J/ψ production at high $p_T$ at STAR

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Abstract

We report results on J/ψ-hadron azimuthal angular correlations in 200 GeV $p+p$ collision in the STAR experiment at RHIC. The extracted $B$-hadron feed-down contribution to inclusive J/ψ yield is found to be 10-25% in $4 < p_T < 12$ GeV/$c$ and has no significant center-of-mass energy dependence from RHIC to LHC. The $p_T$ spectrum of charged hadron associated with high-$p_T$ J/ψ triggers on the away side is found to be consistent with that from di-hadron correlations. J/ψ signal from partially produced Au+Au 39 GeV data will also be presented to demonstrate STAR's J/ψ capability at RHIC low energy run.

Keywords: J/ψ, high $p_T$, color screening, correlation

1. Introduction

The dissociation of J/ψ due to color-screening of their constituent quarks in a Quark-Gluon Plasma (QGP) is a classic signature for deconfinement in relativistic heavy-ion collisions [1]. Results from the PHENIX experiment at RHIC show that the suppression of J/ψ as a function of centrality (the number of participants) is similar to that observed by NA50 and NA60 at the CERN-SPS, even though the temperature and energy density reached in these collisions is significantly lower than at RHIC [2]. This indicates that additional mechanisms, such as recombination of charm quarks in the later stage of the collision and/or suppression of feed-down contribution from charmonium excited states or B-hadrons, may play an important role; they will need to be studied systematically before conclusion from the observed suppression pattern can be drawn. Recently, the STAR experiment has extended J/ψ suppression measurement to high $p_T$ in Cu+Cu collisions and found that the J/ψ nuclear modification factor $R_{AA}$ is consistent with no J/ψ suppression at $p_T > 5$ GeV/$c$, in contrast to the prediction from a theoretical model of quarkonium dissociation in a strongly coupled liquid using an AdS/CFT approach [3, 4]. The project is not yet complete and we need to increase the statistics, investigate the mechanism of J/ψ formation, and perform the same measurement with a larger system (Au+Au). On the other hand, measurements from CDF shows that the contribution of B-hadrons relative to the inclusive J/ψ yield in $p + \bar{p}$ collisions at 1.96 TeV significantly increases with increasing $p_T$. The same measurement at RHIC energy will be also essentially needed to disentangle the physics origin of the high-$p_T$ J/ψ suppression measurements [5].

$B$ was rarely studied at RHIC in the past ten years. The $B \rightarrow J/\psi$ measurements in heavy-ion collisions at STAR are still difficult without a precise vertex detector. But it can be done in $p + p$ collisions through J/ψ-hadron correlations, originally proposed and studied by UA1 [6]. Furthermore, J/ψ-hadron correlations can be also used to study the hadronic activity produced in association with a high-$p_T$ J/ψ to investigate its production mechanism which is still poorly understood more than 30 years after the discovery of J/ψ.

In this paper we present the measurement of the correlation between high-$p_T$ J/ψ’s and charged hadrons at mid-rapidity with the STAR experiment in $p + p$ collisions at $\sqrt{s} = 200$ GeV in RHIC year 2009 high luminosity run. We
also report the status of measurement of $J/\psi$ in Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV (an energy between CERN-SPS and RHIC top energies) at STAR with newly fully-installed Time-Of-Flight (TOF) detector \cite{7,8,9}.

2. high-$p_T$ $J/\psi$ production in $p+p$ collisions at 200 GeV

In this analysis, the $J/\psi$ is reconstructed through its decay into electron-position pairs, $J/\psi \rightarrow e^+e^-$ (Branching ratio (B) = 5.9\%). The data sample used was triggered at level-0 by the STAR Barrel Electromagnetic Calorimeter (BEMC) by requiring the transverse energy deposited in any tower ($\Delta p \times \Delta \phi = 0.05 \times 0.05$) above a given high-energy threshold to enrich high-$p_T$ electrons. This effectively enriches high-$p_T$ $J/\psi$ with limited data acquisition rate. The integrated luminosity is 1.8 $pb^{-1}$, 3.2 $pb^{-1}$ and 23.1 $pb^{-1}$ with transverse energy threshold 2.6 GeV < $E_T$ < 4.3 GeV, $E_T$ > 4.3 GeV and $E_T$ > 6.0 GeV respectively. The reconstruction method is similar as what we used in year 2005 and year 2006 data. We tightened the $dE/dx$ cut slightly to enhance the signal-to-background (S/B) ratio for the correlation

![Figure 1: Invariant mass distribution for unlike-sign (solid circles) and like-sign (grey band) electron pairs at mid-rapidity ($|y| < 1$) in $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV.](image1)

![Figure 2: $J/\psi$-hadron azimuthal angular correlations in the $J/\psi$ $p_T$ range of 8 < $p_T$ < 12 GeV/c at mid-rapidity ($|y| < 1$) in $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV.](image2)

