Production of J/ψ and Υ mesons in proton-lead collisions at $\sqrt{s_{NN}} = 5$ TeV

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Abstract

The production of J/ψ and Υ -mesons decaying into dimuon final state is studied at the LHCb experiment, with rapidity $1.5 < y < 4.0$ or $5.0 < y < 2.5$ and transverse momentum $p_T < 15$ GeV/ c , in proton-lead collisions at a proton-nucleon centre-of-mass energy $\sqrt{s_{NN}} = 5$ TeV. The analysis is based on a data sample corresponding to an integrated luminosity of 1.6 nb^{-1} . The nuclear modification factor and the forward-backward production ratio are determined for J/ψ and $\Upsilon(1S)$ mesons. At large rapidity clear suppression of prompt J/ψ production is observed with respect to the production in pp collisions, while the suppression of J/ψ from b -hadron decays is less pronounced. The nuclear modification factor for $\Upsilon(1S)$ mesons in the forward region is found to be similar to those for J/ψ from b -hadron decays, and there is an indication of antishadowing effect in the backward region.

Keywords: proton-lead, quarkonium, heavy ions, cold nuclear matter effects, nuclear modification factor

1. Introduction

In ultra-relativistic heavy-ion collisions, the production of heavy quarkonia are expected to be suppressed with respect to proton-proton collisions, if the quark-gluon plasma (QGP), a hot nuclear medium, is created [1]. This suppression is considered as a good probe to QGP, since heavy quarkonia are produced at the early stage of heavy-ion collisions. On the other hand cold nuclear matter effects, such as nuclear shadowing and energy loss, also have similar signature. Cold nuclear matter effects can be disentangled using the measurement of quarkonium production in proton-nucleus (pA) collisions. Therefore, it is important to study cold nuclear matter effects in pA collisions for quantitative understanding of the property of QGP.

In early 2013, the LHCb detector [2] collected around 1.6 nb^{-1} data of $p\text{Pb}$ collisions, the centre-of-mass energy of the nucleon-nucleon system, $\sqrt{s_{NN}}$ is around 5 TeV. During the data taking, the LHC swapped the directions of the proton beam and the lead beam, which makes it possible to study the physics in both forward region and backward region, where “forward” means the direction of the proton beam, and the rapidity y in this direction is positive. With these samples LHCb studied the productions of J/ψ and Υ -mesons using the dimuon final state and the corresponding cold nuclear matter effects [3, 4]. This talk reported the recent results.

2. Production of J/ψ and Υ mesons

In the analysis both J/ψ and Υ mesons are reconstructed with dimuon final states. Owing to its excellent vertex detector, the LHCb detector has the ability to distinguish prompt J/ψ mesons and J/ψ mesons from b -hadron decays,

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Figure 1. Projections of the combined fit on (a,b) dimuon invariant mass and (c,d) in two representative bins in the (a,c) forward and (b,d) backward regions.

use a combined fit to the dimuon invariant mass and pseudo-proper time distributions [3]. Figure 1 shows the projections of this combined fit in two representative bins in the forward and backward regions. Figure 2 shows the dimuon invariant mass distribution around $\Upsilon(nS)$ masses.

The trigger efficiency is determined using an unbiased data sample, which means that the event is still triggered even if the tracks of the signal are removed. The muon identification efficiency is also determined using a data-driven tag-and-probe method [5]. Figure 3 shows the single differential production cross-sections for prompt J/ψ and J/ψ from b as functions of transverse momentum p_T and rapidity y in the forward and backward regions. Their integrated cross-sections with $p_T < 14 \text{ GeV}/c$ are measured to be

$$\begin{aligned}\sigma_F(\text{prompt } J/\psi, +1.5 < y < +4.0) &= 1168 \pm 15 \pm 54 \text{ } \mu\text{b}, \\ \sigma_B(\text{prompt } J/\psi, -5.0 < y < -2.5) &= 1293 \pm 42 \pm 75 \text{ } \mu\text{b}, \\ \sigma_F(J/\psi \text{ from } b, +1.5 < y < +4.0) &= 166.0 \pm 4.1 \pm 8.2 \text{ } \mu\text{b}, \\ \sigma_B(J/\psi \text{ from } b, -5.0 < y < -2.5) &= 118.2 \pm 6.8 \pm 11.7 \text{ } \mu\text{b},\end{aligned}$$

