



Searches For Exotics New Physics With ATLAS

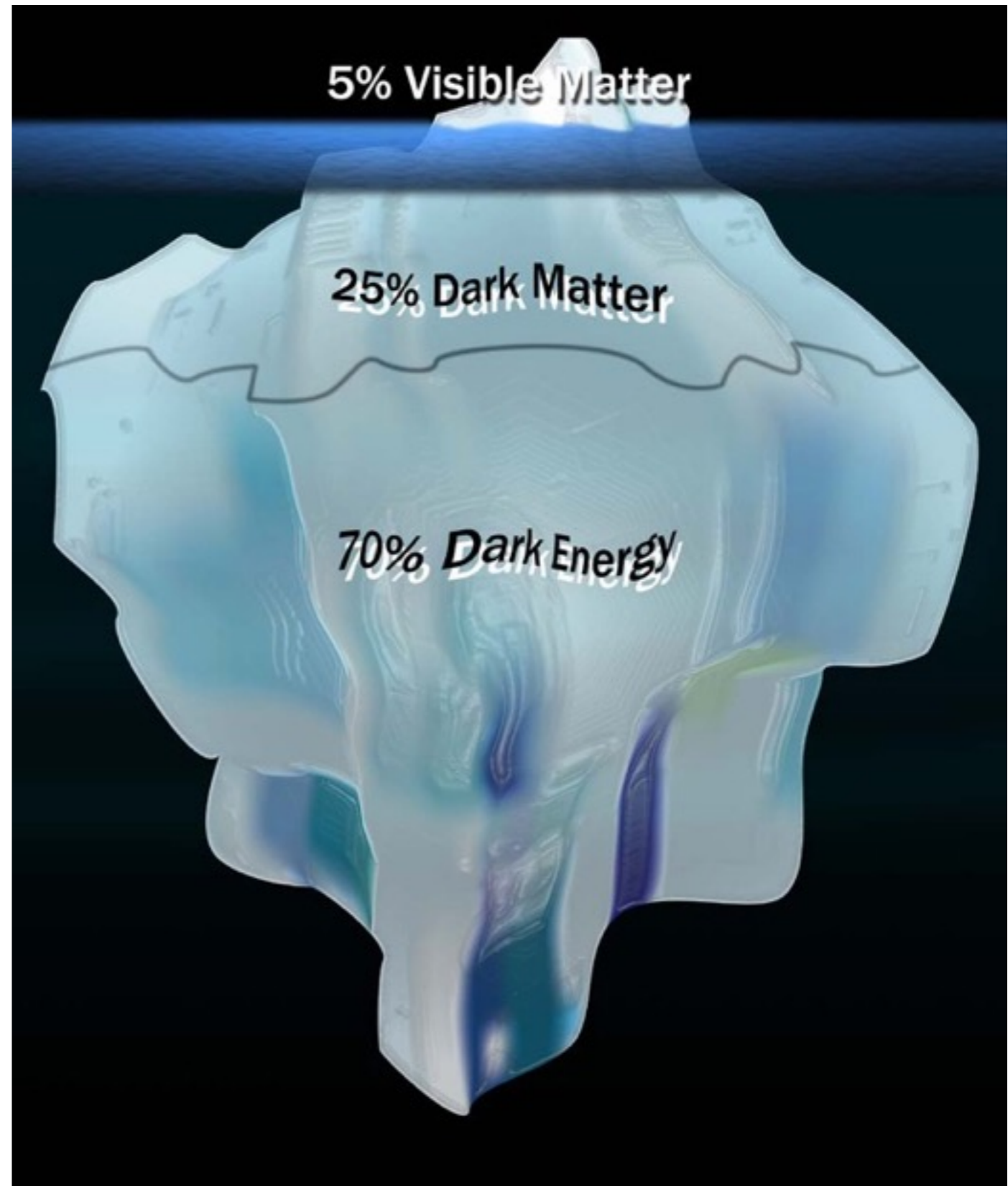
Nils Krumnack (Iowa State University)
on behalf of the ATLAS collaboration



Glimpse of our Ignorance



- SM has passed all experimental tests, but still not complete
- Several problems with the SM:
 - ▶ Dark Matter
 - ▶ Dark Energy
 - ▶ Neutrino Oscillation
 - ▶ Matter-Antimatter Asymmetry
 - ▶ Fermion mass hierarchy
 - ▶ Higgs mass stability
- More than sufficient reasons to look for Physics beyond the SM

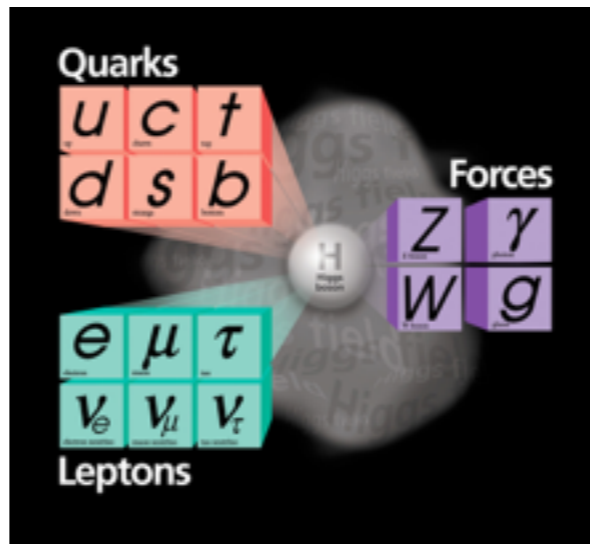




Propositions for beyond the SM



Standard Model



Super-Symmetry

- Several variants of SUSY
- Can resolve
 - Hierarchy problem
 - Higgs mass stability
 - Dark Matter problem
- Predicts heavy super-partners, scalar particles, neutral light Higgs
- Searches more theory motivated

Exotics

- Several independent models
- Aims to resolve
 - Matter Anti-Matter Asymmetry
 - Higgs mass stability
 - Dark Matter problem
- Predicts new heavy quarks, new heavy bosons, composite Higgs
- Searches more signature driven



ATLAS Exotics Searches



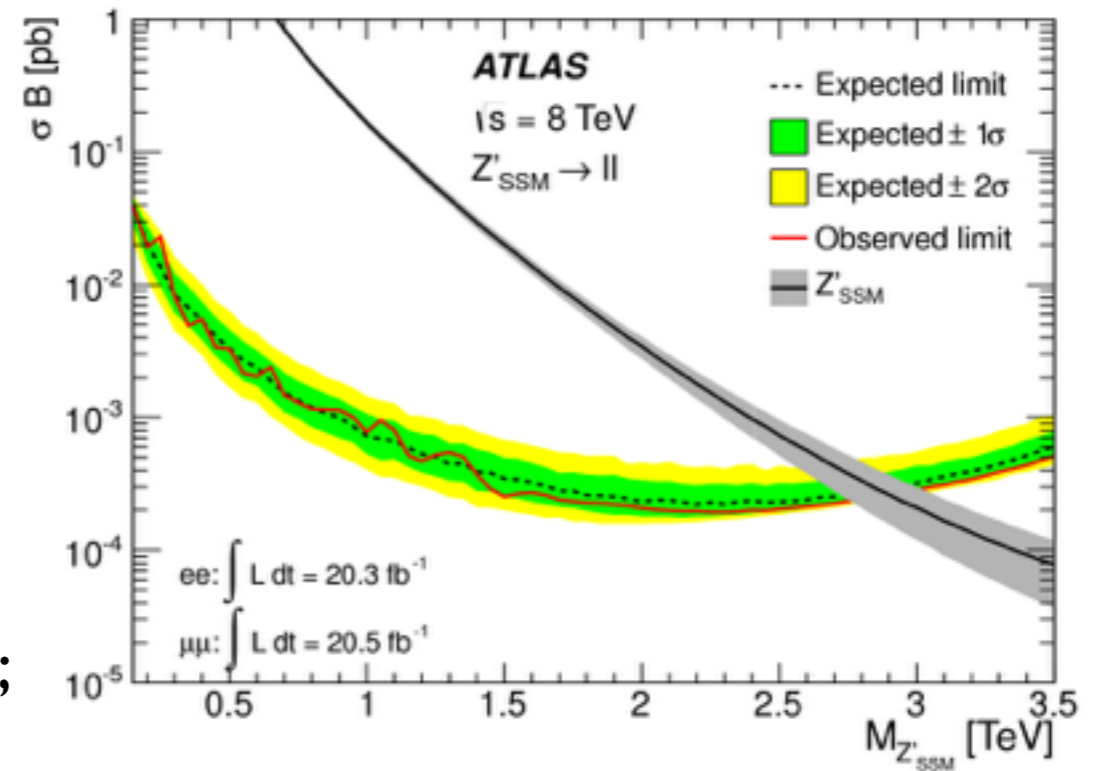
- ATLAS has a vast program searching for exotic physics
 - ▶ far too many to do them all justice here
 - ▶ trying to focus on recent results instead
- run I physics results:
 - ▶ large dataset (20.3 fb^{-1}) and mature searches
 - ▶ results published or publication ready
- run II physics results:
 - ▶ limited dataset ($< 100 \text{ pb}^{-1}$)
 - ▶ only a few weeks to "look" at data
 - ▶ mostly "retuning" searches for higher energies
 - ▶ no complete searches yet
- higher energy extends mass range:
 - ▶ sensitivity soon competitive (for some searches)



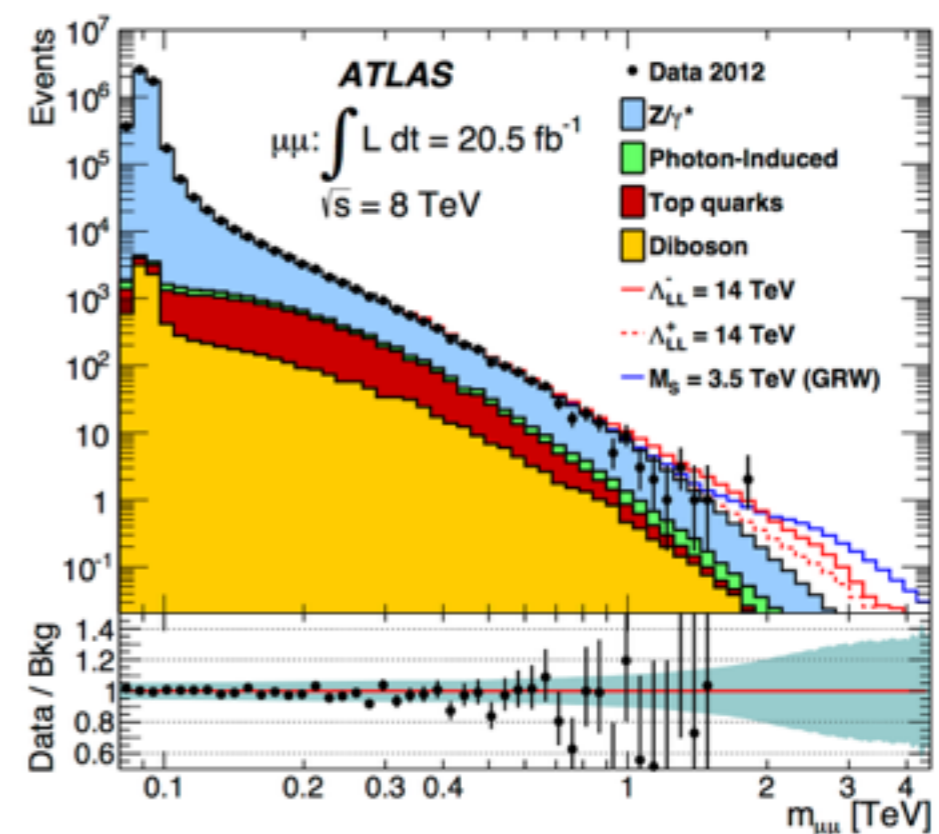
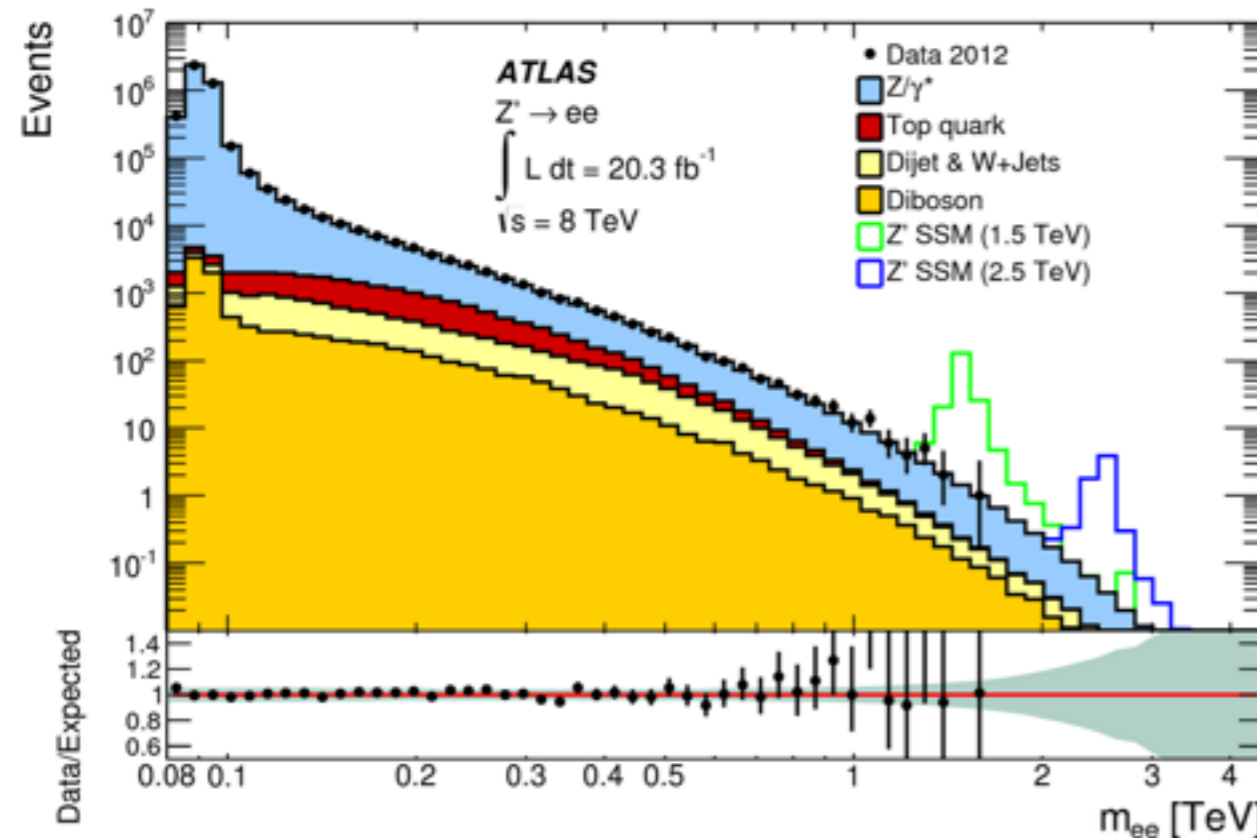
8 TeV: dilepton search



- looking for $Z' \rightarrow ll$
- require two same flavor opposite-sign leptons
- $p_T > 40, 30 \text{ GeV (e), 25 GeV (\mu)}$
- $m_{Z'} > 2.90 \text{ TeV}$

