

Search for VV resonances in semileptonic final states with the ATLAS detector

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Outline:

- Motivation and signal models
- Introduction to analysis
- Results on limit calculation
- Summary



Motivation and signal models

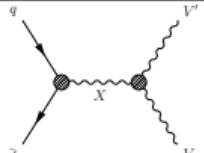
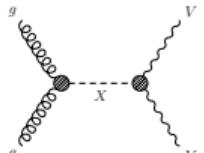
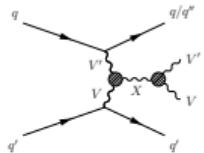
- Many SM extensions predict existence of heavy resonances decaying to VV:
 - ▶ Models with two higgs doublet, composite higgs, technicolour and others.
- Focusing in three types of diboson resonances:

spin 0 radion (R) from some Randall-Sundrum (RS) models.

spin 1 W' and Z' parametrized in the Heavy Vector Triplet (HVT) framework.

spin 2 graviton (G_{KK}) of the first Kaluza-Klein excitation in a bulk RS model.

Production, decay and final state

Production	Decay		
	$X \rightarrow WW$	$X \rightarrow WZ$	$X \rightarrow ZZ$
	HVT Z' (model A and B)	HVT W' (model A and B)	\times
	R and G_{KK}	\times	R and G_{KK}
	R , G_{KK} , HVT Z' (model C)	HVT W' (model C)	R and G_{KK}
Final state			
$\nu\nu qq$	\times	✓	✓
$\ell\nu qq$	✓	✓	\times
$\ell\ell qq$	\times	✓	✓

R RS radion: $k\pi r_c = 35$, $\lambda_R = 3$ TeV.

G_{KK} RS graviton: $k/\bar{M}_{Pl} = 1.0$.

- HVT Z' and W' :

A $gv = 1$: coupling with SM fermions and bosons similar.

B $gv = 3$: coupling with SM fermions suppressed.

C $g_F = 0$: coupling with SM fermions not allowed: only VBF production.

Semileptonic final state:

- 0 lepton channel: $\nu\nu qq$
- 1 lepton channel: $\ell\nu qq$
- 2 lepton channel: $\ell\ell qq$



Signal and background samples

Sample	Generator	Parton shower	PDF Set and Tune
Signal HVT	MADGRAPH5_AMC@NLO v2.2.2	PYTHIA 8.186	NNPDF23lo A14
Signal R	MADGRAPH5_AMC@NLO v2.2.2	PYTHIA 8.186	NNPDF23lo A14
Signal G_{KK}	MADGRAPH5_AMC@NLO v2.6.1	PYTHIA 8.230	NNPDF23lo A14
$V+jets$	SHERPA v2.2.1	SHERPA v2.2.1	NNPDF30nnlo
$t\bar{t}$	POWHEG-BOX v2	PYTHIA 8.230	NNPDF30nlo A14
Single-top	POWHEG-BOX v2	PYTHIA 8.230	NNPDF30nlo A14
Dibosons VV	SHERPA v2.2.1	SHERPA v2.2.1	NNPDF30nnlo
Dibosons $VVjj$	MADGRAPH5_AMC@NLO v2.4.3	PYTHIA 8.186	NNPDF23lo A14

- Signal and background modelled and estimated by MC simulation.
- QCD multijet contribution obtained with data-driven methods.
- Main background ($t\bar{t}$ and $V+jets$) normalisation obtain from control regions.
- Modelling systematic uncertainties:
 - ▶ Alternative generators for backgrounds.
 - ▶ Internal weight variations for signal.

