NEUTRON-PROTON ELASTIC SCATTERING FROM 8 TO 30 GeV/c *

Bruce G. Gibbard, Lawrence W. Jones, Michael J. Longo, and John R. O'Fallon†
Randall Laboratory of Physics, University of Michigan, Ann Arbor, Michigan 48104

and

Jack Cox, Martin L. Perl, and William T. Toner
Stanford Linear Accelerator Center, Stanford, California 94305

and

Michael N. Kreisler
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey 08540
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The differential cross section for neutron-proton elastic scattering was measured in the diffraction region with incident-neutron momenta between 8 and 30 GeV/c. The experiment was a spark-chamber—counter experiment, conducted at the alternating-gradient synchrotron. Results are presented and compared with currently available lower energy np data and comparable energy pp data.

This Letter reports results of an experiment to study neutron-proton elastic scattering in the diffraction region for incident-neutron momenta between 5.4 and 29.4 GeV/c. This experiment, performed at the Brookhaven National Laboratory alternating gradient synchrotron (AGS), is a continuation of work done previously at the Bevatron[1] and employed the same techniques.

The experimental arrangement is shown schematically in Fig. 1. The internal AGS proton beam, at a momentum of 29.4 GeV/c, was steered onto a small beryllium target. A neutron beam was taken off at an angle of 1° with respect to the circulating proton beam. This beam was carefully collimated so that at the hydrogen target it had a diameter of 1.3 in. with a negligible halo surrounding it. The defining collimator was a 1.0-in.-diam aperture located 125 ft from the internal AGS target.

Charged particles were removed from the beam by means of several sweeping magnets. Lead filters, each 0.5 in. thick, placed ahead of the first two sweeping magnets effectively removed γ's from the beam. The contamination of K^0's and $\bar{n}$'s in the beam was negligible. The estimated flux in the beam was approximately 10^6 neutrons per 10^{11} interacting protons with a nominal neutron-momentum range from 5 to 29.4 GeV/c.

The neutron beam was incident on a 12-in.-long hydrogen target (Fig. 1). The scattered neutron was detected by its interaction in an array of thick-plate spark chambers. The array

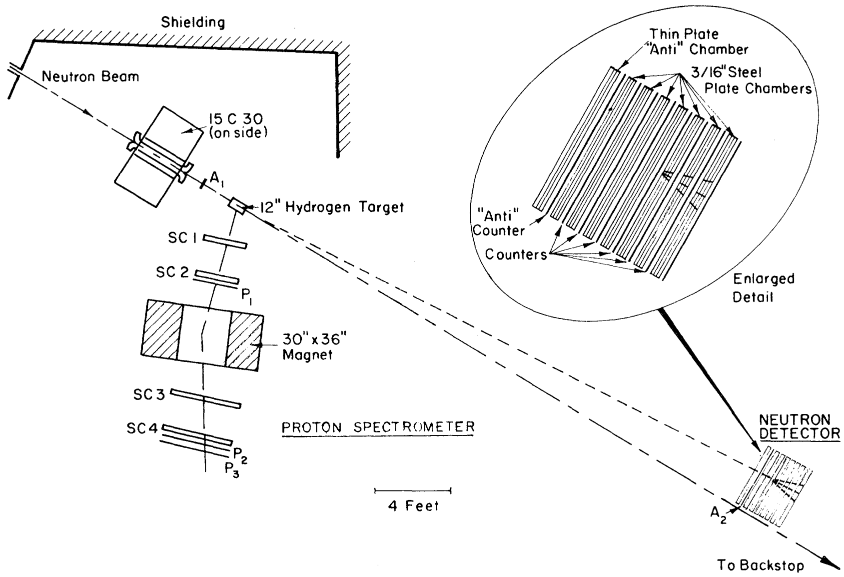

FIG. 1. Experimental arrangement.

contained a total of 130 g cm^{-2} of steel, corresponding to about 1.3 collision lengths. The chambers were interspersed with scintillation counters to provide a trigger corresponding to a neutral-particle interaction in the array. The neutron angle was determined with an accuracy of about ±2 mrad by connecting the vertex of the neutron-initiated shower in the chambers with the proton track extended into the hydrogen target.

