Search for VV resonances with the ATLAS detector at the LHC

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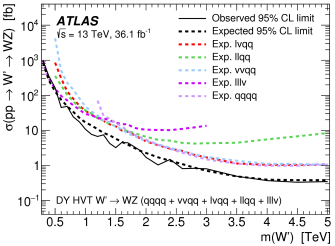
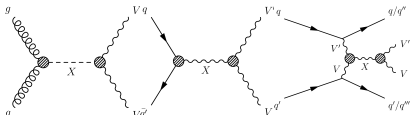
Introduction

- Several Standard Model extensions predict the existence of heavy diboson resonances:
  - Extended Higgs/Gauge sectors, Quantum Gravity .
- Look for resonances decaying into different pairing of W or Z in semileptonic final states
  - One boson decays to lepton (**Clean signature**)
  - The other boson decays hadronically (**High branching ratio**)
- Several production modes are considered
  - Gluon-Gluon Fusion (ggF), Drell-Yan (DY) and Vector Boson Fusion (VBF)

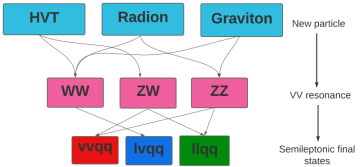


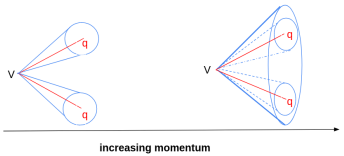
ggF DY VBF

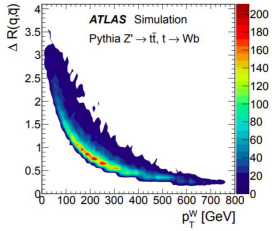


Analysis Overview

- Look for a bump in invariant mass spectra in the top of a smoothly falling background
- 3 leptonic channels according to the number of charged leptons
  - 0-lep: $ZV \to \nu\nu qq$
  - 1-lep: $WV \to l\nu qq$
  - 2-lep: $ZV \to llqq$
- 2 Event topologies:
  - Resolved: $V \to qq$ are reconstructed by 2 Small-R calo jets
  - Merged: $V \to qq$ are reconstructed by 1 Large-R jet







Event selections and regions in VV

1 SR and 3 CRs to constrain $W+jets$ (WCR), $Z+jets$ (ZCR) and $t\bar{t}$ (TCR)

- SR: Mass window with no Extra b-$jets$
- VCR: Sidebands with no Extra b-$jets$
- TCR: Mass window with Extra b-$jets$

In Merged each region is further split into:

- **High purity (HP) (Pass D_2)**
- **Low purity (LP) (Fail D_2)**

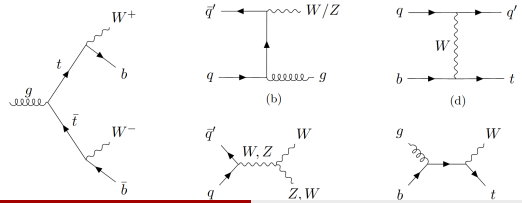
Mass window

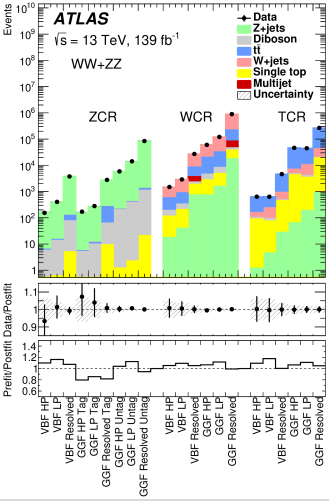
- **Merged**
  - m_J is p_T-dependent cut
- **Resolved**
  - $W \to jj$: $62 < m_{jj} < 97$ GeV
  - $Z \to jj$: $70 < m_{jj} < 105$ GeV

