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MEASUREMENT OF THE SPIN-CORRELATION PARAMETER C_{NN} IN PROTON-PROTON SCATTERING AT 680 MeV[‡]

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Abstract

Using a polarized beam and polarized target we have measured the spin-correlation parameter C_{NN} in proton-proton scattering for an incident-proton laboratory-system kinetic energy of 680 MeV. The polarized beam was made by scattering unpolarized protons from the 184-in. cyclotron in an external first target of liquid hydrogen resulting in a polarization of 0.44. To reverse the beam polarization, the incident-proton scattering angle was reversed. The target protons were polarized by a solid-state technique called "dynamic polarization" to 0.40 on the average. The elastic proton-proton interactions involving the polarized protons were kinematically separated from other interactions by counting both protons in coincidence. The angular region covered by the 13 data points extends from 51.2 to 88.7 deg in the center-of-mass system. The results show the C_{NN} rises in this region from about 0.5 to 0.9 with a typical standard deviation of 0.1.

I. INTRODUCTION

Among the important parameters to be measured for a quantitative description of the nucleon-nucleon interaction are the spin correlation parameters, C_{NN} and C_{KP}.[1,2] While the phenomenological picture of nucleon-nucleon scattering is now fairly complete up to 300 MeV lab kinetic energy, few experiments of any kind have been done above this energy. A complete phase shift analysis at a single energy would require 9 independent experiments to describe the elastic scattering alone, and many more to describe the inelastic channels. We report here the results of a measurement of C_{NN} in proton-proton elastic scattering at 680 MeV in the angular region 50° to 90° center of mass system (cms), in the expectation that future experiments will enable a complete analysis to be carried out.

In the past, C_{NN} has been measured using unpolarized beams and targets, and simultaneously measuring the polarization of the scattered and recoil nucleons.[3] In this experiment, C_{NN} was measured with polarized beam and target, avoiding the necessity of measuring final-state polarizations.[4] It can be shown that the result of these two types of measurement is the same, and that this does not depend on the assumption of invariance of the scattering matrix under time reversal.[5]

In this paper, only polarizations perpendicular to the scattering plane are considered. The counting rate with beam polarization P_B and target polarization P_T is given by[3]

$$I(\theta) = I_o(\theta) \quad 1 + (P_B+P_T)P(\theta) + P_B P_T C_{NN}(\theta) \qquad (1)$$

where $I_o(\theta)$ is the unpolarized counting rate, $P(\theta)$ is the polarization parameter. All polarizations are taken to be positive in the direction $\vec{n} = \vec{k}_i \times \vec{k}_q$, where $\vec{k}_i$ is the momentum of the incident proton and $\vec{k}_q$ is the momentum of the faster outgoing proton in the lab system. Equation 1 defines $C_{NN}(\theta)$, the spin-correlation parameter normal to the scattering plane.

The experimental procedure consisted of measuring $I(\theta)$ successively with the four possible combinations of P_B and P_T . Using these four counting rates the four unknown quantities $C_{NN}(\theta)$, $P(\theta)$, P_B , and $I_o(\theta)$ were extracted.

II. EXPERIMENTAL APPARATUS

A. Polarized Beam

The geometry of the polarized target used in this experiment is such that the orientation of the scattering plane is vertical. The target is polarized horizontally and perpendicular to the scattering plane. To measure C_{NN} we have polarized the beam horizontally by a first scattering in the vertical plane. Unpolarized protons extracted from the 184-in. cyclotron at fixed energy (nominally 740 MeV) are collimated by a set of 4-in. brass jaws of the pre-magnet collimator, bent into the proton cave direction by the steering magnet, and passed through an 8-in.-bore quadrupole doublet focusing magnet that focuses the protons at the first scattering target in the proton cave. From here on the system is shown in Fig. 1.

