### Title

ANGULAR DISTRIBUTIONS FOR n- p->n|n AT 315 AND 371 MeV




### Authors

Kurz, Richard J.
Lind, Don L.



### Publication Date

1964-07-06

## DISCLAIMER

UCRL-11548

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

# ANGULAR DISTRIBUTIONS FOR $\pi^- p \rightarrow \pi^0 n$ AT 315 AND 371 MeV.

Richard J. Kurz and Don L. Lind

July 6, 1964

# ANGULAR DISTRIBUTIONS FOR $\pi^-p \to \pi^0 n$ AT 315 AND 371 MeV*

Richard J. Kurz and Don L. Lind†

Lawrence Radiation Laboratory
University of California
Berkeley, California

July 6, 1964

We report here an analysis of the angular distribution of the reaction $\pi^-p \to \pi^0 n$ incorporating four classes of data: (a) previously-published $\gamma$-angular distributions at $T_{\pi^-} = 317$ and 371 MeV[1] ($T_{\pi^-}$ = incident $\pi^-$ kinetic energy); (b) the neutron differential cross section at $T_{\pi^-} = 374$ MeV in the range $84 \leq \theta_n^* \leq 133$ deg[2] ($\theta_n^*$ = c.m.-system neutron angle = $\pi - \theta_{\pi^0}^*$, * denotes c.m.-system variable), (c) neutron differential cross sections at $T_{\pi^-} = 313$ and 371 MeV in the range $21 \leq \theta_n^* \leq 123$ deg[3]; and (d) the differential cross section at $\theta_{\pi^0}^* = 0$ deg calculated from the forward-direction, fixed-momentum-transfer dispersion relations for pion nucleon scattering.[4] A least-squares analysis was performed to fit these data to the c.m.-system differential cross section in the form:

$$\frac{d\sigma}{d\Omega^*}(\cos\theta_{\pi^0}^*) = \sum_{\ell=0}^{N} a_\ell P_\ell(\cos\theta_{\pi^0}^*) \quad . \tag{1}$$

The $\gamma$-data were incorporated into the least-squares analysis according to the procedure used by Caris et al. If $d\sigma/d\Omega^*$ is represented as in Eq. (1), the expected experimental $\gamma$-angular distribution in the c.m. system, taking into the account the $\gamma$ detection efficiency of the experimental system, is given by:

$$\frac{d\sigma^\gamma}{d\Omega^*}(\cos\theta_\gamma^*) = \sum_{\ell=0}^{N} a_\ell P_\ell(\cos\theta_\gamma^*) \int_{-1}^{1} \frac{dx P_\ell(x)\epsilon(k)}{(\gamma - \eta x)^2} \, , \tag{2}$$

where x is the cosine of the angle between the photon and the $\pi^0$ in the c.m. system, $\gamma$ and $\eta$ denote the motion of the $\pi^0$ rest system with respect to the c.m. system, and $\epsilon(k)$ is the $\gamma$-detector efficiency as a function of the photon lab-system energy, k, which in turn is a function of x and $\cos\theta_\gamma^*$.

The present analysis started with the uncorrected data of Caris et al. (see Table IV, Ref. 1). The correction of the observed distributions to take into account photons originating from the reactions $\pi^- p \rightarrow \pi^0\pi^0 n$ and $\pi^-\pi^0 p$ was reperformed. The availability of more precise information on these reactions made a more accurate estimation of the correction feasible.[5] For each reaction we assumed that the $\pi^0$'s had an invariant phase-space energy distribution and an isotropic angular distribution in the c.m. system. We calculated the corresponding lab-system distribution of photons in energy and angle, $d^2\sigma/dkd\Omega$, with a normalization determined by the total cross sections for the $\pi^0\pi^0 n$ and $\pi^-\pi^0 p$ reactions. To obtain the values of $d\sigma^\gamma/d\Omega^*$ used in this analysis, we subtracted the quantity,

$$\frac{d\sigma^{inel}}{d\Omega}(\theta_\gamma) = \int dk \, \frac{d^2\sigma(k,\theta_\gamma)}{dkd\Omega} = \epsilon(k) \ , \qquad (3)$$

from the uncorrected data points of Caris et al. We used their original values for the remaining corrections that they discuss. The values used in the least-squares analysis are given in Table I.

