

# Exotic Searches at ATLAS

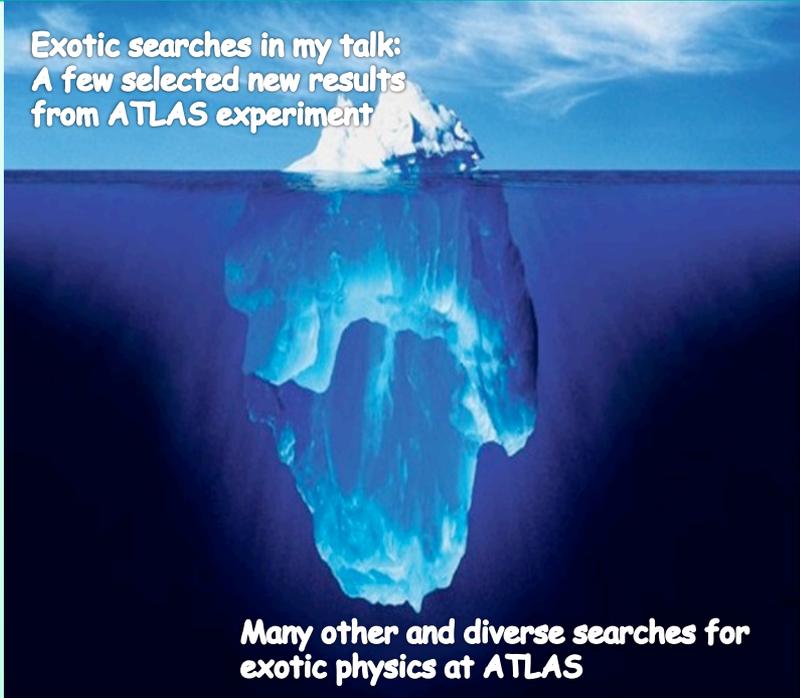
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Iowa State University  
On behalf of the ATLAS Collaboration

International Symposium on Higgs Boson and  
Beyond Standard Model Physics  
Shandong University, Weihai  
August 15-19, 2016



# Introduction and Outline

- Exotic physics at ATLAS:
  - ✓ Searches for NP beyond the SM
    - Many well motivated theories
  - ✓ Many diverse & broad topics
    - Large overlap with SUSY searches
- Outline of the talk:
  - ✓ Organized as signature based searches
    - High  $p_T$  lepton final state
    - Jet final states
    - SM boson final states
    - Unconventional signature
- Only a few selected new results from ATLAS
- Many new exotic results covered in other talks at this workshop
  - ✓ SUSY searches
  - ✓ Exotic Higgs beyond SM
  - ✓ Diboson resonances in  $llqq$  and  $vvqq$  final states
  - ✓ VBF  $WW \rightarrow l\nu l\nu$  resonance search
  - ✓  $HH \rightarrow bbbb$
  - ✓ Dark matter searches
- Focus in basic search strategy without too much details

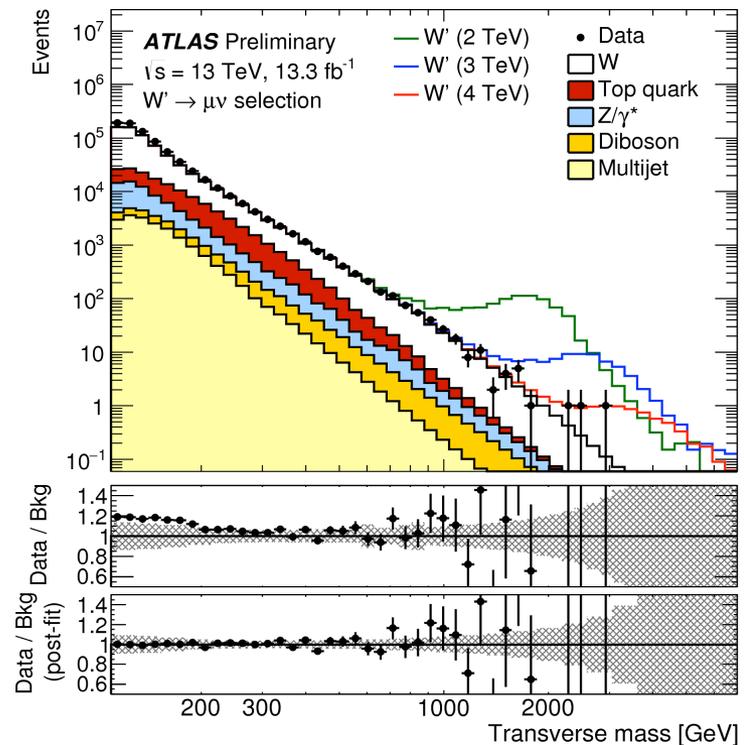
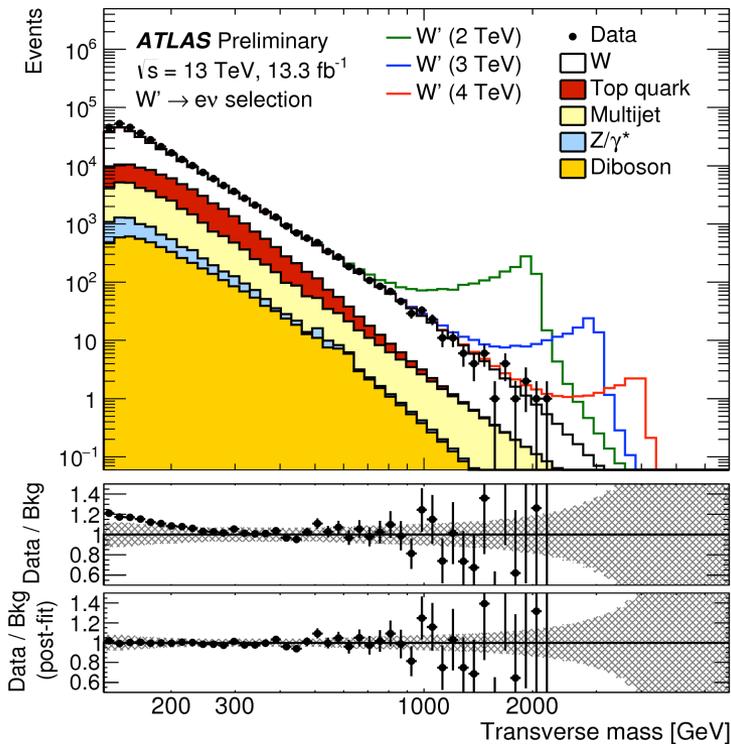
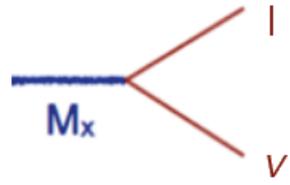
An image of an iceberg floating in the ocean. The small tip of the iceberg is above the water surface, while the much larger, submerged part is below. The water is a deep blue, and the sky is a lighter blue with some clouds. The iceberg is white and blue, with some internal structures visible.

Exotic searches in my talk:  
A few selected new results  
from ATLAS experiment

Many other and diverse searches for  
exotic physics at ATLAS

# Searches in high $P_T$ lepton final states

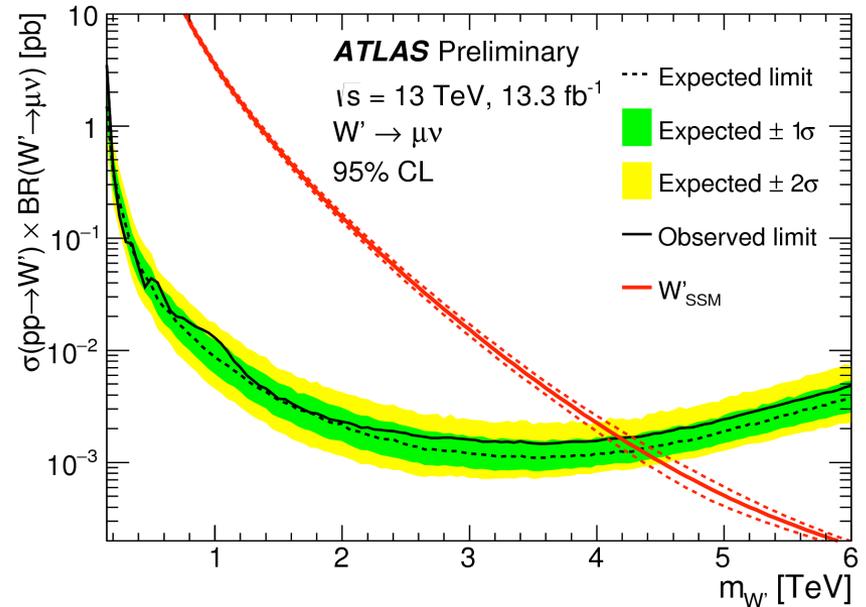
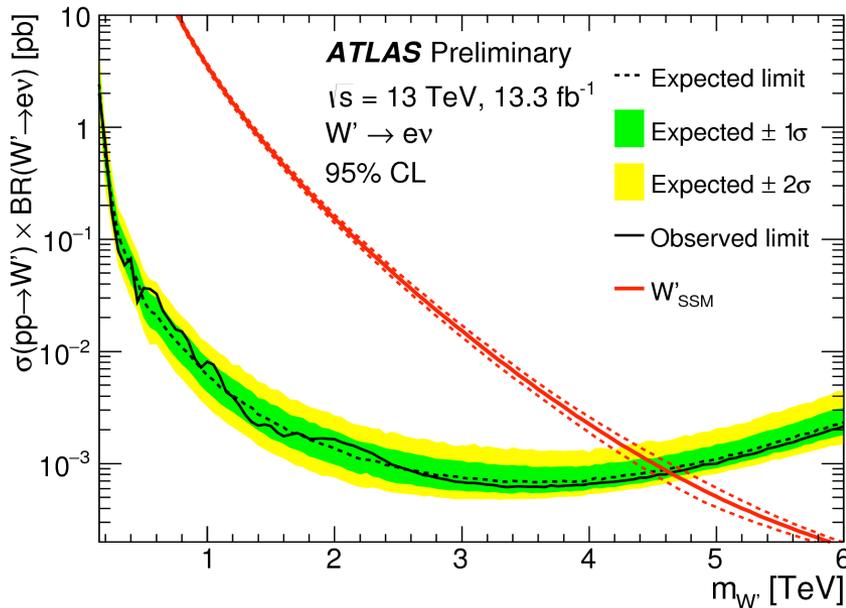
# Lepton + Miss $E_T$



- $W' \rightarrow l\nu$ : interpreted with a Sequential SM gauge boson with same coupling to fermion as SM
- Fit the transverse mass to look for peaking structure
- Background estimate:
  - ✓ SM production of  $W$ , top and diboson: MC simulation
  - ✓ Multijet background due to jet fake lepton: data driven matrix method
    - Measured lepton efficiency and fake (loosen lepton ID) rate from data
    - Infer true lepton and fake lepton numbers based on observed "good" & "fake" lepton numbers

