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Open beauty measurements in pPb collisions with CMS

Hyunchul Kim for the CMS Collaboration

Abstract

We report the first measurements of fully reconstructed B mesons in collisions involving heavy ions. Rapidity and transverse momentum cross sections, measured at $\sqrt{s_{NN}} = 5.02$ TeV with the CMS detector, will be presented. For the same collision system, we will also report on the production of inclusive b-hadrons identified via their decays into J/ψ displaced from the primary collision vertex, and measured in a similar kinematic range as the identified B mesons. The nuclear modification factors, which are constructed using a theoretically calculated pp reference, will be shown together with cross-section asymmetries between equivalent positive and negative pseudo-rapidity ranges in the center-of-mass frame of the collision.

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Nuclear Physics A

Open beauty measurements in pPb collisions with CMS

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Abstract

The B^{+}, B^{0}, and B_s^0 mesons are exclusively reconstructed in proton-lead (pPb) collisions at $\sqrt{s_{NN}} = 5.02$ TeV by the CMS collaboration at the Large Hadron Collider (LHC). The cross sections are measured in the range of transverse momentum of 10 to 60 GeV/c and the center-of-mass rapidity smaller than 1.93. The nuclear modification factor for each particle species is estimated using theoretical calculations as the pp reference, and the experimental data are consistent with unity within the current uncertainties. The forward-to-backward asymmetry of B^{+} is also analyzed and does not show any nuclear effect in the measured rapidity range.

Keywords: B meson, pPb collision, CMS

1. Introduction

The heavy quarks generated in high-energy proton-proton (pp) collisions are useful to test perturbative Quantum-chromodynamics (pQCD) because they are produced in the hard processes. In addition, they are also useful to probe the hot and dense QCD medium via their interactions with the matter over the course of their propagation. On the other hand, there may be effects not related to hot nuclear matter, such as nuclear modifications to the parton distributions. pPb collisions may be used to isolate such effects as they are not expected to form an extended hot medium. Taking advantage of the large cross section of b quark production at the LHC, the CMS collaboration has measured the production cross sections of various B mesons, for the first time, in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

Previously, the CMS collaboration studied the b-hadron production in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV by using inclusive non-prompt J/ψ in the 2010 and 2011 data sets [1]. The analysis technique developed for non-prompt J/ψ has been extended to the exclusive B reconstruction via the combination of one or more charged particle tracks to the reconstructed J/ψ in the pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV recorded in 2013.

The B-meson species analyzed for this study are $B^{\pm}$, B^{0}, and B_s^0 that consist of u (or $\bar{u}$), d (or $\bar{d}$), and s (or $\bar{s}$) quark, respectively, in addition to the b ($\bar{b}$) quark. Although each B meson has many decay modes, the specific decay channel for J/ψ and a strange meson is selected for this analysis. Here, J/ψ is reconstructed from opposite charge-signed muon pair and the associated decay mesons are $K^{\pm}$, $K_0^*(892)$ and ϕ, respectively. Then, $K_0^*(892)$ and ϕ are reconstructed by $K^{+}\pi^{-}$ (or its charge conjugate $K^{-}\pi^{+}$) and $K^{+}K^{-}$, respectively. Note that in this document the contribution from the corresponding antiparticles is implicit in the notation for B^{+}, B^{0} and B_s^0.

The detailed description of the CMS detector elements are given in Ref. [2]. Among them, this analysis primarily uses the inner tracker and muon systems. The inner tracker system is located in the 3.8 T magnetic field generated by the superconducting solenoid, and consists of 1440 silicon pixel and 15 148 silicon strip detector modules with

