Inclusive searches for squarks and gluinos with the ATLAS experiment at LHC

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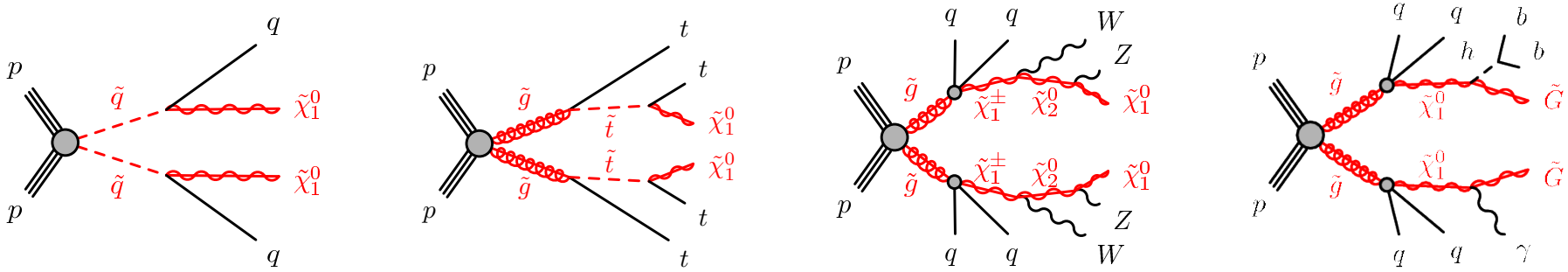
Overview

- Scenarios : $pp \to \tilde{q}\tilde{q}, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$ with R-parity conserving + prompt decays



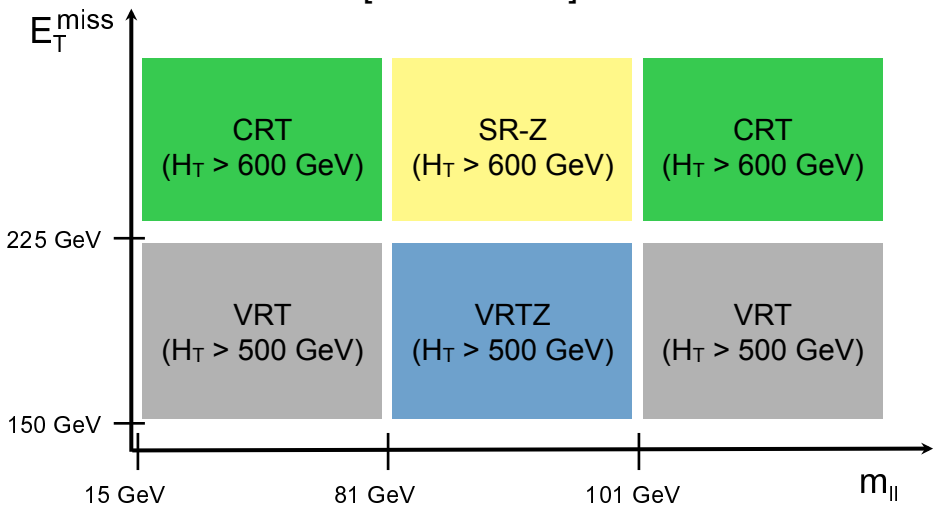
- Results released this Summer by the ATLAS SUSY group:
  - Summary of run-1 analyses [1507.05525]: combination of published analyses exclusion limits for multiple scenarios, new signal regions, new interpretations, new analysis (0 lepton razor)...
  - Photon + X searches [1507.05493] : analysis of full 2012 dataset

Typical search strategies

Discriminant variables

- Build Signal Regions (SRs) by using missing transverse momentum E_T^{miss}, number of jets, effective mass $m_{\text{eff}} = \sum_{j,\ell} p_T + E_T^{\text{miss}}$, transverse masse m_T
- Exclusions limits set from best expected, or statistical combination of orthogonal SRs

[1503.03290]



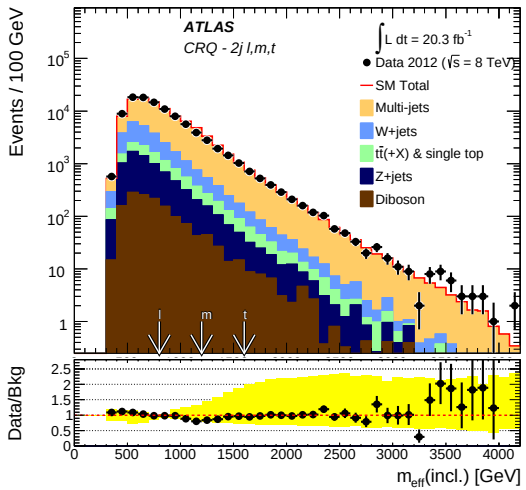
Background estimate

- Control regions (CRs) for W, Z or $t\bar{t}$ processes to normalize MC samples near the Signal Regions
- Data-driven methods for backgrounds less accurately described by the simulations
- Pure MC prediction for rare processes, with theoretical uncertainties
- Validation Regions (VRs) to check the background estimates close to the SRs

Data-driven background estimates

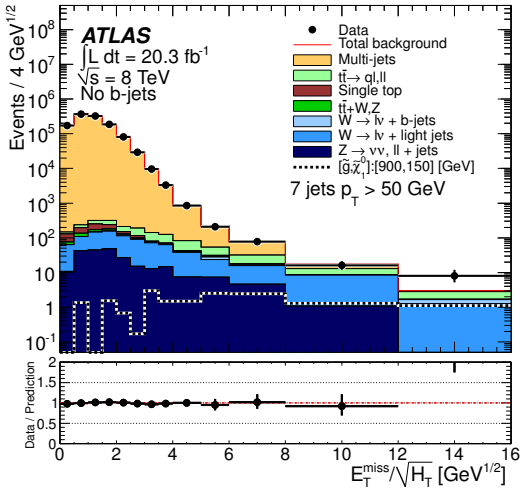
Jet smearing

Smear jet p_T in low-E_T^{miss} seed data events, with the measured energy response
$\rightarrow$ 0L, $Z + E_T^{\text{miss}}$, τ searches



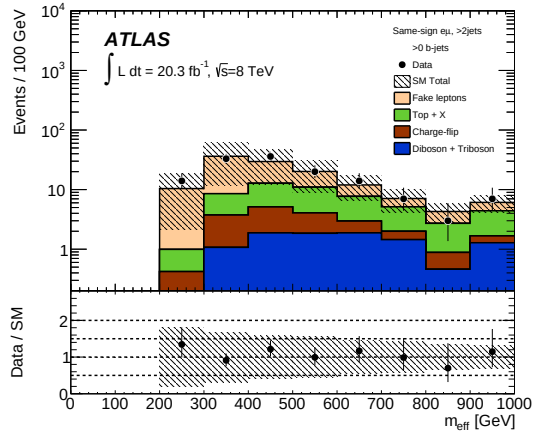
QCD template

Extrapolate $E_T^{\text{miss}}/\sqrt{H_T}$ shape in data from low to high jet multiplicity
$\rightarrow$ multijets search



Matrix method, fake factor

Obtain rates of misidentified $e/\mu/\gamma/\tau/b$ by exploiting the different responses of real/fake objects to iso/PID/tagging
$\rightarrow$ used by $\sim$ all searches



ABCD method

Rely on two uncorrelated discriminant variables to define orthogonal background-rich regions
$\rightarrow \tau + X$, $\gamma + X$ searches for multijets bkg

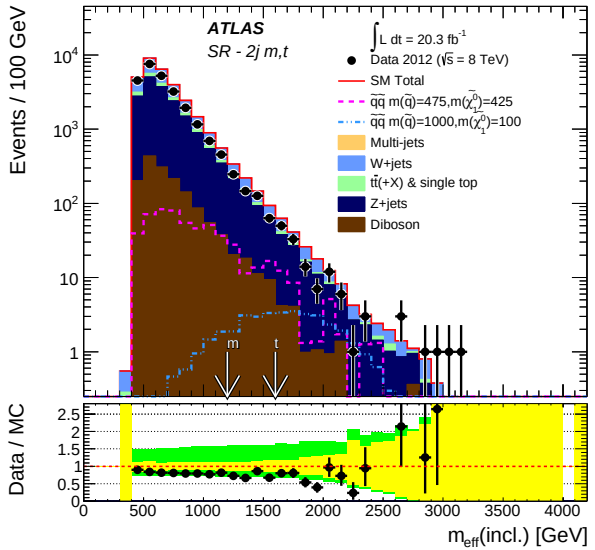
Universality of EW interactions

Control regions for $W \rightarrow \tau_h \nu$ or $Z \rightarrow \nu\nu$ use $W \rightarrow \ell\nu$, $Z \rightarrow \ell\ell$ or $Z \leftrightarrow \gamma$

Direct squark/gluino decays

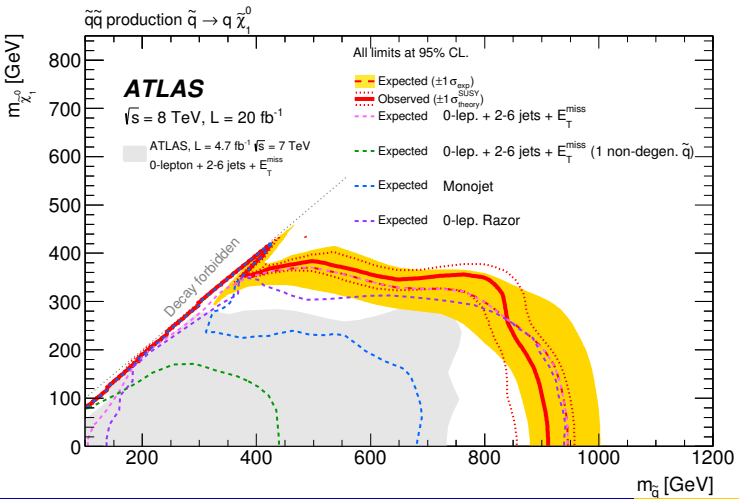
0 lepton + 2-6 jets + E_T^{miss} [1405.7875]

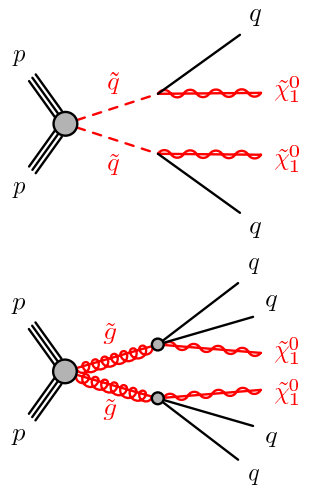
- 17 SRs split by jet multiplicity and variable tightness of m_{eff} and E_T^{miss} "significance" cuts
- 2 of them require $W \to qq$ candidates (resolved or not)
- background: $Z \to \nu\nu$, $W/t\bar{t} \to \tau\nu$ or missed e/μ