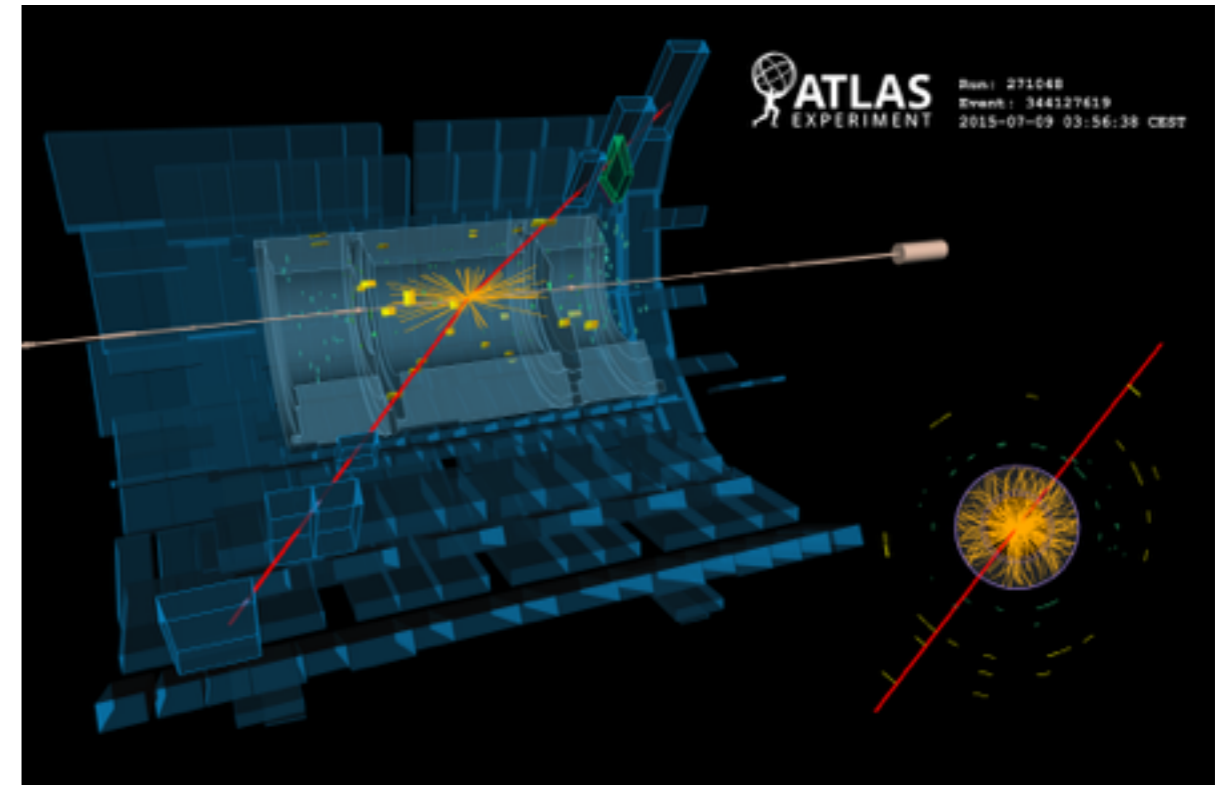
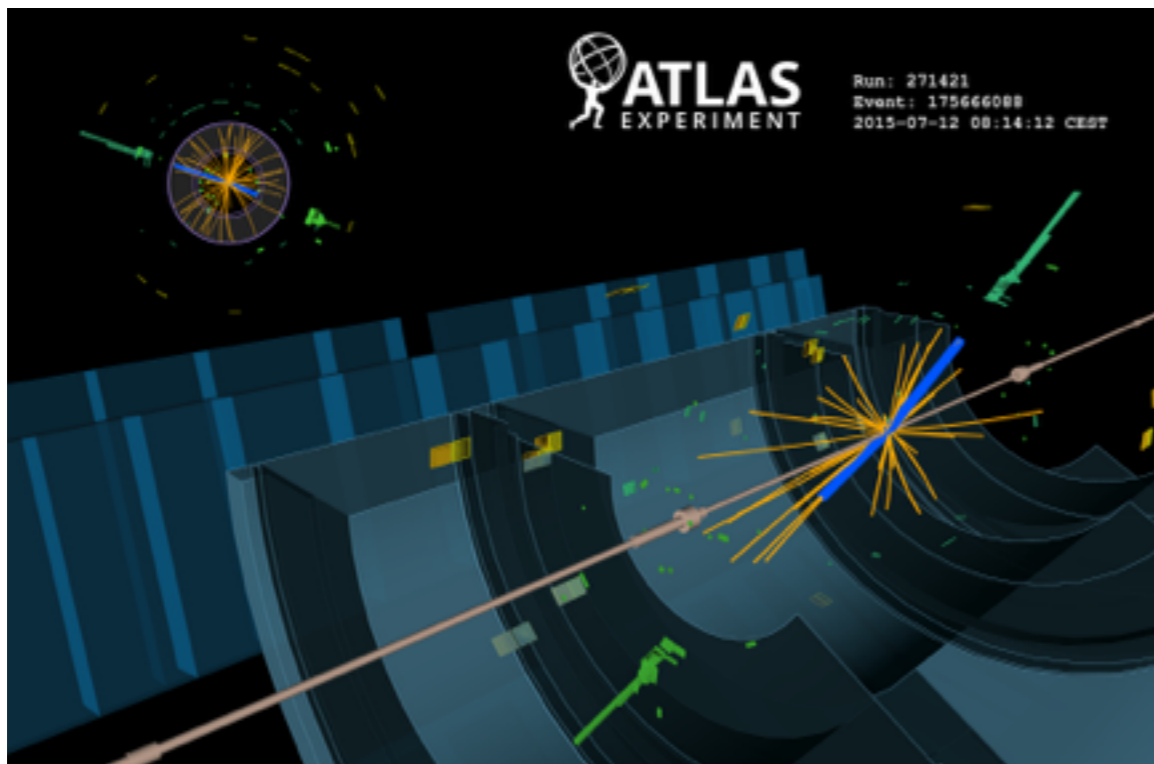
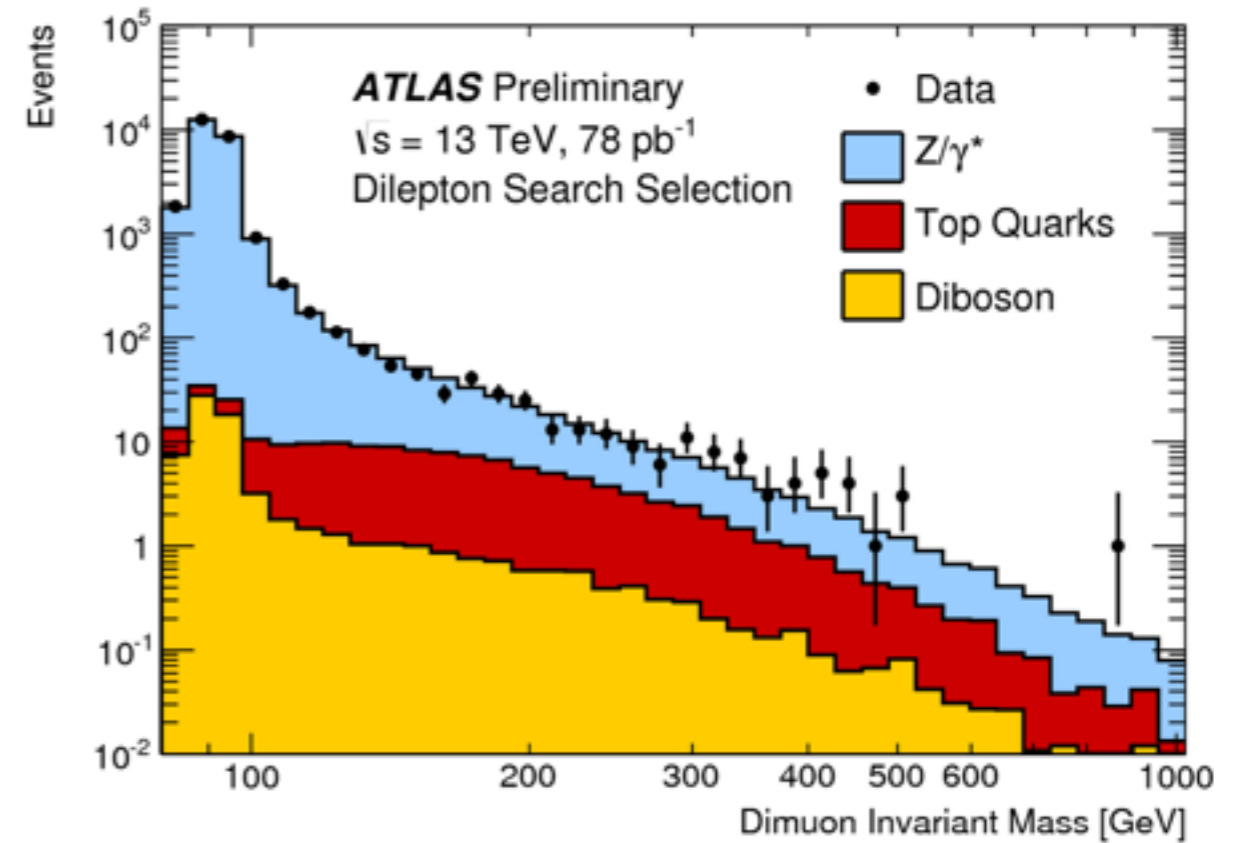
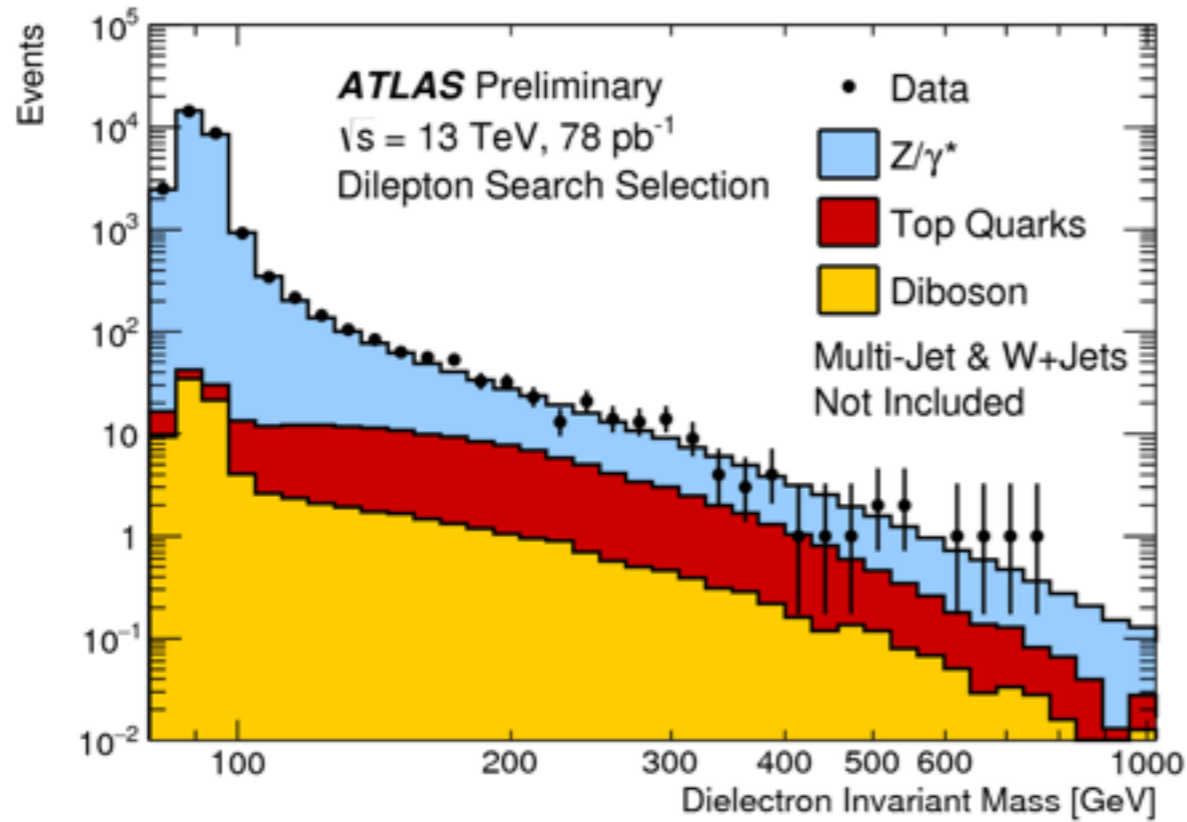


Phys. Rev. D. 90, 052005 (2014), arXiv:1405.4123;
 Eur. Phys. J. C (2014) 74:3134, arXiv:1407.2410





13 TeV: dilepton search

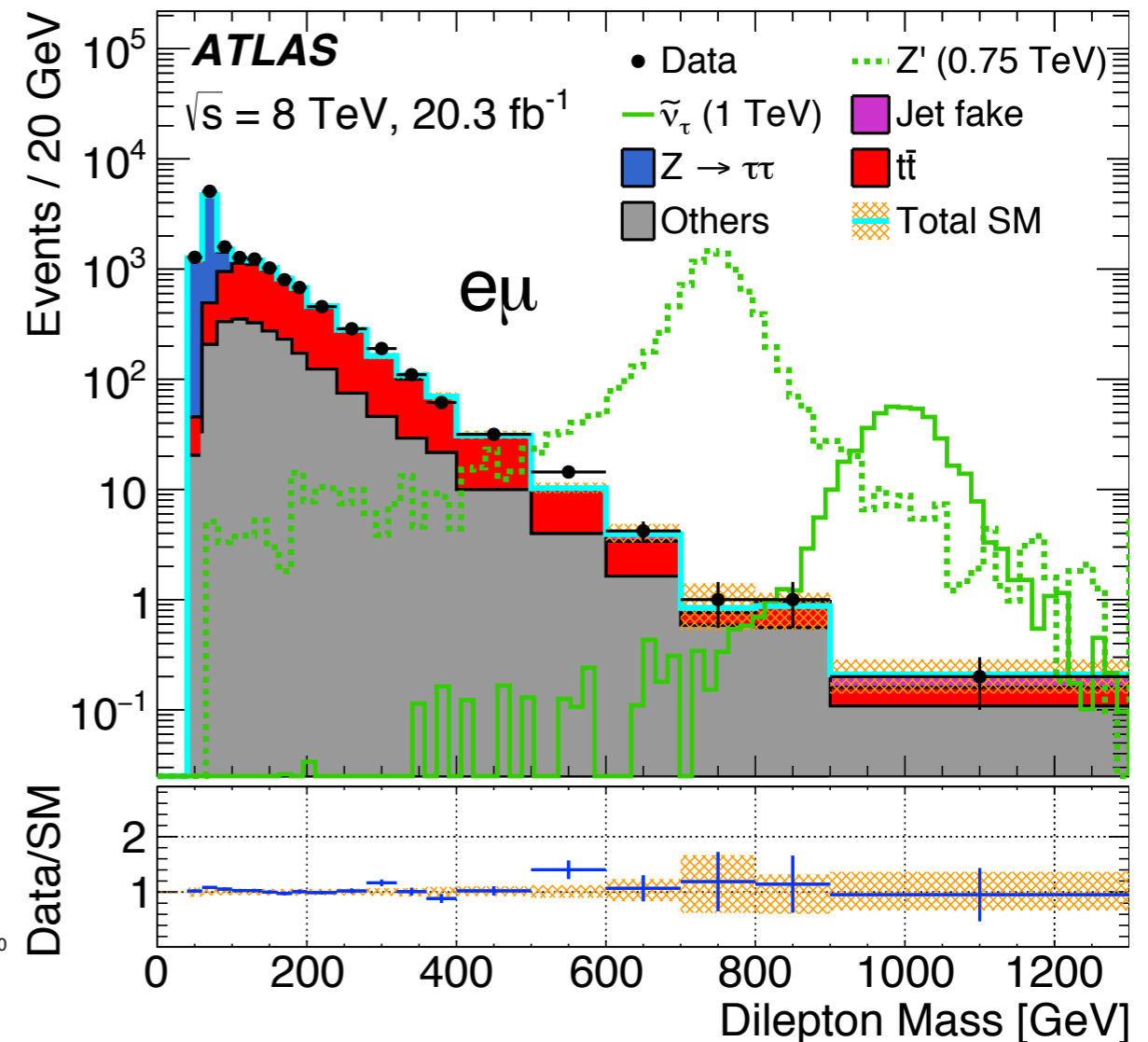
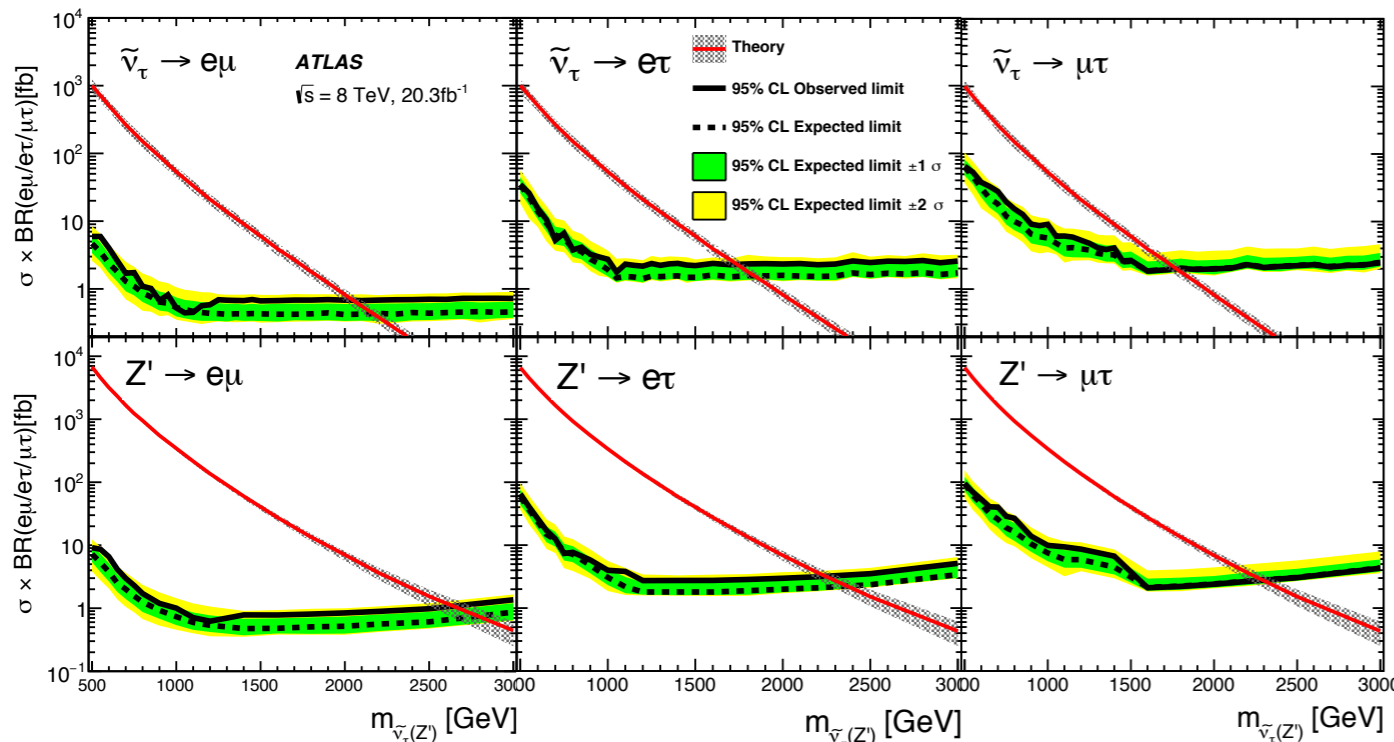
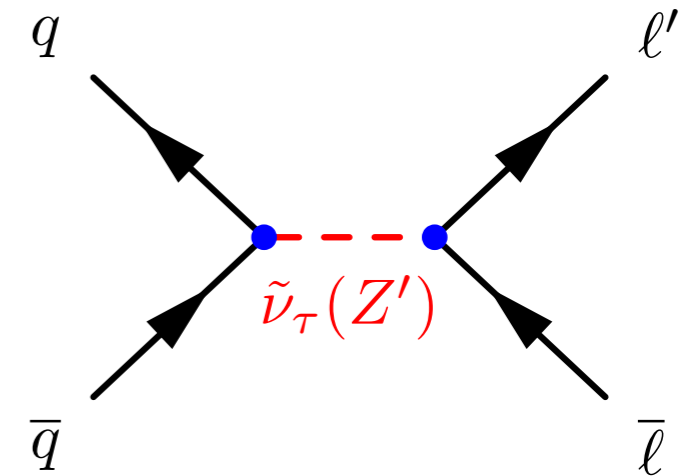




