Searches for heavy resonances with the ATLAS detector

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November 21st, 2013

Motivation

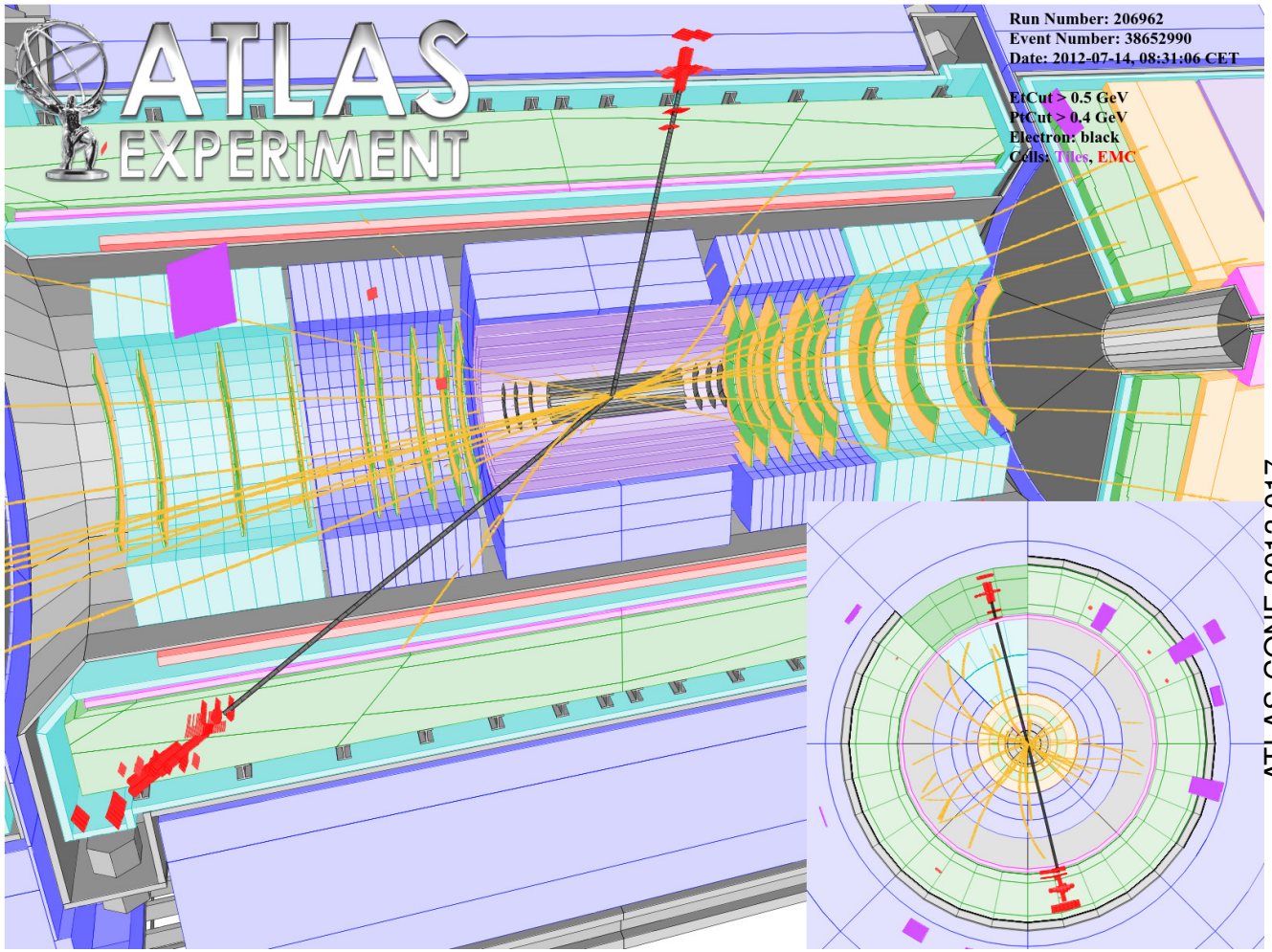
Highest energies at the LHC make it possible to look for New Phenomena
With data taken in 2012 in pp collisions at $\sqrt{s} = 8$ TeV ATLAS looked in:

- Dilepton (Z', spin-2 graviton G*)
- Diboson WZ $\rightarrow$ l ν l'l' (W', techni-mesons)
- Diboson ZZ $\rightarrow$ lljj/llJ (G*)
- Lepton+Jet (quantum black hole)
- Photon+Jet (q*, quantum black hole)
- Dijet (q*)

Testing different theory models:
Compositeness, sequential standard model, E6 grand unified theory, extended gauge model, low scale technicolor, Randall-Sundrum, ADD

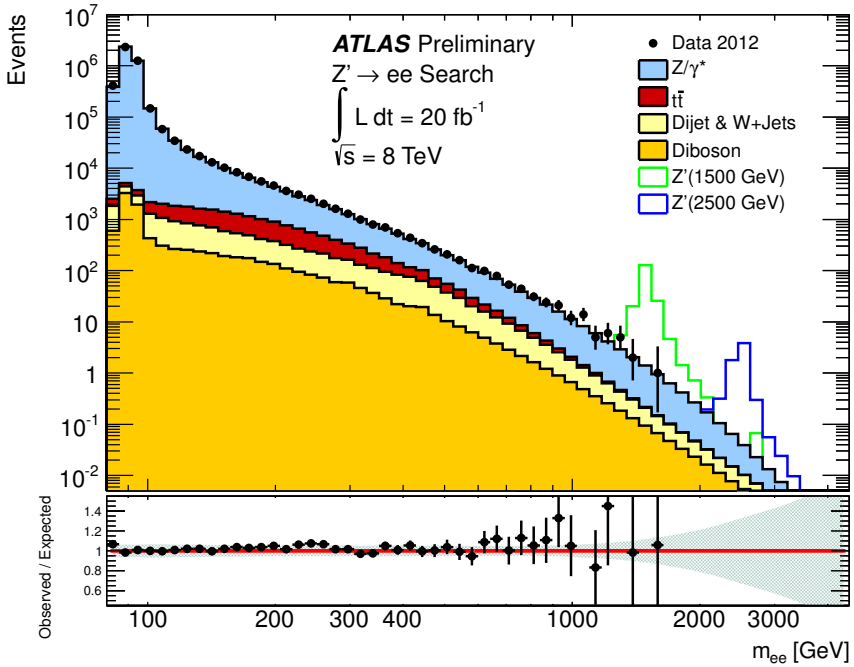
High mass di-electron event

$m_{ee} = 1.5\,\text{TeV}$, p_T=0.59/0.58 TeV

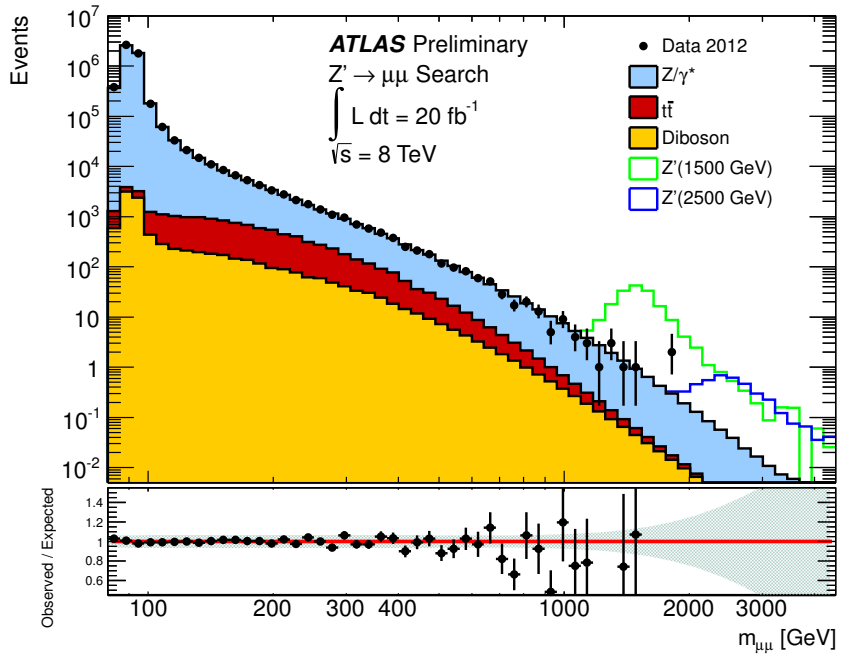


Dilepton(e/μ-channel)

- Models: Z'(SSM,E6), G*(RS)
- Signature: l^+l^- (with l=e,μ)
  - two electrons $|\eta| < 2.47$ $E_T > 40/30$ GeV
  - two muons $|\eta| < 2.4$ $E_T > 25$ GeV
- Spectrum: mass lepton-pair



- Normalized to Z-peak
- Backgrounds:
  - From simulation: Drell-Yan, diboson and $t\bar{t}$
  - Data-driven: W+jet and dijet
- Signals: From LO simulation



