Search for heavy diboson resonances in semileptonic final states in pp collisions at $\sqrt{s}$ =13 TeV with the ATLAS detector

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Introduction

- Di-boson searches are highly motivated and have been proven fruitful in the past (Higgs discovery)
- Many theories predict di-boson resonances with different properties(charge, spin, width, production mechanism) such as:
    - Extended Higgs/Gauge sectors, Quantum Gravity ...

Three Benchmark Models

- Spin 0 Randall-Sundrum Radion
- Spin 1 HVT (W', Z')
- Spin 2 RS Graviton

Model			Spin	m = 800 GeV			m = 3 TeV		
				σ [pb]	$\mathcal{B}$	Γ/m	σ [fb]	$\mathcal{B}$	Γ/m
RS radion ($k\pi r_c = 35$, $\Lambda_R = 3$ TeV)		$R \to WW$ $R \to ZZ$	0	0.54 (ggF) 1.1×10^{-3} (VBF)	0.43 0.21	2.6×10^{-3}	1.38 (ggF) 5.5×10^{-3} (VBF)	0.44 0.22	0.032
HVT	Model A	$W' \to WZ$ $Z' \to WW$	1	53 26	0.024 0.023	0.026	79 36	0.020	0.025
	Model B	$W' \to WZ$ $Z' \to WW$		1.6 0.86	0.43 0.41	0.040	5.5 2.5	0.47	0.031
	Model C (VBF)	$W' \to WZ$ $Z' \to WW$		4.0×10^{-3} 2.7×10^{-3}	0.50 0.49	3.5×10^{-3}	1.6×10^{-3} 1.0×10^{-3}	0.50	3.3×10^{-3}
Bulk RS G_{KK} ($k/\overline{M}_{Pl} = 1.0$)		$G_{KK} \to WW$ $G_{KK} \to ZZ$	2	1.9 (ggF) 0.050 (VBF)	0.28 0.14	0.037	0.47 (ggF) 1.6×10^{-2} (VBF)	0.20 0.10	0.062

- Search for new particles that decay into pairs of W/Z bosons in semileptonic channel

Leptonic decays

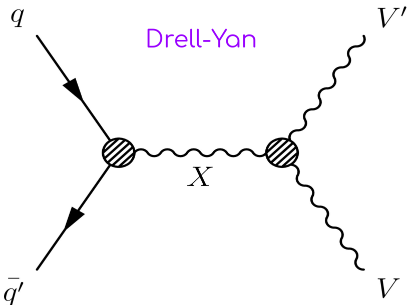
-Cleaner signature
-perform better at low masses

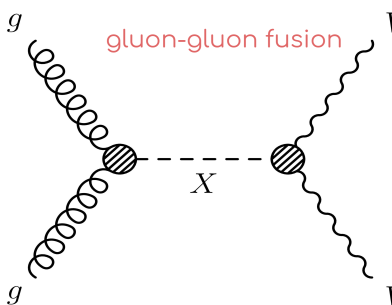
Hadronic decays

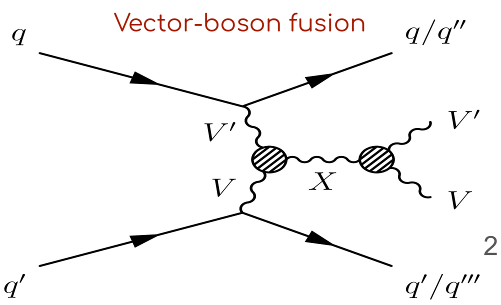
-Large branching ratio
-perform better at high masses where SM background fall off

Different production modes:

ggF/DY and VBF







Analysis overview

- Physics signature: WW/WZ/ZZ resonance with semi-leptonic decay

  One boson decays leptonically (Based on electron/muon and $\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$)

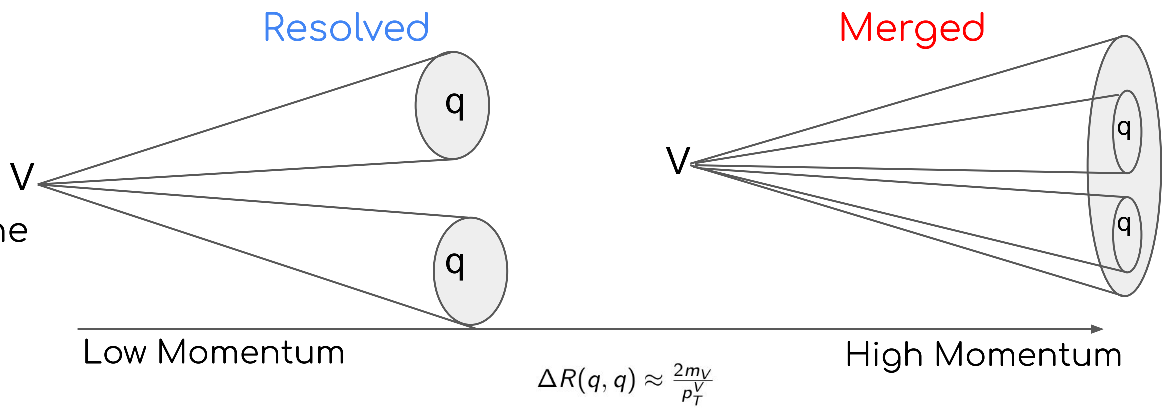
  0-lepton: $Z \rightarrow \nu\nu$ 1-lepon: $W \rightarrow \ell\nu$ 2-lepon: $Z \rightarrow \ell\ell$ (ℓ = μ or e)

  the other boson decays hadronically

depending on pT of V boson we have :

-Resolved: W/Z boson reconstructed with 2 Small-R jets (Calo jets)

-Merged: W/Z boson reconstructed by one Large-R jet (TCC jets)



Search strategy: look for excesses above the background in the reconstructed m(VV) or mT distribution
New ideas: TCCs Large-R jets, ML-based ggF/VBF classification...

