Investigating Bottom Quark Energy Loss, Hadronization, and B Meson Nuclear Modification Factors in B^+ and B_s^0 Decays: Insights from CMS in pp, pPb, and PbPb Collisions

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Abstract. In this paper, using the exclusive decay channels $B_s^0 \rightarrow J/\psi\phi$ and $B^+ \rightarrow J/\psi K^+$, we present two studies made by the CMS Collaboration. The first is the p_T-differential cross sections of B_s^0 and B^+ mesons in pp collisions at 5.02 TeV. By utilizing previous PbPb collision data at the same nucleon-nucleon (NN) center of mass energy, R_{AA} factors for the B mesons are determined. The second one corresponds to the measurement of the B^+ meson production cross section with respect to meson transverse momentum inclusively and, for the first time, in different charged particle multiplicity ranges. This study is conducted in proton-lead collisions at a per nucleon center-of-mass energy of 8.16 TeV.

1 Introduction

Quantum chromodynamics (QCD) matter at high density under extreme conditions can form an exotic medium known as the quark-gluon plasma (QGP). In this state, quarks and gluons are no longer confined within hadrons but form a strongly interacting collective medium. Extensive research on the QGP has been conducted with heavy ion collisions. Recent observations of QGP-like phenomena in small collision systems, such as proton-proton (PP) and proton-lead (pPb) collisions [1, 2], challenge our understanding of high-energy heavy ion physics [3]. In particular for beauty quarks, there are still significant theoretical uncertainties in the hadronization process in the presence of the QGP because of a lack of understanding of the phenomena that can affect the production of hadrons. In particular, the strangeness content of the medium formed in heavy ion collisions is enhanced since the QGP temperature is larger than the strange quark mass. Therefore, through a quark-recombination mechanism, production of hadrons containing strangeness is expected to be enhanced relative to hadrons that do not contain strange quarks [4]. Recent studies of open-charm [5] and open-beauty [6] mesons in PbPb collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV at the LHC hinted an enhanced production of strange-charm and strange-beauty hadrons. Recently, this line of studies has been extended to heavy quarkonia B_c [7] and exotic hadron $X(3872)$ [8] production in PbPb collisions. To further investigate the hadronization of heavy quarks, the measurements of various flavors of beauty hadrons are essential, though they are notoriously difficult because of relatively small production cross sections compared to charm hadrons, large and varied background sources, and detector resolution limitations. In this paper, two recent results in this field are reviewed.

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2 Constraining bottom quark energy loss and hadronization with B^+ and B_s^0 nuclear modification factors in pp and PbPb collisions at 5.02 TeV with CMS

The CMS Collaboration reports on the production yields of B_s^0 and B^+ mesons in proton-proton (pp) collisions recorded in 2017 at the CERN LHC with a center-of-mass energy of 5.02 TeV. Utilizing an integrated luminosity of 302.3 pb^{-1}, the analysis focuses on the exclusive decay channels $B_s^0 \rightarrow J/\psi\,\phi$ and $B^+ \rightarrow J/\psi\,K^+$ in a transverse momentum (p_T) range of $7 < p_T(B) < 50$ GeV and a rapidity interval $|y| < 2.4$. Combining with the previous measurements in lead-lead collisions at the same center of mass, we measure the nuclear modification factor, R_{AA}, of the B mesons [4].

The p_T-differential production cross sections of B^+ (left) and B_s^0 mesons are presented in Fig. 1. The result is compared to the cross sections obtained from FONLL calculations [9], which are obtained by scaling the FONLL total b quark production by the world-average production fractions of B^+ (B_s^0) of 40.2 (10.5)%. The calculated FONLL reference spectra are consistent with both mesons' measured pp spectra within the quoted uncertainties.

