PROCEEDINGS OF SCIENCE

J/ψ production in proton-lead collisions at LHCb

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The production of prompt J/ψ and J/ψ from b-hadron decays has been studied in proton-lead collisions with the LHCb detector at the proton-nucleon centre-of-mass energy $\sqrt{s_{\rm NN}} = 5$ TeV. The nuclear modification factor and forward-backward production ratio for prompt J/ψ are determined for the first time. The results show clear suppression of the J/ψ yield with respect to pp collisions in the forward region. Theoretical predictions are in good agreement with the experiment results. The analysis is based on a data sample corresponding to an integrated luminosity of 1 nb^{-1}.

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1. Introduction

Quarkonium production suppression is one of the most distinctive signatures of the formation of quark-gluon plasma (QGP) [1]. However, in heavy-ion collisions cold nuclear matter effect can also lead to the suppression of quarkonium [2–4]. Proton-nucleus (pA) collisions, where a QGP is not expected be created, provide a good platform to study cold nuclear matter effects [3]. The nuclear modification factor $R_{p\text{A}} \equiv \sigma_{p\text{A}}/(A \times \sigma_{pp})$ and the forward-backward production ratio $R_{\text{FB}} \equiv R_{p\text{A}}^{\text{forward}}/R_{p\text{A}}^{\text{backward}}$ discussed below provide a quantitative measure for cold nuclear matter effects, where A is the atomic mass number of the nucleus [4].

The asymmetric layout of the LHCb experiment [5] allows a measurement of $R_{p\text{A}}$ for both the forward (pA) and backward (Ap) regions, taking advantage of the inversion of the proton and lead beams during the pPb data-taking. The centre-of-mass energy of the proton-nucleon system is 5 TeV. Due to the asymmetry in the energy per nucleon in the two beams, the proton-nucleon centre-of-mass system has a rapidity in the laboratory frame of $+0.47$ (-0.47) for pA (Ap) collisions. Therefore, the rapidity range $1.5 < y < 4.0$ is studied for pA collisions, and $-5.0 < y < -2.5$ for Ap collisions.

This analysis is based on a data sample acquired during the pPb run in early 2013, corresponding to an integrated luminosity of 0.75 nb^{-1} (0.30 nb^{-1}) for pA (Ap) collisions. In this analysis the differential production cross-sections of prompt J/ψ and J/ψ from b-hadron decays are measured. The measurements of $R_{p\text{A}}$ and R_{FB} for prompt J/ψ are presented. The results are preliminary and based on Ref. [6].

2. Event selection and cross-section determination

The J/ψ production cross-section measurement follows the approach described in Refs. [7–9]. The J/ψ candidates are reconstructed and selected using dimuon final states. The candidates are selected from pairs of oppositely charged particles with transverse momentum $p_{\text{T}} > 0.7\,\text{GeV}/c$, which are identified as muons by the muon detector and have a track fit χ^2 per degree of freedom less than 3. The difference between the logarithms of the likelihoods for the muon and the pion hypotheses $\text{DLL}_{\mu\pi}$ [10] is required to be greater than 1.0. The two muons are required to originate from a common vertex with a χ^2-probability larger than 0.5%. Candidates are kept if the invariant mass falls in a mass window of $\pm 120\,\text{MeV}/c^2$ around the known J/ψ mass [11].

The numbers of prompt J/ψ and J/ψ from b-hadron decays in bins of the kinematic variables y and/or p_{T} are obtained by performing a combined fit to the distributions of the dimuon invariant mass and the pseudo-proper time t_z in each kinematic bin. The pseudo-proper time of the J/ψ meson is defined as $t_z = \frac{\Delta z \times M_{J/\psi}}{p_z}$, where Δz is the distance along the beam axis z between the J/ψ decay vertex and its associated primary vertex refitted after removing the two muon tracks from the J/ψ candidate, p_z the measured J/ψ momentum in z direction, and $M_{J/\psi}$ the known J/ψ mass [11].

