Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 00 (2016) 1–4

Nuclear Physics A

www.elsevier.com/locate/procedia

Charge-dependent anisotropic flow in Cu+Au collisions

Takafumi Niida for the STAR Collaboration[1]

Wayne State University, 666 W. Hancock, Detroit, MI 48201

Abstract

We present the first measurements of charge-dependent directed flow in Cu+Au collisions at $\sqrt{s_{NN}}$= 200 GeV. The directed flow has been measured as functions of the transverse momentum and pseudorapidity with the STAR detector. The results show a small but finite difference between positively and negatively charged particles. The difference is qualitatively explained by the patron-hadron-string-dynamics (PHSD) model including the effect of the electric field, but much smaller than the model calculation, which indicates only a small fraction of all final quarks are created within the lifetime of the initial electric field. Higher-order azimuthal anisotropic flow is also presented up to the fourth-order for unidentified charged particles and up to the third-order for identified charged particles (π, K, and p). For unidentified particles, the results are reasonably described by the event-by-event viscous hydrodynamic model with η/s=0.08-0.16. The trends observed for identified particles in Cu+Au collisions are similar to those observed in symmetric (Au+Au) collisions.

Keywords: flow, asymmetric heavy-ion collisions, initial electric field

1. Introduction

At the early stage of a non-central heavy-ion collision, a strong magnetic field perpendicular to the reaction plane is created. In asymmetric Cu+Au collisions, due to the difference in the number of spectators, not only the magnetic field but also a strong electric field would exist pointing along the reaction plane from the Au-nucleus to Cu-nucleus. The lifetime of the electric field might be short, of the order of a fraction of a fm/c. The quarks and antiquarks that have been already produced at this time would experience the Coulomb force, which results in a charge dependence of particle directed flow [1, 2]. Thus, the measurement of the charge-dependent directed flow in Cu+Au collisions provides an opportunity to test different quark (charge) production scenarios, e.g. two-wave quark production [3, 4], and shed light on the (anti-)quark production mechanism in heavy-ion collisions. Understanding the time evolution of the quark densities in heavy-ion collisions is also very important for detailed theoretical predictions of the Chiral Magnetic Effect and Chiral Magnetic Wave, for which various experiments are actively searching. In these proceedings, the charge-dependent directed flow in Cu+Au collisions at $\sqrt{s_{NN}}$= 200 GeV measured with the STAR detector is presented. Results of higher-order flow are also presented.

[1]A list of members of the STAR Collaboration and acknowledgements can be found at the end of this issue.

2. Analysis method

Azimuthal anisotropies were measured with the event plane method defined below:

$$v_n = \langle \cos n(\phi - \Psi_n) \rangle / \mathrm{Res}\{\Psi_n\}, \quad (1)$$

where ϕ is azimuthal angle of particles and $\langle\rangle$ means average over all particles in the events of the same centrality bins. The Ψ_n denotes n$^{\mathrm{th}}$-order event plane. The first-order event plane was reconstructed with the Zero Degree Calorimeter (ZDC). The ZDC measures spectator neutrons and thus would minimize non-flow effects such as those from the momentum conservation. For higher harmonics measurements, the event planes were reconstructed from charged tracks ($0.15<p_T<2$ GeV/c) reconstructed in the Time Projection Chamber (TPC) and the Endcap Electro-Magnetic Calorimeter (EEMC). In case of using the TPC, charged tracks were divided into two subevents ($-1<\eta<-0.4$ and $0.4<\eta<1$) and v_n of charged particles of interest was measured with an η-gap of 0.4 using the event plane method (e.g. particles of interest are taken from $0<\eta<1$ when using the subevent from the backward angle). The results from both subevents are consistent and the average of two measurements was used as final results. The event plane resolution Res$\{\Psi_n\}$ was estimated by three subevents method [5]. Systematic uncertainties were estimated by varying event z-vertex and track quality cuts. The effect of the event plane determination was also taken into account in the systematic uncertainty. For higher-order v_n, the scalar product method [6] was also tested just as a cross-check.