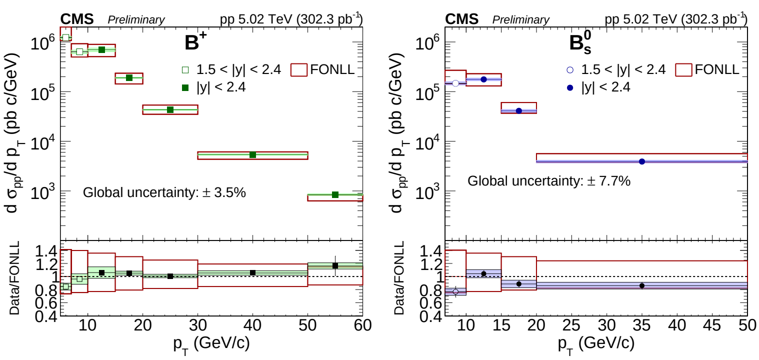

Figure 1. The p_T-differential cross section of B^+ (left) and B_s^0 (right) mesons in pp collisions at 5.02 TeV. The vertical bars (shaded boxes) correspond to statistical (systematic) uncertainties. The global systematic uncertainty includes uncertainties in the integrated luminosity and the external branching fractions. The comparison with the calculation from FONLL (open boxes) is also shown. The bottom panels show that the measured cross sections deviate from the FONLL calculations by less than 20%, and they are consistent within uncertainty [4].

The nuclear modification factors of B^+ (left) and B_s^0, are shown in Fig. 2 as a function of p_T. For B^+, a strong suppression is observed, and R_{AA} is around 0.3 to 0.6 in $7 < p_T < 50$ GeV. In $10 < p_T < 50$ GeV, R_{AA} of B_s^0 is also smaller than unity but compatible within uncertainties than that of B^+. Higher statistics in PbPb collisions are needed to verify this effect.

The B^+ and B_s^0 R_{AA} are compared in Fig. 3 to the CMS measurements of the R_{AA} of charged particles [10], D^0 mesons [11] performed at the same energy and in a similar centrality range. For B^+ mesons, the R_{AA} values are consistent with those of charged particles and D^0 mesons for $p_T > 10$ GeV. At lower p_T a hint of a reduced level of suppression is present for B^+ mesons, which is in line with expectations based on the quark mass dependence of parton energy loss.

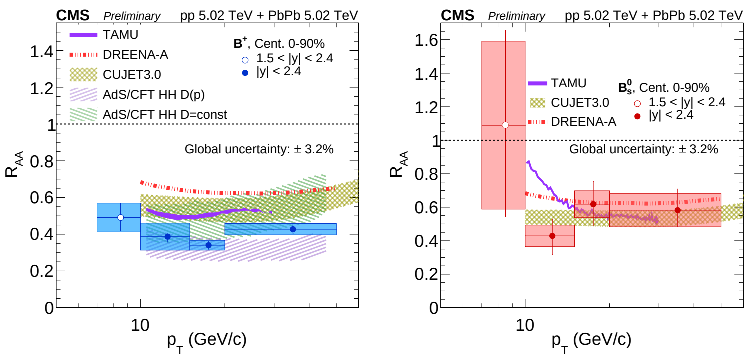

Figure 2. The p_T dependence of the nuclear modification factor of B^+ (left) and B_s^0 mesons in PbPb collisions at 5.02 TeV. The vertical bars (boxes) correspond to statistical (systematic) uncertainties. The global systematic uncertainty comprises the uncertainties in luminosity, T_{AA} and the number of minimum-bias events. Theoretical calculations are also shown for comparison [4].

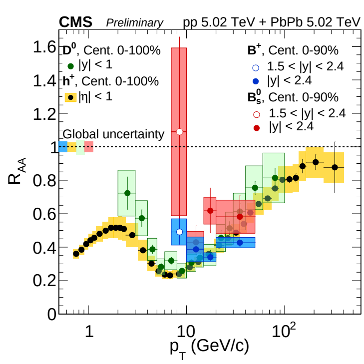

Figure 3. Comparison of the nuclear modification factor of B^+ and B_s^0 mesons with D^0 mesons [11] and charged hadrons [10] in PbPb collisions at 5.02 TeV. The global systematic uncertainties, depicted in shaded boxes around R_{AA} = 1, comprise the uncertainties in T_{AA}, the number of minimum-bias events, and the luminosity in pp collisions [3].

3 Measurement of the B^+ differential cross section as a function of transverse momentum and multiplicity in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV

The measurement of the B^+ meson production cross section with respect to the transverse momentum inclusively and, for the first time, in different charged particle multiplicities, in proton-lead collisions at a per nucleon center-of-mass energy of 8.16 TeV was performed. The data were collected by the CMS during 2016 and correspond to an integrated luminosity of 175 nb^{-1}. The measurement uses the exclusive decay channel $B^+ \to J/\psi K^+$ [3].

