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THE ($\bar{p},2p$) REACTION ON ^2H , $^3,^4\text{He}$ AND ^{40}Ca AT 200 MeV

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Recent experiments with intermediate energy protons have examined inclusive $A(p,p')$ reactions in the quasi-free scattering (QFS) region, measuring not only cross sections but also analyzing powers, and in some cases, spin-transfer coefficients. These studies are, in part, motivated by an attempt to understand possible modifications of the N-N interaction in the nuclear environment. Within the framework of relativistic dynamics models, *inclusive* QFS spin observables are predicted to be modified from their corresponding free-space values.¹ This possibility hinges strongly on the assumption that the QFS peak present in *inclusive* (p,p') data originates from a single scattering process. This assumption has not been tested in any detail, and such tests require *exclusive* measurements allowing the decomposition of the (p,p') spectrum into its various components.

In the recently completed experiments (E336/337), we have performed such measurements for a range of nuclear targets: $^1,^2\text{H}$, $^3,^4\text{He}$, and ^{40}Ca . Included were measurements of the cross section, analyzing power, and spin-transfer coefficient ($D_{nn'}$) for concurrently measured *inclusive* (p,p') reactions and *exclusive* $(p,2p)$ reactions, utilizing a large solid angle array of NaI detectors (LSAA) as a second-arm detector in coincidence with the K600 spectrometer. The 0.75 sr solid angle of the LSAA covers approximately 50% of the associated particle cone expected for single-step *exclusive* QFS. The NaI array provides a better than 1% determination of the kinetic energy thus enabling separation of the hole

states excited in the knockout reaction. The segmentation of the array provides the rate capability necessary to complete polarization-transfer measurements. The detector subtends angles extending above the plane defined by the momentum vectors of the beam and the particles detected in the K600 arm. The yield is expected to be symmetric above and below this reaction plane.

The installation of the E336/337 apparatus in the K600 cave began in August, 1991. The initial shakedown of the experiment occurred during a 16-shift, primary-user run in September. Final checkout and adjustments were accomplished during a split-beam run in November. Data collection for the experiment was completed in a single 46-shift production run ending in December, 1991. This report emphasizes the technical details and performance of the apparatus used in the experiment.

Figure 1 shows the detector layout set up around the target in the K600 area for E336/337. The exclusive measurements were completed using the K600 as one of the two