The momentum and angle of the recoil proton were measured in a spark-chamber spectrometer. The proton spectrometer was mounted on rails to facilitate changing its position. In the course of the experiment the proton spectrometer assumed four positions covering overlapping angular ranges while the neutron detector assumed two positions. Relative normalization between the various settings was accomplished by means of several monitor telescopes in the neutron beam.

The neutron and proton spark chambers were viewed with separate cameras. The triggering requirement was a fast coincidence between counters P_1, P_2, P_3, and any two successive counters in the neutron array with no vetoing pulse from either of the anti counters, A_1 and A_2 (Fig. 1).

There was no attempt to make an absolute normalization internal to the experiment. The data presented are normalized to the optical-theorem point, neglecting the contribution from the real part of the forward-scattering amplitude, so that

$$\left.\frac{d\sigma}{d|t|}\right|_{t=0}=\frac{1}{\pi}\left(\frac{\sigma_T}{4\hbar}\right)^2.$$

The total cross section σ_T was taken to be constant at 38 mb between 5 and 30 GeV/c.[2] Since each incident-momentum range was independently normalized, a knowledge of the incident-neutron spectrum was not necessary. For the same reason, the only thing which need be known about the neutron-detection efficiency was that, for any single incident momentum, it did not change appreciably over the range of four-momentum transfers studied. In this experiment the difference in energy between the incident and scattered neutron was at most 0.7 GeV so a constant efficiency could be assumed.

Approximately 350 000 event candidates were scanned. All of the neutron film and 15% of the proton film was scanned and measured on a conventional focal-plane digitizing machine. The remaining 85% of the proton film was scanned and measured by the Michigan Automatic Scanning System.[3] The good-event yield of the film ranged from as high as 45% at the small-angle setting to as low as 0.1% at the large-angle setting.

The measured quantities for each event are the neutron angles, the proton angles, and the proton momentum. The momenta of the incident and scattered neutron are unknown. This allows a two-constraint fit to an elastic scattering. Events that gave satisfactory fits were binned according to the incident-neutron momentum and four-momentum transfer. The effective solid angle for each setting, incident-neutron momentum, and four-momentum transfer was determined from a Monte Carlo calculation.

Corrections to the data were made in the form of target-empty and inelastic-background subtractions. These corrections range from 0.6% target-empty and (1.4 ± 0.3)% inelastic-background at small $|t|$ to 0% target-empty and (29 ± 11)% inelastic-background at large $|t|$. The uncertainties assigned to the cross sections include estimated errors in the Monte Carlo, the target-

Table I. Cross sections and their uncertainties in mb/(GeV/c)^2 as a function of $|t|$ in (GeV/c)^2 for various ranges of incident momentum.

7.4 ±2GeV/c		11.4 ±2 GeV/c		15.4 ± 2 GeV/c	
|t|	dσ/dt	|t|	dσ/dt	|t|	dσ/dt
.174	22.0 ±1.3	.175	21.0 ±.93	.175	20.7 ±.87
.223	15.4 ±1.0	.224	15.5 ±.88	.223	14.1 ±.77
.274	10.3 ± .86	.274	10.6 ±.70	.273	10.0 ±.63
.323	8.20 ± .75	.323	7.18 ±.57	.323	7.46 ±.54
.372	5.70 ± .66	.374	5.34 ±.51	.373	5.13 ±.45
.423	3.69 ± .54	.422	3.50 ±.43	.423	3.20 ±.37
.473	2.57 ± .56	.474	2.59 ±.39	.474	2.18 ±.32
.538	2.60 ± .46	.545	1.83 ±.26	.549	1.54 ±.23
.649	1.16 ± .34	.651	.799 ±.17	.649	.555 ±.14
.743	.764± .27	.744	.426 ±.13	.745	.294 ±.10
.851	.423± .21	.846	.306 ±.11	.846	.128 ±.067
.934	.208± .070	.974	.173 ±.096	.969	.0560±.022
		1.170	.0690±.021	1.197	.0104±.0058
		1.476	.0339±.0123	1.515	.0187±.0078

