Searches for new resonances decaying into bosons with the ATLAS detector

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On behalf of the ATLAS collaboration
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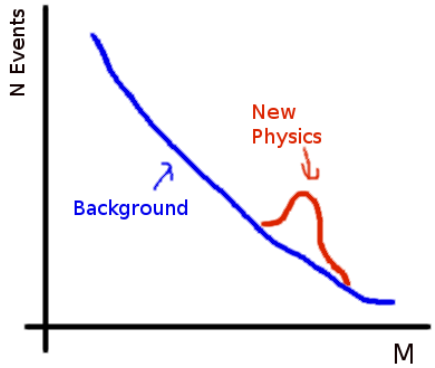
Introduction

- Benchmark models:
  - Spin 0: Extended Higgs sector
  - Spin 1: Heavy Vector Triplets (HVT)
  - Spin 2: Randall-Sundrum Graviton (RSG)

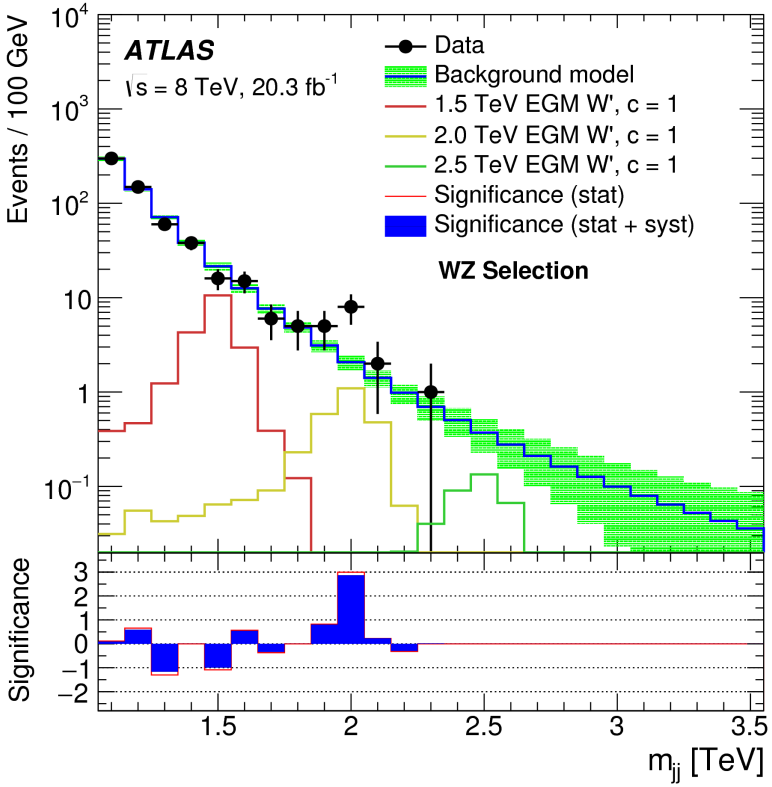
- Search for heavy resonances decaying to pair of bosons
  - VV$\rightarrow$qqqq [1]
  - VV$\rightarrow \nu\nu$qq [2], VV$\rightarrow \ell\nu$qq [3], VV$\rightarrow \ell\ell$qq [4]
  - VV combination [5]
  - VH$\rightarrow \nu\nu$bb, $\ell\nu$bb, $\ell\ell$bb [6]
  - hh$\rightarrow$bbbb[7]
  - Zγ[8]

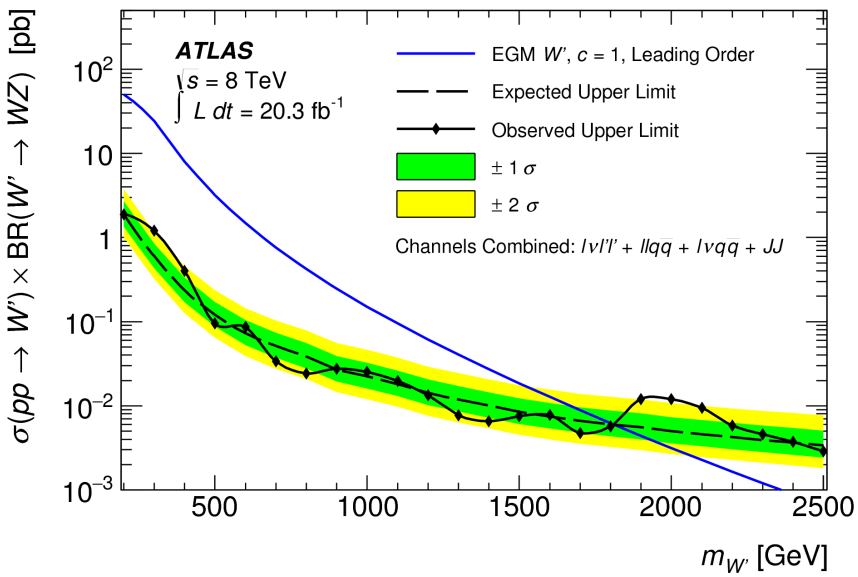


- Will focus on diboson resonance searches sensitive to high mass
  - Results with sensitivity also to lower masses available ([9], [10])

