In-plane Flow and Elliptic Flow for Ar + Al, Ti and Ni at 47 MeV/nucleon

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Studies on collective flow have been used as a useful tool to explore the nuclear equation of state and in-medium nucleon-nucleon cross sections for some years. For review articles, see [1, 2]. Usually, in-plane flow has been studied by plotting the mean in-plane transverse momentum per nucleon ($<Px/A>$) versus the rapidity (Y). The linear behavior of $<Px/A>$ vs Y around mid-rapidity indicates the magnitude of the in-plane flow. On the other hand, the elliptic flow, extracted from the azimuthal distribution or correlation, displays the collective rotational motion in this energy domain.

In this work, we perform a flow analysis for light nucleus reactions, namely ^{40}Ar + ^{27}Al, ^{48}Ti and ^{58}Ni at 47 MeV/nucleon. The experiments were performed at the Texas A&M University Cyclotron Institute. Five impact parameter bins (B1 to B5 from the most central to the most peripheral) were identified using the total multiplicity of charged particles and neutrons emitted on an event-by-event basis.

To extract the in-plane transverse flow, the experimental reaction plane must be reconstructed event by event. The simplest method is to define the plane containing the largest fragments as the reaction plane. In this work, we use this method.

Fig. 1 shows the average in-plane transverse momentum per nucleon versus the rapidity for p and α of 47 MeV/nucleon ^{40}Ar+^{58}Ni for the different impact parameter zones. The characteristic signature of in-plane flow is observed for all light particles and fragments: around mid-rapidity (Y_{nn}/Y_P = 0.5). The participants exhibit the linear increase of $<Px/A>$ versus rapidity. Since it is not possible to decide whether the particles were deflected to positive or negative angles in the reconstruction of reaction plane, only the absolute values of flow are obtained.

The in-plane flow parameter (***F***) can be defined as the slope at mid-rapidity. This value is uncorrected for the difference between the true and reconstructed reaction plane and is thus a low-limit. The different reconstruction methods for the reaction plane can result in different dispersions, i.e., the apparent flow parameter may be different. In this context, care should be taken when one wants to make a quantitative comparison with the data by using transport theory [3].

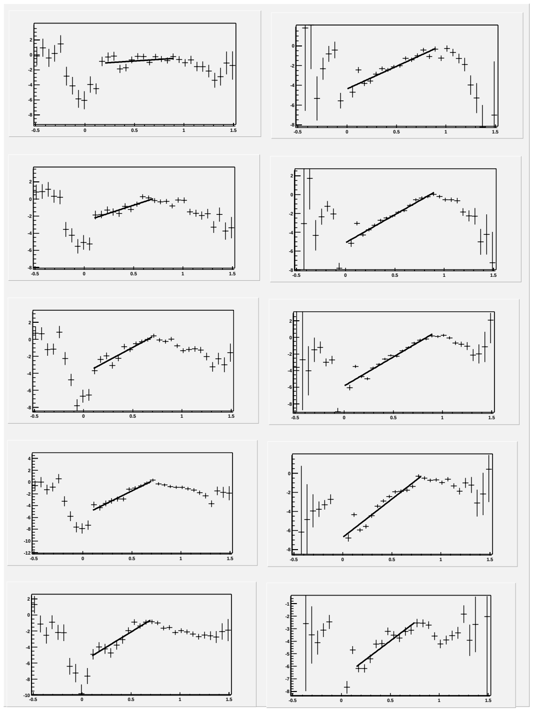

Figure 1: The average in-plane transverse momentum per nucleon (<Px/A>: Y-axis) versus the normalized rapidity (Y/Y_P: X-axis) for p (left group) and α (right group) for 47 MeV/nucleon ^{40}Ar+^{58}Ni. From the top to the bottom, panels correspond to the most central (B1) to the most peripheral collision (B5). The lines are the linear fits around the mid-rapidity region, used in extracting the flow parameter.

Elliptic flow can be studied by measurement of the azimuthal distribution or correlation function. The azimuthal angle is relative to the reconstructed reaction plane. Fig. 2 shows the azimuthal distribution in the mid-rapidity zone (Y_{nn}/Y_P: 0.3-0.7) for p (left) and α (right) for 47 MeV/nucleon ^{40}Ar+^{58}Ni at different impact parameter. The distributions were fit by the second-order Fourier series. In $dN/d(\varphi) \propto 1 + v_1 \cos(\varphi) + v_2 \cos(2\varphi)$, the parameter V_1 relates to the in-plane flow and the parameter V_2 represents the elliptic flow.

