NUCLEON-NUCLEON

CHARGE SYMMETRY BREAKING IN $\vec{n} - \vec{p}$ SCATTERING

C. Bloch, T. Bowyer, S. Fray, W.W. Jacobs, J. Sowinski, S.E. Vigdor
C. Whiddon, S.W. Wissink, and G. Xu
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

L.D. Knutson
University of Wisconsin, Madison, Wisconsin 53706

R.C. Byrd
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

P.L. Jolivette
Hope University, Holland, Michigan 49423

The experimental search for charge symmetry breaking (CSB) in the scattering of 183 MeV polarized neutrons from polarized protons completed data acquisition with over 100 days of running on the cyclotron between October, 1987 and September, 1988. The run procedures and performance were summarized in the last IUCF Scientific and Technical Report[1] and the October 1988 Newsletter. Replay and analysis of the data has been progressing steadily since the completion of the production runs. We expect to present a preliminary result of the experiment at conferences during Summer, 1989, and hope to complete the analysis by the end of 1989.

The experiment performed at IUCF differs in several important respects from the one recently completed at TRIUMF (Ref. 2) at a bombarding energy T_n=477 MeV and from the follow-up experiment planned at TRIUMF for T_n=350 MeV. In all of these experiments the CSB observable measured is essentially the analyzing power difference $\Delta A(\theta) \equiv A_n(\theta) - A_p(\theta)$, where the subscripts denote sensitivity to the spin projection of the neutron beam (n) vs. polarized proton target (p). However, in Ref. 2, A_n and A_p were determined in separate measurements, with beam and target alternately polarized, while at IUCF we measured both quantities at the same time, with the beam and target simultaneously polarized. More significantly, the TRIUMF experiments determine ΔA at a single angle, namely, that (θ_0) at which the average analyzing power $A(\theta) = 1/2[A_n(\theta) + A_p(\theta)]$ crosses zero. In contrast, our measurements are sensitive to the angular dependence of $\Delta A(\theta)$ over a fairly broad range ($60° \leq \theta_{cm} \leq 120°$). Strictly, we determine the angular dependence of $\Delta A(\theta)/A(\theta)$, i.e., the measurements are insensitive to any contribution to $\Delta A(\theta)$ which can be expressed as a constant times $A(\theta)$. The latter insensitivity is unavoidable at the required precision level, because a contribution $\Delta A(\theta) \propto A(\theta)$ yields only a small overall normalization difference between the measured beam-related ($P_b A_n(\theta)$) and target-related ($P_t A_p(\theta)$) asymmetries; such a CSB-induced normalization difference cannot be distinguished from a small error in determination of the absolute beam (P_b) and/or target (P_t) polarization.

Our sensitivity to the angular dependence of $\Delta A(\theta)$ is significant in the light of theoretical calculations[3-5] of the expected effects. These reveal quite different angular shapes (see Fig. 1) for the contributions associated with the two different forms of the spin- and isospin-dependence allowed for a CSB (but parity-conserving) potential in the n-p system:

$$V_1 = [\vec{\tau}(1) \times \vec{\tau}(2)]_3 (\vec{\sigma}_1 \times \vec{\sigma}_2) \cdot \vec{\mathrm{L}}\; w(r);$$
$$V_2 = [\tau_3(1) - \tau_3(2)](\vec{\sigma}_1 - \vec{\sigma}_2) \cdot \vec{\mathrm{L}}\; v(r).$$

The angular shape difference arises from a difference between V_1 and V_2 in the relative phase of even-J vs. odd-J partial-wave contributions. Within a meson-exchange picture,[5] the most important short-range contribution to V_1 arises from the effect of the n-p mass difference on one-pion exchange, while that to V_2 arises from the mixing of the ρ^0 and ω mesons. Different calculations[3-5] agree well concerning the magnitude of the former

