Searches for new physics with bosons at the ATLAS detector in LHC Run II

8th Feb 2016

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On behalf of the ATLAS collaboration

Lake Louise Winter Institute 2016

INTRODUCTION

- Resonant production of two massive bosons

  Run I and Run II results

- Diphoton resonance production

  Run II results

Diboson Resonance Searches

Benchmark Models and Event Topology

Diboson resonances are predicted in a number of proposed extensions to the SM.

- Technicolor
- Warped extra dimensions
- Two Higgs doublet model (2HDM)
- Grand Unified Theories (GUTs)
- Sequential Standard Model (SSM)

Benchmark models:

Bulk RS graviton – Run I & II
Extended Gauge Model (EGM) – Run I
Heavy Vector Triplet (HVT) Model A – Run II

Parameters in the models are different to those used in the $V'/G_{RS} \rightarrow ll, qq$ analyses.

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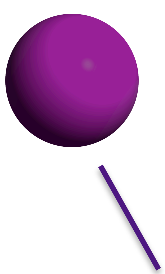

Mass ~ TeV

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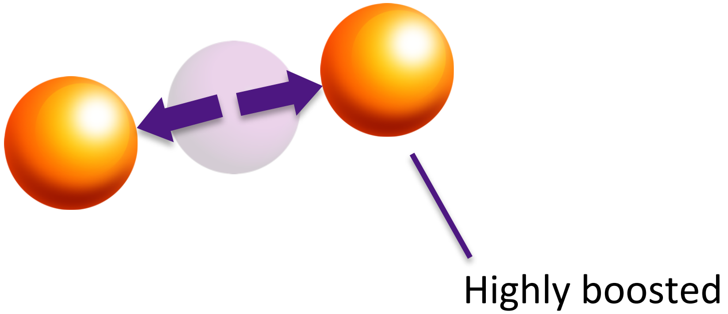

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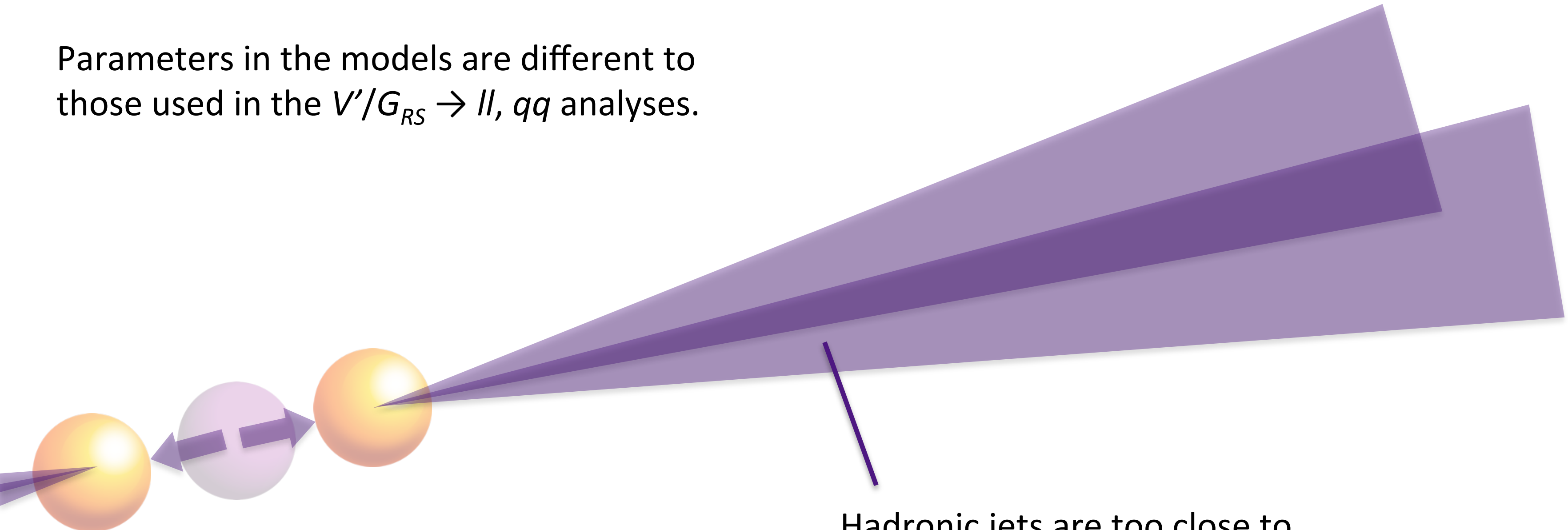

Hadronic jets are too close to each other to be resolved

Benchmark Models and Event Topology

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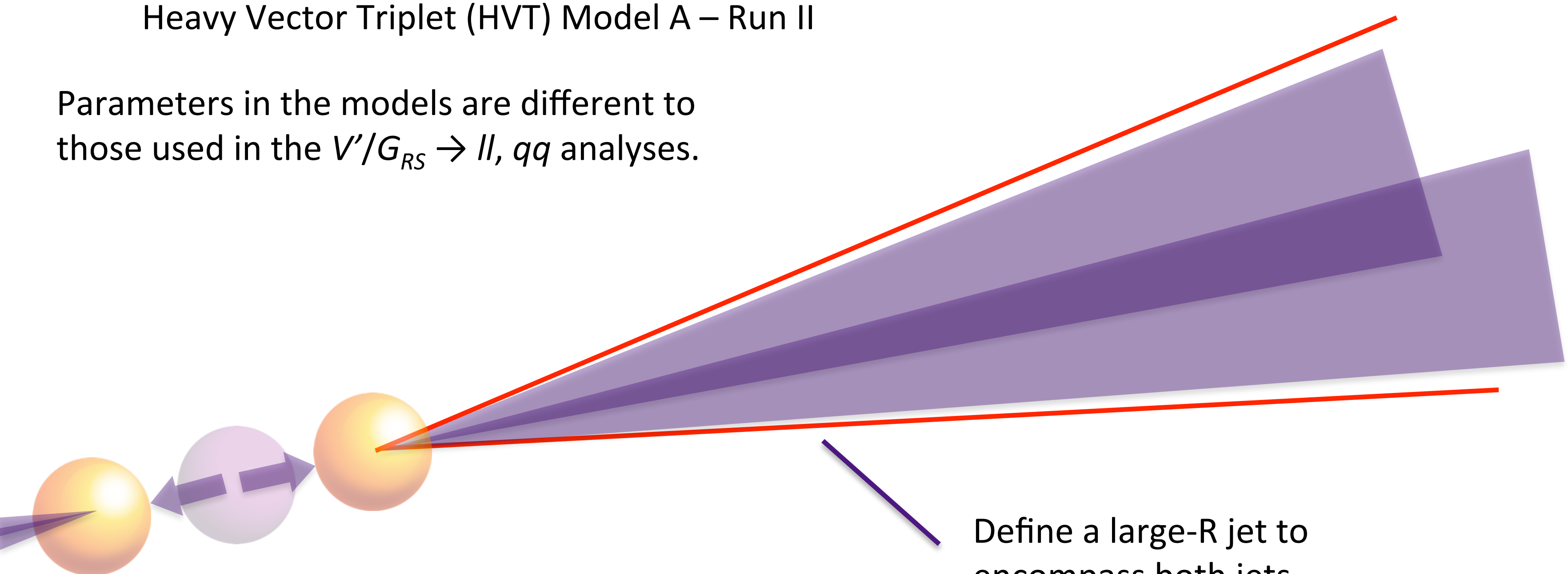


Define a large-R jet to encompass both jets

Trimming and boson tagging applied to large-R jets

Run I Combination

$VV \rightarrow q\bar{q}^{(\prime)}q\bar{q}^{(\prime)}$
$WV \rightarrow l\nu q\bar{q}^{(\prime)}$
$ZV \rightarrow llq\bar{q}^{(\prime)}$
$WZ \rightarrow l\nu l\bar{l}$

EXOT-2013-08 (JHEP)
EXOT-2013-01 (EPJC)
EXOT-2013-06 (EPJC)
EXOT-2013-07 (PLB)

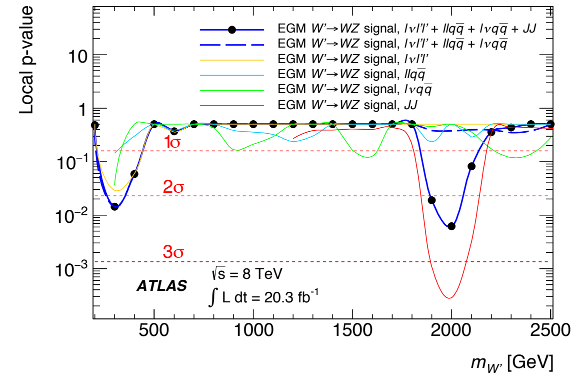
EXOT-2014-18 (PLB)

Several final states probed in Run I

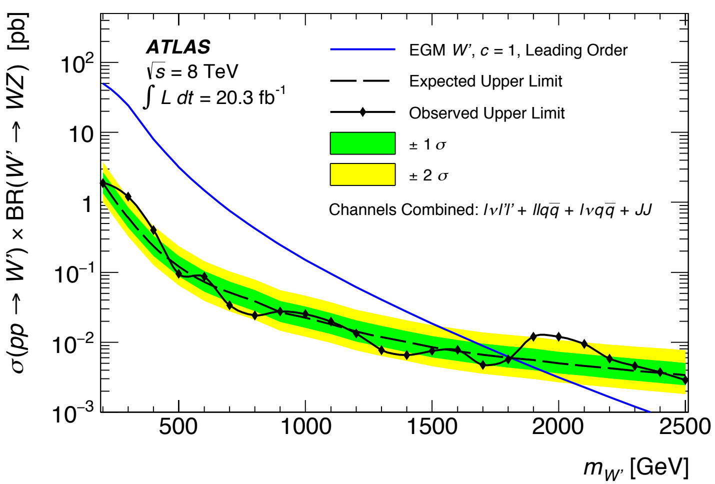
Share object definitions and tools
Search for resonances in the range 300 GeV to 3000 GeV

