ELASTIC p-p CROSS SECTIONS AT HIGH-MOMENTUM TRANSFERS*

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At present elastic p-p scattering at high momentum transfers is of special significance in that it can be used to test what is called the Regge-pole hypothesis, which involves fundamental concepts of strong interactions and the nature of "elementary particles."[1]

For the past two years experiments at CERN[2] have measured elastic p-p scattering cross sections for energies in the region 10 to 25 GeV and for squared four-momentum transfers, $-t$, as high as ~5 $(\mathrm{GeV}/c)^2$. The elastic events were selected at CERN by momentum analysis of the forward scattered protons.

The experiment reported here has measured the p-p elastic cross section at $-t=6.15$ $(\mathrm{GeV}/c)^2$ as well as an upper limit on the same cross section at $-t=11.1$ $(\mathrm{GeV}/c)^2$, using the 30-GeV AGS at the Brookhaven National Laboratory. The main difference between our experiment and those of CERN is that we have selected the elastic events by requiring the coincidence of both recoil and scattered protons.

The p-p elastic scatterings, produced in an internal target by the circulating proton beam of 11.2 GeV/c momentum, were detected by recording the coincidences between the protons scattered at 15° on the left side of the target, and the corresponding recoil protons at 30° on the right side. The momenta of the two protons, $p_L=7.89$ GeV/c and $p_R=4.09$ GeV/c, were selected by two magnets providing deflections of 5° and 6°, respectively, as shown in Fig. 1. The scintillation counters on the right side were smaller and defined the solid angle $\Delta\Omega=1.68\times10^{-5}$ steradian. The counter sizes on the left side were such that elastic events could be detected in both telescopes for a region of incoming beam momentum of 11.2 ± 0.2 GeV/c. Monitoring was provided by a third and smaller telescope looking directly at the target at 21° from the beam direction. The monitor readings were normalized to the beam proton path length in the target by measuring the total activity of the Be^7 spallation product from C (0.48-MeV γ). The spallation cross section for $p+\mathrm{C}\rightarrow Be^7$ is 7.9 mb, at 10 GeV, and is energy independent over a range of several BeV.[3]

The p-p cross section was to be obtained by alternately flipping polyethylene and carbon targets into the internal beam, and taking CH_2-C differences. However, a most gratifying result was that, within statistics, no left-right coincidences were observed with the carbon target, so that its use could be discontinued. A one-standard-deviation limit on this zero result corresponds to less than 10% of the effect observed when CH_2 was used as the target. This is consistent with an estimate of the effect of Fermi motion in carbon nuclei made using the impulse approximation. For our stringent geometrical requirements we estimated that quasi-elastic scatterings of the beam protons by the protons in the carbon nucleus would contribute about a 2% background to the truly elastic scatterings on hydrogen in CH_2. Hence, in this type of experiment, an internal polyethylene target behaves as an almost pure H_2 target, about 20% efficient.

Our final result for the elastic p-p scattering cross section is

$$(d\sigma/d\omega)_{\mathrm{c.m.}}=(1.80\pm0.12)\times10^{-32}\ \mathrm{cm}^2\ \mathrm{sr}^{-1}$$

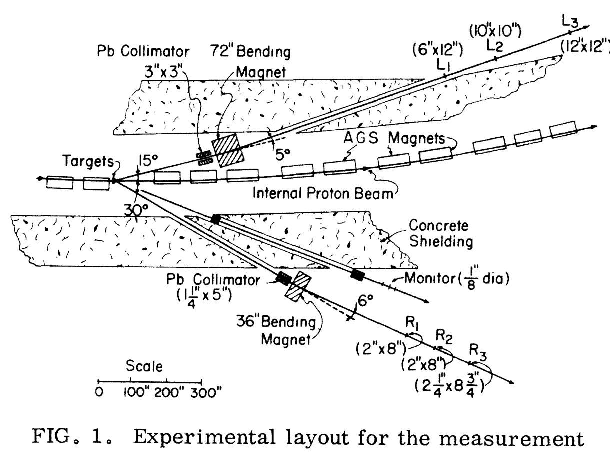

FIG. 1. Experimental layout for the measurement of the elastic differential cross section at the internal beam momentum $p_0=11.2$ GeV/c and squared four-momentum transfer $-t=6.15$ $(\mathrm{GeV}/c)^2$.

for $p_0 = 11.2$ GeV/c, $-t = 6.15$ (GeV/c)^2, and $\theta_{\text{c.m.}} = 68.5°$. The error given above is purely statistical. The over-all systematic error should be less than 25%, the largest contributions arising from the evaluation of what fraction of the internal beam is in the proper energy interval and from the radiochemical analysis of the targets.

