J/ψ production in Cu+Cu and Au+Au collisions at RHIC-PHENIX

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Abstract. The J/ψ is considered to be among the most important probes for the deconfined quark gluon plasma (QGP) created by relativistic heavy ion collisions. While the J/ψ is thought to dissociate in the QGP by Debye color screening, there are competing effects from cold nuclear matter (CNM), feed-downs from excited charmonia and bottom quarks, and regeneration from uncorrelated charm quarks. Measurements that can provide information to disentangle these effects are presented in this paper.

1. Introduction

The yield of heavy quarkonia is expected to be suppressed in the QGP due to the Debye screening of the color charge [1]. The J/ψ is especially promising because of its large production cross section and di-lepton decay channels, which make it easily detected. The PHENIX experiment at RHIC is able to detect the J/ψ at midrapidity ($|y| < 0.35$) via its decay to e^+e^- and at forward rapidity ($1.2 < |y| < 2.2$) via its $\mu^+\mu^-$ decay. Models of J/ψ production in heavy ion collisions at RHIC energy contain a number of important competing effects, including modification of the J/ψ yield by the CNM effects, destruction of J/ψ due to interactions with thermal gluons in the QGP, reduced feed-down from excited charmonium states that melt just above the QGP transition temperature, bottom quark decay and enhancement of the yield due to coalescence of uncorrelated charm pairs [2]. The PHENIX Au+Au data at $\sqrt{s_{NN}} = 200$ GeV showed that J/ψ suppression at forward rapidity is larger than that at midrapidity and the suppression at midrapidity is similar to that observed by NA50 at SPS in Pb+Pb collisions at $\sqrt{s_{NN}} = 17.3$ GeV [3]. However, these results are not well understood theoretically. Systematic study of J/ψ production in heavy ion collisions across the entire range of N_{part} is needed to disentangle the competing effects. PHENIX recorded Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV to obtain precise data in the range $N_{part} \leq 126$, where Au+Au data is limited by statistics and systematic uncertainty [4]. Feed-downs into J/ψ in $p+p$ collisions were measured at the same energy and are important in the picture of the sequential dissociation of quarkonia. The elliptic flow of J/ψ can set a constraint on coalescence of charm quarks and the measurement is reported in [5].

2. Measurement of feed-downs into J/ψ in $p+p$ collisions

An inclusive J/ψ measurement in $p+p$ collisions at $\sqrt{s}$=200 GeV has been reported by PHENIX [6]. Recently, PHENIX separately measured the feed-down contributions of χ_c, ψ' and bottom quarks to J/ψ in $p+p$ collisions at midrapidity ($|y| < 0.35$) at the same energy. The preliminary results are described in this section.

The fraction of J/ψ from the χ_c decay, R_{χ_c}, was measured via the decay chain of $\chi_c \to J/\psi + \gamma \to e^+e^-\gamma$ with 4.1×10^3 reconstructed J/ψ. Branching ratios of χ_{cJ} to $J/\psi + \gamma$ are 1.3% (χ_{c0}), 36% (χ_{c1}) and 20% (χ_{c2}) [7], and the contribution of χ_{c0} was neglected in the analysis. The 90% confidence level upper limit obtained for R_{χ_c} is 0.42. Figure 1 shows the upper limit of R_{χ_c} with results from other experiments.

