MEASUREMENT OF J/ψ ELLIPTIC FLOW IN Au + Au COLLISIONS AT $\sqrt{s_{NN}} = 200$ GeV IN STAR EXPERIMENT*

Hao Qiu

for the STAR Collaboration

Institute of Modern Physics, Chinese Academy of Sciences
730000 Lanzhou, China
and
Brookhaven National Laboratory, Upton, NY 11973-5000, USA

(Received January 16, 2012)

The measurement of J/ψ elliptic flow is presented as a function of transverse momentum for 20%–60% central 200 GeV Au + Au collisions. Total number of reconstructed J/ψ used for this measurement is 13,000, which is unprecedented in relativistic heavy ion collisions so far. Extracted value of elliptic flow is found to be consistent with no flow within errors for transverse momentum larger than 2 GeV/c. This suggests that either J/ψ with high transverse momentum is dominantly produced by direct pQCD processes, or charm quarks are not fully thermalized in the medium.

DOI:10.5506/APhysPolBSupp.5.323
PACS numbers: 25.75.Cj

1. Introduction

In relativistic heavy-ion collisions, the $c\bar{c}$ bound state is subject to dissociation due to the color screening of the binding potential in the deconfined medium. As a consequence, the J/ψ production is expected to be suppressed, and such suppression has been proposed as a signature of QGP formation [1]. However, J/ψ suppression observed in experiments [2, 3] can also be affected by other hot and cold nuclear effects. In particular, the recombination of J/ψ from thermalized (anti-)charm quarks is an important unknown factor [4, 5, 6]. By measuring J/ψ elliptic flow (v_2) one can test if J/ψ are produced by direct pQCD processes or by recombination. J/ψ produced from direct pQCD processes, which do not have collective motion involved, should have little azimuthal preference. The produced J/ψ will

* Presented at the Conference "Strangeness in Quark Matter 2011", Kraków, Poland, September 18–24, 2011.

then gain limited azimuthal anisotropy because of azimuthally different absorption due to the different path length in the azimuth. On the other hand, J/ψ produced from recombination of thermalized charm quarks will inherit the flow of charm quarks, exhibiting sizable flow.

Many models that describe the experimental results of heavy-ion collisions depend on the assumption that light flavor quarks in the medium reach thermalization on an extremely short timescale (~ 0.5 fm/c) [7]. However, why the thermalization happens so fast is not well understood, neither is it well quantified to what extent the thermalization applies. The flow pattern of heavy quarks provides a unique tool to test the thermalization. With much larger mass than light quarks, heavy quarks are more difficult to be moved around thus are expected to thermalize much more slowly than light partons. Furthermore, through the interaction with the medium, heavy quarks are also sensitive to its transport properties. Thus by measuring elliptic flow of J/ψ one can study the flow of charm quarks and the extent of thermalization reached in the medium created by relativistic heavy ion collisions.

In year 2010, with the combined particle identification capability from STAR's Time Projection Chamber (TPC) [8], Barrel Electromagnetic Calorimeter (BEMC) [9] and the newly installed Time-of-Flight detector [10], STAR is able to clearly identify electrons from J/ψ decay over a wide momentum range. To cope with the large data volume coming from collisions at high luminosity, a High Level online tracking Trigger (HLT) is implemented to reconstruct J/ψ events online and tag them for fast analysis. In addition, the low material budget in STAR setup in run 2010 allows us to dramatically improve J/ψ identification, with unprecedented statistics. In this paper, J/ψ v_2 as a function of p_{T} in 20%–60% central 200 GeV Au + Au collisions measured with data taken in 2010 is reported.