where the first uncertainty is statistical and the second is systematic, a convention used in the following. Limited by statistics, only the total cross-sections of Υ mesons are measured. The products of production cross-sections and branching fractions for $\Upsilon(nS)$ mesons with $p_T < 15 \text{ GeV}/c$ are

$$\begin{aligned}\sigma(\Upsilon(1S), -5.0 < y < -2.5) \times \mathcal{B}(1S) &= 295 \pm 56 \pm 29 \text{ nb}, \\ \sigma(\Upsilon(2S), -5.0 < y < -2.5) \times \mathcal{B}(2S) &= 81 \pm 39 \pm 18 \text{ nb}, \\ \sigma(\Upsilon(3S), -5.0 < y < -2.5) \times \mathcal{B}(3S) &= 5 \pm 26 \pm 5 \text{ nb}, \\ \sigma(\Upsilon(1S), 1.5 < y < 4.0) \times \mathcal{B}(1S) &= 380 \pm 35 \pm 21 \text{ nb}, \\ \sigma(\Upsilon(2S), 1.5 < y < 4.0) \times \mathcal{B}(2S) &= 75 \pm 19 \pm 5 \text{ nb}, \\ \sigma(\Upsilon(3S), 1.5 < y < 4.0) \times \mathcal{B}(3S) &= 27 \pm 16 \pm 4 \text{ nb},\end{aligned}$$

where $\mathcal{B}(nS)$ ($n = 1, 2, 3$) represents the branching fraction of the $\Upsilon(nS) \rightarrow \mu^+\mu^-$ decay. All these production results are obtained assuming that the J/ψ and $\Upsilon(nS)$ mesons are produced with no polarisation.

3. Cold nuclear matter effects on J/ψ and Υ mesons

Using the measured production cross-sections in the forward and backward regions, the cold nuclear matter effects on prompt J/ψ , J/ψ from b and $\Upsilon(1S)$ mesons are studied. To determine the nuclear modification factor R_{pPb} , the reference cross-sections in pp collisions at $\sqrt{s_{NN}} = 5 \text{ TeV}$ are needed. These reference cross-sections [6] are obtained by a power-law fit to the previous LHCb measurements of J/ψ and $\Upsilon(nS)$ productions at 2.76 TeV, 7 TeV and 8 TeV [7, 8, 9, 10, 11].

Figure 4 shows the nuclear modification factors (the left two plots) and the forward-backward production ratios (the right two plots), as defined in Ref. [3], for prompt J/ψ mesons and J/ψ from b -hadron decays as functions of rapidity, compared with different theoretical predictions [12, 13, 14, 15]. The nuclear modification factor and forward-backward production ratio for J/ψ from b reflect the cold nuclear matter effects on b hadrons. A clear suppression at

Figure 2. Dimuon invariant mass distribution around $\Upsilon(nS)$ masses in the (left) forward and (right) backward regions. Figure 3. Single differential production cross-sections for prompt J/ψ and J/ψ from b as functions of (a,b) p_T and (c,d) y in the (a,c) forward and (b,d) backward regions.

large rapidity is observed for prompt J/ψ production, while the suppression of J/ψ production from b -hadron decays is smaller than that of prompt J/ψ production. This means that the cold nuclear matter effects on b hadrons are smaller than those on prompt J/ψ mesons. The calculations in Refs. [12, 15] consider the modification effects of the gluon distribution function in nuclei with the parameterisation EPS09 [16] or nDSg [17]. The parton shadowing effects in Ref. [13] are parameterised with EPS09. Reference [14] gives theoretical calculations of a coherent parton energy loss effect in both initial and final states, with or without additional parton shadowing effects parameterised with EPS09. Due to the large uncertainties, the data and theoretical predictions agree.

