Observation of Electroweak Production of Two Jets and a Z-boson Pair with the ATLAS Detector

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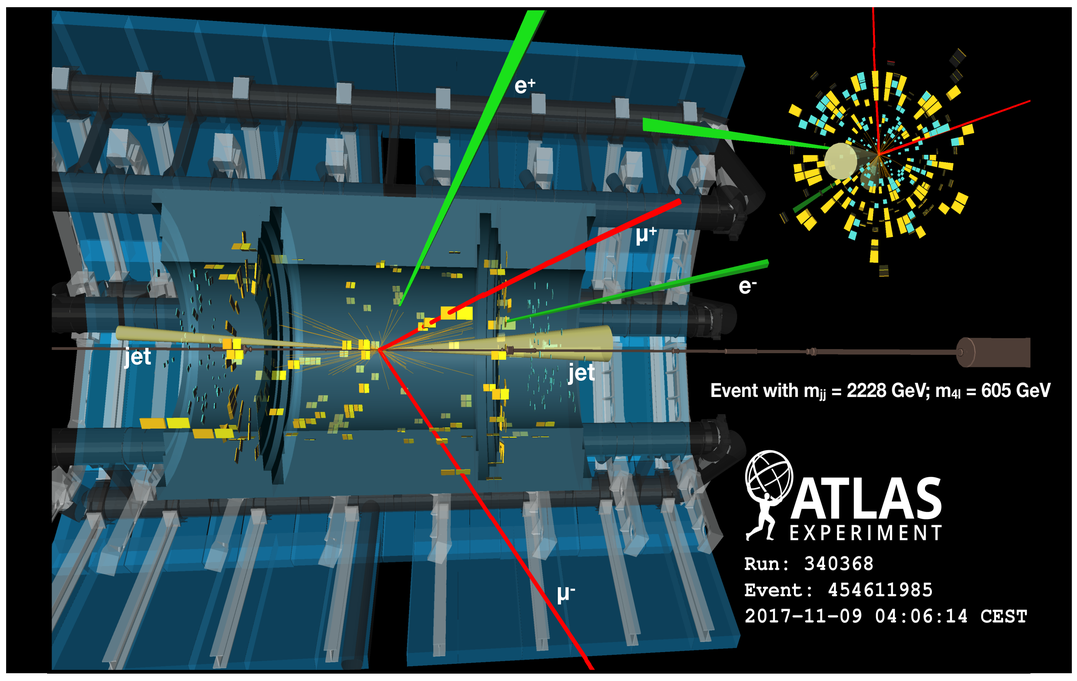
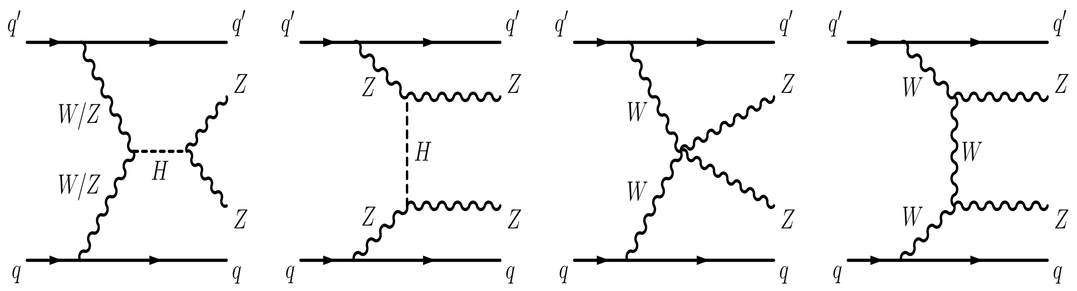
Introduction

The study of vector boson scattering (VBS) allows to probe the nature of electroweak symmetry breaking (EWSB). At the LHC, the scattering of massive electroweak gauge bosons is accessible through the measurement of purely electroweak (EW) production of two jets and two gauge bosons. Among all the EW VVjj processes, ZZjj offers a clean and competitive channel to study EWSB physics. The ATLAS experiment has measured the cross-sections for inclusive production of ZZ plus two jets and the observed signal strength of the EW production with 139 fb^{-1}of pp collision data at $\sqrt{S} = 13$ TeV collected during 2015-2018. Two final states, $\ell\ell\ell\ell jj$ and $\ell\ell\nu\nu jj$, are considered. Combined these two final states, the hypothesis of no electroweak production is rejected with a statistical significance of 5.5 σ.