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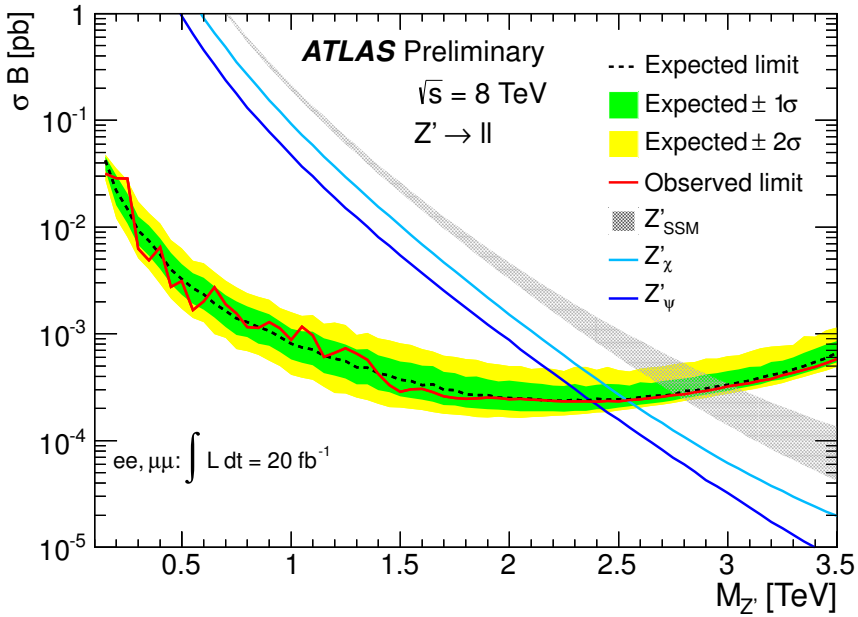
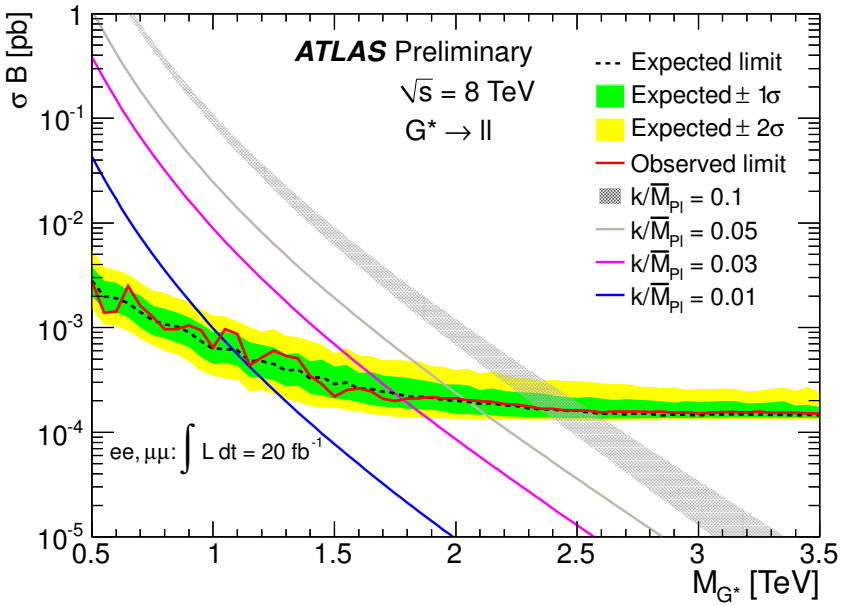
Dilepton(e/μ-channel)

- Systematics(dominant):
  - Drell-Yan background (PDF)
  - Data-driven background



- 95% CL mass limits
- $\kappa/M_{\mathrm{Pl}} = 0.1$ for G*



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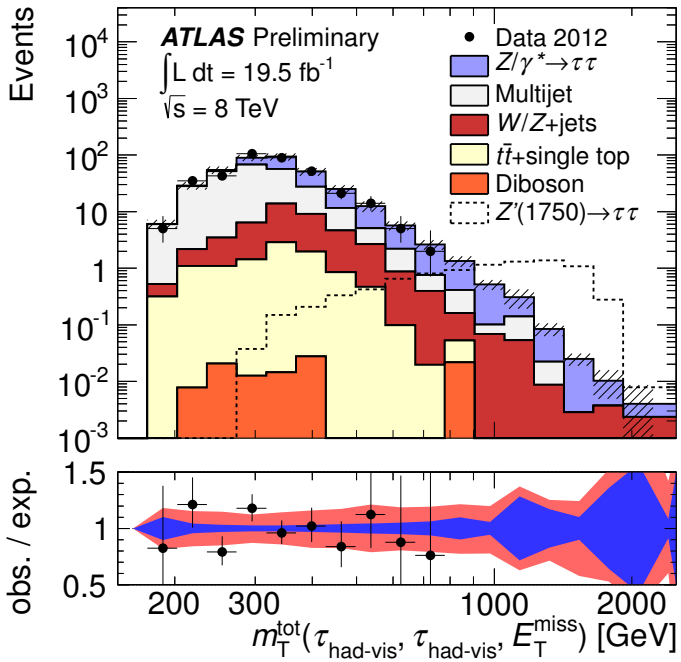
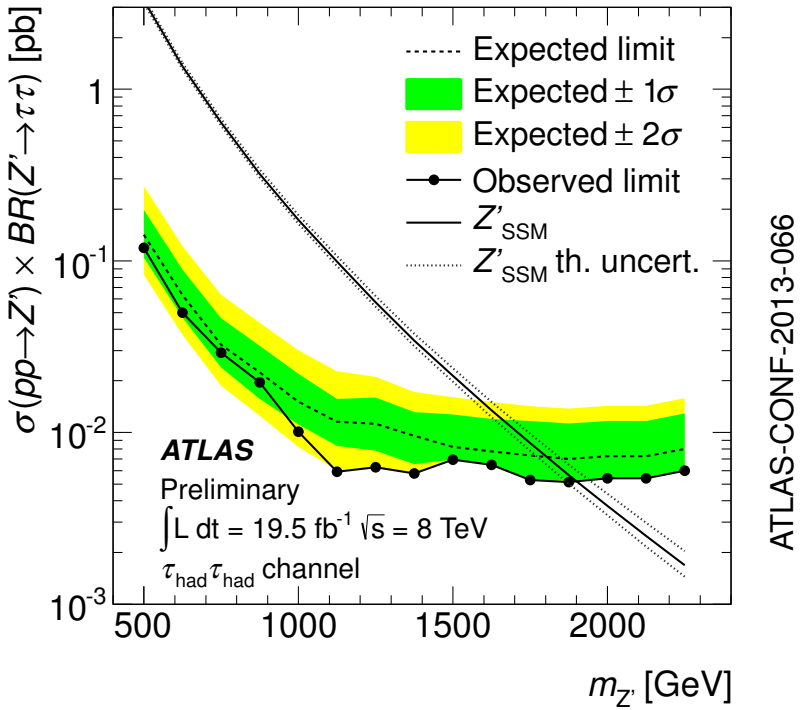
	Z'_ψ	Z'_χ	$Z' \to ee$	$Z' \to \mu\mu$	Z'	G^*
Obs. limit[TeV]	2.38	2.54	2.79	2.48	2.86	2.47
Exp. limit[TeV]	2.37	2.53	2.76	2.52	2.85	2.47

Dilepton(τ-channel)

- Models: Z'(SSM)
- Signature: $\tau^+\tau^-$
  - two τ in $|\eta| < 2.5$ with $p_T^{\text{lead}} > 150\,\text{GeV}$
- Spectrum: Total transverse mass m_T^{tot}



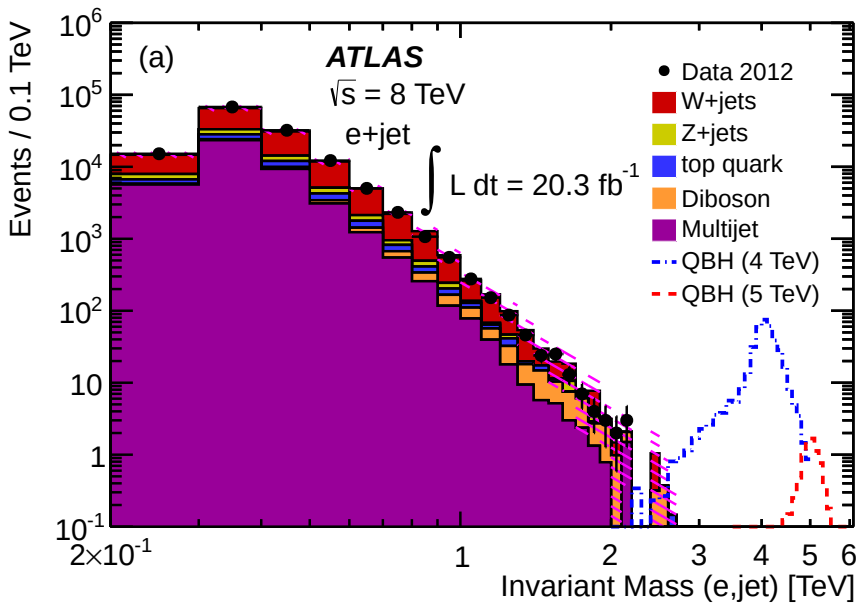
- Backgrounds:
  - Drell-Yan(MC)
  - Multijet(data-driven)
- Systematics(dominant): Multijet estimation and τ energy scale
- Limits:1.90/1.80 TeV (obs/exp) 95% CL

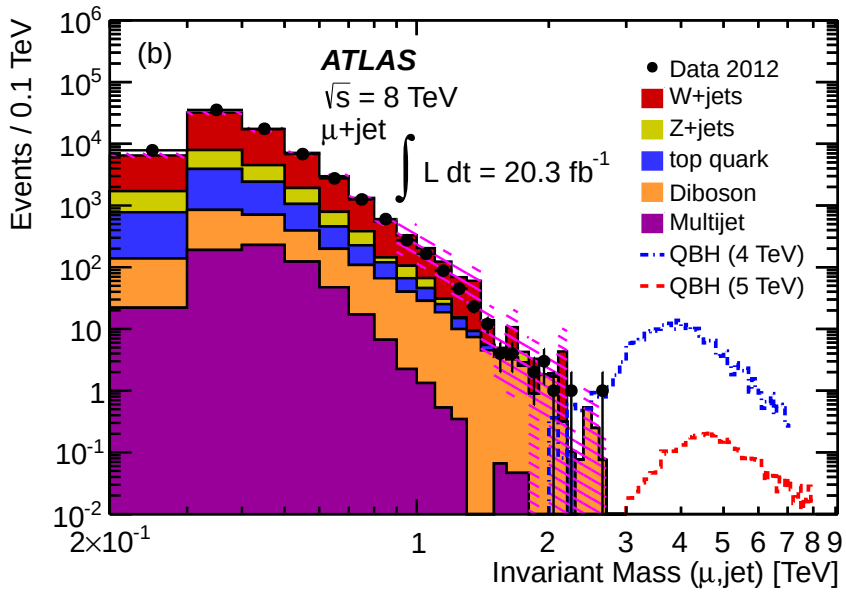


Lepton+Jet

- Models: QBH (ADD)
- Signature: l+j (l=e,μ)
  - e/μ: $|\eta| < 2.4$; $p_T > 130$ GeV
  - jet: $|\eta| < 2.5$; $p_T > 130$ GeV
- Spectrum: inv. lepton-jet mass

