Transverse collective flow of isotopically identified light charged particles

Z. Kohley, L. W. May, S. Wuenschel, M. Di Toro, M. Colonna, M. Zielinska-Pfabe, K. Hagel, R. Tripathi, A. Bonasera, G. A. Souliotis, D. V. Shetty, S. Galanopoulos, M. Mehlman, W. B. Smith, S. N. Soisson, B. C. Stein, and S. J. Yennello

The transverse flow of light charged particles (LCPs) has been investigated for the 35 MeV/u $^{70}Zn+^{70}Zn$, $^{64}Zn+^{64}Zn$, and $^{64}Ni+^{64}Ni$ systems. The experimental data was obtained at the Texas A&M University Cyclotron Institute using the NIMROD-ISiS array [1]. 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. The mid-peripheral collisions were used to investigate the effects of different isospin concentrations in both the colliding system and the LCPs.

The azimuthal correlations method [2] was used to reconstruct the reaction plane from the experimental data. The transverse flow is often quantified as the slope of the average in-plane momentum, <Px/A>, over mid-rapidity. In Fig. 1, the average in-plane momentum per nucleon is plotted as a function of the reduced rapidity, $Y_r=Y_{cm}/Y_{cm,proj}$, for the different isotopically identified LCPs. The solid line, shown in each panel, represent a linear fit over the region $-0.35 \leq Yr \leq 0.35$. The extracted slope of the linear fit represents the transverse flow of the LCPs and is referred to as the flow parameter.

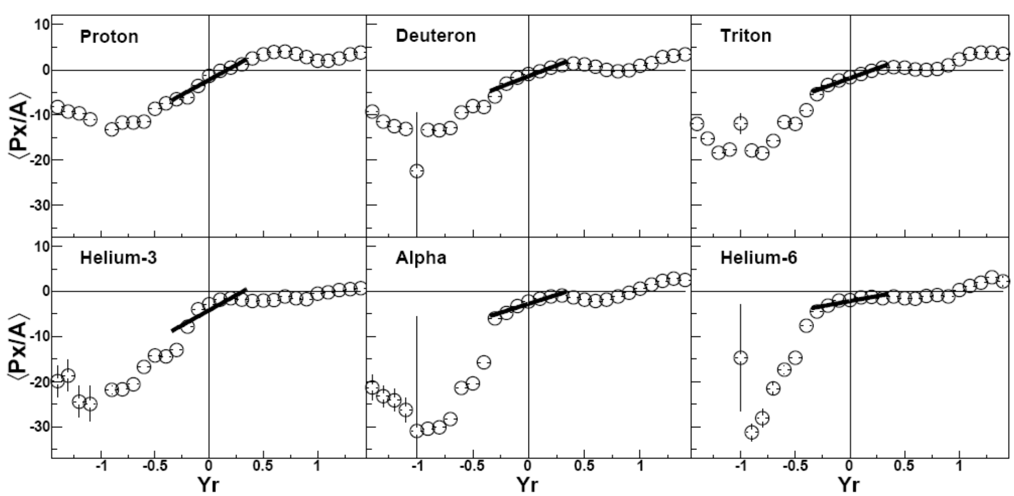

FIG. 1. Average in-plane momentum, <Px/A>, as a function of the reduced rapidity for protons, deuterons, tritons, ^{3}He, alpha and ^{6}He particles. The results shown are from the mid-peripheral collisions of the $^{64}Ni+^{64}Ni$ system. The solid black line represents a linear fit from $-0.35 \leq Yr \leq 0.35$.

The flow of the isotopically identified light charged particles is shown in Fig. 2 for the mid-peripheral collisions. An enhancement in the transverse flow for the ^{64}Ni (N/Z=1.28) system is observed in comparison to the ^{64}Zn (N/Z=1.13) system demonstrating an $(N/Z)_{sys}$ dependence. This expands on the work of Pak *et al*. for inclusive Z=1-3 fragments from systems with the same mass (A_{sys}) and different $(N/Z)_{sys}$ [3]. Additionally, the results from the ^{70}Zn (N/Z=1.33) system show, for all isotopes except tritons and ^{3}He, a decreased flow in comparison to the A_{sys}=128 systems, which can be attributed to the mass dependence of the transverse flow [4].