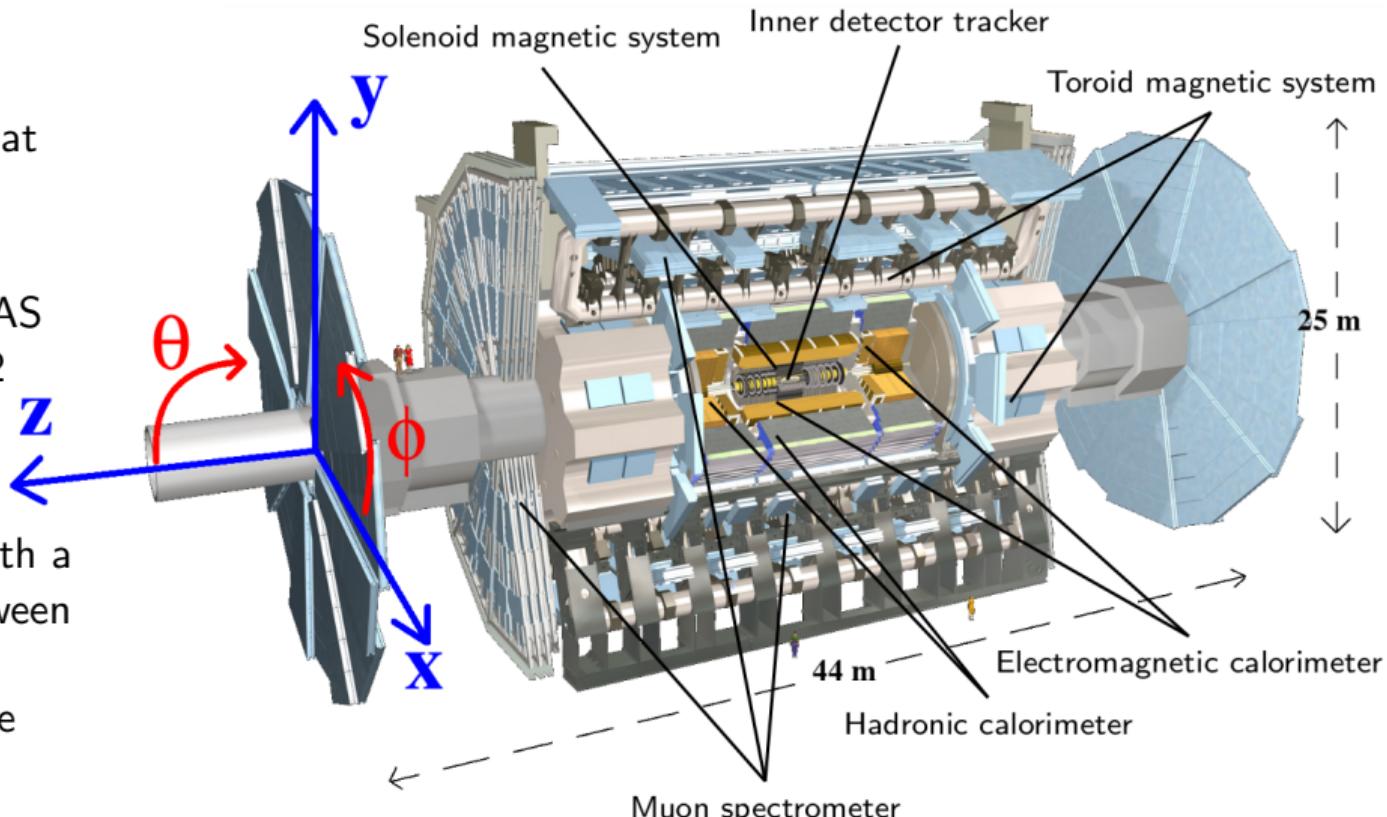
ATLAS detector and data sample

Data sample

- $p\bar{p}$ collision data at $\sqrt{s} = 13 \text{ TeV}$.
- $139.0 \pm 2.4 \text{ fb}^{-1}$ recorded by ATLAS detector in Run 2 (2015-18).

Trigger

- Data recorded with a combination between single-lepton and missing transverse energy triggers.



