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J/ψ production in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV

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In this contribution, we present the measurements of inclusive J/ψ production at midrapidity ($|y|$ < 1.0) in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV by the STAR experiment. The dependences of nuclear modification factor (R_{AA}) on centrality and transverse momentum are measured with improved precision compared to previous measurements at 39 and 62.4 GeV. Combining newly measured R_{AA} of J/ψ at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV and previous results at SPS, RHIC, and LHC energies, no significant energy dependence of R_{AA} is found within uncertainties up to 200 GeV. The comparision to model calculations is presented and its physical implications are discussed.

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1. Introduction

In nucleus-nucleus collisions, heavy-flavour hadrons (containing open or hidden charm and bottom flavour) are ideal probes to study the properties of the hot and dense Quark-Gluon Plasma (QGP), because they are mainly produced via initial hard partonic scatterings and thus experience the entire evolution of the produced QGP medium. A heavy quark and its anti-quark, such as charm-anticharm and bottom-antibottom, can form a quarkonium bound state and the potential holding the bound state could be screened by partons in the QGP [1]. Therefore, the quarkonium production is expected to be suppressed in heavy-ion collisions with respect to those in p+p collisions scaled by the number of binary nucleon-nucleon collisions, $N_{\rm coll}$, at the same energy. Besides the color screening in the QGP, there are other effects that are important for the quarkonium production, such as the recombination of $c\bar{c}$ or $b\bar{b}$ pairs in the medium (regeneration) [2, 3], modifications from cold nuclear matter (CNM) effects [4–7], and other final state effects, like dissociation by co-movers [8].

Various measurements of the J/ψ meson production in high-energy heavy-ion collisions have been performed in different collision systems at SPS, RHIC, and LHC energies, and suppressions of the J/ψ production have been observed by different collaborations [9–14]. A smaller suppression of the J/ψ meson production at LHC energies [11, 14], compared to that at 200 GeV [13], is seen because of the increased regeneration contribution. In previous measurements by the STAR Collaboration [12], the collision energy ($\sqrt{s_{\rm NN}}$) dependence of the J/ψ suppression between 39 and 200 GeV was studied and found to be insignificant within uncertainties. In 2017, about ten times more statistics for Au+Au collisions at 54.4 GeV, compared to that used for the previous measurement at 62.4 GeV, was collected by the STAR experiment. This will help to study the collision energy dependence of the regeneration contribution and the J/ψ suppression with improved precision.

2. Experiment and Analysis

The data sample used in this analysis contains about 1.3 billion minimum-bias Au+Au events at $\sqrt{s_{\rm NN}}$ = 54.4 GeV collected in 2017 by the STAR experiment. The $J/\psi \rightarrow e^+e^-$ decay channel is used to reconstruct J/ψ candidates. Electron candidates are reconstructed and identified using information mainly from the Time Projection Chamber [15], Time-of-Flight [16], and the Barrel Electromagnetic Calorimeter [17]. Figure 1 shows the J/ψ meson invariant mass distribution for the 0-60% most central collisions. The J/ψ counts are extracted by subtracting combinatorial background, estimated using the unlike-sign distribution from mixed-events, and fitting the J/ψ signal with lineshapes obtained from simulations that are tuned to match to data in terms of momentum resolution. The residual background is described by a straight line. The transverse momentum (p_T) dependence of the J/ψ invariant yields in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 54.4 GeV for different centrality bins are shown in Fig. 2 with a p_T > 0.2 GeV/c cut to exclude coherent photon induced production. Nuclear modification factors ($R_{\rm AA}$, $R_{\rm CP}$) are used to quantify the suppression of the J/ψ production and defined as:

$$R_{\rm AA} = \frac{1}{\langle T_{\rm AA}\rangle}\frac{d^2N_{\rm AA}/dp_T\,dy}{d^2\sigma_{\rm pp}/dp_T\,dy},$$

$$R_{\mathrm{CP}} = \frac{\frac{dN/dy}{\langle N_{\mathrm{coll}} \rangle}(central)}{\frac{dN/dy}{\langle N_{\mathrm{coll}} \rangle}(peripheral)},$$

where $d^2N_{\mathrm{AA}}/dp_T dy$ is the J/ψ yield in A+A collisions and $d^2\sigma_{\mathrm{pp}}/dp_T dy$ is the J/ψ cross section

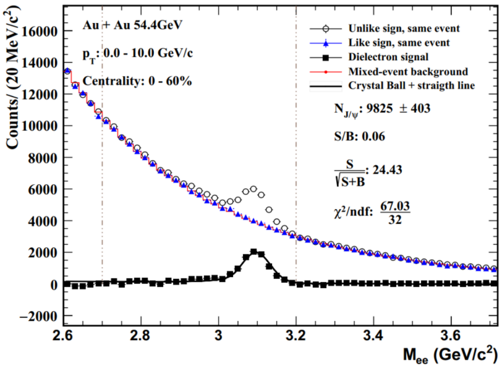

Figure 1: The J/ψ meson invariant mass peak in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV for 0-10 GeV/c transverse momentum bin and 0-60% centrality bin.