![Figure 3: Fraction of $B \rightarrow J/\psi$ over the inclusive $J/\psi$ yield from two sets of run at STAR. The same ratios measured by UA1, D0, CDF and CMS collaborations are also shown for comparison.](image3)

![Figure 4: Associated charged hadron $p_T$ distributions on the away side with respect to high-$p_T$ $J/\psi$ triggers and charged hadron triggers at mid-rapidity in $p+p$ collisions at $\sqrt{s_{NN}} = 200$ GeV.](image4)
study [3][10]. In year 2009, STAR installed 72% TOF trays at mid-rapidity ($|\eta| < 0.9$). This detector combined with the Time Projection Chamber (TPC) can clearly identify electrons from low to high $p_T$ by rejecting hadrons at low and intermediate $p_T$ range. To further improve the S/B ratio of $J/\psi$, we also require the electron which does not trigger the BEMC to have $1/\beta$ measured by TOF within 0.97-1.03 when its $p_T$ is less than 1 GeV/c [11]. Figure 1 shows the invariant mass distribution for unlike-sign (solid circles) and like-sign (shaded band) electron pairs. We reconstructed 376 $J/\psi$ with $3.0 < M < 3.2$ GeV/$c^2$ at $p_T > 4$ GeV/c. The S/B ratio in this range is 22. Such high S/B ratio is very suitable for the $J/\psi$-hadron correlation study. We do the correlation in 3 $J/\psi$ $p_T$ slices: $4 \text{–} 6$ GeV/c, $6 \text{–} 8$ GeV/c and $8 \text{–} 12$ GeV/c. Figure 2 shows the azimuthal angle correlations between high-$p_T$ $J/\psi$ of $8 \text{–} 12$ GeV/c and charged hadrons. The correlated yield on the near-side is not as significant at that in the di-hadron correlation measurements [12]. The lines show the results of a PYTHIA calculation. The dot-dashed line exhibits a strong near-side correlation compared to the away-side dominantly from the decay $B \to J/\psi + X$. The solid line shows a $\chi^2$ fit with the two simulated components to extract the relative contribution of $B$-hadron feed-down to the inclusive $J/\psi$ yield. This ratio is 10%-25% in the measured $p_T$ range, shown in Fig. 3 in red solid circles, increases with increasing $p_T$. The results are consistent with STAR’s previous measurement (solid star symbol), but with better precision [3]. The same ratios measured by UA1 in $p+\bar{p}$ collisions at 630 GeV, by D0 (CDF) in $p + \bar{p}$ collisions at 1.8 (1.96) TeV and by CMS in $p + p$ collisions at 7 TeV in various rapidity ranges are also shown for comparison [3][6][13][14]. They are consistent with each other even though the center-of-mass energies differ by an order of magnitude. The ATLAS and LHCb collaborations also observed a similar behavior [15][16]. The physics origin of this consistency is still unclear. With such an amount of $B$-hadron feed-down fraction, combined with this $J/\psi$-hadron correlation study, further study of $J/\psi$ cross-section will allow us to constrain the $B$ cross-section substantially in the future.

Figure 4 shows the associated charged hadron $p_T$ distribution on the away side with respect to high-$p_T$ $J/\psi$ triggers and high-$p_T$ charged hadron triggers. The $p_T$ spectra of charged hadron associated with high-$p_T$ $J/\psi$ are consistent from different runs, but year 2009 results have a better precision. To compare the results with those from di-hadron correlation, we require $J/\psi$ triggers in year 2009 run within the same $p_T$ window as charged hadron triggers: $4 \text{–} 6$ GeV/c. The $p_T$ spectra of the associated charged hadrons with respect to both kinds of triggers are consistent with each other, which indicates that the hadrons on the away side of $J/\psi$ triggers are dominantly from light quark or gluon fragmentation, instead of heavy quark fragmentation.

3. $J/\psi$ production in Au+Au collisions at 39 GeV

![Invariant mass distribution of electron pairs in BEMC triggered events](image1)

![Invariant mass distribution of electron pairs in Minimum bias triggered events](image2)

Figure 5: Invariant mass distribution of electron pairs in BEMC triggered (left) and minimum-bias (right) triggered Au+Au events at $\sqrt{s_{NN}} = 39$ GeV. The solid and dashed histograms represent background reproduced using like-sign and mixed-event technique respectively.

The consistency of $J/\psi$ $R_{AA}$ at midrapidity at RHIC and SPS top energies is still a puzzle. Two kinds of models with very different physics origins (recombination models and sequential dissociation models) can qualitatively explain this feature. The measurements of $R_{AA}$ in heavy-ion collisions at a center-of-mass energy between RHIC and SPS top energies are crucial to test these models. The RHIC Beam Energy Scan (BES) program enables such measurements (the reference data for $R_{AA}$ determination already exist). STAR has recorded hundreds of million Au+Au collisions.
events at $\sqrt{s_{NN}} = 39, 62$ and $200$ GeV respectively during year 2010 run. Figure 5 shows $J/\psi$ signal from partially produced $39$ GeV Au+Au data to demonstrate STAR’s $J/\psi$ capability at RHIC low energy run.

