The Compact Muon Solenoid Experiment

Conference Report

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27 March 2014 (v2, 31 March 2014)

Transverse momentum and pseudorapidity dependence of charged particle production and nuclear modification factor in proton-lead collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV with CMS

Krisztian Krajczar on behalf of the CMS Collaboration

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The transverse momentum (p_{T}) spectra of charged particles at various pseudorapidity ranges up to a p_{T} of 100 GeV/c are presented for proton-lead collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV. The nuclear modification factor is measured by dividing the measured mid-pseudorapidity proton-lead spectrum by a proton-proton referenced distribution constructed based on earlier measurements at several collision energies using an interpolation method. In addition, the asymmetries in the charge particle yields between positive and negative pseudorapidity ranges are presented as a function of p_{T} up to 100 GeV/c.

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

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The transverse momentum (p_T) spectra of charged particles at various pseudorapidity ranges up to a p_T of 100 GeV/c are presented for proton-lead collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The nuclear modification factor is measured by dividing the measured mid-pseudorapidity proton-lead spectrum by a proton-proton reference distribution constructed based on earlier measurements at several collisions energies using an interpolation method. In addition, the asymmetries in the charge particle yields between positive and negative pseudorapidity ranges are presented as a function of p_T up to 100 GeV/c.

Keywords:

Nuclear modification factor, CMS, LHC, pPb, proton-lead, charged particle

1. Introduction and Experimental Setup

Proton-nucleus (pA) collisions serve as baseline measurements for the study of nucleus-nucleus (AA) collisions, because in pA systems final-state medium effects are expected to be largely absent [1]. However, initial-state effects, such as the modification of parton distribution functions in the bound nucleons (nPDFs) will contribute to the observed physics signals allowing for a characterization of such effects relative to a proton-proton (pp) reference.

The modification of particle yields in pA collisions relative to pp baseline is typically accessed via the nuclear modification factor of charged particles, R_{pA} , which is defined as the ratio of the particle yields measured in pA collision and the particle yield of pp collisions, scaled by the average number of binary nucleon-nucleon collisions in the pA interaction, N_{coll} . In order to reveal nPDF properties a second observable is also constructed. It is the forward-backward asymmetry of the charged particle yields, Y_{asym} , defined as the particle yield on the Pb-going side over the p-going side in opposite centre-of-mass pseudorapidity regions.

The instrument used for the measurements is the CMS detector [2]. The central feature of the CMS apparatus is a superconducting solenoid, providing a magnetic field of 3.8 T. Immersed in the magnetic field are the silicon pixel and strip tracker, which are designed to provide a transverse momentum resolution of about 0.7 (2.0)% for 1 (100) GeV/c charged particles at normal incidence, the lead-tungstate electromagnetic calorimeter, the brass/scintillator hadron calorimeter, and the gas ionization muon detectors. The pseudorapidity, η , of a particle (in the laboratory frame) is defined as $\eta = \ln[\tan(\theta/2)]$, where θ is the polar angle with respect to the proton beam direction.

This measurement is based on a data sample corresponding to an integrated luminosity of 26 nb^{-1} , collected by the CMS experiment from pPb collisions during the 2013 LHC running at a centre-of-mass energy per nucleon pair of $\sqrt{s_{NN}} = 5.02$ TeV. The colliding proton beam had a larger per nucleon energy than the lead beam resulting in a rapidity shift of $\Delta y = 0.465$ towards the p-going side.

Minimum bias events were collected by requiring at least one track with $p_T > 400$ MeV/c reconstructed with the pixel detector. Offline selection of events were based on the hadron forward calorimeters (HF; $2.9 < |\eta| < 5.2$): only events depositing at least a total energy of 3 GeV on both sides were accepted. Events were expected to have at least one reconstructed primary vertex; beam related background was suppressed using standard techniques [3].