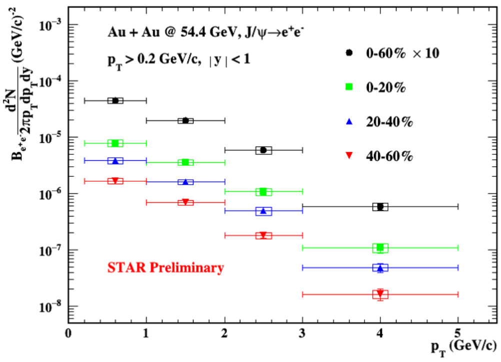

Figure 2: J/ψ invariant yields in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV as a function of p_T for different centralities. The error bars represent the statistical uncertainties. The boxes represent the systematic uncertainties

in p+p collisions. The nuclear overlap function is defined as $T_{\mathrm{AA}}(\mathbf{b}) = \int T_{\mathrm{A}}(\mathbf{s})T_{\mathrm{A}}(\mathbf{s} - \mathbf{b})d^2s$, where $T_{\mathrm{A}}(\mathbf{s})$ is the transverse nucleon density and $\mathbf{b}$ is the impact parameter. $\langle N_{\mathrm{coll}} \rangle$ is the average number of nucleon-nucleon collisions in a given centrality bin.

3. Results

The R_{CP}, as a function of the mean number of participants $\langle N_{\mathrm{part}} \rangle$ for different collision energies, is shown in the left panel of Fig. 3. The 40-60% centrality bin is used as the peripheral centrality bin and a suppression is observed in central Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 54.4 GeV, which is similar to that at 62.4 and 200 GeV.

In the right panel of Fig. 3, the p_T-integrated R_{AA} as a function of $\langle N_{\mathrm{part}} \rangle$ is shown in Au+Au collisions at different collision energies. The p+p baselines at 39, 54.4, and 62.4 GeV are extracted from interpolations of world data since no measurements of inclusive J/ψ cross section are available in p+p collisions at these three energies [18]. Suppression of the J/ψ production is observed in Au+Au collisions at 54.4 GeV with improved precision compared to previous results at 39 and 62.4 GeV. Figure 4 shows the collision energy dependence of R_{AA} for different collision systems in central collisions. There is no significant energy dependence within uncertainties from SPS to RHIC top energy. The theoretical calculation of the total J/ψ R_{AA} is shown as the solid line [19], and the blue dash-dotted line represents the suppressed primordial production due to CNM effects and dissociation in the QGP medium, while the red dashed line denotes the regeneration contribution. The theoretical calculation is consistent with the observed energy dependence, indicating that the

