sion and lowering the apparent cross section. This difference would be expected to diminish as the solid angle subtended by the transmission counter is decreased. By extrapolating the measured cross sections linearly to zero solid angle (as was done with hydrogen), we can estimate the total cross section. This yields a total cross section of 292 mb for π^+ scattering at 3 BeV/c and 294 mb for π^- scattering. This excellent agreement is somewhat fortuitous, but in any case, there is no evidence for a violation of charge symmetry. For π^--C scattering at 4.0 BeV/c we find a total cross section of 281 mb, in contrast to Wikner's result of 386 ± 20 mb. We also made measurements with a Be target and again found good agreement between the π^+ and π^- results.

We wish to express our gratitude to the University of Michigan spark chamber group, particularly to Dr. Lawrence Jones and Dr. Martin Perl, for their help and cooperation, which made this work possible. We are deeply indebted to Robert A. Profet for his generous assistance in the preparation and execution of the experiment.

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PION-PROTON ELASTIC DIFFRACTION SCATTERING AT 3, 4, AND 5 GeV/c†

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The elastic differential cross section of negative pions on protons at 3.15, 4.13, and 4.95 GeV/c and of positive pions on protons at 2.92 GeV/c has been measured in a spark chamber experiment using the Bevatron of the Lawrence Radiation Laboratory.[1] The data in the diffraction region for these momenta are reported in this Letter. The interest in these diffraction data centers about the recent theoretical developments in the field of strong interactions, which predict that at sufficiently high energies the differential cross section in the diffraction region should be an exponential function of the four-momentum transfer, and that the width of the diffraction peak should decrease with increasing energy.[2] Our data show the predicted exponential behavior for small four-momentum transfers, but no statistically significant shrinkage of the π^-+p diffraction peaks over the 3- to 5-GeV/c interval is observed. Comparison with other published π^-+p data[3-5] up to 16 GeV/c also gives little evidence of shrinkage, although this observation is strongly influenced by the data at 15.9 GeV/c which have relatively large published errors. This appears to be in contrast to the proton-proton case, where the data are in remarkable agreement with the Regge behavior.[6,7]

The experimental data are plotted on a semilogarithmic scale in Fig. 1 where the errors shown are statistical.[8] The data consist of about 1200 elastic events at each momentum, obtained from an analysis of one half of the data film. The points at $t=0$ are calculated from zero-momentum-transfer dispersion relations and the optical theorem using the recent total cross section data taken by Longo and Moyer in the 3- to 5-GeV/c range.[9] For the π^-+p data the over-all error in normalization may be ±8%. However, there are some uncertainties in the composition of our π^+ beam, and therefore the normalization error for those data may be as great as ±30%.

The Regge pole theory[2] predicts that the elastic diffraction scattering may be expressed by

$$d\sigma/dt=(d\sigma/dt)_{t=0}F(t)(s/s_0)^{2[\alpha(t)-1]}, \qquad (1)$$

if only a single Regge trajectory is involved. Here s is the square of the total center-of-mass energy; and t, the square of the four-momentum transfer, is given by