The neutron data provided information on the portion of the angular distribution in which the uncertainties in the $\gamma$ data are greatest. The relative magnitude of the calculated corrections to the $\gamma$-angular distribution is greatest for $\theta_\gamma^* > 90$ deg. In addition, the statistical weight of the $\gamma$ data is lowest in this region.

Two experiments with similar neutron detectors and time-of-flight techniques were performed to obtain the two classes of neutron differential cross section data. It was not possible to make a separation between the neutrons from the $\pi^- p \rightarrow \pi^0 n$ reaction and those from the $\pi^0 \pi^0 n$ reaction for $\theta_n < 40$ deg with the arrangement of the experimental system used in the $T_{\pi^-} = 374$ MeV measurements. To provide a clear separation for $\theta_n \geq 10$ deg the second set of neutron measurements of $T_{\pi^-} = 313$ and 371 MeV were made with a configuration of the system yielding higher neutron-energy-resolution. The values of the neutron differential cross section in the c.m. system that we used in the least-squares analysis are given in Table I.

The forward-dispersion-relation values of the differential cross section at $\theta^*_{\pi^0} = 0$ deg that we employed in the analysis are also given in Table I.

We performed the least-squares analysis with (a) the recorrected $\gamma$ data alone, (b) the neutron data and the dispersion-relation points, and (c) all data simultaneously. The results are given in Table II. At $T_{\pi^-} = 315$ (the average $T_{\pi^-}$ for the various data) and 371 MeV the probability of fit was not significantly increased for $N > 2$ for case (a) and for $N > 3$ for cases (b) and (c). At $T_{\pi^-} = 315$ MeV for case (c) the $\gamma$-data point at $\cos \theta^*_\gamma = -0.869$ was deleted since the inclusion of this point decreased the probability of fit for $N = 3$ to 0.03. Similarly, at $T_{\pi^-} = 371$ MeV the $\gamma$-data point at $\cos \theta^*_\gamma = -0.955$ was deleted since the inclusion of this point decreased the probability of fit to 0.001.

The differential cross section for $\pi^- p \rightarrow \pi^0 n$ at $T_{\pi^-} = 315$ and 371 MeV as determined by the least-squares analysis of the recorrected $\gamma$ data and by the analysis of the combined data are plotted in Fig. 1. The non-zero value of $a_3$ obtained in the combined data analysis is consistent with the requirement of at least D-waves in other analyses of pion-nucleon interactions at $T_{\pi^\pm} = 310$ MeV.[6] However, the behavior of the angular distribution in the region of $\theta^*_{\pi^0} = 180$ deg is not consistent with any of the SPD-solutions of Vik and Rugge. The same comment applies to the results of measurements of the neutron polarization in $\pi^- p \rightarrow \pi^0 n$ at $T_{\pi^-} = 310$ MeV.[7] The differential cross section obtained here corresponds most closely to predictions obtained from SPDF-solutions II and IV of Vik and Rugge.[8] We note that the SPDF-solution II of Vik and Rugge is preferred by the recent theoretical analysis of pion-nucleon scattering of Donnachie et al.[9] The angular distribution at $T_{\pi^-} = 315$ and 371 MeV presented here deviates from that determined from the $\gamma$ data alone in a manner which is in agreement with the predictions of an energy-dependent phase-shift analysis of pion-nucleon scattering by Roper.[8,10] The predictions by Roper at $T_{\pi^-} = 310$ and 370 MeV are also plotted in Fig. 1. He used the data of Caris et al. in his analysis as well as all other available data on pion-nucleon scattering (including the neutron polarization data referred to above). At both energies, $d\sigma/d\Omega^*$ for $\theta^*_{\pi^0} > 90$ deg is lower than the predictions by Roper. At $\theta^*_{\pi^0} = 180$ deg, isotopic spin considerations place a lower limit on $d\sigma/d\Omega$ for $\pi^- p \rightarrow \pi^0 n$ in terms of the differential cross sections for $\pi^\pm p \rightarrow \pi^\pm p$ at $\theta_\pi = 180$ deg.

