

ATLAS Searches for VH and HH Resonances



$$H \rightarrow bb \oplus H/V \rightarrow [bb, qq]$$

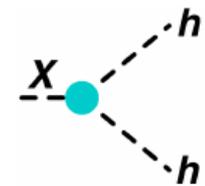
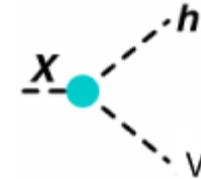
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(for the ATLAS Collaboration)

- Motivation and Models
- Some tools: trimming and combined mass
- HV, $H \rightarrow bb$, $W/Z \rightarrow qq'$... 36.1 fb⁻¹ @ 13 TeV, ATLAS-CONF-2017-018
- $HH \rightarrow bbbb$, ... 13.3 fb⁻¹ @ 13 TeV, ATLAS-CONF-2016-049
- Conclusions

Motivation and Models

- $HV, H \rightarrow bb, W/Z \rightarrow qq'$
 - Resonant production possible in NP models
 - composite Higgs, Little Higgs, MSSM, nMSSM,...
 - This paper interprets results in terms of **simplified Heavy Vector Triplet models**: **JHEP 09** (2014) 060
 - SM + triplet vector describing one charged and one neutral heavy spin-one particle
 - Model A: extended gauge symmetry
 - Model B: Minimal Composite Higgs Model

- $HH \rightarrow bbbb$
 - Analysis results for Randall-Sundrum KK resonances



- Still best ATLAS ref: JHEP09 (2013) 076
- Recluster subjets ($R=0.2$) and remove if $p_T^{\text{sub}} < 0.5 * p_T^J$
- Applied for W-tagging Eur. Phys. J. C 76(3) (2016)
 - $W \sim 2$ subclusters; multijets ~ 1
- For H tagging: associate $R=0.2$ track jets to fat J and require 1 or 2 b-tags

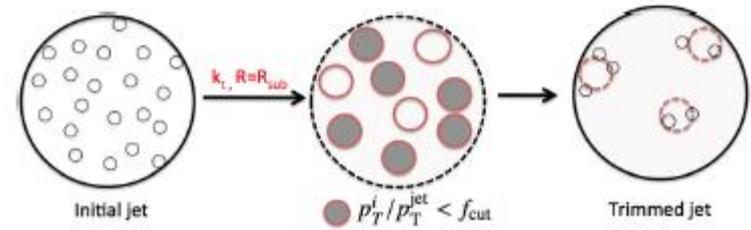
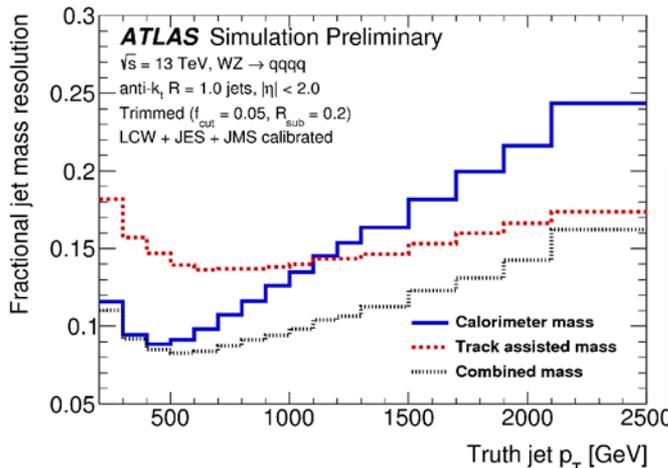
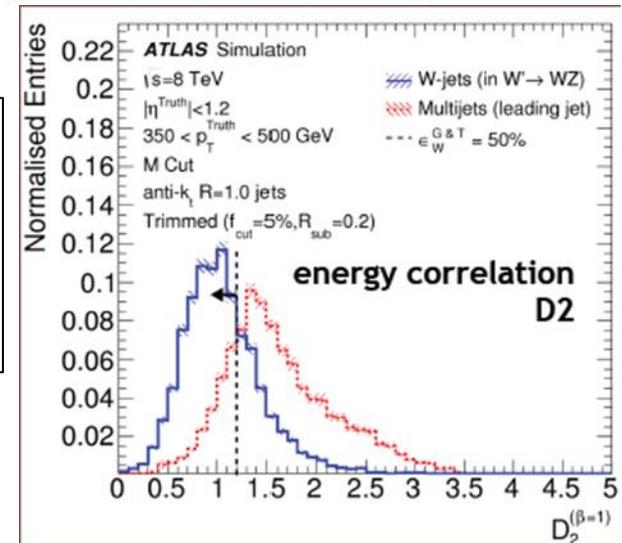


Figure 4. Diagram depicting the jet trimming procedure.

