J/ψ production within a jet in p+p collisions at $\sqrt{s}$ = 500 GeV by STAR

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The suppression of J/ψ production caused by the color-screening effect in heavy-ion collisions is considered as an evidence of the creation of quark-gluon plasma. However, the production of J/ψ in hadronic collisions remains not fully understood. Further studies are needed to provide a good understanding of its production mechanism in p+p collisions for interpreting the observed suppression in heavy-ion collisions. Recently, the J/ψ production in jets was proposed as a useful observable to help explore the J/ψ production mechanism and to differentiate various J/ψ production models.

We report the measurement of the fraction of charged jet transverse momentum carried by the J/ψ meson, $z(J/\psi) \equiv p_{\mathrm{T}}^{\mathrm{J}/\psi}/p_{\mathrm{T}}^{\mathrm{jet}}$, at mid-pseudorapidity ($|\eta| < 0.6$) with kinematic cuts of $p_{\mathrm{T}}^{\mathrm{jet}} > 10$ GeV/c and $p_{\mathrm{T}}^{\mathrm{J}/\psi} > 5$ GeV/c in p+p collisions at $\sqrt{s}$ = 500 GeV by the STAR experiment. The comparison to model calculations and similar measurements carried out at the LHC are presented, and its physics implications are discussed.

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1. Introduction

The J/ψ meson is a bound state of charm and anti-charm quarks ($c\bar{c}$) and was discovered several decades ago. J/ψ is a multiscale system. Production of charm and anti-charm pairs can be described by perturbative quantum chromodynamics (QCD), but the evolution of charm and anti-charm quark pair to a J/ψ is a nonperturbative process which can only rely on phenomenological model description. Thus, studying its production provides valuable knowledge for the understanding of all regimes of QCD. However, the J/ψ production mechanism results in a rich phenomenology that is yet to be fully understood [1].

The most successful approach of describing J/ψ production in hadronic collisions is the nonrelativistic QCD (NRQCD) factorization formalism [2]. In NRQCD models, the evolution of $c\bar{c}$ pairs of different quantum states to J/ψ is characterized by a set of universal NRQCD long-distance matrix elements (LDMEs). Differential J/ψ production cross section measurements in p+p system from RHIC to the LHC energies can be well described by the NRQCD approach [2]. However, the LDMEs extracted by different groups show significant difference [3]. Furthermore, experimental measurements showed minimal J/ψ polarization which contradicts to the large degree of transverse polarization from the NRQCD predictions [4]. These discrepancies indicate that further studies are needed to gain a better understanding of the J/ψ production.

Recently, Ref [5] showed that J/ψ production within a jet provides a strong discriminative power for different models, and thus can be used to study the J/ψ production mechanism. At the LHC, LHCb collaboration and CMS collaboration reported their measurements of J/ψ production within a jet [6, 7]. The discrepancies between measurements and the NRQCD predictions are shown in Ref [8]. Measuring the J/ψ production within a jet at a very different collision energy will provide further insight to the J/ψ production mechanism.

2. Experiment and Analysis

The data sample used in this analysis was collected from p+p collisions at $\sqrt{s}$ = 500 GeV in 2011 by the STAR experiment. The integrated luminosity of the data set is 22.1 pb^{-1} sampled by the Barrel Electromagnetic Calorimeter (BEMC) trigger which requires a BEMC tower with an energy deposition larger than 4.3 GeV. The $J/\psi \rightarrow e^+e^-$ decay channel is used for J/ψ reconstruction. Electron and positron candidates are reconstructed and identified using information from the TPC and BEMC detectors. The details of e$^\pm$ candidates selection and the J/ψ reconstruction can be found in Ref [9].

With a J/ψ candidate in an event, jet reconstruction is performed on this event by clustering the J/ψ candidate with charged particles. The J/ψ candidates, rather than their decayed e$^\pm$, are used in the clustering to prevent $e^\pm$ from the same J/ψ decay being clustered into separate jets. The jet reconstruction using the anti-k_T clustering algorithm as implemented in the FASTJET package [10] and the jet cone size is set to R = 0.2, 0.4 and 0.6. Events passing kinematic cuts for reconstructed jets (p_T > 10 GeV/c, $|\eta^{jet}|$ <1-R) and J/ψ candidates ($p_T^{J/\psi}$ > 5 GeV/c and $|\eta^{J/\psi}| < 1$) are kept for further analysis, where p_T and η denote transverse momentum and pseudo-rapidity, respectively.