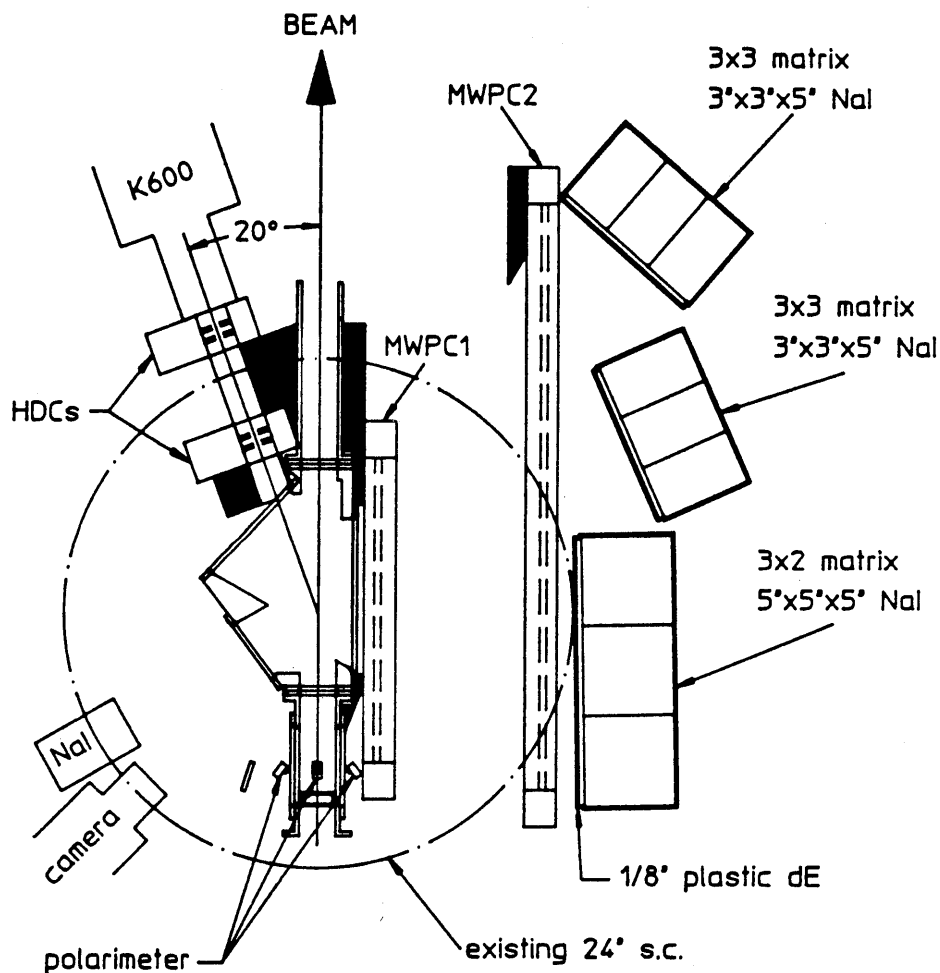


Figure 1. Layout of the E336/337 detector apparatus around the K600 target.

“arms” of the experiment. The existing focal-plane detectors and focal-plane polarimeter (FPP)² were used to detect protons in the momentum range, $465 \leq p_0 \leq 635$ MeV/c, where p_0 is the central momentum of the spectrometer. This experiment was the first application of the FPP over such a broad momentum range. Some lower-energy measurements of the FPP efficiency, effective analyzing power, and instrumental asymmetries were obtained in the course of the tuneup and production runs. In addition to the (p,2p) coincidence data, a sample of the K600 single-arm trigger rate was used to obtain measurements of the cross section, analyzing power, and $D_{nn'}$ observables from the *inclusive* $A(p,p')$ reactions.

The entrance to the K600 was modified to mount front-end multiwire drift chambers (FEC)³ immediately upstream of the existing aperture cassette. A 25- μ m Kapton foil was used to isolate the K600 vacuum system from a ~ 30 cm air gap between the target and the spectrometer entrance. The pair of x,y-sensitive drift chambers were mounted on a rail system in this gap. A Nd-Fe-B permanent magnet was mounted between the target chamber and the front FEC to sweep energetic electrons out of the acceptance of the FEC. The FEC provided localization of the event vertex from the extended gas target used in part of the experiment as well as software definition of the K600 solid angle. Most of the production measurements were completed without an entrance aperture to the K600. The aperture was removed to eliminate slit-edge scattering contaminations to the continuum spectra. As well, elimination of the entrance aperture enabled use of the full spectrometer solid angle (nearly 5 msr) for the experiment.

The FEC vertex reconstruction was calibrated by measuring $^{12}\text{C}(p,p)$ elastic scattering from a set of four 2.2 mg/cm² CH₂ targets distributed along the beam spaced at 2.54 cm. The change in the optics of the spectrometer⁴ enabled independent identification of the targets from the focal-plane detectors when the K600 fields were adjusted to look at elastic scattering events. Figure 2 shows the reconstruction of the event vertex position along the beam from the solid target array. The traceback resolution is 4.4 mm, limited by the 2-mm diameter beam size at the target. The FEC efficiency was typically 95% per plane. No rate dependence to the detector performance was observed over the entire K600 angular range utilized for the experiment at luminosities of nearly 1×10^{31} cm⁻².s⁻¹ with either the ^{40}Ca solid target or the gas targets.

The standard K600 24-inch target chamber was replaced by a combination gas/solid target chamber designed and built for the experiment. A 25- μ m thick Kapton window (15.7 cm \times 3.4 cm, transverse dimensions) clamped onto the target chamber served as a particle exit window. The window dimensions enabled K600 angle settings in the range $17^\circ \leq \theta \leq 60^\circ$. A second Kapton window mounted on the beam left side was used as a camera port, providing a view of the beam spot on a scintillator for tuneup. An extended gas target was utilized in the experiment to minimize coincidence event rate from the entrance and exit windows. Kapton foils (25- μ m thick) isolated the gas target from the upstream and downstream beamline vacuum systems. The total gas target length was 24.4 cm, most of which was within the K600 acceptance.⁴ Typical target pressures utilized in the experiment were 850 Torr. The $^3,^4\text{He}$ target gases were continuously recirculated through a liquid nitrogen cold trap eliminating hydrocarbon contaminants using a metal-bellows pump to establish a 100-cm³/s flow rate. Elastic scattering runs completed at the beginning and end of the production runs indicated no buildup of contaminant gases.

