

PROGRESS ON THE EXPERIMENTAL SEARCH FOR CHARGE SYMMETRY BREAKING (CSB) IN  $n$ - $p$  SCATTERING

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Most of the equipment construction and testing and preparatory work for the CSB experiment<sup>1,2</sup> has been completed during 1983. The extensive progress includes: (1) fabrication and testing of all detectors, plus final assembly and alignment of the rotatable arms and mounting hardware for the left-right symmetric detector arrays; (2) completion and successful operation of the laser-optical fiber diagnostic system for the ~200 phototubes used; (3) completion of cabling to, and installation of the "C" Harris computer in, the electronics hut located just outside the QDDM cave; (4) complete setup and debugging of the CSB electronics, front-end microprocessor hardware and acquisition software; (5) initial study of possible sources of systematic error with the complete CSB apparatus, except for the polarized proton target; (6) significant progress on the development of the polarized target; (7) completion of the polarized neutron facility (PNF) and detailed measurement of beam properties; (8) major improvements to and calibration of the  $n$ -beam monitor/polarimeter. Details concerning the first six areas above are summarized in the present section, while the status of the PNF and  $n$ -beam monitor are described in the technical section of this Report.<sup>3</sup>

Figure 1 shows a view from above of the two multi-celled liquid scintillator neutron detectors mounted on the rotatable arms in the PNF area, during an early stage in the assembly of the detector arrays. In the final arrays, a large pair of x-y multi-wire

proportional chambers (MWPC's), a small pair of x-y MWPC's, and a wedge-shaped plastic scintillator are mounted in front of the liquid scintillator detector on each arm. Each array spans a laboratory angle range of  $\pm 18^\circ$  horizontally and  $\pm 14^\circ$  vertically as seen from the target position. The plastic scintillator and small MWPC's are mounted on rails which permit the detectors to be moved backward on the arm from their normal location when the polarized-target dewar assembly has to be removed from the beam for maintenance. For a run in December, 1983, the complete mounting and alignment hardware was assembled and all detectors were aligned both optically and in-beam in their final CSB locations. The in-beam alignment procedures, described previously,<sup>2</sup> include measurement of the zero-crossing angle for the p-p scattering analyzing power ( $\theta_{lab}=43.64^\circ$ ) and of a kinematic crossing for free p-d scattering ( $\theta_{p,lab}=\theta_{d,lab}=51.12^\circ$ ). The two measurements were performed simultaneously with the secondary polarized proton beam (obtained by turning off the PNF sweeping magnet) incident on a mixed  $CH_2$ - $CD_2$  target. These methods, when combined with precise measurement of the opening angle for free p-p scattering, ray-tracing reproduction of the measured target location, and relative alignment of the liquid scintillators with respect to the MWPC's via proton ray-tracing, permit an absolute calibration of all detector angles to  $\sim 0.1$ .