Event selection	0-lepton ($ZV \to \nu\nu V_h$)	1-lepton ($WV \to \ell\nu V_h$)	2-lepton ($ZV \to \ell\ell V_h$)
V_ℓ selection	No *Loose* lepton $E_T^{miss} > 250$ GeV $p_T^{miss} > 50$ GeV	1 *Tight* electron or 1 *Medium* muon with $p_T^\ell > 30$ GeV $E_T^{miss} > 60$ GeV $p_T^{V_\ell} > 75$ GeV	2 *Loose* leptons with $p_T^\ell > 30$ GeV from the $Z \to \ell\ell$ candidate
Event veto	No additional *Loose* leptons Veto events with b-jets not associated with the $Z \to qq$ candidate		
Event categorisation	≥ 1 large-R jets or ≥ 2 small-R jets VBF and ggF/DY classification according to RNN score		
V_h selection (Merged)		$E_T^{miss} > 100$ GeV $p_T^{V_\ell} > 200$ GeV	
	≥ 1 large-R jets The leading jet passing p_T-dependent m_J requirement		
		$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.25$ (VBF)	$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.25$ (VBF)
V_h selection (Resolved)	Not Performed	Failed merged selection ≥ 2 small-R jets with $\lvert\eta\rvert < 2.5$ $62 < m_{jj} < 97$ GeV for $W \to jj$ $70 < m_{jj} < 105$ GeV for $Z \to jj$	
		$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.25$ (VBF)	$\mathcal{R}_{p_T/m} > 0.35$ (ggF/DY) $\mathcal{R}_{p_T/m} > 0.35$ (VBF)

Background modeling

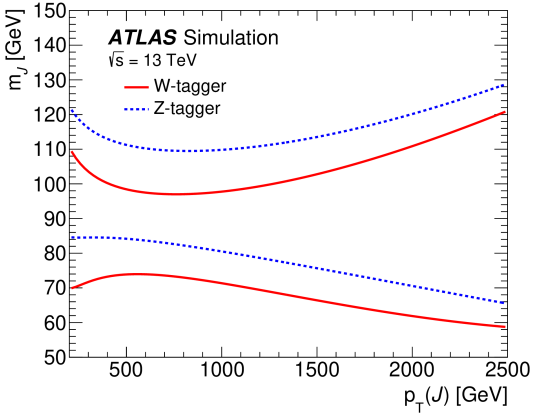
- Main backgrounds: $V+jets$ and $t\bar{t}$
  - Use data from control regions to constraint normalization
- Minor backgrounds: Single top and SM Diboson
  - Normalized to their theoretical cross section
- Multi jet QCD background (only in resolved 1-lep)
  - Modeled using a Data-driven method
  - Derive MJ shape for a MJ-enriched region
  - Obtain normalization from fit on E_T^{miss} distribution in WCR

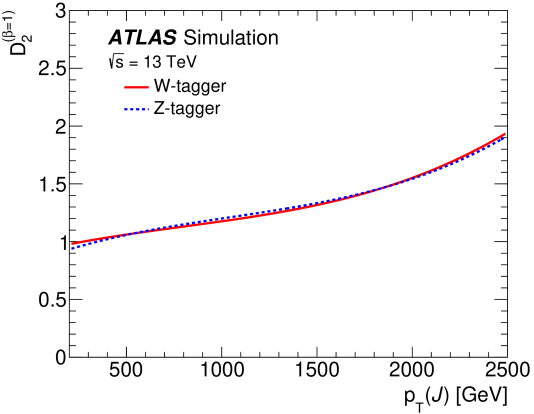




W/Z tagger with TCC jets

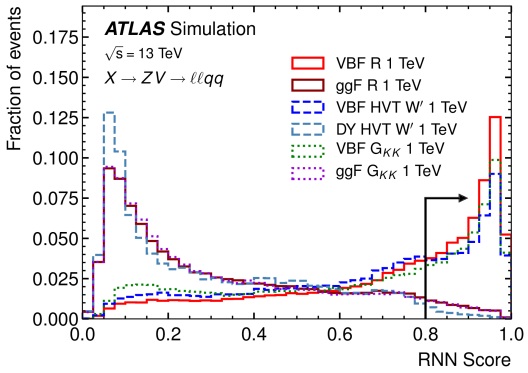
- Design a W/Z tagger based on TrackCaloClusters (TCCs) to reconstruct Large-R jet
- Optimize W/Z tagger working points with m_J and D_2
- Brought 30% improvements wrt the past round