Z_{tgt} Distribution

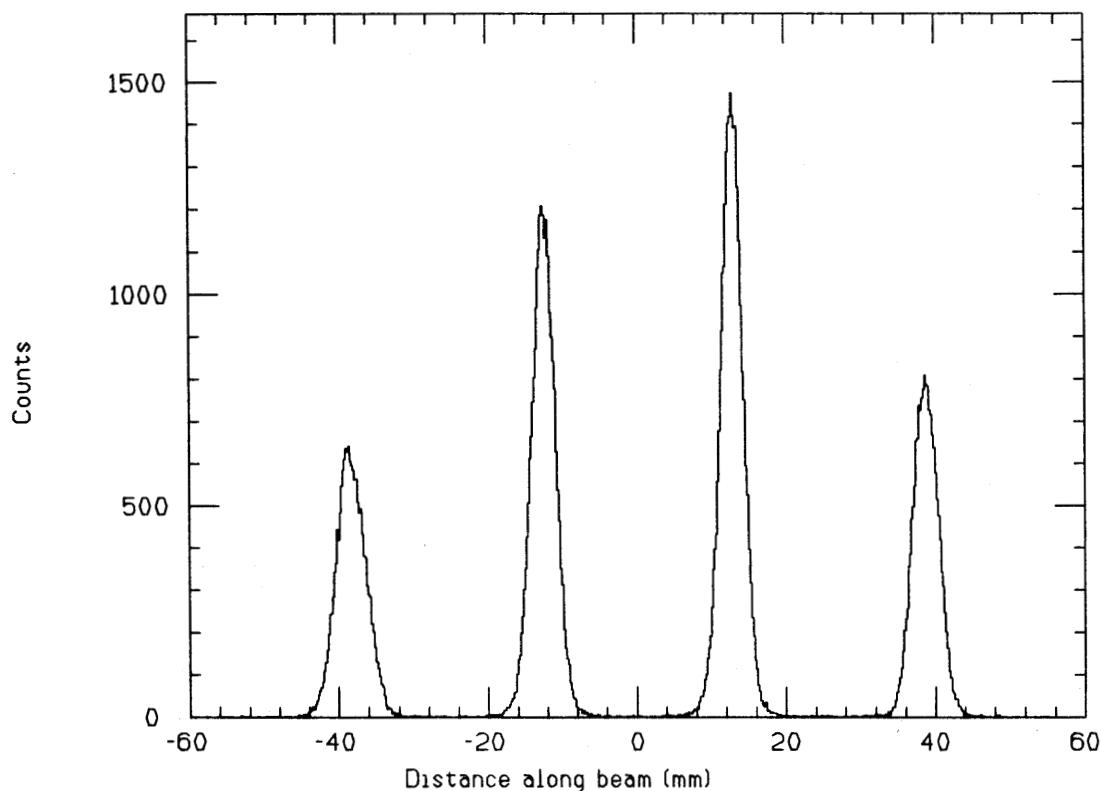


Figure 2. Vertex reconstruction from the K600 front-end drift chambers (FEC). The targets are 2.2-mg/cm^2 CH_2 foils mounted at 2.54-cm intervals along the beam.

The hydrogen and deuterium gas targets were operated as static targets. Again, elastic scattering runs at the beginning and end of production runs indicated minimal buildup of contaminant gases. The target pressure and temperature were continually monitored during the course of the experiment.

