NEGATIVE PION-PROTON ELASTIC SCATTERING AT 10 GeV/c

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(Received 29 March 1963)

The result that the width of the diffraction peak in proton-proton elastic scattering shrinks with increasing energy[1,2] has given rise to several speculations, particularly in terms of Regge poles.[3-5] The simplest version of this theory assumed that elastic scattering should be dominated by the Pomeranchuk pole, and hence it was expected that in pion-proton elastic scattering a similar shrinking should be seen.

Here we present the results of the analysis of 1706 events of elastic scattering of (10.0 ± 0.6)-GeV/c negative pions on proton. Preliminary results on 300 of these elastic events have already been discussed.[6] The experiment was performed at the CERN proton-synchrotron accelerator with the Saclay 81-cm hydrogen bubble chamber. Comparison of these results with those obtained at other energies shows that the shrinking of the diffraction peak between 3 and 10 GeV/c, if any, is much smaller than that observed for $p-p$ scattering. Our differential cross section at small momentum transfers seems to deviate from the exponential shape usually assumed, presenting an upward curvature. This, if confirmed, would require a revision in the interpretation of the elastic scattering data at high energies, in particular, in comparing the extrapolated value at $t=0$ with the optical theorem point.

The selection of elastic events was based on fits to four kinematical restraint equations plus a check on the ionization of the positive track, which could be measured up to ≈ 2 GeV/c. From checks made on the goodness of the selection criteria and from measurements of inelastic events, it was estimated[7] that the background of inelastic events in our sample is smaller than 1%.

The observed and corrected numbers of events in each interval of t, the square of the four-momentum transfer, as well as the value of the differential elastic cross section, are given in Table I. The corrections take into account scanning losses due to steeply dipping tracks, and were based on the azimuthal distribution of the events in the t interval considered; they were important only up to $t=0.04$ (GeV/c)^2. The 84 events observed in the first interval, which correspond to recoil protons with ranges between 2 and 10 mm, were not used in the final analysis, as the azimuthal correction was large and uncertain; however, the estimated corrected number is not inconsistent with the rest of the data.

To compute absolute cross sections, we have normalized the value measured by von Dardel et al.,[8] for the total $\pi^- - p$ cross section, $\sigma_{tot} = (26.5\pm 0.35)$ mb, to the corrected total number of interactions counted on the photographs, so that our results are independent of the μ-meson contamination in the beam (which is $\approx 10\%$). The presence of $\approx 1\%$ K^- mesons and $\leq 1\%$ antiprotons in the beam produces a negligible effect.

In Table I, the values of $d\sigma/dt$ are listed to-

Table I. Experimental results for the differential elastic cross section of 10-GeV/c $\pi^- - p$.

t interval [(GeV/c)^2]	Number of events observed	corrected	$d\sigma/dt$ [mb (GeV/c)$^{-2}$]
O.T.P.,[a] $t=0$	...	328	35.0 ±0.75
0.009-0.02	84	390 ±64	not used
0.02 -0.04	201	288.4	30.68 ±2.81
0.04 -0.06	234	264.5	28.14 ±2.08
0.06 -0.08	165	175.0	18.62 ±1.45
0.08 -0.10	152	157.1	16.71 ±1.35
0.10 -0.12	108	109.2	11.62 ±1.12
0.12 -0.14	96	96.8	10.30 ±1.05
0.14 -0.16	85	86.1	9.16 ±1.00
0.16 -0.18	70	70.7	7.52 ±0.89
0.18 -0.20	71	71.7	7.63 ±0.91
0.20 -0.22	61	61.9	6.59 ±0.84
0.22 -0.24	47	47.5	5.05 ±0.74
0.24 -0.28	72	72.8	3.87 ±0.45
0.28 -0.32	64	64.8	3.45 ±0.43
0.32 -0.36	45	45.4	2.41 ±0.36
0.36 -0.42	46	46.7	1.65 ±0.24
0.42 -0.50	45	45.7	1.22 ±0.181
0.50 -0.60	25	25.1	0.534 ±0.106
0.60 -0.80	15	15.2	0.162 ±0.042
0.80 -1.00	7	7.1	0.0755 ±0.028
1.00 -1.20	5	6.4	0.068 ±0.029
1.20 -1.60	3	3.8	0.020 ±0.011

[a]Optical theorem point.

