Title

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DISCLAIMER

MEASUREMENT OF THE $\pi^- p \to n\gamma$ DIFFERENTIAL CROSS SECTION NEAR THE $P_{11}(1460)$, ROPER RESONANCE*

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ABSTRACT

We measured six differential cross sections for $\pi^- p \to n\gamma$ at 490 MeV/c incident π^- momentum. Our data do not agree with recent theoretical predictions. We find no evidence, in the sense suggested by Donnachie, for the classification of the Roper resonance, $P_{11}(1460)$, in an SU(3) antidecuplet. Our angular distribution is consistent with the classification of the Roper resonance in an octet, as predicted by the simplest quark models. Using detailed balance, our results agree well with the reported cross sections for the inverse reaction, which are deduced from γd data.

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We report results of a measurement of the differential cross section for $\pi^- p \to n\gamma$, which tests whether the Roper resonance[1] -- $P_{11}(1460)$, with $I(J^P) = 1/2(1/2^+)$ -- can be strongly photoproduced from neutrons.[2] The Roper resonance has been seen in many experiments involving peripheral interactions of $\pi^\pm$, $K^\pm$, p or $\bar{p}$ with p and d targets.[3] The Roper has not been observed in π^+ or π^o photoproduction from protons,[4,5] which could be explained by a small radiative decay rate of the Roper resonance. Another possibility, emphasized by Donnachie,[2] is that only the charged Roper has a small radiative decay rate. Thus, $P_{11}^+ \to p\gamma$ is forbidden, but $P_{11}^o \to n\gamma$ is allowed. This follows from U-spin conservation, provided that the Roper belongs to an SU(3) antidecuplet, as originally proposed by Lovelace[6] and recently by Brehm et al.[7]

In terms of a conventional multipole anlaysis, the Donnachie interpretation means that the two relevant isospin components[8] of the Roper-producing M_1- multipole cancel one another in photoproduction from protons and enhance one another in photoproduction from neutrons. This remarkable behavior of the M_1- multipole is very apparent in the parameter-free multipole analysis of Berends et al.[9] Their analysis is based on fixed-t dispersion relations and is in good agreement with most photoproduction experiments, all of which employ a proton target.

The SU(3) classification of the Roper is of particular interest for the following reason. One expects the existence of an antidecuplet in the Eightfold Way,[10] since

$$8 \times 8 = 1 + 8 + 8 + 10 + \overline{10} + 27 .$$

However, the simplest quark models exclude the antidecuplet and predict an octet classification of the Roper.[11] In these models the baryon resonances are formed from three quarks, and

$$3 \times 3 \times 3 = 1 + 8 + 8 + 10 .$$

Moorhouse[12] has pointed out that in the non-relativistic quark model one expects the photoproduction of the Roper resonance to be suppressed with both proton and neutron targets. A similar suppression appears in the quark model calculations of Copley et al.[13,14]

The shape and magnitude of the differential cross section for $\gamma n \to p\pi^-$ are necessary to determine the isospin decomposition of the pion photoproduction multipoles and serve to distinguish between the conflicting symmetry classifications of the Roper resonance. In the absence of a neutron target, our approach is to investigate the reaction $\pi^- p \to n\gamma$. The incident π^- momentum selected is 490 MeV/c, corresponding to an invariant mass of 1363 MeV/c^2. It is the maximum energy for which the multipole analysis of Berends et al.[9] is thought to be reliable and is sufficiently high to observe possible Roper production.[2]

