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EXPERIMENTAL STUDY OF π-π INTERACTION IN THE REACTION $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ AT INCIDENT π^- ENERGY OF 378 MeV

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EXPERIMENTAL STUDY OF π-π INTERACTION IN THE REACTION $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ AT INCIDENT π^- ENERGY OF 378 MeV

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Experimental Study of π-π Interaction in the Reaction $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$ at Incident π^- Energy of 378 MeV*

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In a study of the reactions

$$p + d \rightarrow He^3 + 2\pi \tag{1a}$$

and

$$p + d \rightarrow H^3 + 2\pi \tag{1b}$$

Abashian, Booth, and Crowe (ABC)[1] observed a peak in the momentum distribution of He^3, which was subsequently interpreted as a strong S-wave $I = 0$, π-π scattering-length effect. We have completed an experiment in which we measured the differential neutron time-of-flight distribution from the reaction

$$\pi^- + p \rightarrow n + \pi^0 + \pi^0 \tag{2}$$

at a π^- laboratory kinetic energy of 378 MeV, to look for this effect.

We measured the neutron spectrum at 45 deg (lab) in coincidence with the γ rays produced in reaction (2). The experimental setup is as shown in Fig. 1. Negative pions, produced at an internal target of the 184-In. Cyclotron were momentum-analyzed and focussed on a 3-in. diameter by 10-in.-long liquid-hydrogen target, which was completely surrounded by scintillation counters. The pion beam was designed to have less than ±1.5 deg of angular divergence. Fourteen liquid-scintillation neutron counters and six lead-scintillator sandwich counters were used to detect the neutrons

and π^0 -decay γ rays, respectively. When the direction of the neutron is fixed, the charge-exchange π^0 has a unique energy and direction in space. Therefore, only one of the two γ rays from the charge-exchange π^0 is detected on any one side of this direction. We utilized this fact and placed the γ-ray detectors on one side of this space direction. Two or more γ rays were then required in coincidence with an interacted pion signal before the gate for the neutron time-of-flight measurement was opened. The charge-exchange neutron contamination was thus reduced by a factor of about 100.

Resolution of the neutron time-of-flight system was measured by turning off the γ requirement, and was found to be 4.5 nsec (full width at half maximum). Calibration of the time-of-flight system was checked by measuring the prompt γ ray and the charge-exchange neutron time-of-flights. The calibration agrees within $\pm$ 0.25 nsec with the calculated values. The measured total cross section for reaction (2) is 1.40 $\pm$ 0.21 mb at 500 MeV/c, in agreement with the published data of Barish et al.[2]

Superimposed on the raw time-of-flight data is:

(a) The charge-exchange neutron peak, which although reduced in magnitude by the gamma requirement, appears around $\beta = 0.458$.

(b) The inelastic neutron distribution starting at $\beta = 0.41$.

Assuming a Gaussian resolution function and using the measured neutron resolution width, we have subtracted the charge-exchange peak from the raw data to separate out the inelastic distribution. The subtraction is presented

in Fig. 2. Because of the relatively long flight path for the neutrons, there is very little overlap between the times of flight of the charge-exchange and the inelastic neutrons.

A strong I = 0 two-pion interaction around a dipion mass of 400 MeV was observed in several pion-production experiments.[2-6] To explain the experimental results, Brown and Singer proposed a two-pion resonance with an effective mass of 400 MeV and a width of 100 MeV.[7,8] The data of the K^+_{e4} decay experiment of Birge et al.[9] do not show any evidence of the Sigma. The appearance of the Sigma-type enhancement in the inelastic pion-nucleon interactions has been explained most recently by Dalitz and Moorhouse as being caused by a strong P_{11} π-N absorption.[10] The presence of this enhancement can mask the π-π scattering-length effect present in the data. We therefore chose to limit the available π-π effective mass to a maximum of 316 MeV to minimize its contribution.

The inelastic neutron time-of-flight data are presented in Fig. 3. Also shown in the figure are the following calculated distributions:

(1) Relativistically invariant phase space, (P.S.).

(2) Phase space multiplied by a Brown-and-Singer-type resonance (called Sigma) between the two pions at a dipion mass of 400 MeV with a full width of 100 MeV, (P.S.) x σ.

(3) Phase space multiplied by (a) the effect due to an S-wave π-π scattering length of 2.0 pion Compton wavelengths, as given by the S-dominant solution of the π-π effective-range equation of Chew and Mandelstam,[11] plus (b) a Sigma resonance of 400 MeV and full width 100 MeV, (P.S.) x $[\alpha(\pi\pi) + \beta(\sigma)]$.

(4) Phase space multiplied by the effect due to an S-wave π-π scattering length of 2.0 pion Compton wavelengths, as in (3) above, P.S. x $(\pi\pi)$.