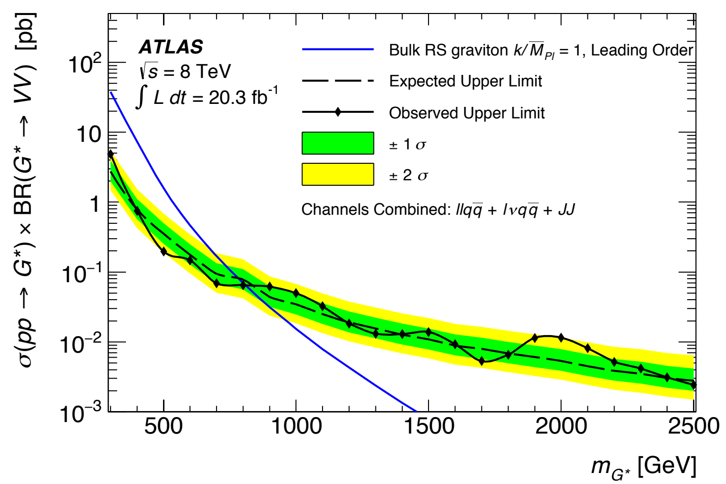
Most interesting result comes from the *qqqq* analysis.
Local (global) significance of 3.4 σ (2.5 σ) at 2 TeV.

The local significance at 2 TeV reduces to 2.5 σ in the combination



EGM *W′* excluded below 1.81 TeV
Bulk RS graviton excluded below 810 GeV





Run II Overview

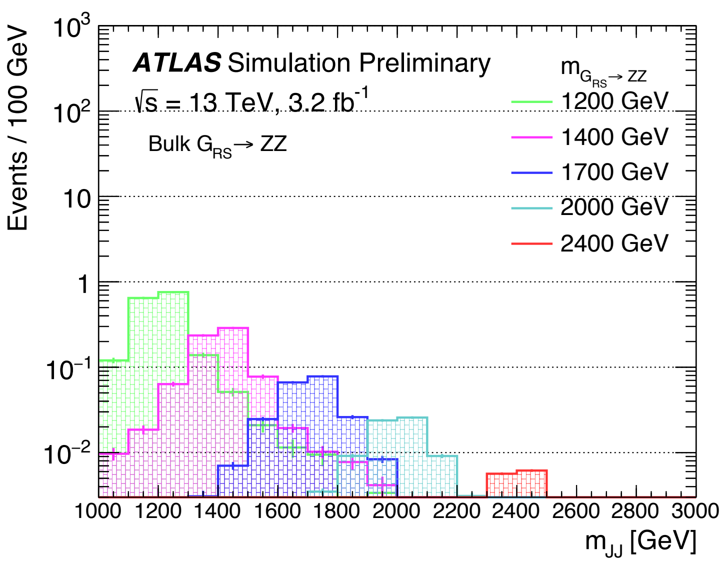
Several final states probed
Share object definitions and tools
Search for resonances in the range
700 GeV to 3000 GeV

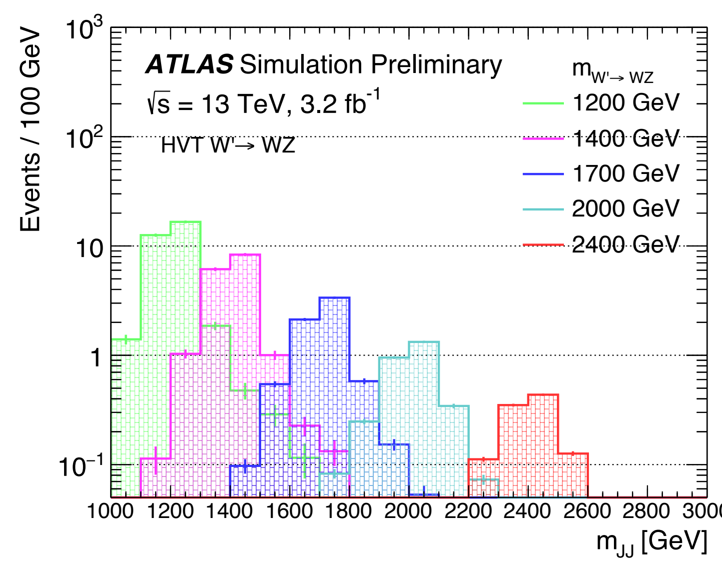
Benchmark Models
- Bulk RS graviton
- Heavy Vector Triplet (HVT)

Parameters are chosen such as to resemble the Run I EGM benchmark

Veto placed on *qq* systems to remove b-tagged jets.

$VV \to q\bar{q}^{(\prime)}q\bar{q}^{(\prime)}$		ATLAS-CONF-2015-073
$ZV \to \nu\nu q\bar{q}^{(\prime)}$		ATLAS-CONF-2015-068
$WV \to l\nu q\bar{q}^{(\prime)}$		ATLAS-CONF-2015-075
$ZV \to llq\bar{q}^{(\prime)}$		ATLAS-CONF-2015-071
$VH \to llb\bar{b},\ l\nu b\bar{b},\ \nu\nu b\bar{b}$		ATLAS-CONF-2015-074





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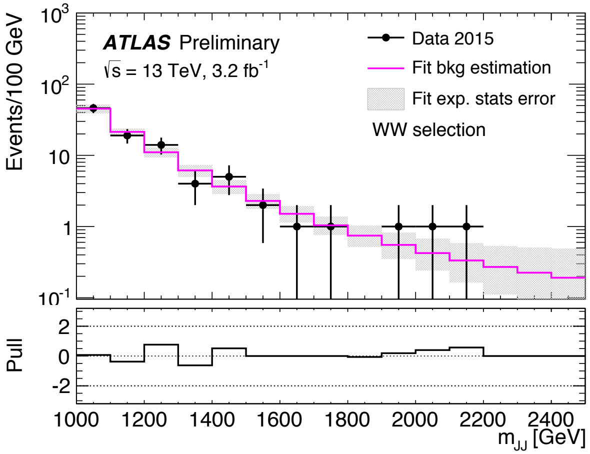
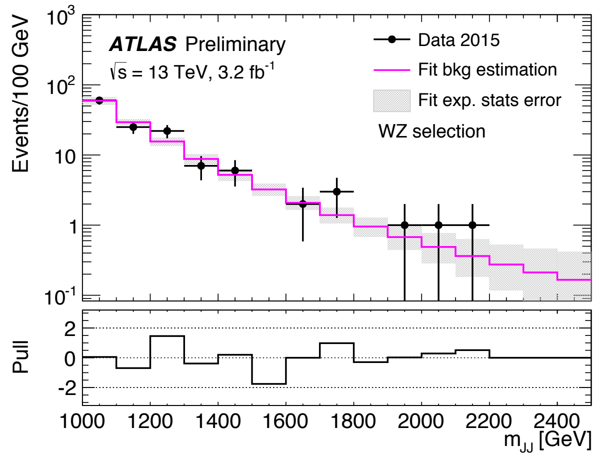
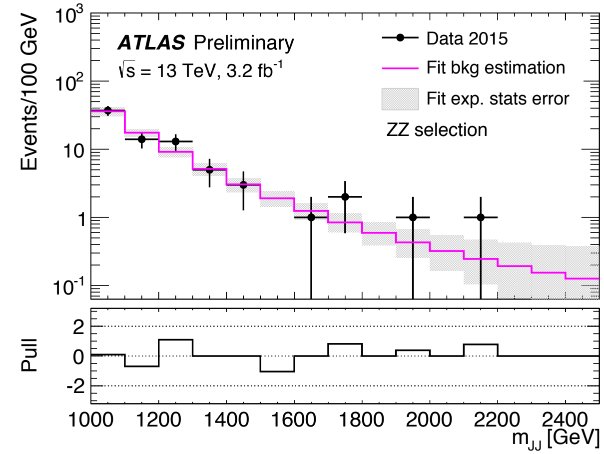






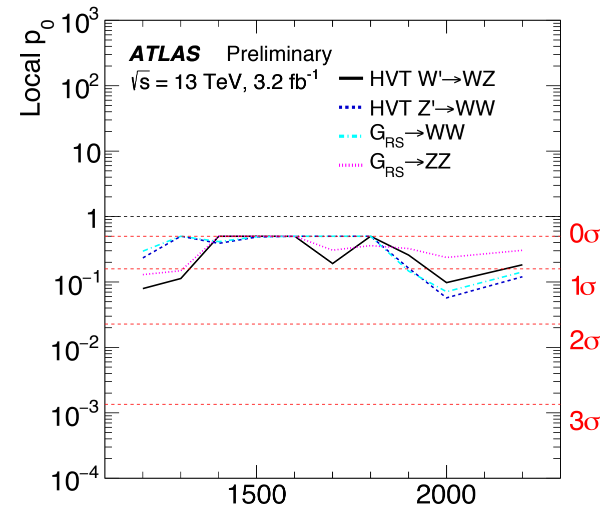
Three (overlapping) signal regions are defined by placing cuts on the jet masses.
Background modelled with a smoothly falling distribution.

Selection Criteria

- No charged leptons
- 2 large-R jets
- $p_T^{J1} > 450$ GeV
- $p_T^{J2} > 200$ GeV
- $|m_V - m_J| < 15$ GeV
- Reject jets in the range 110 GeV < m_J < 140 GeV
- $E_T^{miss} < 250$ GeV

QCD multijet background dominates.

