Measurement of the ZZ production cross section and limits on anomalous neutral triple gauge couplings in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

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We present a measurement of the ZZ production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV, using 1.02 fb^{-1} of data collected by the ATLAS experiment at the LHC. Events are selected that contain two candidate Z bosons in their decays to electrons or muons. In addition, first limits are set on anomalous neutral triple gauge couplings in proton-proton collisions at $\sqrt{s} = 7$ TeV [1].

Introduction

• Standard model ZZ production is an irreducible background to the important Higgs decay channel $H \rightarrow ZZ(*) \rightarrow 4l$.

• A test of the gauge structure of the Standard Model electro-weak sector through probing anomolous triple gauge couplings (nTGCs), which appear as enhanced cross sections at high p_T^{ZZ} and m^{ZZ} [3].

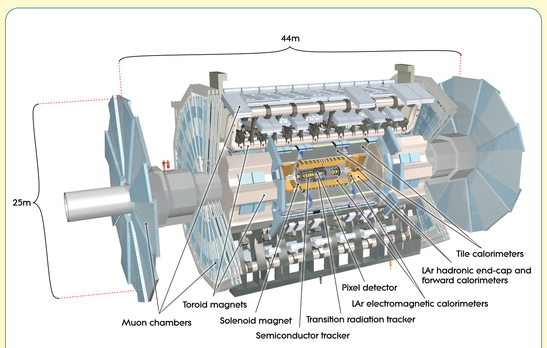
• Direct probe of new physics through heavy resonances decaying to ZZ. A search for new physics in four lepton events is presented in [5].

• Measure the ZZ cross section in a fiducial volume close to the experimental selection cuts using ZZ decays to electrons and muons.

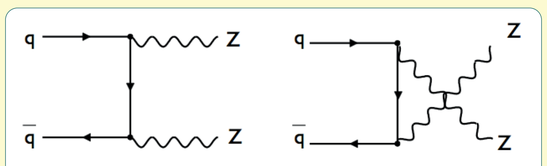
• The measured cross section is then used to set limits on the nTGCs.

Fiducial volume definition

1. $p_T^l < 15$ GeV
2. $|\eta^l| < 2.5$
3. 66 GeV $< m_{ll} <$ 116 GeV



The ATLAS detector [2].



SM allowed ZZ production diagrams.

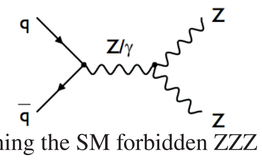
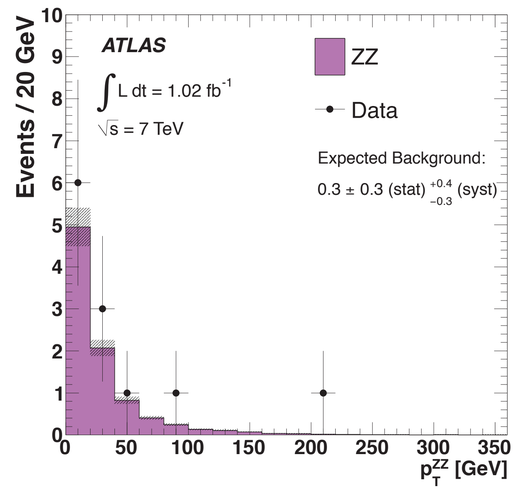
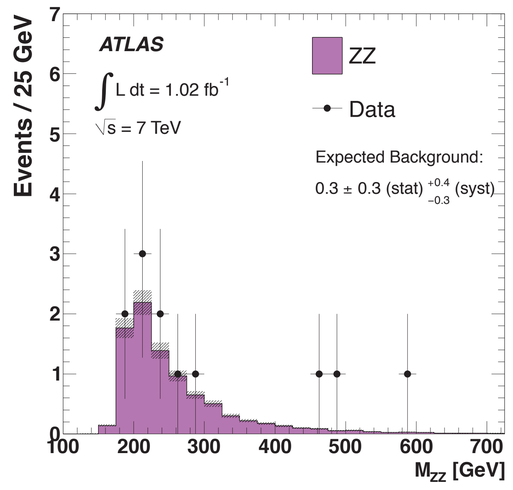


Diagram containing the SM forbidden ZZZ vertex.

