ANGULAR DISTRIBUTION IN $\pi^{\pm}-p$ ELASTIC SCATTERING IN THE RANGE 530 TO 1550 MeV (*)

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(presented by R. W. Kenney)

Angular distribution for pions elastically scattered from protons were measured at the Berkeley Bevatron in November and December of 1961. The laboratory kinetic energies of the pions selected for the measurements were: 530, 580, 700, 870, and 990 MeV for π^+ and π^-, and 1310 and 1550 MeV for π^+. Pions produced by protons striking a ceramic target in a field-free region of the Bevatron were transported to a 4-inch long liquid-hydrogen target by means of a magnetic optical system. The magnet system selected a momentum band of $\pm$ 3% about the central momentum by means of a copper slit placed at the intermediate focus. The number of protons in the positive beam was reduced at this same slit after passing through a velocity spectrometer, and the number counted was reduced to a negligible amount by time-of-flight. The beam was refocused at the hydrogen target after passing through a monitor system consisting of three scintillation counters. The counting rate was approximately 20,000 pions per 10^{11} protons incident on the ceramic target; i.e., approximately 220,000 pions per minute, and did not vary appreciably with energy or charge. The monitor system was capable of rejecting the pulses from two pions that were so closely spaced in time that they would have given a single count. The total muon and electron contamination of the beam, as measured by a gas Čerenkov counter, varied from 5 to 20% depending on the energy.

The value of the differential cross section was measured simultaneously at 21 different angles ranging from 40° to 170° in the pion centre-of-mass scattering angle. Elastically scattered pions were identified by coincident pulses from the monitor telescope, a counter placed at a given pion scattering angle, and a counter placed at the proper kinematic angle for the recoil proton. The geometric restrictions of the pion counters and their conjugate proton counters were such that few charged inelastic events were recorded in these channels. A measure of the number of charged inelastic events was obtained by simultaneously recording coincidences between each of the pion counters and various nonconjugate proton counters. A total of 63 channels of data, 21 elastic and 42 inelastic, were measured by a coincidence matrix and stored in the magnetic cores of a pulse-height analyzer. After each data run the number of counts in each channel was read out through an automatic typewriter and an IBM card punch. An IBM computer code processed portions of the data at various times during the experiment in order to verify that there were no gross defects in the experimental set-up.

In addition to the previously mentioned corrections for inelastics, muons and electrons, it was necessary to correct the cross-sections for reverse elastic events, i.e., elastic events in which the proton counted in the pion counter and the pion counted in the proton counter. This was a substantial effect at a few angles and is reflected in the size of the standard deviation quoted for those points. The number of accidental counts in all parts of the system was measured and found to be negligible. The statistical accuracy of the experiment averaged about 3-4% for the 21 elastic channels. The errors in normalization and other systematic errors are thought to be $\lesssim 3\%$.

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

Although further refinements to the data are in progress, the results quoted here are not expected to change substantially.

For each energy the measurements of the differential cross-section at each of the 21 angles, along with the dispersion-relations point at 0 deg, were fitted with a curve having an equation of the form

$$\frac{d\sigma}{d\Omega^*}(\theta^*) = \sum_{n=0}^{N} a_n \cos^n \theta^* ,$$

where θ^* is the angle in the centre-of-mass at which the pion is scattered. Acceptable values of χ^2 were obtained in all cases. Fits were also made without the point at 0°. These yielded essentially the same values for the a_n. The results from the $\pi^- - p$ measurements are in essential agreement with those obtained by Wood *et al.*[1], the main difference being that absolute normalizations, and hence total elastic cross sections, were obtained in the present experiment. In addition, the energies of these measurements are slightly lower than Wood's; however, this does not prohibit comparison of the two experiments.

The data points and the fitted curves are shown in Figs. 1 and 2. Attention should be directed to the backward peak and subsequent sharp drop-off of the cross-section at 180 deg in the $\pi^- - p$ scattering in the vicinity of the 900-MeV peak, and also to the sharp rise of the cross sections near 180 deg in the $\pi^+ - p$ scattering in the vicinity of the 1350-MeV peak.