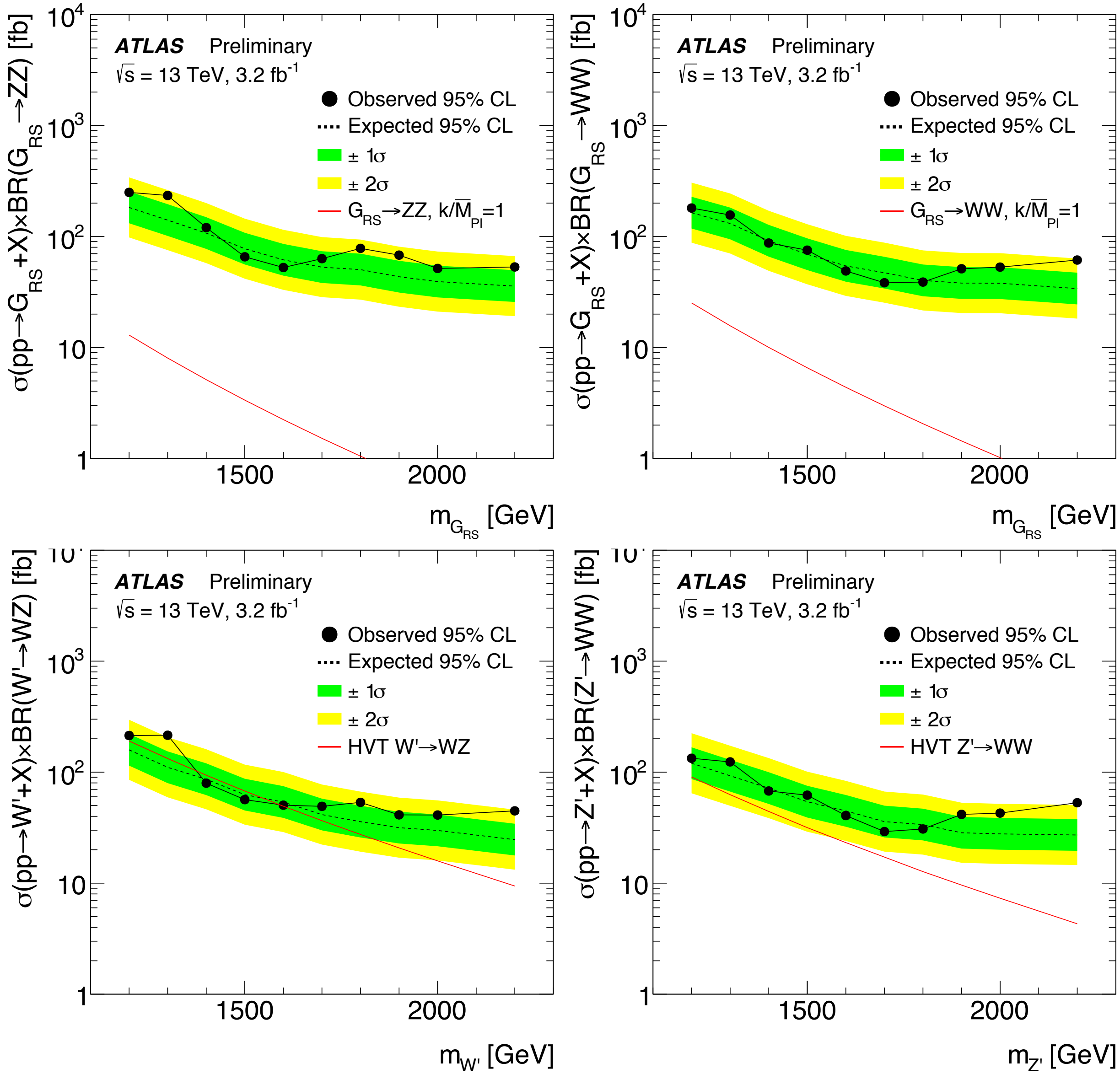
Dominant uncertainties relate to large-R jet mass and energy measurement.



No significant excesses are observed.

DIBOSON $VV \rightarrow qqqq$

ATLAS-CONF-2015-073



Mass limits set for
1.2 TeV < m_{JJ} < 2.2 TeV

W' is excluded in the range
1.38 TeV < $m_{W'}$ < 1.60 TeV

At 2 TeV, the Run I *qqqq* analysis was sensitive to cross-sections a factor of 3 smaller.

At this point there is no tension between the results.

$ZV \rightarrow llqq$

ATLAS-CONF-2015-071

Selection Criteria

- Exactly two same flavor leptons
- Muons are required to have opposite charge
- p_T^{μ}, E_T^{e} > 25 GeV
- p_T^{J} > 200 GeV
- 83 GeV < m_{ee} < 99 GeV
- 66 GeV < $m_{\mu\mu}$ < 116 GeV
- p_T^{ll} > 0.4 m_{llJ}
- p_T^{J} > 0.4 m_{llJ}

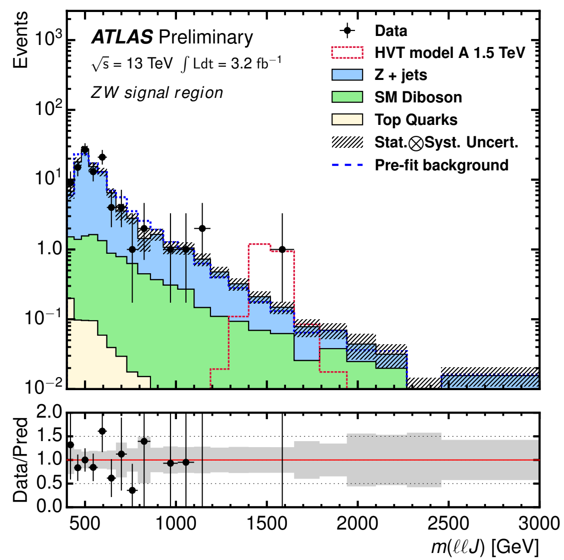
The *vvqq* and *lvqq* analyses aren't described in detail, but follow a similar strategy

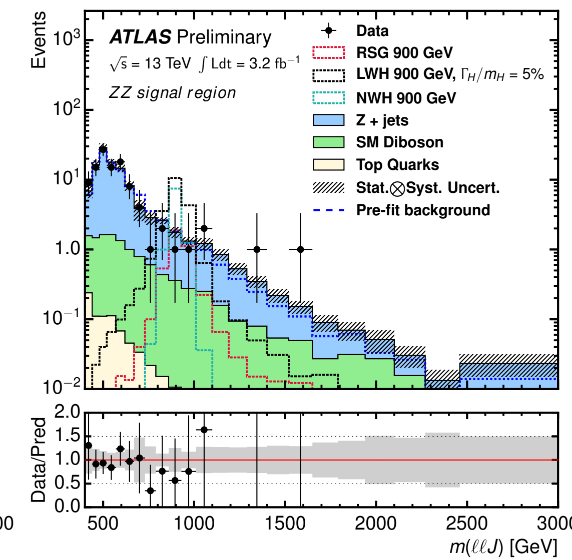
Background is dominated by *Z*+jets.

This background is estimated through a combination of MC and data-driven methods.

Dominant uncertainties relate to large-R jet mass and energy measurement.

A good agreement is seen between background only prediction and data.