The protons emerge from the evacuated beam tube and enter the proton cave. Here the beam is deflected by a pair of bending magnets to cross over its original trajectory at an angle of 12 deg at the position where the first scattering target is located. At this point the beam spot measures about 1.5 in. horizontally by 0.5 in. vertically. The beam's path through 6 in. of liquid hydrogen, viewed at an angle of 12 deg from the beam, then appears as a particle source about 1.5-in.-square. Before it buries itself in a beamstopper of 10 ft. of concrete, the beam passes through a split ion chamber to provide a signal for the experimenter as a check on the course of the beam.

Particles scattering elastically in the first target in the same direction as the protons entering the cave from the cyclotron make up the polarized beam. They are focussed onto the polarized target crystals by an 8-in.-bore symmetric quadrupole triplet focussing magnet buried in the wall of shielding near the center of the cave. The beam stoppers are part of the same shielding wall. The magnification of this focusing magnet in both vertical and horizontal planes is about -1, giving a beam spot approzimately 1.5-in.-square at the polarized target. A 2-in.-thick brass collimator with 4-in. by 6-in. oval opening, located in the first section of the focusing magnet, limits the solid angle of acceptance to about 6×10^{-4} sr. The range of scattering angles thus accepted from the first target is 12.1 ± 0.6 deg.

Range curve measurements of the polarized beam indicate a beam energy of 683 MeV. During the experiment the proton flux from the 184-in. was about 1.5×10^{11} particles/sec., a factor of two or more below maximum capable. It was thought best to clip the beam somewhat in order to keep the spot size small. The flux of elastically scattered protons at the polarized target was about 3×10^{6}/sec.

One of the numbers resulting from the data analysis is the average beam polarization. It is found to be 0.44 ± 0.02. Since the beam contains a small amount of inelastic contamination, this number is not exactly equal to the elastic-scattering polarization.

B. Polarized-Proton Target

The polarized-proton target has been described by Schultz[6] and Shapiro[7]. Details of the target-polarization measurement procedure are given in these references and in Ref. 8.

C. Counters and Electronics

Counters and electronics were identical with those in Ref. 8. The physical layout is shown in Fig. 2. Kinematic resolution was sufficient to give elastic-peak to background ratios of 4 to 1. The following effects were considered as possible sources of systematic errors:[5]

a) contamination of the polarized proton beam by inelastic protons and pions

b) energy variation of the polarized proton beam across the face of the polarized target

c) uncertainty in the subtraction of the non-hydrogen background by the dummy target method[6,7]

d) errors in the computation of the target polarization

e) non-uniformity of the target polarization over the volume of the target.

It was found that a), b), c), and e) contribute negligibly to the systematic error in C_{NN}, compared to the contribution from d). The error in the measurement of the target polarization is estimated at 10%. This must be added as an overall normalization uncertainty to the results quoted for C_{NN}. The relative errors are due to counting statistics and are indicated in the results.

III. RESULTS

Results for $P(\theta)$ and $C_{NN}(\theta)$ are given in Table I and shown in Figs. 3 and 4. The results for $P(\theta)$ are in good agreement with those of Ref. 8.

IV. DISCUSSION

Stapp has pointed out that at 90 deg center-of-mass the value of C_{NN} contains information about the singlet-triplet content of the interaction.[2] A value of +1 represents pure triplet scattering, while -1 is pure singlet. Evidently at this energy the triplet amplitudes predominate.

Recently, other measurements of C_{NN} using polarized beams and targets have been performed.[10,11] The availability of polarized targets has also led to a number of new measurements of $P(\theta)$ at a variety of energies.[12] It is to be hoped that further measurements of C_{NN} and other parameters will lead to an eventual quantitative understanding of the nucleon-nucleon problem in this energy region.

V. ACKNOWLEDGMENTS

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Table I. Results for $P(\theta)$ and $C_{NN}(\theta)$ of proton-proton elastic scattering at 680 MeV; t is the invariant four-momentum transfer squared; in addition to the random errors quoted, there are systematic fractional errors of 10% on all values.