- For W tagging we use the D_2 variable invented by Larkoski, Moult and Neill: DOI: 10.1007/JHEP12(2014)009
 - Employs energy correlation functions to measure “graininess” of jet



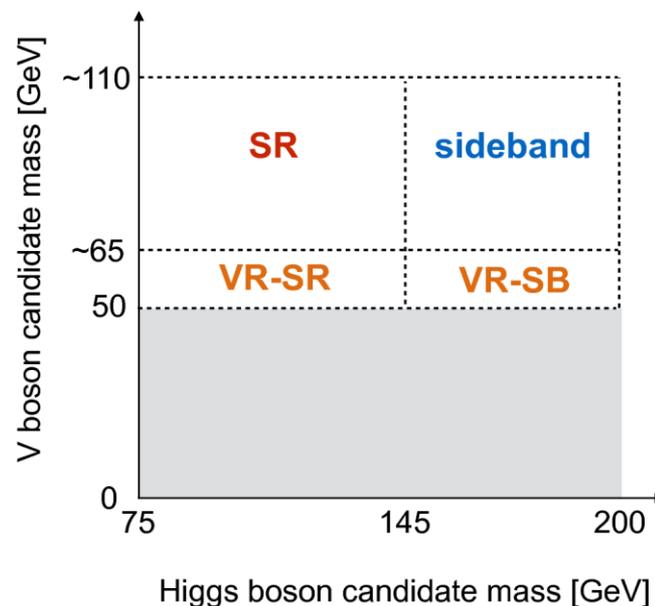
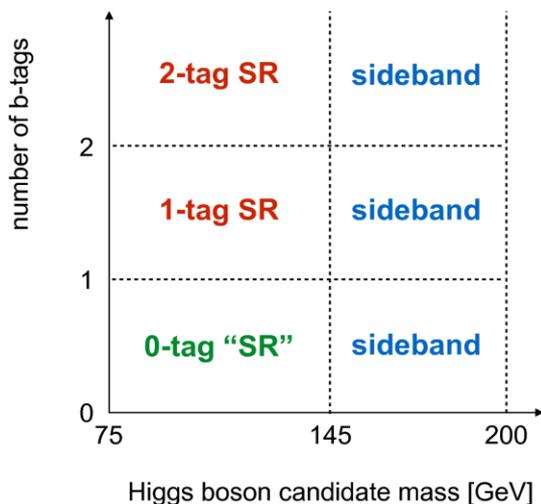
- bbqq is first analysis to use calo+track **combined mass**
 - ATLAS-CONF-2016-03500
 - good angular resolution of tracks used to improve jet mass resolution

HV, H \rightarrow bb, W/Z \rightarrow qq' (ATLAS-CONF-2017-018)

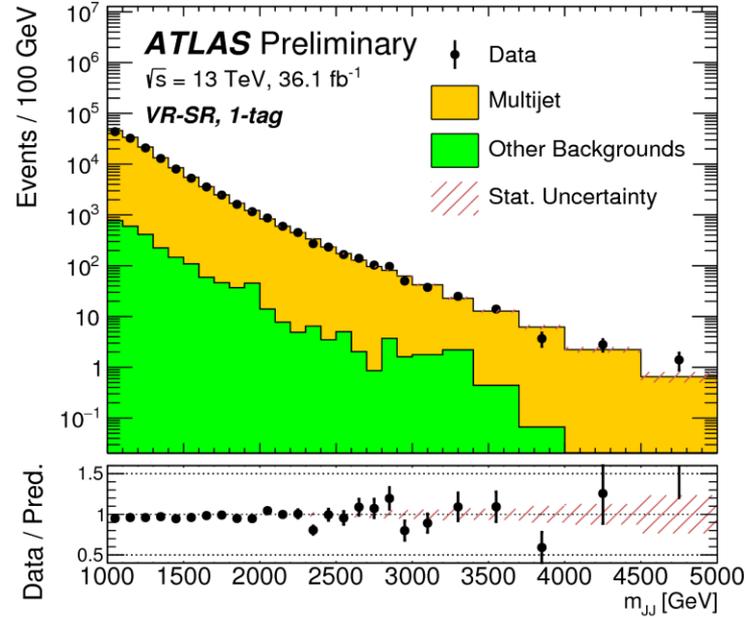
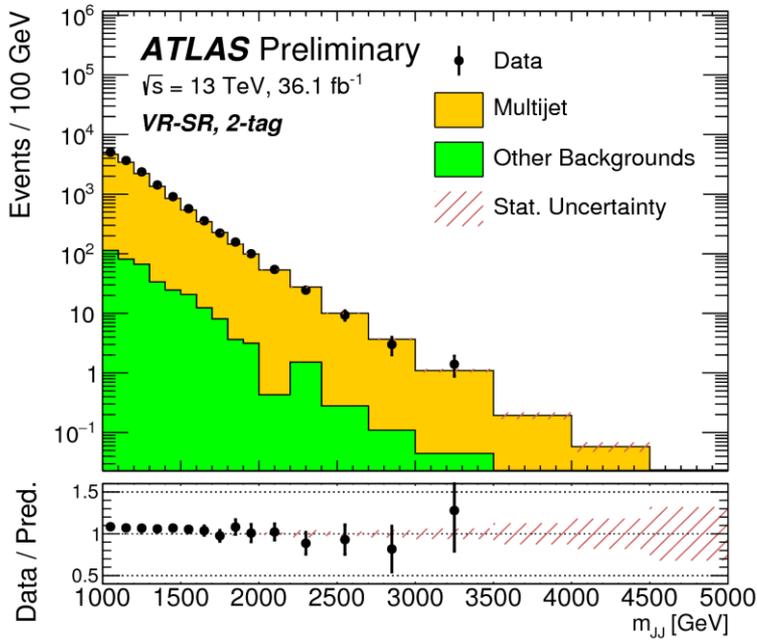
- High mass search: boosted Jets will merge
- Two R=1.0 anti- k_t Jets with $|\eta| < 2$ are proxies for the h and V
- Trigger: leading jet with $p_T > 420$ (360) GeV in 2016 (2015) due to higher 2016 rates
 - Offline: $p_T > 450$ GeV, 99% efficient
- H = leading J, $75 < m_J < 145$ GeV, b-tag using track-jets (ATL-PHYS-PUB-2015-035)
 - Benefits from improved b-tag using Inner B-Layer tracker (ATL-PHYS-PUB-2015-022)
 - Trimming used to reduce effect of pileup and soft radiation in large-R jets
- V = subleading J, $p_T > 250$ GeV ... (ATL-PHYS-PUB-2015-033)
 - IVB probability strengthened by tagging J as 2-prong vs 1-prong... D_2 energy correlation
 - V tag efficiency=50%, constant in p_T ; 2% multijet mis-ID probability

