NUCLEON-NUCLEON AND FEW-BODY STUDIES

MEASUREMENT OF THE pp ANALYZING POWER A_y IN THE COULOMB-NUCLEAR INTERFERENCE REGION

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There is considerable interest in developing the Cooler into a facility for spin correlation measurements with internal polarized gas targets. The targets would consist of polarized hydrogen or deuterium atoms in a storage cell open to the circulating beam.[1] The major advantage of such targets in a storage ring environment is that the lack of non-hydrogeneous material in the storage ring target significantly reduces the background compared to the same experiment performed with a single pass beam and a cryogenic polarized target. Before attempting spin correlation measurements, however, we decided to first measure an analyzing power using a polarized beam and unpolarized target. We have thus measured the analyzing power A_y of 185.4 MeV proton-proton (pp) elastic scattering at forward angles ($\theta_{cms} = 5.0° - 21.8°$). The physics motivation of this measurement is the interest in having high quality data in the Coulomb-nuclear interference region, where the nuclear amplitudes can be determined from interference with the Coulomb amplitude.[2] This measurement was the first nuclear physics experiment with a polarized beam in the Cooler. The polarized beam was injected into the Cooler using RF stacking of the injected beam pulses.[3] The beam was stored from one 5-second data cycle to the next, resulting in an average of $\approx 6 \times 10^8$ orbits for the proton beam. We verified that the stored beam remained polarized during this time by measuring the polarization of a beam stored (with target off) for a significantly longer period (3×10^9 orbits). The resulting 1/e polarization lifetime of the beam was at least 6 hours at a 99% confidence level. The luminosity extracted from the data rate was $\approx 7 \times 10^{28}$ cm^{-2}sec^{-1}.

The apparatus is shown in Fig. 1. This experiment was located in the G-region of the Cooler and most of the equipment was that used in the the CE-01 experiment.[4] The major change to the apparatus was the addition of four 300 μm thick silicon strip detectors near the target to detect the low energy recoil proton at large angles ($\theta_{lab} \approx 83°$).[5] Slits were mounted to eliminate the direct path from the detector to the differential pumping apertures near the entrance and exit of the first stage of the gas jet target. The forward detector consisted of a thin segmented plastic scintillator (F), four multi-wire proportional chambers (MWPC) which were mounted as two pairs (WC1, WC2), and a 10-cm thick

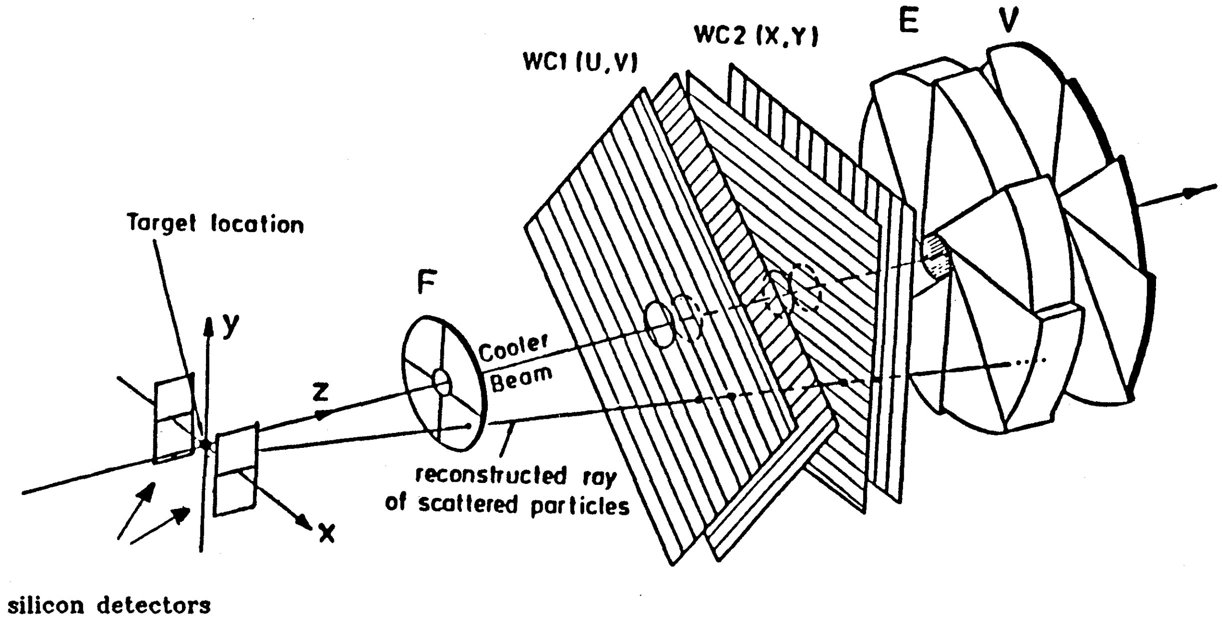

Figure 1. The experimental apparatus used in this measurement.

