PHENIX RESULTS ON J/ψ AND ψ' FROM d+Au COLLISIONS AND IMPLICATIONS FOR COLD NUCLEAR MATTER

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Heavy quarkonia suppression is one of the highly cited signatures of quark gluon plasma (QGP) formed in relativistic heavy ion collisions. However, theoretical predictions remain diverse due to lack of precise knowledge of heavy flavor meson production, suppression, regeneration in hot and dense medium and other cold nuclear effects. PHENIX has carried out a comprehensive study of heavy flavors which includes baseline measurements of heavy flavor, J/ψ and Upsilon in p+p collisions, and the measurements from d+Au, Cu+Cu and Au+Au collisions over the past decade. This talk is focusing on the most recent and exciting results of J/ψ and ψ' from PHENIX in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. An implication of these results on cold nuclear matter effects on heavy quarkonium production in heavy ion collisions is also discussed.

1 Introduction

The experimental study of matter properties at extremely high temperature and high density at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) is about to complete its 13th year of physics data taking since the first RHIC physics run in 2000. Data from these runs clearly demonstrate that a high temperature and density state of matter has been achieved at RHIC. This state of matter, called quark-gluon plasma (QGP), provides exciting possibilities of experimentally exploring the phase transition from hadronic to partonic degrees of freedom. This state of matter, contrary to early suggestions of a quasi-ideal state of free quarks and gluons, behaves like a dense fluid with very low kinematic viscosity, exhibiting strong hydrodynamic flow, and nearly complete absorption of high momentum hadronic particles initially created from the colliding nuclear matter [1,2].

Heavy quarkonia suppression is one of the highly cited signatures of QGP formed in relativistic heavy ion collisions [3]. The modification in the quark pair potential by the hot dense medium will lead to quarkonium suppression in comparison with quarkonium production in p+p collisions. Because of different binding energies of the quarkonium states one could gain access to the temperature of the medium [4]. However, theoretical predictions remain diverse due to lack of precise knowledge of heavy flavor meson production, suppression, regeneration in hot and dense medium and other cold nuclear effects. The understanding of the modification of the properties of the quarkonium states is very crucial for exploring the onset of a deconfined state in the hot and dense nuclear medium. In the PHENIX experiment heavy quarkonia have been measured from p+p, d+Au, Cu+Cu and Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and several energy scans of Au+Au collisions [5]. In this paper, we highlight the most recent J/ψ and ψ' results in d+Au collisions following a brief description of the PHENIX detector systems.

2 PHENIX Experiment

The PHENIX experiment was designed and optimized for the measurement of rare probes in heavy ion collisions[6]. Figure 1 shows the PHENIX detector setup in beam and side views. The beam view (on left) shows the West and the East arm detectors in the central rapidity region, which covers $|\eta| < 0.35$ and 90° in azimuth for both arms. The side view (on right) shows the South and the North muon arms in the forward and backward rapidity region, which covers $1.2 < |\eta| < 2.4$ and 360° in azimuth for both arms. The J/ψ results reported in this proceeding were measured in both the central arms and the muon arms, while the ψ' results were measured in the central arms only.

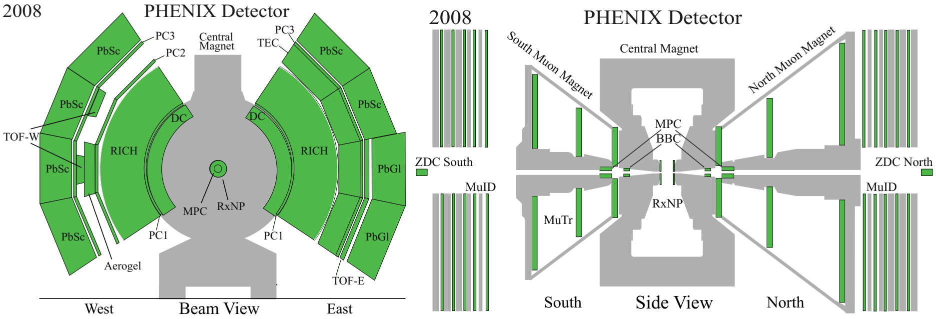

Figure 1: PHENIX detector setup: (left) Central Arms in beam view; (right) Muon Arms in side view.