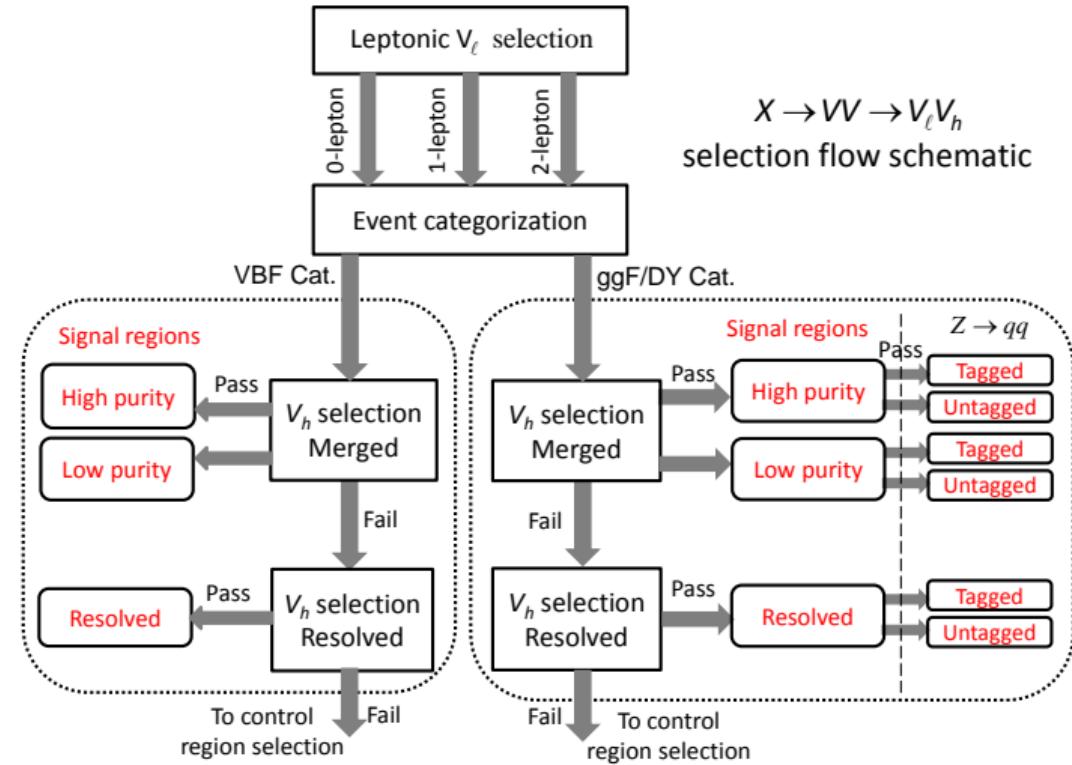
Event selection

- Objects selection:
 - ▶ Leptons: electrons and muons.
 - ▶ Small-R jets, large-R jets, variable-R track jets.
 - ▶ Overlap removal.
- Renormalised NN for VBF vs DY/ggF categorization.
- Priority to the merged selection.
 - ▶ With ≥ 1 large-R jet.
- No 0-lepton resolved analysis.

Event selection	0-lepton ($ZV \rightarrow \nu\nu V_h$)	1-lepton ($WV \rightarrow \ell\nu V_h$)	2-lepton ($ZV \rightarrow \ell\ell V_h$)
V_ℓ selection	No <i>Loose</i> lepton $E_T^{\text{miss}} > 250 \text{ GeV}$ $p_T^{\text{miss}} > 50 \text{ GeV}$	1 <i>Tight</i> electron or 1 <i>Medium</i> muon with $p_T^\ell > 30 \text{ GeV}$ $E_T^{\text{miss}} > 60 \text{ GeV}$ $p_T^{V_\ell} > 75 \text{ GeV}$	2 <i>Loose</i> leptons with $p_T^\ell > 30 \text{ GeV}$ from the $Z \rightarrow \ell\ell$ candidate
Event veto	No additional <i>Loose</i> leptons Veto events with b -jets not associated with the $Z \rightarrow qq$ 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)	$E_T^{\text{miss}} > 100 \text{ GeV}$ $p_T^{V_\ell} > 200 \text{ GeV}$	≥ 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 $ \eta < 2.5$ $62 < m_{jj} < 97 \text{ GeV}$ for $W \rightarrow jj$ $70 < m_{jj} < 105 \text{ GeV}$ for $Z \rightarrow jj$	$\mathcal{R}_{p_T/m} > 0.35$ (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)