19.4 ±2 GeV/c		23.4 ±2 GeV/c		27.4 ±2 GeV/c	
|t|	dσ/dt	|t|	dσ/dt	|t|	dσ/dt
.223	14.8 ±.79	.227	11.7 ±.82		
.274	9.94 ±.63	.273	6.56 ±.47		
.323	6.62 ±.51	.324	4.61 ±.38	.325	4.84 ±.68
.374	4.88 ±.44	.373	3.03 ±.31	.373	3.08 ±.49
.423	3.58 ±.39	.422	2.16 ±.27	.422	2.19 ±.43
.473	2.38 ±.32	.474	1.37 ±.22	.472	1.37 ±.25
.550	1.14 ±.22	.550	.721 ±.15	.553	.951 ±.26
.638	.633 ±.14	.650	.421 ±.11	.651	.391 ±.16
.743	.328 ±.10	.743	.0720±.039	.738	.0649±.026
.851	.147 ±.069	.848	.110 ±.051	.881	.0124±.0090
.985	.0617±.020	.982	.0157±.0088		
1.201	.0360±.013	1.185	.0118±.0056		
1.638	.0021±.0026				

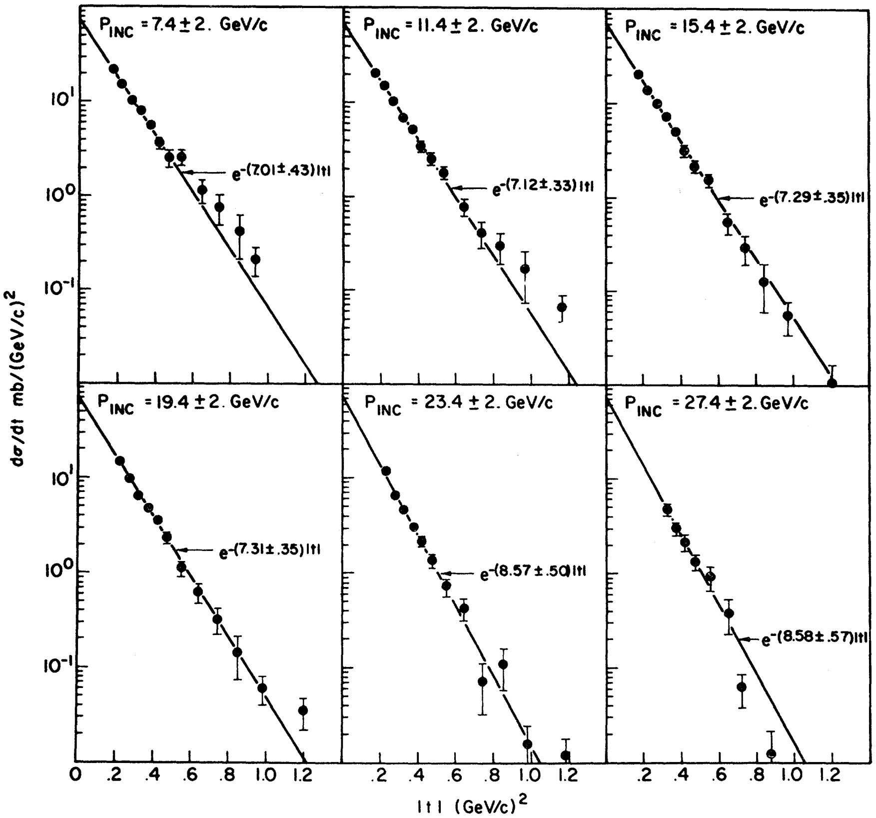

FIG. 2. Cross sections and fits by $e^{a-b|t|}$ with $|t| \leq 0.5$ (GeV/c)^2.

empty subtraction, and the inelastic-background corrections, as well as statistical errors.

Our results are summarized in Table I. In Fig. 2 the cross sections are plotted as functions of $|t|$ along with curves for the least-squares fit by $e^{a-b|t|}$ for that portion of the data where $|t| \leq 0.5$ (GeV/c)^2. These cross sections are consistent with comparable energy proton-proton and meson-proton elastic cross sections in that they are smoothly falling in t and show no structure at least out to $|t| = 1.0$ (GeV/c)^2.