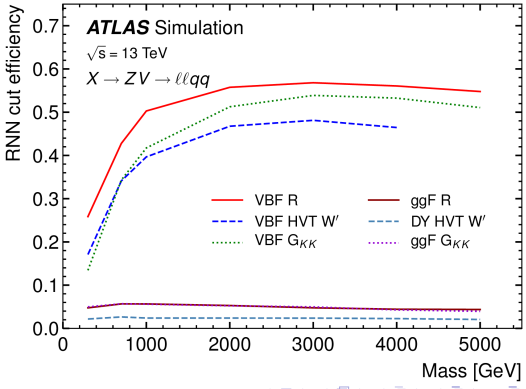




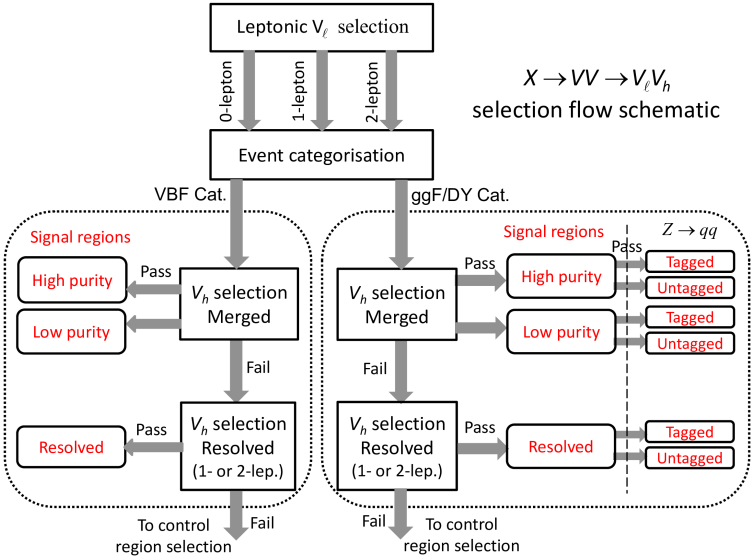
VBF-to-ggF classification with machine learning

- Use a Recurrent Neural Network (RNN) to classify ggF/DY and VBF event topologies.
- RNN uses as inputs Small-R jets 4-momenta (p_T, η, ϕ and E), Excluding those from V^{had}
- Events with score > 0.8 are considered as VBF events
- RNN recovers 30% of VBF events