This talk covers results from Full Run 2 (139 /fb) data with three lepton channels

Object definition

- Leptons, jets and $\vec{E}_T^{miss}$ are the basic objects for this analysis

leptons

	Loose	Tight
pT	> 7 GeV	> 30 GeV
$\|\eta\|$	< 2.47 (2.5) for e(μ)	
ID	Loose	Tight
isolation	FCLoose at pT <100GeV	FixedCutHighPt CaloOnly
|d0(σ)|	<5 (3) for e(μ)	
Z0sin(θ)	< 0.5 mm	

$\vec{E}_T^{miss}$ is the negative vectorial sum of the transverse momenta of calibrated electrons, muons, small-R jets, and unassociated tracks

Small-R jets

	Signal	VBF
Collection	AntiKt EMTopo R=0.4	
$\|\eta\|$	< 2.5	< 4.5
pT	> 30 GeV	
JVT	0.59 for pT < 120 GeV, $\|\eta\|$ < 2.5	

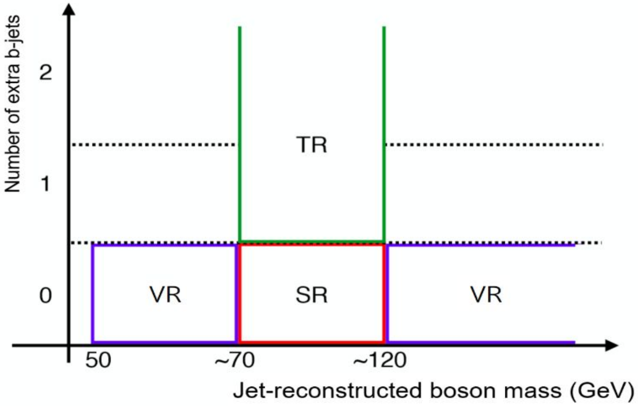
Large-R jet

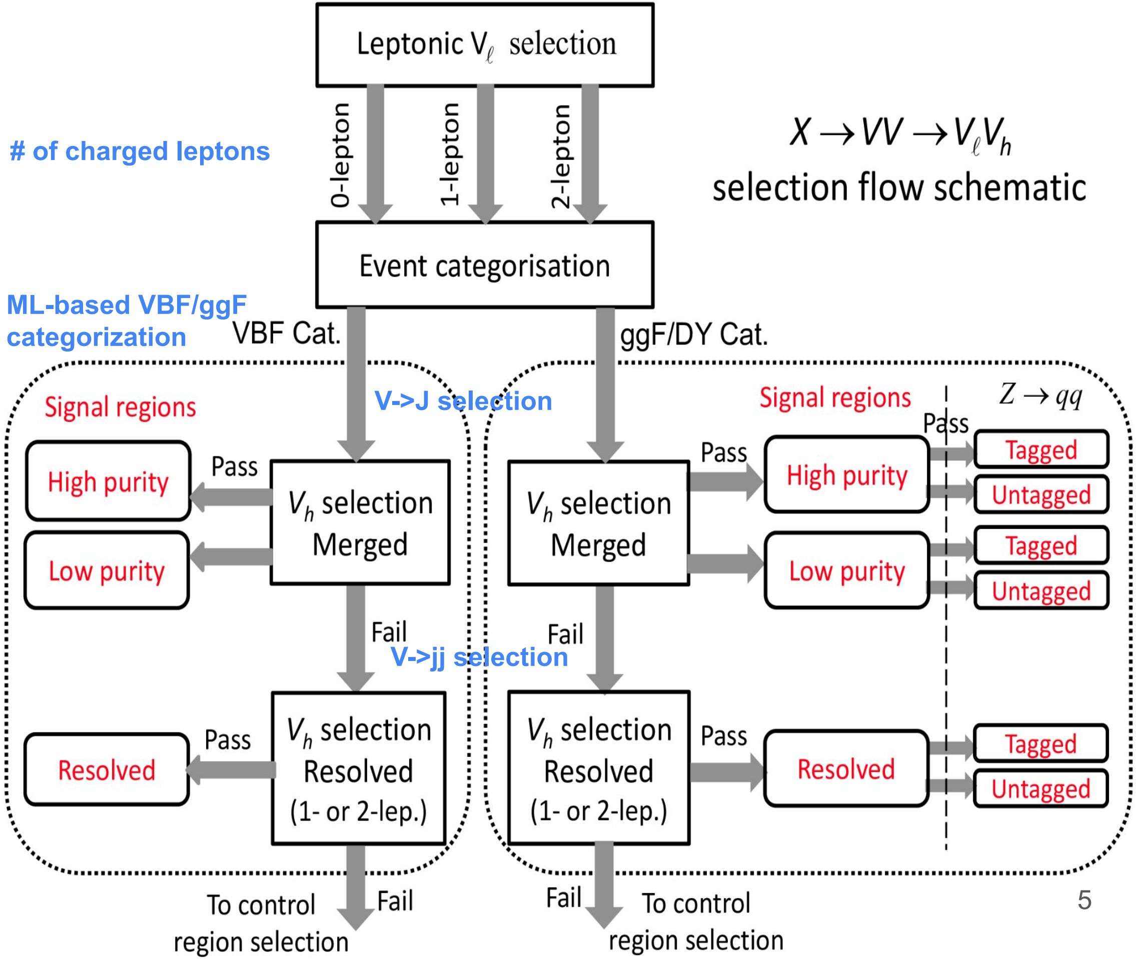
Collection	AntiKt TCC R=1.0
$\|\eta\|$	< 2.0
pT	> 200 GeV
mass	> 50 GeV

Event selection and Categorization

- SR: W/Z mass window cut (No extra b-jets)
  - Merged: pT dependent cut
  - Resolved: Fixed cut

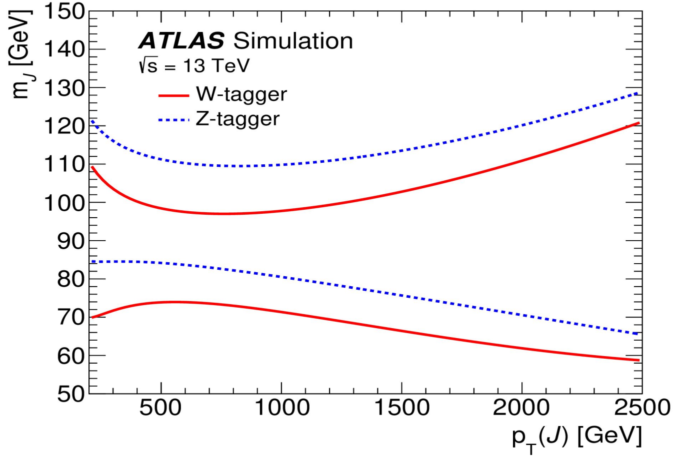
- CR: W+jets, Z+jets, ttbar
  - WCR/ZCR (W/Z mass sideband)
  - TCR (Extra b-jets required)





W/Z tagging in TCC jet

- Highly boosted hadronic W/Z decays have small angular separation between the outgoing subjets
- Track information can improve both mass and substructure resolutions
- TrackCaloClusters used instead of LCTopo for Large-R jet reconstruction
  - Support of ID tracks gives better D2 resolution



