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Beyond nPDFs effects : Prompt J/ψ and ψ(2S) production in pPb and pp collisions

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Abstract

A multi-dimensional analysis of prompt charmonia in pp and pPb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV with the CMS detector is presented. The pPb differential cross-sections of prompt J/ψ are shown in a wide kinematic region, for transverse momentum $p_{\rm T}$ spanning from 2 to 30 GeV/c and a rapidity interval between -2.4 to 1.93 in the center of mass of the collision. The final results on prompt ψ(2S) meson production cross section in pp and pPb collisions at 5.02 TeV are also reported as a function of $p_{\rm T}$ and rapidity, for $p_{\rm T}$ from 4 to 30 GeV/c. The nuclear modification factor is found to be smaller than that of prompt J/ψ in all measured bins, especially at low $p_{\rm T}$ and at backward rapidity. Such a different behaviour between the ground and excited states cannot be reproduced considering nPDF effects alone.

Keywords: Quarkonia; Charmonia; Prompt J/ψ; Prompt ψ(2S); Production;

1. Introduction

CMS has measured many charmonium observables in lead-lead (PbPb), proton-proton (pp), and proton-lead (pPb) collisions, in order to study the similarities and differences among the three systems and in the process to understand the cause of the suppression observed in the quark gluon plasma (QGP). A few of these measurements have been presented in the talk. The results shown are based on samples collected by the CMS experiment in the LHC Run 1 (the pPb results) and Run 2 (the pp and PbPb results) at a centre-of-mass energy per nucleon pair of $\sqrt{s_{\rm NN}}$ = 5.02 TeV [1, 2, 3]. The nuclear modification factor ($R_{\rm AA}$) of the ground (J/ψ) and excited (ψ(2S)) charmonium states, reconstructed via their decays to $\mu^+\mu^-$, were studied as function of meson rapidity (y) and transverse momentum ($p_{\rm T}$), and event centrality ($N_{\rm part}$). The results versus $N_{\rm part}$, shown in Fig. 1 for two y and $p_{\rm T}$ regions, show that the ψ(2S) meson production is more suppressed than that of J/ψ mesons, while both of them show an increased suppression with centrality. The results are remarkable in that they show an ordered suppression (looser bound state is more suppressed than the tighter bound state), in a $p_{\rm T}$ region considered 'high' ($p_{\rm T}$ > 6 GeV/c) for effects as color screening (which had sequential suppression as the predicted effect). These PbPb results are affected not only by QGP effects but also by effects that can be found also in pp and pPb collisions.

The CMS experiment measured the prompt J/ψ and ψ(2S) production in pPb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV over the range 4 < $p_{\rm T}$ < 30GeV/c and center-of-mass rapidity range −2.4 < $y_{\rm CM}$ < 1.93. The nuclear modification factor $R_{\rm pPb}$ and the production cross sections were measured for both states [2, 3].

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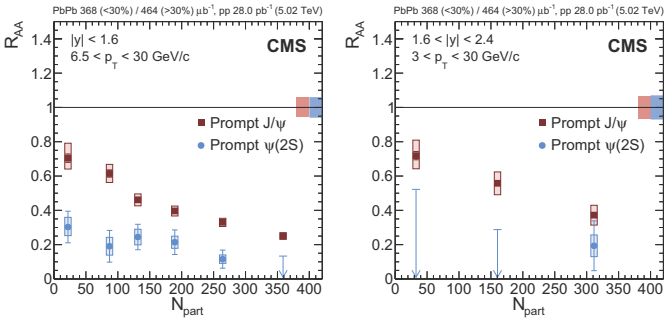

Fig. 1. The nuclear modification factor of prompt J/ψ and ψ(2S) mesons as a function of N_{part}, at central (left, starting at $p_{\mathrm{T}} = 6.5$ GeV/c) and forward (right, starting at $p_{\mathrm{T}} = 3$ GeV/c) rapidity [1]. The vertical arrows represent 95% confidence intervals in the bins where the measurement is consistent with 0. The most central bin corresponds to 0–10% (0–20%), and the most peripheral one to 50–100% (40–100%), for $|y| < 1.6$ ($1.6 < |y| < 2.4$). The bars (boxes) represent statistical (systematic) point-by-point uncertainties. The boxes plotted at $R_{\mathrm{AA}} = 1$ indicate the size of the global relative uncertainties.

