Observation of electroweak production of a same-sign WW boson pair in association with two jets in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector

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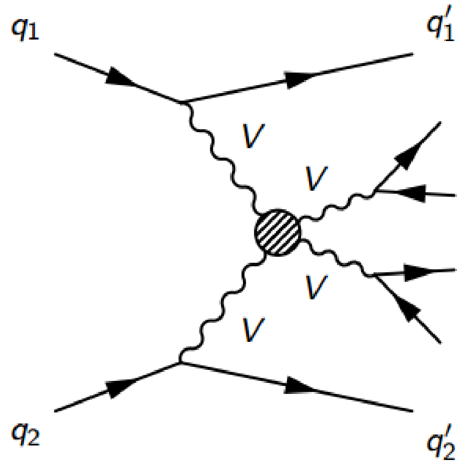
Introduction

Same sign $W^{\pm}W^{\pm}$ scattering

- Motivation
  - Same sign $W^{\pm}W^{\pm}$ is a promising means to understand the electroweak symmetry breaking mechanism
  - It involves quartic gauge couplings(QGC), is used to search for new physics: anomalous QGC(aQGC)
- Advantage
  - Has good signal-to-background ratio compare to $W^{\pm}W^{\mp}$
- Goals
  - Discover same sign WW process
  - Measure cross sections of same sign WW process
  - Search the aQGC



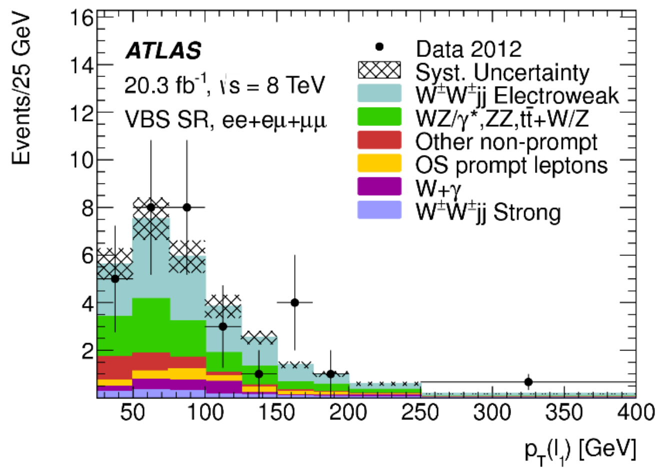
Vector Boson Scattering

Previous results

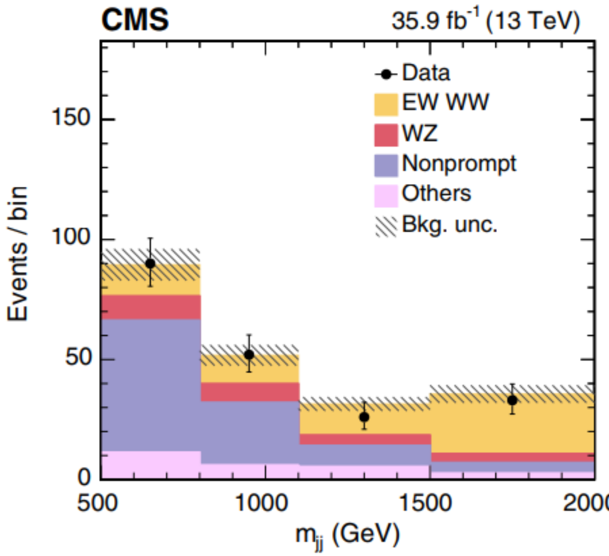
- Same sign WW production
  - ATLAS: 8TeV, 20.3 fb^{-1}, significance of 3.6σ
  - CMS: 8TeV, 19.4 fb^{-1}, significance of 2.0σ
    13TeV, 35.9 fb^{-1}, significance of 5.5σ