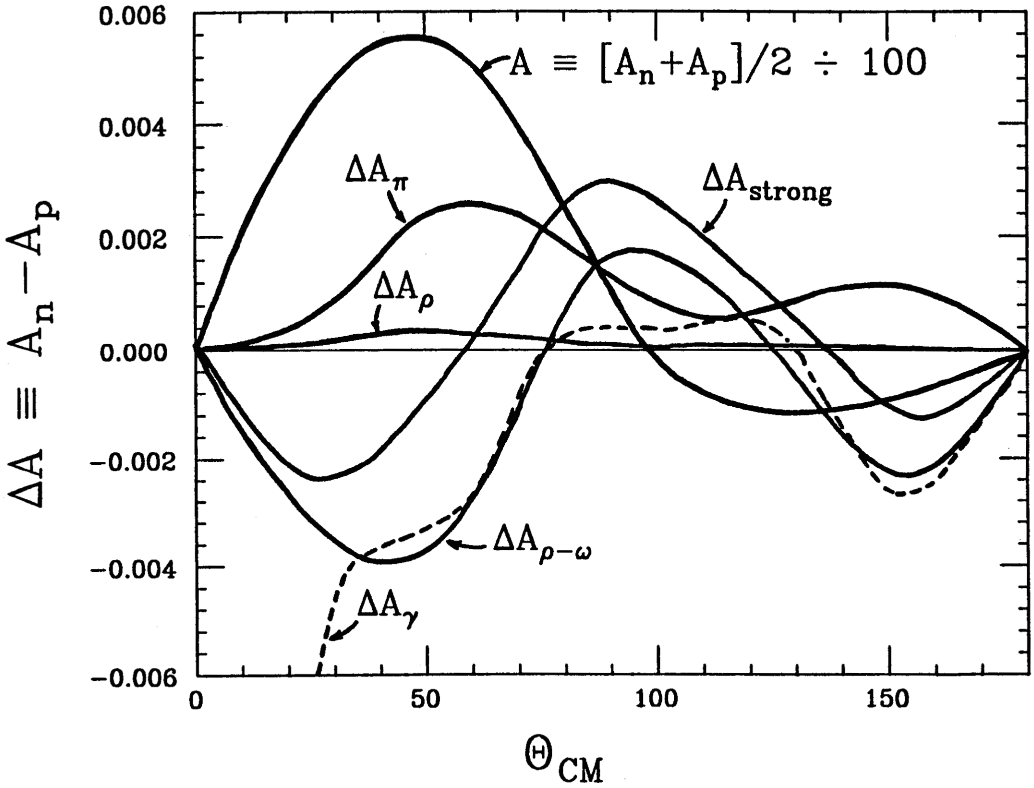

Figure 1. Calculations by Holzenkamp, Holinde and Thomas[5] of various contributions to $\Delta A(\theta)$ at a bombarding energy of 188 MeV, compared with a phase shift calculation of the average analyzing power $A(\theta)$. The n−p mass difference effects on one-pion (ΔA_π) and one-rho (ΔA_ρ) exchange arise from CSB potentials of the form V_1 described in the text, while the $\rho - \omega$ mixing ($\Delta A_{\rho-\omega}$) and electromagnetic spin-orbit (ΔA_γ) contributions are of the form V_2. ΔA_γ should be added to $\Delta A_{\mathrm{strong}}$ to obtain the total predicted effect.

effect, but not about the latter, which depends on the poorly known ρNN and ωNN coupling constants. Since V_2 is sensitive both to the spin-dependence and to the isospin-mixing characteristic of the vector mesons, a sufficiently precise measurement of $\Delta A(\theta)$ near T_n=200 MeV could provide unique information on their role in mediating the short-range nucleon-nucleon interaction. Similar sensitivity appears not to be available in the T_n=350-500 MeV range, since the calculations suggest that $\Delta A_{\rho-\omega}(\theta)$ at those energies crosses zero very nearly at θ_0, and thus happens to be essentially proportional to $A(\theta)$ in the vicinity of θ_0; as mentioned above, an experiment cannot be sensitive to such ΔA contributions without far more accurate absolute measurements of P_b and P_t than can currently be made.

The sensitivity we actually attain to $\rho - \omega$ mixing contributions will be limited, of course, by the statistical and systematic uncertainties in our measurements. We acquired a total of $\sim 45\times10^6$ $\vec{n}-\vec{p}$ free-scattering events with average beam and target polarizations of 0.54 and 0.42, respectively. This data sample should yield a statistical precision $\sim \pm 0.0013$ for ΔA in each of $\sim$ 8 angle bins spanning the range $60^\circ \leq \theta_{cm} \leq 120^\circ$ (in comparison with $\pm$ 0.0020 for the published[2] TRIUMF datum at T_n=477 MeV, $\theta_{cm} = 71^\circ$).

