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J/ψ and $\psi(2S)$ production in pp and PbPb collisions at 5.02 TeV with ATLAS

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Abstract

A measurement of J/ψ and $\psi(2S)$ production is presented. It is based on data from lead-lead collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and pp collisions at $\sqrt{s}$ = 5.02 TeV recorded by the ATLAS detector at the LHC in 2015, corresponding to integrated luminosities of 0.49 nb^{-1} and 25 pb^{-1} in Pb+Pb and pp, respectively. The measurements of differential cross sections, nuclear modification factors, and non-prompt fractions were performed in the dimuon decay channel. A strong suppression was found for both prompt and non-prompt J/ψ, as well as for prompt and non-prompt $\psi(2S)$, becoming more pronounced with increasing event centrality. The suppression of prompt $\psi(2S)$ was observed to be stronger than that of J/ψ, while the suppression of non-prompt $\psi(2S)$ was equal to that of the non-prompt J/ψ within uncertainties, consistent with the expectation that both arise from b-quarks propagating through the medium. The dependence of nuclear modification factors with centrality for prompt and non-prompt J/ψ was found to have a similar form, despite the quite different physical origins expected to have given rise to their production: a composite meson formed within the medium and a b-quark propagating through and out of the medium, respectively.

Keywords: Quarkonia, A-A collisions, ATLAS, QuarkGluonPlasma, QCD

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1. Introduction

Three decades ago, Matsui and Satz first suggested that charmonia, bound states of c and $\bar{c}$ quarks, could be a unique probe to study the hot, dense system created in nucleus-nucleus (A+A) collisions [1]. In this work they postulated that Debye screening of the quark colour charge in a hot plasma would tend to prevent the formation of a composite bound state of quarkonia in that medium when the Debye radius becomes smaller than the quarkonia binding radius, and thus that the reduction of quarkonia production in heavy ion collisions would provide information related to the temperature and degree of deconfinement of the medium.

Since then, there have been numerous experimental and theoretical investigations [2] that have demonstrated that other effects are also present in addition to the possibility of colour screening in a deconfined plasma. First, it has been shown that over a wide range of interaction energies there is already a modification in the production of J/ψ mesons in systems where a

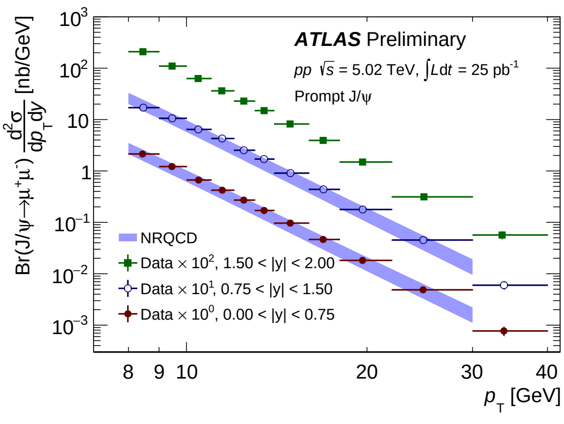

Figure 1: Cross section of prompt J/ψ production as a function of p_T for three $|y|$ slices, $1.50 < |y| < 2.0$ (top), $0.75 < |y| < 1.50$ (middle), $0.00 < |y| < 0.75$ (bottom), [2].