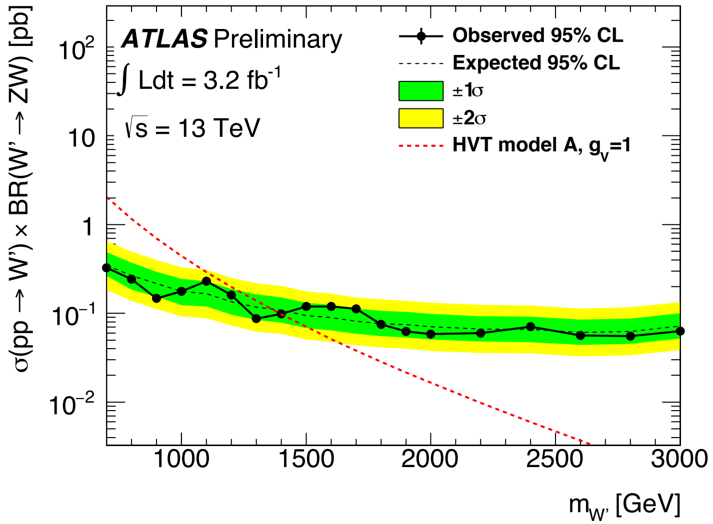




$ZV \rightarrow llqq$

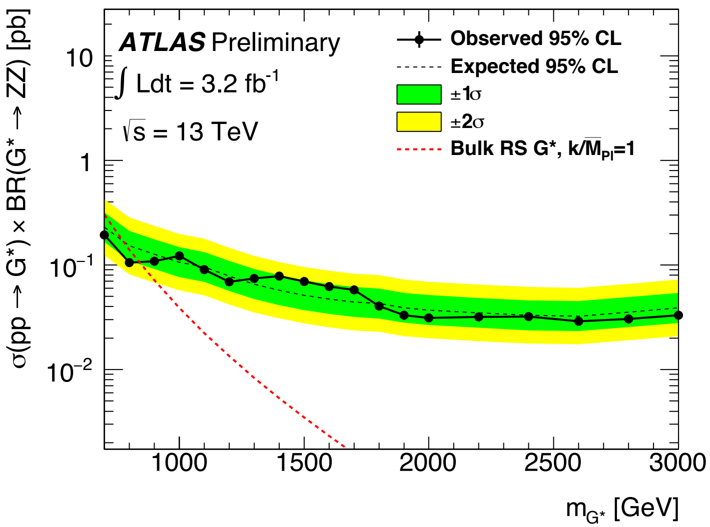
ATLAS-CONF-2015-071

W′ excluded below 1400 GeV

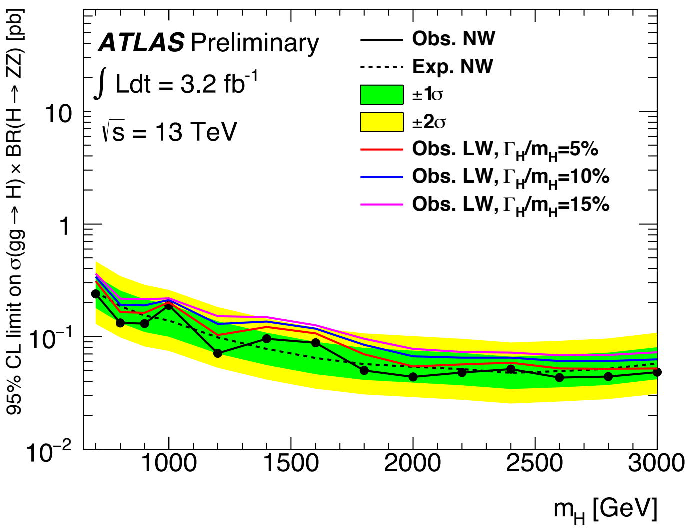


Comparable sensitivities are present in the *vvqq* and *lvqq* analyses.

G_{RS} excluded below 850 GeV



Heavy Higgs model also tested. Not optimized for this signal.



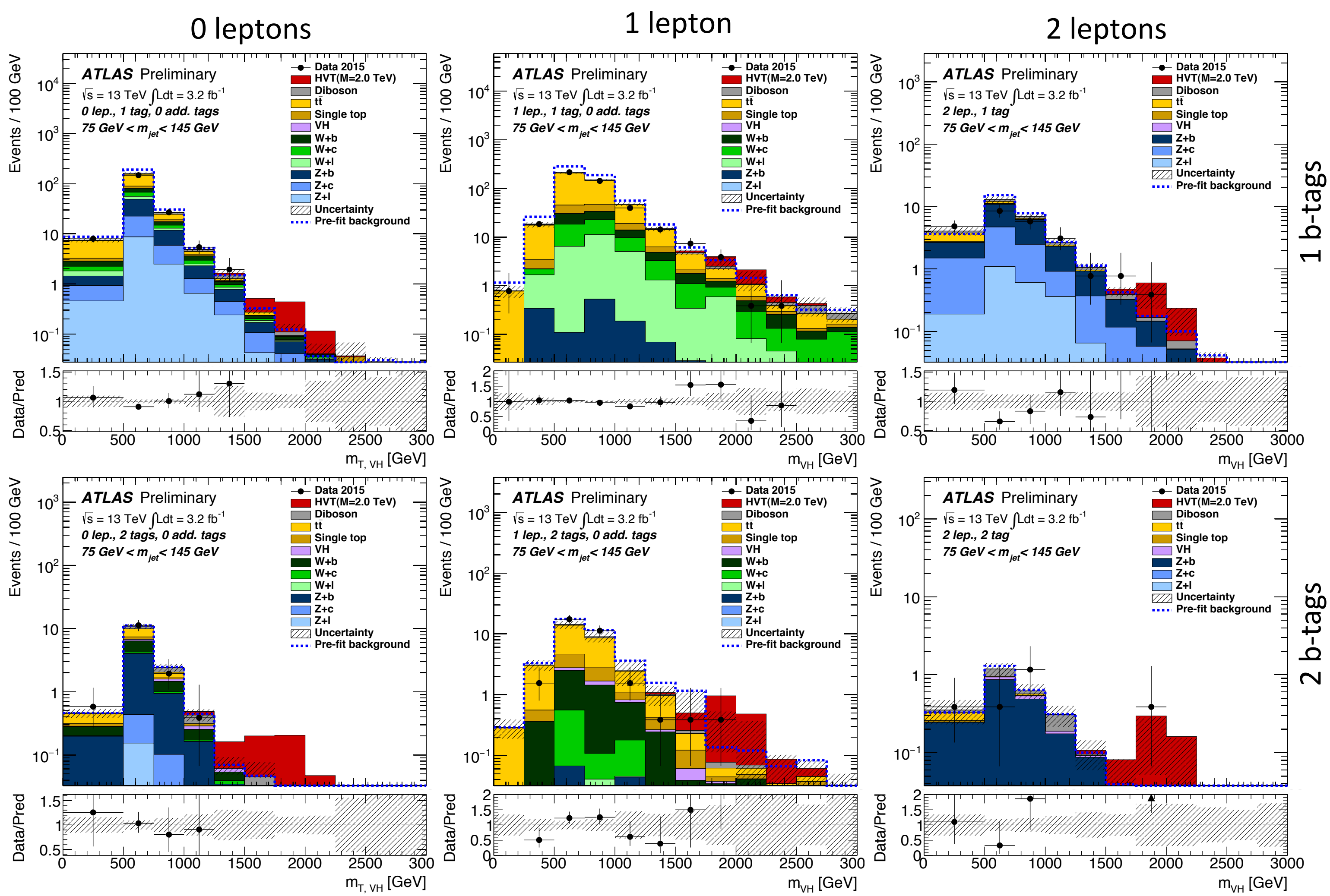
DIBOSON $VH \rightarrow \nu\nu bb, l\nu bb, llbb$

ATLAS-CONF-2015-074

The background is dominated by *V*+jets.
Dominant uncertainties relate to large-R jet mass and energy measurement.

The large-R jet is required to have either one or two b-tagged jets associated to it.

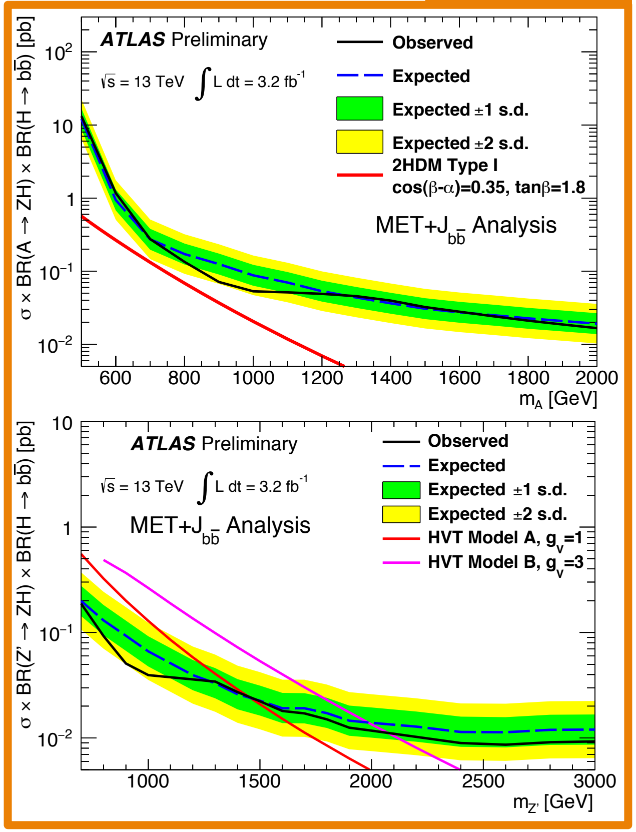
A good agreement is seen between background only prediction and data.



ATLAS-CONF-2015-074

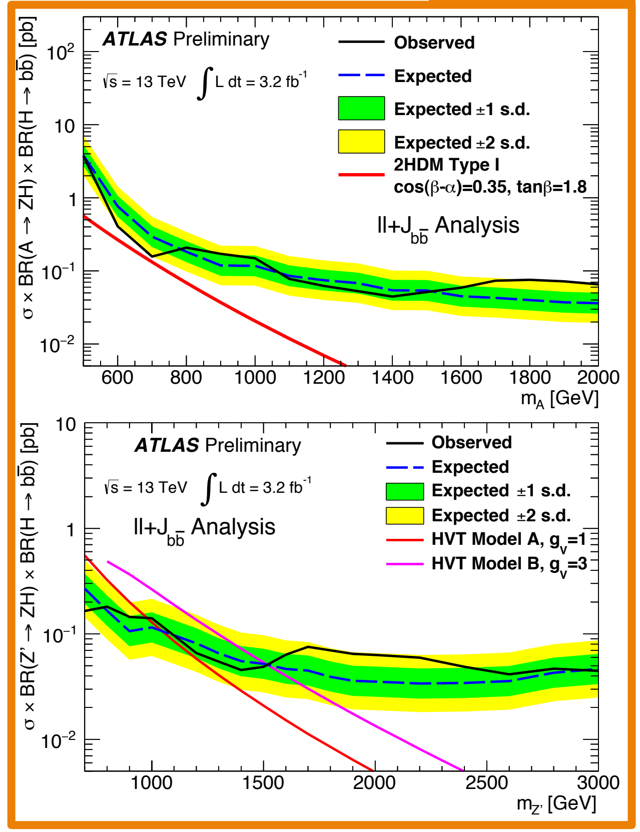
Limits are set independently on the 0, 1 and 2 lepton channels
Two HVT models are tested: Model A and B.
Mass exclusions are given for the same model used in the previously described analyses

0 leptons

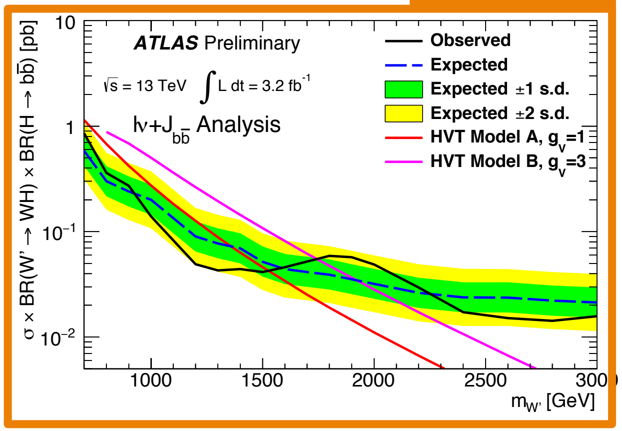


Heavy CP-odd scalar *A*, is also tested.

