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Zero-crossing Angle of the *np* Analyzing Power Below 300 MeV

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To improve significantly upon the current knowledge of the nucleon-nucleon interaction requires experimental results of higher accuracy as input to phase shift analyses of scattering data. A particularly sensitive experimental test at intermediate energies is obtained by determining the scattering angle, θ_{zx}, at which the $n-p$ analyzing power crosses zero. Present phase shift solutions[1] disagree by as much as ±1° for the value of θ_{zx}. We have recently completed an experiment at TRIUMF (E498) to measure θ_{zx} to an accuracy of ±0.25° at four neutron beam energies. In this energy range, current phase shift predictions for θ_{zx} range from 99° to 80°. In contrast, above 300 MeV, θ_{zx} decreases much more slowly, reaching 69.74° at 477 MeV as measured by Abegg et al.[2].

The TRIUMF measurements made use of the neutron beam facility and specialized detectors that were assembled for the high precision measurements of charge symmetry breaking in the n-p system[3,4,5], see Fig. 1. Measurements of θ_{zx} were carried out at neutron beam energies of 174.3, 202.4, 216.5 and 260.3 MeV (all ~ ±300 keV). Cuts on the opening angle, coplanarity, and x momentum balance of the outgoing n-p pair, as well as a cut on the difference between the energies of the incident neutron and

the outgoing particles, determined from time-of-flight, serve to identify n-p elastic scattering events, see Fig. 2. These cuts are optimized to reduce the background contamination from $C+n \rightarrow p+n+X$ reactions to ~0.2-0.3%, as determined from background measurements performed with carbon targets. The background-corrected n-p elastic data are then used to determine the scattering asymmetry (analyzing power × beam polarization) as a function of scattering angle, see Fig. 3. The shape of the scattering asymmetry is first fit to the phase shift predictions[1] using a simple cubic expression:

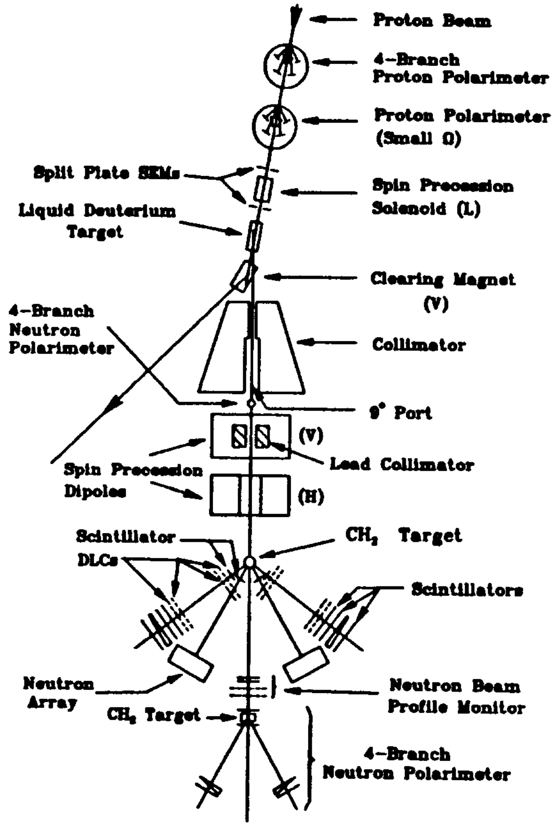

FIGURE 1. Layout of the beamline and experimental apparatus.

$$\epsilon(\theta) = s[(\theta-\theta_{zx}) + a(\theta-\theta_{zx})^2 + b(\theta-\theta_{zx})^3]$$

with a and b fixed to the values determined from SAID, the curve is fit to the data allowing s and θ_{zx} to vary. Such a fit is shown in Fig. 3.