Introduction

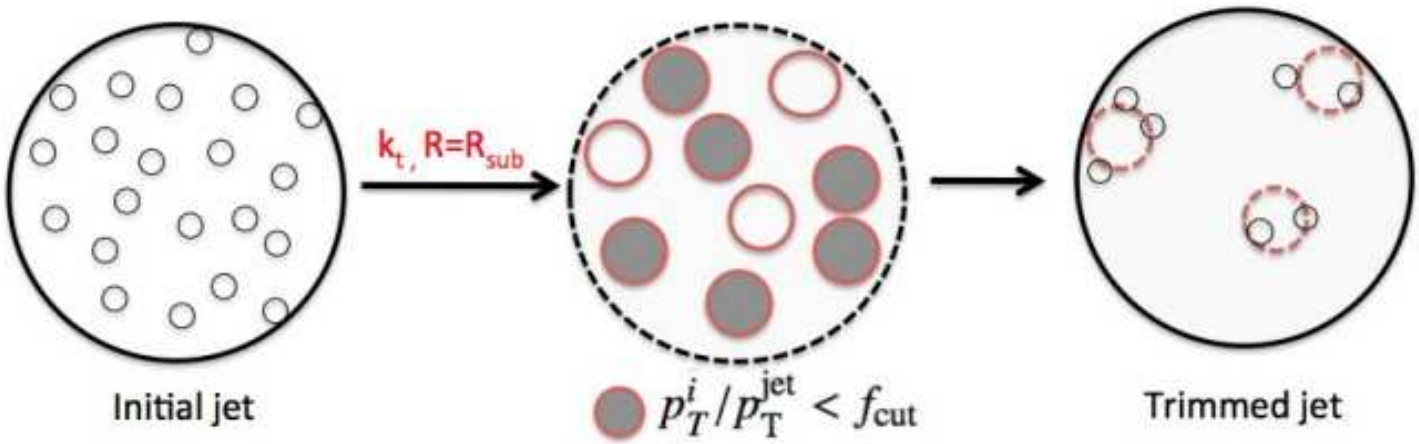
- Some interesting results from Run 1





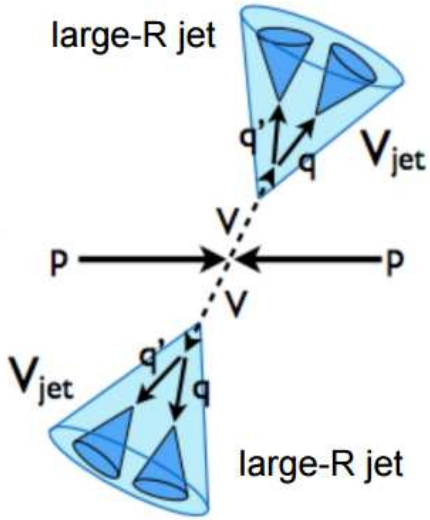
Boosted Boson Tagging

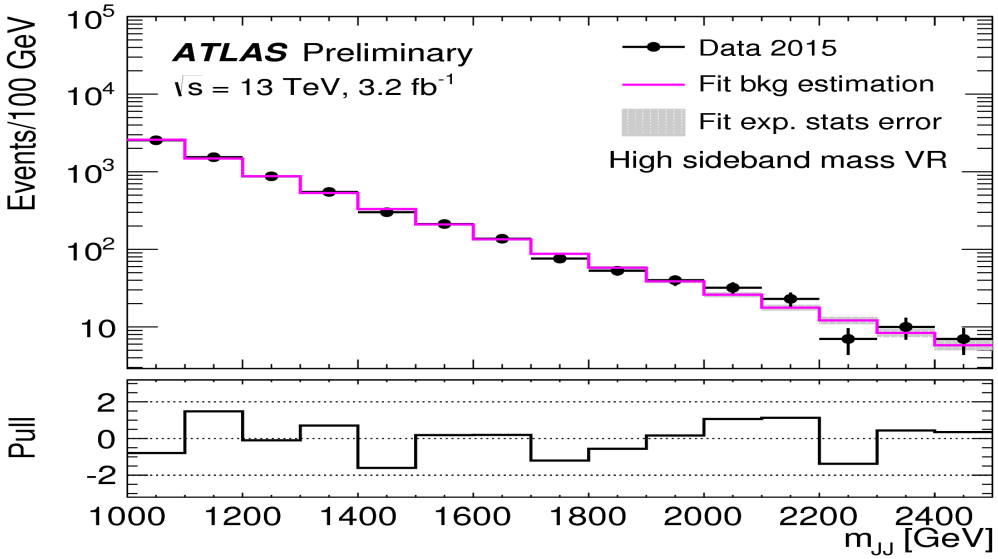
- Boosted topology requires identification of boosted hadronic boson decays
- Look for large-R jets (anti-kT R=1.0)
  - Use jet grooming techniques to remove contributions from pile up and soft QCD
  - Exploit jet mass and substructure (D_2) to identify W/Z/H bosons



VV→JJ

- Look for two large-R jets (anti-kT R=1.0), boson tagged, $p_T^{J1(2)}$ >450 (200) GeV
- N tracks associated with jet < 30
- $|y_{J1} - y_{J2}| < 1.2$, $\frac{p_T^{J1} - p_T^{J2}}{p_T^{J1} + p_T^{J2}} < 0.15$
- Background dijet events modelled with a power law function; validated in MC and data control regions.

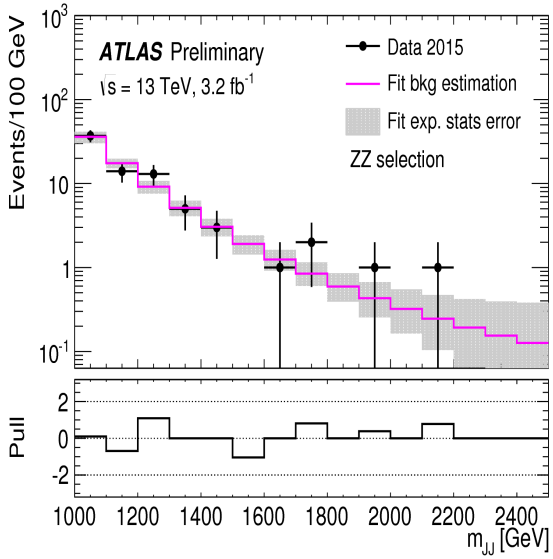


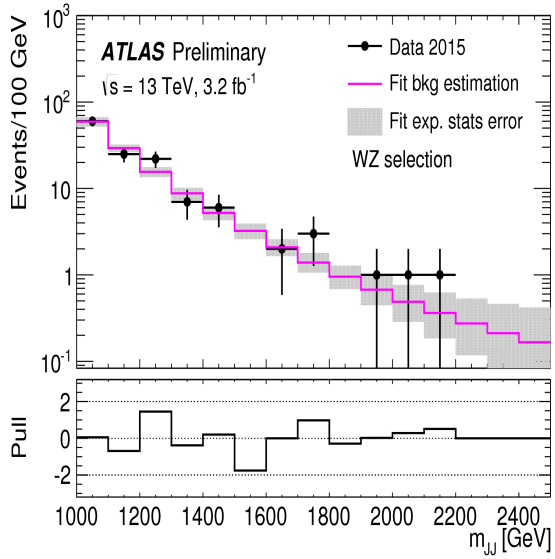


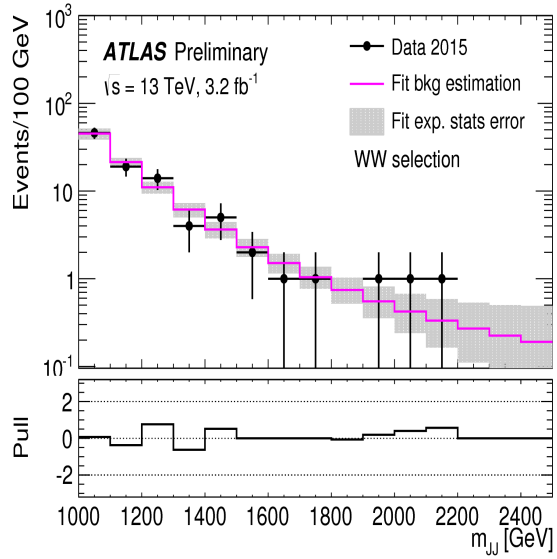
$$\frac{dn}{dx} = p_1(1-x)^{p_2+\xi p_3} x^{p_3}$$

$$x = m_{JJ}/\sqrt{s}$$

VV→JJ


ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
Data 2015
Fit bkg estimation
Fit exp. stats error
ZZ selection
Events/100 GeV
Pull
mJJ [GeV]


ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
Data 2015
Fit bkg estimation
Fit exp. stats error
WZ selection
Events/100 GeV
Pull
mJJ [GeV]


ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
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Fit bkg estimation
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WW selection
Events/100 GeV
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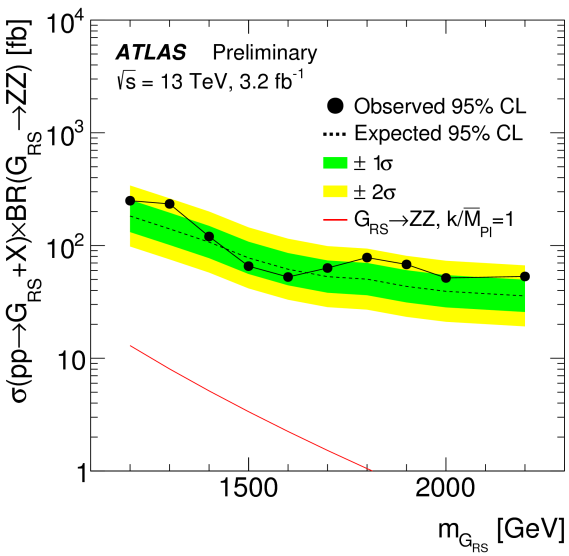
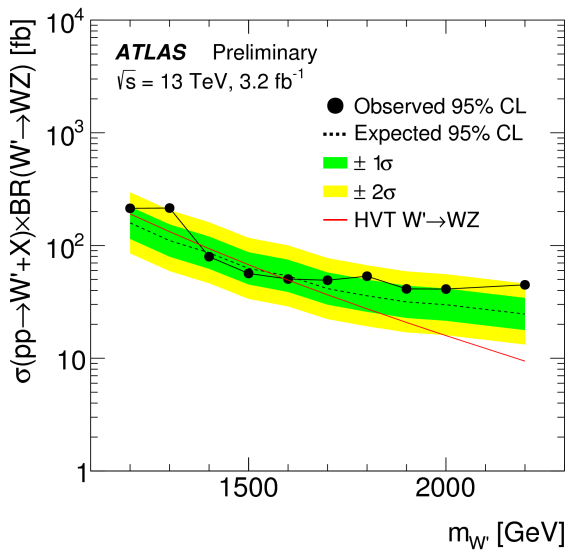
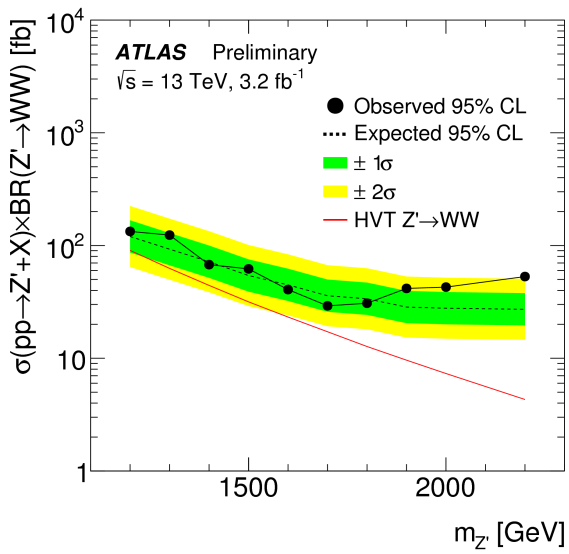
mJJ [GeV]

