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The differential elastic scattering of pions on protons furnishes information on the magnitude of the various partial waves included in the interaction. Precise measurements of this process up to 333 Mev[1,2] have been interpreted in terms of S and P waves and their six associated charge-independent phase shifts. No D or higher waves were necessary to give a statistically significant fit to the data. In this letter, we report our values of the elastic-scattering cross section for negative pions on protons at 370 ± 9 and 427 ± 10 Mev.

The experimental set-up is shown in Fig. 1. The pion beam from an internal Be target in the 184-in. cyclotron was deflected out of the machine by its magnetic fringing field. The beam was then momentum-analyzed and focused by the wedge and quadrupole magnets shown. The intensity of the 2-in. diam. beam was greater than 15,000 negative pions per second. The beam energy and its muon and electron contaminations were determined from ranges in copper.

The pion beam was scattered in a 4-in.-thick liquid-hydrogen target. The elastically scattered pions were detected by a three-scintillator counter telescope which discriminated against recoil protons and inelastic pions on the basis of range in the copper absorbers placed between the first and last scintillators of the telescope. A different thickness of copper absorber was used for each of the elastically scattered pions. This energy was a unique function of the angle of scattering and was calculated from the kinematics of the two-body final state.

The efficiency of the telescope was measured as a function of pion energy, with essentially the same pion beam set-up shown in Fig. 1. Beam energy and contamination were determined from range curves.

The main corrections to the data are for Coulomb scattering, finite target and telescope size, and π^0 photons from charge-exchange scattering.[3] The results of the experiment are shown in Fig. 2. Also shown is the differential cross section at zero degrees. The imaginary part of the forward-scattering amplitude was obtained from total cross-section data,[1,4] and the real part was obtained from dispersion theory.[5] Because of the relatively small contribution to the cross section of the real part compared to the imaginary part at these energies, even a 100% error in the real part does not significantly effect the cross-section magnitude or its error. Thus the zero-deg. differential cross sections shown depend effectively only upon the experimentally determined total cross sections.

The data was fitted to a power series in $\cos\theta^*$, where θ^* is the center-of-mass scattering angle,

$$d\sigma/d\Omega^* = \sum_{k=0}^{n} A_k (\cos\theta^*)^k ,$$

for various values of n. Three of the least-squares fits made at each energy are shown in Fig. 2. The dashed curve represents the fit to the points, excluding the calculated zero-deg point and using only S- and P-wave contributions (n = 2). The dot-dash curve represents the fit to the same points obtained for a value of n that was chosen on the basis of a χ^2 test to have its most probable value. The solid curve represents the fit obtained for the most probable value of n when the zero-deg point is included. The values of the best-fit parameters, A_k, are given in Table I. The table also gives the probabilities, p, that χ^2 for a random sample would exceed the value found.

The probabilities that the data are consistent with the fits based on S and P waves alone is less then 1%. Thus the inclusion of D waves is necessary to obtain a reasonable fit to the data. In fact, the most probable values of n obtained include an F-wave interference term (n = 5) at 370 Mev and an F-wave term (n = 6) at 427 Mev. The conclusion is that D waves are present, and that F waves may be present, especially at 427 Mev.

The total elastic cross sections, obtained from integrating the solid-line fits, are $10.8 \mid \pm 0.2 \mid$ mb at 370 Mev and 13.00 ± 0.34 mb at 427 Mev. The zero-deg differential cross sections obtained by extrapolating the dot-dash curves to zero deg are 1.38 ± 0.23 mb/sterad at 370 Mev and 1.78 ± 0.55 mb/sterad at 427 Mev. Within statistics these values agree with those predicted from dispersion relations.

References

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Table I

Least-squares-fit parameters, A_k, in millibarns/steradian, for the most probable values of n, for which p is the probability that χ^2 for a random sample would exceed the value found.