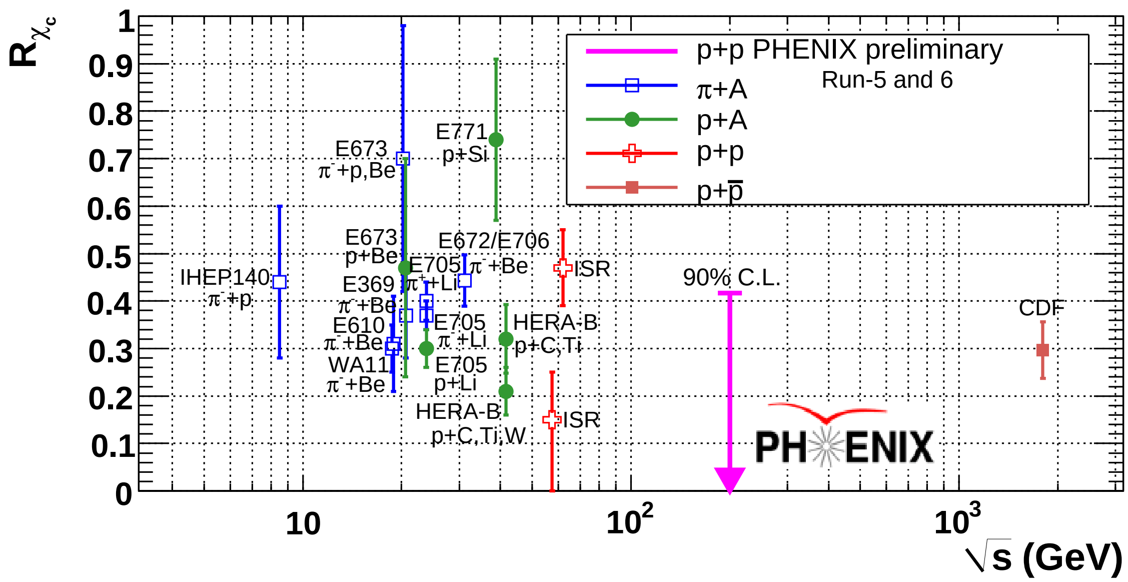

Figure 1. The fraction of J/ψ from the χ_c decay, R_{χ_c}, as a function of the center of mass energy, $\sqrt{s}$. The 90% confidence level upper limit of R_{χ_c} in $p+p$ collisions at $\sqrt{s}$=200 GeV which is the PHENIX preliminary result is represented by the arrow.

The ratio of cross sections of ψ' to J/ψ was measured in the e^+e^- decay mode and the feed-down fraction of J/ψ from ψ' decay is 0.086 ± 0.025. The cross section of bottom quarks was measured by electron-hadron correlation [8] and the feed-down fraction of J/ψ from decay of bottom and anti-bottom quarks is $0.036^{+0.025}_{-0.023}$ for $p_{T,J/\psi} > 0$ GeV/c. Branching ratios of [7] were used to obtain these feed-down fractions. A set of theoretically predicted feed-down fractions [9] is almost consistent with the PHENIX preliminary results.

3. Measurement of J/ψ in Cu+Cu and Au+Au collisions

The final results of the J/ψ measurement in Cu+Cu collisions are reported here and in [4] with the published results in Au+Au collisions [3]. The numbers of observed

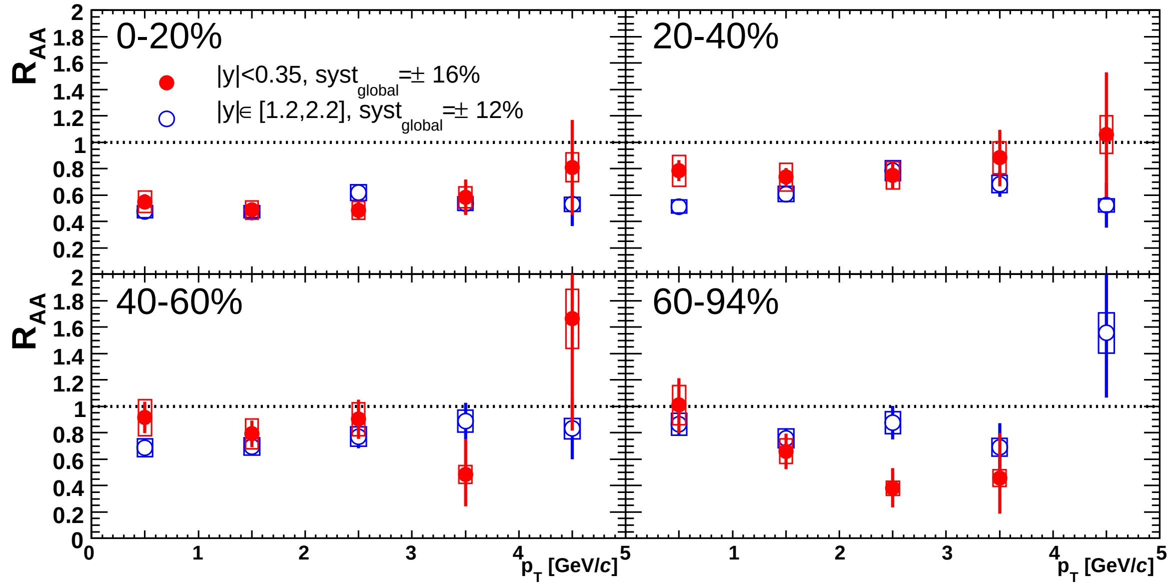

Figure 2. R_{AA} vs transverse momentum p_T for J/ψ production in Cu+Cu collisions via e^+e^- decay at midrapidity (closed circles) and $\mu^+\mu^-$ decay at forward rapidity (open circles). Centrality bins are written in figures.