2. J/ψ identification

J/ψ is reconstructed through $J/\psi \rightarrow e^+e^-$ channel, with a branching ratio of 5.9%. The electrons and positrons are identified firstly by their mean energy loss per unit track length ($\langle dE/dx \rangle$) inside the TPC. The Time-of-Flight information from the TOF detector is used together with $\langle dE/dx \rangle$ to select electrons and positrons. With the measured Time-of-Flight and the path length measured by the TPC, the inverse velocity ($1/\beta$) can be calculated. With a very small mass, electrons and positrons should travel almost at the speed of light. Allowing a more than 2 σ range of TOF resolution, a selection of ($0.97 < 1/\beta < 1.03$) can be imposed on top of $\langle dE/dx \rangle$ selection to identify electrons and positrons. At large momentum ($p > 1.5$ GeV/c), with energy measured by towers from BEMC, a cut of momentum to energy ratio of $(0.3 < p/E < 1.5)$ can be applied to select electrons and positrons and suppress hadrons. The integration of information from the three systems above provides acceptable efficiency and purity for electron identification in a wide momentum range.

The data consists of 350 million sampled minimum bias triggered events, 270 million central triggered events, a set of BEMC high tower triggered events that is equivalent to 7 billion minimum bias events at high $p_{\rm T}$ region, and 16 million J/ψ enriched events selected by the HLT. The invariant mass spectrum of electron pairs with the J/ψ signal is shown in Fig. 1. A total of about 13,000 J/ψs are reconstructed in the entire $p_{\rm T}$ range of 0–10 GeV/c, and there is still significant signal of more than 700 J/ψs in the $p_{\rm T} > 6$ GeV/c region which was previously not possible because of the higher material budget in STAR setup in previous years.

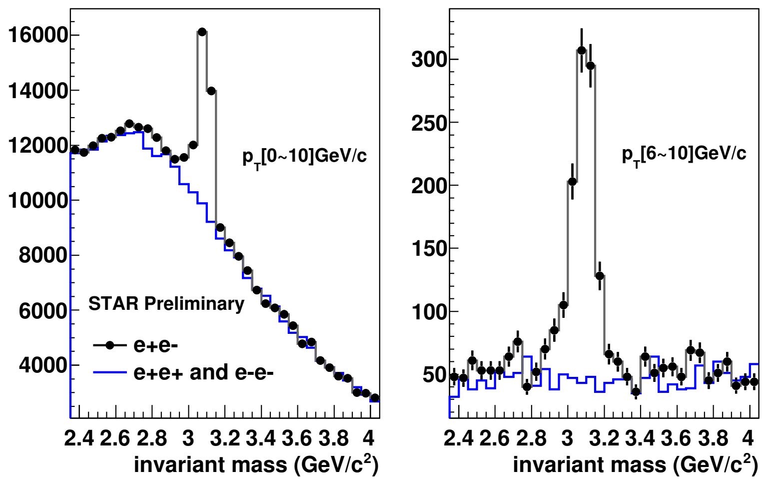

Fig. 1. Invariant mass spectrum of electron pairs for $0 < p_{\rm T} < 10$ GeV/c (left) and $6 < p_{\rm T} < 10$ GeV/c (right). The points are unlike sign pairs with the J/ψ signal; The solid line histogram shows the like sign background.

3. Elliptic flow method

The elliptic flow of J/ψ is calculated with three different methods. In the first method, the 0–π range of $\phi - \psi$ are divided into 10 bins, and two bins that are symmetric to $\pi/2$ are combined into one. Here ϕ represents the azimuthal angle of J/ψ, and ψ is the event plane, a representative of reaction plane reconstructed from TPC tracks [11]. The J/ψ yield within a combined $\phi - \psi$ bin is obtained by fitting the e^+e^- pair invariant mass distribution with a Gaussian signal on top of a second order polynomial background. Then v_2 is obtained by fitting J/ψ yield *versus* $\phi - \psi$ with a functional form of $\sim 1 + 2v_2\cos(2(\phi - \psi))$. At the end, the observed v_2 is scaled by average inverse event plane resolution in order to take into account the uncertainty in the event plane reconstruction [11]. The second method is almost the same as the first one, except that the J/ψ yield in each combined $\phi - \psi$ bin is obtained not from fitting, but from subtracting the like sign background from unlike sign within the possible invariant mass range of J/ψ. In the third method, the v_2 of J/ψ and background together is considered as a function of invariant mass [12]. Fitting the overall v_2 (already scaled by inverse event plane resolution) *versus* invariant mass with an average of J/ψ v_2 and background v_2 weighted by their yield as a function of invariant mass, the J/ψ v_2 can be obtained. The background v_2 here is described by a first order polynomial function of invariant mass.