2 leptons



1 lepton



Z' is excluded below 1450 GeV

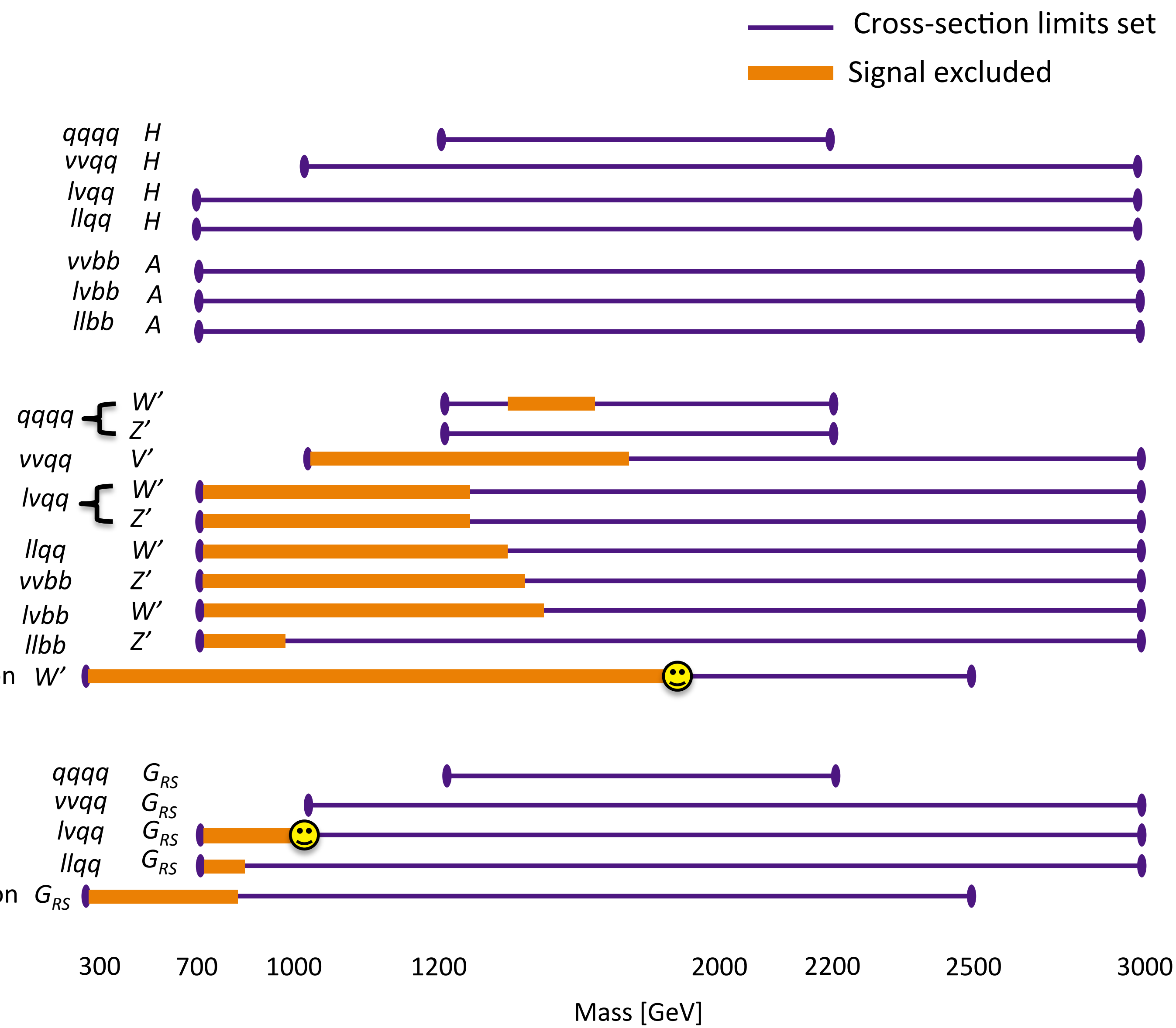
W' is excluded below 1520 GeV

Z' is excluded below 980 GeV

Summary

Cross section limits range from 700 GeV to 3 TeV.

Diboson analyses performed in a large range of final states.



Best mass limit exclusions

V' < 1.81 TeV

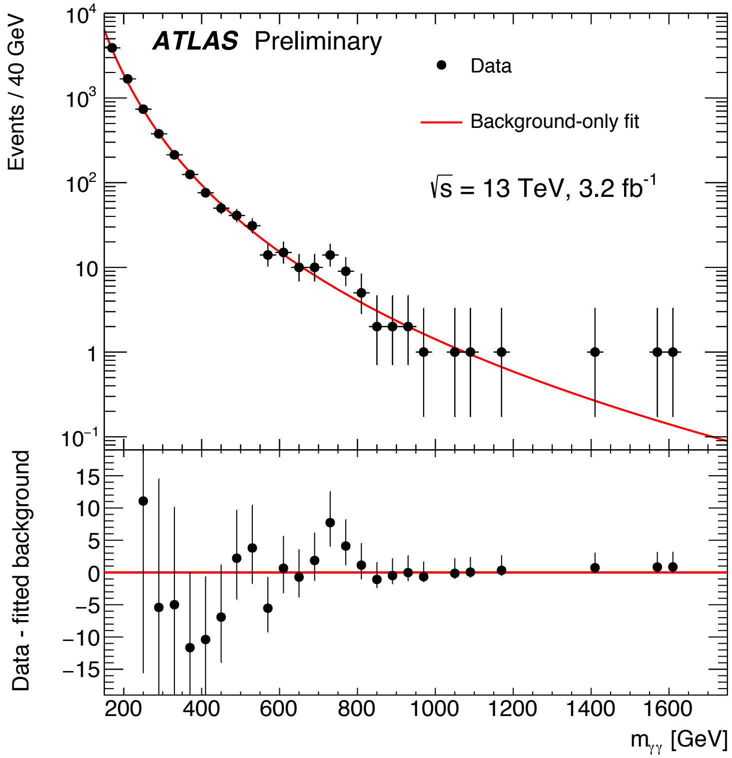
G_{RS} < 1.06 TeV

Diphoton Resonance Search

ATLAS-CONF-2015-081

Search for resonant production in $m_{\gamma\gamma}$ distribution
Optimised for scalar production using NWA and LWA

Background is dominanted by QCD production of two prompt photons



Selection Criteria

- Leading photon $E_T > 0.4\ m_{\gamma\gamma}$
- Subleading photon $E_T > 0.3\ m_{\gamma\gamma}$

Having relative E_T cuts leads to a 10% -> 20% increase in sensitivity.

Data driven background modelling
Smoothly falling distribution fitted to the signal region

$$f_0(x; b, a_0) = (1 - x^{1/3})^b x^{a_0}$$

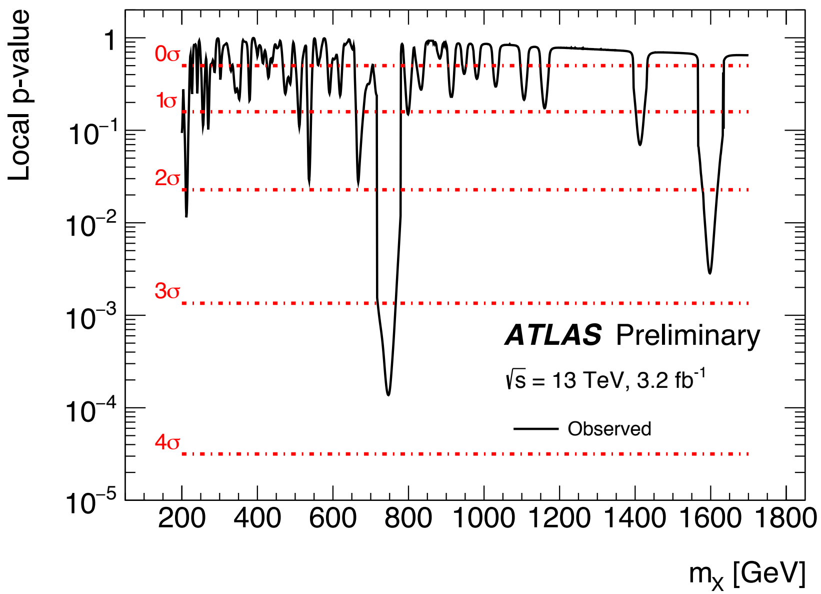
Background fit performed for 170 GeV < $m_{\gamma\gamma}$ < 2000 GeV

Signal modelled with a Double-Sided Crystal Ball function
200 GeV < m_H < 1700 GeV

Dominant uncertainties are from the photon energy measurement and background fit.

