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Measurement of the inclusive W and Z cross sections in pp collisions with the CMS detector

Piergiulio Lenzi[*][†]
Università di Firenze e INFN
E-mail: piergiulio.lenzi@cern.ch

We describe methods developed with simulated events for an early measurement of the inclusive W and Z cross sections with the CMS detector, assuming 10 pb^{-1} of proton proton collisions. A simple and robust selection is used. The selection is intended to be tolerant of the anticipated imperfections in calibration and alignment of the CMS detector in the early data-taking period. Data-driven methods have been devised to measure selection efficiencies, to tune the selection cuts, and to estimate the backgrounds for the W channel. The main sources of systematic uncertainty in the W and Z yield measurement are described.

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[*]Speaker.
[†]on behalf of the CMS collaboration

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1. Introduction

The signature of W and Z bosons decaying into leptons is very distinctive in the environment of proton proton collisions at the LHC. The presence of high transverse momentum leptons makes these events relatively easy to identify, with limited contamination from background.
The measurement of W and Z cross section in the electron and muon decay channel will be one of the earliest measurements at the LHC and it will play an important role in the commissioning of electron and muon reconstruction and identification algorithms of the CMS experiment.
This measurement will also prove a precision test of perturbative QCD and of the proton's parton distribution functions.
A precise measurement of W and Z inclusive cross section will also provide us with a handle to determine the luminosity delivered by the LHC.

The main characteristics of the strategy we propose are: a) a simple and robust cut based event selection strategy; b) data driven methods to estimate selection efficiency and background contamination. These characteristics aim at providing a robust measurement, that should be able to cope with the imperfections of the calibration and alignment for early data.

The study presented in this note is based on simulated events, for proton collisions at 10 TeV center of mass energy, and is intended to illustrate CMS analysis strategy for early electroweak analyses, for an integrated luminosity of the order of 10 pb^{-1}.

2. Reconstruction and event selection

The muon reconstruction algorithm combines a track reconstructed in the inner silicon tracking system and a corresponding track reconstructed in the muon spectrometer, housed in the magnet's return yoke. Muons are reconstructed in the pseudorapidity (η) region $|\eta| < 2.4$, and the transverse momentum (p_T) resolution is of the order of 1% in the momentum range relevant for this analysis. Electrons are reconstructed with the combined use of the inner tracking system and the electromagnetic calorimeter. A cluster of energy is identified in the electromagnetic calorimeter, that matches a track in the tracker. The cluster reconstruction extends in the azimuthal direction in an attempt to recover the energy of Bremsstrahlung photons. The matched track is fitted with a Gaussian Sum Filter algorithm [1], that is able to deal with possibly large energy loss in the tracker layers due to Bremsstrahlung. Electrons are reconstructed in the pseudorapidity region $|\eta| < 2.4$.

The event selection is based, for both W and Z in both decay channels, on the following ingredients [2, 3]:

- Single, non isolated, lepton triggers;
- Robust lepton identification criteria;
- Lepton isolation.

The selection for the Z boson additionally requires at least two leptons with p_T greater than 20 GeV and an invariant mass constraint.
The selection for the W requires exactly one lepton with p_T greater than 25 GeV for the muon channel, or 30 GeV for the electron channel. The missing transverse energy E_T^{miss} is used in the

electron channel to discriminate between signal and background, while the transverse mass M_T is used in the muon channel. In both the electron and muon channels we can either cut on the variable used to discriminate signal and background (E_T^{miss} for the electrons, M_T for the muons), or we can extract the signal yield fitting the signal plus background shape to the measured distribution.