8 TeV: LFV dilepton search

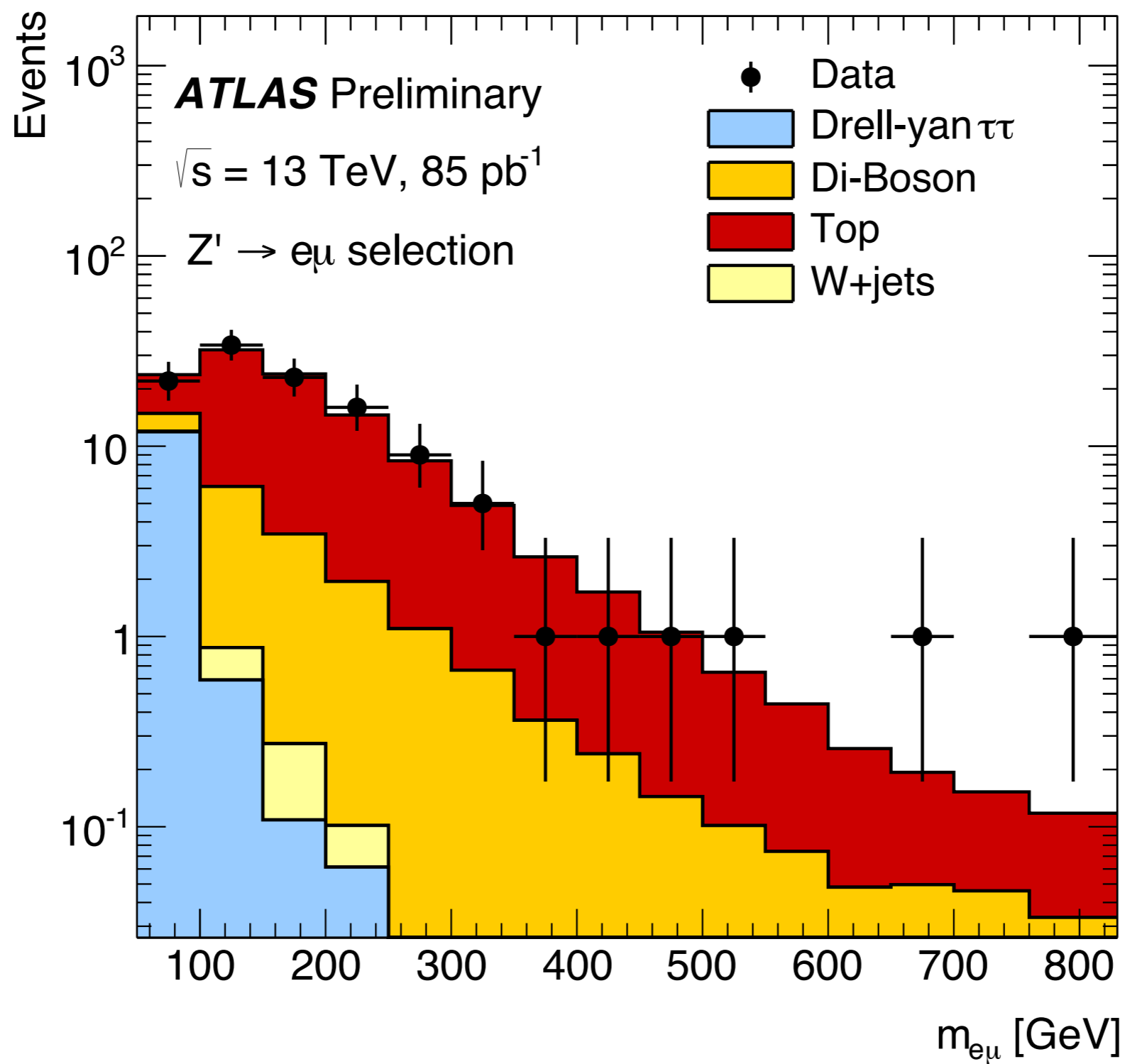


- looking for $Z' \rightarrow l'l'$
- require two different flavor opposite-sign leptons
- $p_T > 25$ GeV (e, μ)





13 TeV: LFV dilepton search

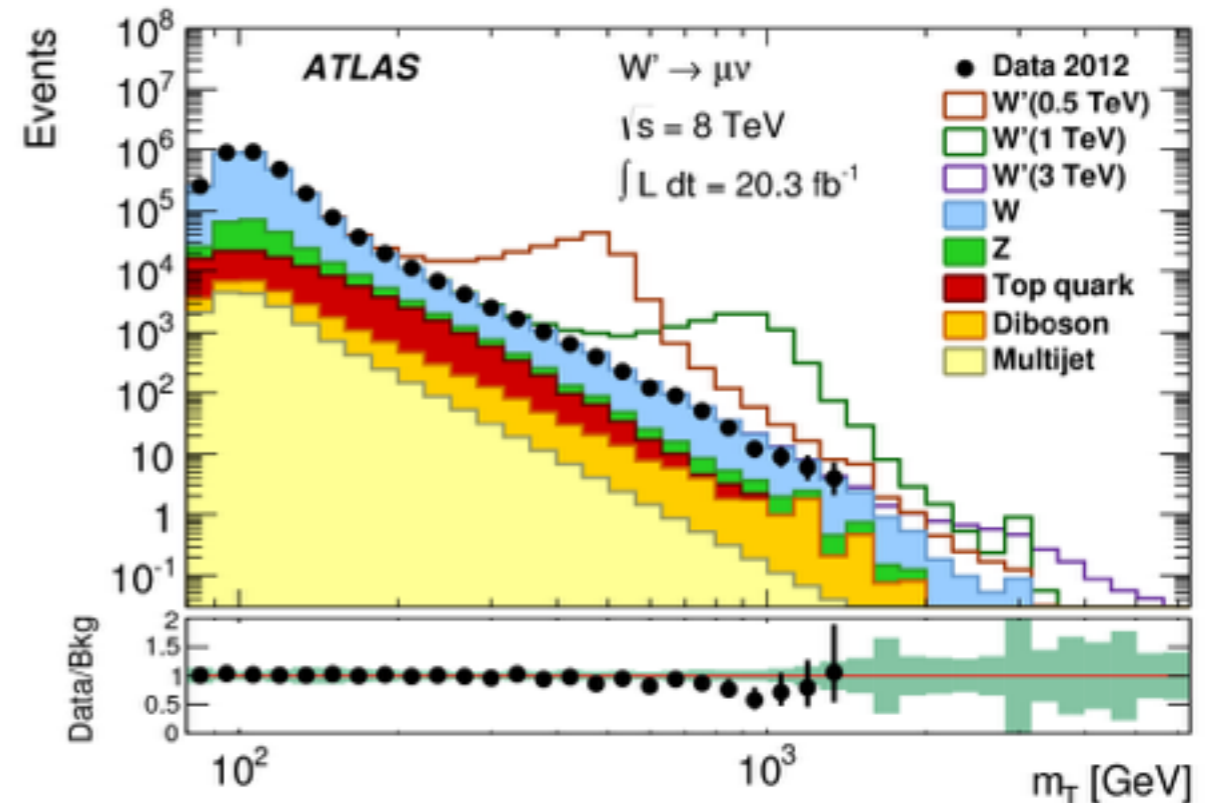
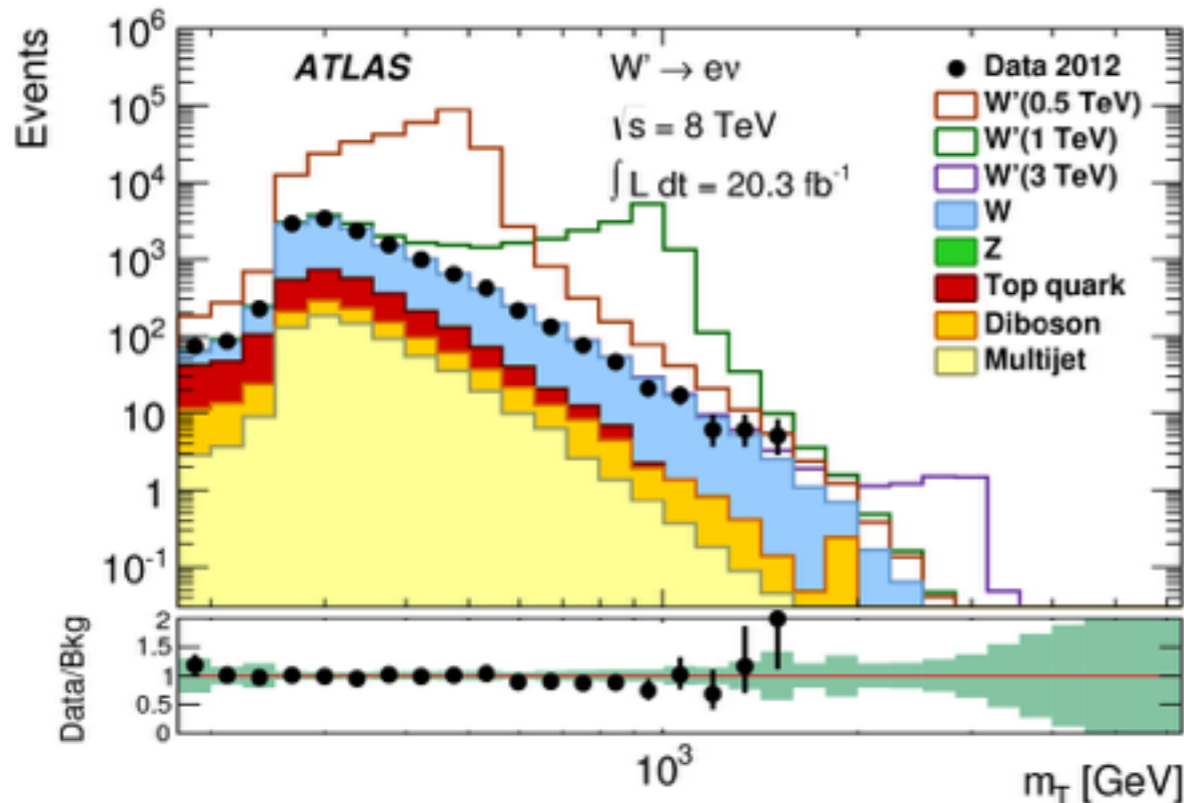
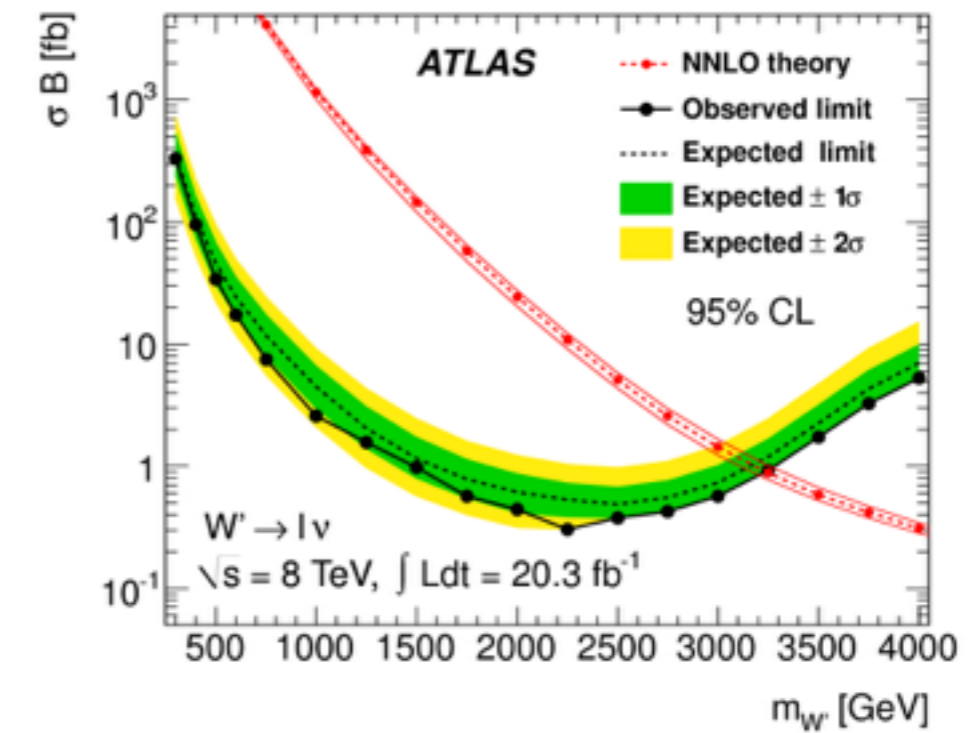




