Fully Hadronic Diboson Searches in ATLAS

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On behalf of the ATLAS Collaboration

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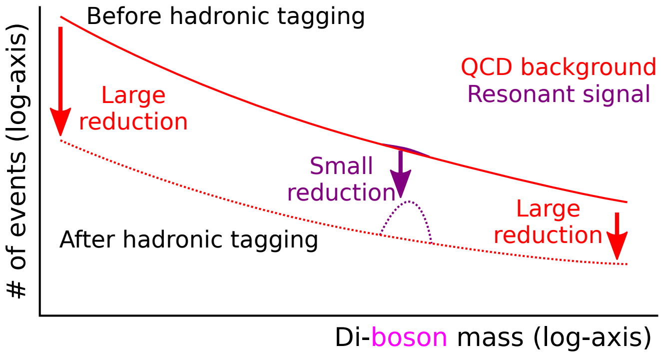
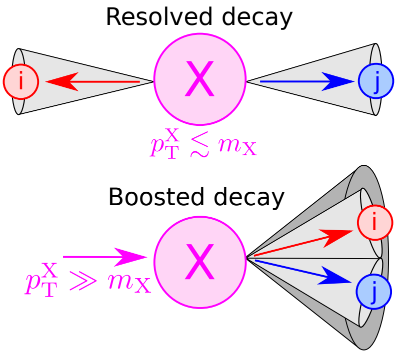
Searching for fully-hadronic di-boson resonances

- Many theories of new physics predict the decay of new particles to pairs of bosons
  - These cover spin 0 (radion), 1 (HVT), and 2 (graviton) parent particles: lots of possibilities!
- Bosons have **large hadronic branching fractions**: motivates high-mass hadronic searches
  - Typically looking for di-boson resonances over a smooth QCD background
  - Searches use taggers to identify jets containing **boosted** hadronic bosons, suppressing QCD

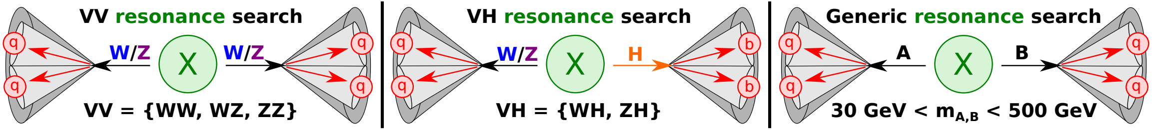




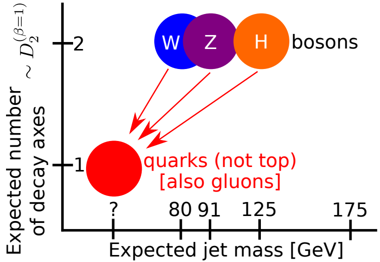
Reconstructing and tagging hadronic decays

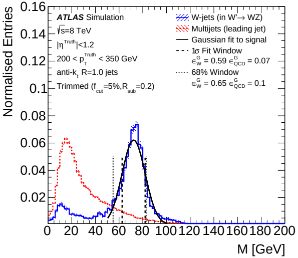
Plots: PERF-2015-03

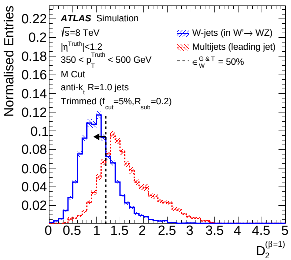
- Study several final states: WW, WZ, ZZ; WH, ZH; and A, B with $m_{A,B} \in [30, 500]$ GeV



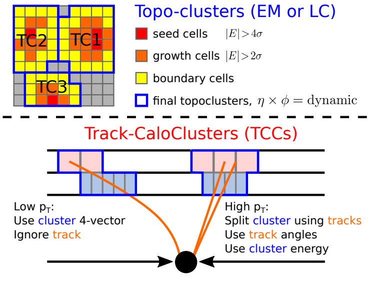
- Reject QCD background using boosted jet taggers: mass + substructure (+ flavour)
  - Jet substructure: angular and energy correlations of objects within a given jet, e.g. $D_2^{(\beta=1)}$