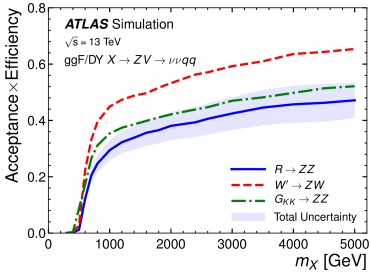


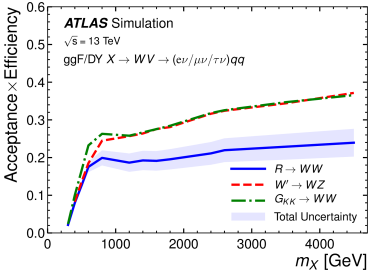


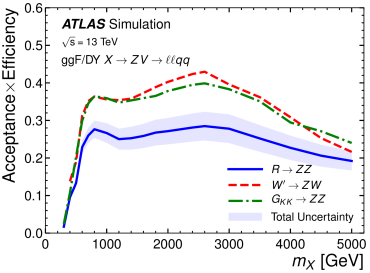
Analysis Flow

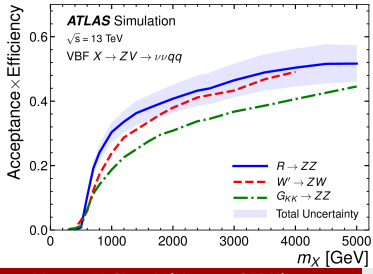


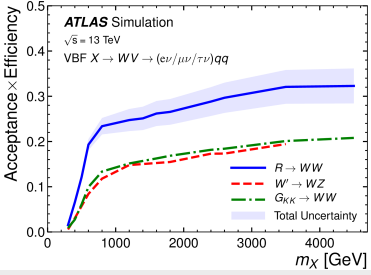
Signal Efficiency × Acceptance

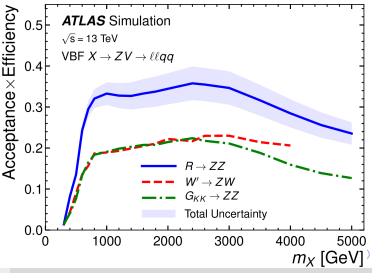










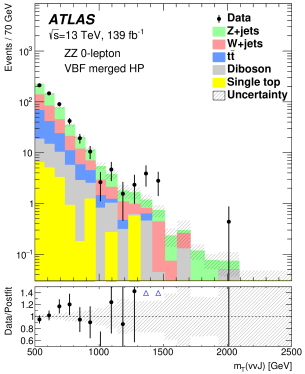


m(VV) distribution

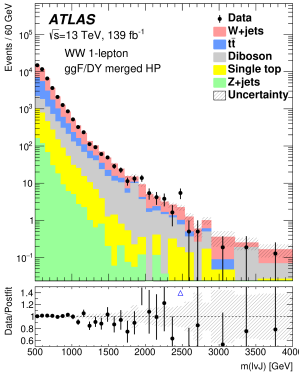
- Transverse mass is defined as

$$m_T = \sqrt{(p_T^J + E_T^{miss})^2 - (\vec{p}_T^J + \vec{E}_T^{miss})^2}$$

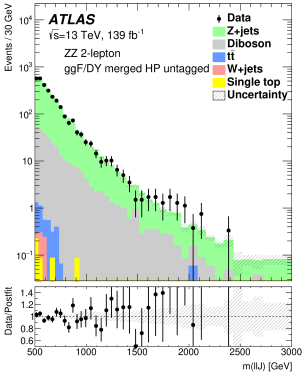
0-lep



1-lep

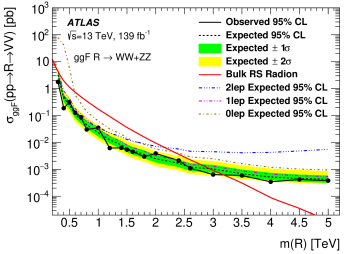


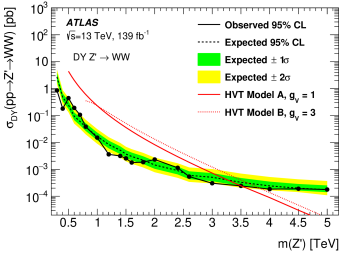
2-lep

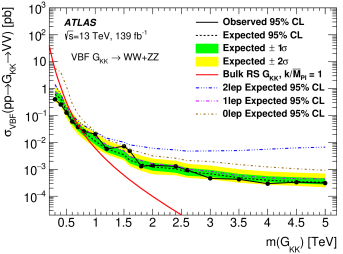


Upper Limits

- Data are found to be in good agreement with SM expectations
- 95% CL Upper limits on $\sigma \to X \to VV$ in the mass range [300, 5000] GeV are set







Summary

- A search for diboson resonances in semileptonic final states has been performed using full Run-2 data collected with ATLAS detector at $\sqrt{s} = 13$ TeV
- No significant excess of events is observed above the SM predictions
- Upper Limits on the production cross section have been set on several benchmark models
- Up to 500% improvements in the limits wrt 36 fb^{-1} result

Backup

Substructure variable D_2

The variable D_2 is defined as

$$D_2^{(\beta=1)} = E_{CF3}\left(\frac{E_{CF1}}{E_{CF2}}\right)^3$$

where the energy correlation functions (E_{CF}) are defined as:

$$E_{CF1} = \sum_i p_{T,i}$$

$$E_{CF2} = \sum_{ij} p_{T,i}p_{T,j}\Delta R_{i,j}$$

$$E_{CF3} = \sum_{ijk} p_{T,i}p_{T,j}p_{T,k}\Delta R_{i,j}\Delta R_{j,k}\Delta R_{k,i}$$