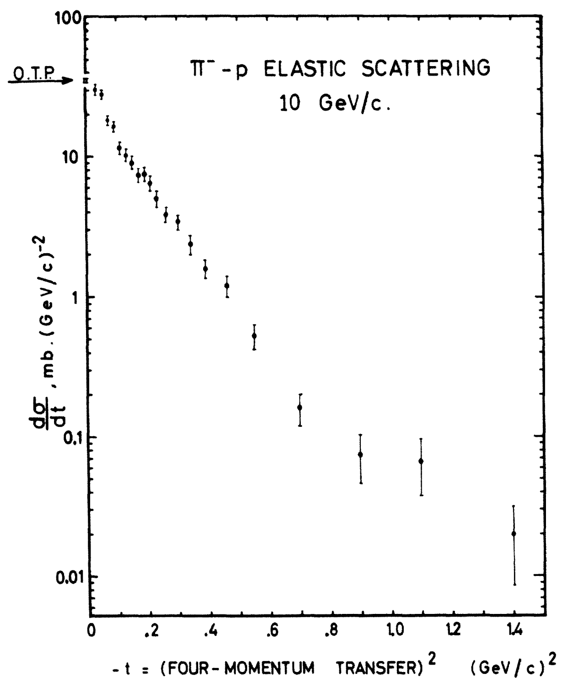

FIG. 1. Elastic differential cross section. The point at $t=0$ is the calculated optical theorem point.

gether with their statistical errors which are based on the number of events used in each t interval; when taking into account terms due to normalization, the errors are slightly increased (by <10%). In Fig. 1 the results are plotted with their statistical errors, as these are the errors to be used when fitting functions which are independent of the absolute value of the cross section. The point at $t=0$ (optical theorem point) is given for the sake of comparison and was calculated by assuming that the forward scattering amplitude has no real part, so that

$$d\sigma/dt = \sigma_{\text{tot}}^2/16\pi\hbar^2 = \sigma_{\text{tot}}^2/20.1 \text{ mb } (\text{GeV}/c)^{-2}. \quad (2)$$

The total elastic cross section was found to be (4.59 ± 0.16) mb.

Previous experiments on diffraction scattering have been analyzed assuming that the two-parameter equation

$$d\sigma/dt = Ke^{At} \quad (3)$$

holds, with K and A independent of t. The upper limit of the region of Eq. (3) is conventionally put at $t=0.4$ $(\text{GeV}/c)^2$, which is about the edge of the optical model "black disc." We shall use the symbols $A(t_1, t_2)$ and $K(t_1, t_2)$ to indicate the coefficients fitted over the range from t_1 to t_2.

The fit of Eq. (3) to our data in the t region from 0.02 to 0.4 $(\text{GeV}/c)^2$ gave a slope $A(0.02, 0.4) = (8.2 \pm 0.28)$ $(\text{GeV}/c)^{-2}$ and a value of $K(0.02, 0.4) = (35.2 \pm 1.7)$ mb $(\text{GeV}/c)^{-2}$, in good agreement with the calculated optical theorem point of (35.0 ± 0.75) mb $(\text{GeV}/c)^{-2}$. However, the fit has a χ^2 corresponding to a probability of 6%. It can be observed in Fig. 1 that this rather low probability seems to result not from a random scatter of the experimental points, but rather from systematic deviations, the points at very small t values being above the fitted line. The significance of this possible deviation from the assumed linear behavior was estimated in two ways. Firstly, the t region was divided into two parts and the data in each were fitted with Eq. (3). The fit between $t_1 = 0.02$ and $t_2 = 0.16$ $(\text{GeV}/c)^2$ gave $A(0.02, 0.16) = (11.2 \pm 0.9)$ $(\text{GeV}/c)^{-2}$, whereas $A(0.16, 0.4) = (7.2 \pm 0.7)$ $(\text{GeV}/c)^{-2}$. These two values of A differ by 3.5 standard deviations. Secondly, the data have been fitted to the three-parameter function

