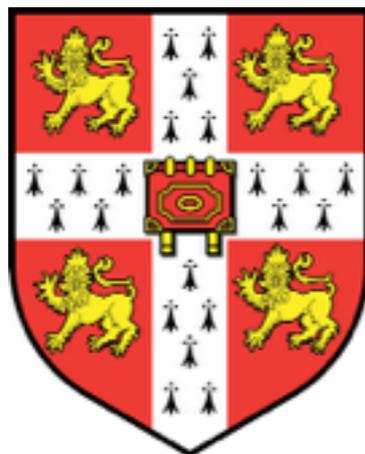


Inclusive searches for squarks and gluinos with the ATLAS detector

Thomas Gillam

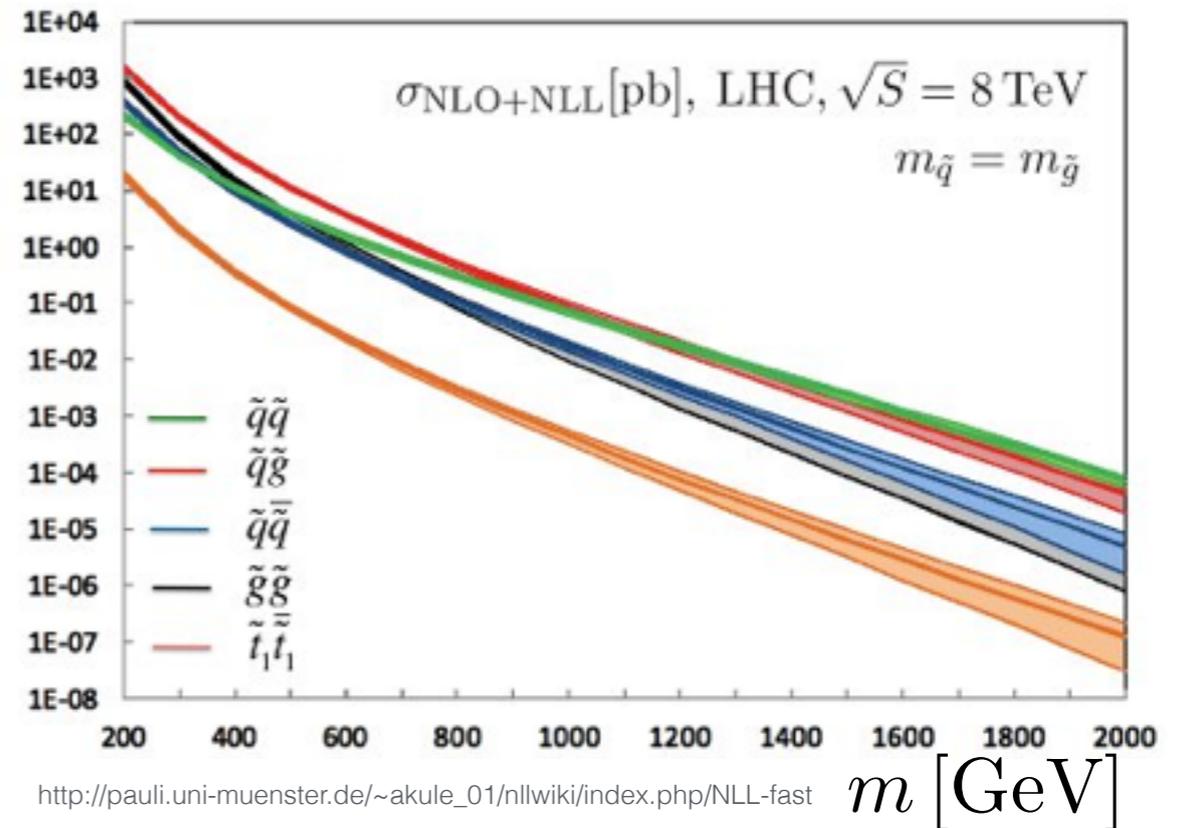
University of Cambridge, ATLAS collaboration



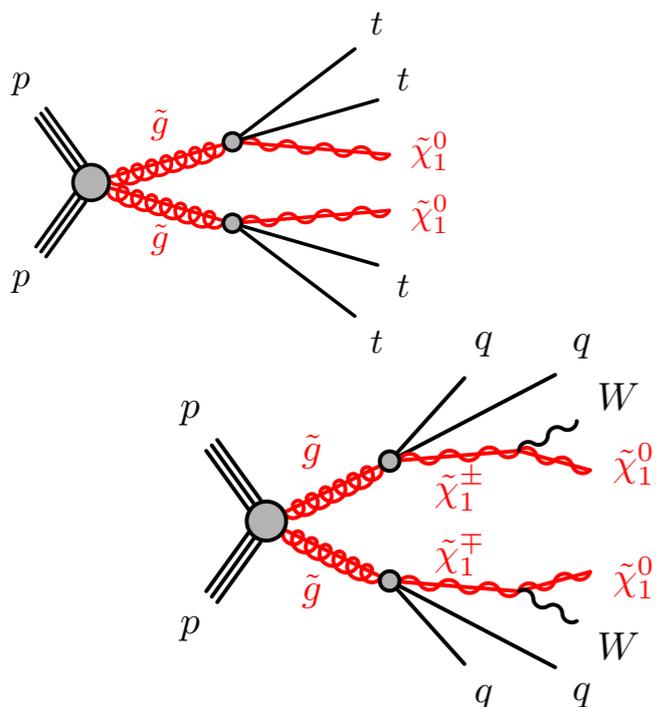
What are we looking for?

Strong production — gluino pair, squark pair, gluino with associated squark

Many possible decays — place limits in specific scenarios:



Simplified



etc.

mSUGRA/CMSSM Minimal supergravity

GMSB Gauge mediated symmetry breaking

GGM General gauge mediation

... and more!

