## Title

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## Authors

Robrish, Peter R
Chamberlain, Owen
Field, Richard D, Jr.
et al.

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Peter R. Robrish, Owen Chamberlain, Richard D. Field, Jr.
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# BACKWARD np SCATTERING WITH A POLARIZED TARGET*

Peter R. Robrish, Owen Chamberlain, Richard D. Field, Jr.,
Raymond Z. Fuzesy, W. Gorn, Charles C. Morehouse, Thomas Powell,
Stephen Rock, Stephen Shannon, Gilbert Shapiro, and Howard Weisberg

University of California, Lawrence Radiation Laboratory
Berkeley, California 94720

and

Michael J. Longo

University of Michigan, Ann Arbor, Michigan 48104

## ABSTRACT

We have measured the polarization parameter P in neutron-proton elastic scattering near the backward direction, using a polarized proton target. Measurements covered the range of incident neutron momenta from 1.0 to 5.5 GeV/c and of four-momentum transfer squared u from -0.005 to -0.5 $(\text{GeV}/c)^2$. Forward going protons were detected by means of a wire-spark-chamber spectrometer. Slow neutrons near 90 deg lab angle were detected in coincidence by means of an array of plastic scintillation counters. P was determined from the change in counting rate I of scattered particles upon reversal of the target polarization $\underline{P}_T$ according to

$$I = I_0\left[1 + P\left(\underline{P}_T \cdot \frac{\hat{k}_{\substack{\text{incident}\\ \text{neutron}}} \times \hat{k}_{\substack{\text{final}\\ \text{neutron}}}}{\sin\theta_{\substack{\text{final}\\ \text{neutron}}}}\right)\right]$$

We find that P is consistently negative and shows no marked structure as a function of u and of incident momentum. Our data roughly follow the simple form

$$P = -0.5\sqrt{-u}/m_p$$

Measurements of the differential cross section for np scattering near 180 deg, sometimes referred to as np charge-exchange scattering, have shown a very sharp peak near $u = 0$.[1] There have been many attempts to explain the behavior of the cross section using Regge models, but only those models employing conspiring trajectories[2] or absorptive corrections[3] seem to have had some measure of success. There has also been some success using modified one-pion-exchange models.[4] We therefore decided to measure the polarization in order to provide new information about this reaction and to help to distinguish between the various theoretical models.

We measured the polarization parameter by directing a neutron beam having a broad spectrum of momenta from 1 to 5.5 GeV/c at a polarized target. Using a magnetic spectrometer, we determined the direction and momentum of protons emerging near the forward direction. An array of neutron counters was used to measure the direction of the outgoing neutron and, somewhat crudely, its velocity. By using both the velocity of the neutron and the angular correlation between the directions of the outgoing neutron and proton, we were able to determine whether a given event was elastic scattering. We used the measured momentum of the outgoing proton along with its direction to calculate the momentum of the incident neutron.

The experiment was performed at the Bevatron in a neutron beam produced at 0 deg from a 7.5-cm-long Cu target located in the external proton beam. The defining aperture of the collimator was 1.6 cm in diameter at 4.6 m from the production target, and gave a beam spot of about 3 cm diam at our target, which was 8.5 m from the production target.

Four and one-half radiation lengths of Pb were put in the beam line 1 m down-stream of the production target to convert $\gamma$-rays. Sweeping magnets before and after the collimator removed charged particles from the beam. The neutron intensity at our target was about $3 \times 10^6$ neutrons per $10^{11}$ incident protons.

The polarized target consisted of about 6 g/cm$^2$ of $LaMg_3(NO_3)_{12}\cdot 24H_2O$ in which the free protons in the water of hydration (3% by weight) were polarized by dynamic nuclear orientation. The average polarization during the experiment was 50%. The sign of the polarization was reversed about every 90 minutes. The NMR signal used to obtain the polarization of the target was measured after every Bevatron pulse.

Figure 1 is a diagram of the apparatus used to detect the final-state particles. Outgoing protons were detected in a magnetic spectrometer consisting of three counters P1, P2, P3, and six wire spark chambers, SC1 - SC6, with magnetostrictive readout, three before and three after the spectrometer magnet. This spectrometer was used to measure the momentum, and direction of each proton.

