Measurement of the ZZ Production Cross Section in pp Collisions at $\sqrt{s} = 13$ TeV with the CMS Detector

Nate Woods
University of Wisconsin—Madison

Abstract

The ZZ production cross section is measured in proton-proton collisions at $\sqrt{s} = 13\ \mathrm{TeV}$ with the CMS detector at the LHC. A data sample corresponding to an integrated luminosity of 1.34 fb^{-1} is used. The cross section $\sigma(\mathrm{pp} \to \mathrm{ZZ})$ is inferred from the yield measured in the leptonic decay modes $\mathrm{ZZ} \to \ell\ell\ell'\ell'$, where $\ell, \ell' = \mathrm{e}, \mu$. The measured cross section $\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 16.7^{+2.9}_{-2.6}\,(\mathrm{stat})^{+0.7}_{-0.5}\,(\mathrm{syst}) \pm 0.3\,(\mathrm{theo}) \pm 0.8\,(\mathrm{lum})$ pb, for both Z bosons produced in the mass region $60 < m_{\mathrm{Z}} < 120\ \mathrm{GeV}$, is consistent with standard model predictions.

Introduction

Multiboson production of massive vector bosons: ZZ

- Precision test of the electroweak gauge structure of Standard Model
- Small cross section, but clean $\mathrm{ZZ} \to 2\ell 2\ell'$ ($\ell, \ell' = \mathrm{e}, \mu$) signal visible in small data set
- Resonant Z and Higgs boson production
- Nonresonant ZZ production
  - Primary irreducible background to Higgs measurements
- Potential early sign of new physics
  - Anomalous triple and quartic gauge couplings
  - Resonant production of new particles decaying to ZZ

Data and Monte Carlo Samples

Data Sample

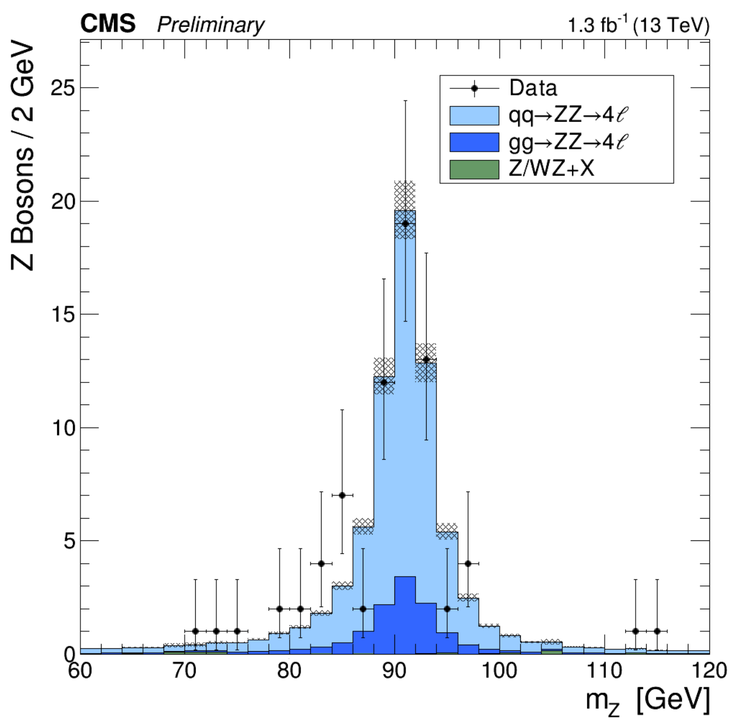
- Sample of $\sqrt{s} = 13\ \mathrm{TeV}$ proton-proton collisions collected by CMS during 2015 LHC run
- Integrated luminosity of the sample is $1.34 \pm 0.06\ \mathrm{fb}^{-1}$

Simulated Samples

- $\mathrm{q\bar{q}} \to \mathrm{ZZ}$ signal samples generated with POWHEG 2.0
  - Generated at next-to-leading order (NLO)
  - Scaled to next-to-next-to-leading order (NNLO) cross section
- $\mathrm{gg} \to \mathrm{ZZ}$ signal samples generated with MCFM
  - Generated at leading order (LO)
  - Scaled to next-to-leading order (NLO) cross section
- PYTHIA package used for parton showering, hadronization, and underlying event simulation.
- Detector response simulated with GEANT4.

