Searches for TeV-scale resonances in di-boson final states with ATLAS at 13TeV

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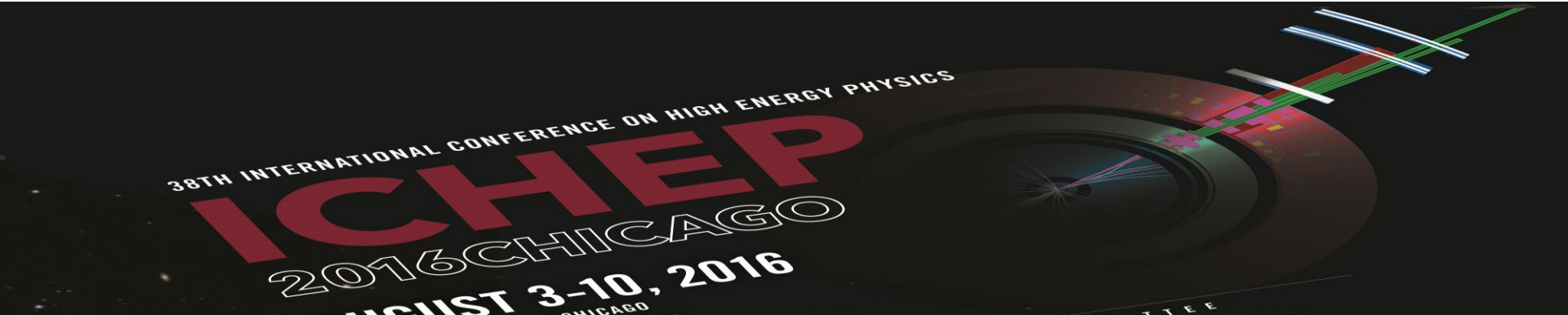
for the ATLAS Collaboration



Introduction

- Many BSM physics models predict TeV-scale resonances decaying with large branching fractions to two EW bosons

- This talk: ATLAS preliminary results with 10-15fb^{-1} of 13TeV data on
  - X→HH→ bbbb
  - X→VH→ qqbb
  - X→VV→ qqqq, lvqq, llqq, vvqq

- Related ATLAS talks at ICHEP
  - X→γγ (by B.Lenzi)
  - X→Zγ (by G.Marchiori)
  - Other HH channels (by T.Varol)
  - Leptonic VV channels (by K. Köneke)
- Related ATLAS posters at ICHEP
  - HH→ bbbb (J.Alison)
  - HH→ ττbb (P.Saha)

Benchmark signal models used:

spin-0: heavy H in extended Higgs sector

spin-1: W'/Z' in Heavy Vector Triplet models

spin-2: Randall-Sundrum KK Graviton

Reconstructing W/Z/H → qq

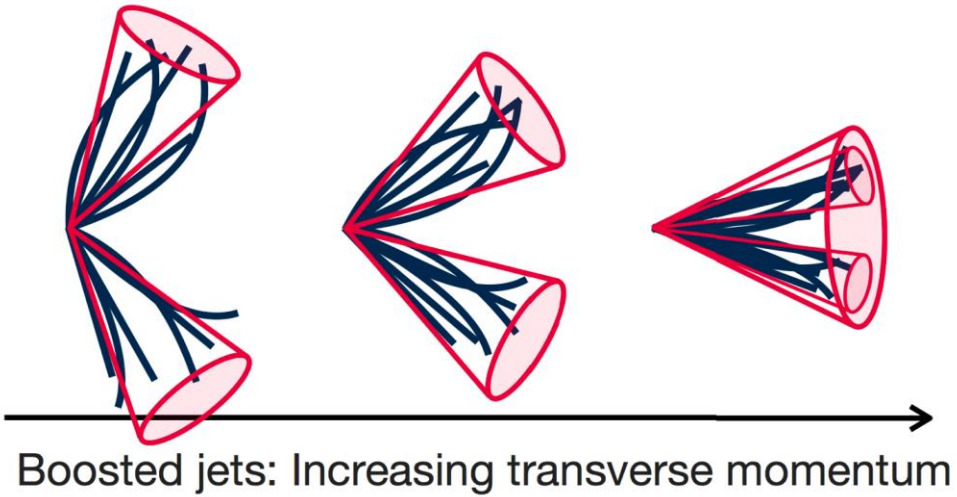
- EW bosons have masses O(~100GeV)

- Searches for resonances with m_X in the range few hundred GeV to a few TeV
  - Wide range of boson p_T's leading to distinct topologies for their hadronic decays:

    Resolved: reconstruct as 2 anti-k_t R=0.4 (akt4) jets for boson p_T up to a few hundred GeV

    Boosted: reconstruct as a single ant-k_t jet R=1.0 (akt10) jet (large-R jet) for higher boson p_T

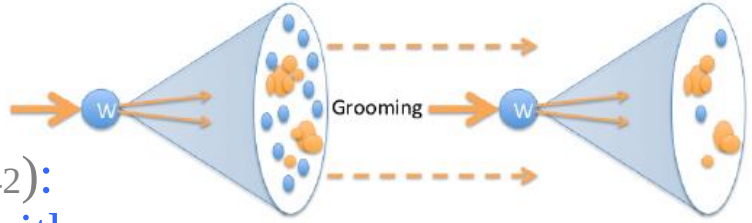
    (Notation: "j" for akt4 jets, "J" for akt10 jets)



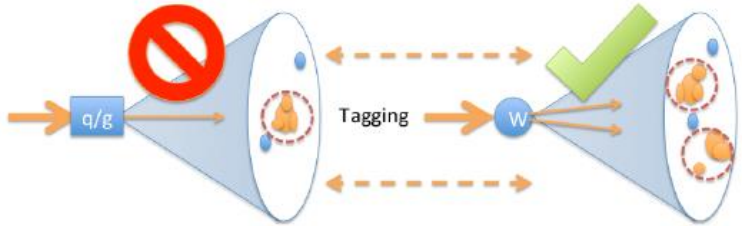
Large-R jet techniques

- **Grooming:** to minimize impact of energy deposits from pile-up interactions
  - ATLAS mainly uses "Trimming" (arXiv:0912.1342): re-cluster with k_t R=0.2 and remove sub-jets with

$$p_{\mathrm{T}}^{\mathrm{subjet}} / p_{\mathrm{T}}^{\mathrm{jet}} < 0.05$$



- **W/Z boson tagging:** ATL-PHYS-PUB-2015-033
  - m_J consistent with m_W/m_Z within ±15GeV
    - W and Z windows overlap
  - Sub-structure consistent with two-prong decay
    - Most popular variable: $D_2^{(\beta=1)}$ (arXiv: 1409.6298, 1507.03018)
    - Typical WP: ε=50%, QCD rejection factor ~50