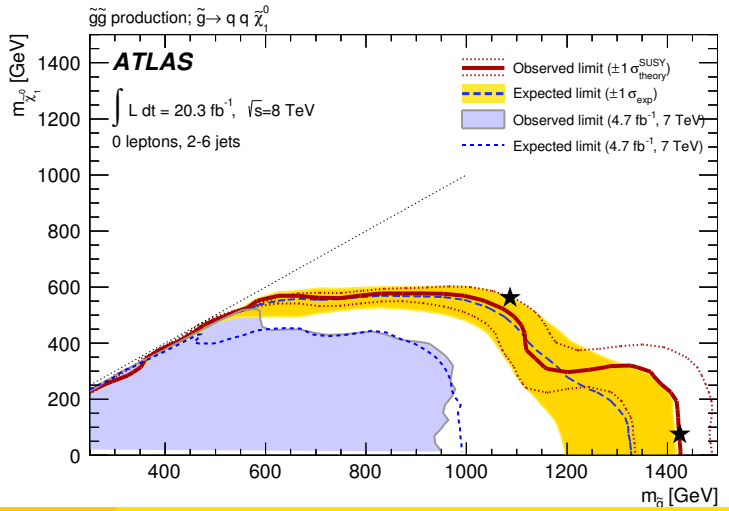


Reinterpretation of monojet+E_T^{miss} [1407.0608]

- small ΔM: 3 SRs selecting hard ISR jet + high E_T^{miss}



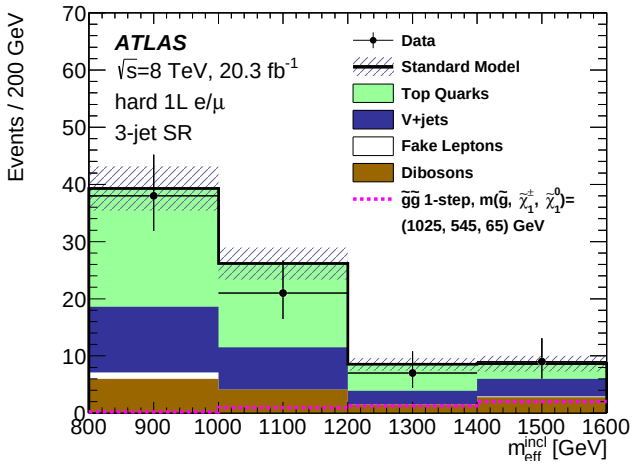


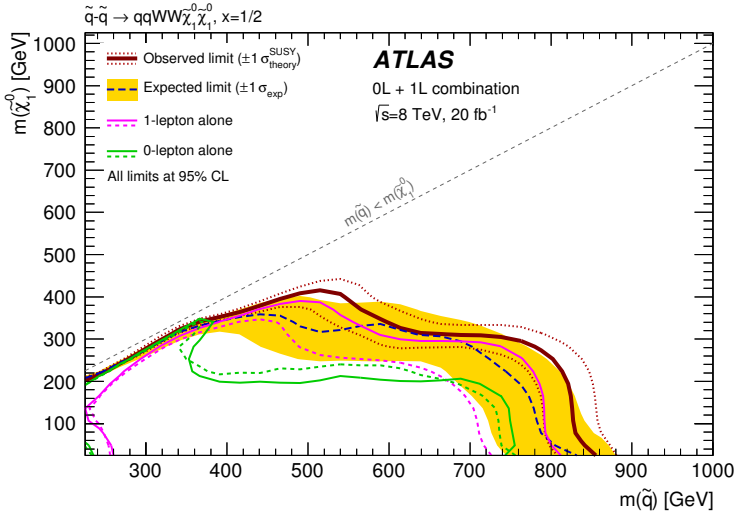


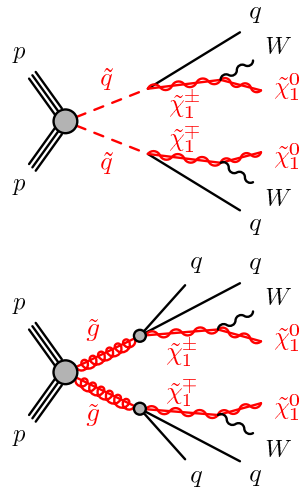
One-step decays and combination

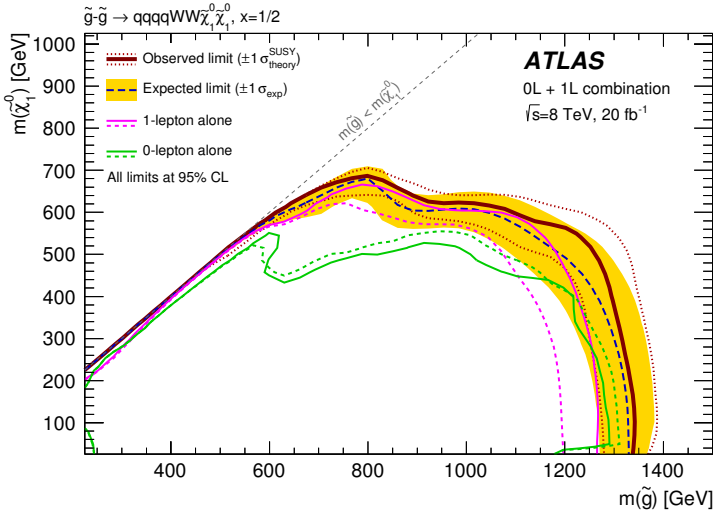
1 lepton + $\geq$ 3-7 jets + E_T^{miss} [1501.03555]

- 7 orthogonal SRs split into hard/soft leptons and #jets, only search (with soft $\mu\mu$) down to $p_T^{\mu(e)} > 6(7)$ GeV
- combined fit of m_{eff}, E_T^{miss} or $E_T^{\text{miss}}/m_{\text{eff}}$ distributions
- bkg: $t\bar{t}$ and W+jets, fake leptons at low p_T
- orthogonal to 0L or 2L $\Rightarrow$ combined where useful $\rightarrow$ single likelihood, correlated uncertainties





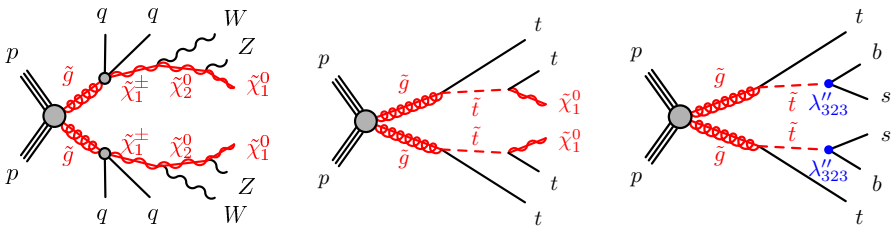




Longer decay chains, general-purpose searches

0 lepton + $\geq$ 7-10 jets [1308.1841]

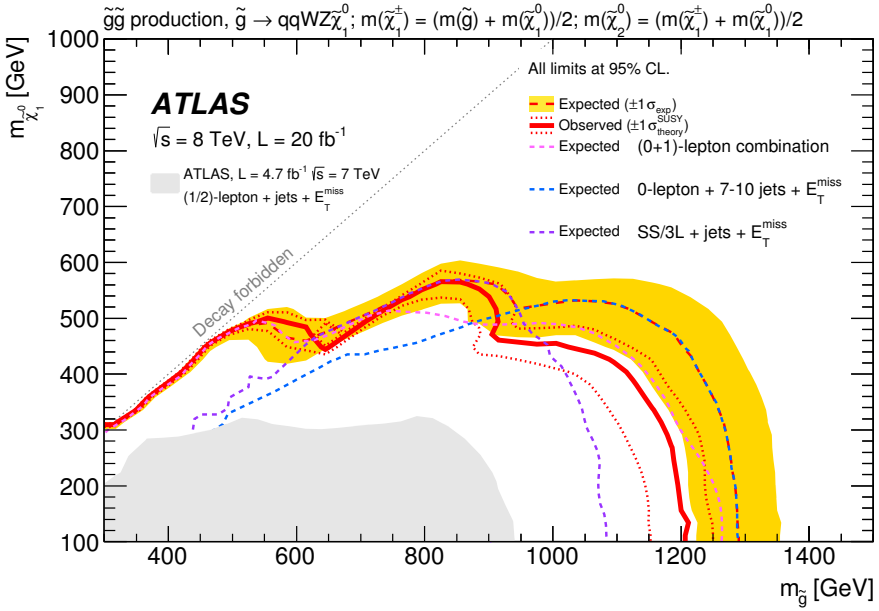
- 13 SRs split by central jets multiplicity
- 6 SRs identifying boosted heavy particles hadronic decays with $\sum M\{\text{fat jet}\}$
- bkg: QCD, $t\bar{t} \to \ell\nu qq$



- Signal regions w/wo b-tagged jets
- Moderate E_T^{miss} requirements

Same-sign / 3 leptons + jets [1404.2500]

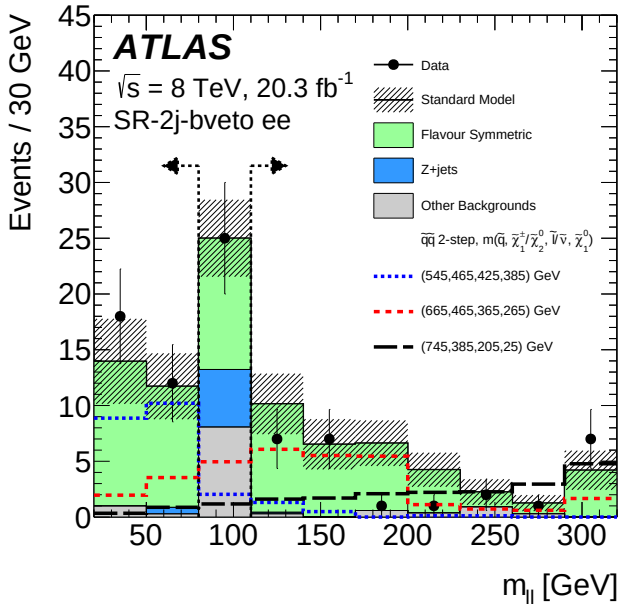
- 5 SRs $\sim$ orthogonal, combined m_{eff} fit
- low bkg : $t\bar{t}V$, VV, non-prompt leptons