8 TeV: lepton+MET search

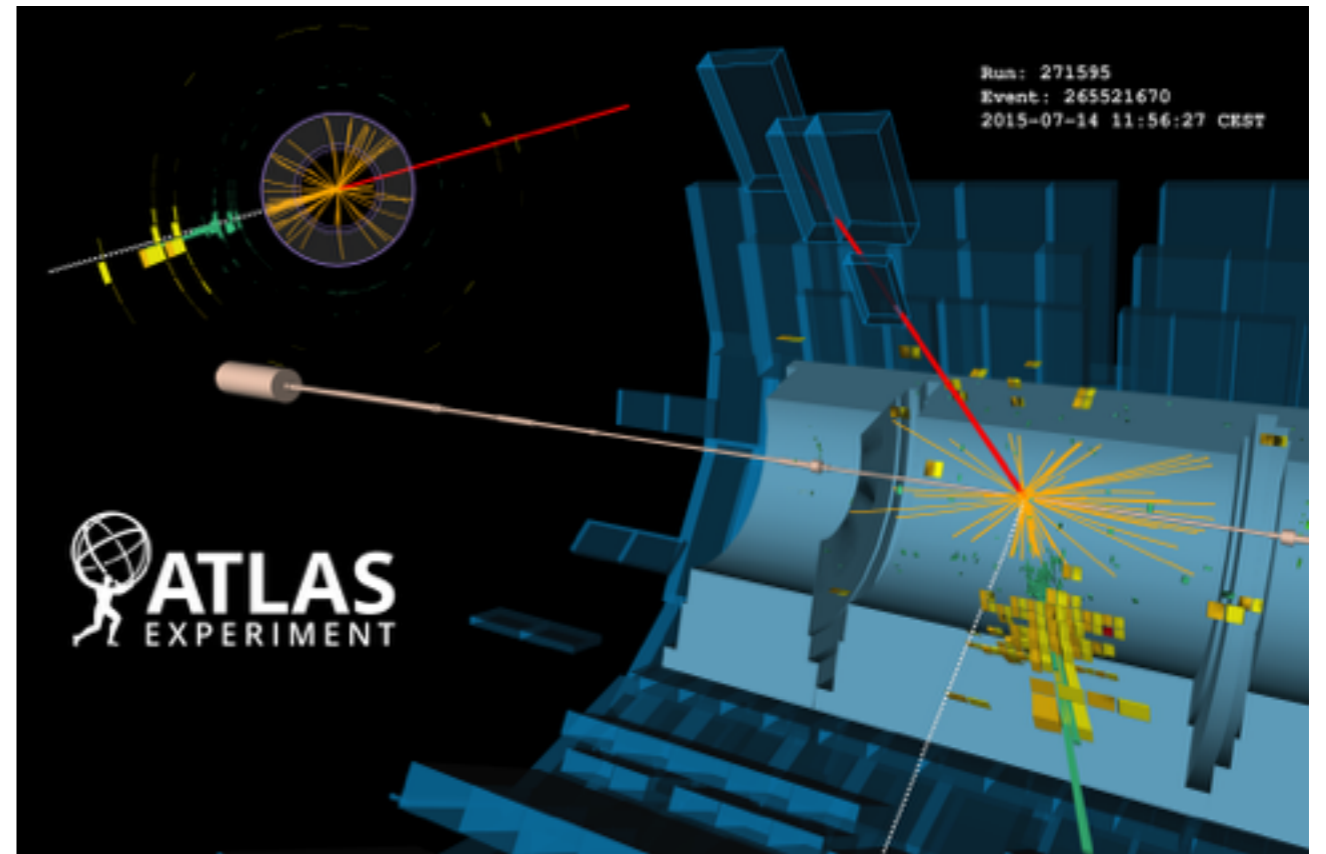
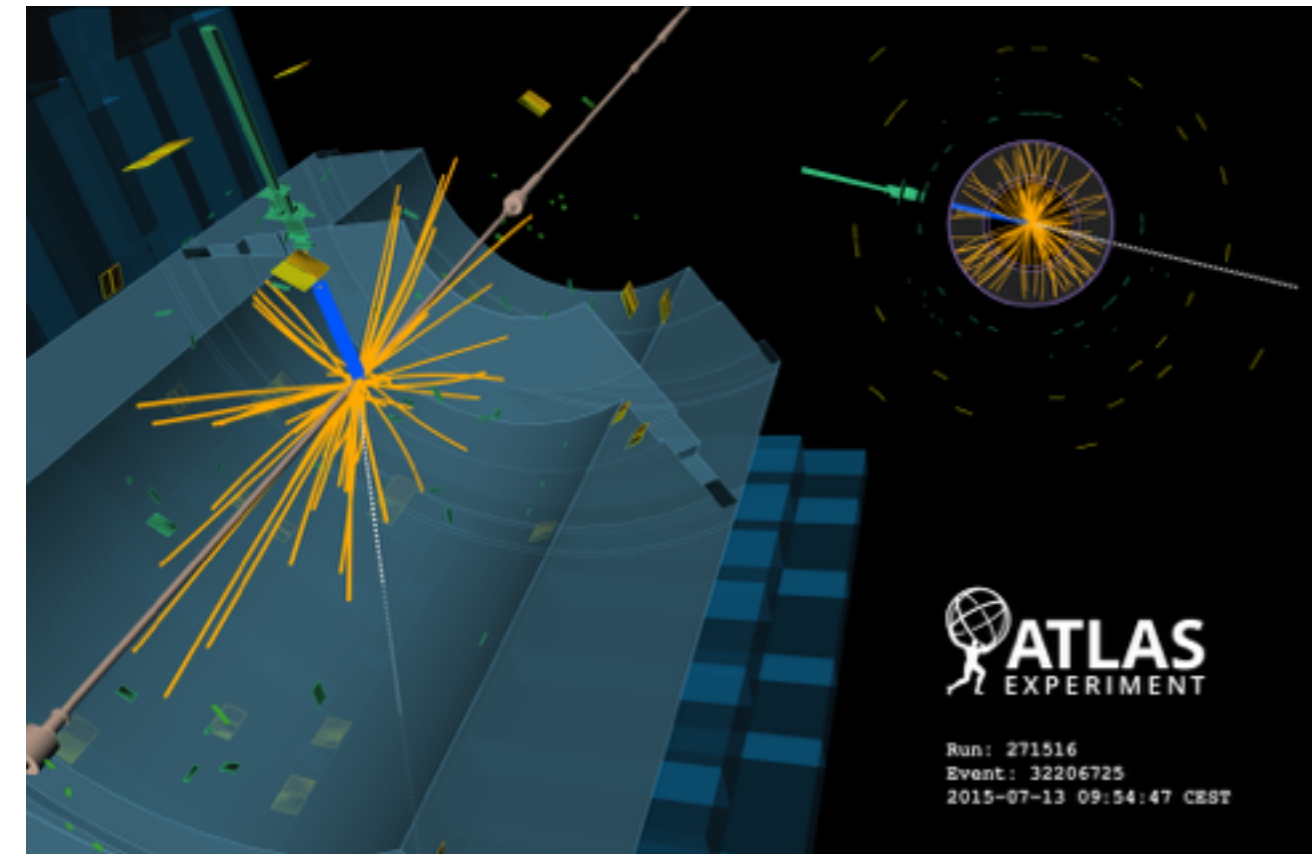
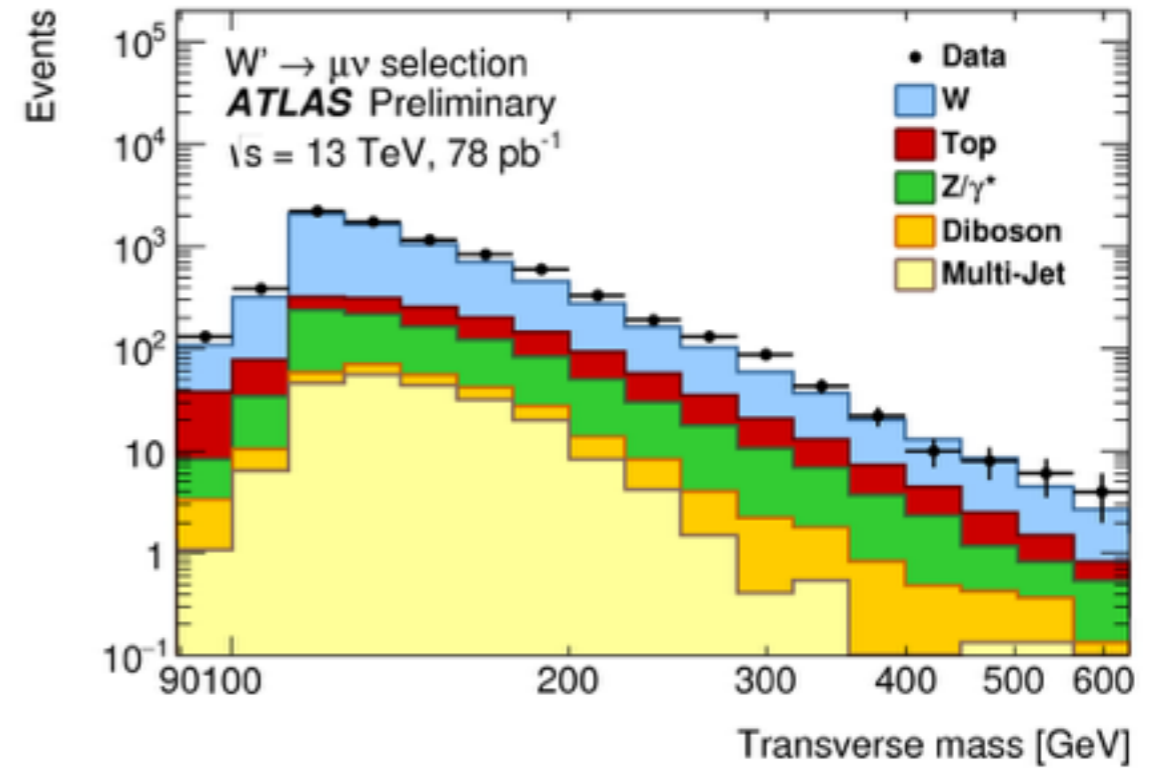
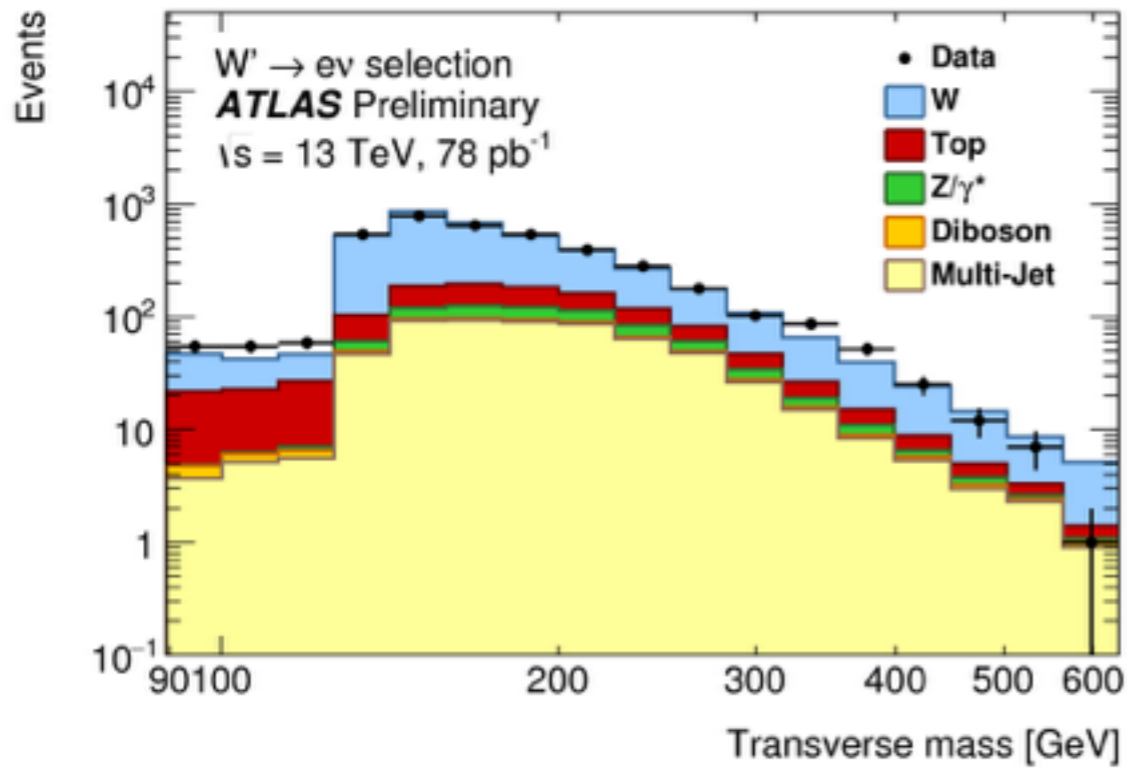
- looking for $W' \rightarrow l\nu$
- High p_T isolated lepton candidate
- $E_{T,miss} > 125$ GeV (e), 45 GeV (μ)
 - ▶ veto second lepton $p_T > 20$ GeV
- no excess in m_T distribution
- $m_{W'} > 3.24$ TeV

JHEP09(2014)037, arXiv:1407.7494





13 TeV: lepton+MET search

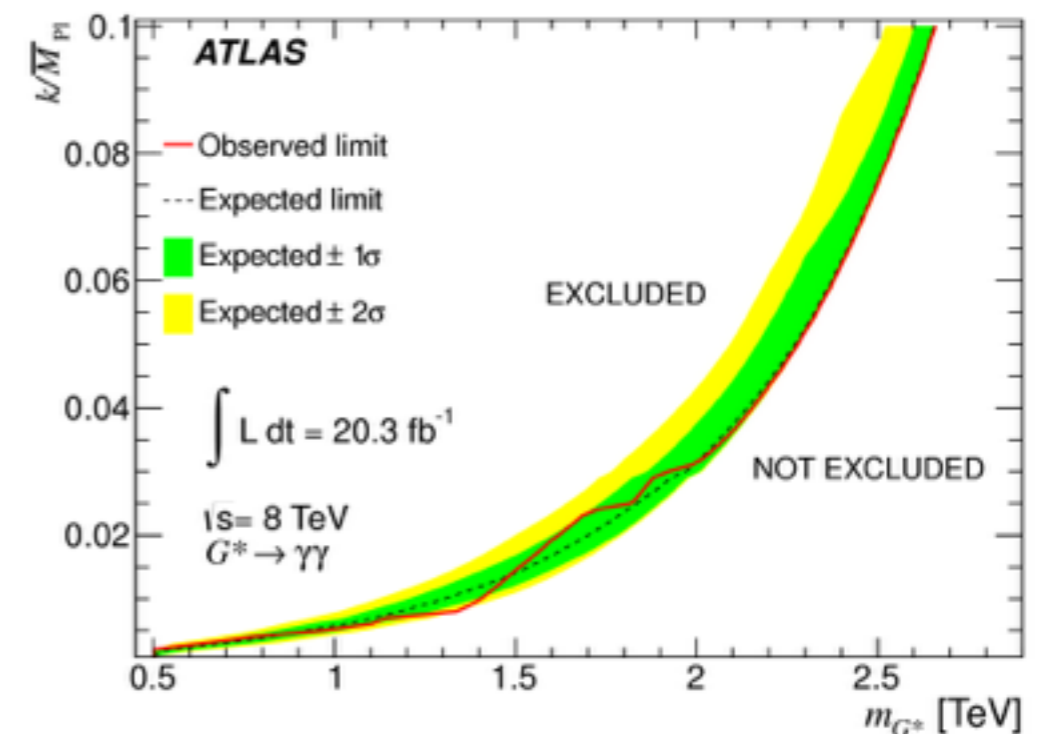
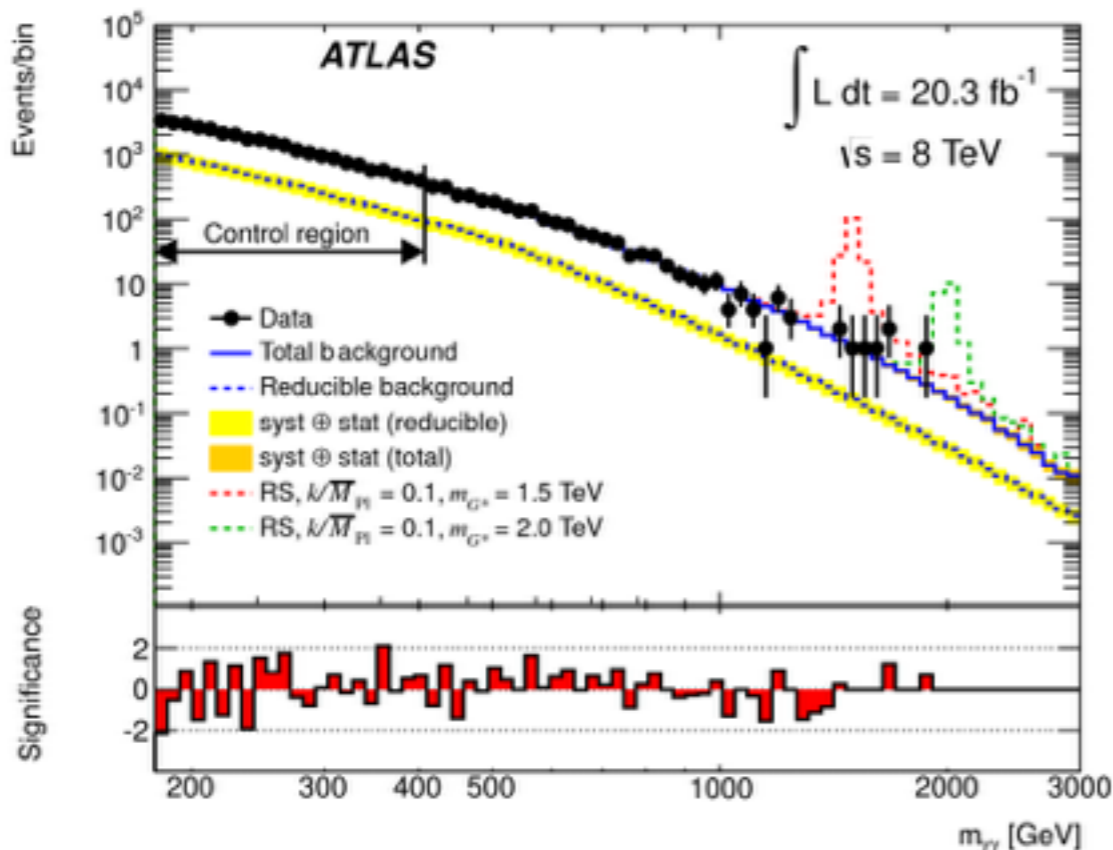
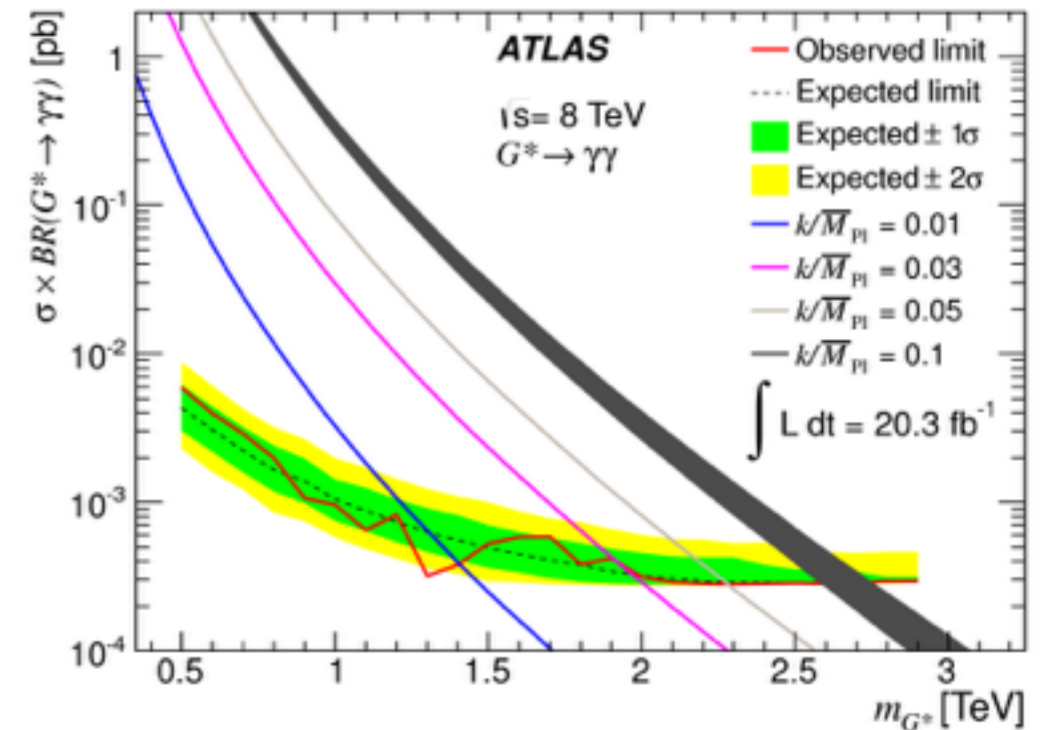




8 TeV: diphoton search



- Two photon candidates
 - ▶ Shower shape quality cuts
 - ▶ Calorimetric isolation
 - ▶ $p_{T\gamma} > 50$ GeV
- No excess in the $m_{\gamma\gamma}$ spectrum
 - ▶ $m_{G^*} > 2.66$ TeV ($k/M_{PL} = 0.1$)
 - ▶ $m_{G^*} > 1.41$ TeV ($k/M_{PL} = 0.01$)