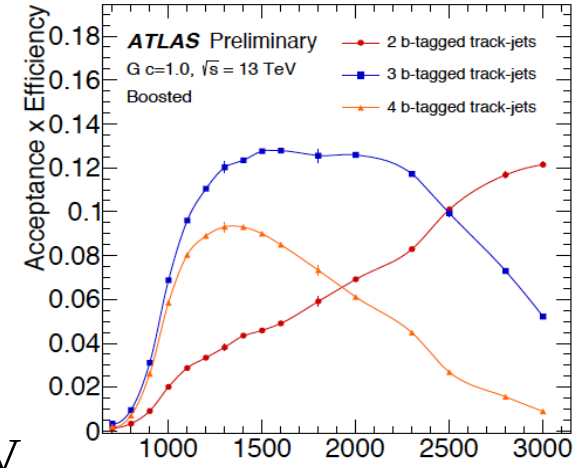


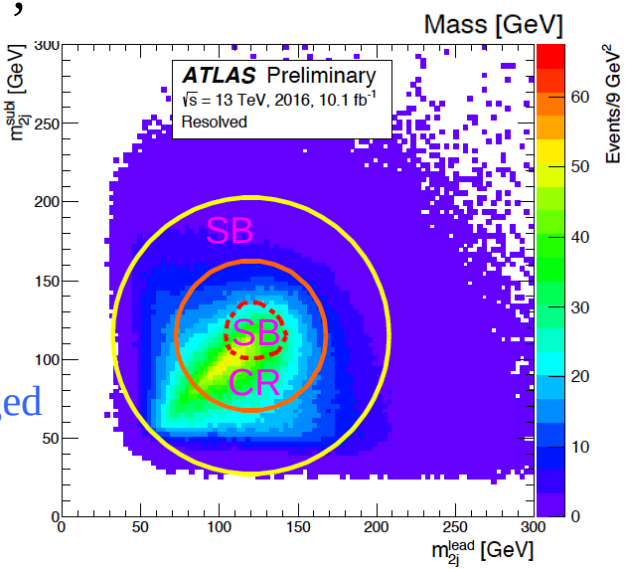
- **Higgs boson (b-) tagging:** ATL-CONF-2016-039
  - Match to anti-k_t R=0.2, b-tagged track-jets

HH → bbbb

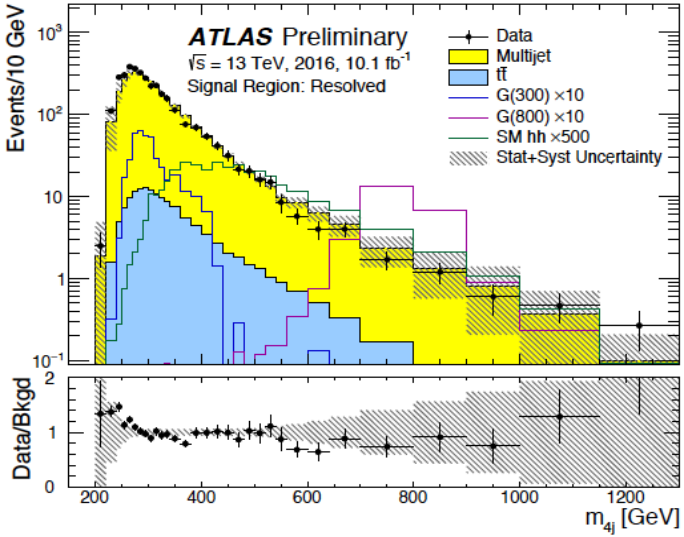
ATL-CONF-2016-049

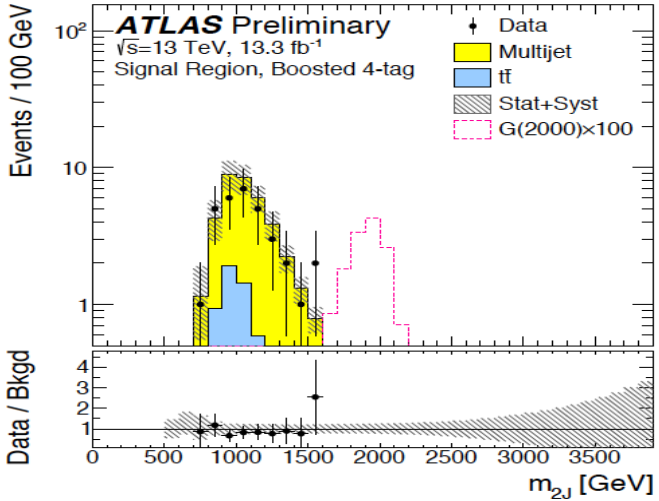
- BR(H→bb)=~57% => BR(HH→bbbb)=~33%
  - Most sensitive HH final state across almost entire search space
- Resolved analysis: 4 b-tagged akt4 jets with p_T>30GeV, forming two Higgs candidates
  - Improved low m_X sensitivity, by relaxing kinematic cuts and dealing with backgrounds & combinatorics
- Boosted analysis: 2 trimmed akt10 jets: p_T>450/250 GeV, masses consistent with m_H and b-tagged sub-jets
  - Addressed acceptance loss at very high m_X by introducing three signal categories (2/3/4-b-tag), based on number of b-tagged track jets within large-R jets
- Dominant bkg is QCD multijets, ~10% ttbar
  - Data-driven QCD bkg estimate by relaxing the number of b-tagged jets (or track jets)
  - Discriminant is di-Higgs invariant mass in signal region (SR)

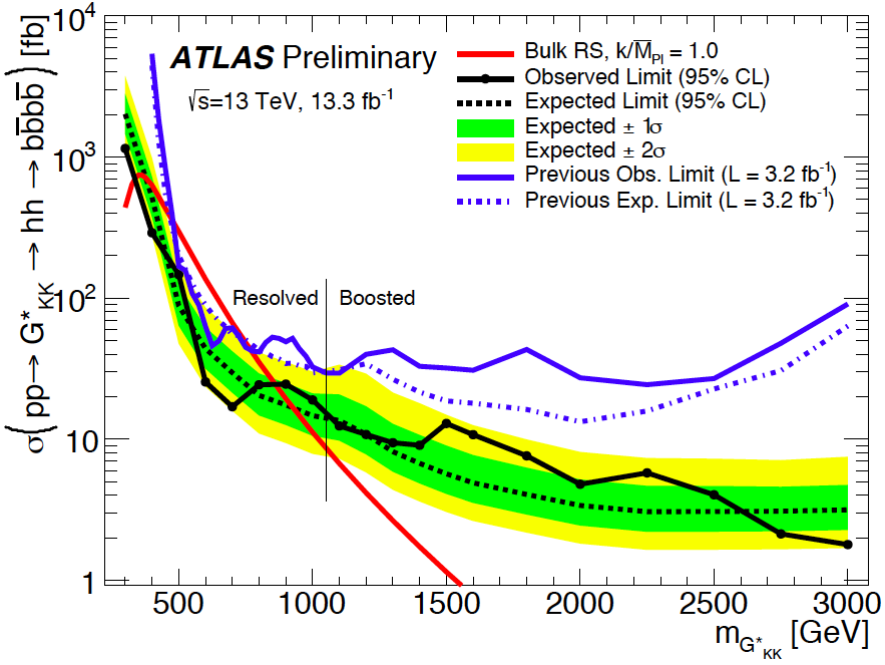




HH → bbbb results







Resolved analysis also sets world's best limit on non-resonant HH production:

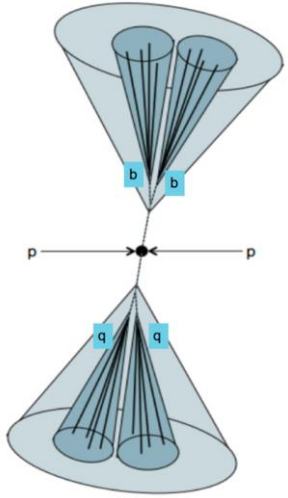
$$\sigma(pp \to hh \to b\bar{b}b\bar{b}) < 330 \text{ fb}$$

(~30x the SM cross section)

VH→ qqbb

New in 2016!

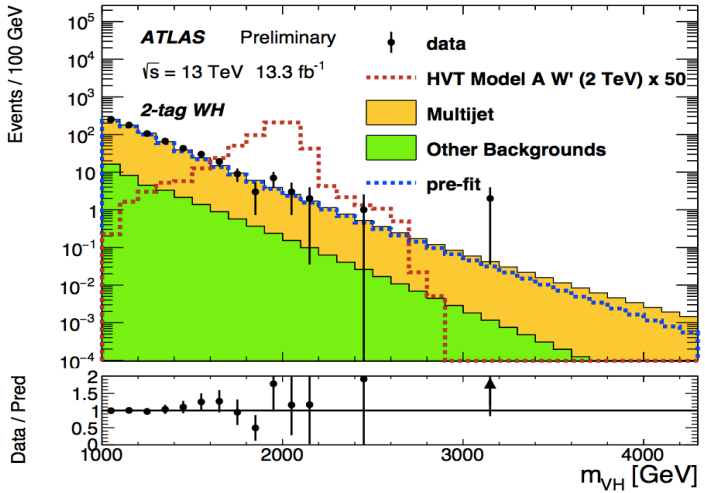
- Complements VH→ llbb/lvbb/vvbb (2015 result just published, updates coming soon)
- Benefits from high branching fraction of W(Z)→qq: 67%(70%)
  - qqbb competitive at high m_X, where multi-jet bkg diminishes

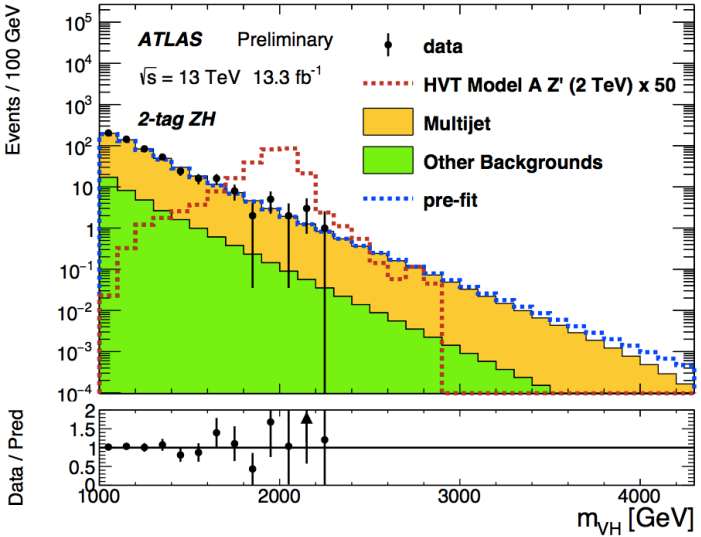


- Topology: 2 trimmed akt10 jets with p_T>450/200GeV
  - V candidate: standard boson tagging (50% working point)
  - H candidate: 75<m_{HC}<145GeV, b-tagged small radius track jets
- Data-driven multijet bkg estimation from 0-b-tag sample
  - Normalization from 0-tag to 1-tag and 2-tag sample in high mass sideband of Higgs candidate
  - Tested in validation region (low mass V candidate sideband)

VH→ qqbb results

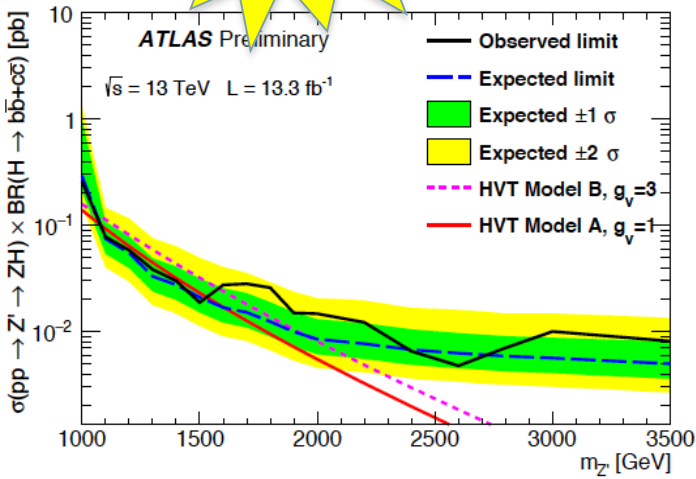
New in 2016!

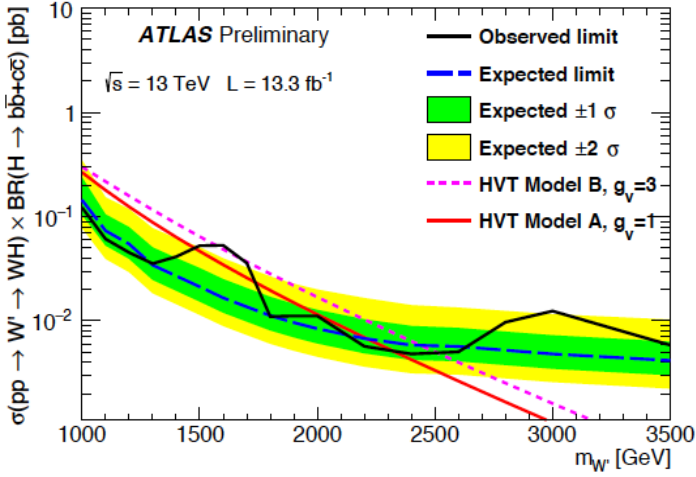




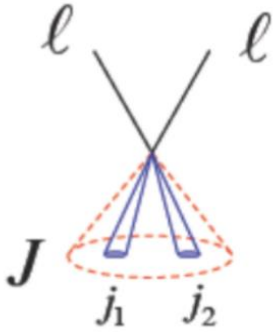
No excess observed in data over the predicted background