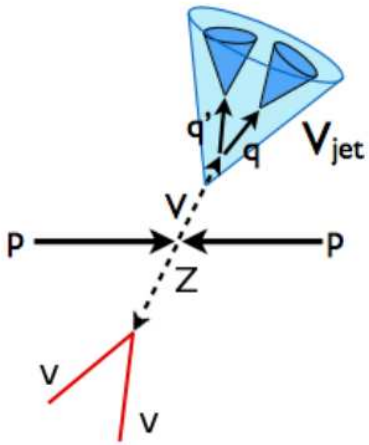

ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
Observed 95% CL
Expected 95% CL
± 1σ
± 2σ
GRS→ZZ, k/M̄Pl=1
σ(pp→GRS+X)×BR(GRS→ZZ) [fb]
mGRS [GeV]

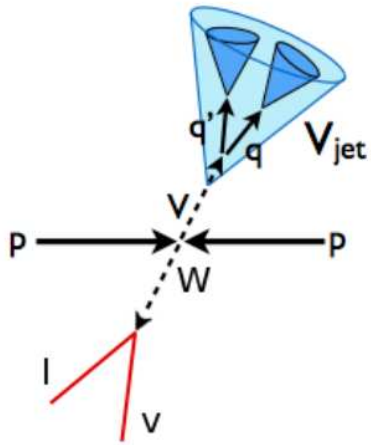

ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
Observed 95% CL
Expected 95% CL
± 1σ
± 2σ
HVT W'→WZ
σ(pp→W'+X)×BR(W'→WZ) [fb]
mW' [GeV]

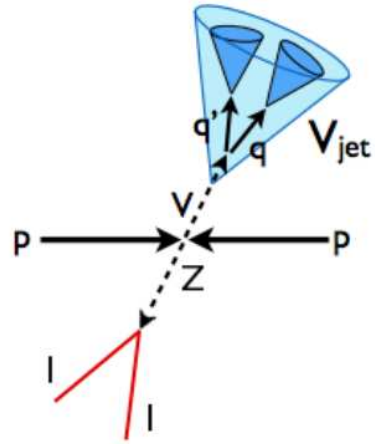

ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
Observed 95% CL
Expected 95% CL
± 1σ
± 2σ
HVT Z'→WW
σ(pp→Z'+X)×BR(Z'→WW) [fb]
mZ' [GeV]

VV→ $\nu\nu$J, $\ell\nu$J, $\ell\ell$J

- One V decays hadronically
  - Reconstructed as large-R jet, boson tagged, p_T^J >200 GeV
- Other V decays leptonically (either 0, 1, or 2 charged leptons)



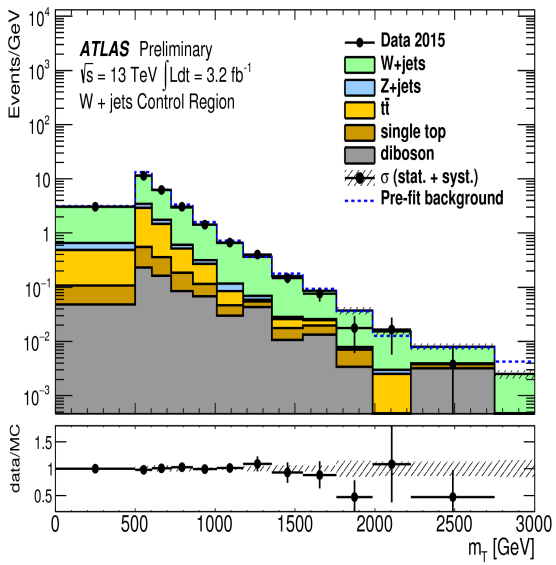


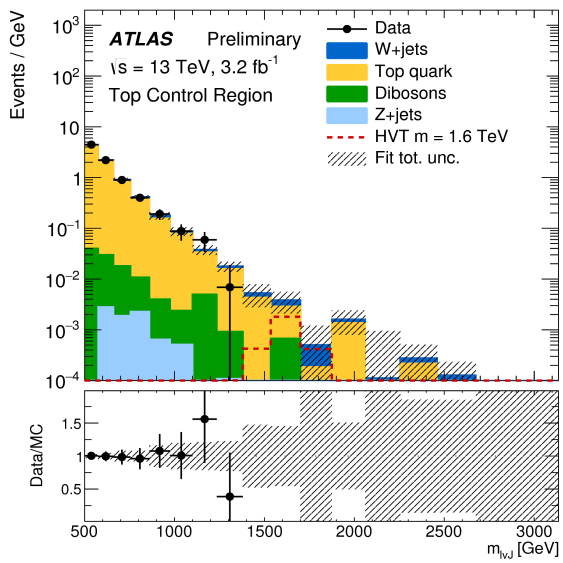


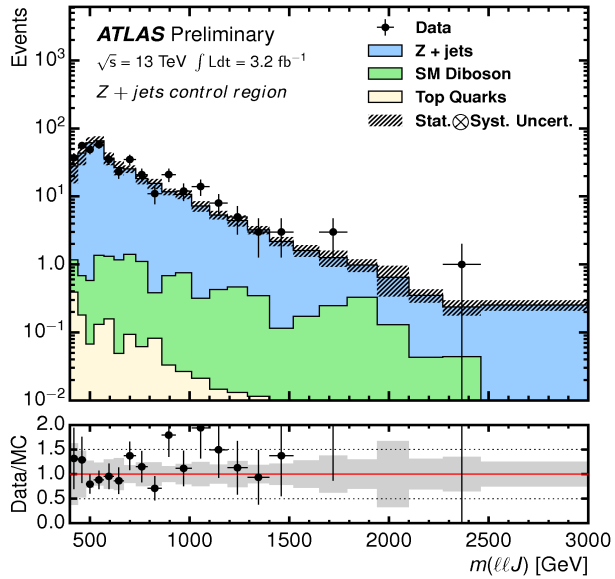
	$\nu\nu$qq	$\ell\nu$qq	$\ell\ell$qq
N_{lep}	0	1	2
E_T^{miss}	>250 GeV	>100 GeV	–
Topology	$\lvert\Delta\phi(E_T^{miss}, J)\rvert > 0.6$	$p_T^V/m_{\ell\nu J}$ >0.4	$p_T^V/m_{\ell\nu J}$ >0.4 $m_{\ell\ell} \sim m_Z$

VV→ $\nu\nu$J, $\ell\nu$J, $\ell\ell$J

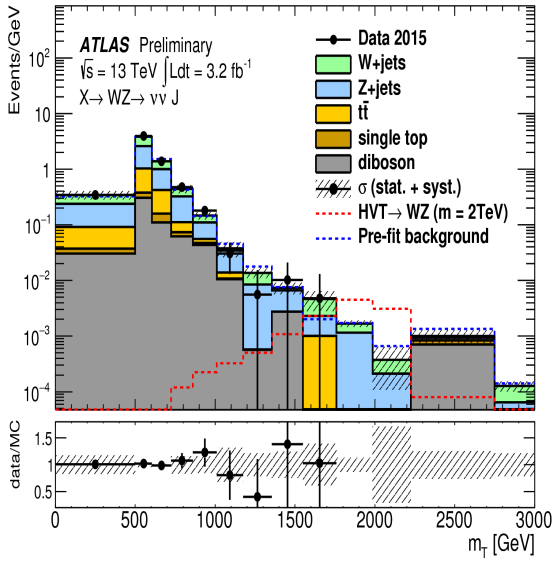
- Backgrounds estimated in MC and validated in control regions