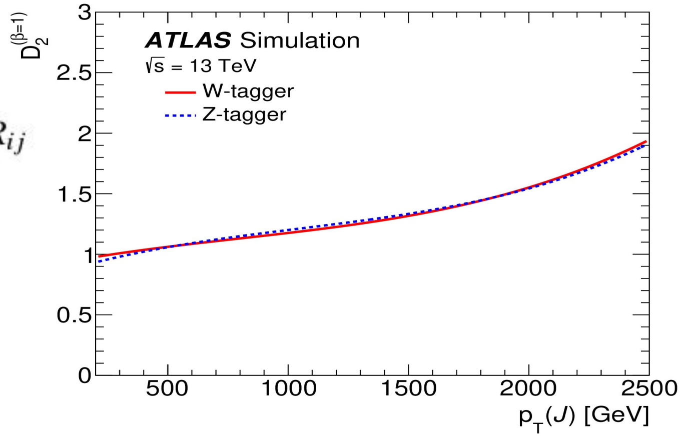
- D2 is reconstructed by the energy correlation functions based on energies and pair-wise angles of the sub-constituents

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

Where

$$E_{CF1} = \sum_i p_{T,i} \qquad E_{CF2} = \sum_{ij} p_{T,i}p_{T,j}\Delta R_{ij}$$

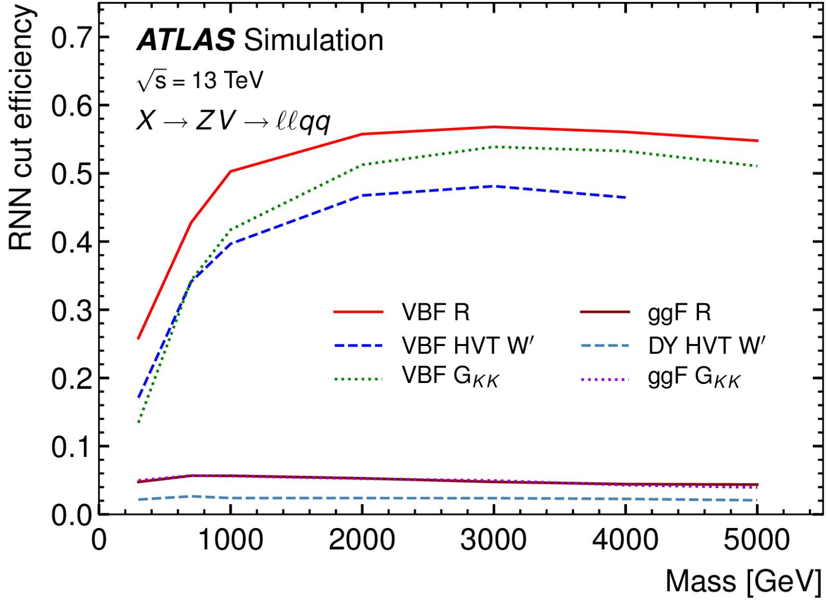
$$E_{CF3} = \sum_{ijk} p_{T,i}p_{T,j}p_{T,k}\Delta R_{ij}\Delta R_{jk}\Delta R_{ki}$$

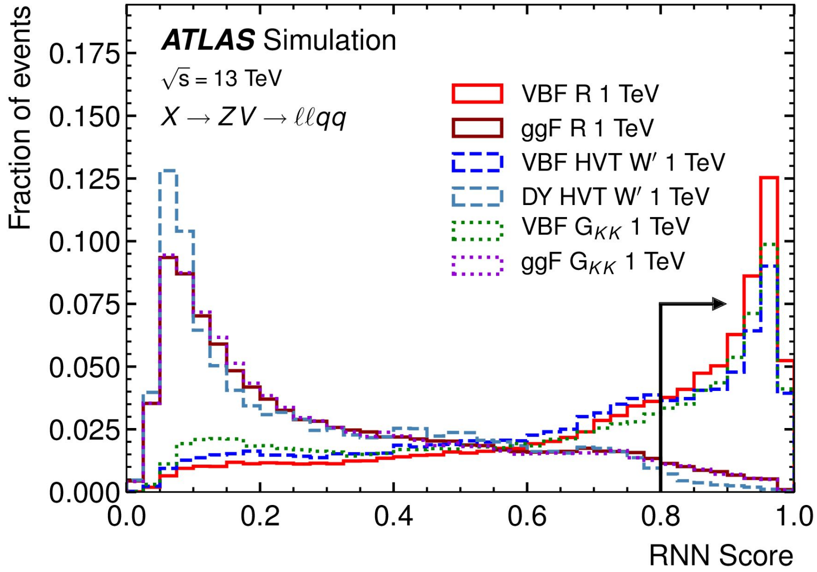


30% of improvement in signal sensitivity for m(VV) > 3 TeV

VBF/ggF Categorization using RNN

- RNN is an architecture able to solve problem in which the inputs are a recurrent sequence of information
- Use a RNN with jet 4-momenta (pT, E, η, ϕ) as inputs
- ggF(DY) vs VBF signal training
- Exclude jets from hadronic boson candidate decay
- With up-to 2 jets used for training





- Events with score > 0.8 are categorized into VBF category
- ~50% sensitivity improvement for VBF signal

