Studies of the relative suppression of excited quarkonium states with CMS

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Abstract. One of the findings of the LHC heavy ion program is the observation of stronger suppression of the excited quarkonium states compared to the ground states in lead-lead (PbPb) and proton-lead (pPb) collisions. Such differences among the states may imply dissociation effects occurring at late stages, after the evolution of heavy quark pairs into well-defined physical states. The variety of binding energies within the quarkonia families offers an experimental tool to characterize the phenomena at play. Measuring the excited states is crucial as they represent significant feed-down contributions to the production of the ground states and must be accounted for in the interpretation of the data. We present studies of the relative suppression of quarkonia in pPb and PbPb collisions performed by CMS. For the first time, the nuclear modification factor has been extended to the strongly suppressed **Υ(3S)** state. Moreover, nuclear modification factors as well as excited-to-ground state cross section ratios are measured as a function of particle transverse momentum and rapidity, and event activity. The results are compared with several model calculations incorporating initial- and final-state effects.

1 Introduction

Measurements of quarkonia production have long been considered an ideal tool to establish the presence of quark-gluon plasma in heavy ion collisions. However, a variety of competing effects that modify quarkonia production have since been proposed and investigated [1]. In order to disentangle the contribution of these effects, it is important to measure quarkonia in different collision systems. These proceedings focus on the measurements of bottomomium ($b\bar{b}$) S-states, i.e., Υ(1S), Υ(2S), and Υ(3S) mesons.

The modifications of the quarkonium states in nucleus-nucleus (AA) collisions are often quantified via the nuclear modification factor R_{AA} (R_{pPb} in the case of proton-lead collisions). The factor is defined as the ratio of the corrected yields in the AA (pPb) collision to the corrected yields in proton-proton (pp) collisions, scaled by the average number of binary nucleon-nucleon collisions. In the absence of any effects that would modify the yields, the factor would be equal to 1.

2 Muon performance from pp to PbPb

The most common way to detect quarkonia in the CMS experiment is by utilizing their dimuon decay channel $Q \rightarrow \mu^- + \mu^+$. Therefore, it is important to study the muon per-

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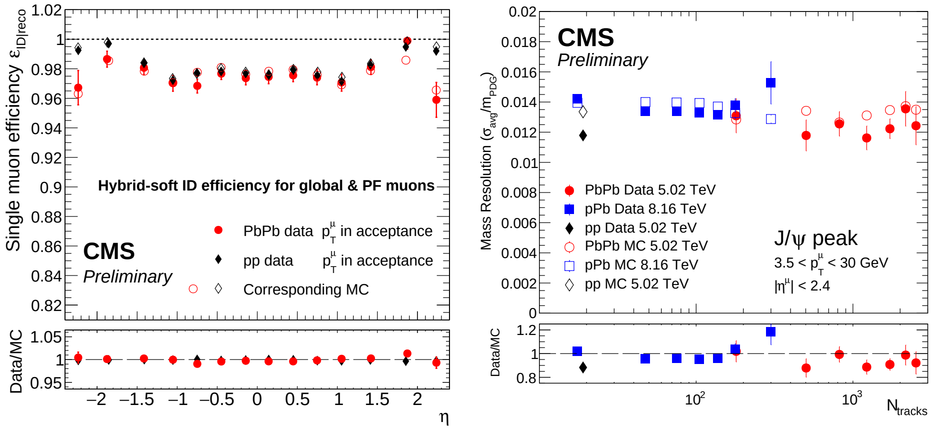

