J/ψ production at the STAR experiment

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This paper reports on STAR measurements of J/ψ production at mid-rapidity. We present results on the ψ(2S) to J/ψ yield ratio in p+p collisions at $\sqrt{s}$=500 GeV. We also report results from Au+Au collisions at $\sqrt{s_{NN}}$ = 39 GeV, 62.4 GeV, 200 GeV together with results from U+U collisions at $\sqrt{s_{NN}}$=193 GeV. Nuclear modification factors are presented as a function of centrality and p_T.

1 Introduction

Suppression of quarkonium production in heavy-ion collisions due to Debye color screening of quark and antiquark potential in the deconfined medium, has been proposed as a signature of quark-gluon plasma (QGP) formation. Since the Debye screening length depends on the temperature attained by the QGP medium, systematic measurements of production of various quarkonium states can provide insight into thermodynamic properties of the QGP. However, there are other effects that may alter the observed yields, such as cold nuclear matter effects (CNM) including shadowing/anti-shadowing of parton distribution functions and final state nuclear absorption, and statistical coalescence of quark-antiquark pairs in the QGP. Measurements of J/ψ yields at different collision energies, collision systems, and centralities help to disentangle the interplay of these effects on the J/ψ production.

2 Data analysis and results

The STAR experiment is a large-acceptance detector which excels at tracking and identification of charged particles at mid-rapidity ($|\eta| < 1$) with full azimuthal coverage. In the bellow discussed analyses J/ψ's are reconstructed at mid-rapidity in the di-electron decay channel, $J/\psi \rightarrow e^+ + e^-$ (branching ratio B_{ee} = 5.9%). Electrons and positrons are reconstructed using the Time Projection Chamber (TPC) which also provides particle identification by measuring ionization energy loss (dE/dx). Furthermore, the particle identification is enhanced by the Time of Flight detector (TOF) in the low-p_T region and by the Barrel Electromagnetic Calorimeter (BEMC) in the high-p_T region.

In order to correctly interpret results from heavy-ion collisions we first need to understand the J/ψ production in elementary p+p collisions. STAR has measured production of J/ψ in p+p collisions at $\sqrt{s}$=500 GeV, the highest collision energy achievable in p+p collisions at RHIC. A p_T-dependent differential cross section for inclusive J/ψ production is shown in Fig. 1. The high precision results at the new collision energy reaching up to p_T = 20 GeV/c provide additional information that can be used to discriminate among different production models.

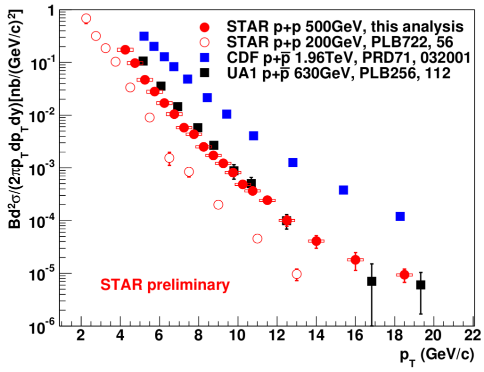

Figure 1: The J/ψ invariant cross section in p+p collisions at $\sqrt{s_{NN}}$=200 and 500 GeV, compared to results from other experiments.

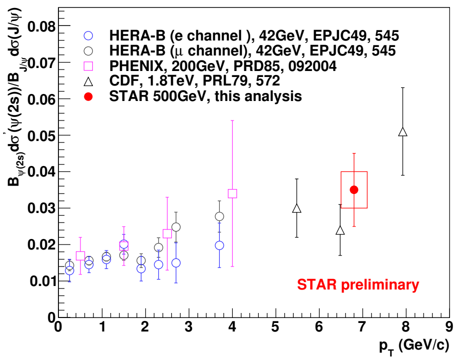

Figure 2: Ratio of $\psi(2S)$ to J/ψ yields in p+p at $\sqrt{s}$=500 GeV, compared to results from HERA-B, PHENIX and CDF experiments.