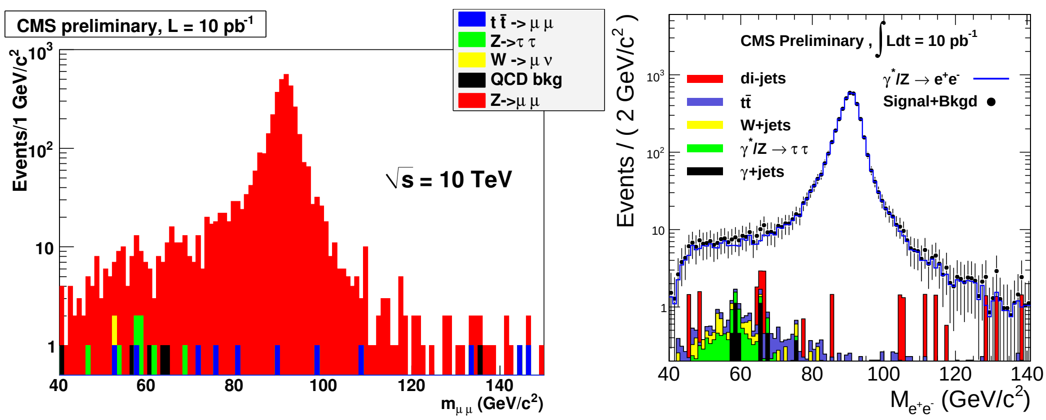
3. Z cross section measurement

The selection strategy that we have outlined is very effective in reducing the background contamination to a negligible level for the Z cross section measurement. The amount of remaining background events in this channel will be estimated from the Monte Carlo simulation, or even neglected, at the price of a small systematic uncertainty. The foreseen signal and background yields are represented in Fig. 1 for the muon (a) and the electron (b) channels.

In order to extract the Z cross section we need to correct the measured yield for the selection efficiency and for the acceptance of our spectrometer. The acceptance correction is derived from the Monte Carlo simulation, while the selection efficiency is measured from data. We have explored two alternative data driven methods to estimate the selection efficiency. One is based on the so called "tag and probe" technique, in which a tight selection is applied on one of the two leptons from the Z decay to identify a pure sample, and the second leg is used to estimate the efficiency under study. The second method is based on a study of the correlation between signal yields obtained with several different selection criteria. We will describe the tag and probe method as applied to the electron decay channel and the sample correlation method as applied to the muon decay channel.

3.1 Z$\rightarrow e^+e^-$ cross section extraction

In the "tag and probe" method [3] we select a very pure sample by applying stringent selection criteria on one of the two leptons in the event, that we will call the "tag" lepton in the following. The other lepton, the "probe", is required to form with the tag an invariant mass laying in a window



(a) (b)

Figure 1: Invariant mass distribution for muon (a) and electron (b) pairs. The contribution of signal and background events is put into evidence with different colors. The yield expected for 10 pb^{-1} is represented.

Luminosity	Selected events	ε_{total}	Acceptance	$\sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \to e^+e^-)$
10 pb^{-1}	4273±65	81.6±0.5%	40.2±0.2%	1300±20 pb (true value is 1296 pb)

Table 1: Summary of Z→ e^+e^- yield extraction, statistical errors only are shown for 10 pb^{-1}.

around the Z mass peak. The tightness of the cuts applied on the tag, plus the invariant mass requirement ensure a high purity sample of probes[1]. The efficiency is measured as the ratio between the total number of probes that pass all the selection cuts including the one under study and the total number of probes that pass all the cuts up to the one prior to that under study. By applying the cuts on the probe in the same order as in the actual signal selection we take into proper account possible correlations between cuts.

Results for the performances of the Z→ e^+e^- yield extraction, using the tag and probe method for efficiencies, are summarized in table Tab. 1. The full selection efficiency is factorized in terms of the trigger efficiency $\varepsilon_{trigger}$, and the reconstruction and identification efficiency $\varepsilon_{offline}$. The latter is applied to both electron, thus the total efficiency is $\varepsilon_{total} = \varepsilon^2_{offline} \times [1-(1-\varepsilon_{trigger})^2]$.

3.2 Z→ $\mu^+\mu^-$ yield extraction

The Z→ $\mu^+\mu^-$ yield and the selection efficiencies are simultaneously extracted in a data driven way through a study of the correlations between five independent samples, selected according to different criteria [2]. The yield in each sample is related to the total Z→ $\mu^+\mu^-$ yield and to four efficiencies: the trigger efficiency, the isolation efficiency, the efficiency for reconstructing a muon track in the tracker and the efficiency for reconstructing a muon track in the muon spectrometer. The Z→ $\mu^+\mu^-$ yield and all the efficiencies are extracted through a simultaneous fit of the invariant mass distribution in the five samples with suitable shapes to model signal and background.

