Inclusive searches for squarks and gluinos with the ATLAS detector

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on behalf of the ATLAS Collaboration

Introduction

At LHC energy, squarks and gluino production have large cross section.

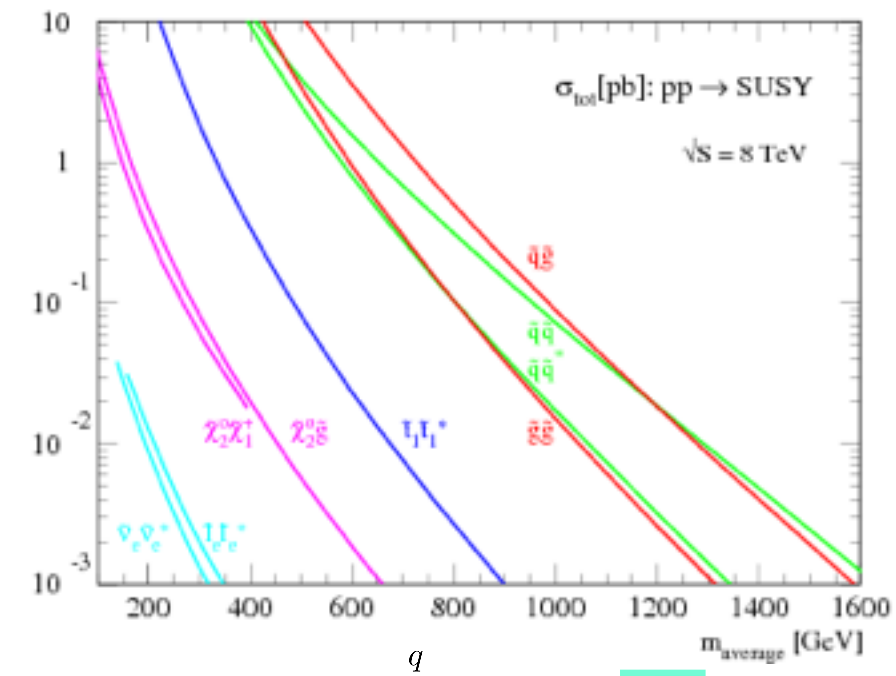
R-parity is conserved:

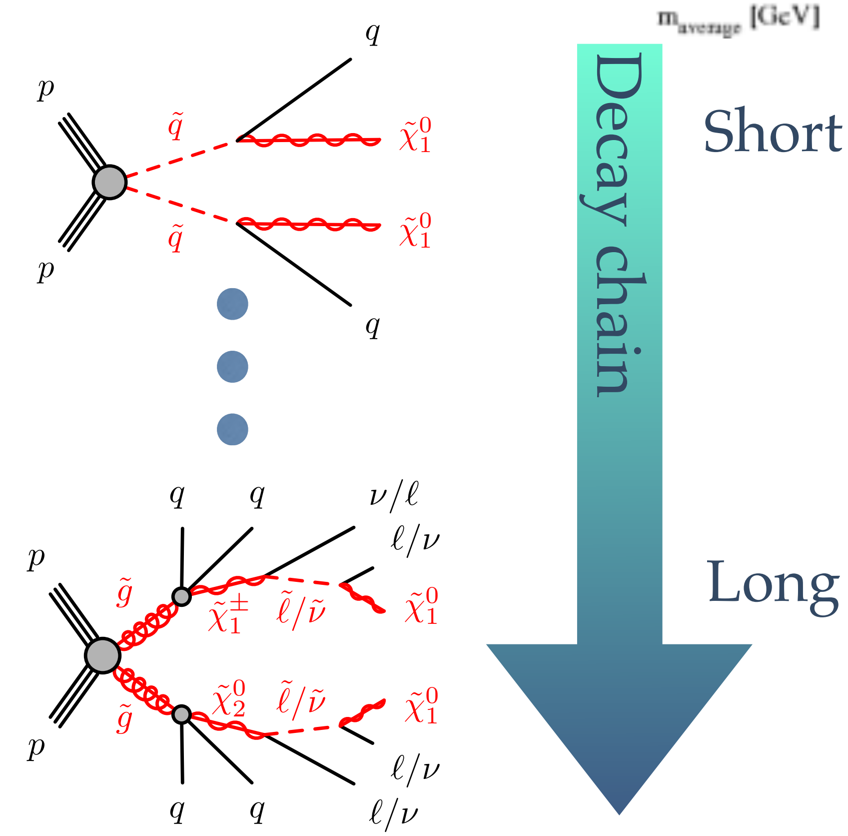
- SUSY particles are pair-produced.

$$pp \to \tilde{q}\tilde{q}^{(*)} \ , \ pp \to \tilde{q}\tilde{g} \ , \ pp \to \tilde{g}\tilde{g}$$

- The lightest SUSY particle (LSP) is stable and will leave the detector undetected leading to missing transverse energy, E_T^{miss}.

The squarks and gluinos are assumed to decay promptly into various final states depending on the decay chain. The analysis selection depends on the studied decay.





Will show a selection of the inclusive searches for squarks and gluinos.

SUSY Search Strategy

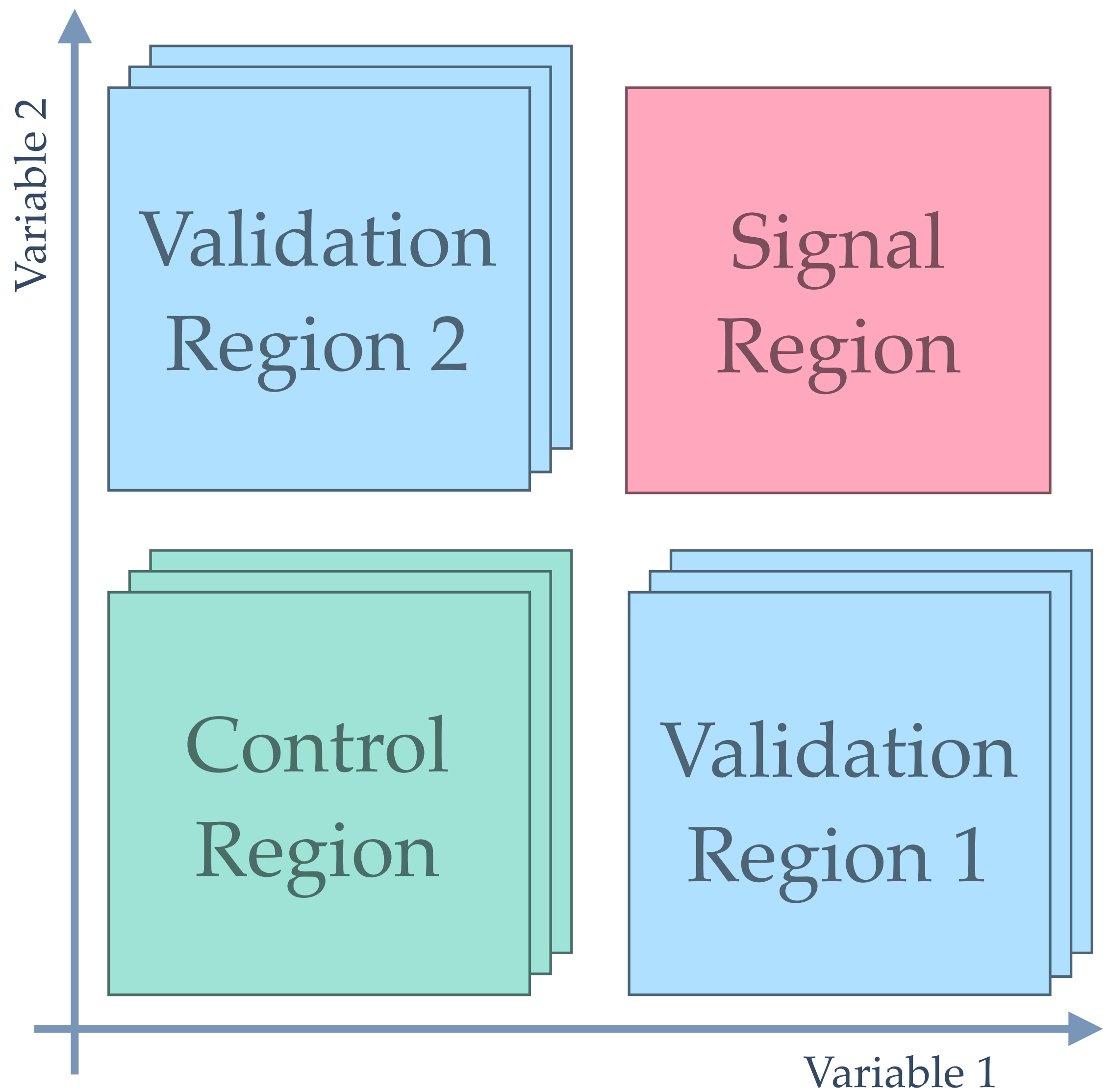
Standard Model is well understood.

SUSY signal will lead to high p_T objects and E_T^{miss}. Usually with low SM prediction.

Three types of background estimation:

- Simulation normalized to data in control regions orthogonal to the signal regions. (W, Z, ttbar, etc.)
- Data driven techniques such as jet smearing. (Multijet events from QCD)
- Simulations. (rare backgrounds like WW, WZ, ZZ, etc.)

Before unblinding: Cross-check background estimation in validation regions.



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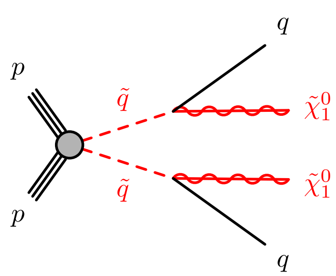
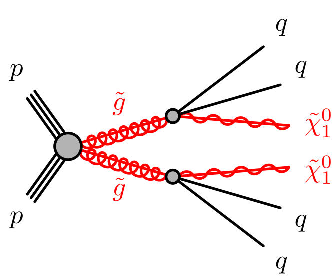
Phys. Rev. D. 90, 052008 (2014)

arXiv: 1507.05525

Direct decays of squarks and gluinos





0 leptons (e/μ),
2-6 jets, E_T^{miss}

Discriminant variable:

$$m_{\mathrm{eff}} = E_{\mathrm{T}}^{\mathrm{miss}} + \sum_{i=1}^{n_{\mathrm{jets}}} |p_{\mathrm{T}}^{i}\,(\mathrm{jet})\,|$$

p_T (jet): transverse momentum of the jets.

17 signal regions.

0 leptons (e/μ),
Exactly 1 jet, E_T^{miss}

Discriminant variable:

$$E_{\mathrm{T}}^{\mathrm{miss}}\ ,\ p_{\mathrm{T}}^{\mathrm{jet}}$$

Targeting initial state radiation jet.

3 signal regions.