Figure 1. Left panel: muon identification efficiency for reconstructed muons [2]. Right panel: mass resolution at the J/ψ resonance as a function of N_{tracks}. [2]

formance and how it varies in different collision systems [2]. The left panel of Fig. 1 shows the muon identification efficiency for muons reconstructed with basic reconstruction criteria, plotted as a function of muon pseudorapidity η. The solid points are results obtained via the data-driven tag-and-probe technique, whereas open points are results from Monte Carlo (MC) simulations. The red points show the efficiency for lead-lead (PbPb) collisions, the black points for pp collisions. The bottom panel shows the ratio of values obtained from data to those obtained from the MC simulation. We observe that the muon identification efficiency is $> 96\%$. The efficiency is as good in PbPb collisions as in pp collisions, with the exception of forward and backward η regions, which have a lower p_{T} acceptance and thus higher multiplicity. The trends observed in data are well modeled in the MC simulation. The right panel of Fig. 1 shows the relative mass resolution at the J/ψ peak, plotted as a function of number of tracks in the event. We observe that the rapidity-integrated resolution is approximately 1.3% across the whole measured multiplicity range, and well described by the MC simulation.

3 Υ states in pPb

The Υ states were measured in pPb collisions at $\sqrt{s_{_{\mathrm{NN}}}}$ =5.02 TeV in the kinematic region of $p_{\mathrm{T}}(\Upsilon) < 30\,\mathrm{GeV}$ and $|y_{\mathrm{CM}}|<1.93$ [3]. Figure 2 shows the R_{pPb} as a function of p_{T} on the left panel, and as a function of y_{CM} on the right panel. The suppression for all three Υ states is consistent with a constant across the measured p_{T} and y_{CM} range. Suppression for individual states is ordered as $R_{\mathrm{pPb}}(\Upsilon(1S)) > R_{\mathrm{pPb}}(\Upsilon(2S)) > R_{\mathrm{pPb}}(\Upsilon(3S))$. The suppression order follows the ordering of the states' binding energies, where more strongly bound states are less suppressed. It is challenging to describe this behaviour by models with initial-state effects only [4, 5]. Models with final-state interactions, such as the comovers model [6], can describe the observed ordering well.

4 Υ(2S) and Υ(3S) in PbPb

The first ever measurement of R_{AA} in PbPb collisions for Υ(3S) was obtained by the CMS experiment, together with an improved measurement of R_{AA} for Υ(2S) [7]. The results are

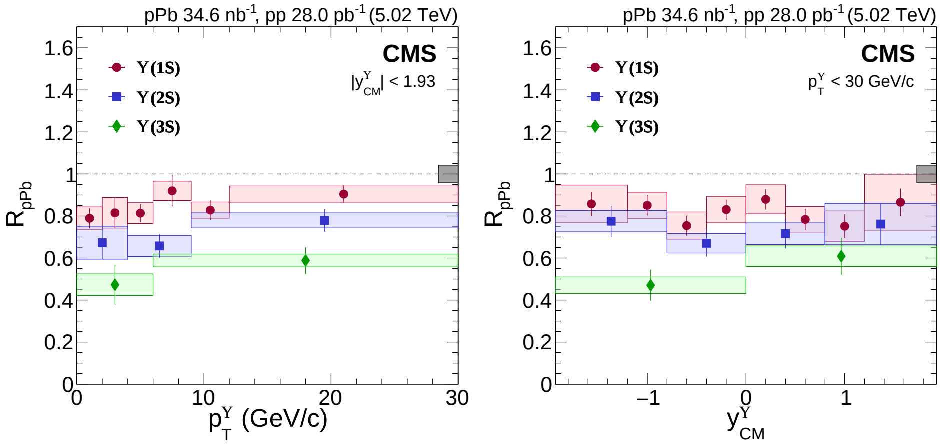

Figure 2. Nuclear modification factor R_{pPb} for Υ states in pPb collisions as a function of p_{T} (left panel) and y_{CM} (right panel) [3].

plotted in Fig. 3, together with Υ(1S) data from Ref. [8]. The left panel of the figure shows the nuclear modification factor as a function of p_{T}. We observe that the more excited Υ states are more suppressed, $R_{\mathrm{AA}}(\Upsilon(1\mathrm{S})) > R_{\mathrm{AA}}(\Upsilon(2\mathrm{S})) > R_{\mathrm{AA}}(\Upsilon(3\mathrm{S}))$. There is not a strong trend of R_{AA} as a function of p_{T}, and within uncertainties the values are consistent with a constant. The right panel shows the dependence on average number of participants in the collision $\langle N_{\mathrm{Part}}\rangle$. All the states are more suppressed in central collisions (large $\langle N_{\mathrm{Part}}\rangle$) than in peripheral collisions. The results are consistent with calculations from selected transport models [9, 10]. A transport model based on the coupled Boltzmann equation [11], a model incorporating in-medium dissociation mechanisms [12], and the comover interaction model [6] describe some observed trends, but do not manage to describe all three Υ states.

