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TOTAL AND DIFFERENTIAL π-π CROSS SECTIONS IN π-p INTERACTIONS AT 1.25 Bev/c*

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The important role played by π-π interactions in $\pi^{\pm}$-p collisions has become more and more apparent as a consequence of a series of experimental results reported since early 1960.

The most important tool in studying these interactions has been the Chew-Low conjecture,[1] which resulted in a relation between the total π-π cross section, $\sigma_{\pi\pi}$, and the differential cross section, $\partial^2\sigma/\partial p^2 \partial\omega^2$, for the process π + p → π + p + π (ω^2 is the total energy of the two final-state pions in their own c.m. frame; p^2 is the four-momentum transfer of the proton.) This relation is given by:

$$\frac{\partial^2\sigma}{\partial p^2 \partial\omega^2} \xrightarrow[p^2 \to -\mu^2]{} \frac{f^2}{2\pi} \; \frac{p^2/\mu^2}{(p^2+\mu^2)^2} \cdot \frac{F(\omega)}{q^2} \cdot \sigma_{\pi\pi}(\omega) , \qquad (1)$$

in which μ is the pion rest mass, q is the laboratory momentum of the incident pion, f^2 is the renormalized pion-nucleon coupling constant, and $F(\omega) = \omega(\omega^2/4 - \mu^2)^{1/2}$, a kinematical factor.

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The Chew-Low conjecture has been applied in two different ways:

a. By performing the required extrapolation to the pole at $p^2 = -\mu^2$, thus determining the wanted $\sigma_{\pi\pi}$ cross section by means of a residue evaluation;[2]

b. By assuming that the right-hand side of expression (1) dominates the true matrix element of the single-pion production process over the "beginning" of the physical region.

This latter assumption can then be exploited in two different ways. Firstly, it can be used to predict the momentum spectrum of the recoil protons (by performing an integration over ω^2, assuming an average $\sigma_{\pi\pi}$);[3] secondly, it can be used to make so-called "physical-region cross-section plots" of $\sigma_{\pi\pi}(\omega^2)$ versus ω^2.[4] In the latter procedure one actually plots

$$\sigma_{\pi\pi}(\omega^2) = \frac{2\pi}{f^2} \cdot \frac{q^2}{F(\omega)} \left\langle \frac{(p^2+\mu^2)^2}{p^2/\mu^2} \cdot \frac{\partial^2\sigma}{\partial p^2 \partial \omega^2} \right\rangle . \tag{2}$$

The symbols used here have the same meaning as in relation (1). The hexagonal brackets indicate an average of the enclosed expression over the region $p^2_{min} \leq p^2 \leq 8\mu^2$, p^2_{min} being a kinematical lower limit for p^2 in the ω^2 region under consideration, and $8\mu^2$ being the upper limit for p^2 dictated by the physical ideas underlying the derivation of expression (1).

The idea of the necessity of a π-π resonance in a T = J = 1 state was introduced by Frazer and Fulco in their effort to explain the electromagnetic iso-vector form factors effective in electron-nucleon scattering.[5] Their calculations suggested the existence of such a resonance at $\omega^2 \approx 11.4\ \mu^2$. Later analyses[6] showed, however, that the Frazer-Fulco resonance could have a location as high as $\omega^2 \approx 22.4\ \mu^2$.

Recently a new model for the nucleon was suggested by Bergia, Stanghellini, Fubini, and Villi, in which they identify (in analogy with Frazer and Fulco) the vector-meson cloud with a T = J = 1 two-pion resonant state, while they consider the extended scalar-meson cloud to be due to a three-pion resonant state.[7]

Using this model, Littauer, Schopper, and Wilson[8] showed that the Cornell data on electron-nucleon scattering would imply a resonant two-pion state at $\omega^2 = 16\ \mu^2$. An identical analysis of the Stanford data[9] suggests that resonance to be at $\omega^2 \approx 19.6\ \mu^2$.

The experimental results referred to above have indeed indicated the existence of such a π-π resonance.[2,4] The location of the resonance has been different from experiment to experiment, and ranges from $\omega^2 \approx 20\ \mu^2$ to $\omega^2 \approx 31\ \mu^2$. The quantum numbers of the resonance have been inferred principally from either the height of the resonance or from branching-ratio considerations.