θ_{cm} (deg)	$-t$ $10^5 (MeV/c)^2$	$P(\theta)$	$C_{NN}(\theta)$
51.2	2.38	0.472 ± .053	0.449 ± .122
54.3	2.66	0.564 ± .041	0.570 ± .097
57.4	2.94	0.528 ± .039	0.543 ± .092
60.5	3.24	0.494 ± .041	0.545 ± .097
63.7	3.54	0.386 ± .042	0.708 ± .100
66.7	3.86	0.375 ± .043	0.665 ± .104
70.8	4.27	0.384 ± .032	0.574 ± .079
73.7	4.58	0.317 ± .027	0.603 ± .069
76.7	4.90	0.252 ± .028	0.752 ± .075
79.6	5.22	0.189 ± .029	0.806 ± .078
82.6	5.55	0.175 ± .030	0.731 ± .079
85.6	5.88	0.129 ± .039	0.909 ± .101
88.7	6.22	0.004 ± .053	0.835 ± .128

FIGURE CAPTIONS

Fig. 1. Polarized-proton beam system. Protons from the 184-in. cyclotron enter from the left.

Fig. 2. Schematic drawing of the polarized target and scintillation counters. The protons scattered up are the faster ones, forward in the cms, and are detected by the array $\alpha_0 \ldots \alpha_9$. The conjugate protons register in the array $\beta_0 \ldots \beta_9$. Auxiliary counters are used to insure that the events originate in the target, that the particles in $\beta_0 \ldots \beta_9$ are slow protons, and to reduce the accidental rate.

Fig. 3. Results of this experiment: $C_{NN}(\theta)$ in elastic proton-proton scattering at 680 MeV. (The open circles are the results of Ref.9 at 640 MeV.) An overall 10% fractional error due to a systematic uncertainty in the target polarization should be added to the errors shown.

Fig. 4 Results of this experiment: $P(\theta)$ in elastic proton-proton scattering at 680 MeV. An overall fractional error due to a systematic uncertainty in the target polarization should be added to the errors shown. The solid straight line represents a good fit to the data of Ref. 8 at this energy while the dashed line corresponds to data of Ref. 9 at 660 MeV.

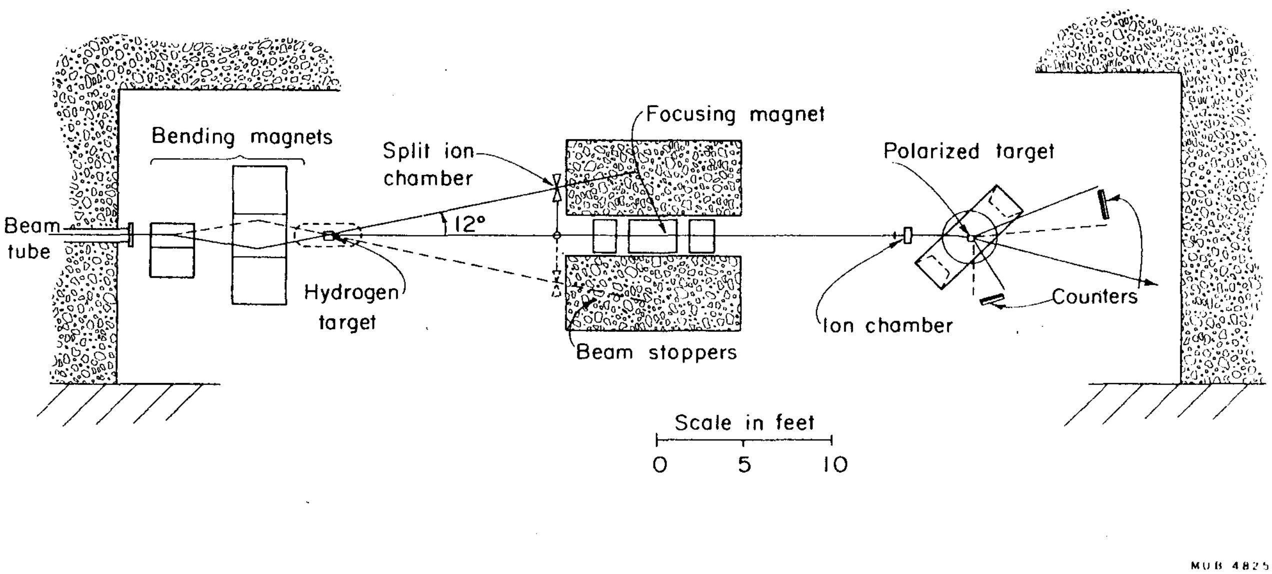
Focusing magnet
Bending magnets
Split ion chamber
Polarized target
Beam tube
12°
Hydrogen target
Counters
Ion chamber
Beam stoppers
Scale in feet
0
5
10
MUB 4825