Measured primary particle yields are corrected to a detector-independent class of “double-sided” (DS) collision events, which are similar to the events that pass the offline event selection described above. A DS event is defined as a collision event producing at least one particle with a proper life time of $\tau > 10^{-18}$ s and energy $E > 3$ GeV in the pseudorapidity range $3 < |\eta| < 5$ on each side.

In order to extend the statistical reach of the p_T spectrum, minimum bias and single-track (reconstructed in the pixel and strip tracker) triggered data (with p_T thresholds of 12, 20, and 30 GeV/c) were combined [4]. Events with multiple pPb collisions (“pile-up”, $\sim 3\%$) were removed from the analysis.

2. Analysis procedure

Charged particles were reconstructed using the standard CMS track finder algorithm. Reconstructed tracks entering the analysis were required to pass a standard set of track quality selections described in Ref. [5]. Further, analysis-specific selections required the relative uncertainty of the p_T measurement to be less than 10%, and the significance of the observed distance of closest approach between the track and the primary vertex to be less than 3σ .

Primary charged particles are defined as all charged particles produced in the interaction with a proper lifetime τ of greater than 1 cm, including the products of strong and electromagnetic decays, but excluding particles originating from secondary interactions. The products of weak decays are only considered primary particles if they are the products of a particle produced in the interaction with a τ of less than 1 cm.

Track-level corrections are applied for the geometrical acceptance of the detector, the efficiency of the reconstruction algorithm, the fraction of tracks corresponding to the same, multiply reconstructed charged particle, the fraction of tracks corresponding to a non-primary charged particle, and the fraction of misreconstructed tracks that do not correspond to any charged particle. These correction factors are calculated as functions of η and p_T using simulated minimum bias HIJING and HIJING-embedded PYTHIA dijet events.

The shape of the measured p_T distribution is distorted due to finite bin widths and transverse momentum resolution effects. This finite bin width effect is corrected for by fitting the measured distribution and using the resulting fit function as a probability distribution to generate entries in a histogram with the same p_T bins as the measurement. The binning correction is then derived from the ratio of the entries in the bin centres of the histogram to the fit function. A similar method was used to study the effect of momentum resolution. The distortion due to resolution was $\leq 1\%$, which is not corrected in our final result but is taken as a systematic uncertainty.

The R_{pPb} measurement requires a pp reference distribution. However, at $\sqrt{s} = 5.02$ TeV collision energy no pp data were ever recorded thus an artificial reference spectrum is to be built. This is achieved by employing a direct interpolation method using measured pp spectra at 0.63, 1.8, and 1.96 TeV collision energies from CDF [6, 7], and at 0.9, 2.76, and 7 TeV collision energies from CMS [8, 9].

The interpolation may be performed as a function of p_T or as a function of $x_T \equiv 2p_T/\sqrt{s}$. For the p_T -based interpolation data at only two collisions energies extend above $p_T \approx 30$ GeV/c. Thus, the p_T -based direct interpolation is well constrained only at low p_T . In case of the x_T -based interpolation constrains from low energy data extend to such x_T values, which translate to $p_T > 30$ GeV/c values at $\sqrt{s} = 5.02$ TeV. The final pp reference spectrum is obtained by combining the p_T and x_T -based reference spectra by choosing the p_T -based interpolated spectrum below 12.5 GeV/c, the x_T -based spectrum above 13.5 GeV/c and implementing a linear weighting of the two between the above-mentioned p_T values. The interpolation is visualized at two p_T in the left side of Fig. 1

3. Results

All the results presented here are from Ref. [4]. In the following η_{CM} refers to centre-of-mass pseudorapidities and positive pseudorapidities correspond to the p-going side.

The measured charged particle yields in $\sqrt{s_{NN}} = 5.02$ TeV pPb collisions in the $|\eta_{CM}| < 1$, $0.3 < |\eta_{CM}| < 0.8$, and $0.8 < |\eta_{CM}| < 1.3$ pseudorapidity bins can be seen in Fig. 1. The forward η spectra have been scaled by multiples of 4 for better visibility. The pp reference spectrum is also shown scaled by the N_{coll} number of 6.9 ± 0.5 [4].

