PROCEEDINGS OF SCIENCE

PHENIX measurements of heavy quark anisotropic flow in Au+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

Kazuya for the PHENIX collaboration[*†]
Hiroshima University and RIKEN
E-mail: kazuyan@quark.hiroshima-u.ac.jp

The measurement of heavy quark collective motion in heavy-ion collisions is a powerful tool to reveal key QGP properties, such as shear viscosity and quark diffusion. PHENIX has new measurements of the second Fourier harmonic, v_2, of separated charm and bottom quarks at mid-rapidity $|\mathrm{y}| < 0.35$ in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The technique utilized in these measurements makes use of the distance of the closest approach of electrons from the semi-leptonic decays of charm and bottom hadrons. In addition, measurements of v_2 of inclusive heavy-flavor particles were performed in the small $d+$Au system using muon decays at forward and backward rapidities covering the range $1.2 < |\mathrm{y}| < 2.2$. The experimental study in small systems will help the understanding of the origins of particle collectivity in hadronic collisions. This presentation will show these results and discuss them in the view of the current theoretical calculations.

International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
30 September - 5 October 2018
Aix-Les-Bains, Savoie, France

[*]Speaker.
[†]for the PHENIX collaboration

PoS(HardProbes2018)166

1. Introduction

Heavy quark provides an important information on the properties of the Quark-Gluon Plasma (QGP). They are mainly produced in the initial stage of the heavy-ion collisions and propagates the QGP. Since heavy quark propagate thorough the QGP with a strong coupling, the modification of their phase space distribution strongly reflects the QGP dynamics.
Ten years ago, we have measured the nuclear modification factor R_{AA} of $c+b \to e$ in Au+Au and $d+$Au collisions which reflects the modification of a momentum distribution as shown in Figure 1 (left) [1]. R_{AA} of $c+b \to e$ in Au+Au collisions indicates a strong yield suppression at high p_{T} compared with that in $d+$Au collisions. It was not expected and we need to reconsider the energy loss mechanism and understand its quark-mass dependence. Recently, we have measured R_{AA} of $c \to e$ and $b \to e$ and observed a quark-mass dependence of the suppression, namely a suppression less pronounced for bottom quarks than for charm quarks [2, 3, 4].
On the other hand, we have also found a large azimuthal anisotropy v_2 of $c+b \to e$ in Au+Au collisions ten years ago as shown in Figure 1 (right) [1]. It indicates that heavy flavors are strongly coupled in the QGP which was also not expected. We now are interested in the quark-mass dependence of the elliptic flow in the QGP. Especially, whether a very heavy bottom quark can be strongly coupled with the QGP is an object of interest. In addition, a heavy-flavor flow in small collision systems is also an object of interest because the flow in small collision systems was found at both RHIC [5] and LHC [6].

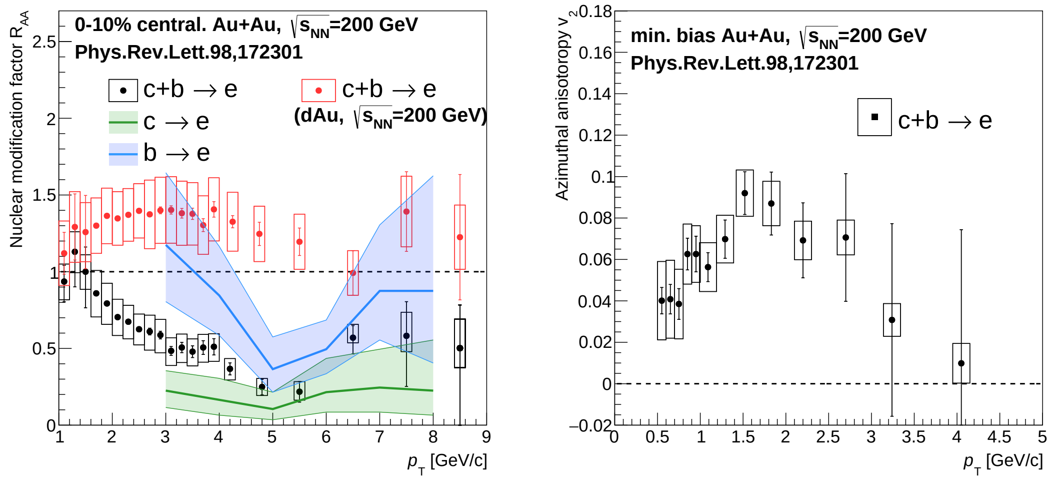

Figure 1: Left: The nuclear modification factor for $c+b \to e$, $c \to e$ and $b \to e$ in $d+$Au and Au$+$Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Right: The azimuthal anisotropy of $c+b \to e$ in Au$+$Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

