WZ$\longrightarrow\ell\nu\ell\ell$ resonance search

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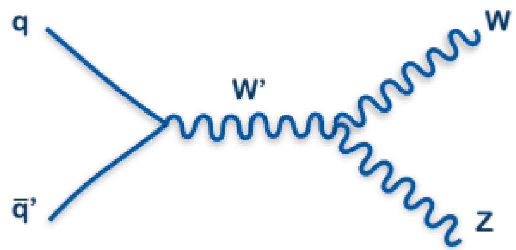
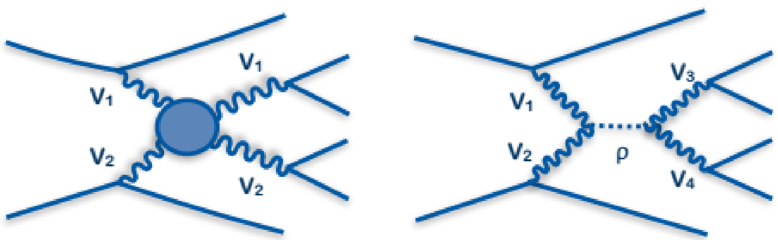
Introduction

Using 36.1 fb^{-1} of $\sqrt{s}$ = 13 TeV pp data collected by the ATLAS experiment at the LHC during the 2015 and 2016 run periods.



qq production mode



VBS/VBF production modes

- Aim of this analysis: fully leptonic WZ decay (e,μ) in exclusive qq and VBS/VBF production modes
  - Clean signature:
    - 3 high pT, isolated leptons,
    - Missing transverse energy
  - Backgrounds
    - WZ SM (dominant), ZZ, Z+jets, Z+γ, VVV and Top
- Two benchmark models:
  - Heavy Vector Triplets (HVT)
  - Georgi-Machacek (GM) Higgs Triplet Model : $H^{\pm}_5$

Event selection

Event Selection

- *Pass single-electron triggers or single-muon triggers*
- *Exactly three leptons with p_T > 25 GeV and $|\eta|$ < 2.5*
- *MET > 25 GeV*
- *ZZ veto: remove events with 4 or more muons or electrons with p_T > 7 GeV*
- *Select Opposite sign, Same Flavour pairs to built Z*
- *$| M_{ll}$ -91.1875GeV $|$ < 20 GeV*
- *If there are multiple choices, choose the pair that has the invariant mass closest to the Z mass*
- *W lepton: Likelihood Tight ID and Gradient isolation*
- *leading lepton p_T > 27GeV (in 2016 the trigger threshold was increased to 26 GeV)*
- *Longitudinal momentum of neutrinos reconstructed using W mass constrain*

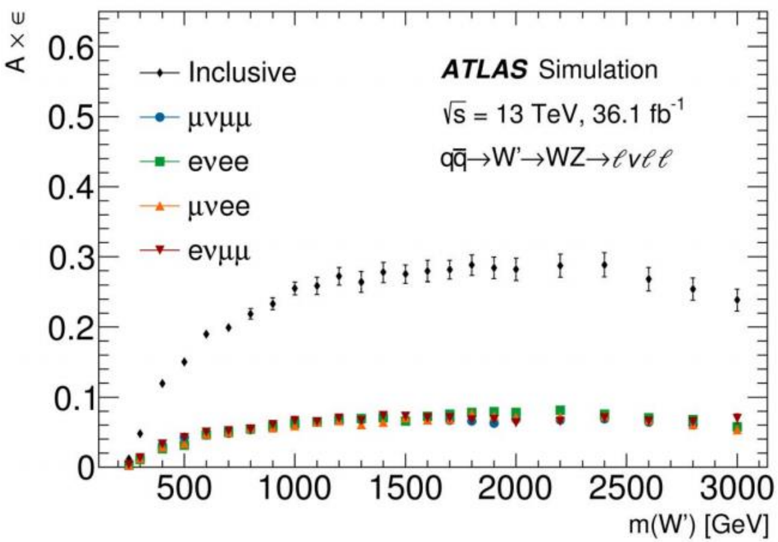
VBS/VBF Category

- *At least 2 jets with p_T>30 GeV and $|\eta|$ <4.5*
- *m_{jj} >500 GeV and $\Delta\eta_{jj}$ >3.5 (using the two p_T -leading ones)*