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

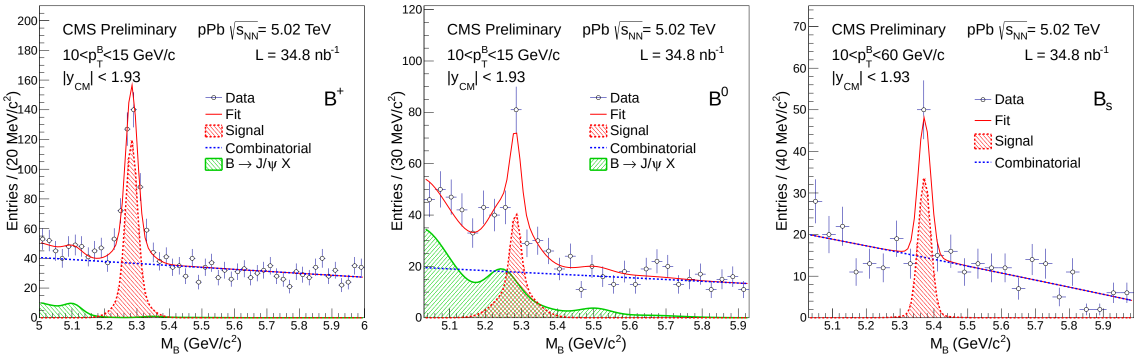

Figure 1. Invariant mass distributions of B^+ (left), B^0 (center) and B_s^0 (right) candidates in the transverse momentum ranges of 10 - 15, 10 - 15, and 10 - 60 GeV/c, respectively. The red-hatched areas represent the fitted B signal distributions, and the green-hatched areas represent the peaking backgrounds caused by wrongly reconstructed B mesons. The blue-dotted lines represent the combinatorial backgrounds.

a typical momentum resolution of 1.5% in p_T for nonisolated particles of $1 < p_T < 10$ GeV/c and $|\eta| < 1.4$. The muon system, consisting of Cathode Strip Chambers (CSC), Drift Tubes (DT) and Resistive Plate chambers (RPC), is dedicated to identifying and tracking the muons.

2. Analysis

The beam energy of $\sqrt{s_{NN}} = 5.02$ TeV is obtained by colliding lead nuclei of 1.58 TeV per nucleon with protons of 4 TeV. Because of the asymmetric beam energies, all produced particles from the collisions are detected with rapidity shift of 0.465 toward the proton-going side in the laboratory frame. The integrated recorded luminosity of the pPb data is 34.8 ± 1.2 nb^{-1}. The events used in this analysis are collected with a single-muon trigger that requires at least one muon with $p_T > 3$ GeV/c. The standard criteria are applied to remove electromagnetic and beam-gas collision events [3].

The B reconstruction starts with the muons that are reconstructed from the inner tracker system and the outer muon system. The muons must satisfy the muon selection criteria including the kinematic limits imposed by the geometry of the detectors: $p_T > 3.3$ GeV/c for $|\eta| < 1.3$, $p > 2.9$ GeV/c for $1.3 < |\eta| < 2.2$ and $p_T > 0.8$ GeV/c for $2.2 < |\eta| < 2.4$. The opposite-signed muon pairs with invariant mass within ±300 MeV/c^2 of the nominal J/ψ mass found in the particle data group [4] are used for further analysis.

The charged hadrons are reconstructed by the inner tracker system within $|\eta| < 2.4$ in the laboratory frame. For the reconstruction of B^+, the kaon mass is assigned to each charged particle and, then, the invariant mass distribution of J/ψ and kaon candidates are produced. The B^0 and B_s^0 analyses are more complicated than the charged B's as they decay into the intermediate states which can be reconstructed by the two charged hadrons. Therefore, for the reconstructions of B^0 and B_s^0, the pion and kaon masses are assigned to any pair of the charged particles.

To reduce the amount of background, each B candidate is required to pass optimized cuts, such as the χ^2 of the secondary vertex fit, the distance between the primary and the secondary vertices (normalized by its uncertainty) and the cosine of the angle between the momentum vector of B and the position vector of the secondary vertex measured from the primary vertex in the transverse plane, etc. For the B^0 and B_s^0 reconstructions, additional constraints on the respective proper mass window of the invariant mass for the intermediate meson states are imposed. When multiple B mesons are reconstructed in one event, the candidate with the best χ^2 of the secondary vertex is chosen because of the possible double counting, especially, for the B^0 case.