2. Result

2.1 Azimuthal Anisotropy of $c+b \to \mu$ in $d+$Au collisions

We have measured the azimuthal anisotropy v_2 of $c+b \to \mu$ in $d+$Au collisions at $\sqrt{s_{NN}} = 200$

GeV. The invariant yield of single muons is measured with the PHENIX muon spectrometer (1.2 $< \eta <$ 2.2) and background components which are hadron decay muons, punch through hadrons, and J/ψ decay muons are subtracted to extract muons from heavy-flavor decays. Focusing on the 0-20% central $d+$Au collisions, the azimuthal anisotropy v_2 of $c+b \to \mu$ with respect to the reaction plane is observed for $1.0 < p_{\mathrm{T}} < 3.0$ GeV/c as shown in Figure 2. v_2 in Au-direction (d-direction) is observed with 99.9% (98.6%) confidence level, indicating the non-zero flow of heavy flavors in the small collision systems. The order of magnitude is similar to charged hadron v_2 [7]. This new result is one of the keys to understand flow in small collision systems.

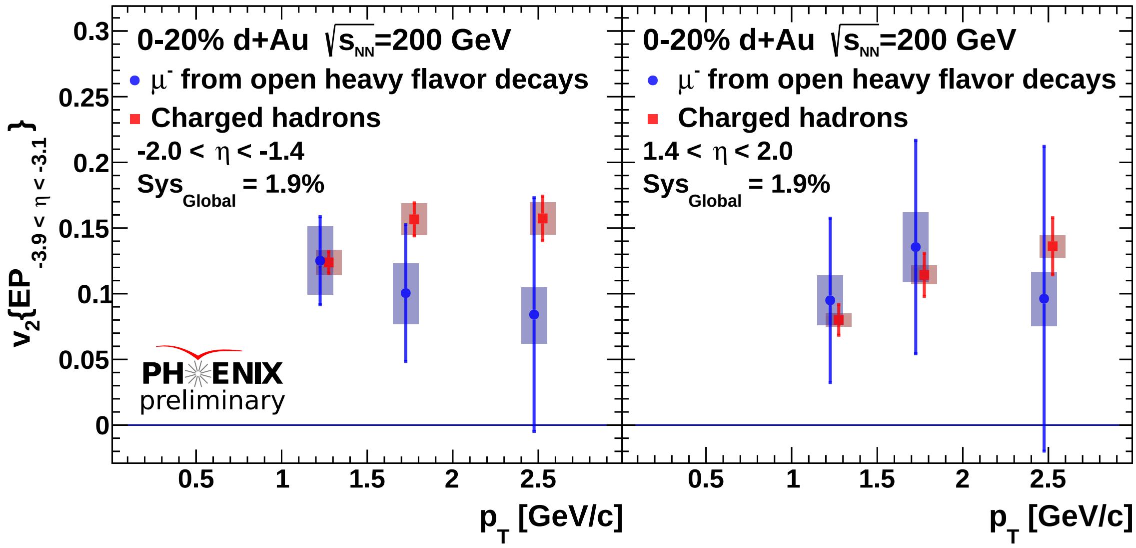

Figure 2: The azimuthal anisotropy of $c+b \to \mu$ (blue points) in $d+$Au collisions at $\sqrt{s_{NN}}$ = 200 GeV for Au-direction (left panel) and d-direction (right panel). Red squares correspond to charged hadron v_2 measured in same η range [7].

