The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

29 March 2014 (v4, 09 April 2014)

Production of W and Z bosons in heavy-ion collisions with CMS

Alice Helene Florent for the CMS Collaboration

Abstract

Weak bosons do not participate in the strong interaction, 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 constraints on 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 channels allows their detection and reconstruction. A first analysis of PbPb data has confirmed the medium-blind characteristic of the electroweak bosons. This paper reports measurements of Z and W bosons, produced in PbPb and pp collisions at nucleon-nucleon centre of mass energy $\sqrt{s} = 2.76$ TeV with the CMS detector. The Z boson yield and the nuclear modification factor (R_{AA}) corresponding to an integrated luminosity of $150 \mu\text{b}^{-1}$ are presented, as a function of the centrality, of the Z rapidity and p_T , both in the muonic and electronic channels. Event centrality and muon pseudorapidity dependencies of the W production yields are presented separately for W^+ and W^- .

Presented at *HardProbes2013 6th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions*

Production of W and Z bosons in heavy-ion collisions with CMS

Alice Florent, on behalf of the CMS collaboration

LLR, Ecole Polytechnique, Palaiseau, France

259162

Abstract

Weak bosons do not participate in the strong interaction, 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 constraints on 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 channels allows their detection and reconstruction. A first analysis of PbPb data has confirmed the medium-blind characteristic of the electroweak bosons. This paper reports measurements of Z and W bosons, produced in PbPb and pp collisions at nucleon-nucleon centre of mass energy $\sqrt{s} = 2.76$ TeV with the CMS detector. The Z boson yield and the nuclear modification factor (R_{AA}) corresponding to an integrated luminosity of $150 \mu\text{b}^{-1}$ are presented, as a function of the centrality, of the Z rapidity and p_T , both in the muonic and electronic channels. Event centrality and muon pseudorapidity dependencies of the W production yields are presented separately for W^+ and W^- .

Keywords: Electroweak bosons, W, Z, PbPb collisions, pp collisions, electron, muon, nuclear modification factor, rapidity, transverse momentum, centrality, muon pseudorapidity, W charge asymmetry

1. Introduction

The unprecedented high energies and luminosities reached in heavy-ion collisions at the LHC have opened the possibility of producing significant yields of the weakly interacting bosons, Z and W. These bosons are produced in the primary binary nucleon-nucleon collisions and decay before the quark-gluon plasma expected formation time [1]. Their leptonic decay products do not interact with the hot and dense coloured matter. They are only sensitive to the initial state of the collision and in particular to the parton distribution functions (PDF) in the nuclei.

2. Lepton reconstruction

One of the particularly strong features of the CMS detector is its muon reconstruction [2]. The muon signature has a very good momentum resolution (1-2 % up to 100 GeV/c at mid-rapidity) due to the precise silicon tracking. Reconstructed tracks from the muon system are matched to tracks from the silicon tracker. The muon tracking efficiency is close to 98% and the large rapidity coverage of the muons chambers results in a large acceptance for single and di-muons. The W detection relies on the single muon detection coupled to the missing energy arising from the undetected neutrino. The Z reconstruction is also performed through the di-electron channel. The electron reconstruction associates tracks to an energy deposit in the electromagnetic calorimeter (ECAL). The ECAL clustering is designed to

Email address: alice.florent@cern.ch (Alice Florent, on behalf of the CMS collaboration)

collect and estimate the proper energy of electrons and photons. Electrons traversing the silicon layers of the tracker emit bremsstrahlung photons with a significant energy spread in the azimuthal direction. A dedicated algorithm, based on the shape of the spread, recovers for the electron radiation loss by finding the corresponding photon deposits. The electron tracking efficiency is about 98% in pp and 85% in PbPb collisions. The results presented in this paper are for $W \rightarrow \mu\nu$, $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$ from PbPb collisions.

3. The $W \rightarrow \mu\nu$ analysis

Data collected in 2010 ($7.2 \mu\text{b}^{-1}$) are used to search for W bosons decaying into muon and neutrino [3]. Only muons with p_T larger than 25 GeV/c are considered in this analysis. The high p_T cut significantly increased the signal to background ratio. Di-muon events, having an invariant mass between 60 and 120 GeV/c², are 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 neutrino are expected to have non-zero MET.

