Quarkonia production and suppression in heavy ion collisions in STAR

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Abstract.

We report on recent STAR results on J/ψ and Υ production and suppression at midrapidity in Au+Au collisions at RHIC. We present the J/ψ nuclear modification factor as a function of centrality and transverse momentum at $\sqrt{s_{NN}}$ = 200, 62.4 and 39 GeV and discuss the energy dependence of J/ψ production. We also present the Υ nuclear modification factor in Au+Au collisions at 200 GeV calculated using high statistics p+p data taken in 2009.

1. Introduction

Measurements of production of various quarkonia states can provide insight into thermodynamic properties of the Quark-Gluon Plasma (QGP). Quarkonia production is anticipated to be suppressed in the presence of a QGP, compared to yields in $p + p$ collisions scaled by the number of binary nucleon-nucleon collisions, due to the Debye screening of the quark-antiquark potential in the deconfined, partonic medium. The Debye screening length depends on the temperature of the QGP. Different quarkonia states have different binding energies and thus different radii. Therefore, they are expected to disassociate at different temperatures. However, there are other effects that may affect the observed suppression. Cold nuclear matter effects (for instance shadowing and nuclear absorption), feed down from exited states, and secondary production via coalescence of uncorrelated heavy quarks can alter the observed yields. Each of these mechanisms has a different energy dependence: color screening increases with energy density thus increases with colliding energy, secondary production is bigger at higher energies due to larger cross section for heavy quark production, and nuclear absorption decreases with the energy [1]. Study of quarkonia production for different colliding systems, collision energies, and centralities can help to disentangle the interplay of these mechanisms and to understand the partonic medium properties.

2. Data analysis

STAR [2] is a large acceptance ($|\eta|$ <1, full coverage in ϕ) multipurpose detector composed of several subsystems making it well suited to measure quarkonia production. We reconstruct quarkonia (J/ψ, Υ) via the di-electron decay channel with a branching ratio $B_{ee} = 5.9\%$ for J/ψ and $B_{ee} = 2.4\%$ for Υ. In the analyses reported here, the STAR Time Projection Chamber (TPC), Barrel Electromagnetic Calorimeter (BEMC), and Time-Of-Flight (TOF) detectors are

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used. The TPC provides charged track reconstruction and particle identification via specific ionization energy loss (dE/dx). The BEMC is used for electron selection at high p_T and also for a high-p_T electron trigger for Υ and high-p_T J/ψ measurements. At low p_T, the TOF is used to improves electron identification. In this article, we present results for J/ψ in $|y| < 1$ and Υ in $|y| < 0.5$ obtained with $p+p$ data taken in 2009, and Au+Au data collected in 2010 at $\sqrt{s_{\rm NN}} = 200$, 62 and 39 GeV.

3. Results

To study the modification of quarkonium production in Au+Au collisions relative to $p+p$ interactions, we calculate the nuclear modification factor R_{AA}: $R_{AA} = \frac{{\rm d}^2N_{Au+Au}/dydp_T}{N_{\rm bin}\times {\rm d}^2N_{p+p}/dydp_T}$, where ${\rm d}^2N_{Au+Au}/dydp_T$ and ${\rm d}^2N_{p+p}/dydp_T$ are invariant yields in Au+Au and $p+p$ collisions, respectively, and $N_{\rm bin}$ is number of binary collisions in a given Au+Au centrality class.

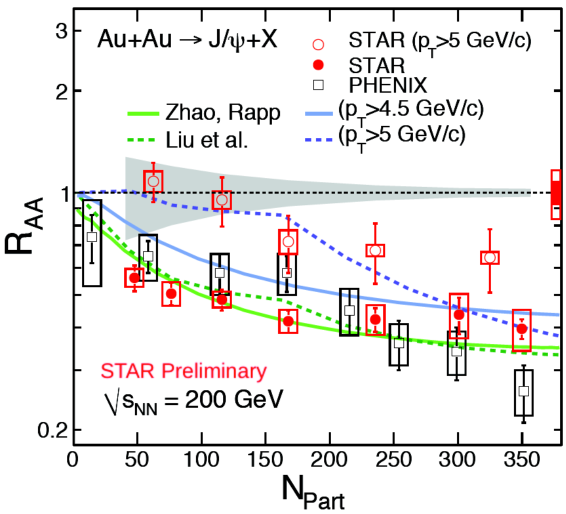

Figure 1. J/ψ R_{AA} as a function of centrality compared with data from PHENIX [3]. The statistical and systematic uncertainties are shown as vertical bars and boxes, respectively. The shaded band about unity shows the systematic uncertainties from estimates of the number of binary collisions and the box about unity shows the normalization uncertainty from the statistical and global systematic uncertainties of the $p+p$ reference data.