HV, $H \rightarrow bb$, $W/Z \rightarrow qq'$: Background (1)

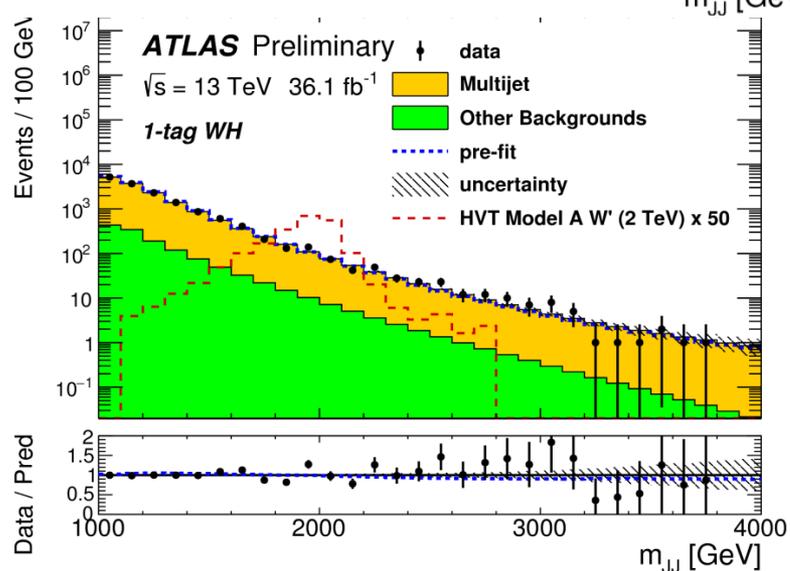
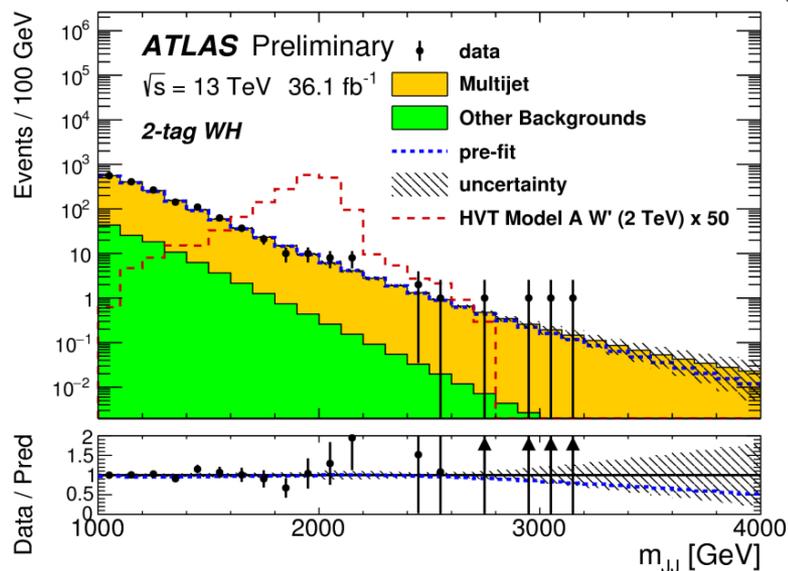
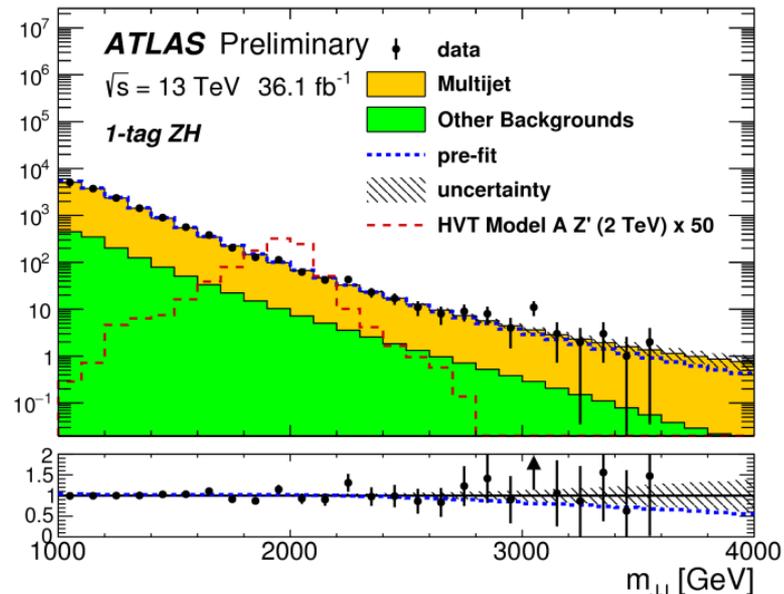
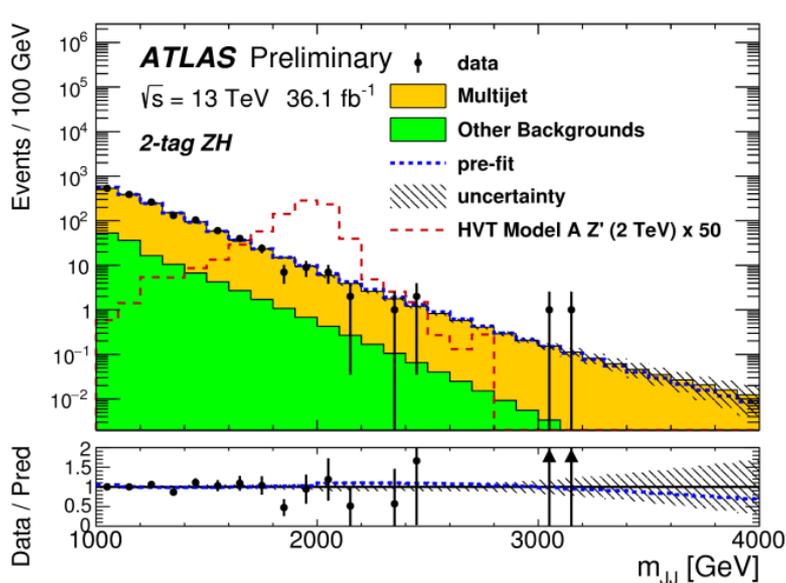
- Data-driven estimation of multijet background: categorize by b tags
 - About 10% $t\bar{t}$ contribution....less than 1% from V+jets
 - Extrapolate background from sideband regions
 - Background shape obtained from 0-tag “SR”, then kinematic correction
 - Verify background estimate by defining Validation Regions VR-SR and VR-SB (signal and sideband-like, respectively)