3. Results

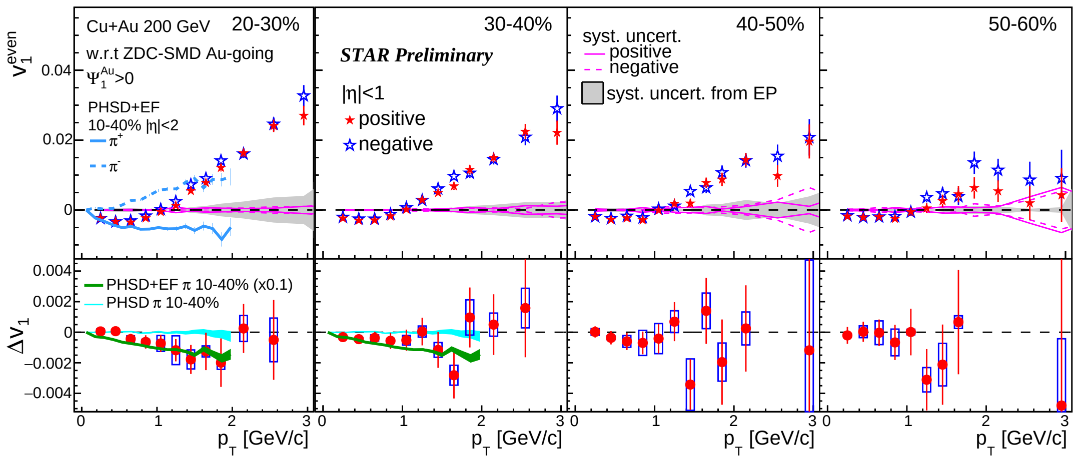

Fig. 1. v_1^{even} of positive and negative particles as a function of p_T in four centrality bins and the difference between both charges, Δv_1. The PHSD model calculations with and without the initial electric field (EF) [2] are compared. The model calculation of Δv_1 with the EF is scaled by 0.1. See the text for the definition of positive direction of v_1 (Ψ_1). This plot has been updated since the presentation[2].

Figure 1 shows v_1 of positive (h^+) and negative (h^-) charged particles as a function of p_T in four centrality bins[2], where v_1 is measured with respect to the spectator plane in Au-going side and the sign of the Ψ_1^{Au} is defined to be positive. In asymmetric collisions, the magnitude of v_1 is no longer symmetric over the pseudorapidity unlike symmetric collisions, therefore the even component of v_1 is measured in this analysis. The v_1 at $p_T<1$ GeV/c has negative value and positive at the higher p_T, which means more low (high) p_T

[2]Note that the figures in these proceedings have been updated since the presentation to account for a software issue in the calculation of the event plane resolution. The final results on v_1 are quantitatively close to those presented at the conference and had no impact on the physics conclusions. The v_2 and v_3 in peripheral collisions become larger after this correction.

particles are emitted to the direction of Cu (Au) spectator. Bottom panels of Fig. 1 show the difference between both charges, $\Delta v_1 = v_1^{h^+} - v_1^{h^-}$. In 20-40% centrality, the Δv_1 seems to be negative in p_T<2 GeV/c, which is qualitatively consistent with the expectation from the initial electric field (EF), i.e. more positively charged particles would move to the direction of the EF and negatively charged particles move to the opposite side.

The parton-hadron-string-dynamics (PHSD) model calculations with and without the effect of the EF [2] are compared to the data, where the Δv_1 for the calculation including the effect of the EF is scaled by 0.1. The model assumes that all electric charges are affected by the EF, resulting in a large separation of v_1 between positive and negative charges as shown in the upper left panel of Fig. 1. The Δv_1 is smaller than the model prediction, which indicates that the electric charges existing within the life time of the EF (~0.25 fm/c) are much smaller than that of all quarks created in the collisions.