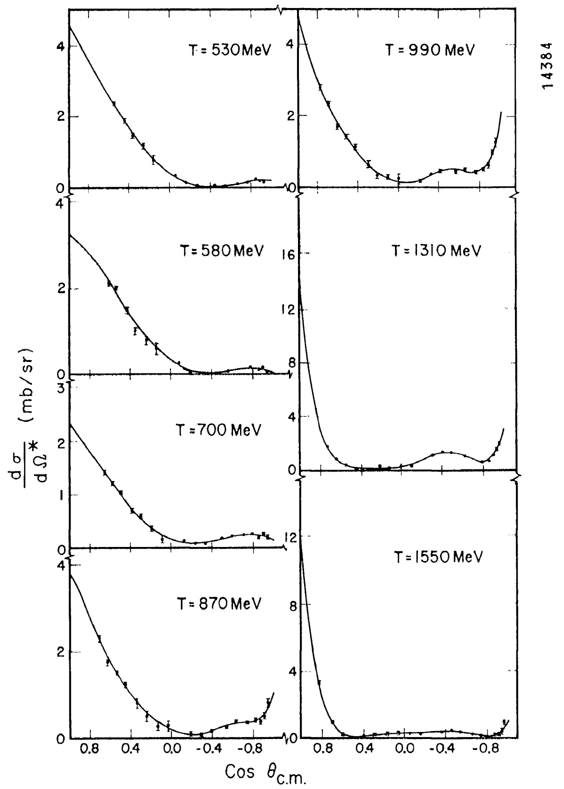

Fig. 2 Differential cross-section for $\pi^+ - p$.

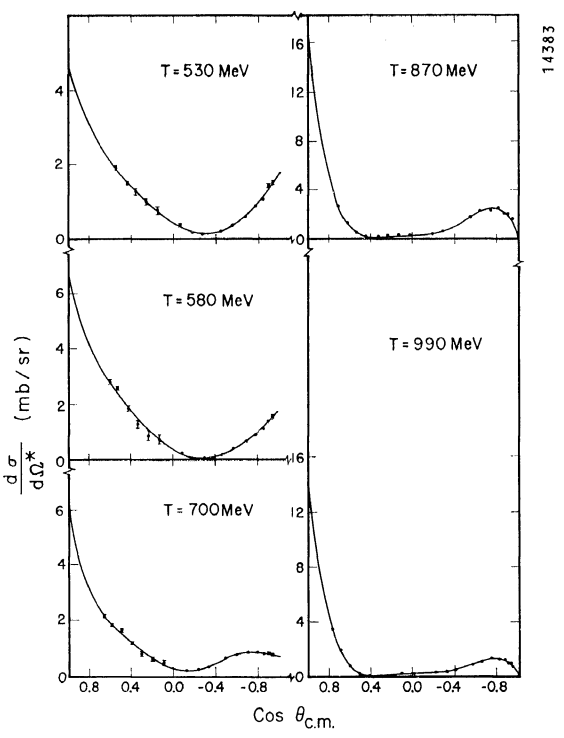

Fig. 1 Differential cross-section for $\pi^- - p$.

The values of the coefficients, a_n, in the equation above are plotted as a function of energy in Fig. 3. The curves for $\pi^- - p$ scattering include data from many experiments in addition to this one [1,2]. At 900 MeV ($\pi^- - p$) the small value of a_6 suggests that there is little scattering from partial-wave states with total angular momentum $J = 7/2$ or higher. The large value of a_5 may indicate that a superposition of $F_{5/2}$ and $D_{5/2}$ partial waves is prominent in the scattering at this energy. One possible explanation is that the $F_{5/2}$ enhancement comes from an elastic resonance in the isotopic-spin $T = 1/2$ state, consistent with the Regge-pole formalism [3], and the $D_{5/2}$ partial-wave state may be enhanced by inelastic scattering in the $T = 3/2$ state.

