DETECTOR DEVELOPMENT AND CALIBRATION

THE INDIANA UNIVERSITY NEUTRON POLARIZATION FACILITY (INPOL)

M. Palarczyk, J. Rapaport, X. Yang, and K. Hicks
Ohio University, Athens, Ohio 45701

C.C. Foster, C.D. Goodman, T. Rinckel, G. Savopulos, and N.R. Yoder
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

D. Cooper and E. Sugarbaker
The Ohio State University, Columbus, Ohio 43210

S. Islam
Ball State University, Muncie, Indiana 47306

B.D. Anderson, A.R. Baldwin, D. Prout, and J. Watson
Kent State University, Kent, Ohio 44242

T.N. Taddeucci
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

I. Van Heerden
Cape Town University, South Africa 7530

One of the principal advantages of the (p,n) reaction for nuclear structure studies involves the excitation of a pure isovector spectrum of final nuclear states. Studies with this reaction at IUCF, LAMPF and TRIUMF have provided beautiful and exciting results. Among these are the systematic studies of the Gamow-Teller, Dipole and Spin-Dipole giant resonances, nuclear stretched transitions, studies of the effective interaction at low momentum transfer, measurements of spin-excitation strength functions and more recently measurements of the nuclear spin response in both the quasifree nucleon and delta sectors. An additional and very important advantage shared by hadronic probes such as (p,n) and (p,p′) is the ability to measure spin-longitudinal structure functions via polarization transfer.[1–3] These structure functions cannot be obtained with electromagnetic probes. The closing of the polarized proton beam line at LAMPF motivated the loan request by IUCF of the LAMPF/NTOF equipment. In December 1993, the IUCF Program Advisory Committee endorsed the idea of cooperation between the IUCF/NTOF and Kent State groups on improvements to the spin capability of the Beam Swinger experimental area at IUCF. The LAMPF/NTOF polarimeter would be located on the 0° neutron flight line and the new high-efficiency 2π polarimeter being commissioned by the Kent State group would be placed on the 24° neutron flight line.

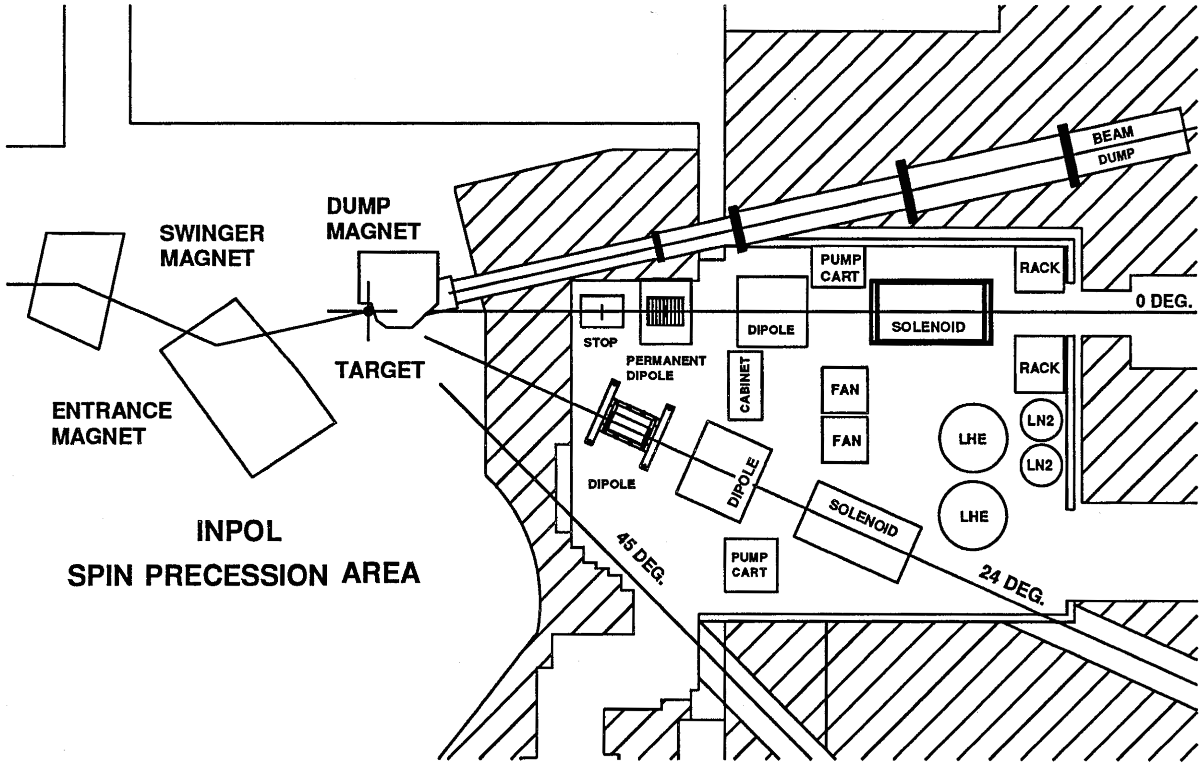

Figure 1. Floor plan showing swinger, dipoles and superconducting solenoids.