The signal dimuon invariant mass distribution in each p_{T} and y bin is modelled by a Crystal Ball (CB) function [12], and the combinatorial background by an exponential function. The t_z signal distribution is described by the sum of a delta function at $t_z = 0$ for the prompt J/ψ and an exponential decay function for the J/ψ from b component, convolved with a resolution function modelled by a double-Gaussian function. The t_z background distribution in each kinematic bin is independently modelled with an empirical function based on the t_z distribution of background using the *sPlot* technique [13]. The total fit function is the sum of the products of the mass and t_z fit functions for the signal and background components. Figure 1 shows projections of the fit on mass and t_z. The resolutions of the dimuon invariant mass in pA and Ap samples are consistent with each other, about $15\,\mathrm{MeV}/c^2$, and are both consistent with that in pp collisions. The yields of prompt

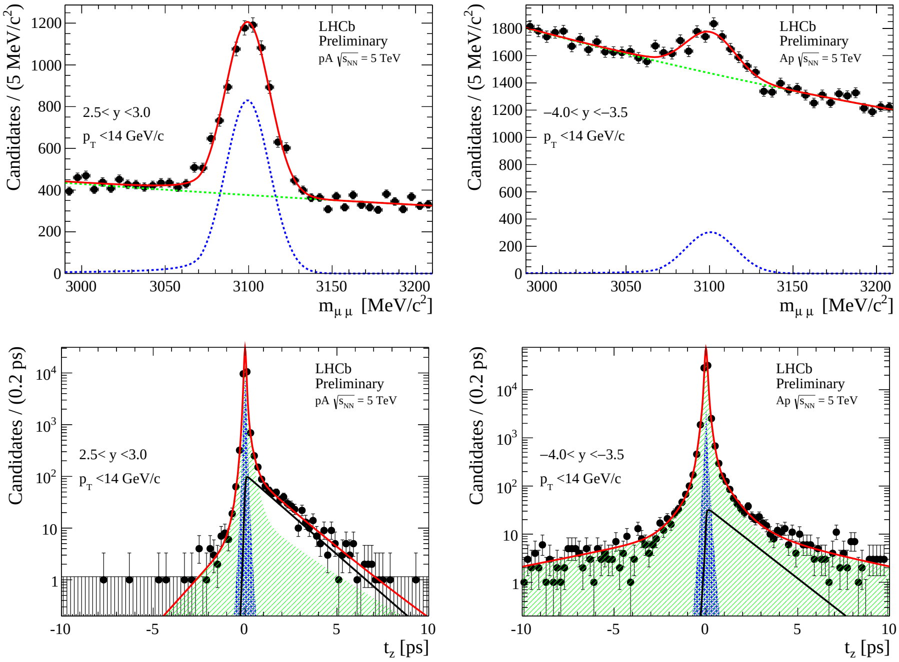

Figure 1: Projections of the combined fit onto (top) invariant dimuon mass and (bottom) t_z in pA (left) and Ap (right) samples. For the mass projection the total fitted function is shown (red solid line) together with the signal distribution(blue dotted line) and background (green dotted line). For the t_z projection the total fitted function is shown by the solid red line, the background indicated by the green hatched area, the prompt signal by the blue area and J/ψ from b by the solid black line.

J/ψ and J/ψ from b are then corrected with the efficiency event-by-event. The efficiency depends on p_{T} and y, and includes the geometrical acceptance, reconstruction and trigger efficiencies. The acceptance and reconstruction efficiencies are estimated from the simulated samples. The trigger efficiency is obtained from the data by exploiting a sample of J/ψ events that would still be triggered if the J/ψ candidates were removed. The differential cross-section is defined as the efficiency corrected number of J/ψ signal candidates in the given bin divided by the integrated luminosity, the branching fraction of the $J/\psi \to \mu^+\mu^-$ decay, and the widths of the p_{T} and y bins.

3. Systematic uncertainties

The different contributions to the systematic uncertainties affecting the cross-section measurement are discussed in the following and summarised in Table 1. The influence of the fit function used to describe the shape of the dimuon invariant mass distribution is estimated by fitting the invariant mass distribution with the sum of two Crystal Ball functions. The uncertainty of the luminosity determination is estimated to be 5% according to earlier studies [14]. The uncertainty due to reconstruction efficiency of the muon tracks is estimated using a data-driven tag-and-probe

Table 1: Relative systematic uncertainties on the differential production cross-section.