In this letter we present new evidence for the existence of a π-π resonance at $\omega^2 \approx 29\ m^2_{\pi^0}$. We also present direct evidence that the spin of that resonance is one. The data are presented here in the form of "physical-region plots." However, successful extrapolations were also performed, and their results, together with more details about the experiment and the analysis, will form the subject of a forthcoming paper.[10]

The experimental results were obtained by analyzing pictures made from an exposure of the 72-inch hydrogen bubble chamber to 1.25 Bev/c π^+ and π^- beams, which were designed by Dr. Frank Crawford of this laboratory. For our scan, we selected a sample of π-p interactions with two visible prongs, one of which was a stopping proton. All the events were measured on the Franckenstein, a precision measuring device, and then processed by means of the chain of computer programs currently used at Lawrence Radiation Laboratory. In this way we isolated a subsample of low-momentum-transfer events (proton momentum $\lesssim$ 400 Mev/c or $p^2 \lesssim 8.0\ \mu^2$). We collected

1684 events of the type

$$\pi^+ + p \rightarrow \pi^+ + p + \pi^0$$

and 411 events of the type

$$\pi^- + p \rightarrow \pi^- + p + \pi^0.$$

The physical-region plots for both the π^+ and π^- data are shown in Fig. 1. The π^+ data show a marked resonance behavior at $\omega^2 \approx 29\ m_{\pi^0}^2$ (or $\omega \approx 725$ Mev). The resonance peak has a height of roughly 70% of the one expected on the basis of a J = 1 resonance. Taking into account the fact that all these cross sections were determined off the energy shell (with a complete neglect of all other possible contributions), one is not too surprised by this difference. The half-width is $\simeq 4.5\ m_{\pi^0}^2$ on the high side of the resonance and $\simeq 7\ m_{\pi^0}^2$ on the low side. (In the ω scale, these numbers become $\simeq$ 55 Mev and $\simeq$ 95 Mev, respectively.)

For the π^- data, the shape of the $\sigma_{\pi\pi}$ curve, and even more the smallness of the cross-section values themselves, show strong deviations from the results one would expect on the basis of a dominating T = J = 1 resonance at the energy indicated by the π^+ data.

These distortions can be attributed to final-state interactions. This explanation is strongly supported by the results of our extrapolations.[7] They show that although the actually observed single-production cross sections are much smaller for the π^- than for the π^+ data, both sets of data do extrapolate in the vicinity of the resonance to values of $\sigma_{\pi\pi}$ compatible both with each other (within the error limits) and with the values expected for a T = J = 1 resonance at the location indicated above. They also show that the curves fitted to the π^+ data invariably cut the p^2-axes near the origin (indicating that the final-state interactions are not too important in that case). On the other hand, the π^- curves do intersect the p^2-axes in points much more distant from the origin (thus underlining the nonnegligibility of the final-state interactions).

On the π^+ data we performed a further analysis analogous to that implied by expression (2), but with the data divided according to $\cos\theta_{\pi\pi}$ ($\theta_{\pi\pi}$ is the angle between the incident pion and the outcoming charged pion, both measured in the dipion c. m. frame).

In Fig. 2 are shown the π-π differential-cross-section values obtained in that way for three different regions of ω^2. The smooth curves represent least-squares fits to the experimental points.

The curve obtained at the resonance region $(27\ m^2_{\pi^0} \leqslant \omega^2 \leqslant 33\ m^2_{\pi^0})$ (Fig. 2b) is very close to a pure $\cos^2\theta$ curve, and is therefore direct evidence for the presence of a J = 1 resonance.[11] The curves obtained below and above the resonance show the absence of this effect and are suggestive of an intermediary occurrence of a phase-shift difference going through 90 deg. The strikingly different behavior of the π-π differential cross section at and away from the resonance provides a convincing demonstration of the important role played by the π-π interaction in the single-pion production process.

It is a pleasure to thank Professor Luis W. Alvarez for his great interest in this experiment. We are indebted to Professor Frank S. Crawford, Jr., who designed the beam, as well as to Professor Arthur H. Rosenfeld, Dr. Phillip G. Burke, and other members of the Alvarez Group for interesting and stimulating discussions.