These ideas have been implemented and we have at IUCF two state-of-the-art neutron polarimeters. With the new HIPIOS source, and solenoids in the beam lines to handle the proton spin, IUCF now has the capability of delivering intense proton beams of all three polarization states. More shielding has been added in the north end of the main building, so that we are able to put as much as 300 nA of $\sim$ 75% polarized beam with a 1:12 pulse selection (pulses every $\sim$360 ns) on target. Thus, spin observables can be measured simultaneously at two lab angles separated by 24°. Varying the beam swinger magnetic fields will allow measurements in the angular range from 0° to 48°, which at $E_p = 200$ MeV corresponds to momentum transfers up to about $q = 2.3$ fm^{-1}.

In the next few sections we discuss the new facilities added to IUCF that make these spin transfer measurements possible. A brief description is presented of the dipoles and superconducting solenoids available in the new room built downstream from the swinger cave. A floor plan of that area is presented in Fig. 1. The LAMPF/NTOF polarimeter with the new data-acquisition system is presented along with the Kent State polarimeter located in the 24° neutron beam line.

DIPOLES AND SUPERCONDUCTING SOLENOIDS

Neutrons are produced on the target located in the swinger, shown in Fig. 1. The incident proton beam spin may be selected in any of the three states: N, S or L. Thus, the outgoing neutron spin may also have any of these three orientations. However, to be measured in the polarimeter, the neutron spin has to be either in an N or S state. Thus, there is the need of a dipole to precess the longitudinal neutron spin into a direction normal to its momentum. To correct for possible geometrical neutron-polarimeter asymmetries, one needs to have a superconducting solenoid to flip the neutron spin direction. This device, together with flipping the proton spin at the HIPIOS source, is sufficient to correct for asymmetries.

Neutrons produced in the target experience a vertical magnetic field due to the "dump-magnet" needed to focus the proton beam in the Faraday Cup. The integral of the magnetic field along the neutron path has been mapped as a function of the dump magnet current. This information is used to correct for the precession of the neutron spin induced by the magnetic field.

In the 0° neutron beam line, we have installed a massive neutron stop that allows personnel to work in the 0° detector area with reduced amount of beam on target. This is followed, as shown in Fig. 1, by a horizontal-field permanent magnet for safety purposes, and a dipole magnet also with a horizontal field. The sum field of these two magnets is enough to precess the longitudinal spin of a 200-MeV neutron into the normal direction. A superconducting solenoid with an 8″ bore and with a field strong enough to flip the spin of a 200-MeV neutron is the last element before the neutrons emerge on the 162-m flight path to the LAMPF/NTOF polarimeter.

In the 24° neutron beam line, a similar set of dipoles and a solenoid have been located to prepare the neutron spin for its final detection in the Kent State polarimeter located at a flight path of 40 m.

THE LAMPF/NTOF POLARIMETER

The polarimeter[4] consists of four parallel detector "planes" oriented perpendicular to the incident neutron flux: three stainless-steel tanks filled with liquid-scintillator (BC-517s, H:C=1.7) and a fourth set of ten plastic scintillators (BC-408). The liquid scintillator tanks are each subdivided into ten optically isolated cells with dimensions of $10 \times 10 \times 107$ cm^3. The plastic-scintillator cells have the same dimensions. The detector cells are viewed on each end by phototubes coupled through lucite light guides. Thin plastic scintillators in front of and between the front and back pairs of neutron detectors are used to tag charged particles. The relative timing and phototube gains of the entire detector system are continuously monitored and calibrated by tracking cosmic ray muons. This procedure yields an intrinsic time resolution of about 300 ps (FWHM) and position resolution of about 4.5 cm (FWHM). The polarimeter is shown in Fig. 2.