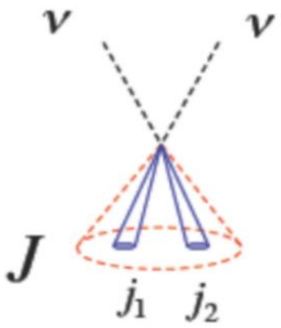
Sensitivity to $\sigma \times BR$ down to a few fb for m_X above 2 TeV

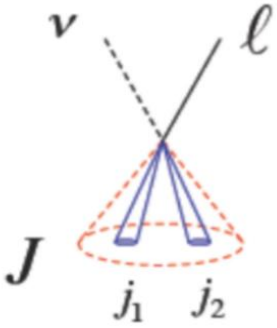


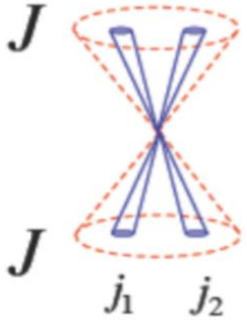


X→VV→ llqq, vvqq, lvqq, qqqq









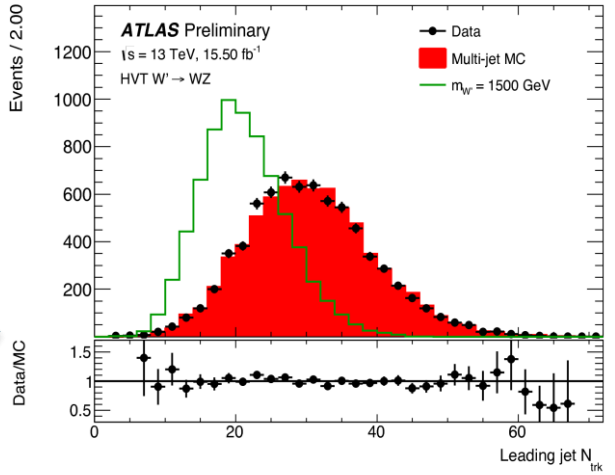
Can be: ZW, ZZ | ZW, ZZ | WW, WZ | WW, ZW, ZZ

- llqq, vvqq, lvqq normally go down to few hundred GeV, hence include both resolved and boosted V→ qq reconstruction
  - In current preliminary results only llqq does
- VV→ qqqq: only looks for resonances with m_X>~1TeV, hence uses only large-R jets and standard boson tagging for both V's
- All channels have comparable sensitivity across all resonance masses
  - llqq has better sensitiviy below ~1TeV and worse above ~2TeV

X→VV→ qqqq

- Slight excess @~2TeV in Run-1 result…

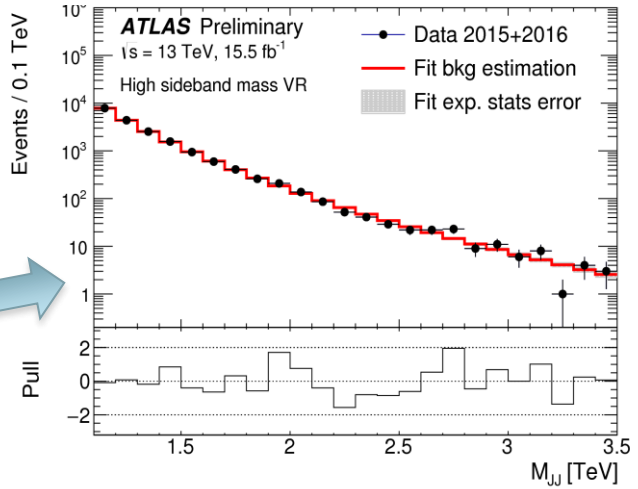
- Run-2 analysis has similar kinematic selection but uses trimmed akt10 jets
  - Two jets: p_T>450/200GeV
  - Standard boson tagging ($D_2^{\beta=1}$)
  - Number of tracks in a jet < 30
    - ~30% improvement in sensitivity



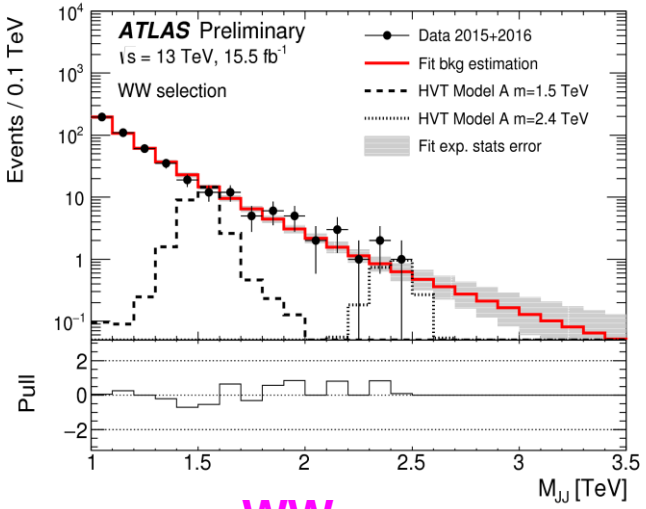
- Multijet bkg dominant (others negligible)
  - Data-driven estimate, modeled with

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

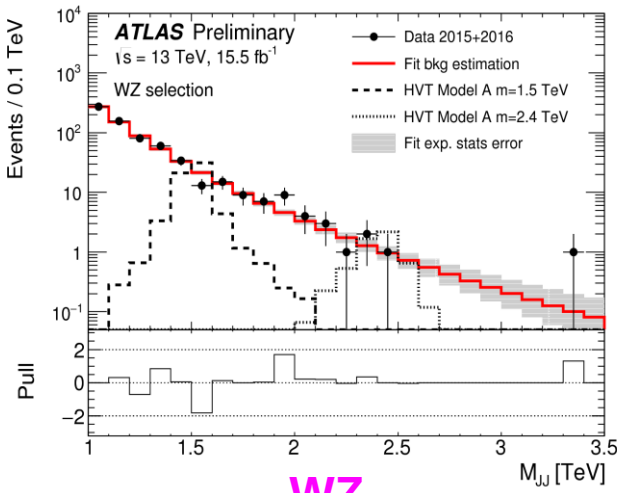
  - Tested in several control regions in data, e.g.
    - Both jets in boson mass sidebands (low, high, mixed)
    - Only one of the two jets satisfies boson-tagging cuts