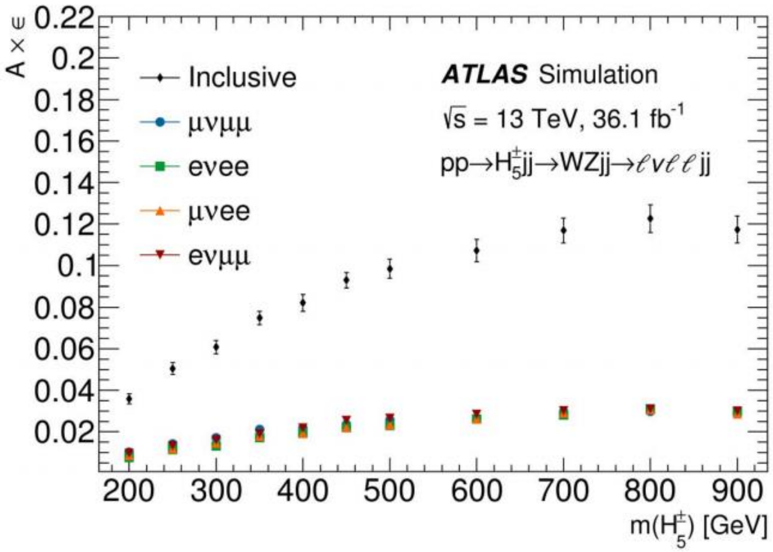
qq Category

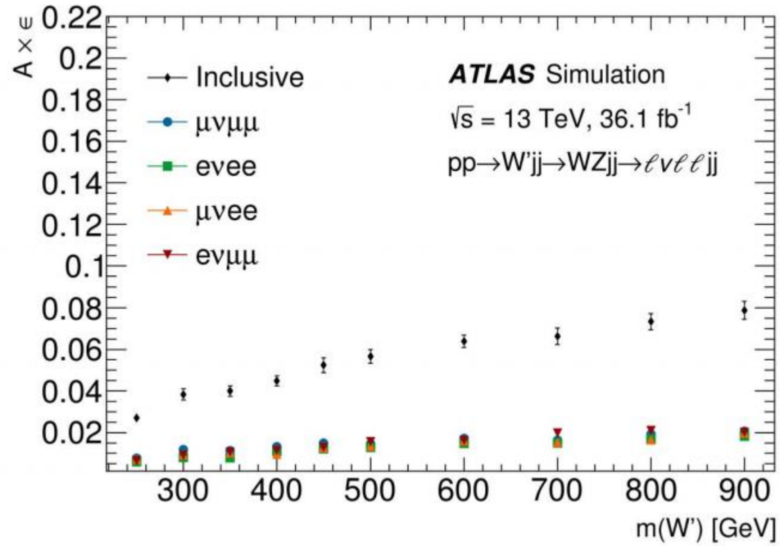
- *Fail VBS/VBF cuts*
- *p_T (Z)/Mass(WZ) >0.35*
- *p_T (W)/Mass(WZ) >0.35*

Event selection: signal $A \times \epsilon$



- **The signal selection acceptance times efficiency (A×ϵ)**
  - *For qq category, the A×ϵ increases from about 15% to 25%. The values decrease for resonance masses above approximately 2 TeV due to the collinearity of electrons from the Z → ee decays which spoils the isolation*
  - *For VBS/VBF category, the A×ϵ falls in the range 2–8% and 3–12% for HVT and H^+_5 respectively. The difference being due, with approximately equal importance, to the generator level selection and to the different angular distributions of the final products*