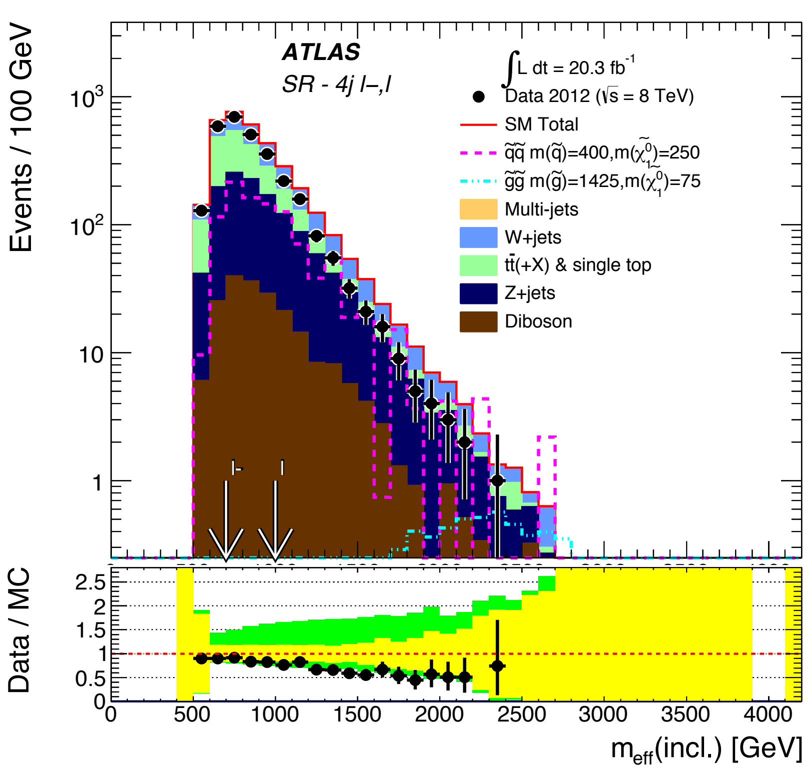
0 leptons (e/μ),
2 or more jets, E_T^{miss}

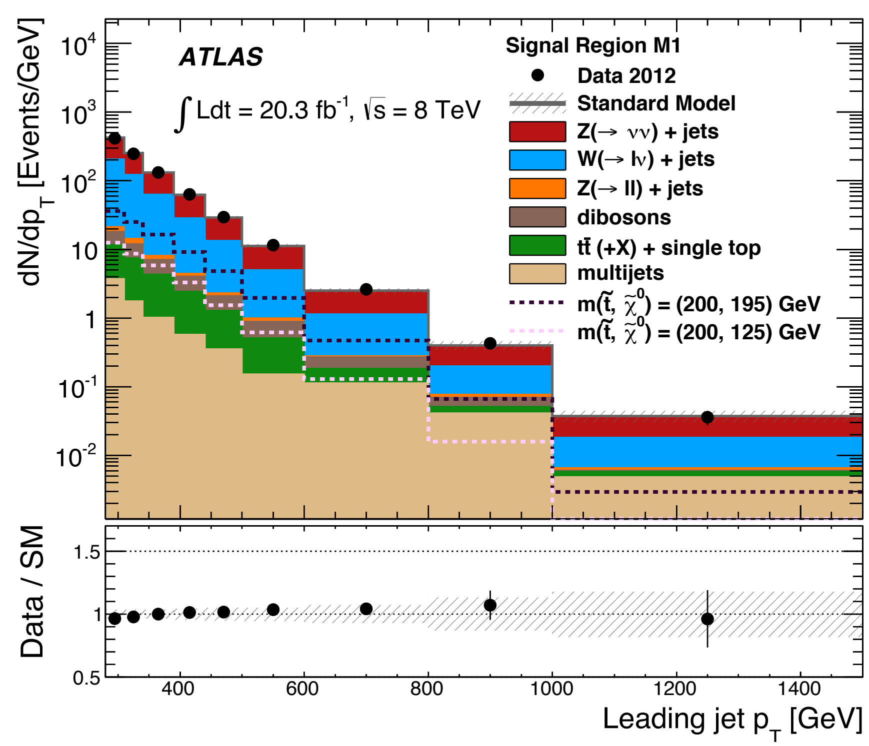
Discriminant variable:

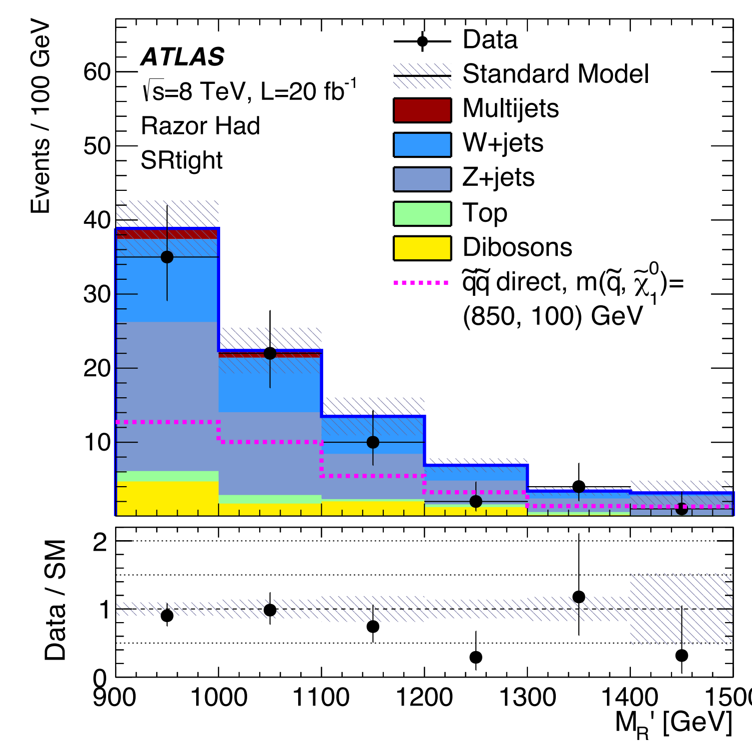
$$M_R' = \sqrt{(j_{1,E}+j_{2,E})^2 - (j_{1,L}+j_{2,L})^2}$$

$$R = \frac{\sqrt{(j_{1,E}+j_{2,E})^2 - (j_{1,L}+j_{2,L})^2}}{\sqrt{\frac{E_{\mathrm{T}}^{\mathrm{miss}}(j_{1,T}+j_{2,T}) - \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}\cdot(\boldsymbol{j}_{1,T}+\boldsymbol{j}_{2,T})}{2}}}$$

2 signal regions.







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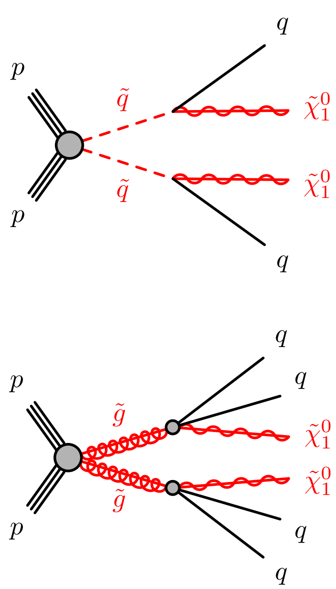
Direct decays of squarks and gluinos



0 leptons (e/μ),
2-6 jets, E_T^{miss}

Discriminant variable:

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Targeting initial state radiation jet.

3 signal regions.

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$$M_R' = \sqrt{(j_{1,E}+j_{2,E})^2 - (j_{1,L}+j_{2,L})^2}$$

$$R = \frac{\sqrt{(j_{1,E}+j_{2,E})^2 - (j_{1,L}+j_{2,L})^2}}{\sqrt{\frac{E_{\mathrm{T}}^{\mathrm{miss}}(j_{1,T}+j_{2,T}) - \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}\cdot(\boldsymbol{j}_{1,T}+\boldsymbol{j}_{2,T})}{2}}}$$

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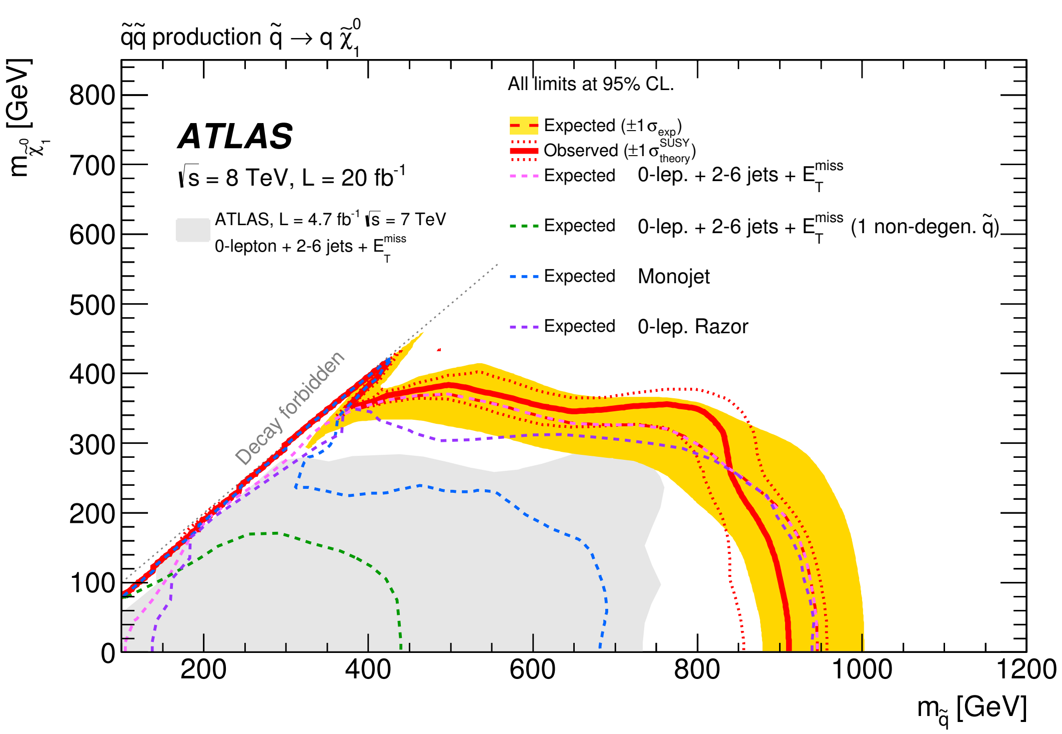
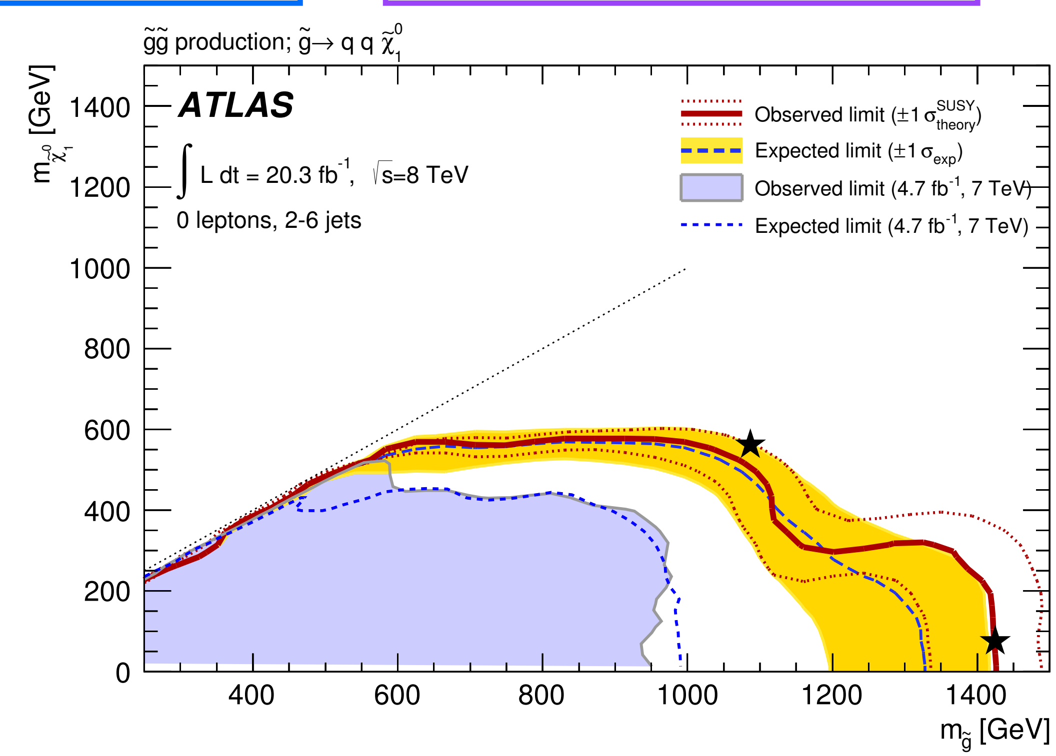
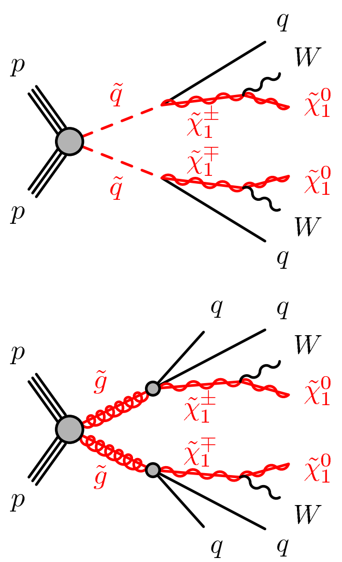