$$m_T = \sqrt{2p_T E_T^{\text{miss}} (1 - \cos \phi_{\ell\nu})}$$

# Lepton + Miss $E_T$



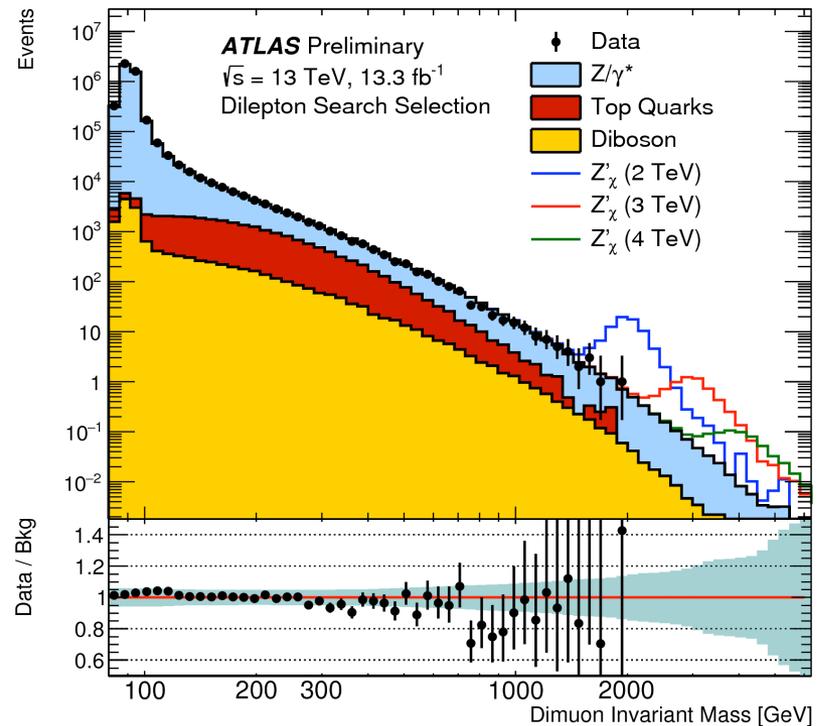
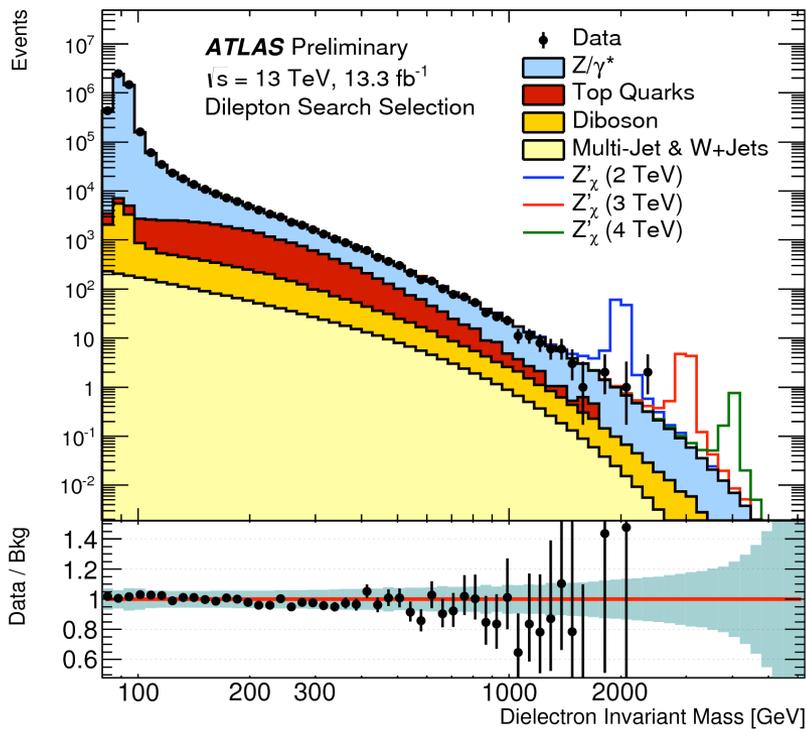
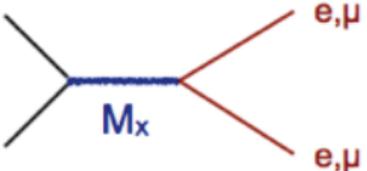
- No evidence of excesses
- Set production limits using profiled likelihood
  - ✓ ~ 500 GeV better than 2015 analysis
- Dominant by statistical uncertainties
- Systematic uncertainties:
  - ✓ Dominated by multijet bg estimate
  - ✓ Significant error from PDF variation of  $W$  production

Decay	$m_{W'}$ lower limit [TeV]	
	Expected	Observed
$W' \rightarrow e\nu$	4.44	4.42
$W' \rightarrow \mu\nu$	4.13	4.06
$W' \rightarrow \ell\nu$	4.62	4.59

Ref: ATLAS-CONF-2016-061

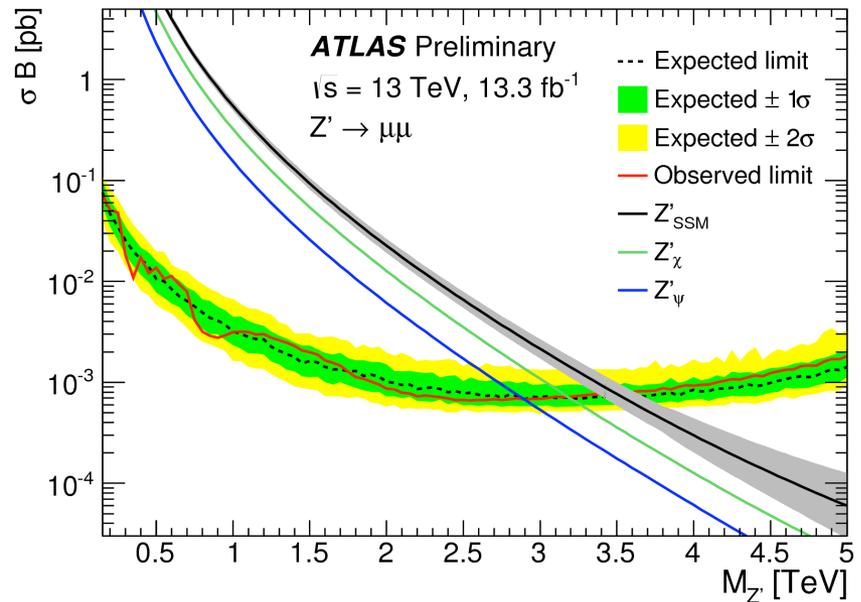
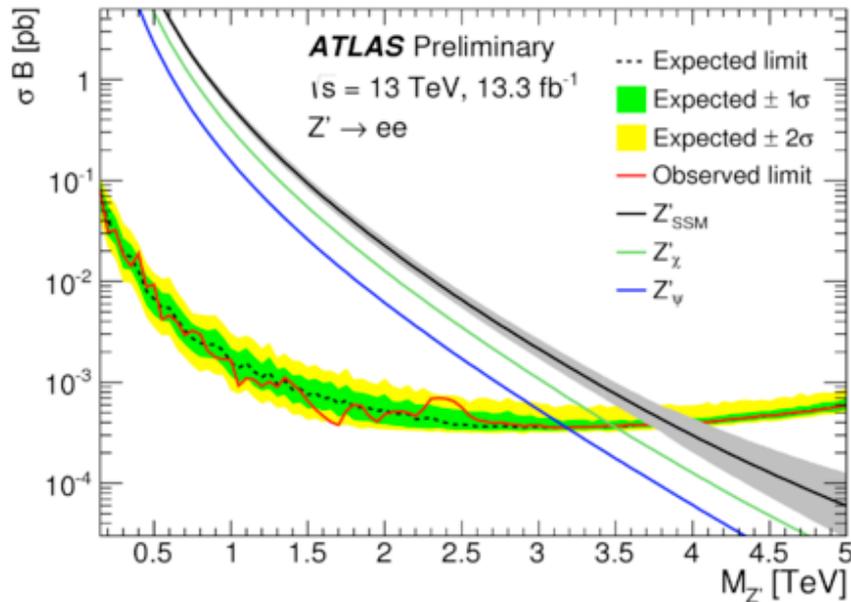
<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-061/>

# Narrow Di-Lepton Resonance



- Theory motivation: Additional a Gauge boson (SSM), Extra-dimension (RS graviton), E6 .....
- Fit the di-lepton invariant mass to look for peaking structure
- Background estimate:
  - ✓ MC for real 2 leptons from SM production: Z, top and diboson:
  - ✓ W+jets and multijet background due to jet fake lepton: data driven matrix method
    - Measured lepton efficiency and fake (loosen lepton ID) rate from data
    - Infer true lepton and fake lepton numbers based on observed "good" & "fake" lepton numbers

# Narrow Di-Lepton Resonance



- No evidence of excesses
- Set production limits using profiled likelihood
  - ✓  $\sim 400\text{GeV}$  better than 2015 analysis
- Dominant by statistical uncertainties
- Systematic uncertainties:
  - ✓ Dominated PDF variation of DY production

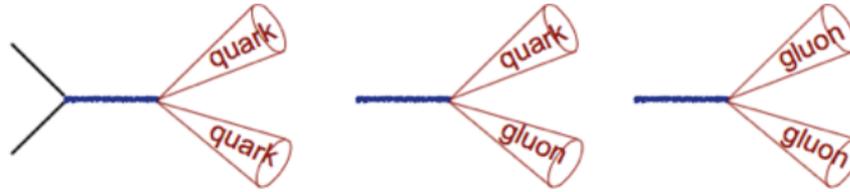
Model	Width [%]	$\theta_{E_6}$ [Rad]	Lower limits on $m_{Z'}$ [TeV]					
			$ee$		$\mu\mu$		$\ell\ell$	
			Obs	Exp	Obs	Exp	Obs	Exp
$Z'_{\text{SSM}}$	3.0	-	3.85	3.86	3.49	3.53	4.05	4.06
$Z'_{\chi}$	1.2	0.50	3.48	3.49	3.18	3.19	3.66	3.67
$Z'_{\text{S}}$	1.2	0.63 $\pi$	3.43	3.44	3.14	3.14	3.62	3.61
$Z'_{\text{I}}$	1.1	0.71 $\pi$	3.37	3.37	3.08	3.08	3.55	3.55
$Z'_{\eta}$	0.6	0.21 $\pi$	3.25	3.25	2.96	2.94	3.43	3.42
$Z'_{\text{N}}$	0.6	-0.08 $\pi$	3.23	3.23	2.95	2.94	3.41	3.41
$Z'_{\psi}$	0.5	0 $\pi$	3.18	3.18	2.90	2.88	3.36	3.35

Ref: ATLAS-CONF-2016-045

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-045/>

# Searches in high $P_T$ jets final states

# Heavy resonance decaying to di-jets



- Particles in NP that can be produced in LHC will couple with partons in proton
  - ✓ Decaying to parton is dominant final states dominated
  - ✓ Possible large production cross section
  - ✓ Excited quarks, new heavy gauge bosons, quantum black holes and contact interaction
- Search Strategy: mass and angular distribution of the dijet events
  - ✓  $Y^*$ : half of the rapidity difference between 2 jets

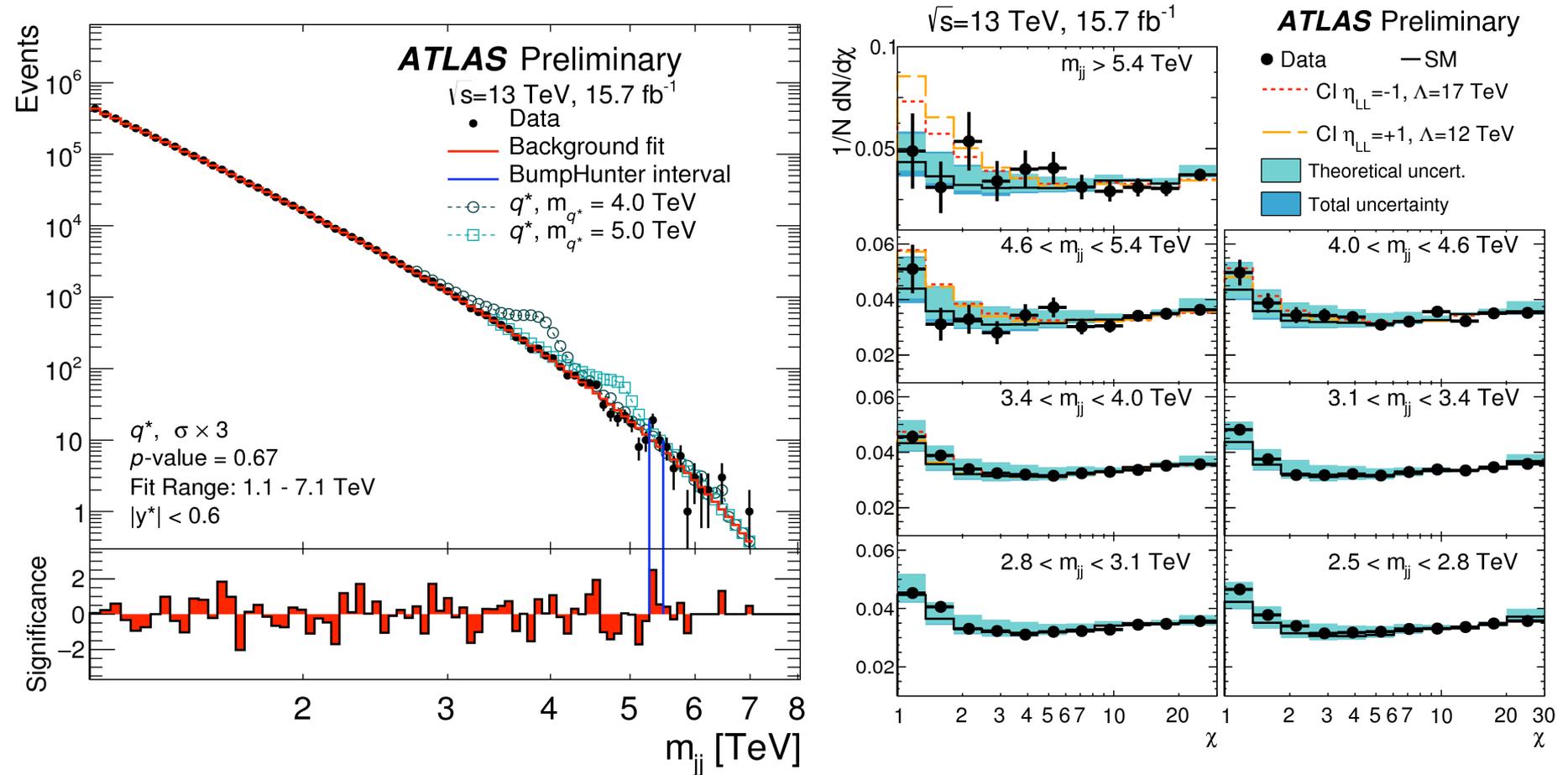
$$\chi = e^{2|y^*|} \sim \frac{1 + \cos \theta^*}{1 - \cos \theta^*}$$