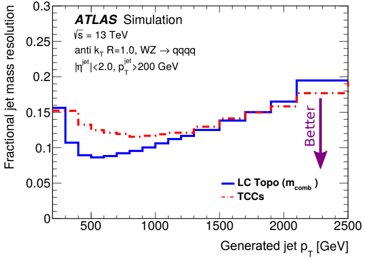


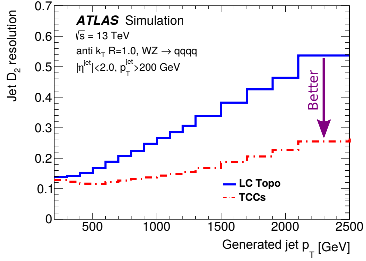




- Picking the right type of jet is important for hadronic diboson searches
  - Needs to be *large-radius* to encapsulate full boson decay: use anti-k_t $R = 1.0$ jets
  - Then remove contributions from pileup and the underlying event: use trimming algorithm
- Also need to keep analysis needs in mind when picking the input to jet reconstruction
  - Generic diboson search uses jets built from topoclusters: generally best jet mass resolution
  - VV and VH searches use jets built from TCCs: best boson tagging performance due to D_2

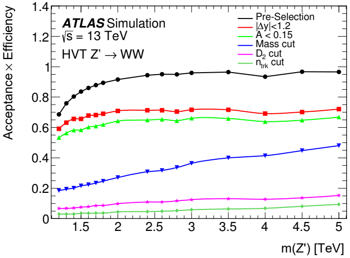


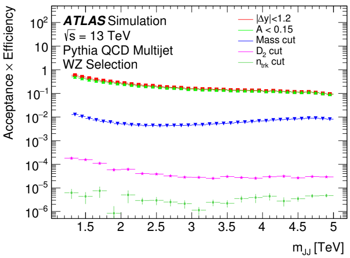


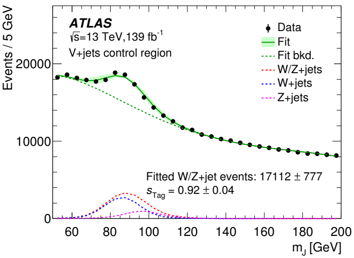


VV resonances: analysis selection

- Define W and Z boson taggers: tight at low p_T, looser at high p_T (less QCD background)
    - Cut on jet mass, D_2, and # of tracks: signal efficiency of 20% at low p_T and 40% at high p_T
- Full analysis selection is very tight: rejects $90-95\%$ of signal events
    - However, it also rejects an enormous amount of background: QCD rejection of $\sim 10^5$
- Control the tagger performance using a dedicated V+jet control region
    - Directly extract the signal tagging efficiency difference between data and simulation