In the calculated distributions we have folded in, (i) the efficiencies

of the neutron counters, (ii) the enhnacement due to the Bose symmetrization effect between the two pions,[12] with a Bose radius of 1.0 pion Compton wavelength, and (iii) the neutron center-of-mass angular distribution of the form $(1.0 + A \cos \theta^* + B \cos^2 \theta^*)$. For the best fit we obtain the values of the coefficients A and B as 3.6 and 3.7, respectively.

Since we do not know the relative contributions of Sigma and the π-π scattering length we interpret the data as being a combination of the two, and vary their weights. The weights for the minimum χ^2 were $\alpha = 20$ and $\beta = 1$. The remaining two parameters for the fit were then R(the Bose radius) and a_{S0}(the S-wave π-π scattering length). The χ^2 values obtained for different values of R and a_{S0} are presented in Table I.

The value of the a_{S0} that we can deduce from the present analysis is dependent on R. Assuming the value of R to be 1.0 pion Compton wavelength, we are able to obtain with 90% confidence a lower limit of 0.65 pion Compton wavelength for the magnitude of the I = 0, S-wave π-π scattering length. Since the momentum transfer is reasonably low -- Δ^2 being between 2 and 7 in units of m_π^2 -- we also used the Chew-Low formula[13] in the physical region to calculate the π-π cross section. At low momentum transfers ($\Delta^2 < 3$) the data does not agree with a pure one-pion-exchange model. Also, the variation of $m_{\pi\pi}$ over the range of our data makes this method of analysis not very reliable. However, using only the data with Δ^2 between 3 and 7, we can conclude that the π-π cross section is 60 mb or larger.

Within the present statistics our results agree with the analysis of Booth and Abashian,[1] whose method we followed in the interpretation of the data. The uncertainty in the Bose radius makes it difficult to obtain

better quantitative results at present. More information at different laboratory angles and incident pion energies is necessary, and further work is now in progress.

We are grateful to Professor G. F. Chew for his interest and helpful suggestions. Thanks are also due to Donald Myer, Allen Peters, M. Piccioti, J. Shively, and Lloyd Themes for their help during the data-taking phase of the experiment, and to the 184-In. Cyclotron crew headed by Mr. J. Vale for providing many hours of steady beam.

Table I. Minimum values of χ^2 as a function of R and a_{S0} for seven degrees of freedom.

	R				
a_{S0}	0	1.0	2.0	3.0	4.0
0	26.6	20.2	10.3	7.76	11.1
0.5	15.6	11.2	7.64	9.71	15.0
1.0	10.3	7.56	6.25	7.24	11.0
1.5	6.63	6.18	6.01	7.55	11.9
2.0	5.80	5.68	5.90	7.92	12.8
3.0	5.10	5.22	5.98	8.80	14.6
4.0	4.92	5.19	6.31	9.67	16.1

FOOTNOTES AND REFERENCES

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

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FIGURE LEGENDS

Fig. 1. Experimental arrangement showing the location of the six gamma counters and the 14 neutron counters.

Fig. 2. Figure showing the subtraction of the charge-exchange neutron peak from the raw data.

Fig. 3. Measured inelastic neutron time-of-flight spectrum, presented together with the following calculated distributions:

(1) P.S.

(2) P.S. x σ

(3) P.S. x $[20(\pi\pi) + \sigma]$ for a_{SO} = 2 pion Compton wavelengths.

(4) P.S. x $(\pi\pi)$ for a_{SO} = 2 pion Compton wavelengths.

The χ^2 values for the best fit of the four curves are 10.6, 35.6, 5.7 and 6.5 respectively, for seven degrees of freedom.