Event classification: signal regions

- HP / LP merged regions:
 - ▶ use new V-tagging (m_J , D_2)
- 10 SR in 0 lepton channel.
- 15 SR in 1 and 2 lepton channels
- $X \rightarrow WW$ and $X \rightarrow ZZ$ regions are orthogonal.
- $X \rightarrow WZ$ can overlap with the other two.
- Events failing SR criteria are used in control regions.



Event classification: control regions

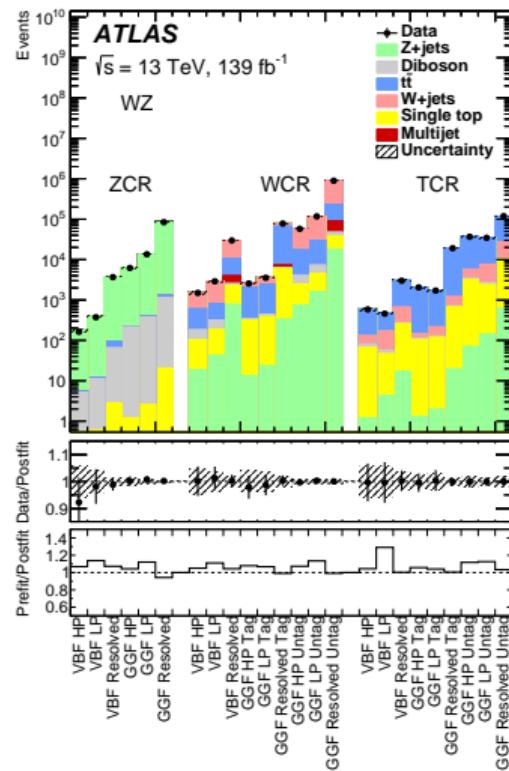
- Control regions have similar topologies as signal regions but inverting one selection:

W/Z CR $50 < m_{jj} < 150$ GeV
excluding W/Z mass window.

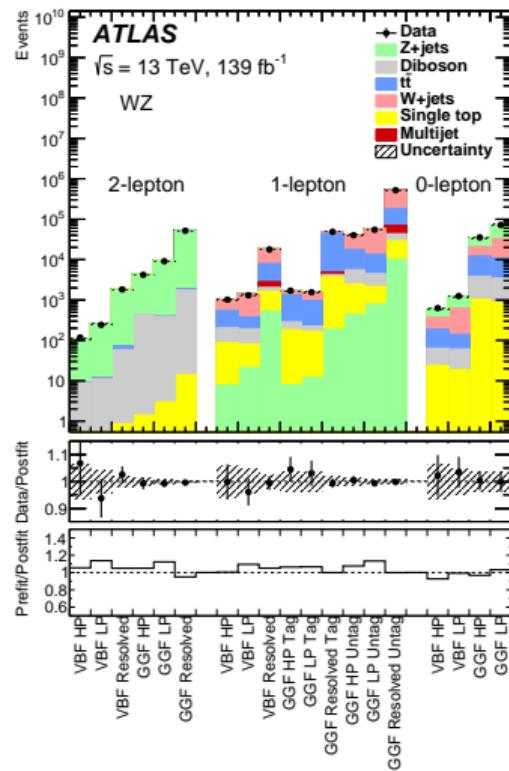
Top CR ≥ 1 small-R b-tagged jet instead of the b-jet veto.

