CPC(HEP & NP), 2010, **34**(9): 1443–1445 Chinese Physics C Vol. 34, No. 9, Sep., 2010

Anisotropic flow at RHIC*

CHEN Jia-Yun(陈佳赟)[1,2;1)] LIU Feng(刘峰)[1,2;2)] (for STAR collaboration)

[1] Institute of Particle Physics, Huazhong Normal University(HZNU), Wuhan 430079, China
[2] The Key Laboratory of Quark and Lepton Physics (HZNU), Ministry of Education, Wuhan 430079, China

Abstract STAR's measurement of directed flow for pions, kaons(K^0_S), protons and anti-protons, for Au+Au collisions at 200 GeV obtained in Run7 are presented, as well as elliptic flow for identified particles measured in Au+Au(Run7) and Cu+Cu(Run5) collisions. It is found that the slope of proton $v_1(y)$ at midrapidity is extremely small. Elliptic flow results are compared to Hydro calculation and the discrepancy is discussed.

Key words heavy ion collisions, elliptic flow, directed flow, anti-flow, ideal hydrodynamic

PACS 25.75.Ld, 25.75.Nq, 25.75.Dw

1 Introduction

Anisotropic flow is regarded as one of the main observables which provides information about the early stage of heavy-ion collisions. It can be quantified by studying the Fourier expansion of azimuthal angle, in the momentum space, of the produced particle with respect to the reaction plane [1]. The various coefficients in this expansion can be defined as:

$$v_{\rm n} = \langle \cos n\phi \rangle, \tag{1}$$

where ϕ denotes the angle between the particle's azimuthal angle and the reaction plane angle in the momentum space.

The first two components are named as directed flow(v_1) and elliptic flow(v_2), respectively. They both play important roles in describing the collective motion in azimuthal space. Elliptic flow describes the elliptic expansion of the source in the preferred direction in the reaction plane. It depends strongly on the interaction of system constituents and the number of re-scatterings, thus it is sensitive to the degree of thermalization of the matter created at the early time [2]. Directed flow describes the "side splash" of particles away from the mid-rapidity [3], and it probes the system dynamics in the longitudinal direction. The directed flow for charged particles has been studied at RHIC by STAR previously [4]. The directed flow of identified particles, in particular, that of protons, carries important additional information about the evolution of the system. The shadowing effect [5] can cause protons and pions to flow in directions opposite to each other; on the other hand, if the system experiences a strong expansion due to the creation of QGP, the collective motion purpendicular to the tilted ellipsoid will result in anti-flow [6]. Anti-flow and usual "bounce-off" motion compete with each other, and as a consequence, the proton v_1 slope at midrapidity becomes small or changes its sign [7]. In this paper, we present STAR's directed flow for identified particles and discuss their implications to the "anti-flow" phenomena. The systematic analysis of elliptic flow for identified particles measured in Au+Au and Cu+Cu collisions at 200 GeV will be presented. The results will be presented and compared with those from ideal hydrodynamic calculations.

2 Experiment and analysis

The data presented here are from $\sqrt{s_{\rm NN}}$ =200 GeV Au+Au collisions at Run7(2007) and Cu+Cu collisions at Run5(2005), recorded by the STAR experiment at RHIC. There are about 60 M and 24 M minibias events collected during the Run7 and Run5, respectively. All errors presented in this paper are statistical. The main detector used here is the Time

Received 19 January 2010

* Supported by NSFC (10775058), MOE of China (IRT0624) and MOST of China (2008CB817707)

1) E-mail: chenjyf@iopp.ccnu.edu.cn

2) E-mail: fliu@iopp.ccnu.edu.cn

Projection Chamber(TPC) [8]. The TPC is used for particle identification. It also used to determine the second order event plane in v_2 analysis from Au+Au collision. The pseudorapidity(η) coverage is from -1.3 to 1.3. The full azimuthal coverage and the good particle identification makes it ideal for flow measurements. The two Forward Time Projection Chambers(FTPC) [9] detect the charged particles in $|\eta|$ range from 2.5 to 4.2 with full azimuthal coverage. It is used to determine the second order event plane for v_2 analysis in Cu+Cu collision. The first order event plane in v_1 analysis is reconstructed by measuring the sideward deflection of the spectator neutrons measured by STAR's shower maximum detector at zero degree calorimeters(ZDC-SMD) [10]. The raw event plane have some preference in the orientation which will introduce non-flow correlations. So the raw event plane can not be applied directly in the analysis. The procedure to flatten the event plane can be found in Ref. [11]. The large η gaps between the detectors (ZDC-SMD & FTPC) used to establish the event plane and the η region (TPC) where the measurements were performed is ultilized to minimize the contribution from the non-flow effects.

