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Studies of W and Z Bosons with the CMS Detector at the CERN LHC

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Abstract

We present the preparatory work on the measurement of the W and Z production cross section and the use of the Z sample as a ”candle” for physics and detector commissioning with the first LHC data. The studies target the early understanding of the W and Z production at the LHC. They provide handles for data-driven extraction of Standard Model backgrounds to New Physics Searches, a direct probe of New Physics, and a benchmark for testing relevant QCD calculations.

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Studies of W and Z Bosons with the CMS Detector at the CERN LHC

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Abstract. Events containing leptonically decaying W and Z bosons provide clean samples that are important for physics and detector commissioning with the first 10 to 100 pb^{-1} of LHC data.

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INCLUSIVE W UND Z PRODUCTION

Due to high cross sections and clean final states with muons and electrons, the inclusive production of W and Z events can already be studied with the first 10 pb^{-1} of data collected with the CMS detector [1]. Basic lepton identification criteria are applied to select samples with high purity. The left-hand plot in Fig. 1 shows the almost background-free invariant mass distribution of two isolated, oppositely charged muons with $p_T > 20$ GeV in $|\eta| < 2$ ($\sqrt{s} = 10$ TeV) [2]. The cross section can be measured with an accuracy of 2 % (statistical uncertainty) with a luminosity of 5 pb^{-1}. The plot in the middle displays the transverse mass[1] distribution for $W \rightarrow \mu\nu$ candidate events containing one isolated muon ($p_T > 25$ GeV, $|\eta| < 2$; $\sqrt{s} = 10$ TeV). The neutrino can not be observed directly, but contributes to missing energy in the transverse plane. The plot on the right-hand side in Fig. 1 shows the distribution of the missing transverse energy in $W \rightarrow e\nu$ candidate events where the electron ($E_T > 20$ GeV, $|\eta| < 2.5$) passes tight electron identification criteria ($\sqrt{s} = 14$ TeV) [3].

DATA-DRIVEN BACKGROUND ESTIMATION METHODS

Muons and electrons from Z decays provide a suitable sample to derive efficiencies using the *tag and probe* method [3, 4]. Here, tight identification cuts are applied to one object (tag), whereas the efficiency is determined using the other object (probe). The plot on the left-hand side in Fig. 2 shows the trigger efficiency for muons estimated with the tag and probe method using 10 pb^{-1}, compared to the efficiency extracted from Monte Carlo generator information.

Misalignment and miscalibration can introduce a bias in the reconstructed Z mass, see right-hand plot in Fig. 2 [4]. On the other hand, this distribution can be used to derive

[1] $M_T = \sqrt{p_T^{\ell} E_T^{\text{miss}} (1 - \cos\Delta\phi(\ell, E_T^{\text{miss}}))}$

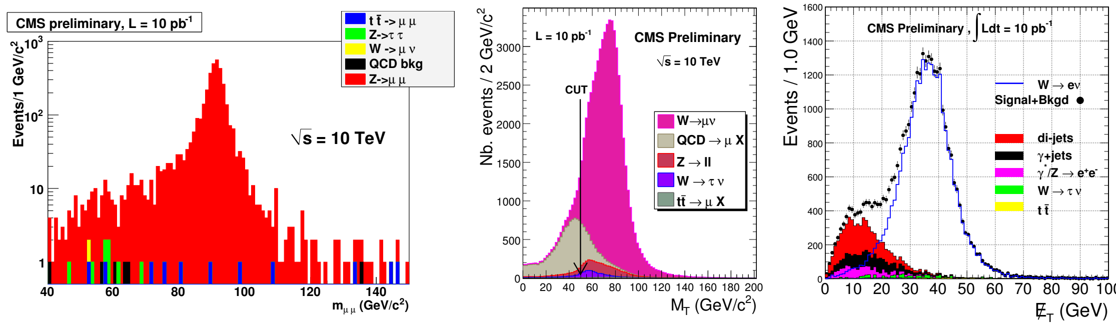

FIGURE 1. Left: Invariant mass distribution of selected $Z \to \mu\mu$ candidate events. Middle: Transverse mass distribution of selected $W \to \mu\nu$ candidate events. Right: Distribution of the missing transverse energy in $W \to e\nu$ candidate events applying a tight electron identification.