For solid target operation, the upstream Kapton window, mounted on a insertible aluminum plug, was removed. Three such 'mode' changes were made during the course of the measurements, involving approximately 1 hour of overhead. The downstream foil was kept in place for the entire experiment. A vacuum of better than 1×10^{-5} Torr was maintained for running with the 16.9-mg/cm^2 ^{40}Ca target. Elastic scattering runs completed at various times throughout the production running indicated essentially no buildup of contaminants on the ^{40}Ca target. The oxygen and carbon contaminants were measured to be smaller than 1%. The four-position target ladder was a 0.16-cm thick aluminum bar to minimize the shadowed portion of the solid angle. The target was rotated by 12° , such that the angular range subtended by the ladder was positioned between the second and third blocks of NaI crystals.

Charged particles exited the target chamber on the beam-right side through a 127- μm thick Kapton window 21.3 cm in length and 3.2 cm in height. The Kapton foil was clamped between aluminum frames to maintain the vacuum seal. Tracking of the charged particles was performed by two sets of multewire proportional chambers (MWPC). All four wire planes had 20- μm diameter wires spaced at 4.38 mm. The grounded wire planes were sandwiched between graphite-coated mylar cathode foils held at negative high voltage (-2.45 kV). The anode-cathode gap was 0.95 cm. The first set of MWPC consisted of one plane (X_f) of 64 vertically-oriented wires, 8.1 cm in length, and one plane (U_f) of 80 wires oriented at a 45° angle. The U_f plane should provide the capability of recovering the tracking information from two-prong events within the LSAA. The second set of MWPC consisted of one plane (Y_r) of 64 horizontally-oriented wires, 83.9 cm in length, and one plane (X_r) of 192 horizontally-oriented wires, 28.2 cm in length. The X_f , U_f chambers were mounted directly onto the target chamber. The X_f plane was a perpendicular distance of 6.4 cm from the beam. A row of Nd-Fe-B magnets sealed within an aluminum framework and mounted in the vacuum chamber provided electron suppression. The perpendicular distance between the X_f and X_r planes was 23.8 cm. The traceback resolution to the event vertex was comparable to that obtained from the FEC. The tracking angular resolution was better than 1° , limited by multiple Coulomb scattering. The tracking also enabled localization of the event on the NaI array.

The MWPC were read out by individual amplifier/discriminator cards (Nanometrics, N-277). The output signals were delayed through 45.7-m long twisted pair delay lines, and encoded by 48-channel hit registers (LeCroy 4448). Initially the MWPC were operated with a gas mixture of 50% Ar and 50% C_4H_{10} bubbled through *n*-propyl alcohol maintained at a 5°C temperature. The multiple-hit probability in the front chamber was larger than 45% at luminosities of $1 \times 10^{31} \text{ cm}^{-2}\cdot\text{s}^{-1}$. Midway through the run, the gas mixture was changed to an 80% CF_4 and 20% C_4H_{10} mixture providing nearly a 50% reduction in the time slewing from the MWPC, thus reducing the multiple-cluster probability. A software combinatorics analysis is able to recover $\sim 90\%$ of the multiple-cluster events.

The measurements of the beam-right proton kinetic energy were made by a 24-element NaI array. The NaI crystals were mounted in three separate hermetically-sealed containers. Two of the containers held 9 elements arranged in a 3×3 matrix, the crystals having square transverse dimensions of length 8.3 cm and thickness 12.7 cm. Each of these NaI crystals were viewed by 7.6-cm diameter photomultiplier (PM) tubes. For a solid target positioned at the K600 pivot, the first NaI block subtended $29.5^\circ \leq \theta \leq 47.5^\circ$ (in-plane angular range) and $-2.0^\circ \leq \beta \leq 16.5^\circ$ (out-of-plane angular range). The second block subtended $49.0^\circ \leq \theta \leq 72.0^\circ$ and $-1.0^\circ \leq \beta \leq 22.5^\circ$. The third container held 6 elements arranged in a 3×2 matrix, the crystals having square transverse dimensions of length 14.0 cm and thickness 12.7-cm and were viewed by 12.7 cm diameter PM tubes. The third block subtended $78.0^\circ \leq \theta \leq 125.0^\circ$ and $-3.0^\circ \leq \beta \leq 29.0^\circ$. The PM tubes viewed the NaI crystals through 1.27-cm thick quartz windows. A port was available on each crystal's quartz window for the mounting of a red light-emitting diode utilized for gain monitoring. The entrance window to each container was a 250- μm aluminum sheet backed by a 500- μm teflon shock absorber. Each crystal within a single container was optically isolated from the other members of the matrix.