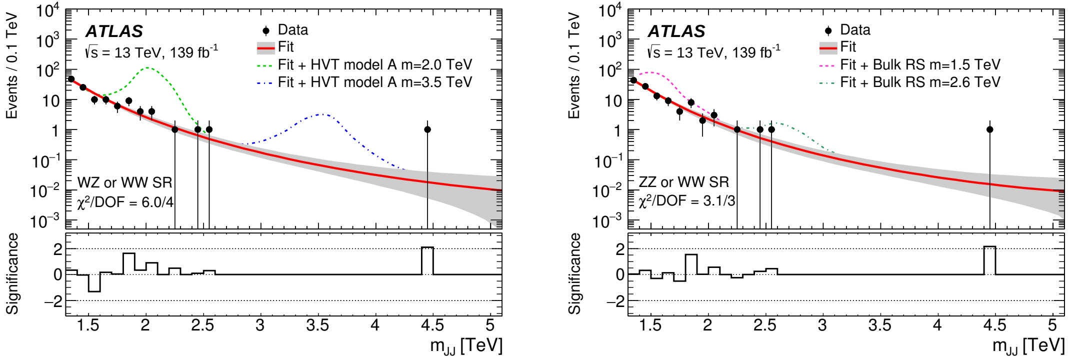






Plots: HDBS-2018-31

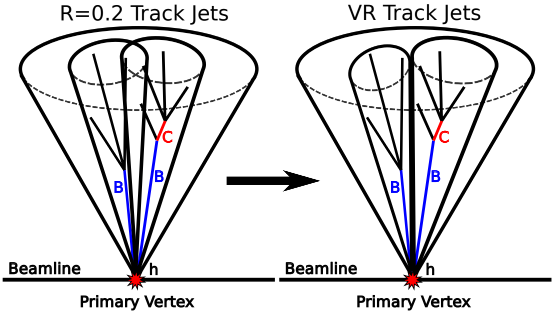
- After applying the full analysis selection, look for bumps in the smoothly falling spectrum
  - Fully data-driven: fit the data to get the background prediction
- Done separately for three overlapping selections: *WW*-, *WZ*-, and *ZZ*-tagged
  - Then combine the results into $WW + WZ$ and $WW + ZZ$ according to signal interpretation

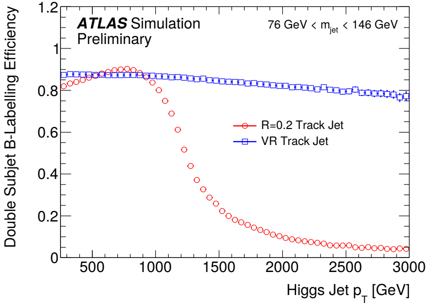


VH resonances: building $H \to bb$ taggers

Plots: PUB-2017-010

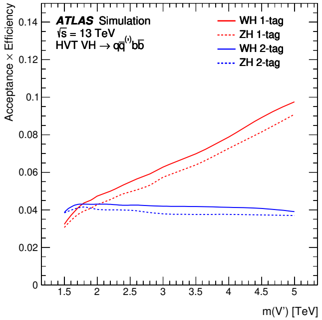
- Most important aspect of $H \to bb$ tagging: identifying two b-hadrons in the $R = 1.0$ jet
- $H \to bb$ tagging historically matched pairs of b-tagged $R = 0.2$ track jets to $R = 1.0$ jets
  - Breaks down at high p_T as b-hadron decays overlap $\to$ switch to variable-radius (VR) jets
  - Important development for VH resonances analysis: large gain at high-p_T

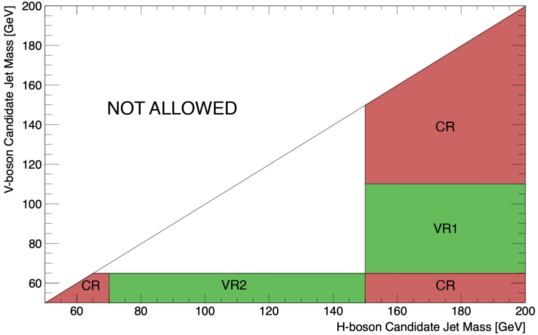




VH resonances: analysis definition

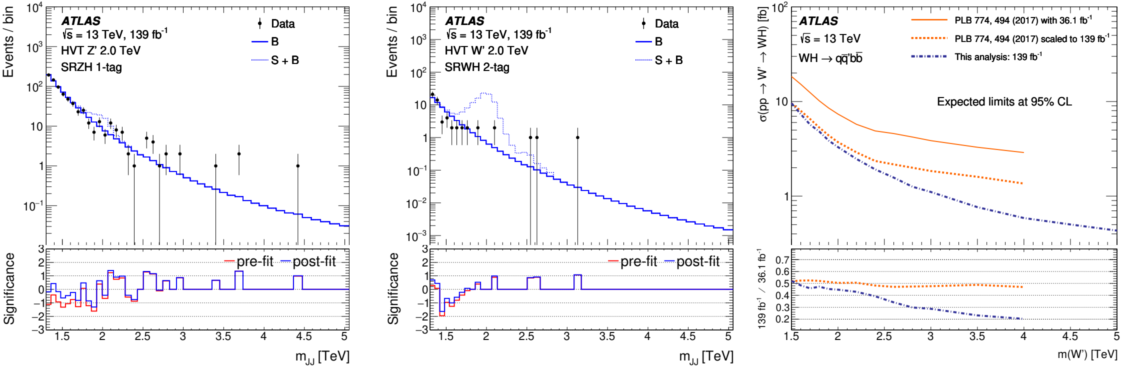
- Analysis selection is similarly strict: rejects 90 – 96% of signal
  - Necessary to reject the very large QCD background
  - Uses the same W/Z boson tagger as the VV resonance search
  - $H \to bb$ tagger uses the jet mass, # of tracks, and # of b-tagged VR track-jet(s) [1 or 2]
- Uses series of control and validation regions to approach WH and ZH signal regions
  - Used to estimate yield and shape corrections to the di-boson mass distribution





