Electroweak bosons in heavy-ion collisions with the CMS detector at $\sqrt{s_{\mathrm{NN}}}$=2.76 TeV

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Abstract. Electroweak gauge bosons W and Z, do not interact strongly, and thus constitute clean probes of the initial state of nucleus-nucleus collisions. The comparison of their production cross-sections in pp and in nuclear collisions provides an estimate of the nuclear parton distribution functions. Despite the low production cross section of weak bosons compared to other nuclear processes, the relatively clean signal of their leptonic decay channel allows their detection. This paper reports measurements of Z and W bosons, produced in PbPb and pp collisions both at nucleon-nucleon center of mass energy $\sqrt{s_{\mathrm{NN}}}$=2.76 TeV with the CMS detector. The Z boson yield and the nuclear modification factor (R_{AA}) corresponding to the integrated luminosity of 150 μb^{-1} for PbPb collisions are presented. The search for W bosons has been performed in the muon plus neutrino channel, using the data sample with integrated luminosity of 7.2 μb^{-1} for PbPb collisions. Event centrality an muon pseudorapidity dependencies are studied for the complete W candidate sample as well as samples separated by charge (W$^+$ and W$^-$).

1. Introduction

The unprecedented high energies reached in heavy-ion collisions at the LHC have opened the possibility of producing weakly interacting bosons, Z and W, with significant cross sections. These vector bosons are produced in the primary binary nucleon-nucleon collisions and decay before formation of the quark-gluon plasma. Their leptonic decay products do not interact with the hot and dense coloured matter and they are sensitive only to the initial state of the collision and in particular to the parton distribution functions (PDF) in the nuclei. They can be used as a reference to normalize the production mechanisms for other processes.

2. Muon reconstruction

One of the particularly strong features of the CMS detector is its muon reconstruction [1]. The muon signature is extremely clear with a very good momentum resolution (1-2% up to 100 GeV/c at mid-rapidity) due to the precise silicon tracking to which tracks in the muon chambers are matched. In addition the large rapidity coverage of the muon chambers results in large acceptance for single and di-muons. The results presented in this paper are for electroweak boson decays with muons in the final state. The dense environment produced in heavy-ion collisons requires special care in particle reconstruction. The pp reconstruction algorithms were re-optimized for PbPb using HYDJET simulations [2]. HYDJET is an event generator that simulates jet production, jet quenching and flow effects in ultra relativistic heavy-ion collisions.

3. The $Z \to \mu^+\mu^-$ analysis

From the 2011 data, 616 Z candidates have been extracted with a dimuon invariant mass between 60 and 120 GeV/c^2 [3]. The invariant mass of pairs of opposite charge muons, having a transverse momentum (p_T) larger than 20 GeV/c and passing all established quality cuts, is shown in Figure 1. No same-charge pairs (combinatorial background) are found passing the kinematic and reconstruction quality criteria. Once corrected for the efficiency and acceptance, the yield of Z's can be described as a function of the collision centrality. If the Z boson is not affected by the dense medium then the yield per binary nucleon-nucleon collisions should not depend of centrality. Figure 2 shows the Z yield per unity of rapidity, represented as a function of the number of participants in the collision. In this figure the Z yield is divided by the average integral of nuclear overlap function (T_{AA}), which is the number of collisions divided by the cross section in pp collisions. The T_{AA} scaling is the natural scale to work with and allows to factor out the dependence of the pp cross section. The results presented in Figure 2 show that the Z yield is independent of collision centrality, moreover, the POWHEG generator describes the data very well. POWHEG is an next-to-leading-order (NLO) generator that is known to reproduce the Tevatron (2 TeV) and the LHC (7 TeV) data. The POWHEG predictions have about 5% uncertainty due to next-to-next-to-leading-order (NNLO) corrections and PDF uncertainties [4].
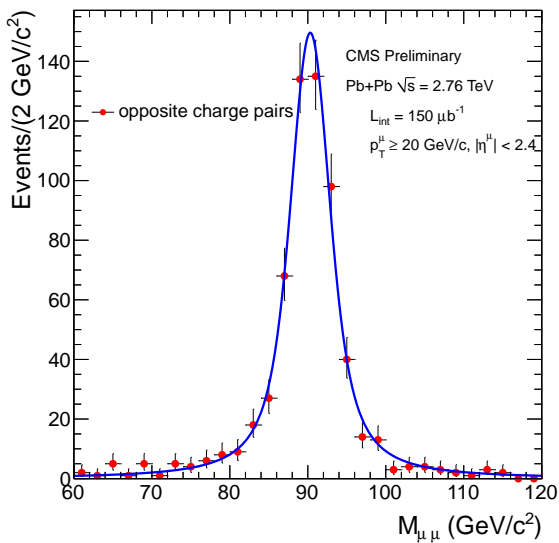

