Centrality Dependence of $J/\psi$ Production in Au+Au and Cu+Cu Collisions by the PHENIX Experiment at RHIC

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Abstract. $J/\psi$ production has been measured in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV by the PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC) during 2004 and 2005, respectively, at mid-rapidity ($|\eta| \leq 0.35$) via $J/\psi \to e^+e^-$ decay and at forward rapidity ($1.2 \leq |\eta| \leq 2.2$) via $J/\psi \to \mu^+\mu^-$ decay. The nuclear modification factor ($R_{AA}$) of $J/\psi$ is presented as a function of the collision centrality for Au+Au collisions (final results) and Cu+Cu collisions (preliminary results) in both rapidity windows. These results are compared to SPS results at lower energy and to various theoretical calculations.

1. Introduction

Heavy quarkonia ($J/\psi$, $\psi'$, $\chi_c$ and $\Upsilon$) has long been considered as one of the most promising probes for the deconfinement of the hot and dense QCD medium. In the deconfined medium, above a critical temperature $T_c$, the yield of heavy quarkonia is predicted to be suppressed due to the dynamical color screening effect \[1\]. The dissociation temperature depends on the binding energy of quarkonia and is extracted to be $\sim 2T_c$ for $J/\psi$ and $\sim 1.1T_c$ for $\psi'$ and $\chi_c$ from quenched lattice QCD calculations \[2\]. While the primordial $J/\psi$ is expected to be dissolved in the deconfined medium, the $J/\psi$ yield is also expected to be enhanced at RHIC energy due to the abundant creation of $c\bar{c}$ pairs and the subsequent recombination of uncorrelated $c\bar{c}$ pairs in the medium and/or at the hadronization stage \[3\].

Cold nuclear matter effects (CNM) such as nuclear absorption and gluon shadowing are expected to modify the $J/\psi$ yield. $J/\psi$ measurement in $d$+Au collisions by PHENIX has shown that CNM effects are smaller at RHIC than those observed at SPS energies \[4\].

* For the full list of PHENIX authors and acknowledgements, see Appendix 'Collaborations' of this volume
2. PHENIX Experiment and Data Analysis

The PHENIX experiment consists of two central arm spectrometers, each of which covers the pseudo-rapidity range $|\eta| < 0.35$ and 90 degrees in azimuthal angle, and two forward spectrometers covering $1.2 < |\eta| < 2.4$ with full azimuthal acceptance [5].

The $J/\psi$ yield is obtained from the unlike-sign dilepton invariant mass spectrum after subtracting combinatorial background using an event mixing method for each centrality class, transverse momentum and rapidity bin. Finally, the numbers of reconstructed $J/\psi$’s are $\sim 1000$ for the di-electron channel and $\sim 4500$ for the di-muon channel in minimum bias Au+Au collisions. The invariant $J/\psi$ yield is extracted by correcting the number of recorded events for the acceptance and efficiency of the spectrometers [6]. The $J/\psi$ yield measured in 2005 $p+p$ collisions at $\sqrt{s}=200$ GeV [7] was used in the calculation of $R_{AA}$ for Au+Au collisions.

3. Results

Fig. 1 (left) shows $R_{AA}$ of $J/\psi$ as a function of the number of participants $N_{\text{part}}$ in Au+Au (circle symbols) and Cu+Cu collisions (square symbols) at mid-rapidity (closed symbols) and at forward-rapidity (open symbols). $R_{AA}$ is similar between mid-rapidity and forward-rapidity up to $N_{\text{part}} \sim 100$ and stronger suppression is observed at forward-rapidity for $N_{\text{part}} \geq 100$. Fig. 1 (right) shows the ratio of $R_{AA}$ at forward-rapidity to that at mid-rapidity, which goes down to $\sim 0.6$ for $N_{\text{part}} \geq 100$.

The left and middle panels of Fig. 2 show comparison of $R_{AA}$ in Au+Au collisions to the models involving only the dissociation of $J/\psi$ by comoving partons and hadrons and by thermal gluons, respectively [10, 11, 12]. These models overestimate $J/\psi$ suppression observed at mid-rapidity at RHIC. The predictions, which take into account the
recombination of $J/\psi$ from $c\bar{c}$ pairs in the medium or at hadronization stage, are shown in the right panel of Fig. 2 [11, 12, 13, 14]. They match the data better than the models with dissociation only. However, charm production and its modifications in Au+Au collisions, which are input information for recombination scenario, are unclear and need to be understood. From the experimental side, measurement of $J/\psi$ azimuthal anisotropy will provide useful and direct information on recombination of $J/\psi$, which will be done in upcoming Au+Au data taking.

To extract the final state effects, $R_{AA}$ was divided by that expected from CNM effects ($R_{AA}$/CNM). CNM effects in Au+Au collisions were extrapolated from those in $d+$Au collisions [9]. Fig. 3 (left) shows $R_{AA}$/CNM as a function of Bjorken energy density in NA50 Pb+Pb collisions ($\sqrt{s_{NN}}=17.3$ GeV), NA60 In+In collisions ($\sqrt{s_{NN}}=17.3$ GeV) and Au+Au collisions ($\sqrt{s_{NN}}=200$ GeV). The formation time here is assumed to be 1 fm/$c$ for both SPS and RHIC, which could be larger than 1 fm/$c$ at the lower SPS energy and smaller at the higher RHIC energy. A nuclear absorption cross section of 1 mb was used in the calculation of $R_{AA}$/CNM for RHIC and the additional systematical uncertainties from CNM effects, which are shown as boxes, were estimated using nuclear absorption cross sections of 0 mb and 2 mb. $J/\psi$ suppression
at SPS can be interpreted as the melting of only $\chi_c$ and $\psi'$ since they are expected to be dissolved at lower temperature than $J/\psi$ and they contribute $\sim 40\%$ of its total yield via decay (feed-down) [16]. It is seen that $J/\psi$ suppression at RHIC is stronger than the expectation from only $\chi_c$ and $\psi'$ melting in central collisions. However, the error is too large to conclude that direct produced $J/\psi$’s are suppressed at RHIC and a more precise measurement of CNM effects is urgently needed. Also the fraction of $J/\psi$ from $\chi_c$ and $\psi'$ decay needs to be measured at RHIC energy. Fig. 3 (right) shows the comparison of $R_{AA}$ to the threshold model, which is associated with the onset of suppression of directly produced $J/\psi$ [17] and reproduce the tendency of $J/\psi$ suppression at mid-rapidity.

4. Summary

PHENIX measured the $J/\psi$ yield in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV at mid-rapidity and forward-rapidity. The stronger suppression is observed at forward-rapidity for $N_{\text{part}} \geq 100$. The destruction of $J/\psi$ by thermal gluons does not reproduce the observed suppression and dissociation/recombination scenario is favored at RHIC energy. However, charm production and its modifications in medium are unclear and need to be understood. $R_{AA}/\text{CNM}$ at RHIC shows that the $J/\psi$ suppression seems to be stronger than expected from the melting of only $\chi_c$ and $\psi'$ in central collisions. However, the error is too large to draw a firm conclusion. What should be done in the future experiments is to measure CNM effects precisely, the feed-down contribution from $\chi_c$ and $\psi'$ at RHIC energy and also the azimuthal anisotropy of $J/\psi$, which provide more detailed information to understand the medium effects for $J/\psi$ production in heavy ion collisions.

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