The data from both the wire chambers and the electronics associated with the neutron counters described below were read into a PDP-5 computer and transferred to magnetic tape between Bevatron pulses. The computer also recorded the polarized target information and provided displays which allowed us to monitor the operation of the experiment.

The neutrons were detected in an array of 30 plastic scintillation counters each 2.5 cm × 15 cm × 96 cm, where the long axis of each counter was perpendicular to the plane of Fig. 1. By measuring the time of flight difference of the scintillation light to two photomultiplier tubes, one located at each end of the counter, we determined the location of the detected neutron vertex along the long axis of each counter to about ± 4cm. We staggered the counters in three rows as shown in Fig. 1 in order to minimize the effect of the "cross talk" caused by the scattering of recoil particles into adjacent counters. We identified the neutron interaction vertex with the row closest to the target in which a count registered and demanded that only one counter in that row have fired ($\approx 7\%$ of the events were lost because of the requirement). The electronic circuitry was arranged so that the time difference information which was recorded always came from this first nonblank row alone; timing information from other rows was lost. For each event we also measured the time difference between counter P1 and a photomultiplier at one end, in order to get time-of-flight information on the final-state neutron.

Using the measured proton momentum and angles and assuming that the event was elastic scattering from a free proton, we calculated the incident momentum and the four-momentum transfer squared. We then made cuts on the difference between the measured outgoing neutron scattering angle, azimuthal angle, and time of flight, and the values calculated from the proton information. These cuts effectively suppressed inelastic events, and also the background from the quasi-elastic scattering from the bound protons in the heavy nuclei of the target. Typically we obtained a ratio of elastic peak to background of about 6:1. We determined the shape of the remaining background in two ways. First we made use of events in which the measured neutron azimuthal angle failed to satisfy the coplanarity condition; and second, we ran with a dummy target similar in nuclear composition to the polarized target, but containing no hydrogenous material. After porper normalization, the background obtained was subtracted from the coplanar events to get the number of events coming from free protons; the results using both types of background subtraction are quite consistent.

The error in our results due to uncertainty in the background subtraction is negligible compared with the error from counting statistics. Checks of the internal consistency of the data indicate that systematic errors, such as instabilities of the monitors and detectors, are also negligible. The only significant error in our data, other than that from counting statistics, is thought to be given by an overall normalization factor of (1.00 ± 0.05) corresponding to our estimate of the uncertainty in the measurement of the target polarization.

The results of our preliminary analysis, which includes about 2,000,000 event candidates of which about 60,000 were elastic events, are shown in Fig. 2. The solid lines represent the purely empirical function $P = -0.5 \sqrt{-u}/m_p$, and are presented to show that this function represents our data fairly well. Our sign convention for P corresponds to defining the normal to the scattering plane as the vector product of the incident and scattered neutron momenta. The features of the data which are probably most important are:

(a) The polarization is significantly different from zero at most points.

(b) The sign of the polarization is consistently negative. In particular, there is no indication that the polarization passes through zero in the range studied.

(c) At a given value of u, the polarization does not seem to vary much with energy.[5]

We note that, according to conventional Regge-pole analysis,[6] the pion trajectory, which is supposed to play an important part in determining the cross section for the np charge-exchange reaction, cannot contribute to $P d\sigma/d\Omega$.[7] Of the other trajectories which can contribute to the polarization for this reaction, the leading ones are the $\rho$ and $A_2$. If only these two trajectories contribute to the polarization, and if they are exchange-degenerate in the most restricted sense (i.e., that both their trajectories coincide and their residue functions are equal), there should be no polarization since the amplitudes would then be relatively real. For $-u < 0.3$, our data seem to agree with a prediction by Arnold and Logan[8] who used a weaker form of exchange degeneracy. Their model, however, predicts that $P(-u)$ will pass through zero at about $-u = 0.5$. We see no sign of this zero-crossing.

We thank Dr. Herbert Steiner for his help in the design of the experiment, and Gary LeBonte and Stephen Wilson for their help with the testing of the spark chambers. Finally we are grateful to the Bevatron operating crew for their excellent support.