Diagnostic signals are provided to each of the

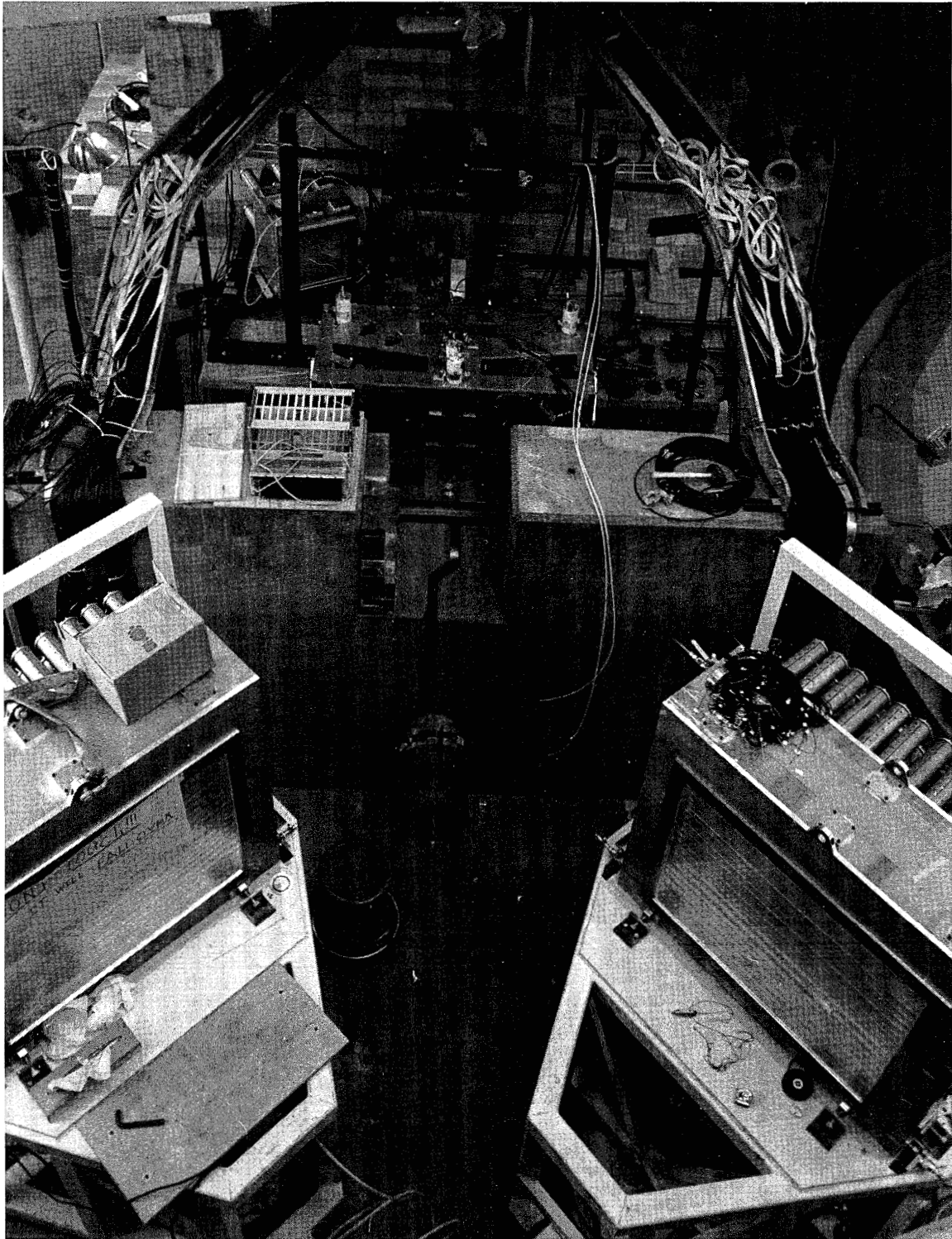


Figure 1. The PNF-CSB experiment setup shown at an early stage during assembly of the detector arms. The two multi-celled liquid scintillator detectors are mounted here on the rotatable arms, but the remainder of the detector arrays was not yet mounted. In the background, one can see the  $\bar{n}$ -beam polarimeter (which has since been considerably improved by the addition of more scintillators, as described in the technical section of this Report).

(Photo by W.W. Jacobs)

~200 phototubes in the detector arrays from a laser-fiber optics system, for purposes of time calibration, dead-time measurement, and gain stability checks. Light from a high-power fast-pulse nitrogen laser,<sup>4</sup> triggered externally at a beam-related average rate ~1 Hz, is optically expanded to a larger diameter beam, shifted into the wavelength region of optimal phototube response, and then routed through optical fibers to the wedge-shaped scintillator in either the left or the right detector array and to four selected liquid scintillator subcells in each detector array. The fibers are arranged in a rectangular matrix of which only one column at a time is illuminated through a slit in an opaque rotatable band. The slit position is stepped from one column to the next with each laser fire, allowing the eight illuminated subcells to be moved around the entire detectors in a 24-pulse cycle. The pulse heights of the diagnostic signals vary over a range of a factor ~2 among the different phototubes, depending largely on the quality of the cuts at the fiber ends, but our experience with stability of the pulse heights over long time durations is very encouraging.