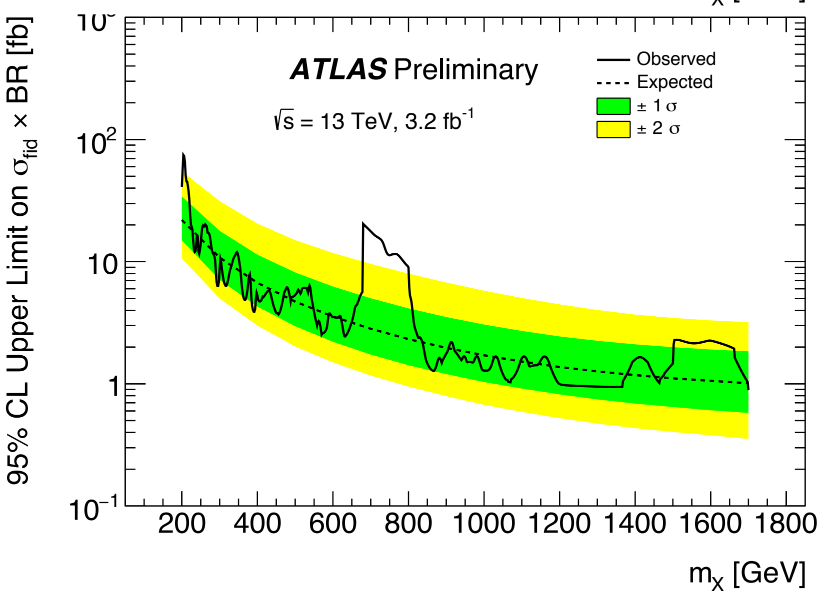
Resolution of $m_{\gamma\gamma}$ increases with mass
2 GeV at 200 GeV
13 GeV at 2 TeV

ATLAS-CONF-2015-081



The largest deviation from background only at 750 GeV
Local (global) excess of 3.6 σ (2.0 σ) for NWA
Local (global) excess of 3.9 σ (2.3 σ) for a width of 45 GeV

At 750 GeV, the mass resolution is 6 GeV



Second largest deviation from background only at 1.6 TeV
Local excess of 2.8 σ for NWA

Limits are set on the product of fiducial cross-section and branching ratio.

Conclusion

CONCLUSION

Luminosities used in analyses

Run I	20.3 fb^{-1}	8 TeV
Run II (2015)	3.2 fb^{-1}	13 TeV
Run II (2016)	30 fb^{-1}	

Diboson Resonances

Diboson resonances have been probed at the TeV scale
Large number of decay channels probed

A local (global) 3.4 σ (2.5 σ) excess is seen at 2 TeV for diboson resonace in the *qqqq* channel (only) in Run I
Run II analyses are limited by the current small data set
Expected 2016 dataset should be sufficient to confirm/exclude this excess.

Diphoton Resonance

A local (global) 3.9 σ (2.3 σ) excess is seen at 750 GeV with a width of 45 GeV
A local (global) 2.6 σ (1.2 σ) excess is seen at 760 GeV in the corresponding CMS analyses

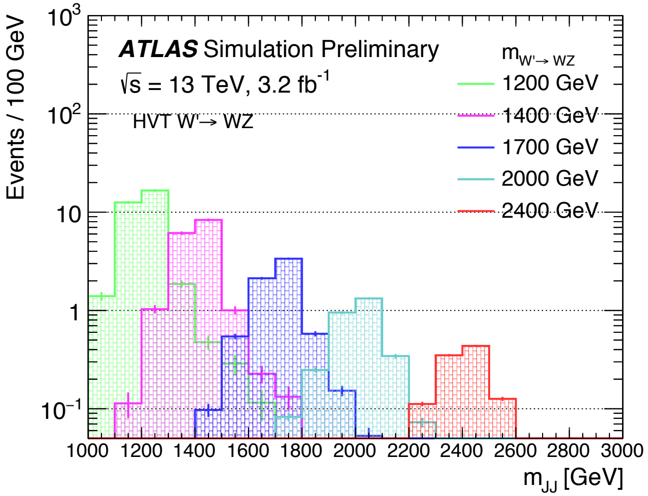
All pointing towards 2016 being an exciting year!

Backup Slides

Benchmark Models

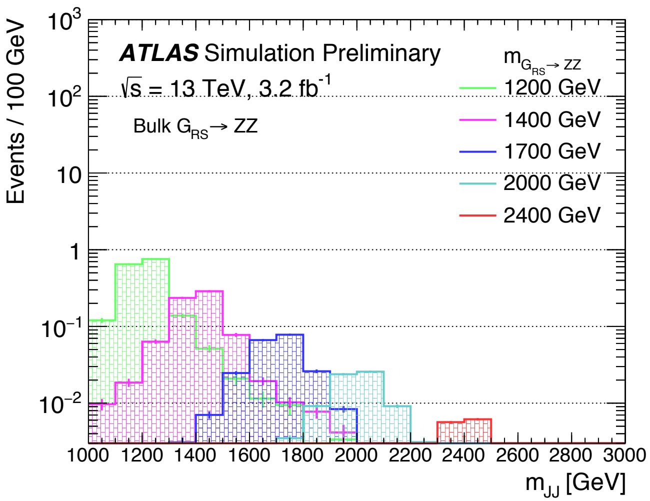
Heavy VectorTriplet (HVT) Model A

- Generic phenomenological Lagrangian
- Introduces a new Heavy Vector Triplet (*W'*, *Z'*)
- Parameters in model A are chosen so as to be similar to the Extended Gauge Model (EGM) which was tested in run 1.
- Branching ratios of $W' \rightarrow WZ$, WH and $Z' \rightarrow WW$, ZH are ≈2%.
- Widths of *W'* and *Z'* are approximately 2.5% of the pole mass.



Bulk RS Graviton

- Extends the original Randall-Sundrum model with warped extra dimesnions.
- Allows SM fields to propagate through the bulk.
- Parameterised by the coupling constant $\kappa/M_{Pl} = 1$.
- Considerable branching ratios to *WW* (17%) and *ZZ (9%).*
- Width of G_{RS} is approximately 10% of the pole mass.



Jet Definitions

Large-R Jets (*J*)

- anti-k_T with R = 1.0
- Boson tagged
- Trimmed

- TeV scale resonances lead to high p_T bosons.
- Boosted hadronic decay products can't be resolved.
- Large-R jets encompass the entire boson decay products.

Boson Tagging

- $D_2^{(\beta=1)}$
- 50% boson efficiency
- 90% QCD rejection.

Trimming

- Large-R jet reclustered using anti-k_T R = 0.2
- Discard sub-jets with p_T < 5% of the original jet.
- Large-R 4 momentum taken as the sum of the remaining subjets.

This is the default jet collection used in the diboson resonance searches.

The dominant uncertainty in a majority of the diboson resonance searches are due to the mass and energy measurements of these jets

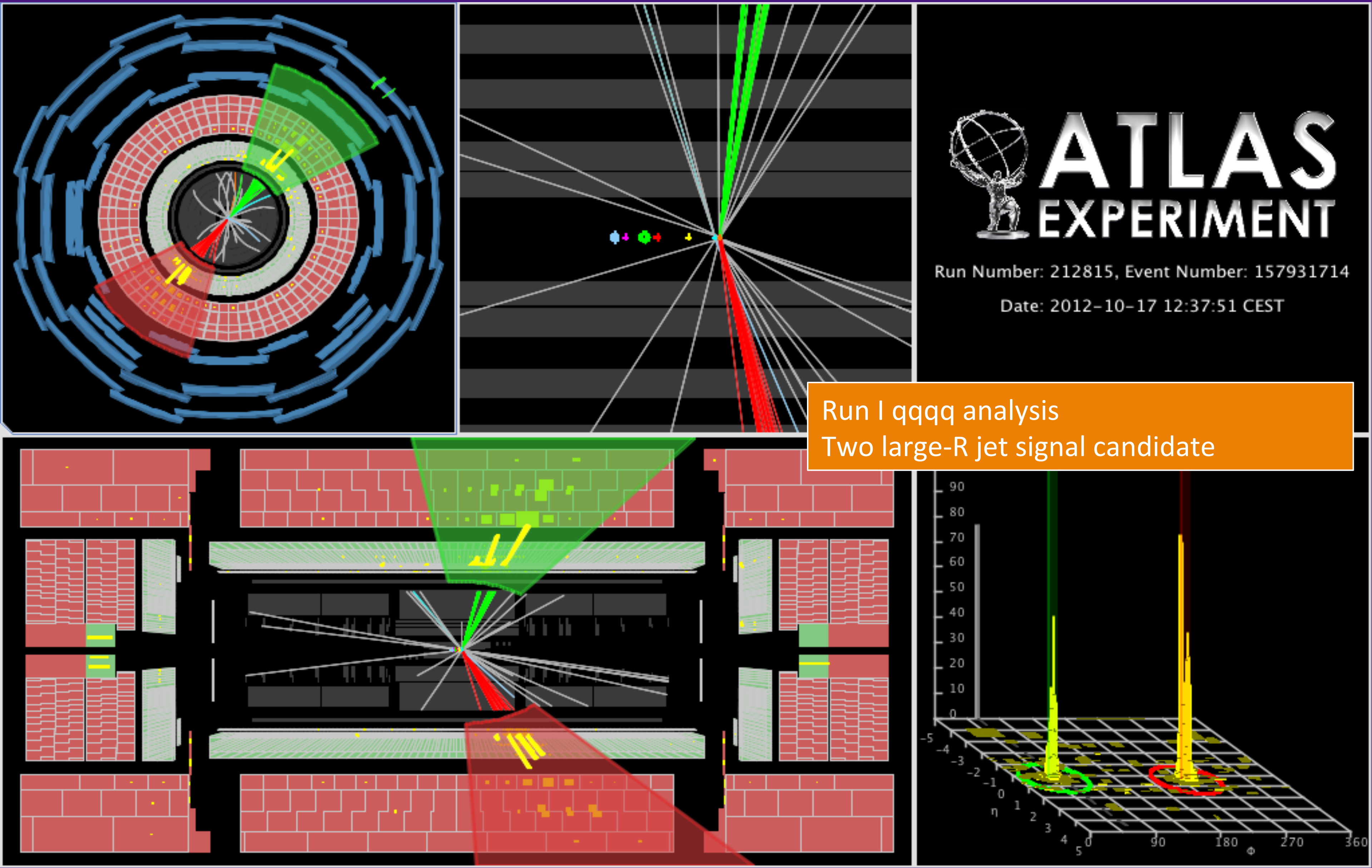
Small-R Jets (*j*)

- anti-k_T with R = 0.4
- Used to identify other QCD activity.