## FOOTNOTES AND REFERENCES

* Work supported by the U. S. Atomic Energy Commission and O.N.R. National Science Foundation Grant GP 9438.

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3. F. Henyey, G. L. Kane, Jon Pumplin, and M. H. Ross, Phys. Rev. 182, 1579 (1969); A. B. Kaidalov and B. M. Karnakov, Phys. Letters 29B, 372 (1969).
4. N. Byers, Phys. Rev. 156, 1703 (1967) and R. J. N. Phillips, Phys. Letters 4, 19 (1963) are examples of this approach.
5. Inspection of Fig. 2 shows that the 3 - 4-GeV/c and 5 - 5.5-GeV/c data up to $-u = 0.3$ lie systematically below the empirical curve $P = -0.5\sqrt{-u}/m_p$, while the 4 - 5-GeV/c data in this region of u lie above it; however, it is not yet clear to us, given the size of our errors, whether this is evidence of significant energy dependence.
6. I. J. Muzinich, Phys. Rev. 130, 1571 (1963).
7. In the notation of Ref. 6, the polarization is given by

$$P\, d\sigma/d\Omega = \mathrm{Im}\, \phi_5(\phi_1 + \phi_2 + \phi_3 - \phi_4)^* \quad .$$

For a pion Regge pole exchanged in the u channel, the only nonvanishing helicity amplitudes are $\phi_2^\pi$ and $\phi_3^\pi$. These amplitudes satisfy the condition $\phi_2^\pi = -\phi_3^\pi$ and hence give zero contribution to $P\, d\sigma/d\Omega$.

We thank G. L. Kane for calling this fact to our attention.

8. R. C. Arnold and R. K. Logan, Phys. Rev. 177, 2318 (1969).

## FIGURE CAPTIONS

Fig. 1. Side view of the experimental arragement. M2 is the polarized target magnet. The neutron beam entered through a hole in the return yoke of this magnet. M3 is the analyzing magnet in the proton spectrometer.

Fig. 2. Measured values of the polarization P in backward np scattering for the indicated values of incident neutron laboratory momentum. Errors due to counting statistics only are shown. There is an additional overall multiplicative factor of (1.00 ± 0.05) due to uncertainty in the average target polarization.