Incident neutron energy is determined by time of flight (TOF) to the front detector planes with respect to a corrected RF stop signal derived from the Cyclotron. Transitions to discrete states with known Q-values are used to provide the absolute energy scale. In polarimetry mode, the front pair of liquid-scintillator planes also serve as neutron polarization analyzers. Time, position, and pulse-height information from front and back planes are used to select n+p interactions kinematically. This kinematic selection also provides a highly efficient filter against background events from cosmic rays, target gamma rays, or slow neutrons from preceding beam bursts. Neutron polarization is determined from the azimuthal intensity distribution of the n+p events. Elastic ^{1}H($\vec{n}$,n) and charge-exchange ^{1}H($\vec{n}$,p) events are identified and sorted separately. At energies below 200 MeV mainly

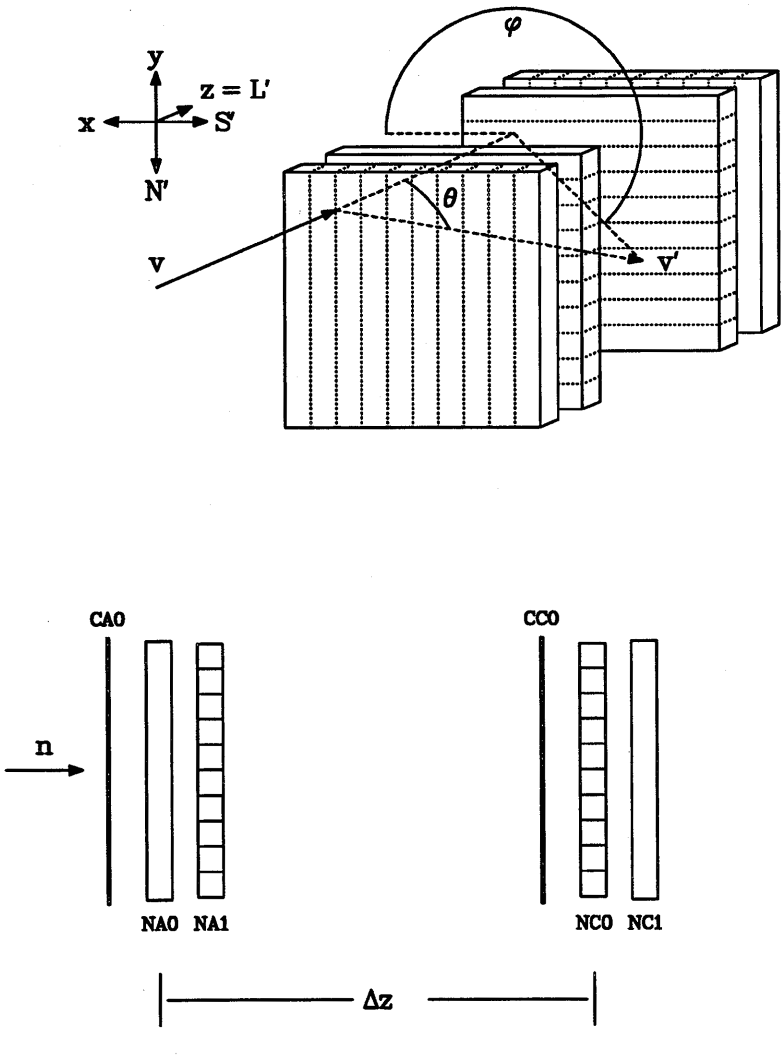

Figure 2. The INPOL detector geometry.

the (n,n) channel is useful because the analyzing power for forward scattered ($\theta_{\mathrm{lab}} < 45^\circ$) protons from (n,p) events is very low.

The resulting figure-of-merit for this polarimeter at 200 MeV is about $\Phi_{\mathrm{nn}} = 1.4\ \mathrm{cm}^2$. This represents an increase of about a factor of 10 over the original IUCF polarimeter that served as a prototype.[4]

The length of the INPOL detector flight path is fixed at 162 m by the placement of its building. At a beam energy of 200 MeV, this yields a typical energy resolution (disregarding target energy loss) of about 400 keV. A resolution of less than 200 keV was achieved in a test run at an incident proton energy of 100 MeV.

Data Acquisition Hardware and Software

The LAMPF/NTOF polarimeter data acquisition system had to be upgraded to meet new requirements at IUCF. Typically at LAMPF, NTOF used to run with less than 100 nA beam and a neutron flight path between 200 and 400 m. All NTOF time and pulse-height signals are fed to FERA ADCs and TDCs. A FERA driver reads these modules via a front bus. At LAMPF the driver transmitted the collected events via a CAMAC memory buffer to an MBD attached to a μVAX III. This configuration, which had been optimized for pulsed-beam operation, permitted data rates up to 500 events/s with a low fraction analyzed and large dead time, typically of the order of 50%.

At IUCF, this system had to undergo substantial modification. The much larger beam current (HIPIOS can deliver 300 nA on target) and shorter flight path imply a much higher event rate. In the recent few years IUCF had developed a data-acquisition front-end system based on VME (for configurations with few CAMAC crates) to replace the MBD CAMAC branch highway controllers. This system uses a Motorola processor to transmit CAMAC data via standard TCP/IP protocol on Ethernet to a host computer. IUCF has developed this system to be combined with its own in-house standard XSYS data acquisition/replay software which runs at the host computer.

