W boson studies in pPb and PbPb collisions with CMS

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Abstract. The electroweak W bosons do not participate in the strong interaction, and thus constitute clean probes of the initial state of nuclear collisions. They provide a unique constraint on the nuclear parton distributions, in particular on the antiquarks from the sea. A first analysis of PbPb data has confirmed the medium-blind characteristic of the electroweak bosons. With the new pPb data collected at the beginning of 2013, nuclear matter without the creation of a hot medium can hence be studied. Being 10 times more prevalent than Z bosons, the yield of W bosons recorded from pPb collisions allows precise comparisons to theoretical predictions. A yield of approximately 20 000 W is observed in pPb collisions in both the muon and electron channels. In this paper the CMS measurements of W bosons in PbPb at nucleon-nucleon center-of-mass energy of $\sqrt{s_{NN}} = 2.76$ TeV and from the new pPb data at $\sqrt{s_{NN}} = 5.02$ TeV are reported. The charge asymmetry, forward/backward asymmetry and fully corrected yields will be shown.

1. Introduction

In proton-nucleus or nucleus-nucleus collisions, electroweak-boson production can be affected by initial-state conditions. Given their high mass and short lifetime, W bosons are produced and decay very early in the collision, and are not affected by the medium created during the collision. In the case of a leptonic decay of the W boson, the decay products are not affected either, thus giving direct access to initial-state effects in heavy-ion collisions. A large difference of W boson production between proton-proton and proton-nucleus or nucleus-nucleus collisions is coming from the presence of neutrons in nuclei. At leading order, the leading-order production processes are $u\bar{d} \to W^+$ and $d\bar{u} \to W^-$, mainly reflecting interactions that take place between valence quarks and sea antiquarks. Due to the mixture of protons and neutrons in the incoming nuclei, hence of u and d quarks, the W^+ and W^- rates are expected to be individually modified relative to pp collisions, but not their sum. This is often referred to as an *isospin effect*. The parton distribution functions (PDFs) can also be modified in nuclei. Such modifications include shadowing at small Bjorken x and anti-shadowing at intermediate Bjorken x, for instance. Precise measurements of W production in heavy-ion collisions can therefore constrain the nuclear PDFs (nPDFs).

2. $W \to \mu\nu$ in pp and PbPb collisions

W boson production has been studied using $(7.3 \pm 0.3)\,\mu b^{-1}$ of PbPb collisions recorded in 2010 and $(231 \pm 14)\,nb^{-1}$ of pp collisions recorded in 2011 [1], in the $W \to \mu\nu$ decay mode.

The muon and neutrino from the W boson are energetic, because of its high mass, and we use this feature to select signal events. The p_T spectrum of good quality muons in PbPb events shows a clear signal at around half the mass of the W boson, while the background is concentrated at low p_T. Furthermore, the information from the undetected neutrino can be partially accessed by reconstructing the missing transverse momentum ($\not{p}_T$) from the tracks in the silicon tracker. These characteristics motivate our selection of events, which must include one good quality, high p_T muon ($|\eta^\mu| < 2.1$, $p_T^\mu > 25\,\mathrm{GeV}/c$) and significant momentum imbalance ($\not{p}_T > 20\,\mathrm{GeV}/c$). We also cut on the transverse mass of the muon and $\not{p}_T$ system, $m_T = \sqrt{2p_T^\mu \not{p}_T(1-\cos\phi)} > 40\,\mathrm{GeV}/c^2$, to define an almost background-free sample, dominated at 98% by the W signal.

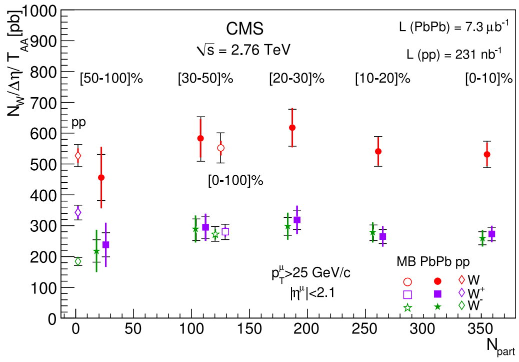

Figure 1. Collision centrality dependence of the nuclear modification factor R_{AA} for PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV compared to pp collisions at $\sqrt{s} = 2.76$ TeV.