3 Most Recent Results

The study of particle production in heavy ion collisions is typically characterized by the so-called nuclear modification factor, R_{AB}, with A and B representing the colliding ions. The R_{AB} is defined as the ratio of the particle yield in the heavy ion collisions to the yield in p+p collisions scaled by the number of binary nucleon-nucleon collisions. The PHENIX experiment has reported J/ψ measurements in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV using data collected in 2008[7].

3.1 J/ψ Nuclear Modification Factor in d+Au Collisions

In Figure 2, a detailed study of the J/ψ R_{dAu} is plotted as a function of p_T in forward, central and backward rapidity, respectively. Also shown in Figure 2 are two model calculations which include a combination of physical effects such as shadowing, nuclear breakup, and the Cronin effect [8]. The shadowing effect is calculated using parameterizations of the nuclear modified parton distribution function (nPDF's). Two nPDF sets are tested against our data points, including deFlorian-Sassot (nDSg) and Eskola-Kolhinen-Salgado (EKS98) parameterizations[9,10]. For J/ψ production in d+Au collisions the relevant distributions are those providing the modification of the gluon distribution within a Au nucleus, as J/ψ's are produced primarily through gluon fusion at RHIC energies (200 GeV). Nuclear breakup is the dissociation of $c\bar{c}$ pairs that would have formed J/ψ's through collisions with nucleons. An effective value of this breakup cross section (also called as nuclear absorption cross section) is chosen as 4.2 mb. The Cronin effect (i.e., the broadening of the p_T distribution) is attributed to multiple elastic scattering of the incoming parton before the hard collision that produces the J/ψ. This effect generally causes a decrease in J/ψ production at low p_T and a compensating increase at higher p_T.

Our data indicate that, for peripheral collisions, the R_{dAu} is consistent with 1.0 in all rapidity regions while a significant deviation from 1.0 is seen in the forward rapidity (d-going direction) in more central collisions for $p_T < 4.0$ GeV/c. The data also shows a slight greater than 1.0 of the R_{dAu} value in the most central collisions in the backward rapidity (Au-going direction). The