The yield of J/ψ in each $z(J/\psi) \equiv p_T^{J/\psi}/p_T^{jet}$ bin is extracted from corresponding e^+e^- invariant mass distribution with detector efficiency and acceptance corrected for. Figure 1 shows an example

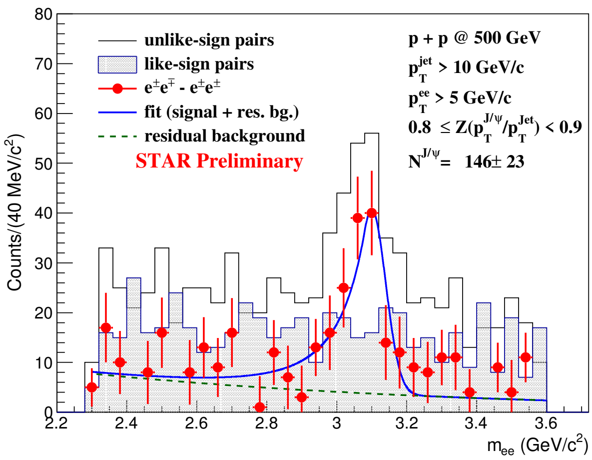

Figure 1: Invariant mass distributions of e^+e^- pairs before and after the like-sign background (gray filled histogram) subtraction as shown in black histogram and red solid circles, respectively. The blue curve is a fit to the mass spectrum. The green-dashed line indicates the residual background and a Crystal-Ball function is used to describe the J/ψ signal. The error bars depict the statistical uncertainties.

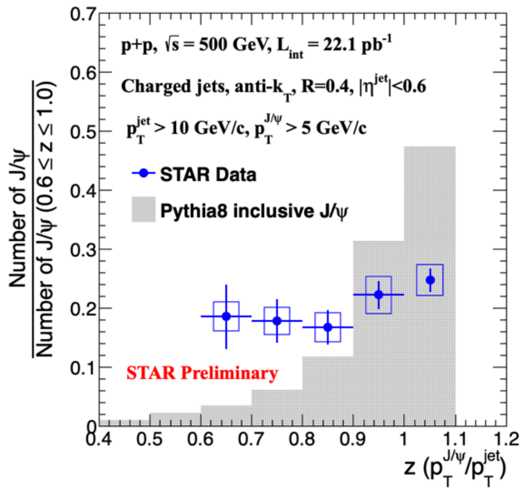

Figure 2: Self-normalized z distributions for inclusive J/ψ mesons produced within a jet compared to prediction from PYTHIA 8 (gray filled histogram). The vertical blue lines represent statistical uncertainties and the blue boxes represent systematic uncertainties. The data point for isolated J/ψ ($z = 1$) is placed at 1.05 for clarity.

of such e^+e^- invariant mass distributions for $0.8 \leq z < 0.9$. The detector effects on reconstructed jet p_T and $z(J/\psi)$ are accounted for via two-dimentional unfolding [11].

3. Physics Results

Figure 2 shows self-normalized $z(J/\psi)$ distribution for inclusive J/ψ mesons produced within a charged jet for $p_T^{jet} > 10$ GeV/c and $p_T^{J/\psi} > 5$ GeV/c. The data point for isolated J/ψ ($z = 1$) is placed at 1.05 for clarity. With current uncertainties, there is no significant $z(J/\psi)$ dependence for $z < 1$ range. Figure 3 shows the jet cone size (R) dependence in the same kinematic cuts for jets and J/ψ as in Fig. 2. A hint of R dependence is observed, but more statistics is needed to draw firm conclusions. The analysis using a large data sample with an integrated luminosity of 336.4 pb^{-1} from 2017 is ongoing, which will significantly improve the precision of the measurement.

