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IN SEARCH OF THE ROPER RESONANCE IN $\pi^- + p \rightarrow \gamma + n$

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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IN SEARCH OF THE ROPER RESONANCE IN $\pi^- + p \to \gamma + n$ *

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We report on a measurement of the differential cross section for $\pi^- p \to \gamma n$ at 490 MeV/c incident π^- momentum. This momentum was selected to test if the Roper resonance [1,2] would be strongly photoproduced on a neutron target[3]. Recent measurements show that the Roper resonance does not manifest itself in either π^+ or π^o photoproduction[4,5] on protons. Presumably this is due to an accidental cancellation of the relevant isospin amplitudes for Roper photoproduction on protons, namely, $M_{1}-^{o} \approx +M_{1}-^{1}$. This condition automatically ensures the maximum enhancement for Roper photoproduction on neutrons, since now $M_{1}-^{o} \approx -M_{1}-^{1}$. This remarkable behavior of the M_1- multipole is very apparent in the parameter-free multipole analysis of Berends et al.[6]. Their analysis is based on fixed-t dispersion relations and it is in good agreement with most photoproduction experiments, all of which employ a proton target. Donnachie[3] has emphasized that the accidental cancellation and enhancement phenomenon in Roper photoproduction can be understood as a consequence of U-spin conservation if the Roper is in an SU(3) anti-decuplet. The existence of an anti-decuplet is expected in the 8-fold way, since

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

However, it would not be allowed in the simple quark models, including the currently fashionable non-relativistic quark models[7], since

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

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The momentum selected for our experiment is the highest for which the multipole analysis of Berends et al.[6] is carried out, and it is sufficiently high to observe possible Roper production.

The experiment was conducted at the 184-inch cyclotron of the Lawrence Radiation Laboratory. The layout of the π^- beam and the detection apparatus is shown in Figure 1. The detection apparatus consists of 4 hodoscope planes, each with 8 to 10 counters; a timing counter; a 4-inch diameter hydrogen target in the form of two half-cylinders which gives us an option on the target thickness; an anti-counter box around the target to eliminate elastically scattered particles; various anti-gamma counters made of lead scintillation sandwiches to reduce the overwhelming $\pi^- p \to \pi^o n$ background; a neutron detector and a gamma detector. The neutron detector consists of 32 liquid scintillator counters, each 2-3/4 inches in diameter and 18 inches long, arranged in a box-type structure with not-quite close packing. The efficiency of these counters, which is 30 to 40%, has been carefully measured, including the neutron cross scattering in the counters. Each counter has its own zero-crossing discriminator to optimize the timing accuracy. The gamma detector consists of a 40-plate optical spark chamber 30" x 30" containing 10 radiation lengths of lead. Interspersed between the modules of the chambers are 8 sets of trigger counters. Pertinent counter information is stored on magnetic tape and displayed by a PDP-5 on-line computer. The spark chamber pictures are scanned and measured by an automatic vidicon system.

To separate the desired $n\gamma$ reaction from the dominant charge-exchange process, we make use of coplanarity, the neutron energy as determined by our time-of-flight measurements, and conservation of energy. The analysis proceeds as follows. Each recorded event is treated as a $\pi^- p \to n\gamma$ event, and the three above-mentioned quantities are determined and compared with the expected values with due allowance for the uncertainties introduced by the finite target size, beam divergence, and the resolution of our detectors. The distribution of the above quantities in each run serves as a check on the alignment of the apparatus, timing calibration, etc.

Figure 2 shows the coplanarity of all recorded events in a typical run. The coplanarity is defined as the perpendicular distance between the triggered neutron counter and the $\pi\gamma$ plane. The coplanar $n\gamma$ events are clearly visible above the non-coplanar background originating from $n\pi^0$ events. Finally, we calculate a χ^2 value for each event, based on two of the above three criteria, and display it in an array vs. the number of standard deviations of the third criterium. Also, a χ^2 plot is made which employs all three criteria simultaneously for all events of a run. The experiment is simulated by an extensive Monte Carlo program. The Monte Carlo-simulated events are processed with the above analysis program to produce χ^2 distributions for the proper evaluation of the background. The number of events is then obtained from one of the above χ^2 plots, usually the χ^2 distribution based on coplanarity and beam-momentum plus a cut in the timing. A good example is shown in Figure 3, which shows the χ^2 distribution at 74^o based on coplanarity and momentum for events which fell within three standard deviations of the $n\gamma$ time. The $n\gamma$ peak stands out clearly above the $n\pi^0$ background. The dashed curve in the picture is the Monte Carlo-generated distribution of the background due to charge exchange and accidentals.

