SYSTEM DEPENDENCE OF EVENT SHAPES, RADIAL FLOW AND FRAGMENT PRODUCTION IN CENTRAL COLLISION OF Ni+Ni, Xe+CsI and Au+Au at 250 AMeV

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Light particles and intermediate mass fragments were measured with the almost complete FOPI detector. For central events the shape of the midrapidity source in phase space, the rapidity distribution and the production probability of fragments are compared. Less stopping and a lower production probability for fragments are observed in smaller systems. The system size dependence of the expansion energy is discussed.

Introduction

In recent years, central nucleus nucleus collisions have been studied with the 4π detector of the FOPI Collaboration. In an early study of Au + Au in the energy region 100 - 800 AMeV with the Phase 1 detector, a midrapidity source of intermediate mass fragments (IMFs) [1] and radial flow [2] was found in the selected highly central collisions; large fragment prodution probability, implying low entropies [3] was also observed. Experimentally the system size dependence of the characteristics of the midrapidity source, for example the shape at midrapidity is still a highly interesting question. On the other hand, there are different microscopic dynamical calculation, which predict different shapes of the midrapidity source. Some models predict a distribution that is strongly accentunated transverse to the beam direction (oblate form in the phase space) [4,5,6], while other models [7,8], advocating different scenarios, predict an isotropic radial expansion.

To study the characteristics of the midrapidity source (its mass and incident energy dependence, radial flow, and fragment production probability) under good global conditions, a series of experiments with Ni + Ni, Xe + CsI, and Au + Au at the energies 90, 150, 250, and 400 AMeV were performed with the almost complete FOPI detector in 1994. Here, the preliminary experimental results at 250 AMeV are presented.

Experiment

In this experiment the Central Drift Chamber (CDC) was used. It covers the angular range $30° \leq \theta_{lab} \leq 140°$ and has a reasonable mass identification for

M = 1, 2, 3, 4, and M = 6,7 fragments. The large acceptance at midrapidity and the good mass identification allows us to select central events under good global conditions and study the shape of the midrapidity source. The details of the experiment can be found in [9].

Event Shape, Rapidity Distribution — Stopping

The central events were selected by combining the global parameters ERAT and directivity D [10]. All the measured fragments are included in the calculation of the global parameters to reduced the fluctuations. The POI (particle of interest) is removed from the calculation in order to avoid autocorrelation effects [10]. To compare the different reaction systems at the same centrality, the most central 50 mb for each system is selected for the comparision.

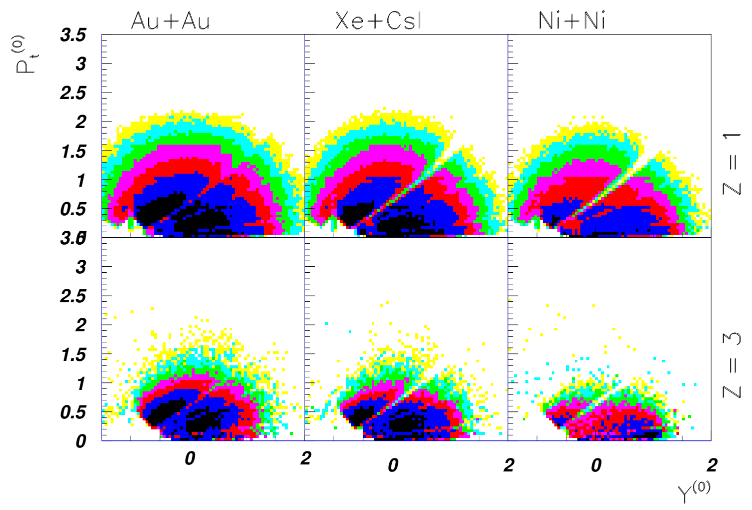

Figure 1: Distributions of invariant cross section $2\pi d^2\sigma/p_t^{(0)}dp_t^{(0)}dy^{(0)}$ of Z = 1, 3 fragments. The lack of intensity in the region of target rapidity is due to the correction of the energy loss in the target. The shadows at $\theta_{lab} = 7°, 21°$, and 30° are the dead zones of the FOPI – Detector.