✓ **Measurements are dominated by statistics in 8 TeV data**

✓ **High statistics in 13 TeV have a significant improvement**



The leading lepton p_T distribution in signal region in 8 TeV ATLAS analysis

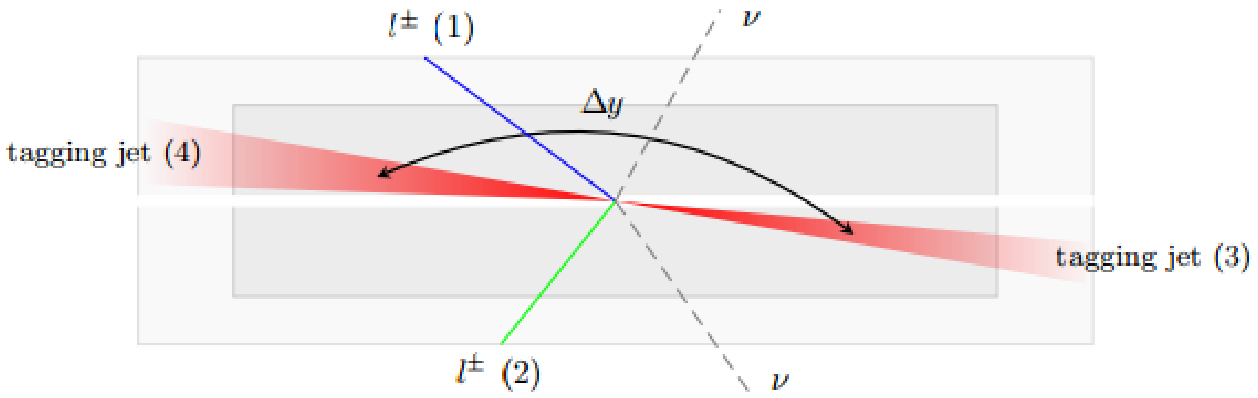


Distributions of M_{jj} in the signal region in 13 TeV CMS analysis.

Analysis strategy

Signal signature

➢ Develop event selection according to signal signature



VBS event topology

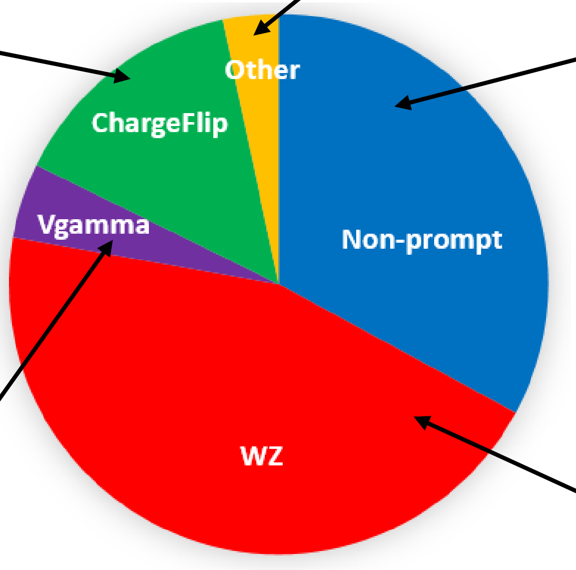
- ➢ two isolated leptons with same electric charge
  - Leptons are separated by flavour and charge (e^+, e^-, μ^+, μ^-)
- ➢ missing transverse energy
- ➢ two forward jets

Background estimation

Other Backgrounds
- Determined by MC.