Fig. 1

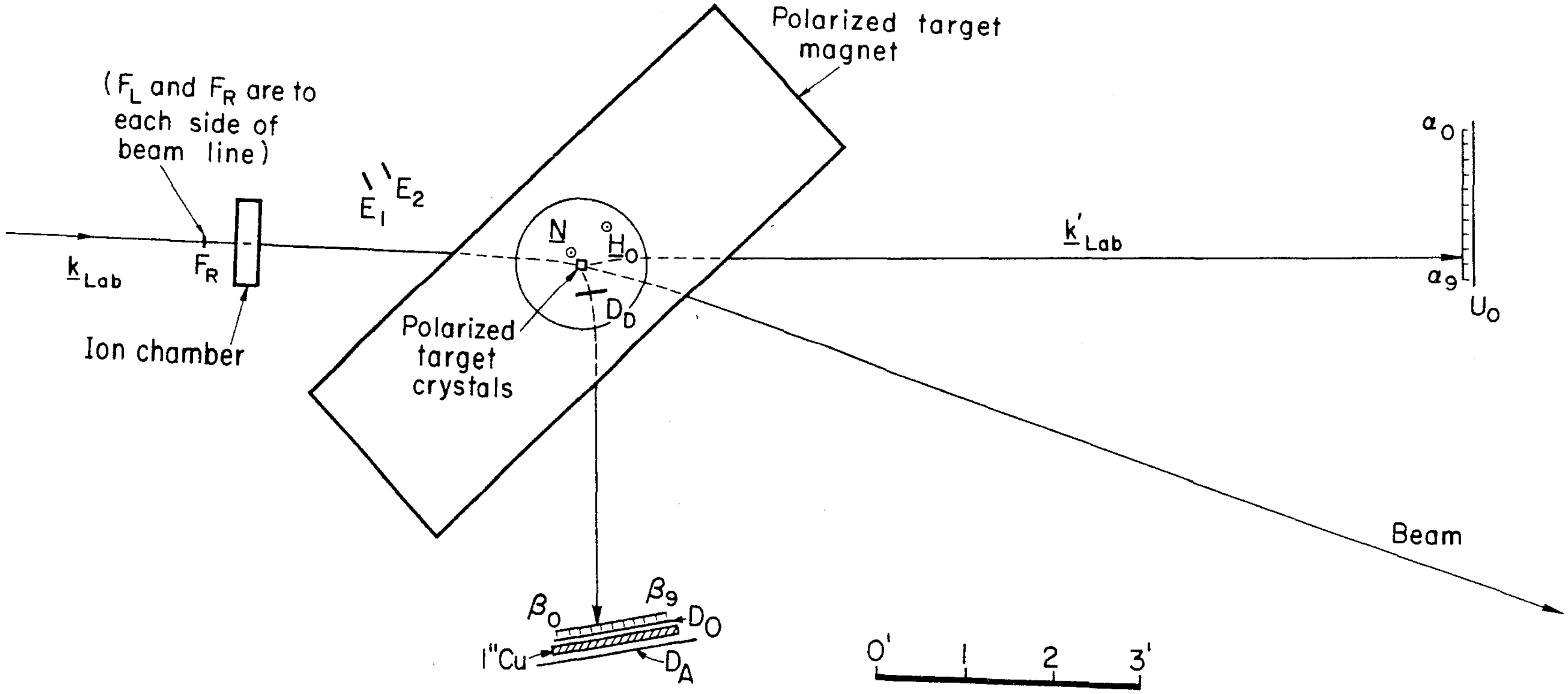

Fig. 2

