W and Z boson Productions in CMS at LHC startup

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Abstract. - We report on potential for measurement of W and Z boson production, as well as the production in association with jets. Of particular interest are jet multiplicity and $P_T$ distributions. The 10 to 100 pb$^{-1}$ datasets expected in the startup year of operation of LHC are likely to already provide information beyond the reach of the Tevatron collider both in jet multiplicity and $P_T$ range. We are especially interested in understanding the ratios of W+jets to Z+jets distributions by comparing them to next-to-leading order Monte Carlo generators, as these processes present a formidable background for searches of new physics phenomena.

1. W(Z) production in CMS

The decays of W and Z bosons into leptons provide a clean experimental signature, and the large production cross section for W(Z) boson, i.e. 190 nb(56 nb) at $\sqrt{s} = 14$ TeV allows to measure these processes with the very early data of LHC. Since the properties of W(Z) bosons are relatively well known, these measurements will be extremely important for understanding of detector performances.

A High Level Trigger (HLT) is used to select events with at least one muon for both W and Z. The offline selection of $\gamma^*/Z \rightarrow \mu\mu$ candidates consists of the requirements of; two isolated$^1$ and opposite charged high $p_T$ (>20 GeV) muons measured in both the Tracker and muon Chambers; invariant mass of the muons system, $M_{\mu\mu} > 40$ GeV. The resulting Z candidates for both signal and backgrounds are shown in Fig. 1 as a function of $M_{\mu\mu}$. In order to reduce the QCD background significantly, the $W \rightarrow \mu\nu$ events are selected with a higher $p_T$ threshold (>25 GeV) and a tighter

$^1$The isolation criteria requires the $p_T$ sum of all tracks in a $\Delta R(= \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2})$ cone of 0.3 around the muon direction to be less than 3 GeV.
isolation criteria on muon candidates can be imposed. Events with two selected muon candidates are rejected in order to reduce Z background to W. The Fig. 1 (left) shows that the QCD background could be further reduced with a $M_T > 50$ GeV requirement. With these selections, 5500 $\gamma^*/Z \rightarrow \mu\mu$ candidates within $70 < M_{\mu\mu} < 140$ GeV, and 64000 $W \rightarrow \mu\nu$ selected events are expected in a data sample of 10 pb$^{-1}$ at $\sqrt{s} = 14$ TeV [1]. CMS studies also the measurements of $Z \rightarrow ee$ and $W \rightarrow e\nu$ decays [2].

The efficiencies of reconstruction, isolation and trigger are measured in data using tag-and-probe methods. A sample of $\gamma^*/Z \rightarrow \mu\mu$ events with high purity is selected, where a higher $p_T$ and tighter isolation requirements are imposed on one of the muons which acts as the event "tag". The efficiencies are measured with the other muon which acts as the "probe". Furthermore, different methods to determine the QCD background in $W \rightarrow \mu\nu$ using data are investigated. In the matrix method the background is estimated by analyzing simultaneously two largely uncorrelated background-discriminating variables, which are in this case the transverse mass of the W system and the isolation variable for muon. The systematic uncertainty due to the QCD background estimation with this method, is 0.4%. Other methods, e.g determining the $M_T$ shape of W from Z events, transverse mass shape of the QCD background (to W) determination by reversing the isolation criteria, are also investigated, and the results found to be consistent with the direct MC shapes at < 1% level.

2. $W(Z)+$jets production in CMS

The production of $W(Z)$ bosons associated with jets at LHC has a wide range of physics potential, which varies from Standard Model (SM) measurements to Super-
symmetry (SUSY) searches. These processes can be used for tests of perturbative quantum chromodynamic (QCD) [3]. The predictions for W(Z)+NJets, where N > 2, are accessible only through matrix element (ME) plus parton shower (PS) computations and in fact, can be considered as a prime testing ground for the accuracy of such predictions. Z+jet events can be also exploited to calibrate jets, measured in the Calorimeter (See [4] for details). Furthermore, W(Z)+jets form a relevant background to many interesting phenomena, including new physics. Therefore, these processes must be measured with great accuracy to allow precision measurements and increase the sensitivity of the searches beyond SM.