Selected Event Kinematics





(Left) Transverse momentum p_T^{ZZ} and (right) invariant mass M^{ZZ} of the four-lepton system for selected events. The points represent the observed data and the histograms show the signal prediction from simulation. The shaded band on each histogram shows the combined statistical and systematic uncertainty on the signal prediction. The predicted number of background events from the data-driven background estimate is indicated on the plot.

Cross Section Measurement

• Maximum likelihood fit used to combine results from the three channels, with systematic uncertainties introduced as nuisance parameters.

• Fiducial cross section extrapolated to total cross section using known Z->ll branching ratios and acceptance of the fiducial cuts estimated from simulation.

Fiducial cross section

$$\sigma_{ZZ}^{tot} = 8.5^{+2.7}_{-2.3}(\text{stat.}) \pm ^{+0.4}_{-0.3}(\text{syst.}) \pm 0.3(\text{lumi.}) \text{ pb}$$

Total cross section

$$\sigma^{\text{fid}}_{ZZ\rightarrow l^+l^-l^+l^-} = 19^{+6}_{-5}(\text{stat.}) \pm 1(\text{syst.}) \pm 1(\text{lumi.}) \text{ fb}$$

Channel	Observed	Bkg(data-driven)	Expected	ZZ
$e^+e^-e^+e^-$	2	$0.01^{+0.03+0.05}_{-0.01-0.01}$	$1.53 \pm 0.03 \pm 0.10$	
$\mu^+\mu^-\mu^+\mu^-$	8	$0.3 \pm 0.3 \pm 0.3$	$3.03 \pm 0.04 \pm 0.06$	
$e^+e^-\mu^+\mu^-$	2	$< 0.01^{+0.03}_{-0.01}$	$4.37 \pm 0.04 \pm 0.14$	
$\ell^+\ell^-\ell^+\ell^-$	12	$0.3 \pm 0.3^{+0.4}_{-0.3}$	$8.9 \pm 0.1 \pm 0.3$	

Summary of observed events, total background contributions and expected signal in the individual four-lepton and combined channels. The first error is statistical while the second is systematic.

Event Selection

Leptons

• Select leptons satisfying identification criteria (*see below*) with $p_T > 15$ GeV, $|\eta| < 2.5$

• Longitudinal impact parameters $|z_0| < 10$mm from primary vertex.

• Transverse impact parameter $|d_0 / \sigma(d_0)| < 10$

• Isolation: Scalar sum of p_T of tracks inside a cone of $\Delta R < 0.2$ [$\Delta R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$] around lepton track must be less than 15% of lepton p_T.

Electron Identification

• Match cluster in EM Calorimeter to track in Inner Detector.

• Reject electron if there is a muon or higher p_T electron within cone size of $\Delta R < 0.1$.

• Apply `medium' identification requirements based on shower shape in calorimeter and inner detector track quality to reject fakes.

Muon Identifcation

• Muon Spectrometer track or track segment matched to Inner Detector track.

• Combine information from the two subsytems, correcting for energy lost in the calorimeters.

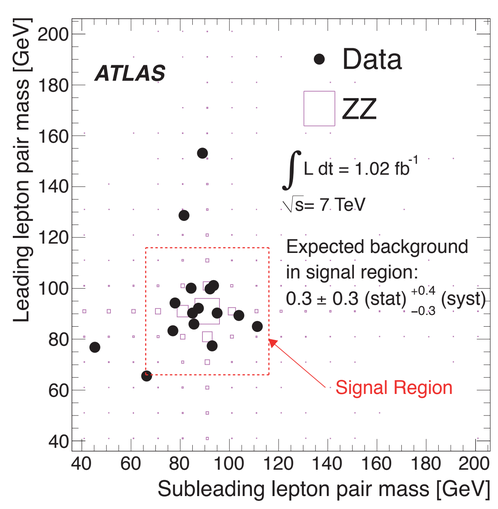
Event Selection

• Events triggered using high p_T single electron or muon triggers.