Track-jets

- anti-k_T with R = 0.2
- Tracks used must have p_T > 0.4 GeV.
- b-tagged, 70% efficiency.
- Associated to large-R jets.

Event Topology



Run I qqqq analysis
Two large-R jet signal candidate

Search for diboson resonances with boson-tagged jets

W', Z', $G_{RS} \to VV \to qqqq$

ATLAS-CONF-2015-073

Aditional boson tagging

- Require the number of charged tracks with $p_T > 0.5$ GeV associated with the large-R jet, $N_{trk} < 30$.
- Reject large-R jets with more than 1 b-tagged track jet.

Selection Criteria

- Trigger: single large-R jet, $E_T > 360$ GeV
- No charged leptons
- 2 large-R jets
- $p_T^{J1} > 450$ GeV
- $p_T^{J2} > 200$ GeV
- $|m_V - m_{JJ}| < 15$ GeV
- Reject jets in the range 110 GeV < m_J < 140 GeV
- $E_T^{\text{miss}} < 250$ GeV

QCD multijet background dominates.

Dominant uncertainties relate to large-R jet mass and energy measurement.

Search for diboson resonances in the *vvqq* final state

H, W', G_{RS} → ZV → vvqq

ATLAS-CONF-2015-068

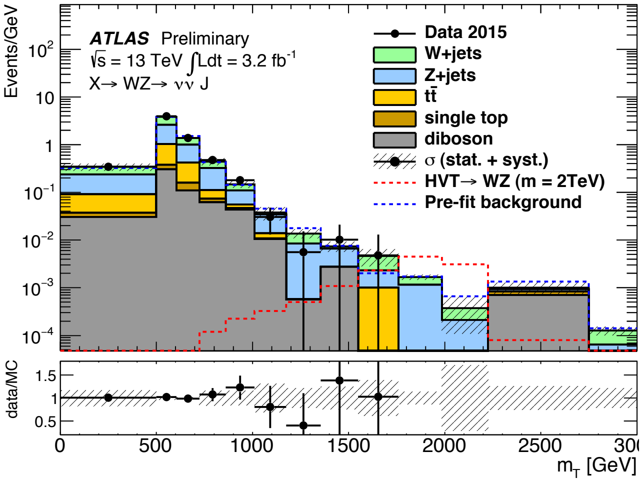
Selection Criteria

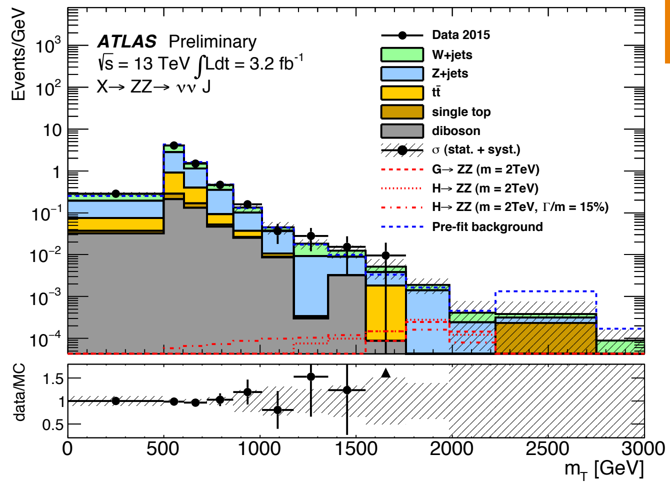
- Trigger: $E_T^{miss} > 80$ GeV
- $E_T^{miss} > 250$ GeV
- $p_T^{miss} > 30$ GeV
- At least one jet with $p_T^J > 200$ GeV
- $|m_V - m_J| < 15$ GeV
- No charged leptons
- $\Delta\phi(E_T^{miss}, j) > 0.6$
- $\Delta\phi(E_T^{miss}, p_T^{miss}) < \pi/2$

The background is dominated by V+jets and top quark pair production.

Dominant uncertainties relate to large-R jet mass and energy measurement.

DIBOSON $ZV \rightarrow \nu\nu qq$





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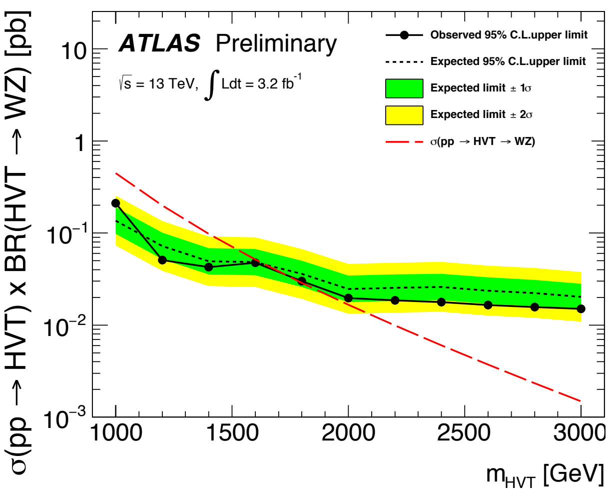
The background is dominated by *V*+jets and top quark pair production.

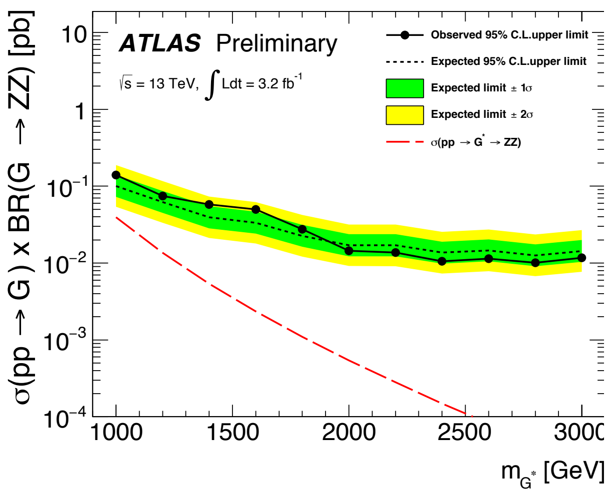
Dominant uncertainties relate to large-R jet mass and energy measurement.

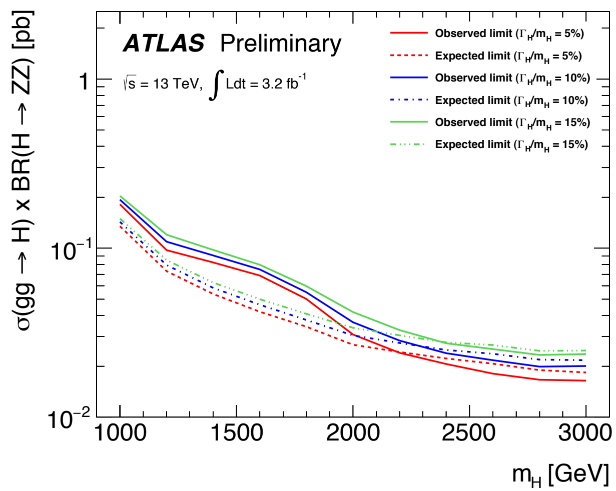
Limits are set on production cross-section times branching ratio for the three models.

The HVT model is excluded for $m_{V'} < 1.6$ TeV.

A heavy Higgs model is also tested







Search for diboson resonances in the *lvqq* final state

$H, W', Z', G_{RS} \rightarrow WV \rightarrow lvqq$

ATLAS-CONF-2015-075

Selection Criteria

- Single lepton trigger
- $E_T^{miss} > 100$ GeV
- Exactly one lepton
- $p_T^{lv} > 200$ GeV
- $|m_{lvJ} - m_V| < 13$ GeV
- No small-R jets tagged as b-jets $\Delta R > 1.0$ from V

The background is dominated by V+jets.

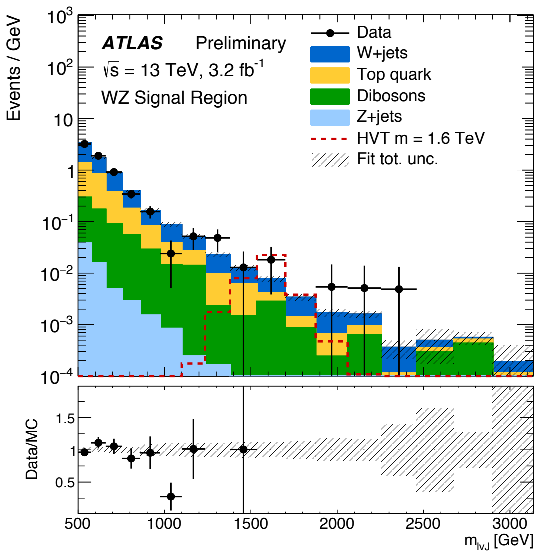
Heavy Higgs model also tested.

