Heavy vector meson results at PHENIX

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Abstract.
PHENIX has measured J/ψ mesons in p+p, d+Au, Cu+Cu and Au+Au collisions. And these measurements serve as bases for attempts to explain the anomalous J/ψ suppression in heavy ion collisions and quantify the cold nuclear matter (CNM) effects of shadowing, nuclear absorption or initial state energy loss of gluon over that anomalous suppression. Recently PHENIX has released new J/ψ suppression in Au + Au collision at $\sqrt{s_{NN}} = 200$ GeV [1], which has three times more statistics than the previous published result [2]. New data shows strong suppression at forward rapidity, 1.2 < |y| < 2.2, comparing to midrapidity, |y| < 0.35, that is same with the previous result. But the lack of understanding the CNM makes it difficult to extract and quantify the hot nuclear matter effect over the CNM effect. As well as J/ψ, PHENIX has also released the ψ' and χ_c feed-down ratios to the J/ψ in p+p collision at midrapidity at $\sqrt{s_{NN}} = 200$ GeV [3]. These measurements on additional quarkonia are compared to the QCD calculations. In addition, PHENIX has measured Υ(1S+2S+3S) in p+p and d+Au collisions for forward rapidity and measured it also in p+p and Au+Au collisions for midrapidity at $\sqrt{s_{NN}} = 200$ GeV. $\Upsilon(1S+2S+3S)$ is showing strong suppression in d+Au collision at forward rapidity. In this proceedings the current status of these quarkonia measurements from PHENIX are shown.

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Recently PHENIX has released the yields of the three charmonia, J/ψ, ψ' and χ_c in p+p collision at $\sqrt{s} = 200$ GeV [3]. Fig. 1-left shows rapidity dependence of J/ψ cross sections, which is described by parton distribution functions (PDFs) with QCD calculations of the Color Evaporation Model (CEM), the Color Singlet Model (CSM) and Non-relativistic QCD (NRQCD) leaving the normalization level arbitrary. The PDF, CTEQ6M is shown to describe the J/ψ rapidity distribution well and treated to give most important role to estimate the shape. And J/ψ p_T distribution has been well described by the CEM and NRQCD [3].

The ψ' feed-down fraction to J/ψ is measured as 9.6 ± 2.4 % at midrapidity in p+p collision. Comparison to another data of fixed target experiments of p+p and p+A collisions shows that the data agree with the world average of 8.1 ± 0.3 %. The χ_c feed-down fraction to J/ψ is estimated as 32 ± 9 % at mid rapidity. This fraction also agree with the world average of 25 ± 5 % after accounting for A dependencies in the fixed target experiments [3]. More data collecting would decrease large statistical uncertainties so allow us to decide between those production mechanisms. These quarkonia measurements can help us to understand the CNM and the hot and dense matter as well as understand the those production mechanisms. Since quarkonia might have different production mechanisms and each quarkonium has different binding radius each other, quarkonium, which has larger binding radius than others, can melt in lower temperature than others [4].

Besides charmonia, PHENIX has preliminary $\Upsilon(1S+2S+3S)$ measurements of mid and forward rapidities for p + p collision. The distribution is compared to CTEQ6M

