STUDY OF INELASTIC PROTON-PROTON SCATTERING AT 12.5 GeV/c*†

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We have tested experimentally the model that the three regions seen in p-p elastic scattering are the diffraction scattering due to π, K, and $\bar{p}$ production. The inelastic p-p cross section was measured on circles of constant $P_{\mathrm{c.m.}}$. One contained a pure sample of inelastic π events; the other, both π and K events. The cross section has a break on both circles showing that the break is not due to K mesons and that the model is wrong.

During the past five years there has been an extensive experimental study[1-5] of proton-proton elastic scattering above 3 GeV/c. Probably the most striking result of this study is that the proton-proton interaction appears to have three distinct Gaussian regions. This was first clearly seen at Argonne National Laboratory[4] and later verified at CERN,[5] and can be best seen in the compilation of all existing data[1-5] by Krisch.[6]

Now that the existence of these three regions seems fairly certain, one must ask why they exist separately. It would be strange if the three regions differed in no property other than interaction probability density. One recent proposal is that the three regions are due to quark-quark single, double, and triple scattering.[7] This is an attractive idea but is not easy to test experimentally.

In 1964 Krisch[8] suggested that the three then proposed regions in elastic scattering were the diffraction scattering caused by inelastic interactions in which π mesons, K mesons, and antiprotons were produced. More recently this idea has been discussed by Allaby et al.,[5] and Kokkedee and Van Hove.[9] The idea appears quite attractive since the forces associated with the $\bar{p}$ and K are expected to have shorter ranges than the π forces, and this agrees with the three radii of 0.34, 0.52, and 0.92 F obtained from elastic scattering. Moreover the total inelastic cross sections for K and $\bar{p}$ production are more or less in agreement[8,9] with the second and third intercepts of the elastic cross section. However, the idea had not been stringently tested and there was some negative evidence. In studying the slopes of the differential production cross sections for π, K, and $\bar{p}$ production in a $P_\perp{}^2$ plot, all three slopes were found to be identical rather than proportional to the three elastic slopes.[10]

The present experiment tests this model in the following way. We measured the differential cross section $d^2\sigma/d\Omega dp$ for inelastic proton-proton scattering at 12.5 GeV/c. We detected only one of the outgoing protons; so we were observing the process[11]

$$p+p\to p+\text{anything}. \tag{1}$$

We made two series of measurements, each on a circle of constant $P_{\mathrm{c.m.}}$. This can be seen in Fig. 1 where we have a momentum plot in the center-of-mass system. The elastic circle is

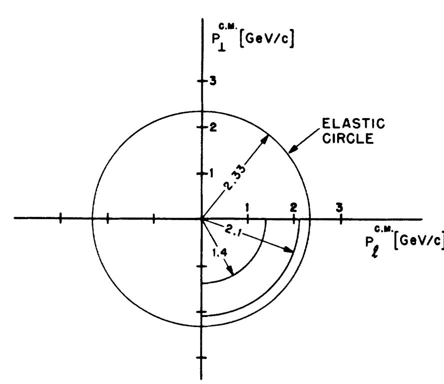

FIG. 1. Momentum plot in the c.m. system showing the elastic circle and the two inelastic circles of this experiment. On the 2.1-GeV/c circle only events in which π mesons alone are produced are kinematically possible. On the 1.4-GeV/c circle both π-meson and K-meson production are possible.

shown to have $P_{\text{c.m.}} = 2.33$ GeV/c. We chose our two inelastic circles to have $P_{\text{c.m.}} = 2.1$ and 1.4 GeV/c.

The essential point of the experiment is that the events on the 2.1-GeV/c circle can produce only π mesons, while the events on the 1.4-GeV/c circle can produce both π mesons and K mesons. This is because a 12.5-GeV/c event, resulting in a proton with $P_{\text{c.m.}} = 2.1$ GeV/c, is just about at threshold for

$$p + p \to p + K^+ + \Lambda^\circ, \tag{2}$$

and below threshold for any other processes involving strangeness. Thus the 2.1-GeV/c circle contains an essentially pure sample of inelastic events in which only π mesons were produced. However, on the 1.4-GeV/c circle both π mesons and K mesons are easily produced, and we have a mixed sample of inelastic events involving both π and K production.