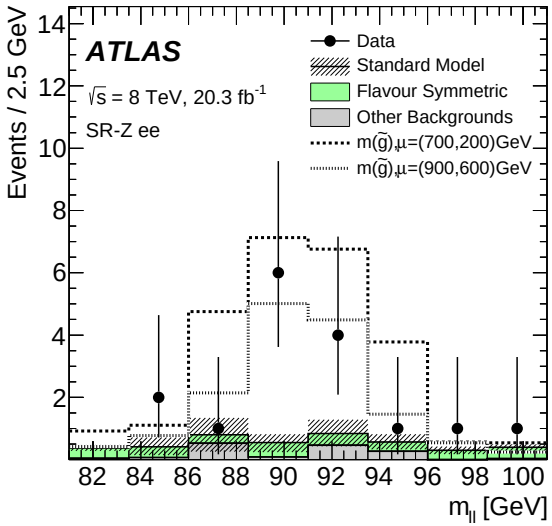


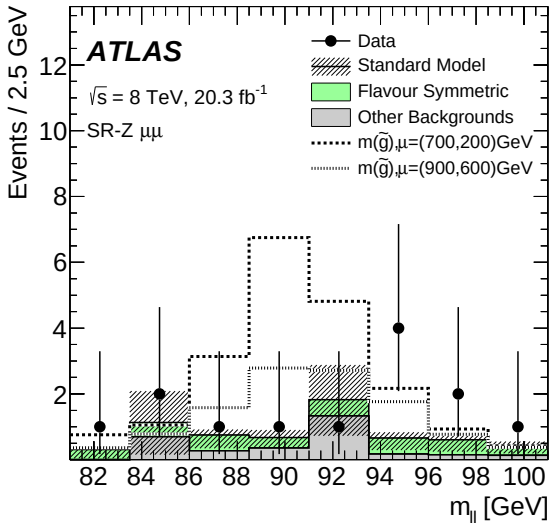
Beyond simple selections : dilepton lineshape

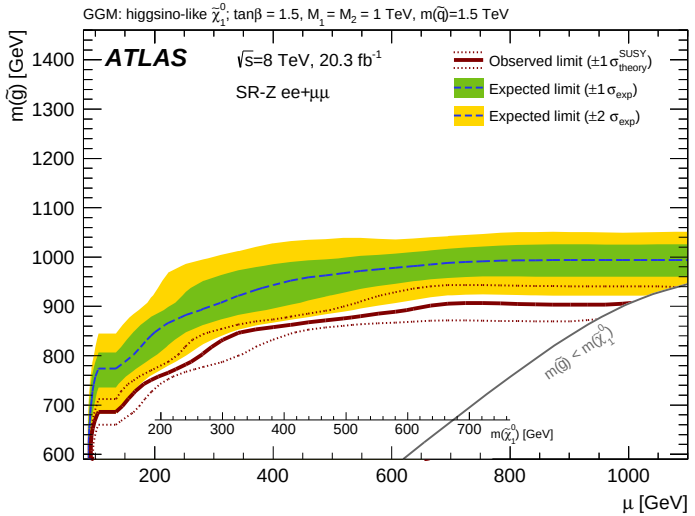
Same-flavor dilepton searches [1503.03290]

- On-Z: targets $\tilde{\chi} \to Z\tilde{\chi}_1^0$ decays (or $\to Z\tilde{G}$) $\to \geq 2$ jets, $E_T^{\text{miss}} > 225$, $H_T > 600$ GeV
- Off-Z: kinematic edge of $\tilde{\chi} \to \ell^+\ell^-\tilde{\chi}_1^0$ through Z^* or $\tilde{\ell}$ $\to$ 4 SRs with $E_T^{\text{miss}} > 200$ and $\geq 2/4$ jets, w/wo b-tag, + 1 looser SR to check CMS observations
- bkg: flavor-symmetric ($t\bar{t}$, VV) estimated from $e\mu$ channel, Z/γ^*+jets
- no excess in off-Z search, but 3.0 σ in on-Z ee channel





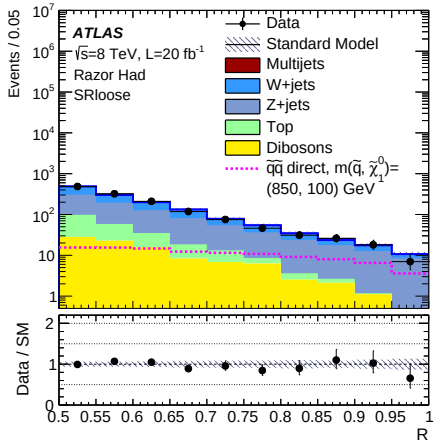


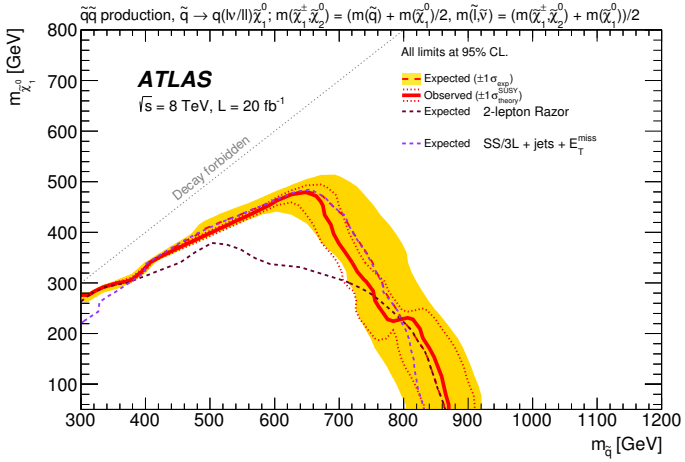


Beyond simple selections : razor variables, m_{CT}

Razor: 0 lepton [1507.05525], 2 leptons [1501.03555]

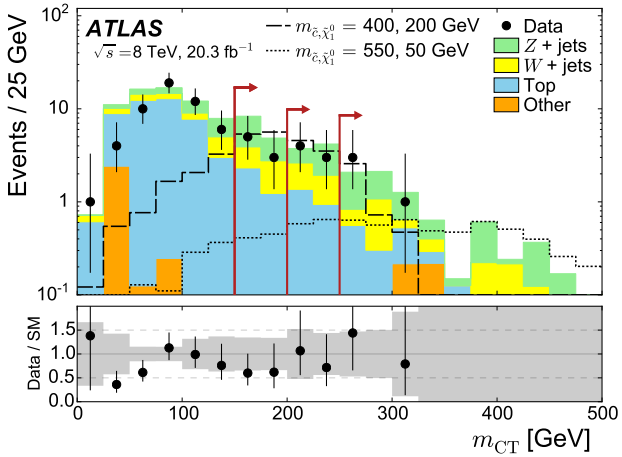
- Build 2 mega-jets from visible reconstructed objects
- M_R' and M_T^R estimate mass scale from topology-based assumptions, or transverse info (including E_T^{miss})
- Ratio R gauges consistency

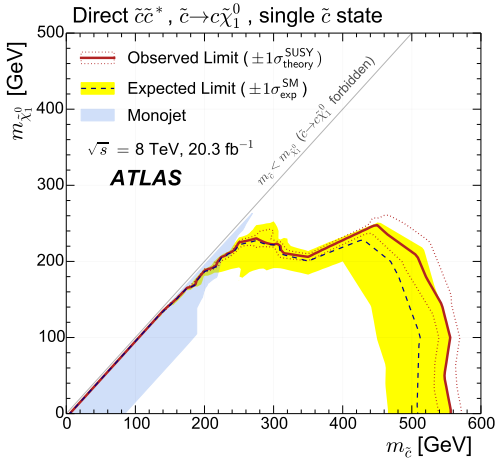




Direct scharm production [1501.01325]

- Two leading jets c-tagged
- Cuts on E_T^{miss} and m_{cc}
- Boost-corrected m_{CT}, cut $> t\bar{t}$ end-point

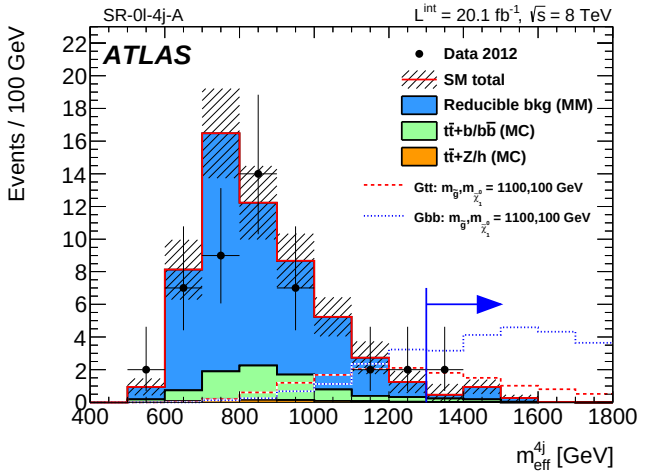




Third generation-mediated decays

0/1 lepton + $\geq$ 4-7 jets, $\geq$ 3 b-tagged [1407.0600]

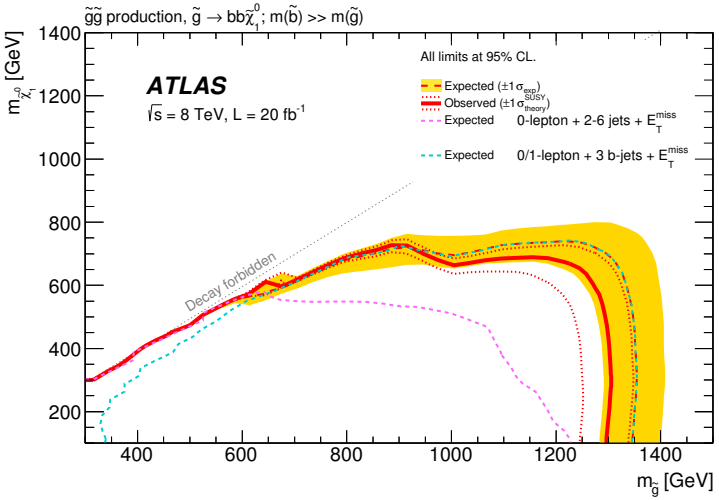
- 0L: 6 SRs with $\geq 4(7)$ jets for $\tilde{b}(\tilde{t})$-mediated decays $\rightarrow$ various cuts tightnesses on E_T^{miss} and m_{eff}
- 1L: 3 SRs with ≥ 6 jets, softer kinematic cuts
- bkg: mostly $t\bar{t}$ with mis-identified b-jet, $t\bar{t} + b\bar{b}$

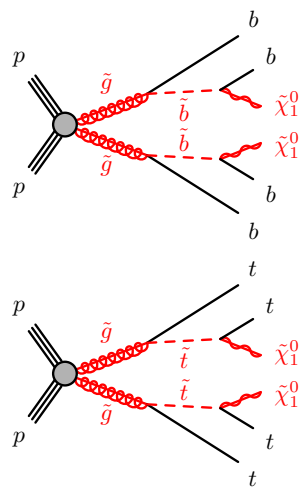


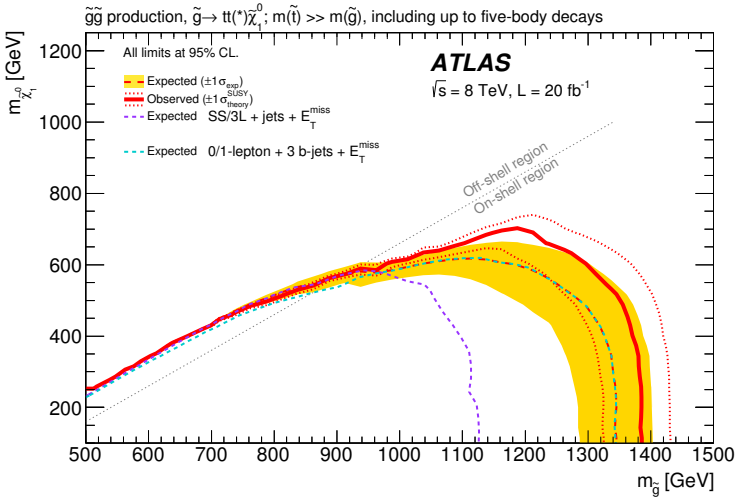
Complementary searches [1507.05525]