The experiment was done at the 184-inch cyclotron of the Lawrence Radiation Laboratory. The layout of the π^- beam and the detection apparatus are shown in Fig. 1. The apparatus consists of 4 beam hodoscope planes, each with 8 to 11 counters; a pion timing counter; a 4-inch diameter liquid hydrogen target in the form of two independent half-cylinders, which gives us an option on the target thickness; an array of charged particle anticounters surrounding the target; 8 lead-scintillator-sandwich counters to reduce the $\pi^- p \to n\pi^0$ background; a neutron detector and a gamma detector, each faced with a charged particle anticounter. The neutron detector consists of 32 independent, cylindrical, liquid scintillator counters, each 2-3/4 inches in diameter and 18 inches long. Each counter points at the hydrogen target when at a distance of 12 feet. The efficiency (40 to 50%) of the detector, as well as the neutron counter cross-scattering probability, have been determined in a separate experiment.[15] The gamma detector consists of a 40-plate optical spark chamber, 30 x 30 inches, containing 10 radiation lengths of lead. Interspersed between the modules of the chamber are 8 sets of trigger counters, each 24 inches high and 27 inches wide. A PDP-5 computer collects, monitors, and transfers the digital data to magnetic tape. The spark chamber pictures are scanned and measured by an automatic PDP-5 vidicon system.[16]

An event is defined as a coincidence of signals in the beam hodoscope, one neutron counter, and two gamma counters, provided no anticounters fired. For each event we determine the neutron and gamma angles relative to the incident π^- and the neutron time of flight. The beam energy has been measured separately. All events are analyzed assuming $\pi^- p \to n\gamma$.

To separate the $n\gamma$ from the charge exchange process, which occurs about a hundred times as frequently, we use three parameters determined for each event, namely, the reconstructed π^- momentum and the measured neutron time of flight and coplanarity. Coplanarity is defined at the neutron array as the perpendicular distance between the center of the triggered neutron counter and the $\pi\gamma$ plane. We define the normalized deviation in each parameter as the difference between measured and expected values divided by the non-gaussian uncertainty introduced by the finite target size, beam divergence, and resolution of the detectors. The expected values are the known beam momentum, the neutron time of flight appropiate for the γ angle and mean beam momentum, and the absolute coplanarity. The distribution of normalized deviations in the three parameters for each run is a check on the alignment of the apparatus, the timing calibration, and the mean beam momentum.

For each event a pseudo-χ^2 value is calculated from two of the three parameters, and its frequency distribution is displayed versus the number of standard deviations of the third parameter. Also, a χ^2 distribution is made which uses all three parameters simultaneously. The detection of the $n\gamma$ and $n\pi^o$ reactions are independently simulated by an extensive Monte Carlo program. The same analysis of the Monte Carlo-simulated events produces χ^2 distributions separately for the signal and background. The number of $n\gamma$ events is obtained from a χ^2 frequency distribution by a maximum likelihood fit of the Monte Carlo $n\gamma$ and $n\pi^o$ χ^2 distribution to the data distribution. The commonly used χ^2 distribution is based on coplanarity and reconstructed π^- momentum, for events with neutron time of flight within 3.5 standard deviations. A good example of such a distribution is shown in Fig. 2. The $n\gamma$ peak stands out clearly above the $n\pi^o$ background. The dashed line is the Monte Carlo-generated background.

Our results for the differential cross section for $\pi^- p \to n\gamma$ have been converted to the reaction $\gamma n \to \pi^- p$ under the assumption of time reversal invariance. They are listed in Table 1 and displayed in Figure 3. The errors shown include the statistical uncertainties only. There is about a 7% normalization uncertainty. Also shown in Fig. 3 are the results of three experiments in which the $\gamma n \to \pi^- p$ cross section has been deduced from γd investigations.[17,18,19] The cross sections reported by Neugebauer _et al._[17] --which are obtained by multiplying the $(\gamma d \to \pi^- x)/(\gamma d \to \pi^+ y)$ ratio by the $\gamma p \to \pi^+ n$ cross section -- have been updated by using more recent γp

measurements[20] and they have been linearly interpolated to our energy. The results of a bubble chamber experiment[19] on $\gamma d \rightarrow \pi^- pp$ have been averaged over 30^o bins; we averaged this data because it has large error bars and the cross section appears to be smooth. Finally, we have included in Fig. 3 the theoretical predictions by Berends et al.[9] and by the Karlsruhe group[21,22] and the speculation by Donnachie[2] (M_1- multipole set to zero, otherwise equal to Berends et al.), all made for 500 MeV photons.