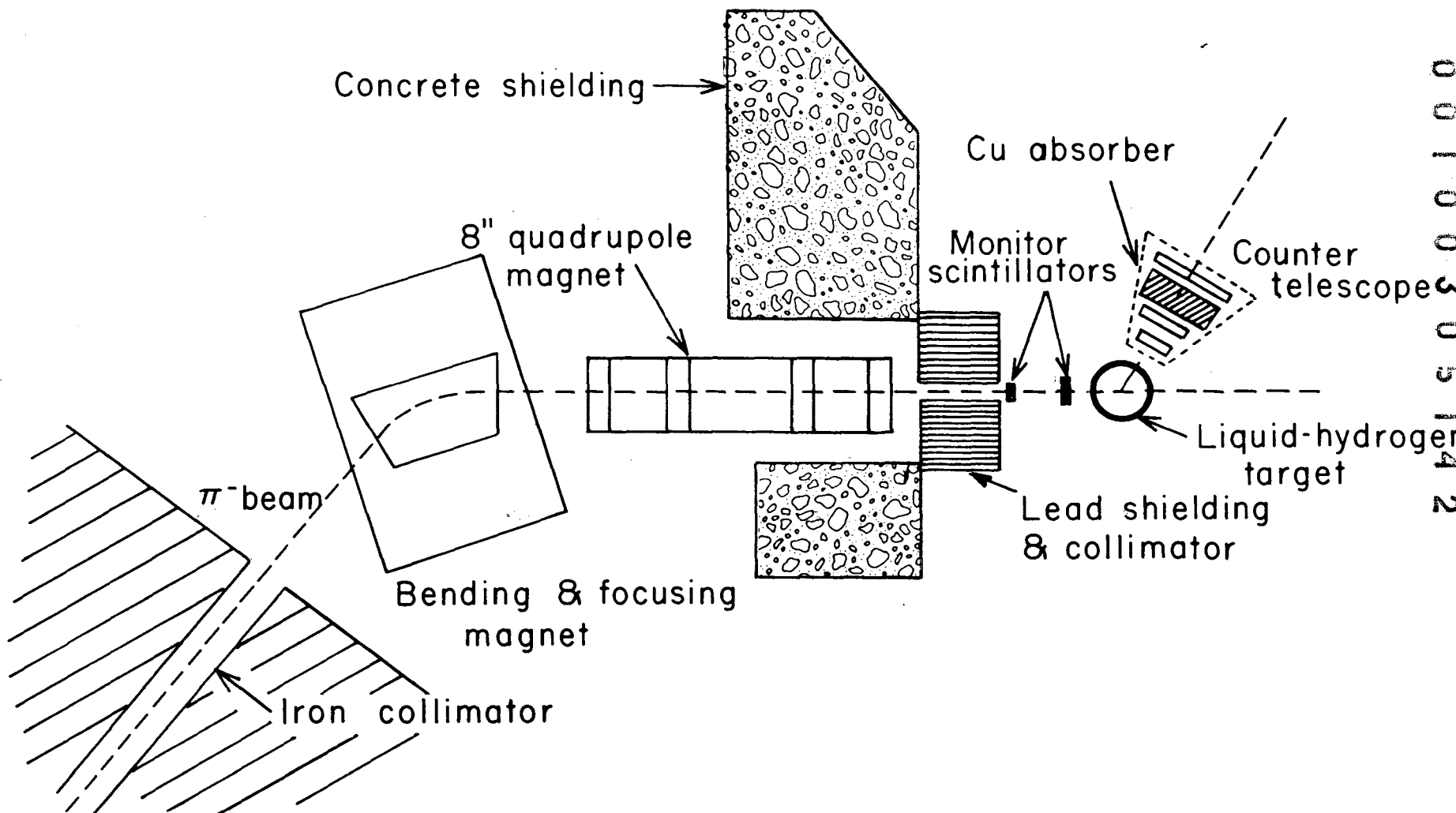| Energy (Mev)	n	Zero-deg. point	A_0	A_1	A_2	A_3	A_4	A_5	A_6	p (%)
370±9	5	included	0.65 ±0.03	1.02 ±0.10	0.97 ±0.18	-1.43 ±0.40	-0.57 ±0.19	0.65 ±0.35		44
370±9	5	excluded	0.66 ±0.03	1.03 ±0.11	0.89 ±0.25	-1.56 ±0.51	-0.45 ±0.32	0.81 ±0.52		28
427±10	6	included	0.77 ±0.04	1.46 ±0.16	0.19 ±0.56	-2.15 ±0.73	2.50 ±1.68	1.04 ±0.65	-2.07 ±1.26	34
427±10	6	excluded	0.77 ±0.05	1.47 ±0.21	0.20 ±0.70	-2.19 ±1.05	2.43 ±2.20	1.10 ±1.06	-1.99 ±1.78	19

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Figure Legends

Fig. 1. Experimental arrangement (not to scale).

Fig. 2. Differential cross sections for π^--P elastic scattering. The square

points on the ordinates represent dispersion-relation predictions.

The solid curve represents the best least-squares fit obtained including the

zero-degree point. The dot-dash curve represents the best fit obtained excluding

the zero-degree point. The dashed curve represents the fit obtained excluding

the zero-degree point and using only S and P waves.

Concrete shielding

Cu absorber

8" quadrupole magnet

Monitor scintillators

Counter telescope

π^- beam

Bending & focusing magnet

Liquid-hydrogen target

Iron collimator

Lead shielding & collimator

Fig 1

55 155-1

370 ± 9 Mev

427 ± 10 Mev

Differential cross section (mb/sterad)

Center-of-mass angle, θ^* (deg)