Figure 2 shows v_1 and Δv_1 as a function of η in 10-40% centrality[2], where p_T is integrated over $1<p_T<2$ GeV and the sign of Ψ_1^{Au} is defined to be negative (opposite to Fig. 1). The v_1 charge separation is clearly seen in $|\eta|<1$ and Δv_1 increases with η, although the magnitude of v_1 also changes with η.

Figure 3 shows v_2, v_3, and v_4 of positive charged particles as a function of p_T using the event plane method and scalar product method. Both methods are in a good agreement. Calculations from an event-by-event viscous hydrodynamic model [7] are compared to the data of v_2 and v_3. The model results using η/s=0.08 and η/s=0.16 qualitatively agree with the data in 0-5% and 20-30% centrality bins. The centrality dependence of v_n are similar to the results in Au+Au collisions [8, 9, 10]. There was no significant difference between positive and negative charged particles for higher-order flows.

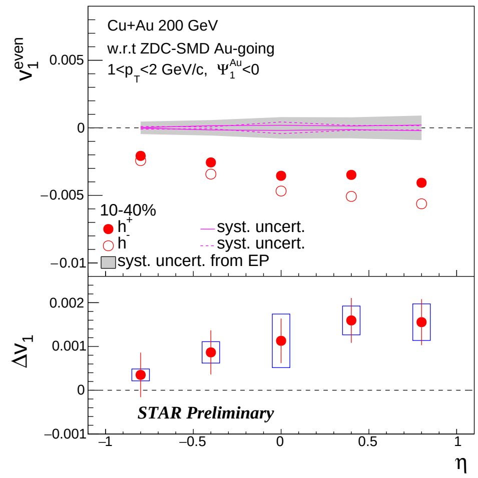

Fig. 2. v_1 of positive and negative particles and Δv_1 as a function of η in 10-40% centrality. This plot has been updated since the presentation[2].

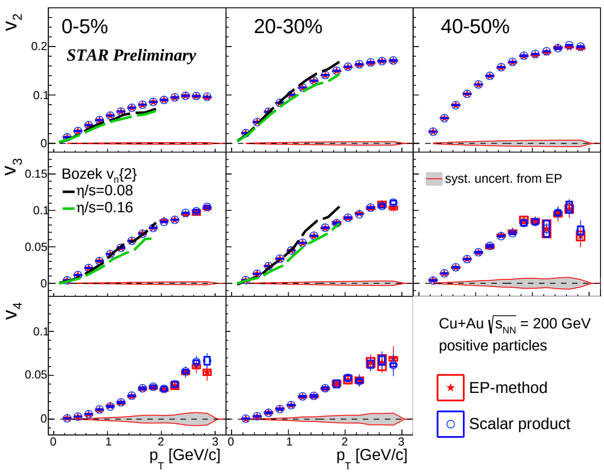

Fig. 3. v_2, v_3, and v_4 as a function of p_T in 0-5%, 20-30%, and 40-50% centrality bins measured with the event plane method and the scalar product method. Calculations from the event-by-event viscous hydrodynamic model [7] are compared. This plot has been updated since the presentation[2].

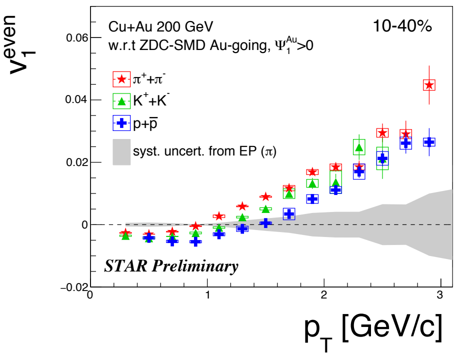

Fig. 4. v_1 of $\pi^{\pm}$, $K^{\pm}$, and $p+\bar{p}$ as a function of p_T in 10-40% centrality. This plot has been updated since the presentation[2].

