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Quarkonia production in pPb collisions

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We present LHCb results on quarkonia production in proton-lead collisions, using the data collected in 2016 at $\sqrt{s_{\rm NN}} = 8.16\,\text{TeV}$. Measurements are performed in the high rapidity region (pseudo-rapidity between 2 and 5), covering both forward (pPb configuration) and backward (Pbp configuration) rapidities. Measurements for charmonium states include prompt and from-b-decay components which are disentangled. The large increase of the data sample, with respect to the 5 TeV sample collected in 2013, allows a remarkable improvement in the accuracy of the studies of nuclear matter effects.

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1. Introduction

Measurements of quarkonia production are a fundamental tool for the understanding of the strong interaction and the phenomenology of heavy ion collisions [1]. Many models predict a modification in the different quarkonia production cross-sections in proton-lead (pPb) collisions relative to scaled proton-proton (pp) collisions. These models involve initial state effects, such as nPDFs [2], the Color Glass Condensate (CGC) [3] or coherent energy loss [4], or final state effects, as in the case of break-up by comovers [5]. The understanding of the pPb system is the necessary step towards the correct interpretation of the more complex PbPb collisions.

LHCb is one of the main experiments located at the Large Hadron Collider at CERN [6]. The detector is a forward spectrometer fully instrumented between 2 and 5 units of pseudo-rapidity (η). It consists of a vertex locator (VELO), a tracking system with excellent transverse momentum (p_{T}) resolution, two ring-imaging Cherenkov detectors (RICH) that provide excellent charged hadron identification, calorimetry and a muon system [7].

The capabilities of the experiment can be fully exploited in the study of quarkonia production in pPb collisions. In particular, the excellent mass resolution allows for a clean separation of some excited quarkonia states very close in invariant mass, such as the $\Upsilon(nS)$ and the χ_{cn}. In addition, the prompt (from the primary interaction) and non-prompt (from decays of b hadrons) contributions of J/ψ and $\psi(2S)$ states can be disentangled thanks to the precise vertexing. These capabilities are demonstrated in Figure 1, where the signal extraction procedures of the $\Upsilon(nS)$ on the one hand, and the prompt and non-prompt J/ψ mesons on the other hand, are illustrated.

The kinematic acceptance in pPb collisions covers the forward ($1.5 < y^* < 4.0$) and the backward ($-5.0 < y^* < -2.5$) rapidity regions in the centre-of-mass system. This is achieved by reversing the direction of the proton and lead beams. Data from p-Pb (Pb-p) configurations have been acquired in two data-taking periods, a first run in 2013 at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ with $1.1\,\mathrm{nb}^{-1}$ ($0.4\,\mathrm{nb}^{-1}$) of integrated luminosity in the forward (backward), and a second run in 2016 at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$ with $12.5\,\mathrm{nb}^{-1}$ ($17.4\,\mathrm{nb}^{-1}$).

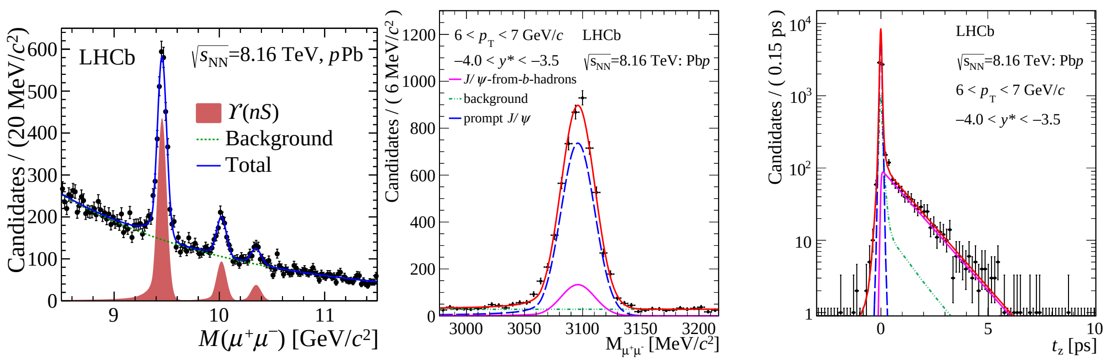

Figure 1: (Left) Dimuon invariant mass distibution in the $\Upsilon(nS)$ region with a fit to extract the $\Upsilon(nS)$ signal [8]. (Center and right) Distributions of the dimuon invariant mass (center) and pseudo-proper time $t_z \equiv (z_{J/\psi} - z_{PV}) \times (M/p_z)_{J/\psi}$ (right) in the 8.16 TeV Pb-p sample [9]. The prompt and non-prompt J/ψ contributions are determined with a fit.