Figure 1 shows the R_{AA} for J/ψ as a function of centrality (represented by number of participants, $N_{\rm part}$) in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV. We compare p_T-integrated results (which are dominated by low-p_T part) from STAR and PHENIX to high-p_T ($p_T > 5$ GeV) data from STAR. In general, the R_{AA} decreases with the centrality and a strong suppression is observed in the most central collisions for p_T-integrated data. High-p_T J/ψ results are systematically higher than the low-p_T measurements. There is no suppression in peripheral events for high-p_T J/ψ while a significant suppression in central collisions is observed, although smaller than minimum bias results. Moreover, the J/ψ is not suppressed in d+Au collisions for $p_T > 5$ GeV/c [4] which indicates that cold-nuclear-matter effects are small at high p_T. Therefore, the observed suppression at high p_T is a manifestation of the QGP effects. Note that feed-down from $B \rightarrow J/\psi$ (which is $\sim 10-25\%$ for $4 < p_T < 12$ GeV/c in $p+p$ collisions) is not removed and part of the suppression could come from $b-$quark energy loss.

STAR data are also compared with two model predictions by Zhao and Rapp [5] and Liu et al. [6]. Both models assume suppression of J/ψ due to color screening and secondary production via recombination and both describe the low-p_T data reasonably well. In the case of high-p_T J/ψ, calculations by Liu et al. agree with the data but the model by Zhao and Rapp underpredicts the R_{AA}.

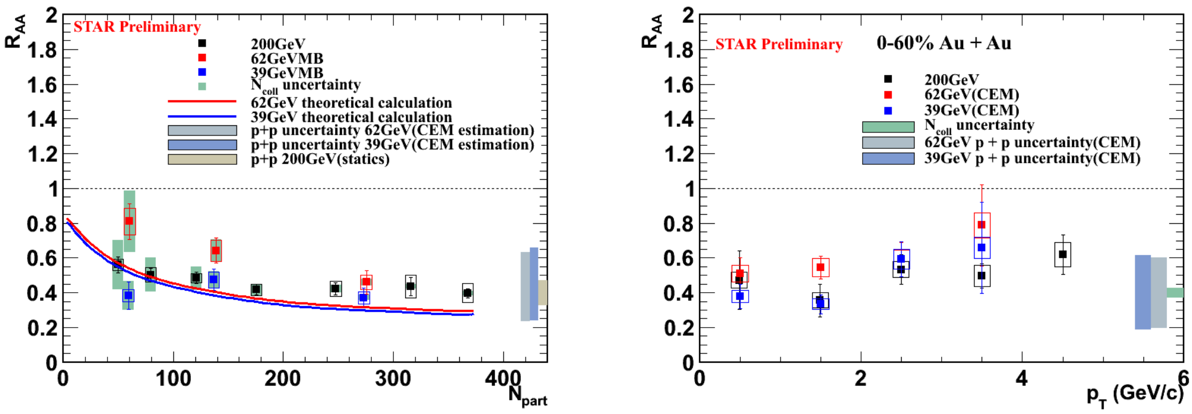

Figure 2. Nuclear modification factor $R_{\rm AA}$ for low-p_T ($p_T < 5$ GeV/c) J/ψ at $\sqrt{s_{\rm NN}} = 200$, 62.4 and 39 GeV as a function of N_{part} (left panel) and p_T (right panel).

Figure 2 shows the nuclear modification factor as a function of centrality and p_T for low$-p_T$ ($p_T < 5$ GeV/c) J/ψ in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$, 62.4 and 39 GeV. In the case of 39 and 62 GeV, predictions of Color Evaporation Model [7] are used as a baseline, with uncertainties indicated by the boxes on the right hand side of the plot. Point-to-point statistical and systematic errors are indicated by bars and boxes on each data point, respectively. We observe a significant suppression at all three energies. The STAR data are compared to predictions from model calculations by Zhao and Rapp which assumes two main components: suppression of direct J/ψ due to color screening and secondary production via recombination of c and $\bar{c}$ quarks. The model predicts very similar suppression for both 39 and 62 GeV, despite a significant difference in energy and thus different initial energy densities. In this model, larger suppression of direct J/ψ production at higher energy is offset by an enhanced regeneration rate due to a larger cross section for charm quarks. These calculations agree reasonably well with our data within errors.

