Polarized Internal Target Experiments with the Cooler

H.O. Meyer, J.T. Balewski, J. Doskow, R.E. Pollock, B. v.Przewoski, T. Rinckel, T.J. Whitaker
Indiana University Cyclotron Facility, Bloomington, IN 47408 USA

W. Haeberli, B. Schwartz, T. Wise
University of Wisconsin-Madison, Madison, WI, 53706

W.W. Daehnick (deceased)
Univ. of Pittsburgh, Pittsburgh, PA 15260

P.V. Pancella
Western Michigan University, Kalamazoo, MI, 49008

P. Thörngren-Engblom
Uppsala University, Uppsala, Sweden

Swapan K. Saha
Bose Institute, Calcutta, India

F. Rathmann
Universität Erlangen-Nürnberg, Erlangen, Germany

B. Lorentz
Forschungszentrum Jülich, Germany

A. Close-out of the 'Polarized Internal Target' (PINTEX) program

After 10 years of experiments with polarized internal targets and stored, cooled, polarized beams, the successful PINTEX program came to a halt with a last run that ended on June 6, 2002. The final phase of this research program was dominated by studies of reactions that involve three nucleons. This was made possible by the development of a polarized deuteron target, as well as a polarized deuteron beam (both described in previous annual reports).

With this new capability, we have measured spin observables in p+d elastic scattering and in the d+p breakup reaction. The analysis of the elastic scattering experiment is completed and a comprehensive paper has been submitted [1]. The analysis of a part of the breakup data forms the subject of a Ph.D. thesis (T.J. Whitaker). This work is expected to be completed in the spring of 2004. The analysis of the remaining breakup data is in the hands of Dr. P. Thörngren, our collaborator in Sweden.

The physics objective of this effort is to test 'exact' three-nucleon Faddeev calculations that have become available in recent years [2]. Given the quality of these calculations, it has been widely argued that the disagreement with observation will shed light on the nature of the three-nucleon force (3NF). Polarization observables then would contain information on the spin dependence of such a force.

In the following, we briefly review the scientific results from the final phase of the PINTEX effort.

B. p+d elastic scattering

The elastic scattering of polarized protons from polarized deuterons was measured at 135 and 200 MeV bombarding energy. We detected one forward-going particle (either p or d) and the corresponding, low-energy recoil, the latter with an array of Si micro-strip detectors that surrounded the target. The beam polarization was vertical and, using a Siberian Snake, longitudinal. The atomic hydrogen beam source [3] was enhanced to produce deuteron targets