- Event selection
  - ✓ Single jet trigger with  $p_T > 380 \text{ GeV}$ :  $\sim 99.5\%$  efficiency for selected offline events
  - ✓ Leading (sub-leading jet) with  $p_T > 440 (60) \text{ GeV}$
- Resonance search using  $m_{jj}$  distribution
  - ✓ Empirical analytical function to describe SM background
    - Used in dijet  $m_{jj}$  searches at lower collision energies
    - Test with MC simulated events with additional free parameters/functions

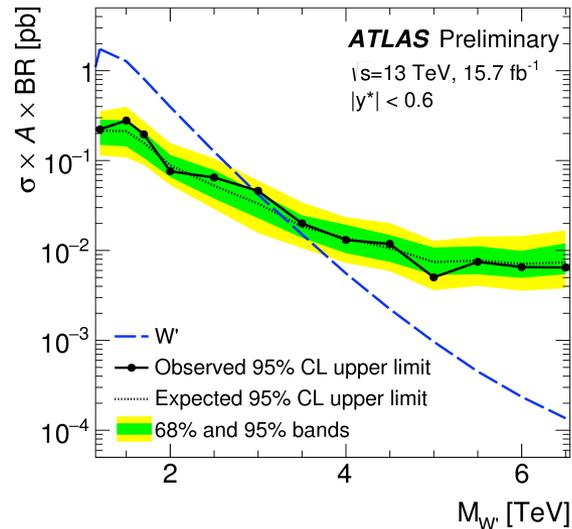
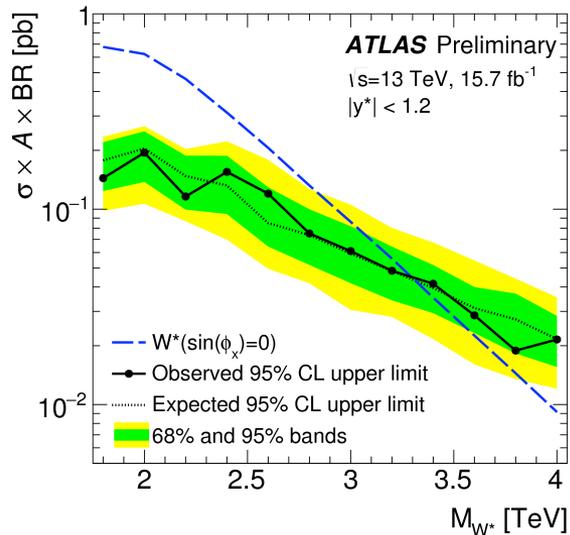
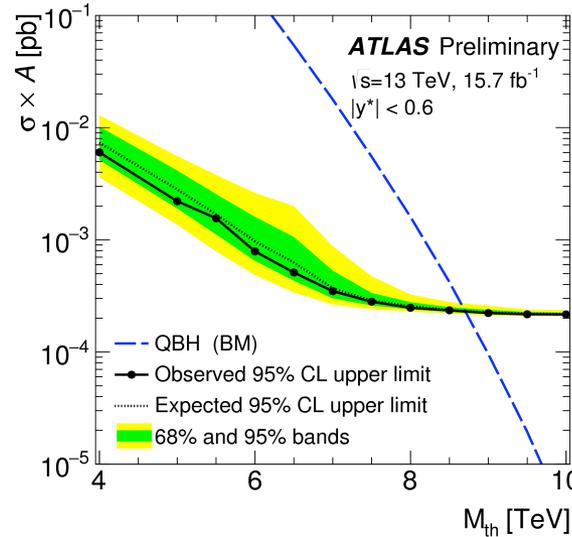
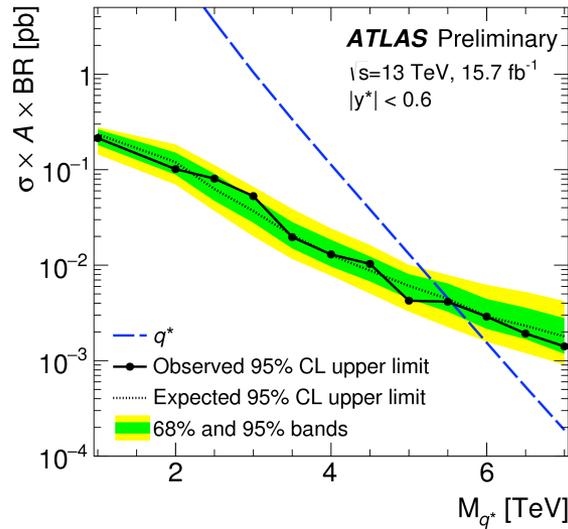
$$f(z) = p_1(1 - z)^{p_2} z^{p_3}$$

- ✓  $z = m_{jj}/\sqrt{s}$ , parameter  $p_1$ ,  $p_2$  and  $p_3$  fitted from data
- Resonance search using angular distribution:  $dN/d\chi$ 
  - ✓ Background distribution modeled from MC simulated events

# Heavy resonance decaying to di-jets



# Heavy resonance decaying to di-jets



Model	95% CL Exclusion limit	
	Observed 13 TeV	Expected 13 TeV
Quantum black holes, ADD (BLACKMAX generator)	8.7 TeV	8.7 TeV
Excited quark	5.6 TeV	5.5 TeV
$W'$	2.9 TeV	3.3 TeV
$W^*$	3.3 TeV	3.3 TeV
Contact interactions ( $\eta_{LL} = +1$ )	12.6 TeV	13.7 TeV
Contact interactions ( $\eta_{LL} = -1$ )	19.9 TeV	23.7 TeV

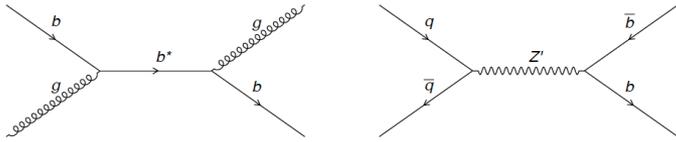
- Upper limits 15% improvement over 2015 13TeV data
- For contact interaction:
  - ✓ Assume  $\eta_{RR}=0$  and  $\eta_{RL}=0$

$$L_{qq} = \frac{2\pi}{\Lambda^2} [ \eta_{LL} (\bar{q}_L \gamma^\mu q_L) (\bar{q}_L \gamma_\mu q_L) + \eta_{RR} (\bar{q}_R \gamma^\mu q_R) (\bar{q}_R \gamma_\mu q_R) + 2\eta_{RL} (\bar{q}_R \gamma^\mu q_R) (\bar{q}_L \gamma_\mu q_L) ],$$

Ref: ATLAS-CONF-2016-069

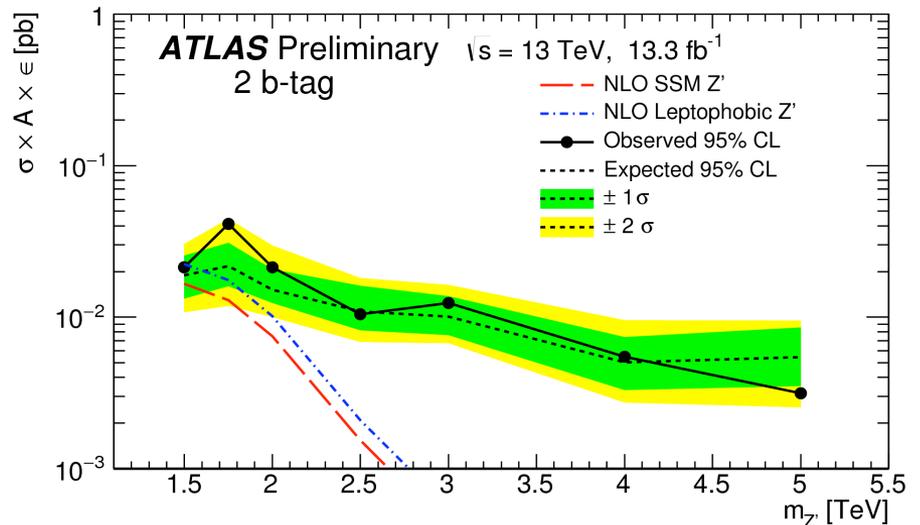
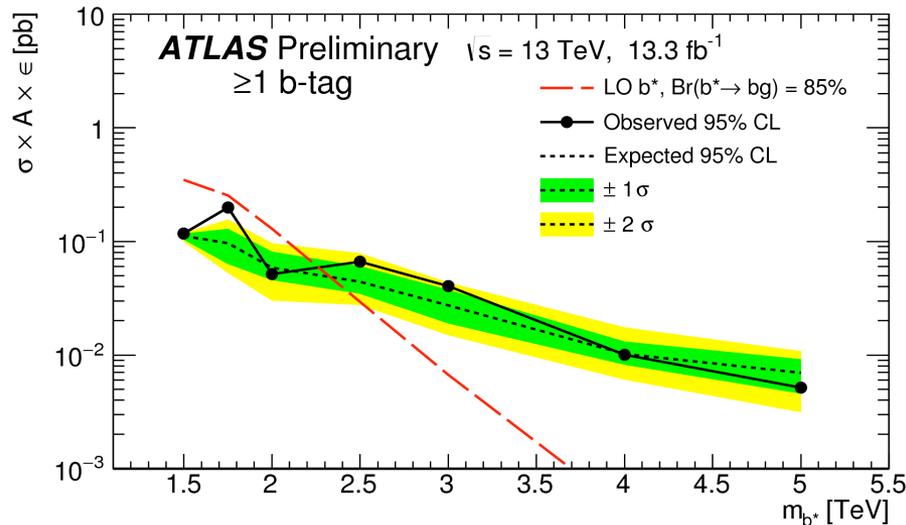
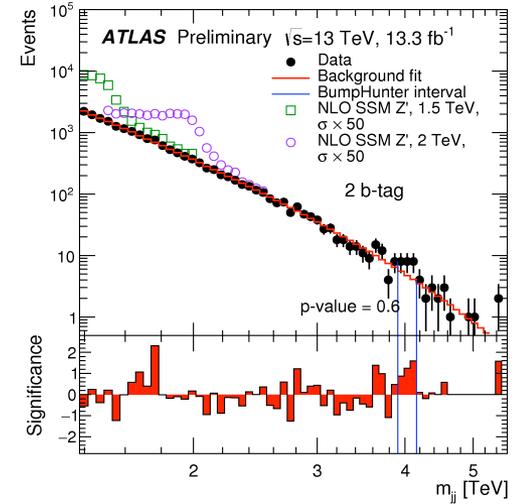
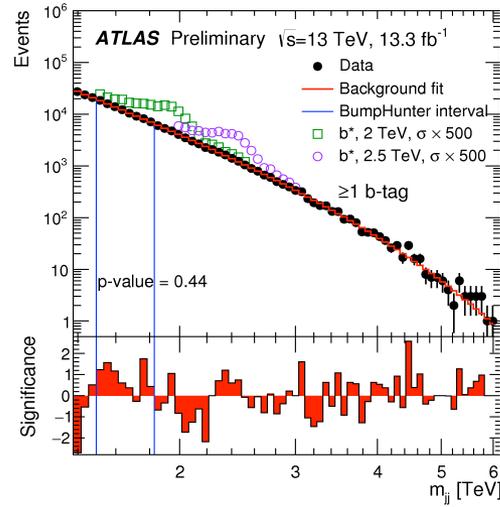
<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-069/>

# Heavy Resonance on b-jet final state



- Empirical analytical function to model background distribution
  - ✓  $x = m_{jj}/\sqrt{s}$ , parameters fitted from data

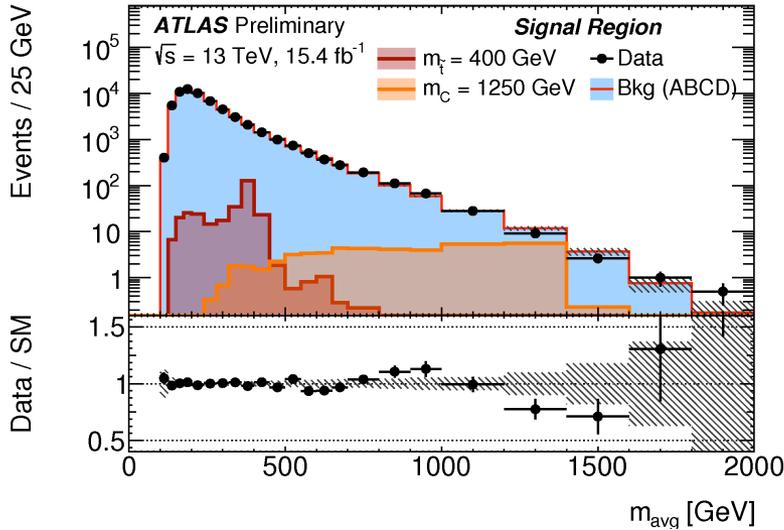
$$f(x) = p_1(1-x)^{p_2} x^{p_3+p_4(\ln x)+p_5(\ln x)^2}$$