A second measurement was performed at $p_0 = 16.0$ GeV/c and $-t = 11.1$ (GeV/c)^2. The setup was similar to that of Fig. 1, with the values of the parameters as follows: $\theta_L = 15°$, $\theta_R = 22.5°$, $p_L = 10.03$ GeV/c, and $p_R = 6.79$ GeV/c. In these conditions no effect emerged from the background counts. The statistical two-standard-deviation upper limit for the elastic scattering cross section is

$$(d\sigma/d\omega)_{\text{c.m.}} < 1.3 \times 10^{-34} \text{ cm}^2 \text{ sr}^{-1}$$

for $p_0 = 16.0$ GeV/c, $-t = 11.1$ (GeV/c)^2, and $\theta_{\text{c.m.}} = 77.5°$.

In Fig. 2 our results are plotted along with the results obtained at CERN for the elastic differential scattering cross sections with $p_0 > 10$ GeV/c and $-t > 1$ (GeV/c)^2. All cross sections are normalized to the forward ($t = 0$) cross section as deduced from the optical theorem, and expressed

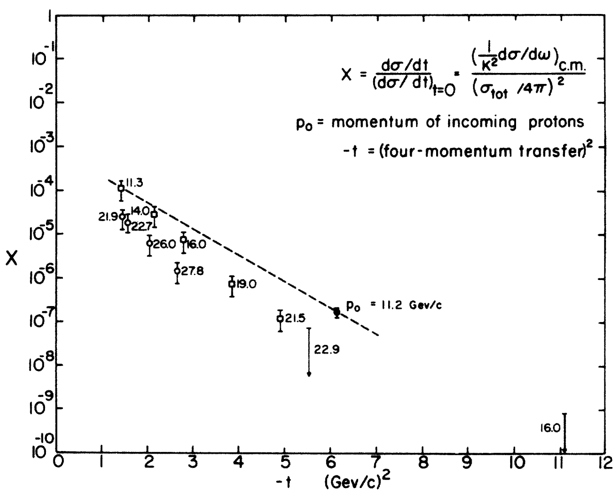

FIG. 2. Elastic differential cross section, normalized to the forward scattering cross section, as a function of the squared four-momentum transfer $-t$. All the points plotted are CERN results, except for the point at $p_0 = 11.2$ GeV/c, $-t = 6.15$ (GeV/c)^2, and for the upper limit at $p_0 = 16.0$ GeV/c, $-t = 11.1$ (GeV/c)^2, which are the results of the Brookhaven-Cornell experiment reported here. The dotted line connects two points at approximately the same energy but different t.

in invariant form, i.e.,

$$X = \frac{d\sigma/dt}{(d\sigma/dt)_{t=0}} = \frac{(k^{-2}d\sigma/d\omega)_{\text{c.m.}}}{(\sigma_{\text{tot}}/4\pi)^2}.$$

The results in Fig. 2 may be interpreted in terms of the proposals in the papers quoted in reference 1. Following Frautschi, Gell-Mann, and Zachariasen, the elastic differential cross section for p-p scattering can be written as

$$X = F(t)(s/2M^2)^{2\alpha(t)-2},$$

where M = proton mass, s = (total c.m. energy)^2 $\approx 2Mp_0$, and $F(t)$ and $\alpha(t)$ are functions only of the momentum transfer. The variation of α with t, which is the crucial information that one can derive from the data, can be obtained by comparing values of X corresponding to different energies s, but the same squared four-momentum transfer t:

$$\alpha(t) = \frac{\ln(X_1/X_2)}{\ln(s_1/s_2)} + 1.$$

In Fig. 2 we have connected our point at $p_0 = 11.2$ GeV/c with a CERN point at about the same beam energy ($p_0 = 11.3$ GeV/c) but lower momentum transfer [$-t = 1.43$ (GeV/c)^2].[4] Then we have estimated α at the t values of the various CERN points by comparing them with corresponding values of X on the dotted line. The results are plotted in Fig. 3. The dashed line indicates the behavior of $\alpha(t)$ at small t values, as deduced by the CERN group. From the value +1 at $t = 0$, $\alpha(t)$