One-step decays of squarks and gluinos

arXiv: 1507.05525



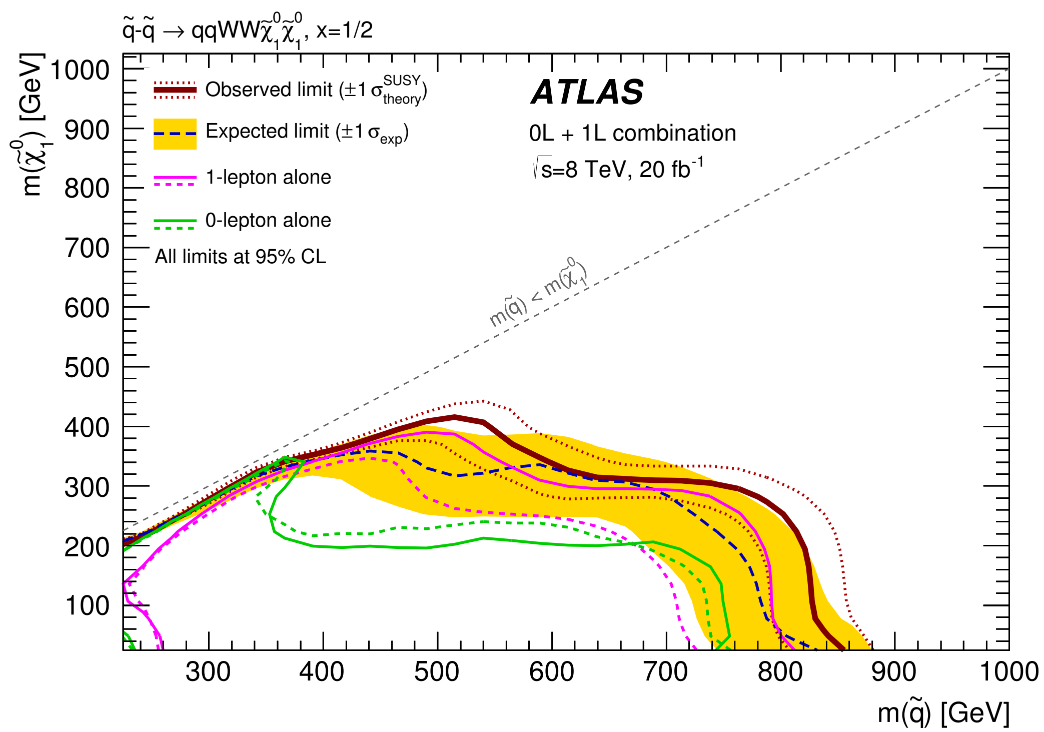
Two analyses are the almost equally sensitive in this model.

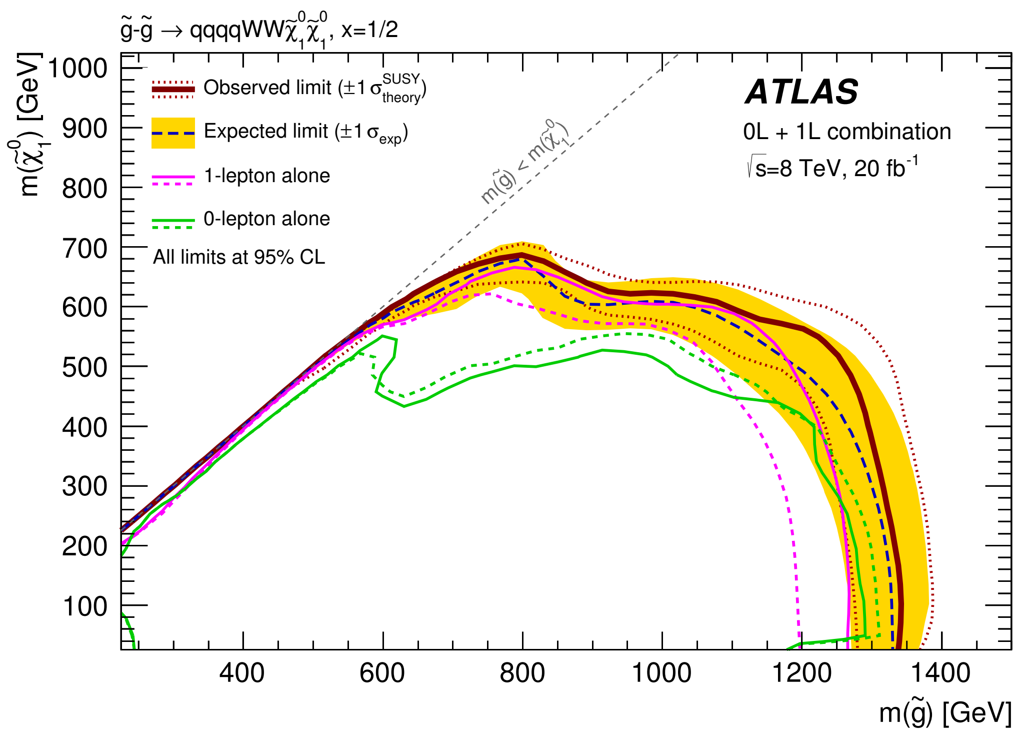
The 0-lepton, 2-6 jets analysis **vetos** events with leptons (e/μ).

The 1-lepton analysis **selects** events with one lepton (e/μ).

No overlap between signal and control regions, but a shared set of systematic uncertainties.

⇒ Analyses can be statistically combined using combination of likelihoods.





Two-step decays with taus

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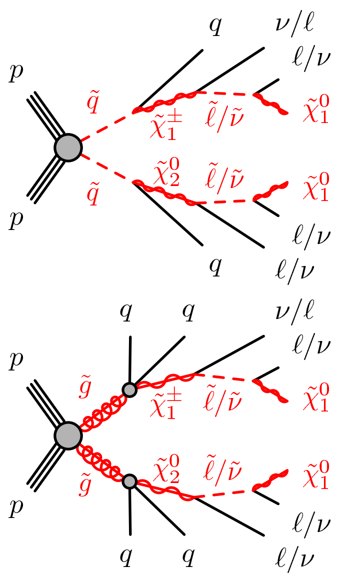
arXiv: 1507.05525



1 or more taus, 0 leptons, jets, E_T^{miss}

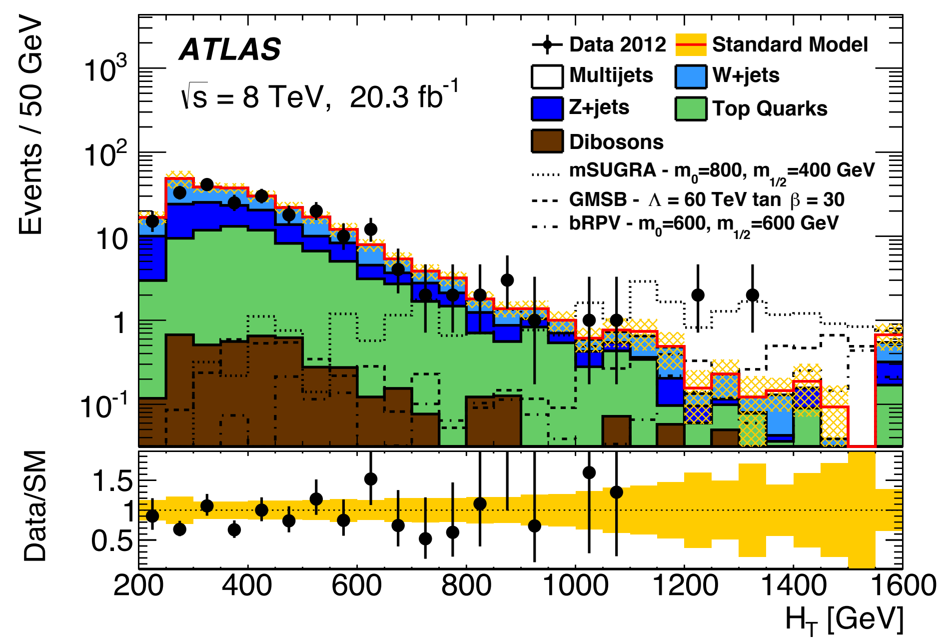
Discriminant variable:

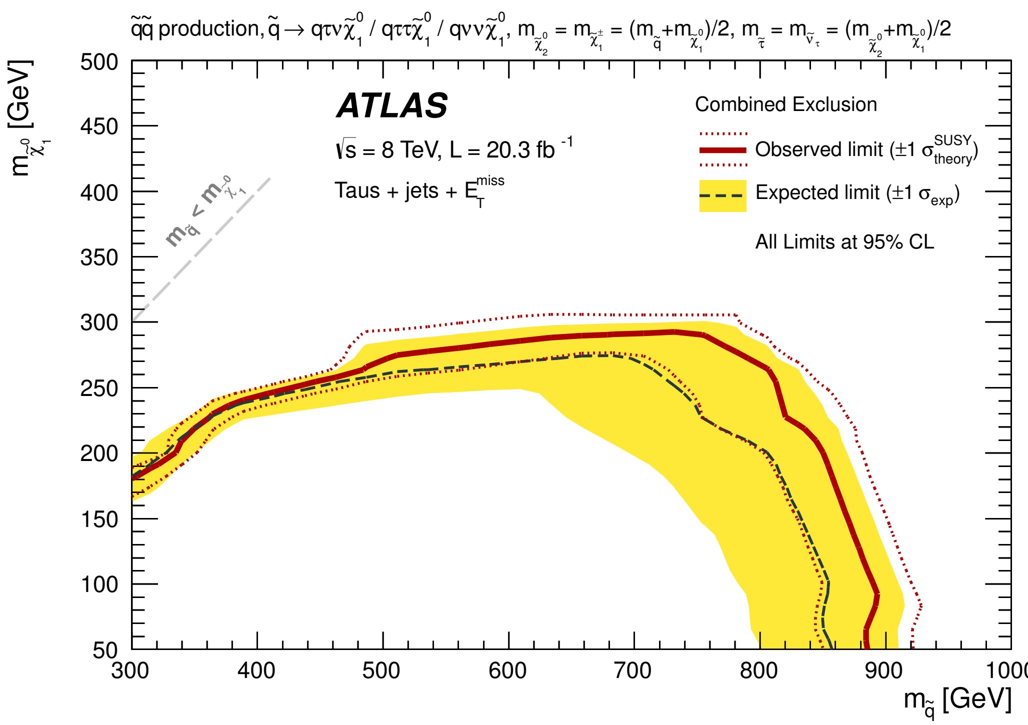
$$m_T^\tau = \sqrt{2 p_T^\tau E_T^{miss}(1-\cos(\Delta\phi(\tau, p_T^{miss})))}$$

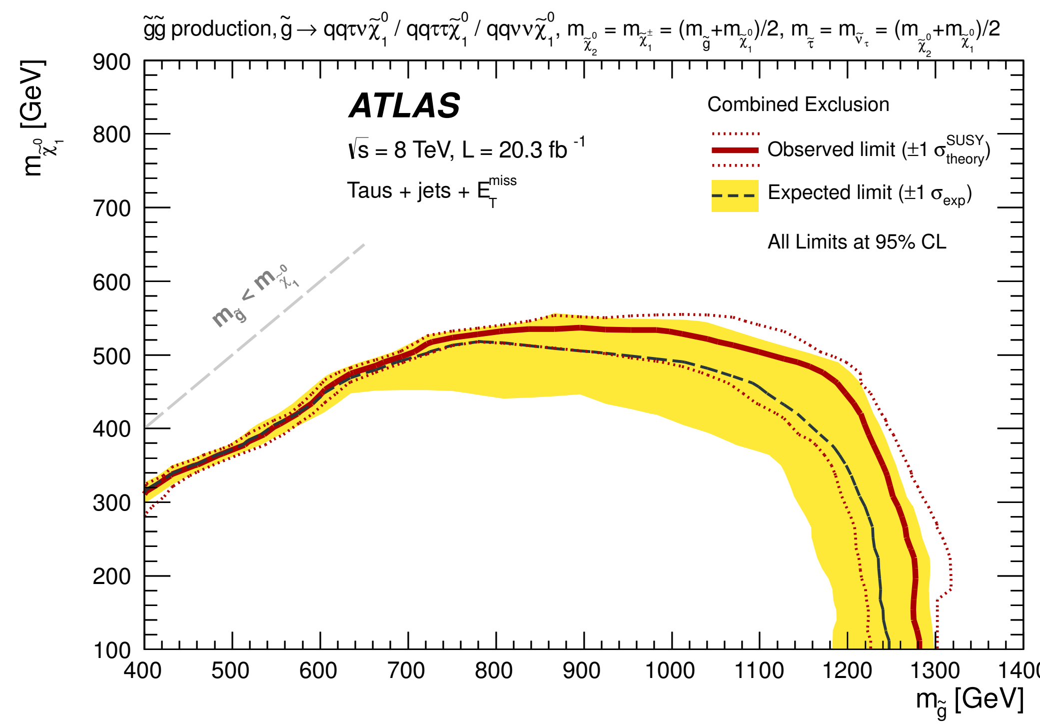
$$H_T = \sum_{i=1}^{n_{obj}} |p_T^i|$$

n_{obj}: Number of jets and taus.