- W and Top control region estimated in 1 lepton channel.
- Z control region estimated in 2 lepton channel.

WZ control region



WZ signal region



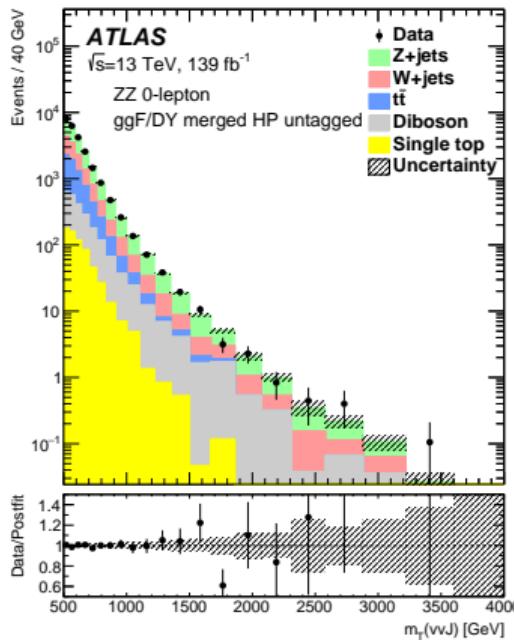
Systematic uncertainties and fit strategy

- Luminosity and lepton uncertainties impacting a few percent.
- Large- R jets with the largest contribution to uncertainty.
- Small- R jet with some impact in resolved analysis uncertainty.
- Background modelling and MC statistics also with relevant systematic contribution.
- Profile-likelihood-ratio fit.
- Parameter of interest: $\sigma(pp \rightarrow X \rightarrow VV)$.
- Final discriminant for maximum-likelihood fits:
 - ▶ transverse mass of $\nu\nu J$ system in 0 lepton channel.
 - ▶ invariant mass of VV system in 1 and 2 lepton channels.
- Top/ $V+jets$ background normalisations extracted from simultaneous fit with the control regions.

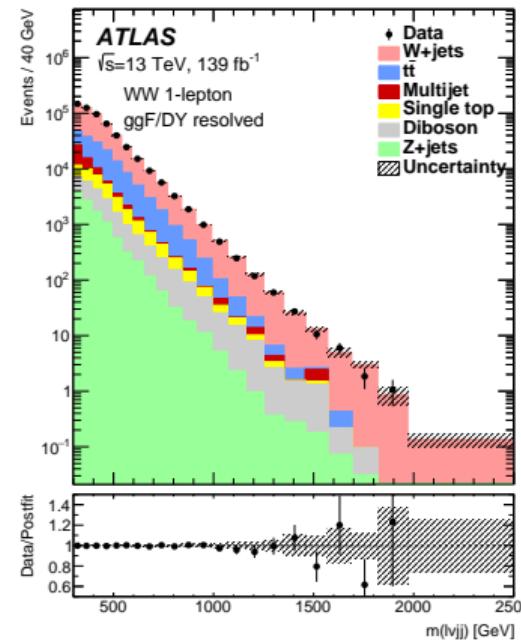
$m(G_{KK}) = 2 \text{ TeV}$	
Uncertainty source	$\Delta\mu/\mu [\%]$
Total	59
Statistical	48
Systematic	34
Large- R jet	24
MC statistics	17
$W/Z+jets$ modelling	15
Flavour tagging	5.5
$t\bar{t}$ modelling	4.2
Diboson modelling	3.9
Single- t modelling	3.3