Ref: ATLAS-CONF-2016-060

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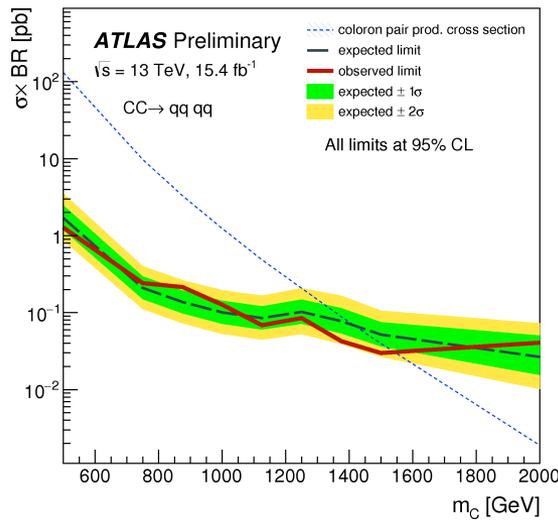
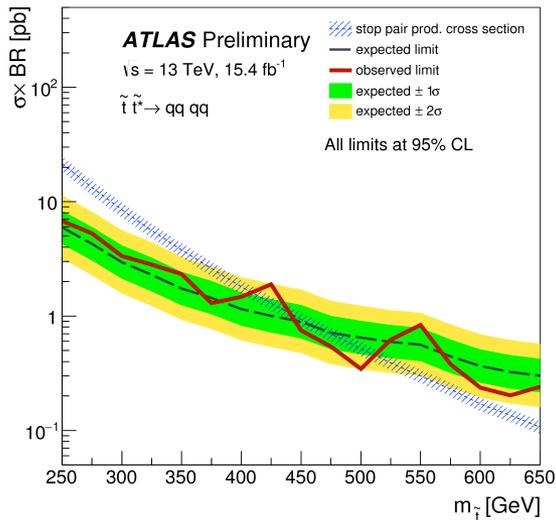
# Pair Produced Resonance



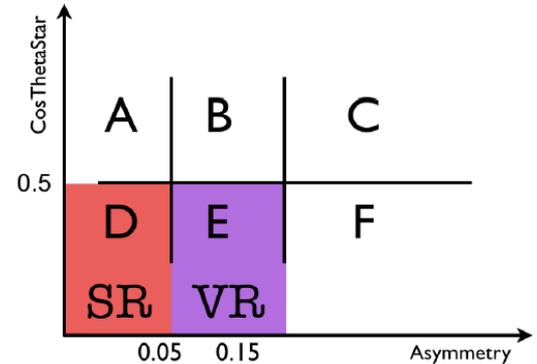
- New particles produced in pair
  - ✓ SUSY, massive color octet resonances
- Event selection:
  - ✓ 4 leading jets with  $p_T > 120 \text{ GeV}$
  - ✓ Choose 2 jet pairs with
 

$$\Delta R_{\min} = \sum_{i=1,2} |\Delta R_i - 1.0|$$

    - ✓ Averaged mass to distinguish signal from bg
- Background modeling
  - ✓ Using control samples from data
  - ✓ Validated using data and MC



Theta: resonance pair production angle in the center-of-mass frame with respect to the beamline

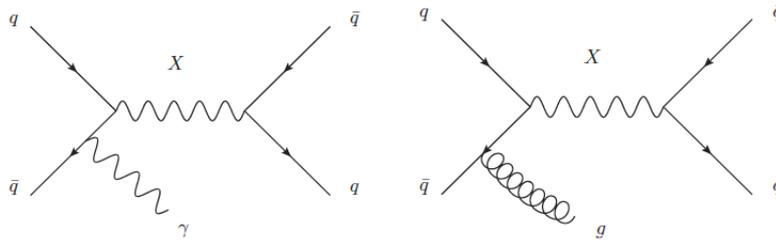


$$\mathcal{A} = \frac{|m_1 - m_2|}{m_1 + m_2} \text{ Mass asymmetry between 2 pairs}$$

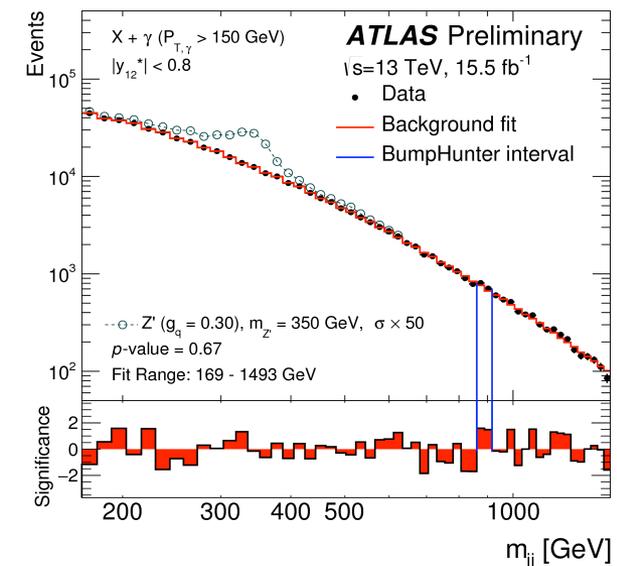
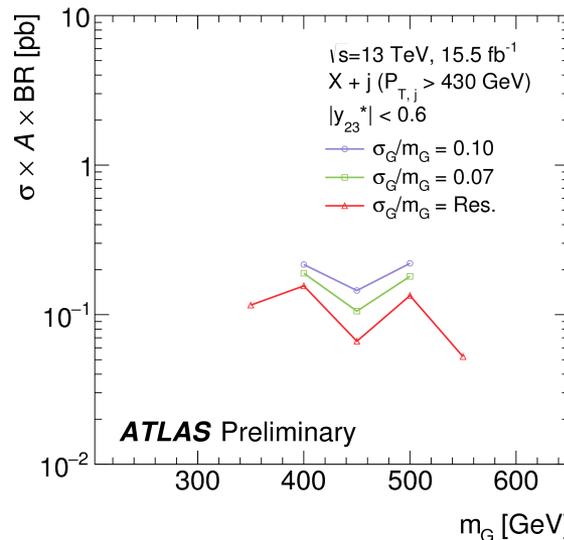
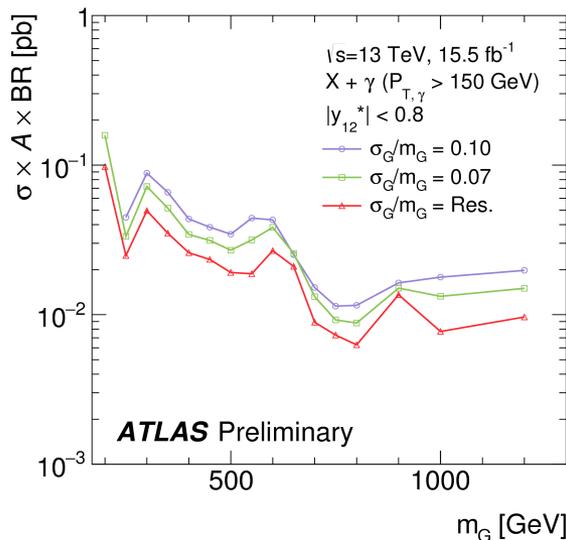
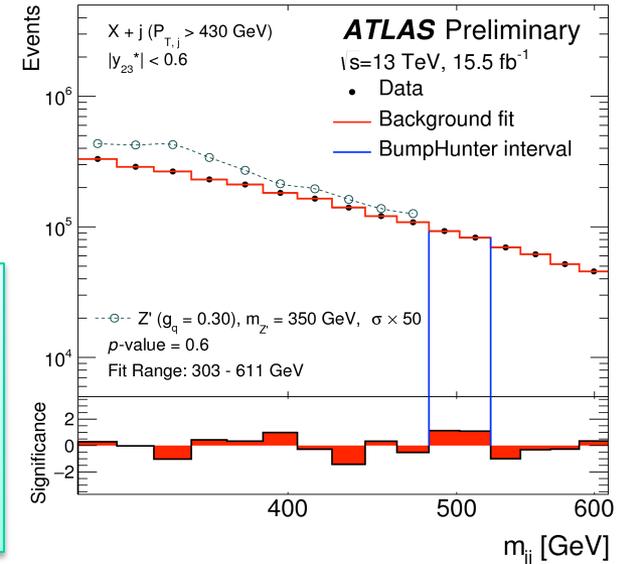
Ref: ATLAS-CONF-2016-084

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-084/>

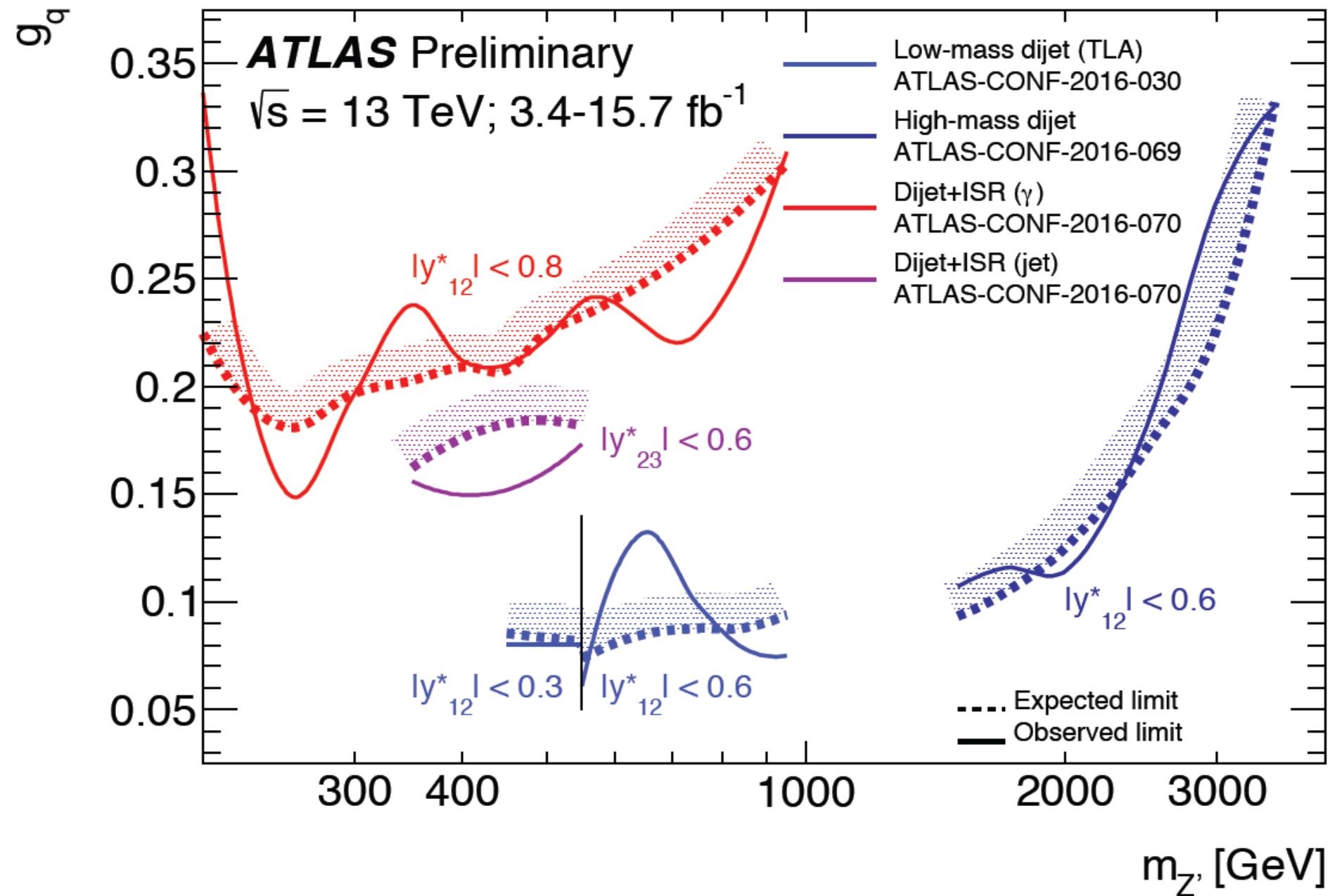
# Light Resonance with ISR



- Light resonance recoiled via a high  $p_T$  ISR photon/gluon
- Event selection:
  - ✓ At least a photon with  $p_T > 150 \text{ GeV}$  + 2 jets or
  - ✓ Leading jet with  $p_T > 430 \text{ GeV}$  + 2 subleading jets
- Background modeling:
  - ✓ Empirical analytical function Similar to di-b jets analysis



Ref: ATLAS-CONF-2016-070 <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-070/>



