Study of J/ψ Production in $\sqrt{s_{NN}} = 200$ GeV $p + p$ and $d + Au$ Collisions in PHENIX

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J/ψ measurements in $p+p$ and $d+Au$ collisions serve as crucial references to understand the J/ψ production in $Au + Au$ collisions at RHIC where quark gluon plasma (QGP) is expected to be formed. It also provides important clues to study various interesting phenomena such as the gluon shadowing and color glass condensate. We report the latest results from PHENIX experiment on J/ψ production in $p + p$ and $d + Au$ collisions at forward, backward and midrapidity.

1. Introduction

J/ψ enhancement[1] or strong suppression[2] is considered to be the signature of QGP formation. To quantify these effects, one needs measurements in $p+p$ and $d+Au$ collisions to understand many cold nuclear effects such as gluon shadowing, nuclear absorption, initial state energy loss, Cronin effect and gluon saturation[3] that can have interesting impact on the J/ψ production.

PHENIX[4] measure J/ψ via dielectron channel using midrapidity ($|\eta| < 0.35$) central arm spectrometer and dimuon channel using forward ($1.2 < \eta < 2.4$) and backward ($-2.2 < \eta < -1.2$) rapidity muon arm spectrometer.

In year 2003, RHIC delieved 2.74 nb^{-1} $d + Au$ and 350 nb^{-1} $p + p$ collisions. PHENIX central (muon) arm collected about 400 (1400) J/ψ in $d + Au$ and 100 (420) J/ψ in $p + p$ collisions. This is the first measurements of cold nuclear effect at RHIC[3]. The final results are reported here.

2. Results and discussion

Figure 1(a) shows the J/ψ rapidity distribution in $p + p$ collisions. The dashed error bars represent systematic uncertainties relevant for comparing the two rapidity bins in each muon arm, while the solid error bars represent the overall uncertainties relevant for comparing points at different rapidity. 10% of overall normalization error is not included. The total cross section is calculated via fitting the data with the PYTHIA predicted rapidity shape using GRV94HO parton distribution function (PDF) and the J/ψ dilepton decay branch ratio of 5.9%. The uncertainty from the PDFs is found to be less than 3% after repeating the calculation using PDFs with very different shapes. The $\sigma_{pp}^{J/\psi} = 2.61 \pm 0.20(\text{fit}) \pm 0.26(\text{abs})$ μb, where the first error is the fitting error and the second one

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[*]for the full list of PHENIX authors and acknowledgements, see Appendix 'Collaboration' of this volume.

comes from the uncertainty of our minimum-bias trigger bias. The result is consistent with our measurements in year 2002 [6]. Figure 1(b) shows the minimum-bias $R_{dAu} = \sigma_{dAu}/(2 \times 197 \times \sigma_{pp})$ versus rapidity (12% overall normalization error is not included). The forward (backward) rapidity corresponds to Bjorken variable $x_{bj} \sim 0.003$ (0.01), where one expected shadowing (antishadowing) to be effective. The midrapidity corresponds to $x_{bj} \sim 0.01$ where minimum nuclear effects are expected. One can see the EKS98 prediction[10] assuming 1mb absorption cross section fits the data best. The models assuming large shadowing effects like FGS [10] and coherence-length model [7] are disfavored.
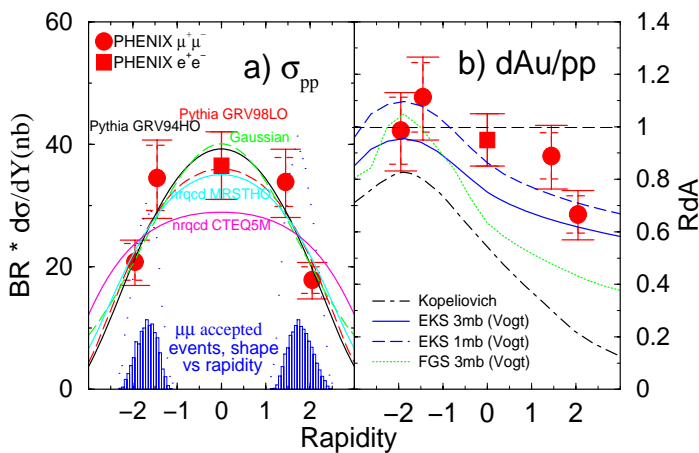