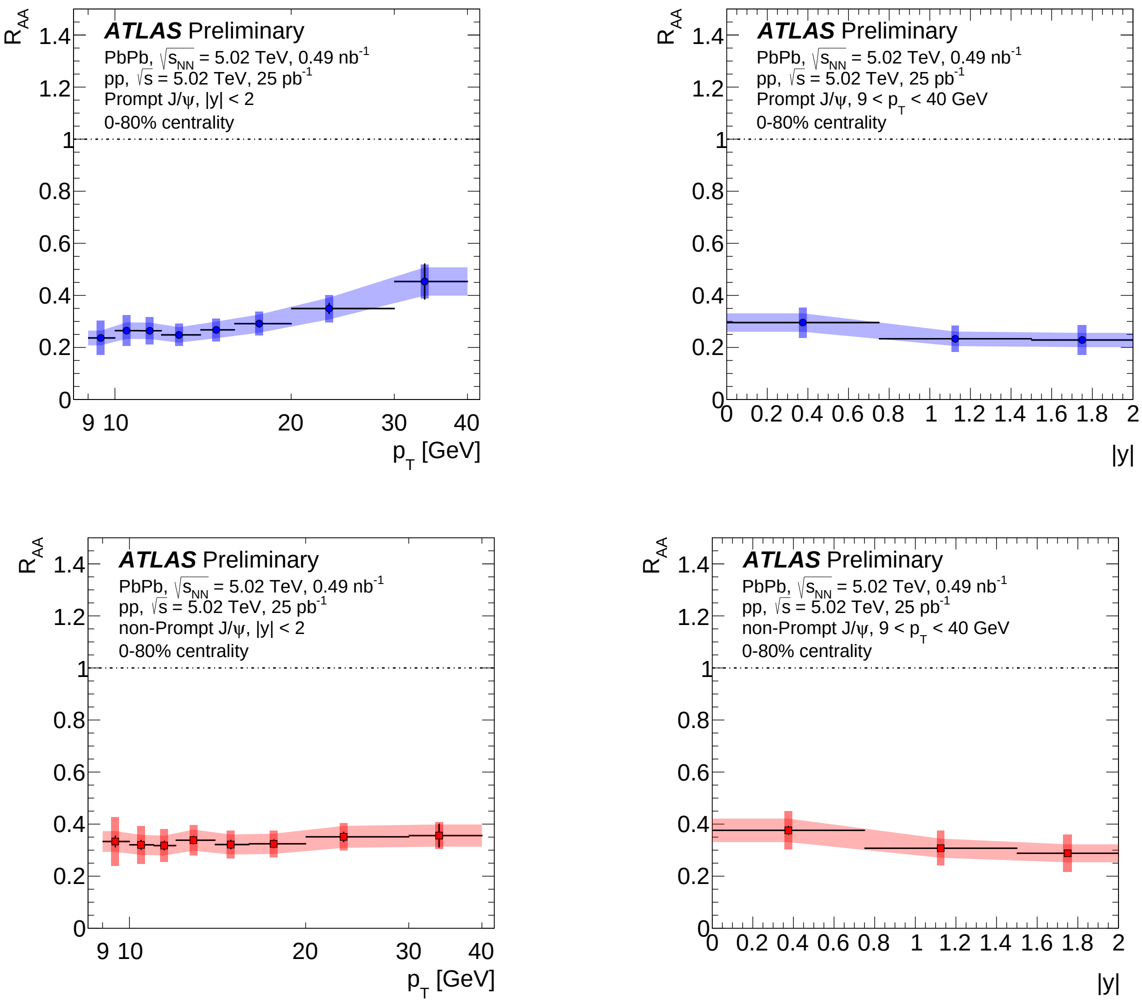

Figure 2: Plots showing the nuclear modification factor R_{AA}. The upper two plots are for prompt J/ψ mesons while the lower two plots are for non-prompt J/ψ mesons. The left column shows the p_T dependence while the right column shows the $|y|$ dependence, [2].

large volume of quark-gluon plasma does not appear to form, such as in proton-nucleus collisions. Second, it has been shown that not only suppression of quarkonia is observed in ion-ion collisions, but an enhancement is also observed at low transverse momentum p_T relative to production in proton-proton collisions. This observation has led to the interpretation that recombination of produced charm quarks and anti-quarks from the medium can play a role by providing an additional source of quarkonium formation. Finally, it is well-known that J/ψ production at high energies originates not only from the immediate formation of the composite $c\bar{c}$ bound state ("prompt J/ψ"), but also from the decay of b-quark systems that result in a decay vertex separated from the collision vertex by macroscopic distances ("non-prompt J/ψ"). Suppression of the production of b-quark systems in the medium, in the most naive picture, is caused by a completely different phenomenon from the suppression of $c\bar{c}$ bound states. While $c\bar{c}$ bound state formation may be inhibited by color screening from a hot and deconfined medium, the suppression of b-quark production is commonly attributed to energy loss of propagating b-quarks by collisional and radiative processes. Simultaneous measurements of prompt and non-prompt charmonia are therefore essential for understanding the physics mechanisms of charmonium suppression in heavy ion collisions.