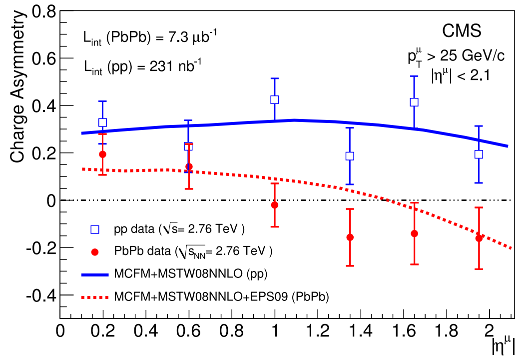

Figure 2. Muon charge asymmetry in W boson decays as a function of muon pseudo-rapidity for pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

The nuclear modification factor $R_{AA} = N_W/(T_{AA} \cdot \sigma_{pp})$ (where T_{AA} is the nuclear overlap function and σ_{pp} the cross section in pp collisions) has been measured for W^+ and W^- bosons separately, and for the combined charge, both inclusively and in bins of centrality, as can be seen on Fig. 1. We measure $R_{AA}(W) = 1.04 \pm 0.07(\mathrm{stat}) \pm 0.12(\mathrm{syst})$ when combining both charges, which is compatible with unity as expected. Qualitatively, such value is expected from the fact that the valence quark content of the proton is two u quarks and one d quark. Therefore we expect approximately twice as much W^+ as W^- bosons in proton-proton collisions, while the presence of neutrons in the lead nucleus, with opposite quark content, leads to the expectation of a more balanced production. The centrality dependence of the nuclear modification factor of W boson production in lead-lead collisions is consistent with being constant.

The charge asymmetry is defined as $\frac{N(W^+)-N(W^-)}{N(W^+)+N(W^-)}$. It should be noted that, due to the undetected neutrino, the rapidity of the W boson cannot be reconstructed, and hence the pseudo-rapidity of the muon is used as a proxy to this quantity. The charge asymmetry in pp and PbPb collisions is shown in Fig. 2 and compared to theoretical predictions. Again, the large difference between the two collision systems is due to the isospin effect, i.e. to the presence of neutrons in the lead nucleus. collisions, while it is closer to 0 in lead-lead collisions.

3. W $\rightarrow \ell\nu$ in pPb collisions

We have also studied W boson production in pPb collisions, using the $(34.6\pm1.2)\,\mathrm{nb}^{-1}$ integrated luminosity recorded in 2013 at $\sqrt{s_{NN}} = 5.02$ TeV [2]. Thanks to an asymmetric initial

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state, the study of W boson production in proton-nucleus instead of nucleus-nucleus collisions allows for the measurement of new observables, namely forward/backward asymmetries. Such asymmetries enhance the sensitivity to nPDF, due to the cancellation of uncertainties, both experimental and theoretical. The higher centre-of-mass energy available in the pPb dataset used ($\sqrt{s_{NN}}$ = 5.02 TeV) also implies a higher production cross section. As a result of the energy difference of the colliding beams, the nucleon-nucleon centre-of-mass frame in the pPb collisions is not at rest with respect to the laboratory frame. Massless particles emitted at $\eta = 0$ in the nucleon-nucleon centre-of-mass frame are detected at $\eta_{\rm lab} = 0.465$ in the laboratory frame. The results presented hereafter are expressed in the laboratory frame, with the proton-going side defining the positive η direction.

The selection of the events has some differences with the one used in the analysis of pp and PbPb collisions presented above. We require a lepton with $p_T^\ell > 25\,\mathrm{GeV}/c$, but we now study both the electron and muon channels, and extend the pseudo-rapidity coverage ($|\eta_{\rm lab}| < 2.5$ for electrons, $|\eta_{\rm lab}| < 2.4$ for muons). Moreover, no explicit missing transverse energy cut is applied: instead, the signal is extracted from a template fit to the missing transverse energy distribution. However, to keep the heavy-flavour and jet backgrounds to a reasonable level, the selected lepton is required to be isolated (the lepton isolation being defined by summing the transverse energy of particle flow candidates in a cone around the lepton). The W boson yields are extracted from a fit to the missing transverse energy distribution (see Fig. 3), the signal and background contribution being estimated from simulation (except for the QCD background, parametrised using data).

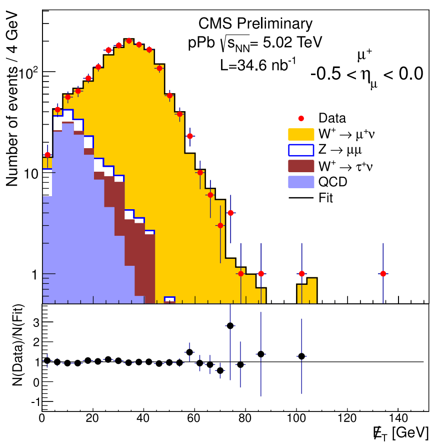

Figure 3. Missing transverse energy distribution for $W^+ \to \mu^+\nu$ in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV within the $-0.5 < \eta_{\rm lab} < 0.0$ range.