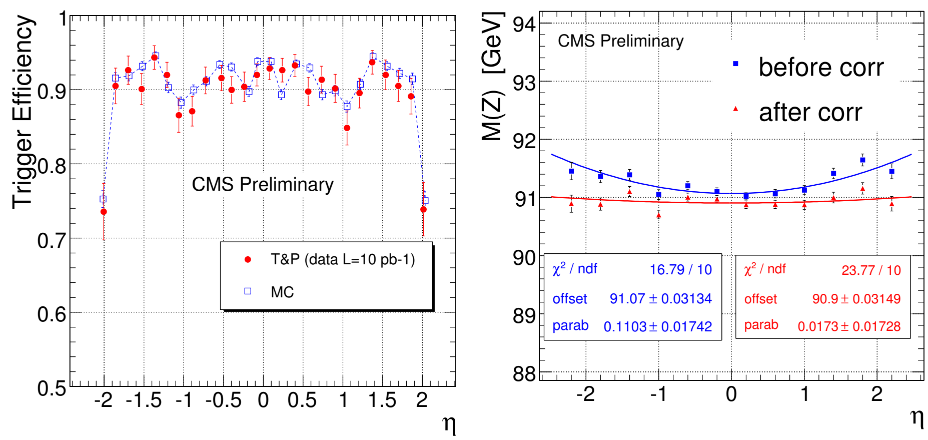

FIGURE 2. Left: Muon trigger efficiency from the tag and probe method compared to Monte Carlo generator information. Right: Bias of misalignment and miscalibration on the reconstructed Z mass before and after applying corrections.

correction functions for the muon momentum scale and thus improve the systematic uncertainty on the cross section measurement.

Since the backgrounds from QCD processes are hard to estimate and control from simulation, they are determined from data using *cut inversion* [3] or the *matrix method* [4]. In the $W \to e\nu$ analysis the QCD contribution is estimated by inverting the electron isolation requirement. The left-hand plot in Fig. 3 shows that the distribution of the missing transverse energy in QCD events does not depend on the isolation of the electron candidate thus validating the method. In the $W \to \mu\nu$ analysis the matrix method is applied which makes use of two largely uncorrelated variables (muon isolation and transverse mass) in order to predict the QCD contribution.

Since the missing transverse energy E_T^{miss} is sensitive to any kind of activity in the detector (e. g. noise), it is difficult to model E_T^{miss} in early data. Because of this, the *template method* is used to predict E_T^{miss} in the $W \to e\nu$ analysis [3]. To obtain the template $Z \to ee$ candidate events are selected. Then, one of the two electrons is removed

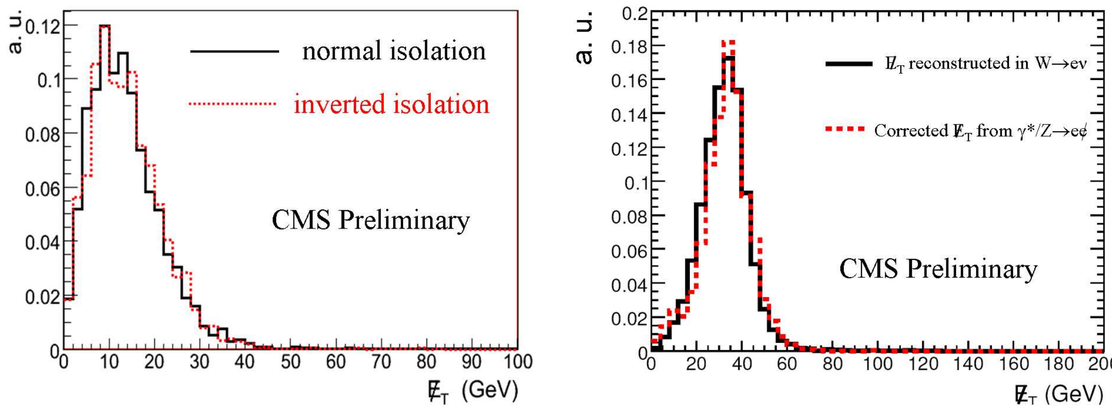

FIGURE 3. Left: Missing transverse energy distribution for isolated and non-isolated electrons in QCD events. Right: Comparison between true and estimated missing transverse energy from $Z \to ee$ events using the template method.

from the event and the E_T^{miss} is recalculated. The difference in kinematics between W and Z events is taken into account. The plot on the right-hand side in Fig. 3 shows the true E_T^{miss} distribution in $W \to e\nu$ events compared to the recalculated and corrected E_T^{miss} template from $Z \to ee$ events.