- Backgrounds:
  - Vector boson+jet (MC)
  - Diboson (MC)
  - $t\bar{t}$ and single t (MC)
  - Multijet (data-driven)



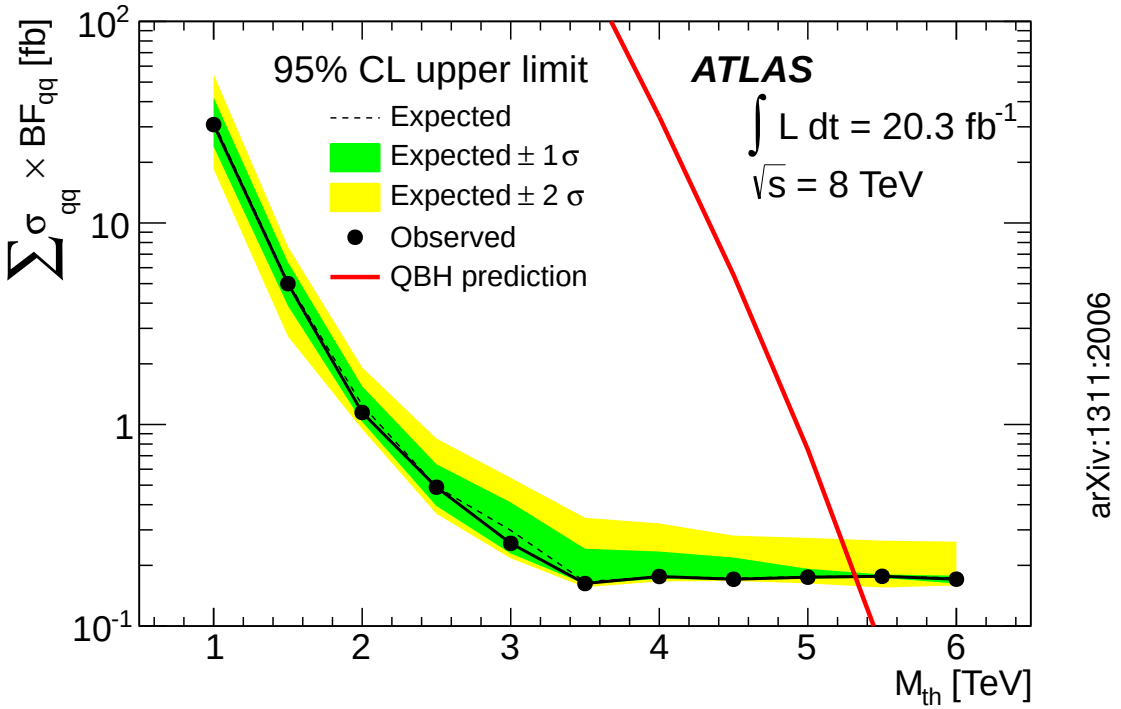


arXiv:1311.2006

Lepton+Jet

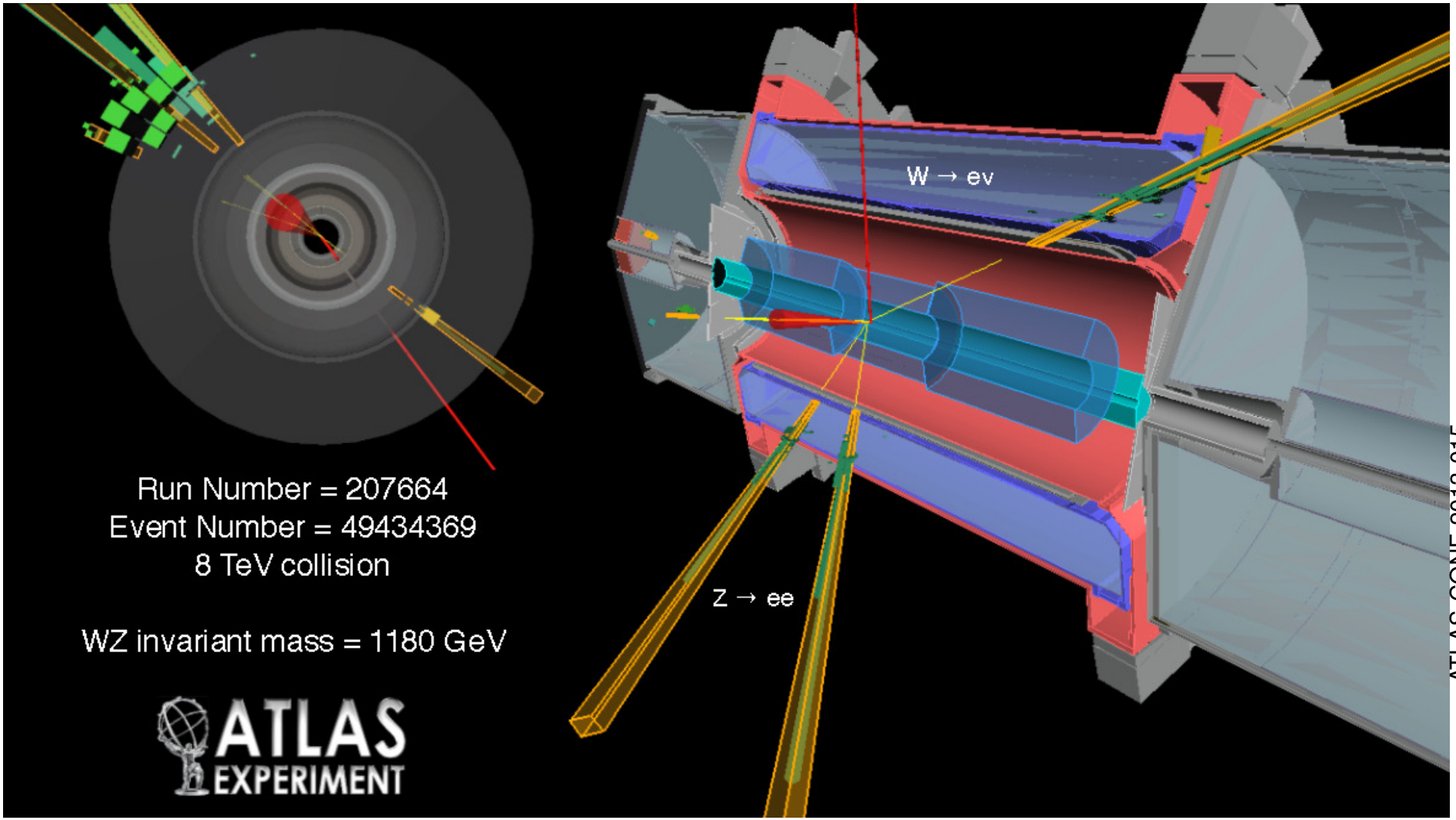
- Systematics(dominant):
  - Extrapolation of background
  - PDF
- Assumptions: n=6, $M_{\text{th}} = M_D$
- 95% CL limits

- Limit on $\sigma \cdot$ BF:
  0.18 fb above 3.5 TeV
- Limit on QBH mass:
  $m > 5.3$ TeV