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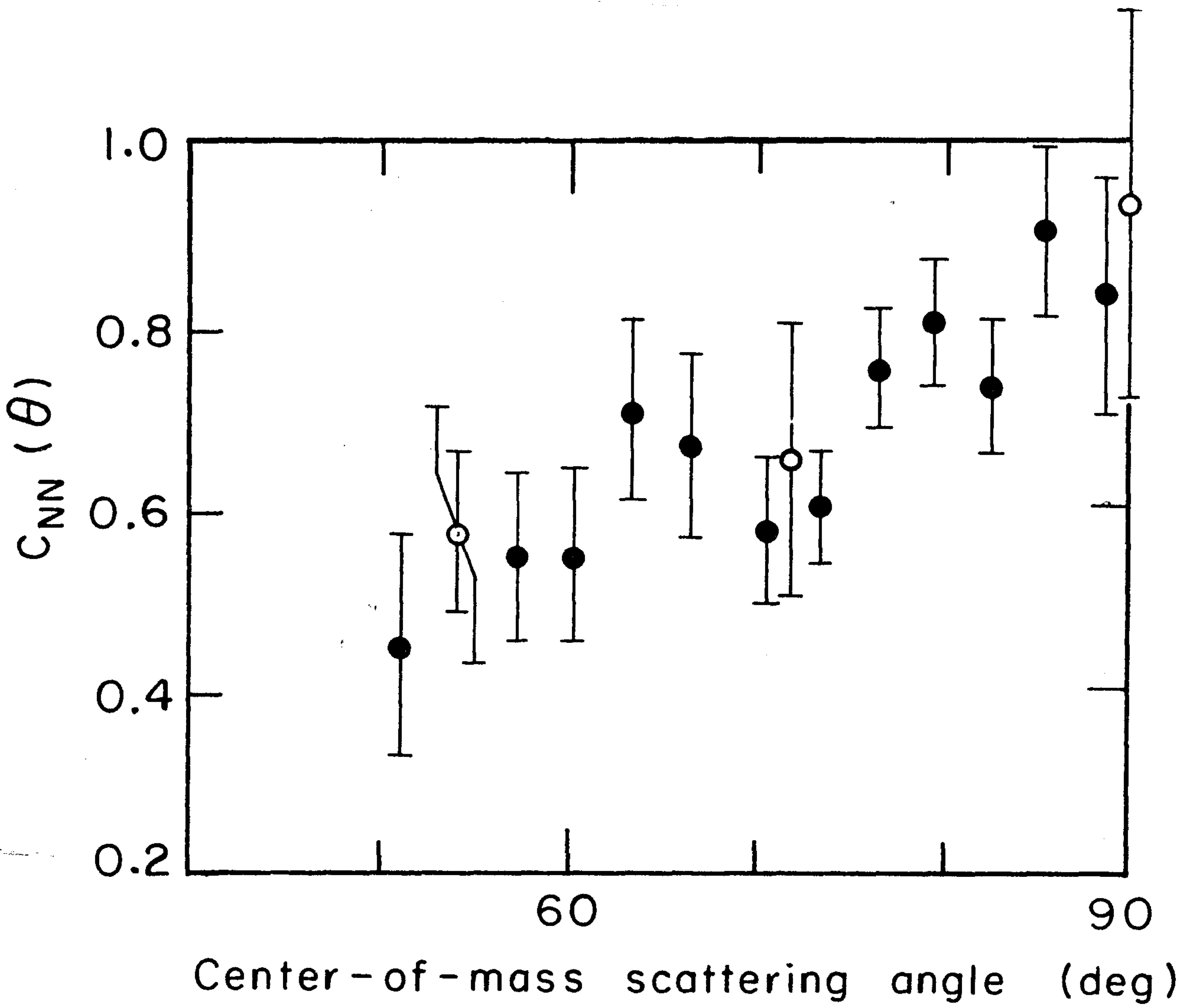

