Fluctuations in Large-Angle $\pi^{\pm}p$ Elastic Scattering

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Large-angle $\pi^{\pm}p$ elastic-scattering cross sections, measured between 2 and 9 GeV/c in fine intervals of incident momentum and scattering angle, are used to search for cross-section fluctuations occurring for small changes in the center-of-mass energy as suggested by Ericson and Mayer-Kuckuck and by Frautschi. Significant fluctuations are observed.

Pion-proton scattering is known to be dominated by s-channel resonances at low energies. These resonances show up as dramatic increases in the total cross section for relatively small changes in incident pion momentum. Above ~ 3 GeV/c, however, the rapid changes in cross section have damped out and the cross section becomes a relatively smooth and slowly changing function of energy. This transition is generally supposed to indicate the emergence of t-channel exchanges, Regge poles, or other "high-energy" mechanisms as the dominant scattering process.

Ericson and Mayer-Kuckuck[1] and Frautschi[2] have suggested that resonances may continue to contribute at high momentum but grow so numerous that their effects overlap. They show that in that case there will still be significant changes in cross sections for c.m. energy changes on the order of a resonance width, but the changes will come from variations of the number and properties of contributing resonances, rather than from the effects of single resonances. Frautschi[2] and Carlson[3] have shown that the amount of structure in forward and backward $\pi^{\pm}p$ elastic-scattering cross sections is consistent with this picture. Such fluctuations should be easiest to observe in the differential cross section in regions where exchange contributions are small relative to s-channel resonances, i.e. at large angles, away from the forward and backward peaks.

Frautschi[2] has made specific predictions for $\pi^{\pm}p$ elastic scattering based on a statistical bootstrap model. He predicts that typical resonance widths, and therefore the scale for significant cross-section fluctuations, will be about equal to the pion mass.[4] In fact, Schmidt *et al.*,[5] analyzing data from a CERN experiment[6] at 5 GeV/c, have reported changes in the differential cross section of up to a factor of 3 in π^+p (but not π^-p) elastic scattering at large angles, for a change of only 30 MeV in $\sqrt{s}$. In the model of multiple overlapping resonances, this result suggested that large-angle π^+p scattering is dominated by small numbers of resonances whose width might be quite small. Confirmation of this conclusion, however, requires closely spaced measurements at other energies.

In this Letter, we present data from an experiment performed at the Argonne National Laboratory (ANL) zero-gradient synchrotron in which we search systematically for fluctuations in π^+p scattering from 2 to 6.3 GeV/c and in π^-p scattering from 2 to 9.7 GeV/c. $K^{\pm}p$ and pp or $\bar{p}p$ elastic-scattering events were recorded at the same time. We ask the experimental question whether the differential cross section is a smooth function of energy or shows rapid changes in magnitude or shape as a function of energy in the measured region.

The apparatus and experimental method have been described previously.[7] However we note here the characteristics of the experiment that are important to the search for fluctuations. Since there are no magnet apertures, the azimuthal acceptance is a smooth function of $\theta_{\text{c.m.}}$. The peak acceptance changes smoothly from 0.17 to 0.27 over the momentum range of the experiment. Thus, narrow structure in the differential cross section cannot be introduced in dividing by the acceptance. Points with acceptance less than

25% of the peak acceptance have not been included in the final data.

Data were taken in such a way that the momentum ranges overlapped for adjacent settings of the beam magnets. These overlapping bins provide an important test of the reproducibility of the data, since often the data at adjacent momentum settings were taken with the spectrometer arms at different angles and/or with weeks or months intervening. Point-by-point comparisons of these overlapping differential cross sections give a satisfactory distribution of χ^2. In making these comparisons, we have allowed the relative normalizations to change within the estimated run-to-run systematic error of $\pm 3\%$. In the cross sections reported here, the overlap bins have been averaged together.

The absolute momentum calibration of the incident beam was determined by Monte Carlo simulation of the magnet system, wire orbit studies, and a separate experiment which detected elastic pp scattering.[8] A further check is provided by the kinematics of the elastically scattered particles. The overall uncertainty of the momentum calibration is estimated to be $\pm 0.5\%$.

The search for fluctuations has been conducted by plotting $d\sigma/dt$ at fixed t vs s. Some of these graphs are shown in Fig. 1. Fixed-t cross sections have been chosen because of the known presence of structures in the cross section at fixed t, in particular a sharp dip at $t=-2.8$ GeV/c^2. If the energy dependence of fixed-angle cross sections were investigated, as might seem more appropriate in a search for resonance effects, extraneous structure would be produced as a fixed-t feature moved past the particular scattering angle.

