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Measurement of the production cross sections of a Z boson in association with b jets in pp collisions at $\sqrt{s} = 7$ TeV with the CMS detector

Adrien Caudron* **on behalf of CMS collaboration**
CP3 - Université catholique de Louvain
E-mail: adrien.caudron@cern.ch

The production of a Z boson, decaying into two leptons and produced in association with one or more b jets, is studied using proton-proton collisions delivered by the LHC at a centre-of-mass energy of 7 TeV and recorded by the CMS detector, with a data sample collected in 2011 and corresponding to an integrated luminosity of 5 fb^{-1}[1]. Cross sections for the Z(ll)+b-jets process (where $ll = ee$ or $\mu\mu$) are measured for Z bosons produced in association with exactly one or at least two b jets. The cross section ratio for a Z boson produced with any number of b-jets relative to a Z boson produced with any number of jets is also measured. These cross sections are compared with different predictions. Kinematic properties of the reconstructed particles are compared with the predictions from the MADGRAPH 5.1.1.0 event generator, interfaced with PYTHIA 6.424 parton shower simulation.

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*Speaker.

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Jets originating from bottom quarks (b jets) and Z bosons are produced copiously in proton-proton collisions at the Large Hadron Collider (LHC). The study of the production of a Z boson in association with at least two b jets, Z+2b-jets production, is of interest since it is a background in many searches for yet unobserved processes, such as the production of heavier supersymmetry-like Higgs bosons via vector boson fusion, and in studies of the Higgs boson, produced in association with a Z boson and decaying to b quarks. The production of a Z boson in association with a single b jet, Z+1b-jet production, is also of interest for precision tests of perturbative QCD.

The data used in this analysis were collected using the CMS detector [2] in 2011 for proton-proton collisions at a centre-of-mass energy of 7 TeV. They correspond to an integrated luminosity of $\mathscr{L} = 5.05 \pm 0.11$ fb^{-1}.

Events containing opposite charged leptons (e^+e^- or $\mu^+\mu^-$) with $p_T > 20$ GeV and $|\eta| < 2.4$ are selected. To suppress the $t\bar{t}$ background, the dilepton invariant mass is required to be in the range 76 < M(ll) < 106 GeV. Anti-k_T jets, with radius size of 0.5, are considered with $p_T > 25$ GeV and $|\eta| < 2.1$. In addition, separation between the leptons and the jets of $\Delta R(l, j) > 0.5$ is requested. Jets originating from b quarks are tagged by taking advantage of the long b-hadron lifetime. The SSV b-tagging algorithm, used in this analysis, employs the three-dimensional flight distance significance between the primary vertex and a secondary vertex in a jet. The discriminant value to define b-tagged jets is chosen such that the fraction of tagging a light quark (mistagging fraction) is below 1%, with a b-tag efficiency of $\sim 55\%$. To further suppress the $t\bar{t}$ background for the Z+2b-jets sample only, a veto is applied on the significance of the missing transverse energy (E^T_{MISS} significance < 10). The E^T_{MISS} significance offers an event-by-event assessment of the likelihood that the observed E^T_{MISS} is consistent with zero given the reconstructed content of the event and known measurement resolutions of the CMS detector.

The main backgrouds are expected to originate from $t\bar{t}$, Z+jets and ZZ production. The fraction of $t\bar{t}$ is estimated from a fit to $M_{\ell\ell}$ in the wide mass window ($61 < M_{\ell\ell} < 121$ GeV) and it is then interpolated to the signal mass window ($76 < M_{\ell\ell} < 106$ GeV). The background due to mistagging c and light jets is estimated from the distribution of the mass of the secondary vertices (M_{SV}) of the b-tagged jets in the events. The expected ZZ yield is estimated from MC simulations, using the cross section and uncertainty from the CMS measurement for the normalisation.

In order to extract a cross section at the particle level, the background-subtracted yields for the Z+1b-jet and the Z+2b-jets are corrected for the efficiencies of the selection of the dilepton pair and the b-tagged jets, as well as for the detector resolution effects:

$$\begin{pmatrix} \sigma(\text{Z+1b}) \\ \sigma(\text{Z+2b}) \end{pmatrix} = \frac{1}{\mathscr{L}} \times \mathscr{E}_{\text{r}}^{-1} \times \mathscr{E}_{\text{l}}^{-1} \times \mathscr{E}_{\text{b}}^{-1} \times \mathscr{E}_{\text{m}}^{-1} \times \begin{pmatrix} N_{\text{sig}}^{\text{Z+1b}} \\ N_{\text{sig}}^{\text{Z+2b}} \end{pmatrix}. \tag{1}$$

The main systematic uncertainties come from the uncertainties on the estimatation of the background contamination, from the b-tagging and mis-tagging efficiencies uncertainties and from the Jet Energy Scale uncertainty.