$$d\sigma/dt = ke^{at+bt^2}. \quad (4)$$

The results are

$$a(0.02, 0.4) = (11.4 \pm 1.07)\ (\text{GeV}/c)^{-2},$$

$$b(0.02, 0.4) = (8.9 \pm 2.8)\ (\text{GeV}/c)^{-4},$$

$$k(0.02, 0.4) = (43.0^{+4.2}_{-3.5}) \text{ mb } (\text{GeV}/c)^{-2}.$$

The Fisher F-test on the significance of the quadratic term in t gave a confidence level of 99%. It is to be noted that the value of k obtained in this case is (23^{+12}_{-10})% higher than the value calculated from the optical theorem, assuming there is no real part to the scattering amplitude.

The behavior observed here does not contradict any published results, as, so far, there are no other data of comparable statistical significance in the region of very small scattering angles. A similar trend of the experimental points seems indicated by published work on p-p scattering.[1]

An important point indicated by these results is that, in comparing different experiments, care must be taken that the expression for the differential cross section be fitted to the data over similar ranges of t.

In Table II are listed the values of the exponent $A(t_1, t_2)$ of Eq. (3) obtained in various experiments. The average value of t_1 for the experiments[9,10] using hydrogen targets with 3- to 5-GeV/c pions is 0.06 $(\text{GeV}/c)^2$. For the purpose of comparison, the present data have been fitted using Eq. (3) over the same range of t values, with the result

Table II. Comparison of the result of the present experiment for the slope $A(t_1,t_2)$ of the diffraction peak with the results published by other authors; s is the square of the total energy in c.m. in $(\text{GeV})^2$.

Pion momentum (GeV/c)	t_1 $[(\text{GeV}/c)^2]$	t_2 $[(\text{GeV}/c)^2]$	ln$s$	$A(t_1,t_2)$ $[(\text{GeV}/c)^{-2}]$	Technique	Reference
3.15	0.05	0.4	1.90	7.5 ±0.4	Spark ch.	Ting et al.[a]
4.13	0.07	0.4	2.14	8.0 ±0.5	Spark ch.	Ting et al.[a]
4.95	0.09	0.4	2.30	7.8 ±0.4	Spark ch.	Ting et al.[a]
4.65	0.04	0.4	2.26	7.7 ±0.4	Hyd. b. ch.	Munir and Zorn[b]
5.17	0.03	0.4	2.34	8.4 ±0.7	Propane b. ch.	Thomas[c]
6.8	0.03	0.4	2.60	7.8 ±1.1	Propane b. ch.	Wang Kang-Ch'ang et al.[d]
7.0	0.03	0.4	2.65	7.3 ±0.7	Propane b. ch.	Hofmokl et al.[e]
10.0	0.06	0.4	3.01	7.5 ±0.34	Hyd. b. ch.	Present expt.
16.0	0.01	0.4	3.45	8.6 ±1.5	Hyd. b. ch.	Czapek et al.[f]

[a]See reference 9.
[b]See reference 10.
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$A(0.06, 0.4) = (7.5 \pm 0.34)$ mb $(\text{GeV}/c)^{-2}$, which is in good agreement with the values obtained at lower energies (the value at 16 GeV/c has a rather large error). It is therefore concluded that from 3 to 10 GeV/c there is little or no shrinking of the diffraction peak in the $\pi^- - p$ elastic scattering. This result has been indicated by the experiments of Ting et al.[9] over the range 3 to 5 GeV/c and has been recently demonstrated to extend to 17 and to 18 GeV/c by the preliminary results first of a counter experiment at BNL[2] and then of a spark chamber experiment at CERN.[11]

We are grateful to the CERN MPS division and the Saclay hydrogen bubble chamber group for their work in providing the photographs. We also wish to thank Professor B. Gregory and Professor Ch. Peyrou for their interest in the experiment and Dr. R. Armenteros for helpful discussions.

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