For decays with less b quarks: $\tilde{t} \rightarrow c\tilde{\chi}_1^0$, $\tilde{t} \rightarrow bs$ (RPV)

added 4/5-body decays for $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ $\rightarrow$ probing experimental sensitivity to more compressed mass spectra



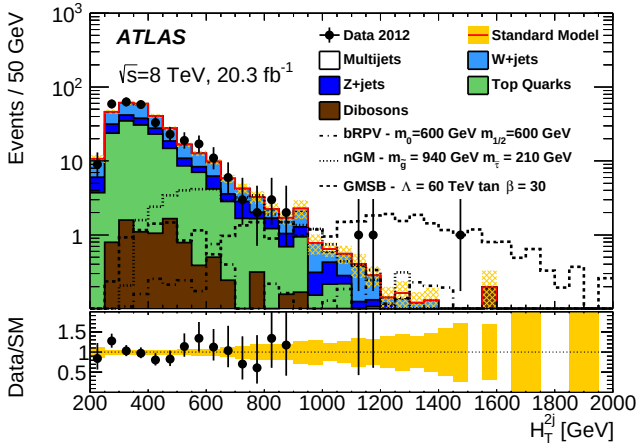




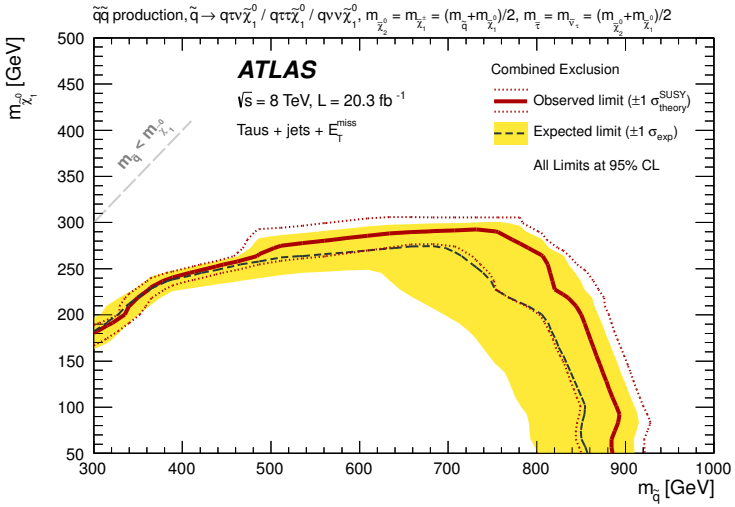
Light(er) staus

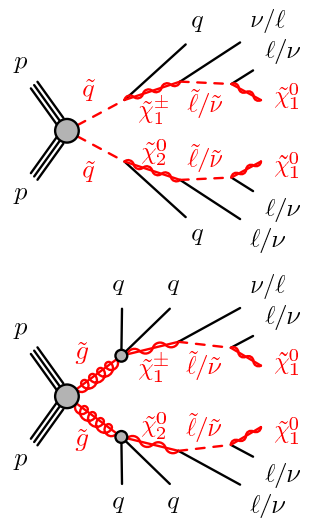
Searches with tau(s) [1407.0603]

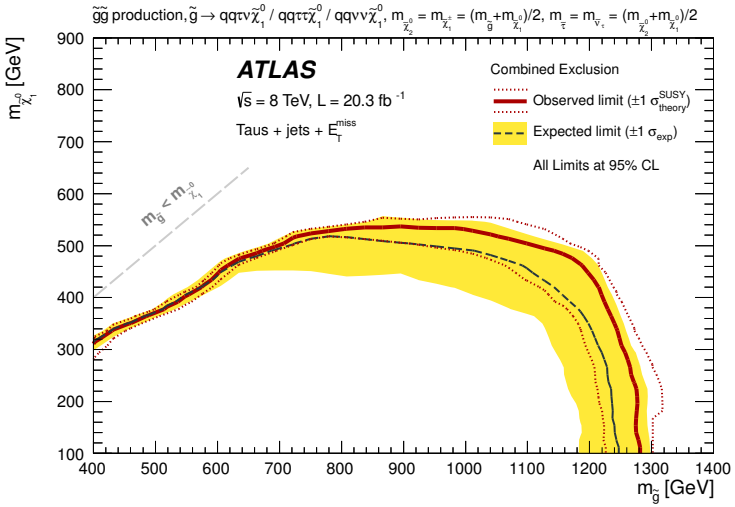
- GMSB scenarios with $\tilde{\tau}$ NLSP; + new reinterpretations
- Split into $1\tau + 0\ell$, $2\tau + 0\ell$ and $\geq 1\tau + 1\ell$ channels
- 10 SRs with $\geq$2-4 jets, E_T^{miss}, m_{eff}, H_T^{2j}, $m_T^{\tau 1} + m_T^{\tau 2}$ cuts
- bkg: V+jets, $t\bar{t}$: CR for each process and real/fake τ contribution; data-driven QCD (jet smearing, ABCD)



here only
$\tilde{\tau}$-mediated decays



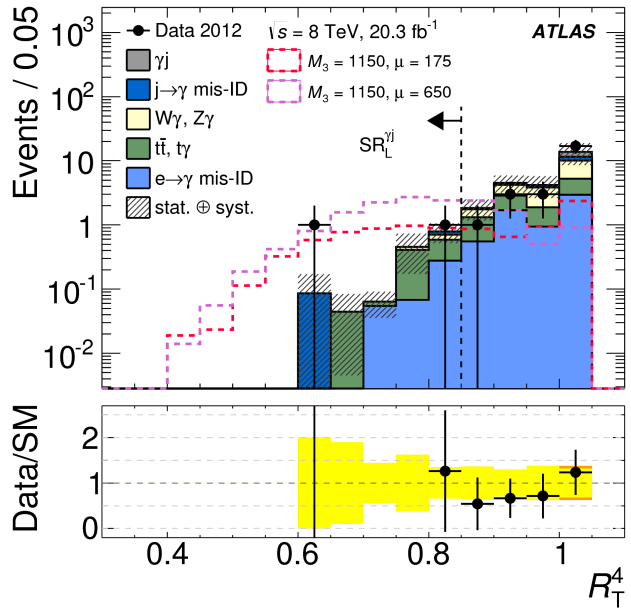


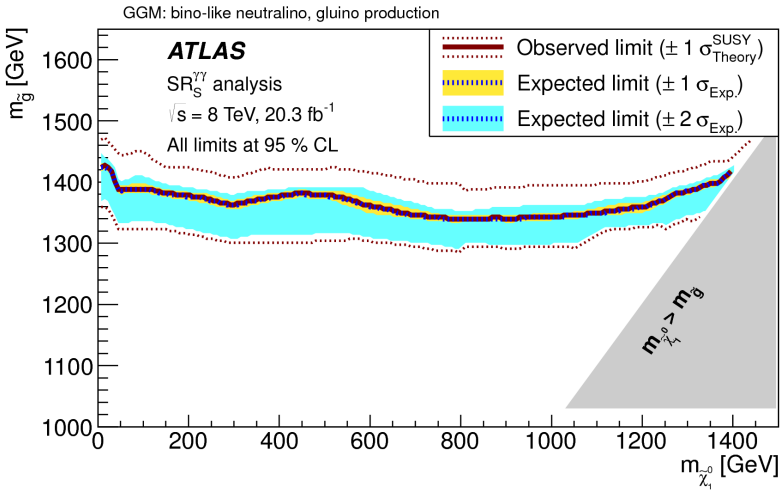


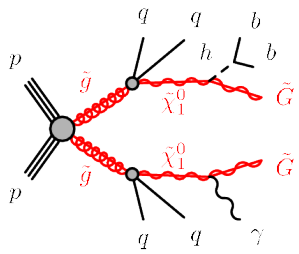
Gauge-mediated SUSY : photon signatures

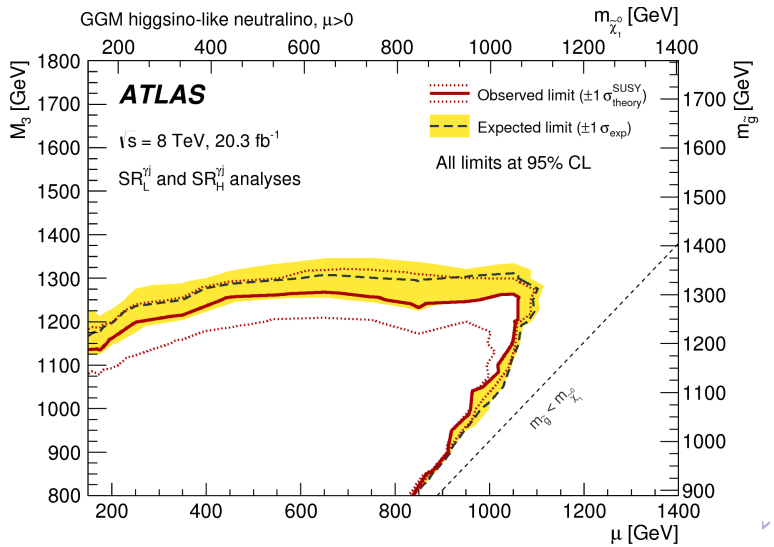
Searches with photon+X ($X = \gamma, j, b$) [1507.05493]

- GGM scenarios with bino- or higgsino-like $\tilde{\chi}_1^0$ NLSP
- 6 SRs for strong production : cuts on E_T^{miss}, m_{eff} or H_T + m_{bb} & m_T^{γ} for γb, jet momentum balance R_T^4 for γj
- bkg: QCD $\gamma\gamma/\gamma j$, $V/t\bar{t} + \gamma$, fake γ from e or jet
  $\rightarrow$ various estimation methods depending on the channel