- Background validation

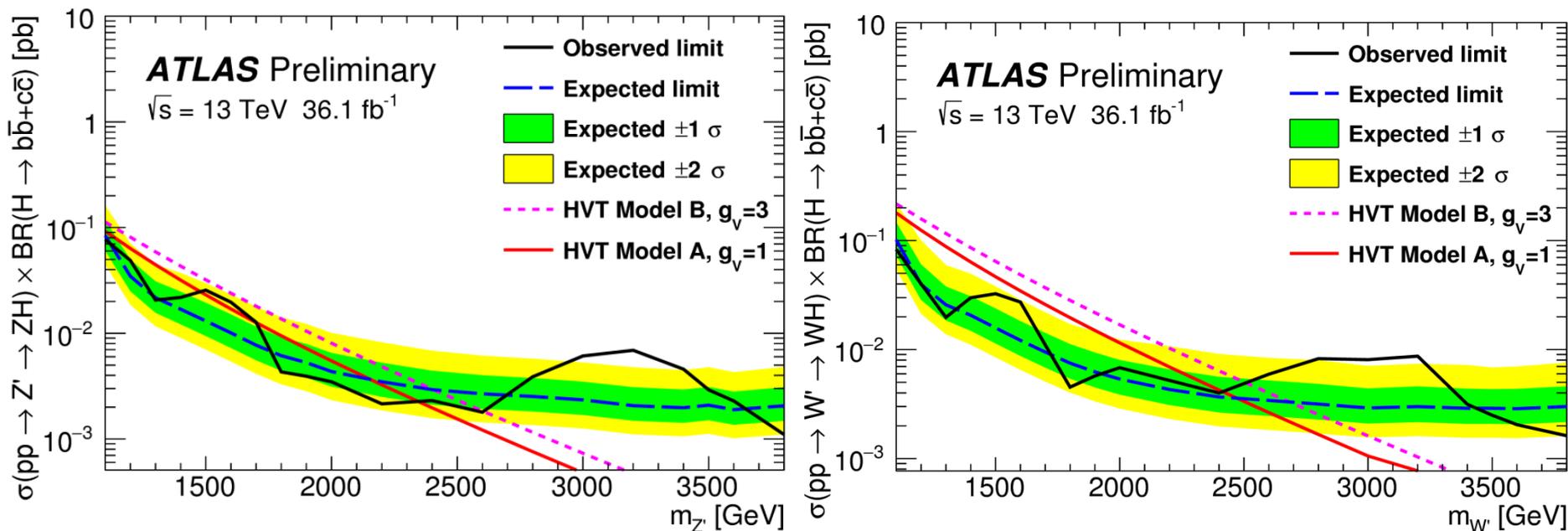


HV, $H \rightarrow bb, W/Z \rightarrow qq'$: Results (1)