• Require primary vertex has at least 3 tracks to reject cosmic background.

• Require two opposite-sign (OS), same-flavour (SF) lepton pairs.

• At least one lepton matched to trigger object with $p_T > 25$ GeV (electron) or $p_T > 20$ GeV (muon).



The mass of the leading lepton pair versus the mass of the subleading lepton pair. The events observed in the data are shown as solid circles and the signal prediction from simulation as boxes. The large dashed box indicates the signal region defined by the cuts on the lepton-pair masses.

• Choose the lepton pairing which minises:

$$|m_{01} - m_{Z,\text{PDG}}| + |m_{23} - m_{Z,\text{PDG}}|$$

• Require both pairs on shell:

$$66 \text{ GeV} < m_{\ell\ell} < 116 \text{ GeV}$$

• Overall efficiencies of the reconstruction and selection criteria for events generated within the fiducial volume are (40 ± 3)% , (79 ± 2)% and (57 ± 2)% for the $e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$ and $e^+e^-\mu^+\mu^-$ channels respectively.

Anomalous Triple Gauge Couplings

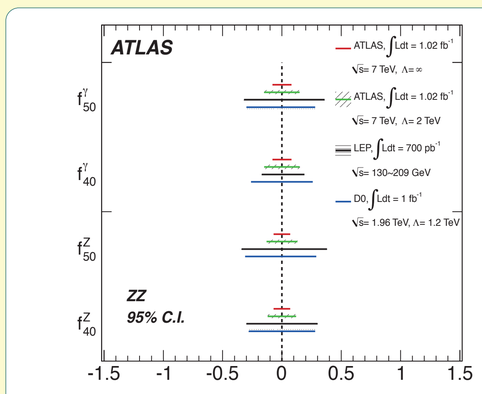
• Many models of new physics predict neutral triple gauge couplings (nTGCs).

• Non-zero nTGCs would show up as an increase of the ZZ cross section at high ZZ invariant mass and high transverse momentum of the Z bosons.

• General ZZV (V=Z,γ) couplings paramertised by two CP-violating (f_4^V) and two CP-conserving (f_5^V) parameters [4].

• One dimensional 95% confidence intervals on the anomalous nTGCs are determined using a maximum profile likelihood fit to the observed number of events only.

• Derived limits are comparable with, or are more stringent than, those derived from measurements at LEP and at the Tevatron.



Anomalous nTGC 95% confidence interval comparison; Λ cut-off values for each experiment are given.

Background Estimation

• Major backgrounds come from W/Z events with additional jets or photons and $t\bar{t}$.

• All these contain "background" leptons, from:

  • Decay of heavy flavour hadrons.

  • In flight decays of pions / kaons to muons.

  • Jets or photons misidentified as electrons.

• Majority of these backgrounds are rejected by the isolation cuts, but since MC statistics are limited and may not model isolation in jets well, a data driven background estimate is used.

• Identify control samples with events passing full selection, but with one or two lepton-like-jets (j), which fail isolation / ID requirements, in place of real leptons (l). These are dominated by Z+X.

• Measure the ratio of the probability of a jet passing the full lepton criteria to the probability of a jet passing the lepton-like-jet criteria (f) in a data sample selected with single lepton triggers, using cuts to reject W/Z events.

	Selected Leptons	Lepton-like jets
Muons	Track iso < 0.15	Track iso > 0.15
Electrons	Track iso < 0.15 and *Medium*	Track iso > 0.15 or ! *Medium*