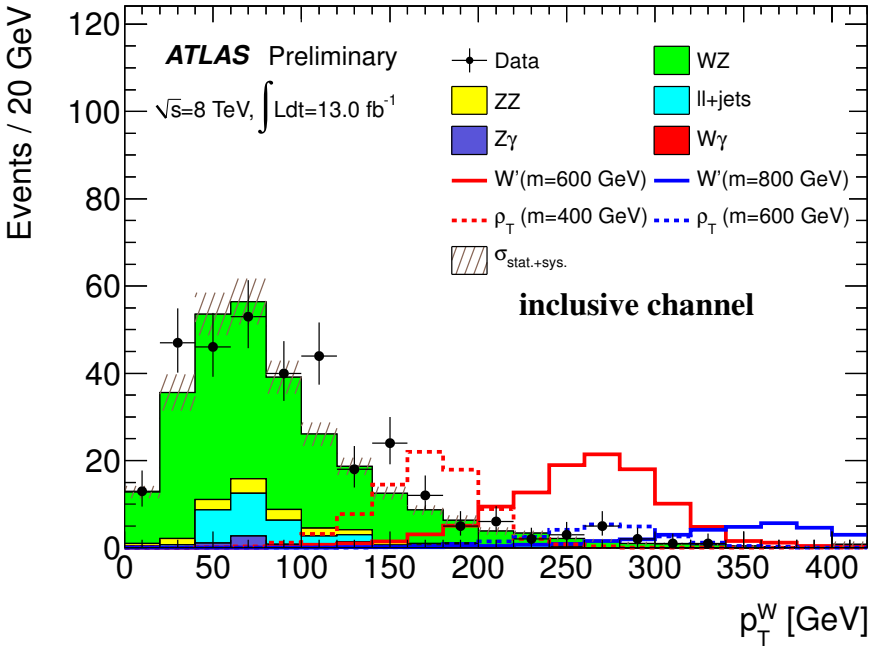
High mass WZ event

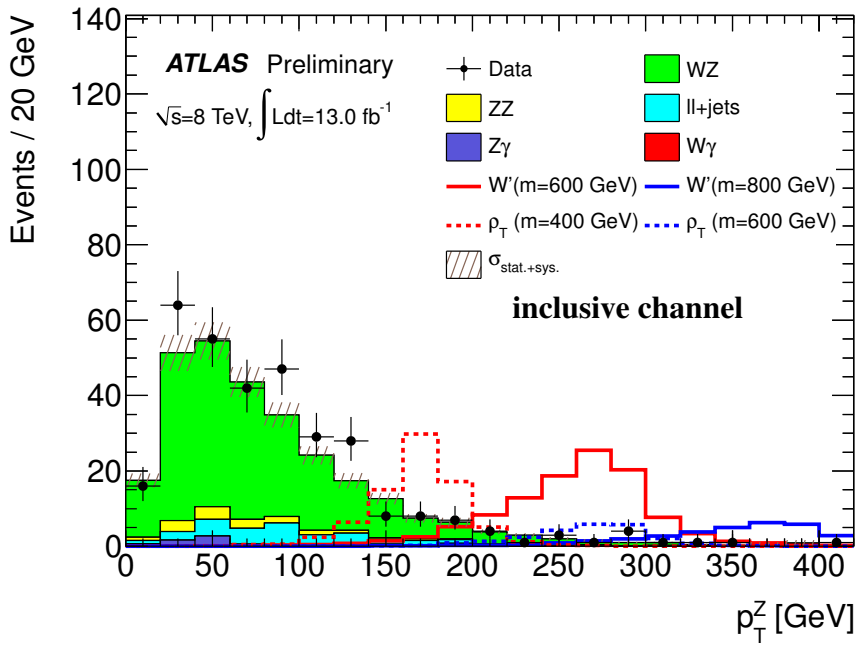
$m_{WZ} = 1.2\,\text{TeV}$



Diboson(WZ-channel)

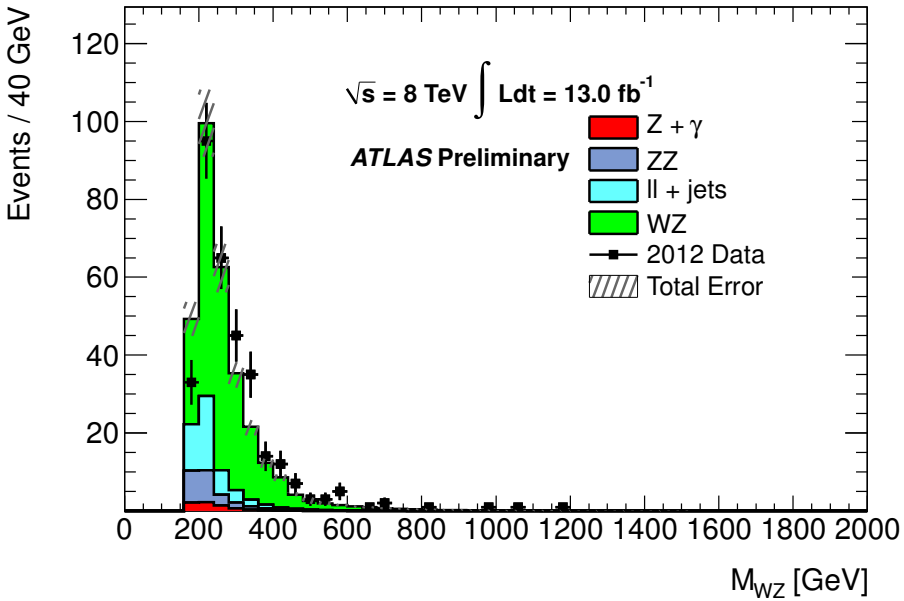
- Models: W'(extended gauge model),technimesons(LSTC)
- Signature: lνl'l' (l,l'=e,μ)
  - l'l': same flavour opposite sign
  - l'l' mass within 20 GeV to Z
  - e: $|\eta| < 2.47$; $p_T > 25$ GeV
  - μ: $|\eta| < 2.4$; $p_T > 25$ GeV
- Spectrum: mass of WZ system
- Divided in four channels: eνee, $\mu\nu ee$, e$\nu\mu\mu$, $\mu\nu\mu\mu$
- Backgrounds:
  - Diboson and Zγ(MC)
  - Z+jets, $t\bar{t}$ and Wt(data-driven)



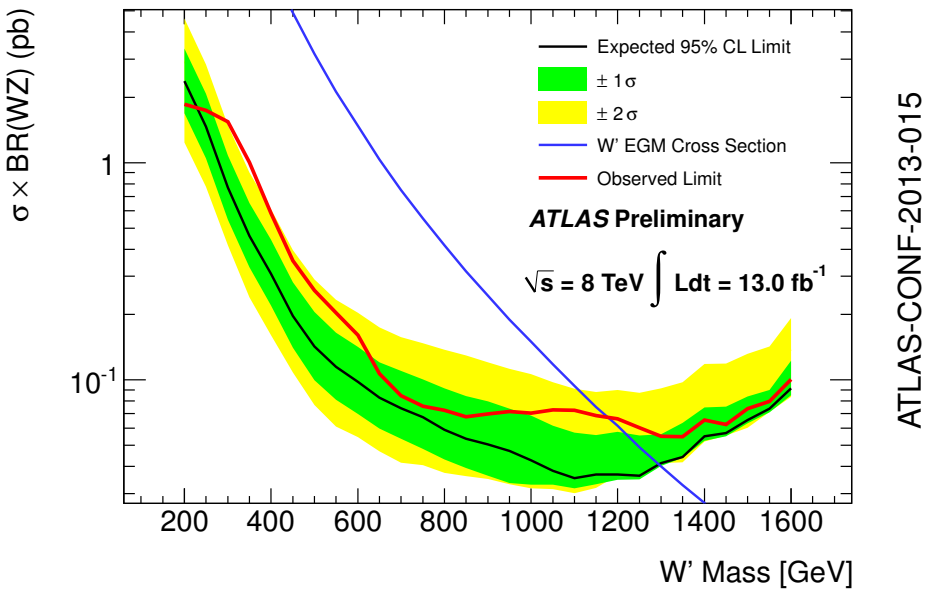


Diboson(WZ-channel)

- Systematics(dominant)
  - WZ sample (σ + higher-order)
- Method: frequentist log-likelihood ratio



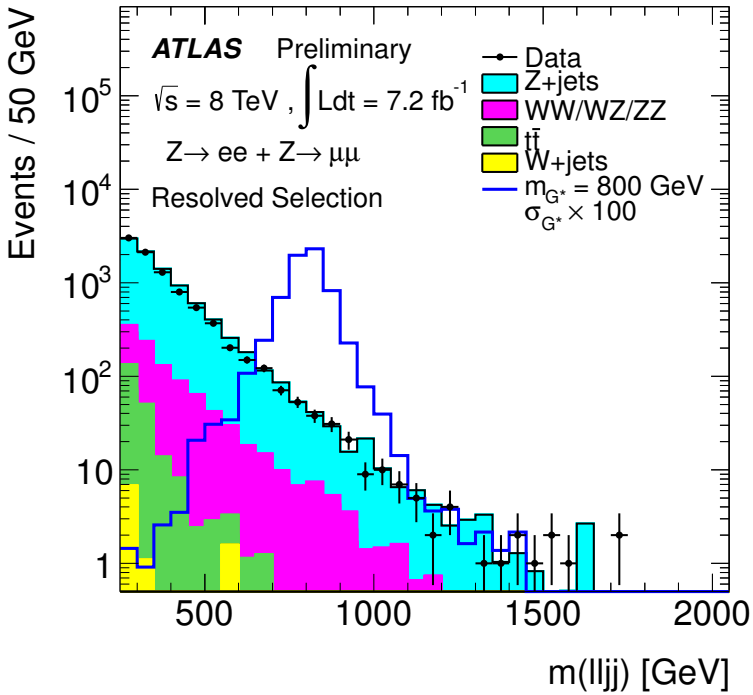
- Using signal templates from crystal ball fit
- Limit(95% CL): $m_{W'}$>1180/1300 GeV (obs/exp)

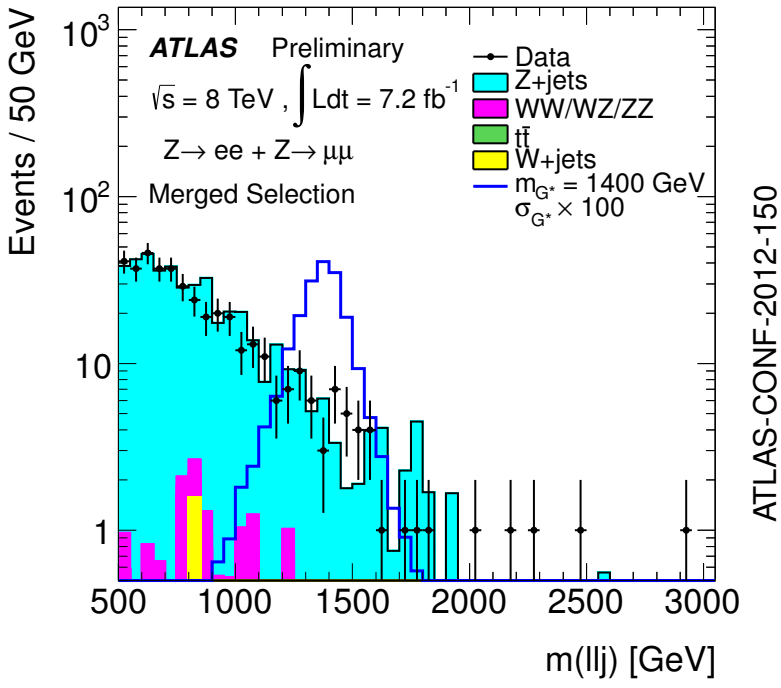


Diboson(ZZ-channel)

- Models: G* (RS bulk)
- Signature: lljj/llJ (l=e,μ)
  - e: $|\eta|$<2.47; E_T> 25 GeV
  - μ: $|\eta|$<2.4; p_T> 25 GeV
- 66 GeV<m_{ll}<116 GeV