The event shapes are shown by the two dimensional invariant cross - section plot ($P_t^{(0)} vs Y^{(0)}$) in Fig.1 for Au + Au, Xe + CsI, and Ni + Ni. $P_t^{(0)} = (p_t/A)/(p_{proj}/A)_{cm}$ and $Y^{(0)} = (y/y_{proj})_{cm}$ are the normalized transversal momentum and the normalized rapidity, respectively. It is obvious that in the Au + Au reactions the intensity maximum is located at midrapidity ($Y^{(0)} \sim 0$).

The shapes of this midrapidity source is approximately isotropic. In the Ni + Ni reactions, the intensity distribution of Z = 1 fragments is enhanced in the longitudinal direction and extends to the projectile rapidity, while for the Z = 3 fragments the intensity maximums shift to the projectile rapidity. The same enhancement in the projectile rapidity region is observed for the heavier fragments (Z = 4 − 6). The event shapes for Xe + CsI reaction can be considered as intermediate in Au + Au to Ni + Ni reactions.

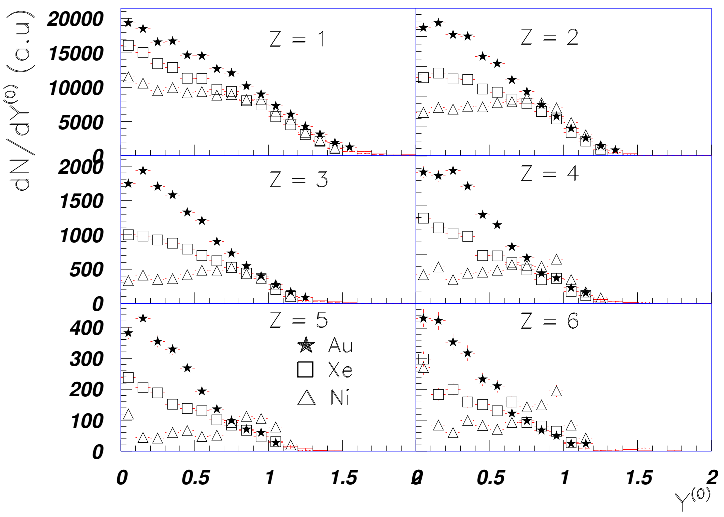

Figure 2: Rapidity distributions of fragment ($Z = 1 \sim 6$) in Au + Au, Xe + CsI, and Ni + Ni reactions .

The event shapes are studied more quantitatively with the rapidity distribution $dN/dY^{(0)}$. The distributions are only shown in the region $Y^{(0)} \geq 0$, because rapidity distibutions must be symmetric about $Y^{(0)} = 0$ for a symmetric system (here the reaction Xe + CsI is considered as symmetrical system). To avoid the possible influence or distortion from the interpolation between the Plastic Wall and the CDC at $\theta_{lab} \sim 30°$ an additional cut on transversal momentum $P_t^{(0)} \leq 0.6$ is used. The rapidity distributions are shown in Fig. 2. All distributions for Xe + CsI are systematically wider than for Au + Au. The distributions of Ni + Ni reaction differ from the other two systems very much, i.e the distributions are characterized by a plateau form. From the distribution of the Z = 2 fragments, the maximum of the distribution appears to be at $Y^{(0)} = 0.8 \sim 0.9$.

In order to estimate the possible influence due to the spectator nucleons, simulations with the IQMD – model [7] are performed for Au + Au and Ni + Ni reactions. From these simulations we found that due to the limited nucleon number, the fluctuation of the global parameters (ERAT and directivity D) for Ni + Ni are larger than for the Au + Au reaction. This leads to the lower centrality reached in the Ni + Ni compared to the Au + Au reactions. Due to the large fluctuations of the global parameters and the low statistics collected for Ni + Ni, the centrality can not be improved by more sharp cuts on the global parameters. However, the centrality is sufficient to make a comparision of the different systems [9]. Based on this simulation, the differences in the observed experimental rapidity distributions are interpreted as mainly due to less stopping in the smaller systems. Considering the experimental rapidity distributions together with IQMD simulation one can say that full stopping is not even reached for the system with $A \sim 130$ and the smaller the system is, the lower the stopping is.