Assume that the model is correct, and that the first break in the elastic cross section is really due to K-meson production. Then there should be a break in $d^2\sigma/d\Omega dp$ on the 1.4-GeV/c circle which contains a mixed sample of π and K events. But there should be no break in $d^2\sigma/d\Omega dp$ on the 2.1-GeV/c circle, for this is a pure sample of π-meson events. Thus if the model is correct, the following are true: (a) The elastic cross section will break (as it does). (b) The inelastic cross section on the inner circle (1.4 GeV/c) will break. (c) The inelastic cross section on the middle circle (2.1 GeV/c) will not break. If this does not happen then the model is almost certainly wrong.

The experiment was performed on the slow extracted beam of the zero gradient synchrotron at Argonne National Laboratory. We used an experimental layout essentially identical to that used in a recent experiment[12] studying particle production at high $P_\perp^2$.

About 5×10^{11} protons of 12.50 GeV/c were extracted every pulse and made to impinge upon a 3-in. hydrogen target. The incident proton flux was measured using two monitor telescopes, calibrated by gold-foil irradiations. The scattered proton was detected by a spectrometer consisting of magnets, scintillation counters, and Cherenkov counters. The experimental details are given in Ref. 12. The present experiment only differs in that the Cherenkov telescope was now set to detect protons.

The differential inelastic cross section was calculated from the formula

$$\frac{d^2\sigma}{d\Omega dp} = \frac{\text{events}}{I_0 (N_0 \rho t) \Delta_\Omega \Delta p}. \tag{3}$$

The quantity I_0 is the number of incident protons as measured by our monitors. The uncertainty in I_0 was about 5%. N_0 is Avogadro's number; ρ is the density of liquid hydrogen, taken as 0.07; t is the target length, taken as 7.62 cm; $\Delta\Omega\Delta p$ is the c.m. phase-space volume.

There were several corrections and uncertainties involved in determining the number of events. The statistical error varied from 1 to 4%. The accidental correction was negligible. The total target-empty subtraction was 9 ± 2%. A correction was made for nuclear interaction of protons in the spectrometer of 1.20 ± 0.02. No correction was made for multiple Coulomb scattering because in-scattering is equal to out-scattering in a single-arm spectrometer with small $\Delta\Omega\Delta p$. Thus the total point-to-point error, obtained by adding statistical and systematic errors in quadrature, was generally less than 5%. There was an additional 5% normalization uncertainty due to the calibration of the incident proton flux. The data are shown in Fig. 2. These values are preliminary but should not change by more than 5%.

In Fig. 2 we have plotted the inelastic differen-

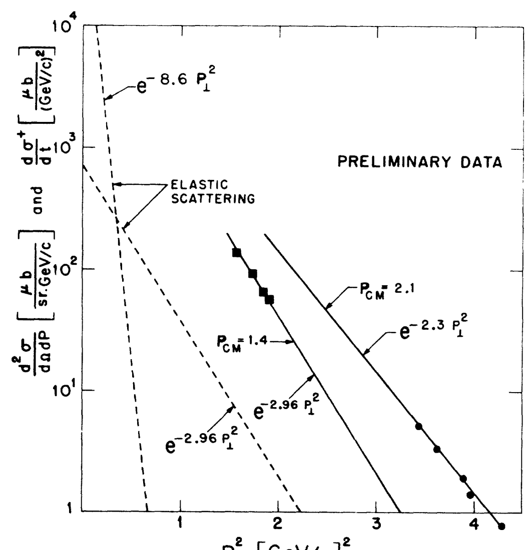

FIG. 2. Plot of the center-of-mass inelastic differential cross section $d^2\sigma/\Omega dp$ against $P_\perp^2$. The lines drawn through the data points for $P_{\text{c.m.}} = 1.4$ GeV/c and $P_{\text{c.m.}} = 2.1$ GeV/c are straight-line fits to the data. The differential elastic cross section is shown on the same scale for comparison.

tial cross section $d^2\sigma/d\Omega dp$ against $P_\perp^2$ for both the 1.4- and 2.1-GeV/c inelastic circles. The elastic cross section is shown on the same scale for comparison. Recall[11] that at small $P_\perp^2$ the inelastic cross section has a slope of about 10 $(\text{GeV}/c)^{-2}$. Thus the inelastic cross section has broken on both circles and has, in both cases, the slope of the second elastic region and not the first. Thus it appears that the model is wrong and the second region is not due to K production. It was not possible at this energy to test whether the third region is due to $\bar{p}$ production.

This data can, of course, be used to test other models. However, we believe that in general it will test other models only weakly while it tests the π, K, and $\bar{p}$ model very stringently. Consequently, we will not discuss the relevance of this data to other models at this time. We plan to make more extensive measurements on inelastic proton-proton scattering later this year to distinquish between the different models.

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