2.2 Azimuthal Anisotropy of $c \to e$ and $b \to e$ in Au+Au collisions

We have measured the azimuthal anisotropy v_2 of $c \to e$ and $b \to e$ via a displaced vertex analysis in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Firstly, we measure the p_{T} spectrum and DCA$_{\mathrm{T}}$ distributions of single electrons and estimate background contributions which include non-electrons, internal and external conversion electrons, J/ψ decay electrons, Kaon decay electrons, and electron tracks mis-associated with uncorrelated inner tracker hits. These background components and DCA$_{\mathrm{T}}$ shapes are estimated by the data-driven method and the PHENIX detector full-simulation. Secondly, each component of $c \to e$ and $b \to e$ are extracted in DCA$_{\mathrm{T}}$ distributions. In this analysis, we employ our Bayesian inference technique [2, 3] and unfold the p_{T} spectrum of parent charm and bottom hadrons because DCA$_{\mathrm{T}}$ shapes depend on parent hadron p_{T} spectrum shape. The refold DCA$_{\mathrm{T}}$ shape from unfolded p_{T} spectrum of parent charm and bottom hadrons describes well the measured DCA$_{\mathrm{T}}$ distribution of electrons as shown in Figure 3 (left). Thirdly, the DCA$_{\mathrm{T}}$ distribution is divided to charm enriched region ($|$DCA$_{\mathrm{T}}| <$ 200 μm) and bottom enriched region (300 $< |$DCA$_{\mathrm{T}}| <$ 1000 μm) as shown in Figure 3 to extract the azimuthal anisotropy of $c \to e$ and

$b \to e$. For both charm and bottom enriched region, the azimuthal anisotropy of $c+b \to e$ as a function of p_{T} is measured with the background v_2 subtraction as shown in Figure 3 (right).

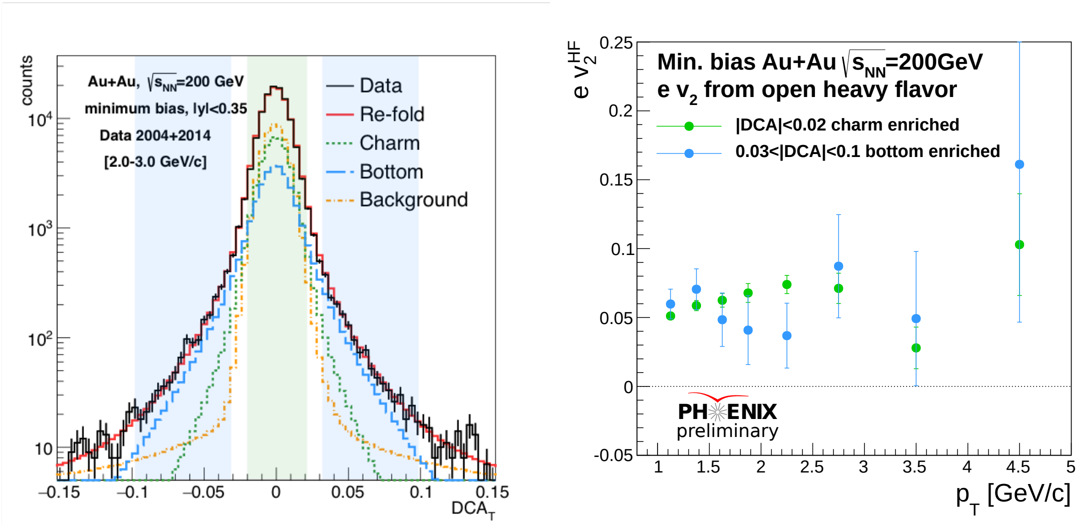

Figure 3: Left: The $\mathrm{DCA_T}$ distribution for measured electrons compared to the decomposed $\mathrm{DCA_T}$ distributions for background components, electrons from charm and bottom hadron decays in minimum bias Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The green (blue) band indicates the charm (bottom) enriched region in $\mathrm{DCA_T}$. Right: The azimuthal anisotropy v_2 of $c+b \to e$ as a function of p_{T} for both charm and bottom enriched region.

These v_2 of $c+b \to e$ in charm and bottom enriched regions are expressed as

$$v_2^{c\ rich} = F_c^{c\ rich} \times v_2^c + F_b^{c\ rich} \times v_2^b \tag{2.1}$$
$$v_2^{b\ rich} = F_c^{b\ rich} \times v_2^c + F_b^{b\ rich} \times v_2^b \tag{2.2}$$