Objects used in the analyses



Leptons — light flavour, electrons or muons

τ

Taus — distinct detector signature cf. e , μ



Photons



Jets



***b*-tagged jets** — from decays of b hadrons



Missing transverse energy

Recent ATLAS analyses that will be covered



1-2 leptons, 3-6 jets, MET

ATLAS-CONF-2013-062



2 leptons

ATLAS-CONF-2013-089



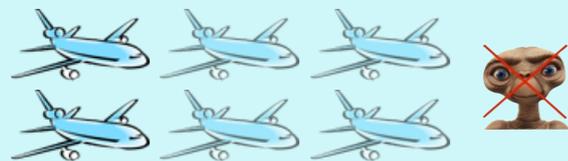
2 same-sign or 3 leptons

arXiv: 1404.2500



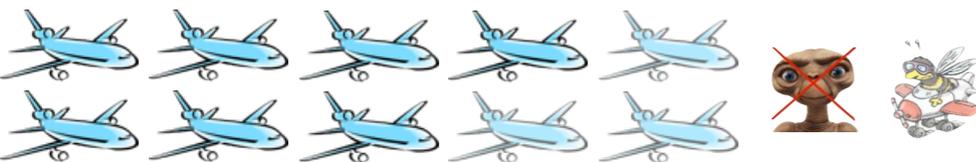
Taus, jets, MET

ATLAS-CONF-2013-026



0 leptons, 2-6 jets, MET

ATLAS-CONF-2013-047



7-10 jets, MET

arXiv: 1308.1841



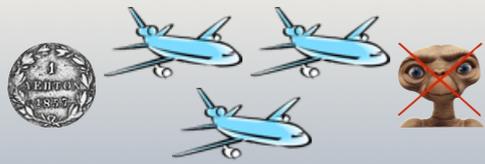
Diphoton, MET

ATLAS-CONF-2014-001



General search

ATLAS-CONF-2014-006



1-2 leptons, 3-6 jets, MET

Soft single lepton

One e or μ , $p_T < 25$ GeV

3 jets

5 jets

$E_T^{\text{miss}} > 400$ GeV : $E_T^{\text{miss}} > 300$ GeV

Soft dimuon

Two μ , $p_T < 25$ GeV

2 jets

$E_T^{\text{miss}} > 170$ GeV

Hard single lepton

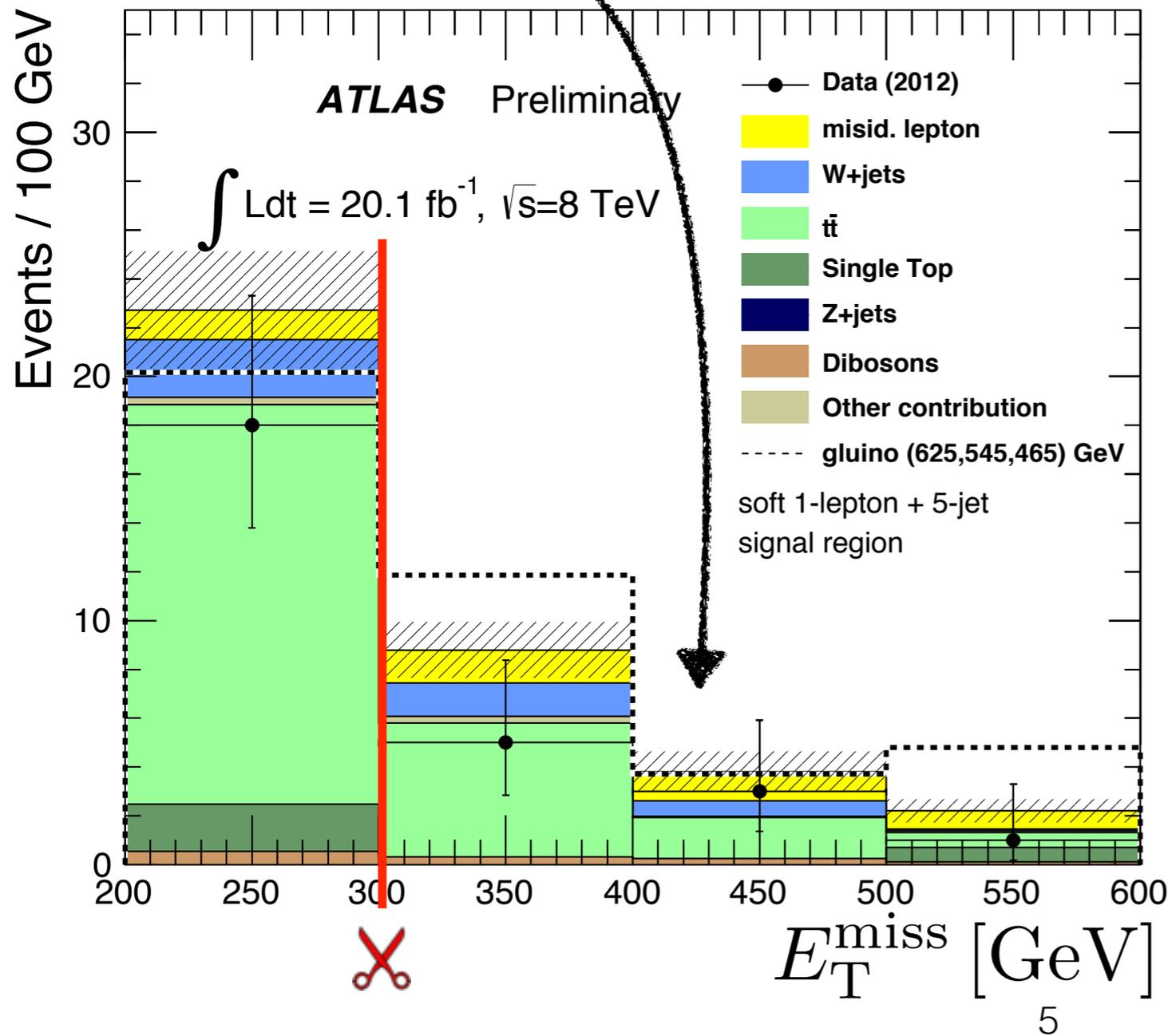
One e or μ , $p_T > 25$ GeV

3 jets

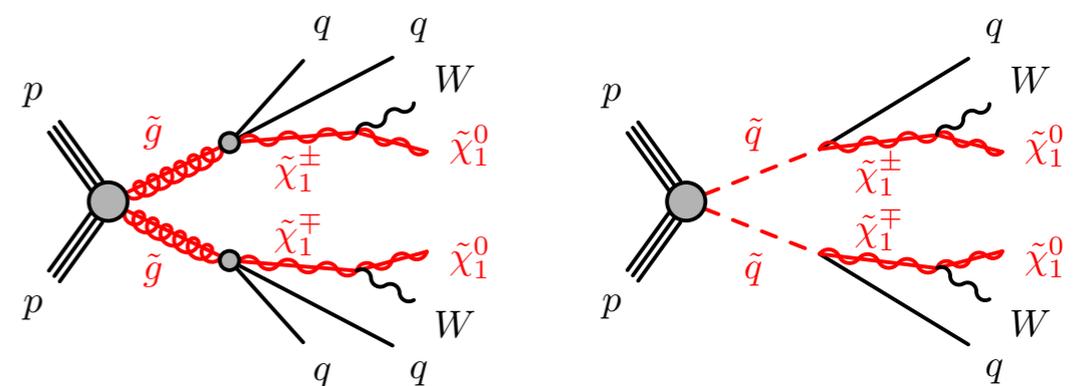
5 jets

6 jets

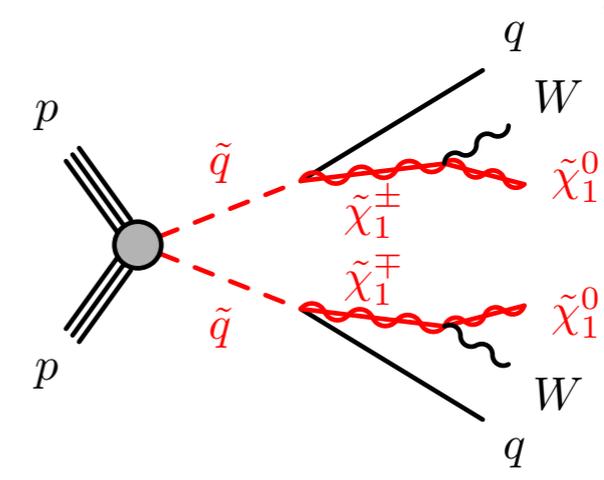
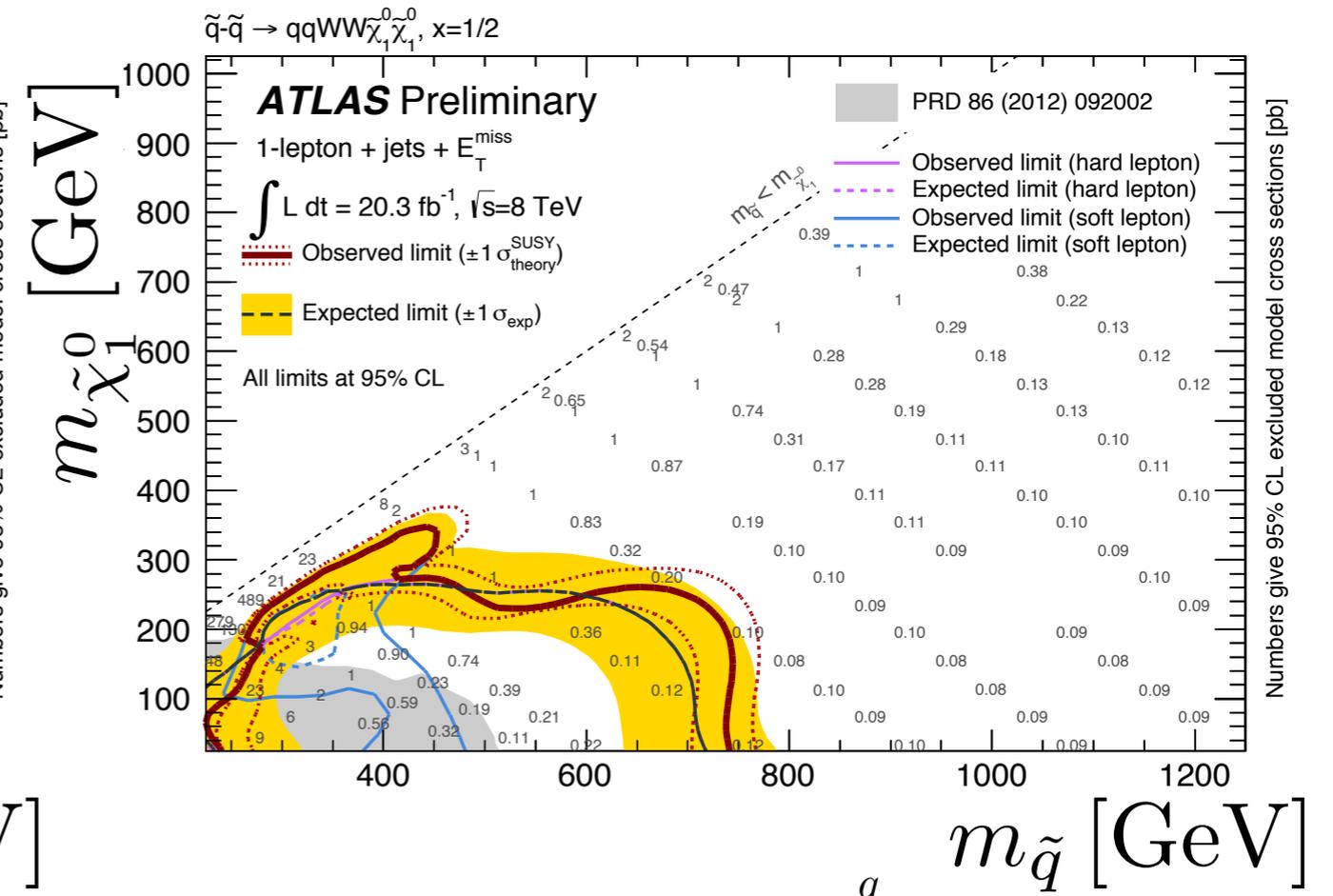
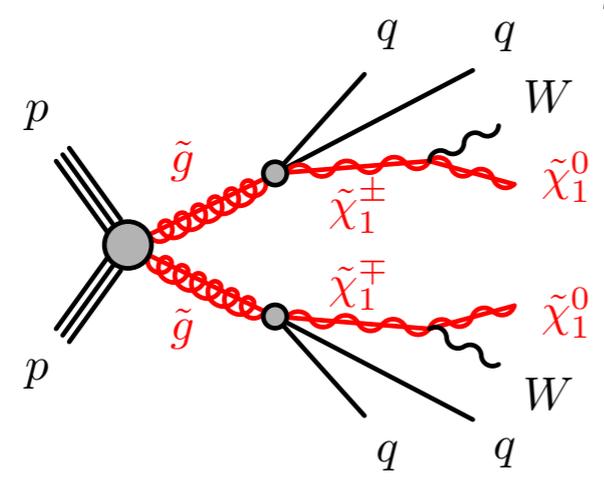
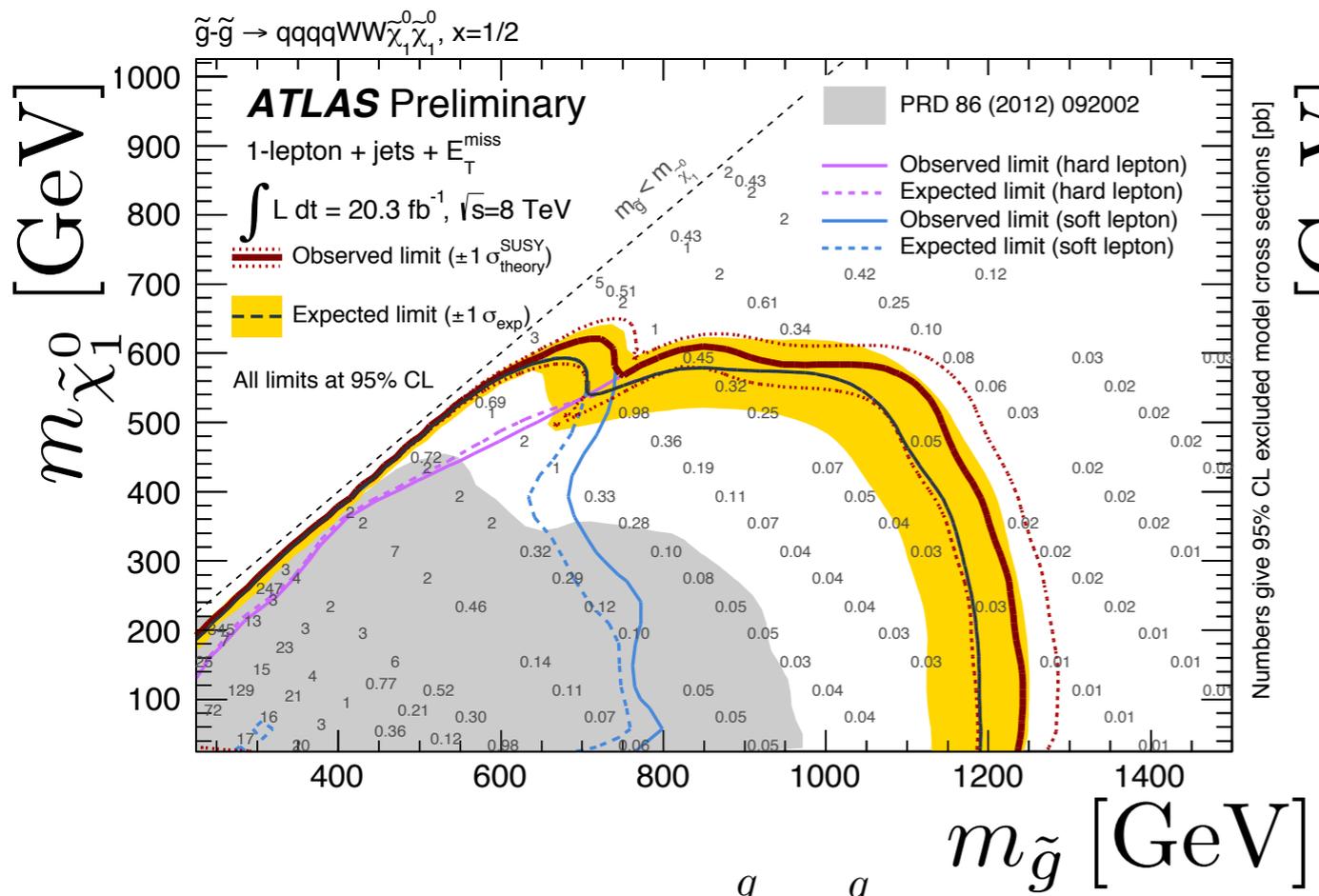
$E_T^{\text{miss}} > 500$ GeV : $E_T^{\text{miss}} > 300$ GeV : $E_T^{\text{miss}} > 350$ GeV



- Target simplified quark/gluino production scenarios, mSUGRA/CMSSM, mUED
- SRs targeting both soft and hard leptons, others require b -tags to target 3rd generation
- $t\bar{t}$, W +jets: MC prediction constrained in CRs. Fake leptons from matrix method



1-2 leptons, 3-6 jets, MET





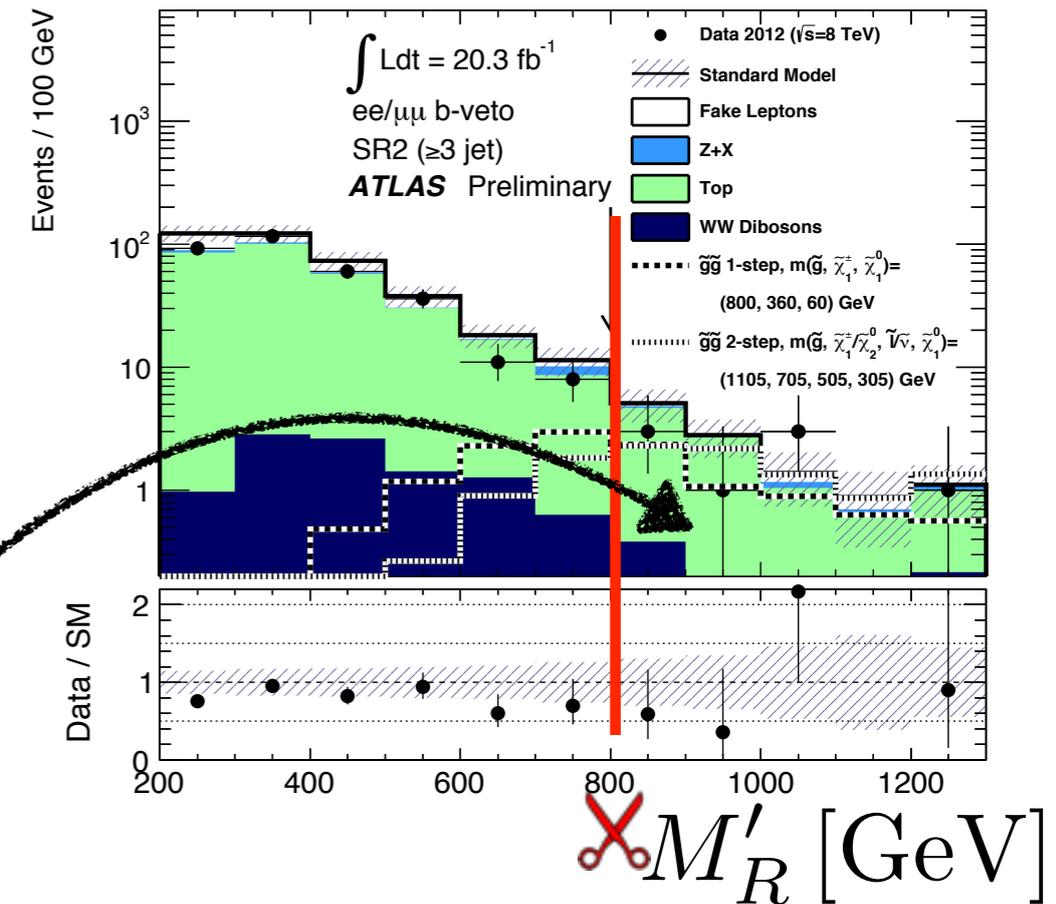
2 leptons



- Target simplified strong production, and direct sbottom (See Steve Muanza's talk)
- Based on "razor" variables, orthogonal phase space to typical M_{eff} SRs
- Discriminates events containing decays from pair produced particles of equal (large) masses

SR1
 $e\mu$ $ee/\mu\mu$
 $M'_R > 400\text{GeV}$
 $R > 0.5$
 $N_{\text{jets}} < 3$

SR2
 $e\mu$ $ee/\mu\mu$
 $M'_R > 800\text{GeV}$
 $R > 0.35$
 $N_{\text{jets}} \geq 3$



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

$$M_T^R = \sqrt{\frac{|\vec{E}_T^{\text{miss}}| (|\vec{j}_{1,T}| + |\vec{j}_{2,T}|) - \vec{E}_T^{\text{miss}} \cdot (\vec{j}_{1,T} + \vec{j}_{2,T})}{2}}$$

$$R = \frac{M_T^R}{M'_R}$$

- M'_R measures how longitudinally split events are
- See e.g. arXiv 1006.2727



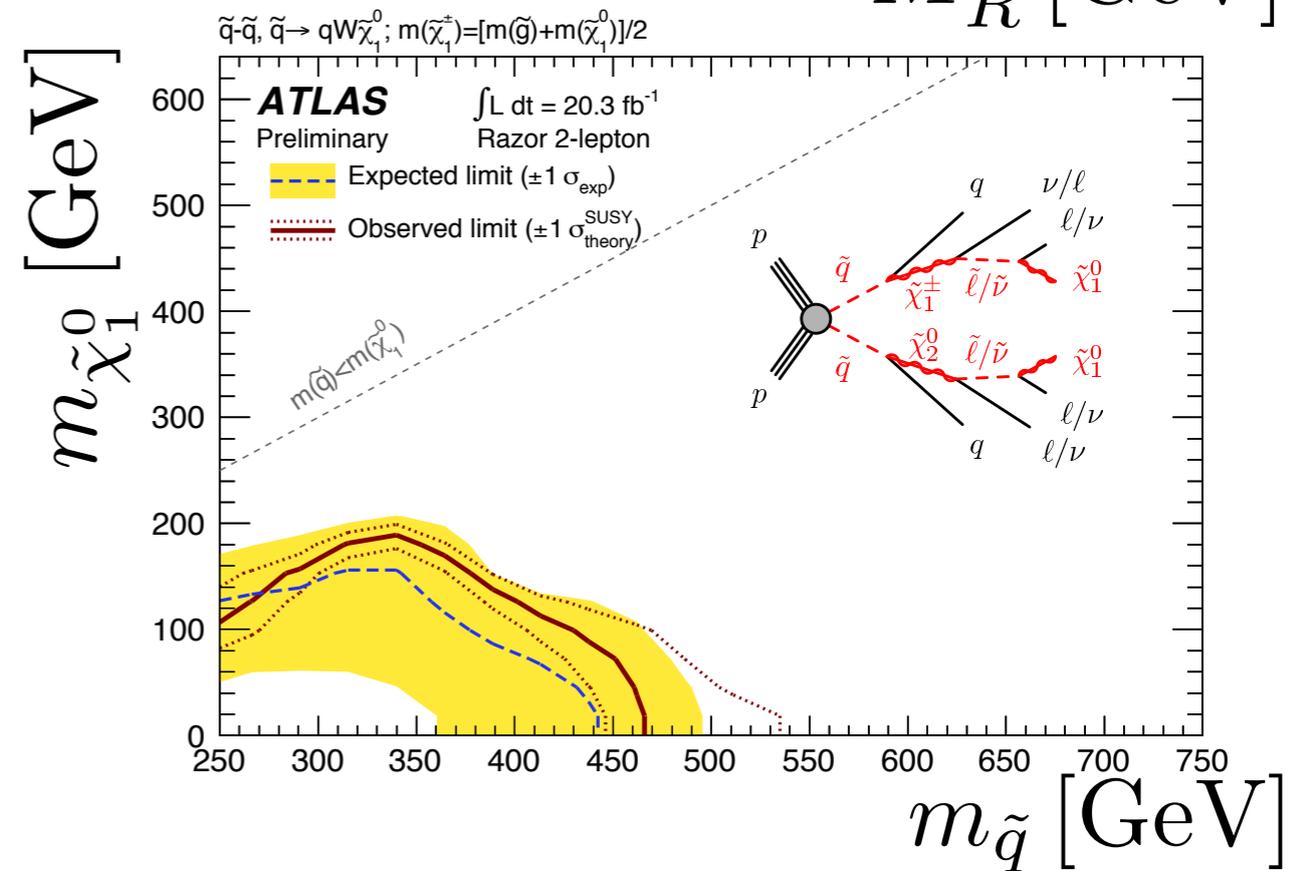
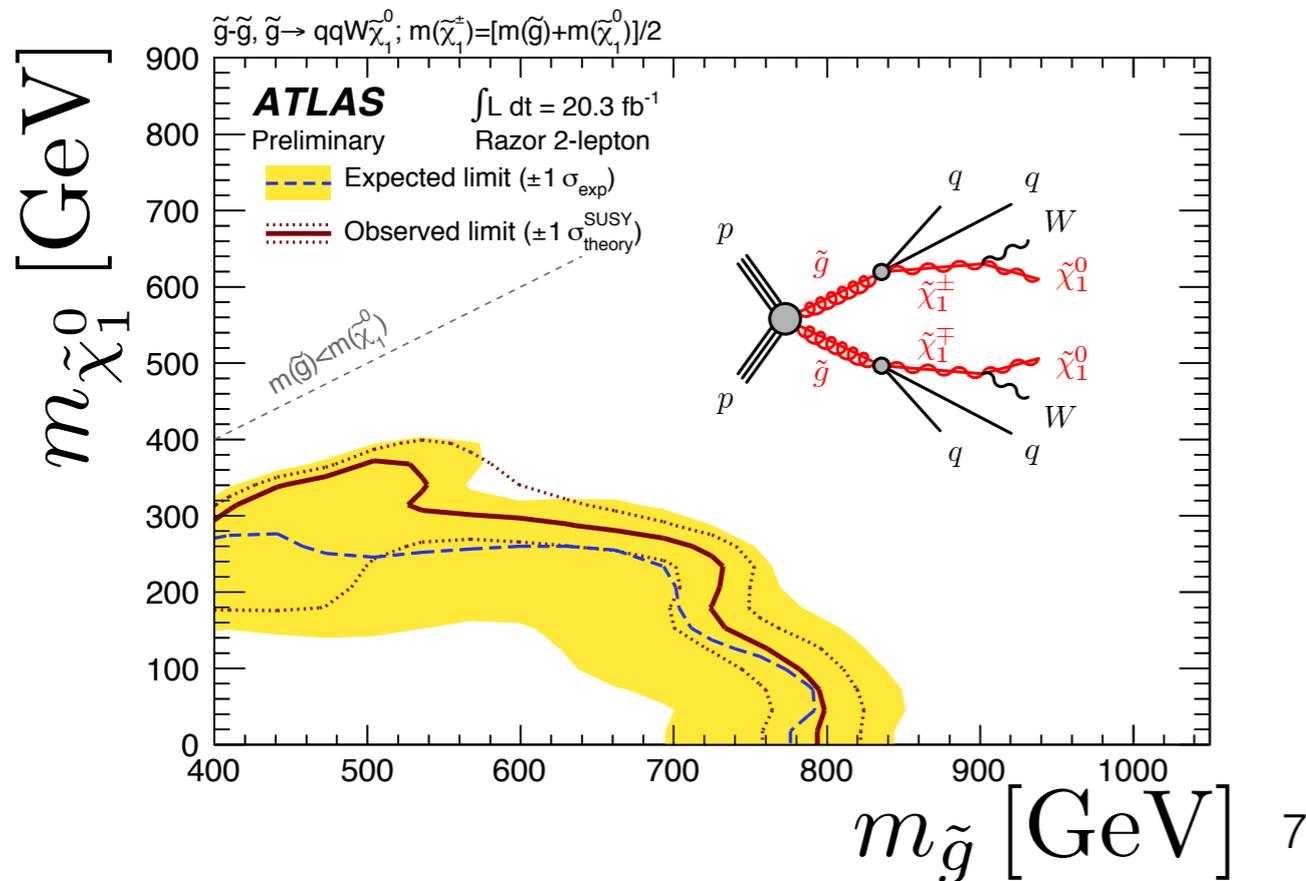
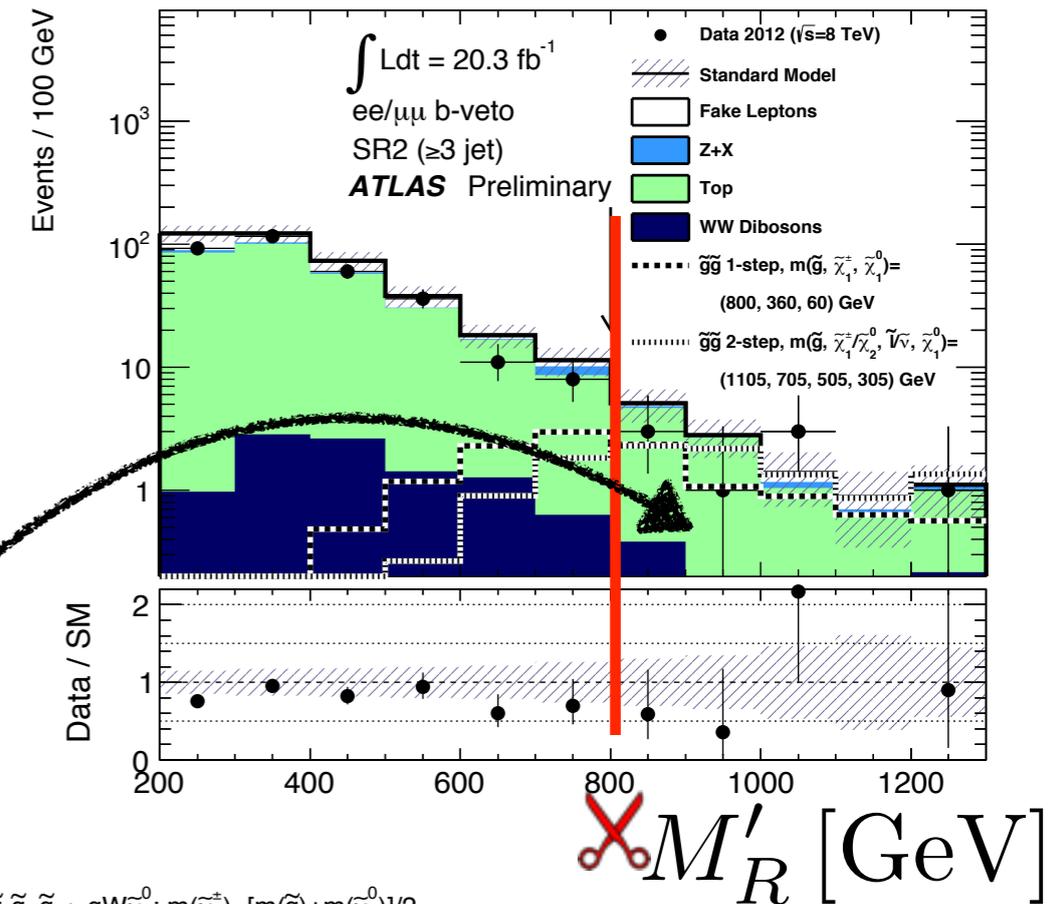
2 leptons



