Searches for diboson resonances with ATLAS

(VV, VH and HH, excl. diphoton resonance)

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Kristian Gregersen (University College London)

on behalf of the ATLAS Collaboration

Introduction

Overview

- ***Diboson*** *searches in this talk*
  - *VV* → *qqqq*
  - *VV* → *vvqq , lvqq , llqq*
  - *VH* → *vvbb , lvbb , llbb*
  - *HH* → *bbbb*

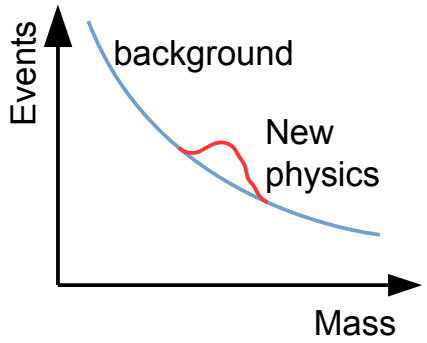
  V : *W* or *Z* boson
  H : Higgs

- ***Boosted topology*** *optimisations in Run II*

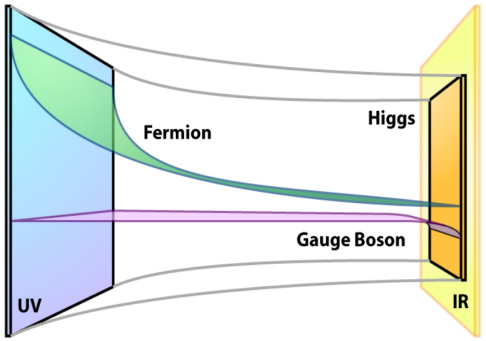
- *Based on* ***2015 data at 13 TeV***
  - Integrated luminosity : 3.2 fb^{-1}

- ***Benchmark*** *models*
  - Spin-0 : Extended Higgs sector
  - Spin-1 : Heavy Vector Triples (HVT)
    - Model A : stronger constraints from leptonic searches
    - Model B : enhanced couplings to dibosons
  - Spin-2 : Randall-Sundrum Gravitons (RSG)

Reconstruct decay product of resonance X
Look for a **peak** on a **smooth background**.



Warped extra dimensions

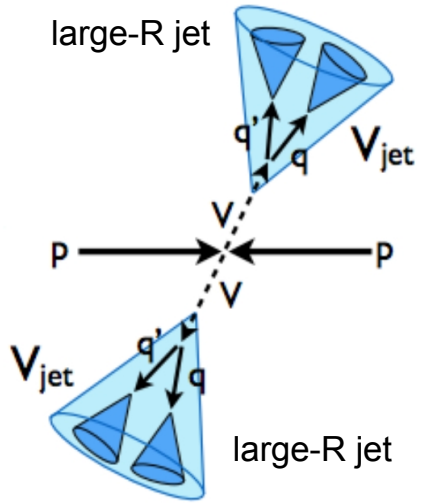


Special ingredients

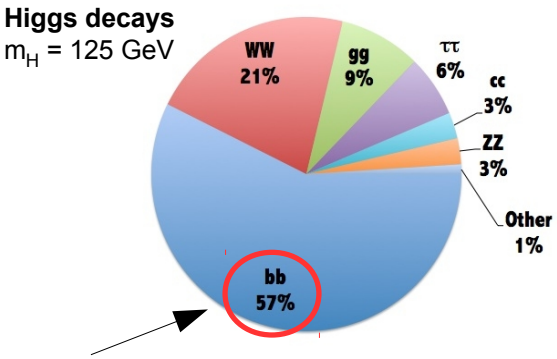
- *Large-R jets (AntiKt R = 1.0)*
  - Boosted decay products become more **collimated**
  - **Rule of thumb** for angular separation of decay products:

    $\Delta R = \sqrt{\Delta\eta^2 + \Delta\theta^2} \sim 2m/p_T$

  - **Grooming** techniques employed to remove pile-up and soft QCD
    - trimming (R_{sub} = 0.2, f_{cut} = 5%)
    - possible due to the fine calorimeter granularity (0.003 x 0.1 to 0.1 x 0.1 in Δη x Δφ)
  - **Substructure** variables exploited to identify source
    - W/Z tagger : [Mass] + [D2] → tuned selections vs. p_T ATL-PHYS-PUB-2015-033
    - Higgs tagger : [Mass] + [b-tagging on R = 0.2 track based jets] ATL-PHYS-PUB-2015-035

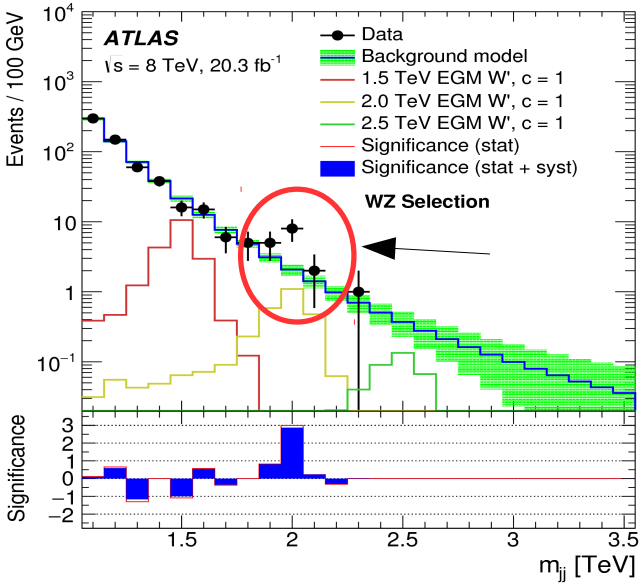


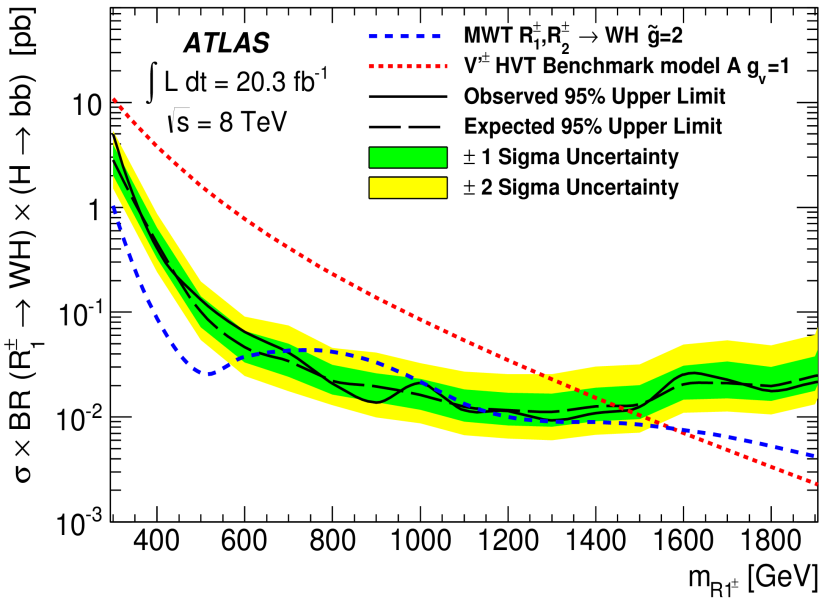
- *b-quark tagging*
  - *H → bb* **larger branching fraction** than all other Higgs decays combined
  - Use dedicated "**b-tagging**" algorithms to identify b-quarks