Background estimation

~ 90% Real leptons : Estimated using MC

- WZ (Sherpa)
  - QCD WZ dominant background (~80% of the total)
  - Uncertainties: 10% normalization, shapes used for PDF and Scale shape uncertainties, EWK corrections not available yet for our phase space
- ZZ (Powheg (qq) and Sherpa (gg)) : 10% theory uncertainty
- ttbarV (V=Z,W) (MadGraphPythia) 13% theory uncertainty for ttW and 12% ttZ
- tZ (MadGraphPythia) 15% theory uncertainty
- VVV (V=Z,W) (Sherpa) 20% theory uncertainty

~10 % Fake leptons : Estimated using Matrix Method

Background estimation Matrix Method

- Tight leptons match the WZ lepton selection.
- Loose leptons are defined by inverting some selection cuts i.e isolation, electron identification.
- We want to determine the background due to “fake” leptons.
  - 3 leptons ⇛ (# of Fake Real Real → Tight Tight Tight) + (# of Fake Fake Real → Tight Tight Tight) + …
- N_{TTT}, N_{TTL} … are related to N_{RRR}, N_{RRF} by the fake matrix:

Observation → Calculated

$$\begin{pmatrix} N_{TTT} \\ N_{TTL} \\ N_{TLT} \\ N_{LTT} \\ N_{TLL} \\ N_{LTL} \\ N_{LLT} \end{pmatrix} = \begin{pmatrix} e_1e_2e_3 & e_1e_2f_3 & e_1f_2e_3 & f_1e_2e_3 & e_1f_2f_3 & f_1e_2f_3 & f_1f_2e_3 \\ e_1e_2\bar{e}_3 & e_1e_2\bar{f}_3 & e_1f_2\bar{e}_3 & f_1e_2\bar{e}_3 & e_1f_2\bar{f}_3 & f_1e_2\bar{f}_3 & f_1f_2\bar{e}_3 \\ e_1\bar{e}_2e_3 & e_1\bar{e}_2f_3 & e_1\bar{f}_2e_3 & f_1\bar{e}_2e_3 & e_1\bar{f}_2f_3 & f_1\bar{e}_2f_3 & f_1\bar{f}_2e_3 \\ \bar{e}_1e_2e_3 & \bar{e}_1e_2f_3 & \bar{e}_1f_2e_3 & \bar{f}_1e_2e_3 & \bar{e}_1f_2f_3 & \bar{f}_1e_2f_3 & \bar{f}_1f_2e_3 \\ e_1\bar{e}_2\bar{e}_3 & e_1\bar{e}_2\bar{f}_3 & e_1\bar{f}_2\bar{e}_3 & f_1\bar{e}_2\bar{e}_3 & e_1\bar{f}_2\bar{f}_3 & f_1\bar{e}_2\bar{f}_3 & f_1\bar{f}_2\bar{e}_3 \\ \bar{e}_1e_2\bar{e}_3 & \bar{e}_1e_2\bar{f}_3 & \bar{e}_1f_2\bar{e}_3 & \bar{f}_1e_2\bar{e}_3 & \bar{e}_1f_2\bar{f}_3 & \bar{f}_1e_2\bar{f}_3 & \bar{f}_1f_2\bar{e}_3 \\ \bar{e}_1\bar{e}_2e_3 & \bar{e}_1\bar{e}_2f_3 & \bar{e}_1\bar{f}_2e_3 & \bar{f}_1\bar{e}_2e_3 & \bar{e}_1\bar{f}_2f_3 & f_1\bar{e}_2f_3 & \bar{f}_1\bar{f}_2e_3 \end{pmatrix} \begin{pmatrix} N_{RRR} \\ N_{RRF} \\ N_{RFR} \\ N_{FRR} \\ N_{RFF} \\ N_{FRF} \\ N_{FFR} \end{pmatrix}$$

i = 1, W lepton
i = 2,3 Z leptons

T = passes tight selection
L = fail tight selection

$\bar{e} = (1-e)$
$\bar{f} = (1-f)$

- e real efficiency : is the probability that a Real lepton is reconstructed as Tight.
- f fake probability : is the probability that a Fake lepton is reconstructed as Tight.
- By inverting the matrix, we calculate the fake contribution to our TTT signal