The expected statistical power of the method is described in Fig. 2, where the ratio of the measured cross section and the true cross section in the Monte Carlo, along with its statistical error, is shown for four values of the integrated luminosity.

3.3 Systematics in Z cross section estimate

The main systematic uncertainty in the cross section measurement comes from the luminosity measurement, which is estimated to contribute a 10%. The systematic uncertainty associated the extrapolation to 4π acceptance has been evaluated with the methods described in [4], using MSTW2008 [5] parton density functions, and it has been estimated to be 2.3%. Systematics related to the tag and probe efficiency estimation and to the momentum scale in the muon case are being estimated at the moment.

4. W cross section measurement

The selection strategy we have devised is very effective in reducing the background contamination in W events, as shown in Fig. 3 for the muon (a) and the electron (b) decay channels. In

[1] Care has to be taken to ensure that the tag selection does not bias the probe sample.

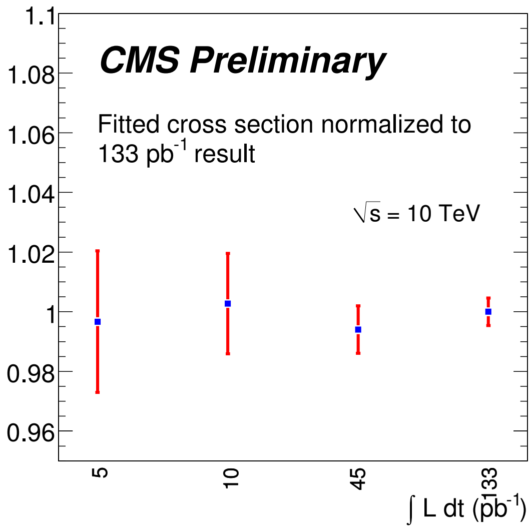
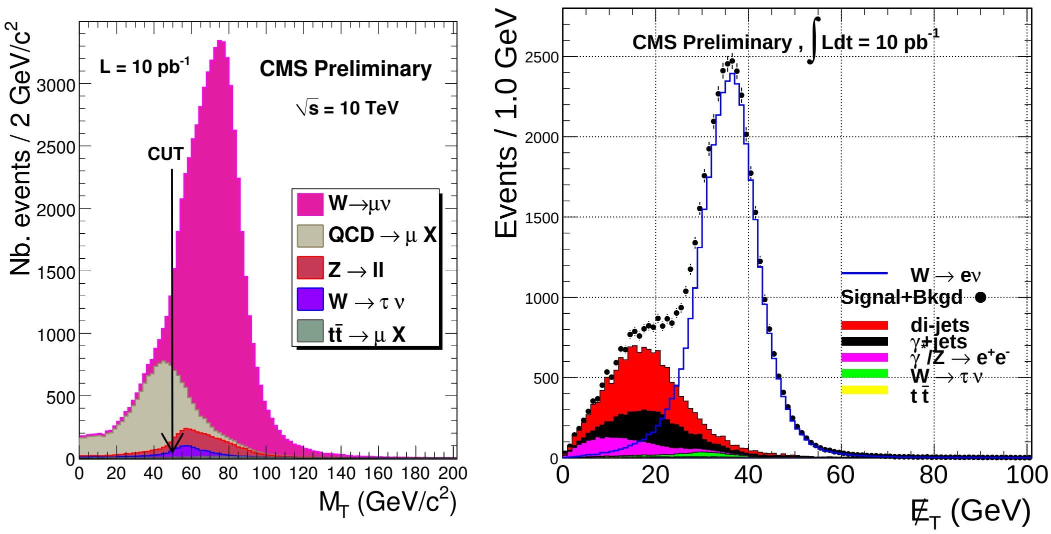


Figure 2: Ratio between the fitted cross section and the true value in the Monte Carlo for Z→ $\mu^+\mu^-$, along with the statistical error on the fitted result, for four values of the integrated luminosity.