Reminder of Run 1 excesses in diboson searches

- ATLAS : **2.5σ excess** ($M_{V'}$ = 2 TeV) for fully hadronic W' → WZ [arXiv:1506.00962]
  - significance decreases in combination with semileptonic channels [arXiv:1512.05099]
- CMS : **1.9σ excess** ($M_{V'}$ = 1.8 TeV) for W' → WH → lνbb [arXiv:1601.0643]
- ATLAS : **no excess** in W' → WH → lνbb [arXiv:1503.08089]
  - Less sensitive to high mass resonances with resolved jet analysis
  - For Run 2:
    - Use **boosted jet selection** (large-R jets)

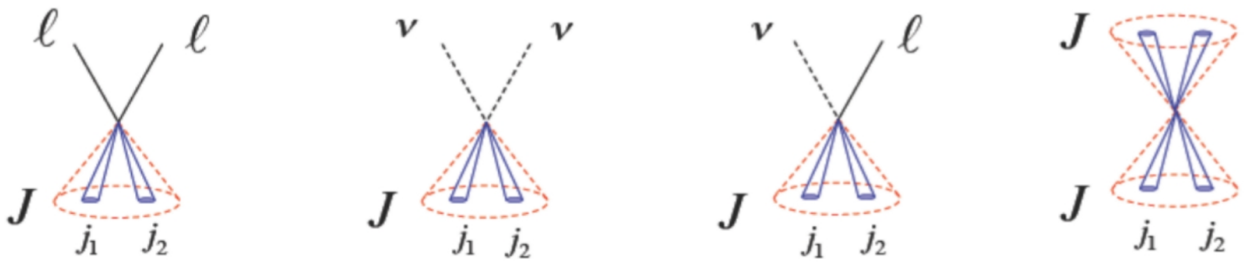




VV searches

Overview

- *At least one hadronically decaying V (reconstructed as large-R jet)*
- *Hadronic W and Z signal regions partially overlap*
- *Different VV states are orthogonal*
- *Interpretations :*
  - Heavy Vector Triplets
  - Randal-Sundrum gravitions
  - scalar resonances



VV searches

arXiv:1606.04833

VV → qqqq : selection

- *Two large-R (R = 1.0) anti-kt jets (groomed)*
  - pT > 450 and 200 GeV
  - W/Z boson tagged
    - 50% efficiency working point
    - QCD rejection factor of 40-70 per jet

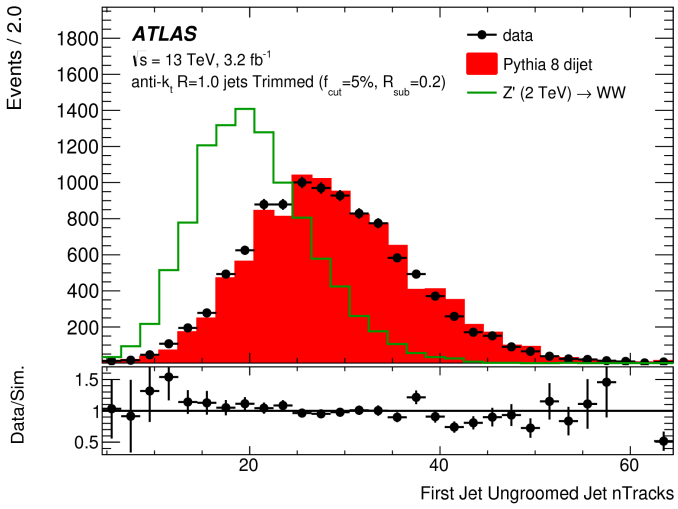
- $N_{track} < 30$
  - N_{track} *is number of tracks :*
    - *ghost-associated to (un-groomed) large-R jet*
    - $p_T > 0.5$ *GeV*
  - large QCD rejection
  - little signal loss

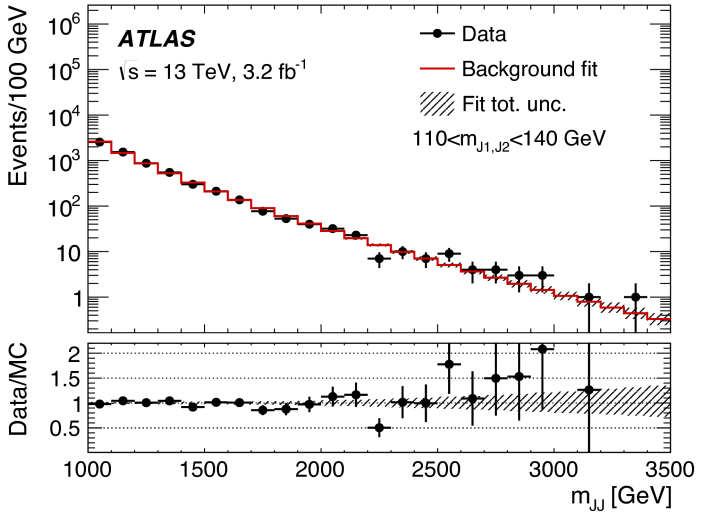
- *Topology selection*
  - $|y_1 - y_2| < 1.2$
  - *Dijet balance :* $(p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2}) < 0.15$