The systematic error is derived from v_2 measured by different methods mentioned above with different cuts in electron/positron identifications. For each method, to estimate possible systematic uncertainties from hadron contaminations, two sets of electron identification cuts are used: a set of standard cuts to get the best J/ψ significance with the least v_2 statistic error, and a set of tighter cuts to get purer electron/positron sample and less influence from the hadron contamination. Assuming that the measurements from the 6 combinations of different methods and electron identification cuts form a uniform distribution, the 1 σ systematic uncertainty is calculated as $(\max - \min)/\sqrt{12}$. The measurement obtained with the first method together with the set of standard electron identification cuts is presented as the central value. To estimate the non-flow influence on this measurement, a method of scaling non-flow in $p+p$ collisions to that in Au + Au collisions [13] is employed. This method assumes that (1) two-particle correlation in $p+p$ collisions is considered to be of 100% non-flow origin, and (2) the non-flow two-particle correlation in Au + Au collisions is similar to that in $p+p$ collisions. Thus the lower bound of J/ψ v_2 can be derived from J/ψ-hadron azimuthal correlation with the same correlation in $p+p$ collisions subtracted. Since the away side correlation may be greatly modified by the medium in heavy ion collisions, this procedure gives only an upper limit of the non-flow effect.

4. Result

In Fig. 2 the J/ψ v_2 for 20%–60% central collisions is presented as a function of transverse momentum. For the reference, two other sets of v_2 measurements are also plotted, one is for light hadron (charged hadron) [14] and the other is for ϕ meson [15] which is relatively heavier than light hadron but not as heavy as J/ψ. Unlike v_2 of hadrons constituting of (relatively) light quarks, J/ψ v_2 at $p_T > 2$ GeV/c is found to be consistent with zero considering the errors. This result disfavors the idea that J/ψ at large p_T is produced dominantly by coalescence from thermalized charm and anti charm quarks.

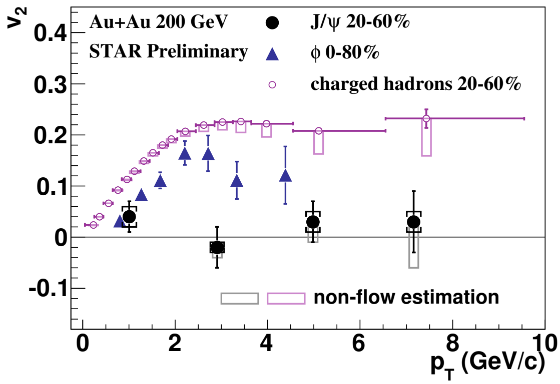

Fig. 2. v_2 *versus* p_T for J/ψ as well as charged hadrons and ϕ meson. The brackets represent systematic error estimated from differences between different methods and cuts. The p_T bins for J/ψ are 0–2, 2–4, 4–6 and 6–10 GeV/c, and mean p_T in each bin for the J/ψ sample used for v_2 calculation is drawn.

In Fig. 3 the J/ψ v_2 is compared to different theoretical model-predictions. v_2 of J/ψ produced by initial pQCD processes stays close to zero (line 1 [16]), and it agrees with the data except the lowest p_T bin. The model that assumes J/ψ is produced by coalescence at the freeze-out predicts v_2 that is more than 3σ above the data for $p_T > 2$ GeV/c (line 2 [17]), and is thus ruled out. Calculations for coalescence in transport model predict smaller J/ψ v_2 and are closer to the experimental data (line 3 [18] and 4 [16]). Models that take the J/ψ from both initial and coalescence