HV, H \rightarrow bb, W/Z \rightarrow qq': Results (2)

- Significance of data near 3 TeV has global significance of 2.2σ
- Limits on (cross section)*BR for resonance mass windows 1.1-3.8 TeV
- Limits expressed in HVT Models A and B of JHEP 09 (2014) 060
- Model B masses excluded in range 1.10-2.50 for WH, 1.10-2.60 for ZH



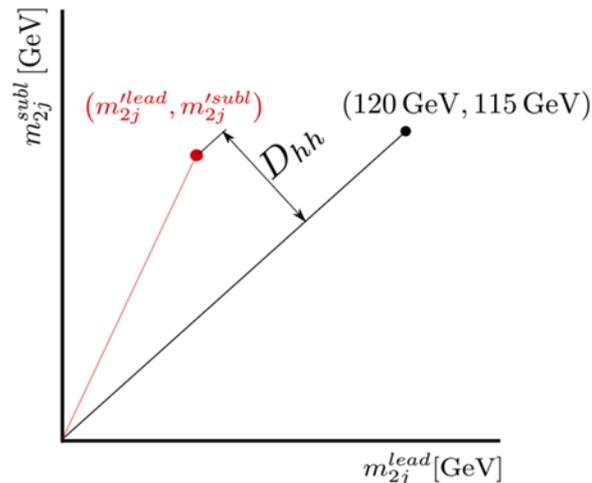
HH \rightarrow bbbb (ATLAS-CONF-2016-049)

- Another updated analysis benefitting from improved (IBL) b-tagging
 - Better sensitivity for $m_x < 500$ GeV, $m_x > 2500$ GeV
- Cover both low (resolved dijet) and high-mass (boosted) resonance masses
 - Resolved best for $m \leq 1$ TeV
- Analysis interpreted in Randall-Sundrum Kaluza-Klein resonance picture
- Unlike bbqq analysis, H mass reconstructed using only calorimeter information
 - Massless topological clusters, anti- k_t jets, $R=0.4$ or 1.0
 - Area-based pileup subtraction + residual μ -dependent correction
 - $R=1.0$ jets trimmed using $r=0.2$ subjets; eliminate if $p_T^{\text{subjet}} < 0.05 p_T^{\text{jet}}$
 - b-tagging is multivariate algorithm using associated tracks
 - ATL-PHYS-PUB-2016-012 and ATL-PHYS-PUB-2014-013
- Two separate analyses for **Resolved** and **Boosted** scenarios

HH \rightarrow bbbb: Resolved Case

- **Resolved:**

- two H candidates from 4 b-tagged anti- k_t R=0.4 jets with $p_T > 30$ GeV, $|\eta| < 2.5$
 - take the 4 jets with highest b-tag probabilities
- Multiple triggers to maintain high efficiency (65% @ $m=300$ to 95% at >500 GeV)
- Slightly different cuts for 2015 and 2016 data
- To select the best hh pairing and reduce multijet background:
 - Reject pairs if ΔR_{jj} not in window based on m_{4j}
- Choose best hh pairing: $\min D_{hh}$
 - basically chooses most-equal mass pairs
- $\Delta R_{hh} > 1.5$
- $p_T^{\text{lead}} > 0.5m_{4j} - 90$ GeV
- $p_T^{\text{sublead}} > 0.33m_{4j} - 70$ GeV