- *QCD multi-jet background is dominant*
  - *data-driven estimation*
  - *modelled with*

$$\frac{dn}{dx} = p_1(1-x)^{p_2+\xi p_3} x^{p_3} \qquad x = m_{JJ}/\sqrt{s}$$

  - *tested on dijet MC and* ***data validation regions***

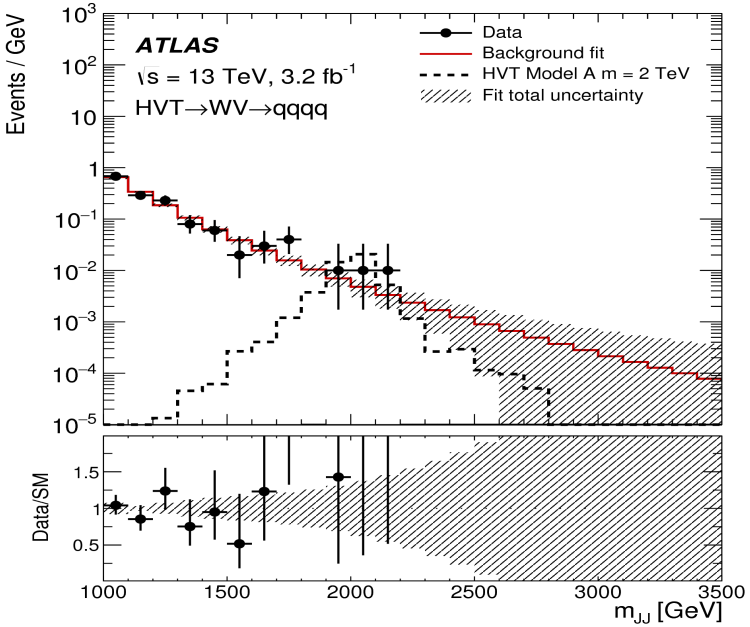


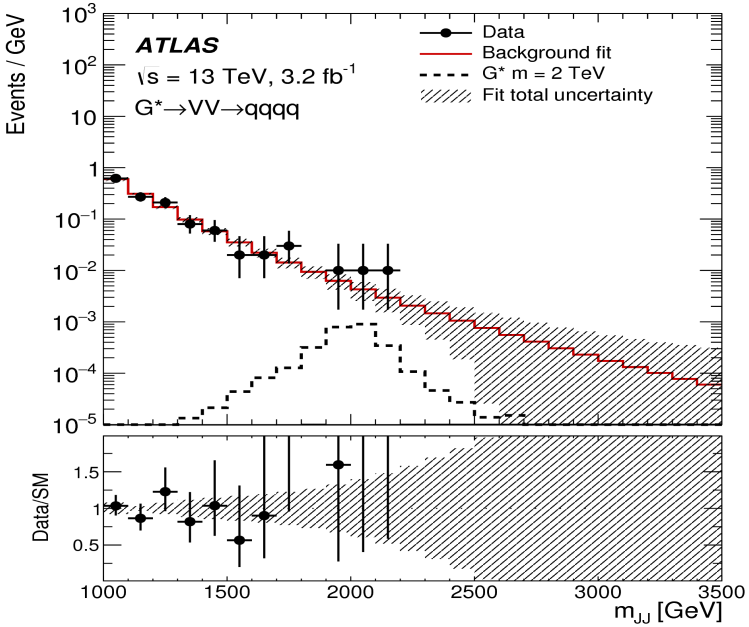


arXiv:1606.04833

VV → qqqq : results

- *Partially overlapping signal regions*
  - ZZ, WW, WZ
  - W/Z mass windows overlapping
- *No significant deviations found in Run II data*
  - Reminder: **Run I excess** ~ 2 TeV
  - **Not seen in Run II** 2015 data
  - (but also lower sensitivity compared to Run I)
- *Limits set on HVT and RSG models*
  - Combined with semileptonic channels
  - Shown on slides 10-11





VV searches

arXiv:1606.04833

VV → vvqq , lvqq , llqq : selection

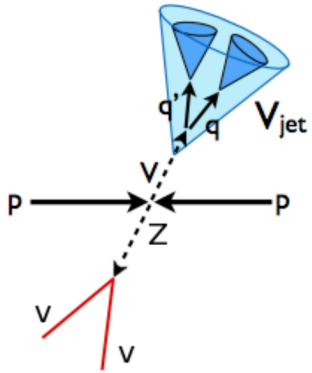
- *One large-R (R = 1.0) anti-kt jet (groomed)*
  - pT > 200 GeV
  - W/Z boson tagged
    - 50% efficiency working point
    - QCD rejection factor of 40-70 per jet

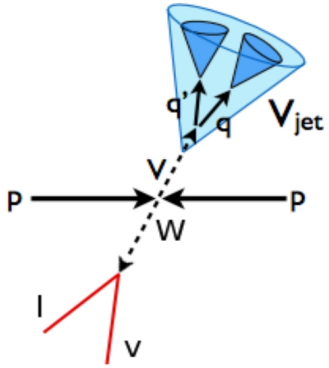
- *Three lepton channels :*

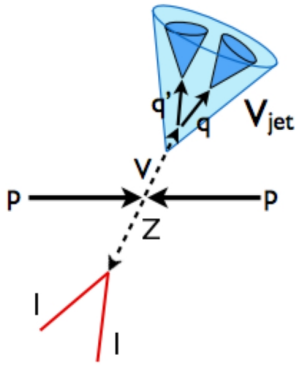
  - **0 lepton channel**
  - veto on leptons
  - E_T^{miss} > 250 GeV
  - E_T^{miss}, p_T^{miss}, jet angular cuts
  - b-jet veto
  - Bkgs: V+jets, tt, Diboson

  - **1 lepton channel**
  - exactly 1 lepton
  - E_T^{miss} > 100 GeV
  - $p_T^{lv\,/\,J} > 0.4m_{lvJ}$
  - b-jet veto
  - Bkgs: W+jet, tt, Diboson

  - **2 lepton channel**
  - exactly 2 leptons
  - $p_T^{ll\,/\,J} > 0.4m_{llJ}$
  - b-jet veto
  - Bkgs: Z+jets, Diboson