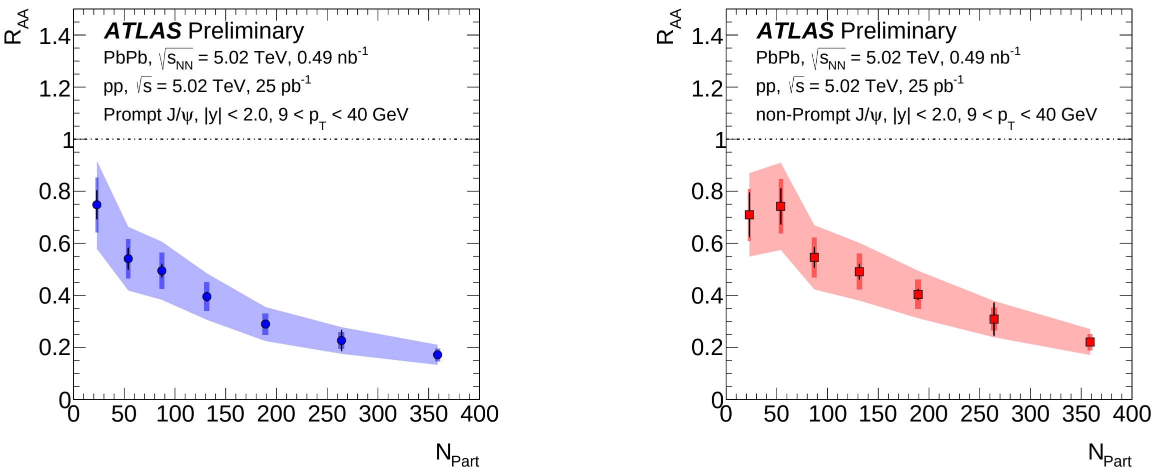

Figure 3: The nuclear modification factor as a function of centrality expressed as the number of participants N_{part} for the prompt J/ψ (left) and non-prompt J/ψ (right) for $9 < p_T < 40$ GeV and for rapidity $|y| < 2$, [2].

2. Experimental Methods

This analysis uses data from Pb+Pb collisions at a nucleon-nucleon centre-of-mass energy of $\sqrt{s_{NN}}$ = 5.02 TeV and pp collisions at centre-of-mass of $\sqrt{s}$ = 5.02 TeV recorded by ATLAS in 2015 [3]. Pb+Pb and pp events were collected using a trigger requiring at least two muons. In the pp sample both muons must be confirmed by the hardware-based first level trigger (L1) and High Level Trigger (HLT) while in the Pb+Pb sample only one muon is required to be confirmed by L1 and HLT; the second muon is required to pass the HLT only. At both levels the muon must satisfy the threshold of $p_T > 4$ GeV. The selected muon pairs from both pp and Pb+Pb must be consistent with being originated from a common vertex, have opposite charges, and an invariant mass in the range $2.6 < m_{\mu\mu} < 4.2$ GeV. The charmonium candidate is further required to satisfy $p_T > 8$ GeV in pp and $p_T > 9$ GeV in Pb+Pb to ensure that the pair candidates are reconstructed in a fiducial region where acceptance and efficiency corrections do not vary significantly relative to the magnitude of the systematic uncertainties quoted on the final results. The number of minimum bias events is used to normalize observables between different centrality classes. These events are selected by requiring at least one minimum bias trigger passed and corrected with the corresponding pre-scale factor to account for the total number of collisions. To distinguish prompt and non-prompt charmonium production, the pseudo-proper decay time is used, measured between the position of the reconstructed secondary vertex and the primary vertex in the event on the transverse plane. After the efficiency corrections are applied, simultaneous fits are performed to the invariant mass and pseudo-proper time distributions of weighted events to eliminate the background in order to determine the yields of the prompt and non-prompt charmonium components. The fit model consisted of four signal terms and three background terms. Each signal term consisted of the weighted sum of a crystal ball function and a Gaussian function in mass multiplied by a term depending on pseudo-proper time. For the latter term, the prompt quarkonium production was modeled by a delta function while the non-prompt quarkonium production was modeled by an exponential decay. This model was convolved with a double Gaussian function in pseudo-proper time to take into account the experimental detached vertex resolution. The prompt background in invariant mass was adequately represented as a constant and as a delta function in pseudo-proper time, while the non-prompt backgrounds were modeled by two exponential functions in both mass and pseudo-proper time. Variations on this model were used to estimate the systematic uncertainties, averaging 2% for J/ψ and 10% for $\psi(2S)$.