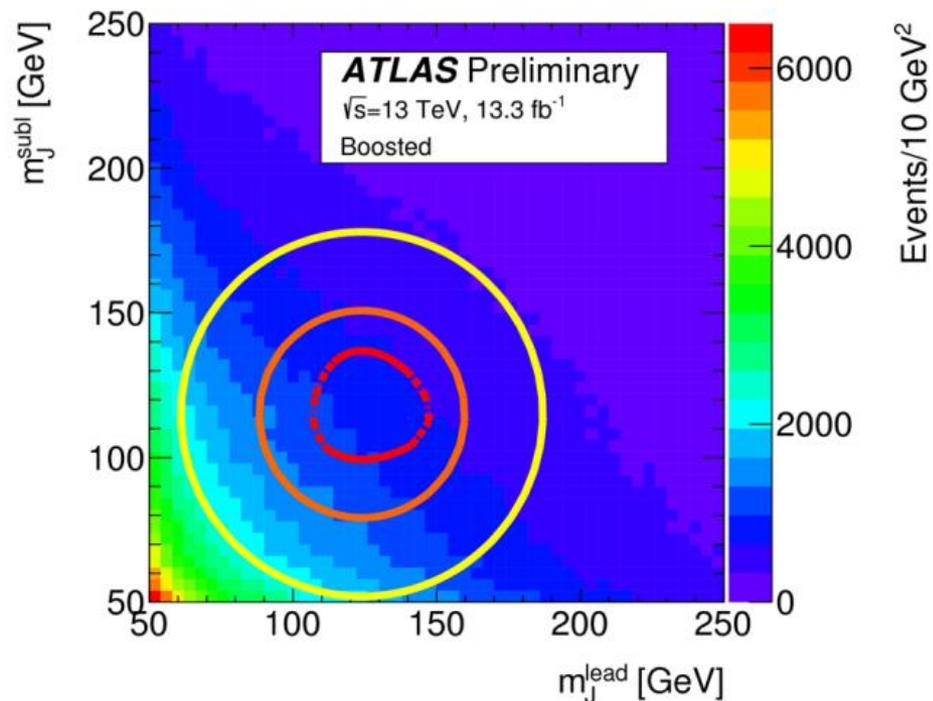
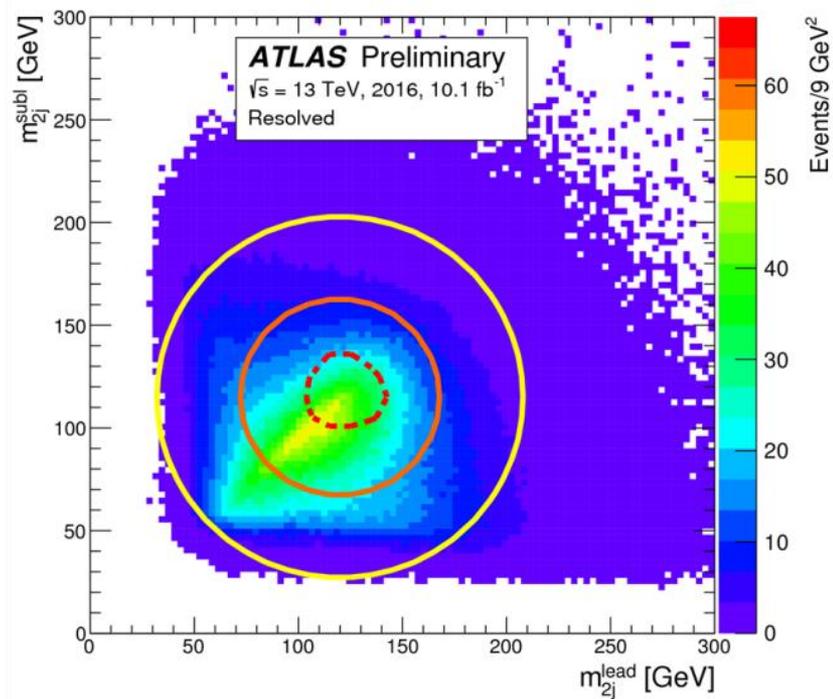


HH \rightarrow bbbb: Boosted Case

- **Boosted:** two $R=1.0$ anti-kt jets, $p_T > 250$ GeV, $|\eta| < 2$, $m_J > 50$ GeV
 - At least one b-tag (from associated track-jet) each
 - $\Delta |\eta_{JJ}| < 1.7$
 - Leading J has $p_T > 450$ GeV (suppresses top background)
 - Little difference between 2015 and 2016 datasets
 - m_{2J} main discriminant of background
 - Three sample regions: 2-tag (1 each), 3-tag, 4-tag

