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W and Z in heavy ion collisions with CMS

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Abstract

Electroweak W and Z boson measurements in PbPb collisions at nucleon-nucleon center of mass energy $\sqrt{s}$ = 2.76 TeV at the LHC using the CMS detector are presented. The W analysis is based on 2010 PbPb data corresponding to an integrated luminosity of 7.3 μb^{-1} and also on 2011 pp data corresponding to an integrated luminosity of 231 nb^{-1}. The Z analysis is based on 2011 PbPb data with an integrated luminosity of 150 μb^{-1} . The dependence of W and Z production as a function of PbPb collision centrality is studied and shown to scale with the number of NN binary collisions. W^+ and W^- yields in PbPb and pp collisions are in agreement once we take into account the proton and neutron composition in Pb nuclei. The muon charge asymmetry is measured as a function of pseudo-rapidity and is in agreement with next-to-leading order perturbative QCD calculations.

1. Introduction

The W and Z bosons were first observed by the UA1 and UA2 experiments at CERN nearly thirty years ago in proton-antiproton collisions at $\sqrt{s}$ = 540 GeV [1]. Since then, their properties have been characterised in detail by a succession of collider experiments. Their properties, such as their mass and their width (as well as their inclusive and differential cross sections) have been well measured at different centre-of-mass energies in electron-positron, proton-proton and proton-antiproton collisions. Thanks to its large centre-of-mass energy and delivered luminosities, the LHC offers the new opportunity to study W and Z boson production in nucleus-nucleus collisions. Based on the first lead-lead collisions corresponding to 7.2 μb^{-1} integrated luminosity, the CMS collaboration has reported first results on the $Z \to \mu\mu$ [2] and $W \to \mu\nu$ [3] processes, showing that electroweak bosons are essentially unmodified by the hot and dense medium created in heavy-ion collisions, often referred to as the quark-gluon plasma. Once produced, electroweak bosons decay within the medium with a typical lifetime of 0.1 fm/c. Leptonic decays are thus of particular interest since leptons pass freely through the medium being probed, regardless of its nature (be it partonic or hadronic) or its properties. At first order, W and Z bosons can thus serve as a reference to the processes expected to be heavily modified in the QGP, such as quarkonium production, or the production of an opposite-side jet in Z+jet processes. However, their production can be affected by initial-state effects. For example, charged W production must be modified in nuclear collisions, as compared to pp, simply due to the different isospin content of the initial state. In the following, after describing the event selection and the trigger used for the analysis, we present the main results of W and Z production in PbPb collisions with CMS [4].

[1]A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

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2. Results

2.1. Z bosons

We count as Z candidates the oppositely charged di-muon pairs which have an invariant mass between 60 to 120 GeV/c^2. We require a p_T cut of 20 GeV/c for each muon and a pseudo-rapidity $|\eta_\mu| < 2.4$, in order to ensure low background [2]. The dimuon rapidity is limited to $|y| < 2$. Under those conditions the total number of Z particles extracted is 616. The yield of Z bosons (dN_{PbPb}/dy) is then measured as a function of different ranges of Z rapidity (8 bins), p_T (7 bins) and event centrality (6 bins) where the centrality of the collisions is determined from the energy deposited in the forward steel/quartz-fibre calorimeters (HF). The centrality classes used here are 50–100%, 40–50%, 40–30%, 30–20%, 20–10% and 0–10% (most central), ordered from the lowest to the highest energy deposited in HF. The results are presented in figure 1 and compared to the pp cross section provided by a next-to-leading-order POWHEG generator, scaled by the proper nuclear overlap function ($d\sigma_{pp}/dy \times T_{\text{AA}}$). The yield of $Z \to \mu^+\mu^-$ per minimum bias