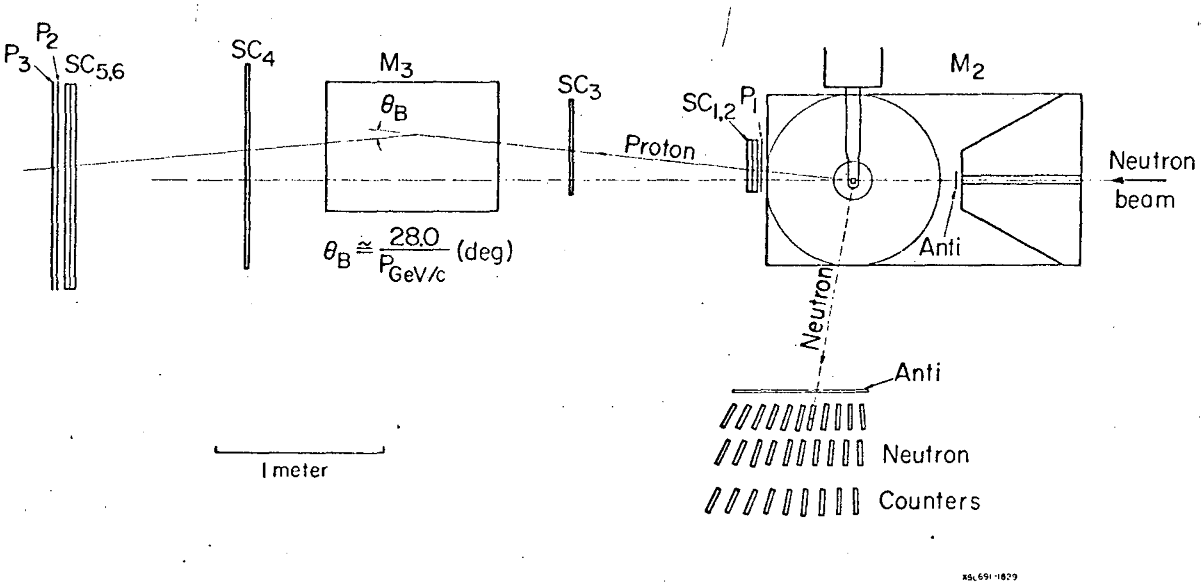
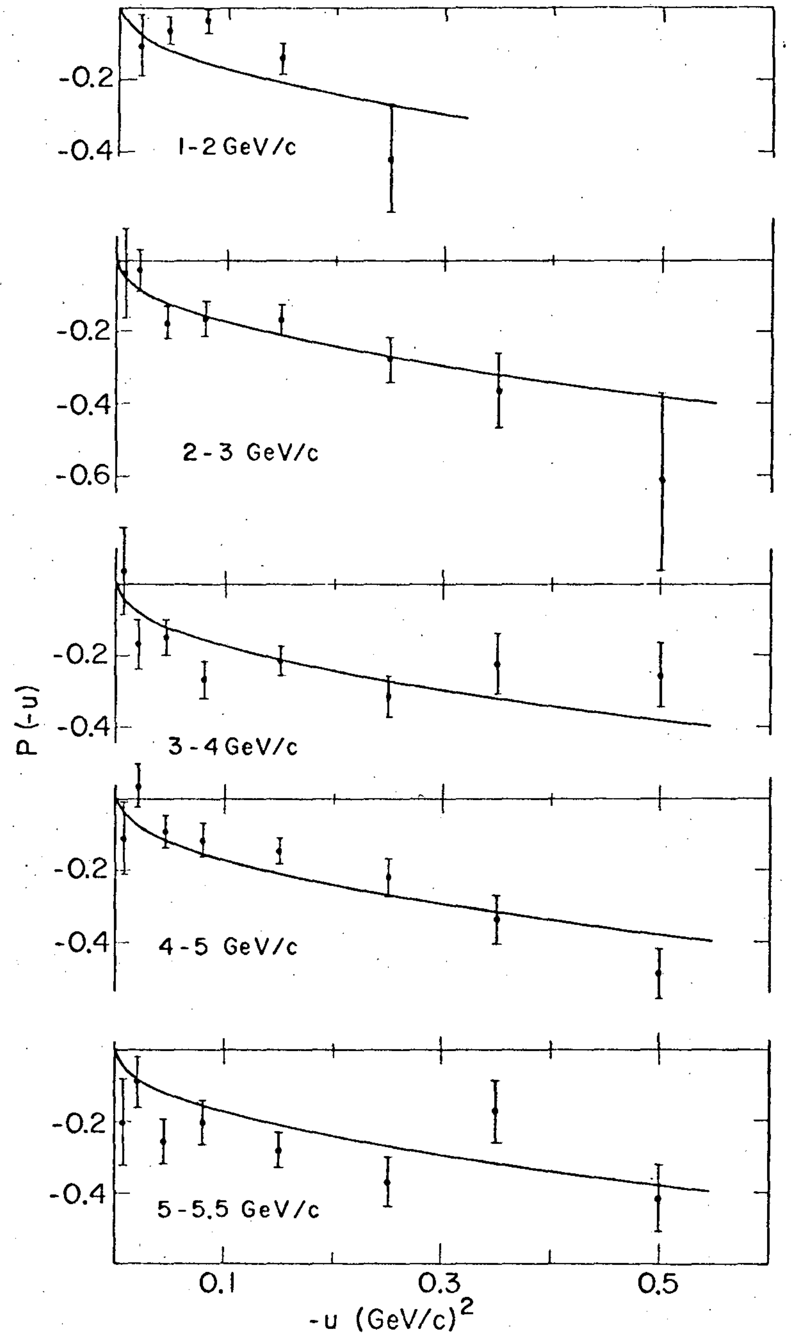

P2
P3
SC5,6
SC4
M3
θB
SC3
Proton
SC1,2
P1
M2
Neutron
beam
Anti
Neutron
Anti
Neutron
Counters
1 meter
$\theta_B \cong \frac{28.0}{P_{GeV/c}}$ (deg)
XBL691-1829

Fig. 1



XBL6910-3961

Fig. 2

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