Figure 2 also shows comparison between the measurement and the leading-order (LO) NRQCD-based PYTHIA 8 prediction [12]. The measured self-normalized z distribution shows a different trend than the prediction, i.e. J/ψ production within a jet is less isolated in data than that predicted by PYTHIA 8. Experimental measurements at LHC energies [6, 7] also show a less isolated production scenario for J/ψ produced within a jet than PYTHIA predictions, despite of very different collision energy, rapidity range as well as jet definition compared to this analysis. It is also informative to study the fraction of J/ψ produced within a jet, as shown in Fig. 4. The y-axis is the ratio of number of J/ψ within a jet for $p_T^{J/\psi} > 5$ GeV/c and $p_T^{jet} > 10$ GeV/c to the total number of J/ψ with $p_T > 5$ GeV/c. The J/ψ cross section with $p_T^{J/\psi} > 5$ GeV/c is measured in Ref [9]. The results show that

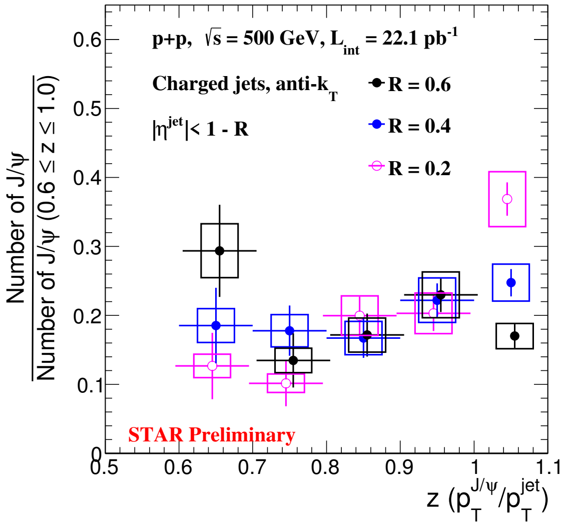

Figure 3: Self-normalized z distributions for inclusive J/ψ mesons produced within a jet for different jet cone size of 0.2, 0.4 and 0.6. The error bars represent statistical uncertainties and the blue boxes represent systematic uncertainties.

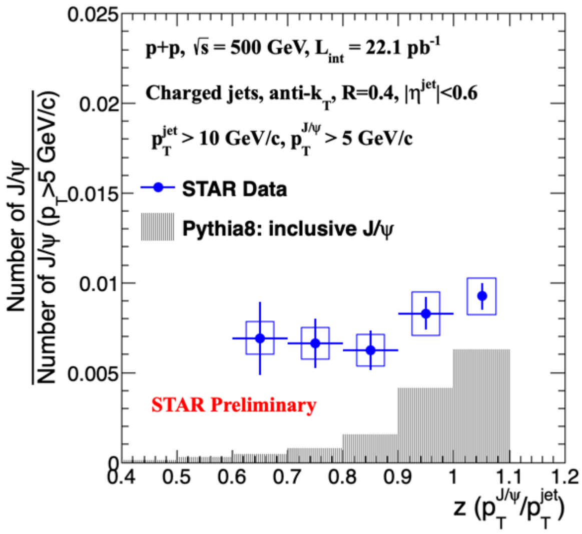

Figure 4: The normalized z distributions for inclusive J/ψ mesons produced within a jet compared to prediction from PYTHIA 8. The data is normalized by the J/ψ cross-section with $p_T^{J/\psi}$ >5 GeV/c at the same collision energy [9].

the probability of producing a J/ψ above 5 GeV/c in a charged jet above 10 GeV/c is systematically higher in data than in PYTHIA 8.

4. Summary

The fraction of charged jet transverse momentum carried by the J/ψ meson at mid-pseudorapidity ($|\eta| < 0.6$) with kinematic cuts of $p_T^{jet} > 10$ GeV/c and $p_T^{J/\psi} > 5$ GeV/c in p+p collisions at $\sqrt{s}$ = 500 GeV is measured. It is the first measurement of J/ψ production within a jet at RHIC energy. The observed $z(J/\psi)$ distribution does not show a significant $z(J/\psi)$ dependence for $z < 1$ within current uncertainties. A hint of jet cone size dependence is observed, but more statistics is needed to draw firm conclusions. Compared to PYTHIA 8 predictions with the same kinematic cuts, J/ψ production within a jet is less isolated and more J/ψ are produced in jets in the measured kinematic range in data.

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