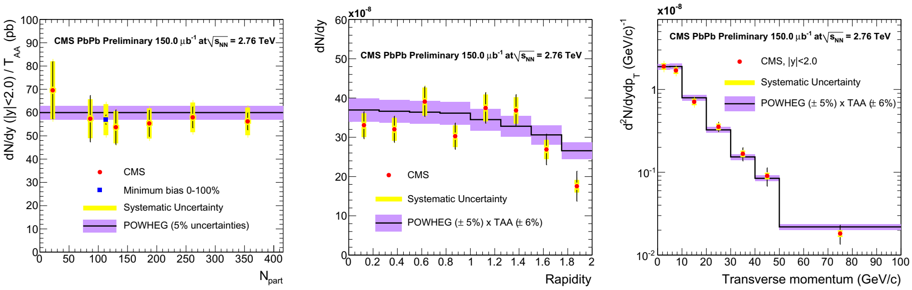

Figure 1: (a) Event centrality dependence of the Z $\to \mu^+ \mu^-$ yield per event divided by the expected average nuclear overlap function T_{AA}. The vertical scale equivalently corresponds to Z yields per binary collision (N_{coll}) times the nucleon-nucleon cross section, and is thus directly comparable to the pp cross section from the POWHEG generator displayed as a black line. On the horizontal axis, event centrality is depicted as the average number of participating nucleons N_{part}. Vertical lines (bands) correspond to statistical (systematic) uncertainties. (b) Z $\to \mu^+ \mu^-$ yields versus the Z boson rapidity. (c) Z $\to \mu^+ \mu^-$ yields versus the Z boson transverse momentum.

event and per unit of rapidity (and p_T) is computed as:

$$\frac{dN}{dy} = \frac{N(Z \to \mu^+\mu^-)}{\alpha\epsilon N_{MB}\Delta y} \quad \text{or} \quad \frac{d^2N}{dydp_T} = \frac{N(Z \to \mu^+\mu^-)}{\alpha\epsilon N_{MB}\Delta y\Delta p_T} \tag{1}$$

where $N(Z \to \mu^+\mu^-)$ is the number of counts found in the di-muon invariant mass range of 60–120 GeV/c^2, N_{MB} is the number of corresponding minimum bias events corrected for trigger efficiency ($N_{MB} = 1.161$ billion events), α and ϵ are acceptance and efficiency corrections and are approximately 70% and 60%, respectively and Δy and Δp_T are the bin ranges in consideration. When the Z yield is sliced according to centrality, N_{MB} is divided by the centrality fraction in consideration. The yields as a function of p_T rapidity and centrality are compared to POWHEG predictions (perturbative QCD at NLO) for $pp \to Z \to \mu^+\mu^-$ scaled with the number of binary collisions. We notice no dependence of the production of Z bosons per binary collision on the number of participants, as shown in 1 (a).

2.2. W bosons

The W boson production has been measured for the first time through its leptonic muon decay channel ($W^{\pm} \rightarrow \mu^{\pm}\nu$) with 2010 PbPb data at $\sqrt{s} = 2.76$ TeV. The first hint of W observation is the bump present in the muon spectrum, as shown in figure 2 (left). The muon spectrum (solid red dots) is performed by plotting the p_T distribution of all the events selected online with a low (2-3 GeV/c) p_T^{μ} threshold and $|\eta^{\mu}| < 2.1$ with strict quality cuts (minimum number of hits used in offline reconstruction, distance in the transverse plane between the muon impact parameter and the primary vertex to be less than 300 μm) and vetoing on the Z candidate. In order to evaluate

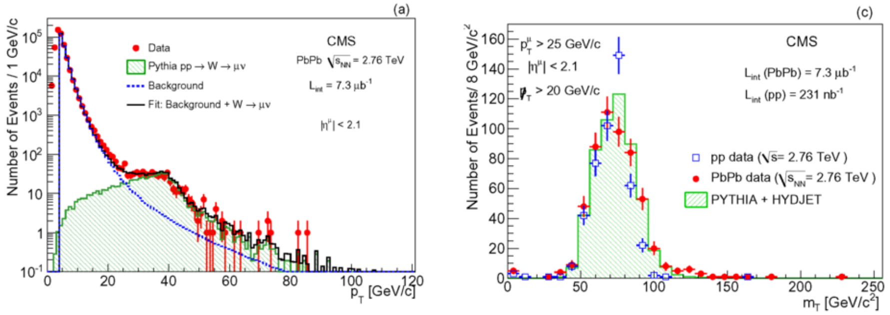

Figure 2: Left: Single-muon transverse-momentum spectrum for $|\mu| < 2.1$ in PbPb data (red points). Signal (green hatched histogram) and background (blue-dashed histogram) contributions are fitted (black-solid line) to the data. Right :Transverse mass distribution for selected events in PbPb (red-filled circles) and pp (blue open squares) data, compared to PYTHIA + HYDJET simulation (hatched histogram). The error bars represent statistical uncertainties. .