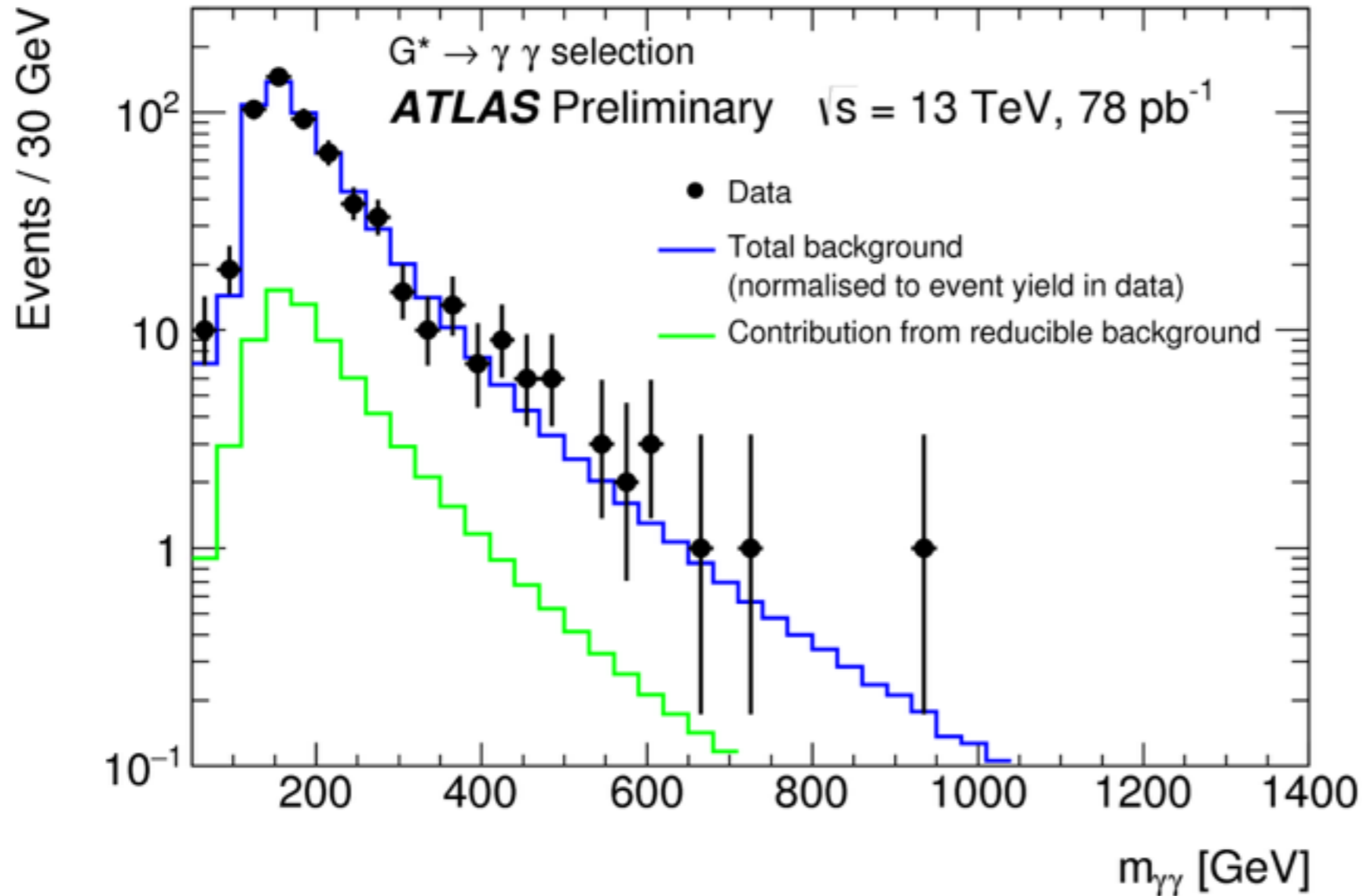
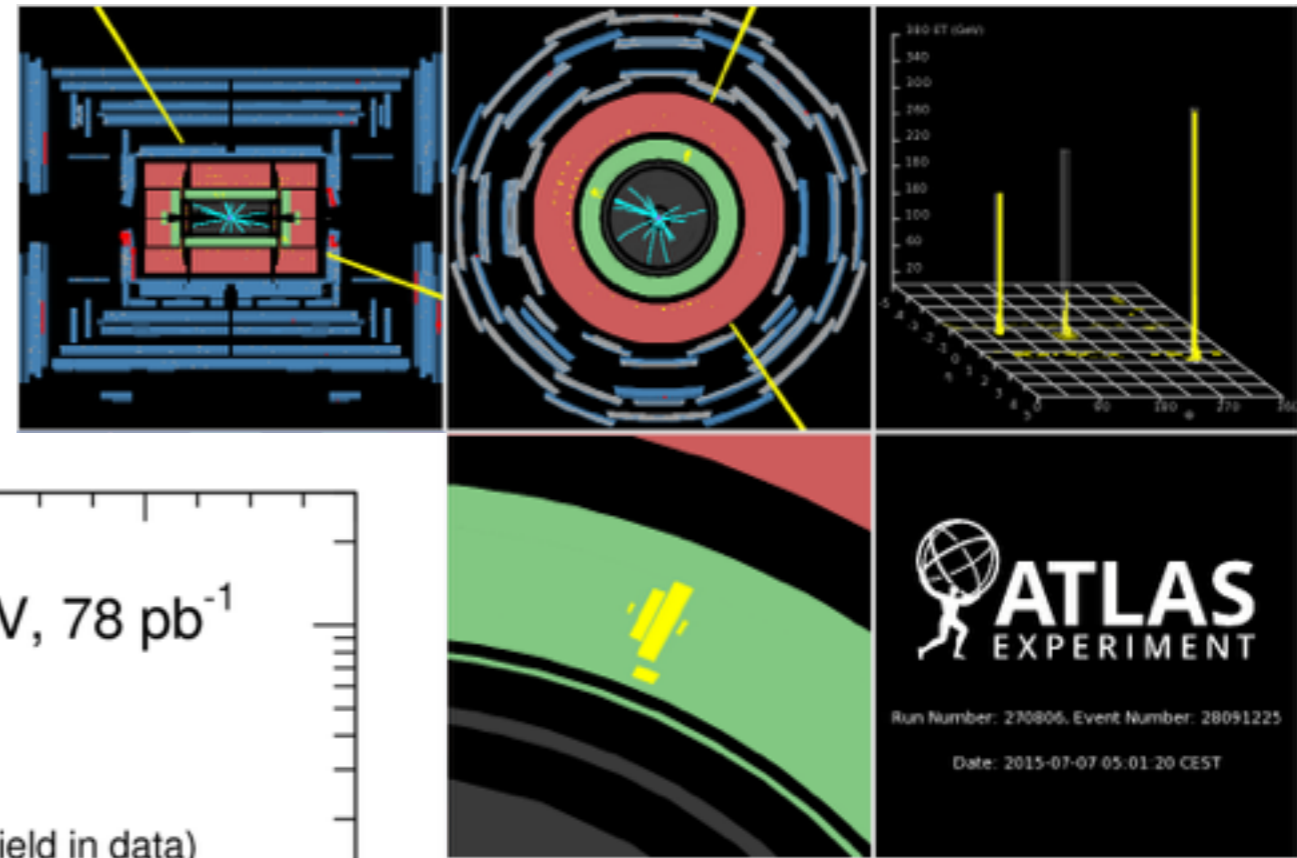




13 TeV: diphoton search



- no excess observed
(expect 1.1 events > 940 GeV)

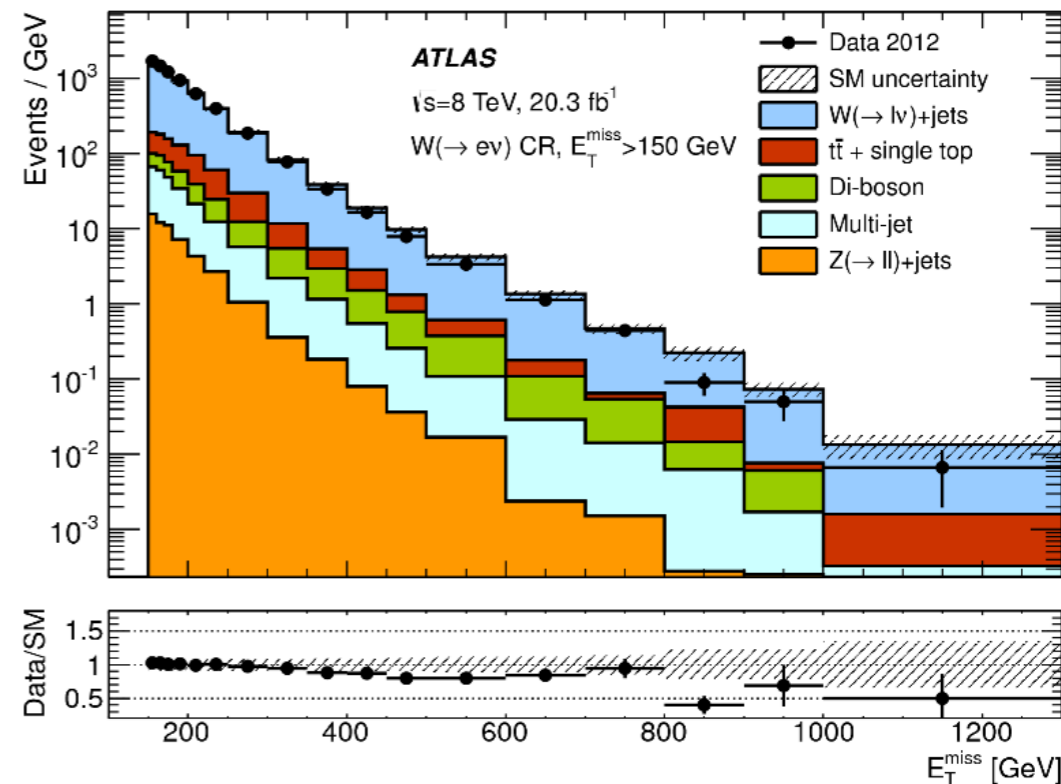




8 TeV: mono-jet search



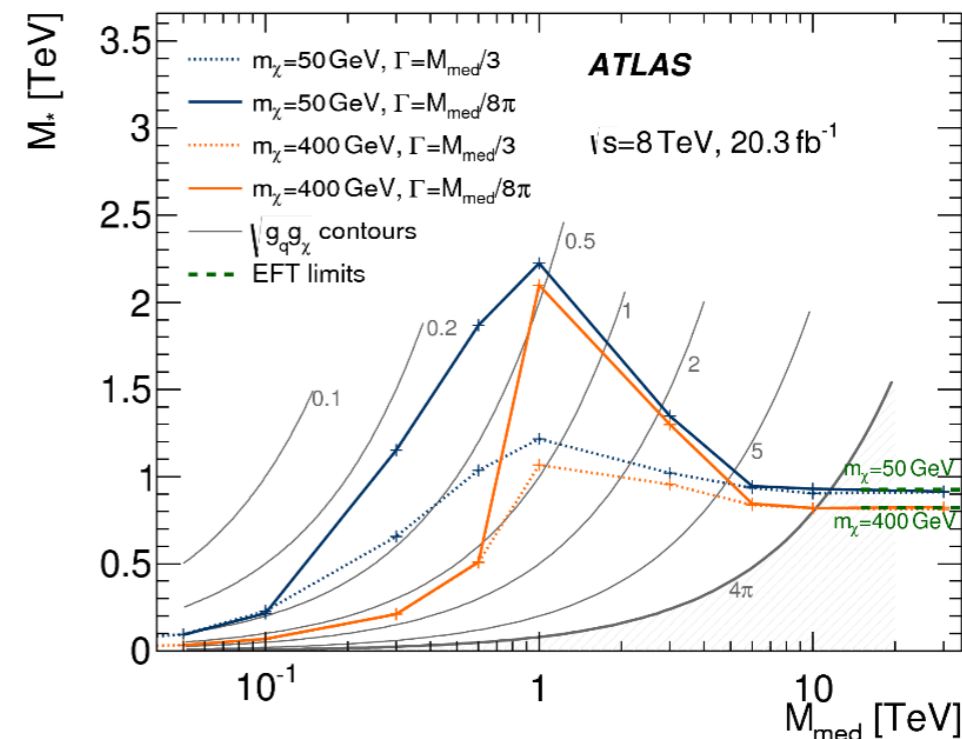
- $E_{T\text{miss}} > 150 \text{ GeV} \dots 700 \text{ GeV}$
- $p_{Tj} > 125 \text{ GeV}$ (central)
- $p_{Tj}/E_{T\text{miss}} > 0.5$
- At least 1 jet
- Lepton and isolated track vetoes
- Background estimation in CRs
- Cross check in VRs
- SR1 (150 GeV) – SR9 (700 GeV)



Limit on $\sigma \cdot A \cdot \epsilon$

Signal Region	95% CL Observed (Expected)
SR1	726 (935)
SR2	194 (271)
SR3	90 (106)
SR4	45 (51)
SR5	21 (29)
SR6	12 (17)
SR7	7.2 (7.2)
SR8	3.8 (3.6)
SR9	3.4 (1.8)