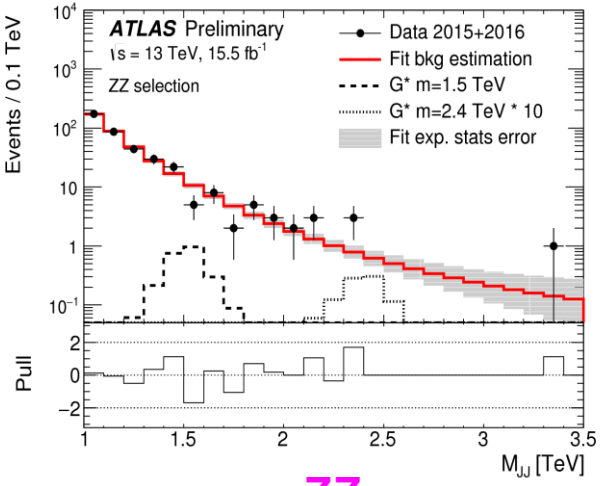
X→VV→ qqqq results



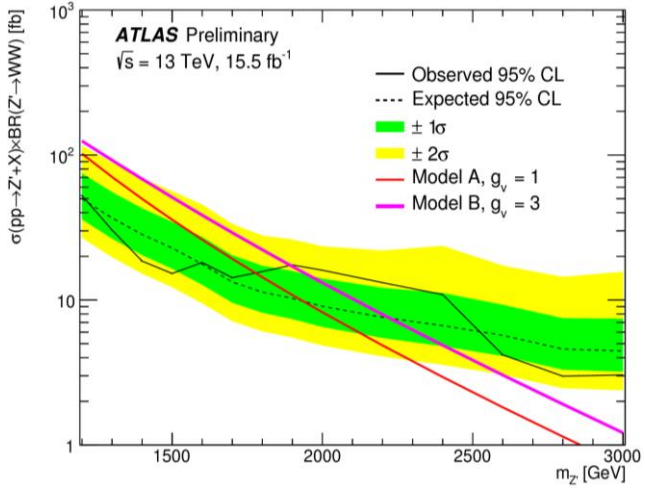
WW

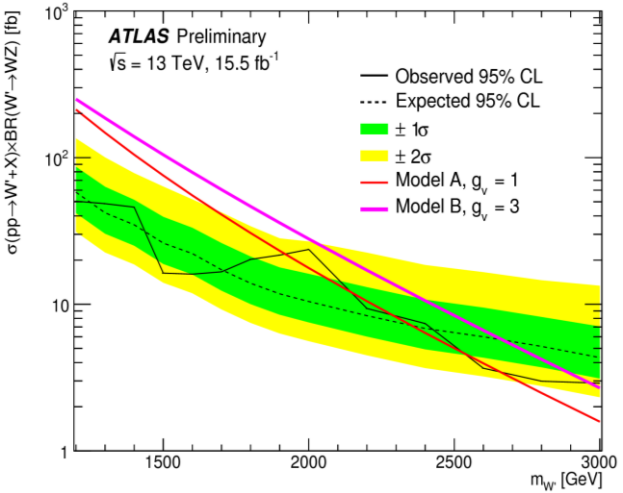


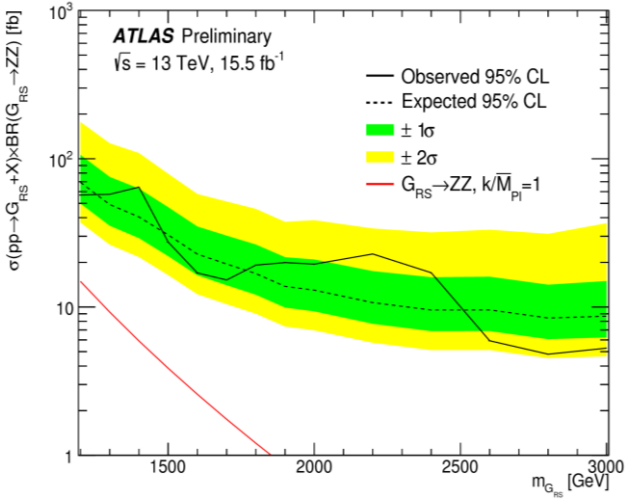
WZ



ZZ

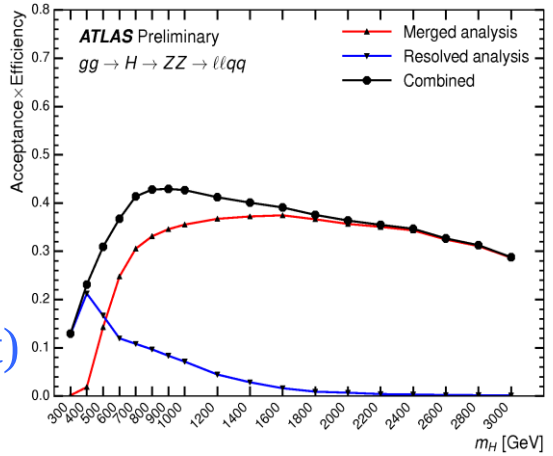




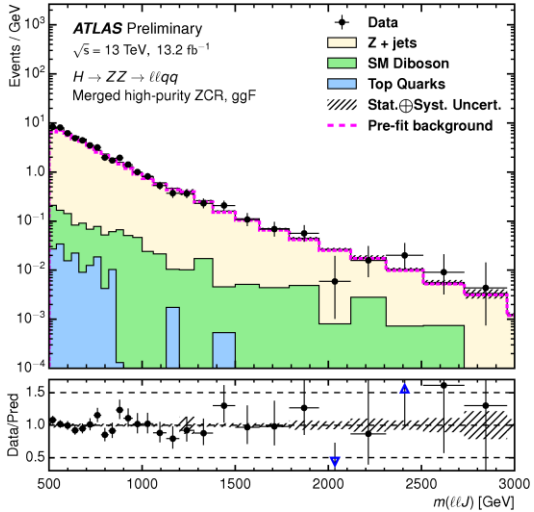


- Standard Z→ ll selection

- V→ qq: large-R jet with pT>200GeV; if not, try resolved reconstruction
  - Merged class: high/low purity regions (pass/fail $D_2^{(\beta=1)}$ cut)
  - Resolved class: b-tagging in ZZ search (for Z→ bb)
  - Also classification as ggF or VBF



- Dominant bkg Z+jets, followed by top, di-bosons
  - Control regions defined in data and used in overall fit to derive normalization factors
    - Z control region in V candidate mass sidebands
    - Top control region: events with opposite flavour leptons