Source	Systematic uncertainty (%)
Correlated between bins	
Mass fits	1.8
Tracking efficiency	1.5
$\mathscr{B}(J/\psi \to \mu^+\mu^-)$	1.0
Luminosity	5.0
t_z fit (*only for J/ψ from b*)	5.0
Vertexing, track quality, etc.	3.5
Uncorrelated between bins	
Binning	0.1 to 14

approach [15] based on partially reconstructed J/ψ decays. The uncertainties related to the radiative tail, vertexing, track quality and muon identification are taken from Refs. [7–9], but have been increased conservatively by 30%, leading to an overall uncertainty of 3.5%. The same has been done for the uncertainty due to the t_z fit procedure, which only affects the component of J/ψ from b. An uncertainty of 5% has been conservatively assigned. Differences in the p_{T} and y spectra between the data and MC can effect the result because of the finite size of the bins. To estimate this affect, the total efficiency has been checked by doubling the number of bins in p_{T} and rapidity. The relative difference with respect to the nominal binning, is taken as systematic uncertainty.

4. Results

The single differential cross-sections for prompt J/ψ production and J/ψ from b in pA and Ap as functions of p_{T} and y, assuming no J/ψ polarization, are shown in Fig. 2. The integrated cross-section for prompt J/ψ with $p_{\mathrm{T}} < 14\,\mathrm{GeV}/c$ in pA ($1.5 < y < 4.0$) and Ap ($-5.0 < y < -2.5$) regions is $\sigma_{\mathrm{pA}} = 1028 \pm 14_{\,(\mathrm{stat.})} \pm 89_{\,(\mathrm{syst.})}$ μb, $\sigma_{\mathrm{Ap}} = 1142 \pm 50_{\,(\mathrm{stat.})} \pm 98_{\,(\mathrm{syst.})}$ μb; that for J/ψ from b is $\sigma_{\mathrm{pA}} = 150 \pm 4_{\,(\mathrm{stat.})} \pm 13_{\,(\mathrm{syst.})}$ μb, $\sigma_{\mathrm{Ap}} = 120 \pm 8_{\,(\mathrm{stat.})} \pm 10_{\,(\mathrm{syst.})}$ μb.

The J/ψ production cross-section in pp collisions at 5 TeV used as a reference to determine the nuclear modification factor $R_{p\mathrm{A}}$ is obtained by a linear interpolation from previous LHCb measurements [7–9] within $p_{\mathrm{T}} < 14\,\mathrm{GeV}/c$ and $2.5 < y < 4.0$. In the left plot of Fig. 3, the nuclear modification factor $R_{p\mathrm{A}}$ as a function of y compared to the theoretical predictions is shown. The forward-backward production ratio R_{FB}, which does not rely on the reference cross-section in pp collisions, is shown in the right plot of Fig. 3.

5. Update of the analysis

The analysis has been updated since the EPS 2013 conference, and the paper has already been submitted to JHEP [16]. The final results are based on a data sample corresponding to an integrated luminosity of 1.1 nb^{-1} (0.5 nb^{-1}) for forward (backward) collisions. The nuclear modification factor and forward-backward production ratio as a function of y are determined not only for prompt