Moreover, the high statistics data recorded in year 2011 allowed to measure for the first time the production of $\psi(2S)$ state in p+p collisions at $\sqrt{s}$=500 GeV. The STAR result on the $\psi(2S)$ to J/ψ yield ratio at mid-rapidity presented in Fig. 2 is in agreement with results from other experiments which exhibit an increasing trend with p_T with no significant dependence on the collision energy.

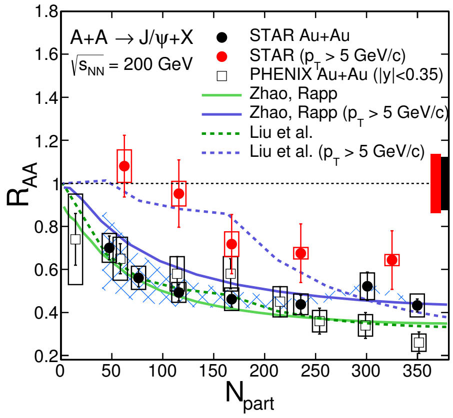

Figure 3: J/ψ R_{AA} as a function of centrality in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV from STAR [1, 2] and PHENIX [3], compared to model calculations [4, 5].

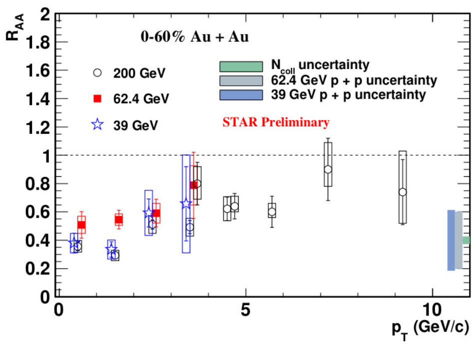

Figure 4: STAR results on J/ψ R_{AA} from 0-60% Au+Au collisions at $\sqrt{s_{NN}}$= 39, 62.4 and 200 GeV as a function of p_T. Open boxes represent systematic uncertainties. The boxes on the vertical axis represent uncertainties from CEM [6] baseline estimation for 39 and 62.4 GeV and $\langle N_{coll} \rangle$ uncertainties.

STAR results [1, 2] on modification of J/ψ production in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV are presented in Fig. 3. The nuclear modification factor R_{AA} is shown as a function of centrality (represented by number of participants, N_{part}) and compared to PHENIX [3] results. Strong suppression in the most central collisions is observed for both the low-p_T dominated result [1] (shown in black) and the high-p_T (p_T>5 GeV/c) results [2] (shown in red). R_{AA} at high-p_T are systematically higher than the low-p_T ones. For high-p_T J/ψ the suppression is observed only in central collisions (0-30%) while in peripheral and mid-peripheral collisions the R_{AA} is consistent with unity. Since d+Au results[7] indicate that at p_T> 5 GeV/c the CNM effects are negligible, the observed suppression in Au+Au collisions is likely to come from suppression in the QGP (due to color screening or other dynamical effects). However, it should be noted that the data are not corrected for B→J/ψ feed-down which can be, based on p+p data, as high as 15-25% in this p_T range. The data in Fig. 3 are compared to models of Zhao and Rapp [5] and Liu et al. [4]. These models contain not only suppression due to the color screening effect, but also secondary production of J/ψ via recombination of thermalized c and $\bar{c}$ quarks. The interplay between direct production and recombination can be studied by varying collision energy. Fig. 4 shows STAR results on p_T dependence of J/ψ R_{AA} in Au+Au collisions at $\sqrt{s_{NN}}$=200, 62.4 and 39 GeV. Centrality dependence of the low-p_T (p_T< 5 GeV/c) part of the data is shown in Fig. 5. At all three energies a similar suppression pattern is observed. The centrality dependence in Fig. 5 is compared to the model by Zhao and Rapp [5]. These calculations, in agreement with the data, predict rather small dependence of the suppression on the collision energy. In these models, the suppression of primordial J/ψ is more significant at a higher collision energy, but it is compensated by the increased contribution from regeneration due to larger charm quark production cross section.

It should be noted that STAR did not measure p+p data at 62.4 and 39 GeV and hence the Color Evaporation Model (CEM) [6] was used as a reference instead. The resulting uncertainties are shown as boxes in Fig. 4 and 5.