ATLAS, Eur. Phys. J. C75 (2015) 299

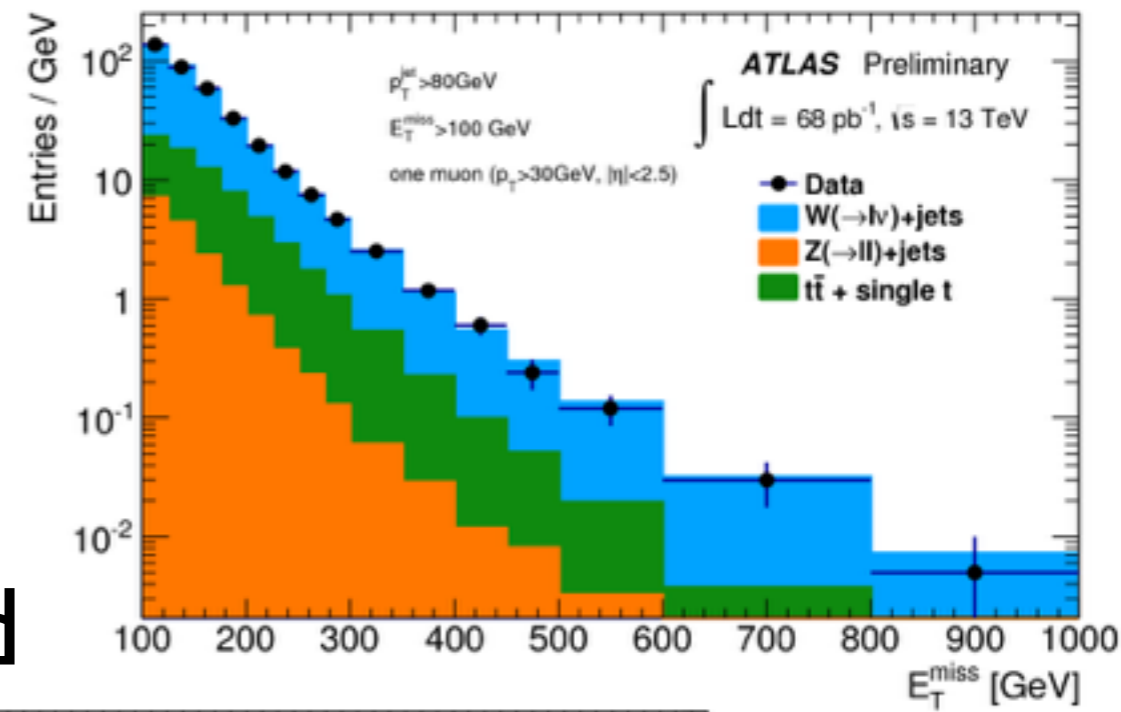




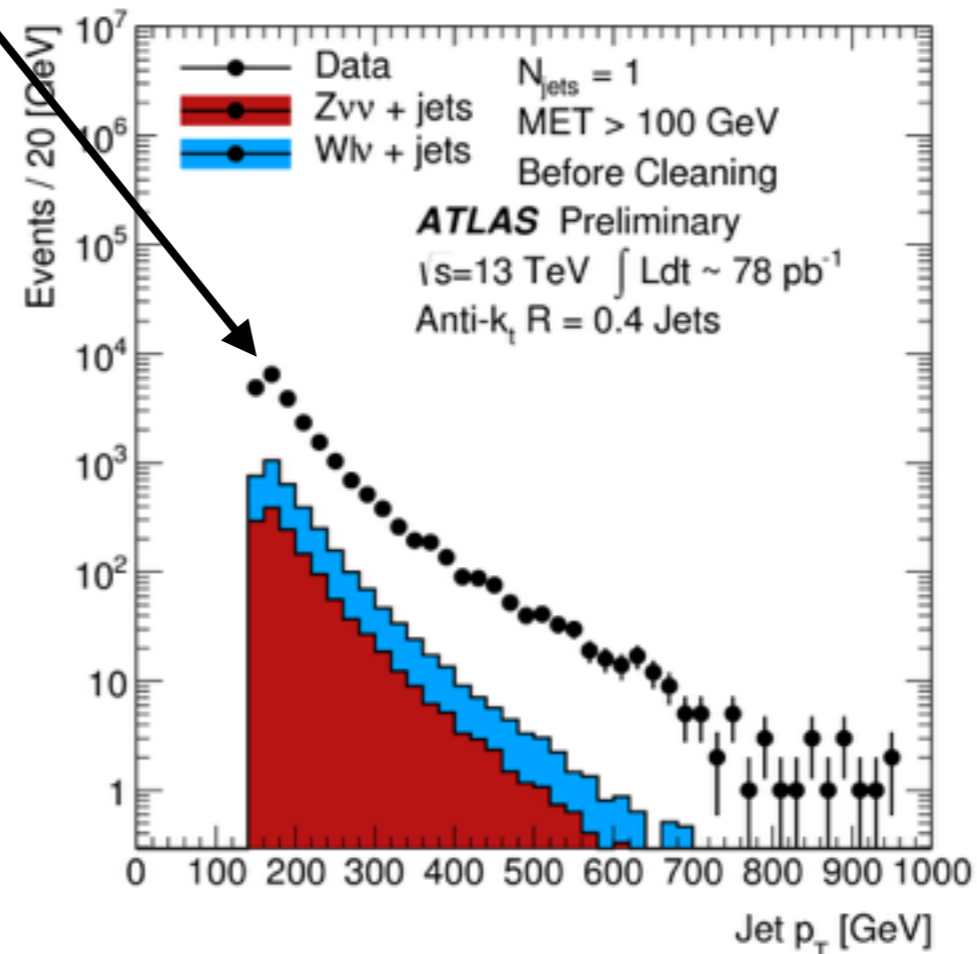
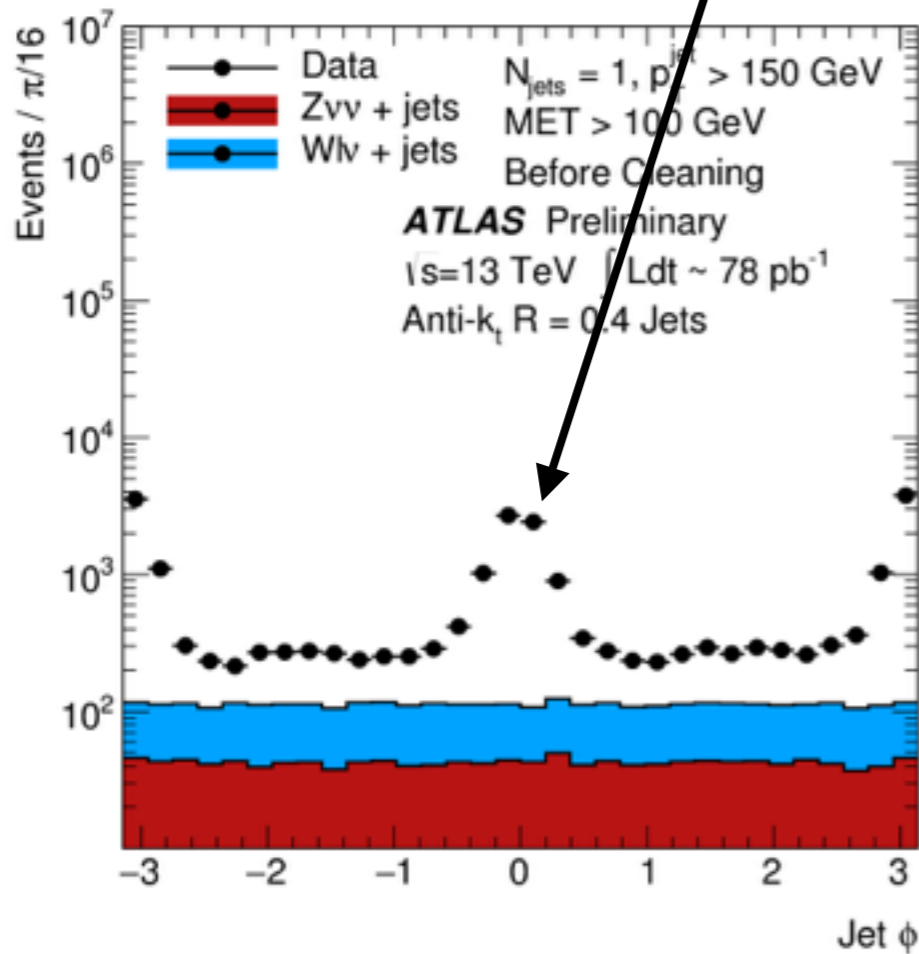
13 TeV: mono-jet search



- looks fine in lepton control region
- non-collision background contamination in signal region
 - ▶ still working on jet cleaning



non-collision background

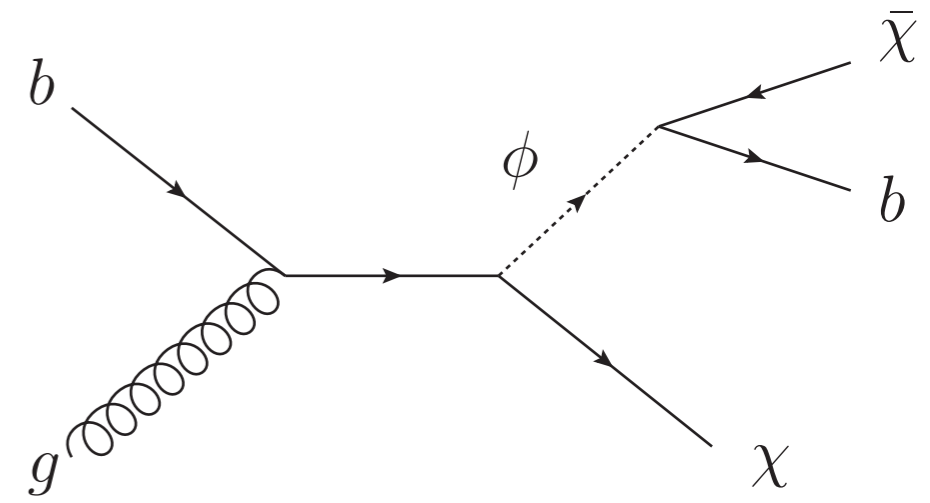




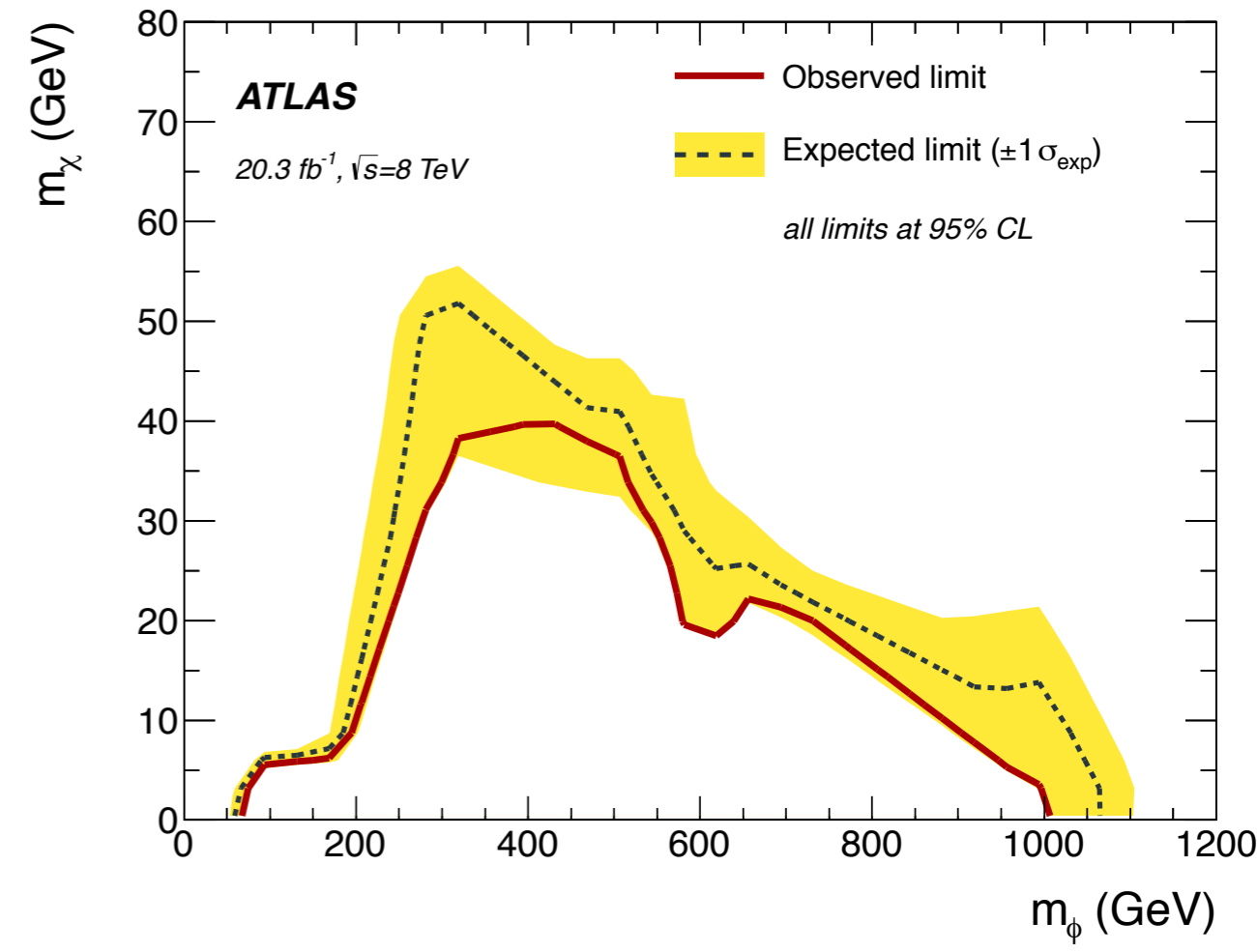
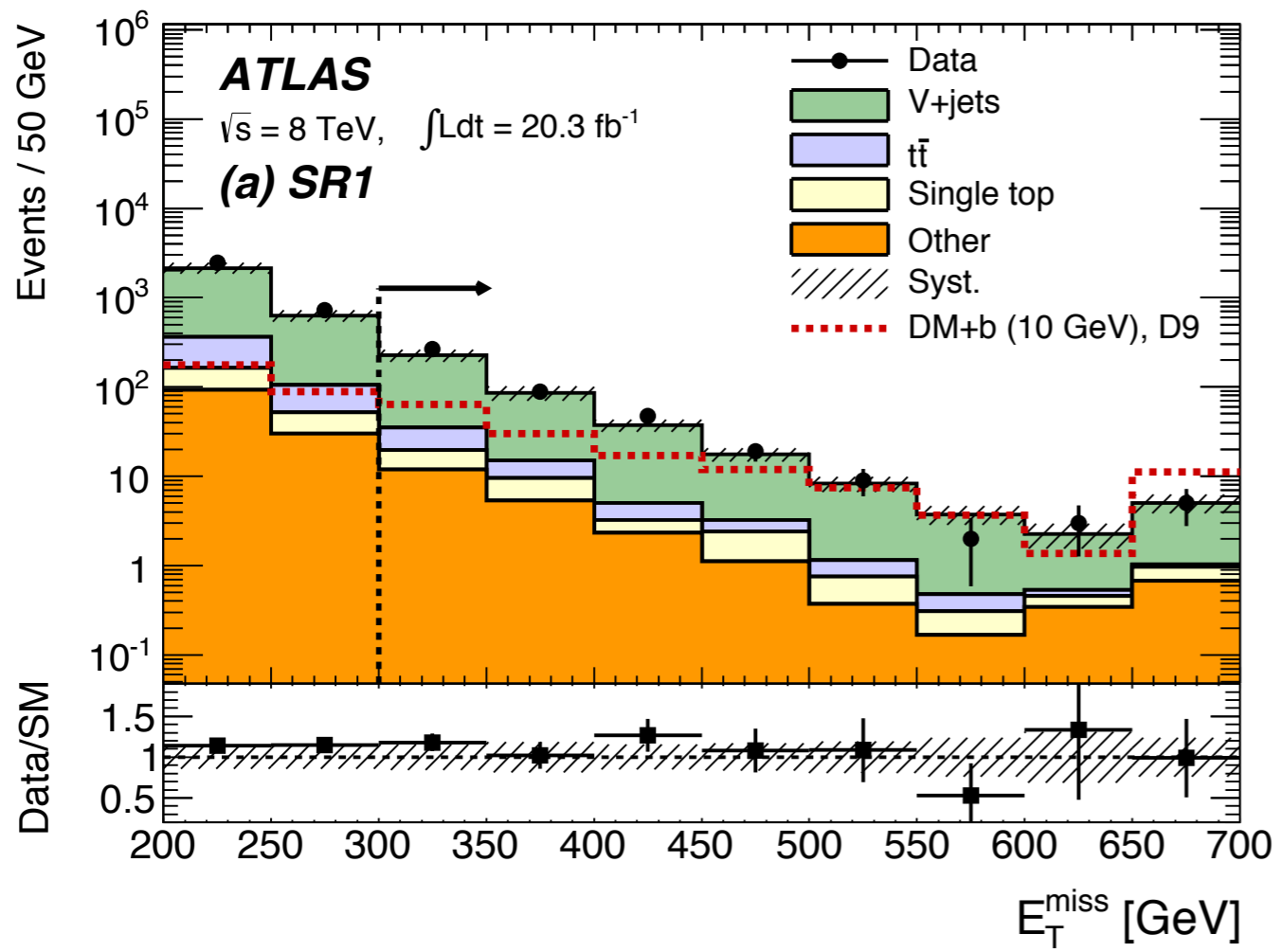
8 TeV: mono-b search



- looking for single b-jet and MET
- four signal regions:
 - ▶ SR1/SR2: b-jets
 - ▶ SR3/SR4: ttbar



Eur. Phys. J. C (2015) 75:92

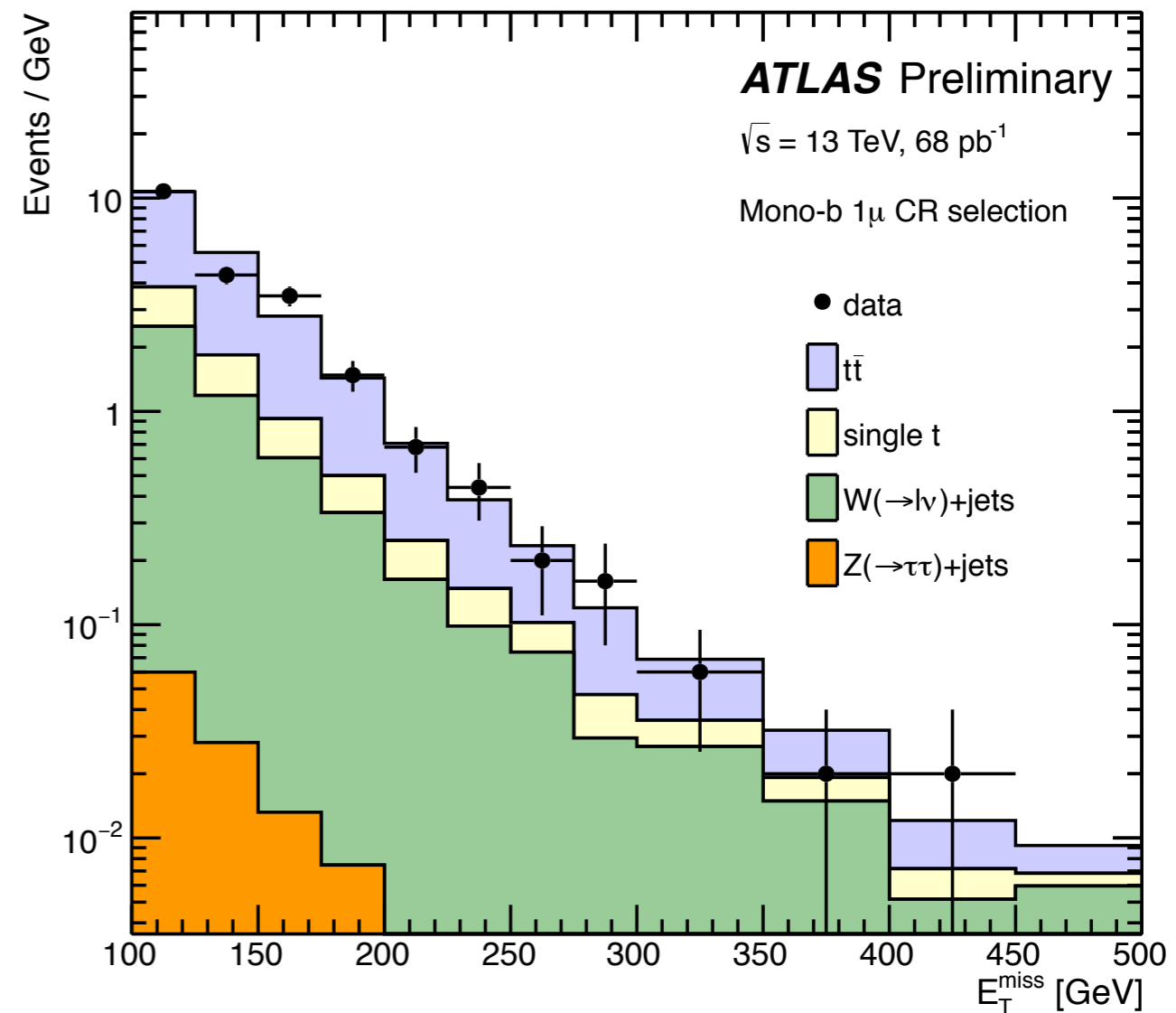
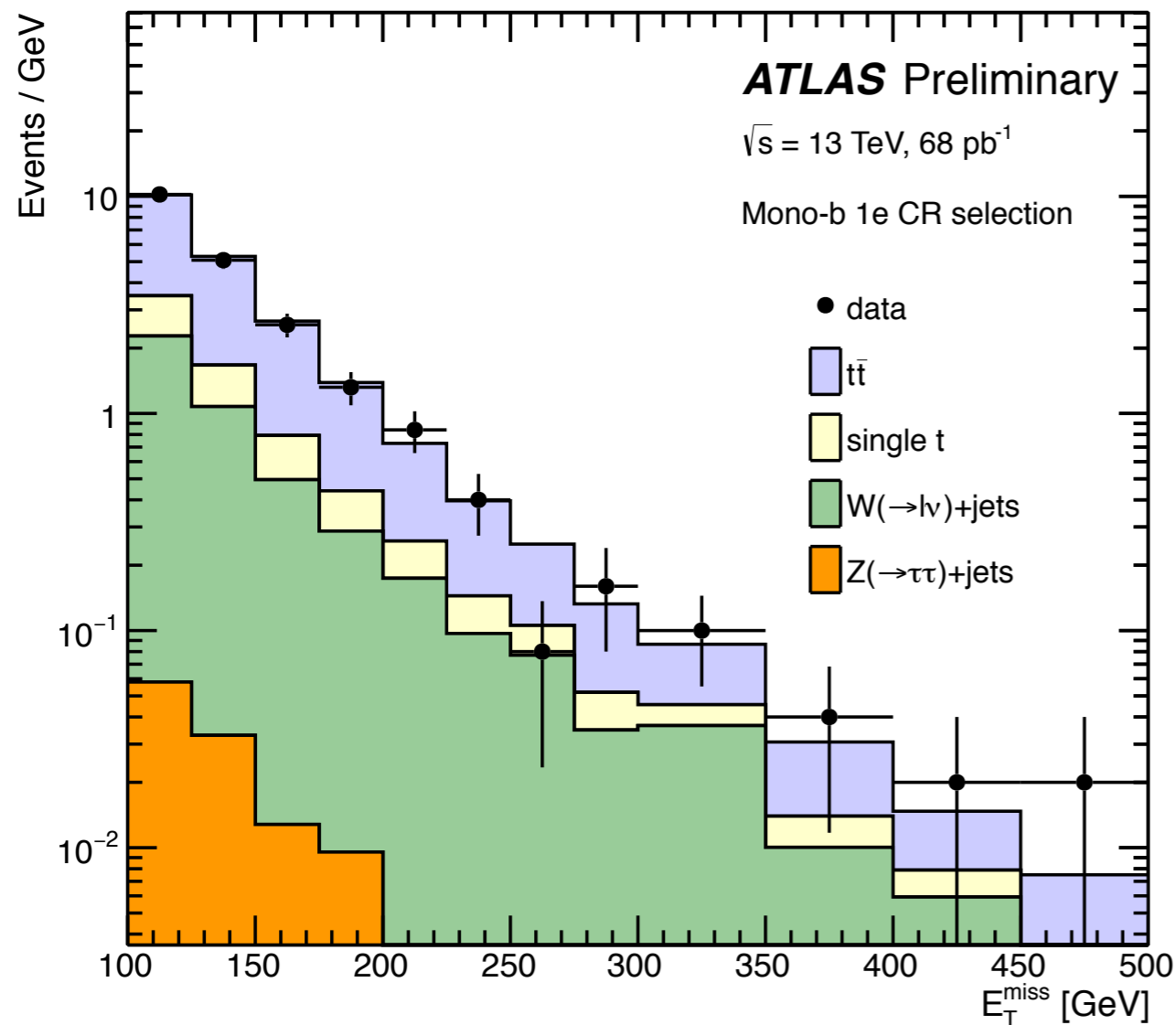