the energy of the neutrino in the event, we compute a missing transverse momentum $\not{p}_T$ by taking the opposite sign of the vectorial sum of the transverse momenta of all charged particles in the event, with $p_T > 3$ GeV/c. When requiring a high p_T muon the average value of $\not{p}_T$ is around 40 GeV/c and its dependence on centrality is very small, however, the dependence becomes stronger once including the events with lower muon transverse momentum. Those results agree with what is expected for the typical $\not{p}_T$ produced by an undetected neutrino originating from W decay. Therefore, we require $p_T^{\mu} > 25$ GeV/c and a $\not{p}_T > 20$ GeV/c and we compute the transverse mass of the W as $m_T = \sqrt{2 p_T^{\mu} \not{p}_T (1 - \cos(\phi))}$ where ϕ is the opening angle between the direction of the high-p_T muon momentum and $\not{p}_T$ vectors. The transverse mass distribution for PbPb data is shown in figure 2 (right) and is superimposed on the transverse mass obtained when analyzing pp data with the same procedure (open blue squares). Both pp and PbPb results are in a good agreement with a W Pythia signal simulation embedded in PbPb events generated with Hydjet (PYTHIA + HYDJET) (green-hatched histogram) and are almost background free. Residual contamination from other electroweak processes ($Z \rightarrow \mu^+\mu^-$ and $W^{\pm} \rightarrow \mu^{\pm}\nu$) (2%) is subtracted, and the QCD background is estimated to be 1% and included as a systematic uncertainty. We count W candidates by placing a cut of 40 GeV/c^2 on the transverse mass. The number of selected candidates are 275 W^+ and 264 W^- in PbPb and 301 W^+ and 165 W^- in pp. The yields (dN/dy) of W, W^+, W^- in PbPb collisions are scaled by the nuclear overlap function T_{AA} and shown as a function of number of participants (N_{part}) in figure 3 (left). The first result observed is that the W production in PbPb collisions does not depend on the centrality of the collision. The second result is that the individual W^+ and W^- charge states in PbPb and in pp collisions reflect the different u and d quark content in Pb nuclei and in the proton, the so called:

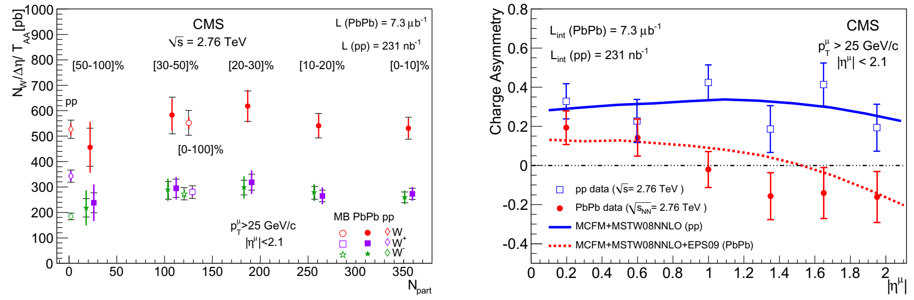

Figure 3: Left: Centrality dependence of normalised W cross sections in PbPb collisions, for all W candidate (red filled points) and separated by charge, W^+ (violet-filled squares) and W^- (green-filled stars). The open symbols at N_{part}= 120 represent the minimum bias events. At N_{part}= 2, the corresponding cross sections are displayed for pp collisions for the same $\sqrt{s}$. The cross sections are given for the phase space region $p_T^\mu > 25$ GeV/c and $|\eta| < 2.1$ [3]. Right: Muon charge asymmetry $A = (N_W^+ - N_W^-)/(N_W^+ + N_W^-)$ as a function of the muon pseudorapidity for PbPb (red points) and pp (blue squares) collisions at 2.76 TeV for muons in the same phase space region.

isospin effect. As a consequence, the nuclear modification factors R_{AA} of W, W^+, W^- are different $R_{AA}(W) = 1.04 \pm 0.07 \pm 0.12$, $R_{AA}(W^+) = 0.82 \pm 0.07 \pm 0.09$, $R_{AA}(W^-) = 1.46 \pm 0.14 \pm 0.16$. The muon charge asymmetry defined as $A = (N_W^+ - N_W^-)/(N_W^+ + N_W^-)$ is studied as a function of the muon pseudo-rapidity for both pp and PbPb collisions and shown to agree – within the uncertainties – with the predictions from MCFM generator using MSTW08 PDF for pp and for PbPb data when adding the EPS09 PDF [3] as presented in figure 3 (right).

3. Conclusion

W and Z electroweak boson production is consistent with the binary-collision scaling hypothesis ($R_{AA} = 1$) and can thus serve as reference to modified probes. More statistics could reveal PDF modification. Already available, the W from the second run, as well as the electronic decay channels of W and Z are still to be analysed. On the longer term, after the first long LHC shutdown, a significant Z+jet event sample will be available. Even with the isospin effect driving the W^+, W^- to have non-unity values of R_{AA}, the fact that they are flat with centrality demonstrates that the underlying hard scattering processes that lead to W and Z production are well understood thereby adding significance to other CMS observations such as jet suppression.

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