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NEGATIVE PION-PROTON ELASTIC SCATTERING AT 600 to 750 Mev

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The total π^--p cross section shows two well-defined peaks, one at 600 Mev and one at 890 Mev (laboratory-system kinetic energy).[1] Peierls[2] has assigned $D_{3/2}$ and $F_{5/2}$, respectively, for the orbital and total angular momentum states based on the photoproduction angular distributions[3] and polarizations of the recoil protons.[4] Landovitz and Marshall[5] suggest that $P_{3/2}$ and $D_{3/2}$ or $D_{5/2}$ assignments are also consistent with the data. Previous π^--p elastic scattering experiments have been made at 425,[6] 460,[7] 600,[7] 770,[7] 810,[8] 925,[9] and 950[10] Mev. These experiments have not led to any definite conclusions, partly because of large energy spreads and low statistics.

This experiment was conceived to try to establish the angular momentum at the peaks from elastic scattering on hydrogen. Negative pions at 610±20, 655±20, and 750±20 Mev were passed through a 30-inch propane bubble chamber operated in a 13-kgauss field.[11] The pions were focused, deflected, and collimated to give a momentum spread of ±1.5 %. The energy spread quoted above comes from energy loss in the chamber. The mean beam momentum was checked by wire orbiting, by measuring the curvature of beam tracks in the bubble chamber, and from kinematics of elastic events with stopping protons. All three methods gave consistent results. Twenty percent

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of the film was scanned twice. All events were measured on digitized microscopes (most of them on a "Franckenstein") and the data reduced on an IBM 650. A kinematics program gave the events a χ^2 test for elasticity using configuration-dependent errors. Good agreement with the expected χ^2 distribution was found. About 40% of the measured events were elastic.

Tracks entering the scanning region were counted in 4% of the pictures. Corrections were made based on calculated muon contaminations (11.5%) and measured electron contaminations (about 3%), and for interactions reducing track length. The resulting track lengths were checked by counting interactions and checking with the π^--p^1 and π^--C^{12} total cross sections.

The numbers of elastic events found were 539, 1159, and 1008 at 610, 655, and 750 Mev, respectively. Analysis of about 20% more events is still in process, and corrections were made for these assuming they were randomly distributed. Corrections were made for scanning efficiency and azimuthal bias, but not as a function of scattering angle. A correction was made for carbon contamination (about 7%) by using the behavior of the non-elastic tail of the observed χ^2 distribution. For the total elastic cross sections, corrections for small-angle scatters which were missed were made by extrapolating the angular distributions to 0 deg. The resulting total elastic cross sections are 16.6±2.2 mb, 16.1±1.6 mb, and 14.4±1.3 mb, at 610, 655, and 750 Mev, respectively. The errors in the cross sections are thought to be about standard deviations, and are not strongly correlated from one energy to another. These results are compared with the results of other workers in Fig. 1. If the latest total cross sections[1] are valid, then the results at 810 and 950 Mev should possibly be scaled to where the crosses indicate. Within the errors shown almost any energy dependence from one with peaks at 600 and 890 Mev to one which increases linearly may be concluded.

The angular distributions are shown in Fig. 2. The crosses indicate the expected forward scattering calculated from the optical theorem and dispersion relations.[13] The extrapolations of the observed angular distributions to 0 deg are compatible with these points if the cross sections are rising at small angles as a diffraction pattern with reasonable values of the radius. Fits of cosine power series were made to the data. In each case the intervals $0.9 \leq \cos\theta^* \leq 1.0$ were not considered, and only statistical errors were used, since other errors affect only the over-all normalization. Fits were made with the data divided into intervals of $\Delta(\cos\theta^*) = 0.05$ (38 points) and $\Delta(\cos\theta^*) = 0.10$ (19 points). The two fits agreed within errors with each other. The 19-point fits are given in Table I. The values of χ^2 reached plateaus at the powers of cosine shown. In all cases the coefficient of the next higher power of cosine was zero within the errors. The errors quoted have the normalization errors folded back in.

The fact that a_2 and a_4 were found to be larger at 655 Mev than at 610 Mev should not be taken too seriously. It is assumed for what follows that a_2 is really at a maximum at 600 Mev. If the peaks in the cross section are resonances--that is, the real part of the phase shift goes through 90 deg--then the size of σ_{elas} compared to $1/2\ \pi\ (2J+1)\ \lambda^2 \left| e^{2i\delta} - 1 \right|^2$ makes it likely that the first peak has $J \leq 3/2$ and the second $J \leq 5/2$. That the coefficient a_2 goes through a maximum at 600 Mev implies that the angular momentum state there is $J = 3/2$. The decrease in a_2 and a_3 and the increase in a_4 and a_5 all imply that the next peak should have $J = 5/2$. If it is assumed that both resonances go through +90 deg and that there is a reasonable energy dependence of the phase shifts, then even relative parity for the two resonances would lead to interference terms that would give negative contributions to a_2 and positive to a_4 around 600 Mev. It does not seem easy to reconcile such

Table I

Coefficients of the various powers of cos θ^* (in mb/sr) for the 19-point fits. The highest power and the value of χ^2 for the fit are given. There were (18 - n) degrees of freedom.

