Study of Charmonia Production vs. Charged Track Multiplicity in $p+p$ Collisions at PHENIX

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Abstract. Charmonia production is a unique probe to explore the dynamics of particle production in hot and cold nuclear matter. Traditionally, charmonia suppression has been studied in heavy-ion collisions to quantify various nuclear effects. Since the “long-range, near-side angular correlation in $p+p$ collisions” discovered at the LHC, collective QCD phenomena in smaller systems have been a hot research topic. A recent PHENIX $d+Au$ results also show intriguing hints that the comover effect may play an important role along with other competing effects. At PHENIX the newly upgraded silicon detector FVTX provides improved dimuon mass resolution at forward rapidity as well as the capability of measuring charged track multiplicity directly. In these proceedings, we present the latest result on $\psi(2S)$ production in $d+Au$ collisions at midrapidity, the first $\psi(2S)$ measurement at forward rapidity at RHIC and the expected precision for the charmonia production vs. charged track multiplicity in $p+p$ collisions at PHENIX.

1. Introduction
Charmonia production in relativistic nuclear collisions has been the subject of intense theoretical and experimental investigation for decades [1]. Charmonia measurements serve as a unique probe of the dynamics of particle production in hot and cold nuclear matter. The PHENIX experiment was designed to measure charmonia production through the di-electron channel at midrapidity and di-muon channel at forward rapidity [2]. In these proceedings, we present final PHENIX results on $\psi(2S)$ production in $d+Au$ collisions at midrapidity [3], and the first $\psi(2S)$ measurement at forward rapidity at RHIC. We also show the expected precision for the charmonia production as a function of charged track multiplicity in $p+p$ collisions at PHENIX.

2. Study Charmonia Suppression in $d+Au$ Collisions
In nuclear collisions charmonia production is sensitive to a variety of competing initial and final state effects: the modifications of the parton distribution function in the nucleus, Cold Nuclear Matter (CNM) initial and final state effects, QGP color screening effects, regenerations, etc. Net charmonia suppression observed in central heavy ion collisions is the result of multiple effects on the total cross-section. Recently after the observation of two particle angular correlations at LHC in $p+p$ collisions [9], the study of collective QCD phenomena in small systems such as $p+p$ began to arouse a major interest in both theoretical and experimental areas. In the context of the charmonia suppression study, the effect of nucleus modification of the parton distribution...
does not exist in $p + p$ colliding system. In heavy ion collisions at RHIC, the estimated $J/\psi$ formation time, $\sim 0.15 \text{ fm}/c$ [4], is much larger than the proper time the $c\bar{c}$ pair spends in the nucleus, $\sim 0.05 \text{ fm}/c$ [3]. Since the charm quarks exist only as a precursor state while in the nucleus, no breakup mechanism that acts within that time scale can affect $J/\psi$ and $\psi(2S)$ production. However, effects which occur after hadronization may very well be more significant for the $\psi(2S)$, as its small binding energy of $\sim 50 \text{ MeV}$ may cause it to be more easily dissolved. With a smaller system size in $p + p$ collisions, the breakup effect in the precursor state is also minimized. Therefore the breakup mechanism after hadronization can be better isolated and studied.

Fig. 1 shows the di-electron invariant mass spectrum in central and peripheral $d + Au$ collisions [3]. In conjunction with results measured in $p + p$ collisions [6] Fig. 2 shows that $\psi(2S)$ production in central $d + Au$ collisions is clearly more suppressed than in peripheral collisions compared with the $J/\psi$. Even with the relatively large uncertainty for the $\psi(2S)$ data points on the plot, we obtain evidence that the $\psi(2S)$ suppression as a function of centrality has very different trend with regarding to the $J/\psi$.

**Figure 1.** (color online) The $e^+e^-$ mass distribution in $d + Au$ collisions, for $(0 - 20)\%$ (left) and (right) $(60 - 88)\%$ [3]

**Figure 2.** (color online) The $\psi(2S)$ and $J/\psi$ $R_{dAu}$ as a function of $N_{\text{coll}}$ at midrapidity in $d + Au$ collisions at $\sqrt{s_{NN}} = 200 \text{ GeV}$ [3].
3. ψ(2S) Measurement at Forward Rapidity

In 2012, PHENIX added new Forward Silicon Vertex detector (FVTX) to the muon arms. It provides us the capability to separate the \( J/\psi \) and \( \psi(2S) \) peak at forward rapidity and to measure charged track multiplicity directly. Therefore we could extend the charmonia suppression measurement to the forward rapidity. The FVTX provide precise tracking measurements of charged particles in front of the hadron absorbers, before these particles undergo any multiple scattering in the absorber material. By matching the FVTX tracks and the existing muon spectrometer tracks, the muon pair opening angle is more precisely determined than using the muon spectrometer alone, which greatly improves the dimuon mass resolution.