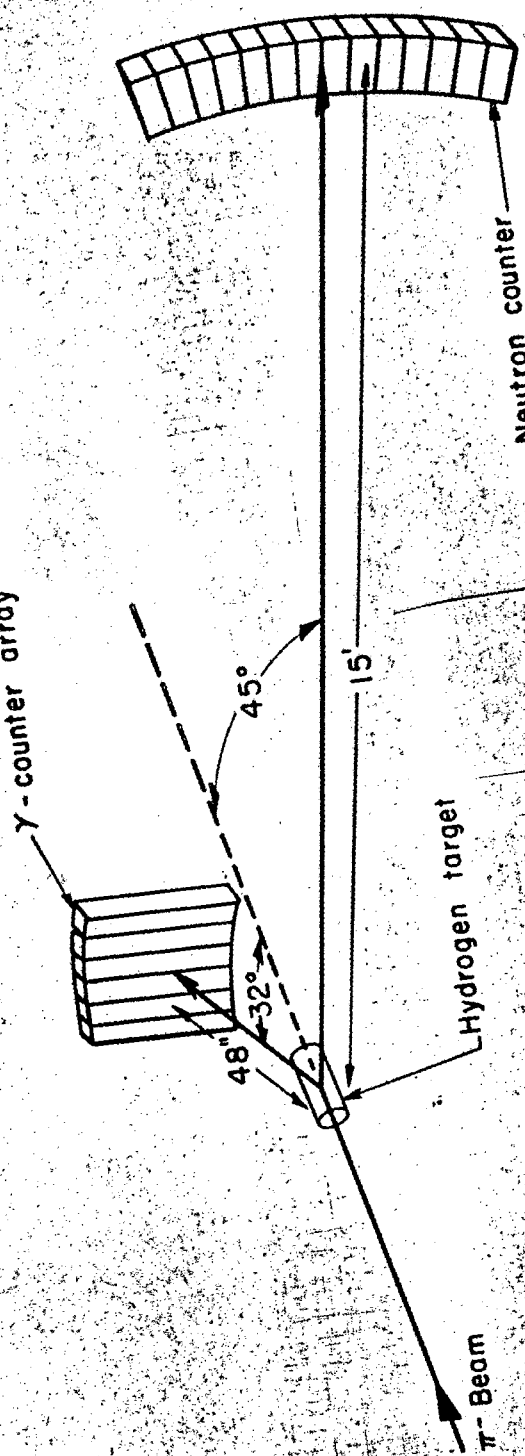
MUB-5764
Neutron counter array
15'
45°
γ - counter array
Hydrogen target
32°
48"
π- Beam