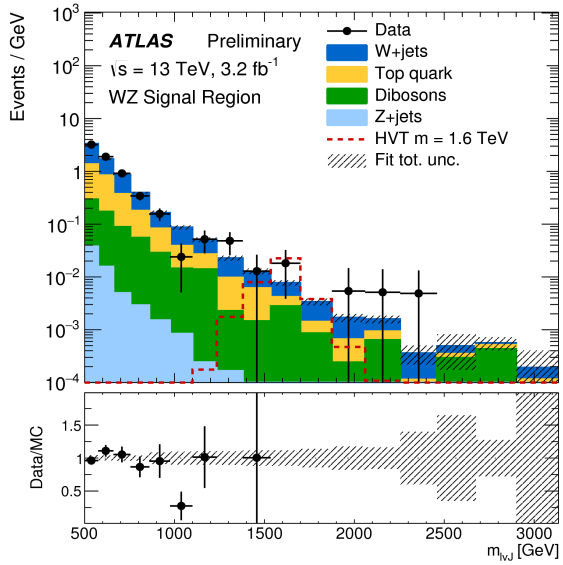


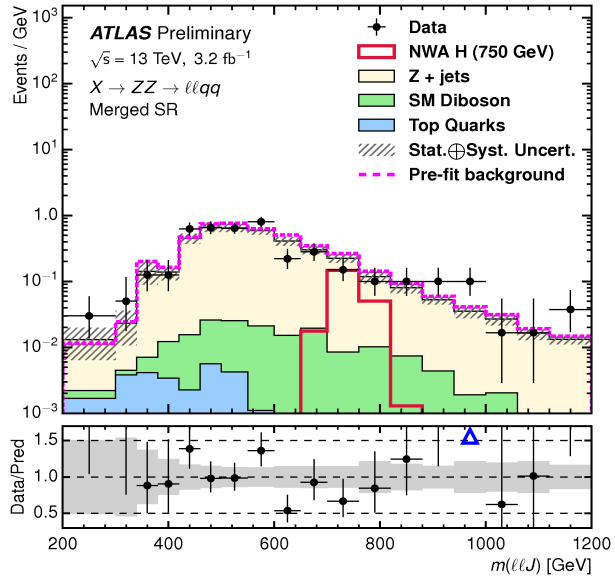


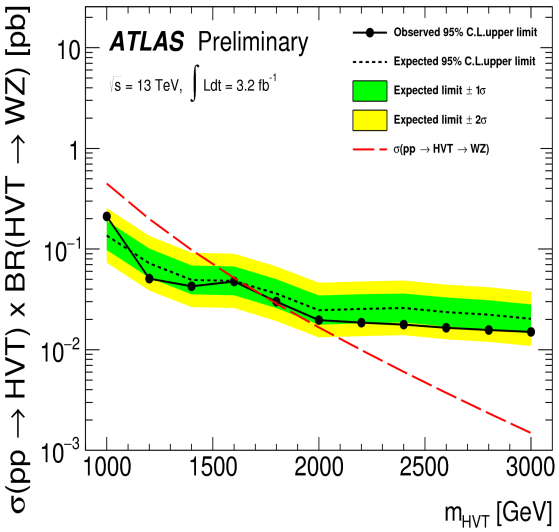


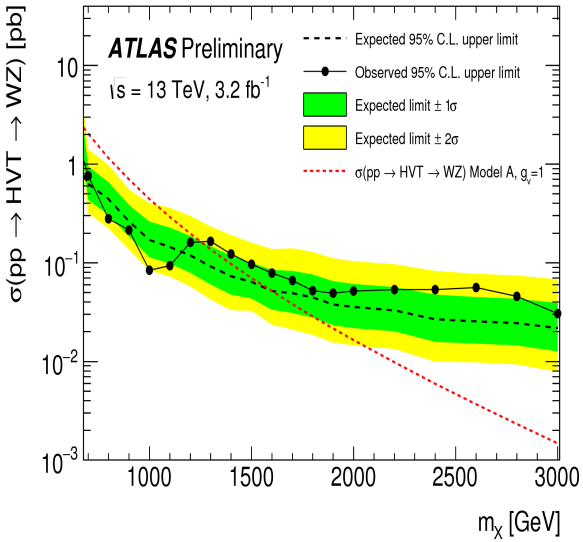
VV→ $\nu\nu$J, $\ell\nu$J, $\ell\ell$J

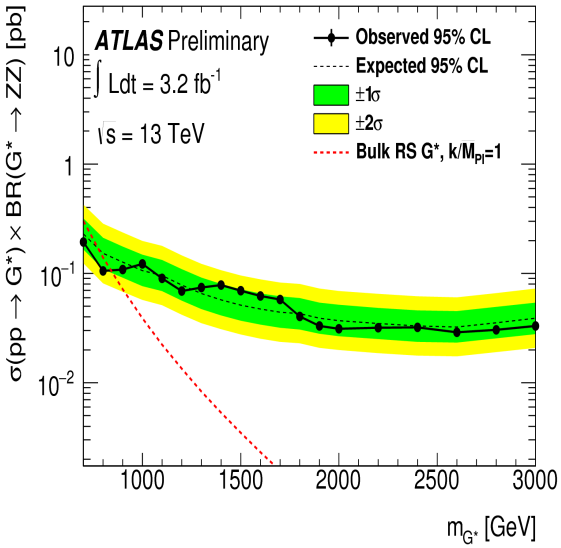




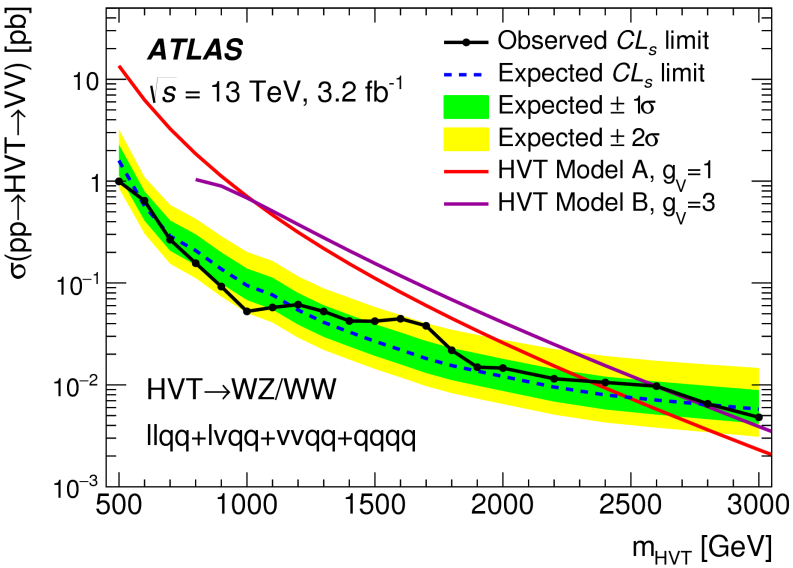


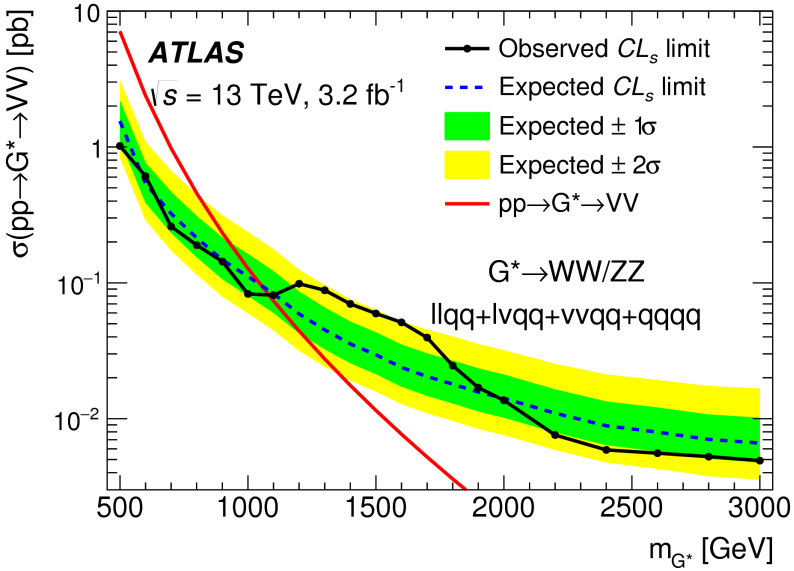






VV Resonances Combination

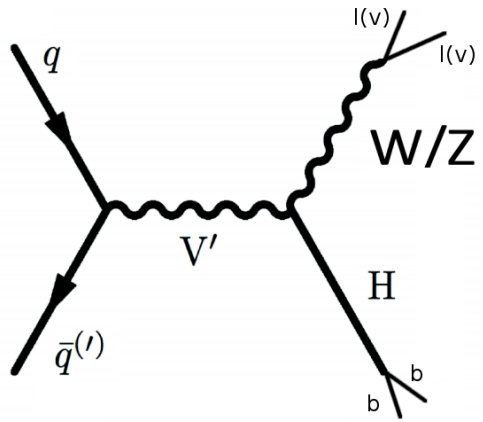




- Better sensitivity after combination when compared to Run-1.