VBS topology:



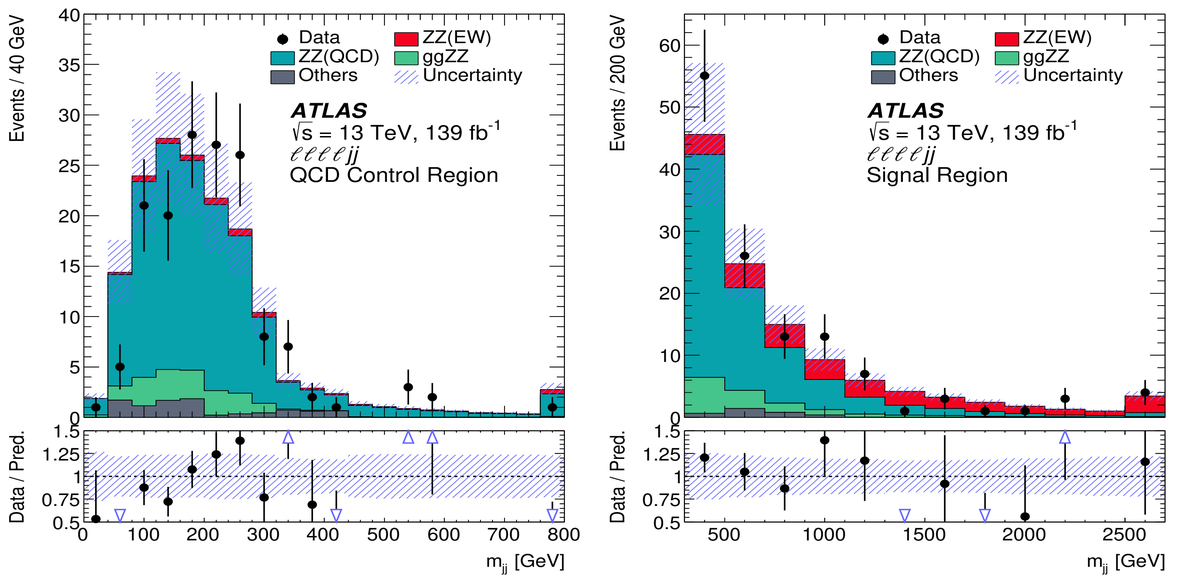
EW VBS diagrams:

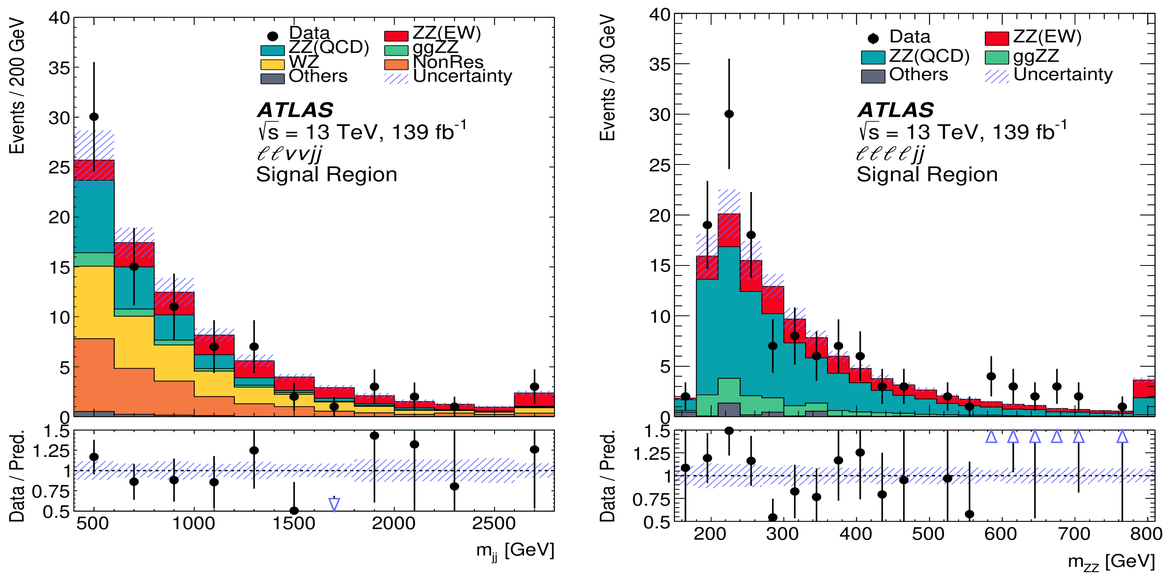


Event Selection

- Large invariant mass and rapidity separation of two jets in the forward and backward region to enhance VBS contributions, m_{jj} > 300 (400) GeV and $\Delta y(jj)$ > 2.0 in $\ell\ell\ell\ell jj$ ($\ell\ell\nu\nu jj$) channel.
- $\ell\ell\nu\nu jj$ channel: one Z boson candidate reconstructed in dielectron and dimuon final state, including additional lepton veto, b veto and large E_T^{miss}-significance requirements to suppress background.
- $\ell\ell\ell\ell jj$ channel: two Z boson candidates reconstructed in dielectron or dimuon final state

Kinematic Distributions





Background Estimation

$\ell\ell\ell\ell jj$ channel:

- QCD CR: the normalization of QCD ZZjj is constrained by a dedicated control region defined in data by reverting either m_{jj} or $\Delta y(jj)$ requirements.
- Fake leptons: contribution from Z+jets, $t\bar{t}$, WZ are estimated from data with the fake lepton method.

$\ell\ell\nu\nu jj$ channel:

- 3lCR: constrain the normalization of WZ background by requiring three selected leptons and a looser event selection.
- $e\mu$ CR, use ϵ−factor to correct the reconstruction efficiency difference between electrons and muons for non-resonant di-lepton backgrounds ($t\bar{t}$, WW).
- Z+jets CR: extrapolate the low E_T^{miss} −significance region distribution in data to the high E_T^{miss} −significance region using an exponential function for Z+jets background.

Signal Region Yields:

Process	$\ell\ell\ell\ell jj$	$\ell\ell\nu\nu jj$
EW $ZZjj$	20.6 ± 2.5	12.30 ± 0.65
QCD $ZZjj$	77 ± 25	17.2 ± 3.5
QCD $ggZZjj$	13.1 ± 4.4	3.5 ± 1.1
Non-resonant-$\ell\ell$	-	21.4 ± 4.8
WZ	-	22.8 ± 1.1
Others	3.2 ± 2.1	1.15 ± 0.89
Total	114 ± 26	78.4 ± 6.2
Data	127	82