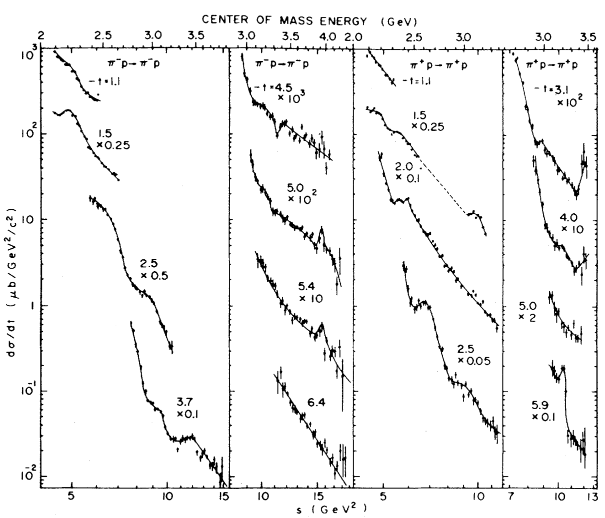

FIG. 1. Differential cross sections at constant t. The top number by each set of data points gives $-t$ in GeV^2/c^2. The bottom number, if present, is a scale factor by which $d\sigma/dt$ has been multiplied for presentation. Cross sections have been averaged over t ranges of approximately $\pm 4\%$.

Lines have been drawn through the data points in Fig. 1 to guide the eye and to indicate the major structures that appear in the data. It is clear that the data cannot in general be represented by smooth curves and that significant, previously unknown structures with widths in s of 1–2 GeV^2 are revealed. Plots at intermediate values of t generally show a smooth transition between the graphs of Fig. 1.

Previous data have been omitted from Fig. 1 for lack of space. They are sparse above $p_{\rm inc}=3$ GeV/c, but are generally in agreement with the present data within quoted errors.

We summarize here the characteristics of the observed structures:

(a) Excursions about a smooth curve are as much as a factor of 2 in either direction.

(b) Full widths are between 100 and 200 MeV in c.m. energy. These widths are significantly narrower than the observed widths of established nucleon resonances, which for $s>6$ GeV^2 are at least 350 MeV.[9]

(c) None of the structures is present in all of the constant-t graphs. About half of the structures are centered at a constant value of u, but are present only for a limited range of t, even though there are data for the particular u value in a wider range of t.

(d) The number and relative amplitude of the structures are qualitatively constant as a function of s or t, and as a function of pion charge in the region where we have data for both π^+p and π^-p. This behavior is in sharp contrast to similar plots of our pp elastic-scattering data, where no significant narrow structure is observed, confirming the negative results of previous searches.[10]

(e) Structures that appear in the same kinematic region for π^+p and π^-p are not more prominent in π^+p by a large factor (the scattering amplitude should be larger by a factor of 3) as they would be if due to pure $I=\frac{3}{2}$ states.

We have paid particular attention to π^+p elastic scattering near 5.0 GeV/c incident momentum because of the sharp structure previously reported.[5] We have followed the analysis of Ref. 5 in computing an asymmetry parameter for adjacent momentum bins. If the two adjacent momenta are $p_1 < p_2$, then

$$A(t) = \left[\frac{d\sigma(p_2,t)}{dt} - \frac{d\sigma(p_1,t)}{dt}\right] \times \left[\frac{d\sigma(p_2,t)}{dt} + \frac{d\sigma(p_1,t)}{dt}\right]^{-1}.$$

This asymmetry parameter is plotted in Fig. 2 for the two bins at 5.10 and 5.20 GeV/c ($\Delta\sqrt{s} = 31$ MeV) along with the data from Ref. 5.

The two bins used have momenta about 3% higher than those of Ref. 5, but have been chosen because they show a structure similar to that of the previous experiment. No other pair of bins between 4.5 and 5.5 GeV/c shows as much structure. A comparison of the two sets of asymmetries shows that the present data substantially confirm the sharp drop to negative values for $-t > 5$ GeV^2/c^2. However, it does not show the large positive values of asymmetry reported near $-t = 4$ GeV^2/c^2. The structure revealed in Fig. 2 is evident in Fig. 1 at $-t = 5.9$ GeV^2/c^2, $s \approx 10$ GeV^2.

We note that there is narrow structure in the nonexotic $\pi^{\pm}p$ channels but not in the exotic pp channel. This suggests an origin in s-channel resonances. The structures are not well explained as constant-u phenomena [see characteristic (c) above]. However the narrow widths and the relationship between π^+p and π^-p structures cannot be explained by known s-channel resonances. Thus it is probable that the structure is due to either new individual resonances or to multiple-resonance fluctuations. In the latter case, the density of states must be different from the exponentially rising mass spectrum of the statistical bootstrap model, since in that model Frautschi[2] finds that the relative size of the structures must fall by about an order of magnitude across the region of s measured by this experiment.

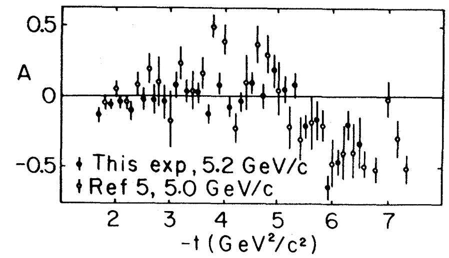

FIG. 2. Asymmetry of $d\sigma/dt$ for two values of p_{inc} separated by 2% centered at the indicated momenta. See text for definition of asymmetry A.

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