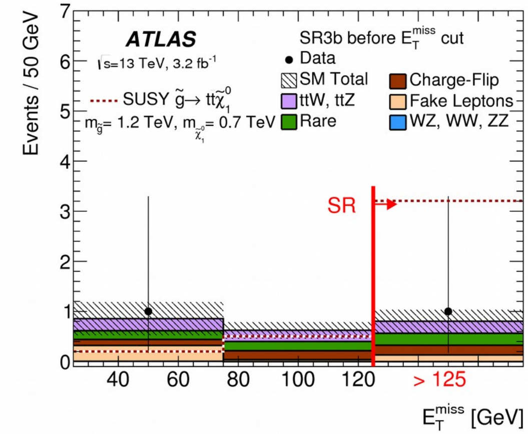
- **At least 1 b-jet**

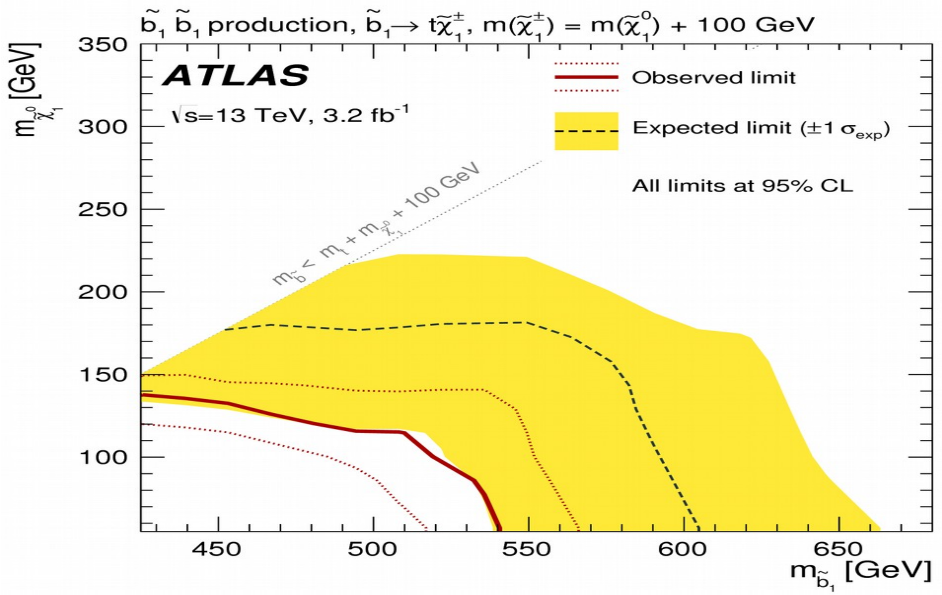


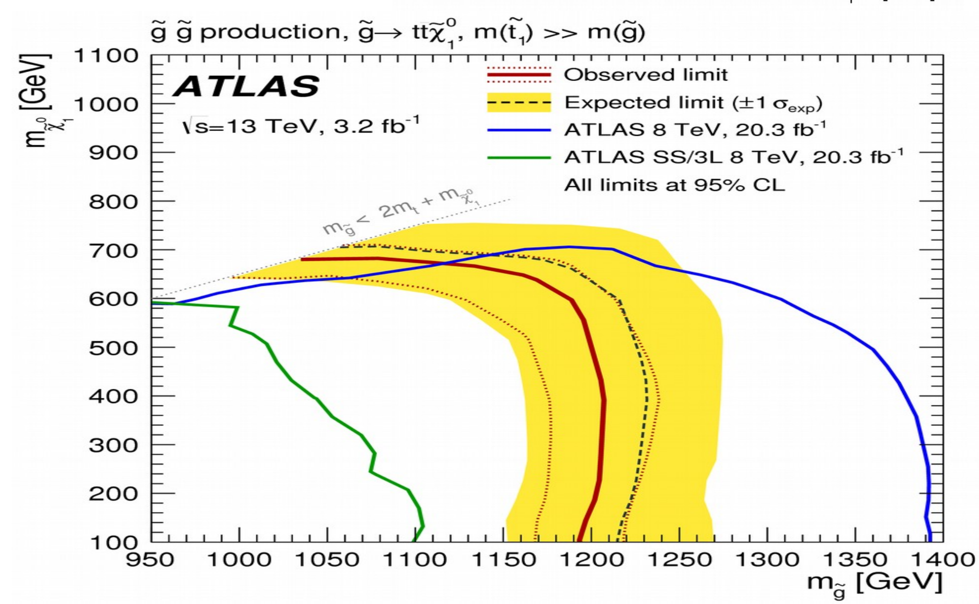


- **At least 3 b-jets**



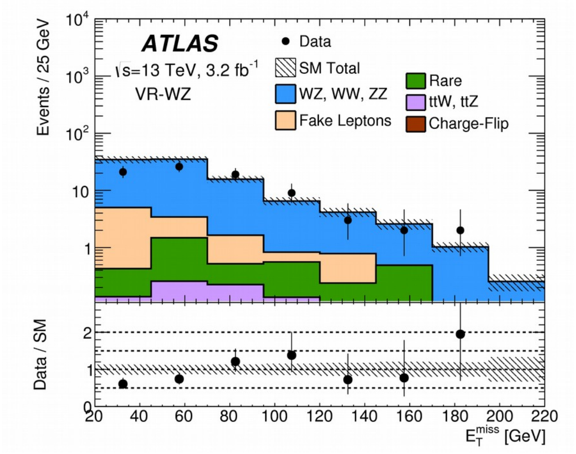


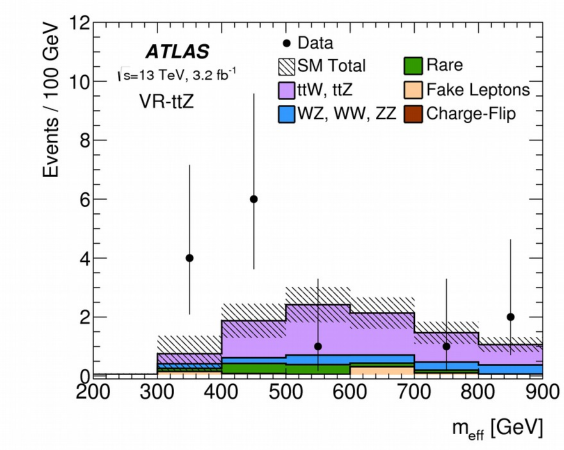


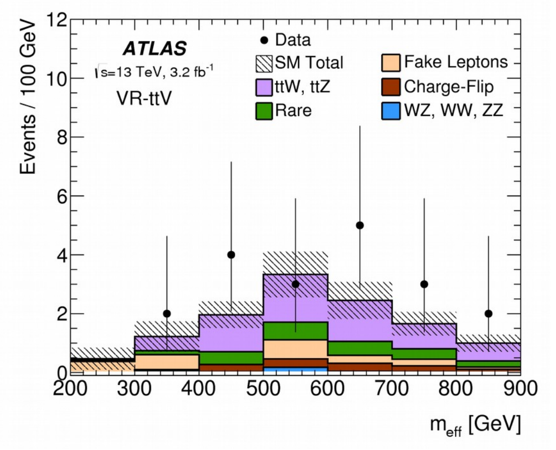


Back-up
2ssl3l VR Def/Yields

	$N_{\mathrm{lept}}^{\mathrm{signal}}$ ($N_{\mathrm{lept}}^{\mathrm{cand}}$)	$N_{b-\mathrm{jets}}^{20}$	N_{jets}^{25}	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	m_{eff} [GeV]	Other
VR-WW	=2 (=2) =1 SS pair	=0	≥2	35–200	300–900	$m(j_1 j_2) > 500$ GeV $p_{\mathrm{T}}(j_2) > 40$ GeV $p_{\mathrm{T}}(\ell_2) > 30$ GeV veto $80 < m_{ee} < 100$ GeV
VR-WZ	=3 (=3)	=0	1–3	30–200	<900	$p_{\mathrm{T}}(\ell_3) > 30$ GeV
VR-ttV	≥2 (-) ≥1 SS pair	≥2	≥5 ($e^{\pm}e^{\pm}$,$e^{\pm}\mu^{\pm}$) ≥3 ($\mu^{\pm}\mu^{\pm}$)	20–200	200–900	$p_{\mathrm{T}}(\ell_2) > 25$ GeV veto $\{E_{\mathrm{T}}^{\mathrm{miss}} > 125$ and $m_{\mathrm{eff}} > 650\,\mathrm{GeV}\}$
VR-ttZ	≥3 (-) ≥1 SFOS pair	≥1	≥4 (=1 b-jet) ≥3 (≥2 b-jets)	20–150	100–900	$p_{\mathrm{T}}(\ell_2) > 25$ GeV $p_{\mathrm{T}}(\ell_3) > 20$ GeV (if e) $80 < m_{\mathrm{SFOS}} < 100$ GeV
All VRs	Veto events belonging to any SR, or if ℓ_1 or ℓ_2 is an electron with $\lvert\eta\rvert > 1.37$ (except in VR-WZ)					