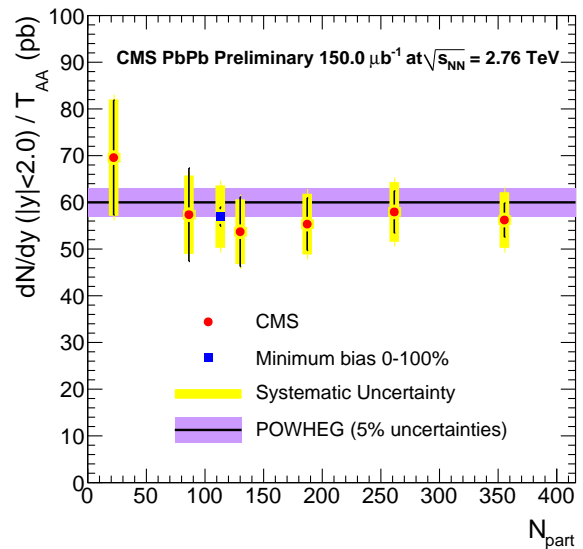Figure 1: Dimuon invariant mass spectrum between 60 and 120 GeV/c^2.

Figure 2: Collision centrality dependence of the Z $\to \mu^+\mu^-$ yield per event divided by expected average nuclear overlap function T_{AA}.

The non-dependence on centrality is a first confirmation that Z bosons are not affected by the dense medium. An absolute comparison to the pp production is provided by the nuclear modification factor (R_{AA}) which is the ratio between the Z yield in PbPb and the Z yield in pp collisions, scaled by the number of collisions. If the ratio is close to one then there are no significant changes between a pp and a PbPb collision. The pp reference for the R_{AA} measurement is calculated using theoretical calculations due to the very low available pp statistics at 2.76 TeV: $R_{AA} = \frac{dN_{AA}}{T_{AA} \times \sigma_{pp}}$ where σ_{pp} is given by POWHEG and $\frac{dN_{AA}}{T_{AA}}$ is extracted from Figure 2. With a $R_{AA} = 0.95 \pm 0.03(stat) \pm 0.13(syst)$, the Z boson through its leptonic decay is, as expected, medium-blind and confirms the previous Z results obtained from the 2010 run [5].

4. The W → μν analysis

Data collected in 2010 (7.2 μb^{-1}) was used to search for the W bosons decaying into muon and neutrino [6]. Only muons with p_T larger than 25 GeV/c were considered in this analysis. The high p_T cut significantly increases the signal to background ratio. Dimuon events were rejected to remove Z decays. A missing transverse energy (MET) is calculated following the principle of energy balance in the transverse plane. Events containing undetected high energy neutrinos are expected to have non-zero MET.

In this analysis, a missing transverse momentum is calculated by summing all the transverse momenta of all charge particle tracks in the detector (p_T). To reduce the background fluctuations only tracks with a p_T above 4 GeV/c are taken into account in the sum. From the muon energy and the obtained MET a transverse mass can be calculated. The distribution is shown in Figure 3 and compared with the W transverse mass obtained in pp collisions and Monte Carlo (MC) describing the W signal embedded in heavy-ion collisions (HYDJET). The three distributions completely match between each other.
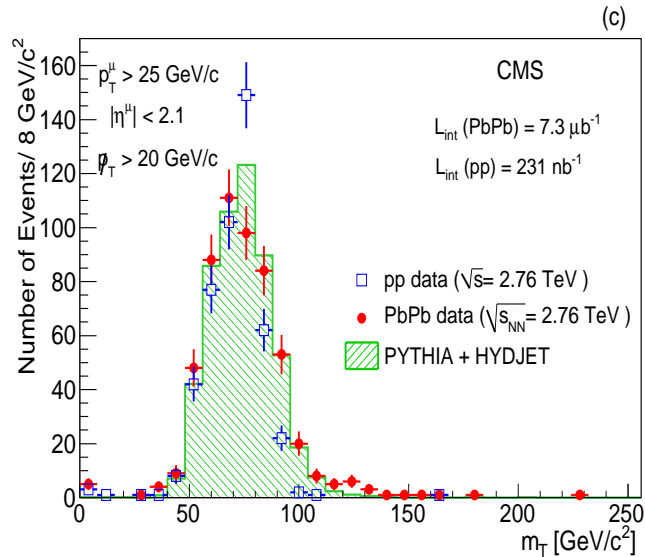
Figure 3: Distribution of transverse mass, m_T (colour online), for the selected PbPb data (red dots), the embedded W MC (green histogram) and pp data at 2.76 TeV after the same selection procedure as the one applied for PbPb (blue dots).