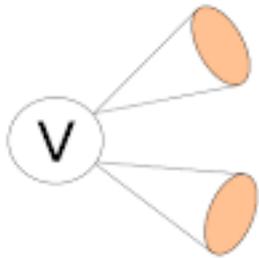
# Searches in SM Boson Final states

# Resonance decaying to SM Bosons

- Most NP models predict heavy resonance ( $\sim \text{TeV}$ ) decay into  $W/Z/H$ :

$$T' \rightarrow Wb, \quad X \rightarrow WW, WZ, ZZ, WH, ZH$$

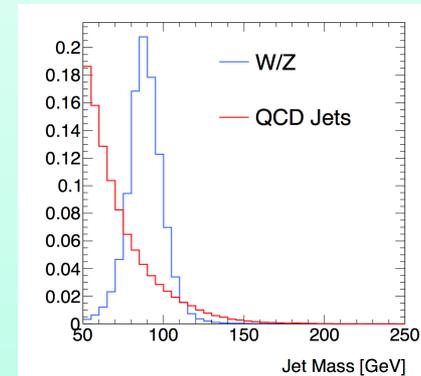
- ✓ Boosted (high  $p_T$ ) jets in the final decay states
- ✓ The hadronic decay products are highly collimated



low-pT



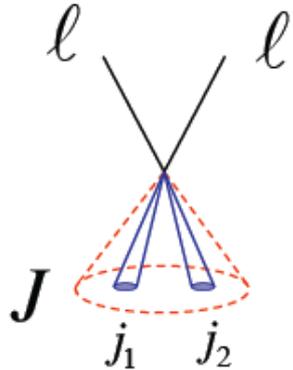
high-pT



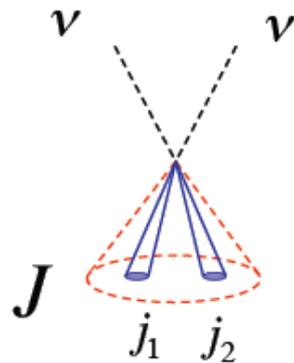
- Traditional jet reco. relying on one-to-one jet-to-parton assignment not adequate
- Solution: reconstruct multi quarks in a single jet (**boosted W/Z/H/Top jet**)
  - ✓ 2 quarks for  $W/Z$  decay, 3 quarks for top decay
  - ✓ Better (only way) to search for certain NP models
- How to identify the boosted  $W/Z/H$ /top
  - ✓ Jet mass
  - ✓ Jet substructure: exam the energy cluster distribution in the single jet

# X → VV (V = W, Z, H) Resonance Searches

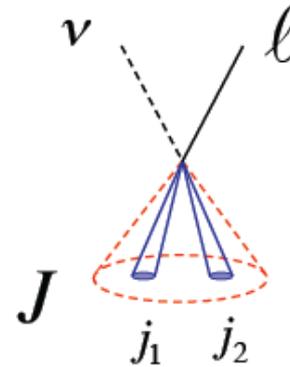
Z(ℓℓ)V



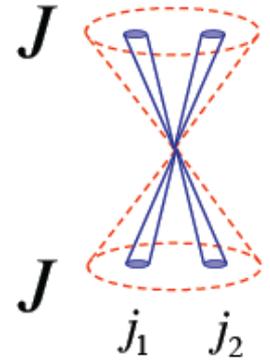
Z(νν)V



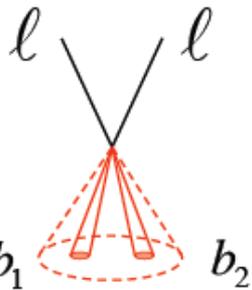
W(ℓν)V



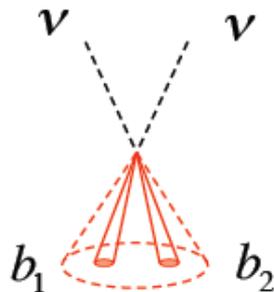
VV(JJ)



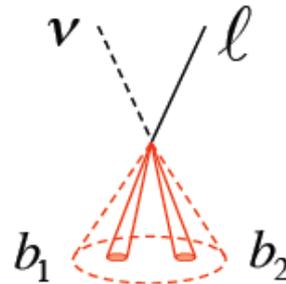
Z(ℓℓ)h



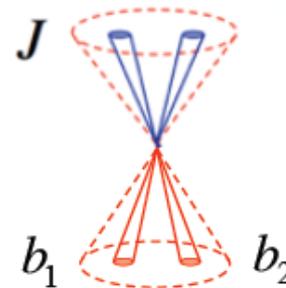
Z(νν)h



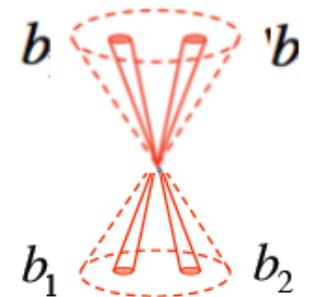
W(ℓν)h



V(J)h



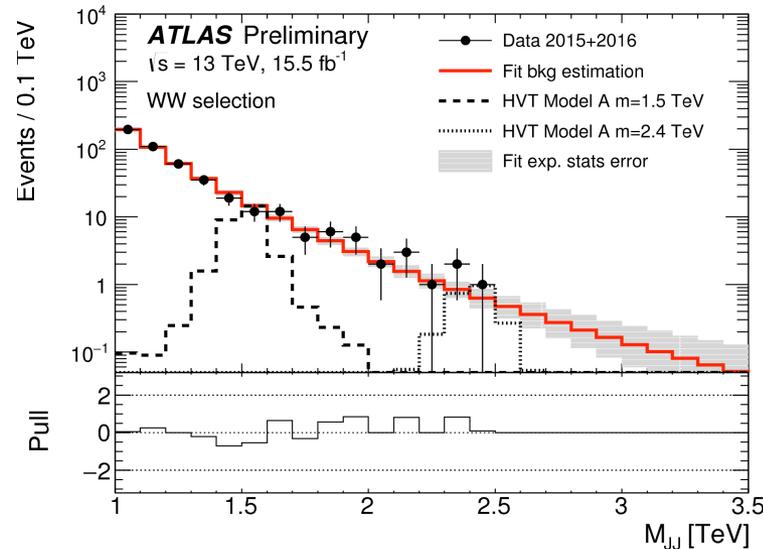
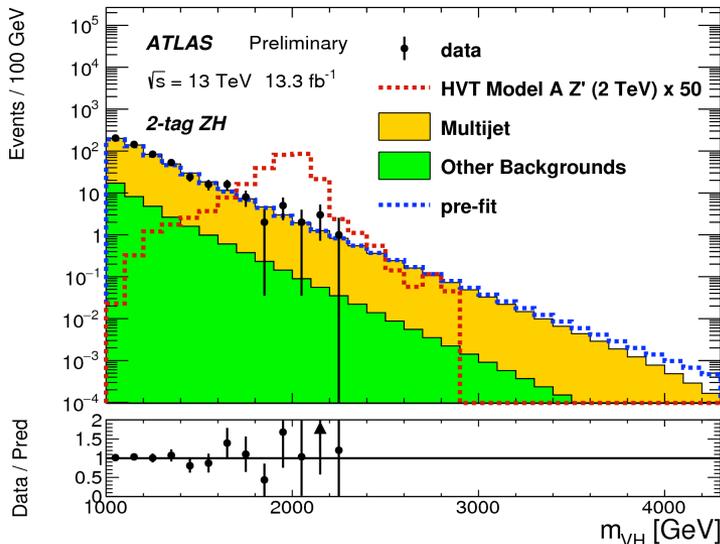
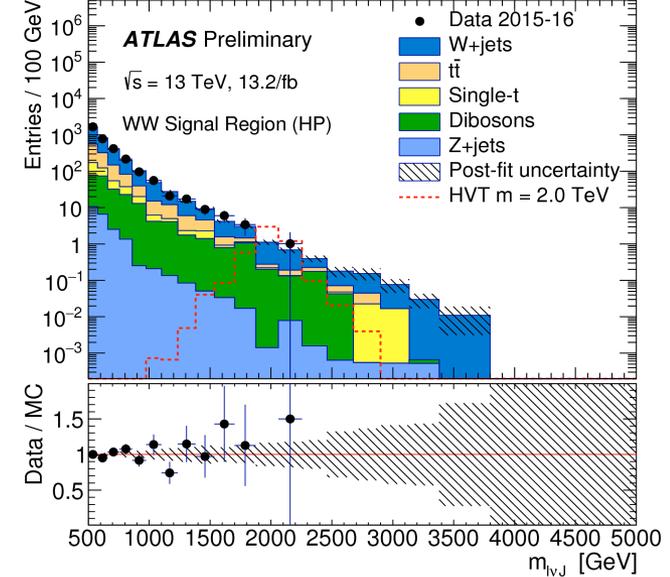
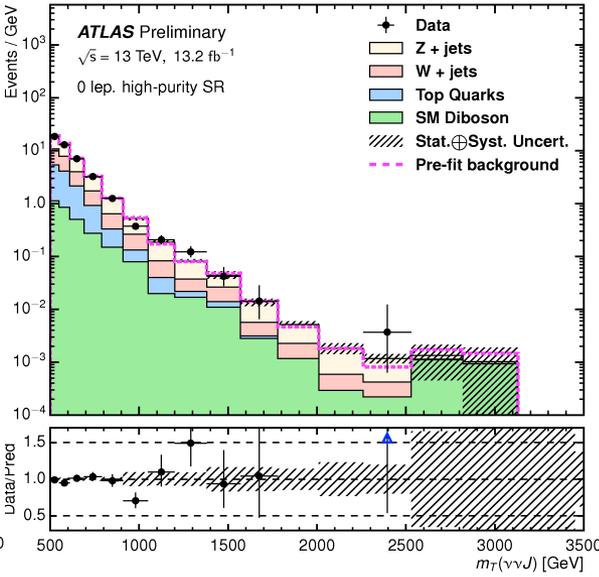
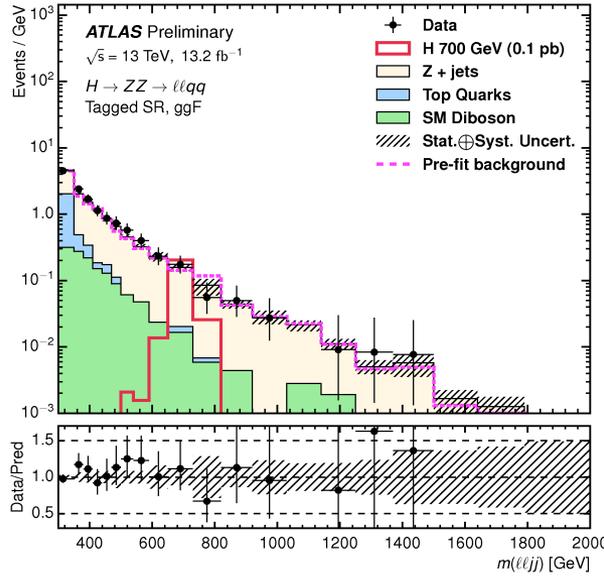
hh



- Many searches in VV final states
  - ✓ Similar analysis strategy: boosted jet for hadronically decaying V
- Some detailed discussion on event selection & analysis in the talk by Steven Patrick