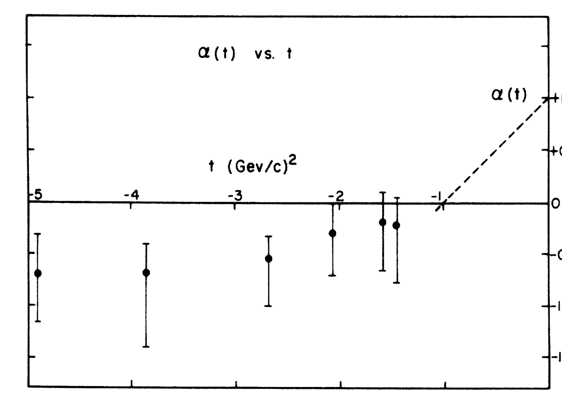

FIG. 3. The t dependence of the Regge term $\alpha(t)$, as derived by using each experimental point in Fig. 2 in association with the value at the same t on the $p_0 \approx 11$ GeV/c line. The errors in the points plotted are only those resulting from the errors given by the CERN group for their points, with no error attributed to the $p_0 \approx 11$ GeV/c line.

decreases rapidly to 0 at $-t \approx 1$ $(\text{GeV}/c)^2$, then has a significant change in slope, so that its value at $-t \approx 5$ $(\text{GeV}/c)^2$ seems to be $\sim -\frac{1}{2}$. If this is the behavior of $\alpha(t)$, the consequent behavior of $F(t)$ is a rapid exponential decrease from +1 at $t=0$ to $\sim 4\times10^{-2}$ at $-t=1$, followed by a very slow decrease to $\sim 1\times10^{-2}$ at $t\approx 5$ $(\text{GeV}/c)^2$.

However, the magnitude of the errors in the experimental points must restrain deductions based on these results only. Further measurements are planned to determine whether or not $\alpha(t)$ is indeed approaching an asymptotic limit. In the framework of the Regge-pole hypothesis, the question of the asymptotic limit of $\alpha(t)$ has a bearing on the "elementarity" of the pion and on the nature of the short-range nucleon-nucleon interaction.

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[4]The extrapolation of the line for $p_0 \approx 11$ GeV/c to the value $-t \approx 11$ $(\text{GeV}/c)^2$ investigated in our second measurement seems to indicate that the elastic cross section there may be a factor of ~10 smaller than our upper limit. Obvious improvements in the experimental techniques ("flat top" beam and better geometry) will probably allow measurements at such momentum transfers.

PROPERTIES OF THE η MESON*

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Since the discovery of the eta meson,[1] its spin and parity have been in doubt because of background contamination and poor statistics in available samples of eta decay. The purest sample has been obtained by Bastien et al.,[2] who have reported 23 charged eta decays $(\pi^+\pi^-\pi^0)$ from reactions of the type $K^- + p \rightarrow \Lambda^0 + \eta^0$, with estimated background of three events. They have tentatively assigned spin zero, negative parity, and positive G-parity[3] to the eta meson.

Since the above conclusions clearly require verification, we report results from 102 charged eta decays with estimated background of only 6%, produced in four-pronged reactions of a π^+ beam in the Brookhaven 20-in. hydrogen bubble chamber at the Cosmotron, at incident kinetic energies of 1090 MeV and 1260 MeV. Our results favor 0^{-+} for the spin, parity, and G-parity of the eta meson, and definitely exclude the simple isospin-conserving assignments 0^{--}, 1^{+-}, and 1^{--}. We also find that at most a small amount of the decay mode $(\pi^+\pi^-\gamma)$ is present in our data.

At 1090 MeV, we have identified 1165 cases of the reaction

$$\pi^+ + p \rightarrow p + \pi^+ + \pi^+ + \pi^- \quad (1)$$

and 85 cases of the reaction

$$\pi^+ + p \rightarrow p + \pi^+ + \pi^+ + \pi^- + \pi^0. \quad (2)$$

The corresponding numbers for 1260 MeV are 265 and 28, respectively. In Reaction (2) either π^+ meson may be combined with the π^- and π^0 mesons to produce a $\pi^+\pi^-\pi^0$ triplet. The effective masses for these two triplets have been computed for each event. A histogram including both effective-mass combinations shows a prominent peak lying at 548 MeV at both energies.[4] Figure 1 shows the effective-mass spectrum obtained by selecting from each event that $\pi^+\pi^-\pi^0$ triplet whose effective mass lies nearest to 548 MeV. It is clear from Fig. 1 that almost every example of Reaction (2) is con-