RQMD predition of directed flow at CSR energy *

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Abstract The predictions of the directed collective flow by using the relativistic quantum molecular dynamics model are presented for the heavy-ion reactions at HIRFL-CSR energies. The directive flow value as a function of the emitting nucleon rapidity in the center-of-mass system is calculated with the azimuthal event plane method and two-particle angle correlation method, respectively. Comparing the rapidity dependence of directed flow in different freeze-out time windows, the evolution and development of the directed flow is investigated. We find that one can reliably obtain the earlier information of the emitting source at this energy by time analysis of the directed collective flow. Such an analysis is useful to the designing of the hadron detector at CSR.

Key words directed flow, azimuthal correlation, heavy-ion collision

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1 Introduction

Directed flow was the first type of collective motion to be identified among fragments from high energy nuclear reaction. [1] It consists of a preferential emission in the plane defined by the incident nuclei (the reaction plane). At high energy, nucleon emission towards the projectile side is favored forward of the center-of-mass rapidity, while the target side is favored at backward rapidities. This behavior is normally attributed to a release of compressional energy, and thus is sensitive to the integrated effect of the nuclear pressure generated in the collision. Models indicate that directed flow is established during the early, high density stage of heavy-ion collisions, and that it is minimally distorted during the subsequent evolution[2—4].

A new accelerator project, Cooling-Storage Ring (CSR) of the Heavy-Ion Research Facility in Lanzhou (HIRFL), has been under a construction. The beams from proton to Uranium with wide energy range will be provided for colliding experiments at CSR[5]. High energy heavy-ion collisions take a unique possibility to study the nuclear matter under extreme conditions of high energy density in the laboratory. The collective motion plays an important role in the dynamical evolution of heavy-ion collisions at high energy.

In this paper we present a prediction of directed collective flow for Uranium ion collisions at CSR energy. The Relativistic Quantum Molecular Dynamics (RQMD) approach is used as an event generator[6]. The Fourier expansion method of the azimuthal angle distribution and the two-particle angle correlation method are used to calculate the flow value. The results are compared to the real value from the model simulations.

2 Directed flow

It is believed that the information about the equation of state (EOS) can be obtained from the study of the collective flow.

In what follows, we simulate a emitting source at

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CSR energy by using RQMD model and calculate the directed flow by using two traditional methods for U+U collisions at 520 AMeV.

The first method we used to obtain the directed flow is Fourier expansion of azimuthal angle distribution. The particle azimuthal distribution with respect to the reaction plane at a given rapidity window can be expanded in term of Fourier components,[7]

$$\frac{d\sigma}{d\phi}=M\left(1+\sum_{n=1}^{\infty}2v_n\cos[n(\phi-\Psi_r)]\right), \qquad (1)$$

where ϕ is defined as the azimuthal angle difference between the particle and reaction plane. Ψ_r denotes the true reaction angle, and the sine terms vanish due to the reflection symmetry with respect to the recation plane. The Fourier expansion cofficient is $v_n=\langle\cos[n(\phi-\Psi_r)]\rangle$. The first and second Fourier cofficients, v_1 and v_2 are connected to the directed flow and elliptic flow, respectively. The main advantage of the Fourier method is that the Fourier cofficients, evaluated using the observed event planes, can be corrected for the event plane resolution caused by the finite multiplicity of the events. In general, we used transverse momentum analysis to obtain the true reaction plane angle Ψ_r[8].

The other method used here is two-particle angle correlation[9]. In an event, the probability of observing two particles with azimuthal angle ϕ_1 and ϕ_2 is

$$\frac{d^2\sigma}{d\phi_1 d\phi_2}=A^2(1+0.5\lambda^2\cos\psi), \qquad (2)$$

where $\psi=\phi_1-\phi_2$. We can use this method to study collective flow with similar sensitivity compared with transverse momentum analysis. This method involves only the azimuthal angle between the transverse momentum of particle pairs. The complications associated with the reaction plane dispersion in conventional flow analysis do not arise.

3 Calculations

In order to assess the nucleon freeze-out conditions, we use a microscopic transport model to calculate the final state phasespace points theoretically. The RQMD model (v2.4) is used as an event generator, because it has been very successful in not only reproducing single-particle distribution but also in collective flow result from Bevalac to SPS energies. In this study, the simulation events of $^{235}U+^{235}U$ collisions at a beam energy of 520 AMeV are generated. In our calculations, only the nucleons with midrapidity ($-0.1<y_{cm}<0.1$) in the center-of-mass system of the colliding nuclei and low transverse momentum ($p_T<1$ GeV/c) are used.