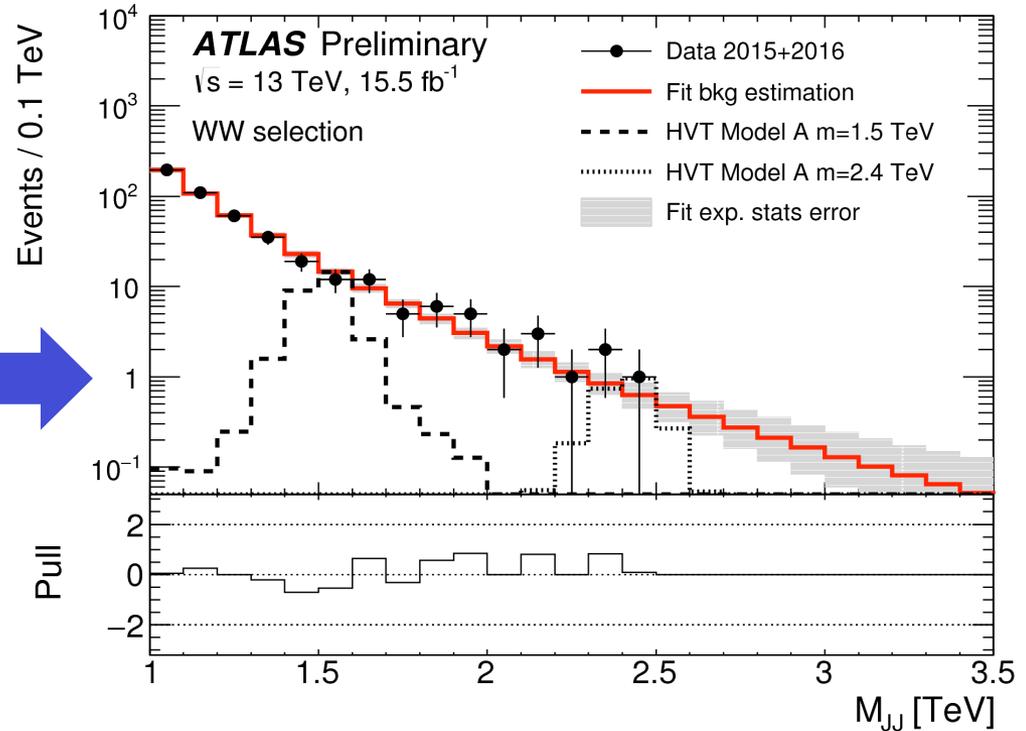
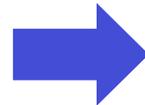
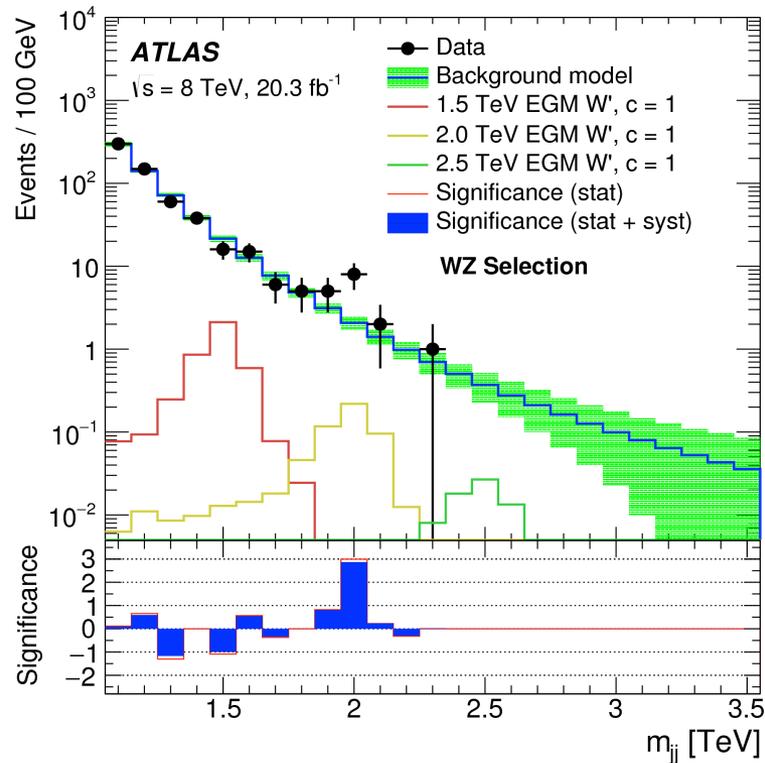
# X → VV (V = W, Z, H) Resonance Searches

A few selected distribution shown here



Ref:  
 ATLAS-CONF-2016-083  
 ATLAS-CONF-2016-055  
 ATLAS-CONF-2016-062  
 ATLAS-CONF-2016-088

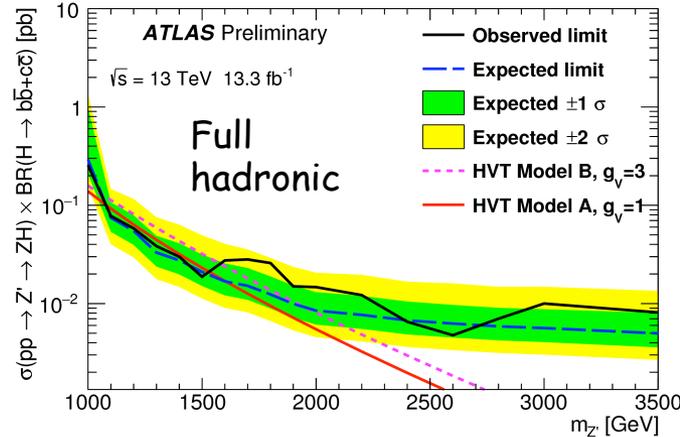
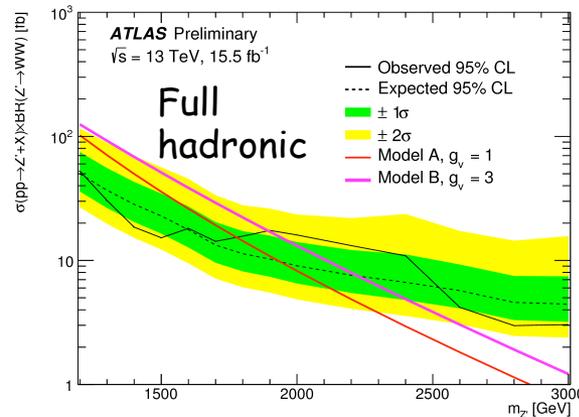
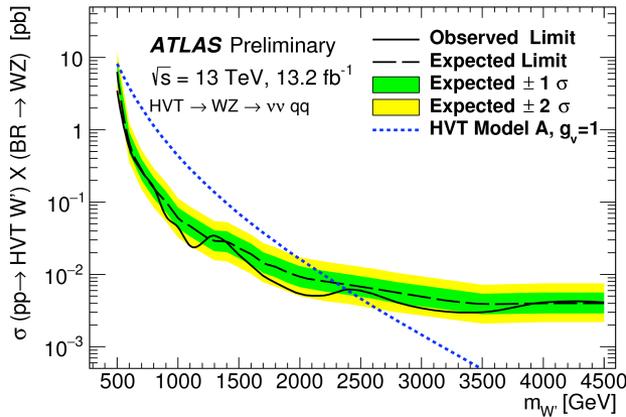
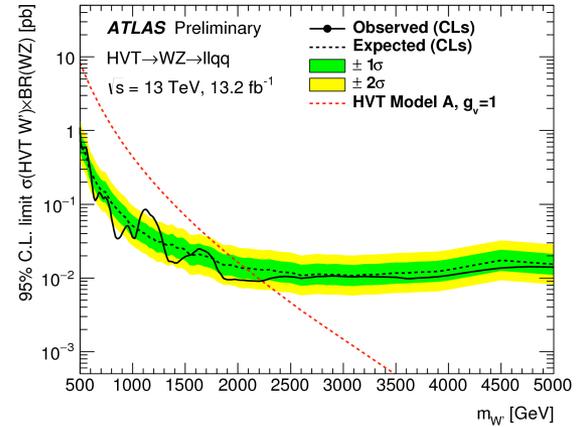
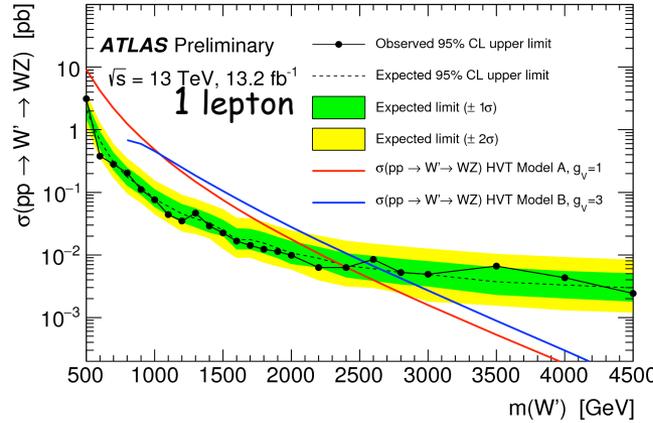
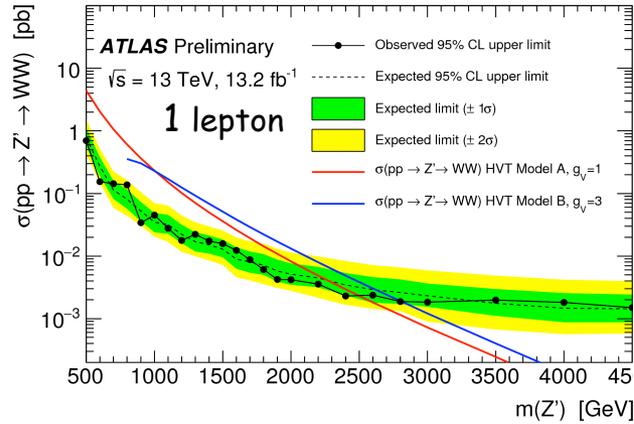
# Comparison between Run 1 & 2 results



- Run 1 excess: 2 TeV, 3.4 sigma (local), 2.5 sigma (Global)
- Not confirmed in Run 2 (2015 + 2016 13 TeV data)

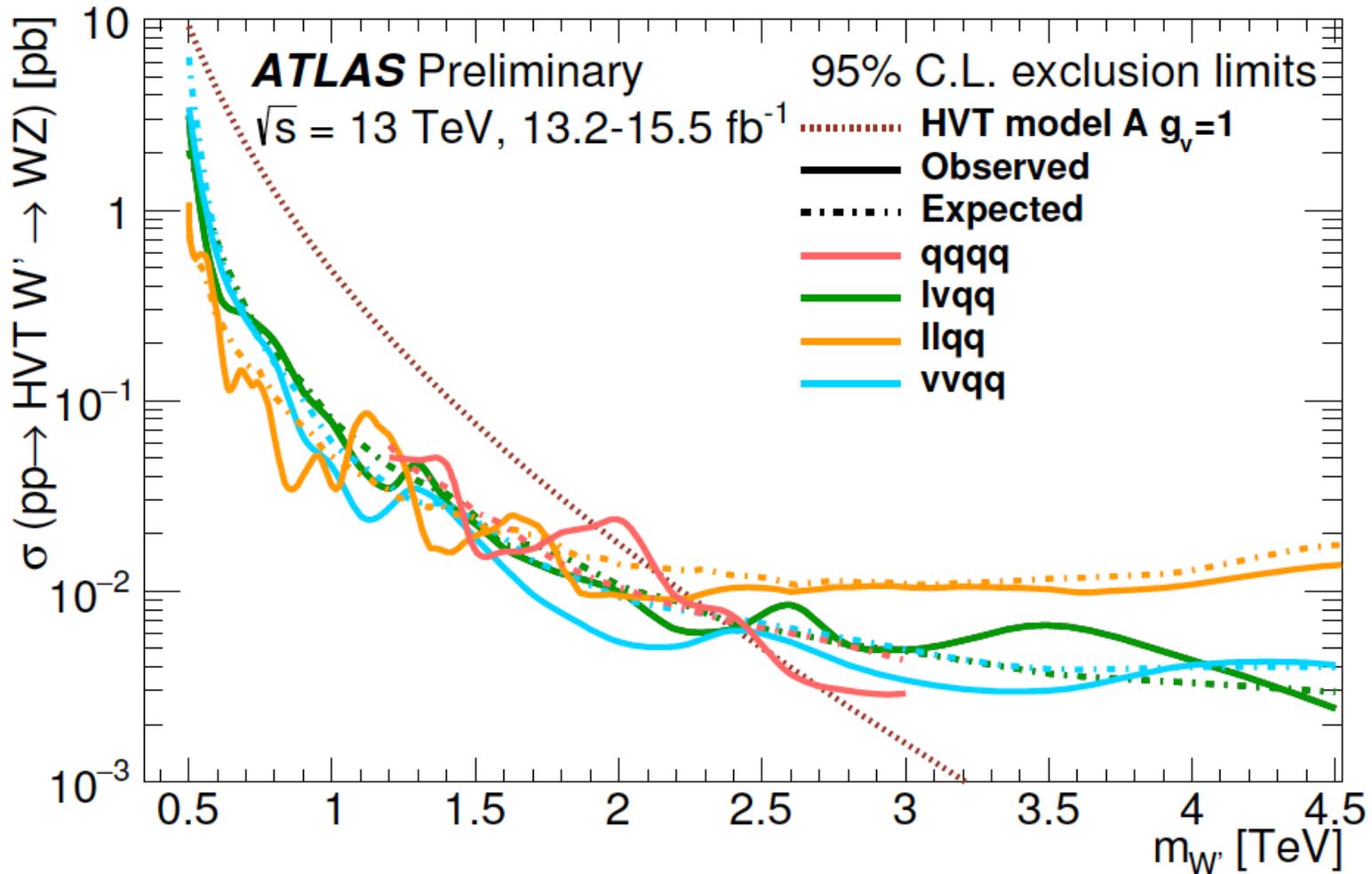
# X → VV (V=W,Z,H) Resonance Searches

A few selected exclusion limits shown here



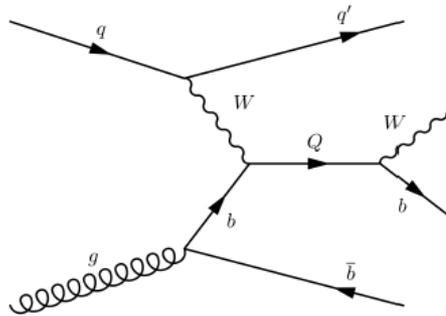
- Limits on other theoretical models as well: Graviton ...
- Similar sensitivity in different final states
- Probe heavy mass at the TeV scale
- Still limited by statistical uncertainties