Energy Spectra — Expansion Energy

Due to the high sensitivity of IMFs to the collective flow, the flow energy E_f (radial flow energy) is determined by the mean total kinetic energy $< E_{kin} >$ as a function of fragment mass A. The spectra of fragments ($Z = 1 - 6$) in the region $\theta_{cm} = 25° \sim 45°$ are used. The mean mass of the Z = 1 fragment is derived from the CDC (1.66), while the mass of Z = 4 fragments is assumed to be A = 9. The obtained mean kinetic energy as a function of mass is fitted with the formula $< E_{kin} > = A \cdot E_f + E_{th}$, where the E_{th} is the thermal energy. The extracted flow value is $E_f = 31.4 \pm 2.4\ AMeV$ for Au + Au. It agrees with the results of [10] within the experimental uncertainty. The extracted values are $E_f = 25.6 \pm 2.4\ AMeV$ for Xe + CsI and $E_f = 21.1 \pm 2.1\ AMeV$ for Ni + Ni. It is worthwhile to point out that the extracted values for Xe + CsI and Ni + Ni can not be regarded as radial flow directly. Because of the influnce from less stopping as discussed above, here the extract values must be consided as the upper limits of the radial flow energies for these two systems. The final determination should be done with the spectra at $\theta_{cm} \sim 90°$.

Production Probability of Fragment

From the charge distribution one can get information about the fragment production probability. In order to avoid the influence from less stopping of the spectators, the differential charge distribution are obtained by using only the spectra in $\theta_{cm} = 25° \sim 45°$ and shown in Fig. 3. The distributions are normalized to the Z = 1 fragments of Au + Au, so that one can compare more

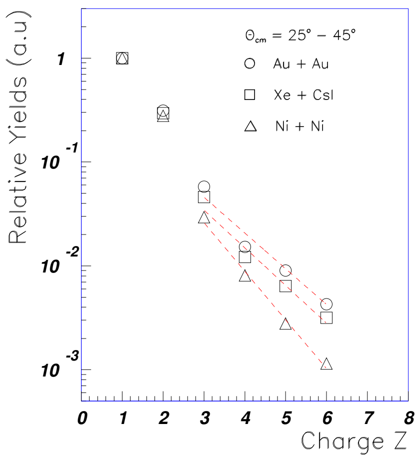

Figure 3: Differential charge distribution obtained by the spectra in the region $\theta_{cm} = 25° - 45°$. The distributions are normalized to the Z = 1 fragments in Au + Au. The dashed lines are fits with a exponential function (see text).

directly. As compared to Au + Au, the production probability is smaller for Xe + CsI and decreases with roughly the same slope with increasing mass. For Ni + Ni the production probability is much smaller than for Au + Au and decreases much faster with increasing mass. Quantitatively the distribution are fitted with the function $N(z) \propto e^{-\sigma z}$. The extracted parameters are $\sigma_{Au} = 0.79$ for Au + Au, $\sigma_{Xe} = 0.84$ for Xe + CsI, and $\sigma_{Ni} = 1.08$ for Ni + Ni respectively. The same type of distributions were also obtained by using the spectra of light particles (M = 1, 2, 3, 4) at $\theta_{cm} = 80° \sim 110°$, which are measured by the CDC.

Summary

The charged fragments in Au + Au, Xe + CsI, and Ni + Ni were measured using almost the full FOPI detector. The full acceptance in phase space makes it possible to compare the physics results of the different systems under good centrality selection ($\sim 1\, fm$), and to study the shape of the midrapidity source.

This work concentrates mainly on the study of the system size dependence of the midrapidity source in very central collisions, i.e the system size dependence of the shape, the collective (radial) flow, and the production probability of fragments. The main results are summarized as follows:

1) In Au + Au the shape of the midrapidity source is approximately isotropic. This can be regarded as an indication of full stopping.

2) A strong system size dependence of the event shape is found. By comparing with the IQMD model this strong dependence is partly interpreted as less stopping in the smaller system at this incident energy, i.e although full stopping is not reached for a symmetric system with mass $A \sim 130$ (Xe + CsI), full stopping is reached for a system with $A \sim 200$ (Au + Au).
3) The expansion energy (radial flow energy) depend on the system size. The smaller the system, the lower is the expansion energy. A more quantitative conclusion can only be drawn with an analysis of spectra at $\theta_{cm} \sim 90°$.
4) The fragment production probability (relative to Z = 1) is lower for the smaller systems. A more rapid decrease of the probability with increasing fragment mass is observed for Ni + Ni reaction.
All the experimental results demonstrate a very strong system size dependence. The less stopping, lower expansion energy and lower production probability for smaller systems can partly be due to surface effect.

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