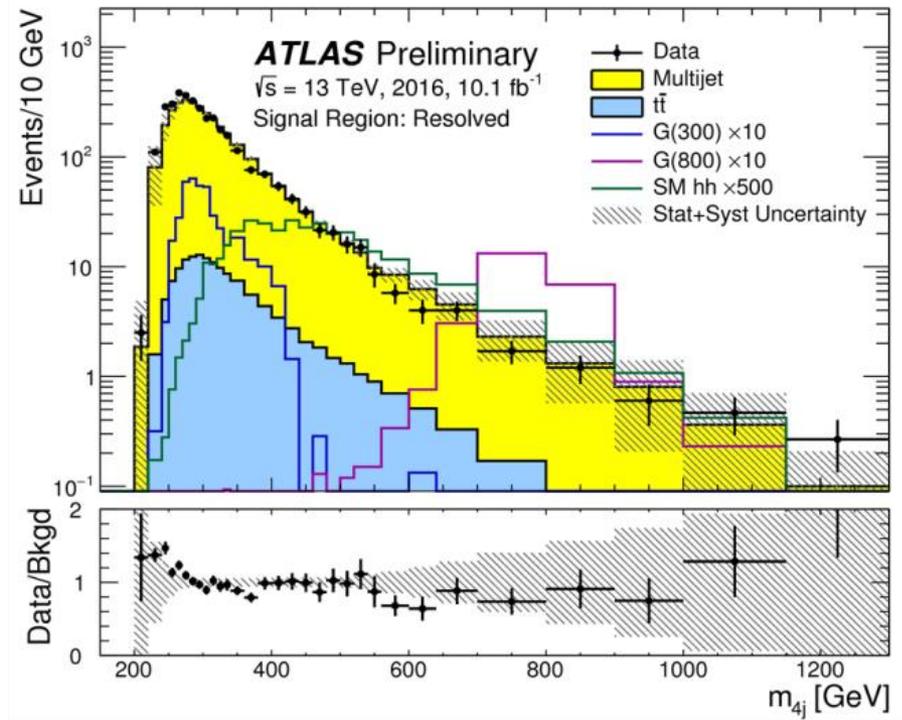
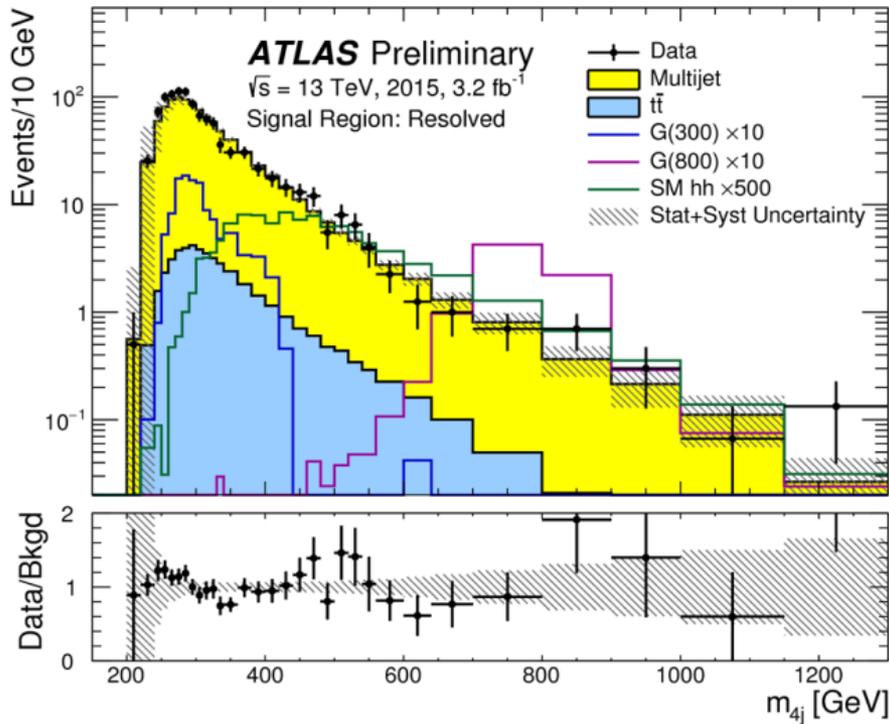
HH \rightarrow bbbb: sidebands

- Background mostly multijet, so calculated from sidebands
- m_{lead} vs $m_{\text{sub-lead}}$ used to define signal and side-band regions
- Outermost region used to calculate background
- Annular region used to validate



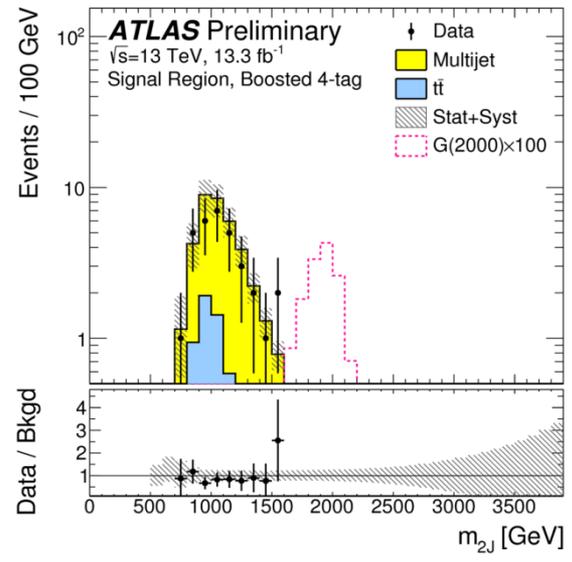
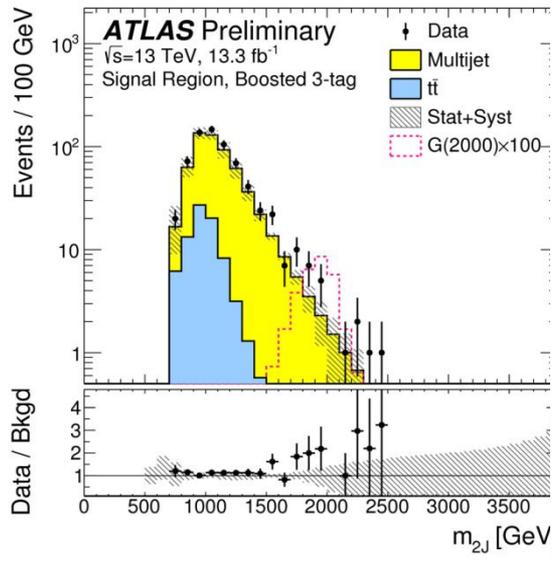
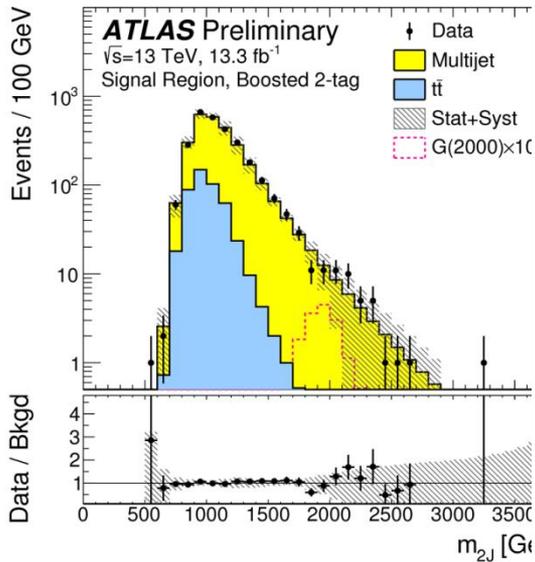
HH \rightarrow bbbb: Results, Resolved