VH Resonances

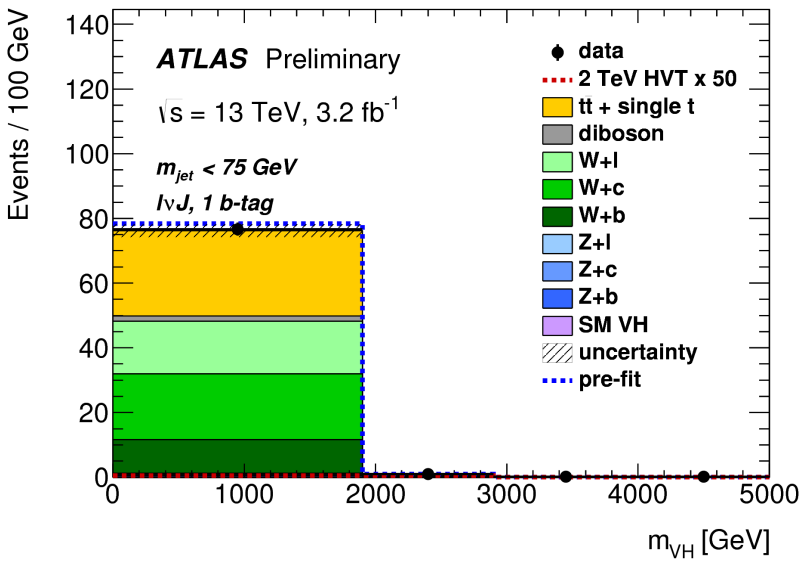
- Look for V→ leptons, H→bb
- Require one large-R jet, p_T >250 GeV, $m_J \sim m_H$
- Use b-tagging on small-R track jets associated to large-R jet
  - Require 1 or 2 b-tags

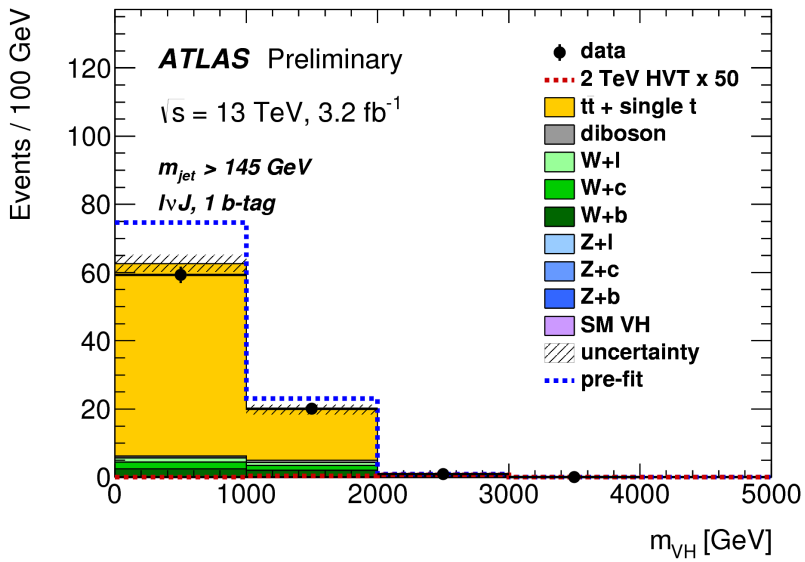


	$\nu\nu$bb	$\ell\nu$bb	$\ell\ell$bb
N_{lep}	0	1	2
E_T^{miss}	>200 GeV	>100 GeV	–
Topology	$\lvert\Delta\phi(E_T^{miss}, J)\rvert > 2\pi/3$		$m_{\ell\ell} \sim m_Z$

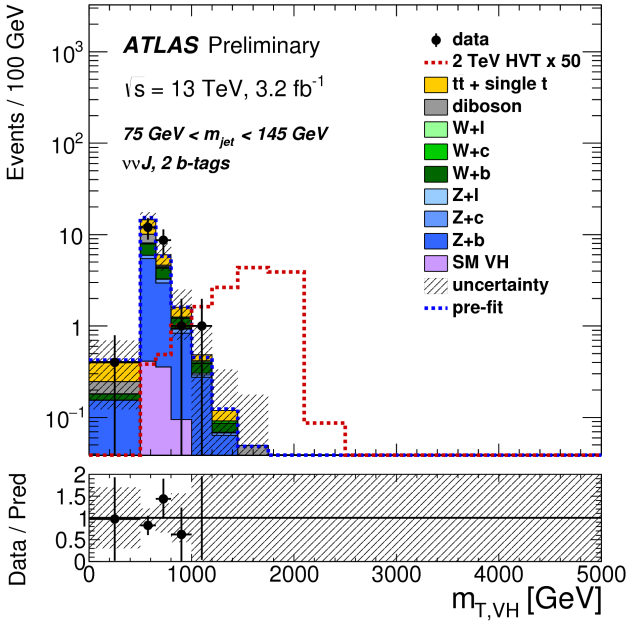
VH Resonances

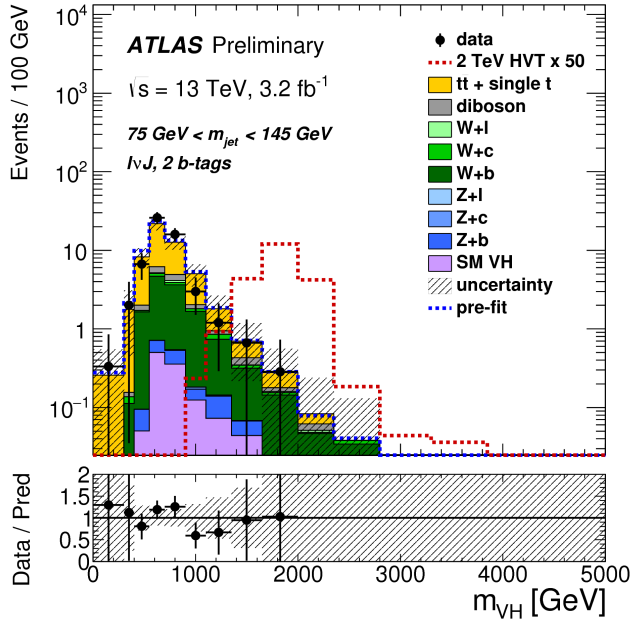
- Backgrounds estimated in MC and validated in control regions