Minimization and estimation of the systematic errors has been our major focus in the data replay since production running was completed. The measurement procedures were designed to cancel some of the more important systematic errors we had foreseen. For example, the bending of recoil protons in the holding field ($\simeq$ 600 G) of the polarized proton target (PPT) leads to an instrumental target asymmetry, and hence to a false $\Delta A(\theta)$, since we normally flipped the target spin by adiabatic reversal of the holding field. Although we are able, with recent improvements in our replay software, to correct for this bending angle to a typical accuracy of $\pm 0.01^\circ$, this is insufficient to reduce the resulting spurious ΔA to a level below our statistical error. We therefore made use of an NMR technique known as "adiabatic fast passage" to reverse the orientation of the target spin with respect to the holding field twice per day. By combining the two halves of the data sample acquired with parallel and anti-parallel orientations of spin and field, we gain more than an order of magnitude <u>additional</u> cancellation of the field-dependent systematic error, reducing it to the desired level $\lesssim 1 \times 10^{-4}$. We achieved a similarly effective extra cancellation of possible systematic errors arising from in-plane spin correlations (between longitudinal beam and sideways target, or vice-versa, polarization components) by acquiring half the data with horizontal beam spin components precessed by $+90^\circ$, and half by -90°, with respect to their orientation resulting from the production reaction. We spent 15% of the production running time acquiring data for a "dummy" target simulating the non-hydrogenic content of the PPT, in order to allow a precise subtraction of, and thereby cancellation of systematic errors associated with, quasifree scattering background events. This background produces a systematic error because it has a generally non-zero beam asymmetry, while its contribution to the measured target asymmetry vanishes (since the <u>bound</u> protons in the target are unpolarized). The residual systematic error from the quasifree background is determined by the accuracy of our relative normalization of dummy vs. PPT runs: a $\pm4\%$ normalization error (including uncertainty in the ratio of target thicknesses) yields a false contribution to $\Delta A \simeq \pm3 \times 10^{-4}$.

Recent replay of the CSB data has revealed an important source of systematic error that we had not foreseen. The neutron beam has a significant energy spread ($\sim$ 20 MeV), arising both from energy loss of the incident protons in traversing the thick liquid deuterium production target and from the spread in excitation energies of the recoiling two-proton pair in the production reaction $^2\mathrm{H}(\vec{\mathrm{p}},\vec{\mathrm{n}})2\mathrm{p}$. The polarization transfer in the production reaction varies significantly with both the proton bombarding energy and the two-proton excitation energy,[6] resulting in a strong correlation between the secondary neutron beam polarization (P_b) and energy (T_n). Because the sensitivity to the beam analyzing power $\mathrm{A}_n(\theta)$ is determined by P_b, the effective average energy ($<\mathrm{P_bT_n}>/<\mathrm{P_b}>$) at which we determine $\mathrm{A}_n(\theta)$ may differ significantly from that ($<\mathrm{T_n}>$) at which we determine $\mathrm{A}_p(\theta)$ (P_t is, of course, uncorrelated with T_n). This energy difference leads to a non-CSB-induced $\Delta\mathrm{A}$, because in the vicinity of $\mathrm{T}_n = 180$ MeV the n$-$p analyzing power angular distribution has an appreciable T_n-dependence; for example, phase shift calculations suggest that the laboratory zero-crossing angle θ_0 changes by $\sim 0.15°$/MeV. The magnitude of the associated systematic error depends on the width of the portion of the T_n spectrum included in the analysis; we estimate that the error may have been as large as 0.003 in $\Delta\mathrm{A}$ for some angle bins in our earlier analyses, where we summed all the events within the charge-exchange peak of the $^2\mathrm{H}(\mathrm{p,n})$ spectrum. We are currently replaying the data with upgraded software, which allows determination of the neutron beam energy on an event-by-event basis from the measured arrival time of detected protons with respect to the cyclotron RF signal, and thereby enables averaging the $\Delta\mathrm{A}$ results for a number of narrow energy slices. This procedure should greatly reduce the systematic error. By comparing the asymmetries measured for different energy bins with phase shift calculations, we can calibrate a model of the neutron energy spectrum and polarization variation upon which we must then rely to make a final small correction to the data to account for the remaining width of the T_n spectrum contributing to our narrow RF time slices. The systematic error in this final correction should be $\lesssim 2 \times 10^{-4}$.

We are presently in the process of evaluating, in addition to the above, other possible systematic errors, associated, for example, with variations in beam and/or target polarization as a function of position of the event origin within the target; the presence of some hydrogen in the dummy target (with a possibly different density profile than that in the PPT); spin-dependence of the neutron-detector response; contributions from two independent scattering events within the target volume; field-dependent gain shifts in scintillator phototubes; correlated changes with time in two or more parameters of the experiment (e.g., bombarding energy, beam polarization, target polarization, detection efficiencies, etc.).