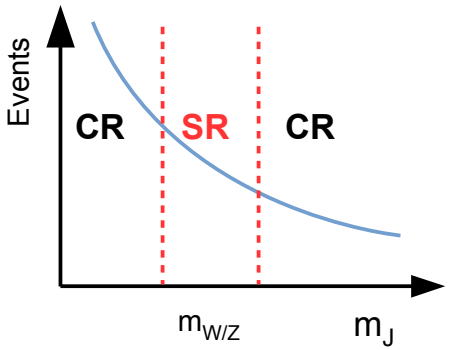


VV searches

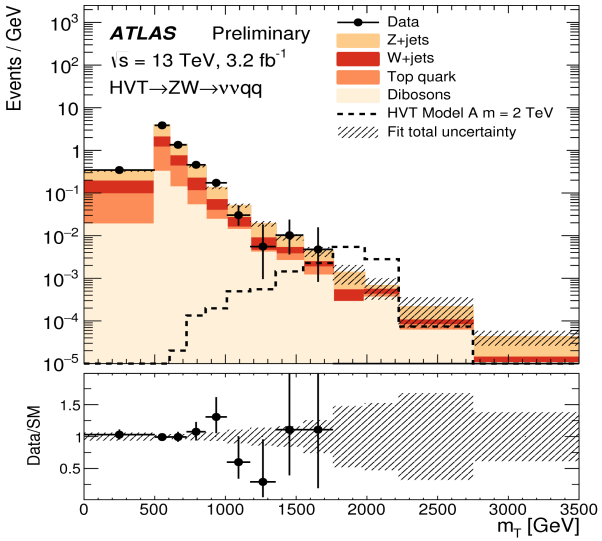
arXiv:1606.04833

VV → νqq , lνqq , llqq : results

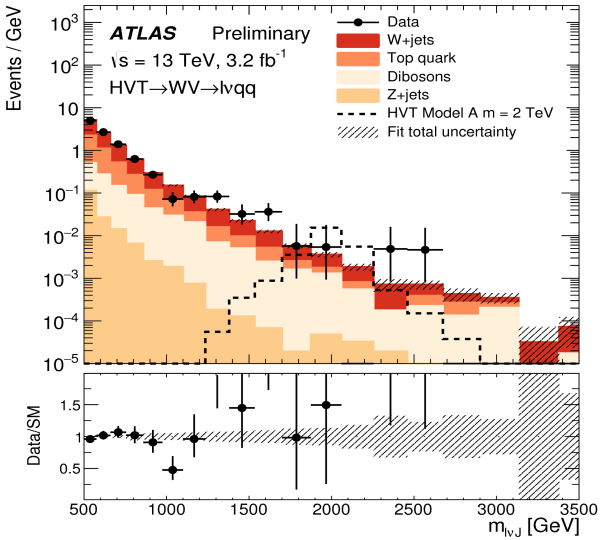
- *Backgrounds estimated from MC and checked in control regions (CR) :*
  - Jet **mass sidebands** for V+jet
  - Additional **b-tags** for $t\bar{t}$
- *CRs included in the final fit*
  - constrain normalisation
- *No significant excesses observed in m_{VV} and $m_{T,VV}$ distributions*



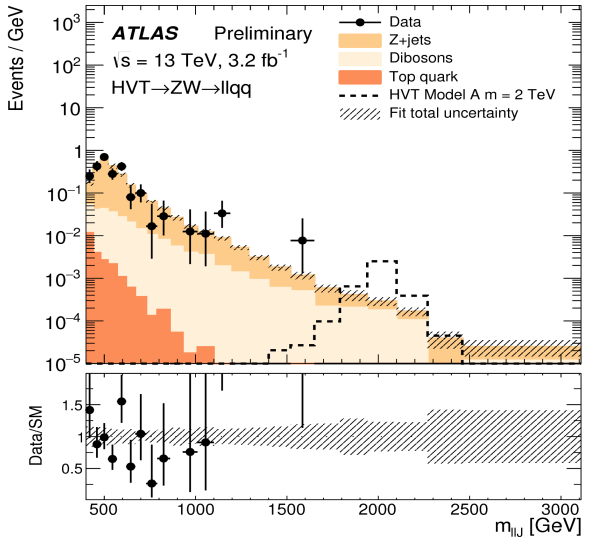
0-lepton



1-lepton



2-lepton



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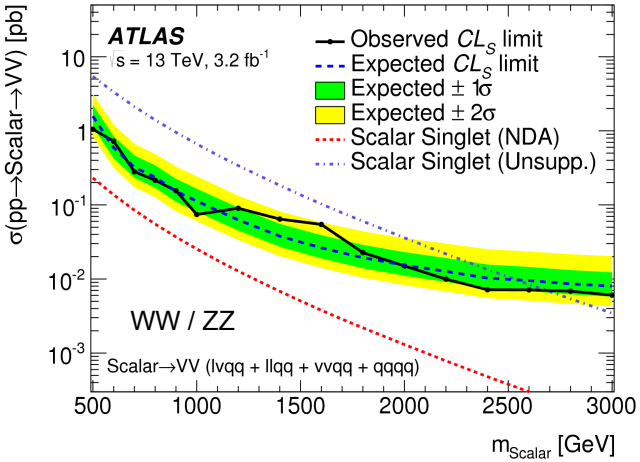
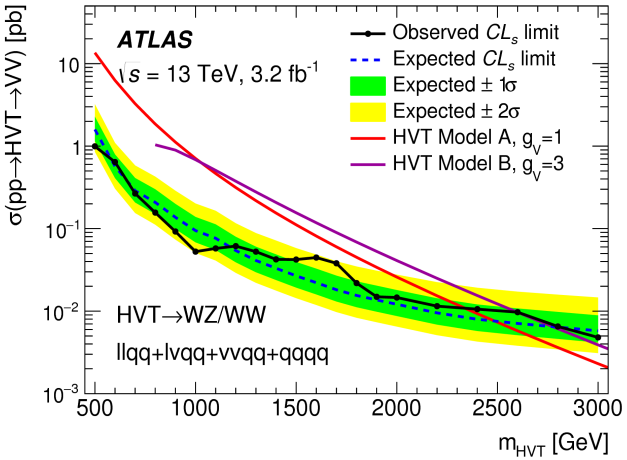
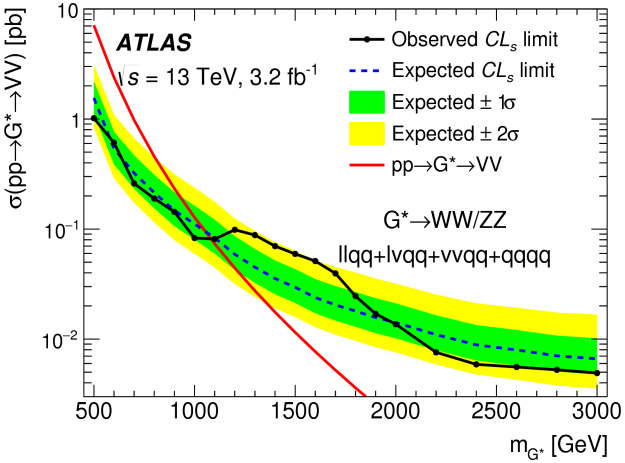
arXiv:1606.04833