- Target simplified strong production, and direct sbottom (See Steve Muanza's talk)
- Based on "razor" variables, orthogonal phase space to typical M_{eff} SRs
- Discriminates events containing decays from pair produced particles of equal (large) masses

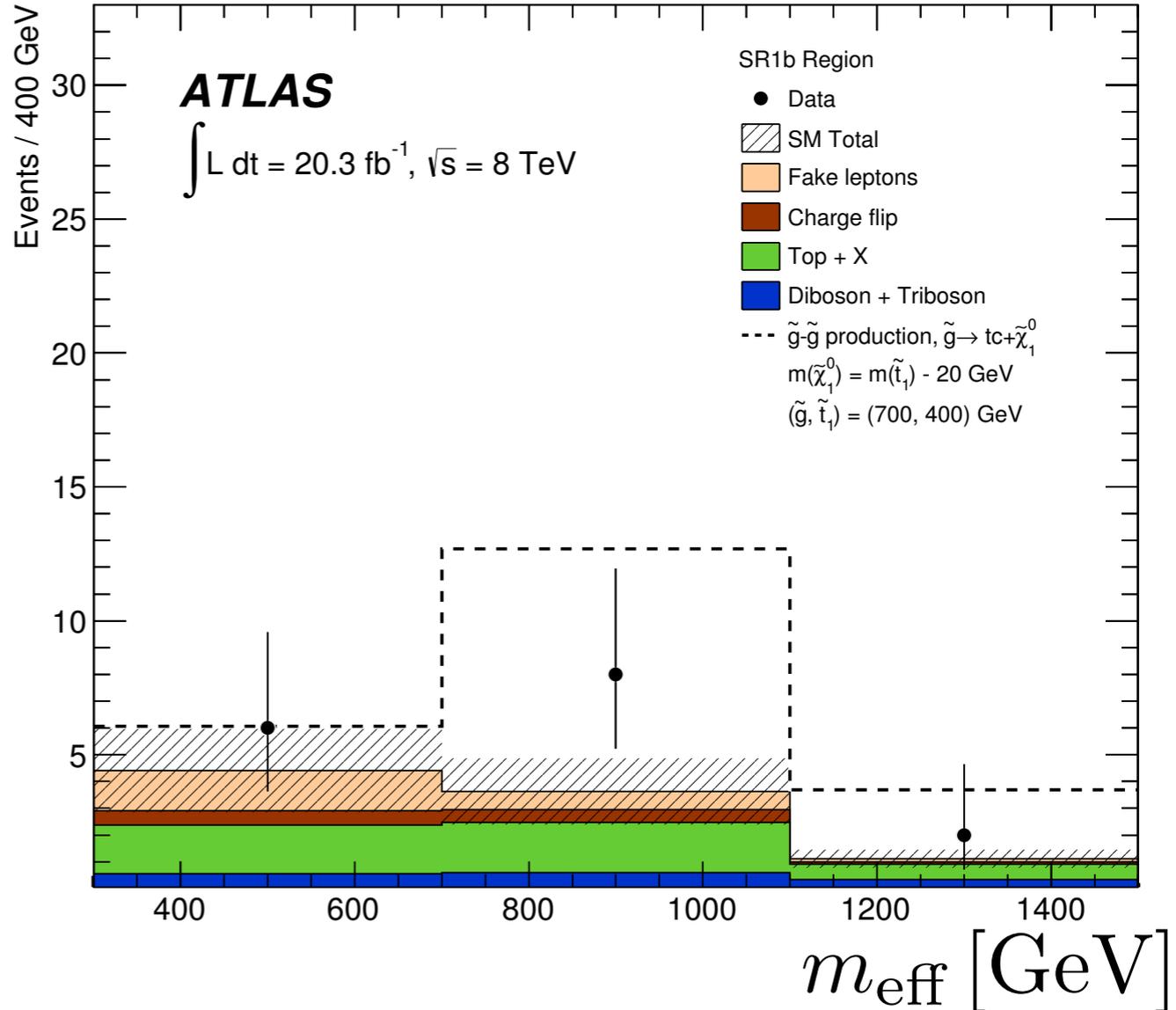
SR1
 $e\mu$ $ee/\mu\mu$
 $M'_R > 400\text{GeV}$
 $R > 0.5$
 $N_{\text{jets}} < 3$

SR2
 $e\mu$ $ee/\mu\mu$
 $M'_R > 800\text{GeV}$
 $R > 0.35$
 $N_{\text{jets}} \geq 3$



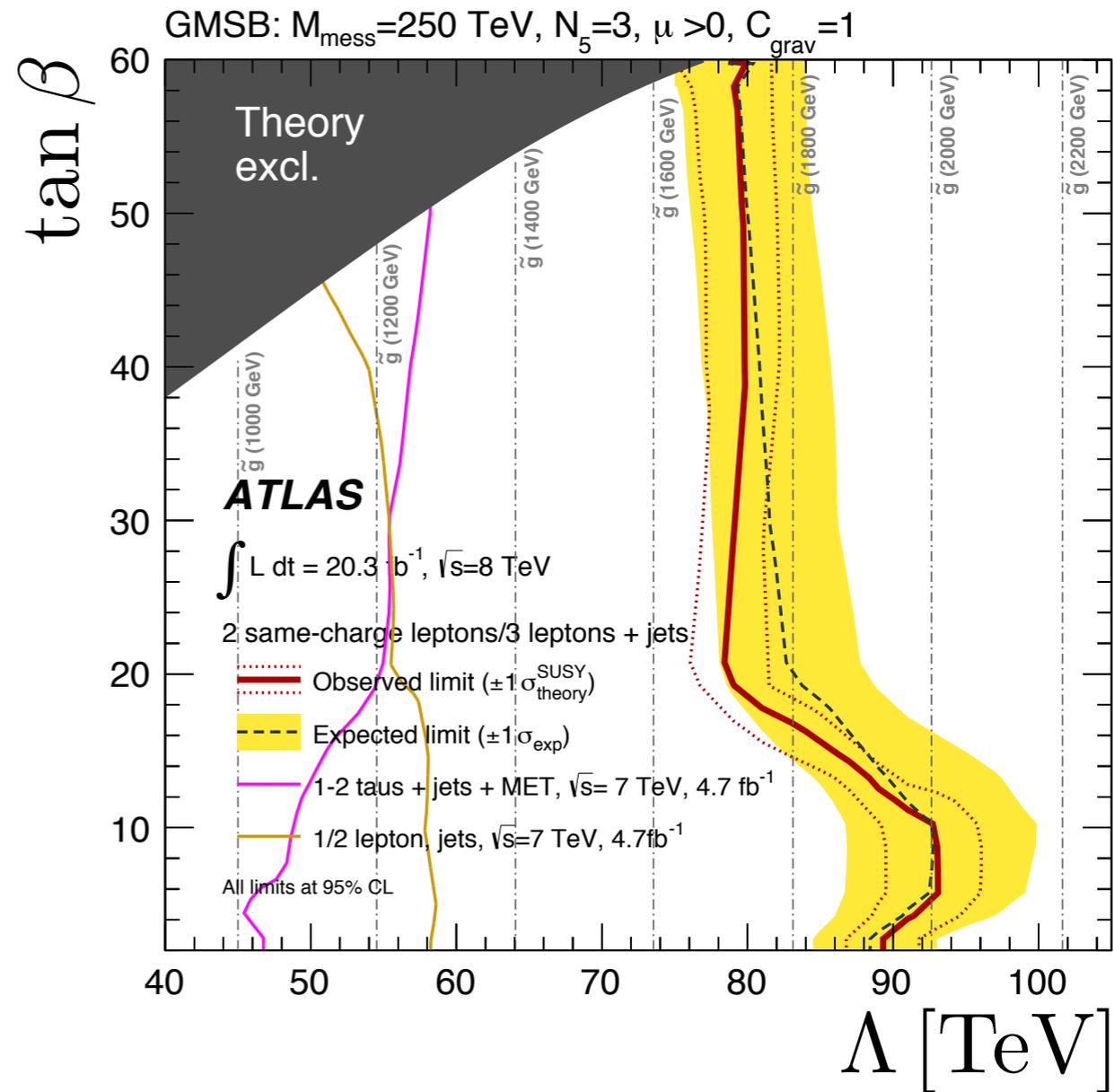
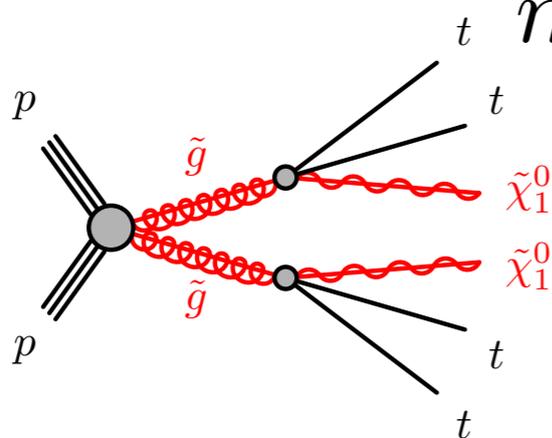
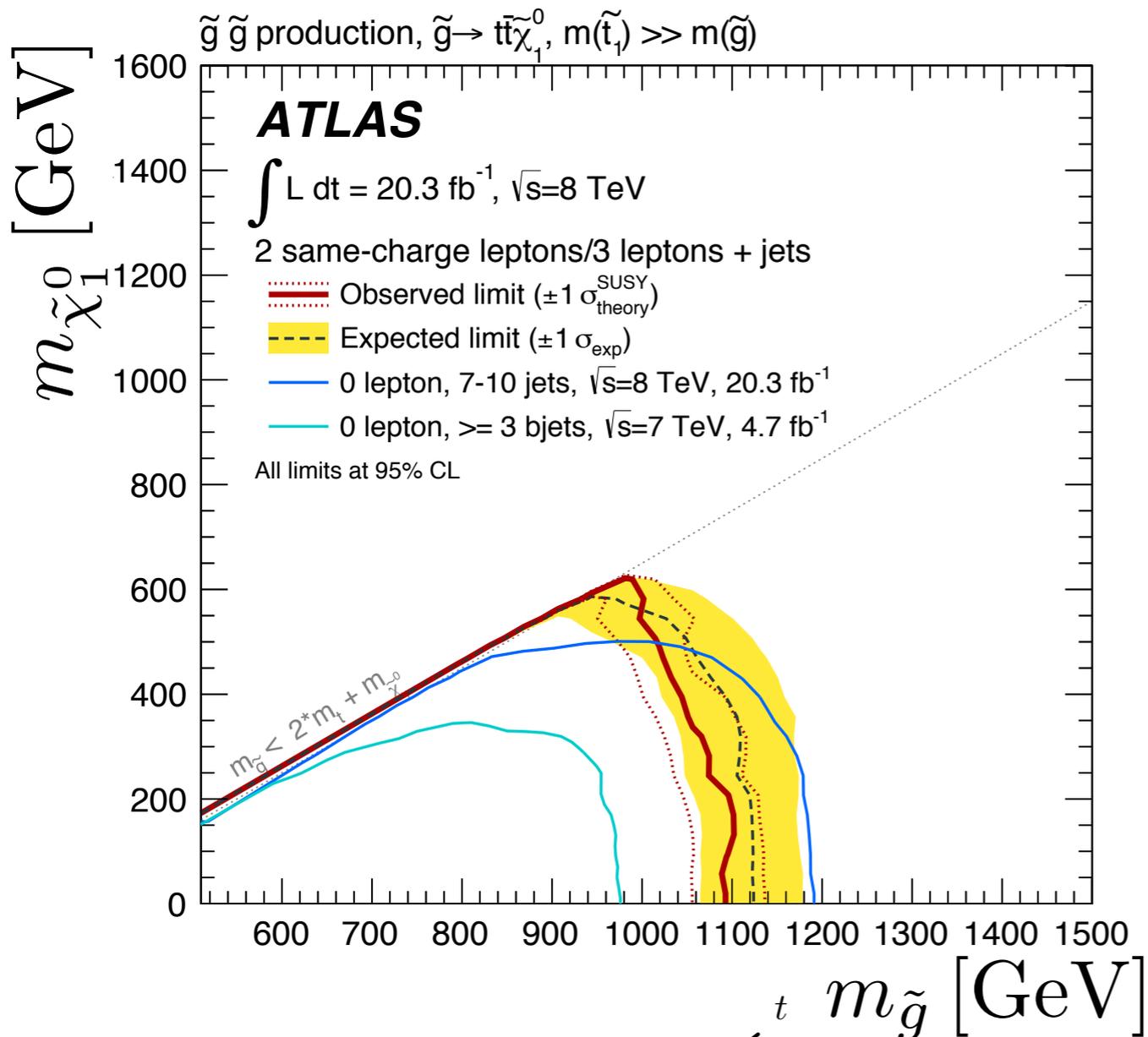
SR0b	SR1b	SR3b	SR3L _{low}	SR3L _{high}
SS	SS	SS / ≥ 3 lep	≥ 3 leptons	≥ 3 leptons
$E_T^{\text{miss}} > 150$ GeV	$E_T^{\text{miss}} > 150$ GeV	–	$50 < E_T^{\text{miss}} < 150$ GeV	$E_T^{\text{miss}} > 150$ GeV
0 <i>b</i> -jets	≥ 1 <i>b</i> -jets	≥ 3 <i>b</i> -jets	–	–

