The Compact Muon Solenoid Experiment
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W and Z bosons in pp, pPb and PbPb with CMS

Emilien Chapon for the CMS Collaboration

Abstract

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W and Z bosons with CMS in pp, pPb and PbPb collisions

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Abstract

Electroweak boson production is an important benchmark process in high-energy heavy-ion collisions at the LHC. W and Z bosons do not participate in the strong interaction and their leptonic decays provide medium-blind probes of the initial state of the collisions. The final results on the W and Z production in pPb collisions at 5.02 TeV, combining both the muon and electron channels, will be presented. When compared to theory calculations that include nuclear modifications to the parton distributions, data show a clear sensitivity to this type of effects. The final results in PbPb collisions at 2.76 TeV, compared to pp collisions at the same centre of mass energy, will also be presented. The centrality dependence confirms the binary scaling of hard probes in heavy-ion collisions, while the differential cross sections points to initial state effects small compared to the statistical precision of the available data.

Keywords: CMS, pPb collisions, PbPb collisions, Electroweak bosons

1. Introduction

Electroweak bosons are excellent probes for the study of heavy ion collisions. Their leptonic decays allow for a very clean experimental signature, with low background. Produced early in these collisions, they are not affected by final state effects in the medium. On the other hand, they are sensitive to several initial state effects, including nuclear modifications to the parton distribution functions (nuclear PDFs), in particular for quark PDFs, which can be studied and constrained using electroweak bosons.

2. W boson production in PbPb and pp

The production of W bosons at $\sqrt{s_{NN}} = 2.76$ GeV has been studied in CMS [1] in the muon channel, using data taken in 2010 (PbPb) and 2011 (pp) [2]. By selecting events with a muon pseudorapidity $|\eta^\mu| < 2.1$, transverse momentum $p_T^\mu > 25$ GeV, and missing momentum $p_T > 20$ GeV, an almost background-free sample of W boson candidates is obtained. The missing momentum is reconstructed using silicon tracks.

When comparing the production yield in PbPb, scaled by the nuclear overlap function T_{AA} , to that in pp, a large difference is found separately for W^+ and W^- bosons, due to the isospin effect, while the nuclear

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modification factor R_{AA} is consistent with unity when both charges are combined together. Moreover, no centrality dependence is observed.

The leptonic charge asymmetry, $(dN(W^+) - dN(W^-))/(dN(W^+) + dN(W^-))$, is also measured both in pp and PbPb collisions, as a function of the muon pseudorapidity (Fig. 1, left). Again, the large difference between pp and PbPb is solely due to the isospin effect, while the sensitivity to nPDF effects is limited.

Fig. 1. Left: the leptonic charge asymmetry measured for W bosons as a function of the muon absolute pseudorapidity, in pp (blue squares) and PbPb (red circles) collisions, overlaid with predictions from MCFM [3]. Right: the R_{AA} distribution for $Z \rightarrow e^+e^-$ (blue squares) and $Z \rightarrow \mu^+\mu^-$ (red circles) events as a function of the event centrality.

3. Z boson production in PbPb and pp

The measurement of Z boson production at $\sqrt{s_{NN}} = 2.76$ GeV in CMS has been made in both the electron and muon channels, using data taken in 2011 (PbPb) and 2013 (pp) [4]. Again, the selection of events (lepton pseudorapidity $|\eta^{\mu(e)}| < 2.4$ (1.44), $p_T^\ell > 20$ GeV, dilepton invariant mass $M_{\ell\ell} \in [60, 120]$ GeV) defines a nearly background free sample of Z boson candidates.

The nuclear modification factor has been measured in both the electron and muon channels, as a function of centrality, and is found to be consistent with unity for all centralities and both lepton flavours (Fig. 1, right). The differential production cross section has also been measured as a function of the Z boson rapidity, an observable having some sensitivity to nPDF effects, but the measurement is too statistically limited to clearly favour theoretical predictions with (CT10+EPS09) [5, 6] or without (CT10 only) nuclear modifications of the PDFs.

4. Z boson production in pPb

The asymmetry of proton nucleus collisions is beneficial to the study of electroweak bosons. Indeed, it allows the definition of forward-backward asymmetries, $R_{FB} = N(+y)/N(-y)$, where positive rapidities are defined on the proton-going side, and negative rapidities on the lead-going side. The sensitivity to nPDFs is much improved: in particular, at a given rapidity, a single Bjorken x in the lead is probed.

The selection of events for measuring the production of Z boson in pPb collisions in CMS [7] is similar to the one used for PbPb: both the electron and muon channels are used, but the main difference is that the pseudorapidity coverage for the electron channel has been extended from 1.44 to 2.4.