In Fig. 3 we compare np and pp results[1, 4-7] for b in the parametrization $d\sigma/dt = e^{a-b|t|}$. The values for b obtained from this experiment agree well with the values obtained from both the low-energy Bevatron data and the intermediate-energy CERN data. Over the energy range of this experiment, the values obtained for b from pp data appear to be equal to or slightly greater than those from our np data. The np data, in addition, show a shrinkage in the diffraction peak (an increase in b) with increasing energy which is similar to that of pp. It is possible to fit our data with the expression suggested by the single Regge-pole model,

$$d\sigma/dt = f(t) \exp\{2[\alpha(t) - 1] \ln s\}.$$

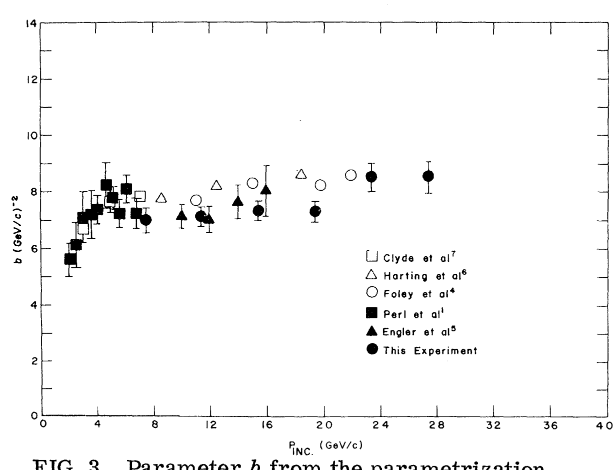

FIG. 3. Parameter b from the parametrization $e^{a-b|t|}$ as a function of incident-particle momentum for np and pp data. Fits were made for $|t| \leq 0.5$ (GeV/c)^2 except for the data of Engler et al. which had an insufficient number of small-$|t|$ points. In that case the authors' own fits for $0.3 \leq |t| \leq 0.8$ (GeV/c)^2 were used at the larger incident momenta where the diffraction slope is constant to larger $|t|$.

Here s is the center-of-mass energy squared in $(\mathrm{GeV}/c)^2$; that is, the Regge parameter conventionally called s_0 is taken to be 1.0 $(\mathrm{GeV}/c)^2$. $f(t)$ is assumed to be essentially constant for $|t| < 1.0$ $(\mathrm{GeV}/c)^2$, and $\alpha(t)$ is taken to be a linear function of t. This expression serves as a useful parametrization to study shrinkage. For the momentum range 5.4 to 29.4 GeV/c and $|t| < 1.0$ $(\mathrm{GeV}/c)^2$ the results are, for np,

$$\alpha(t) = (1.08 \pm 0.06) - (0.86 \pm 0.18)|t|;$$

for pp,

$$\alpha(t) = (1.05 \pm 0.02) - (0.69 \pm 0.05)|t|$$

(Ref. 4); for $\bar{p}p$,

$$\alpha(t) = (0.90 \pm 0.08) + (0.91 \pm 0.38)|t|$$

(Ref. 4). On the basis of this parametrization the np shrinkage appears to be the same as the pp shrinkage within the errors.

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†Present address: Physics Department, St. Louis University, St. Louis, Mo.

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AXIAL-VECTOR FORM FACTOR OF NUCLEON DETERMINED FROM THRESHOLD ELECTROPION PRODUCTION*

Yoichiro Nambu and Motohiko Yoshimura
Enrico Fermi Institute and Department of Physics, The University of Chicago, Chicago, Illinois 60637
(Received 10 November 1969)

Currently available electropion-production data near threshold have been analyzed according to the soft-pion theorem which expresses the threshold cross section in terms of the vector and axial-vector form factors of the nucleon. We determine the axial-vector form factor for q^2 up to ~7 $(\mathrm{GeV}/c)^2$.

As is well known, the condition of partial conservation of axial-vector current (PCAC) and current algebra predict that the amplitudes for electropion production at threshold,[1-5] that is, for

$$e + p \to e + p + \pi^0,$$

$$e + p \to e + n + \pi^+,$$

are expressible in terms of the vector and axial-vector form factors of the nucleon in the ideal soft-pion limit. This enables one to determine the unknown (isovector) axial form factor $G_A(q^2)$ which could otherwise be obtained only from high-energy experiments. Difficulties arise because one has to work with small cross sections along the limits of phase space, taking account of the radiative correction and the deviation from the soft-pion limit due to the finite pion mass. Earlier attempts[5] to determine $G_A(q^2)$ from electroproduction data have been restricted to small