Data-simulation comparisons

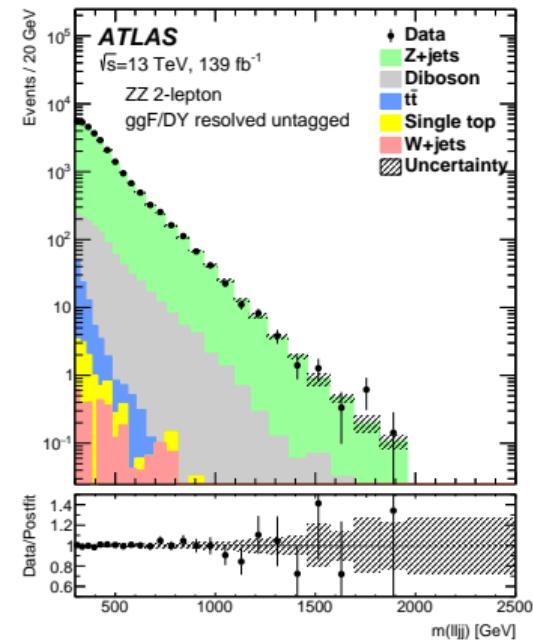
0 lepton ZZ



1 lepton WW



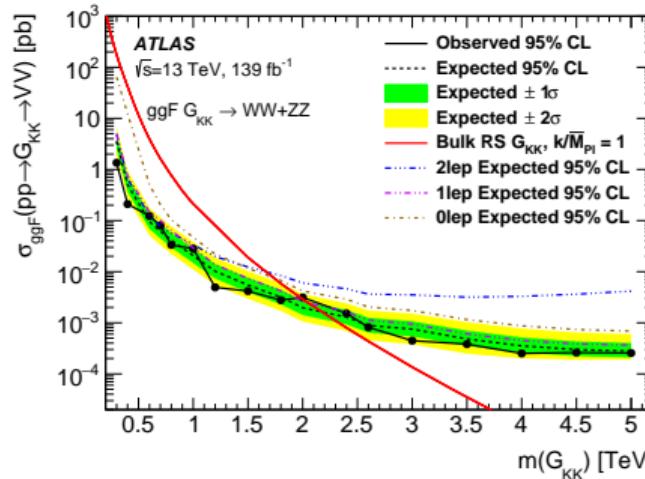
2 lepton ZZ



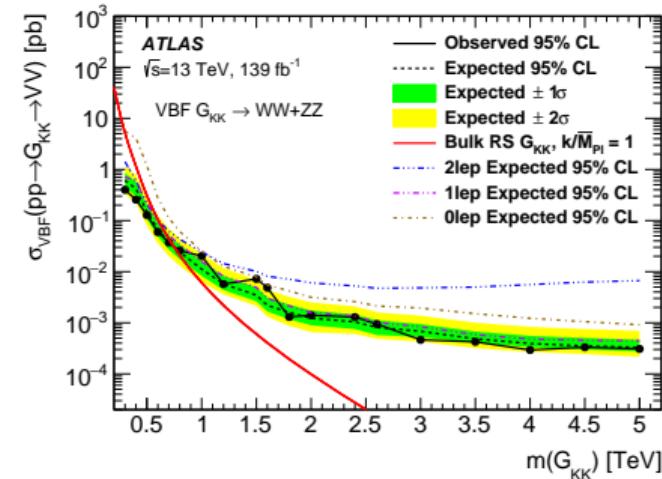
- Good agreement between data and MC simulation after fit.

Results for graviton

ggF production



VBF production



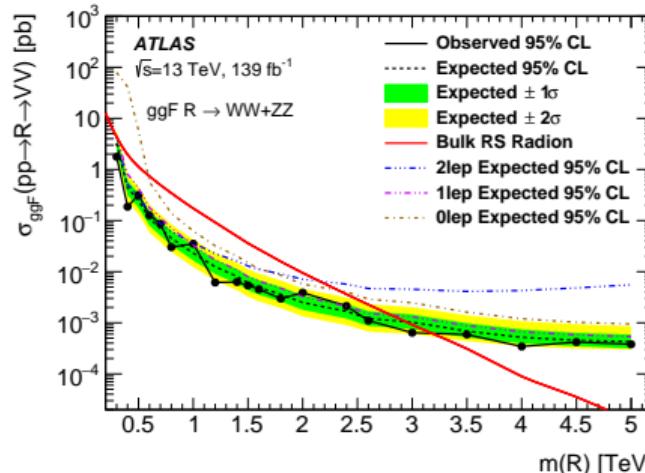
ggF The observed limit varies from 1.4 pb at 300 GeV to 0.26 fb at 5 TeV.

