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Quarkonia production in pPb collisions with LHCb

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Recent results from the LHCb experiment will be discussed, using data collected in proton-lead collisions at $\sqrt{s_{\mathrm{NN}}}$ =8.16 TeV in the rapidity regions -5.0< y^* <-2.5 and 1.5< y^* <4.0. The measurements J/ψ and $\Upsilon(nS)$ production are described and compared with the latest theoretical models.

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1. Introduction

Existing experimental results in collisions of ultra-relativistic heavy nuclei are consistent with the formation of "Quark-Gluon Plasma (QGP)", imagined as a deconfined state of hot partonic matter [1]. One possible signature of QGP is the suppression of heavy-quarkonia production in the collisions of heavy nuclei (AA collisions) with respect to pp collisions. However, such suppression can also occur in the collisions of protons with heavy nuclei (pA collisions), mainly caused by nuclear phenomena unrelated to deconfinement, *i.e.* cold nuclear matter (CNM) effects. The CNM effects are expected to affect quarkonia production through "initial-state" effects happening at a early stage of the collision [1], and "final-state" effects [1]. The size of nuclear effects can be quantified by measuring the nuclear modification factor $R_{p\mathrm{A}}$, which is defined as the ratio of the cross-section in pA collisions to that in pp collisions scaled by the number of nucleons in the nucleus. In the absence of modifications, $R_{p\mathrm{A}}$ is unity. Previous measurements in pA and AA collisions at RHIC [2] and LHC [3–5] have revealed sizable nuclear modification factors for quarkonia states. Using a data sample corresponding to an integrated luminosity of about 1.5 nb^{-1}, the LHCb collaboration measured the production of J/ψ, $\psi(2S)$, $\Upsilon(nS)$ and D^0 mesons in pPb collisions at a per-nucleon centre-of-mass energy of $\sqrt{s_{\mathrm{NN}}} = 5$ TeV. In this proceedings, the production of J/ψ [6] and $\Upsilon(nS)$ [7] mesons in pPb collisions are presented, using data collected at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$ with the LHCb detector.

2. Detector and data taking conditions

The LHCb detector is a single-arm forward spectrometer described in detail elsewhere [8, 9]. Simulation is used in the determination of efficiencies. The pPb collisions are simulated with EPOS-LHC [10] and the dimuon decays with PYTHIA 8.1 [11] in pp collisions where the proton beam energy is equal to the nucleon beam energy in pPb collisions. The interaction of the generated particles with the detector and its response are implemented using the GEANT4 toolkit [12,13]. The mesons are produced unpolarised, justified by the fact that the polarisation of J/ψ and $\Upsilon(nS)$ mesons has been measured by LHCb in pp collisions at similar energies and found to be small [14, 15]. Consistently with what was done previously at LHCb [6], no systematic uncertainty is associated with this assumption.

The pPb collision data collected for these analyses correspond to a total integrated luminosity of $31.8\,\mathrm{nb}^{-1}$, divided in two different configurations, the *forward* (pPb), where the proton beam travels from the VELO detector to the muon chambers, and the *backward* (Pbp), where the proton and lead beams are inverted. The energy of the proton beam is 6.5 TeV, while that of the lead beam is 2.56 TeV per nucleon, resulting in a centre-of-mass energy of the proton-nucleon system of 8.16 TeV. Since the energy per nucleon in the proton beam is significantly larger than that in the lead beam, the proton-nucleon centre-of-mass system has a rapidity in the laboratory frame of $+0.465$ (-0.465) for pPb (Pbp) collisions, resulting in a shift of the range of the centre-of-mass rapidity y^* in the proton nucleus case. This results in a coverage of $1.5 < y^* < 4.0$ for pPb forward and $-5.0 < y^* < -2.5$ for Pbp backward collisions.