Figure 1. (a): Rapidity distribution in $p + p$ collisions. (b): The minimum bias R_{dA} versus rapidity.
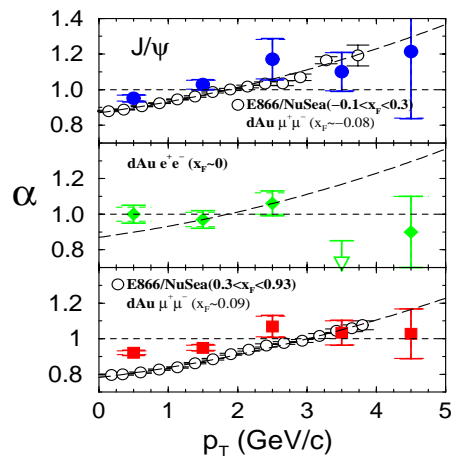
Figure 2. α versus p_T at different rapidity compared to E866 measurements.

Figure 2 shows the nuclear modification factor α ($\sigma_{dAu} = \sigma_{pp}(2 \times 197)^{\alpha}$) versus p_T. An additional 0.02 overall uncertainty is not shown. The dashed lines are simple fits to the E866 results[8]. One can see a similar tendency as shown in E866 results that the α increase towards larger p_T in the forward and backward region. This is consistent with the fact that $< p_T^2 >$ in $p + p$ collisions ($2.51 \pm 0.21 GeV^2/c^2$) is much smaller than in $d + Au$ collisions (forward: $3.63 \pm 0.25 GeV^2/c^2$, backward:$4.28 \pm 0.31 GeV^2/c^2$) as expected from Cronin effect. One interesting observation is that the central arm measurements show no broading. The midrapidity $< p_T^2 >$ in $p + p$ collision ($4.31 \pm 0.85 GeV^2/c^2$) is larger by almost two standard deviations than that in the forward and backforward rapidity. It could either come from statistical fluctuation or indicate something interesting. The results from the high luminosity 2005 $p + p$ run should give a clear answer on this.

Figure 3(a) plots the α against x_{bj} in different collision energies. If shadowing or antishadowing is the dominant nuclear effect, one would expect that alpha scale with x_{bj} since PDF is the function of x_{bj} and Q^2 where $Q^2 = m_{J/\psi}^2$ for J/ψ production. This is in clear contradiction with the data. One possible explaination is that the coherence length increases with collision energy [7]. The initial state energy loss dominate the nuclear

effect at low energy (NA3) since the coherence length is short and the parton has large chance to lose energy before the hard scattering happens. At RHIC energy shadowing is the dominant effect. We also plotted the alpha against x_F as shown in figure 3(b) in different collision energies. The result shows interesting scaling behavior. Some theoretical calculations try to explain the data with the Sudakov effect [9].
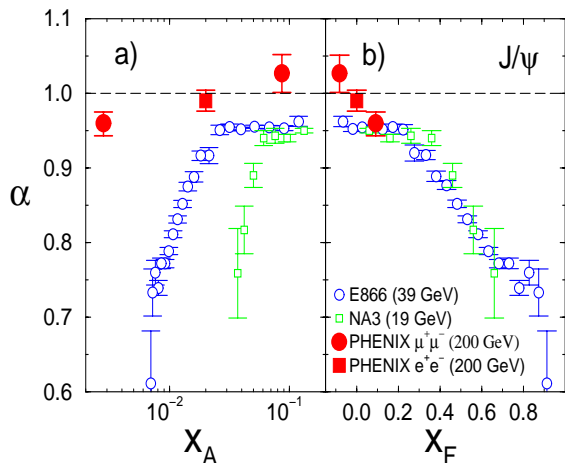

Figure 3. α versus (a) x_A and (b) x_F with present 200 GeV J/ψ results compared to lower energy results [8]. An overall uncertainty of 0.02 in our α values is not shown.
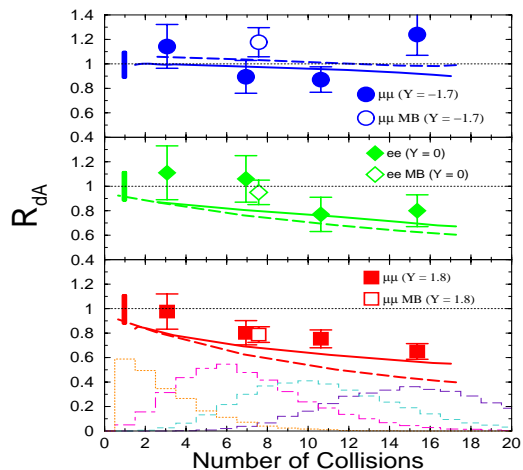
Figure 4. R_{dAu} versus centrality at three different rapidity regions, compared to calculations[10] including absorption and EKS (solid) or FGS (dashed) shadowing.