Charge Flip Background
- An electron's charge is mis-identified
- Mostly Z+jets events and also $t\bar{t}$, $W^{\pm}W^{\mp}$
- Suppressed by Z-mass veto cut
- Determined in a DataDriven way

Non-Prompt Background
- Jet is mis-identified as a lepton
- Mainly from $t\bar{t}$ and also from W+jets or singletop
- Determined in a DataDriven way



Background components in signal region

$V\gamma$ Background
- A photon is reconstructed as an electron
- Determined by MC

WZ Background
- One of leptons is not identified or reconstructed
- Determined by MC

Event selections

Selection	Signal Region
Leptons	exactly two good selected leptons
Lepton p_T	$\geq 27\,GeV$
M_{ll}	$\geq 20\,GeV$
ThirdLepVeto	$\surd$
Leptons	same sign
Jets	at least two jets
$\lvert M_{ee} - M_Z \rvert$	$> 15\,GeV$
E_T^{miss}	$\geq 30\,GeV$
B-jet veto	85% using MV2 tagger
M_{jj}	$> 500\,GeV$
$\lvert \Delta Y_{jj} \rvert$	> 2

reduce low mass Drell-Yan processes

Gets rid of WZ process

reduce Z → ee background

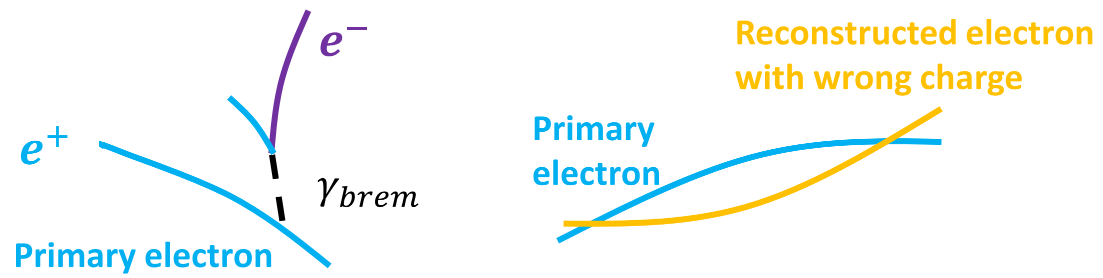
Gets rid of left over Z bosons

Gets rid of fake background from top process

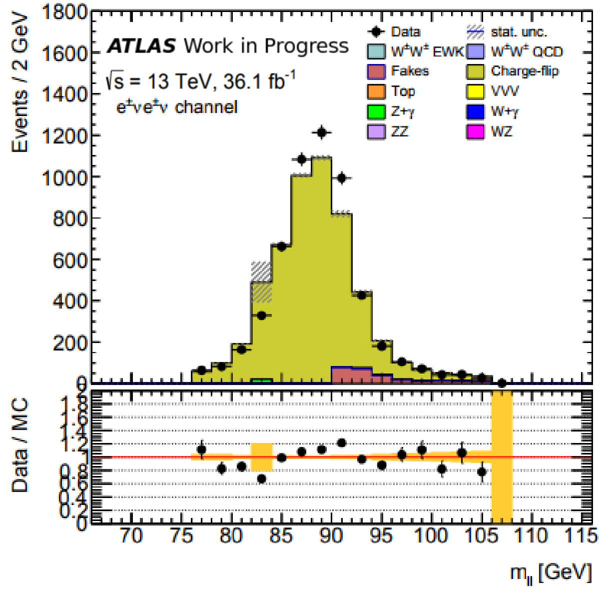
separate signal from the QCD

Background estimation – charge flip

➢ Two sources of charge mis-measurement:



Conversion of bremsstrahlung photon   Wrong tracks reconstruction



Estimated charge flip background in validation region

➢ Estimation:

- ϵ, charge mis-identification rate is estimated in $Z \rightarrow ee$
- Consider opposite-sign electron pair N_{OC}^{data}
- Assign them a weight to derive the estimation of the same-charge (SC)

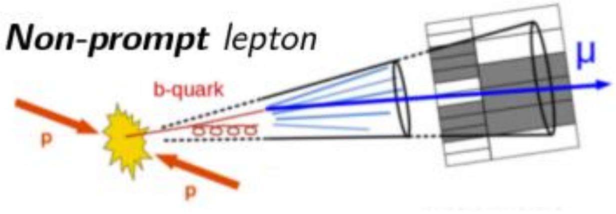
$$N_{bkg}^{charge-flip} = N_{OC}^{data} \cdot weight \qquad weight = \frac{\epsilon_1(1-\epsilon_2)+\epsilon_2(1-\epsilon_1)}{(1-\epsilon_1)(1-\epsilon_2)+\epsilon_1\epsilon_2}$$