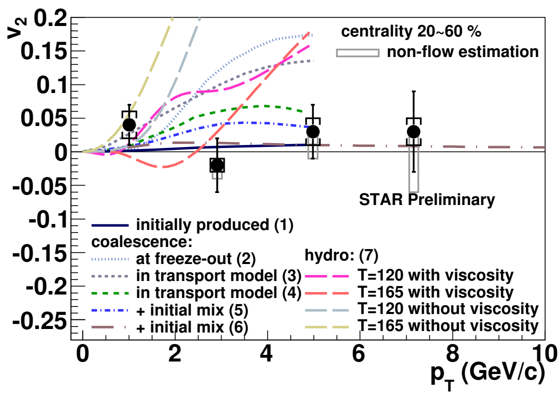

Fig. 3. J/ψ v_2 *versus* p_T comparing with different model predictions.

production predict smaller v_2, and describe the data well (line 5 [19] and 6 [20]). Viscous Hydro calculations (lines group 7 [21]), regardless the freeze-out temperature and the viscosity used as mentioned in the plot, increase rapidly with $p_{\rm T}$ and do not describe the experiment data well at high $p_{\rm T}$ region.

In summary, J/ψ elliptic flow is presented as a function of transverse momentum for 20%–60% central 200 GeV Au + Au collisions. Unlike light flavor hadrons, J/ψ v_2 at $p_{\rm T} > 2$ GeV/c is consistent with zero considering the errors. Comparing to model calculations, the measurement of J/ψ v_2 disfavors the case when J/ψ with $p_{\rm T} > 2$ GeV/c is produced dominantly by coalescence from thermalized (anti-)charm quarks.

REFERENCES

[1] T. Matsui, H. Satz, *Phys. Lett.* **B178**, 416 (1986).

[2] M.C. Abreu *et al.* [NA50 Collaboration], *Phys. Lett.* **B499**, 85 (2001).

[3] A. Adare *et al.* [PHENIX Collaboration], *Phys. Rev. Lett.* **98**, 232301 (2007).

[4] R.L. Thews, *Eur. Phys. J.* **C43**, 97 (2005).

[5] A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, *Nucl. Phys.* **A789**, 334 (2007).

[6] A. Capella *et al.*, *Eur. Phys. J.* **C58**, 437 (2008).

[7] P. Kolb, U. Heinz, `arXiv:nucl-th/0305084`; P. Huovinen, P.V. Ruuskanen, *Annu. Rev. Nucl. Part. Sci.* **56**, 163 (2006).

[8] M. Anderson *et al.*, *Nucl. Instrum. Methods* **A499**, 659 (2003).

[9] M. Beddo *et al.*, *Nucl. Instrum. Methods* **A499**, 725 (2003).

[10] B. Bonner *et al.*, *Nucl. Instrum. Methods* **A508**, 181 (2003).

[11] A.M. Poskanzer, S.A. Voloshin, *Phys. Rev.* **C58**, 1671 (1998).

[12] N. Borghini, J.-Y. Ollitrault, *Phys. Rev.* **C70**, 064905 (2004).

[13] J. Adams *et al.* [STAR Collaboration], *Phys. Rev. Lett.* **93**, 252301 (2004).

[14] B. Abelev *et al.* [STAR Collaboration], *Phys. Rev. Lett.* **99**, 112301 (2007).

[15] J. Adams *et al.* [STAR Collaboration], *Phys. Rev. Lett.* **93**, 252301 (2004).

[16] L. Yan, P. Zhuang, N. Xu, *Phys. Rev. Lett.* **97**, 232301 (2006).

[17] V. Greco, C.M. Ko, R. Rapp, *Phys. Lett.* **B595**, 202 (2004).

[18] L. Ravagli, R. Rapp, *Phys. Lett.* **B655**, 126 (2008).

[19] X. Zhao, R. Rapp, 24th Winter Workshop on Nuclear Dynamics, 2008.

[20] Y. Liu, N. Xu, P. Zhuang, *Nucl. Phys.* **A834**, 317 (2010).

[21] U. Heinz, C. Shen, priviate communication.