2. Results from pPb collisions

Figure 2 shows the prompt ψ(2S) production cross section (multiplied by the ψ(2S) branching fraction to $\mu^+\mu^-$) calculated, for pPb and pp collisions as

$$\mathcal{B}(\psi(2S) \to \mu^+\mu^-)\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}y_{\mathrm{CM}}}(p_{\mathrm{T}}, y_{\mathrm{CM}}) = \frac{N^{\psi}_{\mathrm{fit}}/(\mathrm{acc}\cdot\varepsilon)}{\mathcal{L}\,\Delta p_{\mathrm{T}}\,\Delta y_{\mathrm{CM}}}. \tag{1}$$

where N^{ψ}_{fit} is the extracted raw yield of prompt ψ mesons in a given $(p_{\mathrm{T}}, y_{\mathrm{CM}})$ bin, $(\mathrm{acc}\cdot\varepsilon)$ is the product of the dimuon acceptance and Δp_{T} and Δy_{CM} are the widths of the kinematic bin considered. The pPb cross sections are normalized by A = 208, the number of nucleons in the Pb nucleus. The results are given as a function of p_{T} and in rapidity bins, separately for forward (the direction of the proton beam) and backward (the direction of the Pb beam) rapidities in the case of the pPb measurements.

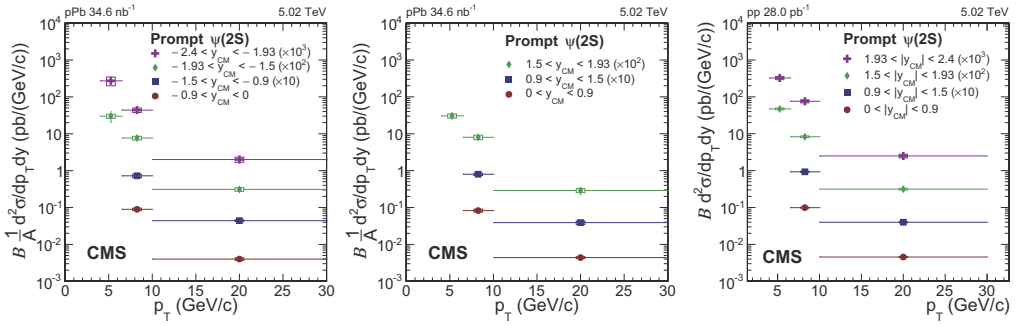

Fig. 2. The differential cross section (multiplied by the dimuon branching fraction and divided by A = 208) of prompt ψ(2S) production in pPb (left and mid panel) collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and pp (right panel) collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, as a function of p_{T}, in several rapidity bins and separately for backward (left panel) and forward (mid panel) rapidity regions to improve visibility [3]. Statistical and systematic uncertainties are represented with error bars and boxes, respectively. The fully correlated luminosity uncertainty of 3.5%(pPb) [5] and 2.3%(pp) [4] is not included in the point-by-point uncertainties.

The second observable considered is the nuclear modification factor, defined as

$$R_{pPb}(p_T, y_{CM}) \equiv \frac{(d^2\sigma/dp_T\, dy_{CM})_{pPb}}{A(d^2\sigma/dp_T\, dy_{CM})_{pp}} \quad (2)$$

If $R_{pPb} = 1$, then there are no nuclear effects present in the pPb measurements.