The VME hardware has been installed. It consists of a single board computer unit MVME167 with the MC68040 microprocessor, CAMAC highway interface CBD 8210 and a MVME167-31A unit with SCSI and Ethernet interfaces. The main event in the polarimeter is up to 208 data words long, delivered by the FERA driver. In the original LAMPF configuration this event has been buffered up to 14 K and read every micropulse (900 μs at LAMPF) via CAMAC. Because the cyclotron at IUCF delivers a "DC beam" it is more appropriate to skip the memory buffer and read directly event by event. To avoid the slow CAMAC cycle, an extra memory has been implemented (1190 LeCroy Dual Port Memory unit), which allows a direct transfer of the main data stream from the FERA driver to the VME, bypassing the CAMAC. In this configuration the only information needed for the CAMAC main event is the event flag, delivered by the event-trigger module.

As the back-end computer, a VAX station 4000-90 has been acquired. It has a 64-Mb memory and a dual Ethernet port making a unique link between the front and back-end computers that does not depend on any foreign network traffic. At this stage there is no local taping possibility at the VME crate, so the data are being taped at the VAX station, where three tape units write event files.

With this modified configuration the IUCF facility has taken data with a rate up to about 2000 events/s. At this peak rate the live time is typically about 87% with a 10% fraction analyzed.

The LAMPF/NTOF facility uses a large software package to monitor, calibrate and analyze recorded events. This software makes use of cosmic rays (mostly muons) which hit the polarimeter planes either perpendicularly or horizontally. The top-bottom hits are used to form a 10-fold software coincidence to calibrate horizontal detectors, while the side-to-side hits form a 10-fold coincidence as well, to calibrate the vertical detectors. The front-to-back hits are being used to calibrate the charged-particle veto detectors and the relative timing of the four detector planes. By tracking the cosmic rays, the calibration software tests the core-analyzer capability to deliver time, position and pulse-height information for each of the detectors separately as well as for entire planes. The cosmic rays are also used during data acquisition to monitor the detector performance continuously, and during beam down time to carry out subsequent calibrations and tests.

The electronics defines three interplane (analyzer-catcher) coincidence triggers: neutron-neutron (nn), neutron-proton (np) and proton-proton (pp) (the last one, pp has its main contribution from horizontal muons). Further it defines also SINGLE hits, COSMIC hits and proton monitor events (from a separate proton detector facing the target near the swinger).

For each of the neutron events the polarimeter provides the time-of-flight to each plane, conversion coordinates on a specific plane and for the coincidence events the relative time-of-flight and relative flight path between analyzer and catcher planes. The electronics and software divides these events into beam-related and cosmic-related events and marks them with different flags. While acquiring data the rare cosmic events may be taken with 100% fraction analyzed. The fraction analyzed of the beam event can be adjusted to meet beam current conditions without limiting the on-line monitoring capability of the cosmic rays.

After applying a series of software filters to the nn and np events, the core analyzer constructs a set of 16 histograms, calibrated in neutron kinetic energy, binned for left, right, top and bottom sections of the polarimeter catcher planes, and sorted according to the incident proton spin. From eight of these histograms (for nn events) the transverse polarization coefficients can be extracted.

The LAMPF/NTOF software included calibration, core-analyzer and additional supporting software all written in LAMPF/FLEX language. This software has been rewritten and is now available in FORTRAN and works with XSYS.

THE KENT STATE POLARIMETER

The design of the Kent State polarimeter[6] is different from the one described above. It consists of a set of four BC-404 plastic scintillators $10 \times 10 \times 51$ cm^3 acting as neutron polarization analyzers and positioned with the long axis along the neutron direction. Scattered neutrons are detected with an azimuthally symmetric array of twelve $10 \times 25.4 \times 102$ cm^3 BC-400 plastic scintillators at a central scattering angle of 20°, which is near the maximum value of $A_y^2 \sigma$ for n+p scattering in the energy range of 100-200 MeV. Here A_y is the analyzing power while $\sigma(\theta)$ is the differential cross section. Because of the full azimuthal coverage, this detector is called the "2π" polarimeter. All 16 detectors are mean-timed with phototubes at both ends of each scintillator. Gains for all phototubes are stabilized with stand-alone microprocessor-based pulser systems utilizing high stability blue LED's. The performance of the scatterers is measured with cosmic rays. A value of 122 ps (FWHM) has been obtained for the intrinsic time resolution and 17 mm (FWHM) for the position resolution. This polarimeter was calibrated in 1993 with an additional calibration at 200 MeV in Feb. 1995. An overall time resolution of 360 ps was obtained. For 170-MeV neutrons this corresponds to an energy resolution of 580 keV.

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