Background estimation Matrix Method

Fakes in our selection

$$N_{TTT} - e_1e_2e_3 N_{RRR} = [\, N_{TTL} - e_1e_2\bar{e}_3 N_{RRR} \,]\, f_3/\bar{f}_3 + [\, N_{TLT} - e_1\bar{e}_2e_3 N_{RRR} \,]\, f_2/\bar{f}_2 + [\, N_{LTT} - \bar{e}_1e_2e_3 N_{RRR} \,]\, f_1/\bar{f}_1 + [$$

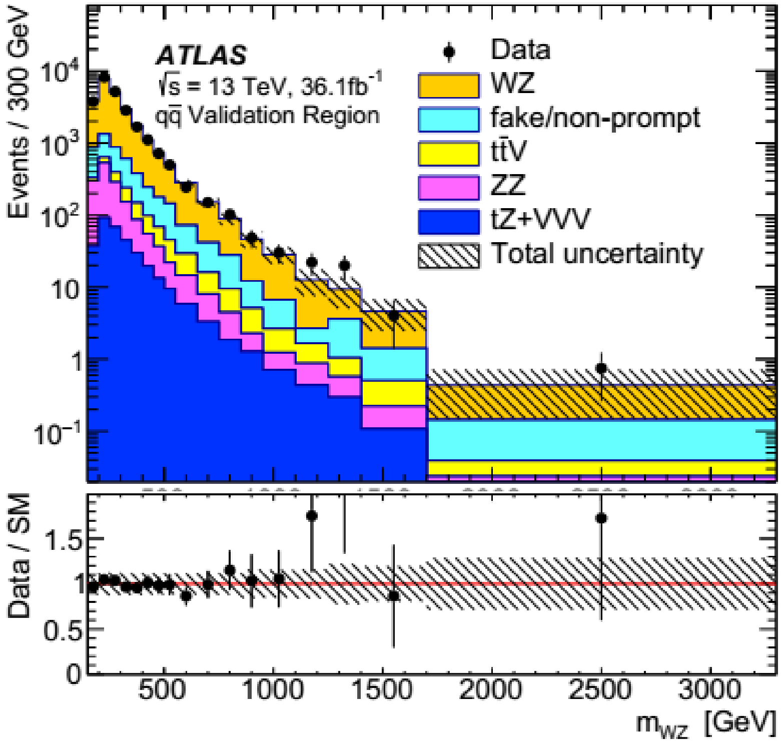
$$N_{TLL} - e_1\bar{e}_2\bar{e}_3 N_{RRR} \,]\, f_2f_3/\bar{f}_2\bar{f}_3 + [\, N_{LTL} - \bar{e}_1e_2\bar{e}_3 N_{RRR} \,]\, f_1f_3/\bar{f}_1\bar{f}_3 + [\, N_{LLT} - \bar{e}_1\bar{e}_2e_3 N_{RRR} \,]\, f_1f_2/\bar{f}_1\bar{f}_2$$

- Background in the signal region
- real leptons ZZ, WZ … from MC
- Loose Control regions
- Fake rates $F_i = f_i/\bar{f}_i$