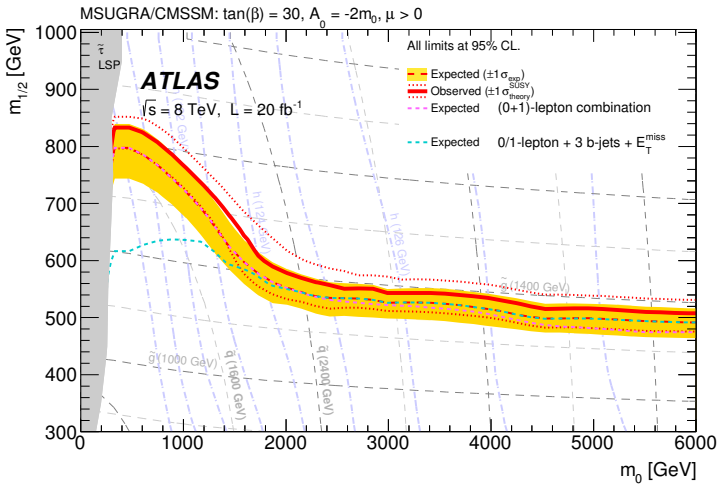


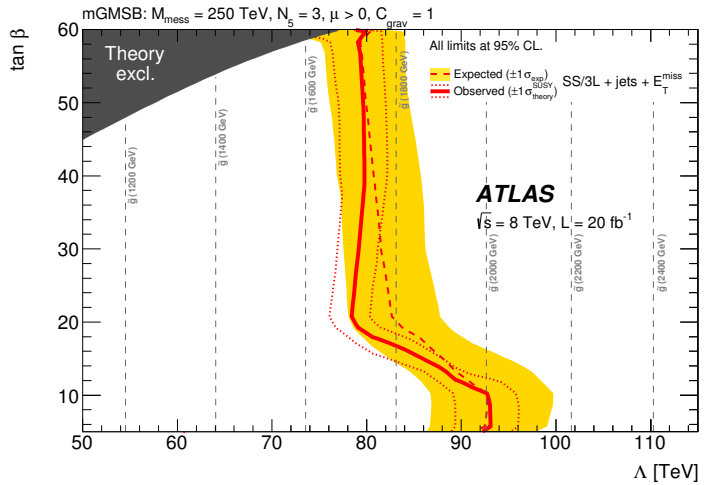


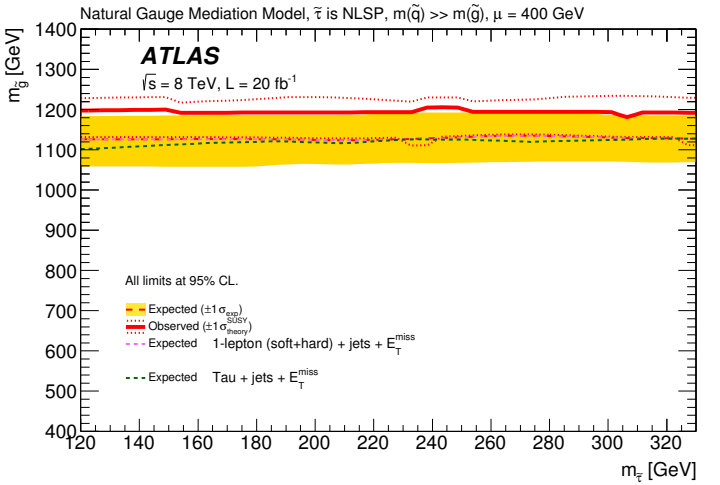


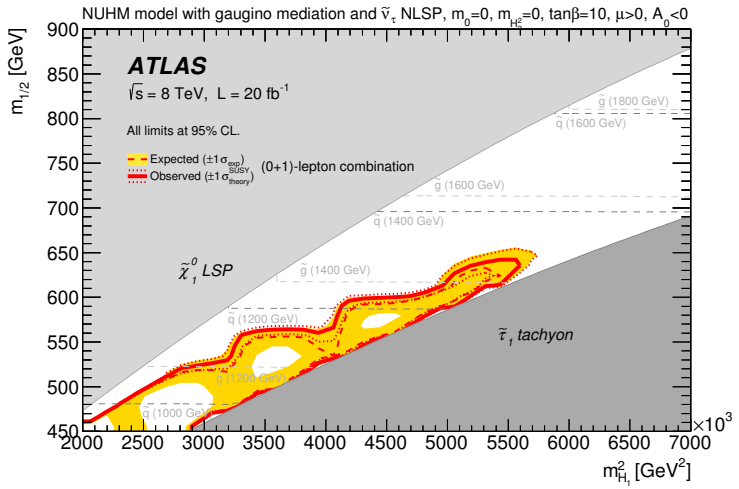
Phenomenological models

- Combined limits also set on several phenomenological models [1507.05525]



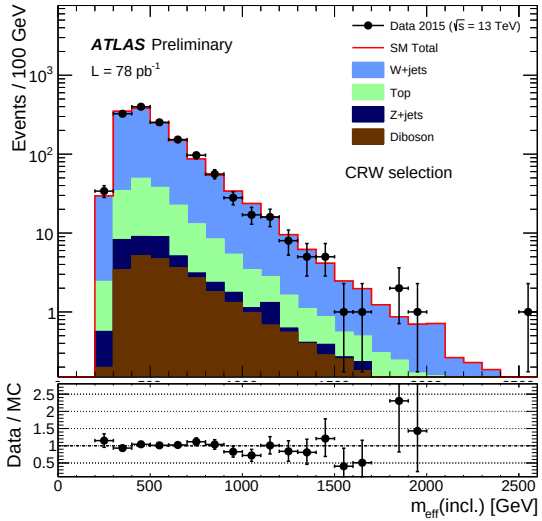




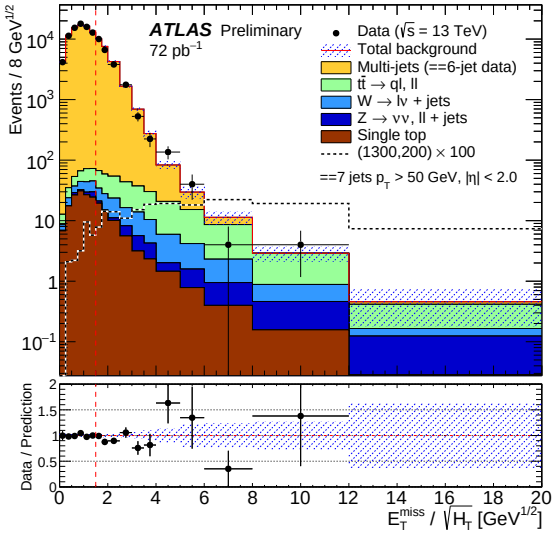


Toward the analysis of the 13 TeV data

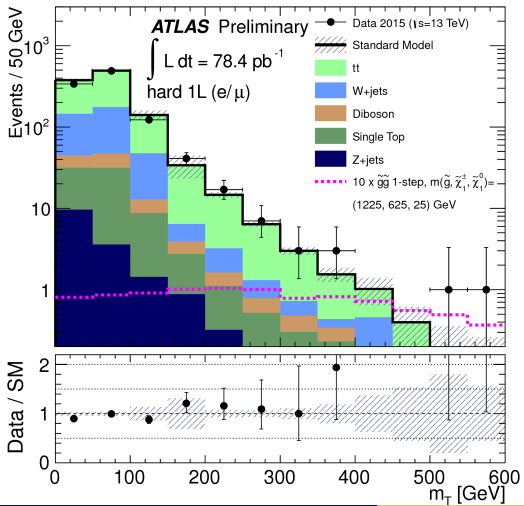
[ATL-PHYS-PUB-2015-028]



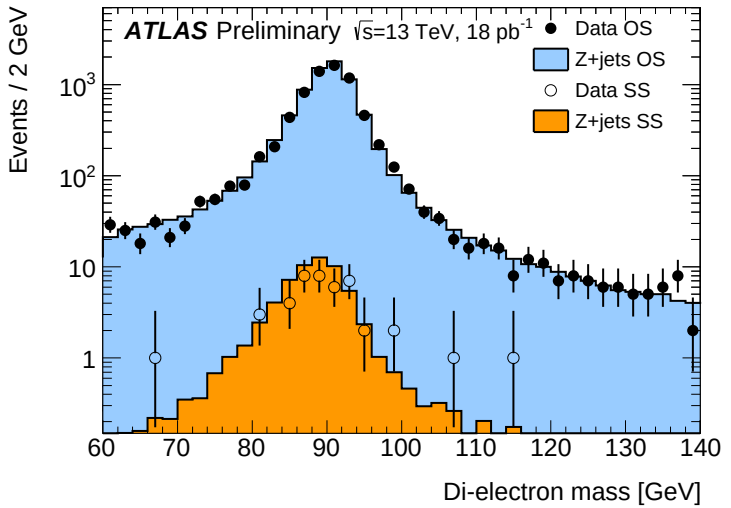
[ATL-PHYS-PUB-2015-029]



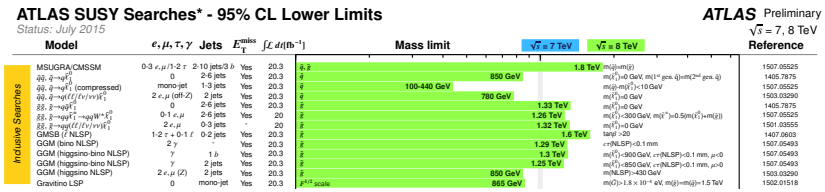
[ATL-PHYS-PUB-2015-030]



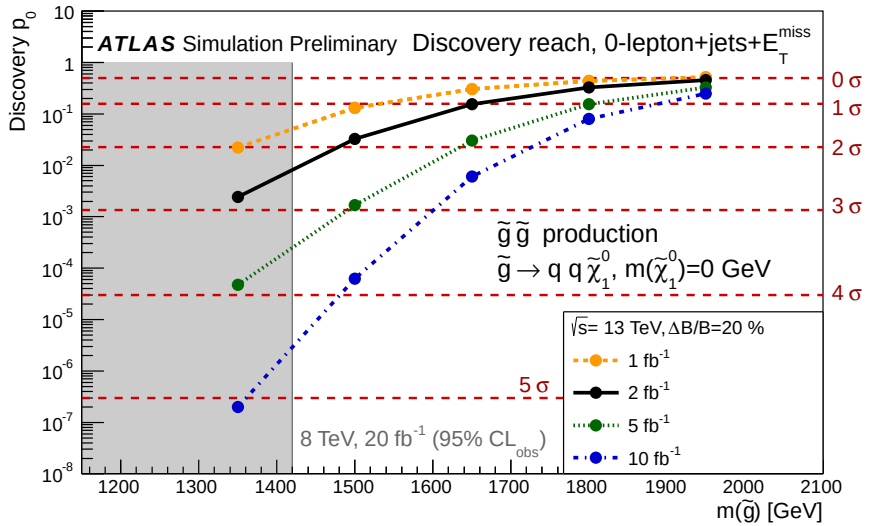
[ATL-PUB-EGAM-2015-003]



Conclusion



[ATL-PHYS-PUB-2015-005]



- Summary of run-1 searches: various complementary topologies analyzed, various signal scenarios probed : no evidence for Supersymmetry
- Starting a new chapter at 13 TeV: soon access to yet unexplored regions!