The results of the measurement of the differential cross section, for the phase space region $3 < p_T(B) < 50$ GeV and $|y(B)| < 1.8$, are displayed in Fig. 4 (left). In the same plot, the pp FONLL predictions [9] at the same energy are superimposed. The FONLL reference cross sections are obtained by scaling the FONLL total b quark production by the world-average B^+ production fraction of 40.2%. The FONLL predictions are scaled by the atomic mass of the Pb nucleus (A = 208), to consider the number of binary NN collisions.

The theoretical predictions of FONLL are in good agreement with the measurements. The event-by-event charged-particle multiplicity is defined using tracks originating from the PV, which must satisfy the following criteria: the impact parameter significance $(d/\sigma(d))$

measured with respect to the PV must be less than 3, both along ($d_z/\sigma(d_z)$), and transverse ($d_T/\sigma(d_T)$) to the beam direction, and the relative p_T uncertainty, $\sigma(p_T)/p_T$, must be less than 10%. To ensure high tracking efficiency and to reduce the rate of misreconstructed tracks, the requirements $|\eta| < 2.4$ and $p_T > 0.4$ GeV must be satisfied. The quantity N_{trk}^{corr} is the corresponding multiplicity corrected for detector and algorithm inefficiencies in the same kinematic region. Figure 4 (right) shows the differential cross section in p_T bins divided into classes of charged particle multiplicity.

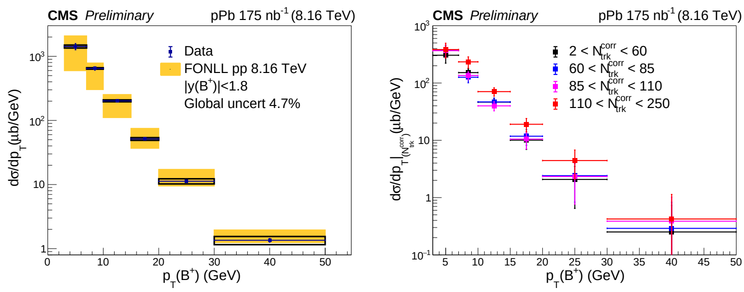

Figure 4. (Left) B^+ differential cross section in p_T bins. The vertical bars (boxes) represent the statistical (systematic) uncertainties. The global systematic uncertainty, not included in the data points, comprises the uncertainties in the integrated luminosity measurement and the B meson branching fractions. Results are compared to FONLL calculations, scaled by the number of binary NN collisions, represented by squares. The yellow boxes represent the theoretical uncertainties from FONLL [9]. (Right) B^+ differential cross section shown in p_T bins divided into classes of reconstructed track multiplicity. The vertical bars represent the total uncertainties [3].

4 Summary

The exclusive decay channels $B_s^0 \rightarrow J/\psi\phi$ and $B^+ \rightarrow J/\psi K^+$ are investigated. The differential cross sections are well-described by fixed-order plus next-to-leading logarithm calculations. Utilizing pp and PbPb collision data at 5.02 TeV R_{AA} factors for the B mesons are determined. Additionally, conducted in proton-lead collisions at 8.16 TeV, the measurement of the B^+ meson production cross section is presented with respect to meson p_T inclusively and, for the first time, in different charged particle multiplicity ranges.

References

[1] CMS collaboration, Phys. Rev. Lett. **115**, 012301 1 2015.
[2] CMS collaboration, Eur. Phys. J. C **77**, 269 4 2017.
[3] CMS collaboration, CMS-PAS-HIN-22-001, 2023.
[4] CMS collaboration, CMS-PAS-HIN-21-014, 2023.
[5] ALICE collaboration, J. High Energ. Phys. **10**, 174 2018.
[6] CMS collaboration, Phys. Lett. B **796**, 168 2019.
[7] CMS collaboration, Phys. Rev. Lett. **128**, 252301 25 2022.
[8] CMS collaboration, Phys. Rev. Lett. **128**, 032001 3 2022.
[9] M. Cacciari and others, J. High Energ. Phys. 137 2012.
[10] CMS collaboration, J. High Energ. Phys. **04**, 039 2017.
[11] CMS collaboration, Phys. Lett. B **782**, 474 2018.