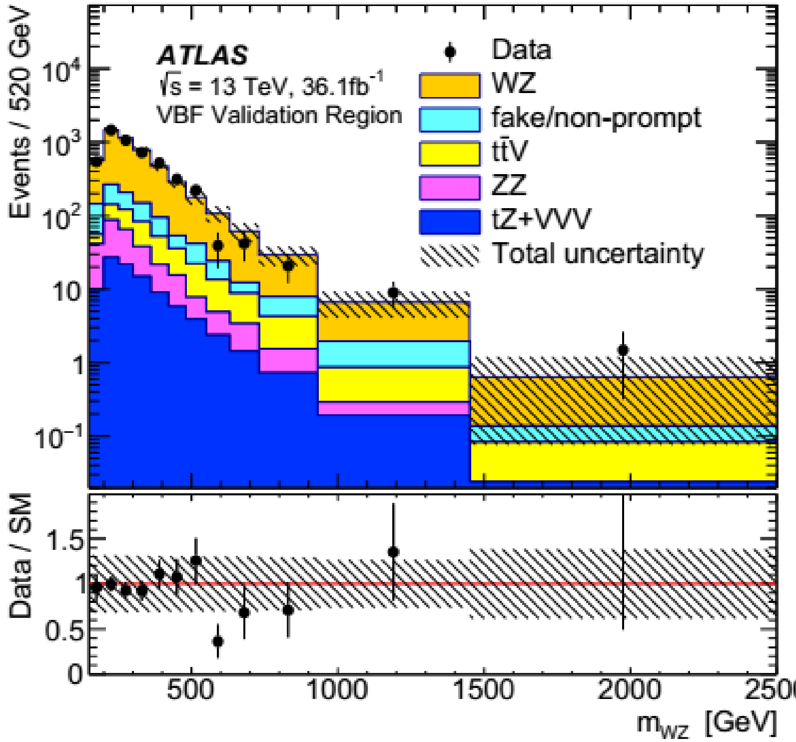
- N_{TTT}, N_{TTL}, N_{TLT} … measured by applying or inverting selection cuts
- $e_1e_2\bar{e}_3 N_{RRR}$, $e_1\bar{e}_2e_3 N_{RRR}$ … real lepton contamination from MC
- Fake Rates :
  - 2 different lepton selection for W and Z leptons→ 2 fake rates f_1 and f_2 ($f_2 = f_3$)
  - Measured in dedicated control regions

Background estimation validation

- **qq Validation Region**
  - *Fail VBF/VBS selecion*
  - *p_T (Z)/Mass(WZ) < 0.35 or p_T (W)/Mass(WZ) < 0.35*



- **VBS/VBF Validation Region**
  - *At least 2 jets with p_T>30 GeV and $|\eta|$ <4.5*
  - *m_{jj} < 500 GeV & m_{jj} > 100 GeV & $\Delta\eta_{jj}$ < 3.5*
  - *p_T (Z)/Mass(WZ) < 0.35 or p_T (W)/Mass(WZ) < 0.35*