VBF The observed limit varies from 0.4 pb at 300 GeV to 0.30 fb at 5 TeV.

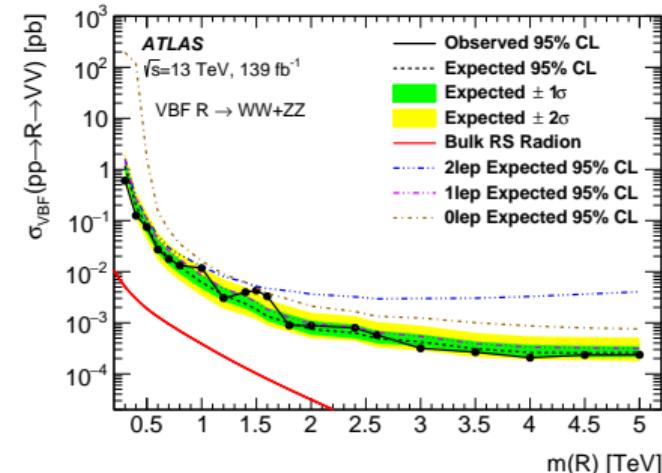
- Graviton excluded for masses 2.0 GeV in ggF production and 0.76 TeV in the VBF process.

Results for radion

ggF production



VBF production



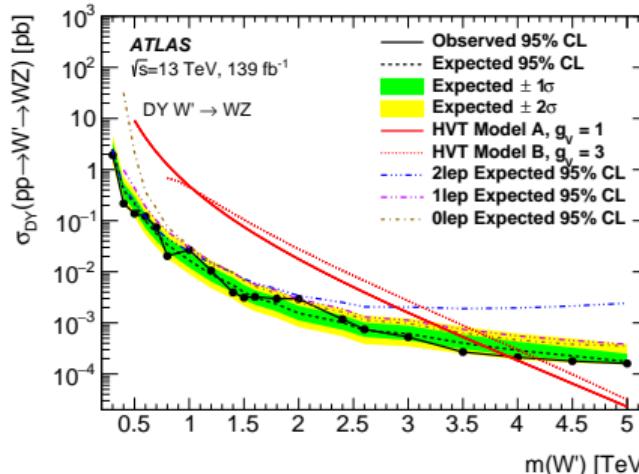
ggF The observed limit varies from 1.8 pb at 300 GeV to 0.38 fb at 5 TeV.

VBF The observed limit varies from 0.60 pb at 300 GeV to 0.23 fb at 5 TeV.

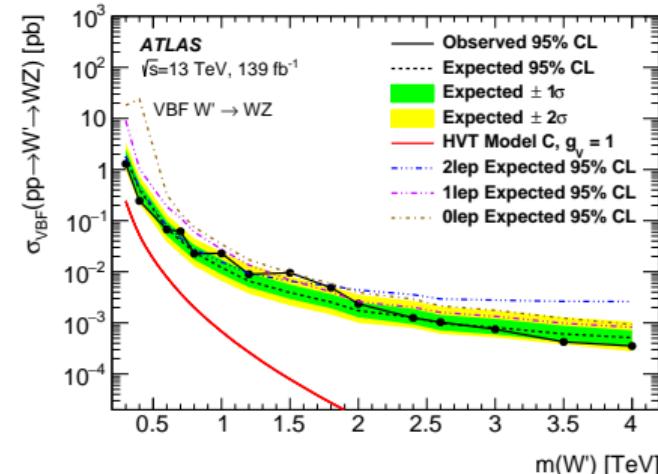
- Radion excluded for masses 3.2 GeV in ggF production and no exclusion for the VBF process.