The NaI PM tube bases were simple resistor strings without active elements to minimize the addition of noise onto the anode and dynode pulses. The anode pulses were sent through 250-ns RG-58 delay lines to FERA for encoding. The gate width to the ADC was 500 ns. Timing information from each crystal was obtained from the dynode pulses, amplified by a filtered, inverting amplifier specially built for the experiment. Leading edge discriminators (LED) on the amplified dynode pulses provided TDC stops from each NaI crystal. The time walk caused by using LED was eliminated by software corrections based on the anode pulse heights.

A 0.32-cm plastic scintillator was mounted immediately upstream of each NaI matrix to provide triggering and energy loss information, the latter utilized for particle identification. A simple logical OR of the constant fraction discriminator outputs fed from the three ΔE detectors was used as the LSAA arm trigger.

Immediately upstream of the primary gas/solid target were mounted two polarimeters⁵ for continuous monitoring of the normal and sideways beam polarization components at the target. The targets for these two polarimeters were 2-mm wide, 1.7-mg/cm² thick CD₂ strips. In addition to the polarization information, these targets provided continuous horizontal and vertical beam-position monitors. Polarization measurements were periodically taken with the BL2 and BL5 polarimeters. Continuous operation of the BL5 polarimeter was prohibited because of the beam halo at the K600 target produced by the upstream polarimeter targets. The longitudinal polarization component at the K600 target was monitored by BL5 polarimeter measurements performed at regular intervals.

To ensure good performance from the detector apparatus mounted around the K600 target, excellent beam preparation was crucial. To minimize the beam halo at the K600 target, all of the beamline quadrupoles between the mainstage cyclotron and the K600 target were initially tuned to eliminate steering. Following this tuneup procedure, slits 3 and 7 in BL3 were closed to constrain the orbit of the beam around BM1-BL3. This procedure successfully produced a stable, halo-free beam requiring little additional adjustment throughout the production measurements. The most significant remaining background originated from the poorly-shielded K600 beam dump. The addition of a temporary 1.8-m thick concrete block shield surrounding the beam dump reduced the neutron background in the cave nearly an order of magnitude. Without the shield, a significant γ -pileup background, dependent only on the beam current, was observed with equal intensity per unit volume in all 24 NaI elements.

Data from four independent event streams were acquired throughout the course of the measurements. Singles data from the K600 spectrometer were obtained from a sample of the fast triggers from the focal-plane scintillator, S₁. Singles data from the LSAA were obtained from a sample of the fast triggers from the OR of the three ΔE scintillator paddles. The coincidence event stream was an overlap between the K600 trigger and the LSAA trigger. A second-level trigger, using a memory-lookup unit, enhanced the fraction of the K600 arm data corresponding to double-scattering in the FPP. This trigger was used when completing $D_{nn'}$ measurements for both the K600 singles and coincidence event streams. The fourth event stream read out the NaI pulse-heights following a pulse to the light-emitting diodes mounted on each crystal.

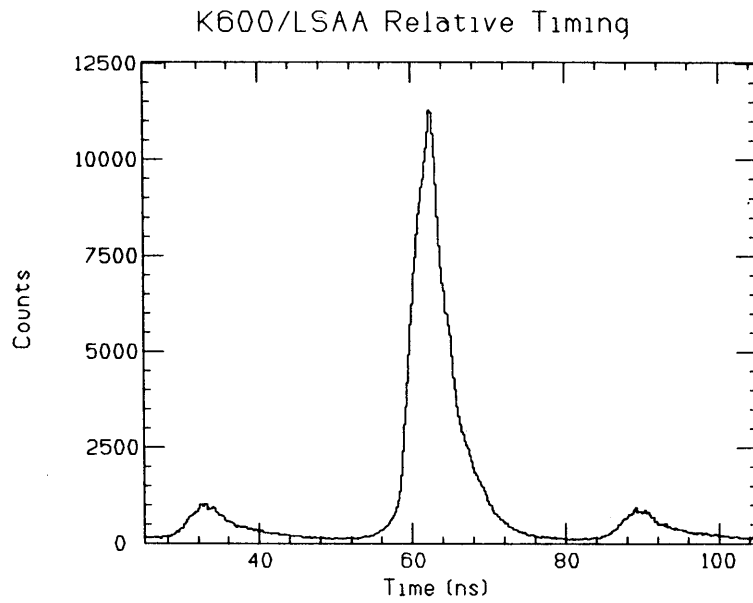


Figure 3. Relative timing between the K600 arm and the LSAA showing the 5:1 reals to accidentals ratio without any additional cuts on the data.