- Target gluino decay modes producing like-charge leptons
- Trilepton SRs increase sensitivity to longer cascades
- Data-driven estimates of charge-flip and fake lepton background



NEW

2 same-sign or 3 leptons



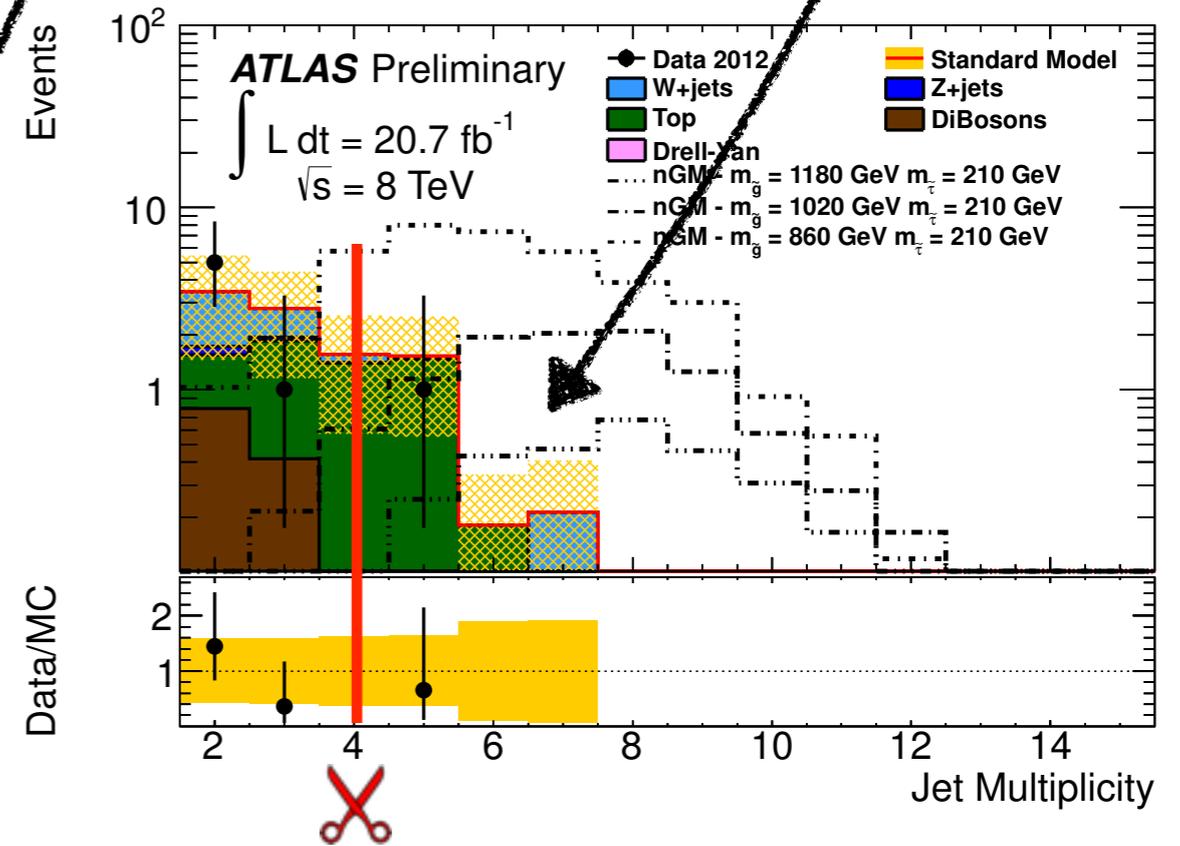
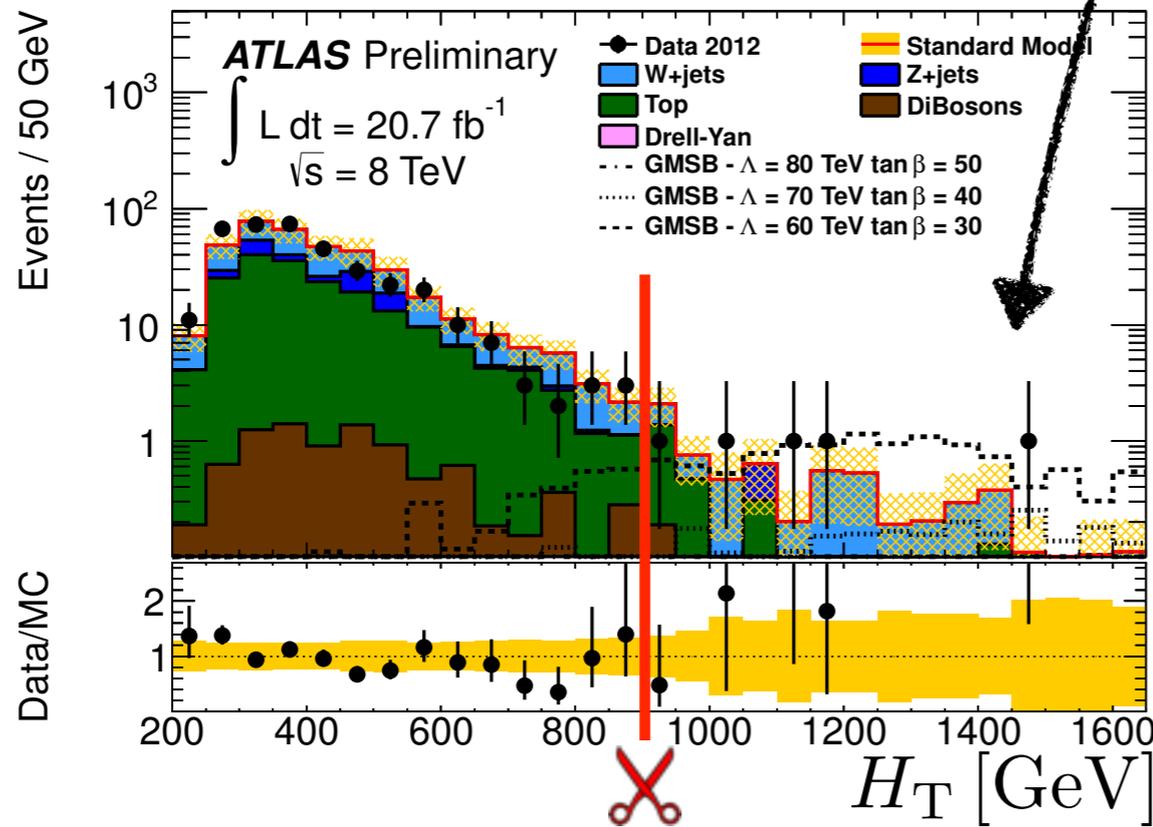
- Sensitive to a variety of SUSY and BSM scenarios — also constrains GMSB, mUED models

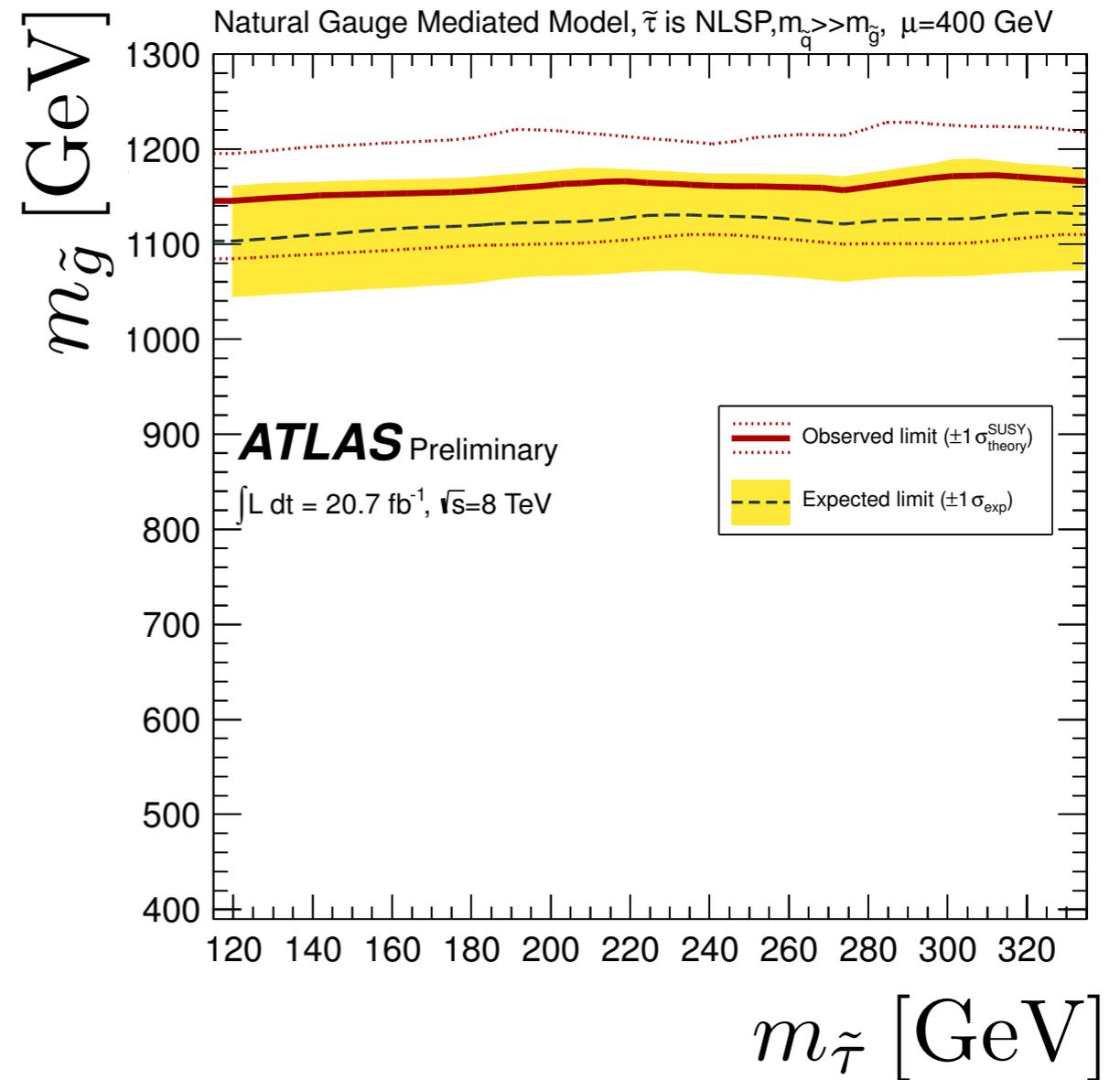
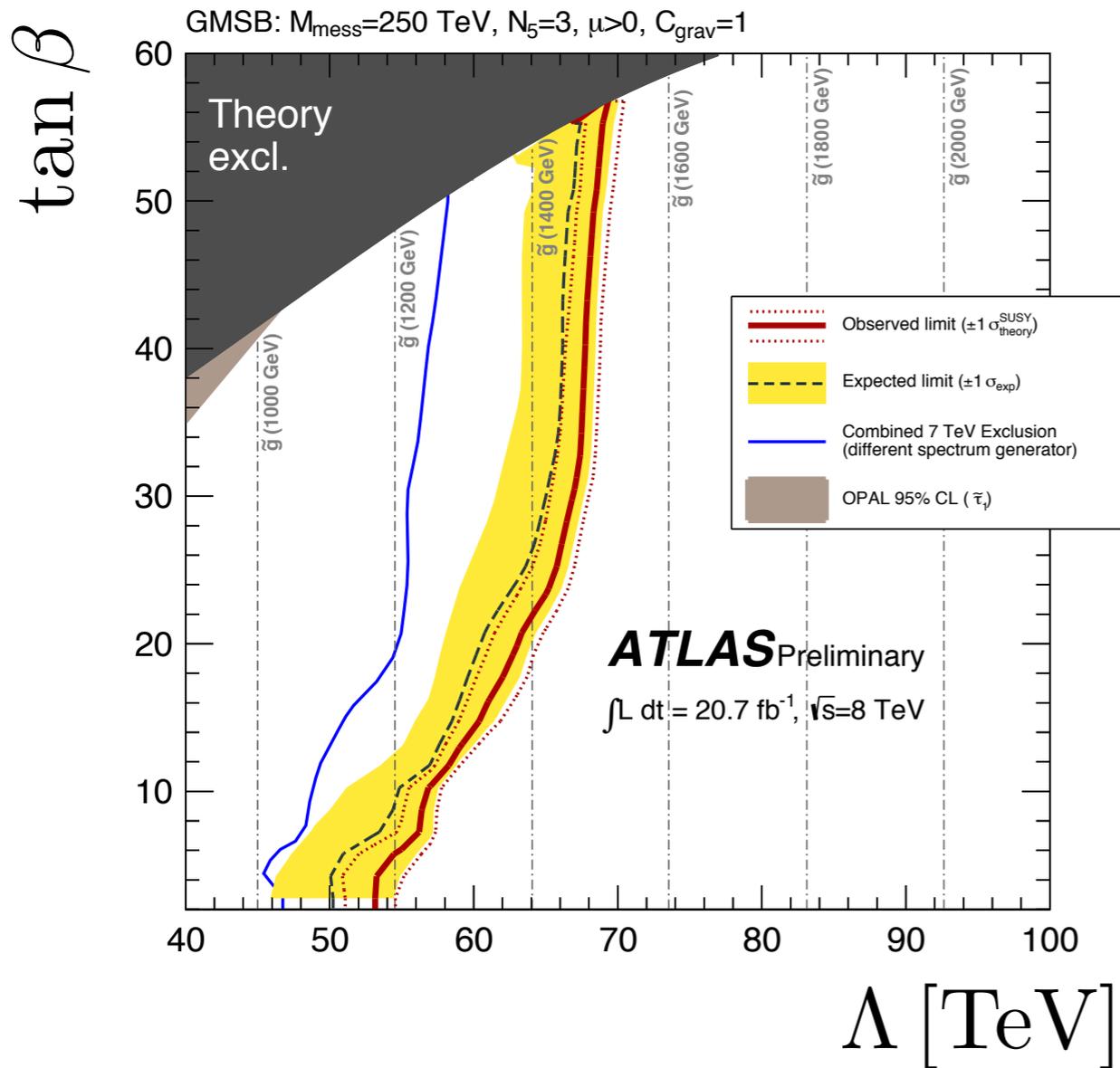


Taus, jets, MET

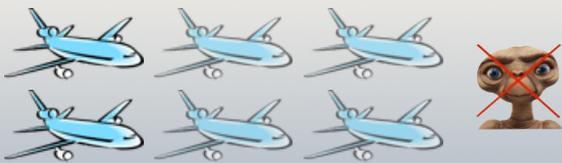
- Exactly 1 tau, or at least two taus — separate SRs to target different models
- Estimate fake tau contribution with data-driven method
- nGM is ‘natural gauge mediation’ — tuned version of GGM to avoid fine tuning in Higgs sector

1 τ SR	2 τ GMSB SR	2 τ nGM SR
$m_T^\tau > 140 \text{ GeV}$	$m_T^{\tau_1} + m_T^{\tau_2} > 150 \text{ GeV}$	$m_T^{\tau_1} + m_T^{\tau_2} > 250 \text{ GeV}$
$H_T > 800 \text{ GeV}$	$H_T > 900 \text{ GeV}$	$H_T > 600 \text{ GeV}$
		$N_{\text{jets}} \geq 4$





- nGM is 'natural gauge mediation' — tuned version of GGM to avoid fine tuning in Higgs sector