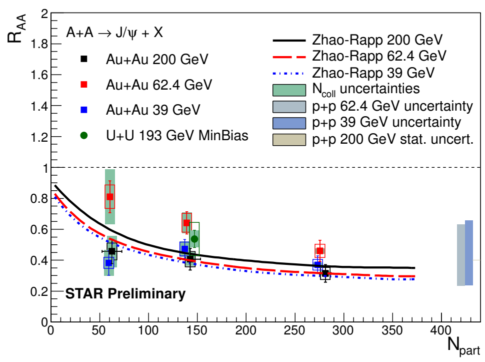

Figure 5: Centrality dependence of J/ψ R_{AA} for p_T<5 GeV/c in Au+Au collisions at different collision energies and U+U (p_T<6 GeV/c) at $\sqrt{s_{NN}}$=193 GeV.

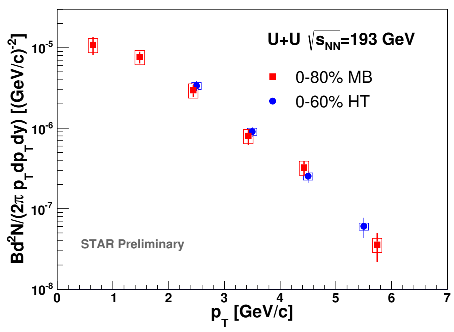

Figure 6: J/ψ invariant yield versus transverse momentum in U+U collisions at $\sqrt{s_{NN}}$=193 GeV from minimum bias (red) events and events triggered by high-p_T electron in BEMC (blue).

To further study the pattern of quarkonium suppression STAR recorded collisions of non-spherical Uranium nuclei at $\sqrt{s_{NN}}$=193 GeV in which an approximately 20% higher energy density can be reached. STAR results on J/ψ invariant yield at mid-rapidity in U+U collisions at $\sqrt{s_{NN}}$=193 GeV are shown in Fig. 6 with p_T reaching up to 6 GeV/c. The presented data are from 0-80% minimum bias (in red) and at high-p_T from events triggered by a signal from high-p_T electron in Electromagnetic Calorimeter (in blue). Spectra from p+p collisions at $\sqrt{s_{NN}}$=200 GeV are used to obtain J/ψ R_{AA} in U+U at $\sqrt{s_{NN}}$=193 GeV. The p_T dependence

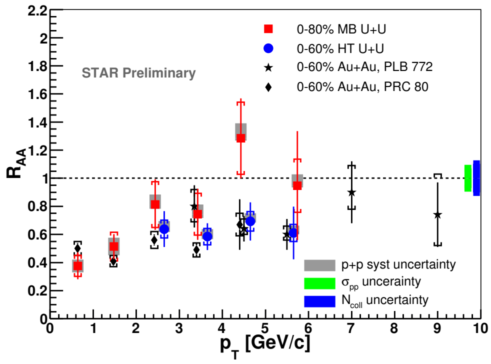

Figure 7: J/ψ nuclear modification factor in U+U collisions at $\sqrt{s_{NN}}$=193 GeV as a function of p_T, compared to results form Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV.

of the R_{AA} shown in Fig. 7 is within uncertainties similar to Au+Au collisions. The data show a strong suppression at low-p_T with a non-negligible suppression remaining even in the high-p_T region. The R_{AA} obtained from the low-p_T dominated 0-80% minimum bias events are compared to the centrality (N_{part}) dependence of R_{AA} at different Au+Au collision energies in Fig. 5. The U+U results are consistent within uncertainties with the suppression pattern observed in Au+Au.

3 Summary

STAR has measured ratio of ψ(2S) to J/ψ in p+p collisions at $\sqrt{s}$=500 GeV and found it consistent with the results at other collision energies. The J/ψ suppression in Au+Au collisions at lower energies of $\sqrt{s_{NN}}$=39 and 62.4 GeV is similar to those at 200 GeV suggesting an important interplay of suppression of primordial J/ψ and regeneration. STAR has also measured J/ψ R_{AA} in U+U collisions at $\sqrt{s_{NN}}$=193 GeV. The U+U data are consistent within uncertainties with the suppression pattern observed in Au+Au collisions.

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