The left panel of Fig. 5 shows the invariant mass distributions for electron pairs in BEMC triggered events. The electron identification and $J/\psi$ reconstruction is similar as what we used in year 2009 $p+p$ data. The S/B ratio is lower than that in $p+p$ collisions as expected, but still very high. To improve the statistics, we also reproduce the combinatorial background using mixed-event technique. It is consistent with that from like-sign technique in the mass range shown in the figure. We observed $82 \pm 13$ ($6 \sigma$) $J/\psi$ from this dataset, mainly at $p_T > 2$ GeV/$c$. To study $J/\psi$ production at low $p_T$, we also analyzed minimum-bias (MB) triggered data. In this analysis, we excluded BEMC from electron identification due to its inefficiency at low $p_T$. The signal is shown in the right panel of Fig. 5. $91 \pm 22$ ($4 \sigma$) $J/\psi$ were observed from this 9% of full dataset, $52$ in $p_T$ range 0-2 GeV/$c$ and $39$ in $p_T$ range 2-4 GeV/$c$. We expect $\sim 1000$ ($13 \sigma$) $J/\psi$ signal from the full MB dataset. Our projection shows STAR even has the capability to measure $J/\psi$ at 27 and 18 GeV with 1-2 weeks beam time in RHIC year 2011 run.

4. Summary

In summary, we reported results on $J/\psi$-hadron correlation in $p+p$ collisions at $\sqrt{s} = 200$ GeV and $J/\psi$ signal in Au+Au collisions at $\sqrt{s_{NN}} = 39$ GeV from the STAR experiment at RHIC. The fraction of $B$-hadron feed-down contribution to inclusive $J/\psi$ yield in $p+p$ collisions was extracted from the $J/\psi$-hadron correlation and found to be 10-25% in $4 < p_T < 12$ GeV/$c$, with no significant dependence on center-of-mass energy. The $p_T$ spectra of charged hadron associated with both high-$p_T$ $J/\psi$ triggers and high-$p_T$ charged hadron triggers on the away side were found to be consistent, which indicates the hadron production on the away side is not dominantly from heavy quark fragmentation. STAR observed $6 \sigma$ $J/\psi$ signal (mainly at $p_T > 2$ GeV/$c$) in BEMC triggered 39 GeV Au+Au events, and $4 \sigma$ signal in 9% produced MB 39 GeV Au+Au events.

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References

[1] T. Matsui, H. Satz, Phys. Lett. B178 (1986) 416. doi:10.1016/0370-2693(86)91404-8
[2] F. Karsch, D. Kharzeev, H. Satz, Phys. Lett. B637 (2006) 75–80. doi:10.1016/j.physletb.2006.03.078
[3] B. I. Abelev, et al., Phys. Rev. C80 (2009) 041902.
[4] H. Liu, K. Rajagopal, U.A.Wiedemann, Phys. Rev. D71 (2005) 032001.
[5] D. E. Acosta, et al., Phys. Rev. D71 (2005) 032001.
[6] C. Albajar, et al., Phys. Lett. B256 (1991) 112–120.
[7] B. Bonner, et al., Nucl. Instrum. Meth. A508 (2003) 181–184. doi:10.1016/S0168-9002(03)01347-0
[8] M. Shao, et al., Nucl. Instrum. Meth. A492 (2002) 344–350. doi:10.1016/S0168-9002(02)01355-4
[9] J. Wu, et al., Nucl. Instrum. Meth. A538 (2005) 243–248. doi:10.1016/j.nima.2004.08.105
[10] Z. Tang, Ph.D. thesis, University of Science and Technology and China (2009).
[11] J. Adams, et al., Phys. Rev. Lett. 94 (2005) 062301. doi:10.1103/PhysRevLett.94.062301
[12] J. Adams, et al., Phys. Rev. Lett. 95 (2005) 152301. doi:10.1103/PhysRevLett.95.152301
[13] S. Abachi, et al., Phys. Lett. B370 (1996) 239–248. doi:10.1016/0370-2693(96)00067-6
[14] CMS Collaboration (2010). arXiv:1011.4193
[15] H. K. Woehri, in: Contribution to 4th Internation Conference on Hard and Electromagnetic Probs of High-Energy Nuclear Collisions (Hard Probes 2010), 2010.
[16] C. Maiani, in: Contribution to 4th Internation Conference on Hard and Electromagnetic Probs of High-Energy Nuclear Collisions (Hard Probes 2010), 2010.