Energy (Mev)	n	χ^2	a_0	a_1	a_2	a_3	a_4	a_5
610	4	10.6	0.23 ± 0.04	1.73 ± 0.28	3.78 ± 0.61	0.27 ± 0.44	-1.23 ± 0.69	-
655	4	7.2	0.25 ± 0.04	1.56 ± 0.20	4.38 ± 0.50	0.17 ± 0.32	-2.54 ± 0.53	-
750	4	16.3	0.25 ± 0.04	0.81 ± 0.20	2.49 ± 0.48	-3.24 ± 1.02	0.52 ± 0.69	5.81 ± 1.22

contributions with the observed coefficients. It would be difficult to explain a_2 and a_4 if one resonance goes through + 90 deg and the other through -90 deg. Therefore it is most reasonable to assign odd relative parity to the resonances: $P_{3/2}$ and $D_{5/2}$, or $D_{3/2}$ and $F_{5/2}$. Thus the same possible angular momentum assignments are arrived at independently of the photoproduction data.

Several nonresonating states are needed to explain the observed angular distributions. Plausible sets of such other states have been constructed. The problem is underdetermined by the data at hand, since the phase shifts are complex. If some of these other states could be determined by other means, then the ambiguity of the orbital momentum of the resonances could possibly be eliminated. Because the nonresonant states are responsible for the negative value of a_4 around 600 Mev, its minimum is probably due to "accidental" cancellations. If the real part of the phase shift of the $J = 3/2$ wave is 90 deg at 600 Mev, then the phase must have a large imaginary part. This conclusion is necessary to account for the observed amount of inelastic scattering when it is kept in mind that there must be some nonresonant elastic scattering. Strong absorption is in keeping with Peierls' conjecture[2] as to the cause of this peak. It should be emphasized that this experiment does not prove that the peaks are true resonances. However, it would be more difficult to account for the data without that hypothesis.

Isospin has been ignored in this qualitative analysis. One difficulty with this analysis is that a_3 and a_5 seem to be changing faster than general considerations would indicate likely. Part of the apparent sudden change may be due to a lack of sensitivity to the fifth and sixth powers of cosine at the lower energies. The supposition of insensitivity is compatible with the results of Goodwin et al.,[6] who find a best fit with a sixth-degree polynomial at 425 Mev.

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LEGENDS

Fig. 1. The total elastic cross section is given as a function of the pion kinetic energy (laboratory system). The crosses show suggested changes in the elastic data based on the latest total cross-section data. (a) – Reference 6; (b) – Reference 7; (c) – Reference 8; (d) – Reference 10.

Fig. 2. The elastic angular distributions are given as a function of the cosine of the angle in the center-of-momentum system. The crosses are the predicted forward scattering cross sections.

