DIRECT OBSERVATION OF THE INVERSION OF FLOW

R.C. Lemmon, M.B. Tsang, W. Trautmann[a], R.J. Charity[b], J. F. Dempsey[b], J. Dinius, W. Dünnweber[c], S.J. Gaff, C.K. Gelbke, M.J. Huang, G.J. Kunde, W.G. Lynch, L. Manduci, R. Popescu, R.M. Ronningen, L.G. Sobotka[b], L. Weathers, and D. White

In this report, we describe an experiment designed to determine the mean sign of the scattering angles of the emitted particles for the ^{14}N + ^{154}Sm at E/A=35, 100 and 155 MeV.

A schematic of the experimental set up is shown in Fig. 1. Two ΔE-E telescopes were positioned at ϕ=0° and ϕ=180° around the beam axis and subtended approximately $10° \leq \theta \leq 35°$, where θ and ϕ are the polar and azimuthal angles respectively. These were used to detect and identify charged particles. The ΔE detector consisted of a 5 cm x 5 cm 16-strip Si detector, 300 µm thick, and was positioned 135 mm from the target position. The E detector consisted of nine tapered CsI(Tl) detectors, 7 cm long. These were arranged in a square 3x3 geometry and placed immediately behind the Si detector. A compact cylindrical multiplicity filter, the Minitube, consisting of 58 scintillating fibers, was placed coaxially around the beam axis in the gap between the two polarimeters. The obtained information on the multiplicity of light charged particles was used to derive the reduced impact parameter, b/b_{max}, during the collision.

The measurements were performed at the National Superconducting Cyclotron Laboratory at Michigan State University. The accelerator provided beams of 35A MeV, 100A MeV and 155A MeV ^{14}N which impinged on an isotropically enriched target of ^{154}Sm (98.7%) of areal density 3.15 mg/cm^2. The circular polarization of γ-rays emitted perpendicular to the reaction plane defined by the beam axis and the coincident light charged particles was measured with two forward-scattering polarimeters [1]. These were positioned at θ=90°, ϕ=90° and θ=90°, ϕ=270°. The sign convention adopted [2,3] to define the polarizations with respect to the quantization axis **n**, is given by $\mathbf{n} = \mathbf{p}_i \mathrm{x} \mathbf{p}_f / |\mathbf{p}_i \mathrm{x} \mathbf{p}_f|$ where $\mathbf{p}_i$ and $\mathbf{p}_f$ are the momentum vectors of the beam and the detected particle, respectively. The measurement relies on the assumption that the angular momentum transferred to the target residue will be preferentially oriented in the direction expected for a friction-like mechanism between the surfaces of the colliding nuclei [3]. Thus, positive circular γ-ray polarizations correspond to a photon spin parallel to **n**, and a deflection of the emitted particle to negative angles by the nuclear mean field. Negative circular γ-ray polarizations correspond to a photon spin anti-parallel to **n** and a deflection of the emitted particle to positive angles, caused by repulsive effects of nucleon-nucleon collisions. Zero polarization values may indicate that either the attractive or repulsive interactions balance each other or that the detected light-charged particles, in the absence of a collective velocity component, are emitted at random azimuthal direction.

Experimentally, the count rate asymmetry, $P_\gamma \mathbf{A}$, is measured. For the doubly symmetric detector system, the count rate asymmetry can be expressed as [1]

$$\frac{N_{21}N_{12}}{N_{11}N_{22}} = \left(\frac{1+P_\gamma A}{1-P_\gamma A}\right)^2 \qquad (1)$$

where N_{ij} are the coincidence count rates of particle detector i and polarimeter j. The analyzing power **A** corresponds to the sensitivity of the overall polarimeter setup to the circular polarization of the emitted γ-rays and varies between 0.85% and 0.95%, similar to values obtained previously for the same reaction at E/A=35 MeV [2]. The direction of the polarimeter magnetic field was reversed every hour during the experiment in order to detect and cancel out spurious count rate asymmetries.