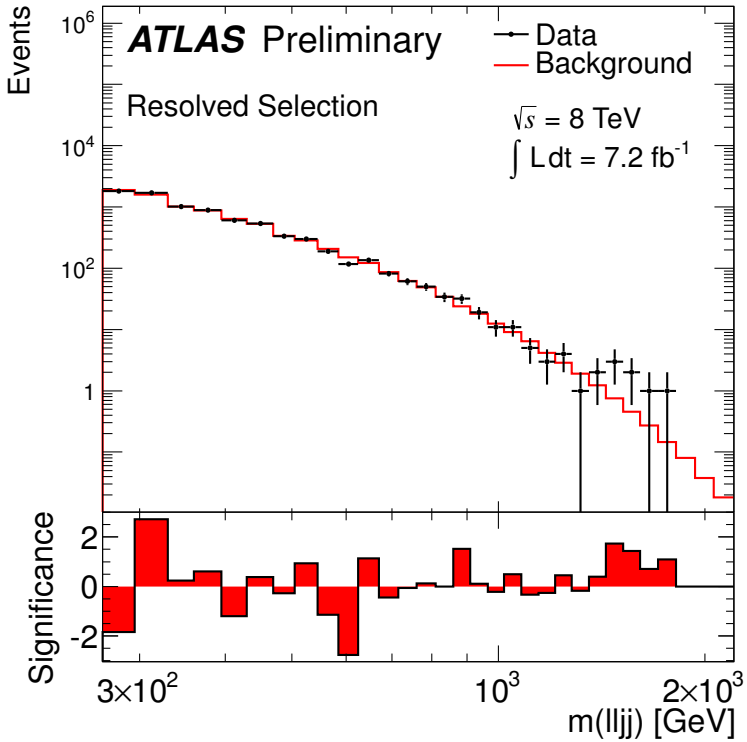
- Spectrum: mass of llqq system
- Consider merged dijet (high m_{jjl})
- Background: From fit to data
- $f(x) = p_0 \cdot \frac{(1-x)^{p_1}}{x^{p_2+p_3 ln(x)}}$ with $x = m/\sqrt{s}$



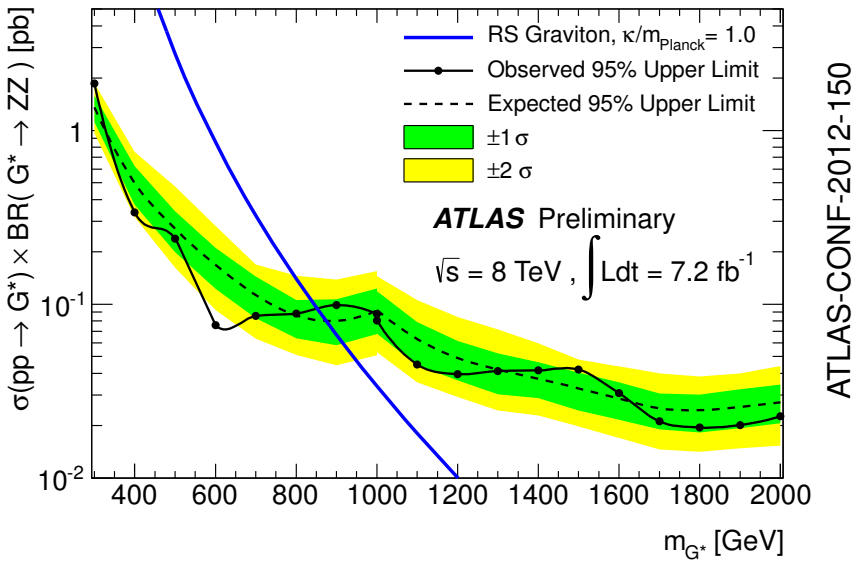


Diboson(ZZ-channel)

- Systematics(dominant):
  - Fit function
- Compare fit with data: *BumpHunter* algorithm
- 95% CL limit

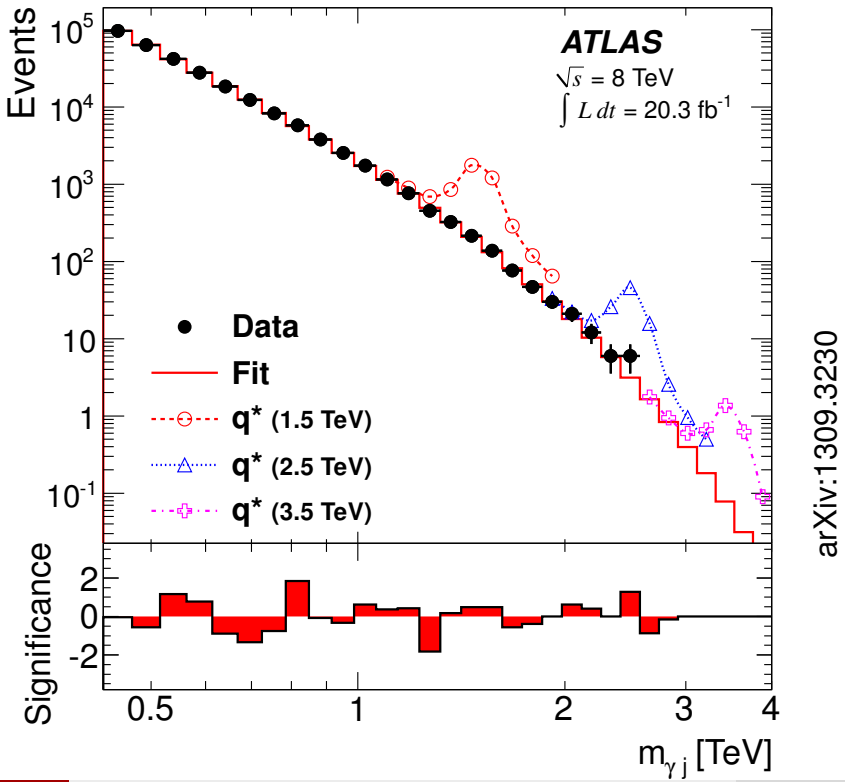


- Combine selections: m <1 TeV (resolved)+m >1 TeV (merged)
- Bayesian limit
- Assumptions: $\kappa/M_{\mathrm{Pl}} = 1.0$
- m>850/870 GeV (obs/exp)



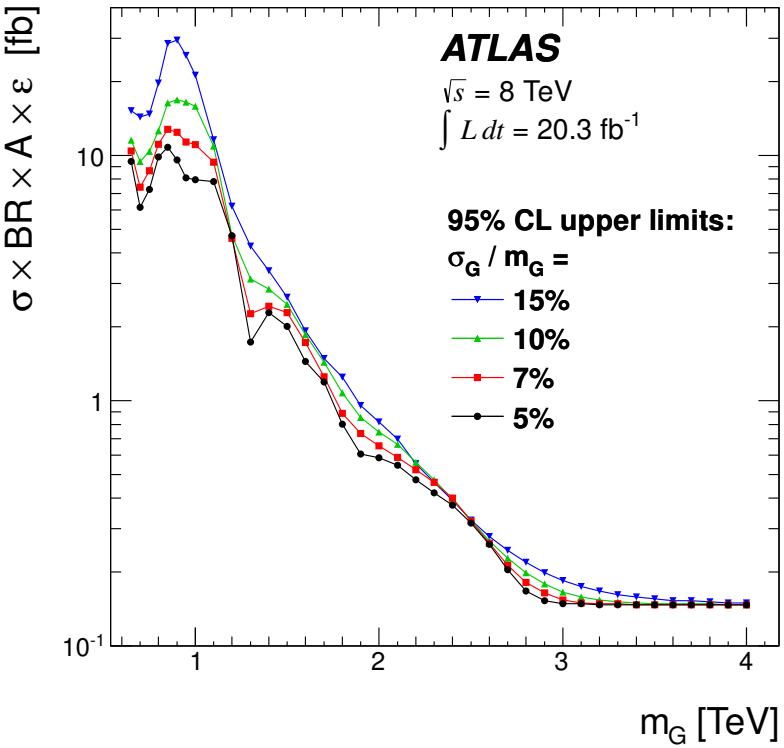
Photon+Jet

- Models: q*,QBH,generic Gaussian resonances
- Signature: γ+jet
  - γ: $|\eta| < 1.37$; $p_T > 125\,\text{GeV}$
  - jet: $|\eta| < 2.8$; $p_T > 125\,\text{GeV}$
- Supress Background: $|\eta_\gamma - \eta_j| < 1.6$
- Background: Fit to data ($f(x)$)
- Search for deviations: *BumpHunter* algorithm