2 signal regions.



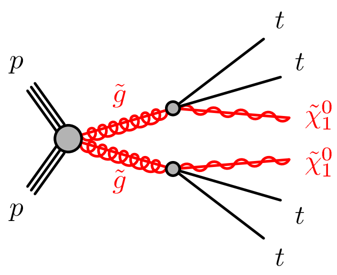


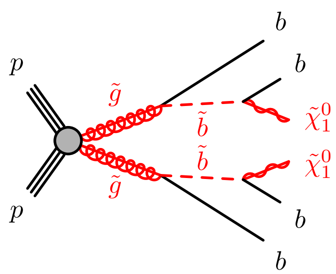


Direct gluino decays with stops or sbottoms

JHEP 06 (2014) 035

JHEP 10 (2014) 024





2 same sign charged leptons or 3 leptons (e/μ), 0-3 b-jets, E_T^{miss}

High lepton multiplicity ⇒ lower E_T^{miss}-cut.

Discriminant variable:

$$m_{\text{eff}} = E_{\text{T}}^{\text{miss}} + \sum_{i=1}^{n_{\text{jets}}} |p_{\text{T}}^{i}\,(\text{jet})\,|$$

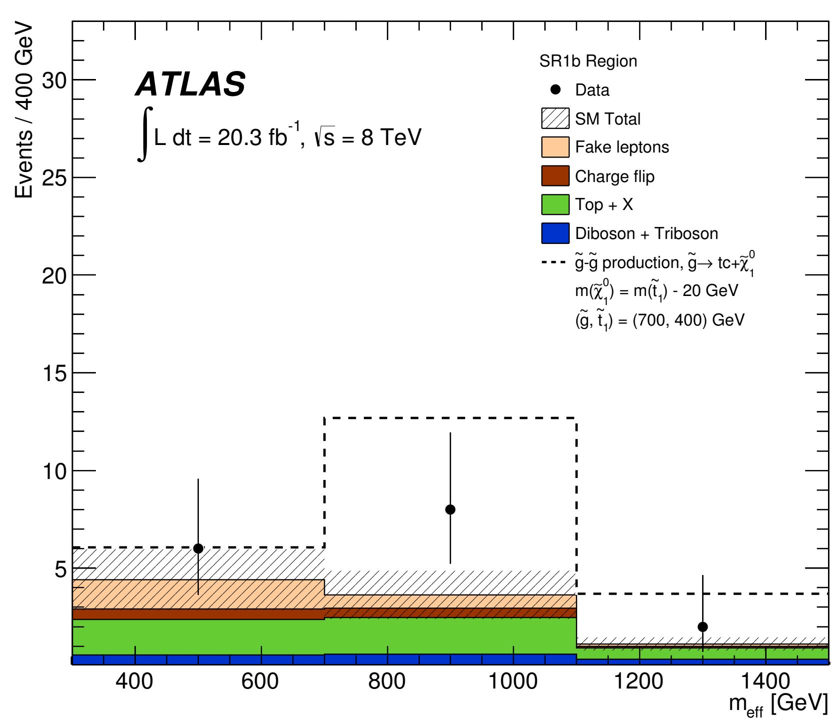
5 signal regions.

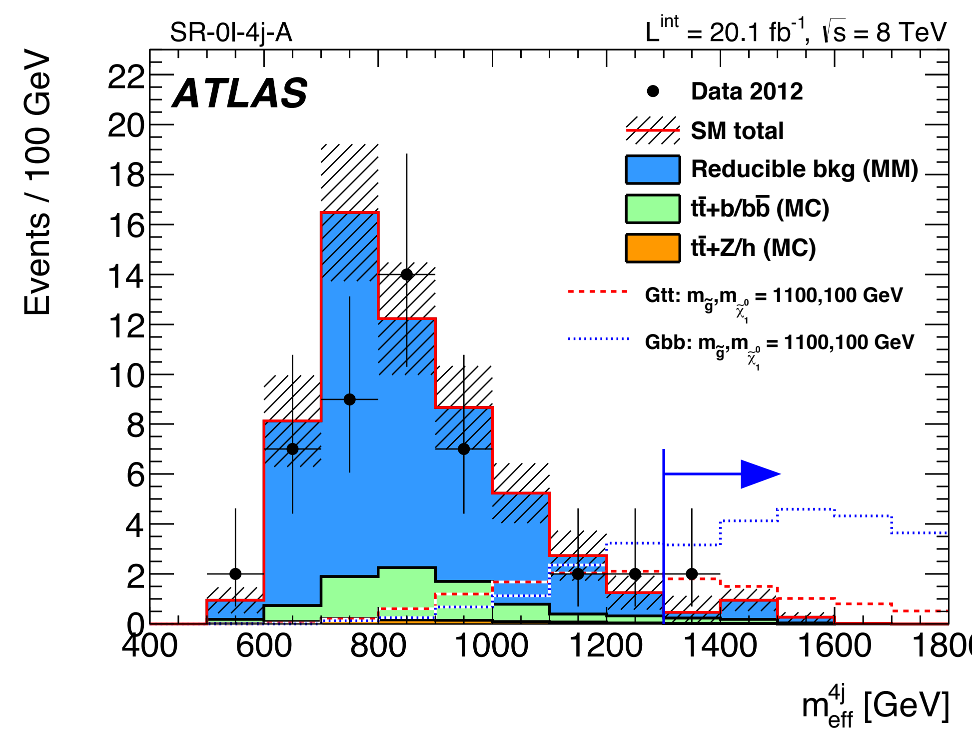
0 or 1 leptons (e/μ), 4-7 jets, at least 3 b-jets, E_T^{miss}

Discriminant variables:

$$m_{\text{eff}}\ ,\ E_{\text{T}}^{\text{miss}}/\sqrt{H_{\text{T}}^{4\text{j}}}\ ,\ m_{\text{T}}$$

9 signal regions.





Direct gluino decays with stops or sbottoms

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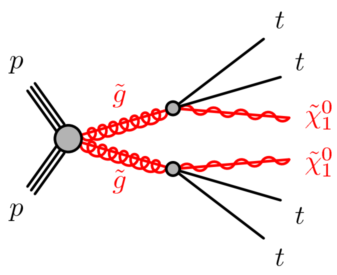

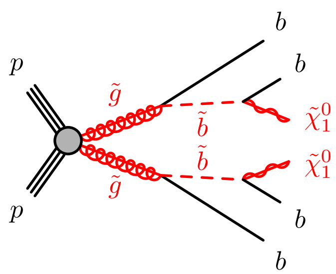

2 same sign charged leptons or 3 leptons (e/μ), 0-3 b-jets, E_T^{miss}

High lepton multiplicity ⇒ lower E_T^{miss}-cut.

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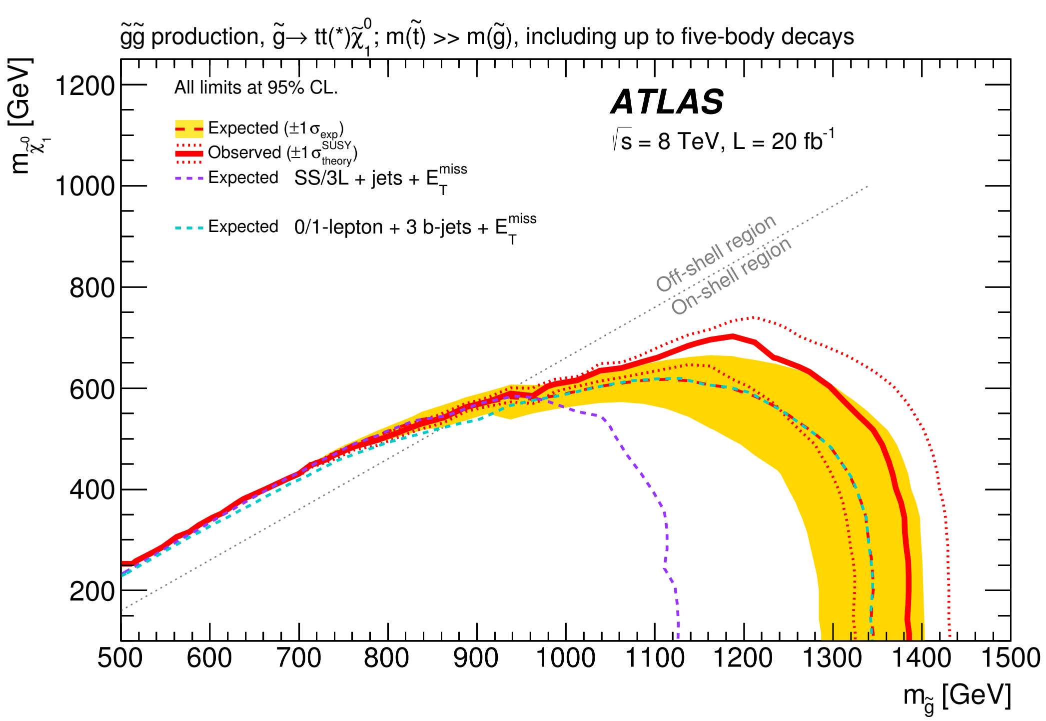
5 signal regions.

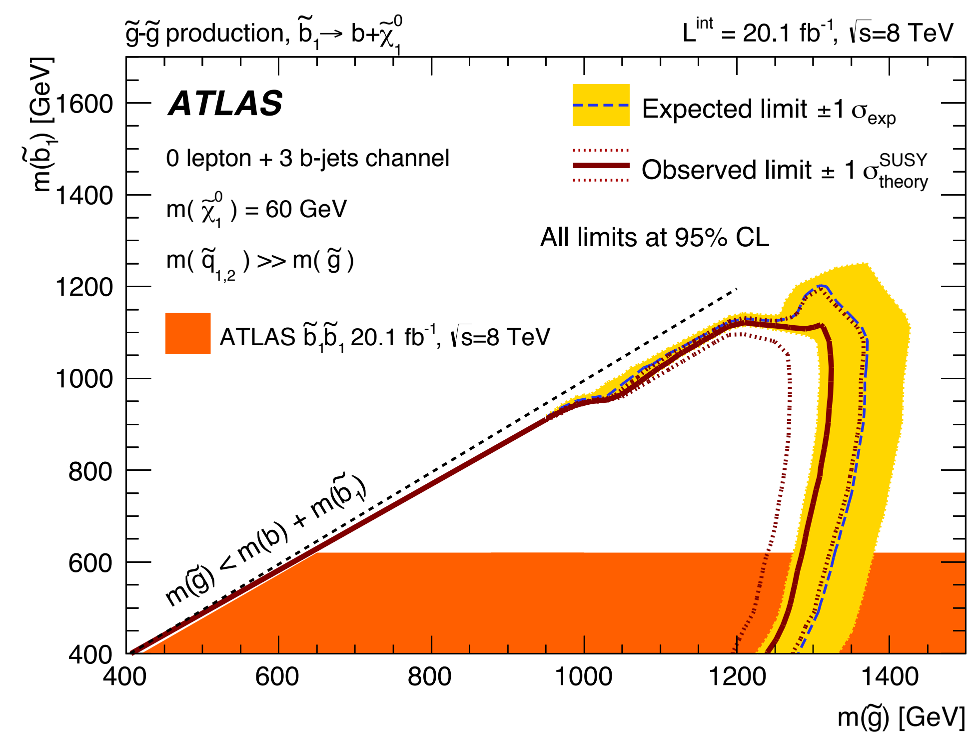
0 or 1 leptons (e/μ), 4-7 jets, at least 3 b-jets, E_T^{miss}

Discriminant variables:

$$m_{\text{eff}}\ ,\ E_T^{\text{miss}}/\sqrt{H_T^{4j}}\ ,\ m_T$$

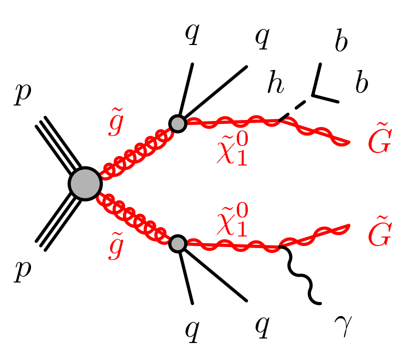
9 signal regions.





