Quarkonia measurement in $p+p$ and $d+Au$ collisions at $\sqrt{s}=200$ GeV by PHENIX Detector.

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Abstract

We report new quarkonia measurements necessary to understand production mechanisms and cold nuclear matter effects in the yields observed at RHIC energy. Results obtained in $p+p$ collisions collected during the 2006 RHIC Run include $J/\psi$, $\psi'$ and $\Upsilon$ differential cross sections as well as $J/\psi$ polarization. Revisited interpretations of the published $J/\psi$ nuclear modification factors and statistically improved observations in $d+Au$ collisions taken in the 2008 Run are also discussed in the view of the recent understanding of the initial state effects and breakup cross section.

1. $p+p$ baseline

The invariant mass spectrum of dielectrons measured during the 2006 RHIC Run, after combinatorial background subtraction (Figure 1), reveals peaks corresponding to the $J/\psi$, $\psi'$ and $\Upsilon(1S,2S,3S)$ quarkonia states. The continuum spectrum is well described by correlated heavy...
flavour ($D\bar{D} \to e^+e^-$ and $B\bar{B} \to e^+e^-$) and Drell-Yan contributions estimated using a PYTHIA simulation\cite{1}, including the detector acceptance and efficiencies.

The $\psi'$ differential cross section shown in Figure 2 is the first $p_T$-dependent result for an excited charmonium state at RHIC. The $\psi'$ to $J/\psi$ ratio is also shown and compared to results from other experimental facilities\cite{2,3}. One can note the stability of this ratio for a vast collision energy and $p_T$. The up-to-date feed-down contributions to $J/\psi$ from $\psi'$ is $8.6 \pm 2.5\%$ and from $\chi_c$ is $< 42\%$ (90\% CL). These numbers are in agreement with world average results\cite{4}.

The new $J/\psi$ rapidity dependence result (Figure 3) is in agreement with that already published\cite{5}. The uncertainties are dominated by systematics. Both mid and forward rapidity yields are well described by the s-channel cut Color Singlet Model (CSM)\cite{7} using two parameters fitted to CDF data at $\sqrt{s} = 1.8$ TeV\cite{3} over $p_T < 10$ GeV/c.

PHENIX started a series of studies of the $p_T$ dependence of the decay angular distribution of the $J/\psi$. The polarization parameter $\lambda$ is defined by $dN/d\cos\theta' = A (1 + \lambda \cos \theta')$, where $\theta'$ is the angle between the positive lepton and the $J/\psi$ momentum direction (Helicity frame). Initial inclusive $J/\psi$ (direct + feed-down) polarization versus $p_T$ is shown in Figure 4. Although the s-channel cut CSM only considers direct $J/\psi$ (no feed-down)\cite{8}, it is in good agreement with the mid-rapidity results. However, the $p_T < 5$ GeV/c result obtained at forward rapidity is $\sim 2\sigma$ away from the model prediction at that rapidity. Upcoming $p_T$ dependent $\lambda$ measurements for the forward rapidity will be important to clarify whether the s-channel cut CSM describes the data at forward rapidity or not. Given the current uncertainties, one cannot rule out the possibility of zero polarization, as expected by the Color Evaporation Model (CEM)\cite{9}.

We counted 12 unlike-sign and one like-sign dielectron pairs in the $\Upsilon(1S+2S+3S)$ mass range $\in [8.5, 11.5]$ GeV/c$^2$ at mid-rapidity. A preliminary study of possible physical contributions in this region indicates correlated open bottom and Drell-Yan can contribute up to 15\% of the number of net counts and is accounted for in the systematic errors. The corresponding $\Upsilon$ family cross section in the dielectron channel is $B_{\Upsilon \to e^+e^-} = 114^{+46}_{-35}$ pb. This result follows the world trend and estimates based on the CEM (Figure 5)\cite{10}. The rapidity dependence of the $\Upsilon$ cross section, adding the preliminary results released at QM06\cite{11}, can be used to test production models for
bottomonium and estimate the total cross section. Given the smaller relativistic contributions, NRQCD calculations for \( \Upsilon \) at RHIC are supposed to be more reliable than for charmonium. The new mid-rapidity measurement was also used as a baseline for the first measurement of the \( \Upsilon \) nuclear modification factor in Au+Au collisions \[12\].

2. Cold Nuclear Matter (CNM) in \( d+Au \) collisions.

The fits performed to the published nuclear modification factors in \( d+Au \) collisions (\( R_{dA} \)) have been revisited taking into account all systematic uncertainties \[13\]. The new fits return a larger uncertainty in the breakup cross sections. Cold nuclear matter “extrinsic” calculations, where one treats the production as a 2→2 process (\( g + g \rightarrow J/\psi + g \)), have shown considerable differences in the breakup cross section compared to those obtained using the standard procedure, using “intrinsic” kinematics with 2→1 processes \[14\].

The integrated luminosity accumulated in \( d+Au \) collisions during the 2008 Run was about thirty times larger than that used in \[13\]. The first nuclear modification factor measurements from the 2008 Run were performed using as a reference the yield in the 60-80% centrality range,

\[
R_{cp} = \frac{\left( \frac{dN_{18}}{dy} / N_{coll} \right)}{\left( \frac{dN_{60-80}}{dy} / N_{60-80} \right)}. \tag{1}
\]

Many systematic uncertainties cancel out in a \( R_{cp} \) measurements. Figure 6 shows the rapidity dependence of \( R_{cp} \) for three centrality ranges. The negative rapidity region, which represents
large x (in the anti-shadowing region) of the gluon distribution, shows no nuclear effects within uncertainties, but a considerable suppression is observed at central rapidity and at forward rapidity. One observes that the strong suppression at forward rapidity and the lack of suppression at backward rapidity cannot be described by the existing nuclear modified gluon distributions (EKS98 shown in Figure 6, EPS08 and NDSG) for any fixed breakup cross section [15]. This observation suggests that additional CNM effects besides the standard shadowing and hadronic interactions must be important.

Upcoming $R_{AA}$ results, using measurements in $p+p$ collisions as a reference, will extend this study of the CNM effects.

Figure 6: Rapidity dependence of the modification factor as defined in (1) and comparison with that from EKS98 parton modification distributions for different breakup cross sections[15].

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