$$\frac{d\sigma^0}{d\Omega} \geq \frac{1}{2} \left[ \left( \frac{d\sigma^+}{d\Omega} \right)^{1/2} - \left( \frac{d\sigma^-}{d\Omega} \right)^{1/2} \right]^2 . \qquad (4)$$

If we use the available data on elastic scattering,[11] this limit is $0.77 \pm 0.20$ mb/sr at $T_{\pi^-} = 310$ MeV and $0.13 \pm 0.06$ mb/sr at $T_{\pi^-} = 370$ MeV. The values corresponding to the N = 3, combined-data fit of Table II are $0.50 \pm 0.11$ mb/sr and $0.07 \pm 0.07$ mb/sr respectively. Thus the present charge-exchange angular distributions at $\theta^*_{\pi^0} = 180$ deg are barely compatible with this limit.

It is a pleasure to thank Dr. L. David Roper for his helpful discussions and cooperation in transmitting the results of his phase-shift analysis. We are grateful to Dr. T. D. Spearman for pointing out the limit on charge-exchange differential cross sections at 180 deg. We are indebted to Dr. Victor Perez-Mendez, Professors Burton J. Moyer and A. Carl Helmholz for their interest and support.

FOOTNOTES AND REFERENCES

* Word done under the auspices of the U. S. Atomic Energy Commission.

† Present address: Goddard Space Flight Center, NASA, Greenbelt, Maryland.


1. John C. Caris, Robert W. Kenney, Victor Perez-Mendez, and Walton A. Perkins, III, Phys. Rev. 121, 893 (1961).
2. Richard J. Kurz, (Ph. D. Thesis) Lawrence Radiation Laboratory Report UCRL-10564, Nov. 1962 (unpublished).
3. Don L. Lind, (Ph. D. Thesis) Lawrence Radiation Laboratory Report UCRL-11435, July 1964 (unpublished); Don L. Lind, Barry C. Barish, Richard J. Kurz, Philip M. Ogden, Victor Perez-Mendez, and Julius Solomon, Bull. Am. Phys. Soc. 9, 538 (1964).
4. David Cheng (Lawrence Radiation Laboratory, Berkeley), private communication, 1964.
5. Barry C. Barish, Richard J. Kurz, Victor Perez-Mendez, and Julius Solomon, Inelastic $\pi^-p$ Interactions in the Energy Region of 310 to 454 MeV, Phys. Rev. (to be published).
6. Olav T. Vik and Hugo R. Rugge, Phys. Rev. 129, 2311 (1963).
7. Roger E. Hill, Norman E. Booth, Robert J. Esterling, David L. Jenkins, Norman H. Lipman, Hugo R. Rugge, and Olav T. Vik, Bull. Am. Phys. Soc. 9, 410 (1964).
8. L. David Roper (Lawrence Radiation Laboratory, Livermore), private communication, 1964.
9. A. Donnachie, J. Hamilton, and A. T. Lea, Prediction of p-, d-, and f-wave Pion Nucleon Scattering, Phys. Rev. (to be published).
10. L. David Roper, Phys. Rev. Letters 12, 340 (1964).
11. Ernest H. Rogers, Owen Chamberlain, James H. Foote, Herbert M. Steiner,

Clyde Wiegand, and Tom Ypsilantis, Rev. Mod. Phys. 33, 356 (1961); Hugo R. Rugge and Olav T. Vik, Phys. Rev. 129, 2300 (1963); Philip M. Ogden, Donald E. Hagge, Jerome A. Helland, Marcel Banner, Jean-Francois Detoeuf, and Jacques Teiger, (UCRL-11180, Rev., June 1964) submitted to Phys. Rev.