GGM models with photons

arXiv: 1507.05493



General models of gauge-mediated SUSY breaking (GGM)

- Gravitino is the LSP
- The final state depends on the nature of the NLSP.

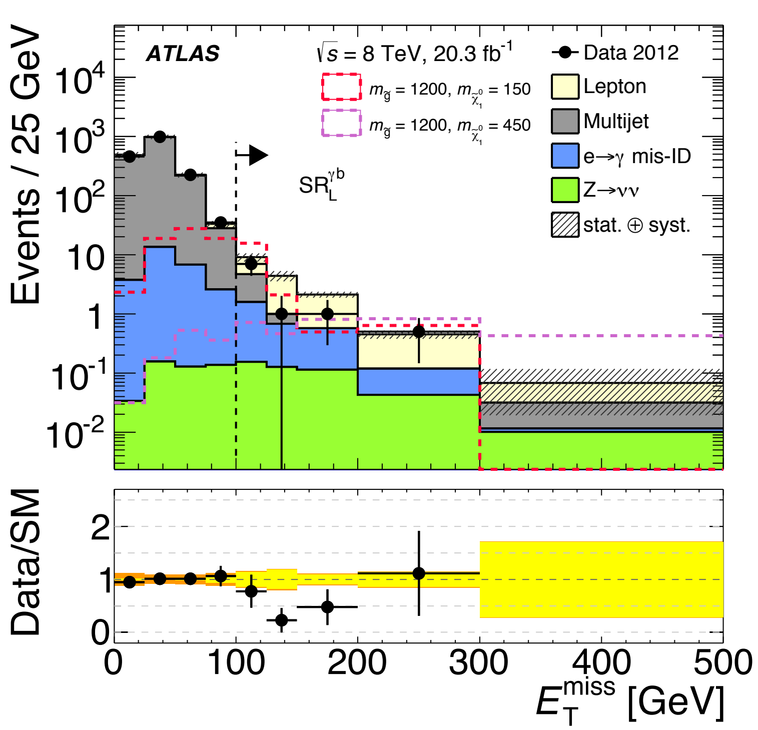
The NLSP considered is a higgsino-bino mixture leading to final states containing photons and a higgs.

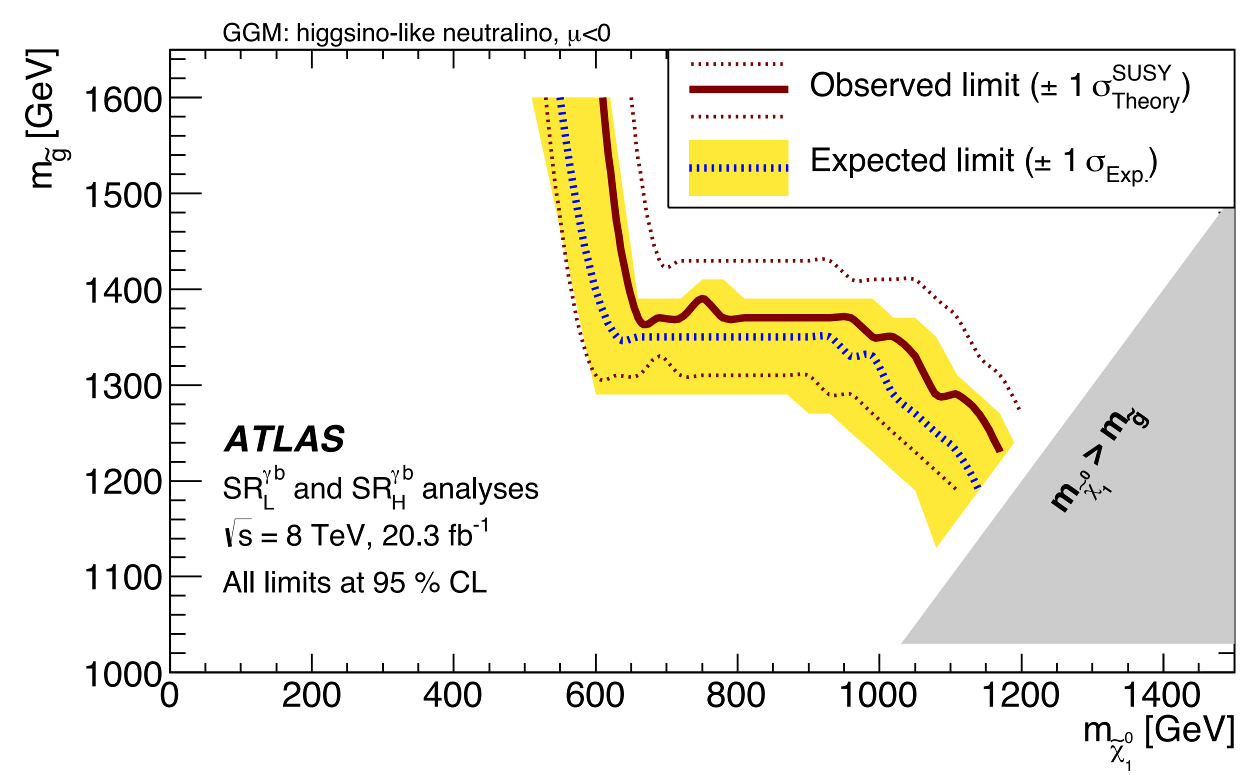
1 or more photons, 0 leptons, 2-4 jets, 1 or 2 b-jets, E_T^{miss}

Discriminant variable:

$$M_{bb} \ , \ M_T^{\gamma, E_T^{miss}}$$

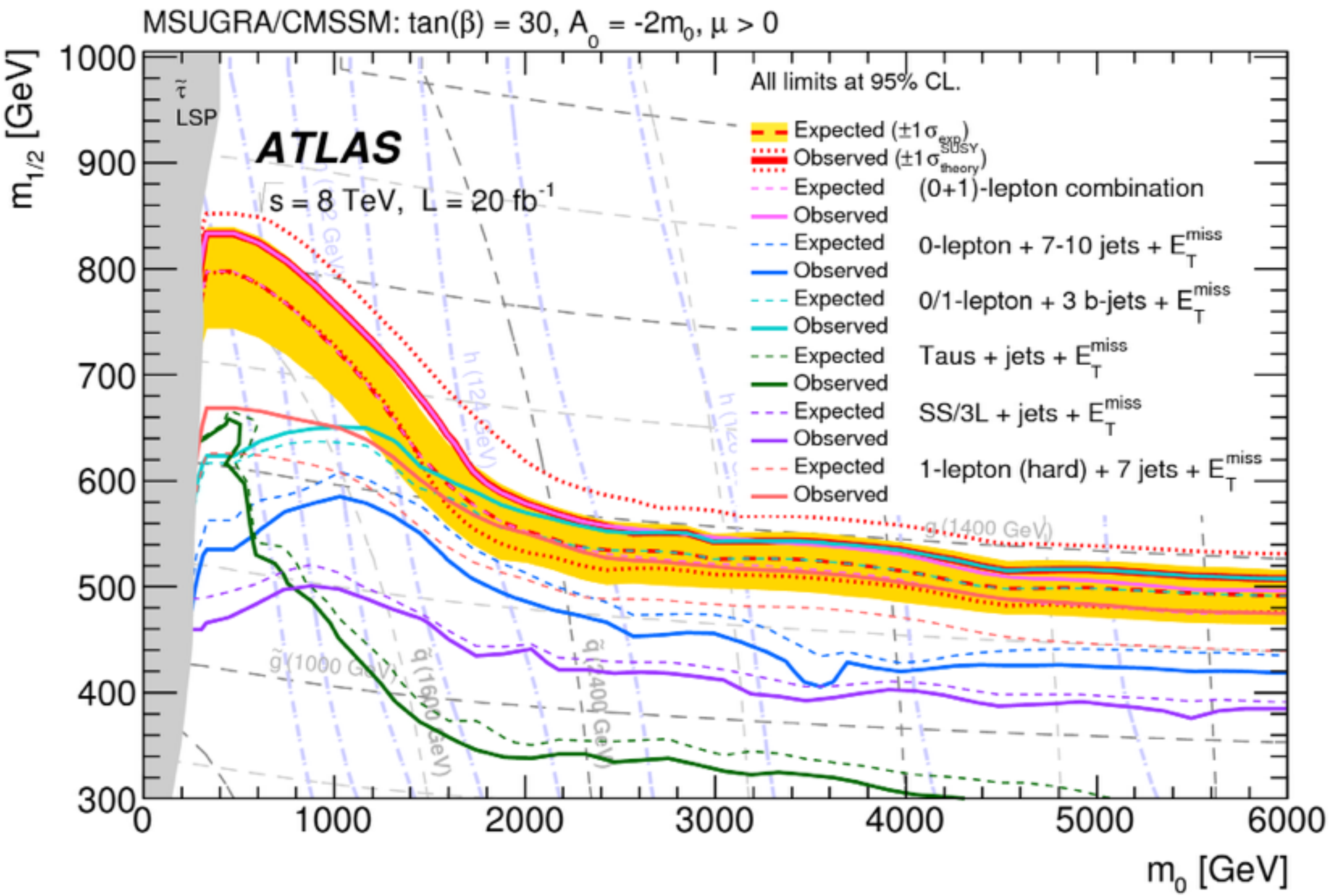
2 signal regions.





MSUGRA summary

arXiv: 1507.05525

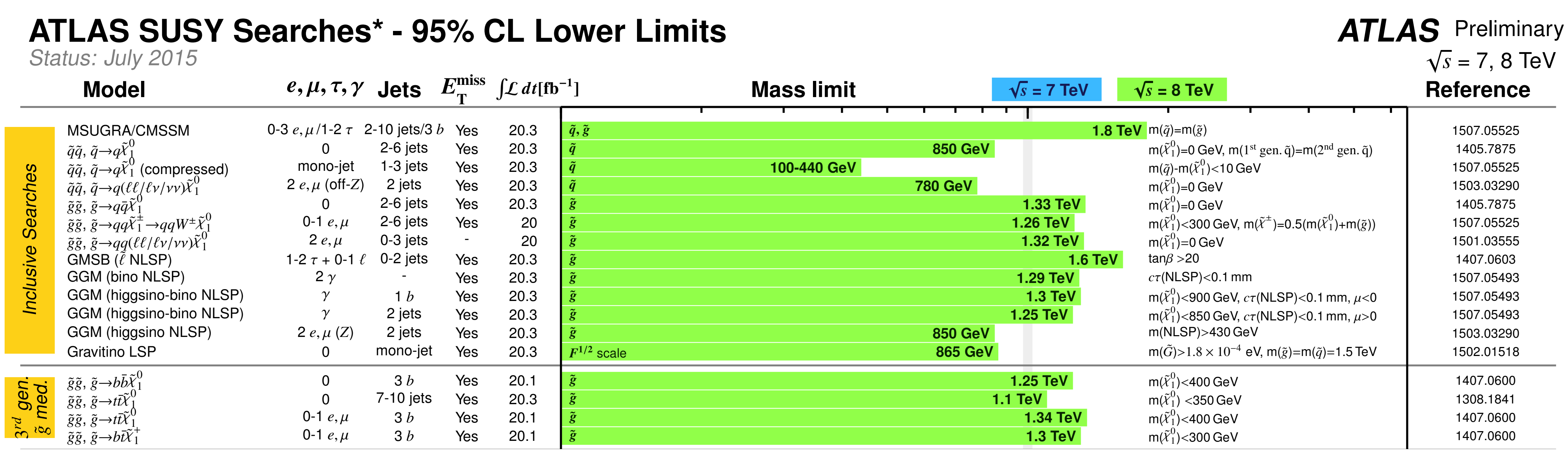


Conclusion of 8 TeV searches

ATLAS has performed a big variety of searches for squarks and gluinos with 8 TeV.

No significant excesses were seen.