3. Results

All B candidates are reconstructed in $10 < p_T < 60$ GeV/c and $|y_{CM}| < 1.93$ in the center-of-mass frame. Figure 1 shows the invariant mass distributions of B^+, B^0 and B_s^0 in their respective lowest p_T bin. The combinatorial

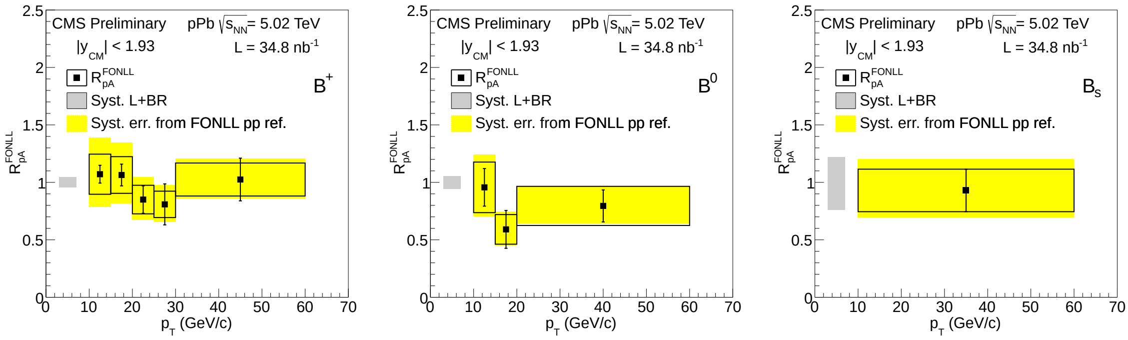

Figure 2. Nuclear modification factor R_{pA}^{FONLL} for B^+ (left), B^0 (center), and B_s^0 (right) within $|y_{CM}| < 1.93$ as a function of p_T in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The FONLL calculations are used as the pp references with the yellow areas representing the theoretical uncertainties. The vertical bars represent the statistical uncertainties, and the boxes around the data points display the total systematic uncertainties. The grey areas at $p_T = 5$ GeV/c represent the systematic uncertainties from the luminosity and the branching ratios of the decay channels.

backgrounds, fitted by first or second order polynomial functions, are dominated by inclusive J/ψ's and charged hadrons associated with different mother particles. In addition, the so-called peaking background is caused by the mis-reconstruction B mesons shown by the green hatched areas in Fig. 1.

In order to understand the signal and background shapes the Monte-Carlo simulations have been intensively performed. The particles in the Monte-Carlo samples are generated by the PYTHIA event generator [5] and decayed by the EvtGen particle decay simulation package [6]. The initial and final state radiations are controlled by the PHOTOS package [7]. Furthermore, the signal particles are embedded in the HIJING minimum-bias events for pPb collisions to mimic more realistic environment [8]. After the estimated backgrounds are properly subtracted, several functions are tried to fit the signal peak shapes for each channel. Finally, each signal peak is fitted by the sum of two Gaussian functions.

The differential cross section for each B species has been obtained by

$$\left.\frac{d\sigma^B}{dp_T}\right|_{|y_{CM}|<1.93} = \frac{1}{2}\frac{1}{\Delta p_T}\frac{N^B\big|_{|y_{CM}|<1.93}}{(\alpha\times\epsilon)\cdot BR\cdot\mathcal{L}}, \quad (1)$$

where Δp_T is the width of the p_T bin, α is the geometrical acceptance, ϵ is the efficiency estimated by the Monte-Carlo simulation, BR is the branching ratio of the decay mode, and $\mathcal{L}$ is the integrated luminosity. Note that the additional factor of 1/2 is multiplied to take into account the charge conjugate of each quark consisting B meson such as B^- for B^+.