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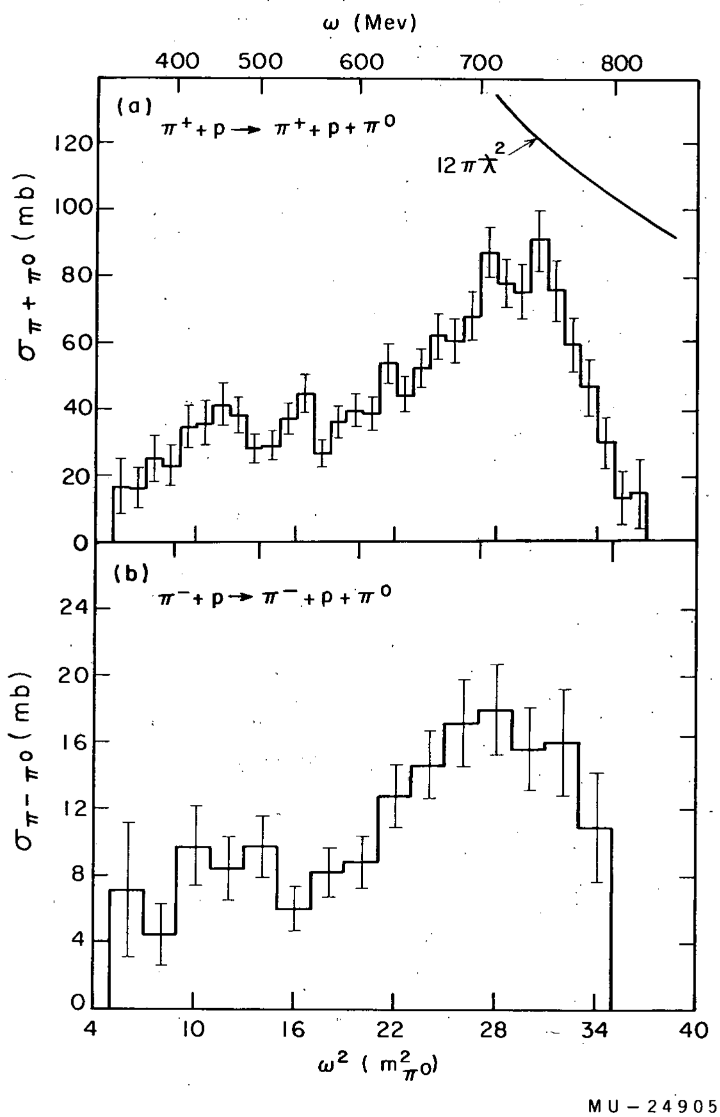

Fig. 1. Histograms (a) for $\sigma_{\pi^+\pi^0}$ and (b) for $\sigma_{\pi^-\pi^0}$ obtained from 1684 events of the type $\pi^+ + p \to \pi^+ + p + \pi^0$ and 411 events of the type $\pi^- + p \to \pi^- + p + \pi^0$.

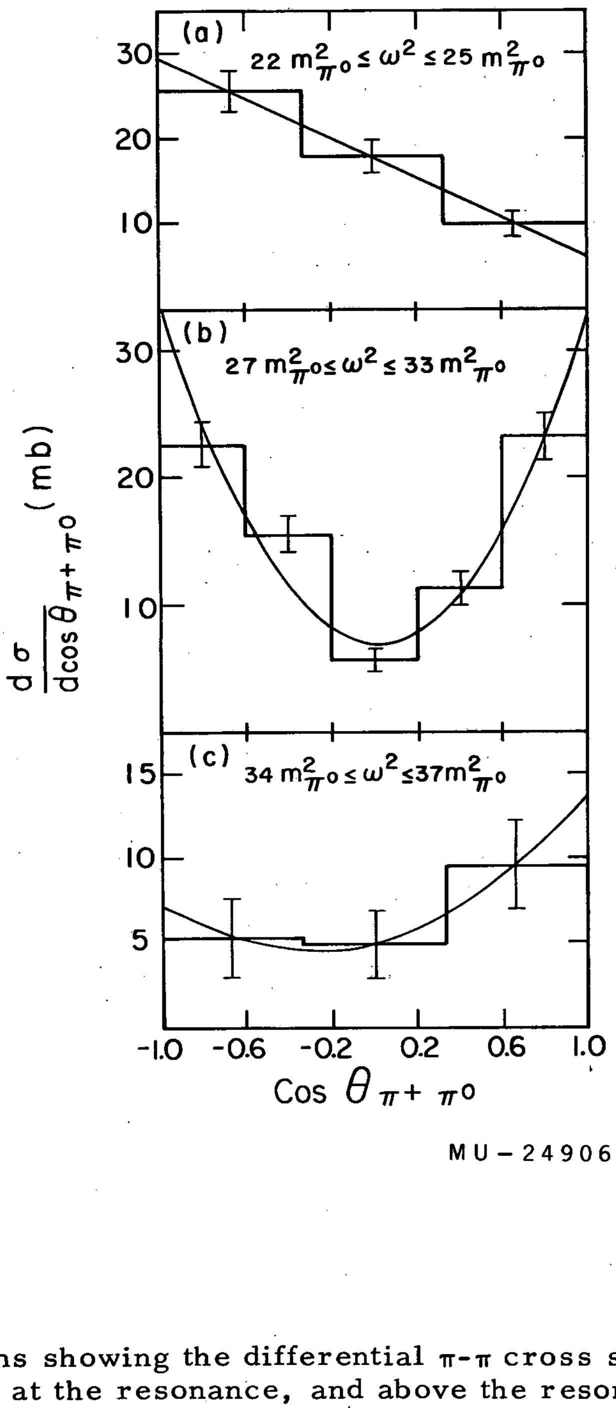

Fig. 2. Histograms showing the differential π-π cross sections below the resonance, at the resonance, and above the resonance. The smooth curves are least-squares fits to the data.

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