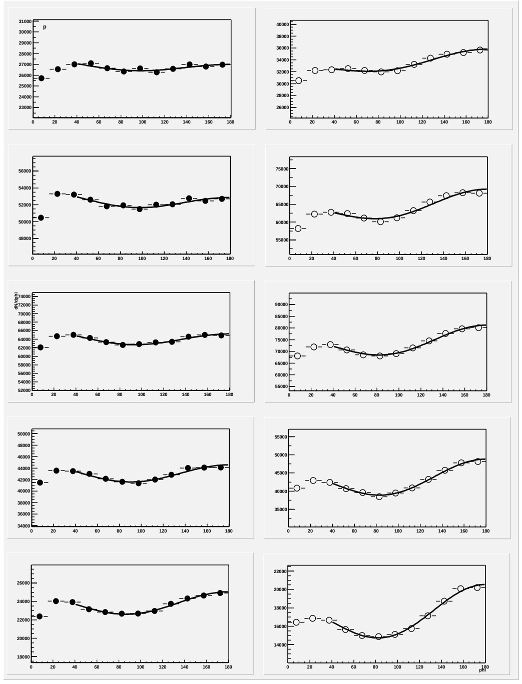

Figure 2: The azimuthal distribution in the mid-rapidity zone (Y_{nn}/Y_P: 0.3-0.7) for p (left) and α (right) for 47 MeV/nucleon ^{40}Ar+^{58}Ni. From top to bottom, panels correspond to the most central (B1) to the most peripheral collision (B5). The lines are the Fourier fits used to extract the elliptic flow parameter.

However, the azimuthal distribution is also subject to the dispersion of the reaction plane determination as is the in-plane flow. In contrast, the azimuthal correlation is free of uncertainties in the reconstruction of reaction plane and some detector effects can be minimized. The correlation function is defined as $R(\Delta\varphi)=N_{corr}(\Delta\varphi)/N_{uncorr}(\Delta\varphi)$, the correlated angles are from particles within one event and the uncorrelated particles are generated by mixed pairs from different events. Mixed events were obtained by randomly selecting each member of a particle pair from different events with the same impact parameter class and the same rapidity window.

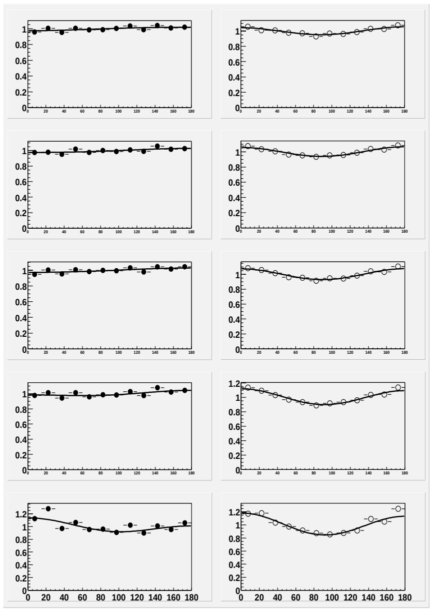

Figure 3: The azimuthal correlation function in the mid-rapidity zone (Y_{nn}/Y_P: 0.3-0.7) for p (left) and α (right) for 47 MeV/nucleon ^{40}Ar+^{58}Ni. From top to bottom, panels correspond to the most central (B1) to the most peripheral collision (B5). The lines are the Fourier fits for extracting the elliptic flow parameter.

Fig. 3 shows some samples of azimuthal correlation functions for p and α at different impact parameters. The curves are second-order Fourier fits to the azimuthal correlation function: $dN/d(\Delta\varphi) \propto 1 + \lambda_1 \cos(\Delta\varphi) + \lambda_2 \cos(2\Delta\varphi)$. Similar to azimuthal distribution parameters, the parameter λ_1 relates to the in-plane flow and the parameter λ_2 represents the elliptic flow.

Summarizing results in Fig. 1-3, we plot the in-plane flow parameter F and elliptic flow parameter V_2 and λ_2 for p and α in Fig. 4. Overall, both flow parameters increase with the impact parameters, and α emission exhibits stronger flow effects than p emission. These observations are consistent with previous experimental results. Furthermore, the dispersion of the reaction plane determination can be deduced via the V_2 and λ_2 as proposed in [4].

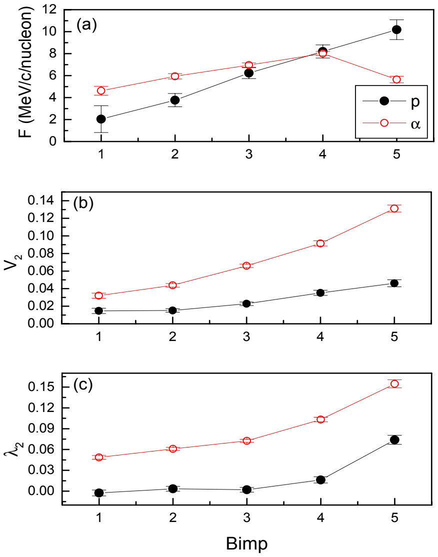

Figure 4: The apparent in-plane flow parameter F (a), the elliptic flow parameter V_2 (b) and λ_2 (c) as a function of impact parameter zone for p and α of 47 MeV/nucleon ^{40}Ar+^{58}Ni.

References

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