The measured charged particle R_{pPb} in $|\eta_{CM}| < 1$ can be seen in the left side of Fig. 2. The light gray uncertainty band represents the uncertainty of the Glauber calculation of N_{coll} . The light brown uncertainty band around the measured values shows the scale uncertainty, while all other uncertainties are shown by the yellow band. The nuclear modification factor shows a steady rise to unity at a $p_T \approx 4$ GeV/c, is flat to approximately 20 GeV/c, and then it seems to increase at higher p_T reaching a value around 1.3–1.4 at 70 GeV/c.

The right side of Fig. 2 and both panels of Fig. 3 show Y_{asym} measurements as a function of p_T for $0.3 < |\eta_{CM}| < 0.8$, $0.8 < |\eta_{CM}| < 1.3$, and $1.3 < |\eta_{CM}| < 1.8$, respectively. In all three η ranges, the value of Y_{asym} rises up to a p_T of 3 GeV/c, then falls to unity at a p_T of 10 GeV/c and remains constant to higher p_T . This rise is more pronounced as the separation between the p and Pb side increases.

Figure 1. *Left*: Measured charged particle invariant cross sections at different collision energies for two example values of $p_T = 3$ and 15 GeV/c. Second-order polynomial fits together with the 5.02 TeV prediction are also shown. *Right*: Measured and interpolated charged particle spectra measured in $\sqrt{s_{NN}} = 5.02$ TeV pPb collisions. Uncertainties are shown in the bottom panel.

Acknowledgements: The author wishes to thank the Hungarian Scientific Research Fund (NK 81447, K 81614) for its support.

References

- [1] C. A. Salgado et al, Proton–nucleus collisions at the LHC: scientific opportunities and requirements, J. Phys. G 39 (2012) 015010.
- [2] CMS Collaboration, The CMS experiment at the CERN LHC, JINST 0803 (2008) S08004.
- [3] CMS Collaboration, CMS Tracking Performance Results from early LHC Operation, Eur.Phys.J. C70 1165–1192.
- [4] CMS Collaboration, Charged particle nuclear modification factor and pseudorapidity asymmetry in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with CMS, CMS Physics Analysis Summary 2013.
- [5] CMS Collaboration, Tracking and Vertexing Results from First Collisions, CMS Physics Analysis Summary 2010.
- [6] CDF Collaboration, Transverse momentum distributions of charged particles produced interactions at $\sqrt{s} = 630$ GeV and 1800 GeV, Phys. Rev. Lett. 61 1819.
- [7] CDF Collaboration, Erratum: Measurement of particle production and inclusive differential cross sections in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV [Phys. Rev. D79 (2009) 112005], Phys. Rev. D82 119903.
- [8] CMS Collaboration, Charged particle transverse momentum spectra in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV, JHEP 08 (2011) 086.
- [9] CMS Collaboration, Study of high- p_T charged particle suppression in PbPb compared to pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Eur. Phys. J. 72 (2012) 1945.

Figure 2. *Left*: Charged particle R_{pPb} as a function of p_T . The light gray uncertainty band represents the uncertainty of the Glauber calculation of N_{coll} . The light brown uncertainty band around the measured values shows the scale uncertainty, while all other uncertainties are shown by the yellow band. *Right*: Y_{asym} of charged particles in $0.3 < |\eta_{CM}| < 0.8$. The ratio shows the yields on the Pb-going side over those on the p-going side.

Figure 3. Y_{asym} in two η_{CM} bins: $0.8 < |\eta_{CM}| < 1.3$ (left) and $1.3 < |\eta_{CM}| < 1.8$ (right). The ratio shows the yields on the Pb-going side over those on the p-going side.