Different kniematic variables relevant in the Z+2b-jets final state have been studied as the transverse momentum of the dilepton (p_T^Z) and dijet (p_T^{bb}) pairs. As example, the p_T^Z distribution

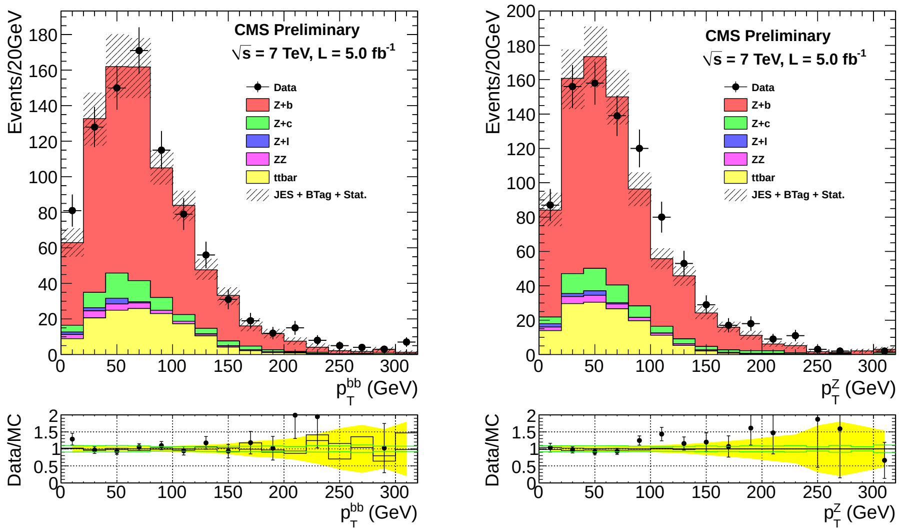

Figure 1: Kinematic observables of the combined electron and muon samples. Left: the p_T distribution of the dijet pair after the Z+2b-jets selection. Right: the p_T distribution of the dilepton pair after the Z+2b-jets selection. Uncertainties on the expectations are shown as a hatched band. In the data/MC ratio, the yellow band represents the statistical uncertainty on the simulated yield, and the lines indicate the uncertainties related to the jet energy scale (black) and the b-tagging scale factors (green).

shows a harder spectrum in data than expected from simulations, as shown in Fig. 1. A harder spectrum of the p_T^Z observable is expected in four-flavour calculations with massive b quarks as well as at NLO.

The final cross sections are shown in Table 1. They are compared with the expectation from MADGRAPH in both the five-flavour (5F) and the four-flavour (4F) schemes, using a global K-factor to correct the inclusive Drell-Yan cross section to the NNLO precision. The comparisons show that the measured cross sections are compatible with the theoretical expectations.

Table 1: Cross sections at the particle level for the production of a Z boson in association with exactly one b jet and at least two b jets, the combination of the two (at least one b jet), and the ratio, showing the statistical and systematic uncertainties. The expectation from MADGRAPH includes the statistical uncertainty.

Multiplicity bin	Measured	MADGRAPH 5F	MADGRAPH 4F
σ(Z($\ell\ell$)+1b) (pb)	$3.52 \pm 0.02 \pm 0.20$	3.66 ± 0.02	3.11 ± 0.03
σ(Z($\ell\ell$)+2b) (pb)	$0.36 \pm 0.01 \pm 0.07$	0.37 ± 0.01	0.38 ± 0.01
σ(Z($\ell\ell$)+b) (pb)	$3.88 \pm 0.02 \pm 0.22$	4.03 ± 0.02	3.49 ± 0.03
σ(Z($\ell\ell$)+b)/σ(Z($\ell\ell$)+j) (%)	$5.15 \pm 0.03 \pm 0.25$	5.35 ± 0.02	4.60 ± 0.03

References

[1] CMS Collaboration, “Measurement of the Z/gamma* + bb-jets cross section in pp collisions at $\sqrt{s} = 7$ TeV”, *CMS Physics Analysis Summary* **SMP-13-004** (2013).

[2] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 3:S08004,2008