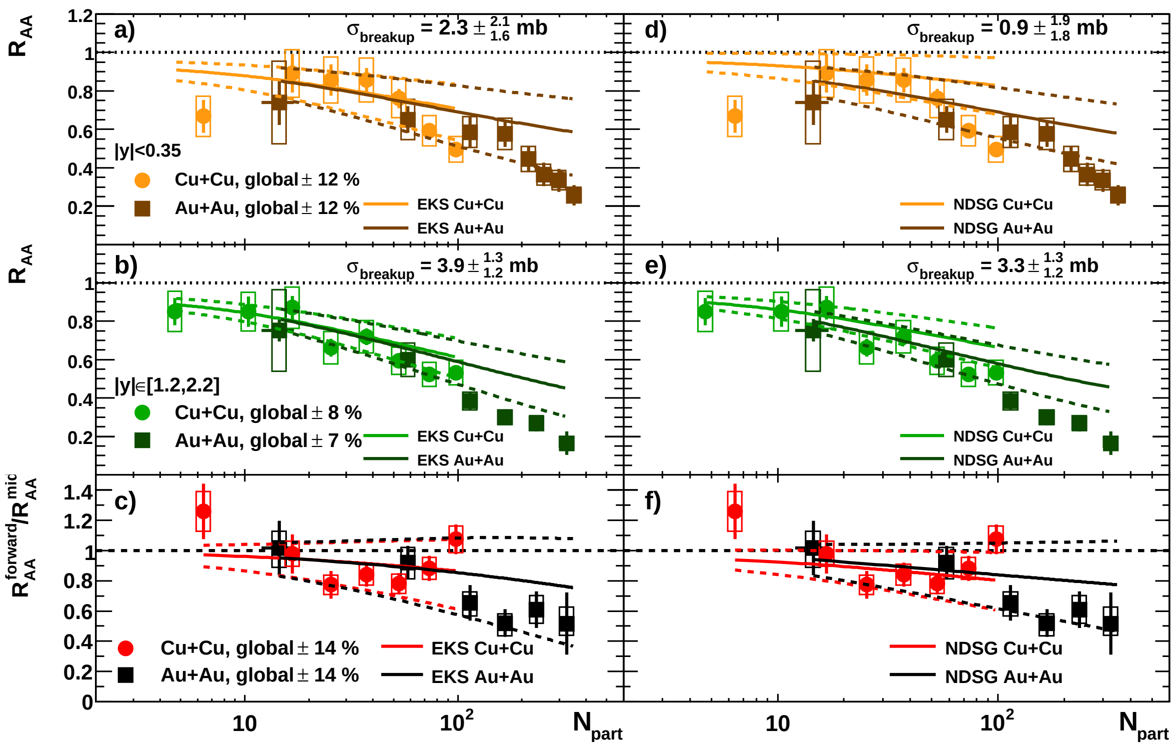

Figure 3. a) R_{AA} vs N_{part} for J/ψ production in Cu+Cu and Au+Au collisions at midrapidity with the prediction curves [13] with the EKS shadowing model [14]. b) The same figure at forward rapidity. c) Forward/mid rapidity R_{AA} ratio. d, e, f) The same figures with the predictions curves with the NDSG shadowing model [15]. The breakup cross sections for the prediction curves are obtained from fits to the d+Au data for each rapidity bin.

J/ψ in Cu+Cu collisions at mid and forward rapidity are about 2050 and 9000, respectively. Compared to the Au+Au data, the Cu+Cu data provides a more precise R_{AA} measurement for $N_{part} < 100$, where the CNM effects might be dominant. Figure 2 shows R_{AA} as a function of p_T for each centrality bin in Cu+Cu collisions at mid and forward rapidity. Suppression by a factor of two is seen at both mid and forward rapidity in the most central collisions. No strong p_T dependence of R_{AA} is observed. Analysis is ongoing to extend R_{AA} beyond p_T=5 GeV/c, where the STAR experiment has a moderate acceptance [10].

Figure 3 shows R_{AA} at mid and forward rapidity and the forward/mid rapidity R_{AA} ratio in Cu+Cu and Au+Au collisions. The Cu+Cu and Au+Au data agree well in the overlap region. The results of the J/ψ measurement in d+Au collisions, which is the primary tool to investigate the CNM effects, were updated and are reported in [11, 12]. PHENIX has interpreted the d+Au data and extrapolated prediction of the CNM effects to heavy ion collisions based on calculations of R. Vogt including nuclear shadowing and nuclear breakup [13]. While the nuclear breakup cross sections of J/ψ, $\sigma_{breakup}$, does not vary with rapidity in the framework of the calculations, PHENIX treated $\sigma_{breakup}$ as a rapidity dependent "effective" parameter and determined it by fitting to the d+Au data [4]. The theoretical prediction curves with $\pm 1\sigma$ bands obtained for the rapidity dependent "effective" $\sigma_{breakup}$ with two nuclear shadowing models (EKS [14] and NDSG [15]) are also shown in figure 3. The expected CNM effects from the PHENIX "effective" model at forward rapidity are larger than those at midrapidity. The J/ψ suppression below CNM effects seems to start at $N_{part} \sim 200$ (100) at mid (forward) rapidity. Rapidity narrowing in central Au+Au collisions is consistent with the expected CNM effects.

While the current uncertainty of the CNM effects is large, it is expected to be reduced by the d+Au collision data collected in 2007–2008 whose statistics are 30 times larger than the currently available d+Au statistics.

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