In 2009, a new, high-statistics $p+p$ dataset was collected by STAR with an integrated luminosity of $L = 19.7$ pb^{-1}. This enabled more precise measurement of Υ production in $p+p$ compared to published results and, in turn, a better R_{AA} determination. STAR measured the $\Upsilon(1S+2S+3S)$ cross section at $|y| < 0.5$ of $B{\rm d}\sigma/{\rm dy} = 92 \pm 17 \pm 19$ pb. The left panel of Fig. 3 shows the energy dependence of Υ cross section; the STAR measurement is consistent with world data trend and Color Evaporation Model [8] predictions. The right panel of Fig. 3 shows the Υ nuclear modification factor as a function of centrality for in Au+Au collisions at $\sqrt{s_{\rm NN}} =$ 200 GeV. The suppression increases with centrality and a significant suppression is observed in the most central collisions. Data are compared to a model by Strickland et al. [9], which assumes a thermal dissociation of Υ in a thermalized, expending partonic medium, simulated with relativistic hydrodynamics. These calculations predict complete suppression of $\Upsilon(2S)$ and $\Upsilon(3S)$ states in the most central collisions. The model reproduces the STAR results well and the data favors the scenario when an internal energy is used for heavy quark potential. However, cold-nuclear-matter effects are not included in that model.

In the near future, the Muon Telescope Detector (MTD) [10] will extend STAR capabilities for quarkonia measurements. It will allow the study of J/ψ elliptic flow with unprecedented

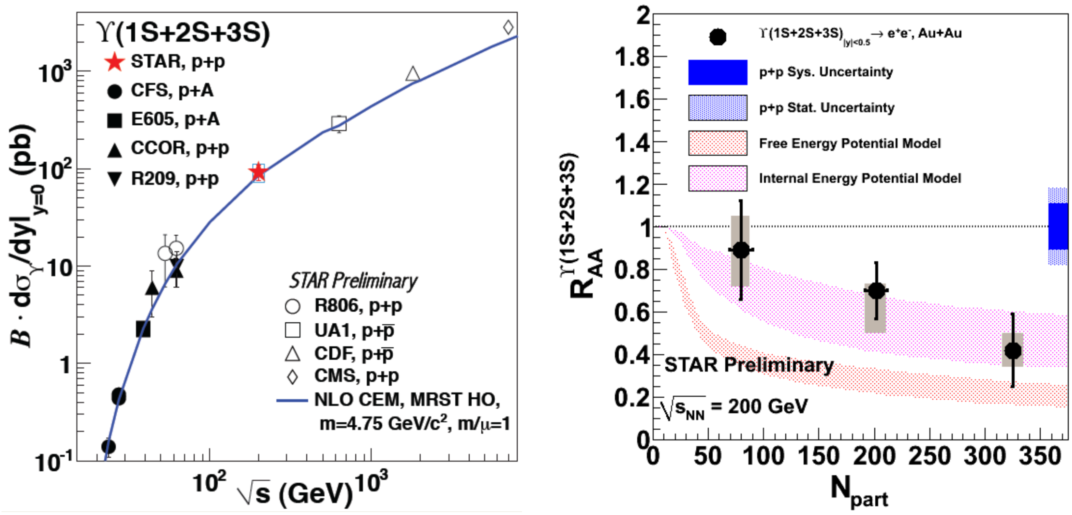

Figure 3. Left panel: The energy dependence of Υ cross section compared with predictions of Color Evaporation Model. Right panel: $R_{\rm AA}$ for Υ in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV.

precision and of suppression of the separate $\Upsilon(1S), \Upsilon(2S)$ and $\Upsilon(3S)$ states. Measurement of suppression of different Υ states will advance the studies of the QGP thermodynamic properties. 63% of MTD was installed in 2013 and the construction will be completed for the RHIC run 2014.

4. Summary

J/ψ suppression at lower energies (39 and 62 GeV) is similar to at 200 GeV. The Υ suppression at $\sqrt{s_{\rm NN}} = 200$ GeV increases with centrality and it is consistent with a model that assumes complete suppression of $\Upsilon(2S)$ and $\Upsilon(3S)$ states. J/ψ suppression is systematically smaller at high p_T compared to low p_T. However, a significant J/ψ suppression at high p_T is observed in the most central Au+Au collisions.

References

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