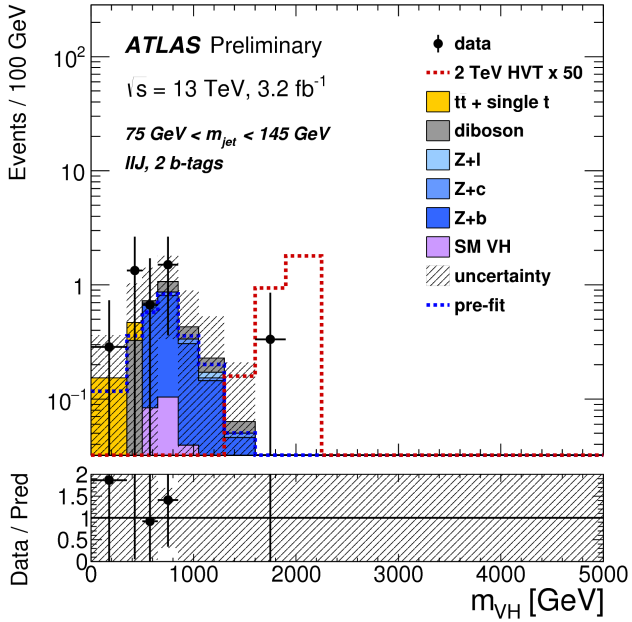




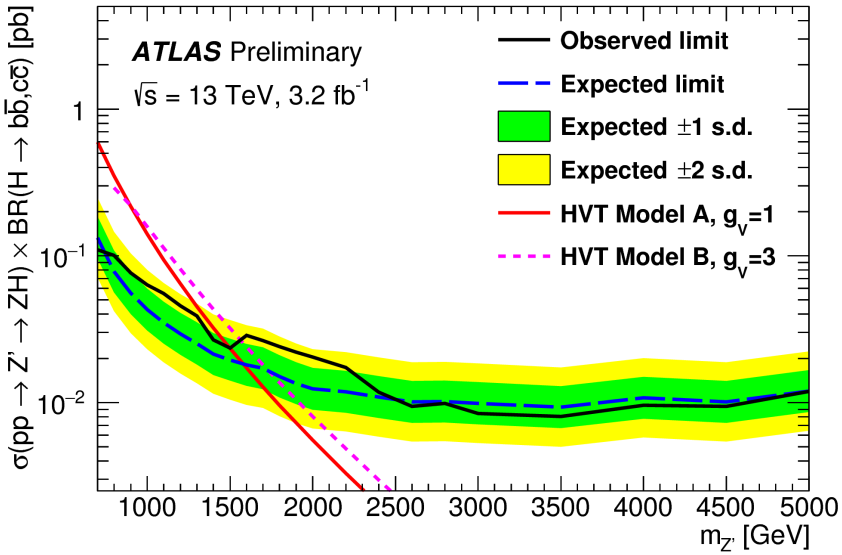
VH Resonances

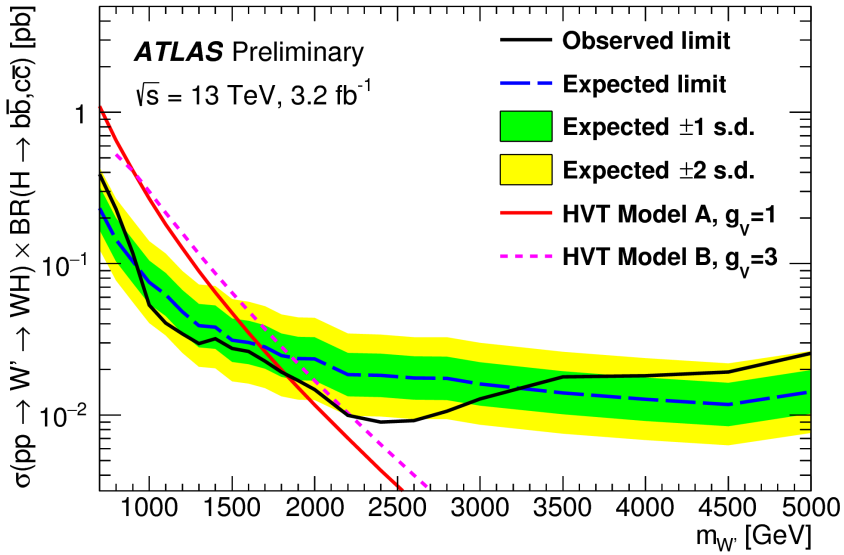






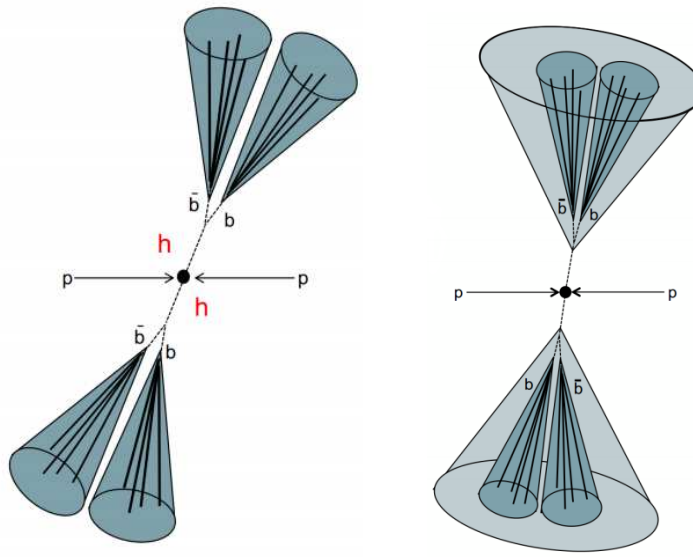
VH Resonances





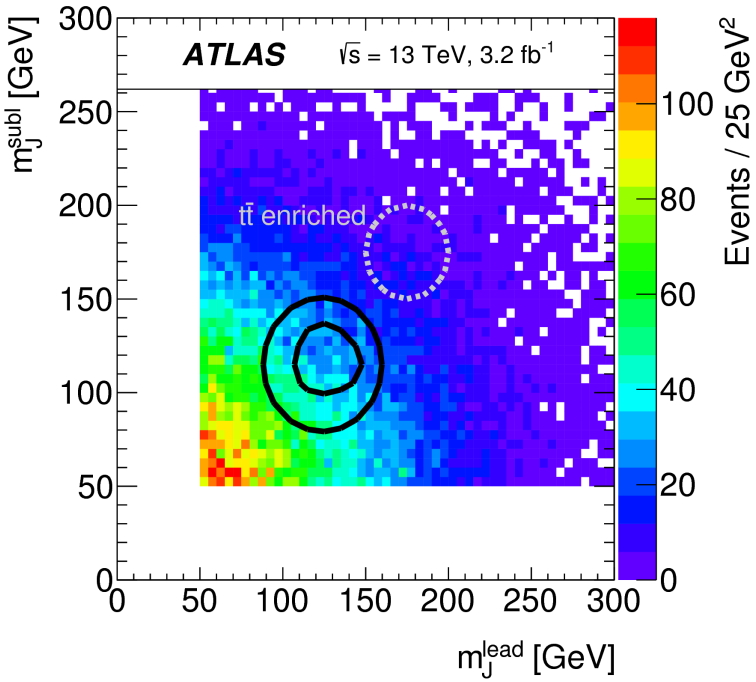
hh Resonances

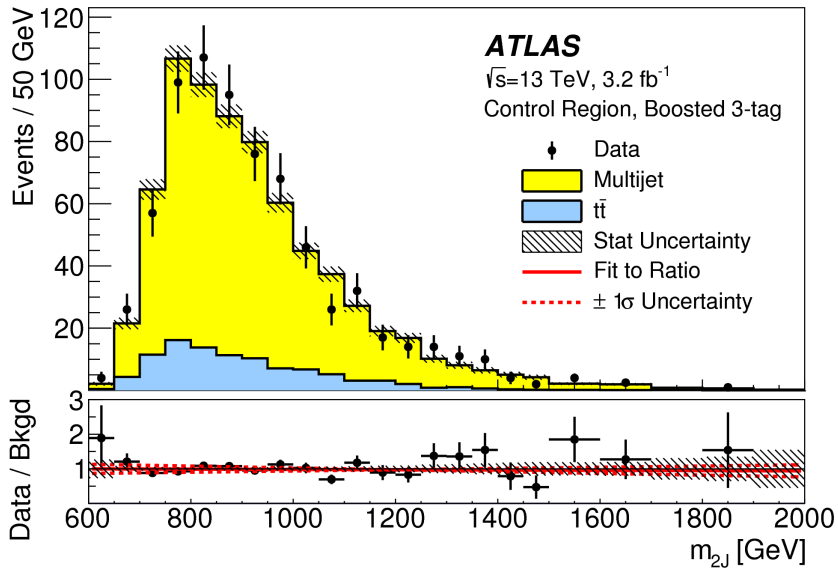
- Look for either 4 resolved small-R (anti-kT R=0.4) jets, or two large-R jets
- Resolved analysis looks for 4 b-tagged jets, $p_T^{jj} > 150$ GeV, $\Delta R(j,j) < 1.5$
- Merged analysis looks for 3 or 4 b-tagged small-R track jets associated to large-R jets, $p_T^{J1(2)}$ >350(250) GeV



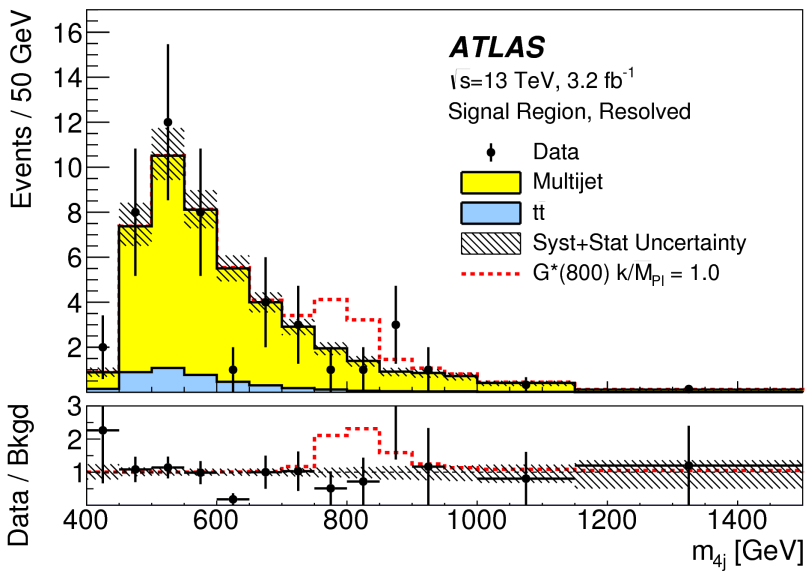
hh Resonances

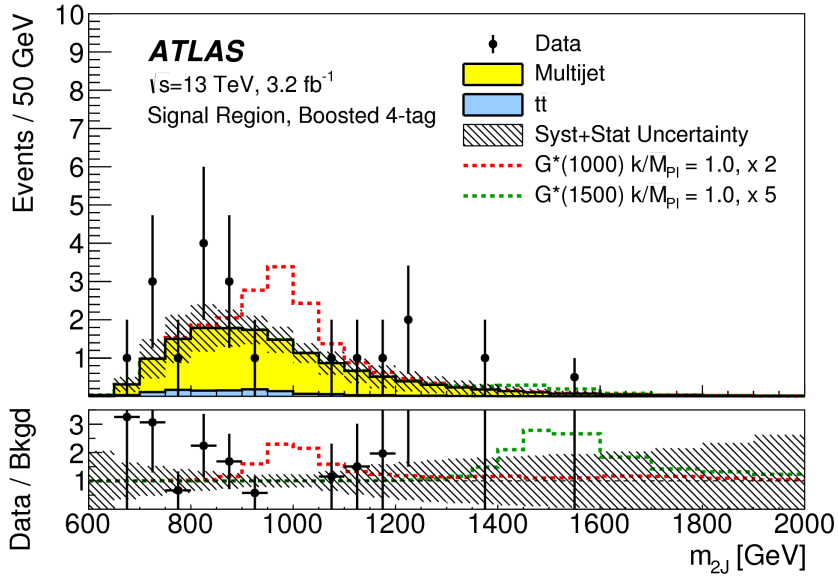
- Multijet background estimated in sidebands and validated in control regions