Our results disagree strongly with the predictions of Berends et al.[9] This casts doubt on their treatment of the M_1- multipole. We find no evidence, in the sense suggested by Donnachie, for the classification of the Roper in an antidecuplet. The flatness of our measured differential cross section is suggestive of a small M_1- multipole and a small radiative decay rate of the neutral Roper. This is consistent with the classification of the Roper in an octet as done in the simplest quark models.[12-14] When we vary the magnitude of the M_1- multipole, keeping the other multipoles fixed at the values of Berends et al.,[9] we do not obtain an acceptable overall fit. This result, and the fact that our measurements disagree with the predictions of the Karlsruhe group,[21,22] who calculate the M_1- multipole from dispersion integrals without contributions from the Roper resonance, lead to the conclusion that in this energy region the results of the above dispersion relation calculations[9,21] are not useful without some revision of the multipoles, or, perhaps, their isospin decomposition.[23]

Using detailed balance, our results agree very well with the reported cross sections for the inverse reaction, as deduced from γd data. There is no apparent violation of time reversal invariance in this process at this energy, barring unexpected cancellation of time reversal effects by the deuterium corrections.

We wish to express our deep appreciation to Dr. J.A. Helland for many valuable contributions in the early phase of the experiment. The cyclotron was operated by Mr. J. Vale and his crew and the experimental equipment was installed by Mr. L. Sylvia and his crew, to whom we are extremely grateful. It has been a pleasure to have the technical support of Mr. R. Belisle of UCLA and the technicians of LRL. Assistance in data collection and analysis by J. Comiso and A. Weiss is gratefully acknowledged. We are particularly indebted to Professor Kenneth M. Crowe for his continued support and interest in this work.

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$$\gamma p \to \pi^+ n \qquad A^+ = \sqrt{2}\,(S_o + \frac{1}{3} V_1 - \frac{1}{3} V_3)$$

$$\gamma p \to \pi^o p \qquad A^o = S_o + \frac{1}{3} V_1 + \frac{2}{3} V_3$$

$$\gamma n \to \pi^- p \qquad A^- = \sqrt{2}\,(S_o - \frac{1}{3} V_1 + \frac{1}{3} V_3)$$

where S_o = isoscalar amplitude;

V_1 = isovector amplitude, with $I_f = 1/2$;

V_3 = isovector amplitude, with $I_f = 3/2$.

The Roper, P_{11}, is produced by S_o and V_1 components of the M_1- multipole.

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Table 1. Experimental Differential Cross Sections for $\pi^- p \rightarrow n\gamma$, with 490 MeV/c Incident π^-.*

$\tilde{\theta}_\gamma$ Degrees	$d\tilde{\sigma}/d\tilde{\Omega}$ ($\pi^- p \rightarrow n\gamma$) Microbarns/Steradian	$d\tilde{\sigma}/d\tilde{\Omega}$ ($\gamma n \rightarrow p\pi^-$) Microbarns/Steradian
44	19.8 ± 1.2	9.4 ± 0.7
72	22.1 ± 1.6	10.5 ± 0.8
92	15.0 ± 1.7	7.2 ± 0.8
111	11.7 ± 1.4	5.7 ± 0.7
132	13.0 ± 0.8	6.2 ± 0.4
151	12.9 ± 0.8	6.2 ± 0.4

*The third column lists the calculated cross sections for $\gamma n \rightarrow p\pi^-$ corresponding to 520 MeV (lab) incident photons. The errors include statistical uncertainties only. The normalization uncertainty is 7%.