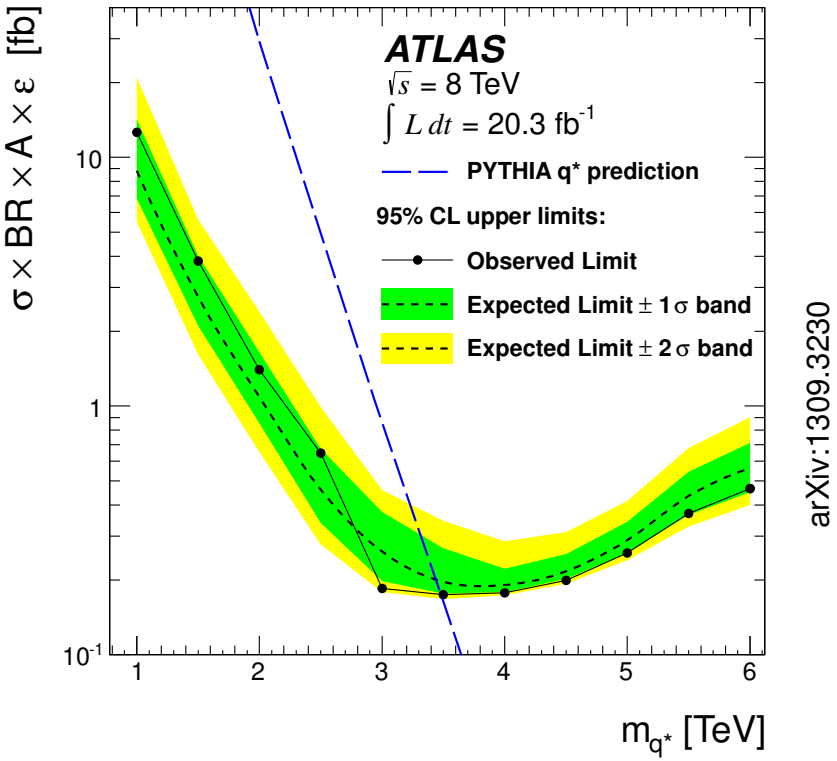


Photon+Jet

- Main Systematics:
  - Fit function
- Limit on generic Gaussian shaped signal

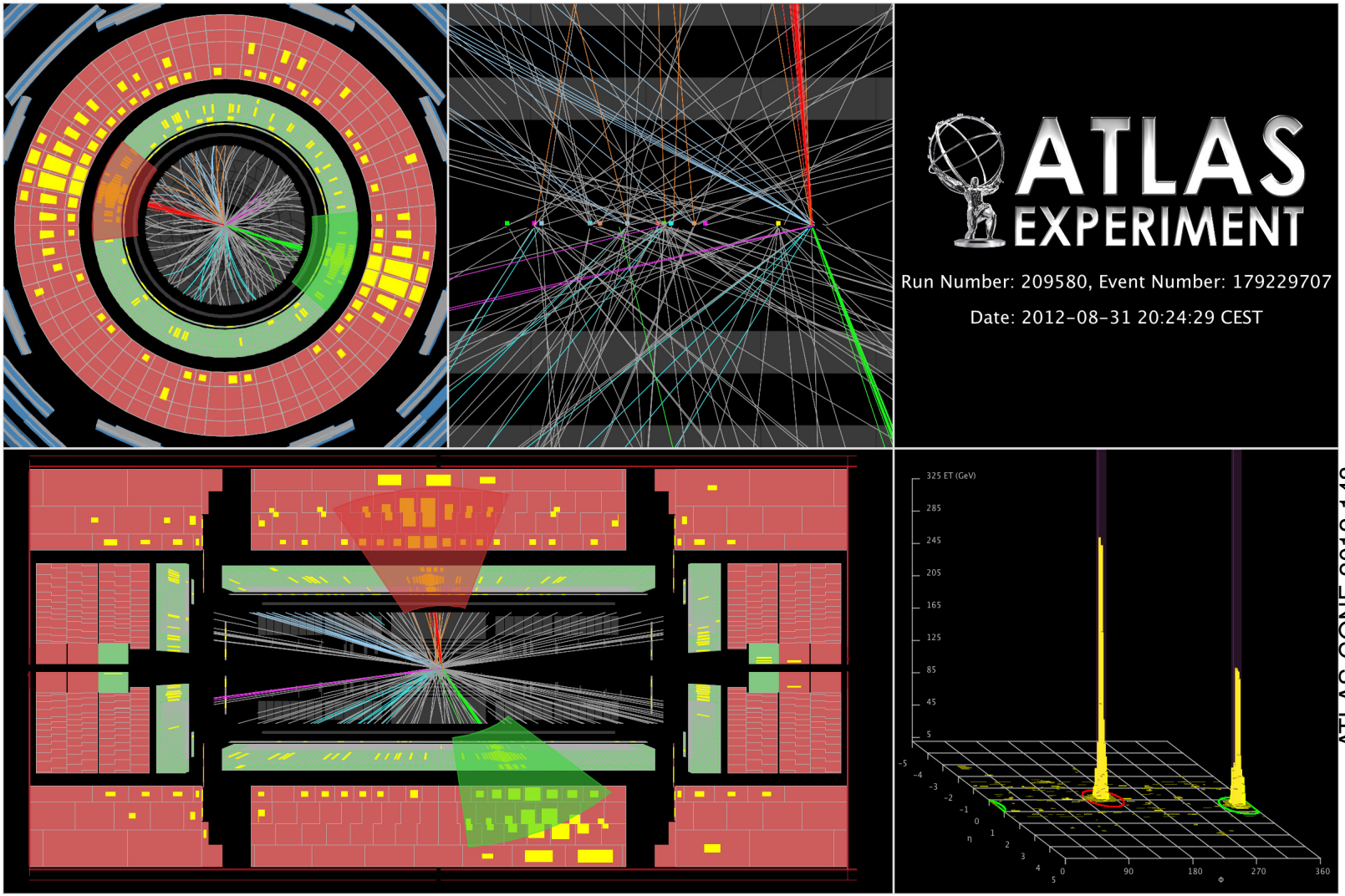


- 95% CL limits:
- m_{QBH}>4.6/4.6 TeV (obs/exp)
- m_{q^*}>3.5/3.4 TeV (obs/exp)



High mass dijet event

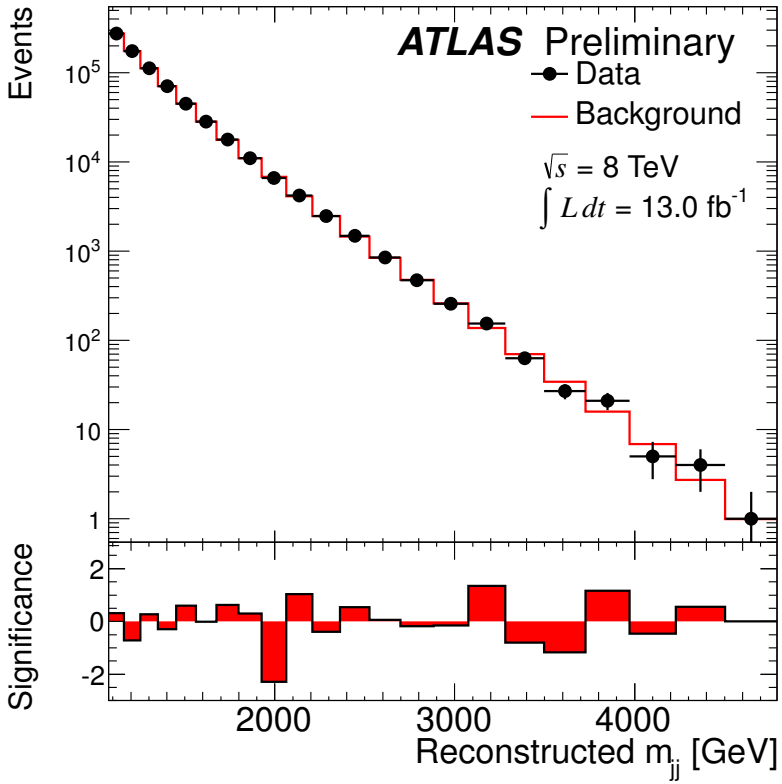
$m_{jj} = 4.7\,\text{TeV}$, p_T=2.3/2.2 TeV

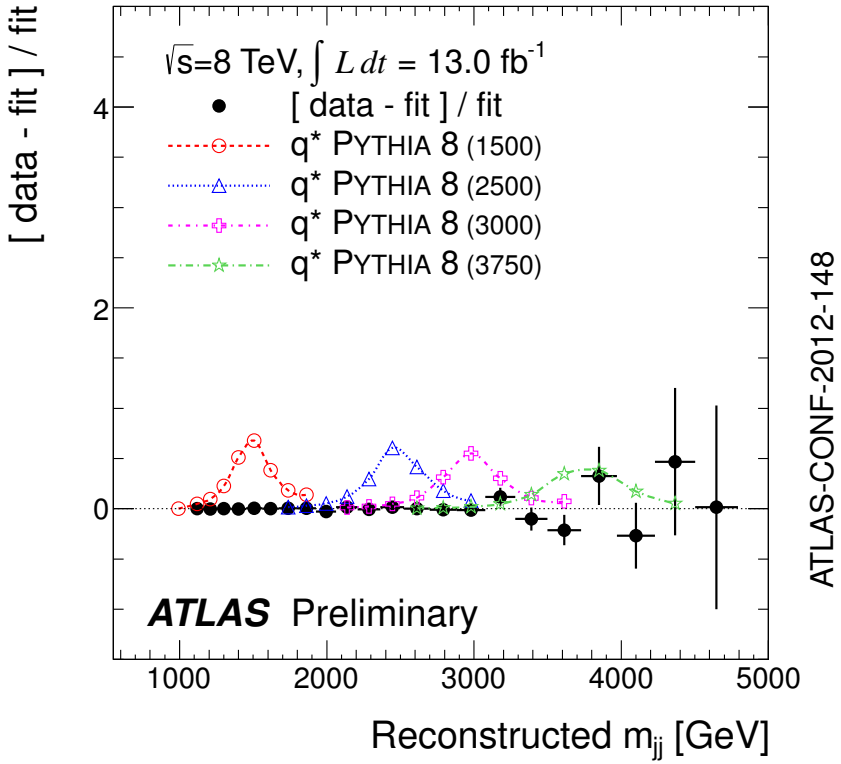


Dijet

- Models: q*
- Signature: jet+jet
  - invariant mass: $m_{jj} > 1$ TeV
  - jet: $|\eta| < 2.8$

