The Compact Muon Solenoid Experiment

Conference Report

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Inclusive $b + Z$, $Z \rightarrow \mu^+ \mu^-, e^+ e^-$ production at CMS

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Abstract

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Abstract. The production of Z bosons in association with at least one b-jet and Z decaying into muons or electrons is studied. This analysis is done by using proton-proton collisions delivered by the Large Hadron Collider (LHC) at a centre of mass energy of 7 TeV and with data recorded by the CMS detector (CMS) in 2010, representing an integrated luminosity of 36 pb^{-1} . We require a final state of two well identified muons or electrons and at least one b-tagged jet in order to perform this study. The event yields and shapes of kinematic variables are compared with Monte Carlo predictions from MADGRAPH. The ratio $\sigma(Z+b)/\sigma(Z+j)$ is found to be 0.054 ± 0.016 (0.046 ± 0.014) in the data for the $Z \rightarrow ee$ ($Z \rightarrow \mu\mu$) selection, compared to 0.043 ± 0.005 (0.047 ± 0.005) estimated from NLO theory predictions.

1. Introduction

The production mechanism of Z in association with b-quarks at the LHC is not yet well understood. A first test consists in the measure of the corresponding cross-section in order to constraints the existing QCD predictions. In addition to this Standard-Model motivation, this process is a large background for many searches related to Higgs sectors and predictions beyond the Standard Model.

of top pairs. The production of Z to ee and $\mu\mu$ in association with jets from any flavour is referred as Z+j. All Monte Carlo samples used, have been generated with MADGRAPH[2] interfaced with PYTHIA 6.4[3], reconstructed through a full simulation of the CMS detector[4] based on GEANT4[5], including tune Z2 and a pile-up scenario comparable to the data. All Monte Carlo samples are normalised to the total data integrated luminosity using the NNLO cross-sections[6, 7].

2. Data and Monte Carlo samples

The total integrated luminosity analysed is $35.9 \pm 4 \text{ pb}^{-1}$ [1]. Events are triggered using the loosest unrescaled single lepton trigger and the most recent alignment and energy calibration. The main backgrounds considered are the associated production of Z with charm jets (Z+c), Z with light jets (Z+l) where $l=u,d,s,g$ and the production

3. Event Selection

In order for the two leptons to be selected as candidates, they should have opposite charges. Furthermore, both electrons are required to be reconstructed with $p_T > 25 \text{ GeV/c}$ and in the detector range of $\eta < 2.5$. For the muon pair these requirements differ with $p_T > 20 \text{ GeV/c}$ and $\eta < 2.1$ [8]. Identification and isolation criteria for the lep-

tons are also applied to ensure background rejection and good signal efficiency. Lepton isolation is defined using the sum of energy around the lepton in a cone size of $\Delta R < 0.3$ in the tracker, ECAL and HCAL detectors divided by the lepton p_T . For muons this variable is required to be less than 0.15 while for the electrons cuts are applied on the individual isolation variables divided by the electron p_T . Electron identification and isolation criteria are chosen such that the rejection efficiency is 85%.

Jets are reconstructed using the Particle Flow (PF) algorithm[9]. Particles are clustered into jets using the anti- k_T algorithm[10]. Jets are required to have $p_T > 25$ GeV/c and to be separated from the selected lepton pair by at least $\Delta R = 0.5$. In addition, jets should be within the detector acceptance of $|\eta| < 2.1$ and fulfill loose jet identification criteria[11].

Identification of b-jets is done by exploiting b-hadron's long lifetime. The Simple Secondary Vertex (SSV) algorithm discriminator [12] is computed from the three dimensional flight distance significance. For the high-efficiency label (HE), at least two tracks are required to be attached to the secondary vertex while for the high-purity (HP) one at least three tracks.

Finally, for further reduction of the $t\bar{t}$ +jets contribution, we require that the invariant mass of the lepton pair is in the range of 60 to 120 GeV/c² and the transverse missing energy less than 40 GeV/c.

4. Results

After applying all the cuts, a good agreement between data and MC is observed in both high-efficiency and high-purity selections, within 2σ at most of the expected statistical uncertainties on the data and without any rescaling of the MC to match the data. The event yields are summarized in Table 1. The shapes of kinematic variables shown in Fig.1, 2 show good agreement between data and Monte Carlo predictions from MADGRAPH.