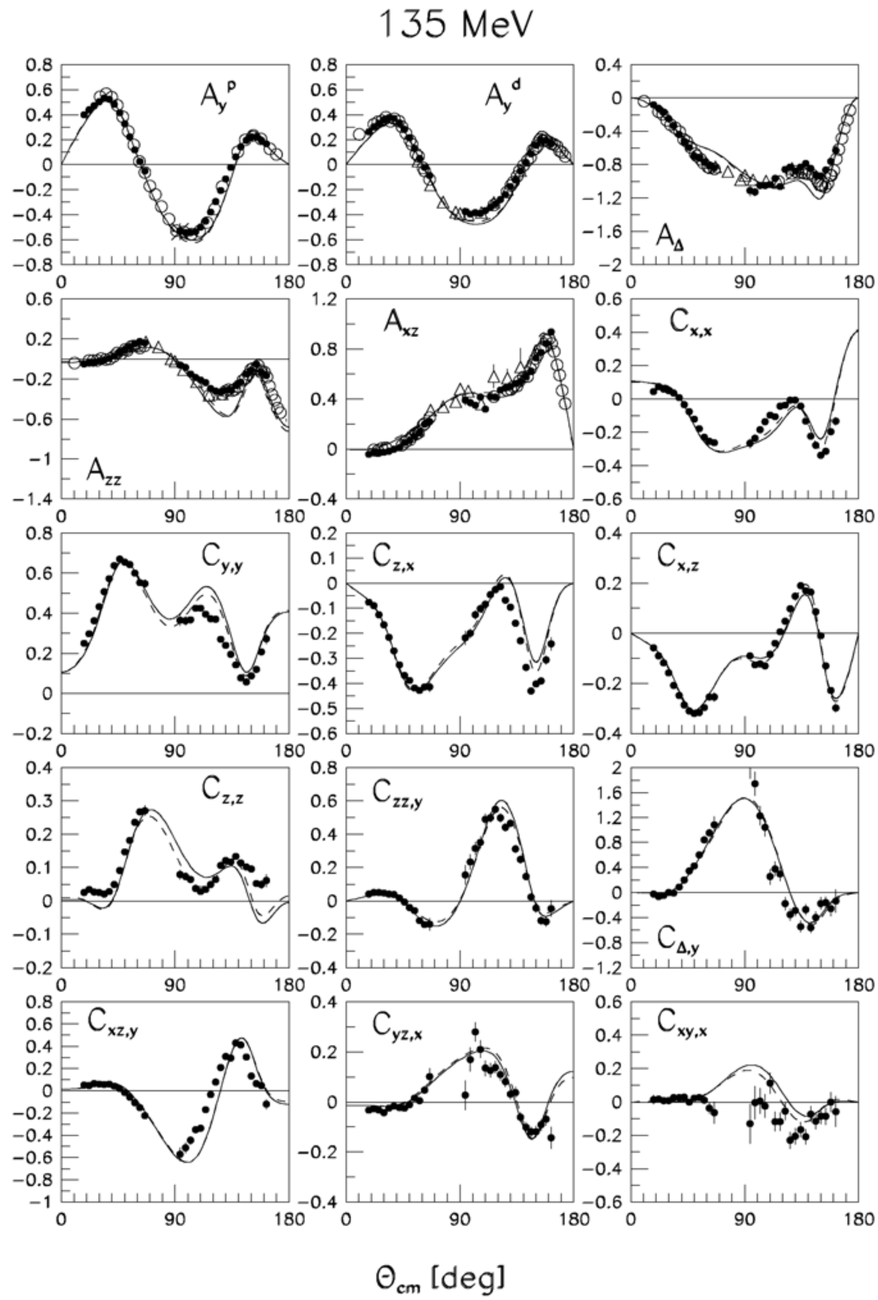

FIG. 1. Spin observables for p+d elastic scattering at T_p = 135 MeV. The solid dots represent the result of this experiment. The errors shown are statistical. The open symbols show previous measurements (see[1]). The solid and dashed curves are 2N force Faddeev calculations based on the CD-Bonn and the AV18 NN potential, respectively.

with pure tensor and vector polarization, and with vertical, sideways and longitudinal spin alignment. With these capabilities, a total of 17 spin observables can be measured. Fig.1 shows angular distributions for all but two spin observables at 135 MeV. The solid dots are from this experiment [1]. The two curves represent Faddeev calculations [4] with two different NN potentials.

We find that the calculations predict the general features of all observables impressively well. Even though the discrepancies between data and two-nucleon-force calculations are relatively small they are still significant. If the 2N input to the calculation is sufficiently well defined, such that it uniquely describes how nature would behave if there were only 2N forces, these differences are a manifestation of additional physics. Our measurement then provides a testing ground for the spin dependence of this missing physics.

Many believe that the prime candidate for the missing physics is a three-nucleon force. It is possible to include theoretical models of three-nucleon potentials in the Faddeev calculations. We have investigated the ability of three different three-nucleon forces to account for the discrepancies between data and 2N calculations. We find that for some observables at some angles the inclusion of a 3NF improves the agreement with the data, but equally often this is not the case. When there is an improvement, it does not depend systematically on the scattering angle, or the energy, or the choice of a particular 3NF. We thus conclude that existing 3NFs are not successful in explaining the spin dependence of p+d scattering.

C. Polarization observables in p+d breakup

The final experiment of the PINTEX group was carried out with a 270 MeV vector and tensor polarized deuteron beam on a polarized proton target. The target cell arrangement was the same as was used for the pion production experiment [5]. The transverse position of the target was a remotely adjustable which greatly facilitates centering the beam in the cell.

The target guide field was cycled through six possible orientations (vertical, horizontal and longitudinal, with both signs in each orientation). The stored beam of typically 150 μA was prepared in five spin states (unpolarized, mixtures of Vector+ and Tensor+, and Vector- and Tensor+, and pure tensor polarization of both signs).

The detector stack consisted of a *ΔE* detector, two wire chambers and a stack of segmented scintillators (see [5] for more detail). The stack was configured to cover the maximum solid angle for the detection of two coincident charged particles. This detector arrangement covers about 40% of the break-up events and pd elastic scattering in a limited angular range at backward center-of-mass angles.

With the employed polarization states, we have measured the proton analyzing power, the deuteron vector- and T_{20} and T_{22} tensor analyzing powers, and three vector- and four tensor correlation coefficients. The measurement is kinematically complete, and we can partition the covered phase space in any way we like.