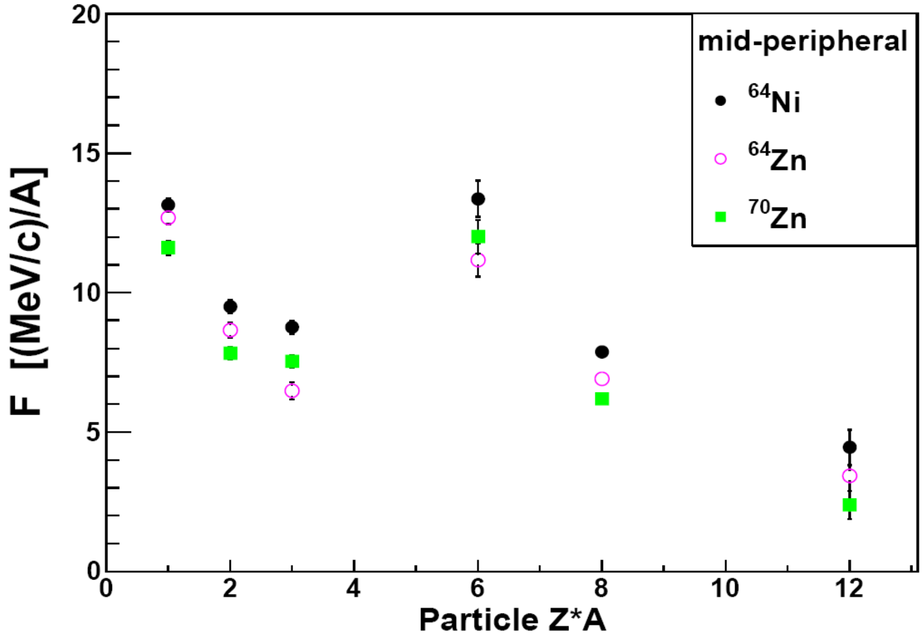

FIG. 2. The extracted flow parameters (F) for the protons, deuterons, tritons, ^{3}He, alpha and ^{6}He particles are shown as a function of the mass times charge (Z*A) of the particle. Results are presented from ^{64}Ni, ^{64}Zn, and ^{70}Zn systems for mid-peripheral collisions as shown by the legend.

Isotopic and isobaric trends can also be explored from the extracted flow parameters in Fig. 2. A distinctive isotopic trend is observed, in which the transverse flow per nucleon is decreasing with increasing neutron content. This would suggest a smaller flow for neutrons in comparison to protons or that the neutron-rich fragments are originating from a different source, such as a neutron-rich neck-like region. Examination of the transverse flow of the triton and ^{3}He fragments provides an isobaric comparison. The results, as shown in Fig. 2, demonstrate an enhancement in the ^{3}He flow in comparison to the triton flow. This, again, demonstrates a decreasing flow with increasing neutron content. Therefore, in comparing fragments with a constant charge (isotopes) or a constant mass (isobars) a consistent trend is observed showing a decreased flow for the more n-rich fragments.

The experimental results were compared to the Stochastic Mean-Field (SMF) model [5]. While the SMF model was unable to reproduce the magnitude of the experimental flow, the $(N/Z)_{sys}$ dependence for the inclusive Z=1 and fragment flow trends were in agreement with the experimental data. In addition, the SMF reproduced the isotopic/isobaric trends, with respect to the experimental results, more closely using a mean-field potential that produces a stiff density dependence of the symmetry energy.

[1] S. Wuenschel *et al*. Nucl. Instrum. Methods Phys. Res. **A604,** 578 (2009).
[2] W.K. Wilson, R. Lacey, C.A. Ogilvie, and G.D. Westfall, Phys. Rev. C **45,** 738 (1992).
[3] R. Pak *et al.*, Phys. Rev. Lett. **78,** 1022 (1997).
[4] G.D. Westfall *et al.*, Phys. Rev. Lett. **71,** 1986 (1993).
[5] J. Rizzo, M. Colonna, M. Di Toro, and V. Greco, Nucl. Phys. **A732**, 202 (2004).