In the December run, signals from all of the detectors were processed with the complete CSB data acquisition system. The electronics define events for computer processing as coincidences between at least one liquid scintillator cell on one arm and the wedge-shaped scintillator plus at least three out of the four MWPC's on the other arm. Hardware resolving times are set wide enough to permit analysis of accidental coincidences in which, for example, the liquid scintillator fires on the succeeding beam burst from the plastic (where the beam burst separation is 57 ns). The front end of the acquisition system, based on two LSI 11/23 microprocessors, selectively reads ADC

and TDC channels corresponding only to those liquid scintillator cells which have actually fired for a given event (as determined by coincidence latches). The double-buffered front end then passes to the Harris computer, through a direct channel, filled buffers comprising efficiently packed information for all MWPC wires and liquid scintillator cells which have fired, without introducing any further hardware cuts which might conceivably cause a spin-dependent bias in the events stored on magnetic tape. Data from the channel, including events from the <sup>+</sup>n-beam monitor/polarimeter interspersed with CSB events, are dumped directly onto event tape. On-line unpacking of the event information, reconstruction into subgroups of variable word length corresponding to each detector where a variable number of hits is possible, calculation of derived variables (e.g., angles of the detected particles), and sorting into histograms are then performed on a sampling basis, as time permits. The above functions are performed by an extensively modified version of the code RAQUEL, utilizing a completely rewritten external sorting program.

In the December run, with on-line sorting of 1/4 of the incoming events, we simultaneously processed 350/s CSB events (induced by <sup>+</sup>n on a plastic scintillator target) with a total dead time of 17% and 100/s polarimeter events with a dead time of 3%. This performance meets our design goals for count rate capability. Of the CSB events, ~150/s did not originate at the target, and may be at least partially eliminated in future runs by use of higher hardware thresholds on the wedge-shaped scintillators. Of the target-related events ~10% arise from free n-p scattering. The free scattering events can be distinguished by a number of parameters, notably the opening angles and time-of-flight vs. angle correlation

for the detected nucleons. In Fig. 2 we show n-p opening-angle spectra acquired with a partial detector setup during a run in early 1983, encompassing events in which neutrons are detected on the left arm and

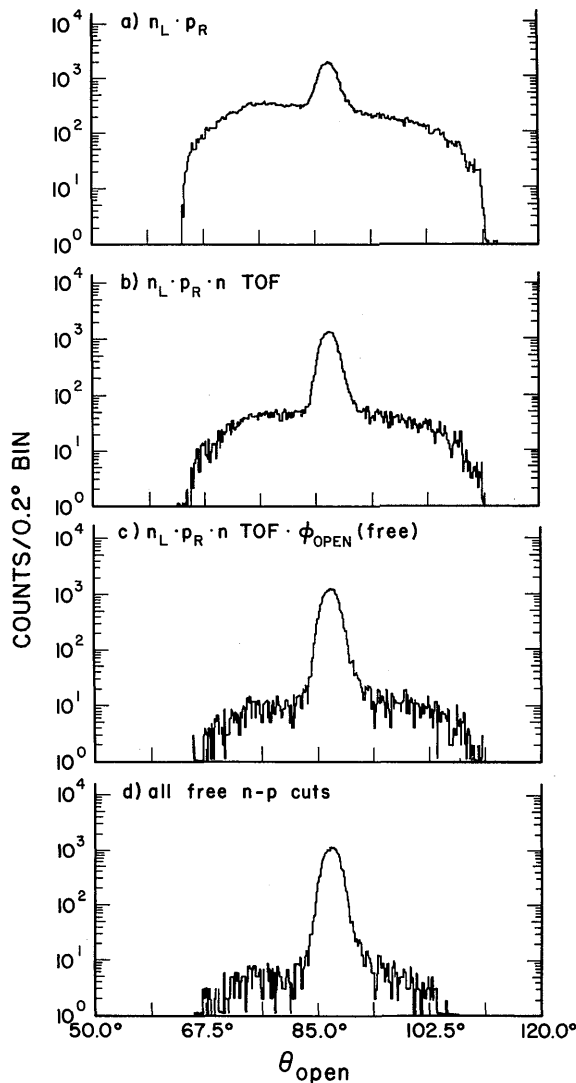


Figure 2. Measured opening-angle spectra for n-p pairs, charting the inexorable emergence of the free-scattering "finger" from the quasi-free background as cuts are added to other parameters to restrict attention to the free-scattering kinematic regime. The opening-angle resolution is  $\Delta\theta(\text{FWHM}) = 2.8^\circ$ . These spectra were obtained with a partial setup of the CSB detector arrays; the peak/background ratio can be improved further with the full setup.