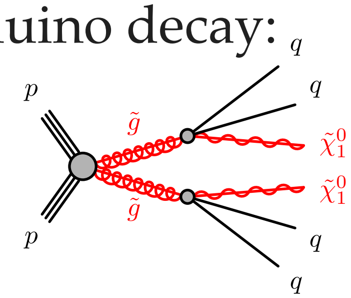
We are ready to keep searching at 13 TeV!



Prospects for Run II

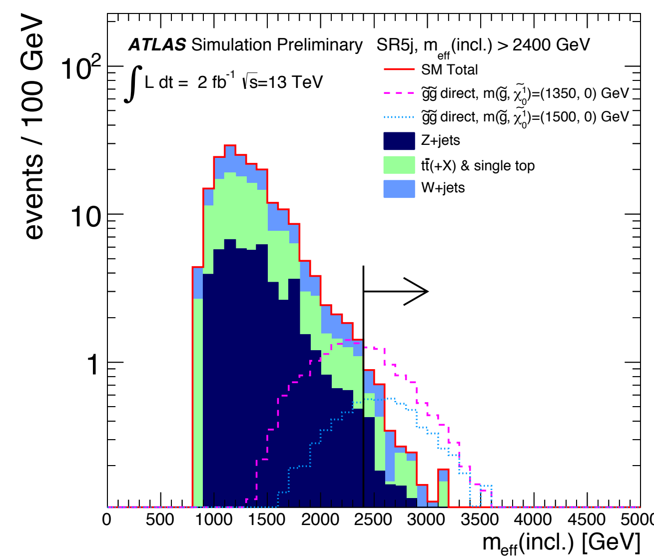
ATL-PHYS-PUB-2015-005

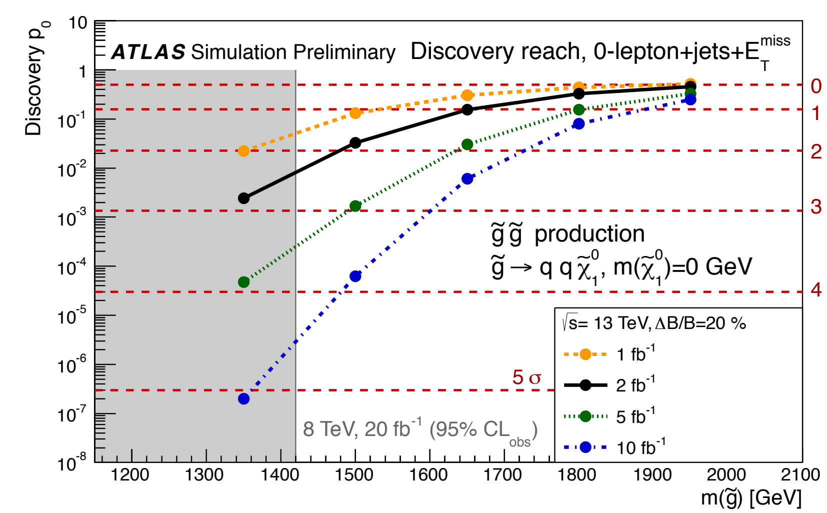
Direct gluino decay:



0 leptons (e/μ), 2-6 jets, E_T^{miss}

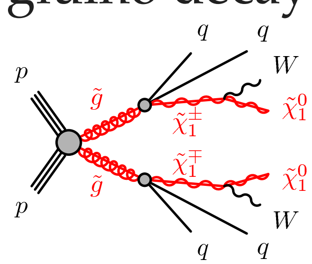
m_{eff}-cut changing w. luminosity





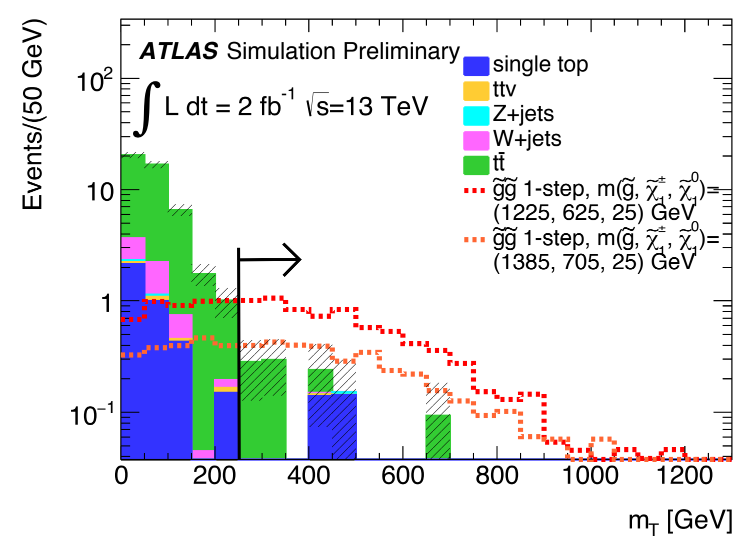
Assumed 20% uncertainty on the background

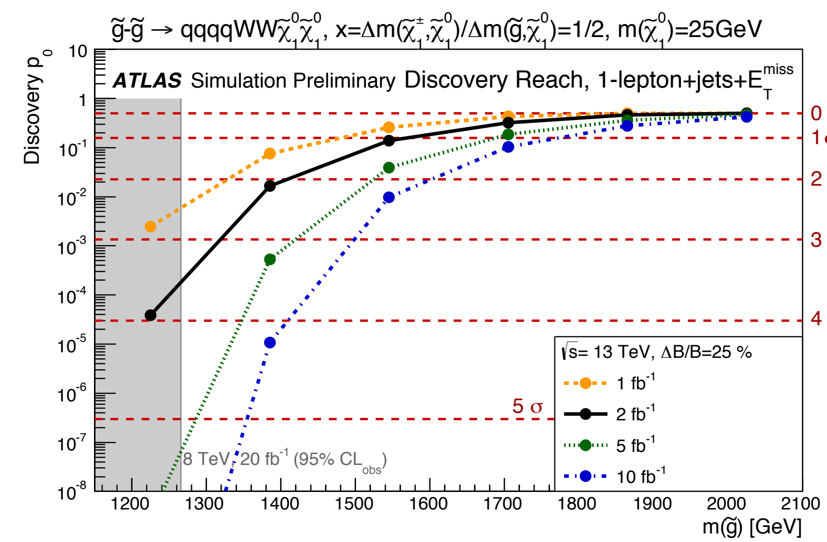
One-step gluino decay:



1 lepton (e/μ), ≥3 jets, E_T^{miss}

Signal region cuts: m_{eff} and m_T





Assumed 25% uncertainty on the background

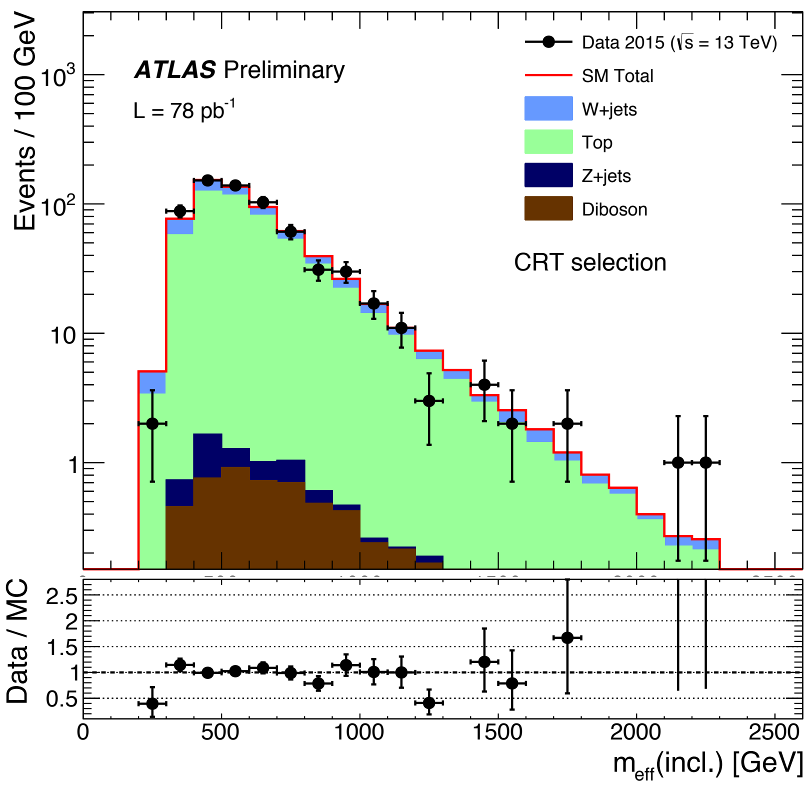
First peek at 13 TeV data

ATL-PHYS-PUB-2015-028

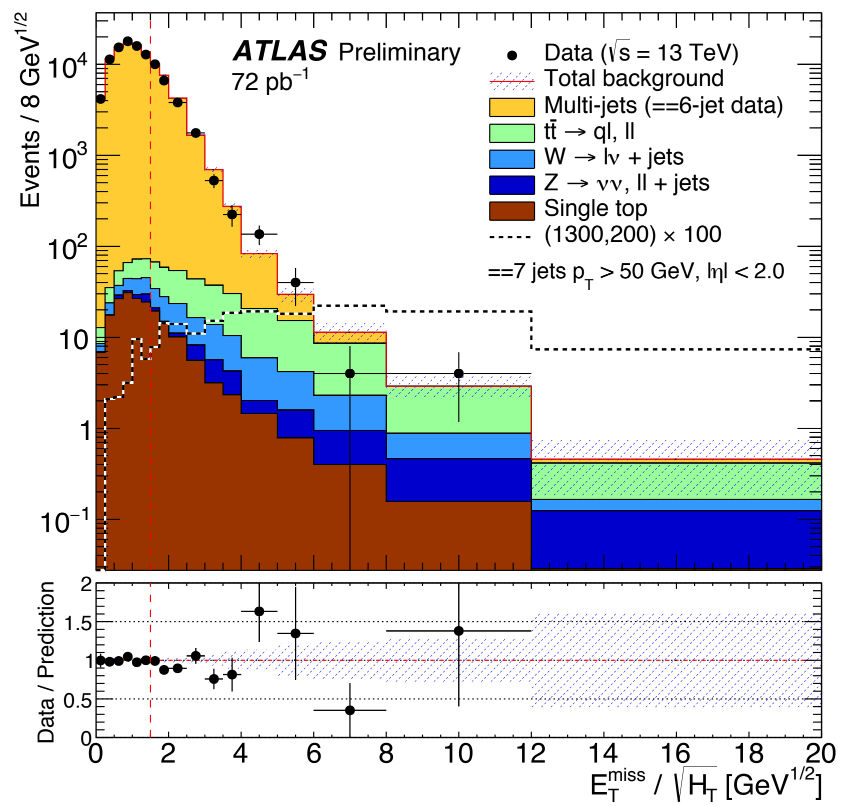
ATL-PHYS-PUB-2015-029

ATL-PHYS-PUB-2015-030

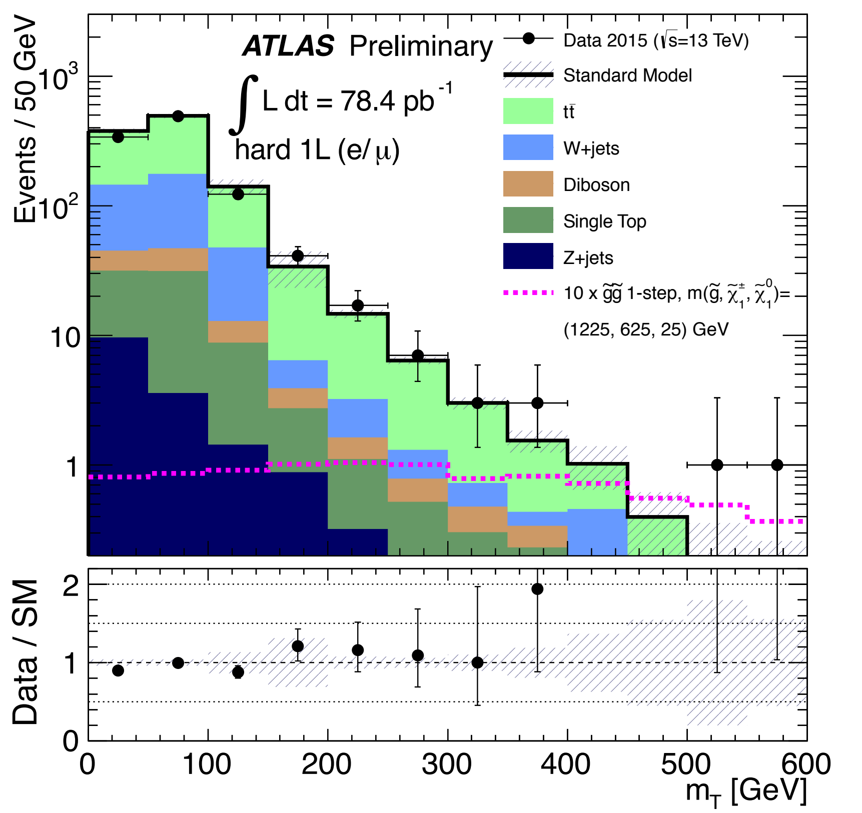
2 jets, 1 b-jet, 1 lepton, E_T^{miss}



7 jets



1 lepton, 4 jets, E_T^{miss}



First look at the control regions with 78 pb^{-1} data shows good agreement between data and simulation!