Figure 4 shows the nuclear modification factor R_{dAu} versus centrality represented by the average number of collisions in each centrality bin at different rapidity regions. The bars at the low end of each plot represent the scaling error in each rapidity region. An additional 12% global error bar is not shown. The histograms at the bottom of the lower panel indicate the distribution of the number of collisions for each of the four centrality bins. One can see that in the small x_{bj} region, the suppression become more significant towards more central collisions but the overall dependence is weak. Similar but weaker centrality dependence is observed at midrapidity. No clear centrality dependency is found in the large x_{bj}. Clearly the FGS overpredicts the suppression in small x_{bj} region.

One can deduce the R_{AuAu} in forward and backward rapidity via multiplying R_{dAu} results in forward and backward rapidity. Similarly R_{AuAu} at midrapidity can be deduced via multiplying R_{dAu} at midrapidity by itself. The R_{AuAu} calculated this way as shown in figure 5 does not fully account for some nuclear effects like the final state comover suppression but it tell us the amount of shadowing and absorption expected to be seen in $Au + Au$ collisions. Theoretical calculations shown in figure 1(b) are also plotted after some rescaling to approximately describe the data. Same calculation is done to get the R_{AuAu} prediction from these theory curves. One can see the interesting change of R_{AuAu} shapes corresponding to different amount of shadowing and antishadowing effect.
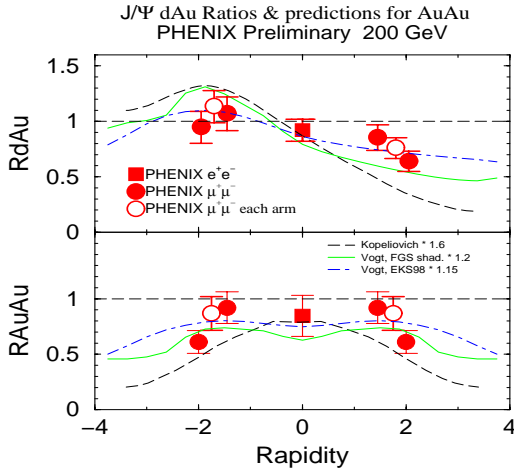
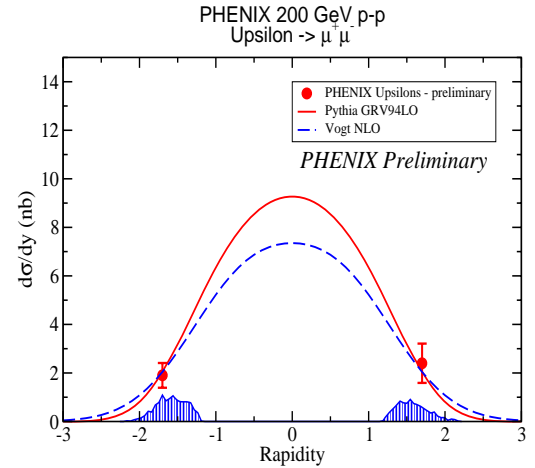Figure 5. R_{AuAu} deduced from measured R_{dAu} at different rapidity region.

Figure 6. First Υ measurements at RHIC.

3. Summary and outlook

In year 2003, PHENIX made the first measurement of cold nuclear effect on J/ψ production in $\sqrt{s_{NN}} = 200$ GeV $d+Au$ collisions at RHIC. The results show weakly increased J/ψ suppression towards more central collision and smaller x_{bj} region. p_T broading is observed although the midrapidity results show no such effect possibly due to the statsitical fluctuation. More luminosity of $d+Au$ collisions is needed to do detailed study on cold nuclear effect. In year 2005, PHENIX accumulated much higher luminosity of $p+p$ collisions than that in year 2003 as being illustrated by first measurements of Υ at RHIC shown in figure 6. This will significantly reduce the uncertainty of our J/ψ measurements in cold nuclear medium.

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