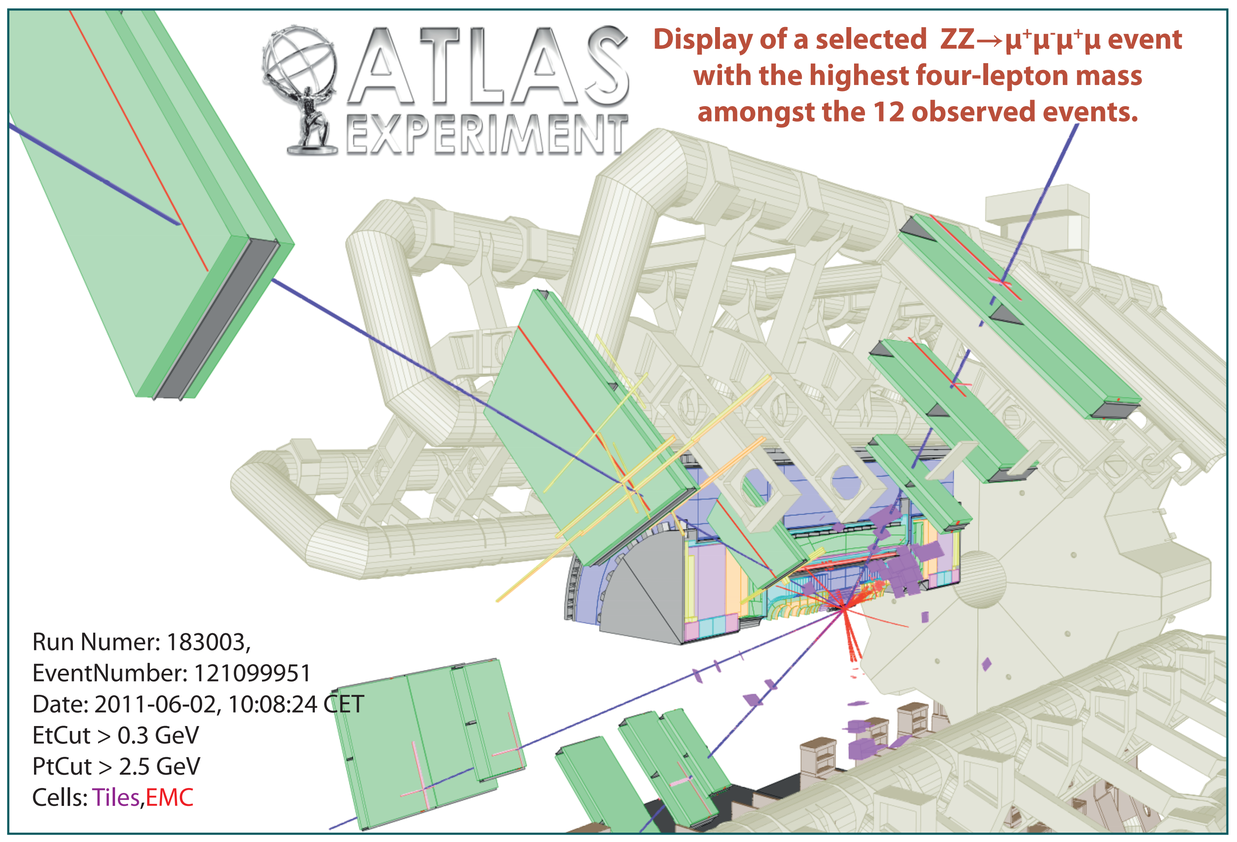
Requirements for electrons (l) and lepton-like jets (j)

• Uncertainty on f is larger of statistical error and difference from value measured in MC

• The control sample with one (two) lepton-like-jets is scaled by f (f^2) to obtain the background contribution.

• To avoid double counting in the background estimate, and to take into account the expected Z contribution in the control region, N(ZZ), the total predicted background is calculated using:

$$N(BG) = N(lllj) \times f - N(lljj) \times f^2 - N(ZZ)$$



Display of a selected $ZZ \rightarrow \mu^+\mu^-\mu^+\mu$ event with the highest four-lepton mass amongst the 12 observed events.

References

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[2] ATLAS Collaboration, G. Aad et al., The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003.

[3] J. Campbell, K. Ellis, and C. Williams, Vector Boson Pair Production at the LHC, FERMILAB-PUB-11-182-T (2011), arXiv:1105.0020v1[hep-ph]

[4] U. Baur and D. L. Rainwater, Probing neutral gauge boson selfinteractions in ZZ production at hadron colliders, Phys. Rev. D62 (2000) 113011, arXiv:hep-ph/0008063

[5] ATLAS Collaboration, G. Aad et al., Search for New Phenomena in Events with Four Charged Leptons, ATLAS-CONF-2011-144