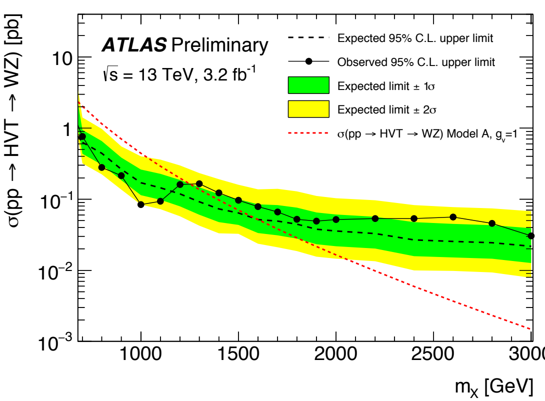
Dominant uncertainties relate to the modelling of the dominant background derived from control regions.

DIBOSON *WV → lvqq*

ATLAS-CONF-2015-075

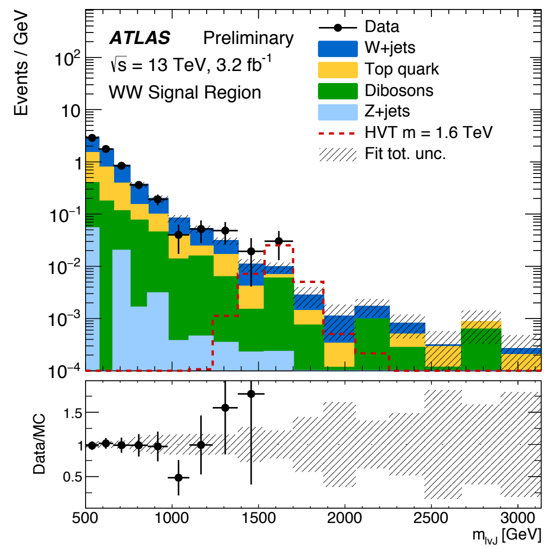
The background is dominated by *V*+jets.

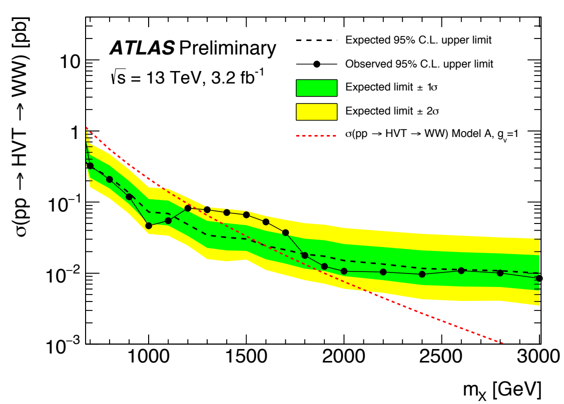




V' excluded below 1250 GeV.

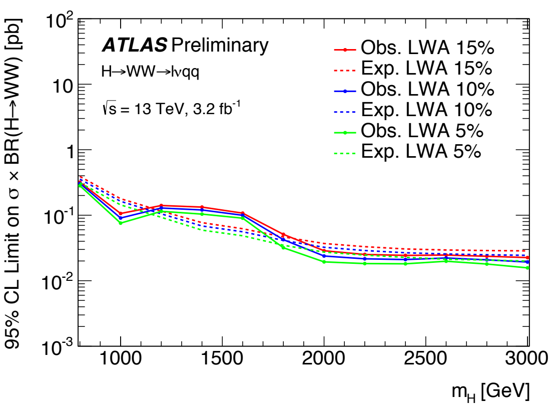
Dominant uncertainties relate to the modelling of the dominant background derived from control regions.





G_{RS} excluded below 1060 GeV.

Heavy Higgs model also tested.



Search for diboson resonances in the *llqq* final state

H, W', G_{RS} → ZV → llqq

ATLAS-CONF-2015-071

Selection Criteria

- Single lepton trigger
- Exactly two SF lepton
- p_T^{μ}, E_T^{e} > 25 GeV
- p_T^{J} > 200 GeV
- 83 GeV < m_{ee} < 99 GeV
- 66 GeV < $m_{\mu\mu}$ < 116 GeV

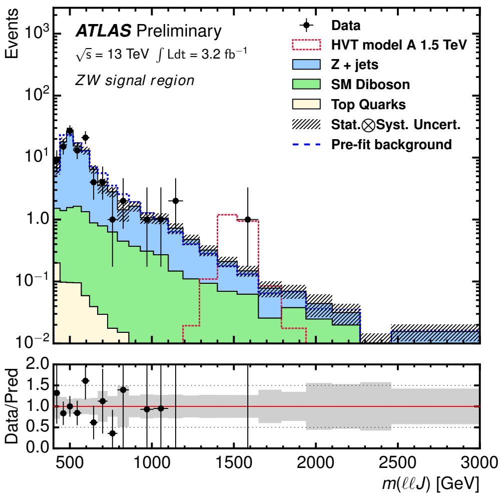
The background is dominated by Z+jets.

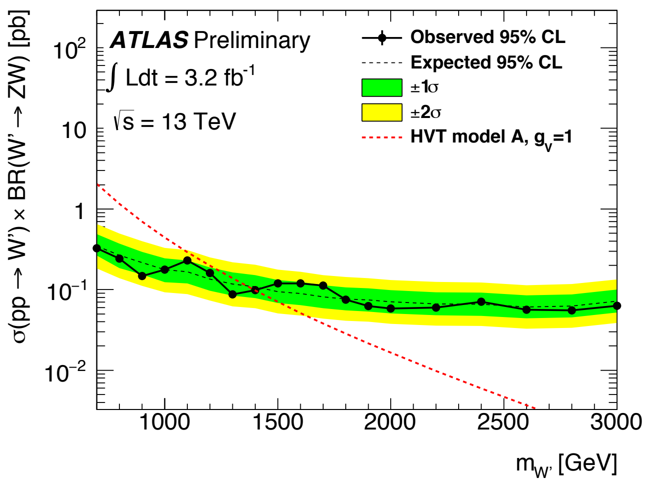
Heavy Higgs model also tested.
Not optimized for this signal.

Dominant uncertainties relate to large-R jet mass and energy measurement.

DIBOSON $ZV \to llqq$

ATLAS-CONF-2015-071





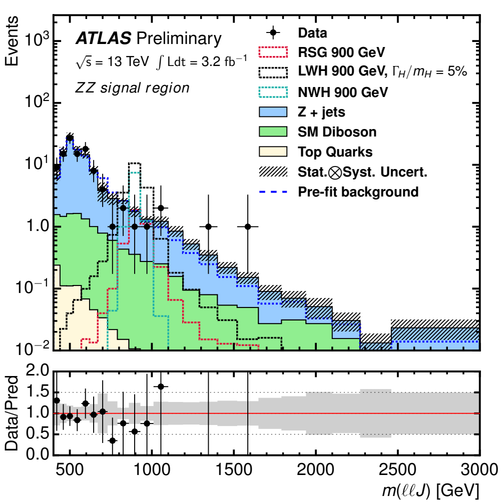
Background is dominated by Z+jets.

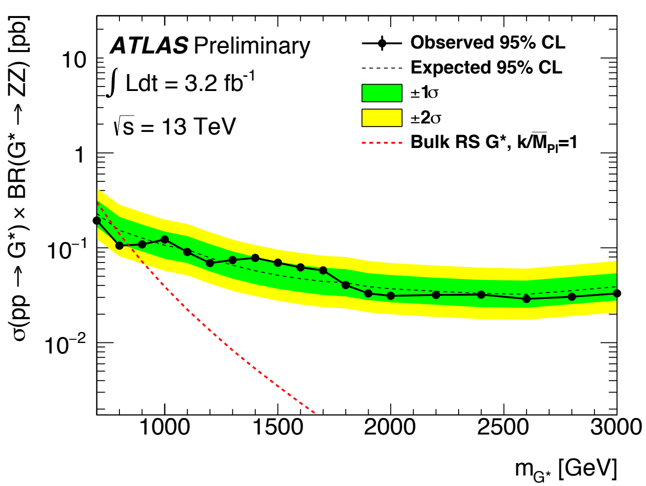
Dominant uncertainties relate to large-R jet mass and energy measurement.

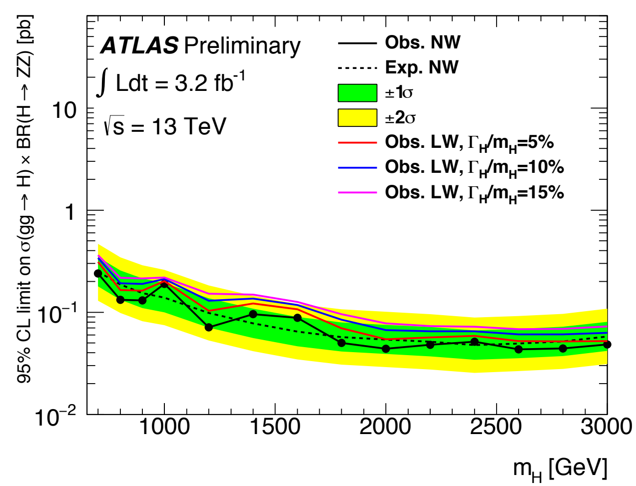
W' excluded below 1400 GeV

G_{RS} excluded below 850 GeV

Heavy Higgs model also tested. Not optimized for this signal.







Search for new resonances decaying to *VH*, in the *llbb*, *lvbb* and *vvbb* final states

A, W', Z', G_{RS} → *VH* → *llbb, lvbb, vvbb*

ATLAS-CONF-2015-074

Selection Criteria

- At least one jet with p_T^J > 250 GeV
- 75 GeV < m_J < 145 GeV
- At least one of the two leading track jets associated to the large-R jet must be b-tagged
- Signal regions split by number of b-tags

The background is dominated by V+jets.

Dominant uncertainties relate to large-R jet mass and energy measurement.

Heavy CP-odd scalar model also tested.

As well as the previously described HVT model A, model B is tested.
In this model fermionic couplings are highly suppressed.