Background modeling

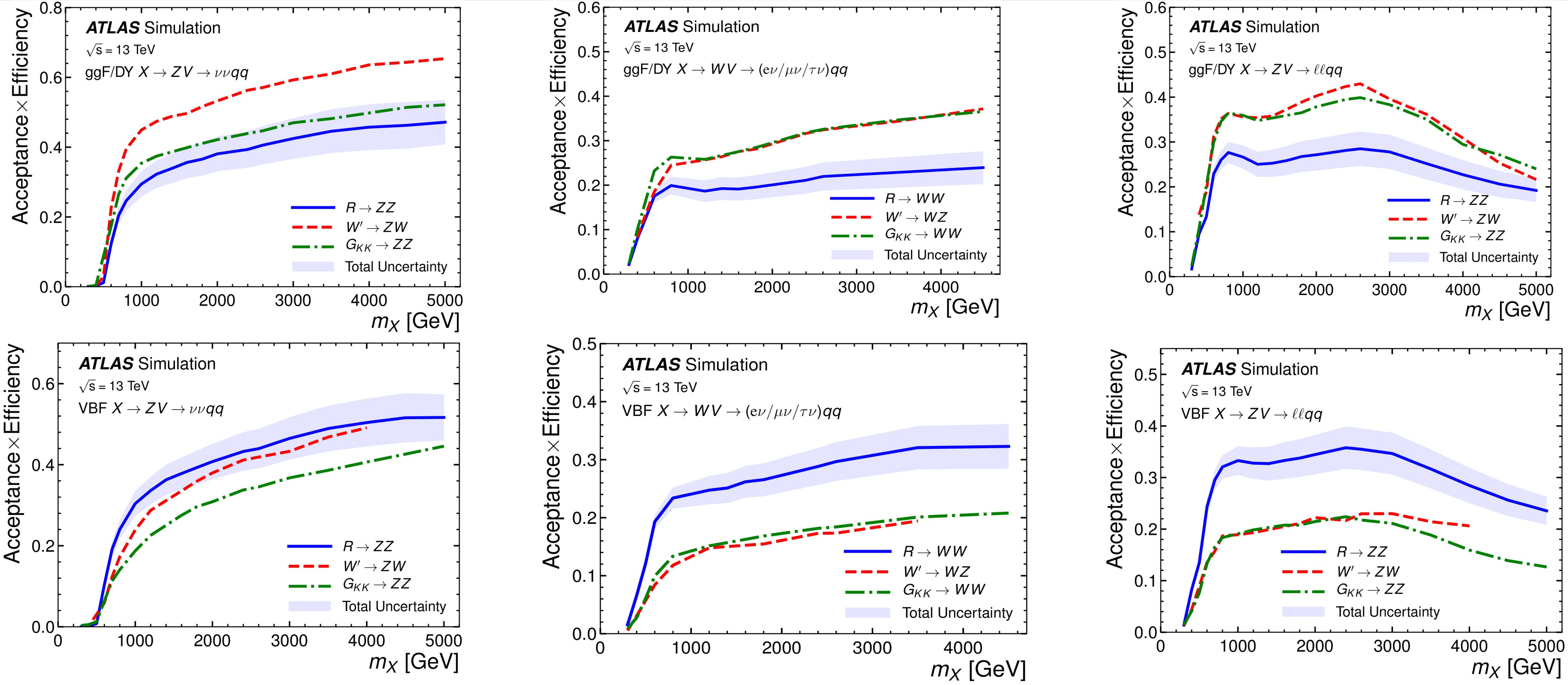
- Background processes
  - W/Z +jets: W/Z production in association with jets
  - Top quark: both top-quark pair (ttbar) and single-top quark
  - Diboson: Non resonant diboson production (WW/WZ/ZZ)
  - Multijet: Non resonant QCD multijet production
- W/Z+jets and ttbar use data from CRs to constraint normalization

Bkg process	Modeling	CR
W/Z+jets	Sherpa	✔
ttbar	Powheg+Pythia8	✔
Single top	Powheg+Pythia8	
Diboson	Sherpa	
Multijet	Data-driven	

In 1 lepton channel, MJ contribution is estimated using a data-driven method which derives the shape of MET distributions of MJ contribution from MJ-enriched region
The normalization is derived from fit on MET in the target SR/CRs

MJ contribution is estimated to be 5%

Signal Acceptance × Efficiency

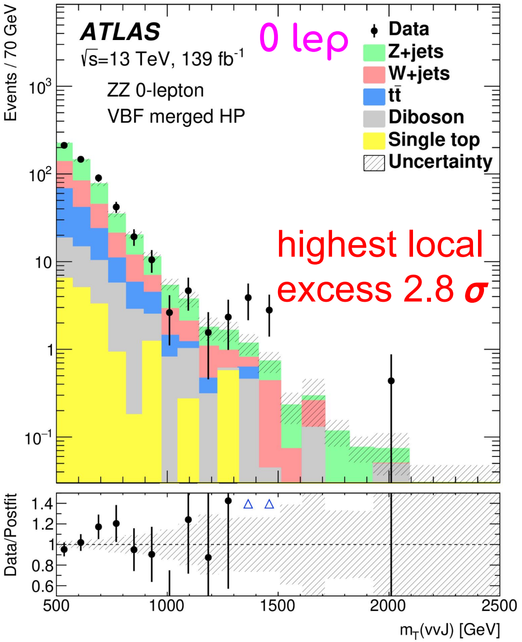


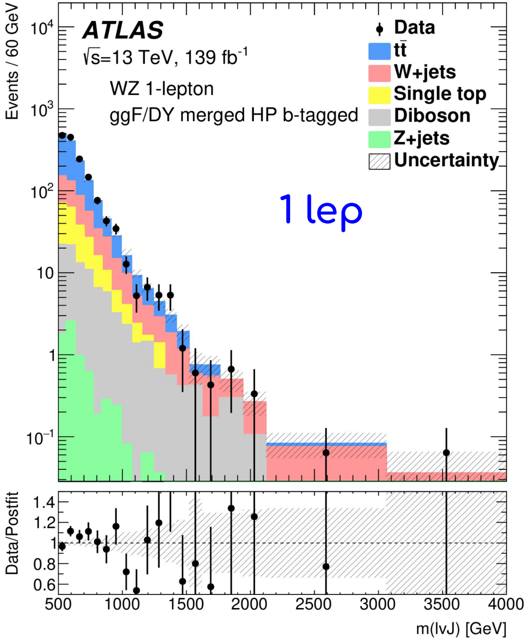
- W/Z boson from V' and Gkk decays tend to be produced in the barrel (endcap) region for ggF/DY(VBF)

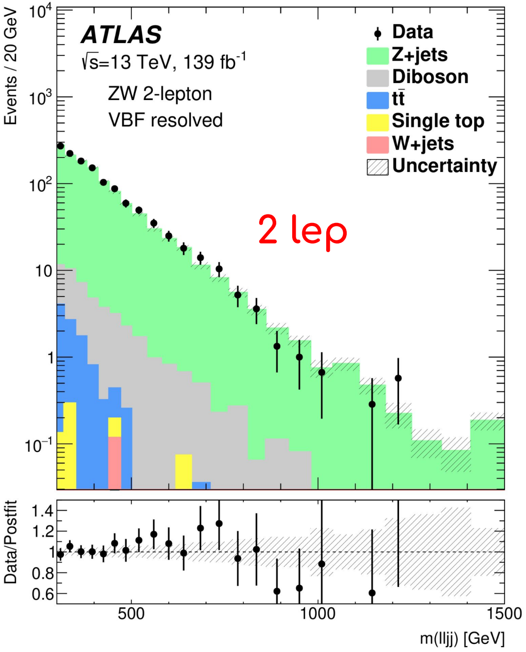
m(VV) spectra

- V+jets is dominant background in most regions
- Transverse mass is used instead of invariant mass in 0-lepton channel

