Investigation of transverse collective flow of intermediate mass fragments

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The transverse flow of intermediate mass fragments (IMFs) has been investigated for the 35 MeV/u $^{70}Zn+^{70}Zn$, $^{64}Zn+^{64}Zn$, and $^{64}Ni+^{64}Ni$ systems [1]. The experimental data was obtained at the Texas A&M University Cyclotron Institute using the NIMROD-ISiS array[2]. An estimate of the impact parameter, for the experimental data, was completed using the minimum bias 2-D distributions of the raw neutron multiplicity plotted against the charged particle multiplicity for each system. Five bins were created in order to examine the transverse flow in the most violent to the peripheral collisions.

The azimuthal correlations method [3] was used to reconstruct the reaction plane from the experimental data. In the NIMROD-ISiS array thresholds produced incomplete detection of IMFs at negative reduced rapidities ($Y_r=Y_{cm}/Y_{cm,proj}$). Therefore, the transverse flow was quantified by calculating the average in-plane transverse momentum from $0.0 \leq Y_r \leq 0.45$. Thus, the flow, or $<\overline{Px}>$, was extracted only from the positive rapidity fragments.

The transverse flow for Z=1-9 particles is shown in Fig. 1 for the five centrality bins, ranging from Bin 0 (most violent collisions) to Bin 4 (most peripheral collisions). A transition from the IMF transverse flow strongly depending on the mass of the system, in the most violent collisions, to a dependence on the charge of the system, for the peripheral reactions, is shown. This demonstrates the importance of both mass and charge dependent forces in the transverse flow.

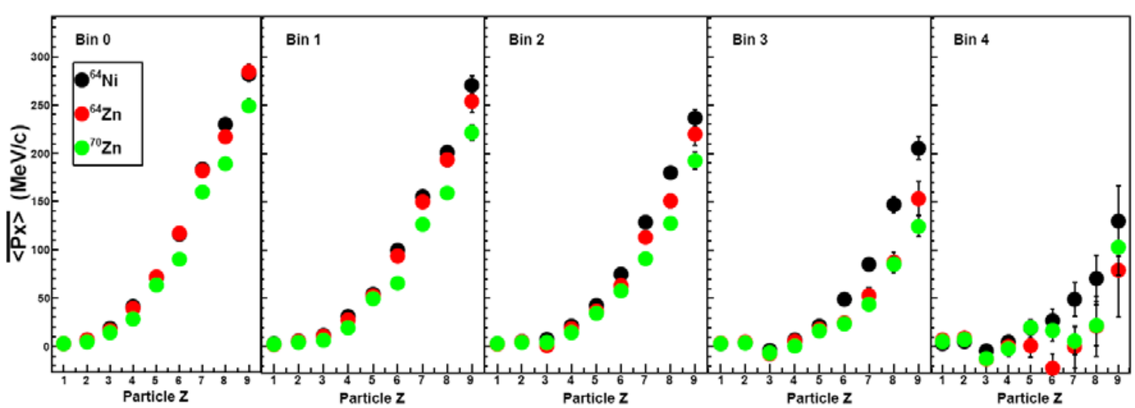

FIG. 1. Transverse flow, $<\overline{Px}>$, for Z=1-9 particles in five different centrality bins. Bin 0 represents the most violent collisions, while Bin 4 represents the most peripheral. The results are shown for the ^{64}Ni, ^{64}Zn, and ^{70}Zn systems as shown in the legend.

The antisymmetrized molecular dynamics model [4] was used to investigate the sensitivity of the IMF transverse flow to the density dependence of the symmetry energy. To compare the system mass to charge dependence of the IMF flow the ratio,

$$R_{Flow} = \frac{\overline{<Px>}_{64Zn} - \overline{<Px>}_{70Zn}}{\overline{<Px>}_{64Ni} - \overline{<Px>}_{70Zn}}$$

can be used to define the magnitude of the flow from the ^{64}Zn system in comparison to the ^{64}Ni and ^{70}Zn systems. Thus, when R_{Flow}=1 the IMF flow of the ^{64}Zn system equals that of the ^{64}Ni system (mass dependent flow) and when R_{Flow}=0 the ^{64}Zn and ^{70}Zn systems (charge dependent flow) have equivalent values of flow. The comparison of theoretical and experimental results are presented in Fig. 2 where the R_{Flow} was averaged over Z=4-9 fragments. The results demonstrate that the choice of interaction, Gogny or Gogny-AS, is important in being able to reproduce the experimental data. The best agreement between the experiment and theory was achieved with a stiff density dependence of the symmetry energy (Gogny-AS interaction).

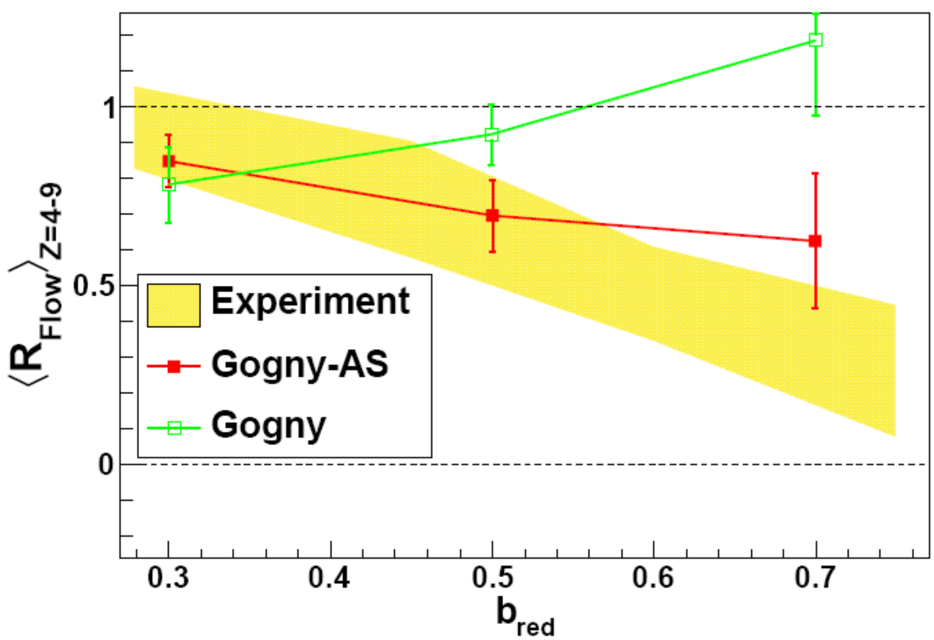

FIG. 2. Average R_{Flow} for Z=4-9 fragments is plotted as a function of the reduced impact parameter, bred, for the experimental data (yellow area) and AMD-Gemini simulation with both a stiff (red squares) and soft (green open squares) Esym(ρ).

[1] Z. Kohley *et al.* Phys. Rev. Lett. (Submitted).

[2] S. Wuenschel, *et al*. Nucl. Instrum. Methods Phys. Res. **A604,** 578 (2009).

[3] W.K. Wilson, R. Lacey, C.A. Ogilvie, and G.D. Westfall, Phys. Rev. C **45,** 738 (1992).