In this analysis, a missing transverse momentum is obtained by summing the p_T of all tracks. To reduce the background fluctuations only tracks with a p_T above 4 GeV/c are taken into account in the sum. In order to reduce the QCD contamination, only events with a missing transverse energy above 20 GeV are kept. The transverse mass is then calculated from the muon energy and the estimated missing transverse momentum. An additional cut of 40 GeV/c² is applied.

The resulting yields are 539 W candidates, 275 W^+ and 264 W^- . These numbers have to be compared with the ones obtained in the pp sample at 2.76 TeV with $L = 231 \text{ nb}^{-1}$: 466 W candidates with 301 W^+ and 165 W^- in the same window of pseudorapidity ($|\eta| \leq 2.1$). In these extracted yields the electroweak background, estimated at 2.1% in PbPb and 3% in pp collisions, has been removed. Simulations of $Z \rightarrow \mu^+ + \mu^-$, potentially losing one muon outside of the acceptance window, as well as $W \rightarrow \tau + \nu$ processes where the τ decays into a muon, are estimated from pp PYTHIA simulated samples, at the proper centre-of-mass energy.

The total systematic uncertainty on the W yield is estimated to be 7.5%. The main contributions are coming from the data-driven efficiency and from the MET calculation, both of the order of 4%. The total systematic uncertainty also includes 1% of remaining QCD contamination.

Figure 1. Muon charge asymmetry as a function of muon pseudo-rapidity for pp and PbPb collisions at 2.76 TeV.

Figure 2. Event centrality dependence of the $W \rightarrow \mu\nu$ yield per event divided by the average of the nuclear overlap function T_{AA} .

A W^+ (W^-) is produced at first order (pQCD) by the fusion of a valence quark u (d) and an anti-quark d (u) from the sea. Hence a pp collision is expected to produce more W^+ than W^- . In PbPb collisions there are more d than u quarks so one would expect more W^- than W^+ . This is known as the isospin effect, and it only reflects the quark content of the projectiles. In addition, lepton spin-momentum conservation redistributes the charge distribution over the η range. When produced, the W is boosted in the direction of the valence quark. This conservation laws imply that W are mainly left-handed, independently of the W charge. Since the neutrino is always left-handed and

the anti-neutrino right-handed, the muon trajectory depends on its charge. The μ^+ coming from W^+ is preferentially right-handed and is then produced backward with respect to the W^+ , at central rapidity. The μ^- coming from W^- is left-handed and thus produced in the W^- direction, at forward rapidity. With $|\eta_{muon}| \leq 2.1$ in the analysis, the yield of W^+ relative to W^- is enhanced. Fig.4 represents the charge asymmetry $N(W^+) - N(W^-)/N(W^+) + N(W^-)$ as a function of $|\eta_{muon}|$, for pp and PbPb data. The muon charge asymmetry is well modeled for both data samples. No nuclear effect, on top of the expected isospin one, can be seen within our given statistics.

The yield of W as a function of the event centrality is also studied. Fig.5 shows the binary-scaled yield of W^+ and W^- as a function of centrality. When no distinction of the W charge is made, the binary-scaled yield in PbPb is compatible with the pp one. The nuclear modification factor R_{AA} , defined as: $R_{AA} = \frac{N_{AA}}{T_{AA} \times \sigma_{pp}}$ is calculated. N_{AA} is the yield estimated from PbPb collisions corrected for acceptance and efficiency, σ_{pp} is the differential cross-section from the pp data obtained by dividing the yields by the integrated luminosity. T_{AA} is the nuclear overlap function, proportional to the number of elementary nucleon-nucleon binary collisions $N_{coll} = T_{AA} \times \sigma_{NN}$, estimated with Glauber models. The values of the nuclear factor for the W summed up over charge and split are: $R_{AA}(W) = 1.04 \pm 0.07$ (stat.) ± 0.12 (syst.), $R_{AA}(W^+) = 0.82 \pm 0.07$ (stat.) ± 0.09 (syst.) and $R_{AA}(W^-) = 1.46 \pm 0.14$ (stat.) ± 0.16 (syst.). The values of the charged boson R_{AA} are different from 1 and agree with the expectation from isospin effect.