scintillator divided into octants (E). The response of the forward detector and one silicon detector is shown in Fig. 2. The recoil proton energy extracted from the forward scattering angle and pp kinematics is within 100 keV of the measured energy at all angles where the proton stops in the silicon detector. The population with anomalously low pulse heights for a given forward scattering angle is thought to be due to a combination of silicon detector inefficiency and scattering of the low energy protons from components of the Faraday cage which surrounds the detector. The analyzing power of this population was the same as that in the locus, indicating a common origin in free pp scattering.

The trigger condition was that at least one F segment, one E segment, and one silicon detector element have a valid signal. All events were written to magnetic tape for off-line analysis. The forward scattering angle was calculated using the position of the gas jet as the origin (an implicit condition due to the slits on the silicon detectors) and the transverse position measured in the most downstream wire chamber. The reconstructed track was required to be consistent with the expected F and E scintillator segments to within a position mismatch of 7 mm. About 90% of all events had one and only one good hit per wire chamber (a "1111" event). The remaining events were almost equally distributed among events with either a missing wire chamber hit ("1110" events) or extra hit ("1112" events) in the wire chambers. The scattering angle of the 1110 events could be almost always be recovered by using the position of the track determined from the segmented F and E detectors. The 1112 events were recovered by requiring internal consistency upon the tracks in all chambers.