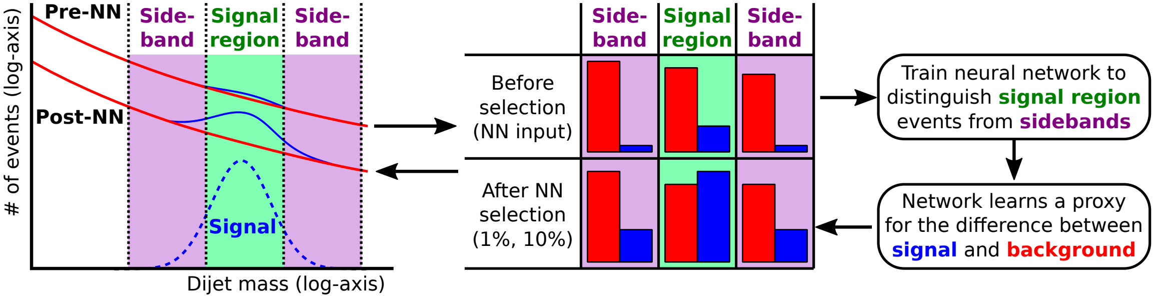
VH resonances: results

- Use a multi-dimensional BDT reweighting to extract the background expectation
  - Performed separately for 1-b-tag and 2-b-tag event selections
- Resulting reweighted CR distributions are fit with a functional form
- Improvements beyond statistics: W/Z taggers, VR b-tagging, H-candidate selection



Generic dibosons: analysis methodology

- Data-driven generic search: make use of machine learning and classification without labels
  1. Define a set of regions as a function of the new particle mass (dijet mass)
  2. Choose on region at a time to be a signal region, use both adjacent regions as sidebands
  3. Train a neural network (using data!) to differentiate between the signal region and sidebands
     - If signal is present, the network learns about differences between signal and background
     - Network inputs: the masses of the two leading jets in the event (which form the dijet mass)
  4. Select events using the network, accepting a desired fraction of background events

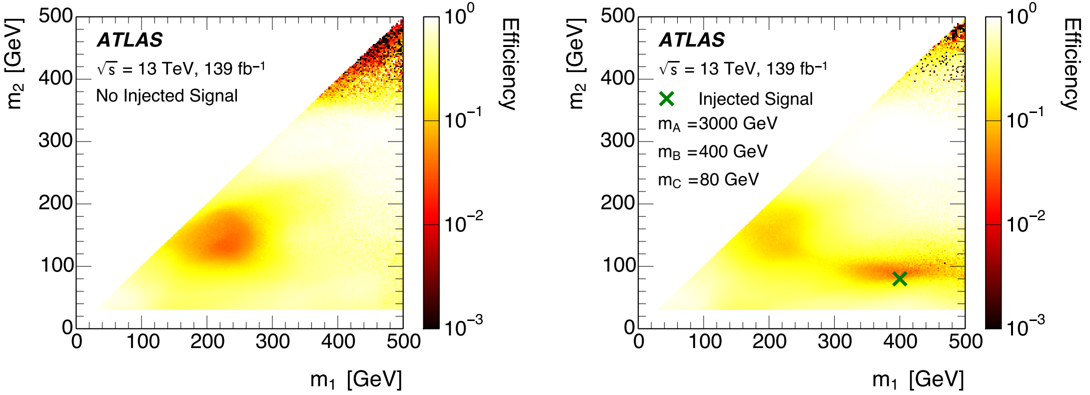


Generic dibosons: signal injection

Recent result (May)

Plots: HDBS-2018-59

- Assuming a new particle A exists and $A \rightarrow B + C$ where B and C both decay hadronically
  - B and C can then both be reconstructed as large-R jets: consider their masses m_B and m_C
- With no signal, there will necessarily be points on the plane with low and high efficiency
  - Injecting signal leads to areas of network inefficiency: the network finds the new physics