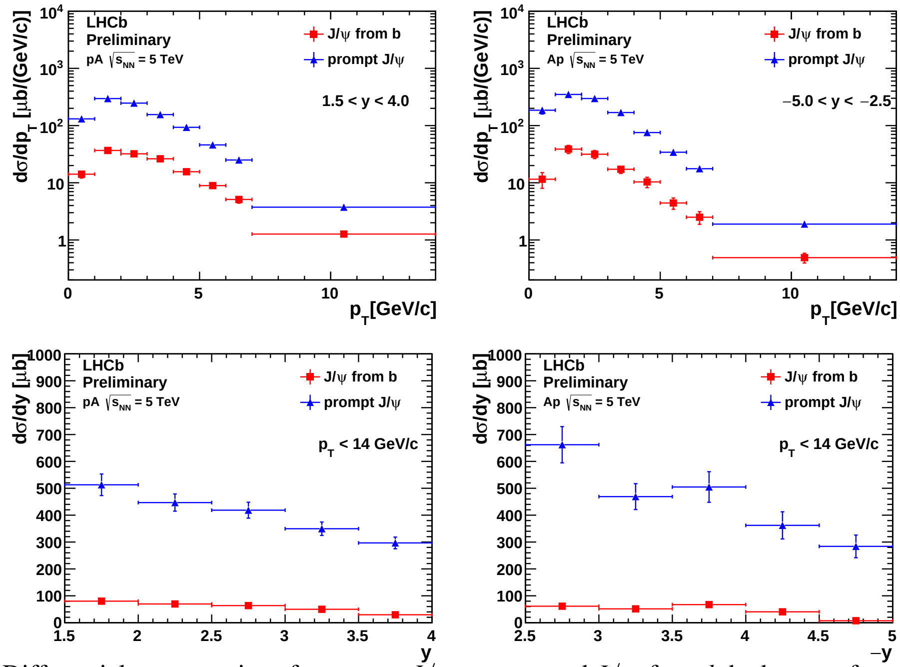

Figure 2: Differential cross-sections for prompt J/ψ mesons and J/ψ from b-hadrons as functions of (top) p_T and (bottom) y in (left) forward and (right) backward regions.

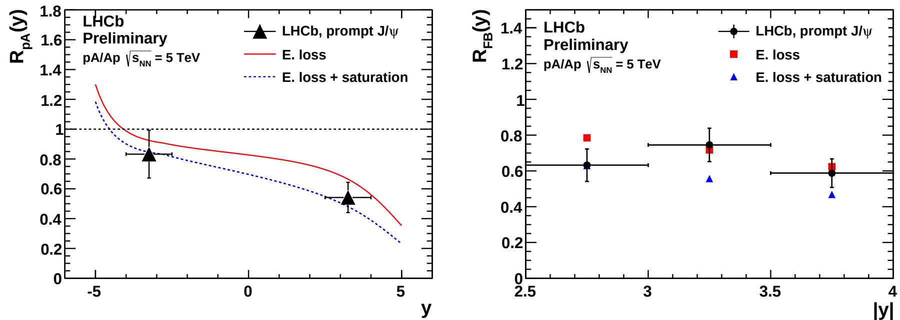

Figure 3: The nuclear modification factor R_{pA} (left) and the forward-backward production ratio R_{FB} (right) as a function of y. The measurements agree well with the theoretical predictions [4].

J/ψ but also for J/ψ from b. The forward-backward production ratio is also measured as a function of p_T. Figure 4 shows the final result for the nuclear modification factor as a function of y.

6. Conclusion

The production of J/ψ mesons with rapidity $1.5 < y < 4.0$ (pA) and $-5.0 < y < -2.5$ (Ap), and transverse momentum $p_T < 14$ GeV$/c$, is studied with the LHCb detector in proton-lead collisions at the proton-nucleon centre-of-mass energy $\sqrt{s_{NN}} = 5$ TeV. The nuclear modification factor R_{pA} and the forward-backward asymmetry ratio R_{FB} are determined as a function of y. The results show clear cold nuclear matter effects, and are in good agreement with the theoretical predictions.

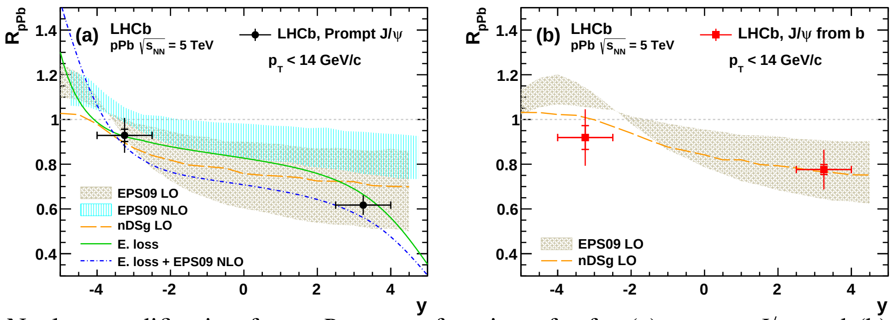

Figure 4: Nuclear modification factor R_{pPb} as a function of y for (a) prompt J/ψ and (b) J/ψ from b, compared with the theoretical predictions [2–4].

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