Additional material

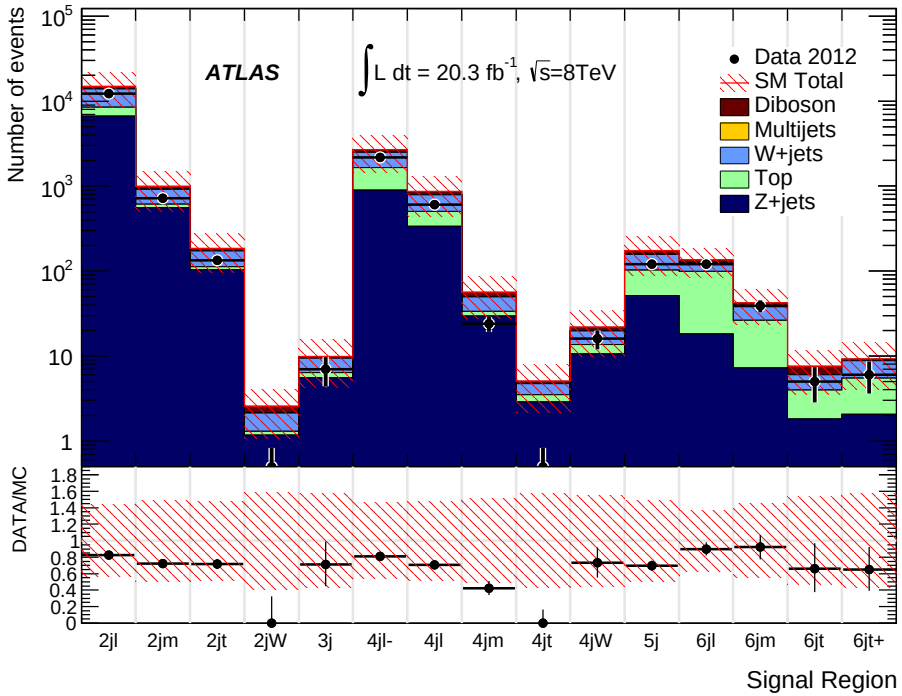
Signal scenarios and complementarity of the searches

Model	(0+1)-lepton combination	MONOJ	0L	MULTJ	0LRaz	1L(S,H)	1L(H)	2L(S)	2LRaz	2L-offZ	SS/3L	TAU	0/1L3B
pMSSM			✓										
mSUGRA/CMSSM	✓			✓			✓				✓	✓	✓
mSUGRA/CMSSM with bRPV			✓	✓		✓	✓				✓	✓	
mGMSB											✓	✓	
nGM			✓			✓						✓	
NUHMG	✓												
mUED			✓			✓		✓	✓		✓		
$\tilde{q}\tilde{q}$ production, $\tilde{q} \to q\tilde{\chi}_1^0$		✓	✓		✓								
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to qq\tilde{\chi}_1^0$			✓										
$\tilde{q}\tilde{g}$ production, $\tilde{q} \to q\tilde{\chi}_1^0$, $\tilde{g} \to qq\tilde{\chi}_1^0$			✓										
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to g\tilde{\chi}_1^0$			✓										
$\tilde{q}\tilde{q}$ production, $\tilde{q} \to qW\tilde{\chi}_1^0$	✓												
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to qqW\tilde{\chi}_1^0$	✓			✓							✓		
$\tilde{q}\tilde{q}$ production, $\tilde{q} \to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	✓								✓	✓	✓		
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	✓			✓		✓			✓	✓	✓		
$\tilde{q}\tilde{q}$ production, $\tilde{q} \to q(\tau\tau/\tau\nu/\nu\nu)\tilde{\chi}_1^0$												✓	
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to qq(\tau\tau/\tau\nu/\nu\nu)\tilde{\chi}_1^0$												✓	
$\tilde{q}\tilde{q}$ production, $\tilde{q} \to qWZ\tilde{\chi}_1^0$			✓								✓		
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to qqWZ\tilde{\chi}_1^0$	✓			✓							✓		
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ (off-shell stop)				✓		✓					✓		✓
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to t\tilde{\chi}_1^0$				✓									✓
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$											✓		✓
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to c\tilde{\chi}_1^0$	✓										✓		
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to bs$				✓							✓		
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to tb\tilde{\chi}_1^0$													✓
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ (off-shell sbottom)			✓										✓
$\tilde{g}\tilde{g}$ production, $\tilde{g} \to \tilde{b}_1 b$, $\tilde{b}_1 \to b\tilde{\chi}_1^0$													✓

Signal regions for the zero lepton + 2-6 jets search

Requirement	Signal region					
	2jl	**2jm**	**2jt**	**2jW**	**3j**	**4jW**
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] >	160					
$p_{\mathrm{T}}^{\mathrm{jet}_1}$ [GeV] >	130					
$p_{\mathrm{T}}^{\mathrm{jet}_2}$ [GeV] >	60					
$p_{\mathrm{T}}^{\mathrm{jet}_3}$ [GeV] >	–				60	40
$p_{\mathrm{T}}^{\mathrm{jet}_4}$ [GeV] >	–					40
$\Delta\phi(\mathrm{jet}_{1,2,(3)}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.4					
$\Delta\phi(\mathrm{jet}_{i>3}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	–					0.2
W candidates	–			$2(W \to j)$	–	$(W \to j) + (W \to jj)$
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] >	8	15		–		
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{N_{\mathrm{j}}}$ >	–			0.25	0.3	0.35
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] >	800	1200	1600	1800	2200	1100

Requirement	Signal region								
	4jl-	**4jl**	**4jm**	**4jt**	**5j**	**6jl**	**6jm**	**6jt**	**6jt+**
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] >	160								
$p_{\mathrm{T}}^{\mathrm{jet}_1}$ [GeV] >	130								
$p_{\mathrm{T}}^{\mathrm{jet}_2}$ [GeV] >	60								
$p_{\mathrm{T}}^{\mathrm{jet}_3}$ [GeV] >	60								
$p_{\mathrm{T}}^{\mathrm{jet}_4}$ [GeV] >	60								
$p_{\mathrm{T}}^{\mathrm{jet}_5}$ [GeV] >	–				60				
$p_{\mathrm{T}}^{\mathrm{jet}_6}$ [GeV] >	–					60			
$\Delta\phi(\mathrm{jet}_{1,2,(3)}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.4								
$\Delta\phi(\mathrm{jet}_{i>3}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.2								
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] >	10		–						
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{N_{\mathrm{j}}}$ >	–		0.4	0.25	0.2			0.25	0.15
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] >	700	1000	1300	2200	1200	900	1200	1500	1700



Signal region name	**0L_4jt+**	**0L_5jt**
Number of jets $\geq$	4	5
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{N_{\mathrm{j}}} \geq$	0.30	0.15
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] $\geq$	2200	1900

Signal regions for the 1-2 leptons + jets searches

Requirement	Signal region			
	Single-bin (binned) soft single-lepton			**Soft dimuon**
	3-jet	**5-jet**	**3-jet inclusive**	**2-jet**
N_ℓ	1 electron or muon			2 muons
p_{T}^{ℓ} [GeV]	[7,25] for electron, [6,25] for muon			[6,25]
Lepton veto	No additional electron or muon with $p_{\mathrm{T}} > 7$ GeV or 6 GeV, respectively			
$m_{\mu\mu}$ [GeV]	–	–	–	[15,60]
N_{jet}	[3,4]	≥ 5	≥ 3	≥ 2
p_{T} $^{\mathrm{jet}}$[GeV] $>$	180, 25, 25	180, 25, 25, 25, 25	130, 100, 25	80, 25
$N_{b-\mathrm{jet}}$	–	–	0	0
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] $>$	400	300	180	
m_{T} [GeV] $>$	100		120	40
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{\mathrm{incl}}$ $>$	0.3 (0.1)		0.1	0.3
$\Delta R_{\mathrm{min}}(\mathrm{jet}, \ell)$ $>$	1.0	–	–	1.0 (2^{nd} muon)
Binned variable	($E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{\mathrm{incl}}$ in 4 bins)			–
Bin width	(0.1, 4^{th} is inclusive)			–

Requirement	Signal region		
	Single-bin (binned) hard single-lepton		
	3-jet	**5-jet**	**6-jet**
N_ℓ	1 electron or muon		
p_{T}^{ℓ} [GeV] $>$	25		
Lepton veto	p_{T} $^{2^{\mathrm{nd}}\mathrm{lepton}} < 10$ GeV		
N_{jet}	≥ 3	≥ 5	≥ 6
p_{T} $^{\mathrm{jet}}$[GeV] $>$	80, 80, 30	80, 50, 40, 40, 40	80, 50, 40, 40, 40, 40
Jet veto	(p_{T} $^{5^{\mathrm{th}}\mathrm{jet}} < 40$ GeV)	(p_{T} $^{6^{\mathrm{th}}\mathrm{jet}} < 40$ GeV)	–
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] $>$	500 (300)	300	350 (250)
m_{T} [GeV] $>$	150	200 (150)	150
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{\mathrm{excl}}$ $>$	0.3	–	–
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] $>$	1400 (800)		600
Binned variable	($m_{\mathrm{eff}}^{\mathrm{incl}}$ in 4 bins)		($E_{\mathrm{T}}^{\mathrm{miss}}$ in 3 bins)
Bin width	(200 GeV, 4^{th} is inclusive)		(100 GeV, 3^{rd} is inclusive)

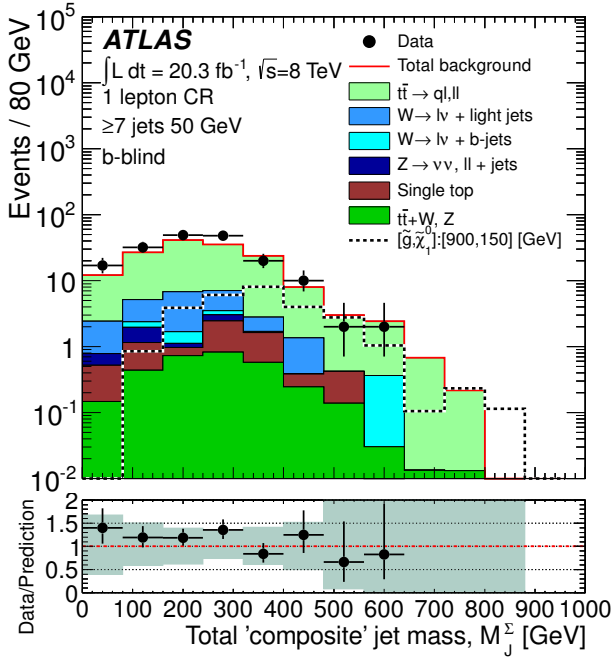
Requirement	Signal region			
	Single-bin (binned) hard dilepton			
	Low-multiplicity ($\leq$ 2-jet)		**3-jet**	
	$ee/\mu\mu$	$e\mu$	$ee/\mu\mu$	$e\mu$
N_ℓ	2, 2 of opposite sign or ≥ 2			
p_{T}^{ℓ} [GeV] $>$	14,10			
$N_{\ell\ell}$ with 81$<$ $m_{\ell\ell}$ $<$101 GeV	0	–	0	–
N_{jet}	≤ 2		≥ 3	
p_{T} $^{\mathrm{jet}}$[GeV] $>$	50,50		50, 50, 50	
$N_{b-\mathrm{jet}}$	0			
R	$>$0.5		$>$0.35	
M_R' [GeV] $>$	600 (400 in 8 bins)		800 (800 in 5 bins)	
M_R' bin width [GeV]	(100, the last is inclusive)			