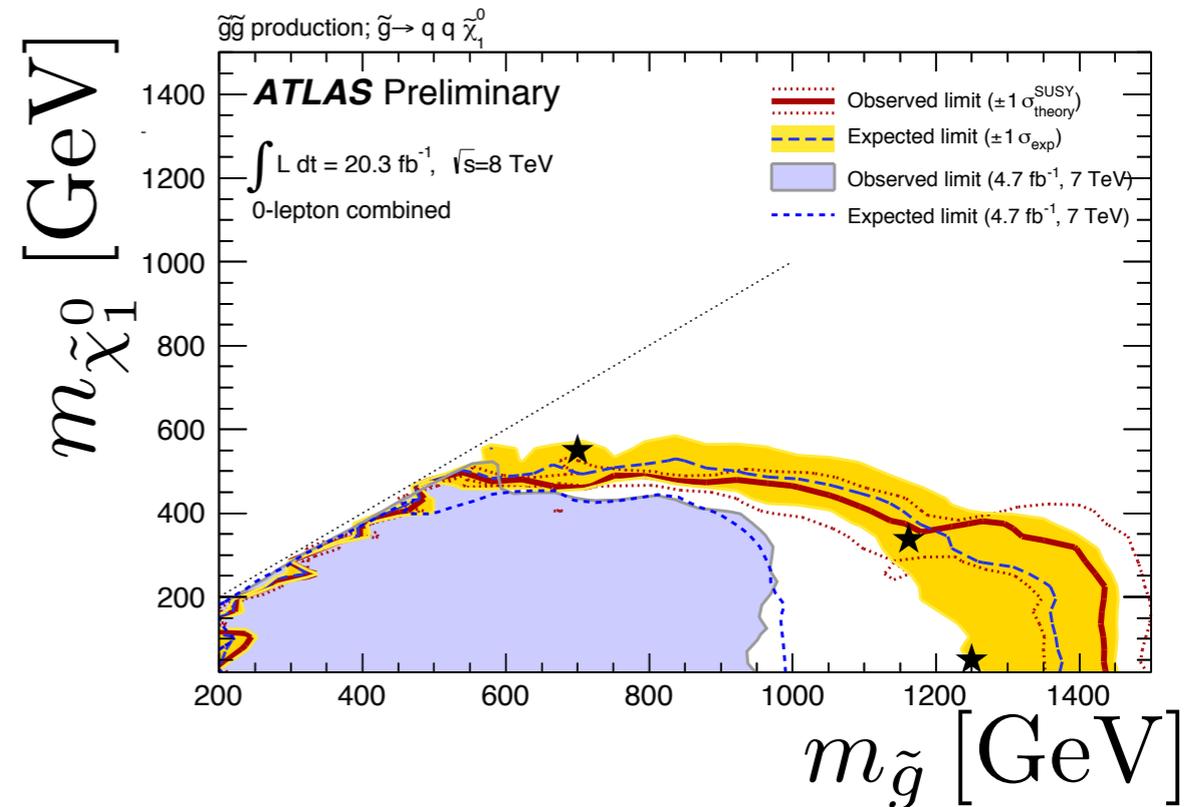
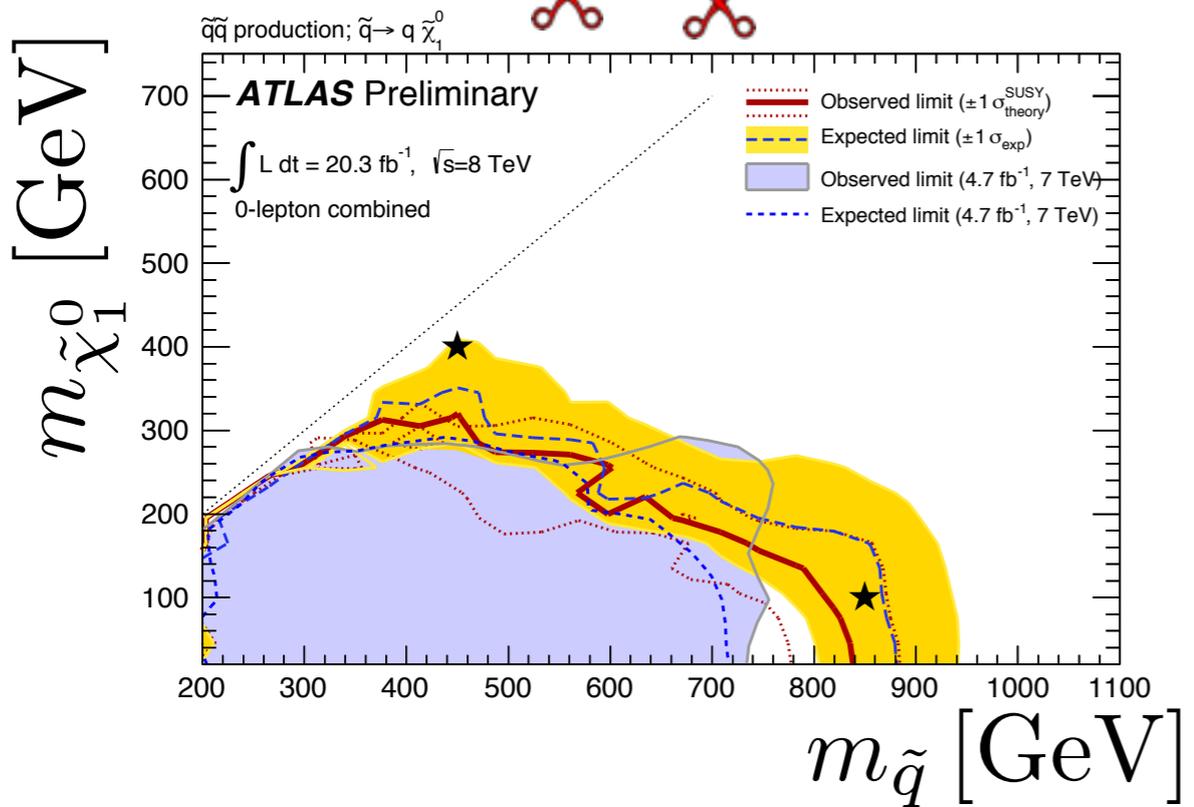
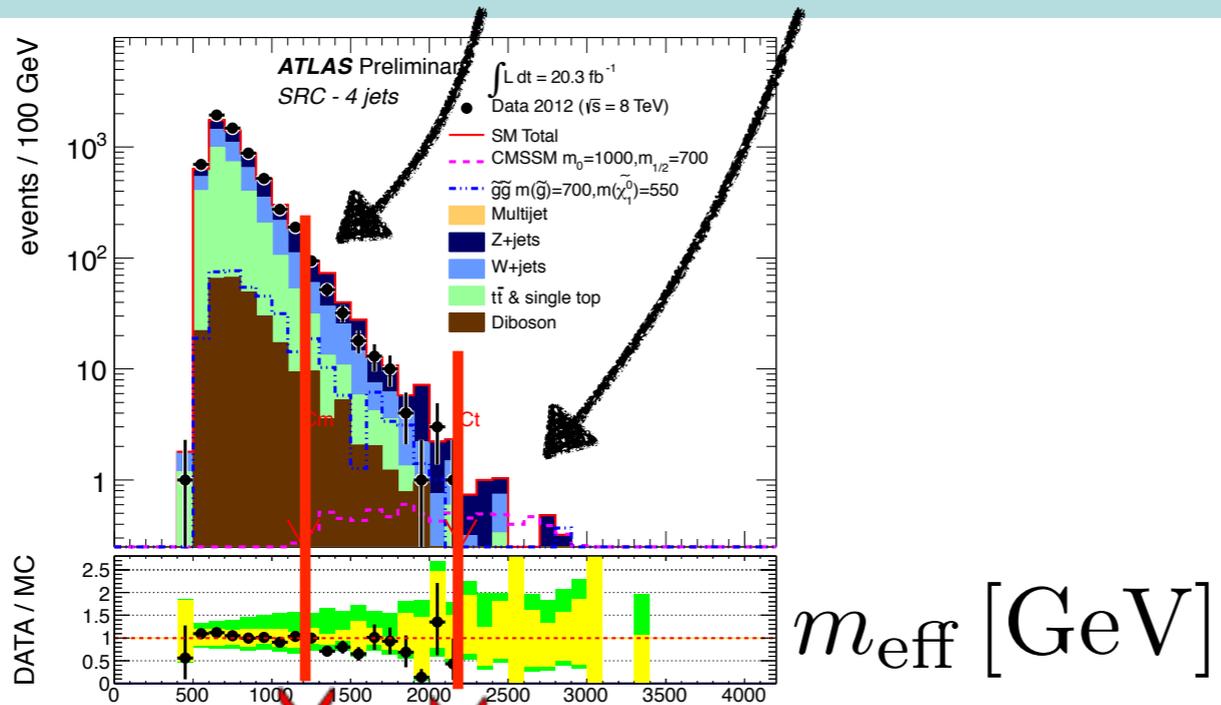


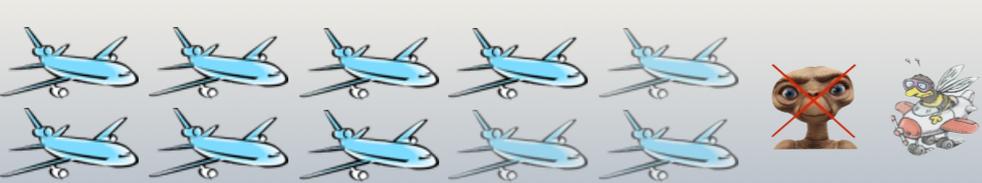
0 leptons, 2-6 jets, MET

2j 3j 4j 5j 6j
 Variations for **loose**, **medium** and **tight** cuts on M_{eff}

- Target generic hadronic decay paths of squarks & gluinos
- Cut on MET/ M_{eff} to reduce mis-measured multijet background
- Constrain $Z \rightarrow \nu\nu + \text{jets}$ background with photon control regions

4 jet SR





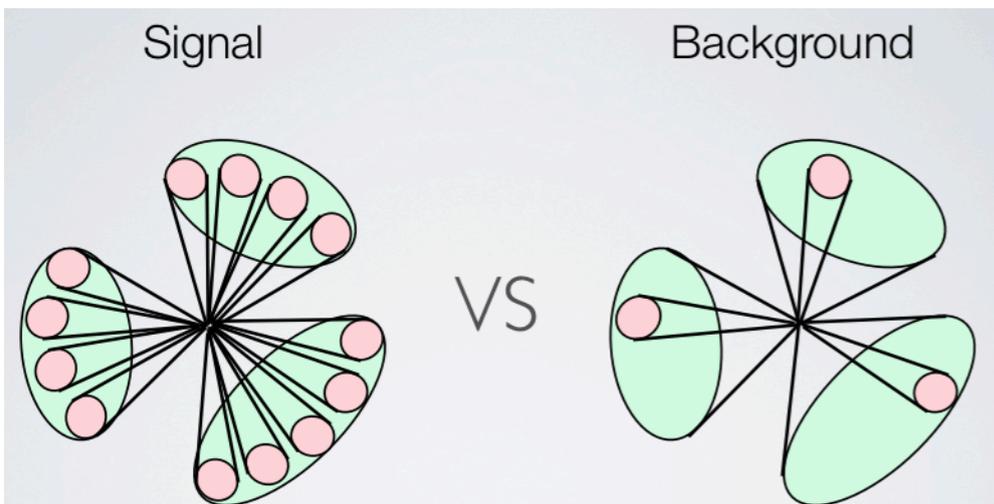
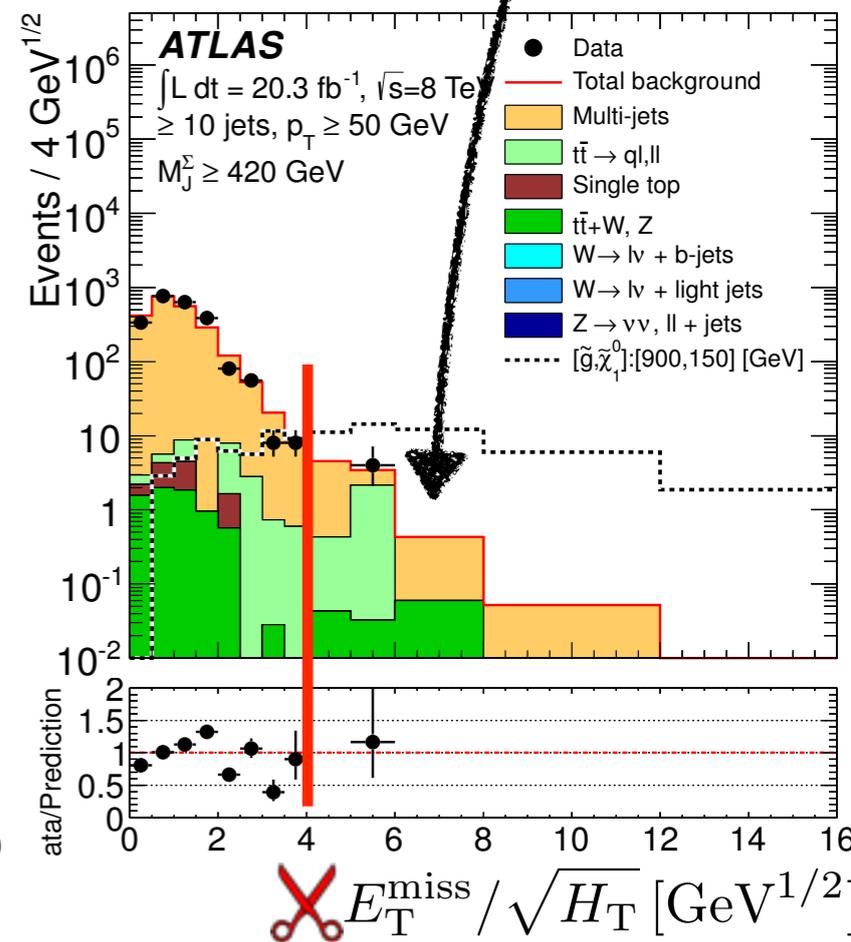
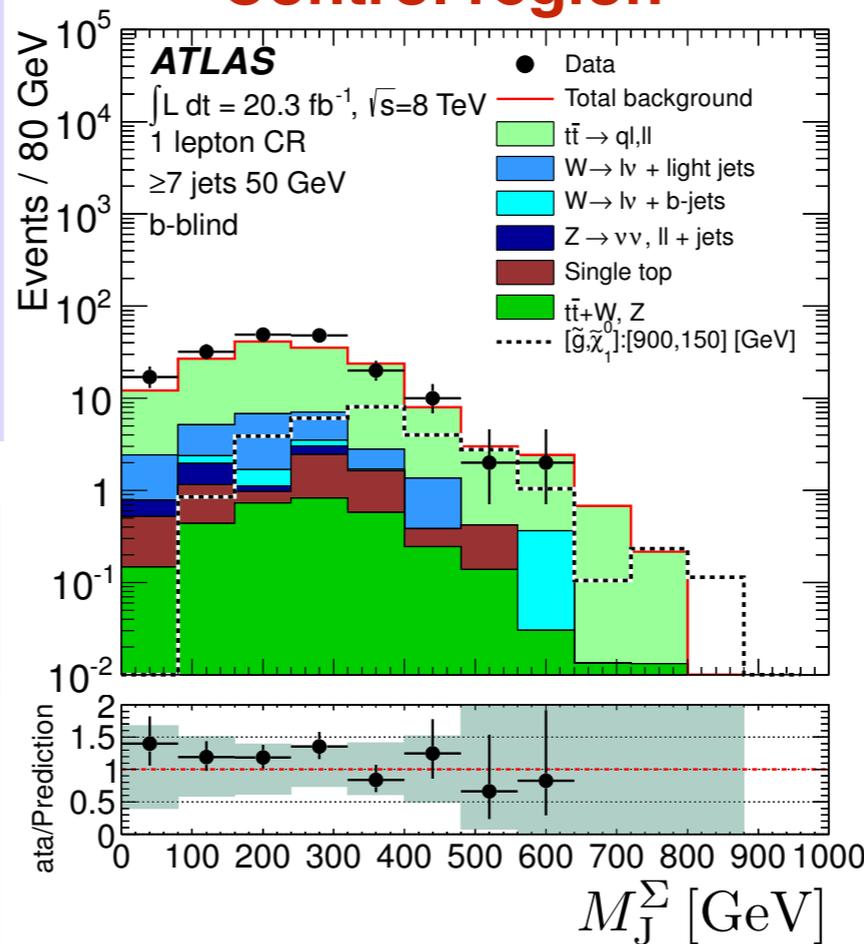
7-10 jets, MET

- Target high jet multiplicity scenarios; simplified cascade decays from strong production
- Estimate background from mis-measured MET with template method
- Fat jet mass to isolate signal
- Fat jets formed from reclustered anti-kt $R=0.4$ jets to $R=1.0$ jets

7j	8j	9j	10j	8j	9j	10j
0, 1, or 2 b-jets				$M_J^\Sigma > 340 \text{ GeV}, > 420 \text{ GeV}$		
$E_T^{\text{miss}} / \sqrt{H_T} > 4 \text{ GeV}^{1/2}$						