At 600 MeV ($\pi^- - p$) the values of the coefficients do not seem to indicate the prominence of any single partial-wave state. The similarity of the differential cross-section curves at 350 and 580 MeV, except for the larger value of the forward diffraction peak at the higher energy, may indicate that the 600 MeV peak

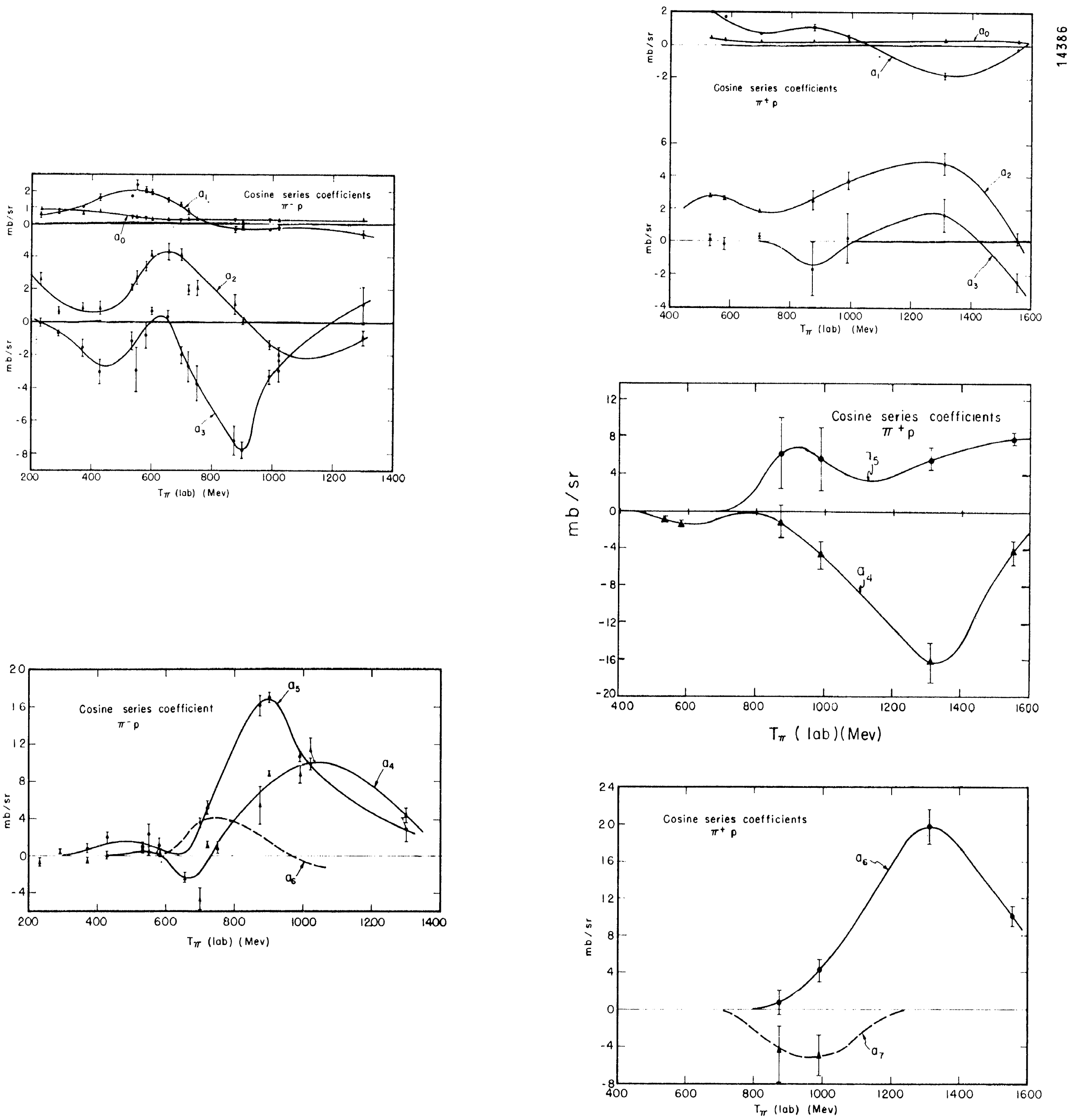

Fig. 3 Coefficients, a_n, for $\pi^-{-}p$ and $\pi^+{-}p$ as a function of energy.