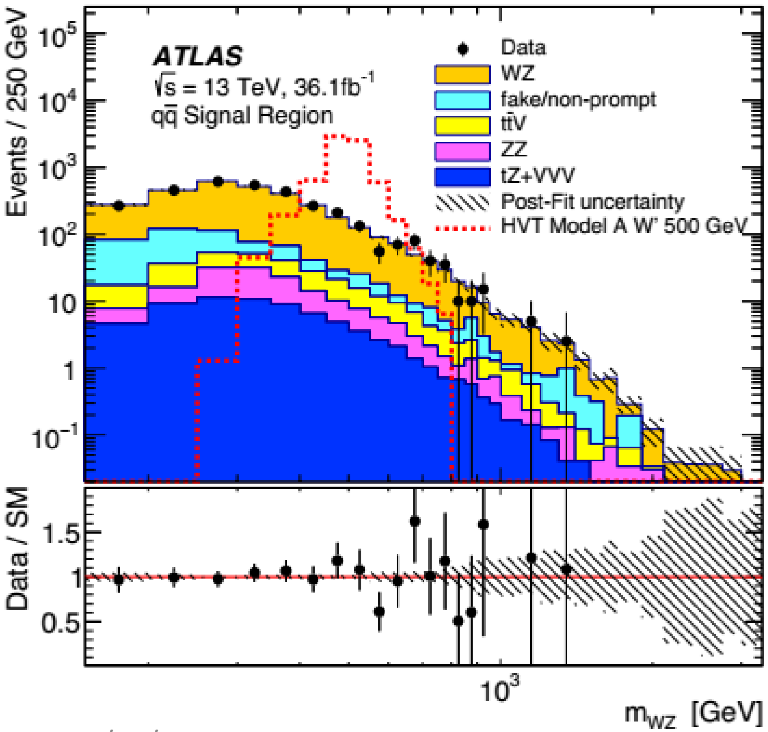
Systematics uncertainties

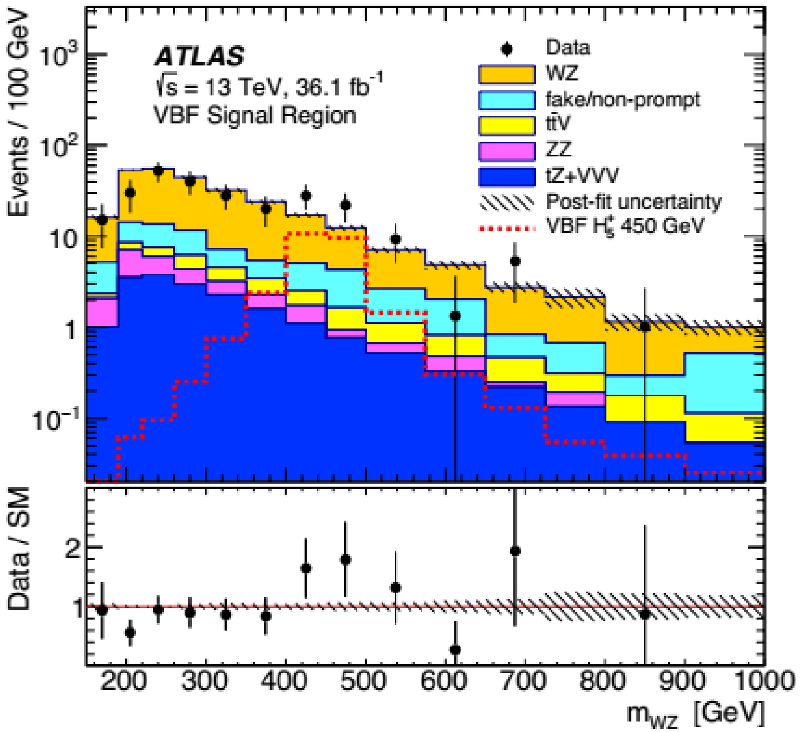
Source	$\Delta\mu/\mu$ [%]	
	$q\bar{q}$ Category $m(W') = 800$ GeV	VBF Category $m(H_5^{\pm}) = 450$ GeV
WZ background modelling : Scale, PDF	5	11
WZ background modelling : Parton Shower	10	6
MC statistical uncertainty	7	8
Electron identification	4	2
Muon identification	3	3
Jet uncertainty	1	8
Missing transverse momentum	2	1
Fake/non-prompt	1	5
Total systematic uncertainty	17	21
Statistical uncertainty	53	52

Results

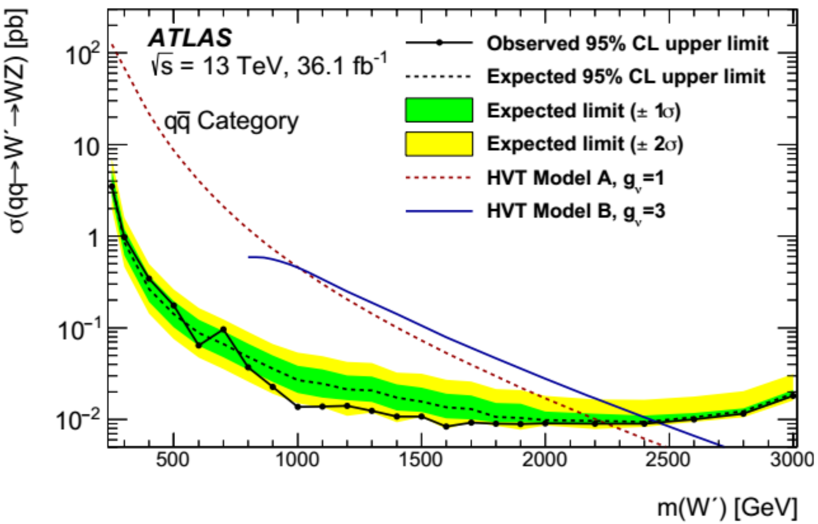
- A binned likelihood function, constructed from the Poisson probability of the sum of the background and of hypothetical signal of strength μ, is used to set limits on the signal