protons on the right. The four  $(\vec{n}, np)$  spectra displayed chart the inexorable emergence of the free-scattering "finger" from the quasi-free background as cuts are added to other parameters to restrict attention to the free-scattering kinematic regime. The observed opening-angle resolution ( $\Delta\theta_{\text{FWHM}} \approx 2.8^\circ$ ) is sufficient to yield a peak/background ratio  $\approx 100$  in spectrum (d). Additional cuts available with the full detector arrays (e.g., on the time and energy signals for protons which penetrate into the liquid scintillator) can improve the peak/background ratio by an additional factor of two or more, adequate for subtraction of quasi-free background to an accuracy of better than 0.1% in the CSB experiment. It is easy to obtain a  $(\vec{p}, pn)$  spectrum for the same target, with all the cuts relevant to free np scattering, via use of the secondary  $\vec{p}$  beam in the PNF. Such a spectrum provides one method for measuring the shape of the relevant quasi-free background in the absence of a free-scattering peak.

We are also now able to examine on-line difference spectra obtained for the free-scattering events with the secondary beam spin up minus spin down, as a function of the measured angle of the detected proton. The zero-crossing of the  $\vec{n}$ -p analyzing power (near  $\theta_{\text{lab}}=43^\circ$ ) is clearly defined by the raw data in such different spectra. In the CSB experiment we will be searching effectively<sup>1</sup> for a small shift in this zero-crossing angle when the scattering is initiated instead by an unpolarized neutron beam on a polarized proton target.

The only major component of the CSB apparatus not yet completed is the "spin refrigerator" polarized target<sup>5</sup> being developed at the University of Wisconsin. Proton polarizations in excess of 50% have been achieved with the Wisconsin target recently as a result

of improvements in polarizing field strength, target rotation speed, Yb-ion doping concentration in the yttrium ethyl sulfate target material, and the use of single crystal rather than polycrystalline samples. Large-area single crystals for use in the CSB experiment are currently being grown. Typical spin relaxation ( $1/e$ ) times have been measured to be  $\sim 50$  hr in a 0.1 T holding field. Repolarization of the sample is accomplished by spinning it in a field of  $\sim 1$  T for 20-30 minutes. The proton spin direction has been successfully reversed, with very little depolarization, by two different methods, with and without accompanying reversal of the holding field orientation. The latter method uses an NMR technique, involving absorption of substantial rf power during a fast ramping of the holding field magnitude through the resonant value. In the experiment we will use a combination of the two methods to aid in cancelling possible systematic errors associated with the passage of detected protons through the region of the holding field. We envision flipping the target spin several times per hour.

We now expect delivery of the polarized target to Bloomington in the spring of 1984, after testing of its performance with the large-area single crystal samples. Systematic error studies in  $n \rightarrow p$  and  $p \rightarrow p$  scattering will then be initiated, to be followed by our first CSB production runs next summer. In the period before the polarized target is available, we plan to implement diagnostic features in the acquisition software (to

check automatically for detector or electronics malfunctions), finish work on certain peripheral features of the detection apparatus (e.g., a liquid scintillator circulation system), catch up on the replay of data already taken, continue work on Monte-Carlo codes to simulate various aspects of the experiment, and carry out in-beam investigations of certain potential sources of systematic error for which the polarized target is not necessary. Work in the latter direction was already begun in the December, 1983 run, with initial measurements concerning the in-plane polarization components in the  $n$  beam and possible sensitivities of the experiment to the orientation (variable with sweeping magnet current) of these components. In a future run we will study the sensitivity to shifts in beam position and displacements of the secondary target from its nominal position.

- 1) S.E. Vigdor et al., Proc. Fifth Intl. Symp. on Polarization Phenomena in Nuclear Physics (Santa Fe, August, 1980), edited by G.G. Ohlsen et al., (AIP, New York, 1981) Vol. II, p. 1455.
- 2) S.E. Vigdor et al., IUCF Scientific and Technical Report 1978, p. 15; 1979, p. 118; 1981, p. 52; and 1982, p. 101.
- 3) IUCF Scientific and Technical Report 1983, p. 203.
- 4) Photochemical Research Associates "Nitromite" laser with 200 kW peak power, 100-350 ps pulse width, 1-100 Hz external trigger capability, 3300 Å output wavelength.
- 5) J. Button-Shafer et al., Phys. Rev. Lett. 39, 677 (1977).