Results

Measurement of Fiducial Cross-sections

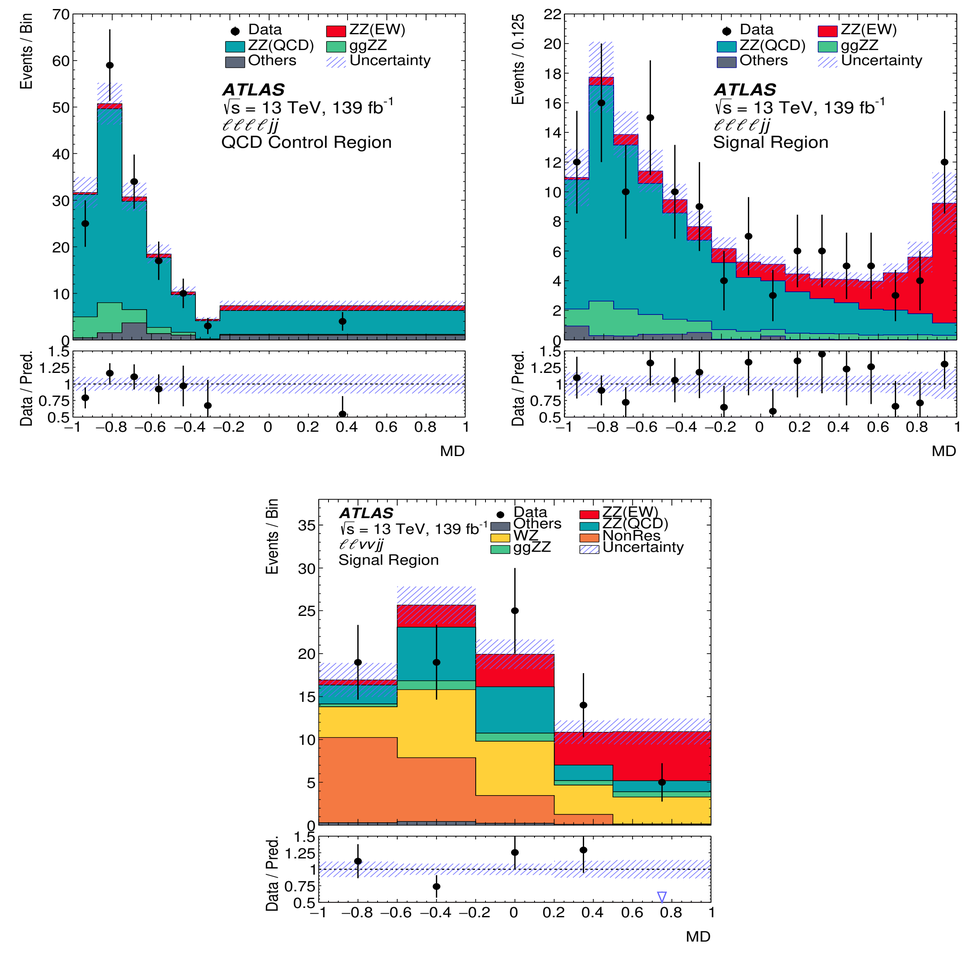
- $\ell\ell\ell\ell jj$ channel fiducial region: Z window loose to [60, 120] GeV (is [66, 116] GeV for detector level) to reduce migration effect.
- $\ell\ell\nu\nu jj$ channel fiducial region: Truth $E_T^{miss} > 130$ GeV instead of E_T^{miss} −significance cut at detector level
- Measured and predicted fiducial cross-section in both $\ell\ell\ell\ell jj$ and $\ell\ell\nu\nu jj$ channel.

$$C_{\text{factor}} = \frac{N_{\text{detector level}}}{N_{\text{F.V. truth}}}, \quad \sigma = \frac{N_{\text{data}} - N_{\text{background}}}{C \times \mathcal{L}}$$

	Measured fiducial σ [fb]	Predicted fiducial σ [fb]
$\ell\ell\ell\ell jj$	$1.27 \pm 0.12(\text{stat}) \pm 0.02(\text{theo}) \pm 0.07(\text{exp}) \pm 0.01(\text{bkg}) \pm 0.03(\text{lumi})$	$1.14 \pm 0.04(\text{stat}) \pm 0.20(\text{theo})$
$\ell\ell\nu\nu jj$	$1.22 \pm 0.30(\text{stat}) \pm 0.04(\text{theo}) \pm 0.06(\text{exp}) \pm 0.16(\text{bkg}) \pm 0.03(\text{lumi})$	$1.07 \pm 0.01(\text{stat}) \pm 0.12(\text{theo})$

Search for Electroweak ZZjj

- To separate the EW ZZjj processes from backgrounds, multivariate discriminants (MDs) based on the Gradient Boosted Decision Tree algorithm are trained for each channel in the signal region with kinematic variables.
- Highest ranking variable in BDT: m_{jj} ($\Delta y(jj)$) in $\ell\ell\ell\ell jj$ ($\ell\ell\nu\nu jj$) channel.



- The MD distribution in both signal regions and QCD control region are used in statistical fit to extract the EW signal strength. The observed μ_{EW} and μ_{QCD}, as well as the observed and expected significance from the individual channels, and the combined fits can be shown as:

	μ_{EW}	$\mu_{\text{QCD}}^{\ell\ell\ell\ell jj}$	Significance Obs. (Exp.)
$\ell\ell\ell\ell jj$	1.5 ± 0.4	0.95 ± 0.22	5.48 (3.89) σ
$\ell\ell\nu\nu jj$	0.7 ± 0.7	fixed	1.15 (1.80) σ
Combined	1.35 ± 0.34	0.96 ± 0.22	5.52 (4.29) σ

The first observation of EW ZZjj production is an important milestone for studies of EW VVjj production and marks the start of the precision measurement program, which will utilize the collected EW VVjj events to strengthen the study of VBS and probe the nature of EWSB.

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