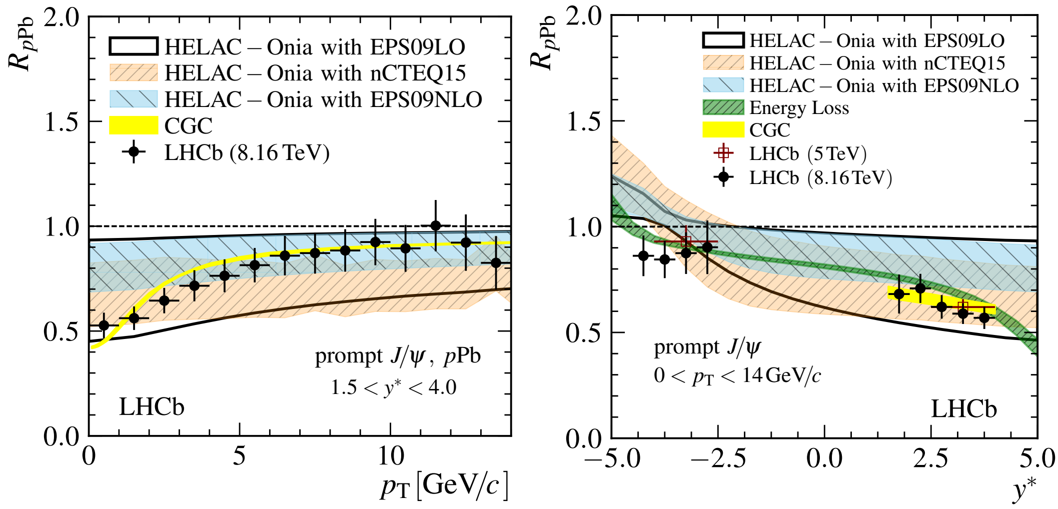

Figure 1: Nuclear modification factor for J/ψ in pPb data as a function of (left) p_{T} and (right) y^*, compared to several theoretical models.

3. Quarkonia results

The production of J/ψ ,ϒ(1S),ϒ(2S)and ϒ(3S)is studied in their dimuon decay channel using data samples corresponding to an integrated luminosity of $12.5 \pm 0.3\,\mathrm{nb}^{-1}$ in the forward configuration and $19.3 \pm 0.5\,\mathrm{nb}^{-1}$ in the backward configuration. The muons are selected through a hardware and software level trigger and undergo a subsequent offline selection, where muon tracks are required to have $p_{\mathrm{T}} > 1(0.7)\,\mathrm{GeV}/c$ for the ϒ(nS) (J/ψ), to be in the geometrical acceptance of the spectrometer ($2.0 < \eta < 5.0$), to satisfy PID requirements, and to have a good track-fit quality.

3.1 J/ψ production

Using the same dataset LHCb measured also the production of J/ψ mesons through their dimuon decay channel [6]. Prompt and nonprompt J/ψ 's from b-meson decays are separated thanks to the pseudo-proper decay time variable t_Z. The double differential production cross-section has been measured in p_{T} and y^* in the range $p_{\mathrm{T}} < 15\,\mathrm{GeV}/c$ and $1.5 < y^* < 4.0$ and $-5.0 < y^* < -2.5$ in rapidity, and integrated in each variable as a function of the other. The nuclear modification factor has also been measured, using as pp reference the extrapolated value of the cross-section at 8.16 TeV. As shown in Fig. 1, a suppression is observed at low-p_{T} and positive rapidity, consistent with previous observations [16, 17] and with several theoretical models (see [6] for a detailed discussion of the models).

3.2 ϒ(nS) production

The ϒ(nS) states are reconstructed through a fit on the dimuon invariant mass distribution shown in Fig.2 for the full sample.

The yields of ϒ(1S), ϒ(2S), ϒ(3S) mesons in the pPb and Pbp samples are summarised in Table 1. With the samples collected several measurements were performed, in both forward and

