ATLAS Searches for VH and HH Resonances

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

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- 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 → bb, W/Z → 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 → bbbb
  – Analysis results for Randall-Sundrum KK resonances
Trimming (Krohn, Thaler, and Wang: JHEP 1002 (2010) 084)

- Still best ATLAS ref: JHEP09 (2013) 076
- Recluster subjets (R=0.2) and remove if $p_T^{\text{sub}} < 0.5 \times p_T^J$
  - $W \sim 2$ subclusters; multijets $\sim 1$
- For H tagging: associate R=0.2 track jets to fat $J$ and require 1 or 2 b-tags
  - 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
• 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
• Data-driven estimation of multijet background: categorize by b tags
  – About 10% ttbar 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)
HV, H → bb, W/Z → qq’': Background (2)

- Background validation

![Graph 1](image1.png)

![Graph 2](image2.png)

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HV, H → bb, W/Z → qq’: Results (2)

- Significance of data near 3 TeV has global significance of 2.2 σ
- 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
Another updated analysis benefitting from improved (IBL) b-tagging
   – Better sensitivity for $m_\chi<500 \text{ GeV}$, $m_\chi>2500 \text{ GeV}$

Cover both low (resolved dijet) and high-mass (boosted) resonance masses
   – Resolved best for $m \leq 1 \text{ TeV}$

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 $\mu$-dependent correction
   – $R=1.0$ jets trimmed using $r=0.2$ subjets; eliminate if $p_T^{\text{subj}}<0.05 \ p_T^{\text{jet}}$
   – 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 $\Delta R_{jj}$ not in window based on $m_{4j}$
  - Choose best hh pairing: min $D_{hh}$
    - basically chooses most-equal mass pairs
- $\Delta R_{hh} > 1.5$
- $p_T^{lead} > 0.5m_{4j} - 90$ GeV
- $p_T^{sublead} > 0.33m_{4j} - 70$ GeV
**HH → 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
• Background mostly multijet, so calculated from sidebands
• $m_{\text{lead}}$ 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 → bbbb: Results, Resolved

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