13 TeV: mono-b search



- good agreement in the control region

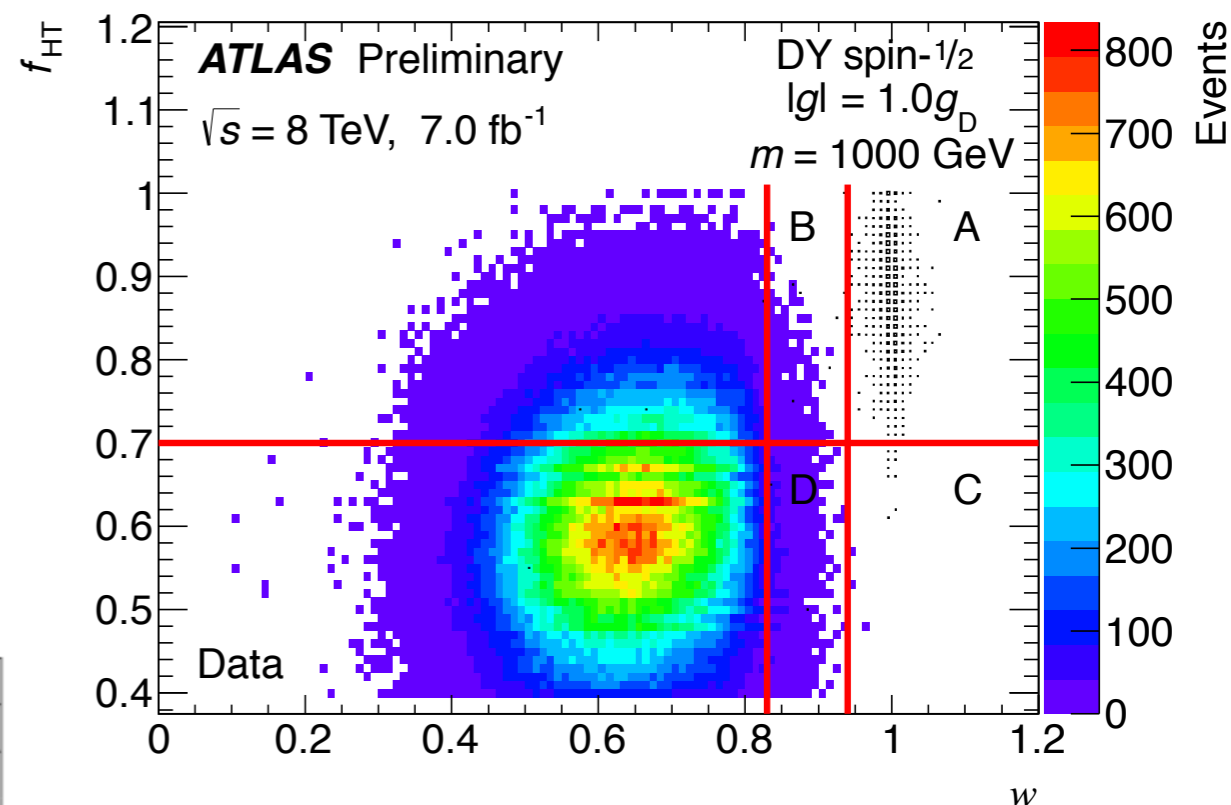
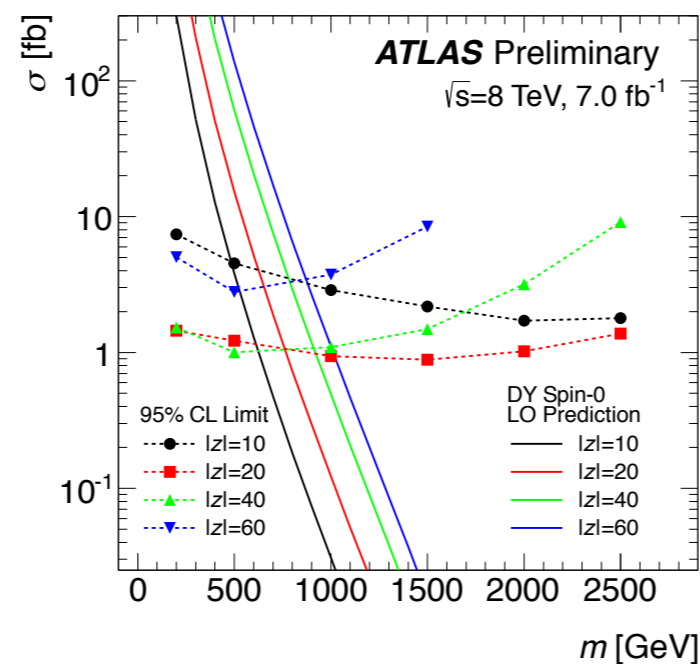
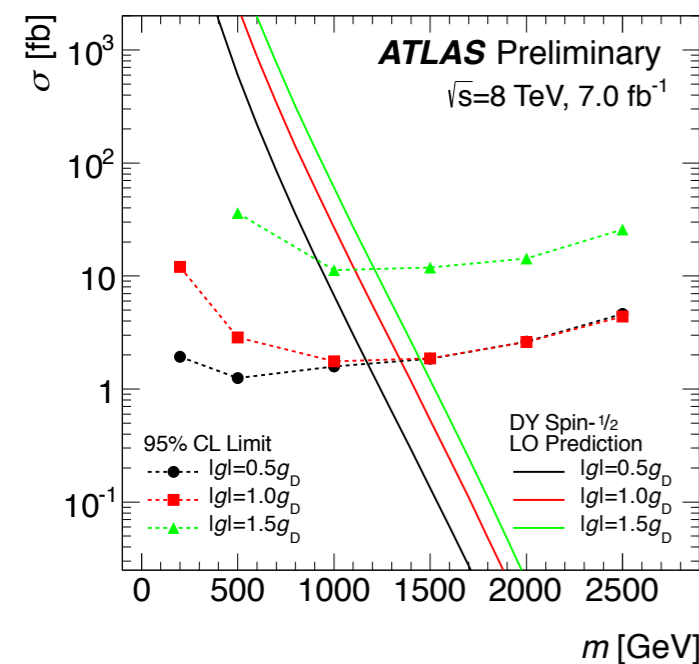




8 TeV: Search for monopoles and stable particles with high electric charges



- Massive stable particles with very high electric charge predicted by several new physics models: theories of magnetic monopoles, strange quark matter, Q-balls, stable black-hole remnants
- Signature to maximise the acceptance for particles predicted by the models (energy in 100 – 500 GeV):
 - ▶ large localised energy deposit in the Electromagnetic calorimeter
 - ▶ a region of high ionisation density in the tracker



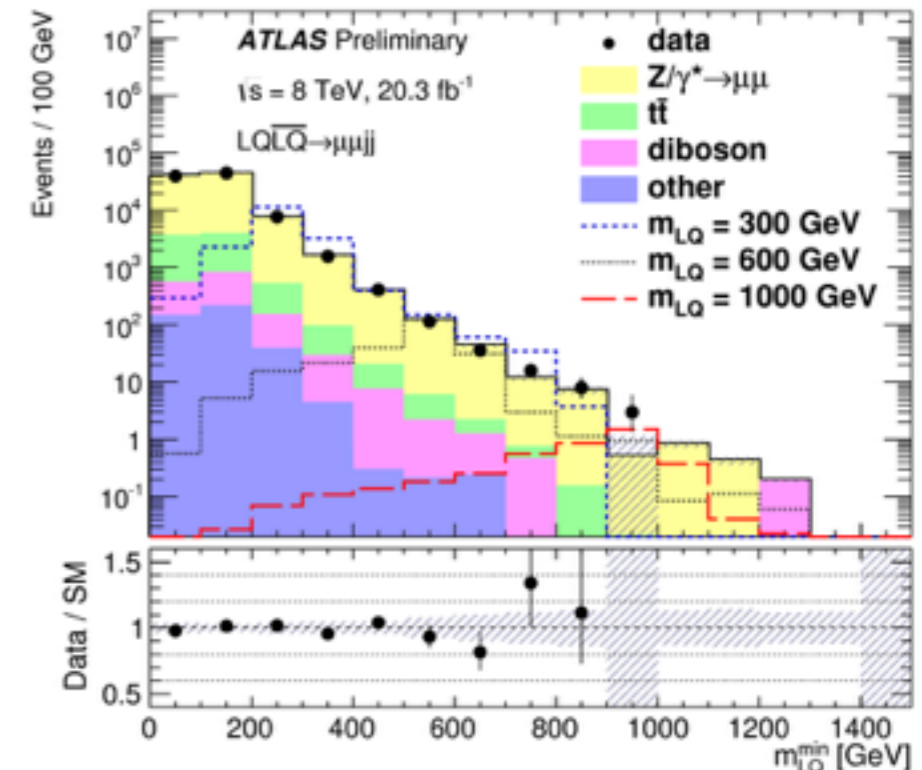
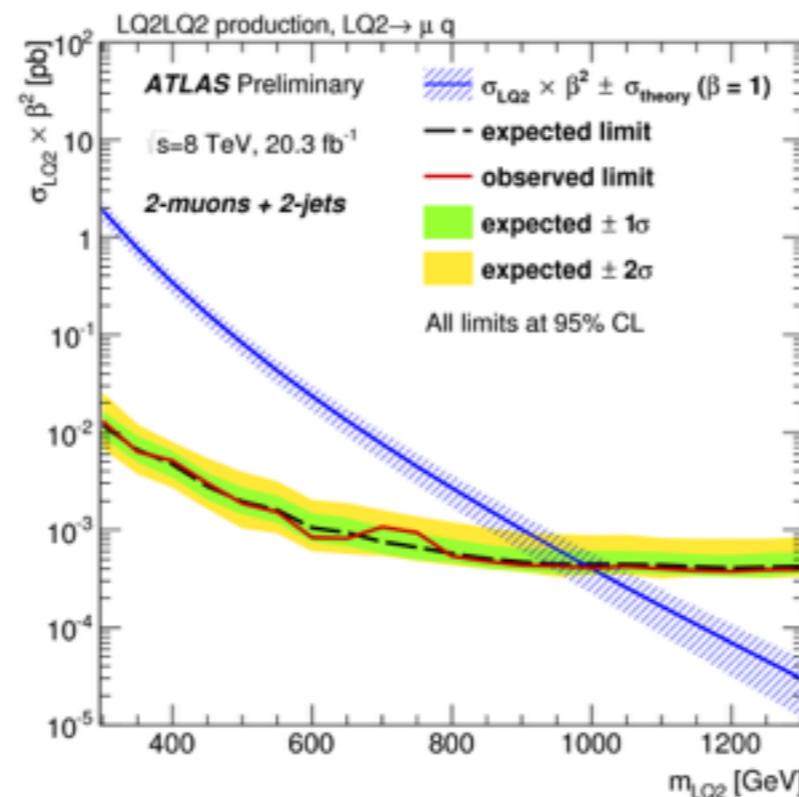
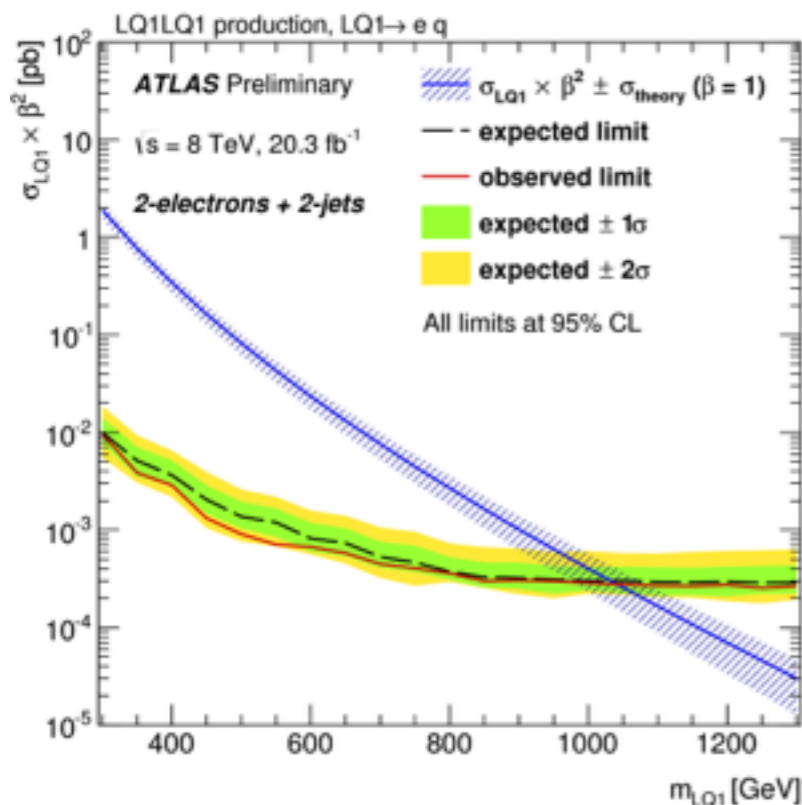
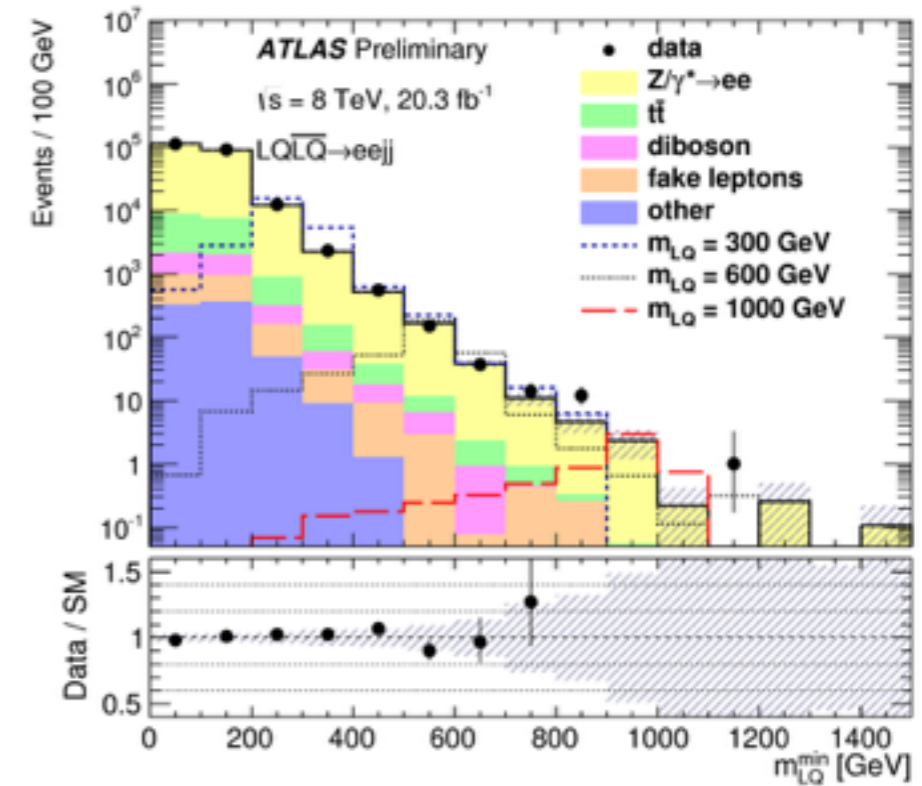
	Drell-Yan Lower Mass Limits [GeV]						
	$ g = 0.5g_D$	$ g = g_D$	$ g = 1.5g_D$	$ z = 10$	$ z = 20$	$ z = 40$	$ z = 60$
spin-1/2	1180	1340	1210	780	1050	1160	1070
spin-0	890	1050	970	490	780	920	880



8 TeV: leptoquark search



- looking for $LQ \rightarrow lq$
- coupling with corresponding SM family
- color triplet bosons, fractional el-charge
- carry both baryon and lepton numbers
- can be scalar or vector
- coupling strength affecting lifetime & width