VV → qqqq , vvqq , lvqq , llqq : summary

- *Limits are set at 95% CL, interpretations : HVT, RSG, Heavy Higgs*







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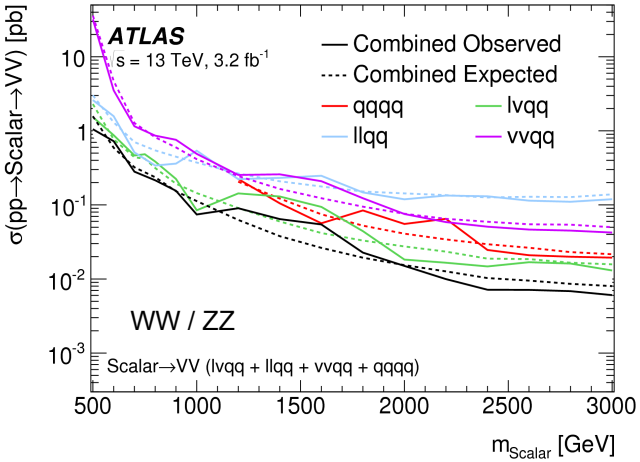
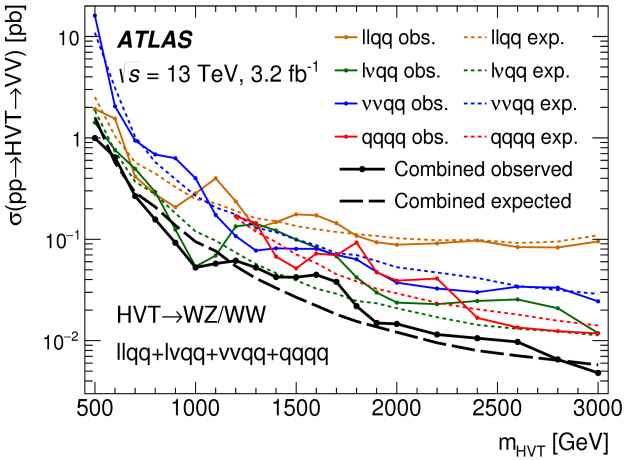
VV searches

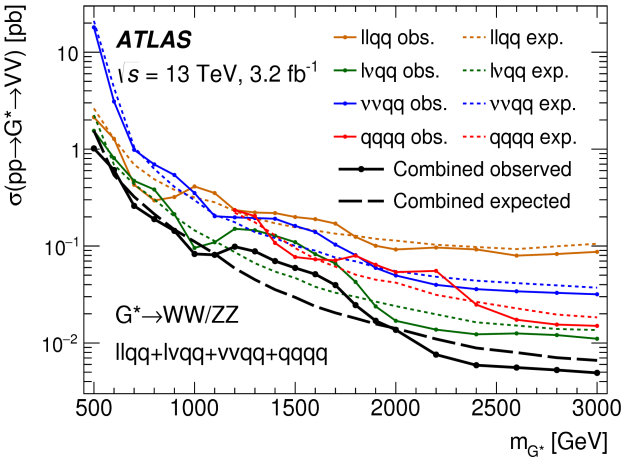
arXiv:1606.04833

VV → qqqq , vvqq , lvqq , llqq : summary

- *Limits are set at 95% CL, interpretations : HVT, RSG, Heavy Higgs*
- *Break-down into individual channels*







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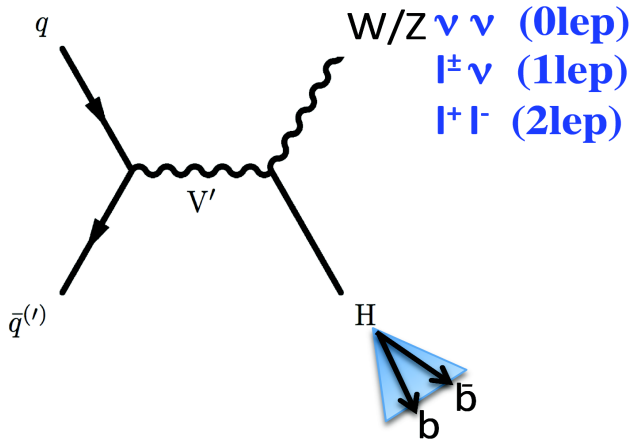
VH searches

Overview

- *H decaying to $b\bar{b}$ (reconstructed as large-R jet)*
- *V decaying leptonically*
- *Interpretations :*
  - Heavy Vector Triplets
  - 2 Higgs Doublet Models (2HDM)

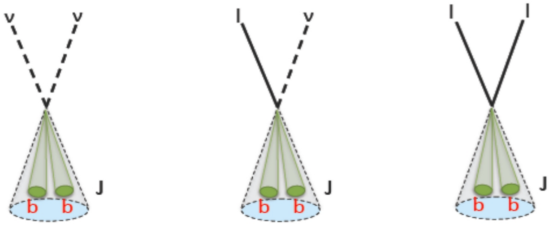


VH searches

ATLAS-CONF-2015-074

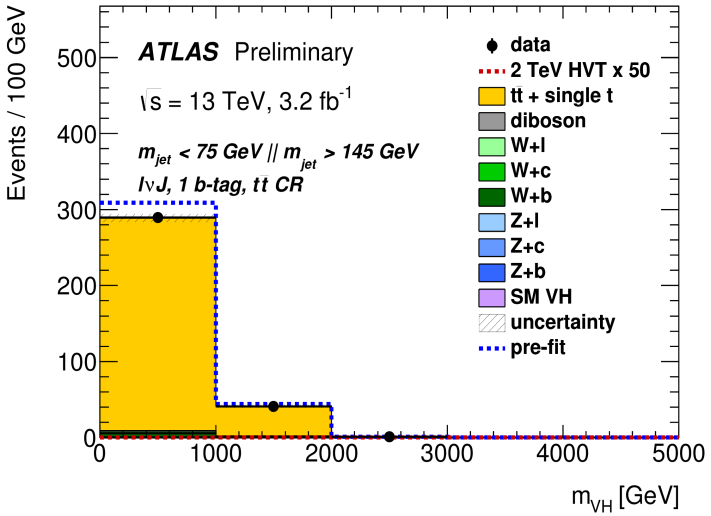
VH → vvbb , lvbb , llbb : selection

- *One large-R (R = 1.0) anti-kt jet (groomed)*
  - pT > 250 GeV,
  - 75 < m_J < 145 GeV
  - 1 or 2 b-tags
    - b-tagging on track-jets assoc. to large-R jet
- *Three lepton channels :*
  - 0 lepton : lepton veto, E_T^{miss} > 200 GeV
  - 1 lepton : one isol. lepton, E_T^{miss} > 100 GeV
  - 2 lepton : two isol. leptons, Z mass constraint

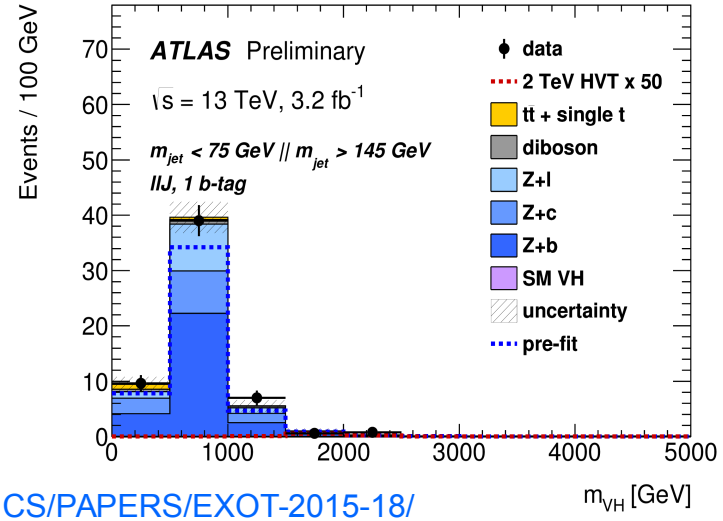


- *Main backgrounds*
  - 0 lepton : Z+jets
  - 1 lepton : tt, W+jets
  - 2 lepton : Z+jets
- *Backgrounds constrained in control regions*
  - *Simultaneous fit to SR and CR*