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Fig. 3

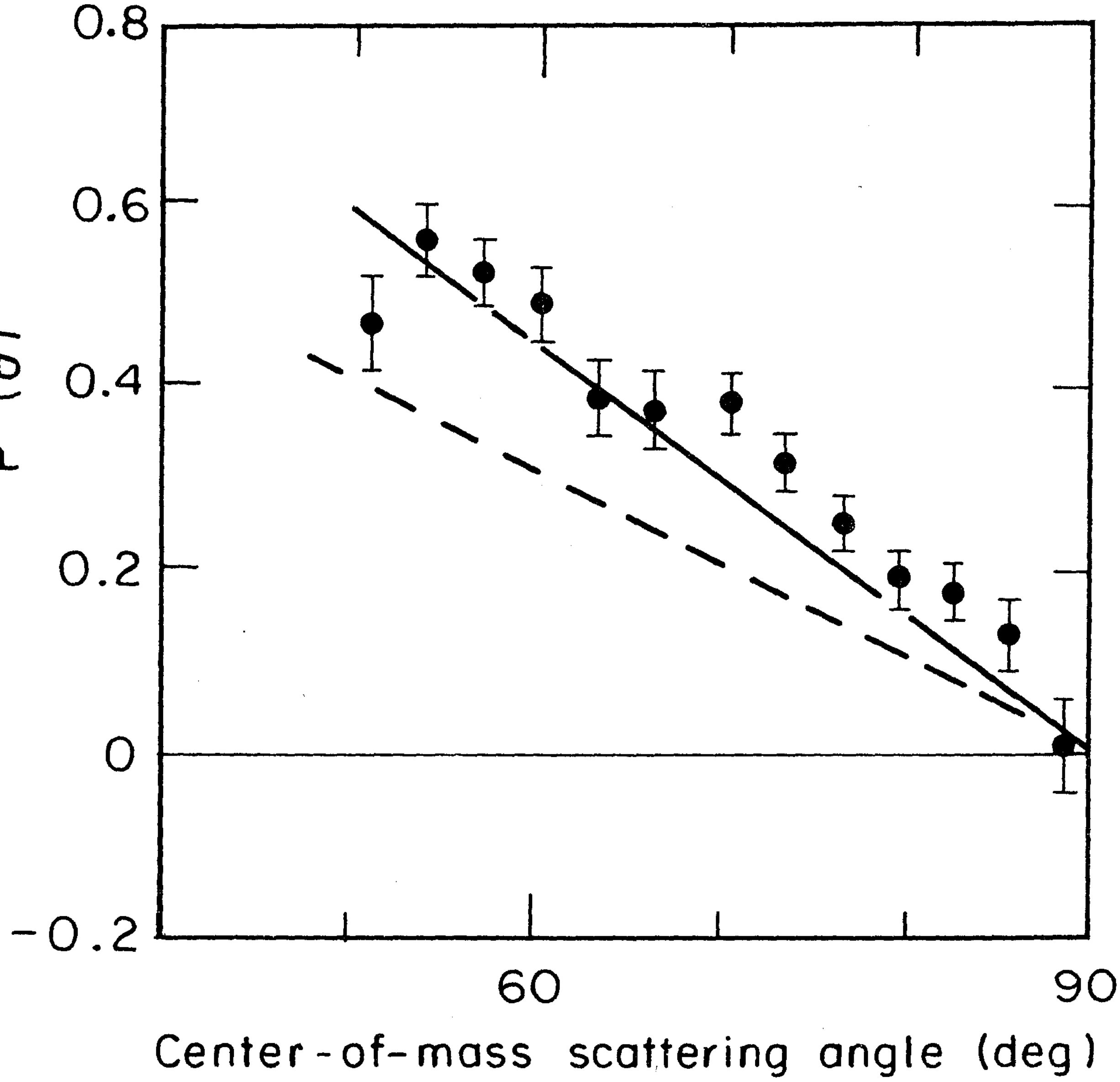

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Fig. 4