However, the individual cross section measurements of W+Njets and Z+Njets will be affected by large systematic uncertainties associated mostly with the definition and measurement of jets. One of the measurements that CMS plans to perform is the ratio of the cross sections of W+jets to Z+jets as functions of jet multiplicity and boson $p_T$. Such a measurement allows partial cancellation of the most relevant experimental systematic uncertainties as well as the theoretical uncertainties due to the choice of renormalization scale, the parton distribution functions, etc. [5]. The jet energy scale forms the largest experimental uncertainty as it increases rapidly with jet multiplicity. This uncertainty cancels in the ratio as long as the $p_T$ spectra, the rapidity distribution and the composition of the jets in both processes are the same at the level of experimental sensitivity. Other uncertainties, i.e. Underlying Event (UE), Multiple interactions, luminosity and detector acceptances, will also cancel to a large extent in the ratio.

The measurements of W(Z)+jets at the Tevatron collider indicate a general agreement between the theoretical predictions based on LO ME plus PS and data [6]. In the studies presented here the ME event generator ALPGEN is used to generate exclusive parton level W(Z)+Njets (N=0,1,2,3,4,5) events. PYTHIA is used for PS and hadronization. The MLM recipe is used in order to avoid double counting of processes from ME and PS. The SM processes $t\bar{t}$+jets, WW+jets, WZ+jets, ZZ+jets and QCD multi-jet are considered as backgrounds and generated with PYTHIA in fully inclusive decay modes for W and Z bosons.

Figure 1(2) shows the $p_T$ distribution of the Z(W) boson in selected Z(W)+≥1jet (left) and Z(W)+≥4jet (right) events for the signal and backgrounds. In both W and Z boson cases the events are selected in the electron and muon channels. The high $p_T$ isolated leptons are selected in order to reduce contamination from QCD events. Furthermore, Z+jets events are selected by a tight di-lepton invariant mass around the Z boson mass and the missing transverse energy is restricted to be small, whereas for W+jets a large missing transverse energy is required. Jet reconstruction is performed using the Iterative Cone algorithm using the energy deposited in the Calorimeter. Jets are calibrated using $\gamma$+jet events and the jets with $p_T > 50$ GeV are counted. The current Z+jets selection provides a rather "clean" sample, and with 1 $fb^{-1}$ of data, up to fourth jet multiplicity can be measured. One crucial point will be the reduction of the background to W+≥2jets from $t\bar{t}$ events (See Fig. 2 right), since the $t\bar{t}$ production rate increases by about a factor of 100 from the Tevatron to the LHC, while W production increases by just a factor of 5. In the studies presented, the QCD
contribution as background to W(Z)+jets is found to be negligible and not shown in the figures. However, we should note that the background processes are simulated using the PYTHIA program, which is known not to produce high jet multiplicities correctly.

3. Conclusions

CMS has established a strategy for early measurements of the inclusive W and Z production cross section with a data of 10 pb$^{-1}$. The data-driven methods for background estimation, measuring the efficiencies are studied. The measurements of W(Z)+jets versus the jet multiplicity will be one of the early measurements carried out with the CMS detector and the analysis strategy will be adapted (to large extent) from the inclusive W(Z) measurement. The ratio measurement of W+Njets to Z+Njets will allow partial cancellation of the most relevant systematic uncertainties. This is an extremely important advantage at the startup, where it will be relatively difficult to control the detector related systematic uncertainties.

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Figure 2: $p_T$ distribution of the W boson in selected $W+\geq 1$jet (left) and $W+\geq 4$jet (right) for signal and background for an integrated luminosity of $1 fb^{-1}$.

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