Measurement of $J/\psi$ via di-electron decay in Cu+Cu collisions at RHIC-PHENIX

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1. Introduction

High-energy heavy ion collision experiments are performed to create and study the quark gluon plasma (QGP). $J/\psi(3097)$ meson will dissociate in the hot QGP by the color Debye screening and its yield will be suppressed [1]. Therefore, $J/\psi$ has been considered as one of the most promising probes of the QGP for twenty years. However, the yield will be modified by other processes such as cold nuclear matter effects [2, 3], feed down from the excited charmonium states ($\psi'$ and $\chi_c$) and bottom quarks [4], and recombination of initially uncorrelated charm quarks [5, 6].

To disentangle these effects, one needs to study the production with several system sizes and energy densities. $J/\psi$ has di-lepton ($e^+e^-$, $\mu^+\mu^-$) decay channels and the leptons have the advantage that they are experimentally easily identified.

2. Experiment and analysis

The PHENIX experiment at RHIC collected $^{63}$Cu+$^{63}$Cu collision data in 2005 to study the dependence on the collision species and energies. The center of mass energies per nucleon pair were $\sqrt{s_{NN}}=200$ and 62.4 GeV, and those integrated luminosities were 3.06 nb$^{-1}$ and 0.19 nb$^{-1}$, respectively. The advantage of light Cu ions is that one can obtain precise data at the small number of participants, $N_{\text{part}} < 100$, with high luminosity.

The analysis of 200-GeV Cu+Cu data is ongoing and the current results are presented in this report.

$J/\psi$ is measured at mid rapidity ($|y| < 0.35$, $\Delta\phi = 90^\circ \times 2$) by the di-electron decay channel ($BR = 5.94\%$) and at forward rapidity by di-muon (5.93%).

The collision vertex and centrality, which corresponds to the impact parameter, of an event are determined by beam-beam counters (BBC) in the Cu+Cu collisions. The $z$-coordinate (beam direction) of collision vertex is required to be located at the detector center within $\pm 30$ cm. The BBC trigger efficiency of an inelastic Cu+Cu collision is estimated to be $94 \pm 2\%$. The number of nucleon-nucleon collisions, $N_{\text{coll}}$, and $N_{\text{part}}$ are estimated by Monte Carlo Glauber calculation. In a peripheral collision, the number of charged particles is small and there is a large ambiguity in centrality determination. Therefore, the maximum number of centrality bins would be seven (0–10, 10–20, · · · , 50–60 and 60–94%) for 200-GeV Cu+Cu collisions.

Charged particle tracks at mid rapidity are measured by drift chambers (DC) and pad chambers (PC). The tracking codes were carefully checked to improve reliability.

Ring imaging Cherenkov counters (RICH) detect Cherenkov photons emitted from electrons. The number of hit photo tubes in the ring region of an electron candidate is required to be greater than one.

Information of electromagnetic calorimeters (EMC) is used for track (in two directions, $z$ and $\phi$) and energy matching for electron identification. Since the effect of the stray magnetic field is not well taken into account in the PHENIX tracking, track matching parameter calibration was needed. The ratio of the EMC energy to the track momentum, $E/p \sim 1$, is used for electron identification. Since the $E/p$ value has the momentum dependence, calibration for the energy matching parameter was also needed. The recalibration was performed so that the three matching parameters have standard normal distributions. $\pm 4\sigma$ cuts for $z$ and $\phi$ directions and a $> -2\sigma$ cut for energy are used in the analysis.

![Figure 1. The $J/\psi$ trigger efficiency as a function of $J/\psi$ transverse momentum for the 1.2-GeV energy threshold and the centrality bin 0-10%.](image)

Data was recorded with a hardware single electron trigger (ERT) requiring a signal above an energy threshold of 1.2 or 0.8 GeV in the EMC and a corresponding RICH hit. The single electron trigger efficiency including random benefit is defined by the ratio of the number of electrons in triggered events and the one of minimum bias (MB) events. The single electron trigger efficiency was determined as a function of momentum for eight EMC sectors and seven centrality bins. $J/\psi$ trigger efficiency was calculated for each centrality bin as a function of transverse...
momentum, $p_{T,J/\psi}$, from the single electron trigger efficiency with single $J/\psi$ simulation samples. Figure 1 shows the $J/\psi$ trigger efficiency as a function of $p_{T,J/\psi}$ for the 1.2-GeV threshold and the centrality bin 0-10\%.

During the data taking, a software di-electron filter was additionally used to reduce the data size for a quick analysis. However, the whole data was reconstructed without the software di-electron filter by the end of 2006 and the final results will be obtained with the whole data.

Quality assurance (QA) of collected data was performed based on the mean numbers of electrons and positrons per event. The QA with MB and ERT events assure detector performance and trigger performance, respectively. The analyzed number of ERT events is 286 million and corresponds to 6.39 billion MB events.

Detector acceptance and electron identification efficiency were evaluated with GEANT3 simulation. In the simulation, detector dead maps of DC, PC, EMC and RICH, made from real data, were used to taken into account detector inefficiency. The acceptance of $J/\psi$ including efficiency is 1.8\% and 0.6\% at $p_{T,J/\psi} = 0$ and 5 GeV/c, respectively. Inefficiency due to high multiplicity was also estimated and it is 4\% for the most central collisions.

Figure 2 shows the invariant mass spectrum of di-electrons. The mass window of 2.9–3.3 GeV/c$^2$ is used to count the number of $J/\psi$ and the like-sign method is used to estimate combinatorial background, $N_{J/\psi} = N_{e^+e^-} - (N_{e^+e^+} + N_{e^-e^-})$. The observed number of $J/\psi$ is 1685 ± 57.

![Figure 2. The subtracted invariant mass spectrum of di-electrons.](image)

3. Results

To quantify the difference between the superposition of nucleon-nucleon collisions and a nucleus-nucleus collision, the nuclear modification factor is defined as follows,

$$R_{AA} = \frac{Y_{AA}/N_{coll}}{Y_{pp}}$$

where $Y_{AA}$ is the $J/\psi$ yield in a nucleus-nucleus collision and $Y_{pp}$ is the $J/\psi$ yield in a $p+p$ collision. The $\sqrt{s}$ = 200 GeV $p+p$ collision data taken in 2003 [7] is used as a reference.

Figure 3 shows the nuclear modification factor as a function of $N_{part}$. The solid lines, brackets and boxes are the statistical, point systematic and overall systematic errors, respectively. Strong suppression is observed in the most central collisions. Lines from model calculations are also shown in Fig. 3. The cold nuclear matter model (dashed line) [2] underpredicts the data. The comover model (dotted line) [3], which was successful in describing the SPS data, overpredicts the suppression at RHIC. The recombination model (solid line) [5] also underpredicts the suppression.

![Figure 3. The nuclear modification factor of $J/\psi$ as a function of the number of participants.](image)

![Figure 4. The mean square of the transverse momentum of $J/\psi$ as a function of the number of collisions.](image)

4. Summary

$J/\psi$ is a good probe for the deconfined QGP. $J/\psi$ created in Cu+Cu collisions was measured via di-electron decay at RHIC-PHENIX and the analysis is ongoing. Strong suppression beyond cold nuclear matter effect is observed.

References