Event Selection

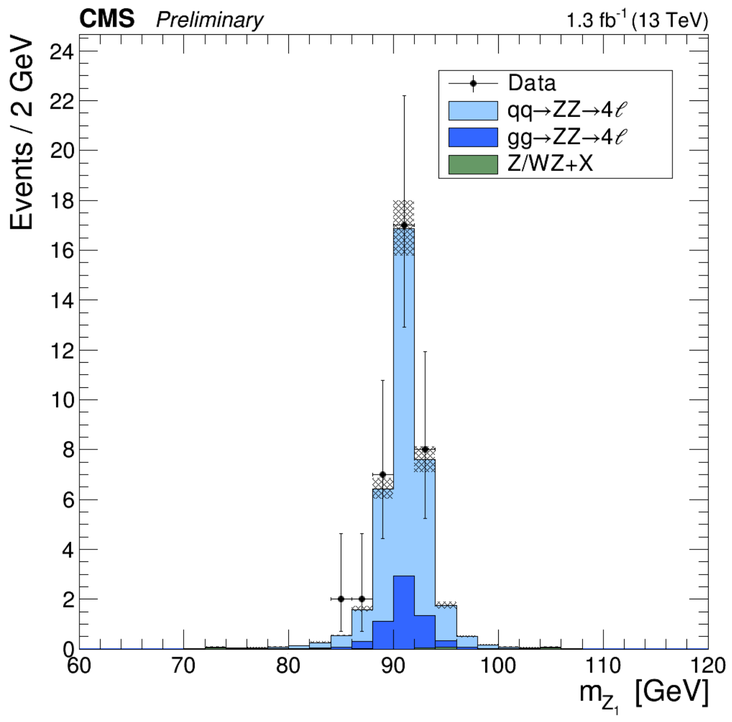
- Events must pass an isolated di-lepton trigger, a triple-lepton trigger, or a single-electron trigger
- Z boson candidates Z_1 and Z_2 formed from pairs of opposite-sign, same-flavor electrons or muons
  - All leptons $p_{\mathrm{T}} > 10$ GeV
  - Leptons must pass identification and isolation criteria
  - $60 < m_{\mathrm{Z}_1,\mathrm{Z}_2} < 120$ GeV
- One lepton with $p_{\mathrm{T}} > 20$ GeV
- All opposite-sign lepton pairs $m_{\ell\ell'} > 4$ GeV



Distribution of the reconstructed Z mass, summed for all decay channels.

Background Estimation

- Major background contributions arise from WZ+jets, Z+jets, and $\mathrm{t\bar{t}}$ events
  - One or more particles from jets misidentified as signal leptons.
  - Difficult to model accurately; contribution estimated from data
- Probability for non-signal particle to pass all selections ("fake rate") found in $\mathrm{Z} + \ell_{\mathrm{loose}}$ control sample
  - Z leptons pass all signal selection requirements
  - ℓ_{loose} passes loosened identification requirements, with no isolation requirement
  - Contamination from WZ removed by requiring low missing transverse energy
- Background yield in signal region extrapolated from two $\mathrm{Z} + \ell'\ell'$ control regions
  - **3 prompt 1 fake:** one ℓ' fails tight identification or isolation
  - **2 prompt 2 fake:** both do
- Fake rates used to reweight each control region to its corresponding contribution to the selected signal



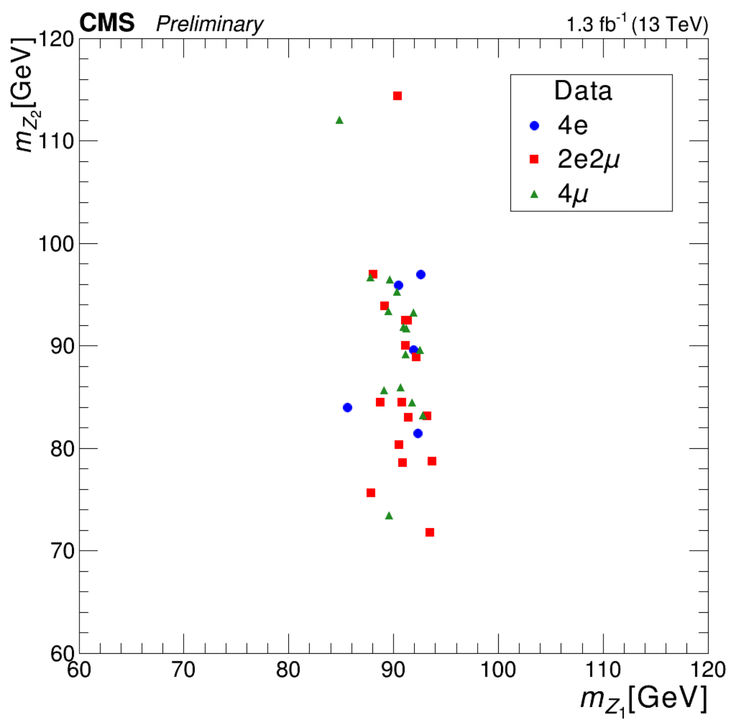
Distribution of the reconstructed mass of Z_1, i.e. the dilepton pair in each event with mass closest to the nominal m_{Z}.

Systematic Uncertainties

Uncertainty on Signal Yield	Uncertainty
LHC integrated Luminosity	4.6%
Trigger efficiency	2%
Lepton identification	1–2%
Lepton isolation	2%
Signal acceptance, pdf, and scale	1%

Experimental systematic uncertainty sources.

Uncertainty on background yield taken to be 40%, due to uncertainties on fake rate and background composition.



Reconstructed mass of Z_2 plotted against the reconstructed mass of Z_1 in data events. In each event, Z_1 is the dilepton pair reconstructed with mass closer to nominal m_{Z}.