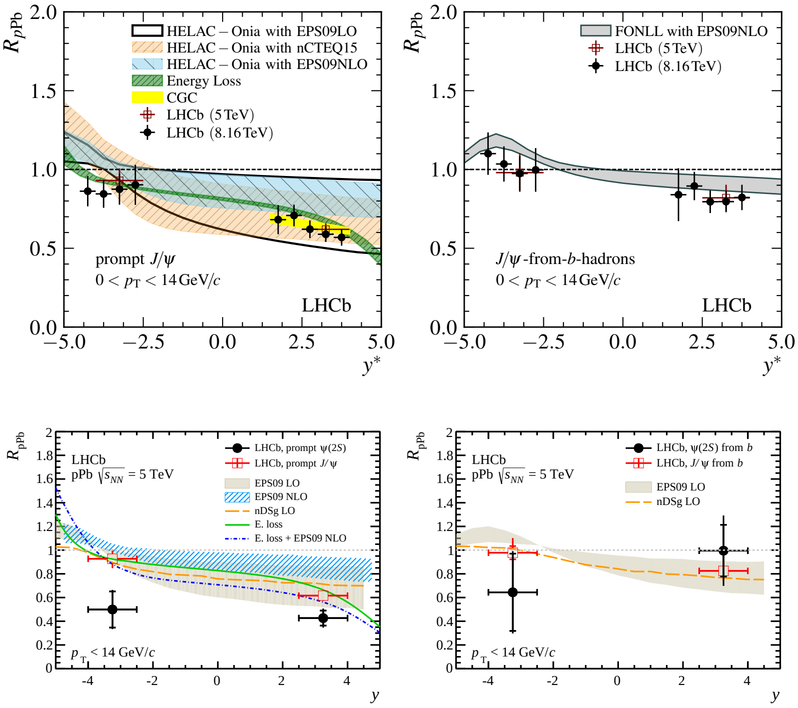

Figure 2: (Top) Nuclear modification factor for prompt (left) and non-prompt (right) J/ψ mesons at 8.16 TeV (black). The result is presented together with the 5.02 TeV measurement and different predictions. (Bottom) Nuclear modification factor for prompt (left) and non-prompt (right) $\psi(2S)$ meson at 5 TeV. Predictions and the result for J/ψ mesons are overdrawn.

2. J/ψ and $\psi(2S)$ production

The LHCb experiment has measured the differential production cross-sections of prompt and non-prompt J/ψ mesons in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV [9]. Nuclear matter effects manifest in the nuclear modification factor $R_{p\mathrm{Pb}}$, defined as $R_{p\mathrm{Pb}} = \sigma_{p\mathrm{Pb}}/(A \cdot \sigma_{pp})$. This observable was previously studied at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV [10] and now the sample size increases by a factor ×20, allowing to reduce the kinematic bin interval and the statistical uncertainties.

J/ψ candidates are reconstructed with its decay into two muons, and then the prompt and non-prompt contributions are distinguished with the simultaneous fit to the dimuon invariant mass and the pseudo-proper time showed in Figure 1. The results for $R_{p\mathrm{Pb}}$ are presented in Figure 2, along with a comparisons with different predictions. A clear suppression is seen in the forward region, more pronounced in prompt than in non-prompt J/ψ. Suppression is less pronounced in the backward region. This suppression pattern is in agreement with different predictions.

In addition to J/ψ, other $c\bar{c}$ states can be studied at LHCb, such as the $\psi(2S)$ [11]. Here, an enhanced suppression is seen for the prompt $\psi(2S)$ compared to the prompt J/ψ, as shown in Figure 2. This is specially significant in the backward region, unpredicted by the presented models. A notable improvement in precision is expected for the analysis of the $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV dataset given the increase of the sample size.