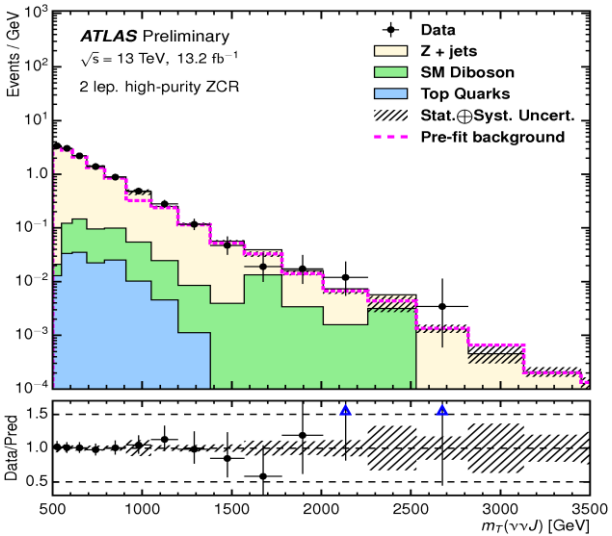


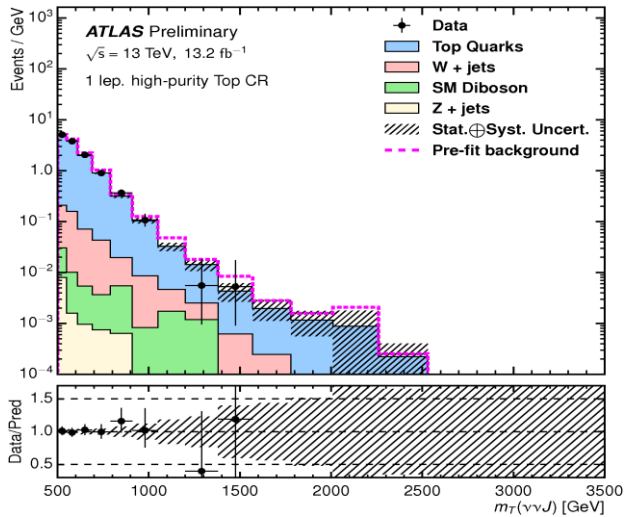
X→ZV→ vvqq

ATL-CONF-2016-082

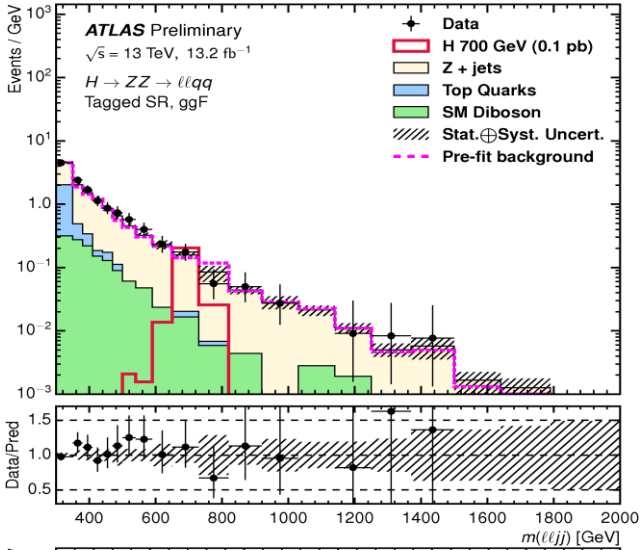
- Large missing E_T > 250GeV for Z→vv
- V→qq with standard boson-tagging
  - large-R jet with p_T>200GeV
- Define high/low purity (HP/LP) signal categories
  - HP: full boson-tagging
  - LP: $D_2^{(\beta=1)}$ variable cut inverted
- Dominant bkgs: Z+jets, W+jets and top
  - Estimated with MC, tested in data control regions
    - 2-lepton CR for Z+jets,
    - 1-lepton/no b-tag for W+jets
    - 1-lepton + b-tag for top
  - Signal & Control regions used in combined fit
- Analysis discriminant: transverse mass

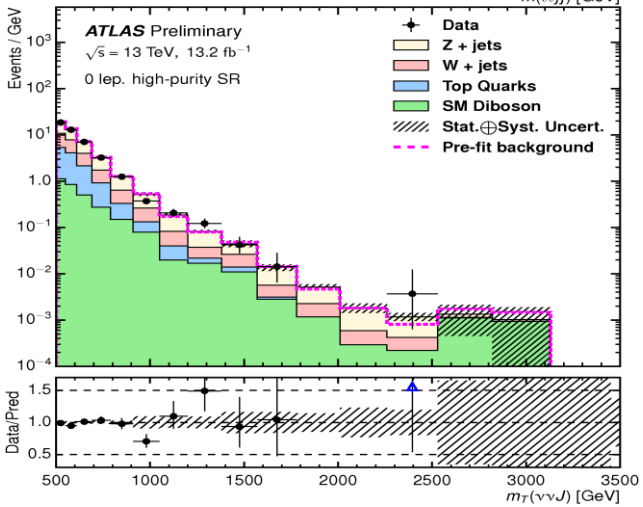
$$m_T^2 = (E_{T,J} + E_T^{\text{miss}})^2 - (\vec{p}_{T,J} + \vec{E}_T^{\text{miss}})^2$$