1-lepton : m_J sideband + 1 add. b-tag CR



2-lepton : m_J sideband CR



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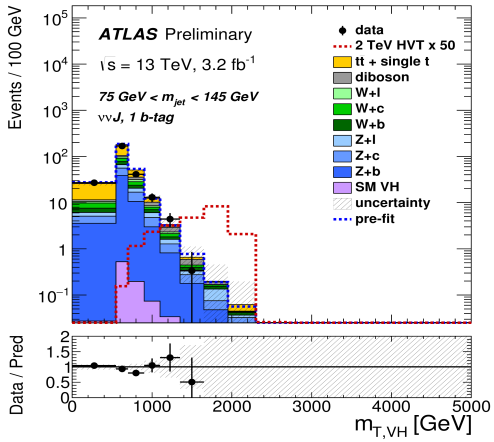
VH searches

ATLAS-CONF-2015-074

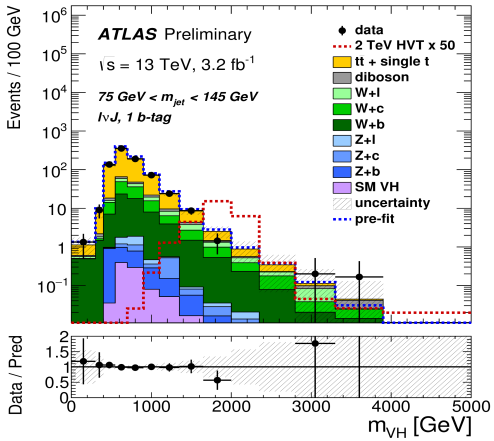
VH → vvbb , lvbb , llbb : results

- *No significant excesses observed in m_{VV} and $m_{T,VV}$ distributions*
- *Limits are set at 95% CL, interpretations : HVT, 2HDM*

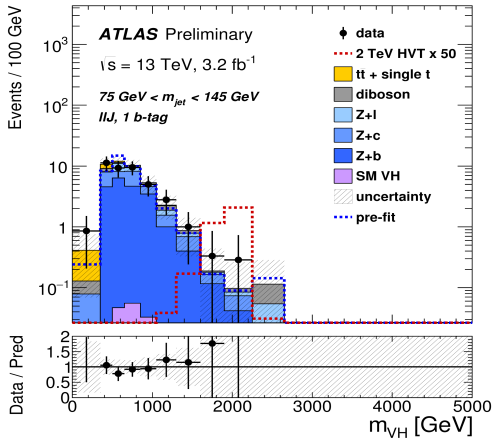
0-lepton (ZH)

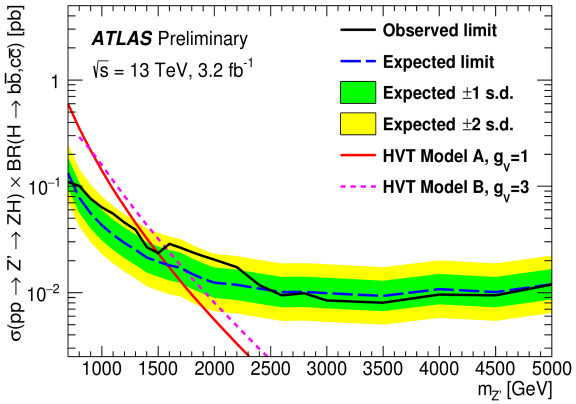


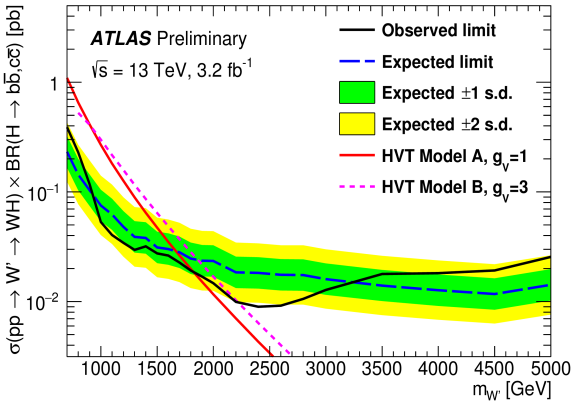
1-lepton (WH)

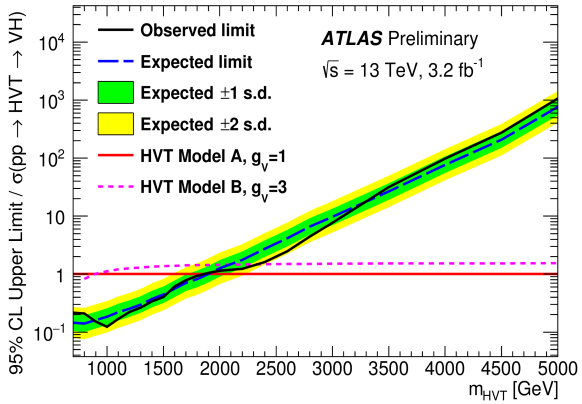


2-lepton (ZH)









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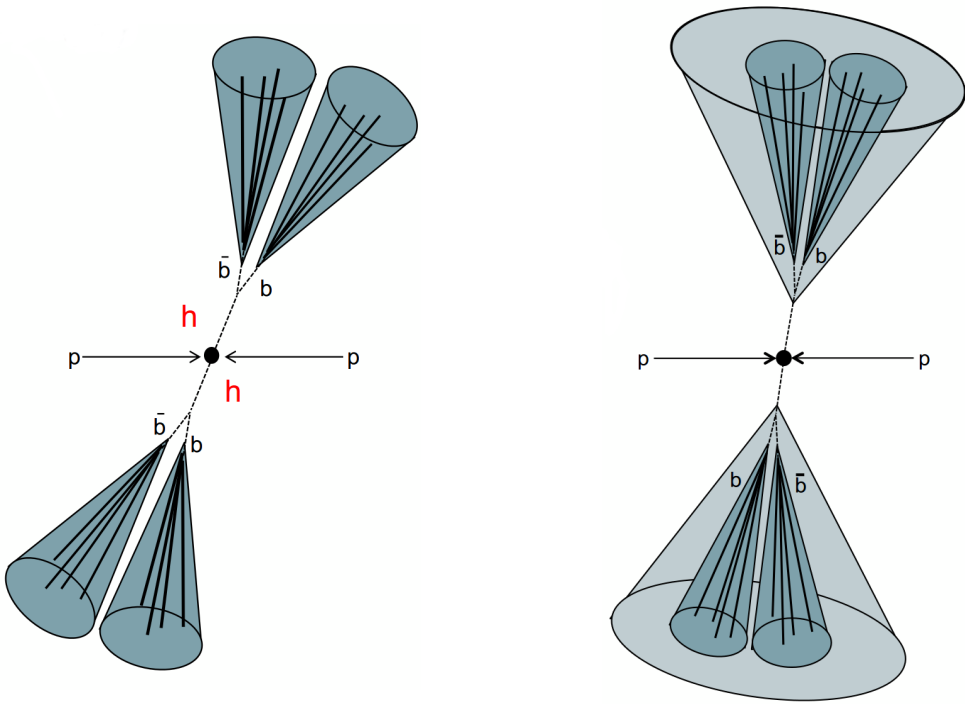
HH searches