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 displayed in Figure 4. This figure also shows the $\gamma + n \to \pi^- + p$ results deduced from the π^-/π^+ ratio in in deuterium[8], interpolated to our momentum; the π^+ cross sections used are those given in the figures of the compilation by Beale et al.[9]. We have also included the recent measurement at 90^o by a spark chamber group[10] of $\gamma + d \to \pi^- + p + p$. The results of a bubble chamber experiment[11] on $\gamma + d \to \pi^- + p + p$ are summed into 30^o bins and also displayed; we have summed this data due to the large error bars. Finally, we have included in Figure 4 the predictions by Berends et al.[6] and Schmidt[12] and the speculation by Donnachie[3], all for 500 MeV photons. Our quoted errors are statistical only. Not included is a possible 10% systematic uncertainty, due to our estimates of the beam contamination, spark chamber efficiency, etc.

The analysis of our data is as follows. We disagree strongly with the predictions by Berends et al.[6] and Schmidt[12]. This casts doubt on their treatment of the M_1- multipole. We find no evidence in the sense suggested by Donnachie[3] for the classification of the Roper in an anti-decuplet. The agreement with the inverse reaction is striking, which supports our hypothesis of time reversal invariance at this energy.

It is a pleasure to make acknowledgment to Dr. Jerome Helland for his assistance in the early stage of the experiment, and to Mr. James Vale and the cyclotron personnel for their skillful work.

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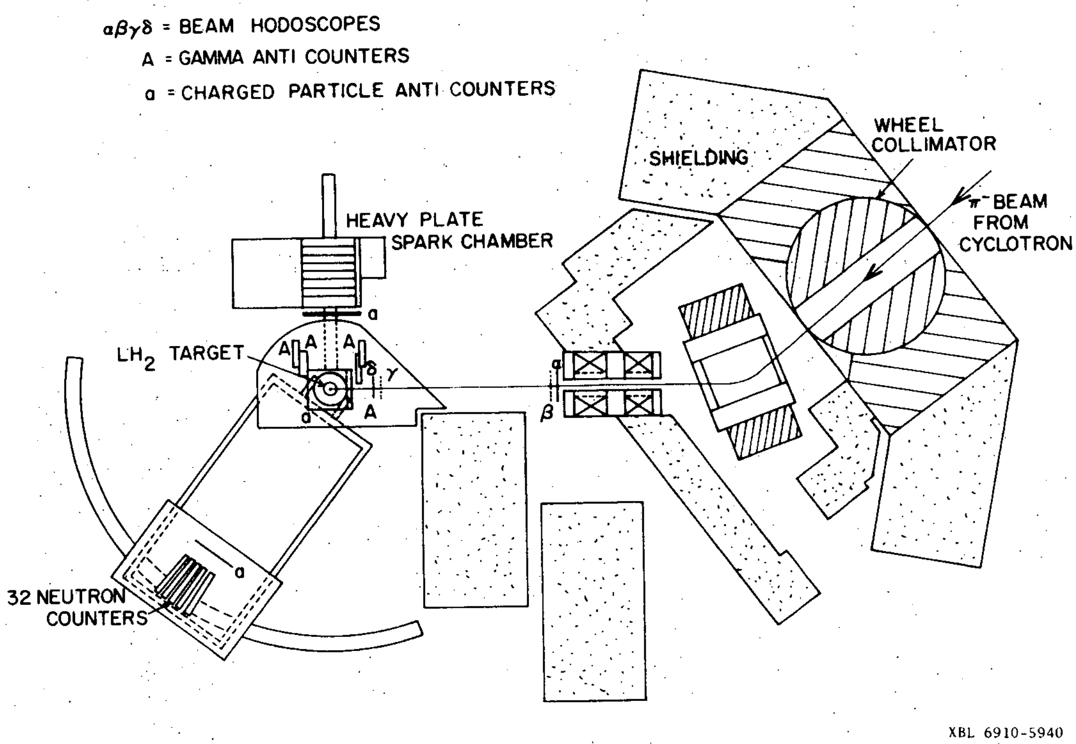

Fig. 1. Beam Layout and Experimental Apparatus.