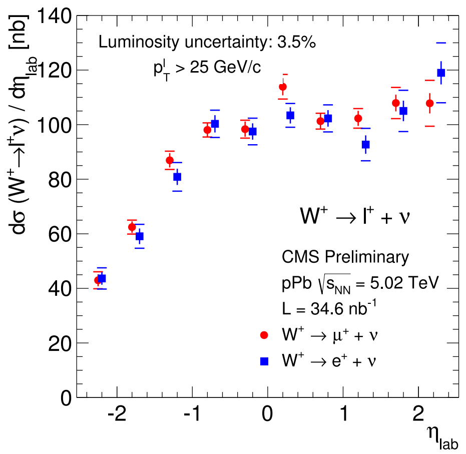

Figure 4. Production cross section for $W^+ \to \ell^+\nu$ in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV as a function of $\eta_{\rm lab}^\ell$.

We measure the W boson production cross section in both the electron and muon decay channels (see Fig. 4) and combine the measurements, for positively and negatively charged leptons separately. The results are consistent with theoretical predictions [3], but uncertainties are too large to probe the nuclear modifications of the PDF. For this reason, we build new observables. The charge asymmetry, for instance, has been introduced before, and is shown in Fig. 5. The theoretical uncertainties are much smaller than in the case of cross sections, but the assumptions of the EPS09 nPDF [4] do not lead to a significant modification of the charge asymmetry as compared to free proton PDF such as CT10 [5]. However the data deviate from

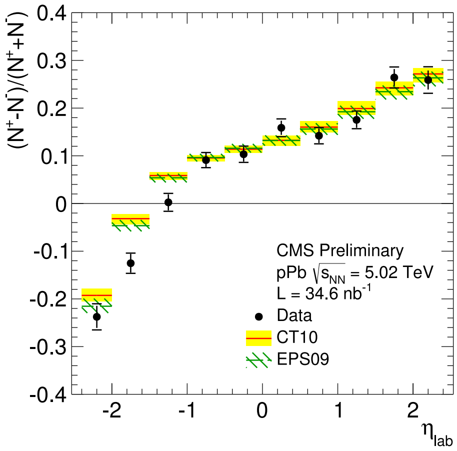

Figure 5. Charge asymmetry in W boson decays in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV as a function of η^{ℓ}_{lab}.

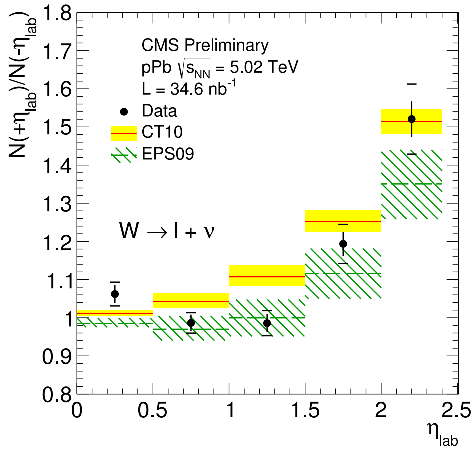

Figure 6. Forward-backward asymmetry in W boson decays in pPb collisions at $\sqrt{s_{NN}} =$ 5.02 TeV as a function of η^{ℓ}_{lab}.

theoretical predictions at large negative lepton pseudo-rapidity. A possible explanation for such deviation would be a different modification of u and d quarks in the nucleus, as opposed to what is assumed by EPS09.

We also measure forward-backward asymmetries: $N(+\eta_{\text{lab}})/N(-\eta_{\text{lab}})$. We first build them for each lepton charge separately. Again theoretical uncertainties are smaller than for cross sections, and here predictions with EPS09 differ significantly from those of CT10. The data seem to favour EPS09 for negatively charged leptons, while the conclusion is less clear for positively charged leptons. For an even better sensitivity to nPDF, we build the forward-backward asymmetry for both lepton charges combined, as shown on Fig. 6. Again the data seem to disfavour the absence of nuclear modifications of the PDFs.

4. Conclusion

We have presented the measurement of W boson production by the CMS experiment in pp, PbPb and pPb collisions at the LHC. In the case of PbPb collisions, we observe a large difference with measurements in pp collisions, which is dominated by the well-known isospin effect. The nuclear modification factor for W boson production, when combining both charges, is compatible with unity.

In the case of pPb collisions, we have built asymmetries in order to be sensitive to nuclear modifications of the PDFs. We see hints of such nuclear effects in the data. Moreover, some tension is seen between data and theory in the charge asymmetry.

Acknowledgments

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