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Detailed studies of prompt J/ψ and $\psi(2S)$ production in pp, pPb and PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the CMS experiment

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The understanding of charmonium production in PbPb collisions requires the inclusion of many phenomena such as dissociation in the QGP, partonic energy loss, statistical recombination, on top of cold nuclear matter effects (modifications of nPDFs, initial-state energy loss, nuclear break-up). Final results on prompt J/ψ and ψ(2S) production, based on the pp and PbPb data collected at 5.02 TeV by CMS in 2015, are reported, showing a stronger suppression of the excited state as compared to the ground state in all measured bins of p_T and centrality, as well as a hint for a weaker J/ψ suppression at low p_T (possibly due to regeneration) and at high p_T (possibly due to partonic energy loss). Final results on prompt J/ψ and ψ(2S) production in pPb data at 5.02 TeV are also reported, showing a different modification of the ground and excited state already in this smaller system, especially in the Pb-going direction, hinting to a possible breakup of the weaker bound excited states from interactions with final state particles. Finally, fully unfolded results of J/ψ production inside jets in pp collisions show that production models are unable to properly model this topology.

International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
30 September - 5 October 2018
Aix-Les-Bains, Savoie, France

*Speaker.

PoS(HardProbes2018)135

1. Introduction

In heavy ion collisions, charmonium states, such as J/ψ and ψ(2S) are used to probe the Quark-Gluon Plasma (QGP). Charm quark pairs are produced in the initial hard scattering. They hadronize during the evolution of the QGP into charmonium states that decay after the freeze-out. But the presence of a hot deconfined matter makes it a bit more complicated. On one hand, the bound states of $c\bar{c}$ can dissociate due to Debye screening. The deconfined colour charges screen the quark potential which leads to the dissociation of the charmonium state [1]. On the other hand, at high energies, the charm density is high enough for the c and the $\bar{c}$ to recombine with other charm quarks to form new charmonium states [2, 3]. This phenomenon is known as recombination.
On top of hot nuclear matter, cold nuclear matter (CNM) effects, like modification of nuclear parton distribution functions, energy loss and nuclear absorption, are required for a complete understanding of charmonia production in PbPb collisions [4]. The way to separate the cold nuclear matter effects from those of the deconfined medium is to study smaller collision systems such as pPb collisions [5].
Even without the presence of nuclear matter, the detailed parton dynamics responsible for the formation of heavy quark bound states remains elusive [6]. Thus measurements of charmonium production in pp collisions are required. J/ψ hadronization dynamics can be studied by measuring the transverse momentum (p_{T}) fraction carried by the J/ψ detected inside a jet, $z \equiv p_{\mathrm{T,J/\psi}}/p_{\mathrm{T,jet}}$.
Although the nonprompt charmonium could also reflect medium effects but on b hadrons, the topic of this talk was the prompt component, since it is affected directly by the QGP. Prompt J/ψ and ψ(2S) nuclear modification factors in PbPb and pPb data taken by the LHC CMS experiment at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV were presented [7, 8, 9]. The integrated luminosities were 28 pb^{-1}, 34.6 nb^{-1} and 0.5 nb^{-1} for pp, pPb and PbPb data samples, respectively. Results relating to collectivity of J/ψ in pPb at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV and jet fragmentation into J/ψ in pp at $\sqrt{s} = 5.02$ TeV were also discussed [10, 11]. The integrated luminosities were 27.39 pb^{-1} and 186 nb^{-1} for pp and pPb, respectively.

2. Prompt charmonia in PbPb collisions

In the left plot of Fig. 1, the R_{AA} of prompt J/ψ as a function of p_{T} is shown in two rapidity regions, $|y| < 1.6$ and $1.8 < |y| < 2.4$ [8]. A lower suppression, caused by the statistical recombination, is seen at low p_{T} in the forward region. A lower suppression is also observed at high p_{T} at mid rapidity. A similar rise, attributed to parton energy loss, is observed for charged hadrons at the same energy [12]. On the right, the R_{AA} of J/ψ and ψ(2S) is shown as function of the number of participants (N_{part}). In the bins where the modification factor is not significant, 95% confidence level intervals on the ψ(2S) R_{AA} are given. A stronger suppression is observed for ψ(2S) for the entire p_{T} range, showing that the excited states are more strongly affected by the medium created in PbPb collisions.