# X $\rightarrow$ VV (V=W,Z,H) Resonance Searches

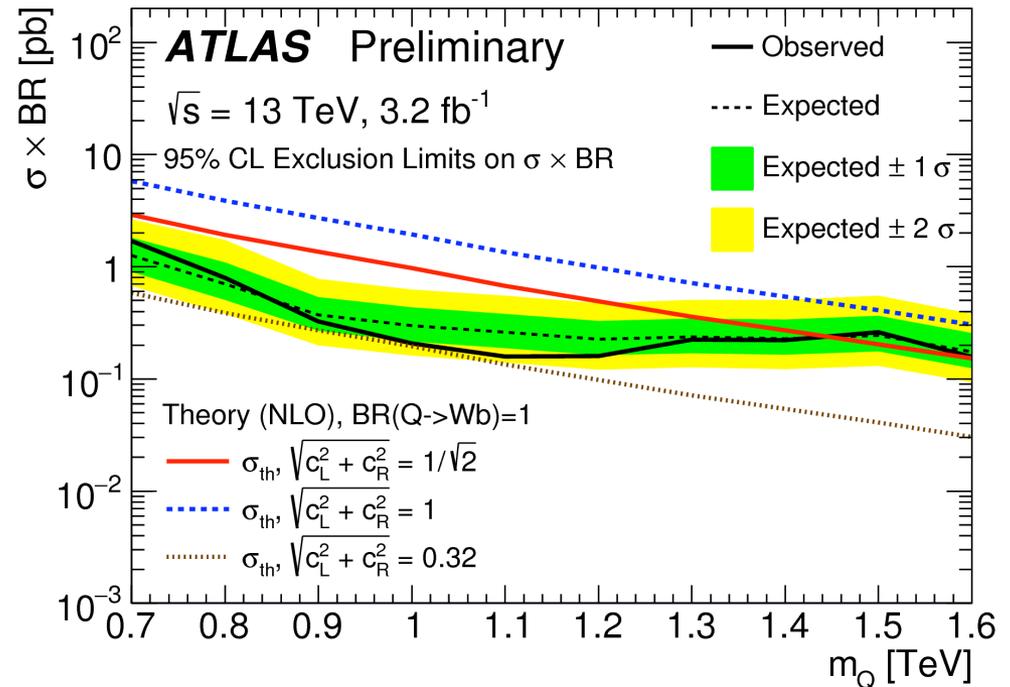
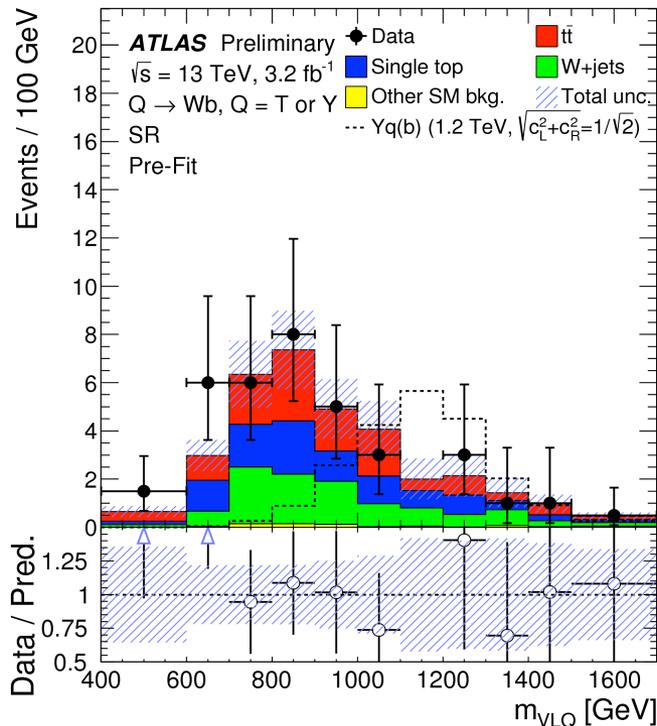


- RS graviton mass limit up to 2 TeV
- HVT  $W'$  mass limit up to 2.4 TeV

# Wb Resonance



- Vector-like Q quark decaying to Wb
  - ✓ Leptonically decaying W
  - ✓ At least 1 forward jets
  - ✓ Full reconstruction of Q mass
- Background modeling
  - ✓ SM W+jets, top, diboson from MC
    - Constrained using control data
  - ✓ Multijets: data driven estimate



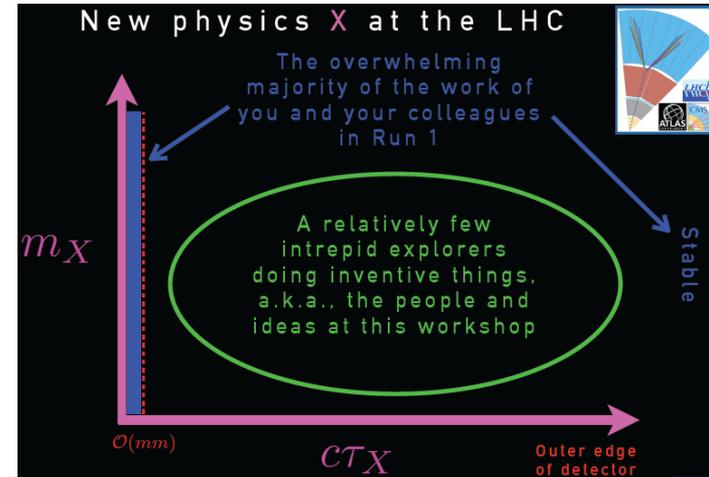
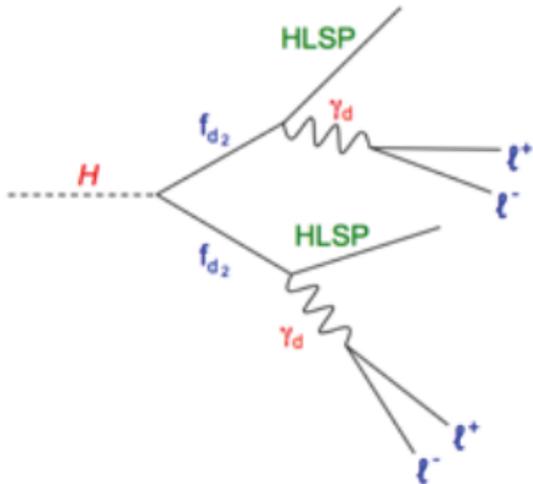
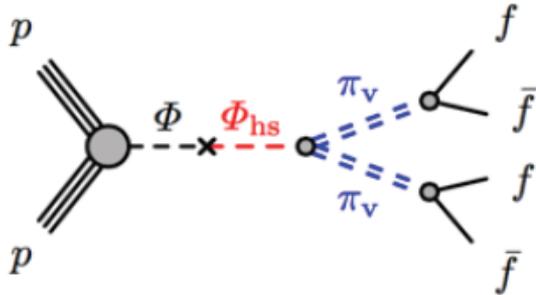
Ref: ATLAS-CONF-2016-072

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-072/>

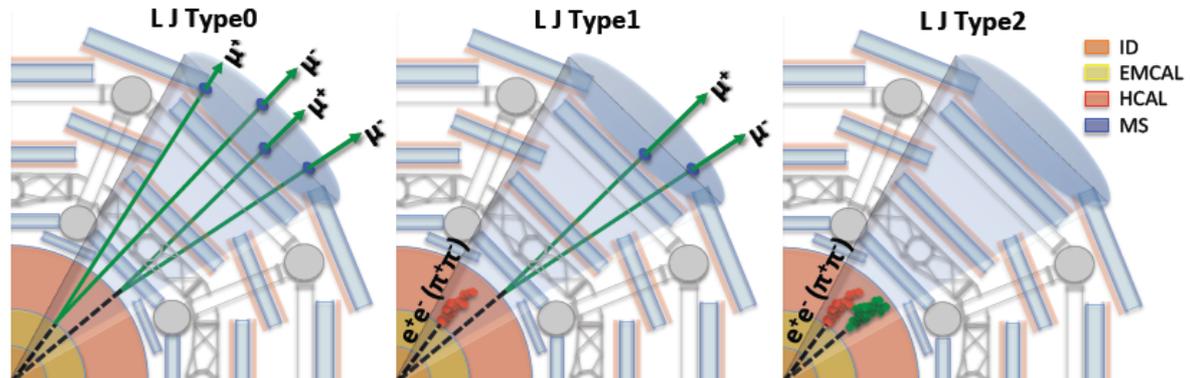
# Unconventional Signature

# Displaced Lepton Jets

- Long lived neutral particles predicted by Hidden sector/Dark sector that don't couple directly with the SM

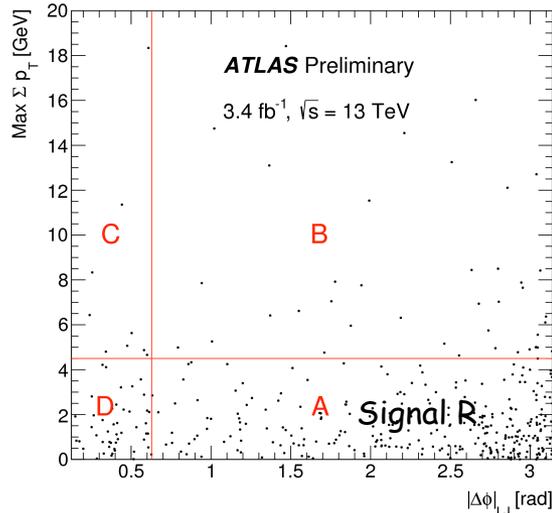


- Displaced jet: narrow jets with litter energy deposition in the EM calorimeter, and no inner detector tracks
- Lepton jet: collinear jet-like structure containing leptons/pions



# Displaced Lepton Jets

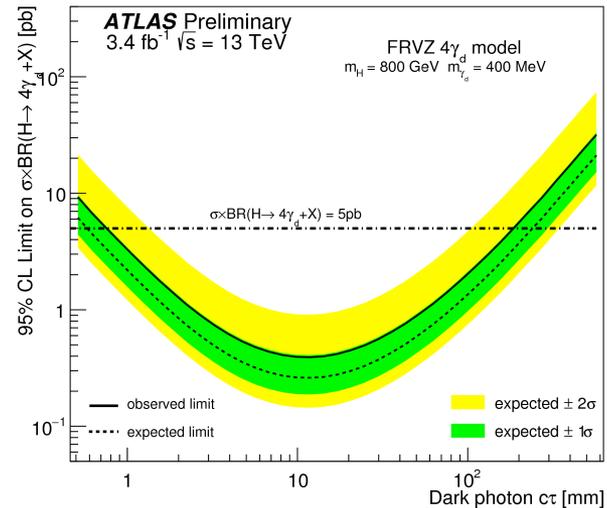
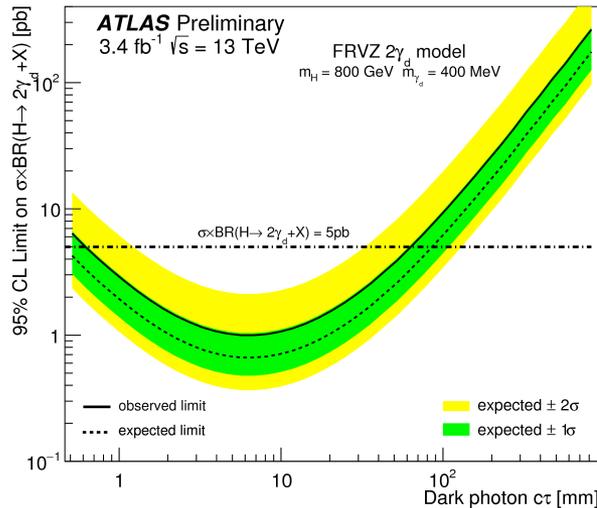
➤ Counting analysis: data driven approach to estimate background (ABCD method)



$|\Delta\phi|$  between the two reconstructed LJs

Category	Observed events	Expected background
All events	285	$231 \pm 12$ (stat) $\pm 62$ (syst)
Type2-Type2 excluded	46	$31.8 \pm 3.8$ (stat) $\pm 8.6$ (syst)
Type2-Type2 only	239	$241 \pm 41$ (stat) $\pm 65$ (syst)

FRVZ model	$m_H$ (GeV)	Excluded $c\tau$ [mm]
Higgs $\rightarrow 2\gamma_d + X$	125	$2.2 \leq c\tau \leq 111.3$
Higgs $\rightarrow 4\gamma_d + X$	800	$3.8 \leq c\tau \leq 163.0$
Higgs $\rightarrow 2\gamma_d + X$	125	$0.6 \leq c\tau \leq 63$
Higgs $\rightarrow 4\gamma_d + X$	800	$0.8 \leq c\tau \leq 186$