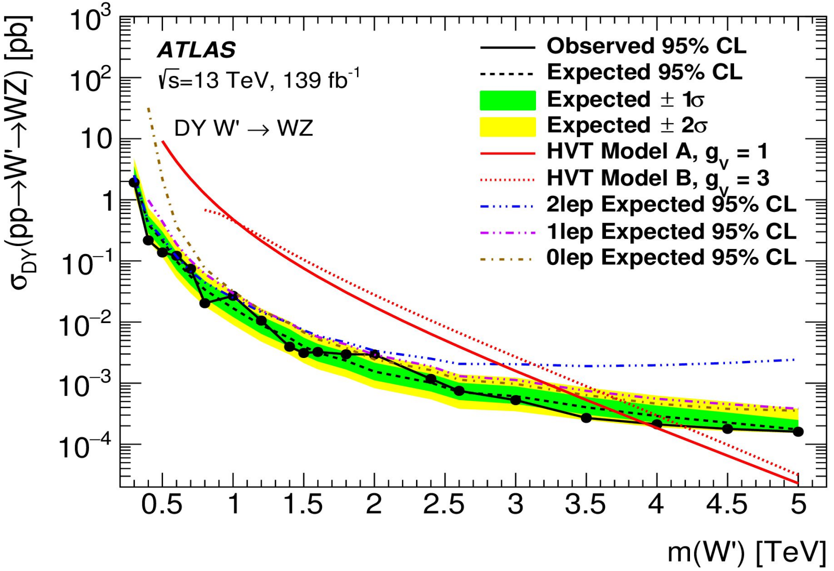
$$m_{\mathrm{T}} = \sqrt{(p_{\mathrm{T}}^{J} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{\mathrm{T}}^{\,J} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

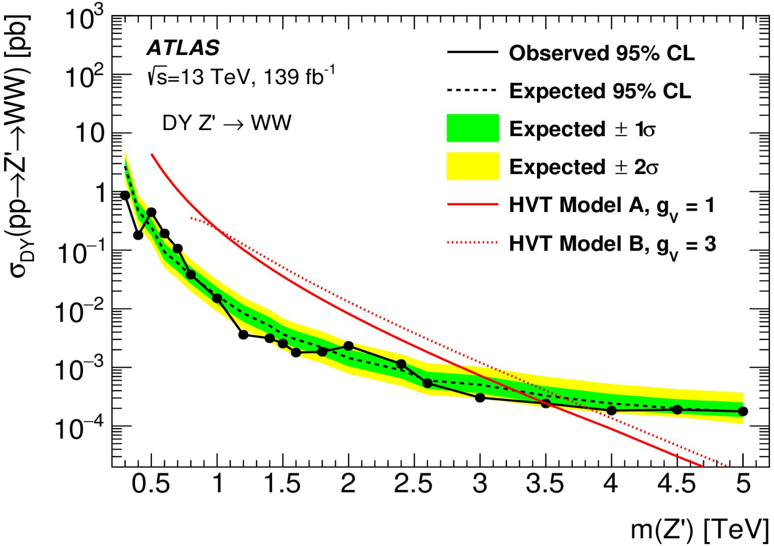






Results





- No significant excess observed
- Limits have been set on benchmark models for each production mode

Summary

- Search for diboson resonance has been performed using full Run 2 data (139/fb)
- Several new ideas have been employed (TCC, ML-based ggF/VBF categorization)
- No significant excess observed
- Limits set on several benchmark models

Current results Eur. Phys. J. C (2020) 80:1165

Production process	RS radion	HVT			RS graviton
			W'	Z'	
ggF/DY	3.2 (2.9)	Model A	3.9 (3.8)	3.5 (3.4)	2.0 (2.2)
		Model B	4.3 (4.0)	3.9 (3.7)	
VBF	–	Model C	–	–	0.76 (0.77)

Observed (expected) 95% CL lower limits on the mass in TeV

Previous 36/fb results JHEP 03 (2018) 042

WW Selection

Excluded Masses	HVT Model A	HVT Model B	RS G_{KK} $k/\bar{M}_{Pl} = 1.0$
Observed	<2750 GeV	<3000 GeV	<1750 GeV
Expected	<2850 GeV	<3150 GeV	<1750 GeV

WZ Selection

Excluded Masses	HVT Model A	HVT Model B
Observed	<2800 GeV	<3000 GeV
Expected	<2900 GeV	<3200 GeV

Using new techniques and more data improved the cross-section upper limits of a factor of three or more w.r.t. 36/fb results