3. Prompt charmonia in pPb collisions

In Fig. 2, on the left, the R_{pA} of prompt J/ψ and ψ(2S) is shown as function of rapidity for $10 < p_{\mathrm{T}} < 30$ GeV [9]. The J/ψ results show that R_{pA} is slightly above unity without any clear

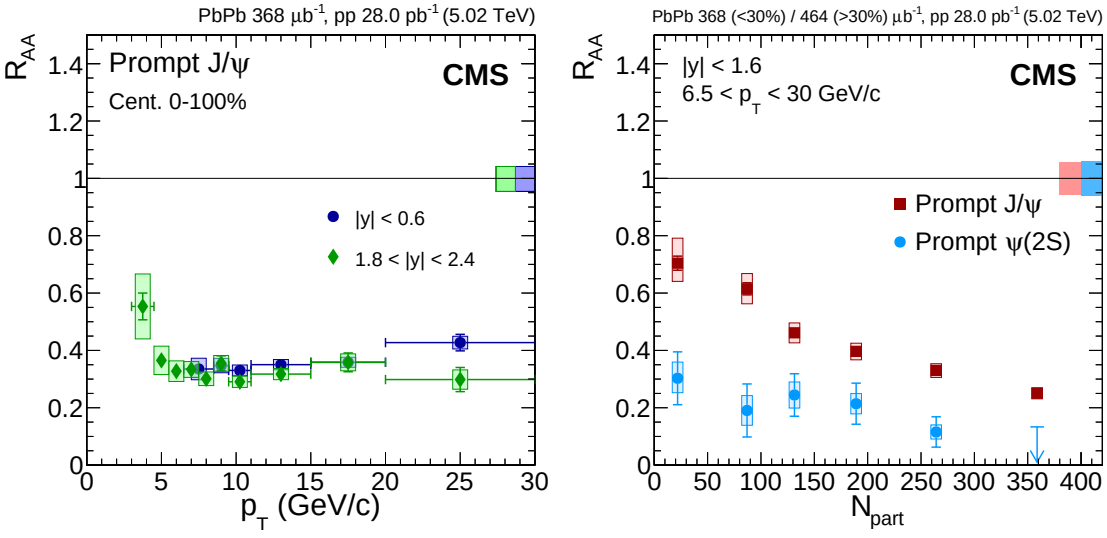

Figure 1: On the left, prompt J/ψ $R_{\rm AA}$ as a function of $p_{\rm T}$ for $|y| < 0.6$ and $1.8 < |y| < 2.4$ [8]. On the right, $R_{\rm AA}$ as a function of $N_{\rm part}$ for J/ψ and ψ(2S) [8].

dependance on rapidity within the uncertainties. The ψ(2S) results show a stronger suppression than that observed for J/ψ which is unexpected from the current theoretical models including only CNM effects, suggesting the presence of additional final-state effects on ψ(2S) production.
On the right of Fig. 2, the results for J/ψ $v_2^{\rm sub}$ in pPb collisions is shown as a function of $p_{\rm T}$ in comparison with prompt D^0, K^0_S and Λ hadrons. A cut of $185 \leq N_{\rm trk}^{\rm offline} < 250$, where $N_{\rm trk}^{\rm offline}$ is the number of primary charged particle tracks, is applied to select high-multiplicity events. The results show a positive v_2 for prompt J/ψ over a wide $p_{\rm T}$ range which provides evidence for charm quark collectivity in high-multiplicity pPb collisions, similar to that observed for light-flavor hadrons.

4. Prompt charmonia in pp collisions

The self-normalized fragmentation function, z, for prompt J/ψ in pp data for $|y| < 1.6$ is presented in Fig. 3 on the left [11]. The J/ψ mesons are clustered in jets with $25 < p_{\rm T} < 35$ GeV using the anti-k_t algorithm [13]. The distribution for prompt J/ψ according to PYTHIA 8 [14] is also shown and it is observed to be different than data. The z distribution is harder in PYTHIA than in the data, indicating that the jet activity accompanying the J/ψ is underestimated.
The fraction of prompt J/ψ mesons that belong to jets within the $p_{\rm T}$ selection is shown on the right. We find that less than 2% of J/ψ mesons are produced in jets in the $p_{\rm T}$ range. This fraction is underpredicted by PYTHIA 8 at mid and forward rapidity. These J/ψ-in-jet fractions have not been computed before and provide complementary information to the z distributions that should be useful for developments of charmonium production models.
Recently, calculations have become available that treat charmonium production not only directly from the hard scattering, but also over the course of the subsequent parton showers [15]. These calculations are able to describe the similar results measured by the LHCb Collaboration [16].