There are 539 W split into 275 W^+ and 264 W^-. These numbers have to be compared with the ones obtained in the pp sample at 2.76 TeV: 466 W with 301 W^+ and 165 W^- in the same window of pseudorapidity ($|\eta| \leq 2.1$). A W^+ (W^-) is produced at first order by the fusion of a valence quark u (d) and an anti-quark d (u) from the sea. Hence a pp collisions is expected to produce more W^+ than W^-. In PbPb collisions there are more d than u quarks because of the neutrons present in Pb nuclei so one would expect many more events containing W^- than W^+, contrary to what we observe. This can be explained by the muon charge asymmetry.

When the W is produced, it is boosted in the direction of the valence quark. The neutrino is always left-handed and the anti-neutrino right-handed. Hence the μ^+ coming from W^+ is by preference right-handed because of spin and momentum conservation. It is then produced backward with respect to the W^+, meaning mainly at central rapidity. The μ^- coming from W^- is this time left-handed and then produded in the W^- direction, at forward rapidity. By chosing $|\eta_{muon}| \leq 2.1$ in the analysis, the yield of W^+ relative to W^- is enhanced. Figure 4 represents the

charge asymmetry $(\frac{N(W^+)-N(W^-)}{N(W^+)+N(W^-)})$ as a function of $|\eta|$, for pp data and PbPb data.
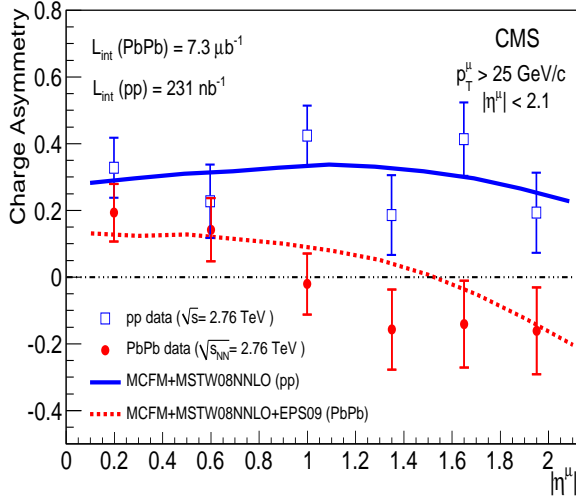

Figure 4: Muon charge asymmetry as a function of muon pseudo-rapidity for pp and PbPb collisions at 2.76 TeV.
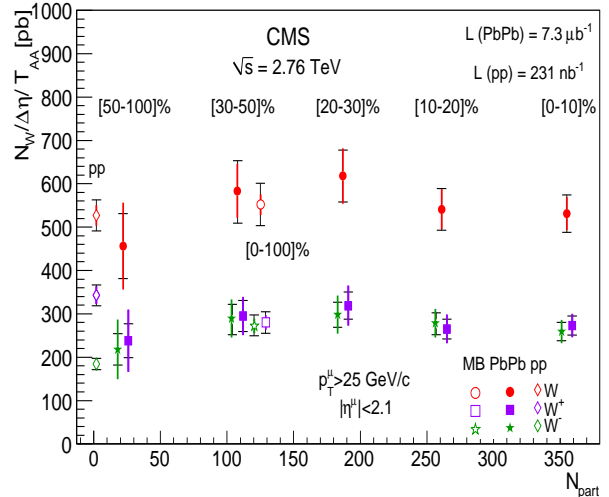
Figure 5: Collision centrality dependence of the W→ $\mu\nu$ yield per event divided by expected average nuclear function T_{AA}.

Similarly to the Z, the yield of W as a function of centrality was studied. Figure 5 shows that the binary-scaled yield of W^+ and W^- is independent of centrality. When no distinction of the W charge is made, the binary collision scaled yield in PbPb is compatible with pp. From these yields a R_{AA} can be calculated by using the pp data instead of POWHEG prediction, since the statistics coming fom the 2010 run in PbPb is close to the one in pp at 2.76 TeV. Hence $R_{AA}(\text{W})=1.04 \pm 0.07(stat) \pm 0.12(syst)$ with $R_{AA}(\text{W}^+)=0.82 \pm 0.07(stat) \pm 0.09(syst)$ and $R_{AA}(\text{W}^-)=1.46 \pm 0.14(stat) \pm 0.16(syst)$. These observed modifications are compatible with this muon charge asymmetry, also called *isospin* effect.

5. Conclusion
The main conclusion of the above studies can be summarized this way : weak boson production isconsistant with the binary-collision scaling hypothesis ($R_{AA}=1$) and can thus serve as reference to modified probes. The further analysis of the 2011 data of W boson and the $Z \rightarrow e^+e^-$ decay channels is in progress and we expect new results shortly. The improved statistics will improved significantly the precision of charge asymmetry and R_{AA} and it could reveal parton distribution functions modifications in the nucleus as compared to proton.

References
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