Results for HVT W'

DY production



VBF production



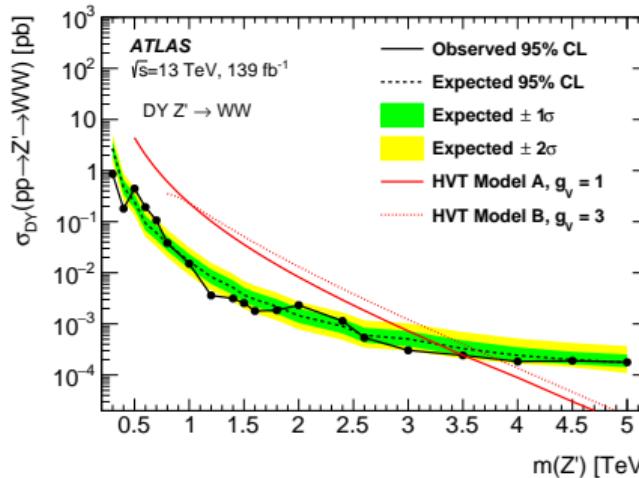
DY The observed limit varies from 1.9 pb at 300 GeV to 0.16 fb at 5 TeV.

VBF The observed limit varies from 1.3 pb at 300 GeV to 0.35 fb at 4 TeV.

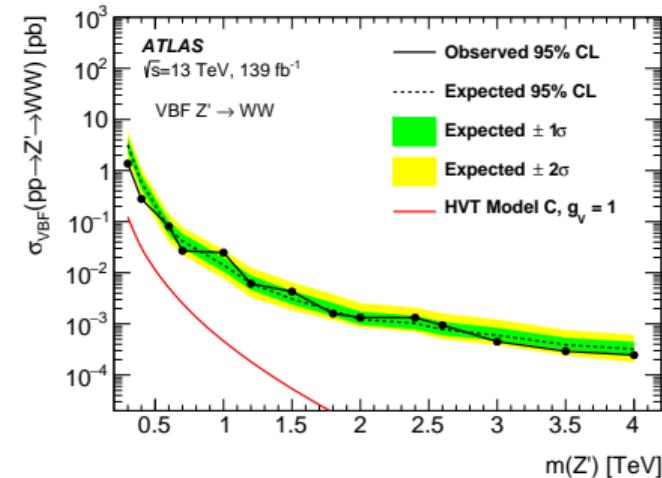
- HVT W' model A (B) excluded for masses 3.9 (4.3) GeV in drell-yan production.

Results for HVT Z'

DY production



VBF production



DY The observed limit varies from 0.9 pb at 300 GeV to 0.18 fb at 5 TeV.

VBF The observed limit varies from 1.36 pb at 300 GeV to 0.25 fb at 4 TeV.

- HVT Z' model A (B) excluded for masses 3.5 (3.9) GeV in drell-yan production.



Summary

- This analysis has quite some complexity...
 - ▶ Signal models: radion, graviton, HVT Z' and HVT W' (3 models).
 - ▶ Production modes: gluon fusion, vector boson fusion and Drell-Yan.
 - ▶ Lepton channels: $\nu\nu qq$, $\ell\nu qq$ and $\ell\ell qq$.
 - ▶ Categories: 1 resolved (2 small-R jets) and 1 merge (1 large-R jet).
 - ▶ 40 signal regions and 45 control regions.
- ... and set several exclusion limits.
- Paper in the final stage of approval: [arXiv:2004.14636](https://arxiv.org/abs/2004.14636)

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)
		Model B	4.3 (4.0)	3.9 (3.7)
VBF	-	Model C	-	0.76 (0.77)

Summary the observed (expected) 95% CL lower mass limits.

THANK YOU