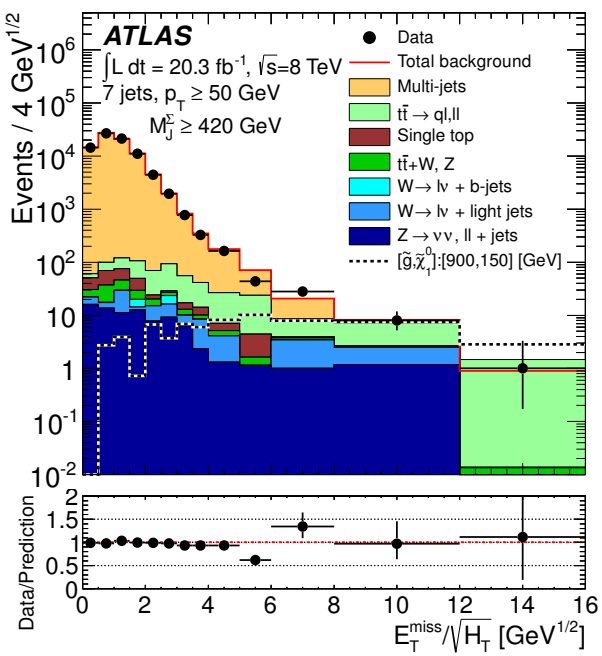
	1L(H)_7-jet	**1L(H)_WR_7-jet**	**1L(H)_TR_7-jet**	**1L(H)_V**
N_{lep}	$== 1$			
$p_{\mathrm{T}}^{\ell_1}$ [GeV]	> 25 (20)			
$p_{\mathrm{T}}^{\ell_2}$ [GeV]	< 10			
N_{jet}	≥ 7			
$p_{\mathrm{T}}^{\mathrm{jet}}$ [GeV]	$> 80, 25, 25, 25, 25, 25, 25$			
$N_{b-\mathrm{tag}}$	–	$== 0$	≥ 1	
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 180	$\in[100, 180]$	$\in[100, 180]$	$\in[1$
m_{T} [GeV]	> 120	$\in[40, 80]$	$\in[40, 120]$	$\in[$
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV]	> 750			

Signal regions for the zero lepton "multijets" search

Requirement	Signal region					
	2jl	**2jm**	**2jt**	**2jW**	**3j**	**4jW**
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] >	160					
$p_{\mathrm{T}}^{\mathrm{jet}_1}$ [GeV] >	130					
$p_{\mathrm{T}}^{\mathrm{jet}_2}$ [GeV] >	60					
$p_{\mathrm{T}}^{\mathrm{jet}_3}$ [GeV] >	–				60	40
$p_{\mathrm{T}}^{\mathrm{jet}_4}$ [GeV] >	–					40
$\Delta\phi(\mathrm{jet}_{1,2,(3)}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.4					
$\Delta\phi(\mathrm{jet}_{i>3}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	–					0.2
W candidates	–			$2(W \to j)$	–	$(W \to j) + (W \to jj)$
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] >	8	15		–		
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{N_{\mathrm{j}}}$ >	–			0.25	0.3	0.35
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] >	800	1200	1600	1800	2200	1100

Requirement	Signal region								
	4jl-	**4jl**	**4jm**	**4jt**	**5j**	**6jl**	**6jm**	**6jt**	**6jt+**
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] >	160								
$p_{\mathrm{T}}^{\mathrm{jet}_1}$ [GeV] >	130								
$p_{\mathrm{T}}^{\mathrm{jet}_2}$ [GeV] >	60								
$p_{\mathrm{T}}^{\mathrm{jet}_3}$ [GeV] >	60								
$p_{\mathrm{T}}^{\mathrm{jet}_4}$ [GeV] >	60								
$p_{\mathrm{T}}^{\mathrm{jet}_5}$ [GeV] >	–				60				
$p_{\mathrm{T}}^{\mathrm{jet}_6}$ [GeV] >	–					60			
$\Delta\phi(\mathrm{jet}_{1,2,(3)}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.4								
$\Delta\phi(\mathrm{jet}_{i>3}, \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$ >	0.2								
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ [GeV$^{1/2}$] >	10		–						
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}^{N_{\mathrm{j}}}$ >	–		0.4	0.25	0.2			0.25	0.15
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] >	700	1000	1300	2200	1200	900	1200	1500	1700





Signal regions for the same-sign/three leptons + jets search

Requirement	Signal region				
	SR3b	**SR0b**	**SR1b**	**SR3Llow**	**SR3Lhigh**
Leptons	SS or 3L	SS	SS	3L	3L
$N_{b-\text{jet}}$	≥ 3	=0	≥ 1	-	-
$N_{\text{jet}} \geq$	5	3	3	4	4
$E_{\text{T}}^{\text{miss}}$ [GeV]		> 150	> 150	$50 < E_{\text{T}}^{\text{miss}} < 150$	> 150
m_{T} [GeV] $>$	-	100	-	-	-
Veto	-	-	SR3b	Z boson, SR3b	SR3b
m_{eff} [GeV] $>$	350	400	700	400	400

SR0b $_{1bin}$	Total	ee	$e\mu$	$\mu\mu$
Observed events	14	7	5	2
Total expected background events	6.5 ± 2.3	1.5 ± 0.9	3.1 ± 1.2	1.9 ± 0.7
Components of the background				
$t\bar{t}V$, $t\bar{t}H$, tZ and $t\bar{t}t\bar{t}$	0.9 ± 0.4	0.2 ± 0.1	0.4 ± 0.2	0.3 ± 0.2
Dibosons and tribosons	4.2 ± 1.7	0.5 ± 0.3	2.3 ± 1.0	1.5 ± 0.6
Fake leptons	$1.2^{+1.5}_{-1.2}$	$0.7^{+0.9}_{-0.7}$	$0.4^{+0.6}_{-0.4}$	$0.1^{+0.2}_{-0.1}$
Charge-flip electrons	0.2 ± 0.1	0.1 ± 0.1	0.10 ± 0.03	–
$p(s = 0)$	0.03	0.01	0.21	0.46

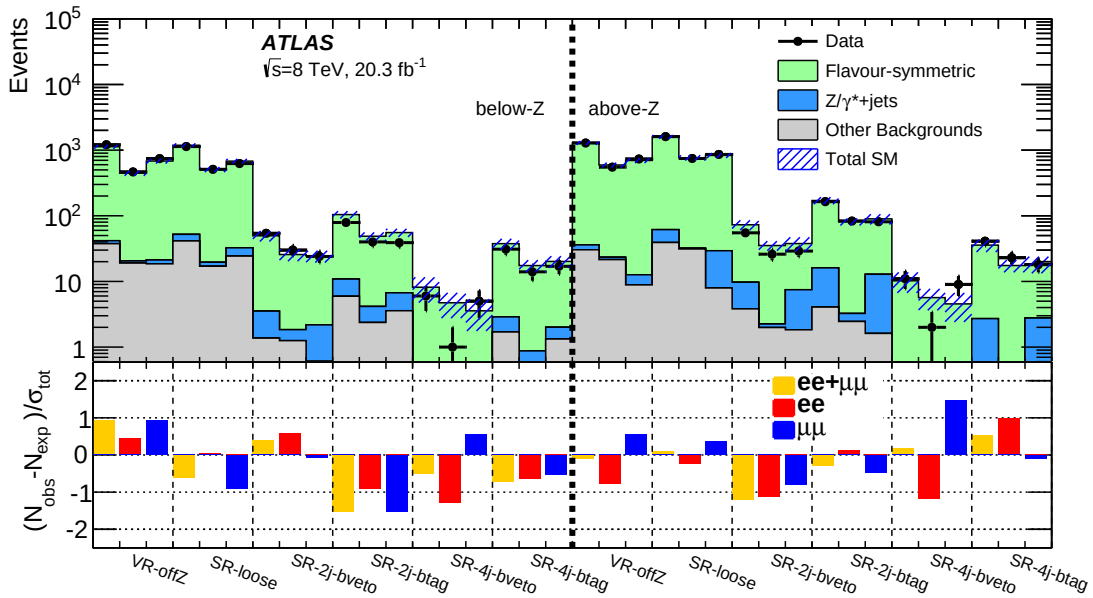
SR1b $_{1bin}$	Total	ee	$e\mu$	$\mu\mu$
Observed events	10	6	4	0
Total expected background events	4.7 ± 2.1	1.4 ± 0.8	2.1 ± 1.1	1.2 ± 0.4
Components of the background				
$t\bar{t}V$, $t\bar{t}H$, tZ and $t\bar{t}t\bar{t}$	2.5 ± 1.7	0.6 ± 0.3	1.2 ± 1.0	0.7 ± 0.3
Dibosons and tribosons	0.9 ± 0.4	0.10 ± 0.04	0.3 ± 0.1	0.5 ± 0.3
Fake leptons	$0.8^{+1.2}_{-0.8}$	$0.4^{+0.7}_{-0.4}$	$0.4^{+0.5}_{-0.4}$	< 0.1
Charge-flip electrons	0.5 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	–
$p(s = 0)$	0.07	0.01	0.18	0.50

SR3b $_{1bin}$	Total	ee	$e\mu$	$\mu\mu$
Observed events	1	0	1	0
Total expected background events	2.2 ± 0.8	0.8 ± 0.4	0.9 ± 0.3	0.5 ± 0.2
Components of the background				
$t\bar{t}V$, $t\bar{t}H$, tZ and $t\bar{t}t\bar{t}$	1.3 ± 0.5	0.3 ± 0.1	0.6 ± 0.2	0.4 ± 0.2
Dibosons and tribosons	< 0.1	< 0.1	< 0.1	< 0.1
Fake leptons	0.7 ± 0.6	0.4 ± 0.4	0.2 ± 0.2	0.1 ± 0.1
Charge-flip electrons	0.2 ± 0.1	0.10 ± 0.05	0.08 ± 0.03	–
$p(s = 0)$	0.50	0.50	0.46	0.50

SR3Llow $_{1bin}$	Total	ee	$e\mu$	$\mu\mu$
Observed events	6	2	2	2
Total expected background events	4.3 ± 2.1	0.8 ± 0.5	2.1 ± 1.1	1.5 ± 0.7
Components of the background				
$t\bar{t}V$, $t\bar{t}H$, tZ and $t\bar{t}t\bar{t}$	1.6 ± 1.0	0.4 ± 0.3	0.7 ± 0.4	0.5 ± 0.3
Dibosons and tribosons	1.2 ± 0.6	0.2 ± 0.2	0.3 ± 0.2	0.7 ± 0.4
Fake leptons	1.6 ± 1.6	$0.2^{+0.3}_{-0.2}$	1.1 ± 0.9	$0.3^{+0.4}_{-0.3}$
$p(s = 0)$	0.29	0.16	0.50	0.36