In RQMD model, because the azimuthal angle of the reaction plane is zero degree, we can calculate the directed flow value $v_1=\langle\cos(\phi)\rangle$ directively. Such value of v_1 is real one. Then, we use two methods mentioned in the second section to analysis the model data. The relation of v_1 and λ is $\lambda=2v_1$, theoritically.

Figure 1 shows the rapidity dependence of the directed flow values calculated by the method of azimuthal Fourier expansion and azimuthal angle correlation, respectively. The emitting nucleons are taken from the final state in the noncentral U+U events with inpact parameter b=7.6 fm generated by the RQMD model at the beam energy of 520 AMeV.

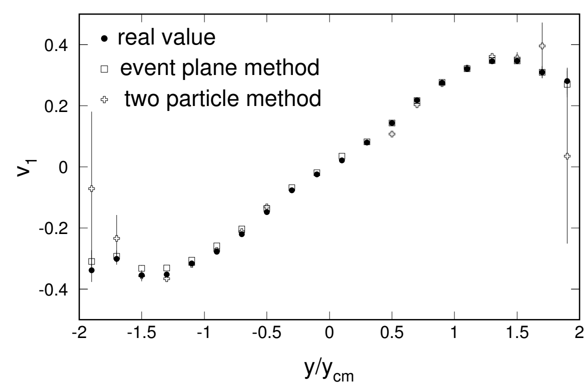

Fig. 1. The directed flow value v_1 as a function of rapidity from the 520 AMeV U+U RQMD events. The results of event plane method (open square) and two particle correlation method (open cross) are compared to the real flow value (filled circle).

As shown in Fig. 1, the results of the two methods are satisfactoyry according to the real flow value calculated directly in the model. The modification has been done in our calculations for the determination of the reaction plane. At current incident energy, where the attractive part of the nucleon-nucleon interaction dominates, the directed flow value v_1 shows a typical 'S' shape for the emitting particles around the mid-rapidity. At the large rapidity, the number of particles is so small that the statistical errors of the two methods are large. At midrapidity, the event anisotropy is so little that we do not need two particle angle correlation to analysis the directed flow.

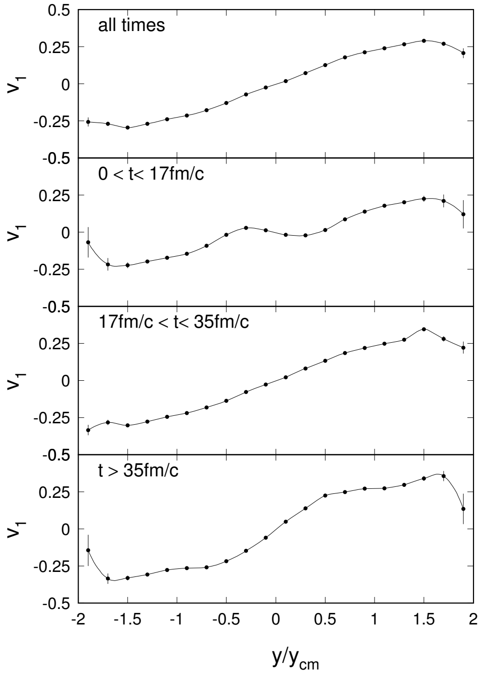

Fig. 2. The time evolution of directed flow from the 520 AMeV U+U RQMD events. The rapidity dependence of v_1 in the different time window is plotted from top to bottom, respectively.

To show the evolution of directed flow, the rapidity dependence of flow value calculated directly from the freeze-out nucloens is plotted in Fig. 2 with difference time windows, respectively. As we can see in the second plotting of Fig. 2, in the early stage, the 'S' shape of mid-rapidity presents a opposite side relative to the initial direction. The integrated flow distribution is mostly similar to that of the middle time stage from 17 fm/c to 35 fm/c. Then the final freeze-out particles show a largely rise of the flow value at mid-rapidity. At the early stage of the collision, the number of freeze-out particles is less and these is a negative slope in midrapidity. The reason is the shadowing from spector of nuclear matter. At the later time, most of the emission particles are multi-scattering , the collectivity of particles reaches the strongest value. At this stage, the maximum of v_1 is achieved, the modification vanished.

4 Summary

In this study, we take a prediction of the directed collective flow for the U+U collisions at the beam energy of 520 AMeV in RQMD framework. We use two methods, Fourier expansion of the azimuthal distribution and particle-pair correlation, to analysis the anisotropy of azimuthal distribution. We find that the method of the particle-pair correlation rises largely a statistical error at large rapidity and breaks down at midrapidity. Then we investigate the time dependence of the directed flow. At the early time, because of the shadowing of the spectator, the directed flow shows a negative slop at the midrapidities. At the later time, the maximum of v_1 is reached, and the negative slope at the midrapidities vanishes.

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