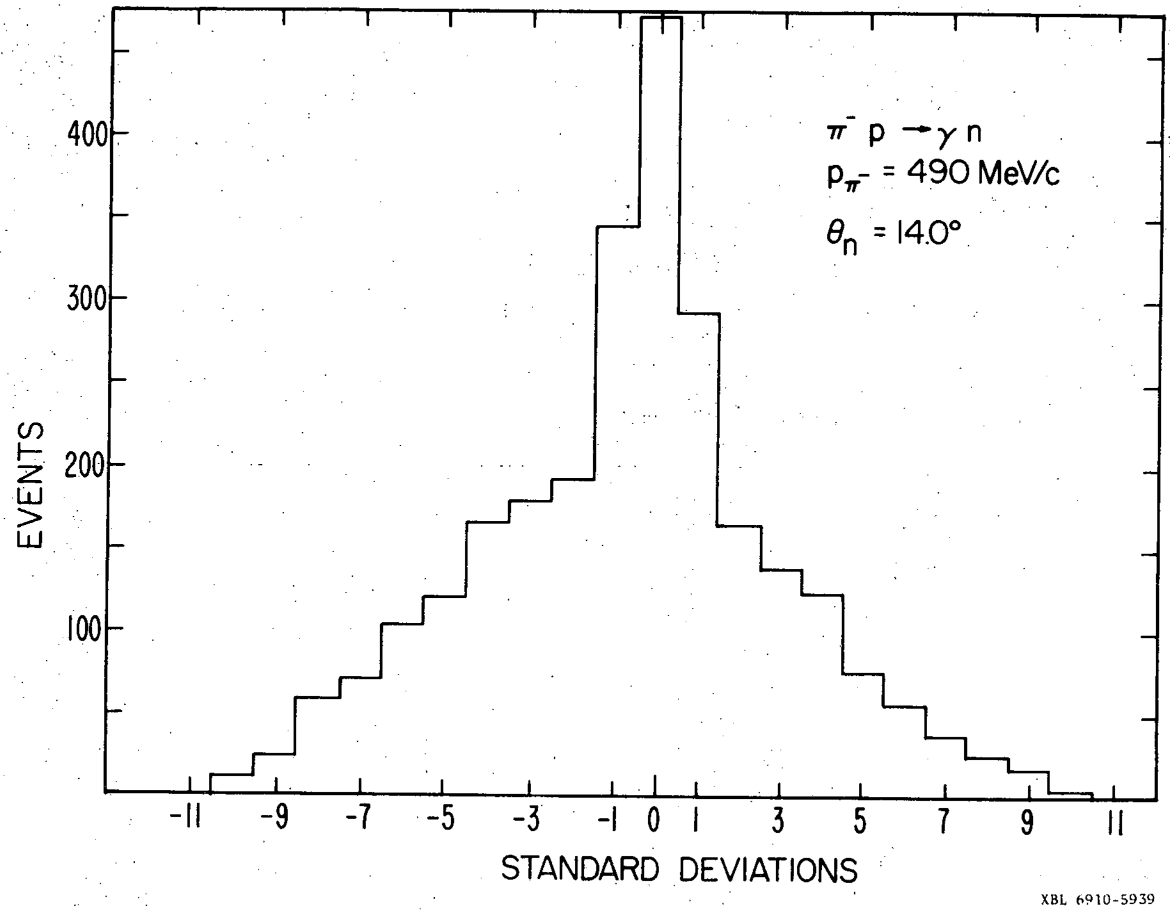

Fig. 2. Coplanarity Distribution.