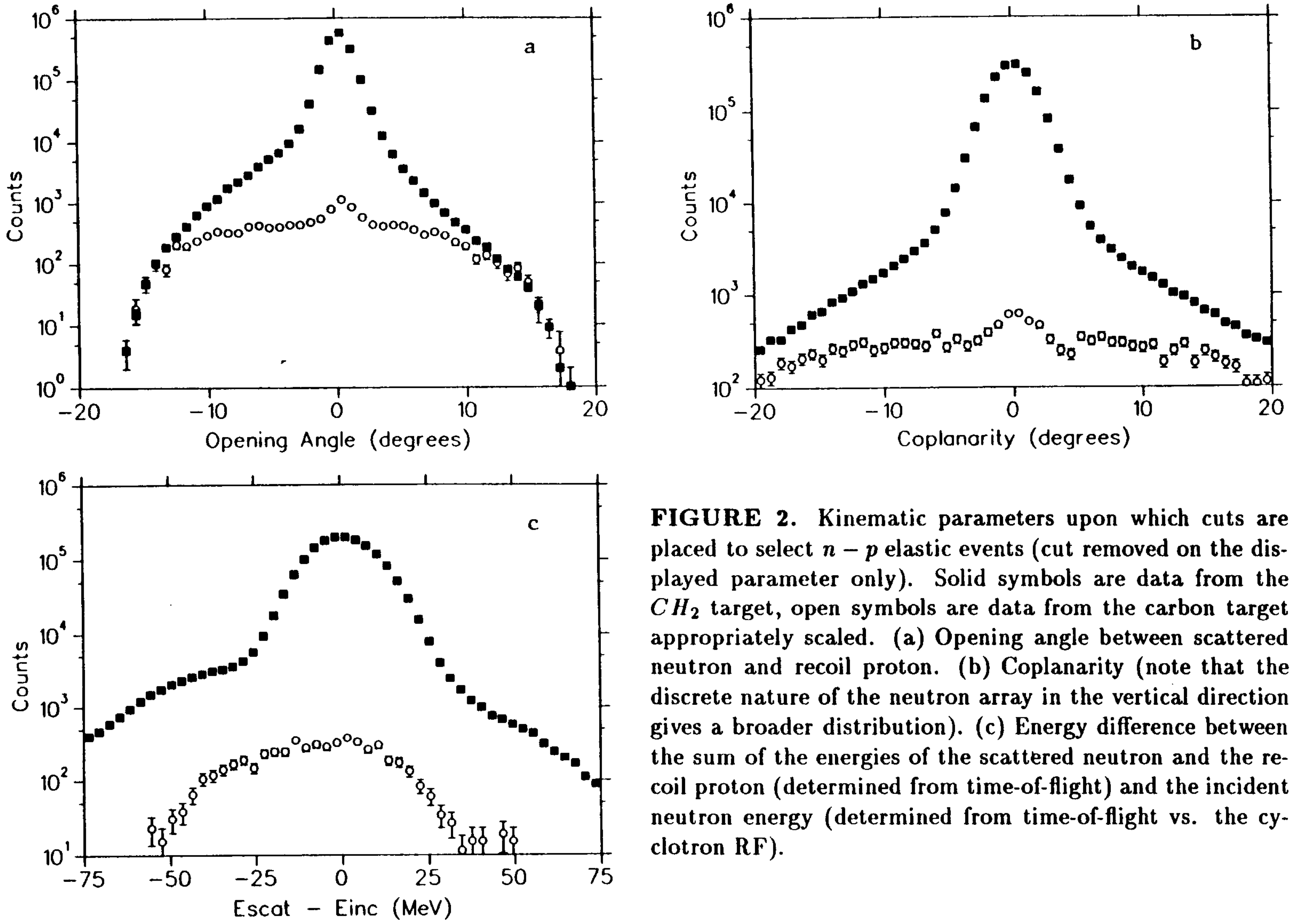

FIGURE 2. Kinematic parameters upon which cuts are placed to select $n-p$ elastic events (cut removed on the displayed parameter only). Solid symbols are data from the CH_2 target, open symbols are data from the carbon target appropriately scaled. (a) Opening angle between scattered neutron and recoil proton. (b) Coplanarity (note that the discrete nature of the neutron array in the vertical direction gives a broader distribution). (c) Energy difference between the sum of the energies of the scattered neutron and the recoil proton (determined from time-of-flight) and the incident neutron energy (determined from time-of-flight vs. the cyclotron RF).

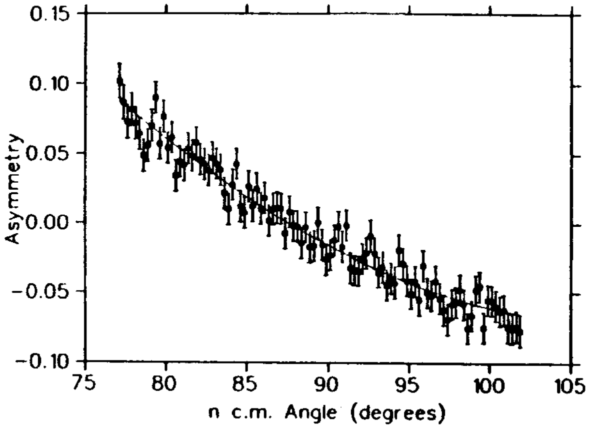

FIGURE 3. Asymmetry as a function of c.m. angle at 216.5 MeV.

The beam energy calibrations are being carefully studied, as θ_{zz} varies strongly with neutron beam energy in this energy range, with a slope varying between $-0.35^{\circ}MeV^{-1}$ (174.3 MeV) to $-0.13^{\circ}MeV^{-1}$ (260.3 MeV). The proton energy was monitored with a range counter telescope (BEM) [3] which was calibrated, at the highest energy by comparison to $np \rightarrow d\pi^0$ near threshold [6] kinematics, and at the other energies by comparing proton elastic scattering from carbon peak positions using the TRIUMF Medium Resolution Spectrometer at the various energies to the calibrated (highest) energy. A Monte Carlo prediction for the neutron beam energy, taking into account the kinematics of the $d(\vec{p},\vec{n})pp$ production reaction [7], energy losses in the deuterium production target, as well as the geometry of the 3.4 m long collimator immediately downstream of the liquid deuterium target, is shown in Fig. 4 for 174.3 MeV. This predicted beam energy distribution, corrected for detector acceptance and efficiency and convoluted with a Gaussian detector response function, is shown compared to the data in Fig 4. The Monte Carlo can also be used to predict and account for variations of average energy and polarization within the neutron beam profile.