For this analysis, the Fixed Order plus Next-to-Leading Logarithm (FONLL) calculations [9, 10] are used as the pp reference because the experimental pp data are not yet available at 5.02 TeV. Note that FONLL has successfully reproduced the CDF data at 1.96 TeV and the CMS/ATLAS data at 7 TeV within the experimental and theoretical uncertainties [11, 12]. Using the analyzed differential cross section data and the FONLL calculations, the nuclear modification factors are calculated by

$$R_{pA}^{FONLL}(p_T) = \frac{(d\sigma/dp_T)_{pPb}}{A\times(d\sigma/dp_T)_{pp}}, \quad (2)$$

where the number of nucleons in Pb, A, is introduced for normalization. The preliminary data on R_{pA}^{FONLL} for B^+, B^0 and B_s^0 are shown in Fig. 2. Considering the systematic and statistical uncertainties, R_{pA}^{FONLL}'s for all three particle species are consistent with unity and, thus, significant cold nuclear matter effects are not observed.

The left panel of Fig. 3 shows the differential cross section as a function of rapidity in the center-of-mass frame for B^+ with the most statistics among the three analyzed particle species. Although the most backward data point toward the Pb-going side is higher than the others, the experimental uncertainties are large and the rapidity dependence cannot

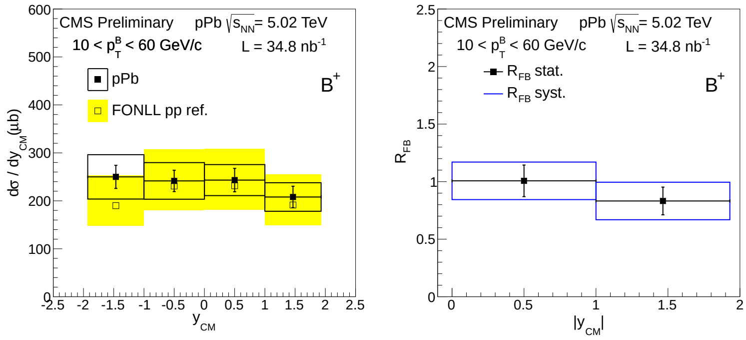

Figure 3. Differential cross section as a function of rapidity (left) and the forward-to-backward asymmetry R_{FB} (right) of B^+ in the center-of-mass frame of pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The vertical bars represent the statistical uncertainties, and the boxes around the data points display the total systematic uncertainties. The yellow areas for R_{pA}^{FONLL} are the theoretical uncertainties for the FONLL calculations.

be claimed. In addition, the right panel of Fig. 3 displays the distribution of the forward-to-backward asymmetry R_{FB} for B^+:

$$R_{FB} = \frac{N_{forward}^{Corrected}}{N_{backward}^{Corrected}}, \tag{3}$$

where the forward and backward imply the proton- and Pb-going directions, respectively. The preliminary data for R_{FB} of B^+ are consistent with unity, and the large uncertainties prevent any conclusion on the rapidity dependence.

4. Conclusions

The B^+, B^0, and B_s^0 mesons are exclusively reconstructed in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV by the CMS Collaboration at LHC. The range of transverse momentum covered is 10 to 60 GeV/c, for the rapidity range (evaluated in the center of mass) of $|y| < 1.93$. Statistically significant peaks are observed for all three B-meson species in the invariant-mass distributions.

The nuclear modification factors (R_{pA}^{FONLL}) for all three particle species are estimated using FONLL calculations as pp references. The nuclear modification factors are consistent with unity within the current uncertainties. The forward-to-backward asymmetry (R_{FB}) of B^+ is also analyzed, and it does not show any modification in the measured rapidity window.

Presently, the CMS Collaboration is preparing for the next LHC run in 2015 with the highest beam energy. The present results will be compared with the B meson data in heavy-ion collisions in the future.

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