Overview

- *H decaying to $b\bar{b}$*
- *Resolved and Boosted analyses*
- *Interpretations :*
  - RS Gravitons
  - Scalar



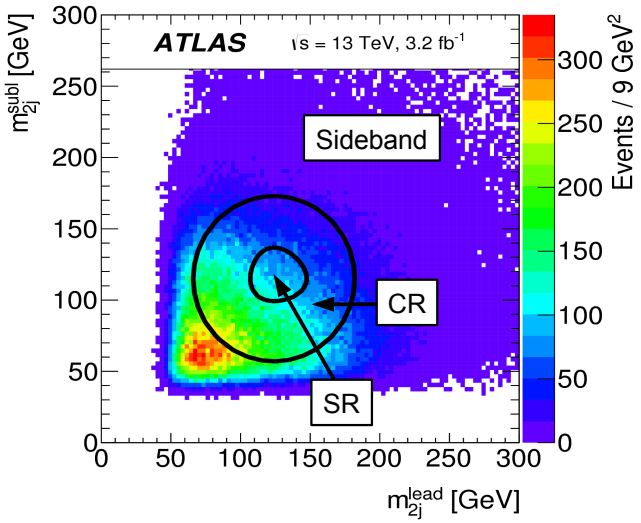
HH searches

arXiv:1606.04782

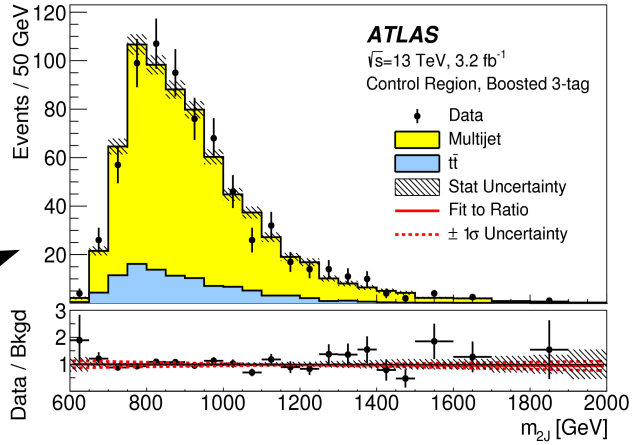
HH → bbbb : selection

- *Run I analyses*
  - bbγγ , bbττ , bbWW , bbbb
  - **bbbb most sensitive** for m_X > 500 GeV
- *Run II*
  - Priority : **push sensitivity** boundary with bbbb
- *Resolved analysis*
  - 4 **small-R** (R = 0.4) anti-kt jets
  - pT(dijet) > 150 GeV, dR(j,j) < 1.5 in dijets
  - 4 b-tags
- *Boosted analysis*
  - 2 **large-R** (R = 1.0) anti-kt jets (groomed)
  - ghost assoc. track jets
  - 3 or 4 b-tags
- *Backgrounds :*
  - ***multi-jet*** *(90%),* ***tt*** *(10%)*
  - multijet estimated with (2-tag SR) * $\mu_{sideband}$
  - validated in CR with (2-tag CR) * $\mu_{sideband}$
    - Resolved : $\mu_{sideband}$ from ratio (4-tag / 2-tag)
    - Boosted : $\mu_{sideband}$ from fit jet mass (top peak)

Resolved analysis



Boosted analysis



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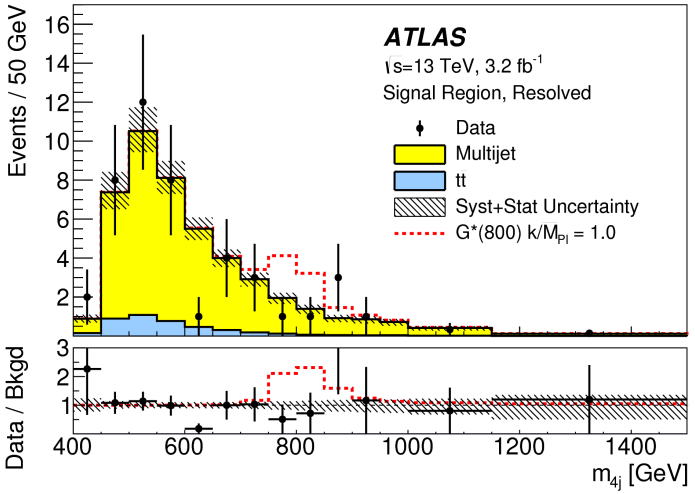
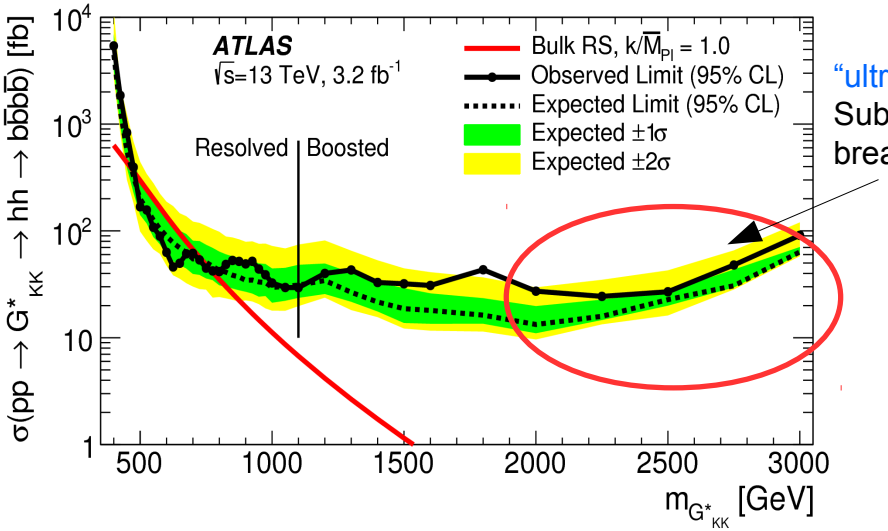
arXiv:1606.04782