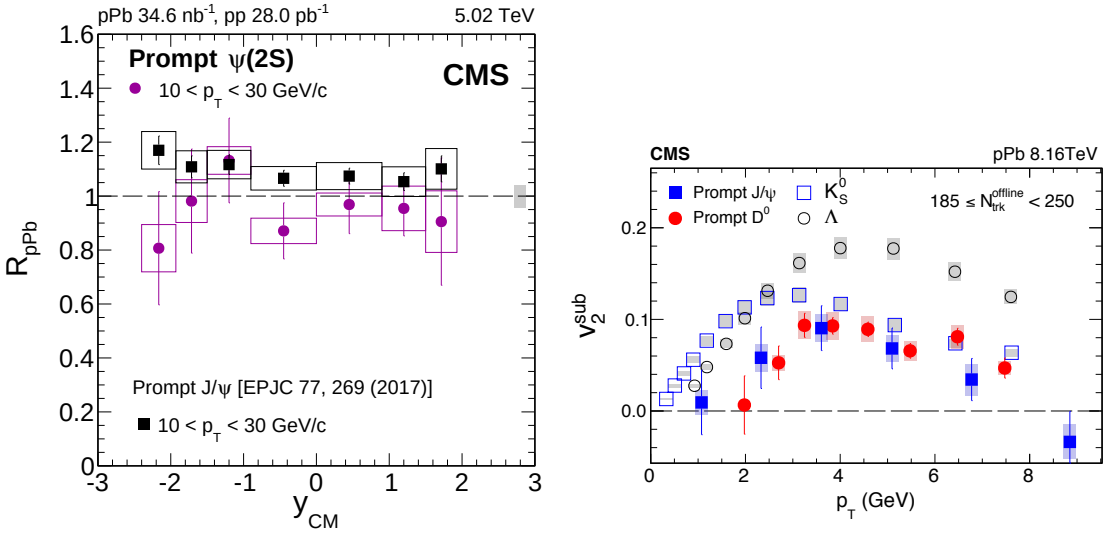

Figure 2: On the left, R_{pA} of prompt J/ψ and $\psi(2\mathrm{S})$ as a function of y_{CM} for $10 < p_{\mathrm{T}} < 30$ GeV [9]. On the right, v_2^{sub} of prompt J/ψ and light hadrons as a function of p_{T} for $185 \leq N_{\mathrm{trk}}^{\mathrm{offline}} < 250$ [10].

5. Summary

The results for prompt J/ψ R_{AA} in PbPb collisions at 5.02 TeV were reported as a function of p_{T}. The results showed less suppression at low p_{T}, caused by regeneration, and less suppression at high p_{T}, caused by parton energy loss. Then, prompt J/ψ and $\psi(2\mathrm{S})$ R_{AA} results were shown as a function of collision centrality. The excited state was observed to be more strongly suppressed than the ground state in PbPb collisions.

The results for prompt J/ψ and $\psi(2\mathrm{S})$ R_{pA} in pPb collisions at 5.02 TeV were also reported as a function of rapidity. The observed difference between the two states cannot be explained only with cold nuclear matter effects and indicates the presence of additional final state effects in the case of $\psi(2\mathrm{S})$. In addition, the results for J/ψ v_2^{sub} showed an evidence of charm collectivity in high multiplicity pPb collisions at 8.16 TeV.

Finally, the fragmentation function of prompt J/ψ in jets in pp collisions at 5.02 TeV were also discussed. The z distributions showed a difference between what is seen in data and what is expected and implemented in PYTHIA, which has an implication that charmonia can be produced in parton showers and not only from the hard scattering. This may have important implications for the interpretation of charmonium nuclear suppression factors in PbPb collisions [8].

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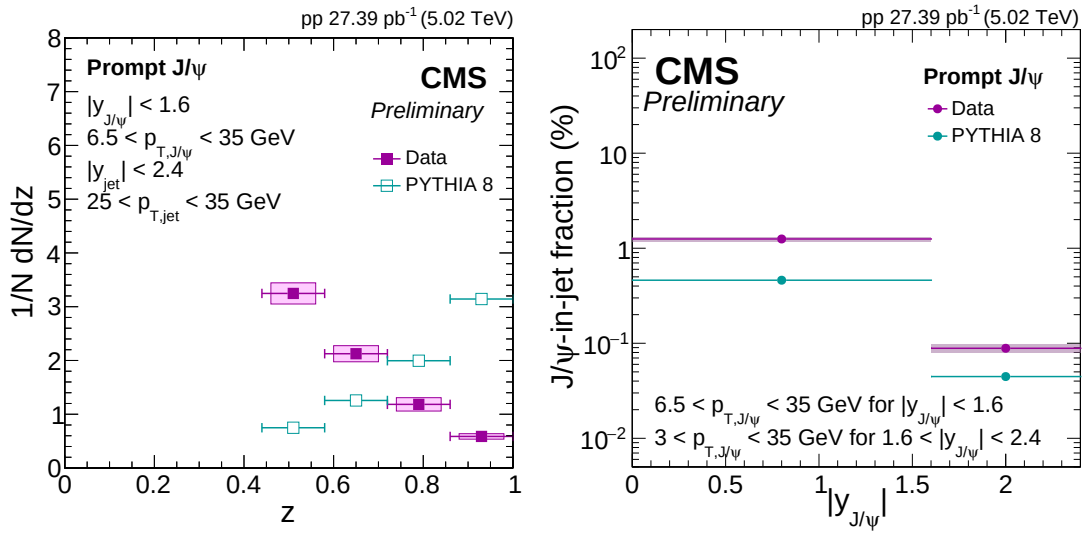

Figure 3: On the left, self-normalized z distributions in the rapidity range $|y| < 1.6$, for prompt J/ψ in pp data and PYTHIA 8. On the right, the fraction of prompt J/ψ in jets of $25 < p_{\mathrm{T}} < 35$ GeV in pp data and in PYTHIA 8, compared to the total number of J/ψ in the relevant the p_{T} interval, as indicated on the figure [11].

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