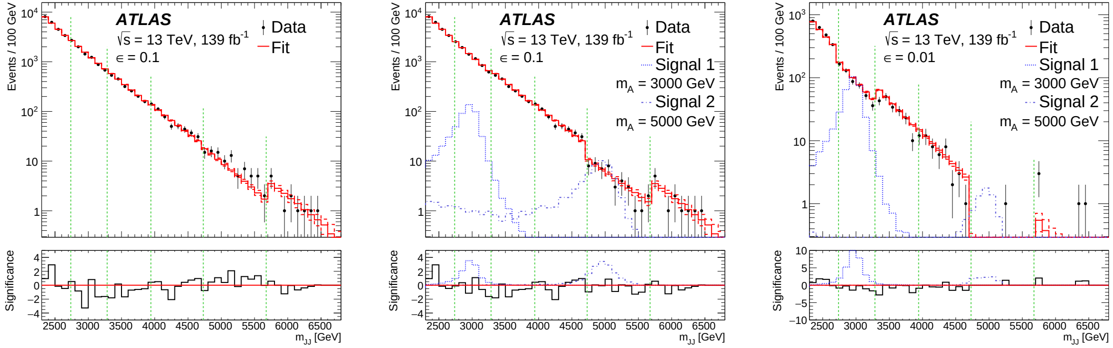


Generic dibosons: results

Recent result (May)

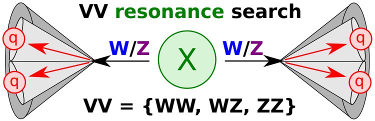
Plots: HDBS-2018-59

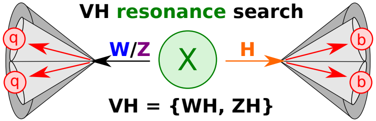
- Apply this procedure to each region, consider network efficiencies of both 1% and 10%
  - Regions don't have to smoothly merge: networks trained separately for each region
- Consider both a model-independent search (left) and model-dependent searches (right)
  - Model-independent only uses data, model-dependent injects signal when training the network

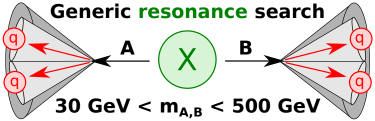


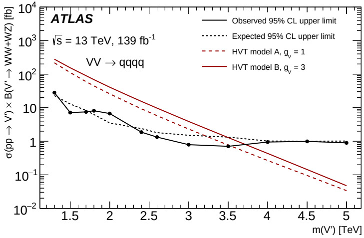
Limits and search complementarity

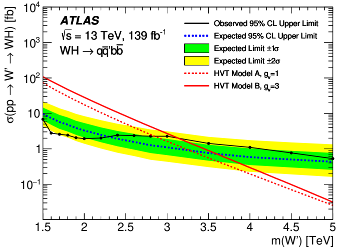
- All three searches are sensitive to spin-1 Heavy Vector Triplets (shown for each analysis)
- However, analyses are also complementary as they study different models
  - Only the VV resonance search directly studies spin-0 and spin-2 interpretations
  - Only the generic resonance search directly looks for massive decays to non-SM particles

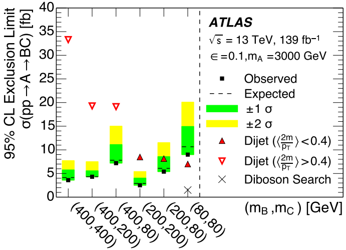












Summary

- Fully-hadronic diboson final states are promising searches for new physics
  - Exploit the large boson branching fractions to quarks to increase high-p_T statistics
  - Complementary to partially hadronic final states, see talk by Stefan Maschek (earlier today)
- ATLAS is continuing to improve its ability to identify hadronic decays of massive particles
  - Improvements in $W/Z/H$ tagging increased the sensitivity to VV and VH resonance searches
- In parallel, pursued new analysis techniques for generic hadronic resonance searches
  - Classification without labels allows for training directly on data
  - Less powerful than dedicated searches, but covers a **much** larger range of parameter space
- These searches are complementary and cover a wide range of possible new physics models
  - No compelling evidence for new physics yet, but it may only be one improved jet-tagger away!