According to an argument by Knutson [6], three-body potentials involve spin operators of a type that is not allowed for two-body interactions. These operators affect the so-called 'axial' observables, of which the longitudinal analyzing power A_z is an example. In reactions with only two outgoing particles, A_z vanishes by parity conservation. The measured A_z in p+d breakup at 9 MeV [7] was A_z<0.003 and zero within errors, but at T_p=135 MeV (or, T_d=270 MeV) it turns out to be quite large and easily detectable. For this reason, we have decided to focus the first phase of the analysis of this

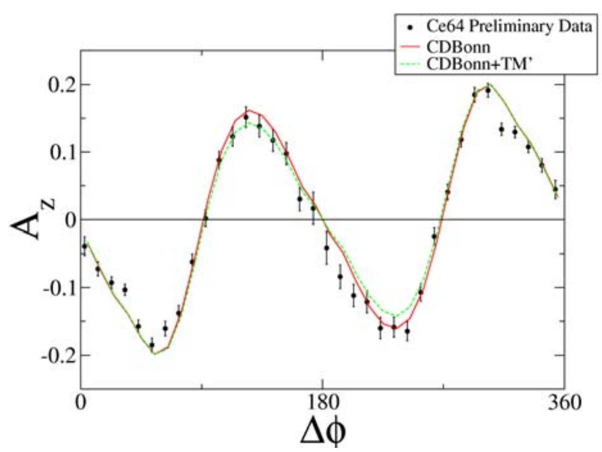

Fig.2: Longitudinal analyzing power Az as a function of the co-planarity angle (partial, preliminary data). The curves are Faddeev calculations based on the CD Bonn potential.only (solid line), or containing also the TM' 3NF (dashed line).

experiment on observables that are only allowed in reactions with a three-body final state. There are five such observables, A_z(p), $C_{zz,z}$, $(C_{y,x} - C_{x,y})$, A_z(d), and $(C_{xz,x} + C_{yz,y})$; the first three have been measured in this experiment.

The results of Faddeev calculations, when one tries to compare them to our data, have to be integrated over the detector acceptance. In collaboration with Dr. J. Kuroś-Żołnierczuk (a research associate at the Nuclear Theory Center), we have developed a new method to average the theoretical values in such a way that the boundaries of the detector acceptance and variations of the efficiency are taken into account correctly. A paper, describing this method is in preparation.

Fig.2 shows the current status of our data for A_z (preliminary) as a function of the 'coplanarity angle' $\Delta\varphi$, together with a Faddeev calculation, obtained with our new method. The variable $\Delta\varphi$ is the azimuthal difference between the neutron momentum and the relative momentum of the two protons. The observable crosses zero at 0^o and 180^o as a consequence of parity conservation.

D. Spin exchange in polarized deuterium

During the course of the p+d elastic scattering experiment, we have studied the interaction between the atomic substates in a dense gas of polarized deuterium. Walker and Anderson [8] predict the loss of polarization of a deuterium target due to spin-exchange collisions by calculating – starting from a given initial state – the evolution of the population of the substates in terms of the parameter t/T_D, where t is the average dwell time of an atom in the target, and $1/T_D$ is the DD spin exchange rate.

We have measured the vector and tensor polarization of an atomic deuterium target as a function of the target density. The polarized deuterium was produced in an atomic beam source and injected into a storage cell. For this experiment, the atomic beam source was operated without RF transitions, in order to avoid complications from the unknown efficiency of these transitions. In this mode, the atomic beam is vector and tensor polarized and both polarizations can be measured simultaneously. We used a 1.2 cm diameter and 27 cm long storage cell, which yielded an average target density between 3 and $9 \cdot 10^{11}$ atoms/cm^3. We find that the tensor polarization decreases with increasing target density while the vector polarization remains constant. The data are in quantitative agreement with the calculated effect of spin exchange between deuterium atoms at low field. This work has been accepted for publication [9].

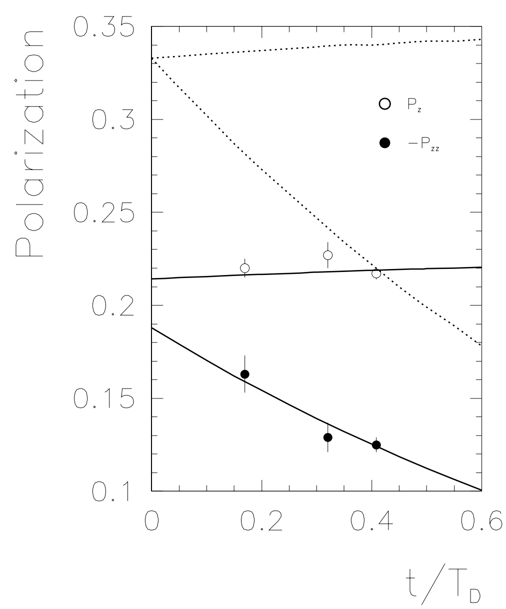

Figure 3: Vector polarization (open circles) and tensor polarization (solid dots) as a function of t/T_D *(proportional to the target density). The dotted curves are the predictions by theory [8]. The solid curves are the same, scaled to best fit the data.*

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