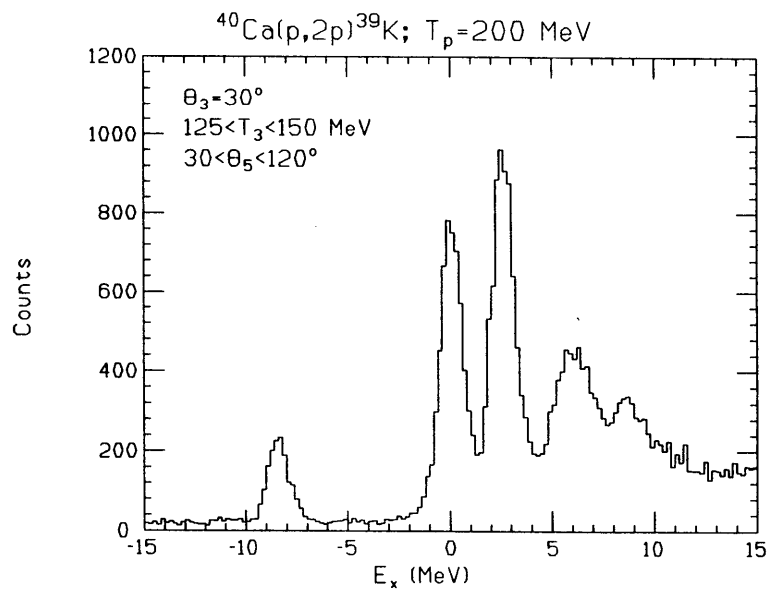


Figure 4. Missing-mass spectrum for the $^{40}\text{Ca}(p,2p)$ reaction summed over the 0.75 sr of the LSAA. Clear separation of the $1d_{3/2}$ and $2s_{1/2}$ hole states is observed.

Figure 3 shows the relative timing spectrum between the K600 arm and the LSAA with no software cuts obtained with 5 nA of beam incident on a 16.9-mg/cm² ⁴⁰Ca target. The ratio of real coincidences to accidental coincidences was always better than 5:1. The segmentation of the NaI array prevented the charged-particle singles rate in any one crystal from exceeding 16.5 kHz for the luminosity quoted. The trigger rate from the OR of the three ΔE paddles was 500 kHz.

The NaI detectors provided stable performance over the entire course of the production running. Figure 4 shows a missing mass spectrum summed over the 24 NaI crystals. The missing mass resolution is 1 MeV (FWHM), sufficient to clearly separate the ³⁹K 3/2⁺ and 1/2⁺ hole states. Accidental coincidences are responsible for the small background observed in the spectrum. The peak at negative missing mass is due to a small hydrogen contaminant in the ⁴⁰Ca target.

Data analysis of the results is presently proceeding. Data from the experiment will be the subject of Ph.D. dissertations for four graduate students: Ben Markham and Ping Li from IUCF and Jeff Huffman and Tao Gu from the University of Maryland.

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REPORT ON QUASIFREE ANALYZING POWERS FOR $\vec{n} - p$ SCATTERING AT 183 MeV

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The purpose of experiment E329 is to study the mass dependence of $A(\vec{n}, np)$ quasifree scattering analyzing powers from deuterium (CD₂-C), carbon, and tantalum. The experiment was performed in the Polarized Neutron Facility, detecting neutrons and protons in coincidence with the left-right symmetric detector apparatus developed previously in the charge symmetry breaking experiment (CSB).¹ Results of the analyzing powers for those events that pass the same kinematic cuts, especially on the opening angle between the two detected nucleons, that were used in the CSB experiment to select free scattering were presented in a previous report.² These results are shown again in Fig. 1, together with a