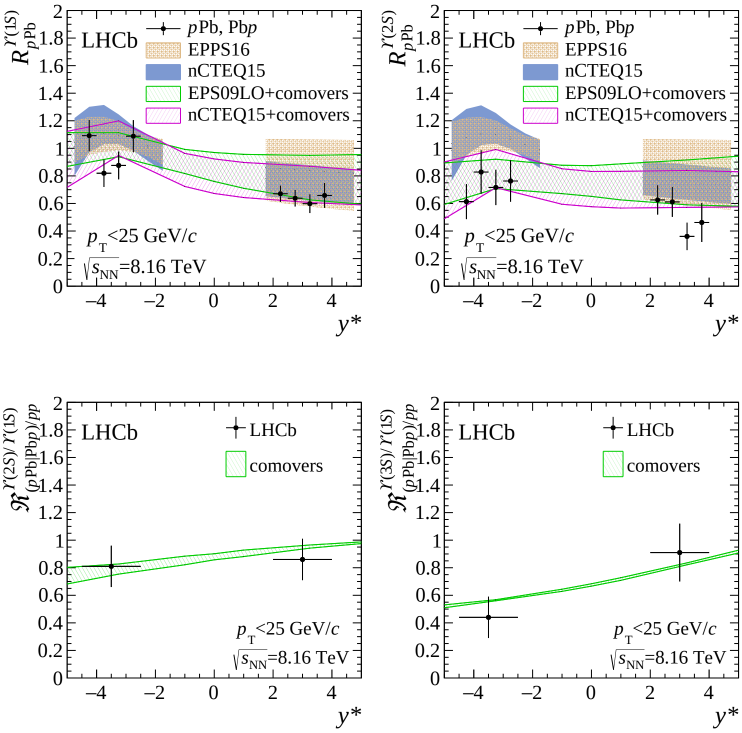

Figure 3: (Top) Nuclear modification factor for the $\Upsilon(1S)$ (left) and the $\Upsilon(2S)$ (right) as a function of rapidity. (Bottom) Double-ratio $\mathfrak{R}^{\Upsilon(nS)/\Upsilon(1S)}_{(p\mathrm{Pb}|\mathrm{Pb}p)/pp} = (\sigma_{\Upsilon(nS)}/\sigma_{\Upsilon(1S)})|_{p\mathrm{Pb}|\mathrm{Pb}p}/(\sigma_{\Upsilon(nS)}/\sigma_{\Upsilon(1S)})|_{pp}$ for $\Upsilon(2S)$ (left) and $\Upsilon(3S)$ (right) as a function of rapidity [8].

3. $\Upsilon(nS)$ production

LHCb has measured the production of $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ mesons in pPb collisions at 8.16 TeV [8]. The three mesons are cleanly observed with the decay to two muons, as shown in Figure 1. The result for the $R_{p\mathrm{Pb}}$ of $\Upsilon(1S)$ and $\Upsilon(2S)$ is presented in Figure 3, where predictions from nPDF and nPDF+comovers model are overdrawn. In the comovers model, dissociation of the quarkonia states is attributed to interaction with final-state particles which are close in phase-space [5]. All predictions reproduce the observed suppression pattern except for the backward region of the $\Upsilon(2S)$, where nPDF+comovers are clearly favoured.

The ratio of the production cross-section of $\Upsilon(2S)$ and $\Upsilon(3S)$ over the $\Upsilon(1S)$ can be divided by the same ratio in pp collisions, which should remove the influence of initial-state effects. This is shown in Figure 3. The comovers model predicts the transition between the backward and the forward region for both states.

4. Conclusions and outlook

The current status of quarkonia studies in pPb collisions at LHCb has been presented. The results indicate different suppression patterns for excited states ($\Upsilon(3S)$, $\Upsilon(2S)$ and $\psi(2S)$) with respect to the ground states, both for charmonia and bottomonia. This is specially remarkable at backward rapidity for both excited charmonium and bottomonium states. Definitely, more experimental measurements are needed to shed light into the picture. In the short term, the $\psi(2S)$ production measurement will be updated with the 8.16 TeV sample, with 20 times more statistics. Additionally, other less common states can be studied with this sample. This is the case of χ_{nc} states, already observed by LHCb in pPb collisions [12]. In the medium term, LHCb will participate in LHC Run 3 and will collect a even larger dataset of pPb collisions. There are bright prospects for quarkonia studies in the coming years.

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