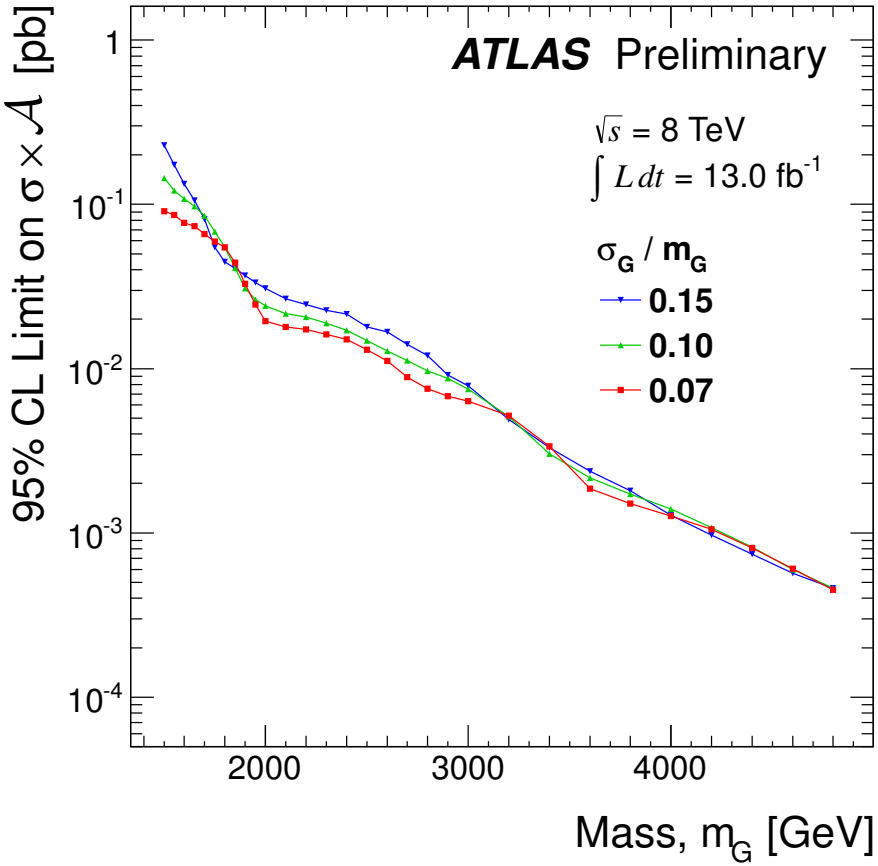
- Supress background: $|y_1 - y_2| < 1.2$
- Background: Fit to data
- Search for deviations: *BumpHunter* algorithm



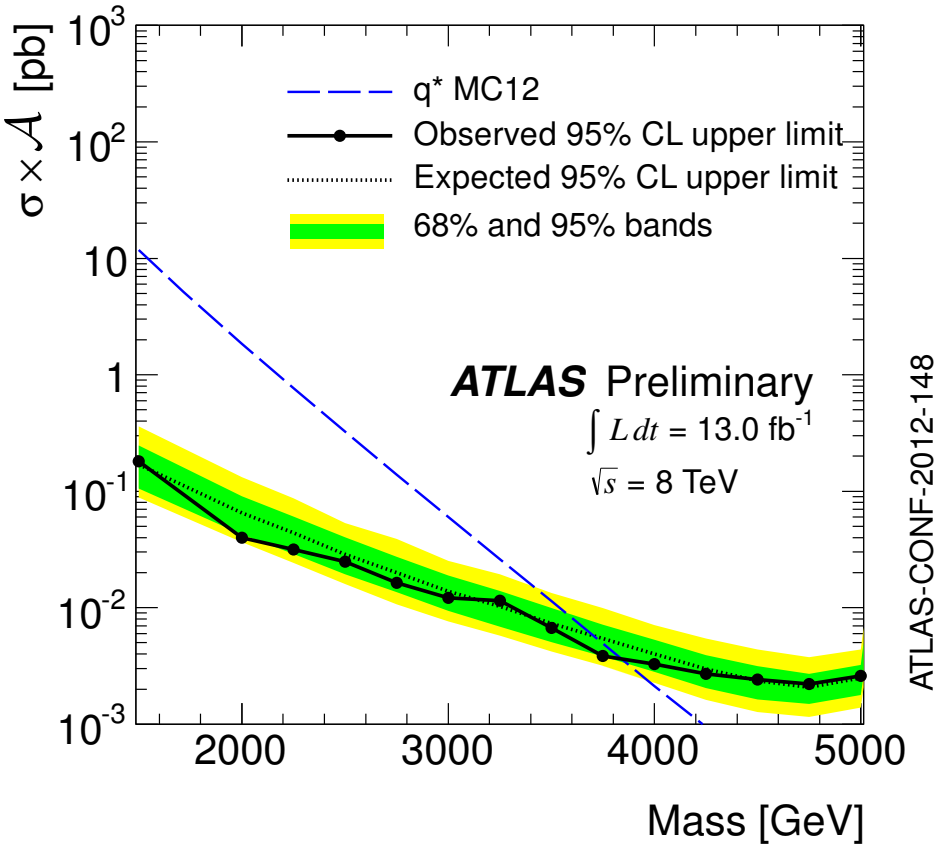


Dijet

- Systematics(dominant):
  - Jet energy scale
- 95% CL limit



- Limit on Gaussian shaped signals
- Limits (q*): m>3.84/3.70 TeV (obs/exp)



Summary

Search for heavy resonances in data recorded in 2012 at $\sqrt{s}$=8 TeV in five final states was presented:

- Dilepton
- Lepton+Jet
- Diboson (WZ,ZZ)
- Photon+Jet
- Dijet

No new physics was found, Upper limits have been improved

Improvement by up to 30% (wrt 7 TeV)
Now most limits in multi-TeV region

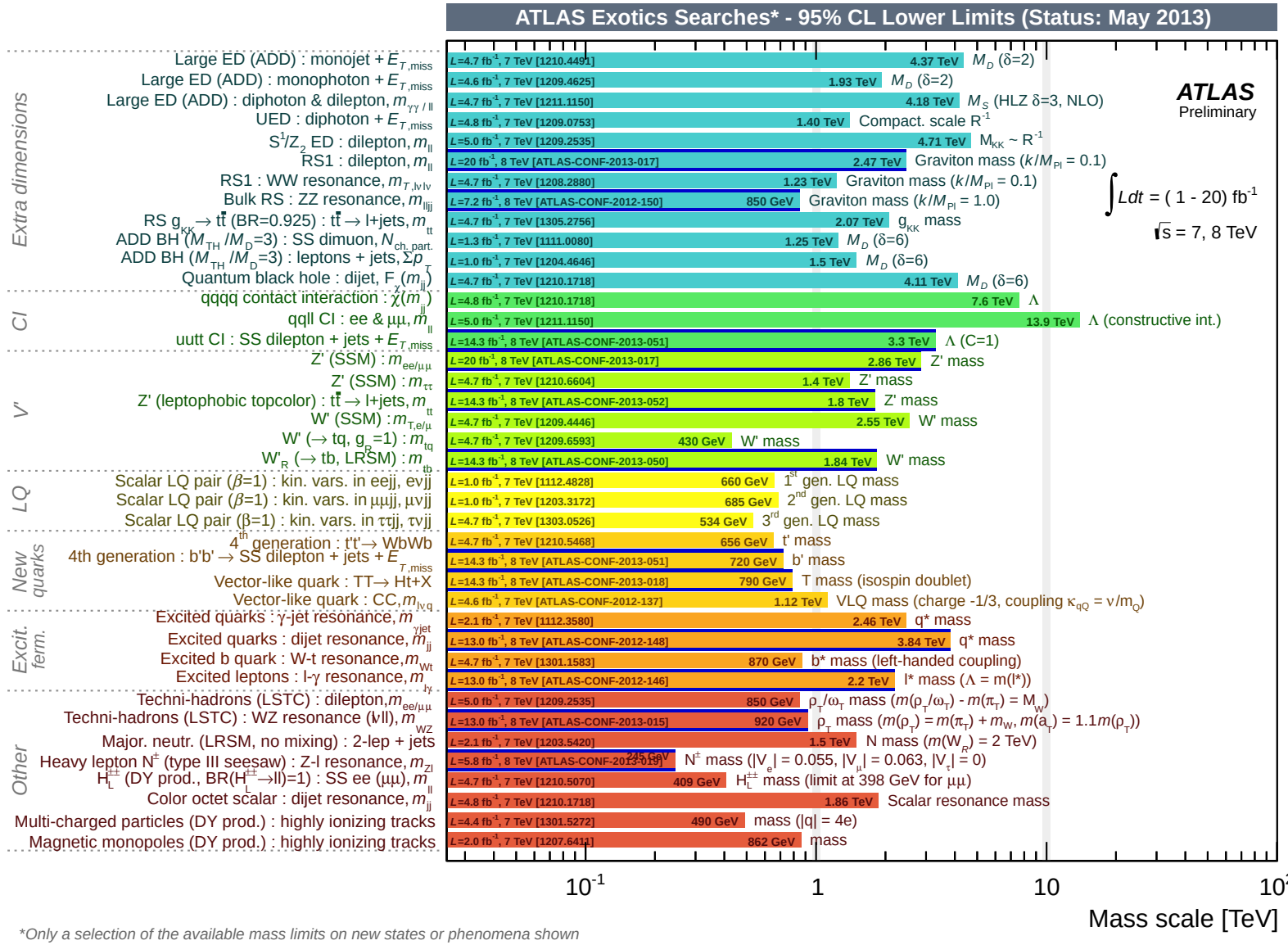
Overview

Signature	Luminosity	Reference
l^+l^-(l=e,μ) $\tau^+\tau^-$	20 fb^{-1}	**ATLAS-CONF-2013-017** **ATLAS-CONF-2013-066**
$l + jet$	20 fb^{-1}	**arXiv:1311:2006**
WZ	13 fb^{-1}	**ATLAS-CONF-2013-015**
ZZ	7.2 fb^{-1}	**ATLAS-CONF-2012-150**
γ+jet	20 fb^{-1}	**arxiv:1309.3230**
dijet	13 fb^{-1}	**ATLAS-CONF-2012-148**

Limits

Analysis	Model	obs. Limit [TeV]	exp. Limit [TeV]
ll (l=e,μ)	Z'	2.86	2.85
	G*	2.47	2.47
$\tau\tau$	Z'	1.90	1.80
WZ	W'	1.18	1.30
ZZ	G*	0.85	0.87
γ+jet	q*	3.5	3.4
	QBH	4.6	4.6
dijet	q*	3.84	3.70