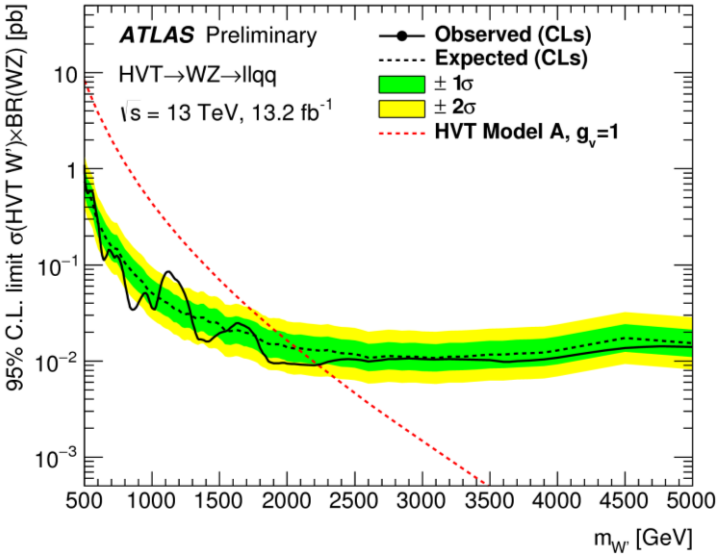
X→ZV→ llqq/vvqq combined results

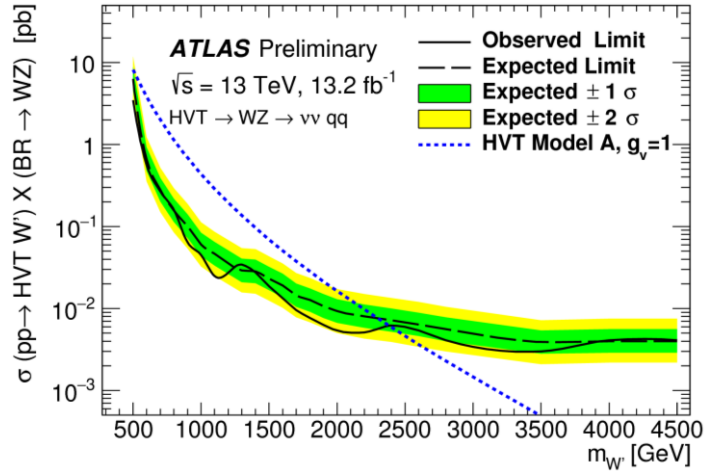




No excess observed in data over the predicted background

Sensitivity to $\sigma \times BR$ down to a few fb for m_X above 2 TeV





X→WV→ lvqq

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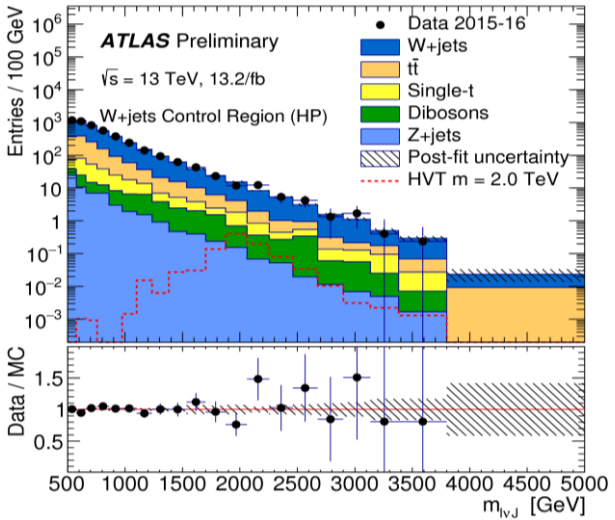
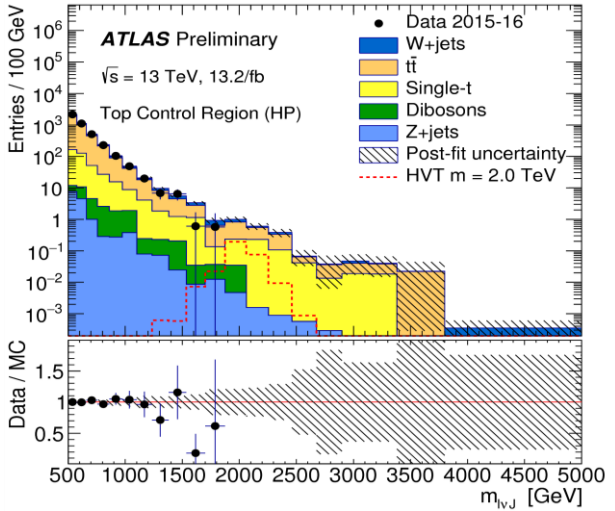
- W→ lv: E_T^{mis}>100GeV, p_T(lv)>200GeV
- V→qq with large-R jet boson-tagging
  - large-R jet with pT>200GeV
  - High/low purity regions (pass/fail $D_2^{(\beta=1)}$ cut)
- Dominant bkgs: W+jets and ttbar
  - Estimated using control regions in data, which are included in the combined fit
    - W+jets CR: m_J sidebands
    - Top CR: at least one b-tagged akt4 jet
- Discriminant: transverse mass m_{lvJ}





X→WV→ lvqq

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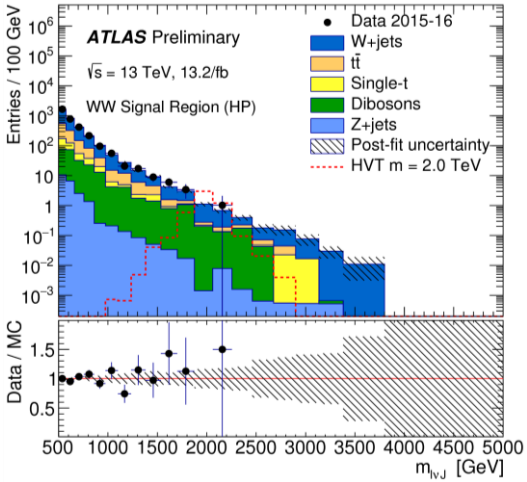
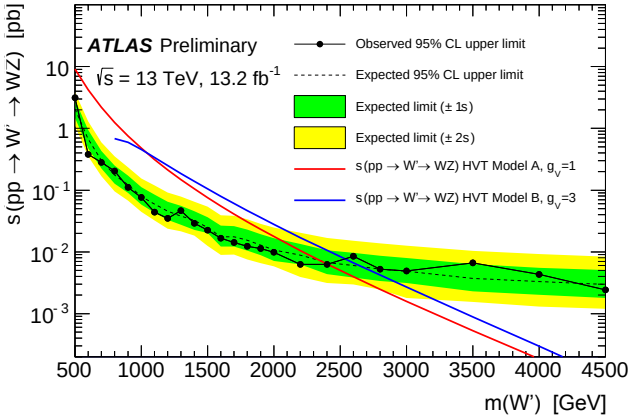
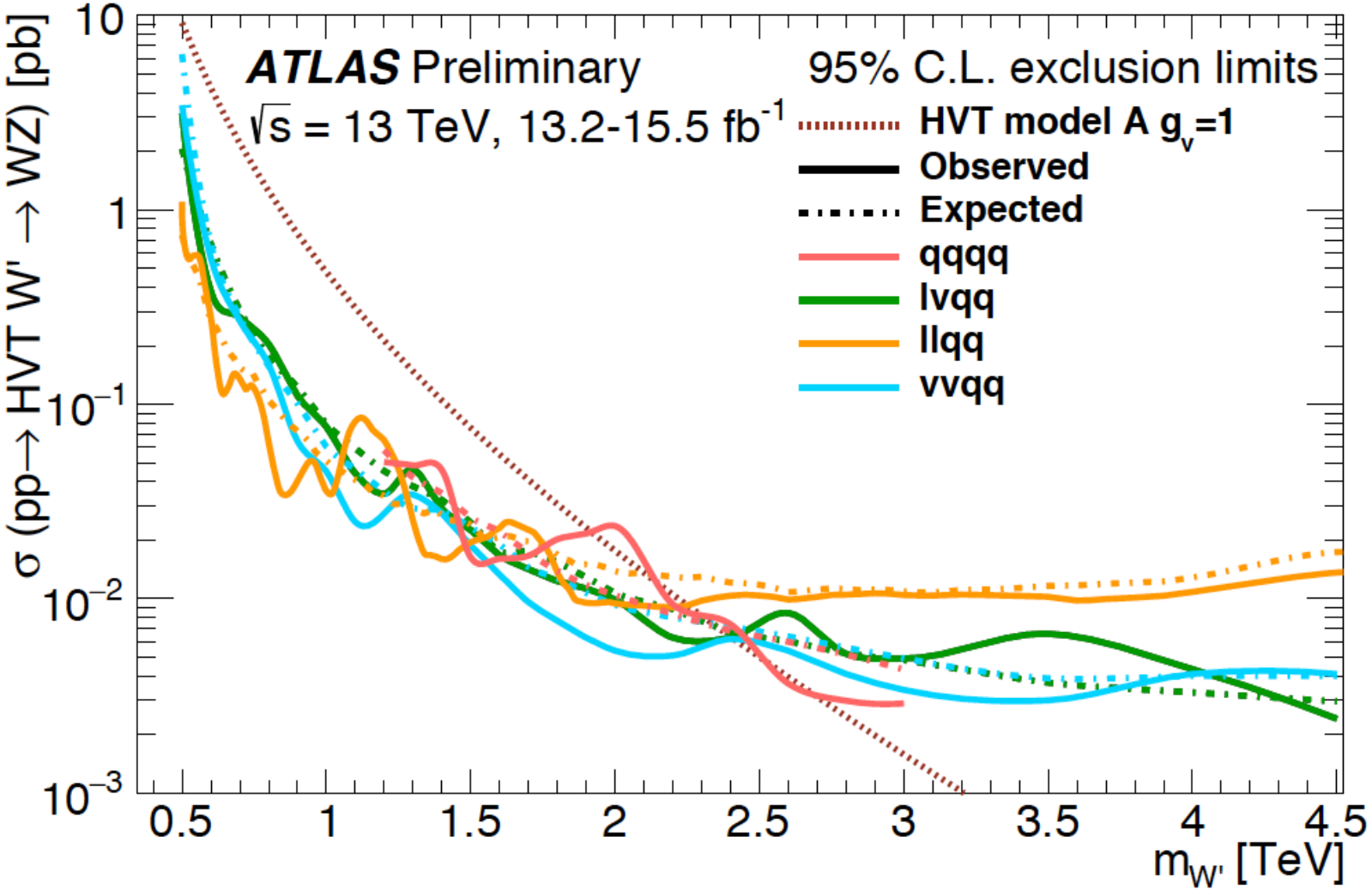