FIGURE CAPTION

Figure 1. Differential cross sections for $\pi^- p \rightarrow \pi^0 n$. —— N = 3, combined-data fit; -·- N = 2, $\gamma$ data fit; -- predictions by the phase-shift solution of Roper.

Table I. $\pi^- p \rightarrow \pi^o n$ Angular Distribution Data

| | a | | b | | c | | d | |
|---|---|---|---|---|---|---|---|---|
| | $\cos\theta^*_\gamma$ | $d\sigma^\gamma/d\Omega^*$ (mb/sr) | $\cos\theta^*_n$ | $d\sigma/d\Omega^*$ (mb/sr) | $\cos\theta^*_n$ | $d\sigma/d\Omega^*$ (mb/sr) | $\cos\theta^*_{\pi^o}$ | $d\sigma/d\Omega^*$ (mb/sr) |
| $T_{\pi^-}$ | 317 MeV | | | | 313 MeV | | 315 MeV | |
| | 1.000 | 2.80±0.20 | | | - 0.536 | 1.77±0.20 | 1.000 | 4.30±0.57 |
| | 0.889 | 2.44±0.15 | | | - 0.385 | 1.40±0.14 | | |
| | 0.779 | 2.18±0.14 | | | - 0.222 | 0.73±0.07 | | |
| | 0.598 | 1.64±0.11 | | | - 0.050 | 0.44±0.04 | | |
| | 0.225 | 0.80±0.06 | | | 0.125 | 0.27±0.03 | | |
| | - 0.199 | 0.29±0.05 | | | 0.297 | 0.23±0.02 | | |
| | - 0.589 | 0.21±0.04 | | | 0.461 | 0.27±0.03 | | |
| | - 0.869 | 0.39±0.04 | | | 0.612 | 0.32±0.04 | | |
| | - 0.952 | 0.31±0.05 | | | 0.745 | 0.37±0.04 | | |
| | | | | | 0.853 | 0.41±0.05 | | |
| | | | | | 0.933 | 0.46±0.10 | | |
| $T_{\pi^-}$ | 371 MeV | | 374 MeV | | 371 MeV | | 371 MeV | |
| | 1.000 | 2.59±0.17 | - 0.678 | 1.69±0.17 | | | 1.000 | 3.65±0.65 |
| | 0.970 | 2.25±0.15 | - 0.545 | 1.31±0.13 | - 0.545 | 1.59±0.16 | | |
| | 0.882 | 2.12±0.13 | - 0.400 | 0.97±0.10 | | | | |
| | 0.766 | 1.84±0.11 | - 0.233 | 0.62±0.06 | - 0.233 | 0.60±0.06 | | |
| | 0.577 | 1.23±0.08 | - 0.062 | 0.41±0.04 | | | | |
| | 0.194 | 0.60±0.05 | | | 0.113 | 0.22±0.02 | | |
| | - 0.230 | 0.23±0.04 | | | 0.500 | 0.14±0.01 | | |
| | - 0.610 | 0.14±0.05 | | | 0.740 | 0.11±0.01 | | |
| | - 0.877 | 0.05±0.05 | | | 0.932 | 0.10±0.01 | | |
| | - 0.955 | 0.26±0.05 | | | | | | |

(a, b, c, and d refer to the designations in the first paragraph of the text.)