Selection	Data	$t\bar{t}$	Z+l	Z+c	Z+b
HE $e\bar{e}b$	54 ± 7	2.0 ± 0.1	13.4 ± 0.5	14.5 ± 0.7	35.5 ± 1.1
HP $e\bar{e}b$	29 ± 5	1.60 ± 0.09	0.8 ± 0.1	5.3 ± 0.4	25.1 ± 0.9
HE $\mu\bar{\mu}b$	91 ± 10	3.0 ± 0.1	18.5 ± 0.6	20.3 ± 0.9	54.4 ± 1.4
HP $\mu\bar{\mu}b$	36 ± 6	2.4 ± 0.1	1.3 ± 0.2	7.2 ± 0.5	37.5 ± 1.2

Table 1. Number of events selected in data and MC samples, and purity and significance in Z+b expected from MC. Only statistical uncertainties are shown. No data/MC scaling factor is applied on the MC

Figure 1. Invariant mass for the high-efficiency (left) and high-purity (right) selections

Figure 2. Leading b-jet p_T (left) and $\Delta\Phi$ between the lepton pair and the leading b-jet (right) after the high-purity selection

Using the results above, an important quantity for the treatment of heavy flavours in matrix element calculations and test of b-quark content of PDFs can be extracted, which is the ratio $\sigma(Z + b)/\sigma(Z + j)$. We calculate $\mathcal{R}$ as:

$$\mathcal{R} = \frac{N_{Z+b}^{data} \times \mathcal{P} - N_{t\bar{t}MC}}{\varepsilon_{MC} \times N_{Z+j}^{data}}$$

where N_{Z+b}^{data} and N_{Z+j}^{data} are the number of data events remaining after the Z+b (and MET) and Z+j selections, $N_{t\bar{t}}^{MC}$ is the number of $t\bar{t}$ events expected from MC after the Z+b and MET selection. ε_{MC} contains the b-tagging and MET selection efficiency and b-jet acceptance effects. The values are found to be $0.43 \pm 0.01(stat) \pm$

0.09(*syst*) for HE and $0.30 \pm 0.01(stat) \pm 0.06(syst)$ for HP. A systematic uncertainty of 20% is assigned to these numbers, which is dominated by the uncertainty on the b-tagging efficiency (15%)[12]. The b-jet acceptance assumed here concerns the fraction of events with a real b-jet in which at least one jet lies within the acceptance cuts, but no b-jet does which was found to be about 18% in the MC Z+b sample. $\mathcal{P}$ is

Figure 3. Binned likelihood fit of the mass of the secondary vertex in data events for HP selection

the purity in b-jet which contains both Z+b and $t\bar{t}$ components. The purity is extracted by a binned likelihood fit to the mass of the secondary vertex in the data, using MC template functions for the b, c and light contributions (Fig.3). The purity in b-jets is found to be $55 \pm 9\%$ ($88 \pm 11\%$) for the HE (HP) selection, in good agreement with the MC estimate of $57 \pm 3\%$ ($82 \pm 4\%$). Results for the ratio are given in Table 2 with the NLO predictions from MCFM.

Sample	$\mathcal{R}(Z \rightarrow ee)$ (%)
Data HE	$4.3 \pm 0.6(stat) \pm 1.1(sys)$
Data HP	$5.4 \pm 1.0(stat) \pm 1.2(sys)$
MADGRAPH	$5.1 \pm 0.2(stat) \pm 0.2(sys) \pm 0.6(th)$
MCFM	$4.3 \pm 0.5(th)$
Sample	$\mathcal{R}(Z \rightarrow \mu\mu)$ (%)
Data HE	$5.1 \pm 0.6(stat) \pm 1.3(sys)$
Data HP	$4.6 \pm 0.8(stat) \pm 1.1(sys)$
MADGRAPH	$5.3 \pm 0.1(stat) \pm 0.2(sys) \pm 0.6(th)$
MCFM	$4.7 \pm 0.5(th)$

Table 2. Extracted ratio $\mathcal{R}$ from data, NLO theory (MCFM) and MADGRAPH+PYTHIA samples

5. Conclusions

First observation of Z+b events is made at $\sqrt{s} = 7$ TeV using 36 pb^{-1} of CMS data.

The ratio $\sigma(Z + b)/\sigma(Z + j)$ is found to be 0.054 ± 0.016 in the data for the Z $\rightarrow ee$ and 0.046 ± 0.014 for the Z $\rightarrow \mu\mu$ selection. The estimation from NLO theory predictions is 0.043 ± 0.005 (0.047 ± 0.005) using the same kinematic selections on the leptons and jets as the selections applied to the data.

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