3 Results and discussion

Figure 1 shows the v_2 vs. p_T for p, π, ϕ and Ω for Au+Au collisions at 200 GeV, for 0–80% centrality. The v_2 of the Ω baryons and ϕ mesons show the similar p_T dependence as p and π. Both Ω and ϕ are argued to freeze out early thus carries information from the partonic stage, yet they show similar flow pattern as light hadrons. This provides the evidence for partonic collectivity [12].

The elliptic flow versus transverse momentum for K^0_S, $\Lambda+\bar{\Lambda}$, $\Xi+\bar{\Xi}$ from 200 GeV Cu+Cu collisions are presented in Fig. 2 for wider centrality range (0–60%) as well as for the 0–20% and 20%–60% centralities. The comparison with the ideal hydrodynamics are shown in lines from top to bottom for K, Λ and Ξ, respectively. As observed in 200 GeV Au+Au collisions [15], the hadron v_2 at $p_T < 2$ GeV/c shows mass hierarchy which predicted by the ideal hydrodynamic calculation. The ideal hydrodynamics have a nice agreement with data for centrality (0–60%), while it under-predicts the data in centrality 0–20% and over-predicts in the centrality 20%–60%. The disagreement between the ideal hydrodynamics and the data in selected centralities may arise from the effect not included in the model calculation, such as the fluctuation of elliptic flow, the finite viscosity effect and the incomplete thermalization.

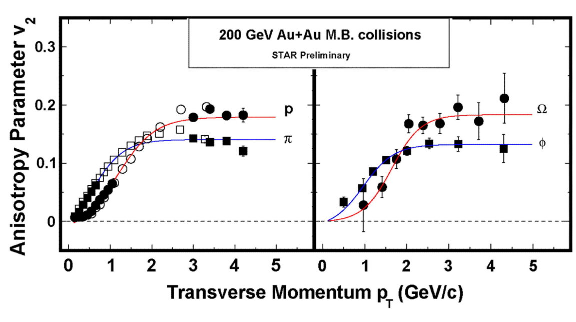

Fig. 1. (color online). v_2 as function of p_T for π, p (left panel) and ϕ,Ω (right panel) in 0-80% Au+Au collisions at 200 GeV. The open symbols represent results from PHENIX [13]. The lines represent NQ-inspired fit [14].

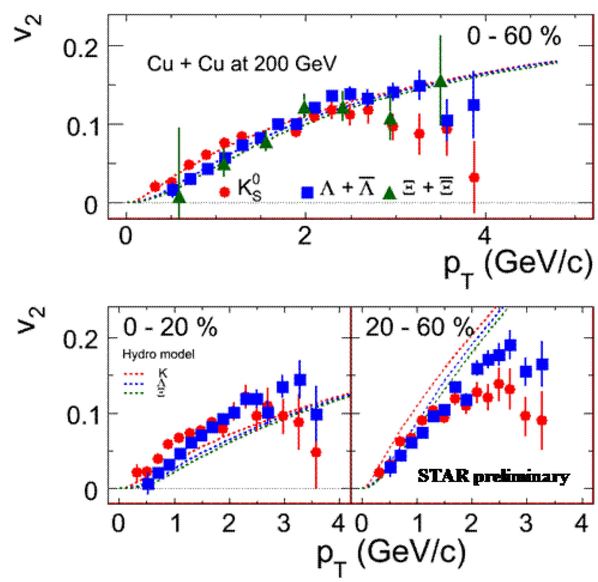

Fig. 2. (color online). v_2 of K^0_S (full circles), $\Lambda+\bar{\Lambda}$ (full squares), $\Xi+\bar{\Xi}$ as a function of p_T in 0–60%(top panel), 0–20%(bottom left panel) and 20%–60%(bottom right panel) Cu+Cu collisions at 200 GeV. For comparisons, the results (the dashed lines) from the ideal hydrodynamic calculations [16] are shown.

Figure 3 (upper panel) presents the rapidity dependence of directed flow of antiproton, proton and pion. The results are for Au+Au collision at 200 GeV in centrality 10%–70%. The directed flow of both antiprotons and pions at mid-rapidity show a negative slope while the proton v_1 is extremely small. The antiproton's v_1 has the same sign of pions, it reflects that that flattening of the proton v_1 is not a mass effect. Kaon has a smaller k/p cross section than that of pions, thus it suffers less shadowing effect, yet we found negative v_1 slope for both charged kaon and kshort-, which is consistent with "anti-flow" picture.