Identified particle v_n are also measured combining the TPC dE/dx and the time-of-flight information from Time-Of-Flight detector. The v_1 of charge-combined $\pi^{\pm}$, $K^{\pm}$, and $p + \bar{p}$ are presented in Fig. 4 and the v_2 and v_3 of $\pi^{+}(\pi^{-})$, $K^{+}(K^{-})$, and $p(\bar{p})$ for different centrality bins are presented in Fig. 3. The same trends observed in symmetric collisions, such as the mass ordering at low p_T (<2 GeV/c) and the baryon-meson splitting at intermediate p_T, are observed.

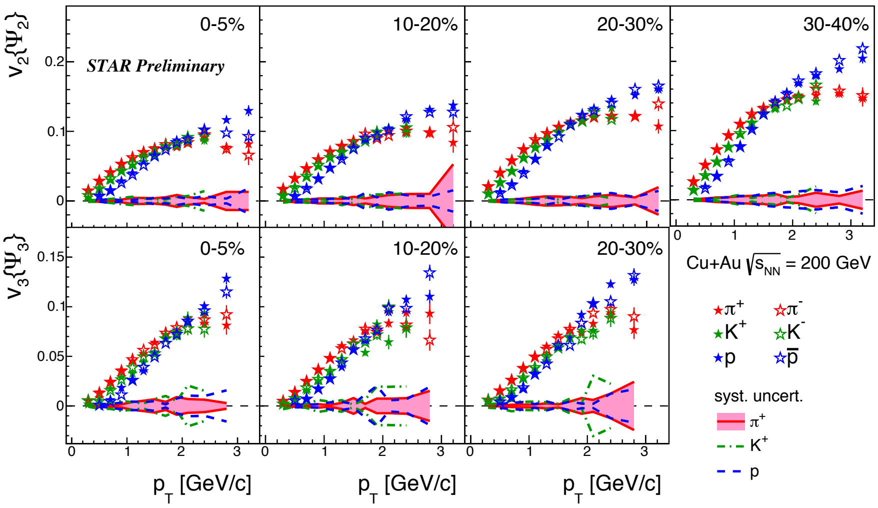

Fig. 5. v_2 and v_3 of π, K, and $p(\bar{p})$ as a function of p_T for different centrality bins. This plot has been updated since the presentation[2].

4. Conclusions

Charge-dependent anisotropic flow in Cu+Au collisions at $\sqrt{s_{NN}}$= 200 GeV has been measured with the STAR detector. Charge difference of v_1 is clearly observed, which is consistent with the effect of the initial electric field. The magnitude of Δv_1 is much smaller than the PHSD model predictions, likely indicating that only a small fraction of all final state quarks are created at the time when the electric field is strong. These results could shed light on the time evolution of quark production in heavy-ion collisions. Higher-order flow v_n have been also presented; they exhibit similar trends observed in symmetric collisions.

References

[1] Y. Hirono, M. Hongo, T. Hirano, Phys. Rev. C90 (2014) 021903.
[2] V. Voronyuk, V. D. Toneev, S. A. Sergei, W. Cassing, Phys. Rev. C90 (2014) 064903.
[3] S. Pratt, PoS CPOD2013 (2013) 023.
[4] B. S. A, P. Danielewicz, S. Pratt, Phys. Rev. Lett. 85 (2000) 2689.
[5] A. M. Poskanzer, S. A. Voloshin, Phys. Rev. C58 (1998) 1671.
[6] C. Adler *et al.* (STAR Collaboration), Phys. Rev. C66 (2002) 034904.
[7] P. Bożek, Phys. Lett. B717 (2012) 287–290.
[8] J. Adams *et al.* (STAR Collaboration), Phys. Rev. C72 (2005) 014904.
[9] J. Adams *et al.* (STAR Collaboration), Phys. Rev. C88 (2013) 014904.
[10] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. Lett. 107 (2011) 252301.