(a) (b)

Figure 3: (a) Transverse mass M_T for $W \to \mu\nu$ and (b) missing transverse energy E_T^{miss} for $W \to e\nu$. The expected yield is shown for 10 pb^{-1} after the full selection. A stacked plot is shown in (a), while the individual contributions are superimposed in (b).

order to extract the W cross section we need to subtract the background contribution from the observed yield and to correct for the selection efficiency. The selection efficiency is extracted using the already described tag and probe method in Z events, exploiting the similar event topology.

In the electron channel, the main background contribution is due to QCD di-jet events, in which one jet is misidentified as an electron, and the E_T^{miss} comes from mis-measurement. Also in the muon channel the main background is QCD di-jets, the muon coming mainly from a decay in flight in one of the two jets. The other sources of background, in both channels, consist mainly of Z events, with one lepton outside the acceptance, and W decaying to τ lepton. These backgrounds are expected to be precisely reproduced in the simulation, and we foresee the use of Monte Carlo based estimates for them.

In order to subtract the QCD background contamination we use a data driven method, called ABCD method in the following. The main prerequisite of the method is the identification of two largely independent variables for the background under study. In the electron channel, such a couple of variables has been identified to be the E_T^{miss} and the isolation[2]. In the muon channel the transverse mass and the relative isolation[3] have been found to satisfy the independence requirement.

We identify four regions in the plane of the two chosen variables, as depicted in Fig. 4, region A being dominated by the signal, and regions B, C, D being dominated by the background. Following the independence requirement of the two variables for the background, assuming null

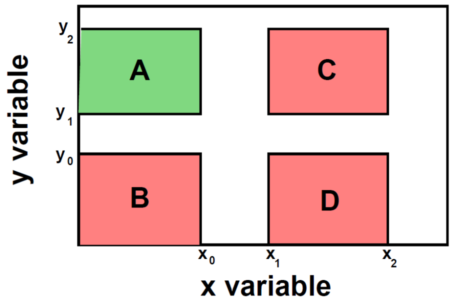


Figure 4: Schematic representation of the four regions that need to be identified to use the ABCD method. Region A is dominated by the signal, regions B, C, D are dominated by the background.

signal contamination in the background dominated regions, the background contamination in the signal region is $N_A = N_B \times N_C / N_D$, where N_i is the number of background events in region i. The method is refined by taking into account the signal contamination in the background region, using a signal template extracted from Z events in which one of the two lepton legs is randomly chosen and removed to simulate the neutrino.

4.1 Systematic uncertainties in the W cross section measurement

The main contribution, which is also common to the Z measurement, comes from the luminosity measurement, and, as already stated, it amounts to 10%. The systematic due to acceptance correction had been estimated with the methods described in [6], and found to be 2.5%. The systematics of the ABCD background subtraction method has been estimated on simulated samples, by comparing the true W yield to the extracted one. The effect has been found to be 2.1% in the electron channel and 0.4% in the muon channel [7]. The systematic effect arising from the selection efficiency determination from Z events has been evaluated to be 2.2% for the electrons and 0.8% for the muons.

[2]The isolation variable is defined as the scalar sum of the transverse components of the energy deposits in the electromagnetic and hadron calorimeters and track p_T in a region of $\Delta R < 0.4$ around the electron direction ($\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$).

[3]Defined as the electron isolation, but requiring $\Delta R < 0.3$ and dividing the resulting sum by the muon p_T.

5. Conclusion

The methods that will be used in the CMS experiment for early W and Z cross section measurement at the LHC in both electron and muon decay channels have been presented. We plan the use of a simple and robust event selection and data driven techniques to estimate selection efficiency and background contamination. The study that we presented is based on simulated samples at 10 TeV center of mass energy and is targeted for an integrated luminosity of 10 pb^{-1}.

The proposed selection of Z events is very efficient and it is able to reduce the backgrounds to a negligible level in both the electron and muon channels. Selection efficiencies are estimated with the tag and probe technique. For the W cross section measurement we plan the use of single lepton efficiencies derived from the Z sample with the tag and probe method, and we have devised a method to extract the background contamination directly from data.

The main systematic effect in both the W and Z cross section measurement is the uncertainty on the luminosity (10%). The acceptance correction has an impact of the order of 2-3% for both W and Z.

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