ZZ Cross Section Measurement

$\mathrm{pp} \to \mathrm{ZZ} \to 2\ell 2\ell'$ cross section calculated from simultaneous fit of observed yields in each channel

Decay channel	N^{exp}_{ZZ}	Background	Total expected	Observed
4μ	$10.53 \pm 0.08 \pm 0.31$	$0.04 \pm 0.09 \pm 0.02$	$10.57 \pm 0.12 \pm 0.31$	15
$2\mathrm{e}2\mu$	$17.83 \pm 0.10 \pm 0.48$	$0 \pm 0.11 \pm 0.10$	$17.83 \pm 0.15 \pm 0.48$	16
4e	$7.81 \pm 0.07 \pm 0.20$	$0.09 \pm 0.12 \pm 0.04$	$7.90 \pm 0.14 \pm 0.21$	5
Total	$36.18 \pm 0.15 \pm 0.61$	$0.10 \pm 0.19 \pm 0.11$	$36.28 \pm 0.24 \pm 0.61$	36

The observed and expected yield of ZZ events, and estimated yield of background events evaluated from data are shown for each decay channel and are summed in the total expected yield ("Total"). The first uncertainty is statistical, the second systematic.

Fiducial definition

- One lepton with $p_{\mathrm{T}} > 20$ GeV
- Other leptons with $p_{\mathrm{T}} > 10$ GeV
- All leptons with $|\eta| < 2.5$
- Both Z bosons with $60 < m_{\mathrm{Z}_1,\mathrm{Z}_2} < 120$ GeV
- All opposite-sign lepton pairs with $m_{\ell\ell'} > 4$ GeV regardless of flavor

Measured fiducial cross section

$$\sigma_{\mathrm{fid}}(\mathrm{pp} \to \mathrm{ZZ} \to 4\ell) = 38.0^{+6.7}_{-6.0}\,(\mathrm{stat}) \; ^{+1.5}_{-1.2}\,(\mathrm{syst}) \pm 1.7\,(\mathrm{lum})\ \mathrm{fb} \quad (1)$$

Total ZZ cross section is found by correcting for detector acceptance and efficiency of reconstruction and selection, and $\mathrm{Z} \to \ell\ell$ branching ratio.

Measured total cross section

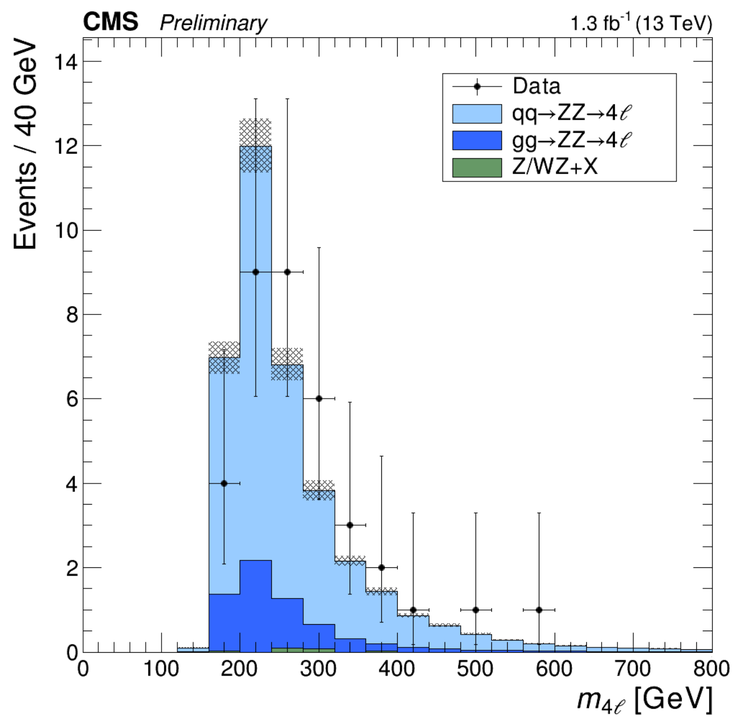
$$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 16.7^{+2.9}_{-2.6}\,(\mathrm{stat})^{+0.7}_{-0.5}\,(\mathrm{syst}) \pm 0.3\,(\mathrm{theo}) \pm 0.8\,(\mathrm{lum})\ \mathrm{pb}. \quad (2)$$

for both Z bosons with mass 60–120 GeV.

Theoretical predictions

Total cross sections can be compared to predictions from theory

- $16.5^{+0.7}_{-0.5}$ pb
  - NNLO
  - Dynamic scales $\mu_R = \mu_F = m_{\mathrm{Z}}/2$
- $15.4^{+0.5}_{-0.4}$ pb
  - Calculated with MCFM
  - Fixed scales $\mu_R = \mu_F = m_{\mathrm{Z}}$



Distribution of the reconstructed mass of the 4ℓ system, summed for all decay channels.

Bibliography

Measurement of the ZZ production cross section in $\ell\ell\ell'\ell'$ decays in pp collisions at $\sqrt{s} = 13\ \mathrm{TeV}$,
CMS Collaboration,
CMS-PAS-SMP-15-005,
http://cds.cern.ch/record/2114822