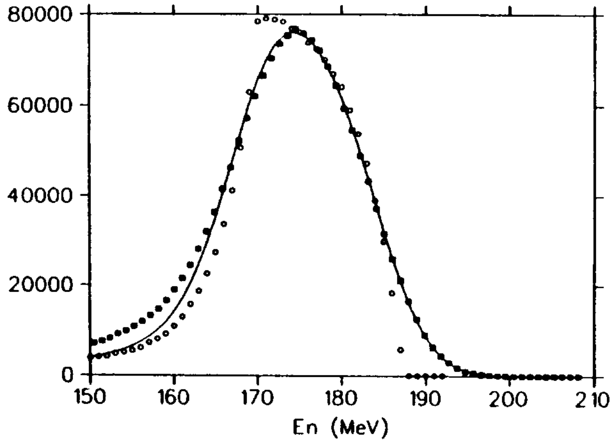

FIGURE 4. Neutron beam energy profile for the lowest energy. The open symbols are the Monte Carlo prediction. The solid line is this prediction corrected for cross section, detector acceptance and timing resolution. The solid symbols are the data.

Additional Monte Carlo studies are currently in progress to evaluate the systematic error contribution due to multiple scattering of the scattered proton. These will be used to correct the final results, accounting for the dependence of θ_{zz} on cuts in opening angle between the recoil proton and scattered neutron used to define elastic scattering events.

The results shown in Fig. 5 are preliminary, as effects of systematic errors, including multiple scattering of the recoil proton, corrections to the energy calibration, and even Charge Symmetry Breaking, continue to be studied. As θ_{zz} changes rapidly over the energy range, Fig. 5 (b) shows the *difference* between the data and the SAID [1] SP94 fit. The results are particularly sensitive to the $^3S_1$, ϵ_1, $^3D_1$, and $^3D_3$ phase shifts, and seem to indicate that the curvature of θ_{zz} is not as pronounced as the present phase shift fit of Arndt et al. would indicate.

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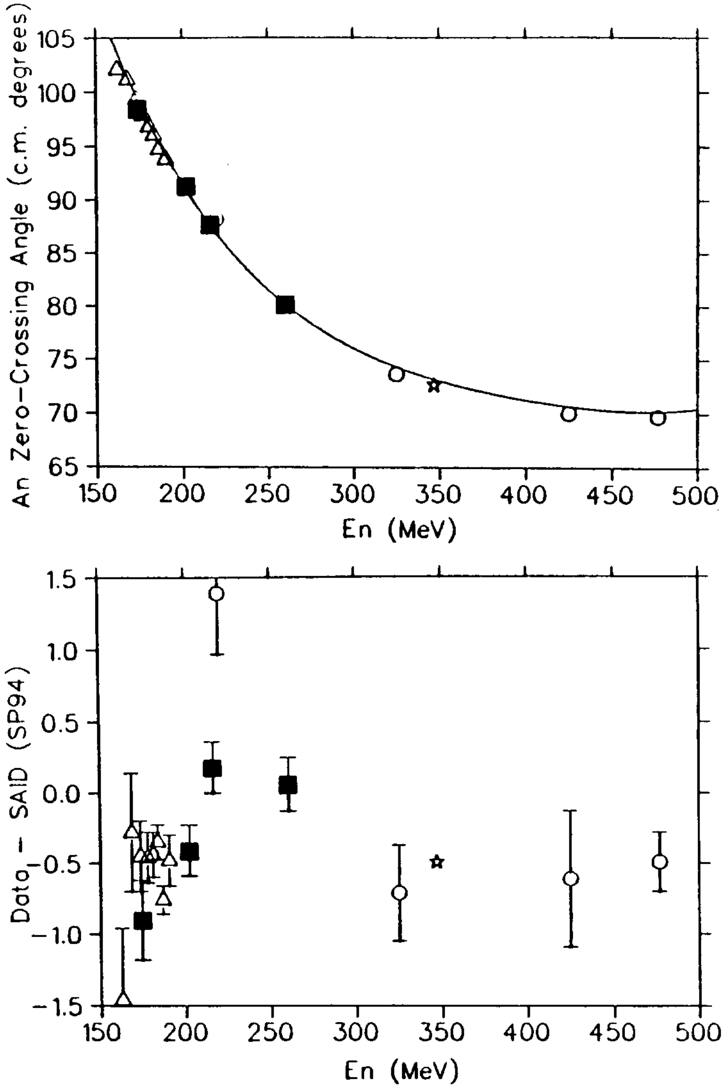

FIGURE 5. (Top) The present data (squares), data from IUCF [8] (triangles), data from Ref. [2] (circles), and preliminary data from the most recent TRIUMF CSB experiment [5] (also see contribution to the Symmetry session of this Conference) are compared to the SAID prediction of Ref. [1]. Note that all but the present data have an energy uncertainty of typically 2 MeV (compared to the present ~300 keV). (Bottom) The same data with the SAID (SP94) predictions subtracted.