Table II. Results of the least-squares fits of the differential cross section for $\pi^- p \rightarrow \pi^0 n$ to the form

$$\frac{d\sigma}{d\Omega^*} (\cos \theta^*_{\pi^0}) = \sum_{\ell=0}^{N} a_\ell P_\ell (\cos \theta^*_{\pi^0})$$

| $T_{\pi^-}$ (MeV) | | N | $a_0$ (mb/sr) | $a_1$ (mb/sr) | $a_2$ (mb/sr) | $a_3$ (mb/sr) | Probability of fit |
|---|---|---|---|---|---|---|---|
| 315 | a | 2 | 1.31±0.04 | 1.86±0.08 | 1.57±0.11 | - | 0.57 |
| | b | 2 | 0.92±0.04 | 1.17±0.08 | 0.96±0.07 | - | $10^{-3}$ |
| | | 3 | 1.13±0.06 | 1.73±0.14 | 1.50±0.13 | 0.44±0.09 | 0.88 |
| | c | 2 | 1.16±0.03 | 1.62±0.05 | 1.31±0.05 | - | $< 10^{-4}$ |
| | | 3 | 1.21±0.03 | 1.88±0.06 | 1.61±0.06 | 0.45±0.06 | 0.40 |
| 371 | a | 2 | 1.00±0.03 | 1.62±0.06 | 1.12±0.08 | - | 0.15 |
| | b | 2 | 0.60±0.02 | 0.89±0.05 | 0.44±0.03 | - | $< 10^{-4}$ |
| | | 3 | 0.80±0.03 | 1.37±0.08 | 0.96±0.07 | 0.31±0.04 | 0.75 |
| | c | 2 | 0.77±0.02 | 1.26±0.03 | 0.67±0.02 | - | $< 10^{-4}$ |
| | | 3 | 0.89±0.02 | 1.57±0.04 | 1.13±0.04 | 0.38±0.03 | 0.12 |

a. $\gamma$ data only.

b. Neutron data and forward direction dispersion relation point.

c. All data combined.

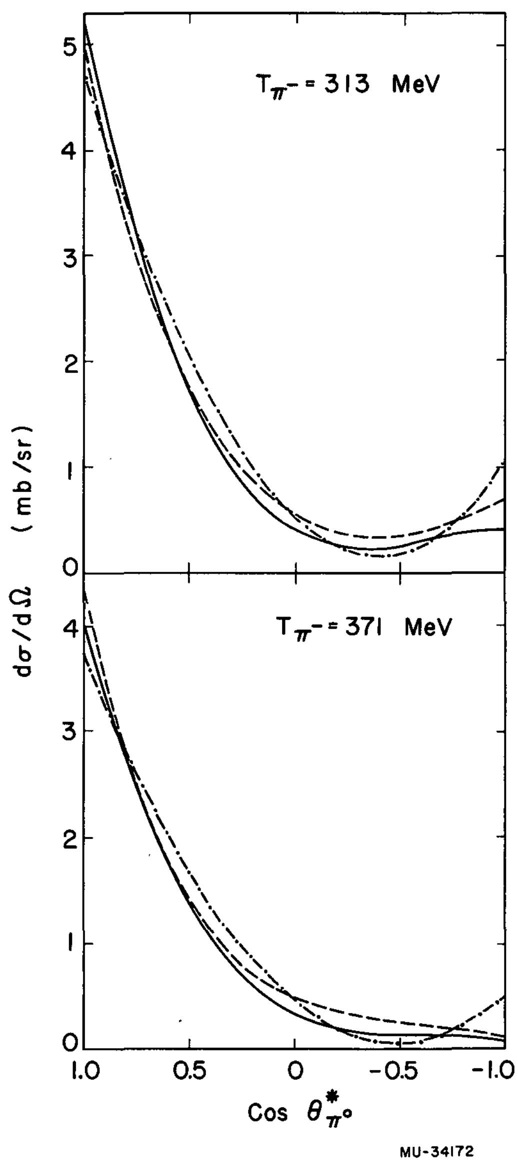
$T_{\pi^-}$ = 313 MeV
$T_{\pi^-}$ = 371 MeV
$d\sigma/d\Omega$ (mb/sr)
5
4
3
2
1
0
4
3
2
1
0
1.0
0.5
0
-0.5
-1.0
Cos $\theta^*_{\pi^0}$
MU-34172

Fig. 1.