FIGURE CAPTIONS

Figure 1 Beam Layout and Experimental Apparatus

Figure 2 χ^2 (coplanarity and momentum) Frequency Distribution with 3.5 Standard Deviation Gate on Neutron Time of Flight

Figure 3 Differential Cross Section for $\gamma n \rightarrow \pi^- p$ at $E_\gamma = 520$ MeV. The theoretical predictions, calculated for $E_\gamma = 500$ MeV, are due to: Berends et al., Ref. 9, indicated by the dashed line; Karlsruhe group, Ref. 20,21, indicated by the solid line; and Donnachie, Ref. 2, indicated by the dashed-dotted line. The experimental points are: ○ from Ref. 16, π^-/π^+ ratio; ✚ from Ref. 18, bubble chamber; ◇ from Ref. 17, spark chamber; and ■ is this experiment, namely, $\pi^- p \rightarrow n\gamma$ at $P_{\pi^-} = 490$ MeV/c.

Notes for printer:

○ is special character number 230;

✚ is special character number 1;

◇ is special character number 248;

■ is special character number 228.

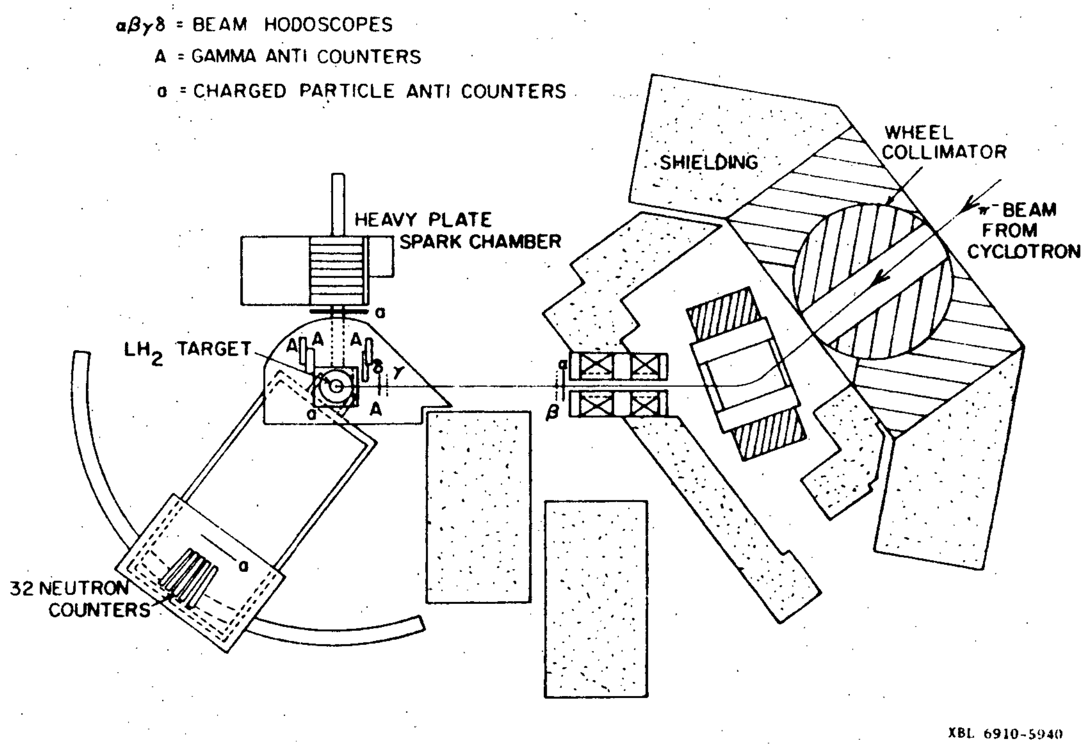

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Figure 1.
Measurement of the $\pi^- p \to n\gamma$ Differential Cross Section Near the $P_{11}(1460)$, Roper Resonance.