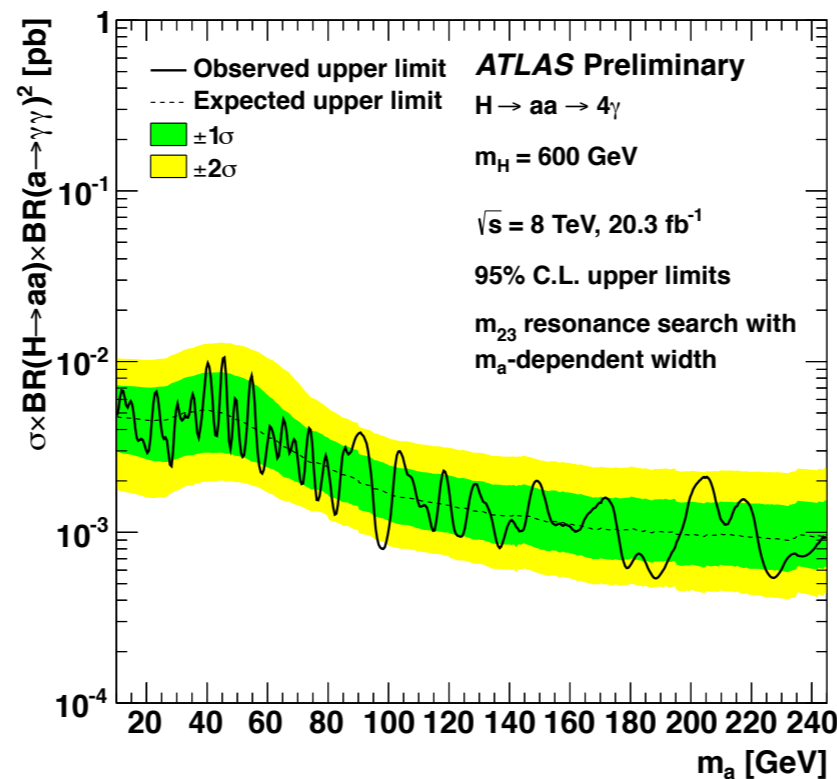
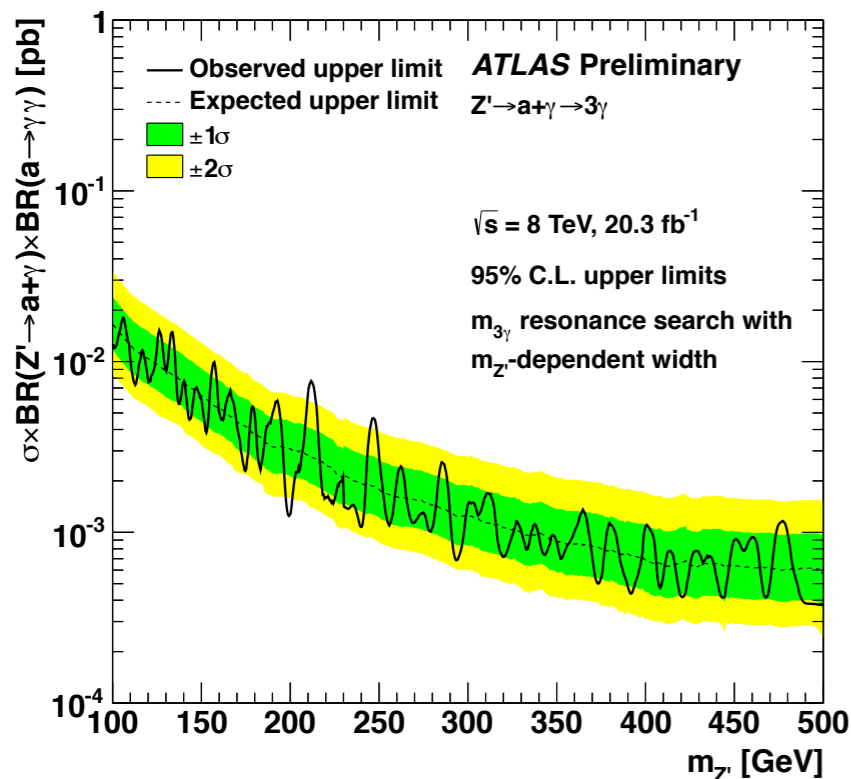
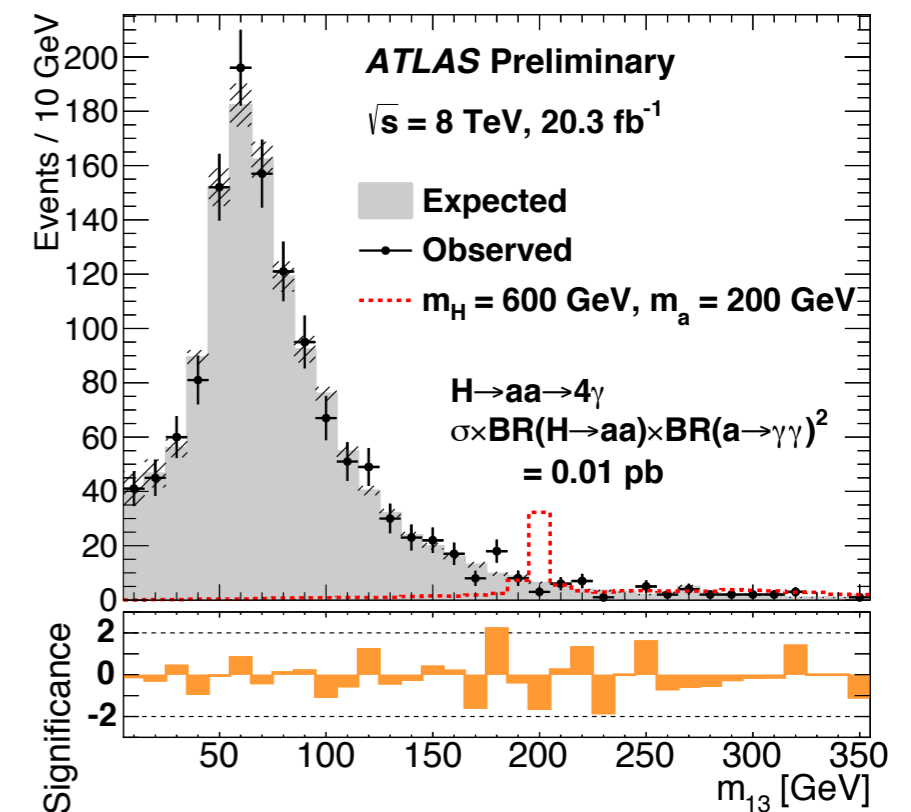
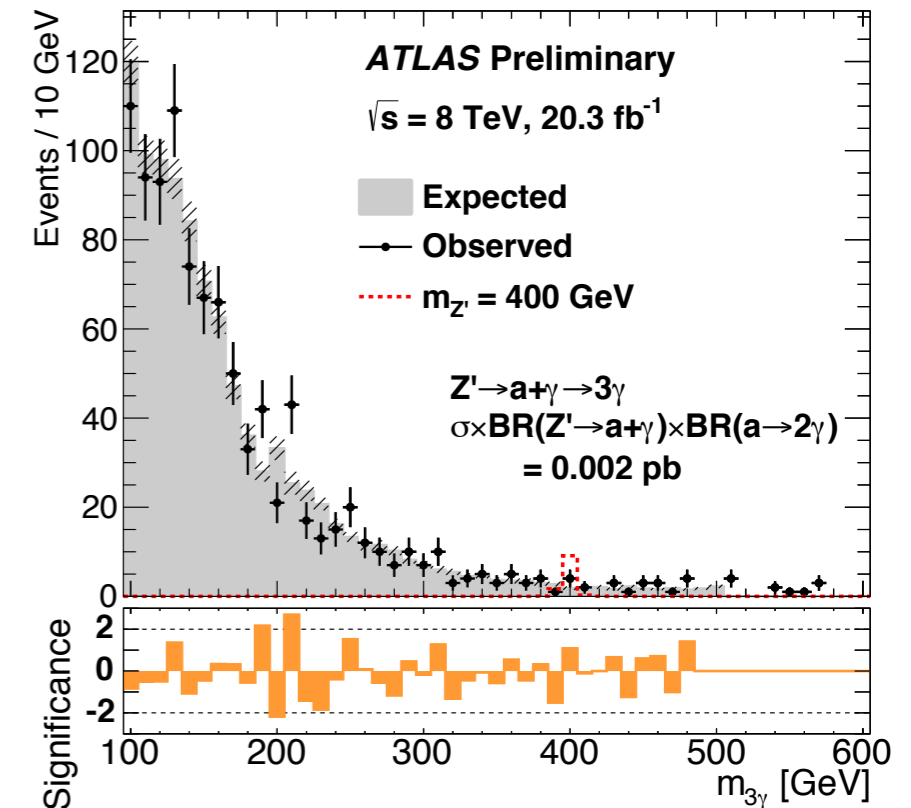




8 TeV: three photon search



- looking for $Z' \rightarrow a + \gamma \rightarrow 3\gamma$ or $H \rightarrow aa \rightarrow 4\gamma$ (with $a \rightarrow \gamma\gamma$)
- requiring three photons
- $p_{T,\gamma} > 22, 22, 17$ GeV
- "tight" cleaning and isolation cuts





and so many more...



ATLAS Exotics Searches* - 95% CL Exclusion

Status: July 2015

ATLAS Preliminary

$\int \mathcal{L} dt = (4.7 - 20.3) \text{ fb}^{-1}$

$\sqrt{s} = 7, 8 \text{ TeV}$

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	-	$\geq 1j$	Yes	20.3	M_D 5.25 TeV	$n = 2$ 1502.01518
	ADD non-resonant $\ell\ell$	$2e, \mu$	-	-	20.3	M_S 4.7 TeV	$n = 3 \text{ HLZ}$ 1407.2410
	ADD QBH $\rightarrow \ell q$	$1e, \mu$	$1j$	-	20.3	M_{th} 5.2 TeV	$n = 6$ 1311.2006
	ADD QBH	-	$2j$	-	20.3	M_{th} 5.82 TeV	$n = 6$ 1407.1376
	ADD BH high N_{trk}	$2\mu \text{ (SS)}$	-	-	20.3	M_{th} 4.7 TeV	$n = 6, M_D = 3 \text{ TeV, non-rot BH}$ 1308.4075
	ADD BH high $\sum p_T$	$\geq 1e, \mu$	$\geq 2j$	-	20.3	M_{th} 5.8 TeV	$n = 6, M_D = 3 \text{ TeV, non-rot BH}$ 1405.4254
	ADD BH high multijet	-	$\geq 2j$	-	20.3	M_{th} 5.8 TeV	$n = 6, M_D = 3 \text{ TeV, non-rot BH}$ 1503.08988
	RS1 $G_{KK} \rightarrow \ell\ell$	$2e, \mu$	-	-	20.3	$G_{KK} \text{ mass}$ 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$ 1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	20.3	$G_{KK} \text{ mass}$ 2.66 TeV	$k/\overline{M}_{Pl} = 0.1$ 1504.05511
	Bulk RS $G_{KK} \rightarrow ZZ \rightarrow qq\ell\ell$	$2e, \mu$	$2j/1J$	-	20.3	$G_{KK} \text{ mass}$ 740 GeV	$k/\overline{M}_{Pl} = 1.0$ 1409.6190
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1e, \mu$	$2j/1J$	Yes	20.3	$W' \text{ mass}$ 760 GeV	$k/\overline{M}_{Pl} = 1.0$ 1503.04677
	Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	-	$4b$	-	19.5	$G_{KK} \text{ mass}$ 500-720 GeV	$k/\overline{M}_{Pl} = 1.0$ 1506.00285
	Bulk RS $g_{KK} \rightarrow t\bar{t}$	$1e, \mu$	$\geq 1b, \geq 1J/2j$	Yes	20.3	$g_{KK} \text{ mass}$ 2.2 TeV	$BR = 0.925$ 1505.07018
2UED / RPP	$2e, \mu \text{ (SS)}$	$\geq 1b, \geq 1j$	Yes	20.3	$KK \text{ mass}$ 960 GeV	1504.04605	
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2e, \mu$	-	-	20.3	$Z' \text{ mass}$ 2.9 TeV	1405.4123
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	19.5	$Z' \text{ mass}$ 2.02 TeV	1502.07177
	SSM $W' \rightarrow \ell\nu$	$1e, \mu$	-	Yes	20.3	$W' \text{ mass}$ 3.24 TeV	1407.7494
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\ell'\ell'$	$3e, \mu$	-	Yes	20.3	$W' \text{ mass}$ 1.52 TeV	1406.4456
	EGM $W' \rightarrow WZ \rightarrow qq\ell\ell$	$2e, \mu$	$2j/1J$	-	20.3	$W' \text{ mass}$ 1.59 TeV	1409.6190
	EGM $W' \rightarrow WZ \rightarrow qqqq$	-	$2J$	-	20.3	$W' \text{ mass}$ 1.3-1.5 TeV	1506.00962
	HVT $W' \rightarrow WH \rightarrow \ell\nu b\bar{b}$	$1e, \mu$	$2b$	Yes	20.3	$W' \text{ mass}$ 1.47 TeV	1503.08089
	LRSM $W'_R \rightarrow t\bar{b}$	$1e, \mu$	$2b, 0-1j$	Yes	20.3	$W' \text{ mass}$ 1.92 TeV	1410.4103
LRSM $W'_R \rightarrow t\bar{b}$	$0e, \mu$	$\geq 1b, 1J$	-	20.3	$W' \text{ mass}$ 1.76 TeV	1408.0886	
CI	CI $qqqq$	-	$2j$	-	17.3	Λ 12.0 TeV	$\eta_{LL} = -1$ 1504.00357
	CI $qq\ell\ell$	$2e, \mu$	-	-	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$ 1407.2410
	CI $uutt$	$2e, \mu \text{ (SS)}$	$\geq 1b, \geq 1j$	Yes	20.3	Λ 4.3 TeV	$ C_{LL} = 1$ 1504.04605
DM	EFT D5 operator (Dirac)	$0e, \mu$	$\geq 1j$	Yes	20.3	M_* 974 GeV	at 90% CL for $m(\chi) < 100 \text{ GeV}$ 1502.01518
	EFT D9 operator (Dirac)	$0e, \mu$	$1J, \leq 1j$	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100 \text{ GeV}$ 1309.4017
LQ	Scalar LQ 1 st gen	$2e$	$\geq 2j$	-	20.3	LQ mass 1.05 TeV	$\beta = 1$ Preliminary
	Scalar LQ 2 nd gen	2μ	$\geq 2j$	-	20.3	LQ mass 1.0 TeV	$\beta = 1$ Preliminary
	Scalar LQ 3 rd gen	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	LQ mass 640 GeV	$\beta = 0$ Preliminary
Heavy quarks	VLQ $TT \rightarrow Ht + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	T mass 855 GeV	T in (T,B) doublet 1505.04306
	VLQ $YY \rightarrow Wb + X$	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet 1505.04306
	VLQ $BB \rightarrow Hb + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	B mass 735 GeV	isospin singlet 1505.04306
	VLQ $BB \rightarrow Zb + X$	$2/\geq 3e, \mu$	$\geq 2/\geq 1b$	-	20.3	B mass 755 GeV	B in (B,Y) doublet 1409.5500
	$T_{5/3} \rightarrow Wt$	$1e, \mu$	$\geq 1b, \geq 5j$	Yes	20.3	$T_{5/3} \text{ mass}$ 840 GeV	1503.05425
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1γ	$1j$	-	20.3	$q^* \text{ mass}$ 3.5 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1309.3230
	Excited quark $q^* \rightarrow qg$	-	$2j$	-	20.3	$q^* \text{ mass}$ 4.09 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1407.1376
	Excited quark $b^* \rightarrow Wt$	$1 \text{ or } 2e, \mu$	$1b, 2j \text{ or } 1j$	Yes	4.7	$b^* \text{ mass}$ 870 GeV	left-handed coupling 1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	$2e, \mu, 1\gamma$	-	-	13.0	$\ell^* \text{ mass}$ 2.2 TeV	$\Lambda = 2.2 \text{ TeV}$ 1308.1364
	Excited lepton $\nu^* \rightarrow \ell W, \nu Z$	$3e, \mu, \tau$	-	-	20.3	$\nu^* \text{ mass}$ 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$ 1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	$1e, \mu, 1\gamma$	-	Yes	20.3	$a_T \text{ mass}$ 960 GeV	1407.8150
	LRSM Majorana ν	$2e, \mu$	$2j$	-	20.3	$N^0 \text{ mass}$ 2.0 TeV	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2e, \mu \text{ (SS)}$	-	-	20.3	$H^{\pm\pm} \text{ mass}$ 551 GeV	$m(W_R) = 2.4 \text{ TeV, no mixing}$ DY production, $BR(H_L^{\pm\pm} \rightarrow \ell\ell)=1$ 1412.0237
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3e, \mu, \tau$	-	-	20.3	$H^{\pm\pm} \text{ mass}$ 400 GeV	DY production, $BR(H_L^{\pm\pm} \rightarrow \ell\tau)=1$ 1411.2921
	Monotop (non-res prod)	$1e, \mu$	$1b$	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$ 1410.5404
	Multi-charged particles	-	-	-	20.3	multi-charged particle mass 785 GeV	DY production, $ q = 5e$ 1504.04188
	Magnetic monopoles	-	-	-	7.0	monopole mass 1.34 TeV	DY production, $ g = 1g_D, \text{ spin } 1/2$ Preliminary

*Only a selection of the available mass limits on new states or phenomena is shown.



Conclusions



- Many final states searched
- No significant excess found
 - ▶ But hints may be already here!
- Great ATLAS performance in Run 1
- Taking run 2 data now, may see discoveries very soon!
 - ▶ Exceeding run 1 sensitivity by the end of this year