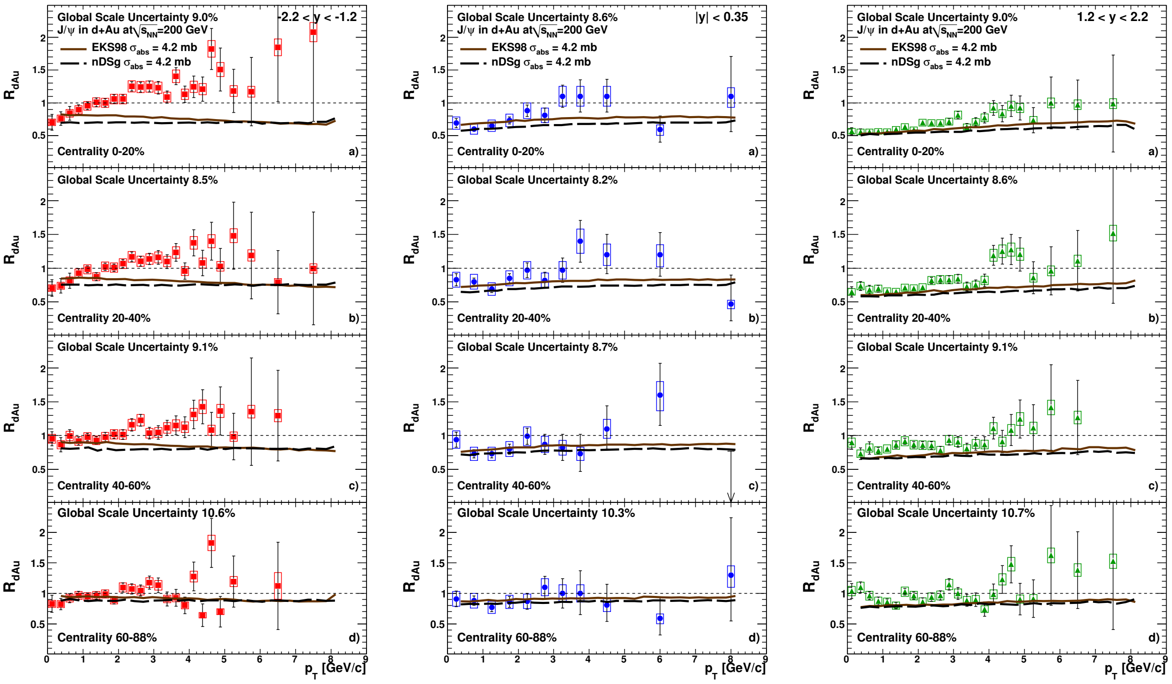

Figure 2: (left panel)) R_{dAu} as a function of p_T for (a) central, (b) midcentral, (c) midperipheral, and (d) peripheral events in the interval $-2.2 < y < -1.2$ (Au-going direction); (middle panel) for the interval $|y| < 0.35$; (right panel) for the interval $1.2 < y < 2.2$ (d-going direction). See text for details.

model calculations of R_{dAu} show a reasonable agreement with the overall level of modification seen at low p_T in the data at central- and forward rapidities, while predicting a flatter distribution with increasing p_T than is seen in the data.

3.2 ψ' Nuclear Modification Factor in d+Au Collisions

The PHENIX experiment has also measured ψ' nuclear modification factor in the central rapidity region. At the present time, there is no ψ' measurements in the forward and the backward rapidity regions. Figure 3 shows the PHENIX preliminary ψ' nuclear modification factor, R_{dAu}, as a function of the number of binary collisions, N_{coll}, which is calculated using a Glauber Monte Carlo model coupled with a simulation of the PHENIX Beam-Beam Counter response [7]. Note that the J/ψ R_{dAu} plotted in Figure 3 is not corrected for ψ' and χ_c feed-down contributions. We observe a stronger suppression of ψ' production than for J/ψ with increasing N_{coll}. The difference of R_{dAu} between J/ψ and ψ' can be intuitively understood because of a smaller binding energy of the ψ' (~ 0.05 GeV) in comparison with the binding energy of J/ψ (~ 0.64 GeV) [11]. However, a quantitative description of this difference is still lacking.

4 Summary

The PHENIX experiment has produced extensive data on J/ψ production in p+p, d+Au, Cu+Cu, Cu+Au, and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and in Au+Au collisions at $\sqrt{s_{NN}} = 39$ and 62.4 GeV. These rich data sets provide essential constraints on theoretical interpretations of heavy quarkonium production and its interaction with hot and dense medium created in heavy ion collisions. Experimentally, it is still imperative to make exclusive measurements of J/ψ in order to systematically test the theory of color-screening [3] assuming that one has a better knowledge of cold nuclear matter effects. Our d+Au data provide the valuable insights on disentangling the multiple effects on quarkonium production and evolution of heavy quark pairs in a nuclear environment. These effects include nuclear breakup, modification of parton-

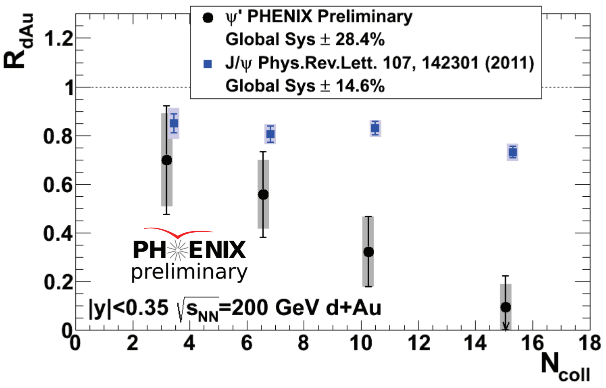

Figure 3: The ψ' nuclear modification factor, R_{dAu}, as a function of N_{coll}, in the central rapidity region. Also included are the J/ψ data points as a function of N_{coll}.

distribution functions, initial-state parton-energy loss, and comoving hadronic interactions, etc. The recent experimental results of p+Pb collisions at the LHC have extended the study of cold nuclear matter effects on quarkonium production to a much broader kinematic regions. The planned future p+A runs at RHIC will further enrich the knowledge of these effects mentioned above.

The PHENIX experiment has the capability of measuring multiple quarkonium states simultaneously with a broad kinematic coverage. Our result of ψ' and J/ψ ratio should provide more stringent test of theoretical models on heavy-quark pair evolution in nuclear medium since the production process is the same for both particles.

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