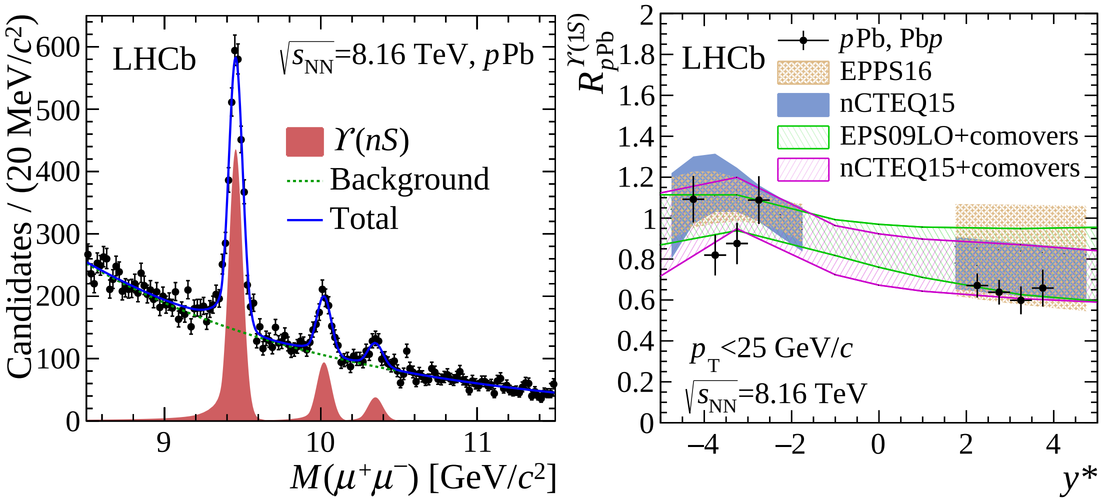

Figure 2: (Left) Invariant-mass distribution of $\mu^+\mu^-$ pairs from the pPb and (right) $\Upsilon(1S)$ nuclear modification factor as a function of y^*, compared to several theoretical models.

Table 1: Yields of $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ mesons in pPb and Pbp samples as given by the fit. The uncertainties are statistical only.

Samples	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	$\mathscr{L}$
pPb	2705 ± 87	584 ± 49	262 ± 44	12.5 nb^{-1}
Pbp	3072 ± 82	679 ± 54	159 ± 39	19.3 nb^{-1}

backward configuration. The production cross-section of each $\Upsilon(nS)$ state, double differential in p_T and y^* for the $\Upsilon(1S)$, single differential for the $\Upsilon(2S)$ and integrated for the $\Upsilon(3S)$. The total efficiency for these measurements includes effects due to the geometrical acceptance, trigger, tracking, PID and offline selection and it is measured using simulation and data driven techniques. The nuclear modification factor has been measured[1] for both $\Upsilon(1S)$ (shown in Fig.2) and $\Upsilon(2S)$, as a function of p_T and y^*. In both cases there is a hint of suppression more pronounced for positive rapidities and at low-p_T, which is consistent with the theoretical models considered [21–27]. The suppression seems stronger for the excited states w.r.t. the ground state, as observed in the measurements of the ratios (Fig. 3) and consistent with the "comovers" model [26, 27]. In addition, the mechanism of suppression looks different in open beauty versus bottomonia, as it appears from the ratio of $\Upsilon(1S)$ vs. nonprompt J/ψ [17] (Fig. 3). More information on this mechanisms is expected from the measurement of the ψ(2S) production in the same dataset, which is close to publication. Forward-backward production ratios have also been measured.

[1]The value of the pp cross-section at $\sqrt{s_{NN}}$ =8.16 TeV has been evaluated interpolating between previous LHCb measurements at different energies [18–20].

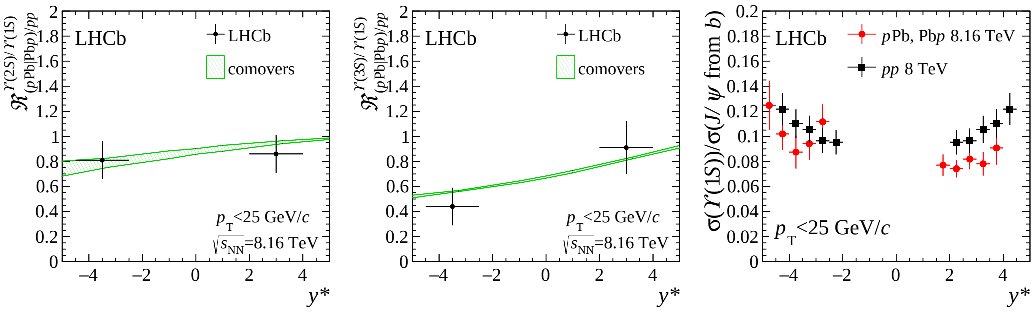

Figure 3: Double ratios for (left) $\Upsilon(2S)$ and (middle) $\Upsilon(3S)$. The bands correspond to the theoretical prediction for the comovers model as reported in the text. (Left) Ratio of $\Upsilon(1S)$ to nonprompt J/ψ cross-sections as a function of y^* integrated over p_{T}, for pPb and Pbp collisions.

4. Conclusions and outlook

The LHCb experiment has successfully collected and analysed data in proton-lead and lead-proton collisions in 2013 and 2016 at 5 and 8.16 TeV. J/ψ and $\Upsilon(nS)$ productions have been studied, indicating a suppression compatible with the theoretical models analysed. Results of $\psi(2S)$ production in the same dataset are on the way, which would shed more light on the mechanism of suppression in cold nuclear matter.

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