PROCEEDINGS OF SCIENCE

Measurement of the Z boson production in association with at least two b jets in pp collisions at $\sqrt{s}$ = 13 TeV

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The cross sections for Z boson production in association with at least two b jets are measured as a function of various kinematic variables, using pp collisions at $\sqrt{s}$ = 13 TeV recorded by the CMS experiment, corresponding to an integrated luminosity of 137 fb^{-1}. Decays of the Z boson to electrons or muons are considered with leading (sub-leading) lepton transverse momentum $p_{\mathrm{T}} >$ 35 (25) GeV and pseudorapidity $|\eta| < 2.4$, and the invariant mass within 71 and 111 GeV. Jets are selected with $p_{\mathrm{T}} > 30$ GeV and $|\eta| < 2.4$. The results are compared to various QCD calculations.

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1. Introduction

Studies of Z boson production in association with jets from b quarks provide important tests of perturbative quantum chromodynamics. These processes are also important since they are major backgrounds for many physics processes, including the Higgs boson production in association with a Z boson, ZH ($H \to b\bar{b}, c\bar{c}$) and searches for new physics phenomena. Figure 1 shows the tree level diagrams of the Z+2b process.

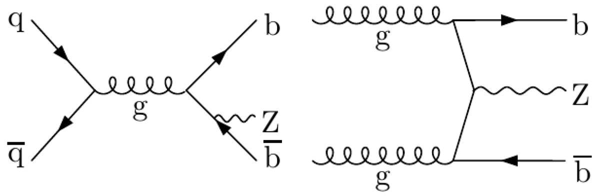

Figure 1: Examples of Feynman diagrams of Z+2b production.

2. Overview of measurements

The cross section is measured in the leptonic decay channel of Z bosons ($Z \to ee$, $Z \to \mu\mu$) using pp collision data at $\sqrt{s}$ = 13 TeV [1] collected by the CMS experiment [2] during the 2016 (35.9 fb^{-1}), 2017 (41.5 fb^{-1}), and 2018 (59.7 fb^{-1}) data-taking periods, corresponding to an integrated luminosity of 137 fb^{-1}.

The collision events are required to pass single lepton triggers. They must have at least one electron (muon) candidate with the minimum transverse momentum p_T of 27, 32, and 32 GeV (24, 27, and 24 GeV) during 2016, 2017, and 2018 data-taking periods.

Several Monte Carlo (MC) event generators are used to simulate signal process. The Drell–Yan (DY) process is simulated by MADGRAPH5_aMC@NLO (denoted as MG5_aMC) [3] calculated at next-to-leading order (NLO). The second sample is simulated by MG5_aMC calculated at leading order (LO), and the third one is simulated by SHERPA [4]. The MG5_aMC predictions are with different PDF settings and underlying event tune corresponding to 2016 and 2017–2018 data-taking periods. The 2016 setting uses NNPDF 3.0 PDF set [5] and tune CUETP8M1 [6], while the 2017–2018 setting uses NNPDF 3.1 PDF set [5] and tune CP5 [7]. Background contributions are from top quark-antiquark ($t\bar{t}$), single top quark (s- and, t-channel, and tW), and diboson (WW, WZ, ZZ) processes.

Electrons and muon are required to be isolated and selected with the kinematic criteria: leading (sub-leading) lepton transverse momentum $p_T > 35$ (25) GeV and pseudorapidity $|\eta| < 2.4$. In the muon channel, Rochester correction [8] is applied to MC samples and data to mitigate the biases occurred during muon p_T reconstruction. The correction is done by applying the Rochester correction scale factor to the muon p_T.

Z boson candidates are reconstructed from two isolated, oppositely charged leptons, selected as described before. Afterwards, Z boson candidates are selected with the dilepton invariant mass range $71 < M_{ll} < 111$ GeV.

Jets are reconstructed using the anti-k_T clustering algorithm [9] with a distance parameter of 0.4. Jets are required to have $p_T > 30$ GeV and $|\eta| < 2.4$. If jets overlap with $p_T > 25$ GeV leptons in a cone, $\Delta R < 0.4$, they are discarded. Jets from pileup events are excluded.

Missing transverse energy (E_T^{miss}) is used in this analysis to reduce the $t\bar{t}$ background by requiring $E_T^{miss} > 50$ GeV. $\vec{E}_T^{miss}$ is defined as the vector sum of the transverse momentum of all observables reconstructed in the event, $\vec{E}_T^{miss} = -\sum \vec{p}_T, i$.

The deep combined secondary vertex (DeepCSV) [10] algorithm is used in this analysis to identify b jets from light or c jets. Tight tagging requirement (50% b quark tagging efficiency with 0.1% misidentification rate for jets originating from gluons or u, d, s quarks) is applied to reduce DY+X backgrounds, where X = light or c jets. b jets are tagged based on unique properties of B hadrons inside the jets, such as relatively long lifetime, which causes the secondary vertex displaced from the primary vertex, and the relatively large B hadron invariant mass.