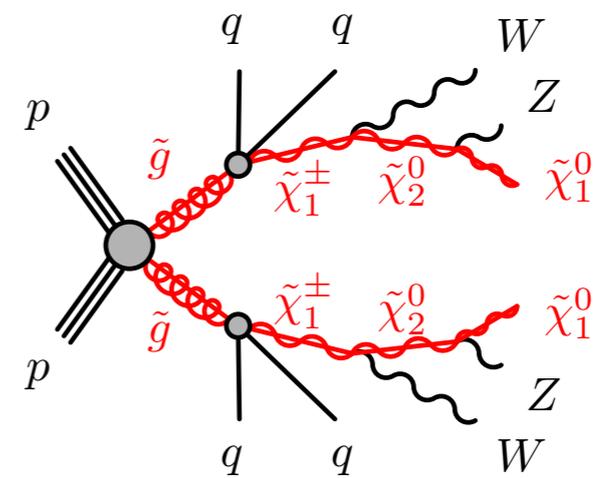
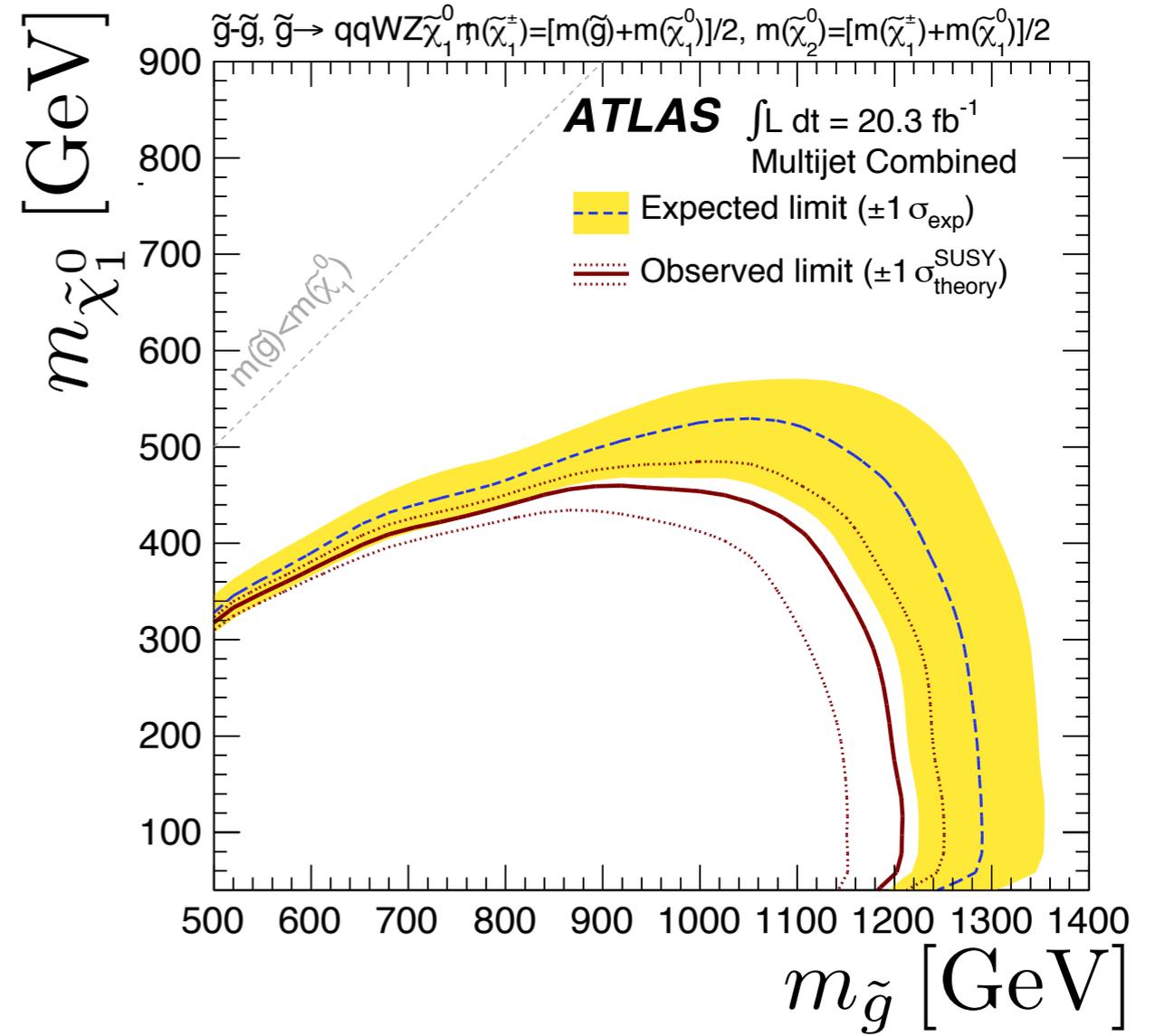
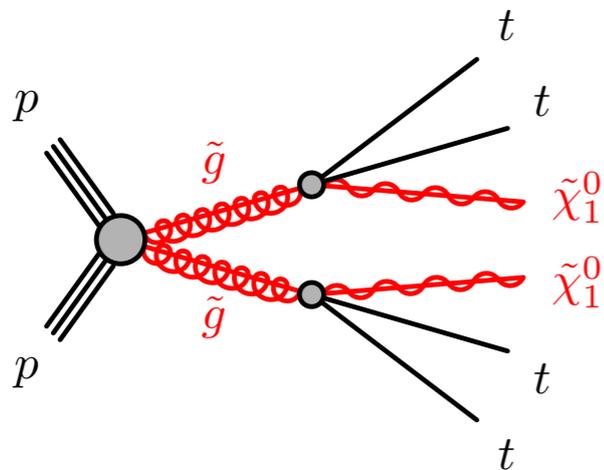
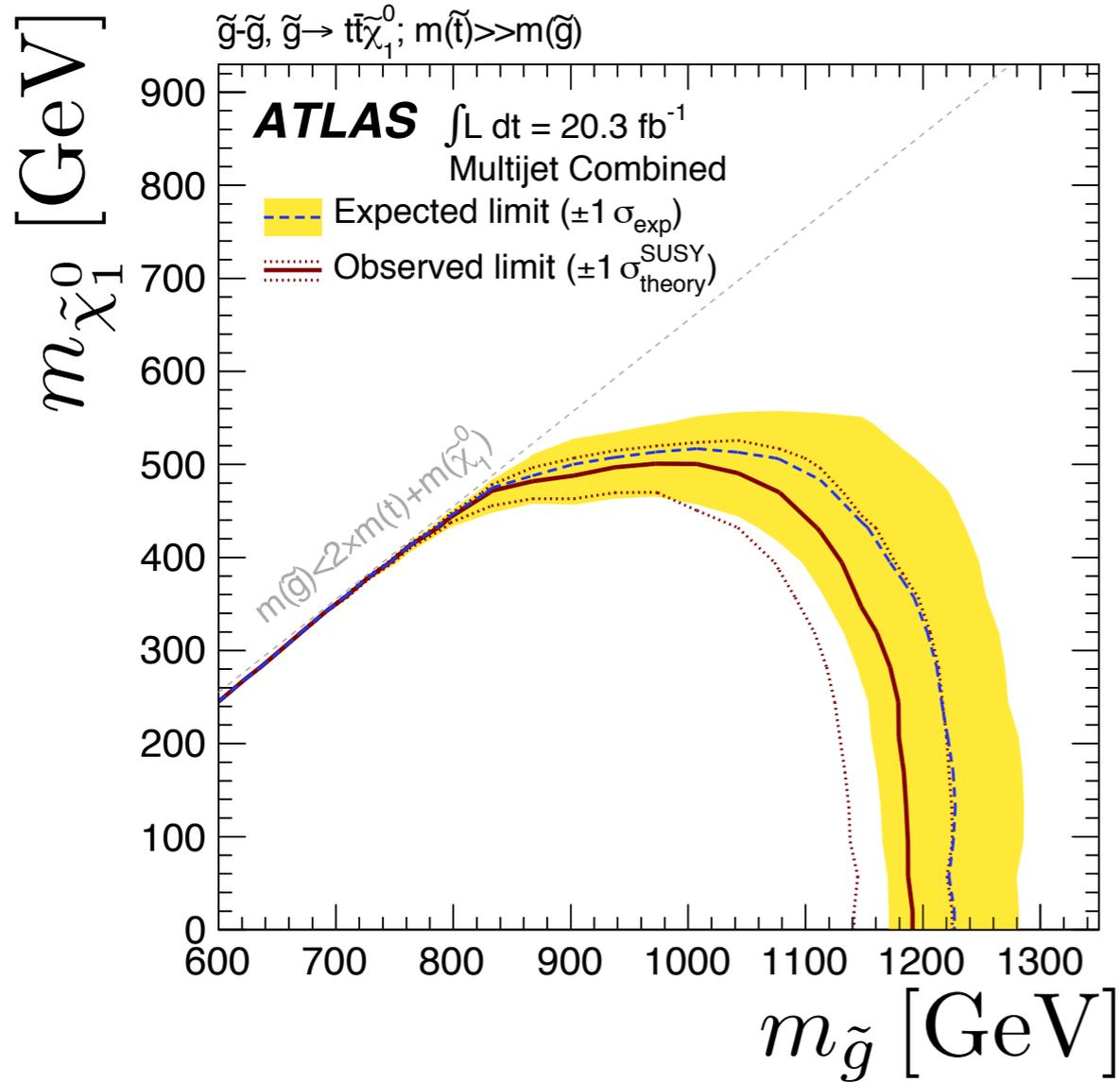
$$H_T = \sum p_T^{\text{jet} > 40 \text{ GeV}}$$

Control region



Jay Wacker, SLAC

7-10 jets, MET



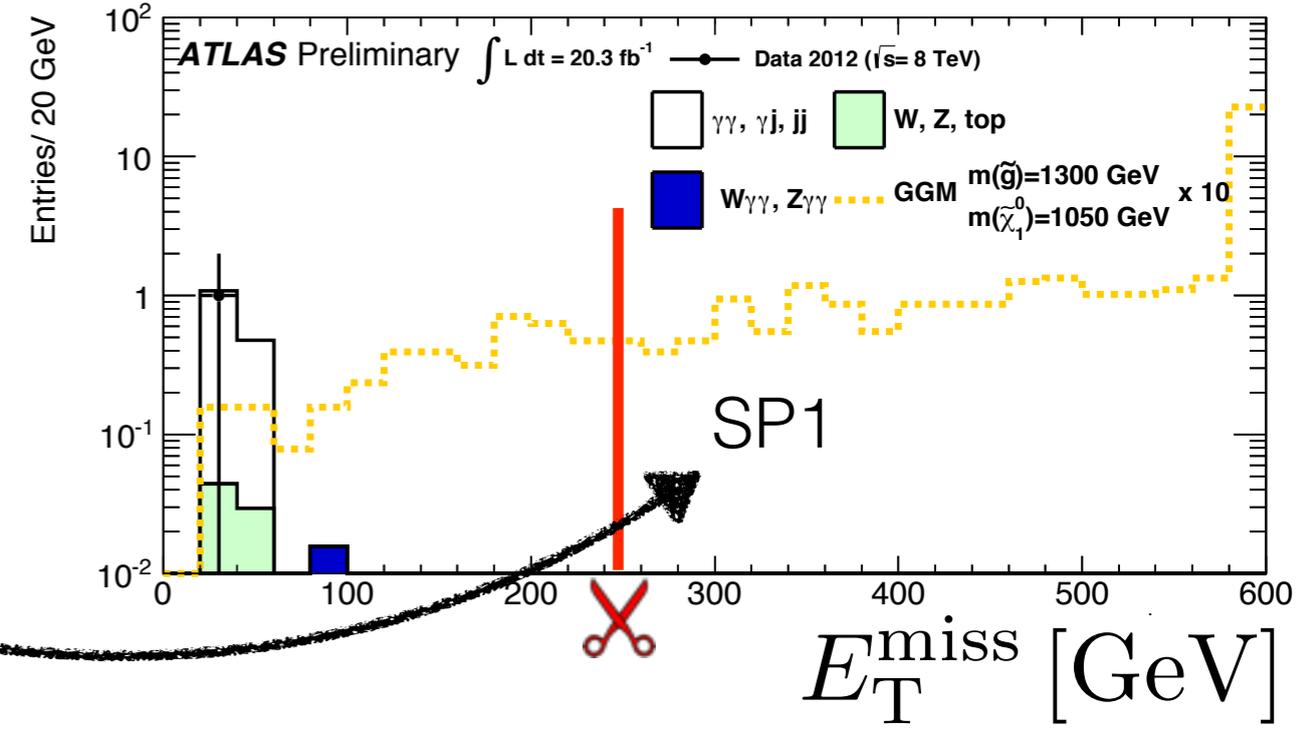
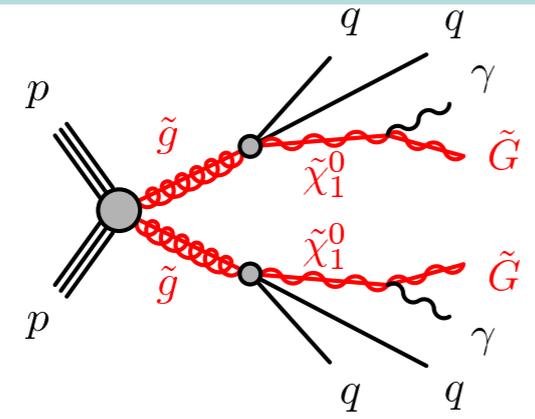
NEW



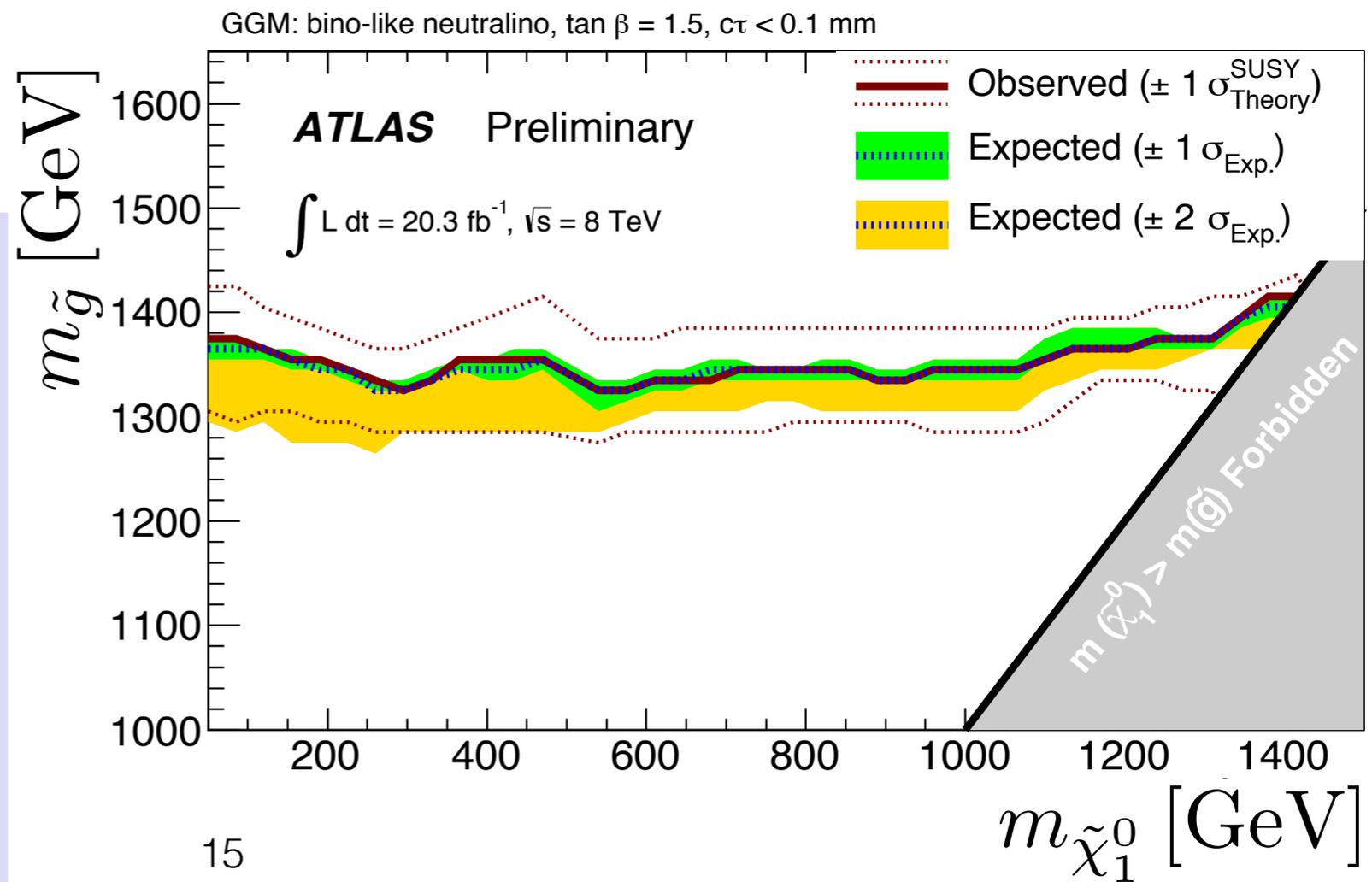
Diphoton, MET

Neutralino mass: High Low

	High	Low
	SP1	SP2
$\Delta\phi_{\gamma}^{\min} >$	0.5	0.0
$\Delta\phi_{\text{jet}}^{\min} >$	0.5	0.5
$M_{\text{eff}} > (H_T >) \text{ (GeV)}$	1500	1800
$E_T^{\text{miss}} > \text{ (GeV)}$	250	150



