

Isospin effects observed in the transverse flow of isotopically resolved fragments below the balance energy

Z. Kohley, E. Bell, K. Hagel, R. Wada, S. Soisson, A. L. Keksis, D. V. Shetty, G. A. Souliotis,
S. Wuenschel, B. Stein, S. Galanopoulos, L. W. May, L. Qin, J. B. Natowitz,
S. J. Yennello, and the NIMROD Collaboration

In heavy-ion collisions (HIC) below the balance energy an enhanced particle emission is observed in the reaction plane due to collective flow and rotation. The examination of the in-plane transverse momentum of the particles provides an opportunity to study these collective effects. The transverse flow observed in HIC allows for the investigation of properties of nuclear matter at temperatures and density away from that of cold nuclei. Collective flow, among other observables, has been used to constrain the compressibility of the nuclear EoS [1-4]. Furthermore, the transverse flow has been suggested to be sensitive to the asymmetric part of the EoS [5-8]. In particular, differences between the transverse flow of neutrons and protons have been predicted to be sensitive to the density dependence of the symmetry energy [5,6]. However, at this time it remains a difficult task to measure the flow of neutrons. Using a BNV (Boltzmann-Nordheim-Vlasov) microscopic transport code, Scalone *et al.*, have shown that a comparison of the flow parameter for ^3H and ^3He light clusters would exhibit a similar dependence on the parameterization of the symmetry energy as the neutron and proton flows [7,8].

In this study, the transverse flow of isotopically resolved fragments has been examined in the $^{58}\text{Fe}+^{58}\text{Fe}$ and $^{58}\text{Ni}+^{58}\text{Ni}$ systems at 35 MeV/u and 45 MeV/u. The K500 Superconducting Cyclotron at the Texas A&M University Cyclotron Institute was used to produce the ^{58}Fe and ^{58}Ni beams. The NIMROD array (ca. 2000) was used to obtain the experimental data. Further experimental details can be found in Ref. [9]. In order to determine the in-plane transverse

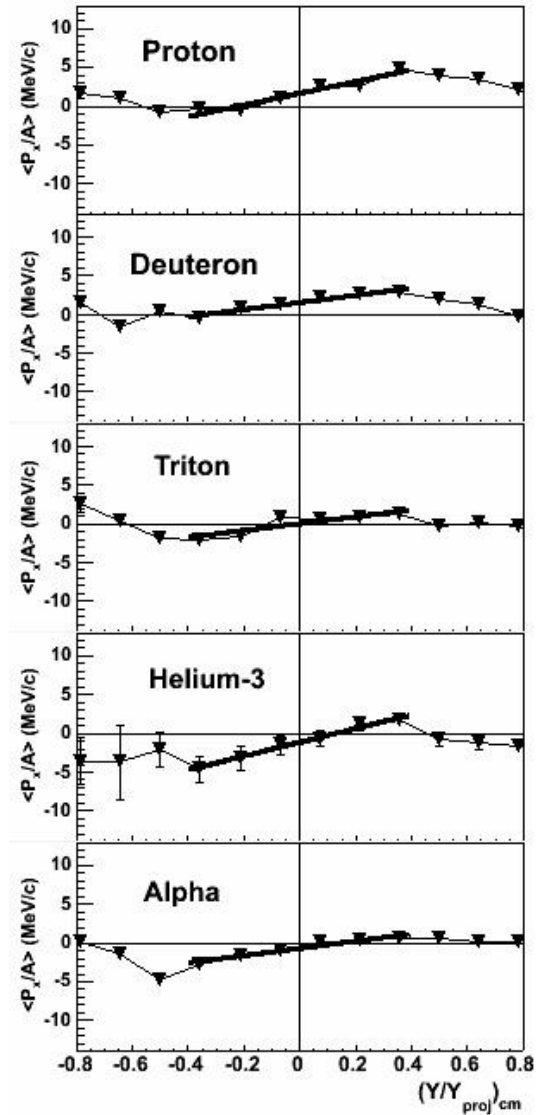


Figure 1. The average in-plane transverse momentum per nucleon, $\langle p_x/A \rangle$, is shown as a function of the reduced rapidity for 45 MeV/u $^{58}\text{Ni}+^{58}\text{Ni}$ system.

flow the reaction plane had to be reconstructed for each event. The Azimuthal Correlations Method by Wilson *et al.* was used to determine the reaction plane [10]. The Transverse Momentum Analysis of Danielewicz and Odnyc was used to determine the forward flow side of the reaction plane [11].