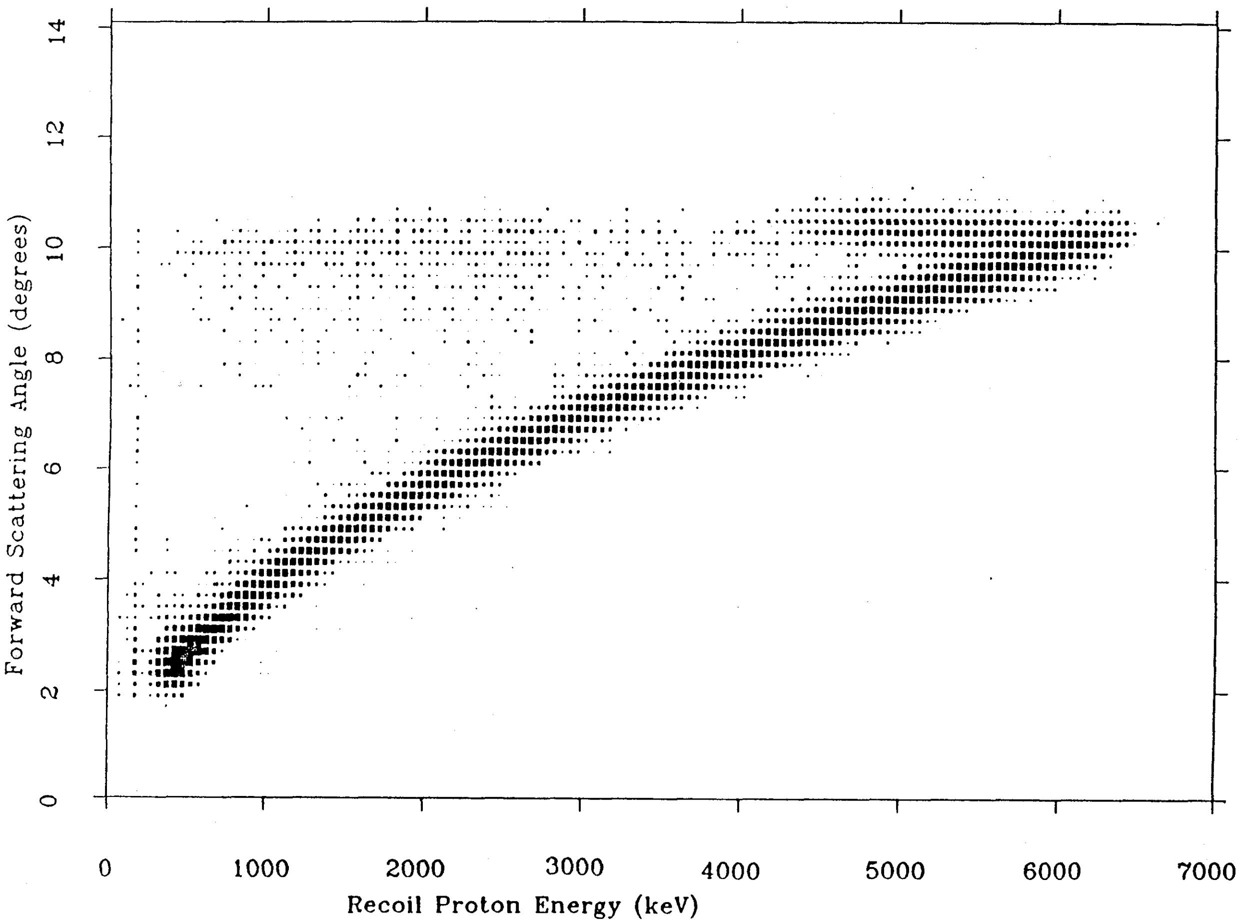

Figure 2. Response of the detector system to 185 MeV elastic proton-proto n scattering. The vertical axis is the angle measured with respect to the beam axis of the forward going proton, the horizontal axis is the kinetic energy of the recoil proton emerging at approximately 90° in the laboratory system, and the size of the dot corresponds to the logarithmic density of events in a given energy-angle bin.

The candidate pp elastic scattering events were distinguished from the background events primarily upon the basis of pulse height in the E scintillator, the time correlation between fast signals from the silicon detector and scintillators, and the kinematic correlation of the forward scattering angle with the recoil proton energy. The track also had to be within the kinematically allowed region of the wire chamber and only events with one E segment were allowed. The background was both energy and angle dependent, peaking at small silicon detector pulse heights and small scattering angles. Very little background survived all the sorting cuts; note that even at the smallest pulse heights and scattering angles there is still a clean separation between the background and the pp locus in Fig. 2. The background is primarily due to a random coincidence between noise in the silicon detector and a very forward proton with energy significantly less than beam energy. The 1111, 1110, and 1112 events were sorted separately with the analyzing power calculated using the cross-ratio technique to reduce systematic errors.[6] The three results were then averaged together for the final result.

Our data have been normalized in a separate measurement using the cyclotron beam.[7] The pp analyzing power was measured to be $A_y = 0.2122 \pm 0.0017$ at an angle of $\theta_{cms} = 18.1^\circ \pm 0.1^\circ$ and incident beam energy of 183.1 ± 0.4 MeV. The quoted error includes all normalization effects. The resulting value for $A_y(18.1^\circ)$ at the Cooler beam energy of 185.4 MeV is 0.2149 ± 0.0017 where the energy dependence of the C200 solution of Arndt has been used to correct for the different incident energies.[8] Our results over the angular range $\theta_{cms} = 16.5^\circ - 19.7^\circ$ are then averaged and used to generate a normalization constant which has been applied to the data in Fig. 3. The angular dependence of predicted A_y values from phase shift and potential models was verified to be linear over this angular range.