3. Results

The inclusive cross section for Z + ≥ 2 b jets for the combination of channels are listed in Table 1. The measured integrated cross section is 0.65 ± 0.03 (stat) ± 0.07 (syst) ± 0.02 (theo) pb. The measured cross section is compared with several predictions: MG5_aMC calculated at NLO, MG5_aMC calculated at LO and SHERPA. The measured integrated cross section is in good agreement with MG5_aMC at LO prediction, while MG5_aMC at NLO and SHERPA predictions overestimate the measured cross section value.

Measured	0.65 ± 0.03 (stat) ± 0.07 (syst) ± 0.02 (theo)
MG5_aMC (LO) (NNPDF 3.1, CP5)	0.71
MG5_aMC (LO) (NNPDF 3.0, CUETP8M1)	0.63
MG5_aMC (NLO) (NNPDF 3.1, CP5)	0.77 ± 0.07
MG5_aMC (NLO) (NNPDF 3.0, CUETP8M1)	0.90 ± 0.09
SHERPA	0.84

Table 1: Measured and predicted integrated cross sections (in pb) for Z + ≥ 2 b jets final states.

The observed distributions at reconstruction-level are unfolded to particle-level by applying corrections for detector effects represented by a response matrix. The response matrix is constructed from reconstruction-level leptons and b jet objects which are spatially matched to the corresponding particle-level objects within $\Delta R < 0.3$.

The unfolded differential cross section distributions as functions of leading b jet p_T, angular separation of two b jets (ΔR_{bb}), and the invariant mass of the two b jets (m_{bb}) are shown in Fig. 2. From the leading b jet p_T distribution in Fig. 2, we can see that MG5_aMC at LO predictions are in good agreement with data, while MG5_aMC at NLO and SHERPA predictions overestimate the data from 20%–50%. In the ΔR_{bb} distribution in Fig. 2, MG5_aMC at NLO and SHERPA predictions overestimate the data at high ΔR_{bb} region, while MG5_aMC at LO predictions have the opposite trend. For the m_{bb} distribution in Fig. 2, none of the predictions agrees with data.

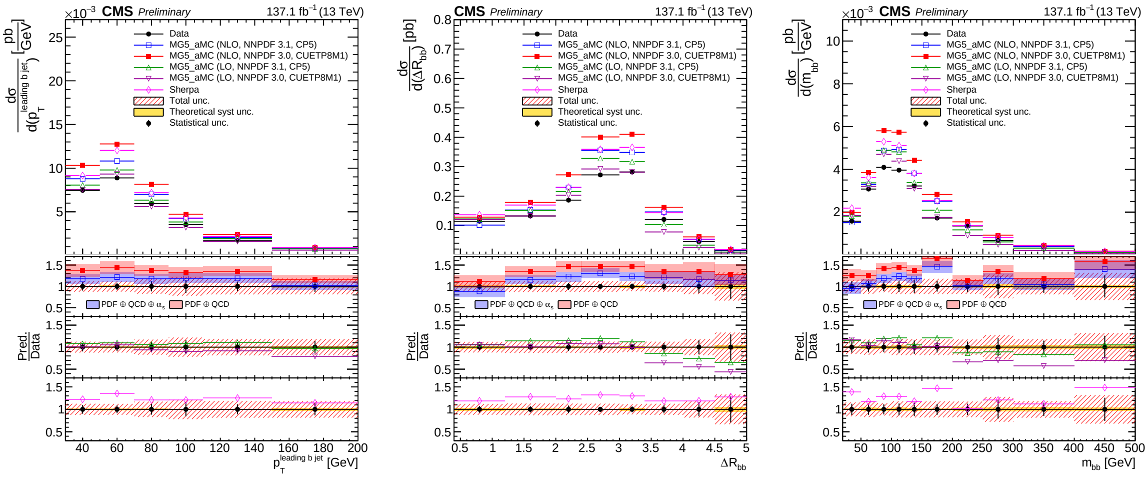

Figure 2: Differential cross section distribution as functions of the leading b jet p_T (left), ΔR_{bb} (middle), and m_{bb} (right). The lower panels show the ratio of each MC prediction and data.

4. Summary

We measured the integrated cross section for Z + ≥ 2 b jets production, and predictions of three different MC simulations (MG5_aMC at LO, MG5_aMC at NLO, SHERPA) have been used to compare with data. The MG5_aMC at LO prediction gives a good description of the measured integrated cross section. For the differential cross sections, the shapes in the data are well described by the predictions from MG5_aMC at NLO and SHERPA.

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