Backup Slides

SR cuts, 0-lepton, 2-6 jets ETmiss

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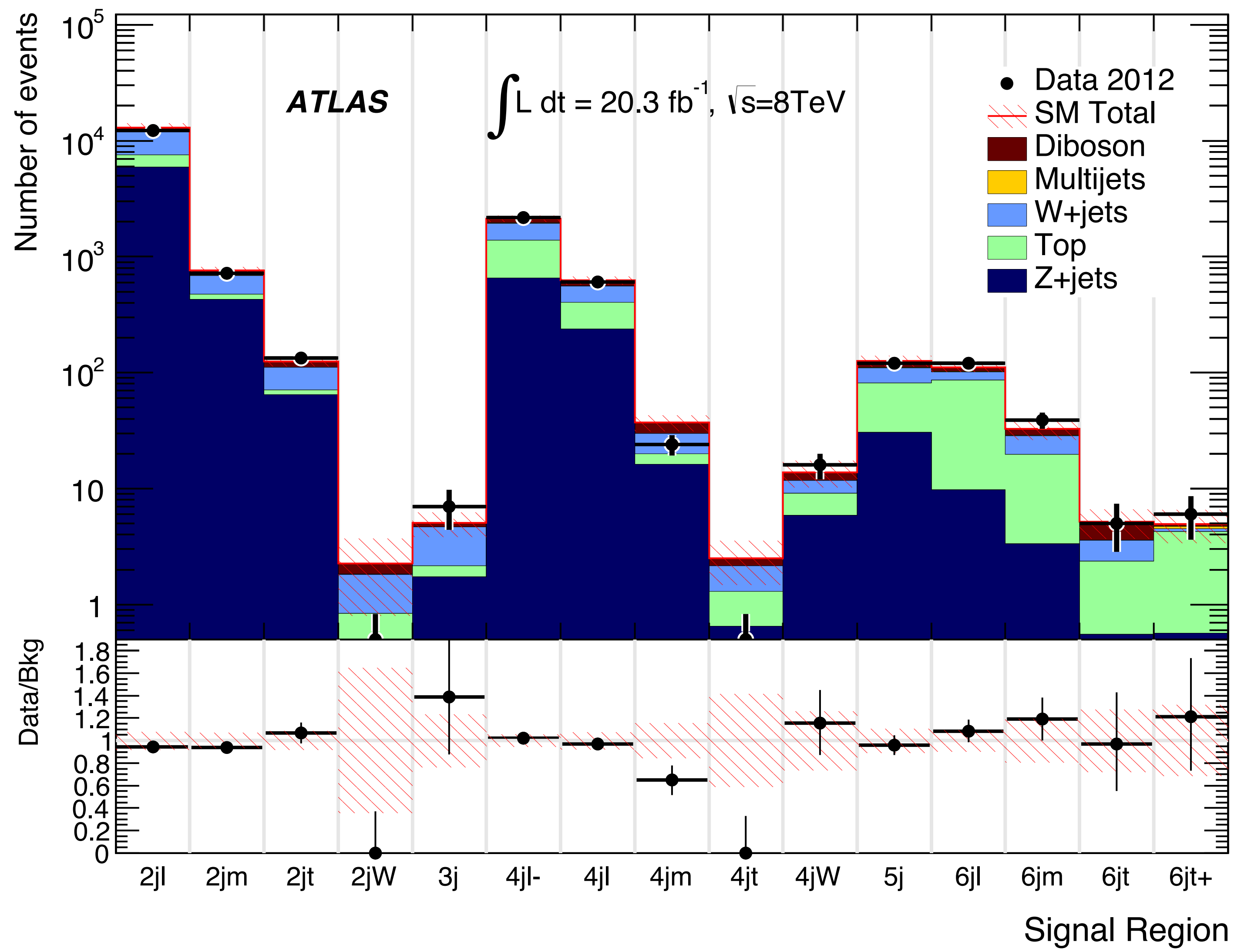
Requirement	Signal Region					
	2jl	2jm	2jt	2jW	3j	4jW
E_T^{miss}[GeV] >	160					
$p_T(j_1)$ [GeV] >	130					
$p_T(j_2)$ [GeV] >	60					
$p_T(j_3)$ [GeV] >	–				60	40
$p_T(j_4)$ [GeV] >	–					40
$\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ >	0.4					
$\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ >	–					0.2
W candidates	–			$2(W \to j)$	–	$(W \to j) + (W \to jj)$
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	8	15		–		
$E_T^{miss}/m_{eff}(N_j)$ >	–			0.25	0.3	0.35
m_{eff}(incl.) [GeV] >	800	1200	1600	1800	2200	1100

Requirement	Signal Region								
	4jl-	4jl	4jm	4jt	5j	6jl	6jm	6jt	6jt+
E_T^{miss}[GeV] >	160								
$p_T(j_1)$ [GeV] >	130								
$p_T(j_2)$ [GeV] >	60								
$p_T(j_3)$ [GeV] >	60								
$p_T(j_4)$ [GeV] >	60								
$p_T(j_5)$ [GeV] >	–				60				
$p_T(j_6)$ [GeV] >	–					60			
$\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ >	0.4								
$\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ >	0.2								
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	10		–						
$E_T^{miss}/m_{eff}(N_j)$ >	–		0.4	0.25	0.2			0.25	0.15
m_{eff}(incl.) [GeV] >	700	1000	1300	2200	1200	900	1200	1500	1700



SR cuts, Monojet and Razor

arXiv: 1507.05525

Requirement	Signal region		
	M1	**M2**	**M3**
Jets preselection	At most three jets with $p_T > 30$ GeV and $\|\eta\| < 2.8$		
$p_T^{jet_1}$ [GeV] >	280	340	450
E_T^{miss} [GeV] >	220	340	450
$\Delta\phi(\text{jet}, \boldsymbol{E}_T^{miss})$ >	0.4		

	0LRaz_SR$_{loose}$	**0LRaz_SR**$_{tight}$
E_T^{miss} [GeV] >	160	
$p_T^{jet_{1,2}}$ [GeV] >	150	200
$\Delta\phi(\text{jet}_{1,2}, E_T^{miss})$ >	0.4	1.4
R >	0.5	0.6
M_R' [GeV] >	700	900

Signal region	**0LRaz_SR**$_{loose}$	**0LRaz_SR**$_{tight}$
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
$\langle\epsilon\sigma\rangle_{obs}^{95}$[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

SR cuts, 1-2 Taus

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Requirement	Signal region	
	1τ **Loose SR**	1τ **Tight SR**
Taus	$N_\tau^{\text{medium}} = 1$ $p_T > 30$ GeV	
$\Delta\phi(\text{jet}_{1,2}, \boldsymbol{E}_T^{\text{miss}}) >$	0.4	
$\Delta\phi(\tau, \boldsymbol{E}_T^{\text{miss}}) >$	0.2	
m_T^τ [GeV] $>$	140	
E_T^{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	$N_\tau^{\text{loose}} \geq 2$ $p_T > 20$ GeV			
$\Delta\phi(\text{jet}_{1,2}, \boldsymbol{E}_T^{\text{miss}}) \geq$	0.3			
$m_T^{\tau_1} + m_T^{\tau_2}$ [GeV] $\geq$	150	250	250	150
H_T^{2j} [GeV] $>$	1000	1000	600	1000
$N_{\text{jet}} \geq$	-	4		

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

SR cuts, SS/3 leptons

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<table>
<tr><th rowspan="2">Requirement</th><th colspan="5">Signal region</th></tr>
<tr><th>SR3b</th><th>SR0b</th><th>SR1b</th><th>SR3Llow</th><th>SR3Lhigh</th></tr>
<tr><td>Leptons</td><td>SS or 3L</td><td>SS</td><td>SS</td><td>3L</td><td>3L</td></tr>
<tr><td>$N_{b-\mathrm{jet}}$</td><td>≥ 3</td><td>=0</td><td>≥ 1</td><td>-</td><td>-</td></tr>
<tr><td>$N_{\mathrm{jet}} \geq$</td><td>5</td><td>3</td><td>3</td><td>4</td><td>4</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]</td><td></td><td>> 150</td><td>> 150</td><td>$50 < E_{\mathrm{T}}^{\mathrm{miss}} < 150$</td><td>$> 150$</td></tr>
<tr><td>m_{T} [GeV] $>$</td><td>-</td><td>100</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Veto</td><td>-</td><td>-</td><td>SR3b</td><td>Z boson, SR3b</td><td>SR3b</td></tr>
<tr><td>m_{eff} [GeV] $>$</td><td>350</td><td>400</td><td>700</td><td>400</td><td>400</td></tr>
</table>

	SR3b	SR0b	SR1b	SR3Llow	SR3Lhigh
Observed events	1	14	10	6	2
Total expected background events	2.2 ± 0.8	6.5 ± 2.3	4.7 ± 2.1	4.3 ± 2.1	2.5 ± 0.9
$p(s=0)$	0.50	0.03	0.07	0.29	0.50
Expected signal events for chosen benchmark models	3.4 ± 0.7	24.3 ± 3.5	16.4 ± 3.0	10.6 ± 1.0	5.0 ± 0.8
Components of the background					
$t\bar{t}V$, $t\bar{t}H$, tZ and $t\bar{t}t\bar{t}$	1.3 ± 0.5	0.9 ± 0.4	2.5 ± 1.7	1.6 ± 1.0	1.3 ± 0.7
Dibosons and tribosons	< 0.1	4.2 ± 1.7	0.9 ± 0.4	1.2 ± 0.6	1.2 ± 0.6
Fake leptons	0.7 ± 0.6	$1.2^{+1.5}_{-1.2}$	$0.8^{+1.2}_{-0.8}$	1.6 ± 1.6	< 0.1
Charge-flip electrons	0.2 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	–	–
Systematic uncertainties on expected background					
Fake-lepton background	± 0.6	$^{+1.5}_{-1.2}$	$^{+1.2}_{-0.8}$	± 1.6	< 0.1
Theory unc. on dibosons	< 0.1	± 1.5	± 0.3	± 0.4	± 0.4
Jet and $E_{\mathrm{T}}^{\mathrm{miss}}$ scale and resolution	± 0.1	± 0.7	± 0.4	± 0.4	± 0.3
Monte Carlo statistics	± 0.1	± 0.5	± 0.2	± 0.4	± 0.4
b-jet tagging	± 0.2	± 0.5	± 0.1	< 0.1	± 0.1
Theory unc. on $t\bar{t}V$, $t\bar{t}H$, tZ and $t\bar{t}t\bar{t}$	± 0.4	± 0.3	± 1.7	± 1.0	± 0.6
Trigger, luminosity and pile-up	< 0.1	± 0.1	± 0.1	± 0.1	± 0.1
Charge-flip background	± 0.1	± 0.1	± 0.1	–	–
Lepton identification	< 0.1	± 0.1	< 0.1	± 0.1	± 0.1

SR cuts, 0/1 lepton, ≥3 b-jets

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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
$m_{\mathrm{eff}}^{4\mathrm{j}}$ [GeV] $>$	1300	1100	1100	-	-	-
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}^{4\mathrm{j}}}$ [$\sqrt{GeV}$] $>$	-	-	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