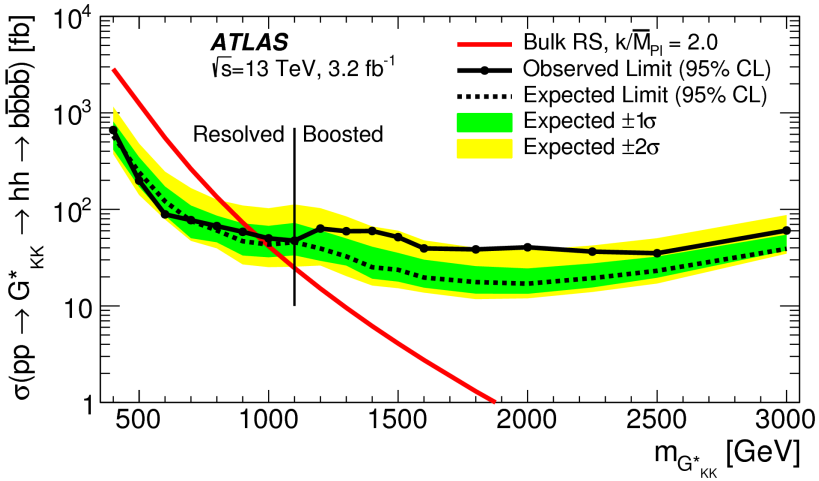


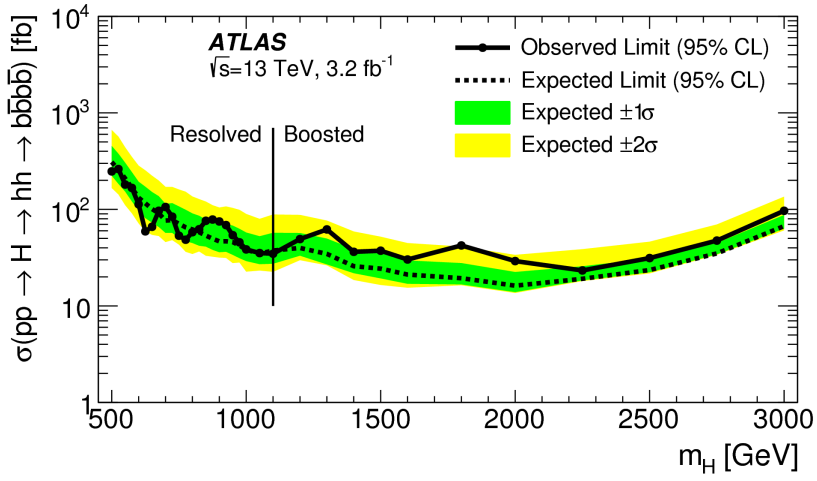


hh Resonances



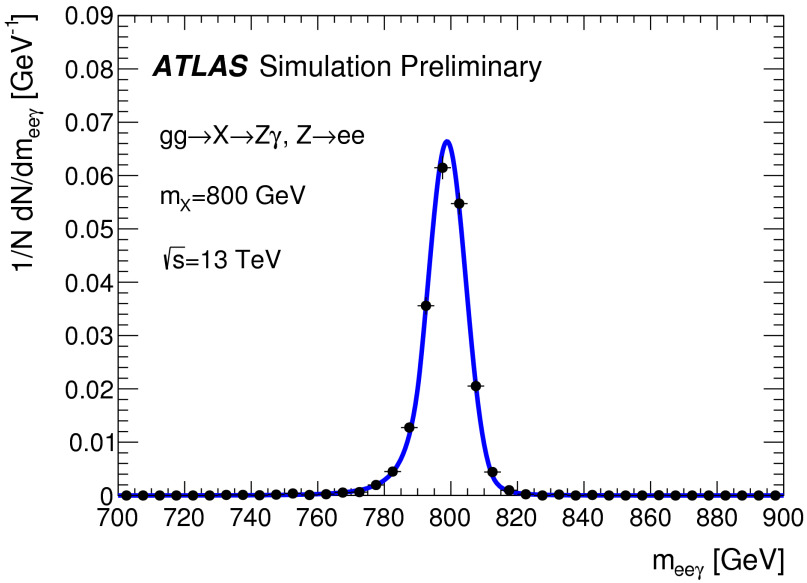


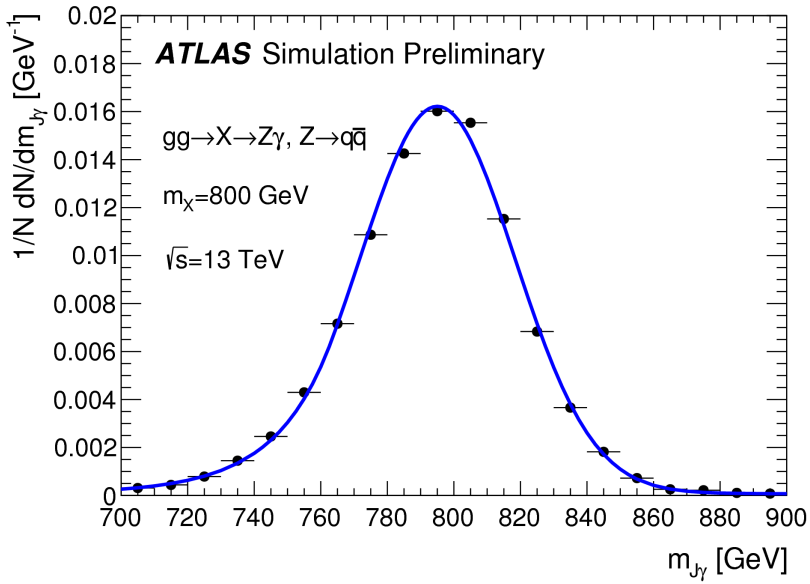




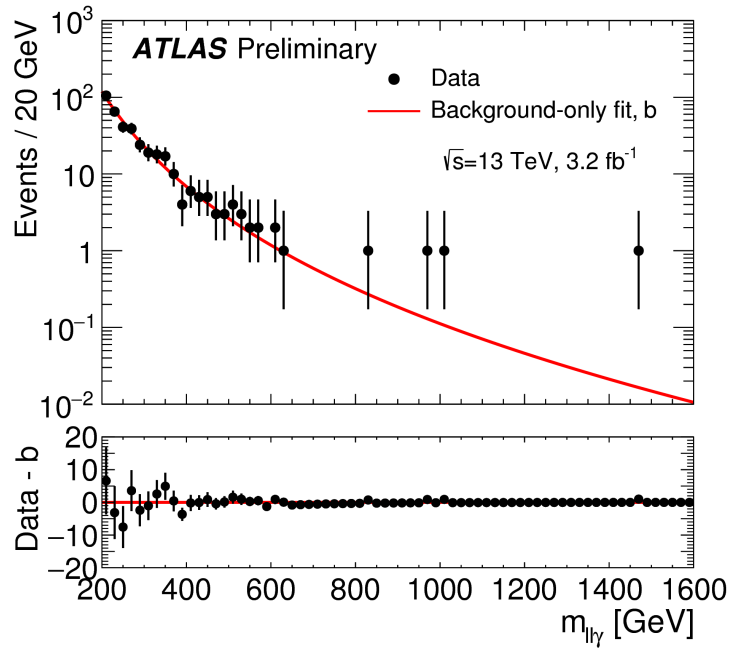
Z/γ Resonances

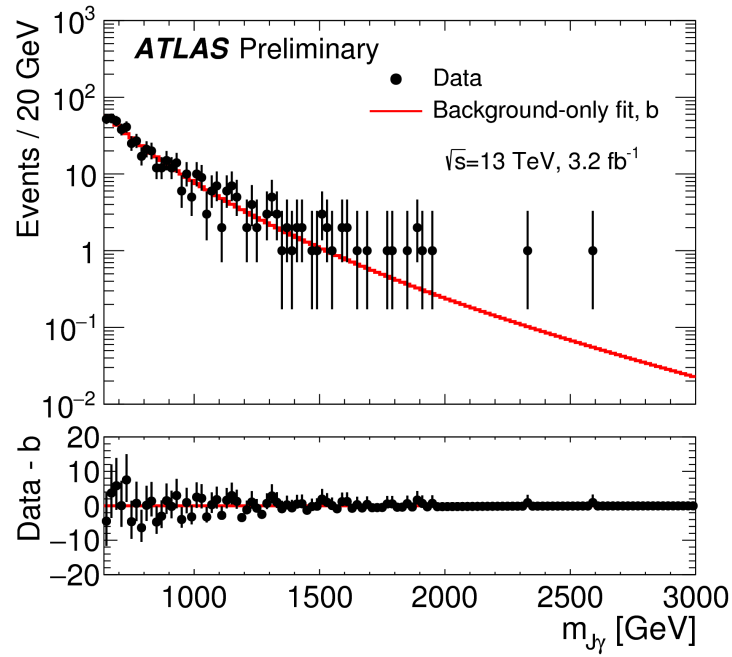
- Consider Z$\rightarrow \ell\ell$
  - $E_T^{gamma} > 0.3 m_{res}$, $m_{\ell\ell} \sim m_Z$
- and Z$\rightarrow qq$ decays
  - Large-R, boson tagged jet, p_T^J >200 GeV, E_T^γ >250 GeV
- Signal modelled by double sided crystal ball ($\ell\ell\gamma$) or crystal ball + gaussian ($J\gamma$)

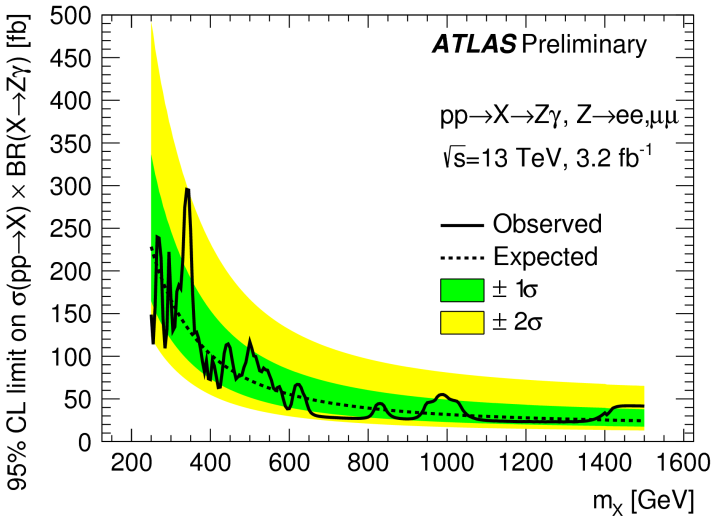


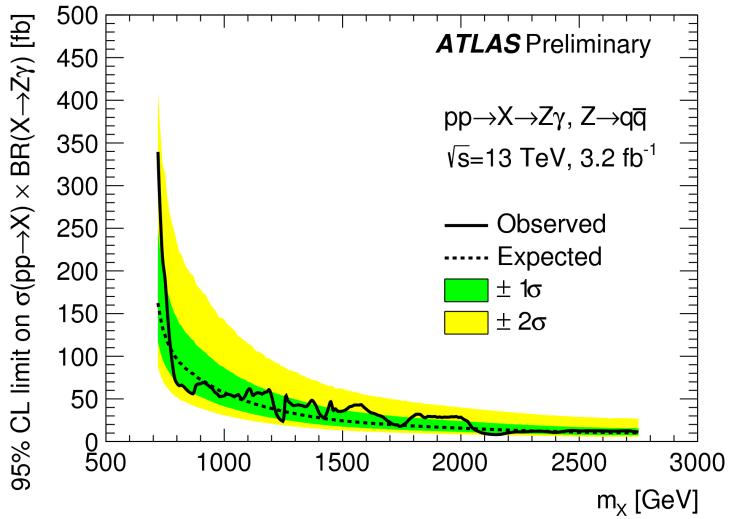


Z/γ Resonances









Summary

- Many searches for diboson resonances ongoing
- So far no significant excesses observed, and limits set on a range of models
- More data coming soon, so stay tuned!

References I

[1] Search for resonances with boson-tagged jets in 3.2 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV collected with the ATLAS detector.
Atlas-conf-2015-073.
https://cds.cern.ch/record/2114845 (2015).

[2] Search for diboson resonances in the vvqq final state in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector.
Atlas-conf-2015-068.
https://cds.cern.ch/record/2114840 (2015).

[3] Search for WW/WZ resonance production in the lvqq final state at $\sqrt{s}$=13 TeV with the ATLAS detector at the LHC.
Atlas-conf-2015-075.
https://cds.cern.ch/record/2114847 (2015).

[4] Search for diboson resonances in the llqq final state in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector.
Atlas-conf-2015-071.
https://cds.cern.ch/record/2114843 (2015).

[5] Searches for heavy diboson resonances in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector.
Submitted to JHEP.
http://arxiv.org/abs/1606.04833 (2016).

References II

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References III

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Backup

8 TeV vs 13 TeV

ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2016

ATLAS Preliminary

$\int \mathcal{L}\, dt$ = (3.2 - 20.3) fb^{-1} $\sqrt{s}$ = 8, 13 TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	M_D 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	3.6	M_{th} 8.3 TeV	$n = 6$	1512.01530
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, M_D = 3 TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, M_D = 3 TeV, rot BH	1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	–	–	20.3	G_{KK} mass 2.66 TeV	$k/\overline{M}_{Pl} = 0.1$	1504.05511
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	1 e, μ	1 J	Yes	3.2	G_{KK} mass 1.06 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2015-075