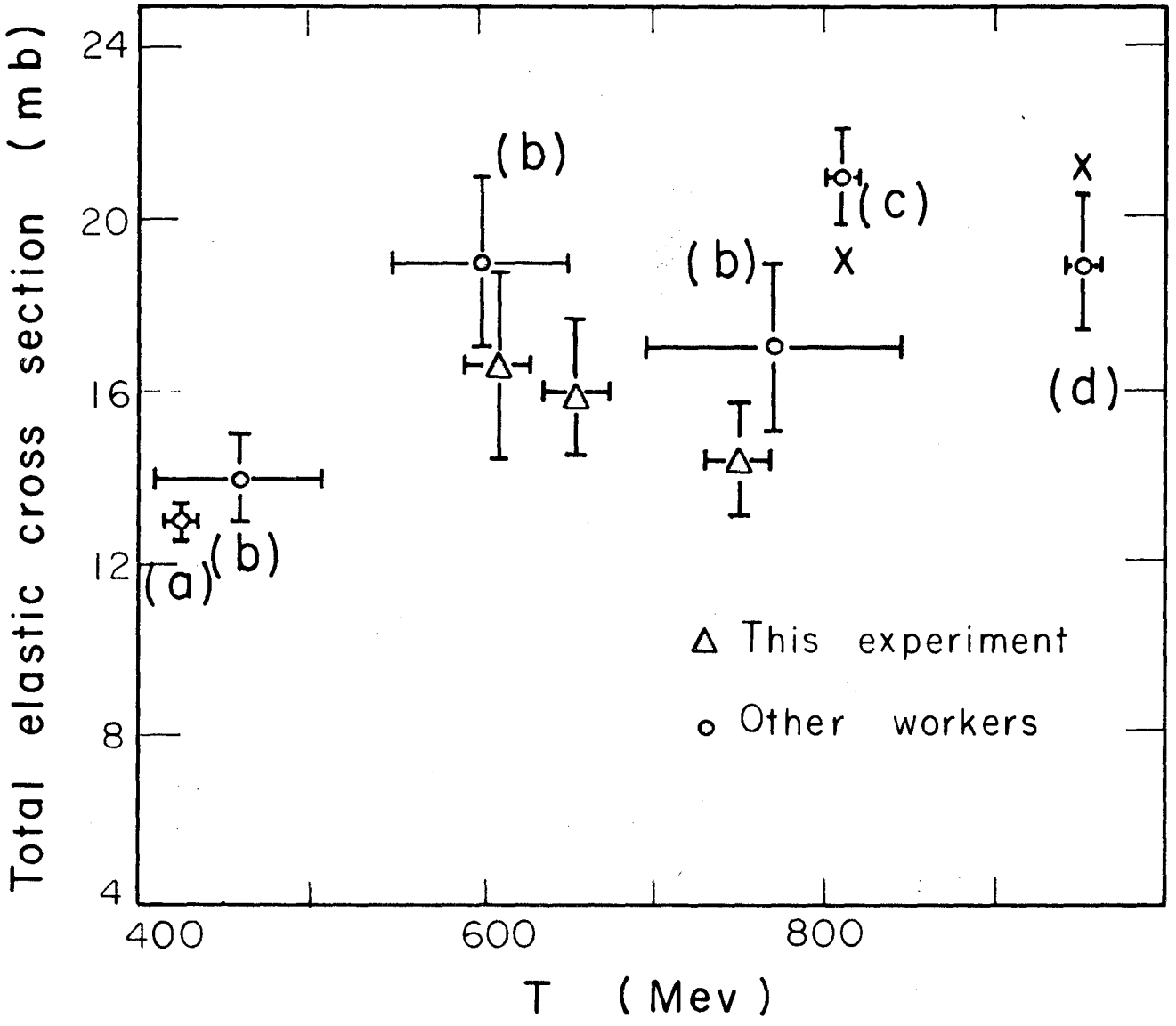
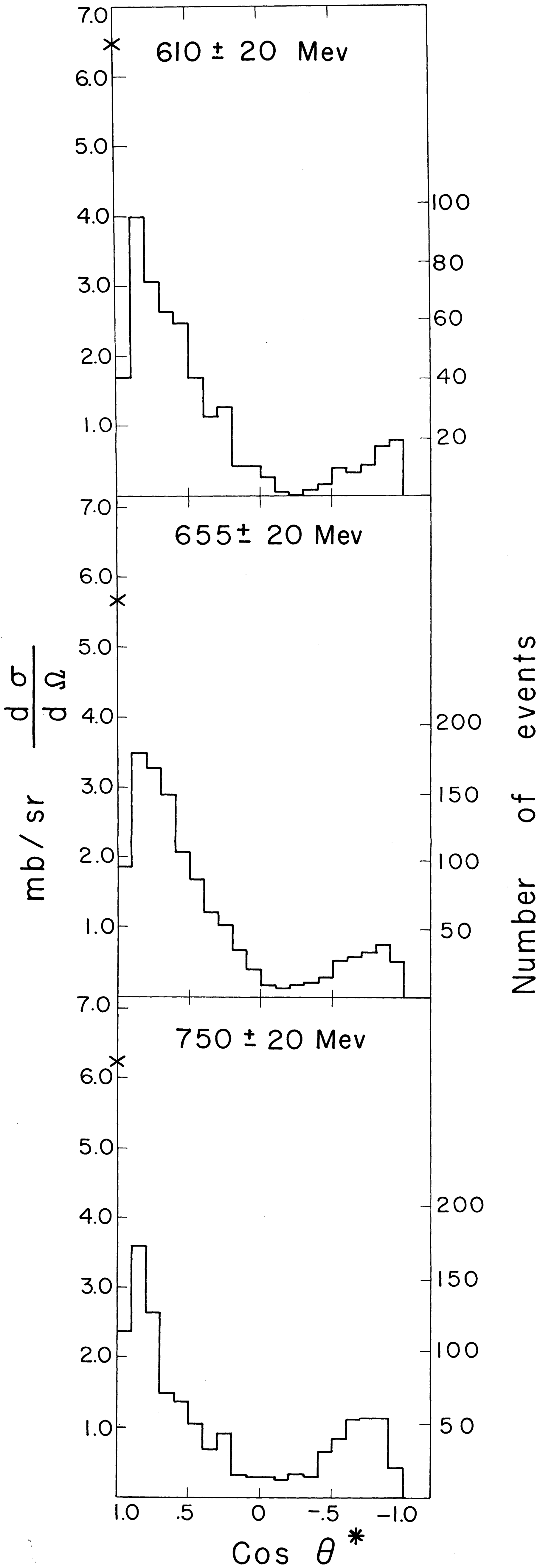

Total elastic cross section (mb)
24
20
16
12
8
4
400
600
800
T (Mev)
(a)
(b)
(b)
(b)
(c)
(d)
X
X
△ This experiment
o Other workers

FIG. 1


610 ± 20 Mev
655 ± 20 Mev
750 ± 20 Mev
$\frac{d\sigma}{d\Omega}$ mb/sr
Number of events
Cos θ^*
7.0
6.0
5.0
4.0
3.0
2.0
1.0
100
80
60
40
20
200
150
50
1.0
.5
0
-.5
-1.0