Fig. 3 shows the dimuon mass distribution. A fit function consisting of a Crystal Ball plus Gaussian is used to extract the \( J/\psi \) and \( \psi(2S) \) yields, with the background represented by the mixed-event combinatorial contribution plus an exponential to describe the open heavy flavor combinations. During fitting, the difference between the peak centers is set to the PDG value of 0.589 MeV/\( c^2 \). The ratio of the yields of these two states is corrected for the difference in detector efficiency, and shown in Fig. 4, along with world data from other experiments (see [6]–[8] and references therein). The error bar on the ratio is the quadrature sum of the statistical uncertainty and the systematic uncertainty due to uncertainties in the relative widths of the Gaussian component of the fit, dimuon trigger efficiency, background contributions, and detector efficiency. The new PHENIX measurement is consistent with the world data and its uncertainty is comparable to other precise measurements.

4. Progress of the Study on Charged Track Multiplicity Using FVTX

In addition to improving the dimuon mass resolution at forward rapidity and providing multiple vertexing capability for PHENIX, the FVTX can also measure charged track multiplicity directly. Fig. 5 shows that the charged track multiplicity distribution measured by FVTX using PHENIX 2013 \( p + p \) data. However in this run, due to high luminosity, we encountered multiple collision issue which we are still working on at this time. In Fig. 6, we provide the statistical uncertainty projection we expect for the normalized \( J/\psi \) yield as a function of normalized charged multiplicity once these cross-checks are completed.
Figure 5. (color online) FVTX charged track multiplicity distribution per bunch crossing for PHENIX 2013 $p+p$ run with $\sqrt{s} = 510$ GeV.

Figure 6. (color online) Normalized $J/\psi$ yield vs. normalized charged track multiplicity, only showing the statistical uncertainty projection for PHENIX 2013 $p+p$ run with $\sqrt{s} = 510$ GeV. As a reference, the ALICE result ([11]) is shown as well.

5. Conclusions and Outlook

The midrapidity data on $\psi(2S)$ production in $d+Au$ collisions at PHENIX indicates that there are additional mechanisms that suppress $\psi(2S)$ more than the $J/\psi$ in $d+Au$ collisions. The short crossing time at RHIC suggests that this suppression occurs outside the nucleus, possibly through interactions with comoving particles. Comparing results from different colliding systems also provide extra evidence to support the comover models. In order to further investigate this at forward rapidity at PHENIX, we utilize the new FVTX detector to measure $\psi(2S)$ to $J/\psi$ ratio and charged track multiplicity. We already get the preliminary $\psi(2S)$ result at forward rapidity for the first time at RHIC. A study of the charmonia production versus the charged track multiplicity is currently under investigation.

References
[1] N. Brambilla, et al. 2011 Eur. Phys. J. C 71 1534 1–178
[2] K. Adeox, et al. 2003 Nucl. Instrum. Meth. A 499 469–479
[3] A. Adare, et al. (PHENIX Collaboration) 2013 Phys. Rev. Lett. 111 202301
[4] F. Arleo, P.-B. Gossiaux, T. Gousset and J. Aichelin 2000 Phys. Rev. C 61 054906
[5] C. Aidala, et al. 2014 Nucl. Instrum. Meth. A 755 44–61
[6] A. Adare, et al. (PHENIX Collaboration) 2012 Phys. Rev. D 85 092004
[7] B. Abelev, et al. (ALICE Collaboration) 2014 Eur. Phys. J. C 74 2974 (Preprint 1403.3648 [nucl-ex])
[8] R. Aaij, et al. (LHCb Collaboration) 2013 J. Phys. G 40 045001
[9] V. Khachatryan, et al. (CMS Collaboration) 2010 J. High Energy Phys. 09 2010 091
[10] A. Capella, A. Kaidalov, A. Kouider Akil, and C. Gerschel 1997 Phys. Lett. B 393 431
[11] B. Abelev, et al. (ALICE Collaboration) 2012 Phys. Lett. B 712 3, 165–75