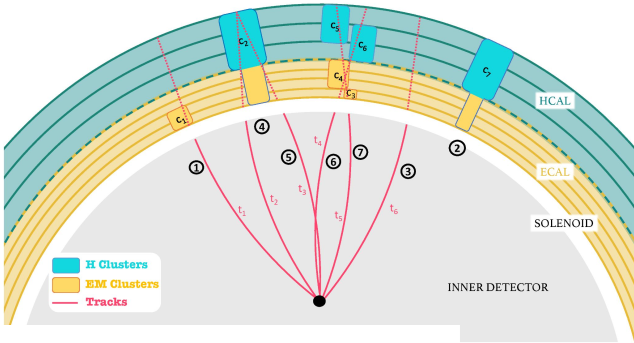
Thank you for your attention

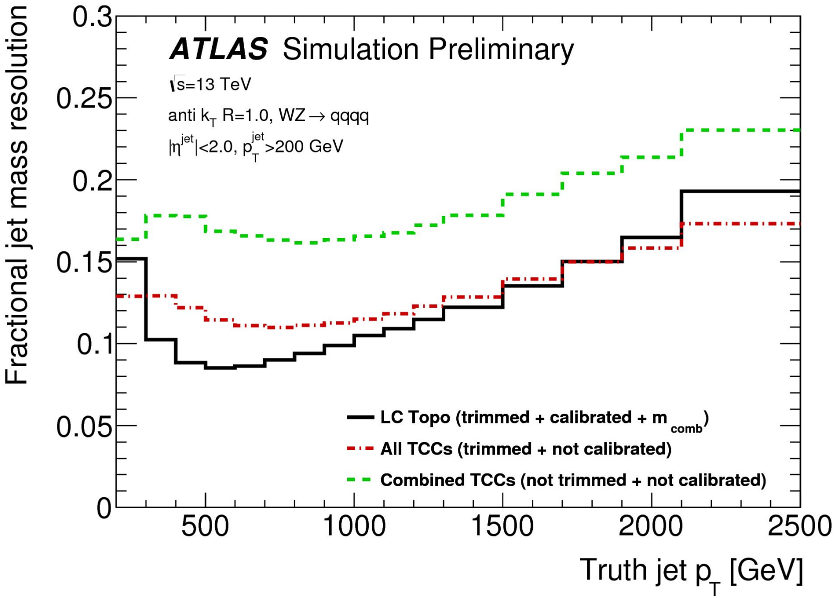
Backup

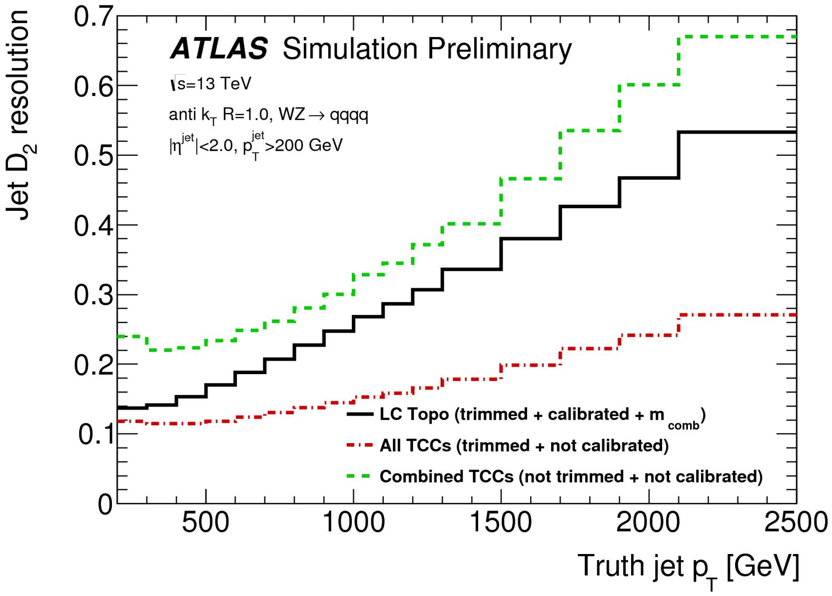
TrackCaloCluster (TCC)

ATL-PHYS-PUB-2017-015

- Take advantage of the tracking detector in jet reconstruction
- Combine track and calorimeter information on jet reconstruction
- Improvement on **mass resolution** at high pT
- Significant improvement **jet substructure resolution (D2)**
    - Good separation between two body decays and QCD jets

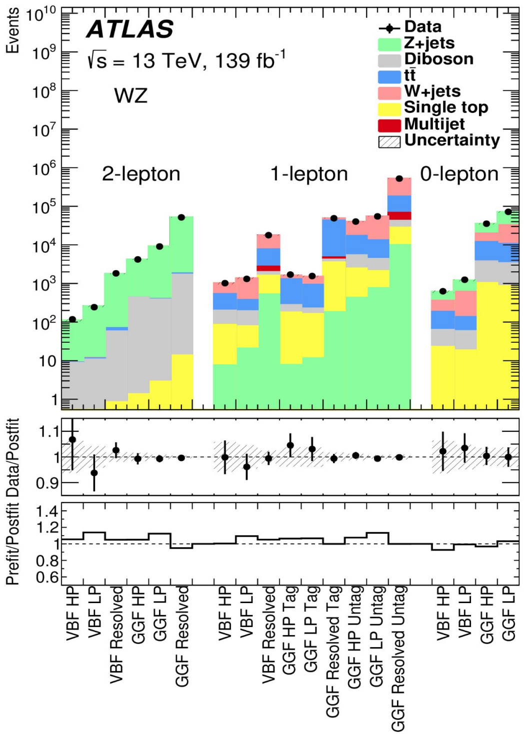


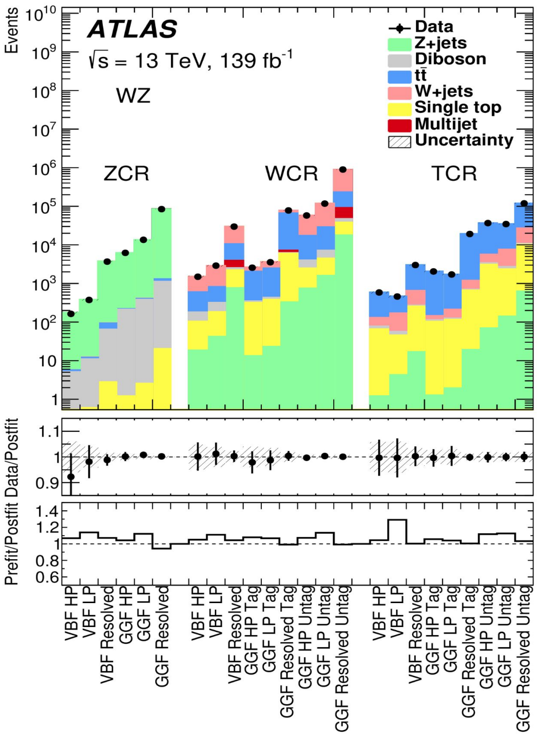




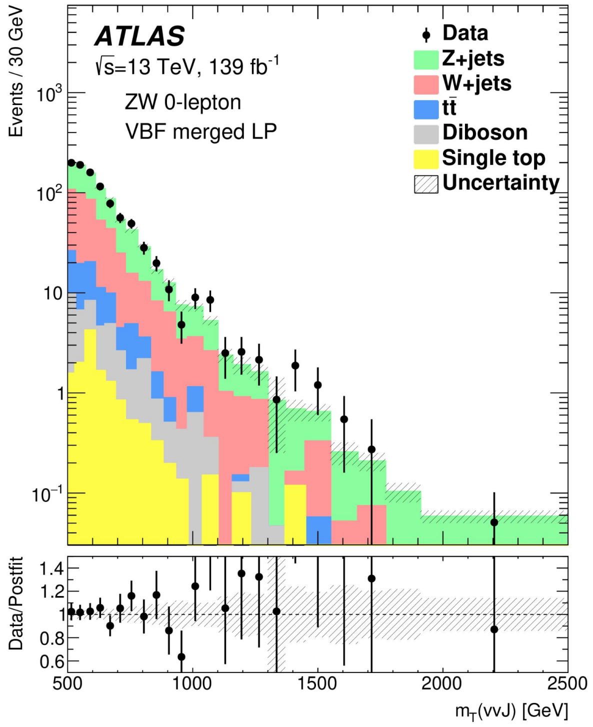
Postfit SR/CR yields

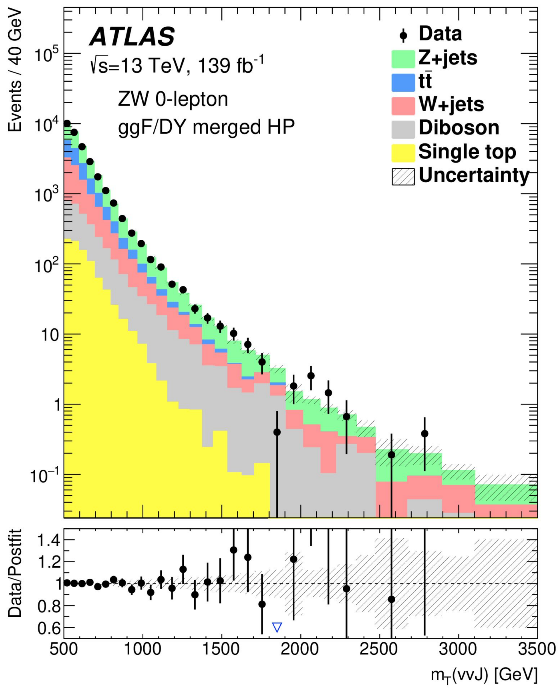
- Fit on invariant (transverse) mass on 1,2 (0) lepton channel
- 21 SR and 21 one-bin CRs