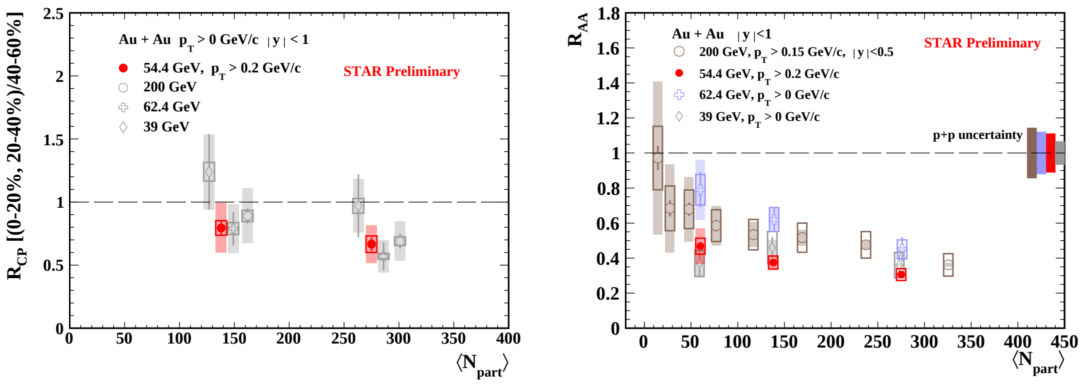

Figure 3: *Left panel*: J/ψ $R_{\rm CP}$, with respect to 40-60% peripheral collisions, for Au+Au collisions as a function of $\langle N_{\rm part}\rangle$. The error bars represent the statistical uncertainties. The boxes represent the systematic uncertainties combined with uncertainties from $\langle N_{\rm coll}\rangle$. *Right panel*: The $R_{\rm AA}$ of inclusive J/ψ as a function of $\langle N_{\rm part}\rangle$ in Au+Au collisions at different collision energies at mid-rapidity [12, 13]. The error bars represent the statistical uncertainties. The boxes represent the systematic uncertainties. The shaded bands on the data points indicate the uncertainties from the nuclear overlap function $\langle T_{\rm AA}\rangle$ [18]. The bands around unity indicate the uncertainties from the p+p baselines.

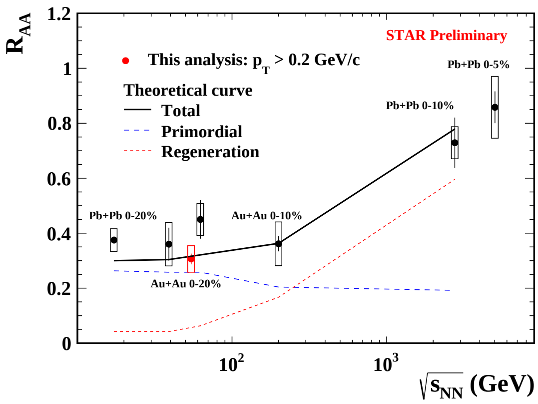

Figure 4: The $R_{\rm AA}$ of J/ψ as a function of collision energy for central collisions [9–14], in comparison with model calculations [19]. The error bars represent the statistical uncertainties and the boxes represent the systematic uncertainties, including those from p+p baselines and uncertainties from $\langle T_{\rm AA}\rangle$.

J/ψ production in high-energy heavy-ion collisions is an interplay of dissociation in the QGP medium, regeneration, and CNM effects.

Figure 5 shows the J/ψ $R_{\rm AA}$ as a function of p_T at different collision energies (left) and centralities (right). A larger suppression is observed at lower p_T and towards more central collisions.

4. Summary

In this contribution, measurements of the J/ψ production in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 54.4 GeV from STAR are presented. The $\langle N_{\rm part}\rangle$ dependence of $R_{\rm CP}$ and $R_{\rm AA}$ shows a suppression in central Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 54.4 GeV. Newly measured $R_{\rm AA}$ of the J/ψ meson at

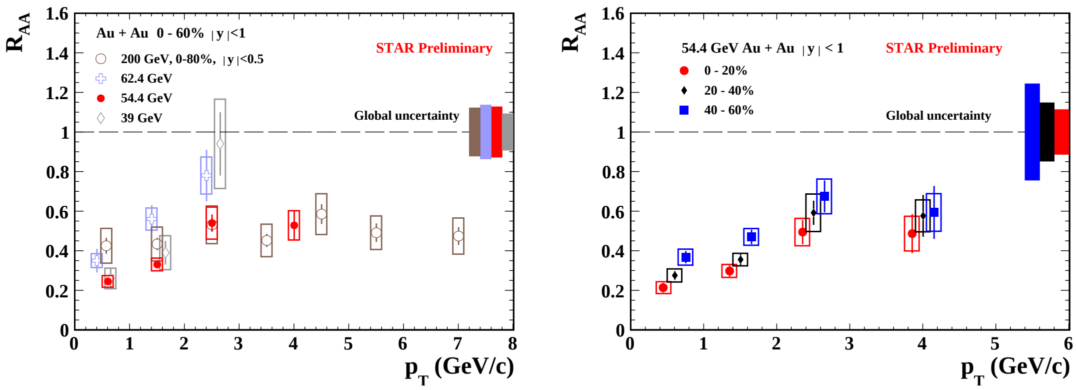

Figure 5: The inclusive J/ψ $R_{\rm AA}$ as a function of p_T (left) and centrality bins (right) in Au+Au collisions at different collision energies [12, 13]. The error bars represent the statistical uncertainties. The boxes represent the systematic uncertainties. The bands around unity indicate combined uncertainties from the $\langle T_{\rm AA}\rangle$ and the p+p baselines.

$\sqrt{s_{\rm NN}}$ = 54.4 GeV is shown as a function of $\langle N_{\rm part}\rangle$ and p_T with improved precision compared to previous measurements at 39 and 62.4 GeV. There is no significant energy dependence of $R_{\rm AA}$ in central collisions from 17.2 to 200 GeV within uncertainties.

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