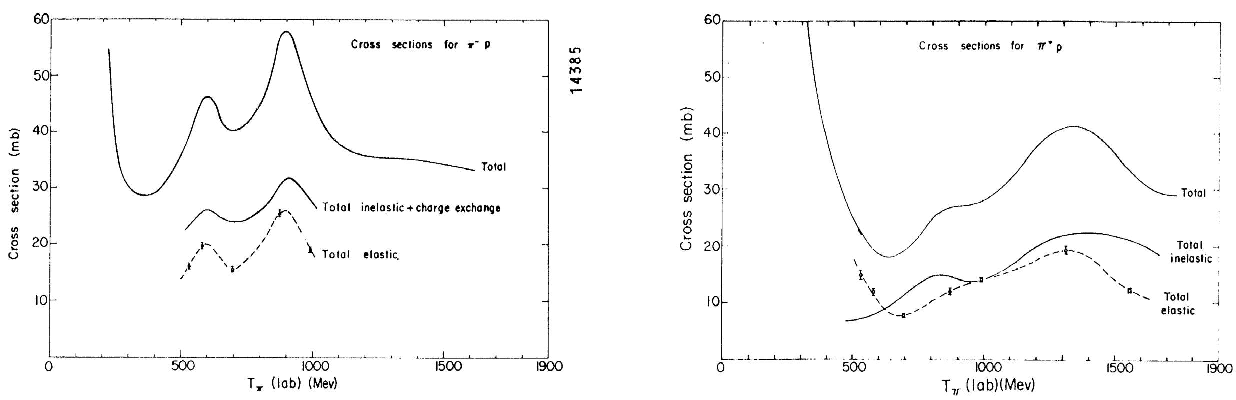

Fig. 4 Total cross-sections and total elastic cross-sections for $\pi^-{-}p$ and $\pi^+{-}p$.

is due to inelastic scattering rather than an elastic resonance.

At 1350 MeV ($\pi^+ - p$) the small value of a_7 suggests that there is little scattering from partial-wave states with $J = 9/2$ or larger. The large value of a_6 may indicate that $F_{7/2}$ scattering is prominent (although $G_{7/2}$ scattering could give the same results). The $F_{7/2}$ assignment is consistent with the Regge-pole formalism [3].

The total elastic cross section curves are shown in Fig. 4.

A report on the electronics used in this experiment is being given by R. W. Kenney at the 1962 International Conference on Instrumentation for High Energy Physics at CERN.

In conjunction with this experiment another experiment [4] was performed that measured the polarization of the recoil proton from $\pi - p$ scattering, using the same beam of pions but a different hydrogen target and experimental set-up. The data are only partly analyzed and hence cannot be presented at this time.

LIST OF REFERENCES

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2. L. K. Goodwin, R. W. Kenney, and V. Perez-Mendez, Phys. Rev. Letters *3*, 522 (1959); J. I. Shonle, Phys. Rev. Letters *5*, 156 (1960); S. Bergia, L. Bertocchi, V. Borelli, G. Brautti, L. Chersovani, L. Lavatelli, A. Minguzzi-Ranzi, R. Tosi, P. Waloschek, and V. Zoboli, Nuovo Cimento *15*, 551 (1960); and M. Chrétien, J. Leitner, N. P. Samios, M. Schwartz, and J. Steinberger, Phys. Rev. *108*, 383 (1957).
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DISCUSSION

FRAZER, W. R.: You assigned to the 900 MeV resonance the state $F\ ^5/_2$, in agreement with the Regge pole analysis. However, you found a large $(\cos\theta)^5$ term in this region, indicating strong interference with another state, perhaps $D\ ^5/_2$.

KENNEY: At 900 MeV a_6 is small. There is therefore little scattering from states of $J = {^7/_2}$ or greater. a_5 is large at 900 MeV, which then indicates a superposition of $D_{5/2}$ and $F_{5/2}$.

SALVINI: The measurements in Frascati (Querzoli, Salvini, Silverman) indicate the predominance of the state $F\,^5/_2$ in the third resonance, in agreement with the results of Helland *et al.* here reported. (Experiment $\gamma + p \rightarrow \pi^0 + p$, and measurement of the polarization of the recoil proton, reported at Rochester 1960).

PUPPI: In the fit of the angular distributions did they take into account for $\left(\frac{d\sigma}{d\Omega}\right)_{0^\circ}$ the constraint from the optical theorem and dispersion relations?

KENNEY: The power series in $\cos\theta_\pi^*$ was fitted to the 21 measured points plus the dispersion point at 0^0 (calculated from the total cross-section).