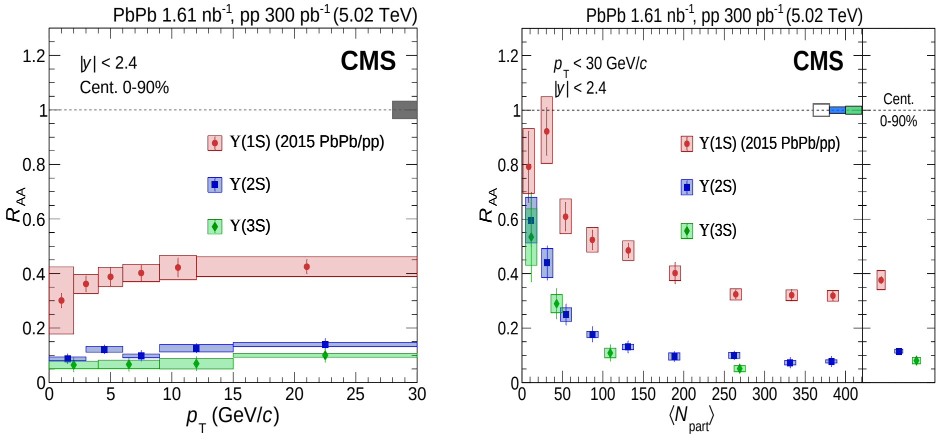

Figure 3. Nuclear modification factor R_{AA} for Υ states in PbPb collisions as a function of p_{T} (left panel) and $\langle N_{\mathrm{Part}}\rangle$ (right panel). The subpanel in the right plot shows the centrality 0–90% integrated results [7].

5 Comparison of nuclear modification between PbPb and pPb collisions

Figure 4 shows the rapidity- and p_T-integrated nuclear modification factors for pPb (red) and PbPb (blue) collisions for the three Υ states. We note that the absolute level of suppression is much larger in PbPb collisions.

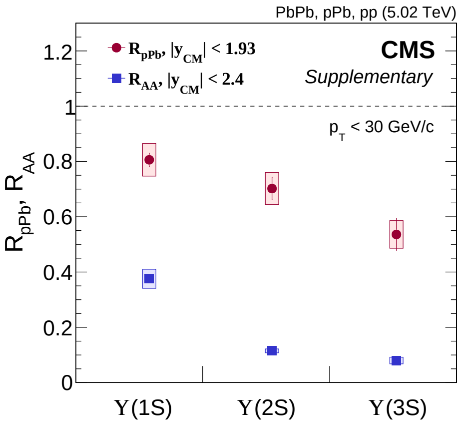

Figure 4. Nuclear modification factor for the three Υ states for pPb collisions (red points) and PbPb collisions (blue points) [7].

6 Summary

We have reported on the performance of the muon detection in the CMS experiment, which we find to be excellent and stable from proton-proton (pp) through proton-lead (pPb) to lead-lead (PbPb) collisions. The detection performance enabled detailed studies of Υ states both in pPb and PbPb collisions. We find that the general ordering of nuclear modification factors $R_{\mathrm{pPb}}/R_{\mathrm{AA}}(\Upsilon(1S)) > R_{\mathrm{pPb}}/R_{\mathrm{AA}}(\Upsilon(2S)) > R_{\mathrm{pPb}}/R_{\mathrm{AA}}(\Upsilon(3S))$ is present both in pPb and PbPb measurements, albeit the overall level of suppression is larger in PbPb collisions.

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