➢ Systematic uncertainties:

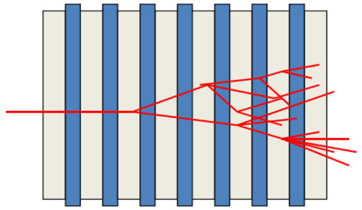
- The variation of the Z mass window selection
- The switching on and off of the background subtraction
- The closure test in MC

Background estimation – non-prompt

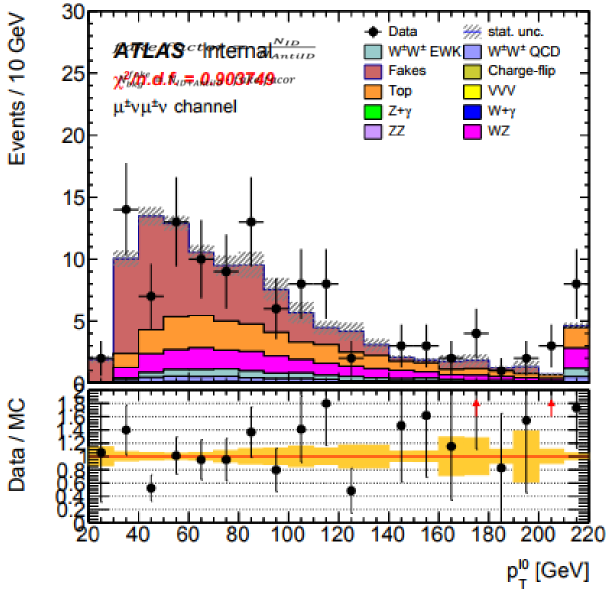
➢ **Two sources of non-prompt lepton**:



Leptons from semi-leptonic decays of B hadrons



Jets mis-identified as charged electron in calorimeter



Estimated non-prompt background in validation region

➢ **Estimation**:

- Estimate fake factor in a fake enriched dijet sample
- Consider ID + AntiID event, $N_{\mathrm{ID+AntiID}}$
- Assign them the fake factor to derive the estimation of the non-prompt background

$$N_{bkg}^{fake} = N_{ID+AntiID} \cdot fake\ facor \qquad fake\ factor = \frac{N_{ID}}{N_{AntiID}}$$

➢ **Systematic uncertainties:**

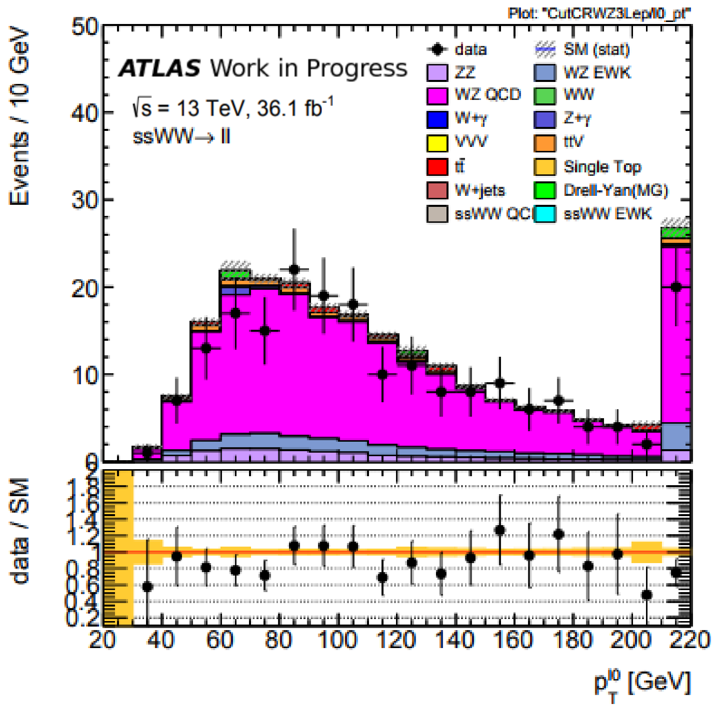
- The variation of dijet event selection
- The prompt lepton subtraction, vary normalization correction