- Target GGM model: neutralino decay to photon + gravitino
- All backgrounds except $Z \rightarrow \nu\nu + \gamma\gamma$ estimated from data. These are largely jets/electrons faking photons
- SP1 and SP2 dominated by PDF and scale systematics



NEW

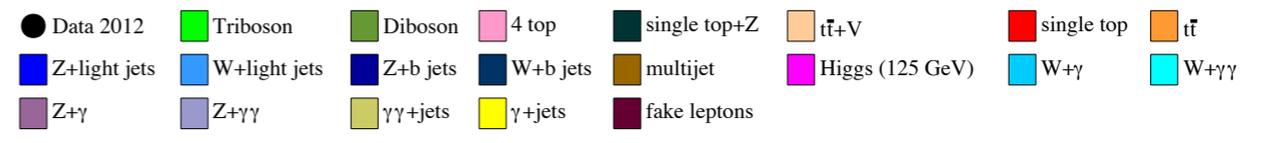


General search

ATLAS-CONF-2014-006

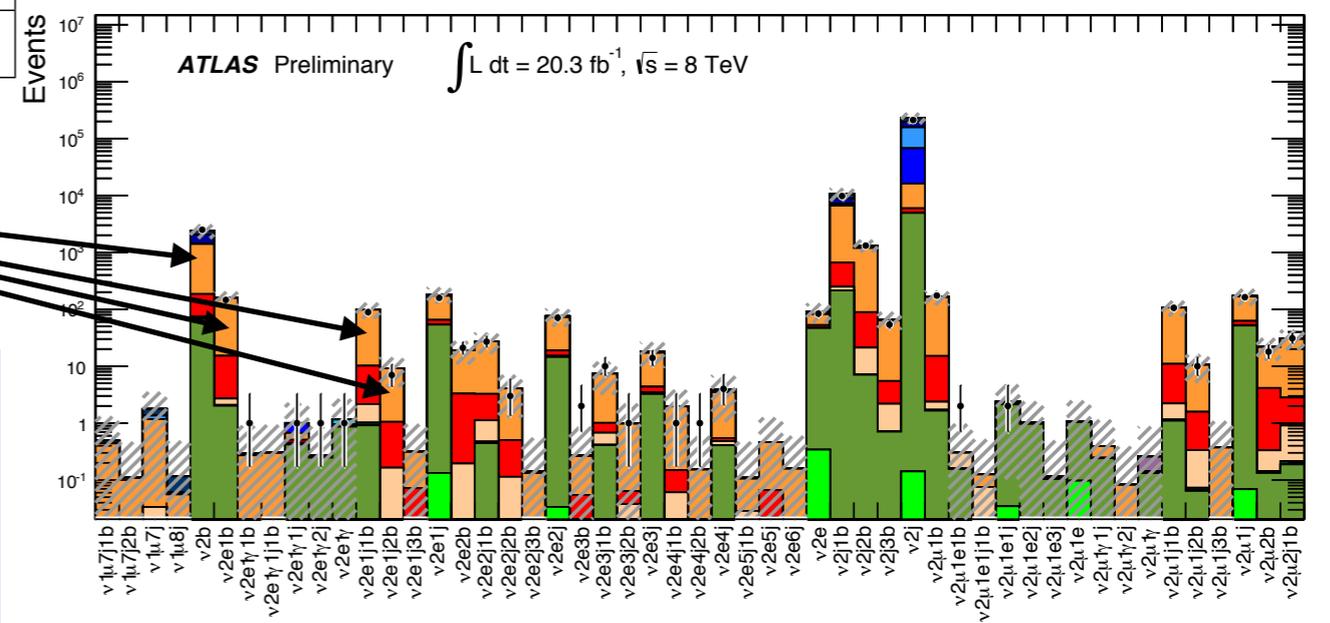
Many channels!

Object	jet	<i>b</i> -jet	electron	muon	photon	E_T^{miss}
Label	<i>j</i>	<i>b</i>	<i>e</i>	μ	γ	ν
Lower p_T cut	50 GeV	50 GeV	25 GeV	25 GeV	40 GeV	150 GeV

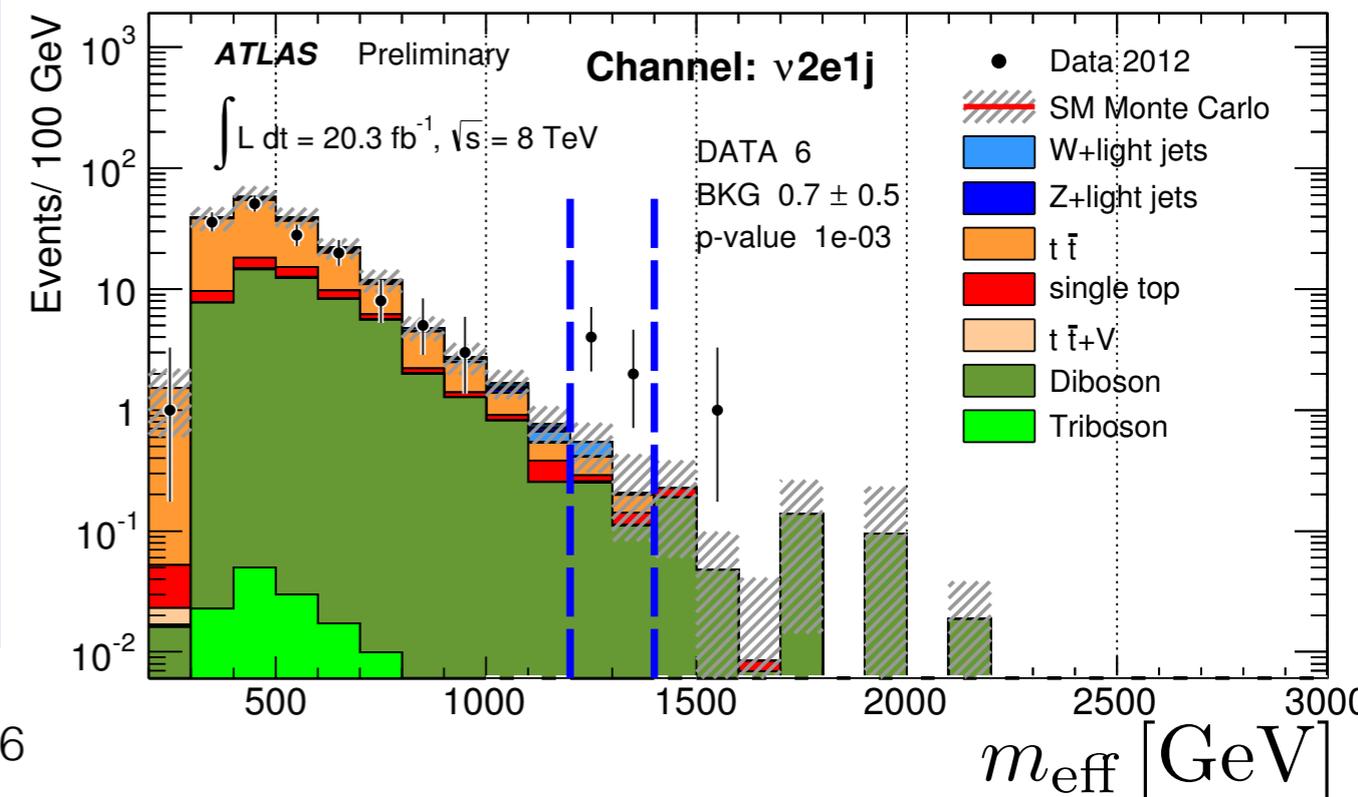


697 exclusive channels

- Purely **discovery** analysis
- All MC backgrounds, except single fake lepton
- Select most discrepant part of each channel as SR
- Omit monophoton, monojet (overlap with other inclusive SRs), inclusive diphoton (poorly controlled multijet background)
- Discard regions with >100% uncertainty

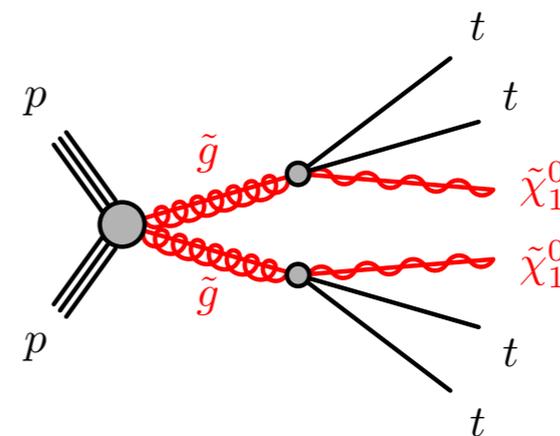
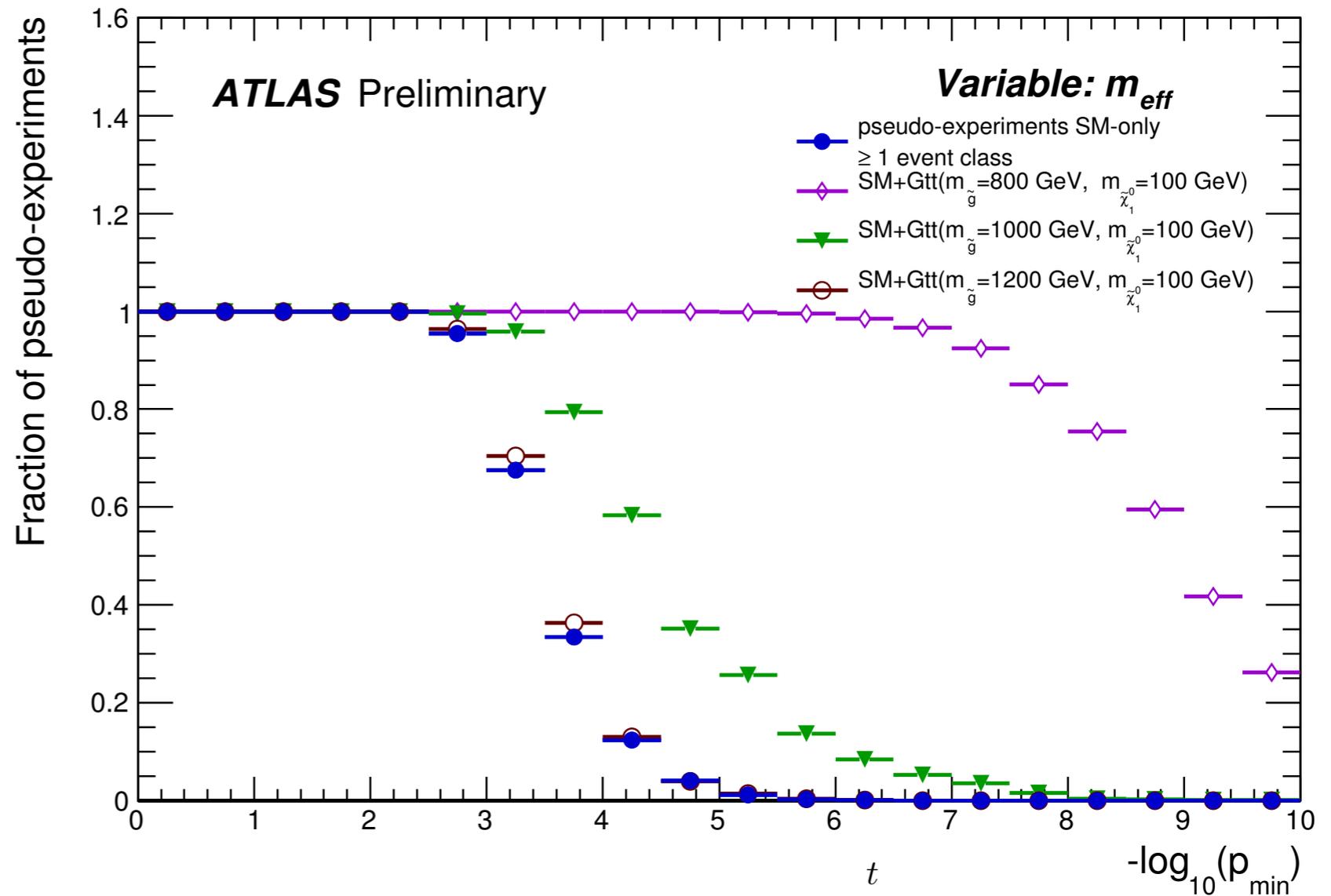


Most discrepant region found



NEW

- Work out a p -value for any discrepancy
- Account for *very large* look-elsewhere effect by performing pseudo-experiments
- No limits calculated, but sensitivity to ~ 1 TeV in the Gtt simplified model is demonstrated