- 2015 and 2016 data treated separately
- No statistically significant deviation from SM



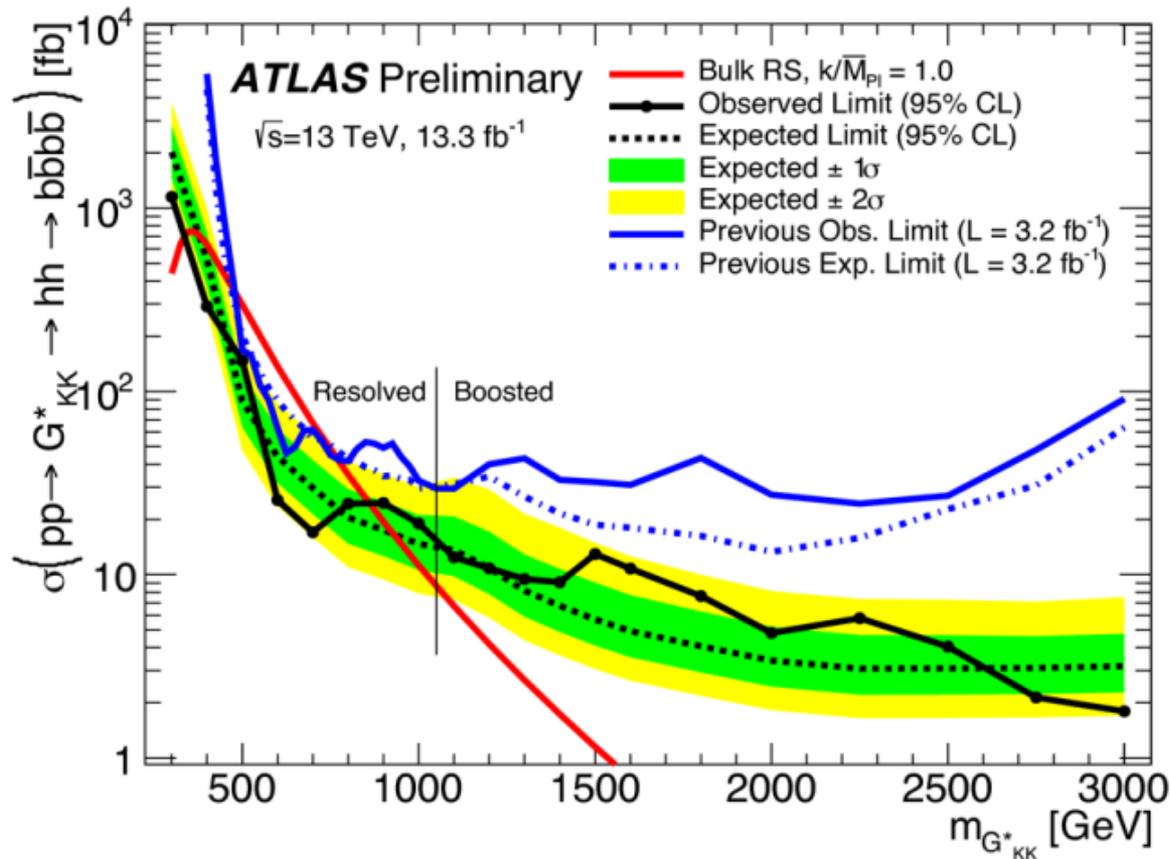
HH \rightarrow bbbb: Results, Boosted

- 2015 and 2016 data combined
- No statistically significant deviation from SM



HH \rightarrow bbbb: Limits

- Significant improvement over last year's results
- Exclude RS graviton in range 360 – 860 GeV
- Inclusive SM nonresonant limit is $\sigma(pp \rightarrow hh \rightarrow 4b) < 330$ fb (SM value is 11 fb)



Conclusions

- ATLAS is searching for NP signals in the HV and HH channels
 - Attractive to numerous models
 - Analyses in hadronic, leptonic, and missing energy channels
 - Run 2 analyses benefit from better b-tagging due to IBL
 - But suffer from increasing pileup
 - Awaiting analysis of full 2016 data sample
 - And then combinations of the channels
- No statistically significant signatures seen so far