The measured circular polarization of γ-rays in coincidence with α particles is shown in Fig. 2 as a function of incident energy. The quoted errors correspond to the statistical uncertainty of P_γ **A** and do not include the uncertainty of A. Three impact parameter bins have been chosen, corresponding to central ($b/b_{max}<0.2$), mid-central ($0.2\leq b/b_{max}\leq 0.6$) and peripheral ($b/b_{max} >0.6$) collisions. The impact parameter bins were chosen to maximize the magnitude of the circular polarization of γ-rays with maximum statistics to reduce the uncertainties. To maximize pre-equilibrium emissions and minimize the contributions from evaporation, an angular gate of 25° ≤ θ ≤ 35° and a threshold energy of 5 MeV per nucleon are imposed on the emitted particles.

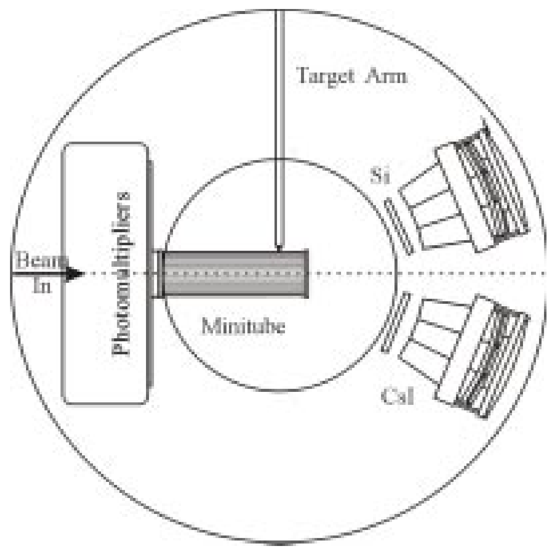

FIG. 1. Cross-sectional view of the detector setup inside the scattering chamber. Two Si-CsI detector arrays were placed symmetrically around the beam axis in forward direction, covering polar angles 10° ≤ θ ≤ 35°. The multiplicity of charged particles was measured with the cylindrical Minitube, mounted symmetrically around the beam axis in the gap between the two polarimeters (not shown). The inner circle indicates the outer diameter of the polarimeters mounted perpendicular to the plane defined by the beam and the two charged particle detector telescopes.

At all incident energies the central impact parameter bin has a polarization that is statistically consistent with zero. Due to lack of statistics, these data have very large error bars and are not plotted here. For peripheral collisions (open points in Fig. 2), the polarization is positive at 35A MeV and very close to zero at the two higher energies of 100A and 150A MeV. Similar trends are observed for the measured P_γ for A≤3. For mid-central collisions (closed points), the most striking feature is the change in sign of the α particle associated polarization from positive values at 35A MeV to negative values at 100A MeV and 155A MeV. This change in sign of the α particle associated polarization provides a direct observation of the change from attractive mean field dominated dynamics at low energies ($P_\gamma >0$) to repulsive nucleon-nucleon collision dominated dynamics at the higher energies ($P_\gamma <0$). The change of sign occurs around E/A=70 MeV. The previous study of the balance energy for symmetric system ranging from C+C to Kr+Nb reactions [4], suggests the same value of about E/A=70 MeV for mass 170. It remains to be understood, however, why the balance energy for an asymmetric system of $^{14}N+^{154}Sm$ should follow the mass dependence established for symmetric systems.

Figure 3 shows the measured γ-ray polarizations in coincidence with protons, deuterons and tritons for the mid central collisions. The magnitude of the polarizations are smaller than the P_γ associated with the emitted alpha particles. This may be partly related to the fact that the statistics are much poorer for deuterons and tritons and that the reaction planes are less well defined.