where F_c (F_b) is the fraction of $c \to e$ ($b \to e$) in each $\mathrm{DCA_T}$ regions, v_2^c (v_2^b) is true azimuthal anisotropy of $c \to e$ ($b \to e$). Simultaneous equations can be solved with each fraction and inclusive v_2 values to extract v_2 of $c \to e$ and $b \to e$. Figure 4 shows extracted v_2 of $c \to e$ and $b \to e$ as a function of p_{T} which is the first measurement at RHIC energy. v_2 of $c \to e$ increases with increasing p_{T} and indicates the large elliptic flow of charm quarks in the QGP. The order of magnitude is less than the charged hadron v_2 [8]. To a direct comparison, an unfolding of parent hadron v_2 and Quark-Constituent-Number scaling are needed. On the other hand, v_2 of $b \to e$ indicates no strong p_{T} dependence and non-zero flow of bottom quarks which is consistent with LHC result [9]. Measured v_2 of $b \to e$ is likely smaller than v_2 for $c \to e$, indicating the quark-mass dependence of flow in the QGP. However, v_2 of $b \to e$ is consistent with zero and v_2 of $c \to e$ within the large uncertainty. The analysis method will be improved to reduce the uncertainty and better understand the quark-mass dependence of flow.

3. Summary

We have observed v_2 of $c+b \to \mu$ in $d+$Au collisions and separated v_2 of $c \to e$ and $b \to e$

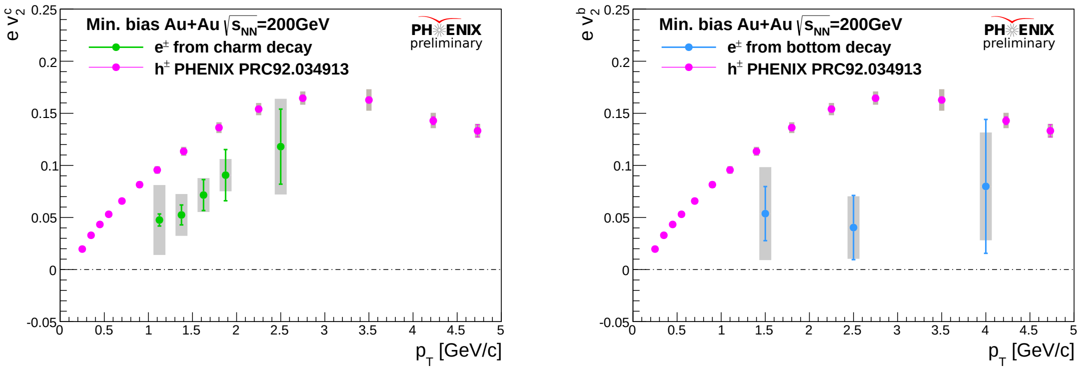

Figure 4: The azimuthal anisotropy v_2 of $c \to e$ (left) and $b \to e$ (right) as a function of p_T compared with charged hadron v_2.

in Au+Au at $\sqrt{s_{NN}} = 200$ GeV. Large v_2 of $c+b \to \mu$ in $d+$Au collisions is found for both Au-direction and d-direction. It indicates that heavy flavors flow in small collision system. We also find large v_2 of $c \to e$ in Au+Au collisions, which indicates that charm quark is strongly coupled in the QGP. On the other hands, v_2 of $b \to e$ in Au+Au collisions show no strong p_T dependence and very small v_2 which is likely smaller than v_2 of $c \to e$. The analysis method will be improved to reduce the uncertainty and better understand the quark-mass dependence of flow in the QGP.

References

[1] A. Adare *et al.* (PHENIX collaboration), *Phys. Rev. Lett.* **98**, 172301 (2007).

[2] A. Adare *et al.* (PHENIX collaboration), *Phys. Rev.* C **93**, 034904 (2016).

[3] K. Nagashima for the PHENIX collaboration, *Nucl. Phys.* A **967**, 644 (2017).

[4] M. Aggarwal *et al.* (STAR collaboration), Phys. Rev. Lett. 105 (2010) 202301.

[5] A. Adare *et al.* (PHENIX collaboration), *Phys. Rev. Lett.* **111**, 212301 (2013).

[6] V. Khachatryan *et al.* (CMS collaboration), J. High Energy Phys. **09**, 091 (2010).

[7] C. Aidala *et al.* (PHENIX collaboration), *Phys. Rev.* C **96**, 064905 (2017).

[8] A. Adare *et al.* (PHENIX collaboration), *Phys. Rev.* C **92**, 034913 (2015).

[9] V. Khachatryan *et al.* (CMS collaboration), Eur. Phys. J. **C77**, 252 (2017).