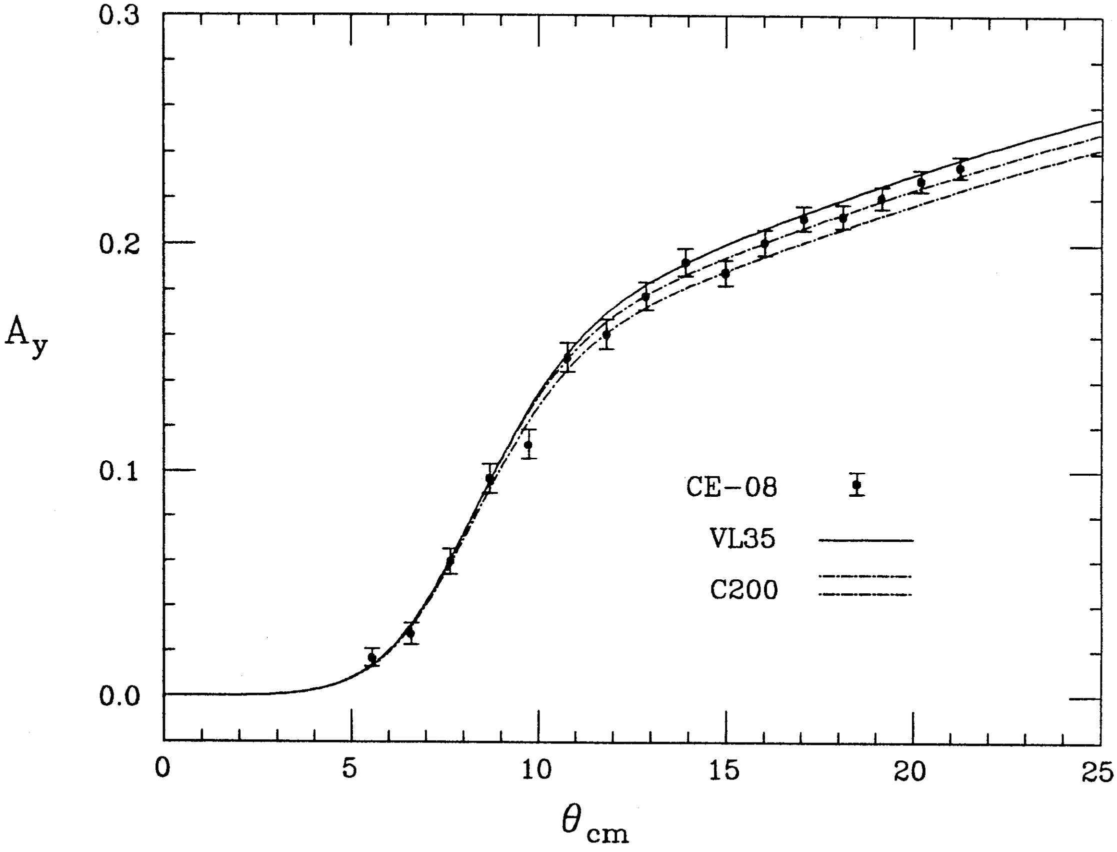

Figure 3. Results of this measurement, normalized to a precise determination of A_y at one angle. This normalization point is shown as the square point in the figure, with errors smaller than the size of the point. The phase shift prediction with an error band is the the C200 (179–225 MeV) solution of Arndt while the solid line is the VL35 (0–350 MeV) solution.[8]

Our preliminary measurement of $A_y(\theta)$ is shown in Fig. 3. The predictions of the C200 and VL35 phase shift solutions of Arndt are also plotted. The difference between these two solutions is that the C200 solution is based only on data from 179–225 MeV while the VL35 solution is based upon data from 0–350 MeV.[8] A detailed comparison of our data to phase shift and potential model predictions is in progress. It is already clear that proper inclusion of higher-order Coulomb effects are important in understanding these data.

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1. W. Haeberli, Proc. Int. Workshop on Polarized Ion sources and Polarized Gas Jets (Tsukuba, Japan, Feb. 1990), KEK Report 90-15, p. 35.
2. C. Lechanoine, F. Lehar, F. Perrot, and P. Winternitz, Nuovo Cim. **56A**, 201 (1980).
3. X. Pei, Ph.D. thesis, Indiana University.
4. H. O. Meyer, M. A. Ross, R. E. Pollock, A. Berdoz, F. Dohrmann, J. E. Goodwin, M. G. Minty, H. Nann, P. V. Pancella, S. F. Pate, B. von Przewoski, T. Rinckel, and F. Sperisen, Phys. Rev. Lett. **65**, 23 (1990).
5. W. K. Pitts, J. S. Price, S. F. Pate, B. von Przewoski, T. Rinckel, and F. Sperisen, Nucl. Instrum. and Methods (to be published).
6. W. Haeberli in Nuclear Spectroscopy and Reactions, Vol. II, ed. Joseph Cerny, Academic Press, New York, 1974.
7. B. von Przewoski, H. O. Meyer, P. V. Pancella, S. F. Pate, R. E. Pollock, T. Rinckel, F. Sperisen, J. Sowinski, W. Haeberli, W. K. Pitts and J. S. Price, to be published in Phys. Rev. C; contribution to this report.
8. R. A. Arndt *et al.*, Phys. Rev. **D35**, 128 (1987), and program SAID.