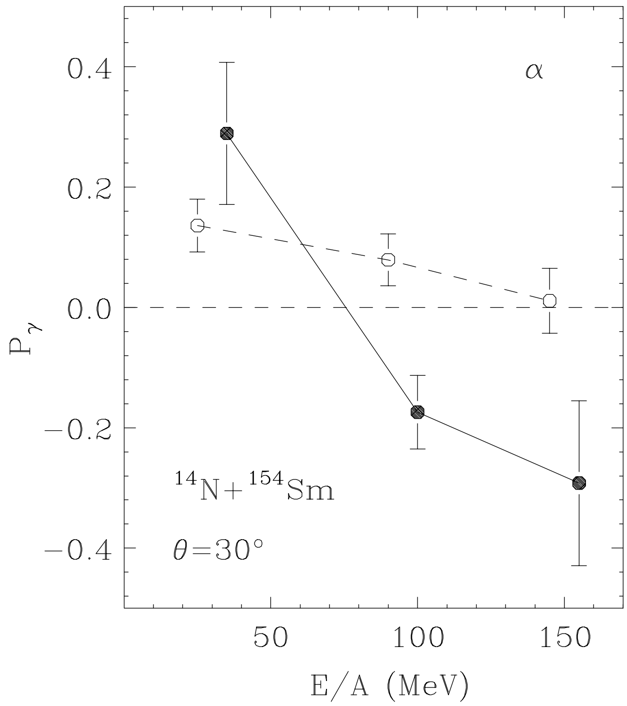

FIG. 2. The circular polarization of coincident γ-rays emitted from residual nuclei for ^{14}N-induced reactions on ^{154}Sm as a function of incident energy for mid-central (solid points) and peripheral collisions (open points) for α particles.

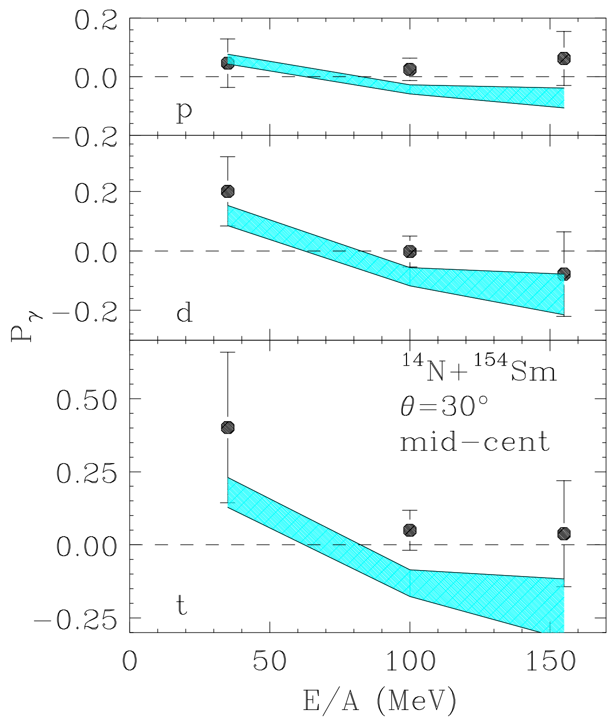

FIG. 3. The circular polarization of coincident γ-rays emitted from residual nuclei for ^{14}N-induced reactions on ^{154}Sm as a function of incident energy for mid-central (solid points) collisions for p, d, t particles. The hatched areas indicate the predicted polarizations extracted by scaling the alpha circular polarization according to the coalescence model.

To provide consistency checks between the measured circular polarizations associated with p, d, t and α particles, we adopt the coalescence model to compute the expected values of P_γ for p, d, t from the measured P_γ associated with the α particles as indicated by the hatched areas in Fig. 3. The magnitude of the measured polarizations are consistently smaller than the scaled P_γ. For tritons, the expected change of sign for the polarization is not observed. However, much more statistics will be needed in order to study the mass dependence on the sign change of the circular polarization associated with emitted light particles.

a. Gesellschaft für Schwerionenforschung, Planckstr. 1, D-64291, Darmstadt, Germany.
b. Department of Chemistry, Washington University, St. Louis, MO 63130, USA.
c. Sektion Physik, Universität München, D-85748 Garching, Germany

References

1. W. Trautmann et al., Nucl. Inst. and Methods 184, 449 (1981).
2. M.B. Tsang et al., Phys. Rev. Lett. 57, 559 (1986).
   M.B. Tsang et al., Phys. Rev. Lett. 60, 1479 (1988).
3. W. Trautmann et al., Phys. Rev. Lett. 53, 1630 (1984).
   W. Trautmann et al., Nucl. Phys. A422, 418 (1984).
   W. Dünnweber and K. M. Hartmann, Phys. Lett. 80B, 23 (1978).
4. G.D. Westfall et al, Phys. Rev. Lett. 71, 1986 (1993); J.P. Sullivan et al, Phys. Lett. B249, 8 (1990); V. de La Mota et al, Phys. Rev. C46, 677 (1992); D. Klakow et al, Phys. Rev. C48, 1982 (1993).
5. C. Cavata, et al., Phys. Rev. C 42, 1760 (1990).
   Y. Lou et al., Nucl. Phys. A 604, 219 (1996).