The top (bottom) four plots in Fig. 5 show the nuclear modification factors R_{pPb} (forward-backward production ratios R_{FB}) for $\Upsilon(1S)$ mesons as functions of rapidity, compared both with the LHCb results of prompt J/ψ and J/ψ from b and with different theoretical predictions displayed one per panel [13, 14, 18]. The data are consistent with a suppression in the forward region and an enhancement in the backward region. In the forward region, the data indicate that the production suppression of $\Upsilon(1S)$ mesons is smaller than that of prompt J/ψ mesons. The central value of R_{pPb} for $\Upsilon(1S)$ mesons is close to that for J/ψ from b -hadron decays, indicating that the cold nuclear matter effects on $\Upsilon(1S)$ mesons and b hadrons are similar. Due to the large uncertainties, the data and theoretical predictions agree.

Figure 4. Nuclear modification factors and forward-backward production ratios for prompt J/ψ and J/ψ from b as functions of rapidity.

Figure 5. (Top) Nuclear modification factors and (bottom) forward-backward production ratios for prompt J/ψ , J/ψ from b and $\Upsilon(1S)$ mesons, compared with different theoretical predictions.

4. Conclusion

Using the 1.6 nb^{-1} $p\text{Pb}$ data collected by the LHCb detector, the productions of prompt J/ψ mesons, J/ψ from b -hadron decays, and $\Upsilon(1S)$ mesons are measured with transverse momentum $p_T < 14$ (15) GeV/c and rapidity $-5.0 < y < -2.5$ or $1.5 < y < 4.0$. The cold nuclear matter effects are studied based on these measurements. The nuclear modification factors and forward-backward production ratios are determined for prompt J/ψ mesons, J/ψ from b -hadron decays, and $\Upsilon(1S)$ mesons. The results are in agreement with most theoretical predictions. The data show that prompt J/ψ production are strongly suppressed by cold nuclear matter effects, much stronger than those effects on b hadrons and $\Upsilon(1S)$ mesons are small. It indicates that the cold nuclear matter effects on $\Upsilon(1S)$ mesons are similar to those on b hadrons.

References

- [1] T. Matsui and H. Satz, Phys. Lett. **B178** (1986) 416.
- [2] LHCb collaboration, A. A. Alves Jr. *et al.*, JINST **3** (2008) S08005.
- [3] LHCb collaboration, R. Aaij *et al.*, JHEP **02** (2014) 072.
- [4] LHCb collaboration, R. Aaij *et al.*, JHEP **07** (2014) 094.
- [5] A. Jaeger *et al.*, CERN-LHCb-PUB-2011-025.
- [6] ALICE and LHCb collaborations, LHCb-CONF-2013-013, ALICE-PUBLIC-2013-002.
- [7] LHCb collaboration, R. Aaij *et al.*, JHEP **02** (2013) 41.
- [8] LHCb collaboration, R. Aaij *et al.*, Eur. Phys. J. **C71** (2011) 1645.
- [9] LHCb collaboration, R. Aaij *et al.*, JHEP **06** (2013) 64.
- [10] LHCb collaboration, R. Aaij *et al.*, Eur. Phys. J. **C74** (2014) 2835.
- [11] LHCb collaboration, R. Aaij *et al.*, Eur. Phys. J. **C72** (2012) 2025.
- [12] E. G. Ferreiro, F. Fleuret, J. P. Lansberg, and A. Rakotozafindrabe, Phys. Rev. **C88** (2013) 047901.
- [13] J. L. Albacete *et al.*, Int. J. Mod. Phys. **E22** (2013) 1330007.
- [14] F. Arleo and S. Peigné, JHEP **03** (2013) 122.
- [15] Z. C. del Valle, E. G. Ferreiro, F. Fleuret, J. P. Lansberg and A. Rakotozafindrabe, arXiv:1402.1747 [hep-ph].
- [16] K. Eskola, H. Paukkunen, and C. Salgado, JHEP **04** (2009) 065.
- [17] D. de Florian and R. Sassot, Phys. Rev. **D69** (2004) 074028.
- [18] E. G. Ferreiro *et al.*, Eur. Phys. J. **C73** (2011) 2427.