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	–	4 b	–	3.2	G_{KK} mass 480-770 GeV	$k/\overline{M}_{Pl} = 1.0$	1606.04782
	Bulk RS $g_{KK} \rightarrow tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \rightarrow tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	3.2	Z' mass 3.4 TeV		ATLAS-CONF-2015-070
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z' \rightarrow bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	3.2	W' mass 4.07 TeV		1606.03977
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	0 e, μ	1 J	Yes	3.2	W' mass 1.6 TeV	$g_V = 1$	ATLAS-CONF-2015-068
	HVT $W' \rightarrow WZ \rightarrow qqqq$ model A	–	2 J	–	3.2	W' mass 1.38-1.6 TeV	$g_V = 1$	ATLAS-CONF-2015-073
	HVT $W' \rightarrow WH \rightarrow \ell\nu bb$ model B	1 e, μ	1-2 b, 1-0 j	Yes	3.2	W' mass 1.62 TeV	$g_V = 3$	ATLAS-CONF-2015-074
	HVT $Z' \rightarrow ZH \rightarrow \nu\nu bb$ model B	0 e, μ	1-2 b, 1-0 j	Yes	3.2	Z' mass 1.76 TeV	$g_V = 3$	ATLAS-CONF-2015-074
	LRSM $W'_R \rightarrow tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \rightarrow tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	3.6	Λ 17.5 TeV	$\eta_{LL} = -1$	1512.01530
	CI $qq\ell\ell$	2 e, μ	–	–	3.2	Λ 23.1 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2015-070
	CI $uutt$	2 e, μ (SS)	≥ 1 b, 1-4 j	Yes	20.3	Λ 4.3 TeV	$\lvert C_{LL} \rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 250$ GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 150$ GeV	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \rightarrow Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \rightarrow Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \rightarrow WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
	$T_{5/3} \rightarrow Wt$	1 e, μ	≥ 1 b, ≥ 5 j	Yes	20.3	$T_{5/3}$ mass 840 GeV		1503.05425
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	3.2	q^* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \rightarrow qg$	–	2 j	–	3.6	q^* mass 5.2 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.01530
	Excited quark $b^* \rightarrow bg$	–	1 b, 1 j	–	3.2	b^* mass 2.1 TeV		1603.08791
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	Λ = 3.0 TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	Λ = 1.6 TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e, μ (SS)	–	–	20.3	$H^{\pm\pm}$ mass 551 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\ell$)=1	1412.0237
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

10^{-1} 1 10 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

†Small-radius (large-radius) jets are denoted by the letter j (J).