Background estimation – WZ+jets & others

- WZ+jets
  - WZ is the dominant background
  - A Trilepton control region is used to check the overall normalization of WZ+jets cross section

- Vγ+jets
  - MC estimation
  - A normalization factor is obtained from a Zγ control region

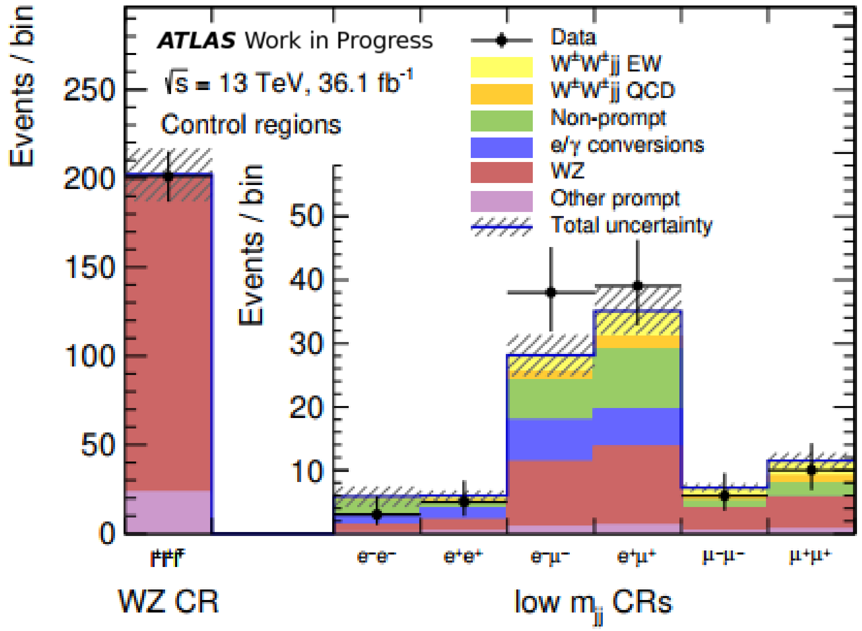
- Other background
  - ZZ, VVV, tZ, ttZ, ttW
  - MC estimation



Estimated WZ background in Trilepton control region

Validation region

- WZ and low M_{jj} Validation Region
  - check the estimation of various backgrounds
  - WZ VR: $N_{lep} = 3$
  - low M_{jj} VR: 200 < M_{jj} < 500 GeV



Event yields for data, signal and background in the WZ and 200 < m_{jj} < 500 GeV validation regions

Systematic uncertainty

- Experimental uncertainty
  - DataDriven estimation uncertainty
    - Non-prompt uncertainty
    - Charge flip uncertainty
  - Standard CP Uncertainties
    - Muon
    - Electron
    - Jet
    - MET
    - Pileup and Luminosity
- Theoretical uncertainty
  - 7-point scale
  - PDF envelope
  - α_s uncertainty
  - Parton shower