The differential cross section for Z boson production as a function of its rapidity in the centre of mass frame is measured separately in the electron and muon channels. After combining the two final states, it is compared to predictions using the MCFM generator [3] and CT10 free proton PDF, with and without nuclear modification of the PDFs, from EPS09 or DSSZ [8] (Fig. 2, left). Good agreement is seen between the data

Fig. 2. Left: the differential fiducial cross section for Z boson production, as a function of its rapidity in the centre of mass frame. The data is compared to predictions from the MCFM generator using CT10 (yellow), CT10+EPS09 (green) or CT10+DSSZ (red), and the ratio of the data and of the predictions to the one using CT10 is shown in the bottom panel. Right: Forward-backward asymmetry, measured in the fiducial region and compared to the same predictions as for the cross section. Again the bottom panel shows the ratio to the prediction using CT10.

and the prediction, even better when nuclear effects, especially important at large absolute pseudorapidity, are accounted for.

An improved sensitivity to nuclear PDFs is obtained by constructing the forward-backward asymmetry (Fig. 2, right). At large absolute rapidity, data favours the presence of nuclear effects even more clearly.

The differential cross section for Z boson production as a function of its transverse momentum has also been measured. The effect of nPDFs is small in this observable, and a good agreement with predictions from Powheg + Pythia is found. However, some deviation of the data from the expectation is found at low p_T , consistent with what has been already observed by the CMS experiment in pp collisions at $\sqrt{s} = 7$ TeV [9].

5. W boson production in pPb

The production of W bosons in pPb collisions has been measured using both the electron and muon channels (with $p_T^\ell > 25$ GeV and $|\eta^\ell| < 2.4$). No explicit cut is applied on the missing transverse energy, which is reconstructed using the particle flow algorithm: instead, the signal yields are extracted using a fit to the E_T distribution.

The production cross section as a function of the lepton pseudorapidity in the laboratory frame is measured for positively and negatively charged leptons, separately for the electron and muon channels. In good agreement with each other, these measurements are combined and compared to predictions, assuming CT10 or CT10+EPS09. The sensitivity to nuclear modifications of the PDFs is poor, but it can be improved by defining asymmetries, allowing the cancellation of part of the uncertainties, both in the data and the theory.

First, the charge asymmetry is measured, and compared to predictions from CT10, CT10+EPS09, but also CT10+DSSZ, CT10+nCTEQ15 [10] and CT10+HKN [11] (Fig. 3, left). This observable has a limited sensitivity to nuclear effects, because nuclear modification of the up and down quarks mostly cancel in the ratio. However, a small deviation of the data at large negative lepton pseudorapidity is observed with respect to predictions. A different modification of the up and down quarks in the nucleus could produce such an effect, a feature which only the nCTEQ15 nPDF set allows (though it does not fit better the data).

Forward-backward asymmetries are also defined, as was done for the Z boson production, for each lepton charge separately, and compared to predictions using CT10 or CT10+EPS09. While the data for negatively charged leptons seem to favour the latter prediction, the conclusion is unclear for positively charged leptons.

Fig. 3. Left: The lepton charge asymmetry, as a function of the lepton pseudorapidity in the laboratory frame, and compared to predictions using the MCFM generator and CT10 (yellow), CT10+nCTEQ15 (green) or CT10+HKN (purple). Right: the forward-backward asymmetry for the charge-summed W bosons, as a function of the lepton pseudorapidity in the laboratory frame. Theoretical predictions with CT10 (yellow), CT10+EPS09 (green) and CT10+DSSZ (blue) are also shown.

For an even better sensitivity, the asymmetries for both lepton charges are combined, and compared to the same predictions as the charge asymmetry (Fig. 3, right). Again, the data favours the presence of nuclear modifications of the PDF: a χ^2 test of the data against the CT10 and CT10+EPS09 predictions yields to a p-value of 29% and 83%, respectively.

6. Summary

The CMS Collaboration has measured W and Z boson in pp, pPb and PbPb collisions, thus probing initial state effects in heavy ion collisions. In PbPb collisions, the nuclear modification factor is found to be compatible with unity for both W and Z bosons, even though a large isospin effect is seen in W boson production. In pPb collisions, a better sensitivity to nuclear modifications of the PDFs is obtained. Hints of nuclear effects are observed in the data, which provide an important input for future nPDF fits. Some tension between data and theory in the charge asymmetry in W boson events points to a possibly different modification of the up and down quarks in the nucleus, an effect not accounted for in most nPDF sets currently available.

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