The flow parameter was extracted for proton, deuteron, triton, helium-3, and alpha particles. The flow parameter is defined as the slope of the average in-plane transverse momentum, $\langle p_x \rangle$, over the mid-rapidity region. Fig. 1 shows the average in-plane transverse momentum plotted as function of the reduced rapidity, $(Y/Y_{\text{proj}})_{\text{cm}}$ for the 45 MeV/u $^{58}\text{Ni}+^{58}\text{Ni}$ system.. The flow parameters were extracted from linear fits, as shown in Fig. 1, over the range of -0.4 to 0.4 $(Y/Y_{\text{proj}})_{\text{cm}}$. The resulting flow parameters are shown in Fig. 2 for each system. The flow parameters for the particles from the 35 MeV/u systems are consistently larger than that of the 45 MeV/u systems due to the increased distance from the balance energy. The results in Fig. 2 also present an isospin dependence of the fragment flows on the N/Z of the compound system. As shown in Fig. 2, there is an enhancement in the fragment flow parameters for the more neutron rich $^{58}\text{Fe}+^{58}\text{Fe}$ at both energies. This difference is best seen in the flow of the deuteron and triton fragments. This enhancement of the transverse flow with the $(N/Z)_{\text{cs}}$ has been previously observed for inclusive Z=1, 2 and 3 particles [12,13]. An isospin dependence on the N/Z of the particle of interest was also observed in comparing the flow parameters of the ^3H and ^3He isobars. Fig. 2 allows for the comparison of ^3H and ^3He for each of the 4 systems. The results show an increased flow for the helium-3 fragments in comparison to the triton fragments for each system, however the error bars for the 45 MeV/u $^{58}\text{Fe} + ^{58}\text{Fe}$ system do overlap. This difference in the transverse flow between the ^3He and ^3H isobars is significant because it has been predicted to be sensitive to the density dependence of the

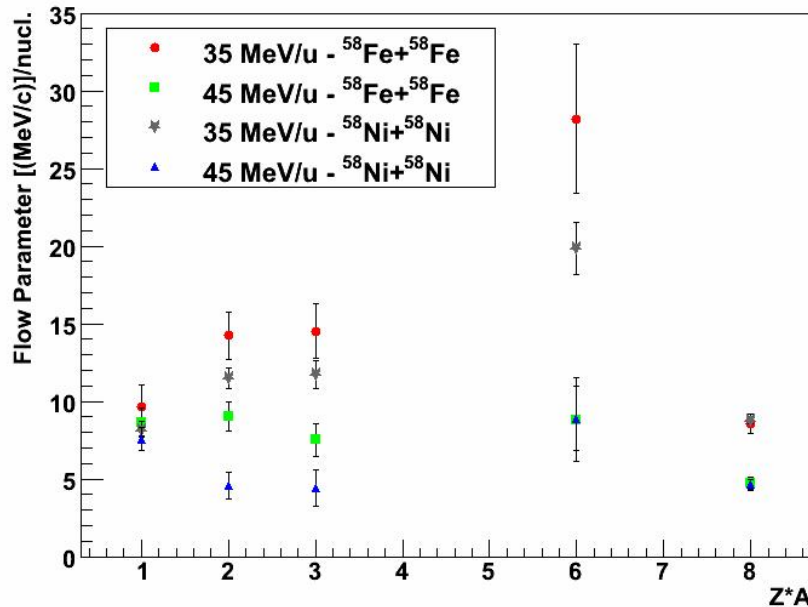


Figure 2. The extracted flow parameters for the protons, deuterons, tritons, helium-3 and alpha particles are shown as a function of the mass times charge ($Z \cdot A$) of the fragment. Results are presented from the $^{58}\text{Ni} + ^{58}\text{Ni}$ and $^{58}\text{Fe} + ^{58}\text{Fe}$ systems at 35 MeV/u and 45 MeV/u.

symmetry energy. The observation of an increased ${}^3\text{He}$, in comparison to the ${}^3\text{H}$ flow, for the ${}^{58}\text{Fe} + {}^{58}\text{Fe}$ systems is in qualitative agreement with an “asy-stiff” calculation of Scalone *et al.* for a 55 MeV/u ${}^{58}\text{Fe} + {}^{58}\text{Fe}$ system.

Overall, the results presented above demonstrate an isospin dependence of the transverse flow on both the N/Z of the compound system and the N/Z of the particle of interest. The observed differences in the triton and helium-3 flow suggest a possible observable which may be sensitive to the density dependence of the symmetry energy. It should be noted that the energy calibrations for this data require corrections and these results should be seen as preliminary. Further experiments to investigate these isospin dependences of the transverse flow with the NIMROD-ISIS array have been planned for the summer of 2008.

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