3. Results

The results for the measurement of the cross section of prompt charmonium states in pp collisions are shown in Figure 1. The cross section as a function of p_T for production of prompt J/ψ mesons is shown for central, mid and forward rapidities out to 40 GeV. The data are shown in the solid and open circles while the shaded band indicates the centroids and uncertainties from the non-relativistic QCD model. As can be seen, the data are in very good agreement with the calculations of this model within the uncertainties. The influence of the hot dense medium on the production of the J/ψ and $\psi(2S)$ mesons is quantified by the nuclear modification factor, which compares these processes in the ion-ion collisions to the same processes in proton-proton scattering, taking geometric factors into account. The results from the ATLAS measurement of this observable are presented in Figures 2 and 3, as a function of p_T, rapidity y, and centrality quantified using the mean number of participants in each interval, $\mathrm{N_{part}}$. The final observable discussed in this note is the ratio of $\psi(2S)$ to J/ψ production which is shown in Figure 4. This ratio, which compares the production of the two mesons, can in principle be interpreted, for example, in models in which the binding energy of the two mesons is estimated, or in which the formation mechanisms differ. These data support the suppression of prompt $\psi(2S)$ relative to J/ψ. This observation is consistent with the simple interpretation that the more tightly bound quarkonium system survives the temperature of the hot dense medium with a higher probability than the more loosely bound quarkonium. Because the kinematic region of our measurement is for $p_T^{\psi} > 9$ GeV, we expect to have less ambiguity in this interpretation due to the effect of quark recombination processes. These are expected to be quite important for $p_T^{\psi(nS)} \approx 0$, an expectation that is supported by measurements in that kinematic domain [4].

4. Conclusions

ATLAS measurements of prompt and non-prompt differential production cross sections and nuclear modification factors, R_{AA}, of the J/ψ and $\psi(2S)$ mesons are presented. A strong suppression of both prompt and non-prompt J/ψ and $\psi(2S)$ mesons is observed. The maximal suppression of both prompt and non-prompt J/ψ is observed for the most central events. The distribution of the dependence of the nuclear modification factor R_{AA} on centrality is approximately the same for both prompt and non-prompt J/ψ. The similarity of this shape for both prompt and non-prompt J/ψ is striking, since in the simplest interpretation the observed prompt mesons come predominantly from potentially fragile composite systems exposed to the hot dense medium, while the non-prompt mesons come predominantly from b-quarks traversing through the medium; thus, one might expect different trends as a function of centrality. The ratio of $\psi(2S)$ to J/ψ meson production is measured for both prompt and non-prompt mesons, and shown as a function of centrality. Values consistent with unity are measured for the non-prompt mesons, while the values observed for the prompt mesons are below unity. This result is consistent with what would be expected for b-quarks in the dense medium with the same behaviour for both mesons, while composite mesons formed in the medium are affected differently. In particular, the $\psi(2S)$ meson is suppressed more than the J/ψ meson, a pattern consistent with the lower binding energy of the $\psi(2S)$ meson causing it to have a lower formation and survival probability for the values of $p_T^{\psi(nS)}$ sampled in this measurement.

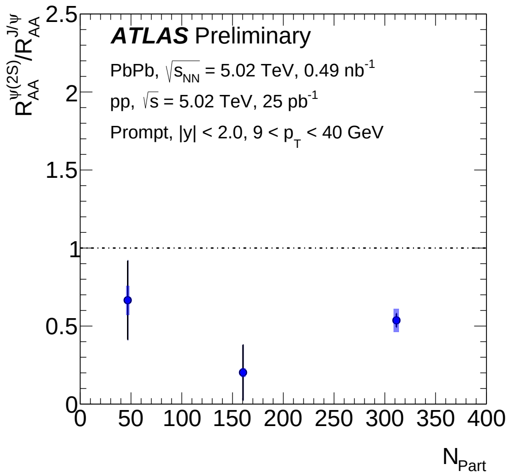

Figure 4: $\mathrm{R_{AA}}$ ratio for $\psi(2S)$ to J/ψ, as a function of centrality expressed as N_{Part}, for prompt meson production. This ratio has the advantage that corrections are similar for the numerator and denominator, and thus systematic uncertainties are reduced, [2].

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