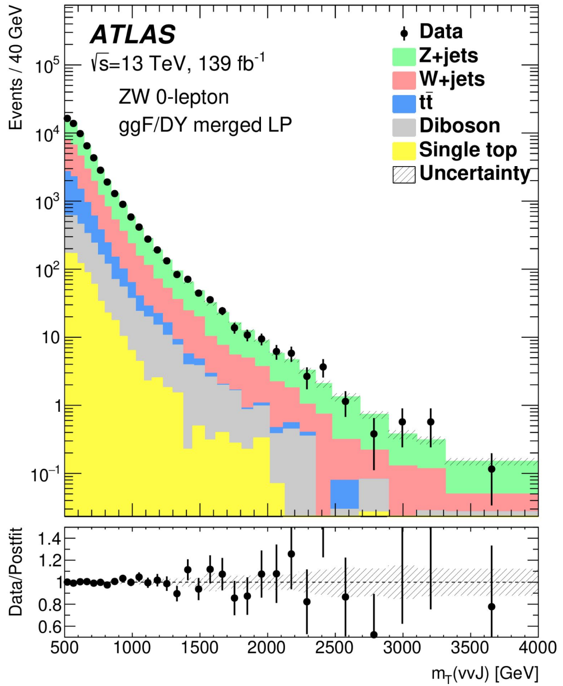




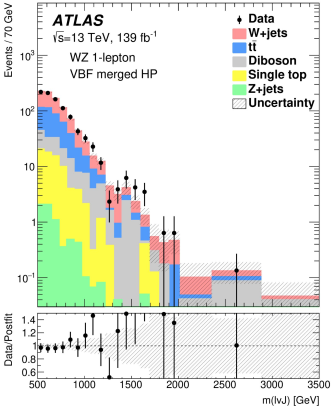
m(VV) spectra (0-lepton channel)

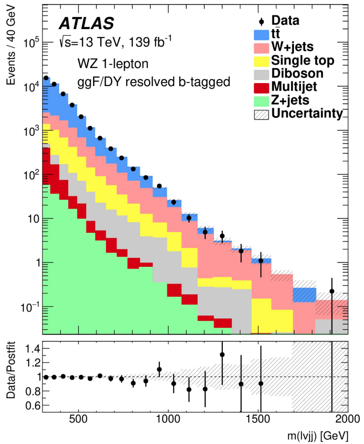


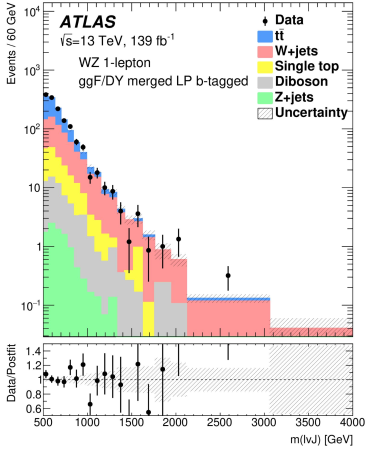


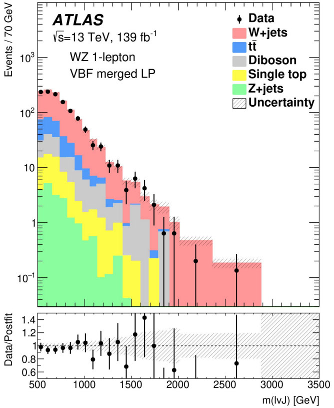


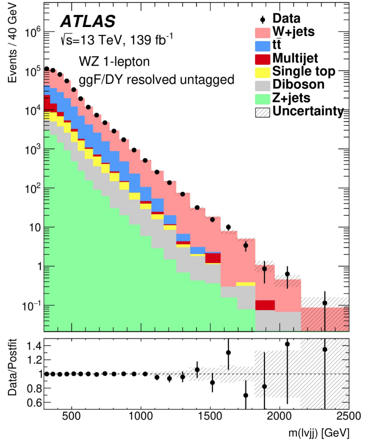
m(VV) spectra (1-lepton channel)