No excess observed in data over predicted background…



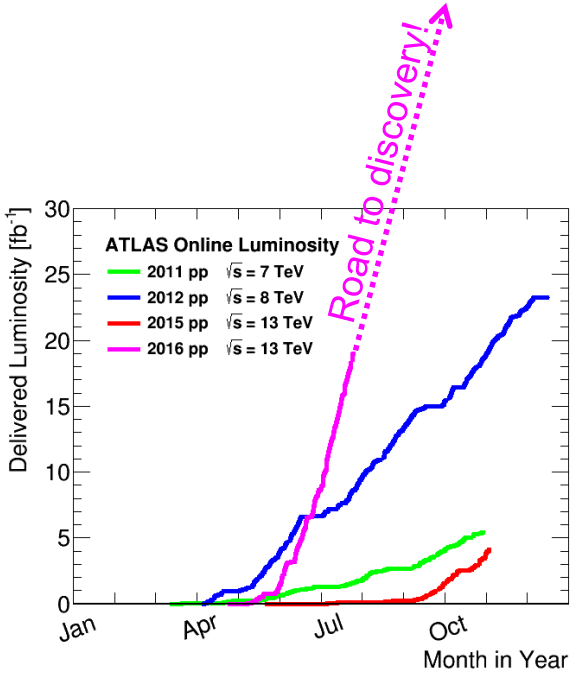
W'→WZ summary plot



Summary

- 13-13 not so lucky for ATLAS!
  - No significant bumps found in searches for di-boson resonances with ~13fb^{-1} at 13TeV

- However: di-boson resonance searches remain sensitive probes of the energy frontier!
  - The fantastic performance of the LHC promises a very exciting journey ahead!

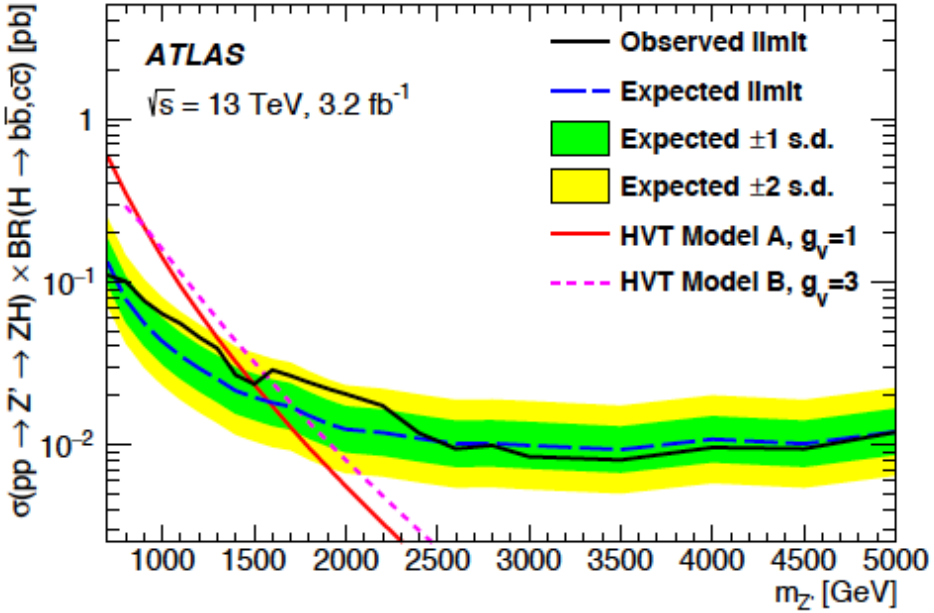


UCL

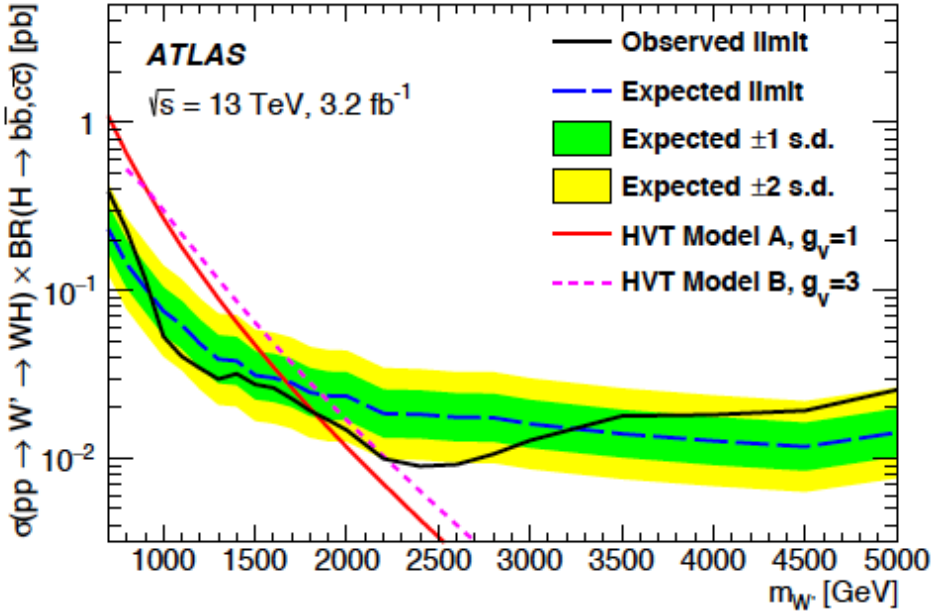
Back-up

X→VH→ lv/ll/vv bb

- Just published result with 2015 data (3.2fb^{-1})



(a) $Z' \to ZH, H \to b\bar{b}/c\bar{c}$



(b) $W'^{\pm} \to WH, H \to b\bar{b}/c\bar{c}$