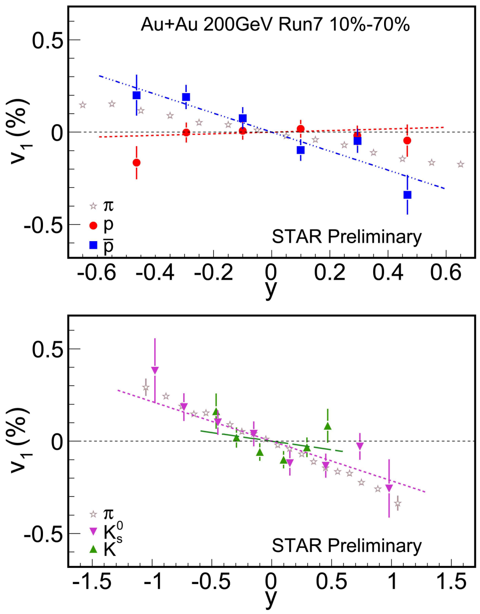

Fig. 3. (color online). v_1 vs. rapidity from Au+Au collisions at 200 GeV in centrality 10%–70%. Upper panel:proton (circle), antiproton (square) and pion (star). Down panel: K^0_S (reverse triangle), pion (star) and kaon (triangle). The dashed lines is linear fit.

4 Summary and outlook

We present the first measurement of directed flow of antiproton, kaon, and K^0_S. Antiproton and kaon, K^0_S's v_1 has the same sign of that of pion (negative slope at mid-rapidity). It is consistent with "anti-flow" picture. We found the slope of the proton $v_1(y)$ at mid-rapidity is extremely small. The results from a systematic elliptic flow v_2 analysis of the identified particles from Au+Au and Cu+Cu collisions at 200 GeV are also presented. The hadron mass hierarchy is observed in p_T <2 GeV/c as expected in the ideal hydrodynamic calculation. The ideal hydrodynamic model fails to reproduce the data in Cu+Cu collisions in selected centralities. The p_T dependence of v_2 from ϕ and Ω follow the similar trend as that of π and p, which suggests that the partonic collectivity has been established at RHIC.

We thank the organizer of the 5-th International Conference on Quarks and Nuclear Physics.

References

1 Poskanzer A M, Voloshin S A. Phys. Rev. C, 1998, **58**: 1671–1678

2 Kolb P, Sollfrank J , Heinz U. Phys. Rev. C, 2000,**62**: 054909

3 Sorge H. Phys. Rev. Lett., 1997, **78**: 2309–2312

4 STAR Collaboration. Phys. Rev. Lett., 2008, **101**: 252301; Phys. Rev. C, 2006, **73**: 34903

5 Snellings R J M, Sorge H, Voloshin S A, WANG F Q, XU N. Phys. Rev. Lett., 2000, **84**: 2803–2805; LIU H, Panitkin S, XU N. Phys. Rev. C, 1998, **59**: 348–353

6 Csernai L P, Röhrich D. Phys. Lett. B, 1999, **458**: 454–459; Brachmann J, Soff S , Dumitru A , Stöcker H, Maruhn J A, Greiner W. Phys. Rev. C, 2000, **61**: 024909

7 Stöcker H. Nucl. Phys. A, 2005, **750**: 121–147

8 STAR Collaboration. Nucl. Instr. Meth. A, 2003, **499**: 624–632

9 STAR Collaboration. Nucl. Instr. Meth. A, 2003, **499**: 713–719

10 STAR Collaboration. Nucl. Instr. Meth. A, 2001, **470**: 488–499; The STAR ZDC-SMD has the same structure as the STAR EEMC SMD: Allgower C E et al. Nucl. Instr. Meth. A, 2003, **499**: 740–750; Crawford H et al. STAR ZDC-SMD proposal STAR Note 2003, **SN-0448**: 6

11 CHEN J (for STAR collaboration). J. Phys. G: Nucl. Part. Phys., 2008, **35**: 044072

12 SHI S (for STAR collaboration). Nuclear Physics A, 2009, **830**:187c–190c

13 Issah M, Taranenko A (PHENIX collaboration). nucl-ex/0604011, 2006

14 DONG X et al. Phys. Lett. B, 2004, **597**: 328–332

15 STAR Collaboration. Phys. Rev. C, 2008, **77**: 054901

16 Huovinen P, Ruuskanen P V. Annual Review of Nuclear and Particle Science, 2006, **56**: 163–206