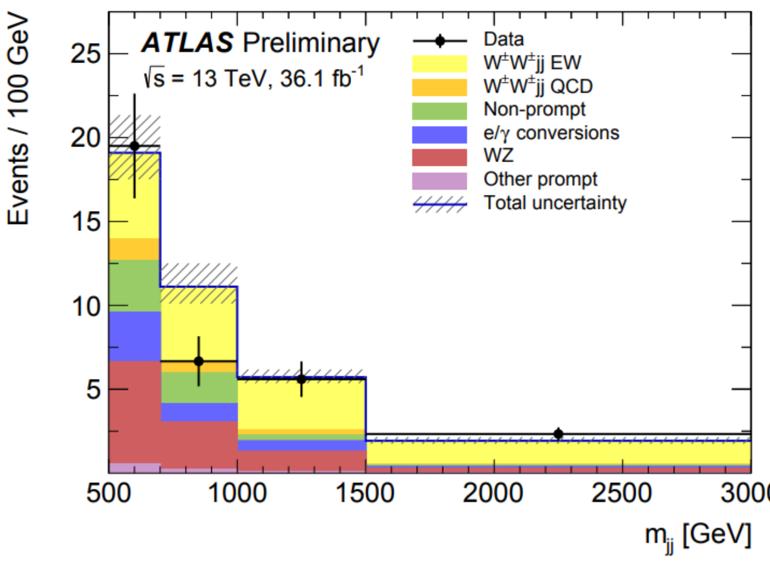
Source	Impact [%]
Reconstruction	± 4.0
Electrons	± 0.5
Muons	± 1.2
Jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	± 2.8
b-tagging	± 2.0
Pileup	± 1.5
Background	± 5.0
Misid. leptons	± 3.9
Charge misrec.	± 0.3
WZ	± 1.3
$W^{\pm}W^{\pm}jj$ strong	± 2.8
Other	± 0.8
Signal	± 3.6
Interference	± 1.0
EW Corrections	± 1.3
Shower, Scale, PDF & α_s	± 3.2
Total	± 7.4

Impact of systematic effects on the measurement of the fiducial cross section

Cross section and significance

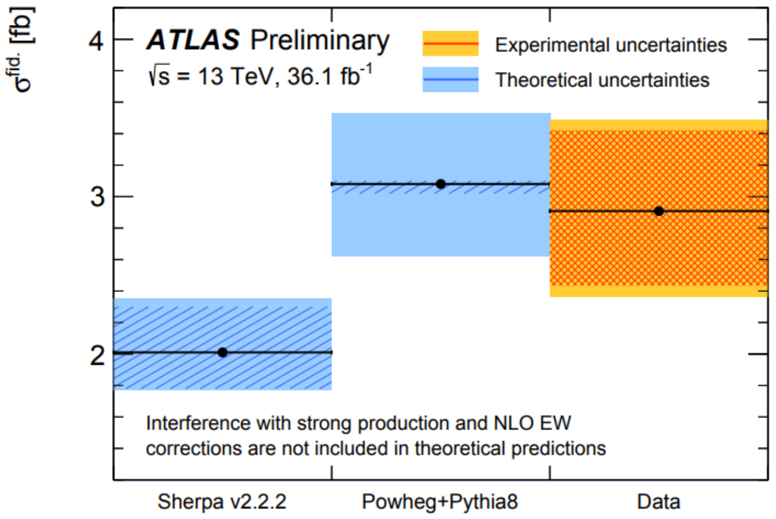
- Signal is extracted in a likelihood fit to M_{jj} distribution
- Observed $W^{\pm}W^{\pm}jj$ production integrated fiducial cross section is

$$\sigma^{\text{fid.}}_{\text{meas.}} = 2.91^{+0.51}_{-0.47}(\text{stat.}) \pm 0.27(\text{syst.})\ \text{fb}$$



m_{jj} distribution in signal region

- The measured fiducial cross section is compared with predicted by Sherpa and Powheg+Pythia8
- Observed significance is 6.9σ (4.6σ expected)



Comparison of the measured fiducial cross section and the theoretical calculations from Sherpa and Powheg

Summary

- The same sign WW VBS production is process of great interest. The studies with 13 TeV data have been done.

- The electroweak production of same sign WW have been observed with >5σ and cross-sections agree with SM predictions