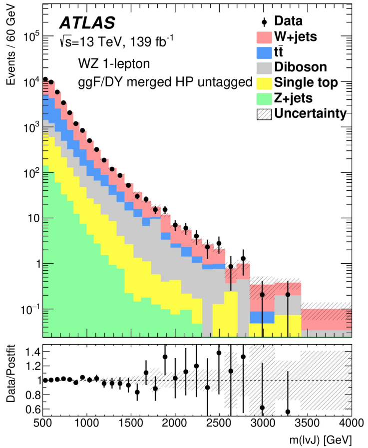




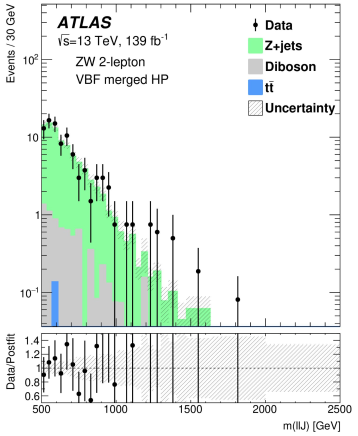


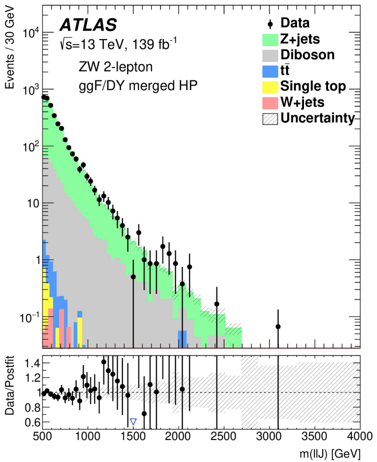


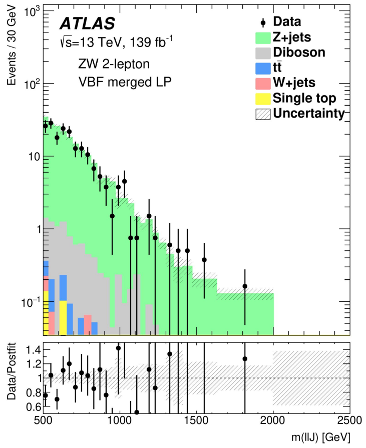


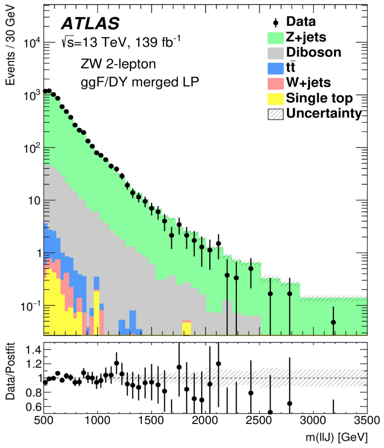


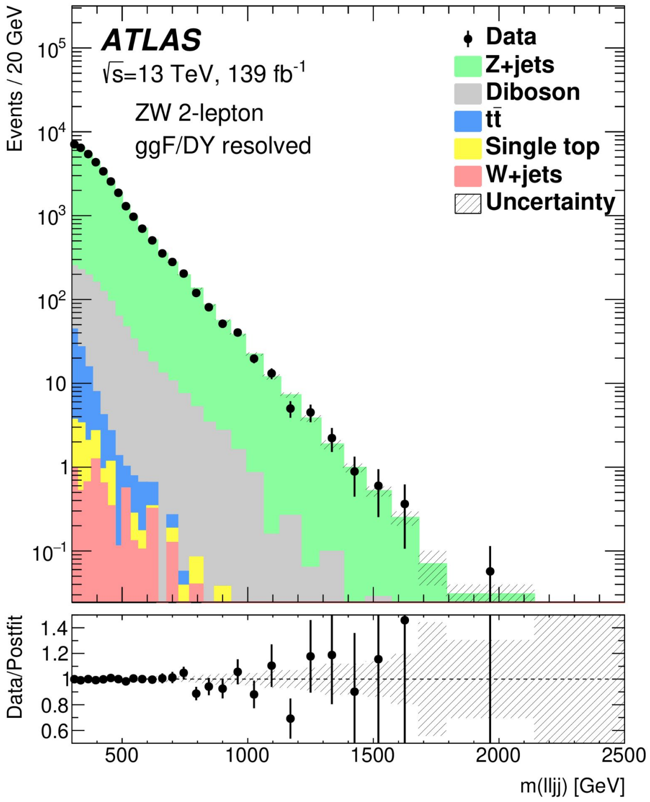
m(VV) spectra (2-lepton channel)



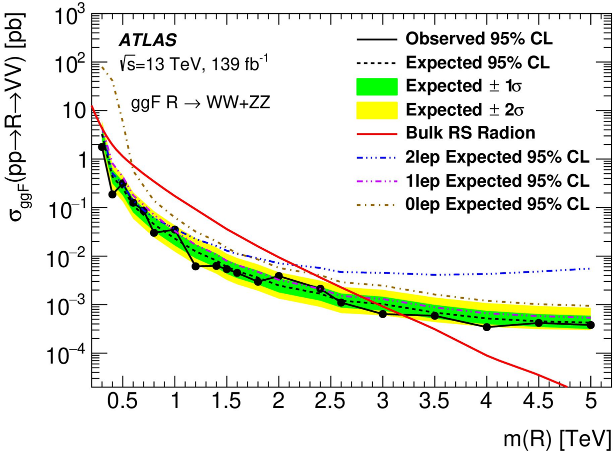


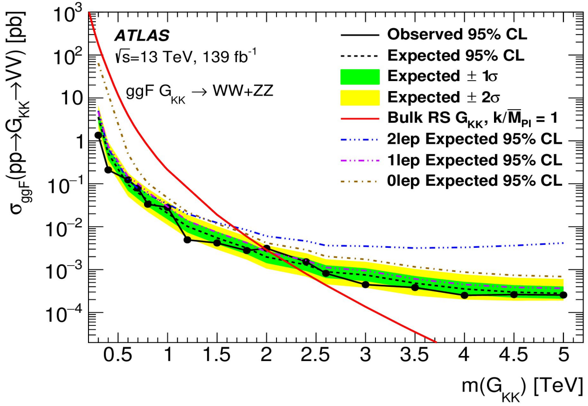


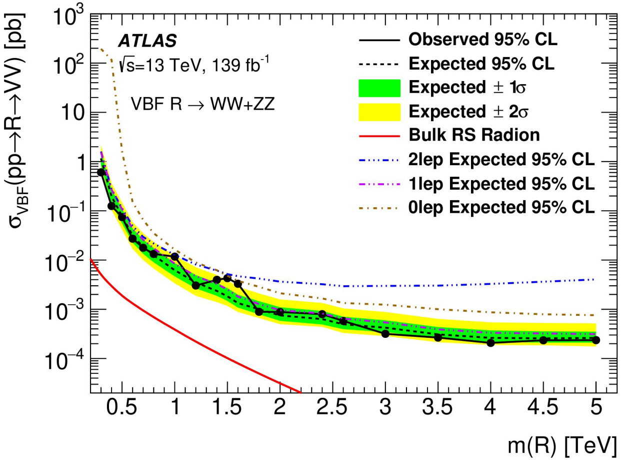


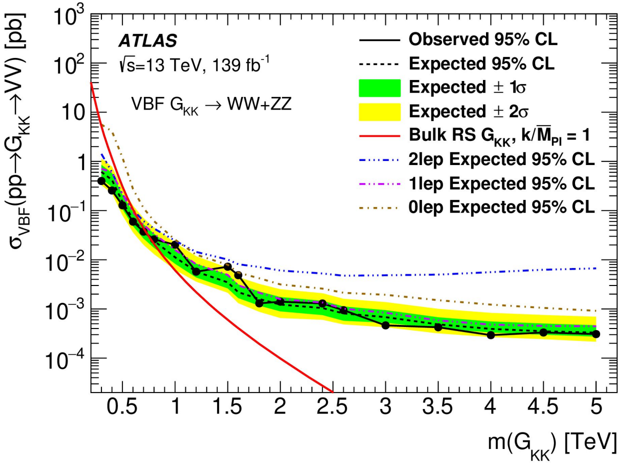


Observed limits









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