MEASUREMENT OF THE $Z + b\bar{b}$ CROSS SECTION

W+jets and Z+jets are important processes for testing QCD calculations and deriving the jet energy scale. Further, these processes are backgrounds to many searches for New Physics, thus requiring a precise knowledge of production cross sections. In the following the measurement of the $Z + b\bar{b}$ production cross section, where the Z decays into two muons or electrons, is presented ($\sqrt{s} = 14$ TeV, 100 pb^{-1}) [5]. Main backgrounds are $t\bar{t}$ production, as well as the associated production of light quark jets, c quark jets and gluon jets together with the Z boson. The latter ones are reduced by requiring b tagging for two jets. For the b tagging an algorithm counting high impact parameter tracks [6] is used. The left-hand plot in Fig. 4 shows the b tagging efficiency as a function of the transverse energy of the jet. The fake rate for c quark [light quark and gluon] jets is $< 10^{-1}$ [$< 10^{-2}$]. Events containing two isolated, oppositely charged leptons with $p_T > 20$ GeV in $|\eta| < 2$ (muons) and $|\eta| < 2.5$ (electrons), respectively, and two b tagged jets with $E_T > 30$ GeV in $|\eta| < 2.4$ are selected. In order to veto against $t\bar{t}$ events, a cut on the missing transverse energy, $E_T^{\text{miss}} < 50$ GeV, is applied. The invariant mass distribution of the two leptons (muons or electrons) is shown in the right-hand plot in Fig. 4, where a signal-over-background ratio of 3.6 can be observed. The contribution of $t\bar{t}$ events in the Z peak region is estimated using the side-bands in the invariant mass distribution where the $t\bar{t}$ background is almost flat. The $Z + b\bar{b}$ cross section can be measured with an accuracy of 30 % using 100 pb^{-1} of data. Main contributions to the systematic uncertainty on the cross section measurement come from the jet energy scale, scale of the missing transverse energy, b tagging efficiency, $t\bar{t}$ background estimation and luminosity.

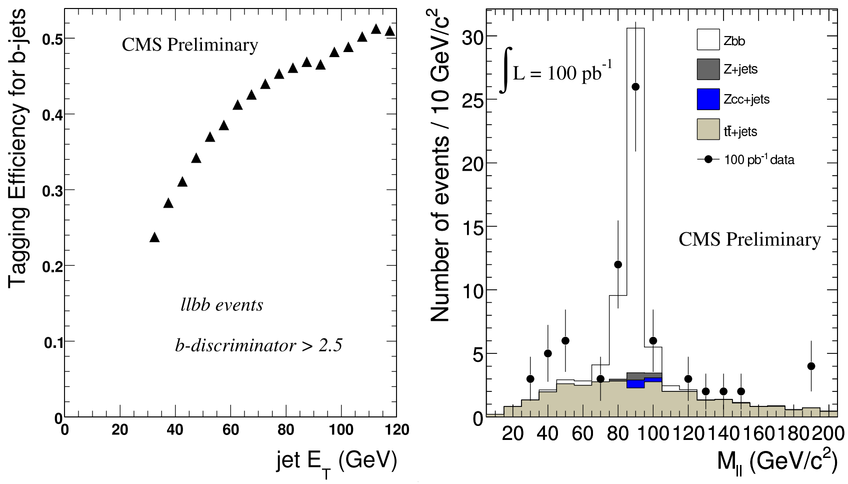

FIGURE 4. Left: *b* tagging efficiency as a function of the transverse energy of the jet. Right: Invariant mass distribution of the two leptons (muons or electrons).

MEASUREMENT OF THE MUON CHARGE ASYMMETRY

The muon charge asymmetry $A(\eta)$ is defined as follows

$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+ \bar{\nu}_\mu) - \frac{d\sigma}{d\eta}(W^- \to \mu^- \nu_\mu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+ \bar{\nu}_\mu) + \frac{d\sigma}{d\eta}(W^- \to \mu^- \nu_\mu)} \quad (1)$$

and has been studied for muons with $p_T > 25$ GeV in the pseudo-rapidity region $|\eta| < 2$ at a center-of-mass energy of $\sqrt{s} = 14$ TeV for integrated luminosities of 10 to 100 pb^{-1} [7]. This measurement allows to probe the parton density functions (PDFs) of the incoming u and d quarks. Since background processes also exhibit small asymmetries, this dilution ($W \to \tau\nu$: 10 %, Drell-Yan: 2 %) has to be corrected for. Systematic uncertainties stemming from misalignment and/or miscalibration have a negligible impact on the asymmetry measurement, as well as the finite momentum resolution and the detection efficiency – given a detector response independent of the muon charge. Further, no exact knowledge of the luminosity is required. With an integrated luminosity of 50 pb^{-1} it is expected to constrain the current PDF sets and improve them.

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