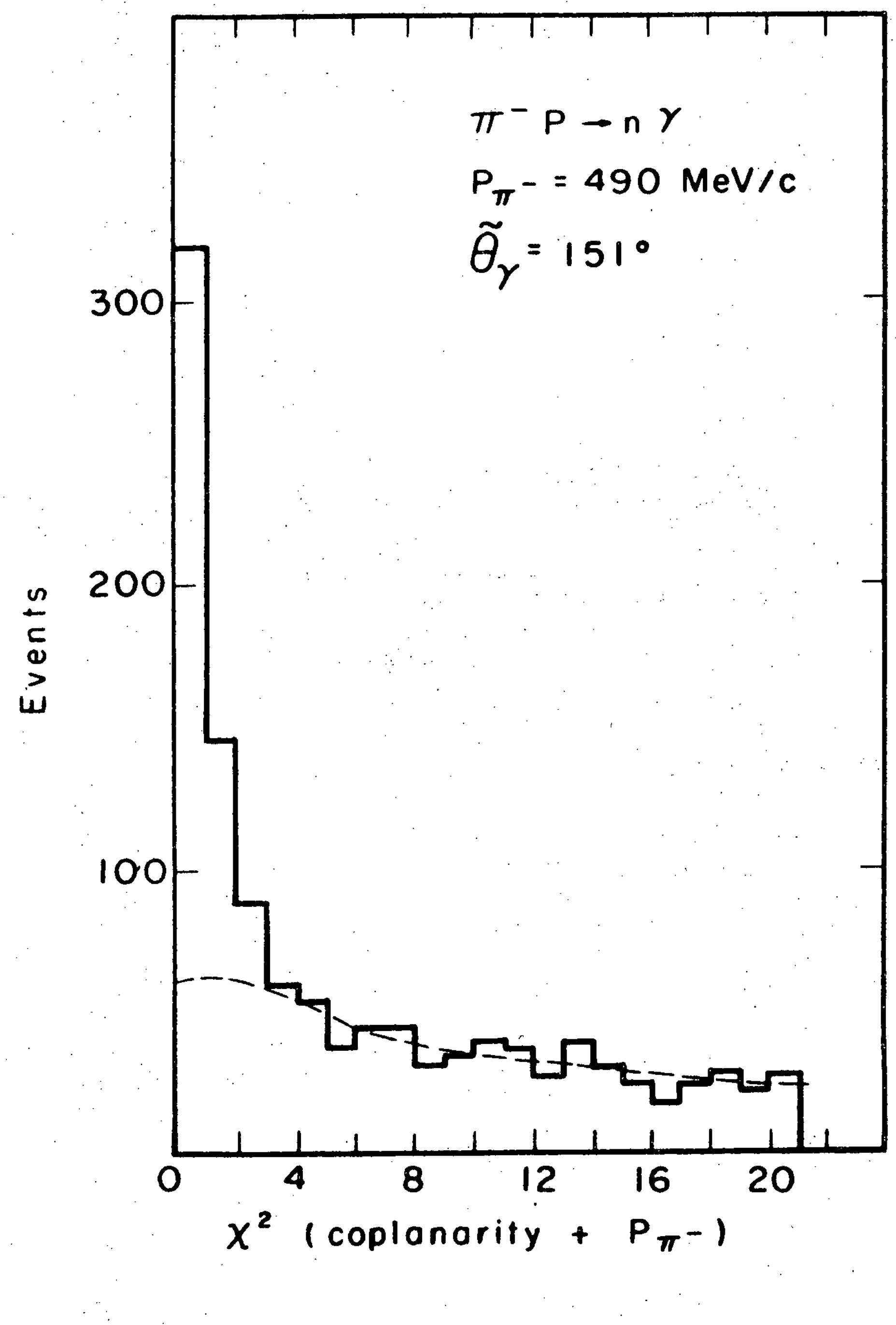

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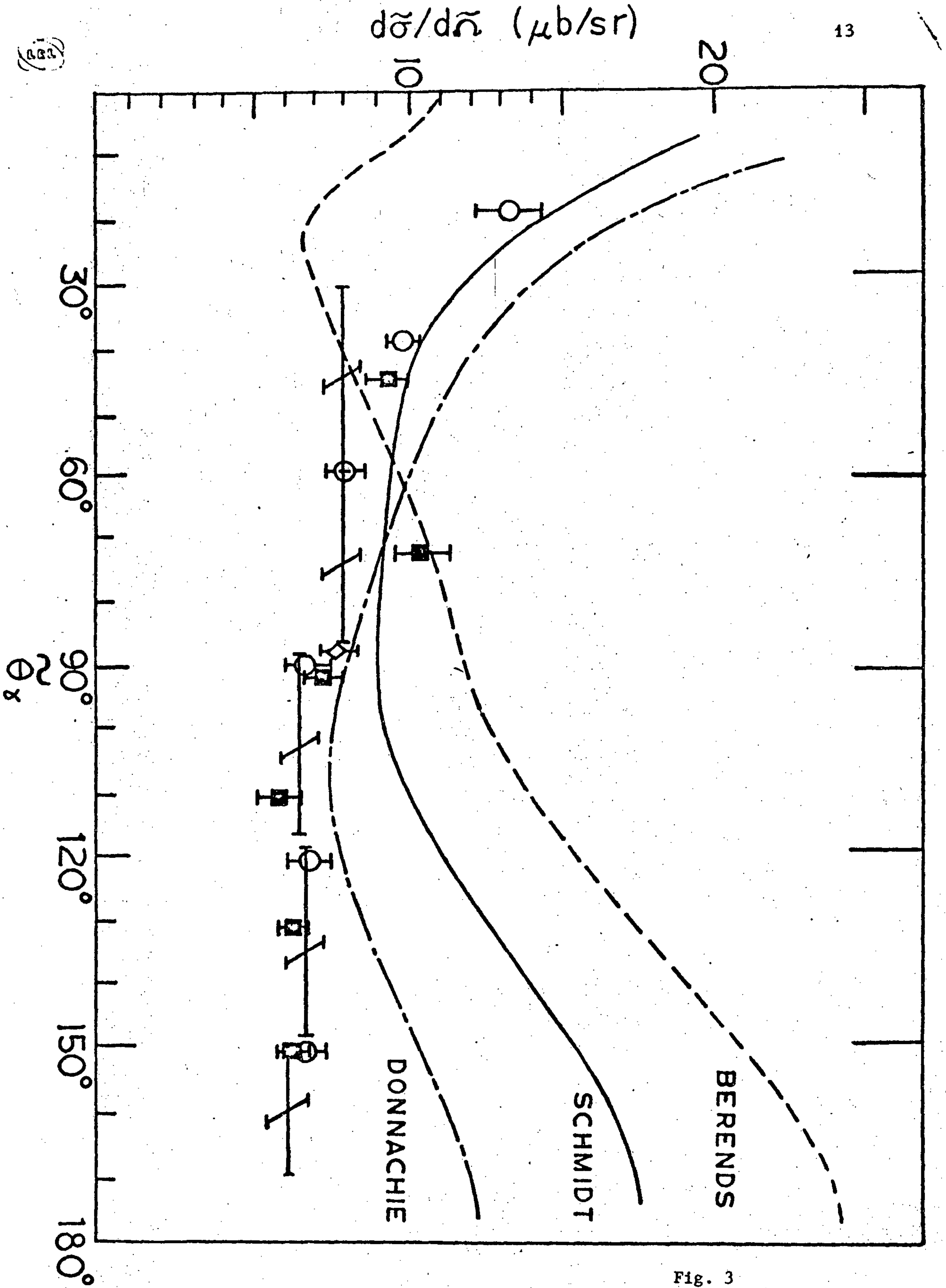
Figure 2.
Measurement of the $\pi^- p \to n\gamma$ Differential Cross Section Near the P_{11}(1460), Roper Resonance.



dσ̃/dΩ̃ (μb/sr)
10
20
30°
60°
90°
120°
150°
180°
BERENDS
SCHMIDT
DONNACHIE

Fig. 3

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