All Limits



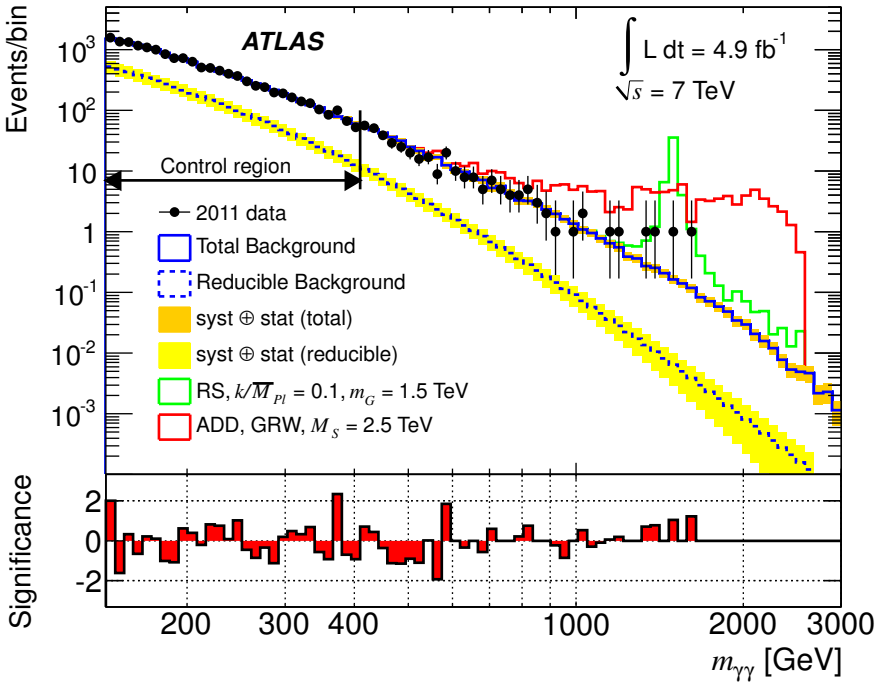
*Only a selection of the available mass limits on new states or phenomena shown

Obs. Limit evolution

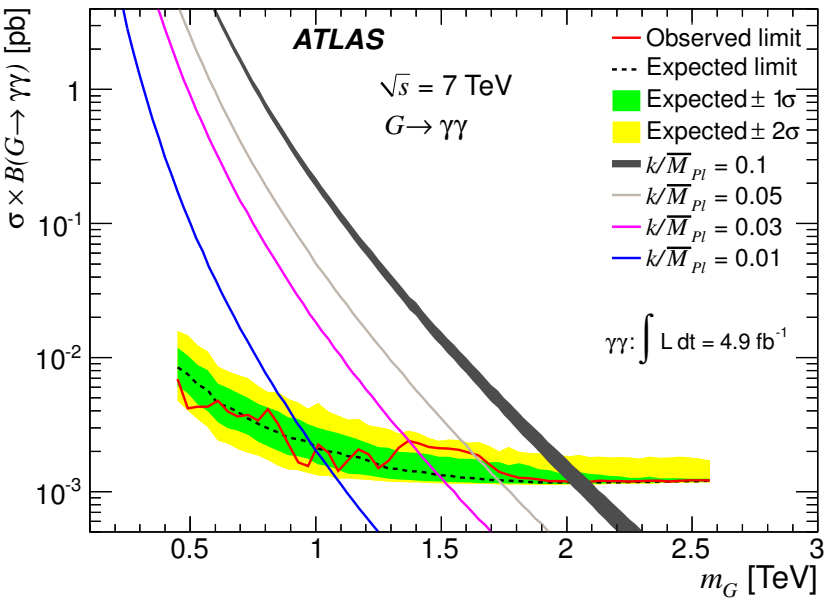
Analysis	Model	Limit 2011 [TeV]	Limit 2012 [TeV]
ll (l=e,μ)	Z'	2.22	2.86
	G*	2.16	2.47
$\tau\tau$	Z'	1.40	1.90
WZ	W'	0.76	1.18
ZZ	G*(RS1)	0.85	
	G*(bulk RS)		0.85
γ+jet	q*	2.46	3.5
dijet	q*	2.83	3.84

Diphoton

- Search with $\sqrt{s} = 7\,\text{TeV}$
- Model: G (RS), M_S-scale (ADD)
- Signature: 2 photons:
  - γ: $|\eta| < 2.37$, $p_T > 25\,\text{GeV}$



- Use *BumpHunter*
- For κ/M_{Pl}
- Limits (G): m>2.06/2.05 TeV (obs/exp)



arXiv:1210.8389

Systematics Dilepton (e/μ)

Table 3: Summary of systematic uncertainties on the expected numbers of events at $m_{\ell\ell} = 2$ TeV. NA indicates that the uncertainty is not applicable, and "-" denotes a negligible entry (i.e. $< 3\%$). Numbers in parentheses on the resolution and total uncertainty lines correspond to the loose dimuon selection.

Source	Dielectrons		Dimuons	
	Signal	Background	Signal	Background
Normalization	5%	NA	5%	NA
PDF variation	NA	15%	NA	15%
PDF choice	NA	17%	NA	17%
Scale	NA	-	NA	-
α_s	NA	4%	NA	4%
Electroweak corrections	NA	3%	NA	3%
Photon-induced corrections	NA	4%	NA	4%
Efficiency	-	-	6%	6%
Resolution	-	-	-	3% (7%)
W + jet and multi-jet background	NA	9%	NA	-
Diboson and ttbar extrapolation	NA	5%	NA	4%
Total	5%	26%	8%	25% (26%)

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Systematics Dilepton (τ)

	$Z/\gamma^* \to \tau\tau$	Multijet	W/Z+jets	Diboson	SM total	$Z'_{\mathrm{SSM}}(1750)$
Expected Events	0.99 ± 0.02	0.17 ± 0.09	0.18 ± 0.03	0.02 ± 0.02	1.36 ± 0.10	5.58 ± 0.14
Theory Cross Section [%]	$^{+9}_{-6}$	–	± 28	± 13	$^{+7}_{-6}$	–
Luminosity [%]	± 2.8	–	± 2.8	± 2.8	± 2.5	± 2.8
Tau trigger [%]	± 10	–	< 1	–	± 7	± 10
Tau ID [%]	± 13	–	± 5	± 5	± 10	± 13
Tau 3-prong [%]	± 4	–	< 1	–	± 3	± 4
Jet-to-tau fake-rate [%]	< 1	–	± 61	± 60	± 9	< 1
Tau energy scale [%]	± 12	–	± 5	–	± 9	± 2
Jet energy scale [%]	< 1	–	$^{+1}_{-5}$	–	< 1	< 1
$E_{\mathrm{T}}^{\mathrm{miss}}$ [%]	< 1	–	$^{-3}_{+0.2}$	–	< 1	< 1
Multijet fake-factor [%]	–	± 58	–	–	± 7	–

Table 2: Summary of the total number of expected events (with statistical uncertainty) and the systematic uncertainties for $m_{Z'} = 1750$ GeV. The systematic uncertainties are listed in %. Entries marked with – are either non-applicable or evaluate to exactly zero. The W/Z+jets contribution includes all W/Z decays to leptons except $Z \to \tau\tau$. The contribution from top-quark production is negligible. As the contribution to the SM total uncertainty from each sample is weighted by the expected events, the relative SM total uncertainty can be lower than the relative uncertainty from an individual contribution.

ATLAS-CONF-2013-066

Systematics lepton+jet

Source	Electron+jet %	Muon+jet %
Lepton reconstruction, scale and resolution	$^{+2}_{-1}$	$^{+30}_{-7}$
Jet reconstruction, scale and resolution	$^{+31}_{-15}$	$^{+5}_{-5}$
Multijet modeling	$^{+27}_{-27}$	-
PDF	$^{+52}_{-33}$	$^{+100}_{-69}$
Fit	$^{+77}_{-77}$	$^{+130}_{-71}$
Total	$^{+100}_{-89}$	$^{+170}_{-100}$

arXiv:1311:2006

Systematics WZ

Cutflow	$evee$ channel	μvee channel	$ev\mu\mu$ channel	$\mu v\mu\mu$ channel
MC Statistics	3.1	2.7	2.3	2.0
Luminosity	3.6	3.6	3.6	3.6
Electron trigger	< 0.1	< 0.1	< 0.1	N/A
Muon trigger	N/A	< 0.1	< 0.1	0.2
Electron ID/reconstruction	3.5	2.3	1.2	N/A
Electron energy scale/resolution	1.1	1.1	0.5	N/A
Electron isolation	1.9	1.3	0.6	N/A
Muon ID	N/A	0.3	0.6	0.9
Muon momentum scale/resolution	N/A	0.1	0.2	0.3
Muon isolation	N/A	0.3	0.6	0.9
Jet energy scale/resolution	1.5	2.2	1.4	1.2
MET in-time and out-of-time pileup	1.3	0.9	1.6	1.3
Total (with statistical uncertainty)	6.6	5.9	5.1	4.7

Table 3: Experimental systematic uncertainties (in %) for the SM WZ process.

ATLAS-CONF-2013-015

Systematics ZZ

Source	rel. uncertainty
Background fit	5-40%
Lepton trigger efficiency	1%
Electron reconstruction/identification efficiency	2%
Muon reconstruction efficiency	<1%
Electron energy scale/resolution	1%
Muon momentum scale/resolution	<1%
JES	1-3%
JER	1-2%
JMS	1-5%
PDF	2%
ISR/FSR	10%
Luminosity	3.6%

ATLAS-CONF-2012-150

Systematics Photon+jet

Source	rel. uncertainty
Luminosity	2.8%
Photon isolation efficiency	1.2%
Trigger efficiency	0.5%
Photon identification efficiency	1.5%
Jet energy scale	1.0-1.5%
Photon energy scale	0.3%
Background fit	1-20%

arXiv:1309.3230

Systematics dijet

Source	rel. uncertainty
Jet energy scale	4%
Luminosity	3.6%
Fit function	
JER	neglible

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