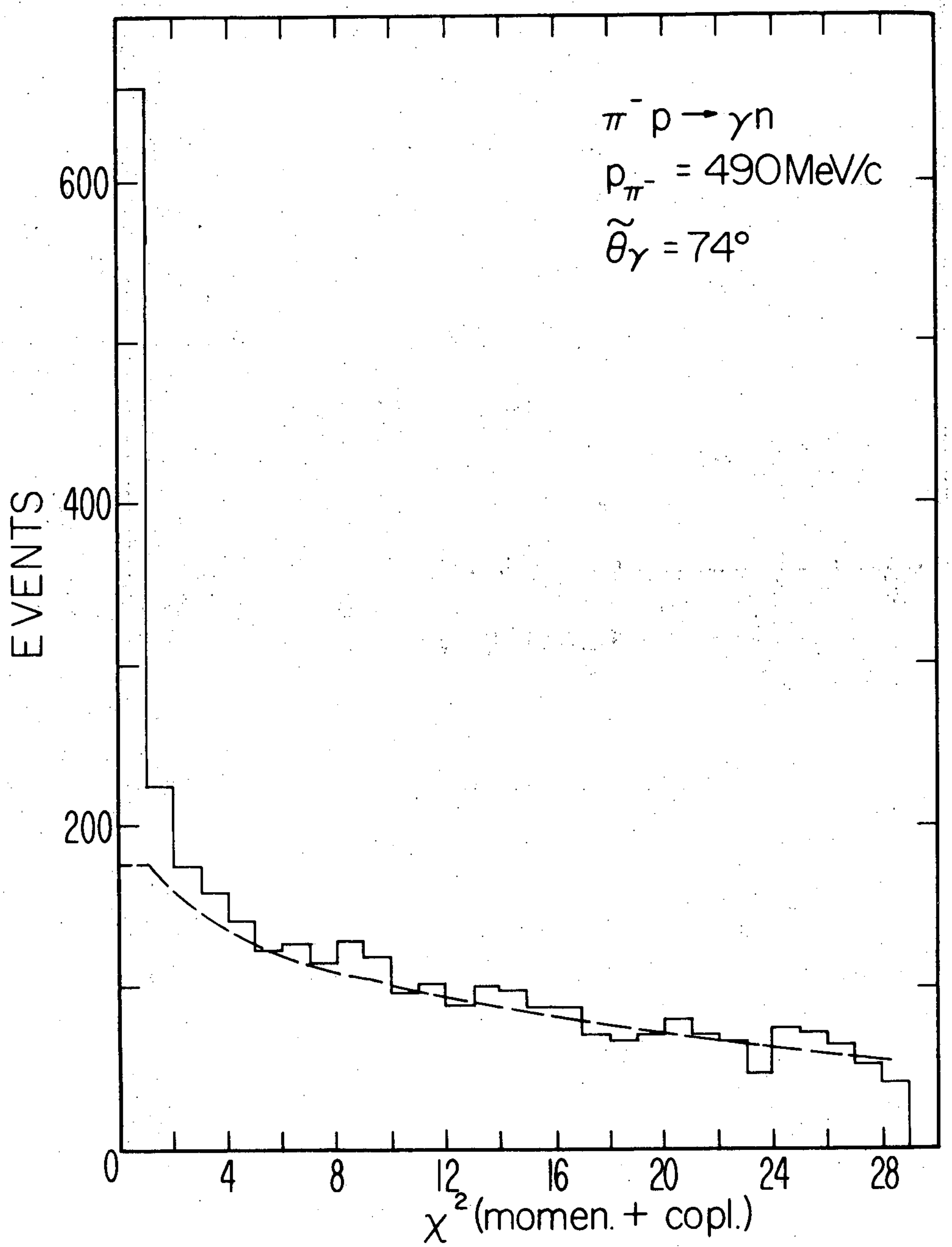

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Fig. 3. χ^2 Distributions.

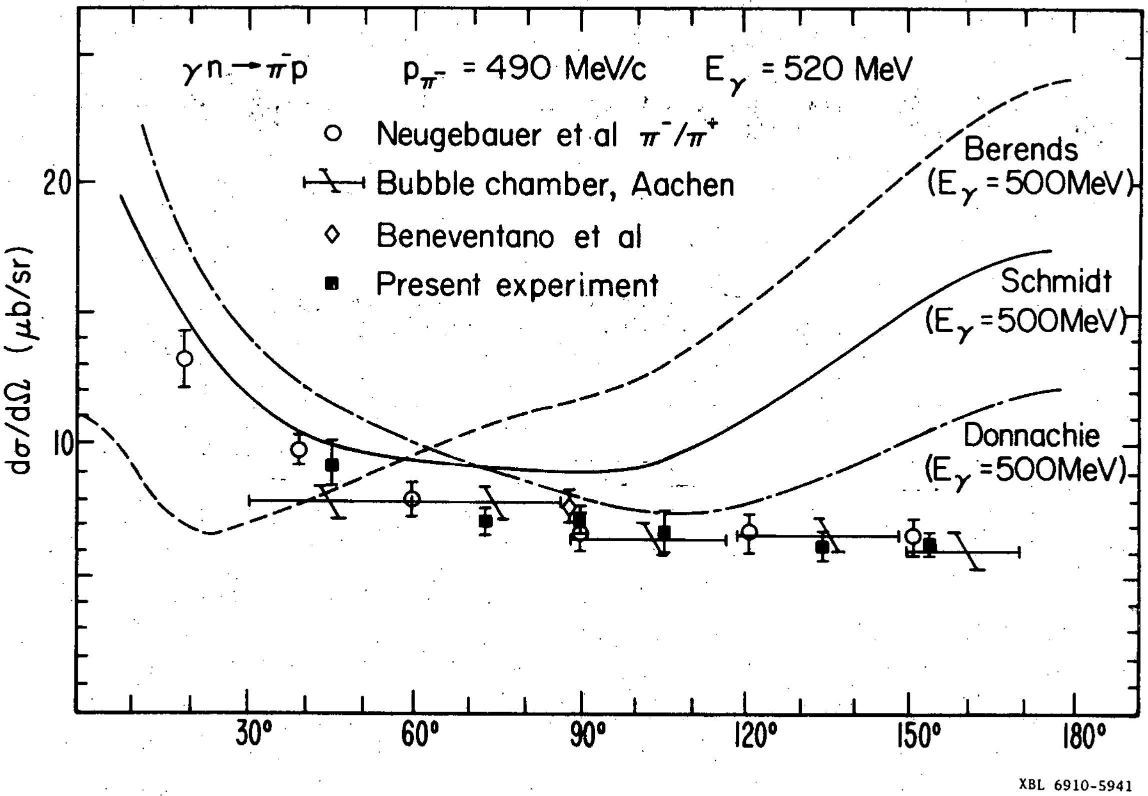

Fig. 4. Experimental results and comparisons with other experiments and theory.

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