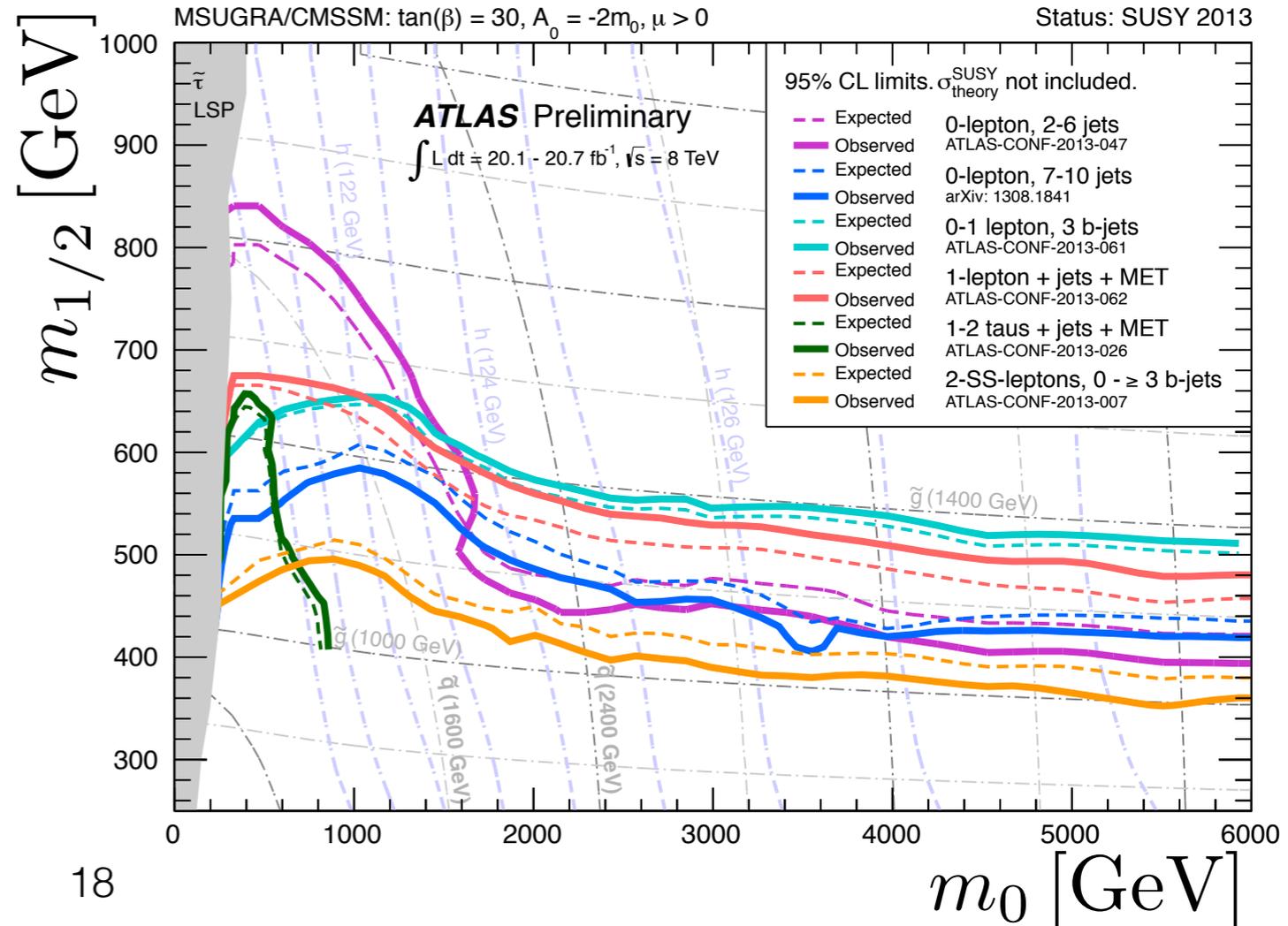
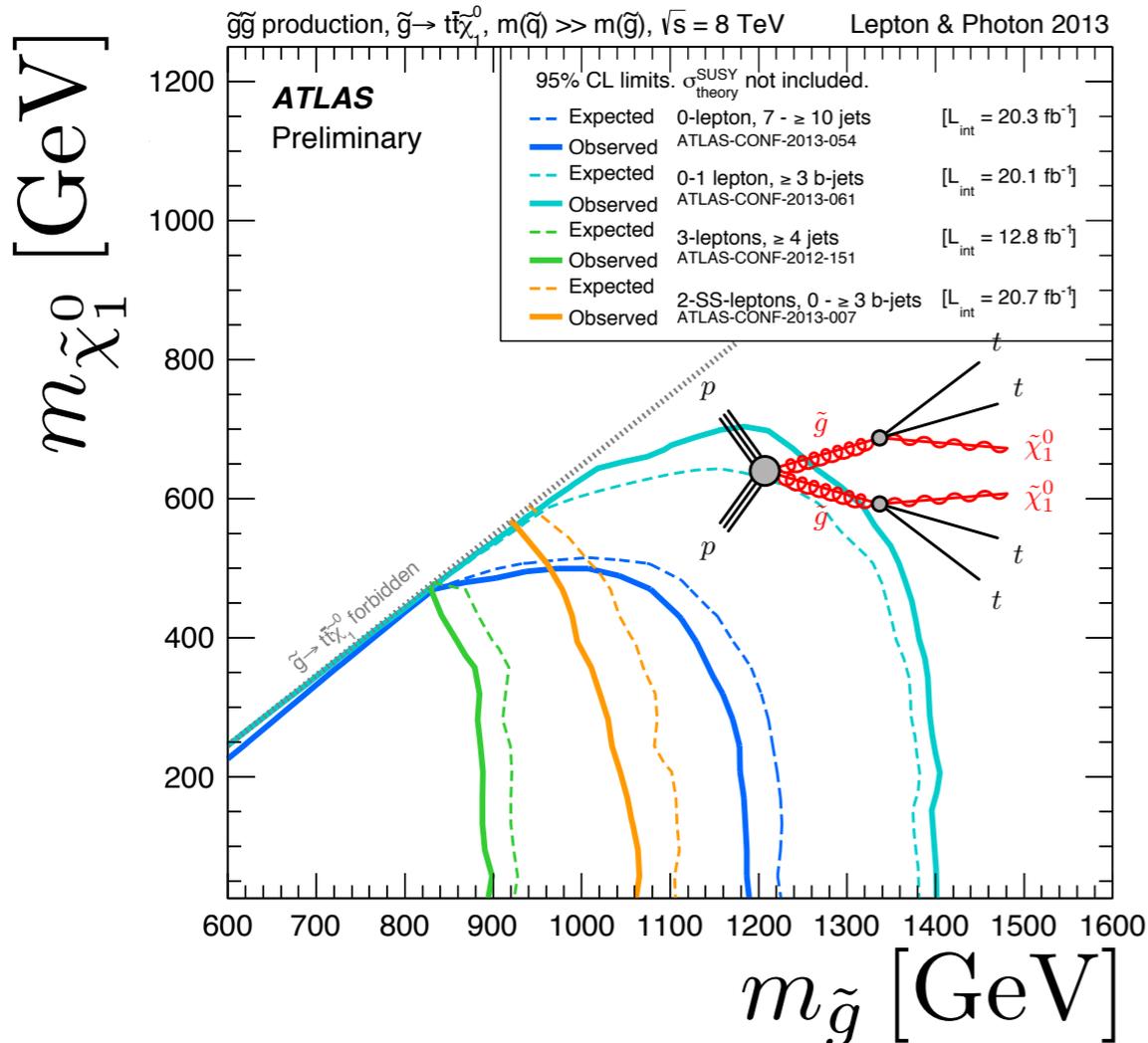
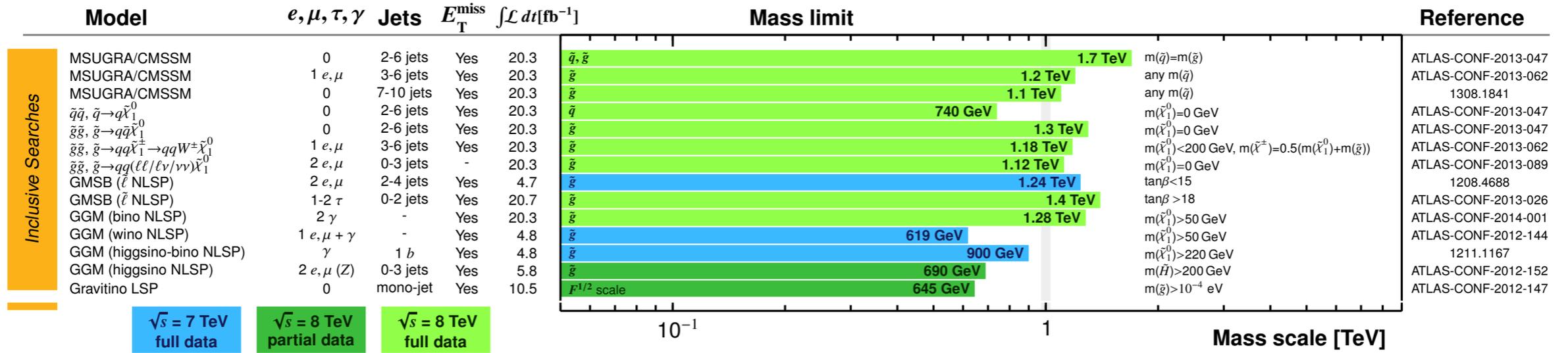
Summary

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Moriond 2014

ATLAS Preliminary

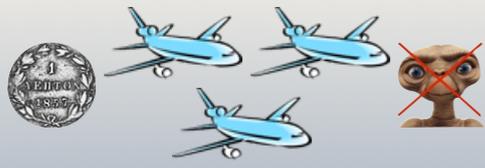
$\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1}$ $\sqrt{s} = 7, 8 \text{ TeV}$



Conclusions

1. No indications of super-partners in a large variety of search channels
2. Naturalness and 'simple' supersymmetric models are under strain
3. Look forward to Run 2, where we hope to see large improvements in mass scale reach

BACKUP



1-2 leptons, 3-6 jets, MET

	soft single-lepton		soft dimuon
	3-jet	5-jet	2-jet
N_ℓ	1 (electron or muon)		2 (muons)
p_T^ℓ (GeV)	[10,25] (electron) , [6,25] (muon)		[6,25]
$p_T^{\text{add. } \ell}$ (GeV)	< 7 (electron), < 6 (muon)		
$m_{\mu\mu}$ (GeV)	–	–	>15 and $ m_{\mu\mu} - m_Z > 10$
N_{jet}	[3,4]	≥ 5	≥ 2
$p_T^{\text{leading jet}}$ (GeV)	> 180		>70
$p_T^{\text{subleading jets}}$ (GeV)	> 25		
$N_{b\text{-tag}}$	–	–	0
E_T^{miss} (GeV)	>400	>300	>170
m_T (GeV)	> 100		> 80
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$	> 0.3		–
$\Delta R_{\text{min}}(\text{jet}, \ell)$	> 1.0	–	> 1.0

	inclusive (binned) hard single-lepton		
	3-jet	5-jet	6-jet
N_ℓ	1 (electron or muon)		
p_T^ℓ (GeV)	> 25		
$p_T^{\text{add. } \ell}$ (GeV)	< 10		
N_{jet}	≥ 3	≥ 5	≥ 6
p_T^{jet} (GeV)	> 80, 80, 30	> 80, 50, 40, 40, 40	> 80, 50, 40, 40, 40, 40
$p_T^{\text{add. jets}}$ (GeV)	– (< 40)	– (< 40)	–
E_T^{miss} (GeV)	>500 (300)	>300	>350 (250)
m_T (GeV)	> 150	> 200 (150)	> 150
$E_T^{\text{miss}}/m_{\text{eff}}^{\text{excl}}$	> 0.3	–	–
$m_{\text{eff}}^{\text{incl}}$ (GeV)	> 1400 (800)		> 600



2 leptons



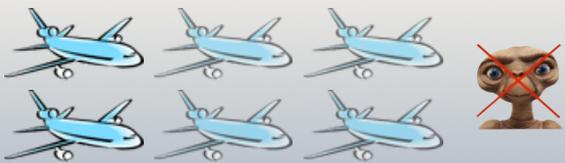
	<i>b</i> -jets	Z-veto	N_{Jets}	Jet p_T	R Range	M'_R Range [GeV]	M'_R bins
Signal Regions							
$ee/\mu\mu$ SR 1	No	Yes	≤ 2	> 50	$R > 0.5$	$400 < M'_R$	8
$e\mu$ SR 1	No	No	≤ 2	> 50	$R > 0.5$	$400 < M'_R$	8
$ee/\mu\mu$ SR 2	No	Yes	≥ 3	> 50	$R > 0.35$	$800 < M'_R$	5
$e\mu$ SR 2	No	No	≥ 3	> 50	$R > 0.35$	$800 < M'_R$	5
Discovery Regions							
$ee/\mu\mu$ DR	No	Yes	≤ 2	> 50	$R > 0.5$	$600 < M'_R$	1
$e\mu$ DR	No	No	≤ 2	> 50	$R > 0.5$	$600 < M'_R$	1
Control Regions							
$ee/\mu\mu$ Z CR 1	No	Yes	≤ 2	> 50	$0.15 < R < 0.3$	$400 < M'_R < 1200$	8
$ee/\mu\mu$ Z CR 2	No	Yes	≥ 3	> 50	$0.05 < R < 0.2$	$800 < M'_R < 1600$	4
$ee/\mu\mu$ Top CR 1	Yes	Yes	≤ 2	> 50	$0.2 < R < 0.4$	$400 < M'_R < 1200$	8
$e\mu$ Top CR 1	Yes	No	≤ 2	> 50	$0.2 < R < 0.4$	$400 < M'_R < 1200$	8
$ee/\mu\mu$ Top CR 2	Yes	Yes	≥ 3	> 50	$0.1 < R < 0.3$	$800 < M'_R < 1600$	4
$e\mu$ Top CR 2	Yes	No	≥ 3	> 50	$0.1 < R < 0.3$	$800 < M'_R < 1600$	4
Validation Regions							
$ee/\mu\mu$ Z VR 1	No	Yes	≤ 2	> 50	$0.25 < R < 1$	$200 < M'_R < 400$	4
$ee/\mu\mu$ Z VR 2	No	Yes	≥ 3	> 50	$0.1 < R < 1$	$200 < M'_R < 800$	6
$ee/\mu\mu$ Top VR 1	Yes	Yes	≤ 2	> 50	$0.5 < R < 1$	$200 < M'_R < 400$	4
$e\mu$ Top VR 1	Yes	No	≤ 2	> 50	$0.5 < R < 1$	$200 < M'_R < 400$	4
$ee/\mu\mu$ Top VR 2	Yes	Yes	≥ 3	> 50	$0.35 < R < 1$	$200 < M'_R < 800$	6
$e\mu$ Top VR 2	Yes	No	≥ 3	> 50	$0.35 < R < 1$	$200 < M'_R < 800$	6

Table 3: Control, validation and signal region definitions. The validation regions are not used to constrain the fit, but the M'_R -binning in these regions is included for completeness.



Taus, jets, MET

	1 τ SR	2 τ GMSB SR	2 τ nGM SR
Pre-selection	$p_T^{\text{jet1}} > 130 \text{ GeV}, p_T^{\text{jet2}} > 30 \text{ GeV}$ $E_T^{\text{miss}} > 150 \text{ GeV}$		
Taus	$N_\tau^{\text{medium}} = 1, p_T^\tau > 30 \text{ GeV}$	$N_\tau^{\text{loose}} \geq 2, p_T^\tau > 20 \text{ GeV}$	
Light leptons	$N_\ell = 0$		
QCD rejection	$\Delta(\phi_{\text{jet}_{1,2}-\mathbf{p}_T^{\text{miss}}}) > 0.3 \text{ rad}$ $E_T^{\text{miss}}/m_{\text{eff}} > 0.3$		$\Delta(\phi_{\text{jet}_{1,2}-\mathbf{p}_T^{\text{miss}}}) > 0.3 \text{ rad}$
Signal cuts	$m_T^\tau > 140 \text{ GeV}$ $H_T > 800 \text{ GeV}$	$m_T^{\tau_1} + m_T^{\tau_2} \geq 150 \text{ GeV}$ $H_T > 900 \text{ GeV}$	$m_T^{\tau_1} + m_T^{\tau_2} \geq 250 \text{ GeV}$ $H_T > 600 \text{ GeV}$ $N_{\text{jet}} \geq 4$



0 leptons, 2-6 jets, MET

Requirement	Channel									
	A (2-jets)		B (3-jets)		C (4-jets)		D (5-jets)	E (6-jets)		
	L	M	M	T	M	T	–	L	M	T
$E_T^{\text{miss}} [\text{GeV}] >$	160									
$p_T(j_1) [\text{GeV}] >$	130									
$p_T(j_2) [\text{GeV}] >$	60									
$p_T(j_3) [\text{GeV}] >$	–		60		60		60		60	
$p_T(j_4) [\text{GeV}] >$	–		–		60		60		60	
$p_T(j_5) [\text{GeV}] >$	–		–		–		60		60	
$p_T(j_6) [\text{GeV}] >$	–		–		–		–		60	
$\Delta\phi(\text{jet}_i, \mathbf{E}_T^{\text{miss}})_{\text{min}} >$	0.4 ($i = \{1, 2, (3 \text{ if } p_T(j_3) > 40 \text{ GeV})\}$)				0.4 ($i = \{1, 2, 3\}$), 0.2 ($p_T > 40 \text{ GeV jets}$)					
$E_T^{\text{miss}} / m_{\text{eff}}(Nj) >$	0.2	– ^a	0.3	0.4	0.25	0.25	0.2	0.15	0.2	0.25
$m_{\text{eff}}(\text{incl.}) [\text{GeV}] >$	1000	1600	1800	2200	1200	2200	1600	1000	1200	1500

(a) For SR A-medium the cut on $E_T^{\text{miss}} / m_{\text{eff}}(Nj)$ is replaced by a requirement $E_T^{\text{miss}} / \sqrt{H_T} > 15 \text{ GeV}^{1/2}$.

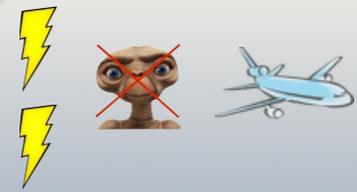


7-10 jets, MET

	Multi-jet + flavour stream						Multi-jet + M_J^Σ stream											
Identifier	8j50			9j50			$\geq 10j50$		7j80	$\geq 8j80$		$\geq 8j50$	$\geq 9j50$	$\geq 10j50$				
Jet $ \eta $	< 2.0						< 2.0						< 2.8					
Jet p_T	$> 50 \text{ GeV}$						$> 80 \text{ GeV}$						$> 50 \text{ GeV}$					
Jet count	= 8			= 9			≥ 10			= 7		≥ 8		≥ 8	≥ 9	≥ 10		
b -jets ($p_T > 40 \text{ GeV}, \eta < 2.5$)	0	1	≥ 2	0	1	≥ 2	—			0	1	≥ 2	0	1	≥ 2	—		
M_J^Σ [GeV]	—						—						> 340 and > 420 for each case					
$E_T^{\text{miss}}/\sqrt{H_T}$	$> 4 \text{ GeV}^{1/2}$						$> 4 \text{ GeV}^{1/2}$						$> 4 \text{ GeV}^{1/2}$					

Table 1: Definition of the nineteen signal regions. The jet $|\eta|$, p_T and multiplicity all refer to the $R = 0.4$ jets. Composite jets with the larger radius parameter $R = 1.0$ are used in the multi-jet + M_J^Σ stream when constructing M_J^Σ . A long dash ‘—’ indicates that no requirement is made.

NEW



Diphoton, MET

	SP1	SP2	WP1	WP2	MIS
$\Delta\phi_{\gamma}^{\min} >$	0.5	0.0	0.5	0.0	0.0
$\Delta\phi_{\text{jet}}^{\min} >$	0.5	0.5	0.5	0.5	0.5
$M_{\text{eff}} > (H_{\text{T}} >) \text{ (GeV)}$	1500	1800	(400)	(600)	0
$E_{\text{T}}^{\text{miss}} > \text{ (GeV)}$	250	150	200	150	250