Back-up
2ssl3l SR/VR yields

SR yields

	SR0b3j	SR0b5j	SR1b	SR3b
Observed events	3	3	7	1
Total background events	1.5 ± 0.4	0.88 ± 0.29	4.5 ± 1.0	0.80 ± 0.25
$p(s=0)$	0.13	0.04	0.15	0.36
Fake/non-prompt leptons	< 0.2	0.05 ± 0.18	0.8 ± 0.8	0.13 ± 0.17
Charge-flip	–	0.02 ± 0.01	0.60 ± 0.12	0.19 ± 0.06
$t\bar{t}W$	0.02 ± 0.01	0.08 ± 0.04	1.1 ± 0.4	0.10 ± 0.05
$t\bar{t}Z$	0.10 ± 0.04	0.05 ± 0.03	0.92 ± 0.31	0.14 ± 0.06
WZ	1.2 ± 0.4	0.48 ± 0.20	0.18 ± 0.11	< 0.02
$W^\pm W^\pm jj$	–	0.12 ± 0.07	0.03 ± 0.02	< 0.01
ZZ	< 0.03	< 0.04	< 0.03	< 0.03
Rare	0.14 ± 0.08	0.07 ± 0.05	0.8 ± 0.4	0.24 ± 0.14
$N_{\mathrm{BSM}}^{\mathrm{obs}}$ ($N_{\mathrm{BSM}}^{\mathrm{exp}}$)	5.9 ($4.1^{+1.6}_{-0.8}$)	6.4 ($3.6^{+1.2}_{-1.1}$)	8.8 ($6.0^{+2.6}_{-1.6}$)	3.8 ($3.7^{+1.1}_{-0.5}$)
$\sigma_{\mathrm{vis}}^{\mathrm{obs}}$ [fb]	1.8	2.0	2.8	1.2

VR yields

	VR-WW	VR-WZ	VR-ttV	VR-ttZ
Observed events	4	82	19	14
Total background events	3.4 ± 0.8	98 ± 15	12.1 ± 2.7	9.7 ± 2.5
Fake/non-prompt leptons	0.6 ± 0.5	8 ± 6	2.1 ± 1.4	0.6 ± 1.0
Charge-flip	0.26 ± 0.05	–	1.14 ± 0.15	–
$t\bar{t}W$	0.05 ± 0.03	0.25 ± 0.09	2.4 ± 0.8	0.10 ± 0.03
$t\bar{t}Z$	0.02 ± 0.01	0.72 ± 0.26	3.9 ± 1.3	6.3 ± 2.1
WZ	1.0 ± 0.4	78 ± 13	0.19 ± 0.10	1.2 ± 0.4
$W^\pm W^\pm jj$	1.3 ± 0.5	–	0.02 ± 0.03	–
ZZ	0.02 ± 0.01	8.2 ± 2.8	0.12 ± 0.15	0.30 ± 0.19
Rare	0.10 ± 0.05	2.8 ± 1.4	2.3 ± 1.2	1.1 ± 0.6

Back-up
2ssl3l Systematics

	SR0b3j	SR0b5j	SR1b	SR3b
Diboson theoretical uncertainties	$\boxed{23\%}$	$\boxed{16\%}$	1%	<1%
$t\bar{t}V$ theoretical uncertainties	3%	4%	$\boxed{13\%}$	9%
Other theoretical uncertainties	5%	3%	9%	$\boxed{15\%}$
MC statistical uncertainties	11%	14%	3%	6%
Jet energy scale	12%	11%	6%	5%
Jet energy resolution	3%	9%	2%	3%
b-tagging	4%	6%	3%	10%
PDF	6%	6%	6%	8%
Fake/non-prompt leptons	$\boxed{18\%}$	$\boxed{20\%}$	$\boxed{18\%}$	$\boxed{21\%}$
Charge flip	–	1%	3%	8%
Total background uncertainties	30%	34%	22%	31%
Total background events	1.5	0.88	4.5	0.80