4. The $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$ analyses

From the 2011 PbPb and pp data, the integrated luminosities are $L = 150 \mu b^{-1}$ and $L = 5.4 pb^{-1}$ respectively. Z candidates have been extracted as the yield between 60 and 120 GeV/c^2 of di-lepton invariant mass [4]. Only leptons with opposite charge, having a transverse momentum larger than 20 GeV/c and a pseudo-rapidity $|\eta^{muon}| < 2.4$ or $|\eta^{electron}| < 1.44$, are kept. The uncorrelated combinatorial background is estimated from the number of same sign pairs passing the analysis criteria. Concerning the muon channel no same sign pairs are found in the PbPb data and a single one is found in pp collisions, representing a negligible background (at about the per-mil level). The fake rate in electron reconstruction combined with the charge mis-identification probability bring a larger background estimated to be 8% in PbPb and 4% in pp collisions. The di-electron invariant mass distribution is displayed in Fig.3 for the pp collisions and in Fig.4 for the PbPb ones. On both the same sign pairs are represented with open black squares.

Figure 3. Di-electron invariant mass spectra with $|\eta^e| < 1.44$ and $p_T^e > 20$ GeV/c in pp collisions at 2.76 TeV.

Figure 4. Di-electron invariant mass spectra with $|\eta^e| < 1.44$ and $p_T^e > 20$ GeV/c in PbPb collisions at 2.76 TeV.

The three main systematic uncertainties are coming from the estimation of the remaining background, from the acceptance correction and from the determination of the degree of agreement between simulation and data. The remaining background, mainly coming from b-hadron decays, is less than 2% for both channel. This estimation is obtained by fitting the di-lepton invariant mass spectra with a normalized $\gamma^* + Z$ line-shape from simulation.

Both electron and muon results are compatible with $R_{AA} = 1$, as shown on Fig.5. Integrated over the entire centrality range, the R_{AA} values are: $R_{AA}^{\mu\mu} = 1.06 \pm 0.03 \pm 0.05$ and $R_{AA}^{ee} = 1.08 \pm 0.09 \pm 0.11$, where the first and second uncertainties are statistical and systematic, respectively. Z bosons are seen to scale with binary collisions. The Z

analysis allow extra observables such as the dependence of the nuclear modification factor as a function of the Z transverse momentum and rapidity. These results are presented on Fig.6 and 7 respectively and are compatible with $R_{AA} = 1$ all over the rapidity and p_T ranges.

Figure 5. R_{AA} extracted from PbPb and pp collisions at 2.76 TeV for $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$ as a function of the number of participants.

Figure 6. R_{AA} extracted from PbPb and pp collisions at 2.76 TeV for $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$ as a function of Z p_T .

Figure 7. R_{AA} extracted from PbPb and pp collisions at 2.76 TeV for $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$ as a function of Z rapidity.

5. Conclusion

The main conclusion of the above studies can be summarized this way : weak boson production is consistent with the binary-collision scaling hypothesis ($R_{AA}=1$) and can thus serve as reference to modified probes. The further analyses of the 2013 pPb data of W and Z bosons are in progress. The improved statistics, about 25,000 W per leptonic channel and the collision asymmetry will improve significantly the precision of charge asymmetry and could reveal parton distribution functions modifications in the nucleus as compared to proton.

Speaker received funding from the European Research Council, grant no. 259612

References

- [1] Conesa del Valle Z 2009 *Eur.Phys.J.* **C61** 729–733 (*Preprint* 0903.1432)

- [2] Chatrchyan S *et al.* (CMS Collaboration) 2008 *JINST* **3** S08004
- [3] Chatrchyan S *et al.* (CMS Collaboration) 2012 *Phys.Lett.* **B715** 66–87
- [4] CMS Collaboration 2013 (*Preprint CMS-PAS-HIN-13-004*)