	$q\bar{q}$ Signal Region	VBF Signal Region
WZ	521 ± 29	87 ± 12
Fake/non-prompt	64 ± 13	15 ± 4
$t\bar{t}V$	29 ± 4	4.9 ± 0.8
ZZ	18.9 ± 2.0	4.4 ± 1.0
$tZ + VVV$	14.1 ± 2.9	8.1 ± 1.8
Total Background	647 ± 25	120 ± 11
Observed	650	114

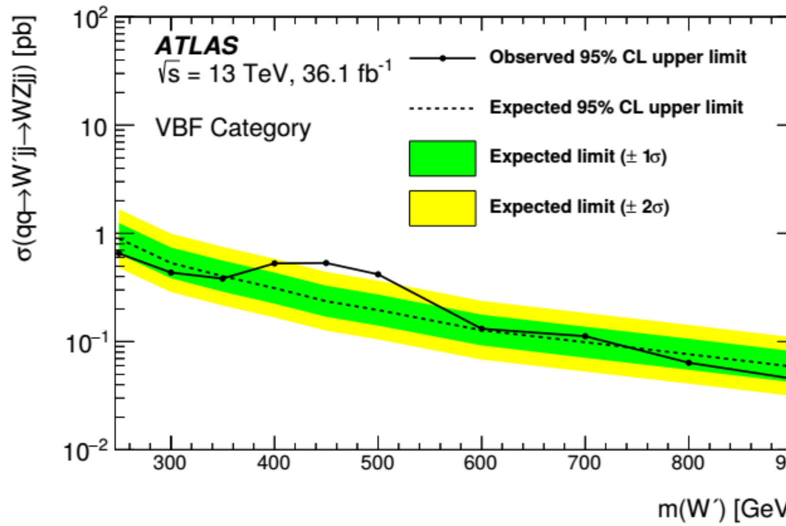




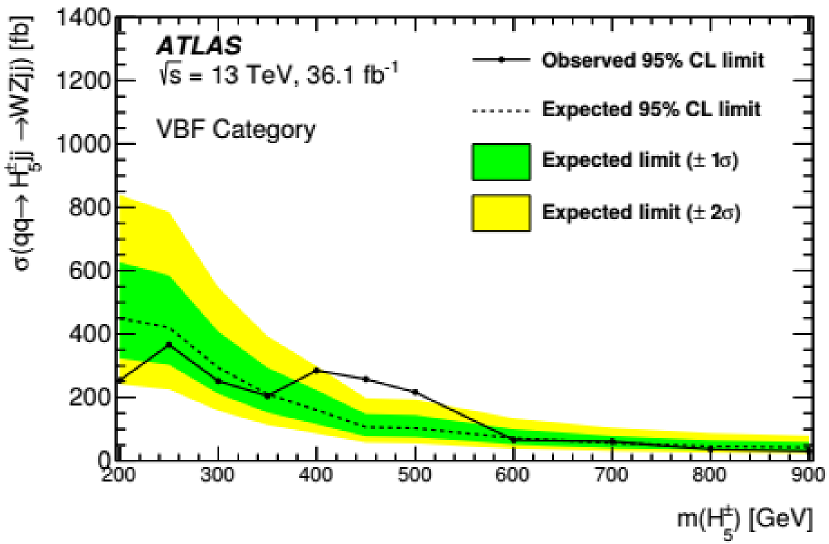
Results



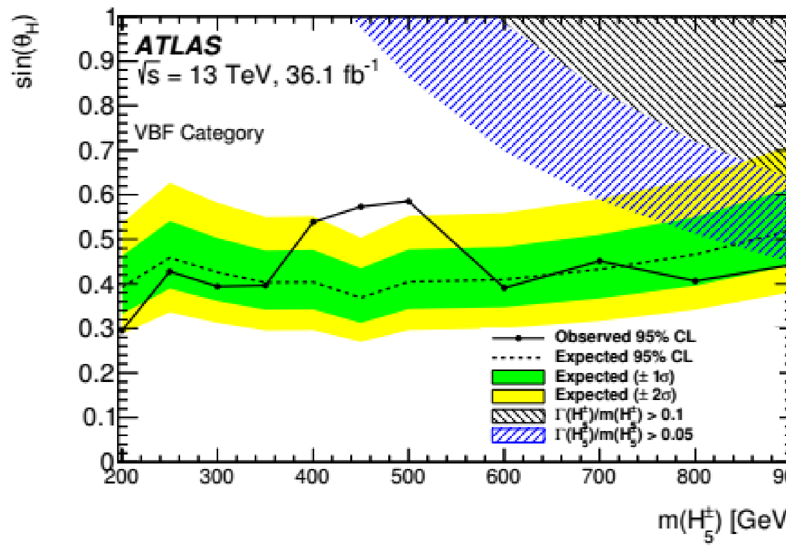
ATLAS
√s = 13 TeV, 36.1 fb⁻¹
qq̄ Category
Observed 95% CL upper limit
Expected 95% CL upper limit
Expected limit (± 1σ)
Expected limit (± 2σ)
HVT Model A, g_v=1
HVT Model B, g_v=3
σ(qq→W′→WZ) [pb]
m(W′) [GeV]



ATLAS
√s = 13 TeV, 36.1 fb⁻¹
VBF Category
Observed 95% CL upper limit
Expected 95% CL upper limit
Expected limit (± 1σ)
Expected limit (± 2σ)
σ(qq→W′jj→WZjj) [pb]
m(W′) [GeV]



ATLAS
√s = 13 TeV, 36.1 fb⁻¹
VBF Category
Observed 95% CL limit
Expected 95% CL limit
Expected limit (± 1σ)
Expected limit (± 2σ)
σ(qq→H5±jj→WZjj) [fb]
m(H5±) [GeV]



ATLAS
√s = 13 TeV, 36.1 fb⁻¹
VBF Category
Observed 95% CL
Expected 95% CL
Expected (± 1σ)
Expected (± 2σ)
Γ(H5±)/m(H5±) > 0.1
Γ(H5±)/m(H5±) > 0.05
sin(θH)
m(H5±) [GeV]

Summary

- **A search is performed for resonant WZ production in fully leptonic final states (electrons and muons) using 36.1 fb^{-1} of $\sqrt{s}$ = 13 TeV pp data collected by the ATLAS experiment at the LHC during the 2015 and 2016 run periods.**
  - *qq category: Masses below 2260 GeV for HVT WZ Model A and 2460 GeV for model B, are excluded at 95% CL*
  - *VBS category: Limits on the production cross-section times branching ratio are obtained as a function of the mass of a charged member of a Heavy Vector Triplet or of the fiveplet scalar in the Georgi-Machacek model. The results show a local excess of events over the Standard Model expectations at a resonance mass of around 450 GeV. The local significances for signals of H^{+}_{5} and of a heavy vector W' boson are 2.9 and 3.1 standard deviations respectively. The respective global significances calculated considering the Look Elsewhere effect are 1.6 and 1.9 standard deviations respectively*

- **For the second round, A full run-II analysis is ongoing**