Because we made our CSB measurements with the beam and target simultaneously polarized, we were able to determine the spin correlation parameter $\mathrm{C}_{NN}(\theta)$ for $\vec{\mathrm{n}}-\vec{\mathrm{p}}$ scattering at the same time. The C_{NN} measurements based on a preliminary production run have already been published.[7] The full data set includes about 40 times more data than were included in Ref. 7 and yields the values shown in Fig. 2 (consistent within errors with the data published in Ref. 7). The error bars on the results in Fig. 2 are significantly smaller than the plotted points. The data are compared with various potential model and phase shift calculations, the latter incorporating our preliminary results from Ref. 7 in the data set used to determine the phase shifts. The absolute normalization

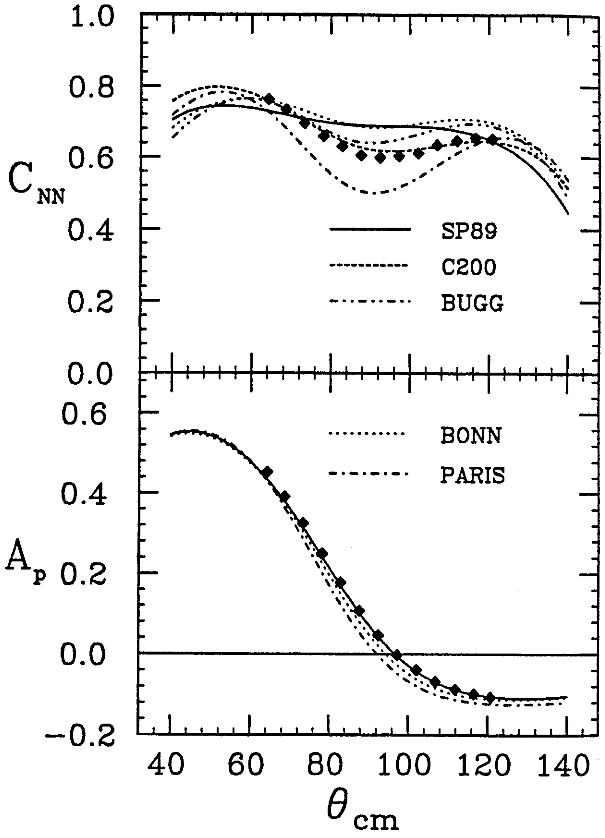

Figure 2. The n−p scattering spin correlation parameter $C_{NN}(\theta)$ and target analyzing power $A_p(\theta)$ measured in the CSB experiment, compared to various phase shift and potential model calculations. The phase shift analyses (SP89 = Arndt global phase shifts, C200 = Arndt local energy-dependent phases, and BUGG) have incorporated our preliminary data (Ref. 7) in the fitting. The analyzing power differences among the three phase shift sets are indistinguishable on the scale of the figure. The experimental uncertainties are significantly smaller than the plotted points.

of our analyzing power and spin correlation measurements is still not well determined experimentally. We aim to tie down the absolute calibration (to an uncertainty ∼ ± 5% in C_{NN}) via a subsequent experiment in which we will use the PPT to measure $\vec{n}-\vec{p}$ and $\vec{p}-\vec{p}$ scattering simultaneously. We can then use the well constrained pp phase shift calculations of $A_y(\theta)$ to determine the absolute target polarization and the ratio $P_bA_n(\theta)/P_tA_p(\theta)$ measured in the $\vec{n}-\vec{p}$ scattering to deduce the absolute beam polarization.

In addition to the above calibration experiment, we also plan to use much of the equipment constructed for the CSB experiment in subsequent measurements of A($\vec{n}$,np) quasifree scattering analyzing powers and of $C_{NN}(\theta)$ for radiative capture $\vec{n}\vec{p} \rightarrow d\gamma$.

1. C. Bloch et al., IUCF Scientific and Technical Report 1987-88, p. 1.
2. R. Abegg et al., Phys. Rev. D **39**, 2424 (1989).
3. A.G. Williams, A.W. Thomas, and G.A. Miller, Phys. Rev. C **34**, 756 (1987).
4. J. Iqbal, J. Thaler and R. Woloshyn, Phys. Rev. C **36**, 2442 (1987); M. Beyer and A.G. Williams, Phys. Rev. C **38**, 779 (1988).
5. B.H. Holzenkamp, K. Holinde, and A.W. Thomas, Phys. Lett. B **195**, 121 (1987); A.W. Thomas, Prog. in Nucl. Part. Phys. **20** (1988).
6. D.V. Bugg and C. Wilkin, Nucl. Phys. **A467**, 575 (1987).
7. J. Sowinski et al., Phys. Lett. **B199**, 341 (1987).