Ref: ATLAS-CONF-2016-042

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-042/>

# Conclusion

- Very broad and rich exotic physics program at ATLAS
  - ✓ Only a few selected new results were reported here
  - ✓ Start to probe many possible new particles/NP scenario at TeV scale
  - ✓ Strong constraint for some NP scenario
- Current results still dominated by statistical limitation
  - ✓ Expect significant better physics reach with more data (HL-LHC)

**ATLAS Exotics Searches\* - 95% CL Exclusion**  
 Status: August 2016

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

Model	$\ell, \gamma$	Jets <sup>†</sup>	$E_{T}^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	-	$\geq 1j$	Yes 3.2	$M_D$ 6.58 TeV	$n = 2$ 1604.07773
	ADD non-resonant $\ell\ell$	$2 e, \mu$	-	- 20.3	$M_S$ 4.7 TeV	$n = 3 \text{ HLZ}$ 1407.2410
	ADD QBH $\rightarrow \ell q$	$1 e, \mu$	$1j$	- 20.3	$M_{\text{th}}$ 5.2 TeV	$n = 6$ 1311.2006
	ADD QBH	-	$2j$	- 15.7	$M_{\text{th}}$ 8.7 TeV	$n = 6$ ATLAS-CONF-2016-069
	ADD BH high $\Sigma p_T$	$\geq 1 e, \mu$	$\geq 2j$	- 3.2	$M_{\text{th}}$ 8.2 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1606.02265
	ADD BH multijet	$2 e, \mu$	$\geq 3j$	- 3.6	$M_{\text{th}}$ 9.55 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	$2 e, \mu$	-	- 20.3	$G_{KK} \text{ mass}$ 2.68 TeV	$k/\overline{M}_n = 0.1$ 1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	$2 \gamma$	-	- 3.2	$G_{KK} \text{ mass}$ 3.2 TeV	$k/\overline{M}_n = 0.1$ 1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq/\ell\nu$	$1 e, \mu$	$1j$	Yes 13.2	$G_{KK} \text{ mass}$ 1.24 TeV	$k/\overline{M}_n = 1.0$ ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	-	$4b$	- 13.3	$G_{KK} \text{ mass}$ 360-860 GeV	$k/\overline{M}_n = 1.0$ ATLAS-CONF-2016-049
Bulk RS $g_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1b, \geq 1J/2j$	Yes 20.3	$G_{KK} \text{ mass}$ 2.2 TeV	BR = 0.925 1505.07018	
2UED / RPP	$1 e, \mu$	$\geq 2b, \geq 4j$	Yes 3.2	KK mass 1.46 TeV	Tier (1,1), BR( $A^{(1,1)} \rightarrow t\bar{t}$ ) = 1 ATLAS-CONF-2016-013	
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	- 13.3	$Z' \text{ mass}$ 4.05 TeV	ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	$2 \tau$	-	- 19.5	$Z' \text{ mass}$ 2.02 TeV	1502.07177
	Leptophobic $Z' \rightarrow bb$	-	$2b$	- 3.2	$Z' \text{ mass}$ 1.5 TeV	1603.08791
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes 13.3	$W' \text{ mass}$ 4.74 TeV	ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	$0 e, \mu$	$1j$	Yes 13.2	$W' \text{ mass}$ 2.4 TeV	$g_V = 1$ ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qqgg$ model B	-	$2j$	- 15.5	$W' \text{ mass}$ 3.0 TeV	$g_V = 3$ ATLAS-CONF-2016-055
	HVT $V' \rightarrow W\gamma/ZH$ model B	multi-channel	$2b, 0-1j$	Yes 20.3	$W' \text{ mass}$ 2.31 TeV	$g_V = 3$ 1607.05621
	LRSM $W'_L \rightarrow tb$	$1 e, \mu$	$2b, 0-1j$	Yes 20.3	$W' \text{ mass}$ 1.92 TeV	1410.4103
	LRSM $W'_R \rightarrow tb$	$0 e, \mu$	$\geq 1b, 1j$	- 20.3	$W' \text{ mass}$ 1.76 TeV	1408.0886
	CI	CI $qqqq$	-	$2j$	- 15.7	$A$ 19.9 TeV $\eta_{LL} = -1$
CI $\ell\ell qq$		$2 e, \mu$	-	- 3.2	$A$ 25.2 TeV $\eta_{LL} = -1$	1607.03669
CI $u\bar{u}t\bar{t}$		$2(SS)/\geq 3 e, \mu \geq 1b, \geq 1j$	-	Yes 20.3	$A$ 4.9 TeV	1504.04605
DM	Axial-vector mediator (Dirac DM)	$0 e, \mu$	$\geq 1j$	Yes 3.2	$m_A$ 1.0 TeV	$g_0=0.25, g_1=1.0, m(\chi) < 250 \text{ GeV}$ 1604.07773
	Axial-vector mediator (Dirac DM)	$0 e, \mu, 1 \gamma$	$1j$	Yes 3.2	$m_A$ 710 GeV	$g_0=0.25, g_1=1.0, m(\chi) < 150 \text{ GeV}$ 1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	$0 e, \mu, 1 \gamma, \leq 1j$	Yes 3.2	$m_A$ 550 GeV	$m(\chi) < 150 \text{ GeV}$ ATLAS-CONF-2015-080	
LQ	Scalar LQ 1 <sup>st</sup> gen	$2 e$	$\geq 2j$	- 3.2	LQ mass 1.1 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 2 <sup>nd</sup> gen	$2 \mu$	$\geq 2j$	- 3.2	LQ mass 1.05 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 3 <sup>rd</sup> gen	$1 e, \mu$	$\geq 1b, \geq 3j$	Yes 20.3	LQ mass 640 GeV	$\beta = 0$ 1508.04735
Heavy quarks	VLO $TT \rightarrow Ht + X$	$1 e, \mu$	$\geq 2b, \geq 3j$	Yes 20.3	T mass 855 GeV	T in (T,B) doublet 1505.04306
	VLO $YY \rightarrow Wb + X$	$1 e, \mu$	$\geq 1b, \geq 3j$	Yes 20.3	Y mass 770 GeV	Y in (B,Y) doublet 1505.04306
	VLO $BB \rightarrow Hb + X$	$1 e, \mu$	$\geq 2b, \geq 3j$	Yes 20.3	B mass 735 GeV	isospin singlet 1505.04306
	VLO $BB \rightarrow Zb + X$	$2/\geq 3 e, \mu$	$\geq 2/\geq 1b$	- 20.3	B mass 755 GeV	B in (B,Y) doublet 1409.5500
	VLO $QQ \rightarrow WqWq$	$1 e, \mu$	$\geq 4j$	Yes 20.3	Q mass 690 GeV	1509.04261
	VLO $T_{5/3} T_{5/3} \rightarrow WtWt$	$2(SS)/\geq 3 e, \mu \geq 1b, \geq 1j$	Yes 3.2	$T_{5/3} \text{ mass}$ 990 GeV	ATLAS-CONF-2016-032	
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	$1 \gamma$	$1j$	- 3.2	$q^* \text{ mass}$ 4.4 TeV	only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ 1512.05910
	Excited quark $q^* \rightarrow qg$	-	$2j$	- 15.7	$q^* \text{ mass}$ 5.6 TeV	only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow bg$	-	$1b, 1j$	- 8.8	$b^* \text{ mass}$ 2.3 TeV	$f_1 = f_2 = f_3 = 1$ 1510.02664
	Excited quark $b^* \rightarrow Wt$	$1 \text{ of } 2 e, \mu$	$1b, 2-0j$	Yes 20.3	$b^* \text{ mass}$ 1.5 TeV	$\Lambda = 3.0 \text{ TeV}$ 1411.2921
	Excited lepton $\ell^*$	$3 e, \mu, \tau$	-	- 20.3	$\ell^* \text{ mass}$ 3.0 TeV	$\Lambda = 1.6 \text{ TeV}$ 1411.2921
	Excited lepton $\nu^*$	$3 e, \mu, \tau$	-	- 20.3	$\nu^* \text{ mass}$ 1.6 TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	$1 e, \mu, 1 \gamma$	-	Yes 20.3	$a_T \text{ mass}$ 960 GeV	1407.8150
	LRSM Majorana $\nu$	$2 e, \mu$	$2j$	- 20.3	$\overline{N} \text{ mass}$ 2.0 TeV	1508.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	$2 e (SS)$	-	- 13.9	$H^{\pm\pm} \text{ mass}$ 570 GeV	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	- 20.3	$H^{\pm\pm} \text{ mass}$ 400 GeV	1411.2921
	Monotop (non-res prod)	$1 e, \mu$	$1b$	Yes 20.3	spin-1 invisible particle mass 657 GeV	$\beta_{non-res} = 0.2$ 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$ 1509.08059

\*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).

# Backup

# The ATLAS Detector

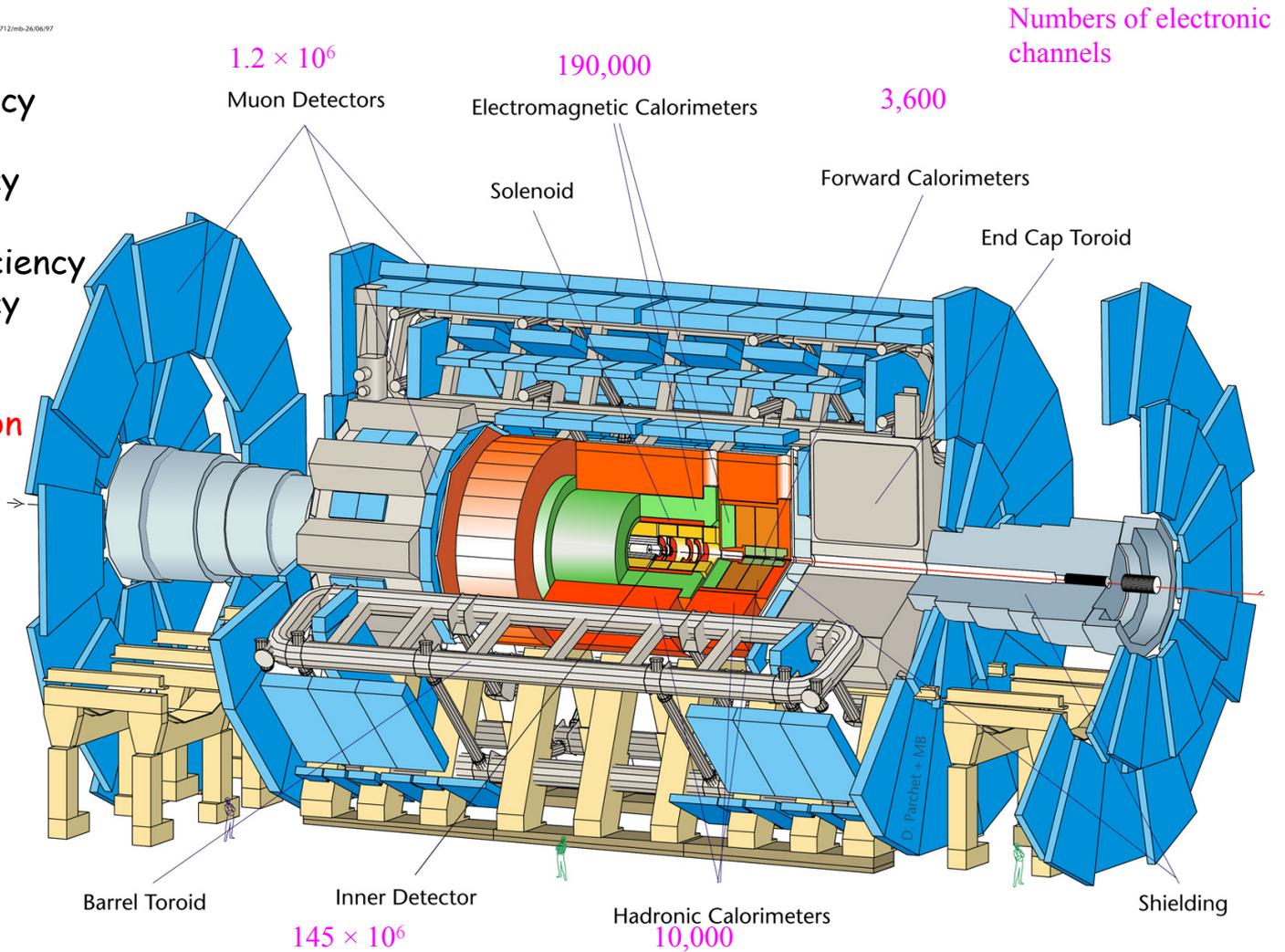
0712mb-26/06/97

e: ~75 - 90% efficiency

muon: ~90% efficiency

b tagging: ~57% efficiency  
~ 0.2% fake efficiency  
from light jets

Efficiency & resolution  
dependents on the  
selection criteria



46 m long, Overall weight: 7000 Tons

Excellent reconstruction efficiency and resolution:  
Electron, muon, track, jets, b-tagging & missing transverse energy