SR cuts, Photon analysis

arXiv: 1507.05493

Signal Region	$SR_L^{\gamma b}$	$SR_H^{\gamma b}$	$SR_L^{\gamma j}$	$SR_H^{\gamma j}$
No. photons (E_T [GeV])	> 0 (> 125)	> 0 (> 150)	1 (> 125)	1 (> 300)
E_T^{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]	$75-150$	–	–	–
$M_T^{\gamma, E_T^{miss}}$ [GeV]	> 90	> 90	–	–
$\Delta\phi_{min}(\text{jet}, E_T^{miss})$ (No. leading jets)	> 0.3 (2)	> 0.3 (4)	> 0.4 (2)	> 0.4 (2)
R_T^4	–	–	< 0.85	
$\Delta\phi_{min}(\text{jet}, \gamma)$	–	–	–	< 2.0

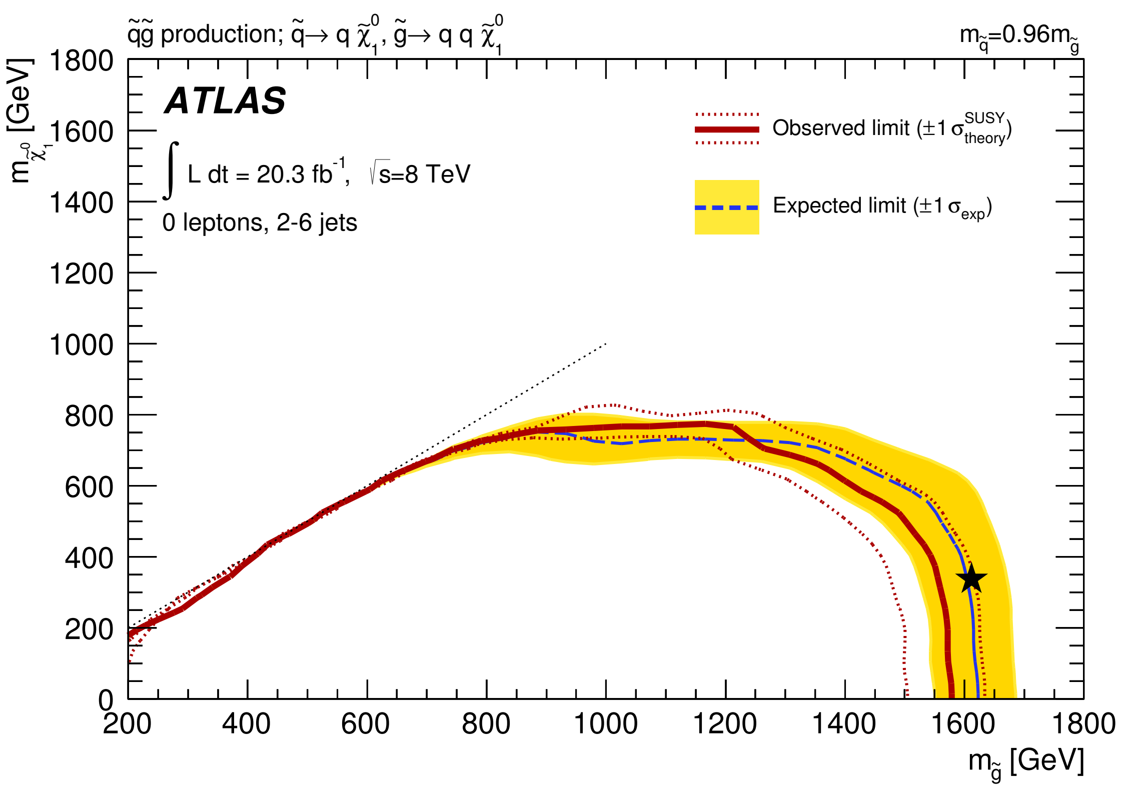
[a] For $SR_L^{\gamma j}$ and $SR_H^{\gamma j}$, the two leading jets are required to have $p_T > 100$ and $p_T > 40$ GeV, respectively.

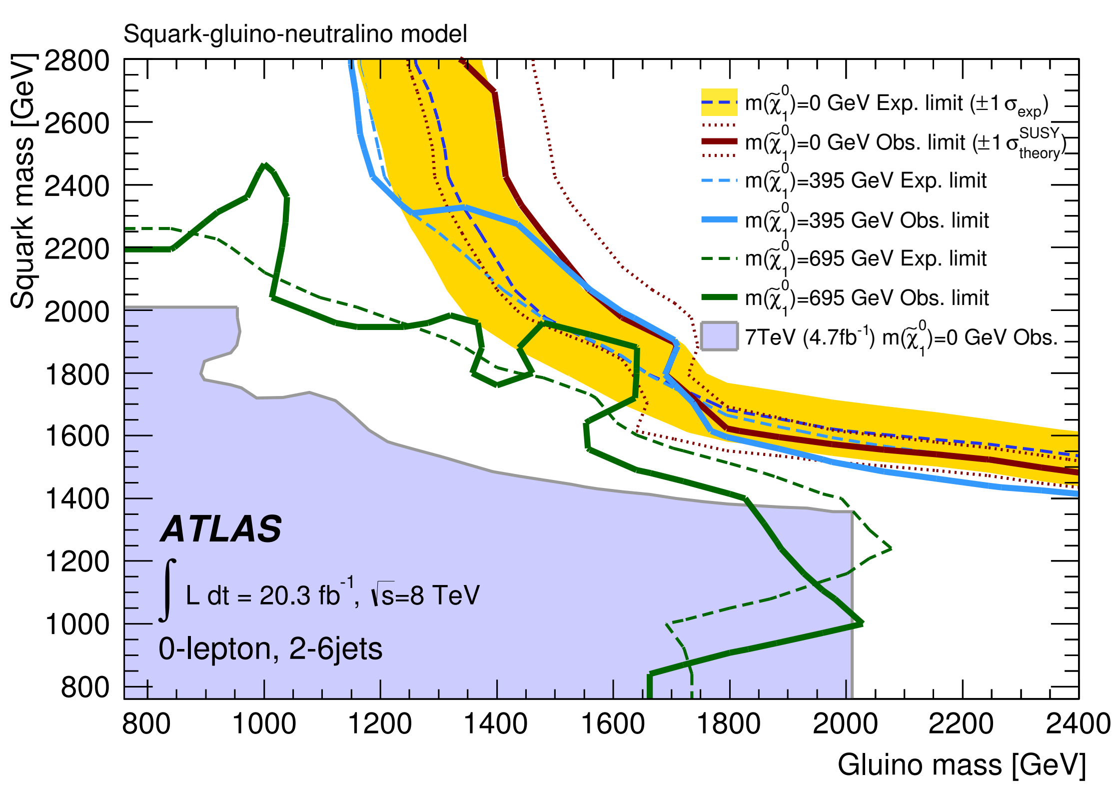
Signal Regions	$SR_L^{\gamma b}$	$SR_H^{\gamma b}$
Expected background events	18.8 ± 5.3	3.82 ± 1.25
$e \to \gamma$	3.2 ± 0.4	0.18 ± 0.08
$W(\to \ell\nu)$	12.6 ± 4.9	3.35 ± 1.05
QCD	2.3 ± 2.1	0.00 ± 0.65
$Z \to \nu\nu$	0.8 ± 0.4	0.29 ± 0.15
Observed events	12	2

Signal Regions	$SR_L^{\gamma j}$	$SR_H^{\gamma j}$
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

Limits on direct decays

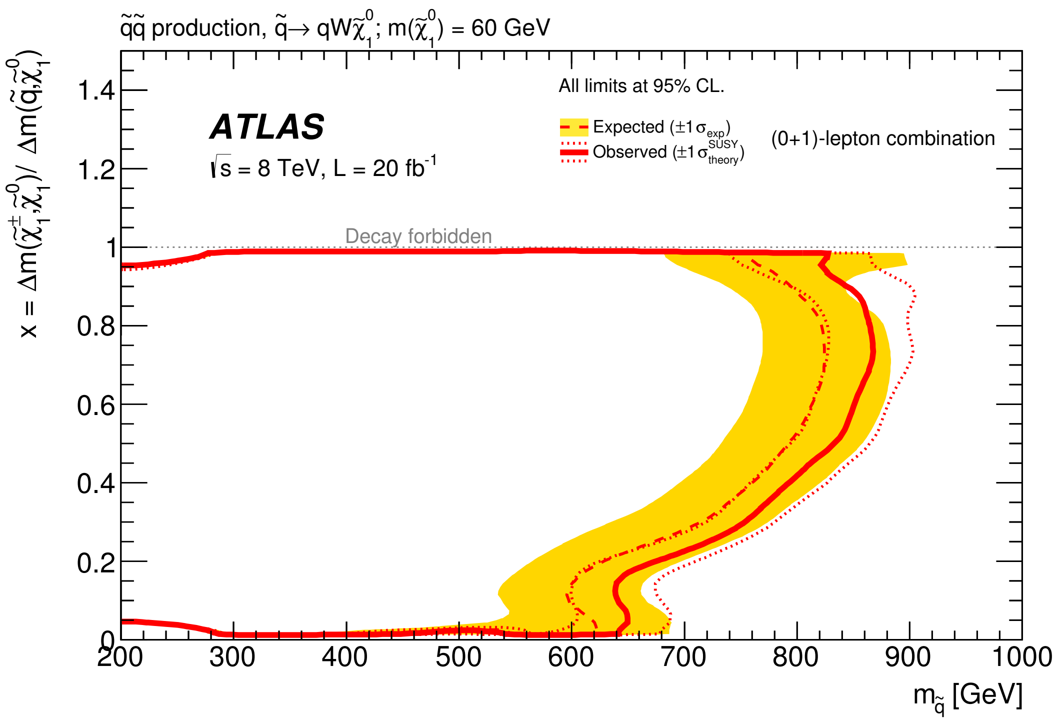
arXiv:
1507.05525

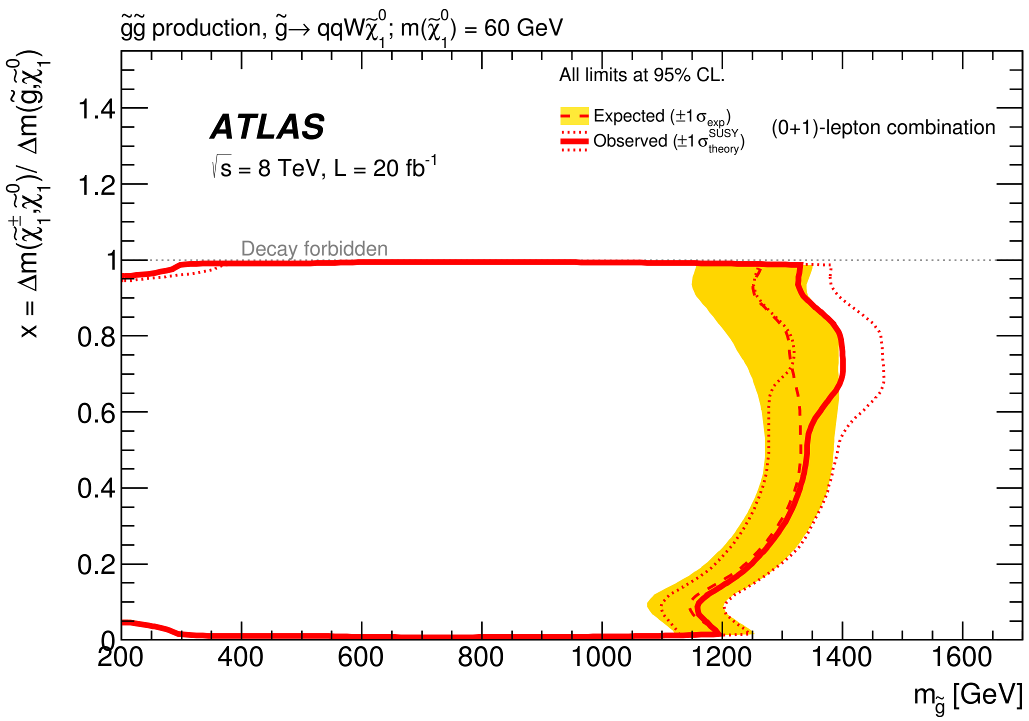




Limits on one-step decays, m(LSP) = 60 GeV

arXiv: 1507.05525





Prospect for run 2 with 50% syst.

ATL-PHYS-PUB-2015-005