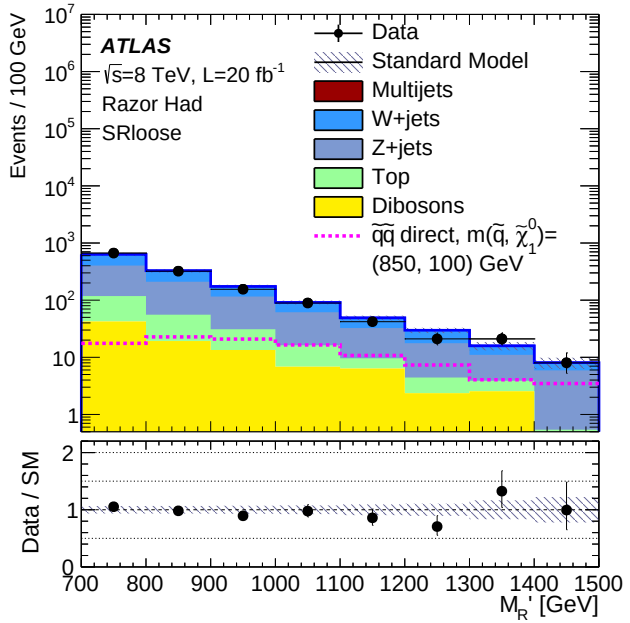
Signal regions for the dilepton "off-Z" search

Requirement	Signal region				
	SR-2j-bveto	**SR-2j-btag**	**SR-4j-bveto**	**SR-4j-btag**	**SR-loose**
$N_{\text{jet}} \geq$	≥ 2	≥ 2	≥ 4	≥ 4	$(2, \geq 3)$
$N_{b-\text{jet}}$	$= 0$	≥ 1	$= 0$	≥ 1	–
$E_{\text{T}}^{\text{miss}}$ [GeV] $>$	200	200	200	200	(150, 100)
$m_{\ell\ell}$ [GeV] $\notin$	[80, 110]	[80, 110]	[80, 110]	[80, 110]	[80, 110]



Signal regions for the zero lepton razor search

	0LRaz_SR$_{\text{loose}}$	**0LRaz_SR**$_{\text{tight}}$
$E_{\text{T}}^{\text{miss}}$ [GeV] >	160	
$p_{\text{T}}^{\text{jet}_{1,2}}$ [GeV] >	150	200
$\Delta\phi(\text{jet}_{1,2}, E_{\text{T}}^{\text{miss}})$ >	0.4	1.4
R >	0.5	0.6
M_R' [GeV] >	700	900



Signal region	**0LRaz_SR**$_{\text{loose}}$	**0LRaz_SR**$_{\text{tight}}$
Expected background events before the fit		
$t\bar{t}$	138	1.8
Single top	23.9	1.6
$t\bar{t}+V$	4.7	0.2
W+jets	794	49
Z+jets	762	58
Diboson	112	10
Fitted background events		
$t\bar{t}$	117 ± 22	1.7 ± 0.5
Single top	24.9 ± 2.6	1.8 ± 0.3
$t\bar{t}+V$	3.7 ± 1.0	0.20 ± 0.07
W+jets	454 ± 40	27.0 ± 3.0
Z+jets	618 ± 76	45 ± 6
Diboson	94 ± 49	10 ± 5
Multi-jet	14 ± 13	2.4 ± 2.4
Total background	1326 ± 84	88 ± 8
Observed events	1322	74
$\langle\epsilon\sigma\rangle_{\text{obs}}^{95}$ [fb]	6.17	0.83
S_{obs}^{95}	125.3	16.8
S_{exp}^{95}	$135.1^{+64.8}_{-42.2}$	$24.3^{+9.9}_{-6.9}$
$p(s=0)$	0.49	0.50

Signal regions for the 0-1 leptons + ≥ 3 b-jets search

Requirement	Signal region					
	SR-0ℓ-4j-A	**SR-0ℓ-4j-B**	**SR-0ℓ-4j-C***	**SR-0ℓ-7j-A**	**SR-0ℓ-7j-B**	**SR-0ℓ-7j-C**
Baseline 0-lepton selection	lepton veto, $p_{\mathrm{T}}^{\mathrm{jet}_1} > 90$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV					
N jets (p_{T} [GeV]) $\geq$	4 (50)	4 (50)	4 (30)	7 (30)	7 (30)	7 (30)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] $>$	250	350	400	200	350	250
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] $>$	-	-	-	1000	1000	1500
$m_{\mathrm{eff}}^{\mathrm{4j}}$ [GeV] $>$	1300	1100	1100	-	-	-
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}^{\mathrm{4j}}}$ [$\sqrt{GeV}$] $>$	-	-	16	-	-	-

Requirement	Signal region		
	SR-1ℓ-6j-A	**SR-1ℓ-6j-B**	**SR-1ℓ-6j-C**
Baseline 1-lepton selection	$\geqslant 1$ signal lepton (e,μ), $p_{\mathrm{T}}^{\mathrm{jet}_1} > 90$ GeV, $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV		
N jets (p_{T} [GeV]) $\geq$	6 (30)	6 (30)	6 (30)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV] $>$	175	225	275
m_{T} [GeV] $>$	140	140	160
$m_{\mathrm{eff}}^{\mathrm{incl}}$ [GeV] $>$	700	800	900

Signal regions for the searches with taus

Requirement	Signal region	
	1τ **Loose SR**	1τ **Tight SR**
Taus	$N_\tau^{\text{medium}} = 1$ $p_{\text{T}} > 30\,\text{GeV}$	
$\Delta\phi(\text{jet}_{1,2}, \boldsymbol{E}_{\text{T}}^{\text{miss}}) >$	0.4	
$\Delta\phi(\tau, \boldsymbol{E}_{\text{T}}^{\text{miss}}) >$	0.2	
m_{T}^{τ} [GeV] $>$	140	
$E_{\text{T}}^{\text{miss}}$ [GeV] $>$	200	300
H_{T} [GeV] $>$	800	1000

Requirement	Signal region			
	2τ **Inclusive SR**	2τ **GMSB SR**	2τ **nGM SR**	2τ **bRPV SR**
Taus	$N_\tau^{\text{loose}} \geq 2$ $p_{\text{T}} > 20\,\text{GeV}$			
$\Delta\phi(\text{jet}_{1,2}, \boldsymbol{E}_{\text{T}}^{\text{miss}}) \geq$	0.3			
$m_{\text{T}}^{\tau_1} + m_{\text{T}}^{\tau_2}$ [GeV] $\geq$	150	250	250	150
H_{T}^{2j} [GeV] $>$	1000	1000	600	1000
$N_{\text{jet}} \geq$	-	4		

Requirement	Signal region			
	τ+ℓ **GMSB SR**	τ+ℓ **nGM SR**	τ+ℓ **bRPV SR**	τ+ℓ **mSUGRA SR**
Taus	$N_\tau^{\text{loose}} \geq 1$ $p_{\text{T}} > 20\,\text{GeV}$			
$N_\ell =$	1			
m_{T}^{ℓ} [GeV] $>$	100			
m_{eff} [GeV] $>$	1700	-	1300	-
$E_{\text{T}}^{\text{miss}}$ [GeV] $>$	-	350	-	300
$N_{\text{jet}} \geq$	-	3	4	3

Signal regions for the searches with photons

Signal Region	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$	$SR^{\gamma\gamma}_{W-L}$	
BWH				
No. photons (E_T [GeV])	> 1 (> 75)	> 1 (> 75)	> 1 (> 75)	> 1 (> 75)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 250	> 150	> 200
H_{T} [GeV]	–	–	> 600	> 400
m_{eff} [GeV]	> 1800	> 1500	–	–
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$ (No. leading jets)	> 0.5 (2)	> 0.5 (2)	> 0.5 (2)	> 0.5 (2)
$\Delta\phi_{\mathrm{min}}(\gamma, E_{\mathrm{T}}^{\mathrm{miss}})$	–	> 0.5	–	> 0.5

Signal Region	$SR^{\gamma b}_{L}$	$SR^{\gamma b}_{H}$	$SR^{\gamma j}_{L}$	$SR^{\gamma j}_{H}$
No. photons (E_T [GeV])	> 0 (> 125)	> 0 (> 150)	1 (> 125)	1 (> 300)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 100	> 200	> 200	> 300
H_{T} [GeV]	–	> 1000	–	> 800
No. jets (No. b-jets)	$2-4$ (> 1)	> 3 (> 0)	$> 3^a$	$> 1^a$
No. leptons	0	–	0	0
M_{bb} [GeV]	$75-150$	–	–	–
$M_{\mathrm{T}}^{\gamma,E_{\mathrm{T}}^{\mathrm{miss}}}$ [GeV]	> 90	> 90	–	–
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})$ (No. leading jets)	> 0.3 (2)	> 0.3 (4)	> 0.4 (2)	> 0.4 (2)
R_{T}^4	–	–	< 0.85	
$\Delta\phi_{\mathrm{min}}(\mathrm{jet}, \gamma)$	–	–	–	< 2.0

Signal Regions	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$	$SR^{\gamma\gamma}_{W-L}$	$SR^{\gamma\gamma}_{W-H}$
Expected background events	$0.06^{+0.24}_{-0.03}$	$0.06^{+0.24}_{-0.04}$	$2.04^{+0.82}_{-0.75}$	$1.01^{+0.48}_{-0.42}$
QCD	$0.00^{+0.24}_{-0.00}$	$0.00^{+0.24}_{-0.00}$	$0.32^{+0.45}_{-0.32}$	$0.22^{+0.33}_{-0.22}$
EW	0.02 ± 0.02	0.0 ± 0.0	0.64 ± 0.27	0.13 ± 0.08
$(W \to \ell\nu)\gamma\gamma$	0.04 ± 0.02	0.05 ± 0.04	1.01 ± 0.62	0.53 ± 0.34
$(Z \to \nu\nu)\gamma\gamma$	0.00 ± 0.00	0.01 ± 0.01	0.07 ± 0.04	0.13 ± 0.07
Observed events	0	0	5	1

Signal Regions	$SR^{\gamma b}_{L}$	$SR^{\gamma b}_{H}$
Expected background events	18.8 ± 5.3	3.82 ± 1.25
$e \to \gamma$	3.2 ± 0.4	0.18 ± 0.08
$W \to \ell\nu$	12.6 ± 4.9	3.35 ± 1.05
QCD	2.3 ± 2.1	0.00 ± 0.65
$Z \to \nu\nu$	0.8 ± 0.4	0.29 ± 0.15
Observed events	12	2

Signal Regions	$SR^{\gamma j}_{L}$	$SR^{\gamma j}_{H}$
Expected background events	1.27 ± 0.43	0.84 ± 0.38
$W + \gamma$	0.13 ± 0.12	0.54 ± 0.28
$Z + \gamma$	$0.03^{+0.05}_{-0.03}$	$0.21^{+0.23}_{-0.21}$
$t\bar{t} + \gamma$	0.64 ± 0.40	0.05 ± 0.05
Single-t + γ	0.06 ± 0.02	0.03 ± 0.01
γ + jet (QCD background)	$0.00^{+0.06}_{-0.00}$	0.00 ± 0.00
$e \to \gamma$	0.38 ± 0.10	0.00 ± 0.00
$j \to \gamma$	$0.02^{+0.08}_{-0.02}$	$0.00^{+0.08}_{-0.00}$
Observed events	2	2