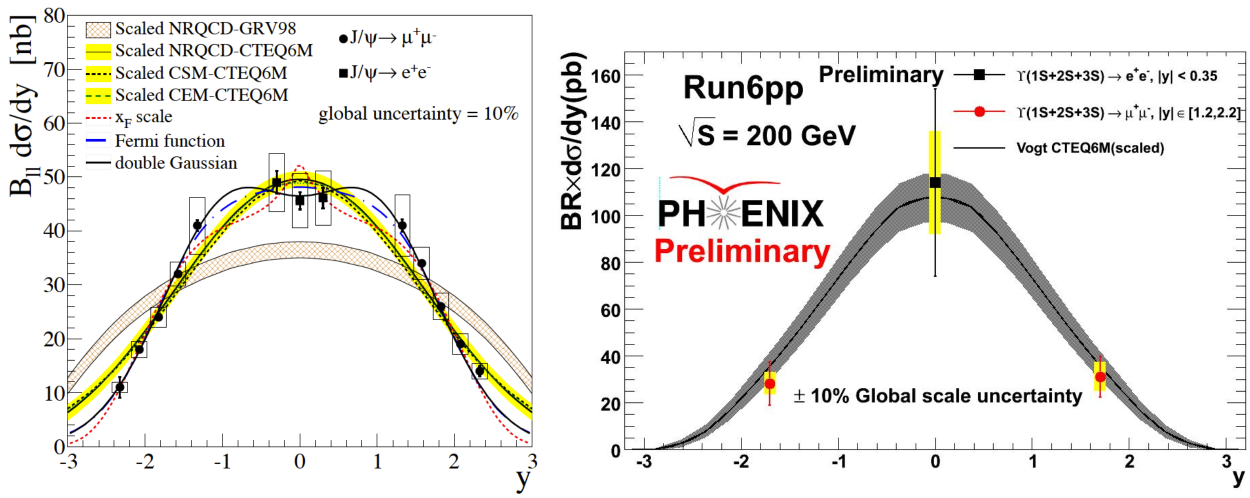

FIGURE 1. (Color online) Rapidity dependence of the J/ψ yield combining dielectron (|y| < 0.35 - full squares) with dimuon channels (1.2 < |y| < 2.4 - full circles) along with the fits. These fits are arbitrarily normalized model predictions (left plot) [3]. Rapidity dependence of the $\Upsilon(1S+2S+3S)$ yields combining dielectron (|y| < 0.35 - full squares) with dimuon channels (1.2 < |y| < 2.4 - full circles) along with the fits. This fit is also scaled up by factor of 2 (right plot).

PDF with CEM and matches to the model when the model is scaled up by factor of 2 (Fig. 1-right).

Based on p+p measurement, the CNM, which is created in d+A, and the hot nuclear matter, which is created A+A, can be studied by scaling the quarkonia yields with the number of binary collisions. Quarkonia measurements in d+A collision have goals to parametrize the CNM effects and quantify the hot and dense matter effects over the CNM. In 2008, the PHENIX has accumulated the integrated luminosity about 40 nb^{-1} in d+Au collision, which is about thirty times larger than the 2003 Run [6]. The J/ψ nuclear modification factors, R_{dAu} and R_{CP} of the 2008 Run have been compared to nuclear-modified parton distribution function (nPDF) of EPS09 parameterization with fixed breakup cross sections. And the J/ψ has been revealed to be suppressed strongly at forward rapidity region. For the models, the centrality dependence on the nuclear effects has been studied. From the study, the nuclear effects have have been assumed to have dependence on the longitudinal thickness, $(\Lambda(r_T) \equiv \frac{1}{\rho_0}\int dz\rho(z,r_T))$, through the gold nucleus, where ρ_0 is the density in the middle of the nucleus and r_T is the distribution of transverse radial positions. Since EPS09 nPDF, which has linear relation, and break up cross section, which has the exponential relation, have not described the suppression of forward rapidity successfully, more studies have been done for the another relation like quadratic for the geometrical dependence [5] [7].

As well as J/ψ, the $\Upsilon(1S+2S+3S)$ have been measured in d+Au collision. Nuclear modification factor, R_{dAu} is showing strong suppression at forward rapidity than backward rapidity like J/ψ. The modification factor of mid rapidity can be drawn from STAR preliminary measurement (Fig. 2). At RHIC energy, $\Upsilon(3S)$ is expected to melt, $\Upsilon(2S)$ is likely to melt and $\Upsilon(1S)$ is expected to survive for Au+Au collision [8] [9]. Nuclear modification factors of Au+Au collision are expected to be measured for mid

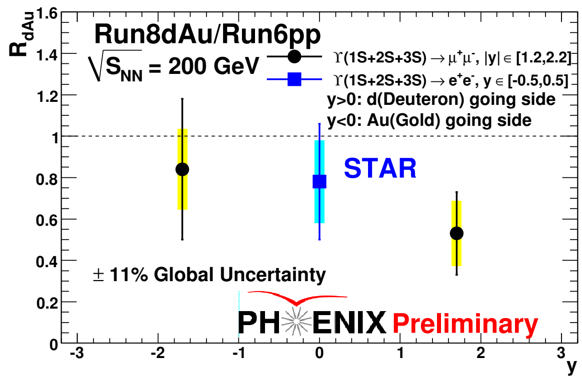

FIGURE 2. (Color online) Rapidity dependence of $\Upsilon(1S+2S+3S)$ R_{dAu}. Positive rapidity is deuteron-going direction. Mid rapidity point has been imported from STAR preliminary result.

and forward rapidities soon. So, by those measurements, more precise interpretation for $\Upsilon(1S+2S+3S)$ might be made about Υ's behavior.