The nuclear modification factor R_{pPb} is shown for ψ(2S) in Fig. 3, versus centre-of-mass rapidity, for three three p_T ranges: 4–6.5, 6.5–10, and 10–30 GeV/c. In the two lowest p_T bins, R_{pPb} remains below unity independent of the rapidity, while in the highest p_T bin, R_{pPb} is consistent with unity (although systematically smaller). For comparison, the prompt J/ψ corresponding results [2] are added in the same figure. The R_{pPb} for prompt J/ψ mesons lies systematically above that of the ψ(2S) state, indicating different nuclear effects in the production of the two states. There are hints of more suppression of ψ(2S) mesons in the region of backward rapidity and for $p_T < 10$ GeV/c. The measured value of R_{pPb} for prompt ψ(2S) mesons, when integrated over p_T and rapidity ($6.5 < p_T < 30$GeV/c, $|y| < 1.6$), is 0.852 ± 0.037(stat) ± 0.062(syst). For comparison, the prompt J/ψ R_{pPb} in the same kinematic range is 1.108 ± 0.021(stat) ± 0.055(syst). This behavior reminisces of the sequential features observed in PbPb results.

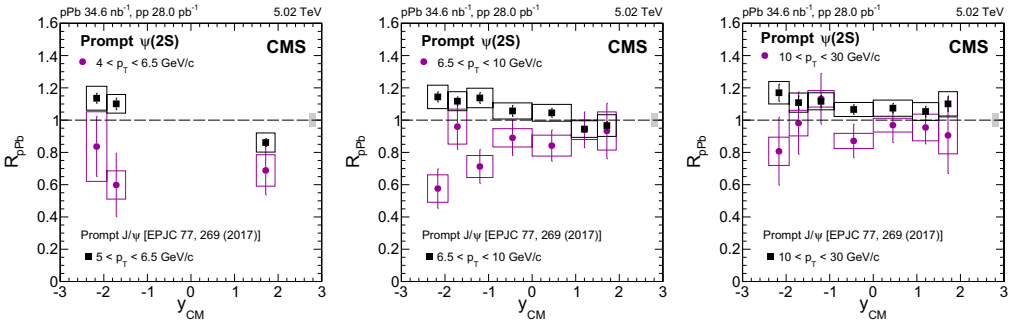

Fig. 3. Rapidity dependence of the prompt ψ R_{pPb} in three p_T ranges [3]. The prompt J/ψ nuclear modification factor [2] is also shown. Statistical and systematic uncertainties are represented with error bars and boxes, respectively. The fully correlated global uncertainty of 4.2% (that affects both charmonia) is displayed as a box around $R_{pPb} = 1$.

3. Summary

The data collected by the CMS detector in pp and pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are used to investigate the prompt ψ(2S) meson production cross sections. The results are based on data samples corresponding to integrated luminosities of 28.0 ± 0.6 pb^{-1} [4] for pp collisions and 34.6 ± 1.2 nb^{-1} [5] for pPb collisions. The nuclear modification factor (R_{pPb}) of prompt ψ(2S), in the kinematic range $4 < p_T < 30$ GeV/c and $-2.4 < y_{CM} < 1.93$, is determined and compared to that of prompt J/ψ mesons, reported in Ref [2]. In the ranges $4 < p_T < 6.5$ and $6.5 < p_T < 10$ GeV/c the value R_{pPb} for prompt ψ(2S) production remains below unity independent of rapidity, while in the highest p_T bin ($10 < p_T < 30$ GeV/c) it is consistent with unity (although systematically smaller). The R_{pPb} values of prompt J/ψ lie systematically above those of prompt ψ(2S) mesons, indicating different nuclear effects in the production of the ground and excited states. The effects of nuclear parton distribution functions or coherent energy loss, are expected to affect the R_{pPb} of prompt J/ψ and ψ(2S) by a similar amount, thus the results hint to presence of final state interactions with the medium produced in pPb collisions.

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