Fig. 1

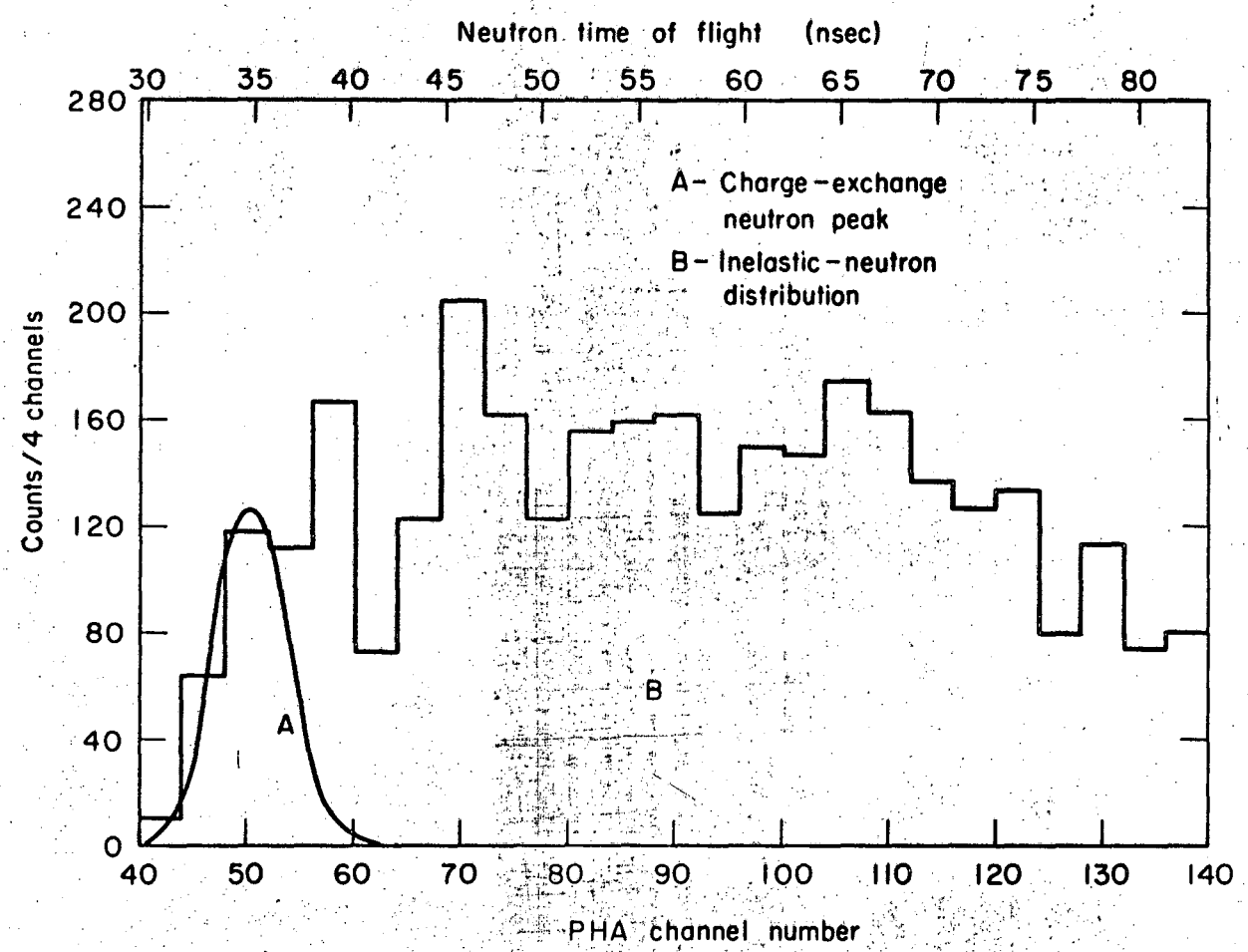

Fig. 2

MUB-9138

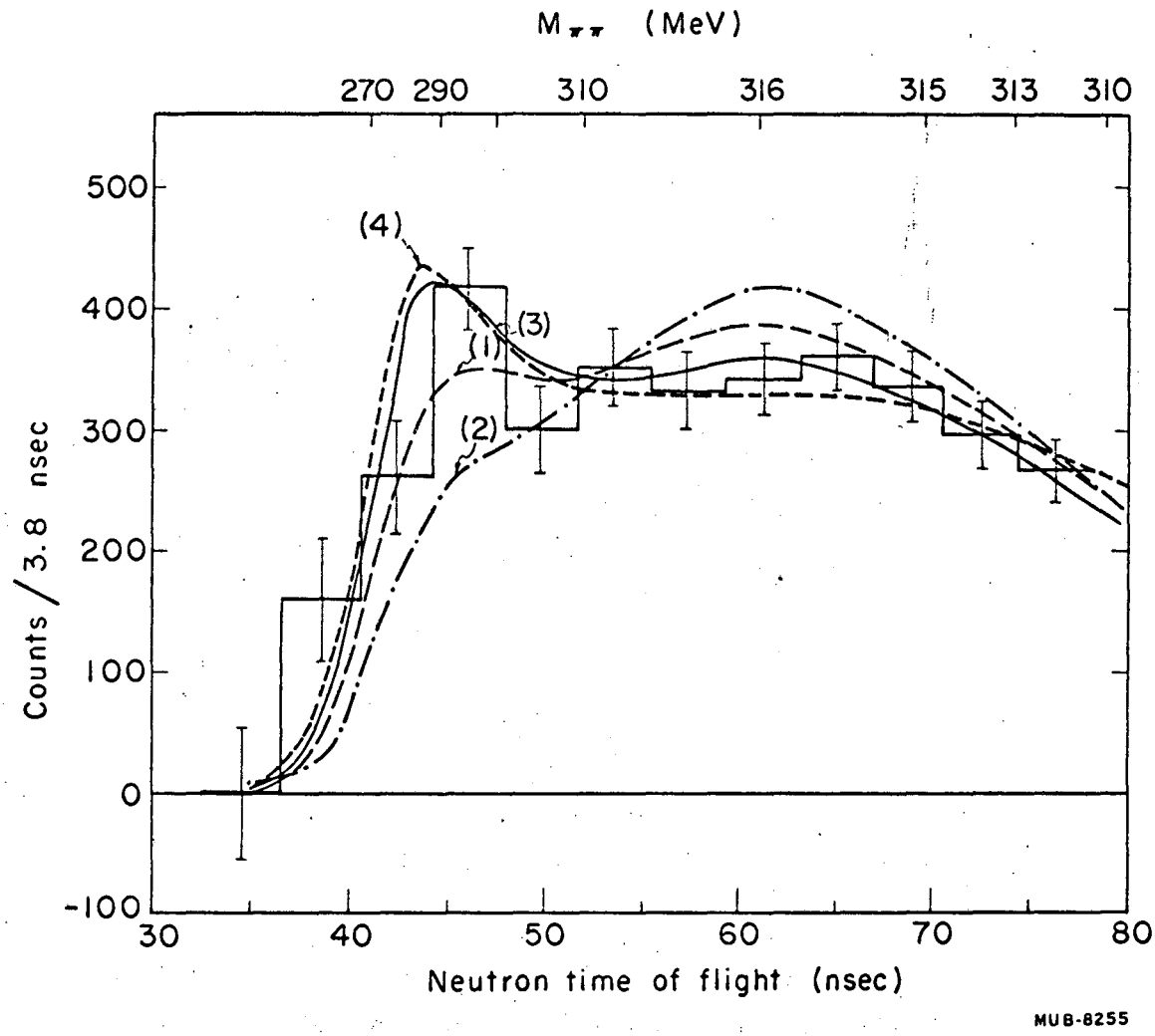
$M_{\pi\pi}$ (MeV)
270 290 310 316 315 313 310
500
400
300
200
100
0
-100
Counts / 3.8 nsec
(4)
(3)
(1)
(2)
30 40 50 60 70 80
Neutron time of flight (nsec)
MUB-8255

Fig. 3

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