1. Introduction

Vector mesons, such as \( \rho, \omega, \phi, J/\psi \) and \( \Upsilon \), have di-lepton \((e^+e^-, \mu^+\mu^-)\) decay channels. Since the leptons do not couple to the strong interaction, they are transparent probes for the early hot dense stage of high energy heavy ion collisions. The leptons also have the advantage that they are easily identified.

Especially, \( J/\psi \) has been considered to be one of the most promising probes for the hot and dense matter consisting of quarks and gluons, because it dissociates in the deconfined matter by the color Debye screening and its yield is suppressed \[1\]. However, the yield will be modified by other competing processes such as cold nuclear matter effect, comover scatterings, recombination and feed down effect. About 40% of \( J/\psi \)'s come from the excited charmonium states \( \psi' \) and \( \chi_c \) and these heavy quarkonia are expected to dissociate at lower temperatures than \( J/\psi \) \[2\]. However, except for \( J/\psi \), measurements of the heavy quarkonia are difficult at the PHENIX experiment at RHIC due to the current small statistics and large background. Therefore, systematic study of \( J/\psi \) production with several system sizes and energy densities is necessary to understand the behavior of \( J/\psi \) in the hot and dense matter.

The light vector mesons are expected to be sensitive to possible in-medium modifications by chiral symmetry restoration which coincides with the deconfinement phase transition, and those yields, masses and/or mass widths will be modified \[3\].

2. Cu+Cu collisions at RHIC in 2005

The PHENIX experiment had collected data for \( p+p \), \( d+Au \) and \( Au+Au \) collisions at \( \sqrt{s_{NN}}=200 \) GeV by 2004. In 2005, the PHENIX experiment recorded \( \sqrt{s_{NN}}=200 \) GeV and \( \sqrt{s_{NN}}=62.4 \) GeV \( Cu+Cu \) collisions (the integrated luminosities are \( 3.06 \) nb\(^{-1}\) and \( 0.19 \) nb\(^{-1}\), respectively) to study the dependence on the collision species and energies.

The collision vertex and centrality of an event are determined by beam-beam counters in \( Cu+Cu \) collisions. Created particles at mid rapidity are tracked by drift chambers and pad chambers. Ring imaging Cherenkov counters and electromagnetic calorimeters are used for electron identification and Level-1 (hardware) electron triggering. Additionally, in the \( Cu+Cu \) 200 GeV data taking, a Level-2 (software) di-electron trigger is used to reduce the data size to be analyzed.

The results of \( Cu+Cu \) 200 GeV data are reported in this report.

3. Results

3.1. \( J/\psi \) meson

Figure 1 shows the invariant mass distribution of di-electrons. The mass window of 2.9–3.3 GeV/c\(^2\) is used to count the number of \( J/\psi (3097) \) mesons and the number of like-sign pairs \((e^+e^-)\) is used to estimate combinatorial background, \( N_{J/\psi} = N_{++} - (N_{++} + N_{--}) \).

![Figure 1. The invariant mass distribution of di-electrons.](image1)

Figure 2. The nuclear modification factor of \( J/\psi \) as a function of the number of participants, \( N_{part} \).

The yield modification between the superposition of nucleon-nucleon collisions and a nucleus-nucleus collision is quantified by the nuclear modification factor defined as
follows, $R_{AA} = (Y_{AA}/N_{coll}) / Y_{pp}$, 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 number of nucleon-nucleon collisions, $N_{coll}$, in a nucleus-nucleus collision is calculated within a Glauber model. The nuclear modification factor of $J/\psi$ is shown in Fig. 2 as a function of the number of participants, $N_{part}$. The solid lines, brackets and boxes associated with the data points represent the statistical, point systematic and overall systematic errors, respectively. Strong suppression is observed in central collisions. Some predicted lines from model calculations are also shown in the figure. The cold nuclear matter model (dashed line) [4] seems to underpredict the observed data. The comover model (dot-dashed line) [5], which was successful in describing the SPS data, seems to overpredict the suppression at RHIC. The recombination model (solid line) [6] also seems to underpredict the suppression.

Figure 3 shows the mean square of the transverse momentum, $\langle p_T^2 \rangle$, as a function of the number of collisions, $N_{coll}$. Data points at the forward and backward rapidity are measured using the PHENIX spectrometers via di-muon decay. Theoretical predictions with recombination (solid line) and without recombination (dashed line) [7] are also shown in the figure. There is no significant centrality dependence of $\langle p_T^2 \rangle$.

Figure 4 shows the rapidity distribution of $J/\psi$. Although a recombination model expects the rapidity shape to become narrower as $N_{part}$ increases [7], no significant change is observed.

3.2. $\phi$ and $\Upsilon$ mesons

The invariant mass plots in the $\phi$ and $\Upsilon(1S, 2S$ and $3S)$ mass regions (1.019 GeV/$c^2$ and 9.46–10.36 GeV/$c^2$, respectively) with a part of collected data are shown in Fig. 5 and the candidates of those mesons are seen. The backgrounds are subtracted using the event-mixing technique for the $\phi$ mass region and estimated from the counts of like-sign pairs for the $\Upsilon$ mass region. About 1000 $\phi$ and $\sim 10$ $\Upsilon$ mesons are expected with the whole Cu+Cu 200 GeV data which will be available by the summer of 2006.

Figure 5. The invariant mass distribution in the $\phi$ (top) and $\Upsilon$ (bottom) mass regions.

4. Summary

Vector mesons are good probes for the hot and dense medium created by high energy heavy ion collisions. The centrality dependence of the yield of $J/\psi$ in Cu+Cu collisions was measured using di-electron decay at RHIC-PHENIX. Strong suppression beyond cold nuclear matter effect is observed and the suppression pattern seems to be different from model calculations.

References