Recently the PHENIX has released the measurement of J/ψ nuclear modification factors from the 2007 Run Au+Au collision [1] which has three times larger integrated luminosity than one of the 2004 Run [2]. New result is consistent with the earlier result showing a larger suppression at foward rapidity comparing to mid rapidity. The nuclear modification factors have been compared to few models. For example, Fig. 3-left is showing comparison to the Color Glass Condensate (CGC) model, which estimates suppression due to the gluon saturation. The normalization level has no fixed parameter and been fixed to match the level of the J/ψ suppression at mid rapidity central collisions. The model matches the suppression pattern of forward and mid rapidities in central collisions. EPS09 parameterization with nuclear absorption and initial-state parton energy loss has been tried to match the suppression pattern (Fig. 3-right). This cold nuclear matter calculation is not describing the suppressions of forward and mid rapidities of data simultaneously. The suppression of Au+Au collision is clearly larger than the model expectation of cold nuclear matter effects. But, since we don't have comprehensive understanding on the cold nuclear effects from d+Au collision, it is difficult to extract quantitative effects from hot nuclear matter of Au+Au collision over d+Au collision.

Now silicon vertex detector has been installed and operating from 2011 Run to cover midrapidity, y < |1.2|. And forward silicon vertex detector is planned to be installed in 2011 summer and start to operate from 2012 Run to cover forward rapidity, 1.2 < |y| < 2.2. These detector upgrades are expected to make for us to measure the contributions of the correlated backgrounds from c and b quarks and Drell Yan process under the quarkonium peaks. Those measurement would be important to test QCD predictions as well as reveal the quarkonia measurement clearly.

For summary, charmonia have been studied for p+p, p+A, d+A collisions to understand the J/ψ suppression of hot and dense matter. Contributions to J/ψ yield from ψ' and χ_c are estimated as 42 $\pm$ 9 % at midrapidity in p+p collision. The J/ψ suppression has been studied to estimate the CNM effects at d+Au collision. nPDF and

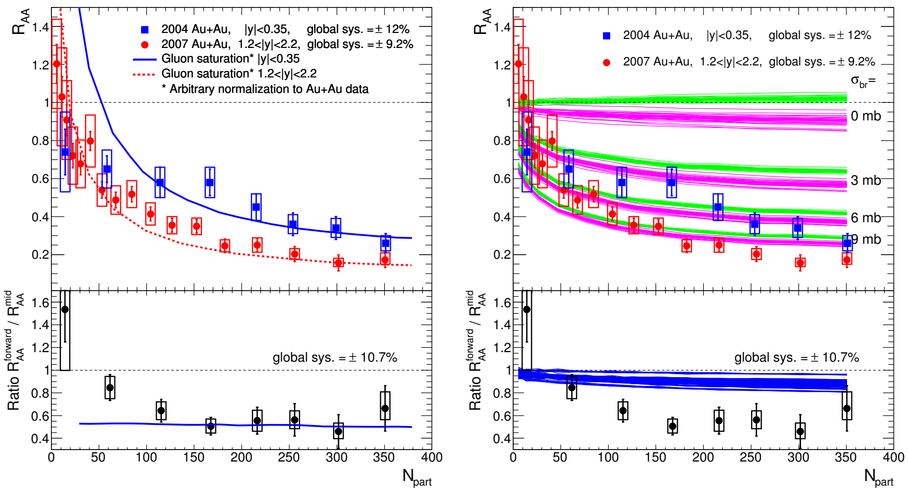

FIGURE 3. (Color online) J/ψ R_{AA} as a function of N_{part}. Lower panel is the ratio of forward to mid rapidity points and curves from the upper panel (left plot). Calculation including cold nuclear matter effects (nPDF and $\sigma_{breakup}$). The green (magenta) lines are the estimation at midrapidity (forward rapidity) for all 31 EPS09 nPDF variations and the labeled value $\sigma_{breakup}$ for 0, 3, 6, and 9 mb. And it is also including initial state parton energy loss with a quadratic length dependence (right plot) [1]

gluon saturation model have tried to describe the strong suppression at forward rapidity with break up cross sections. But we need more studies to understand the geometrical relation of the suppression. The lack of the comprehensive understanding on the CNM makes it difficult for us to interpret and extract the suppression of J/ψ in Au+Au collision over the suppression in d+Au collision. $\Upsilon(1S+2S+3S)$ have been measured at p+p, d+Au at mid and forward rapidities. $\Upsilon(1S+2S+3S)$ of d+Au collision is showing strong suppression at forward rapidities. Coming measurements of Au+Au collision of mid and forward rapidities would help us to study the $\Upsilon(1S+2S+3S)$'s behavior more systematically than now. The PHENIX silicon vertex upgrade would make it possible to trace the contributions from c and b quarks separately and also improve the detector resolution for mid and forward rapidities.

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