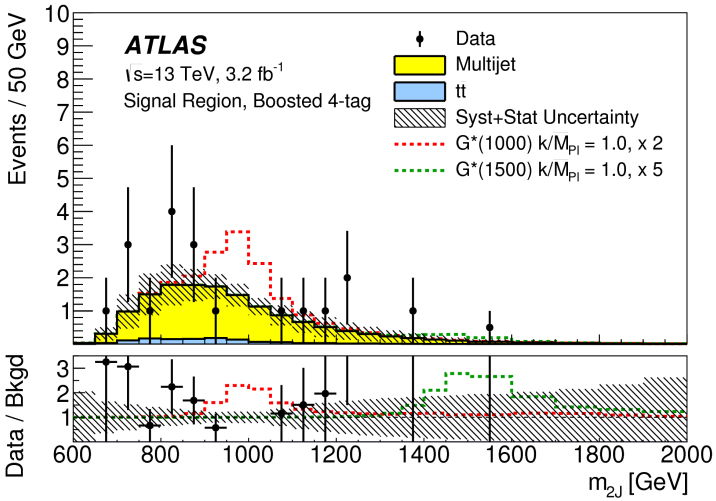
HH → bbbb : results

- *No significant excesses observed in m_X distributions*
- *Limits are set at 95% CL*
  - interpretations : Graviton, scalar resonance
- *Sensitivity to BSM already at Run I level*
  - pushing phase space to "ultra"-boosted region
    → R = 0.2 track jets inside large-R jet start merging
    → b-tagging efficiency drops since tracks become collimated
  - still far away from SM prediction of pp → HH (by a factor ~100)





"ultra"-boosted Sub-structure break down?



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2015-11/

Conclusions

Diboson searches summary

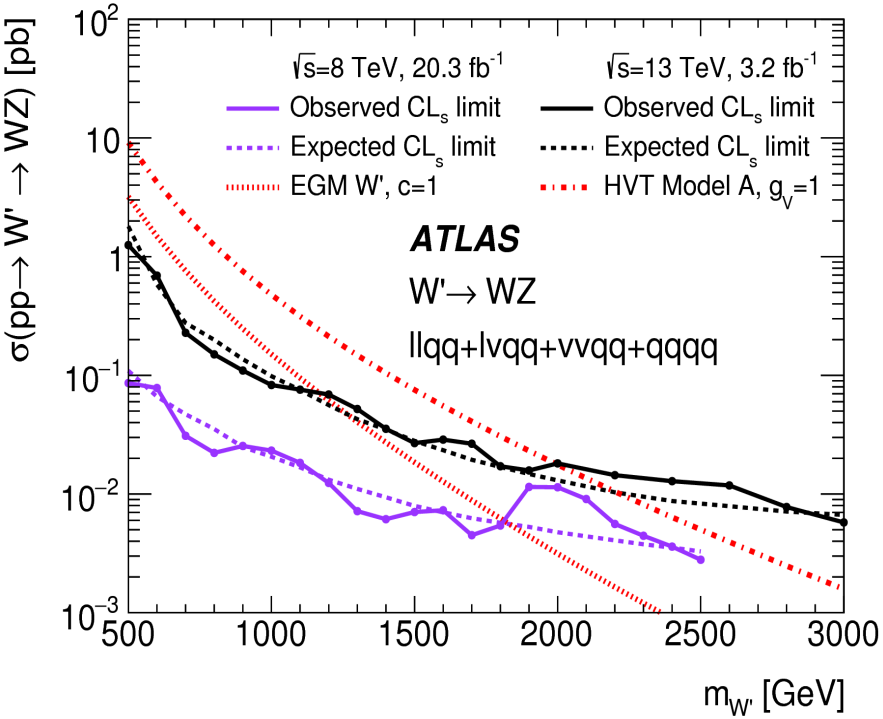
- *Latest ATLAS Run II results of diboson searches presented.*
- *No significant excesses observed with 2015 data at 13 TeV – but not enough data in 2015 to settle the diboson excess observed at the boosted VV at the end of Run I...*
- *Many new resonances decay to VV, VH , HH – one of the most direct ways to discover new physics at the TeV scale.*
- *Boosted object reconstruction important key to probe high mass regions – methodology has matured – but still many opportunities for improvement!*
- *Already started recording data in 2016 – more data coming soon – stay tuned !!*

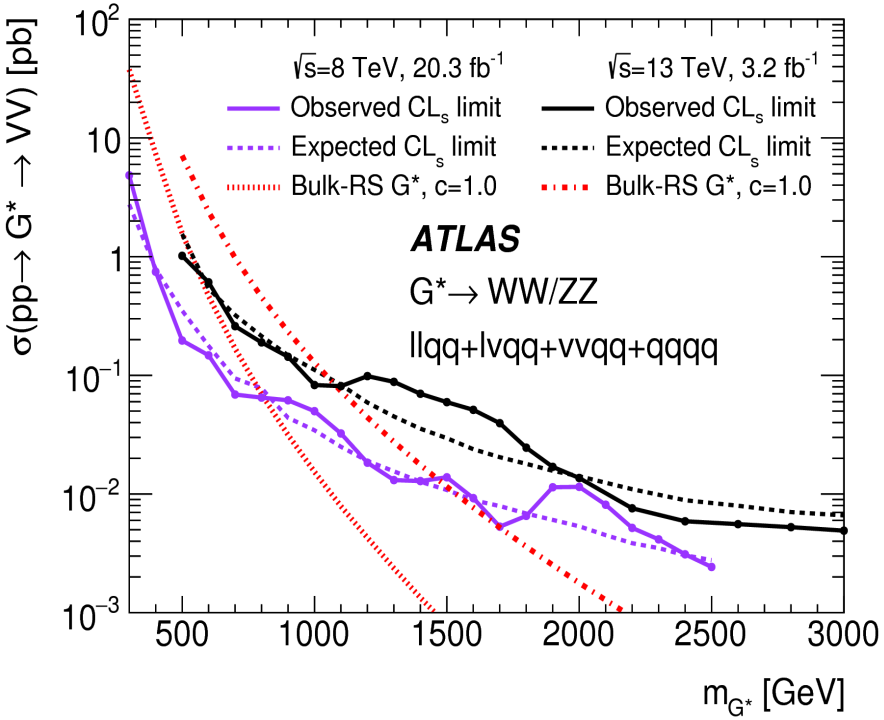
Back-up

arXiv:1606.04833

VV → vvqq , lvqq , llqq : summary

- *Comparison of 8 TeV and 13 TeV results*





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