$$t=-2p^{*2}(1-\cos\theta^*), \qquad (2)$$

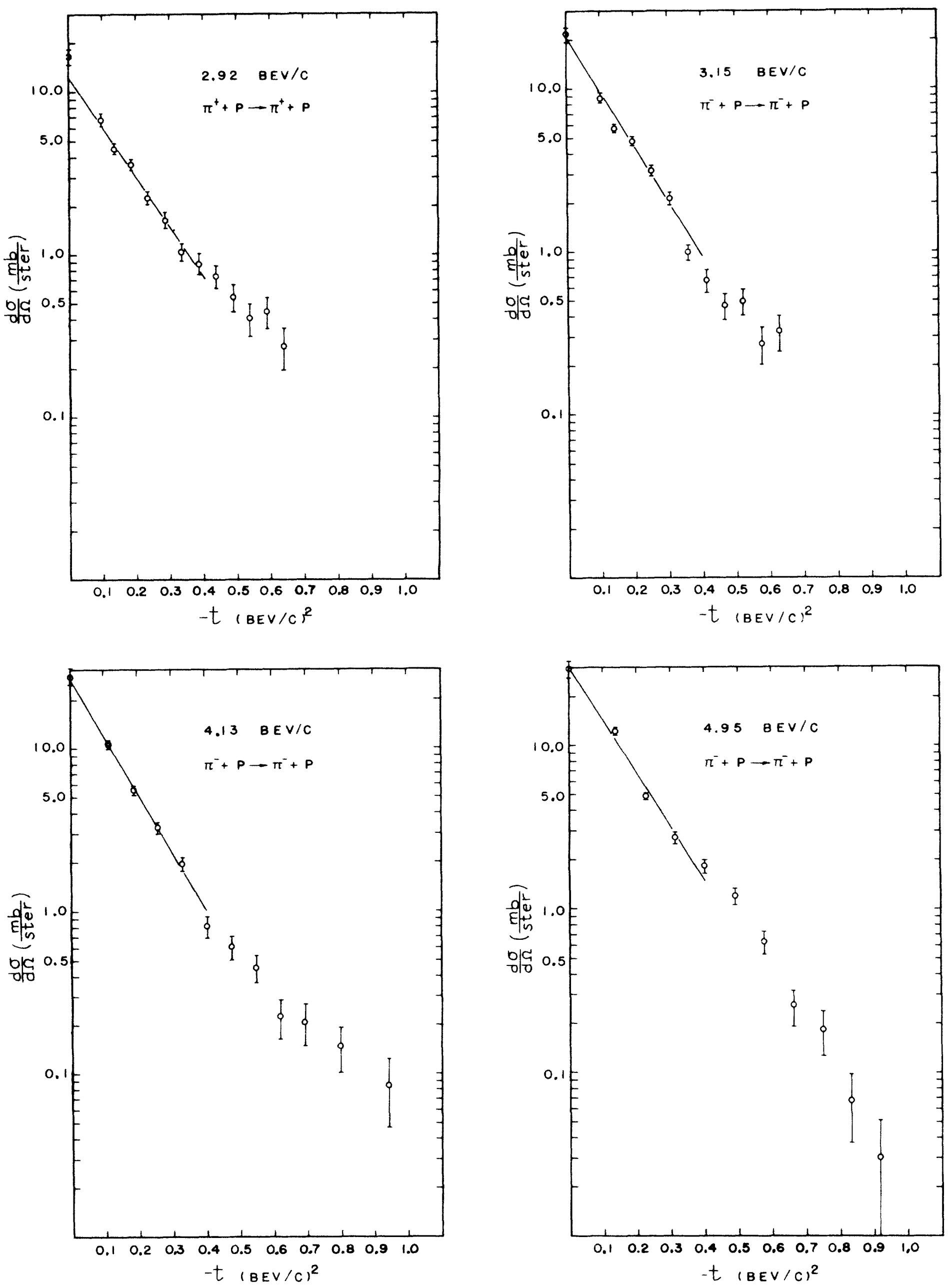

FIG. 1. Differential cross section vs $-t$, the square of the four-momentum transfer, at 3.15-, 4.13-, and 4.95-GeV/c incident negative-pion momenta and 2.92-GeV/c incident positive-pion momentum. The point at $t=0$ is computed using total cross-section data. The lines are fits to the data $0<|t|<0.4$ (GeV/c)^2, assuming $(d\sigma/dt)/(d\sigma/dt)_{t=0}=\exp[A(s)t]$.

where p^* is the three-momentum of the particles in the center-of-mass system, and θ^* is the scattering angle of the pion in the center-of-mass system. The quantity s_0 is a parameter of the theory, usually taken as $2M^2$, where M is the nucleon mass.[6] The usual differential cross section is related to the above expression through

$$d\sigma/d\Omega=-(p^{*2}/\pi)d\sigma/dt. \tag{3}$$

For small t, (1) may be approximated by

$$d\sigma/dt=(d\sigma/dt)_{t=0}\exp[A(s)t]. \tag{4}$$

Table I. Values of $A(s)$ obtained by fitting the results of this and other published experiments to Eq. (4), not including the $t=0$ points. s is the square of the total center-of-mass energy, P_0 is the incident laboratory momentum, and $|t|$ is the absolute value of the square of the four-momentum transfer.

System	P_0 (GeV/c)	$A(s)$ (GeV/c)$^{-2}$	Range of $\|t\|$ (GeV/c)^2	s (GeV)^2	ln$s$	Reference
π^-+p	3.15	7.5 ± 0.4	0-0.4	6.68	1.90	This experiment
π^-+p	3.15	7.3 ± 0.2	0-0.6	6.68	1.90	This experiment
π^-+p	4.13	8.0 ± 0.5	0-0.4	8.48	2.14	This experiment
π^-+p	4.13	7.2 ± 0.2	0-0.9	8.48	2.14	This experiment
π^-+p	4.95	7.8 ± 0.4	0-0.4	9.99	2.30	This experiment
π^-+p	4.95	6.9 ± 0.2	0-0.9	9.99	2.30	This experiment
π^++p	2.92	7.0 ± 0.4	0-0.4	6.26	1.83	This experiment
π^++p	2.92	6.2 ± 0.3	0-0.7	6.26	1.83	This experiment
π^-+p	1.33	7.3 ± 0.4	0-0.4	3.36	1.21	a
π^-+p	1.47	7.3 ± 0.6	0-0.4	3.62	1.29	b, c
π^-+p	1.85	9.3 ± 1.7	0-0.4	4.30	1.46	d
π^-+p	2.00	8.7 ± 0.5	0-0.4	4.57	1.52	e, c
π^-+p	5.17	8.4 ± 0.7	0-0.4	10.4	2.34	f
π^-+p	6.80	7.8 ± 1.1	0-0.4	13.4	2.60	g
π^-+p	15.90	8.6 ± 1.5	0-0.4	30.10	3.40	h
$p+p$	3.08	5.5 ± 0.5	0-0.4	7.71	2.05	i
$p+p$	5.25	6.1 ± 0.3	0-0.4	11.8	2.47	i
$p+p$	7.03	6.8 ± 0.6	0-0.4	15.1	2.71	i
$p+p$	15.5	~9.3	0-0.4	30.3	3.41	j

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[f] See reference 4.
[g] See reference 5.
[h] See reference 3.
[i] See reference 7.
[j] See reference 6.

The straight-line behavior of the data in Fig. 1 shows that (4) is at least a fair approximation to our data. To test it more carefully $A(s)$ was evaluated for two ranges of t, namely, for $0<|t|<0.4$ (GeV/c)^2 and for $0<|t|<t_0$ (GeV/c)^2, where t_0 is the maximum value of t which seems still to lie in the diffraction peak [roughly 0.8 (GeV/c)^2 for this data]. In both cases the $t=0$ point was not included in the fit. These values of $A(s)$ in (GeV/c)$^{-2}$ are presented in Table I, and are plotted for $|t|<0.4$ (GeV/c)^2 in Fig. 2. It appears that the data may not be a simple exponential out to $t=t_0$ (GeV/c)^2, as the diffraction peaks consistently show a broadening (smaller A) when fit over the larger range of t. This same trend is apparent in the proton-proton elastic scattering data.[6]

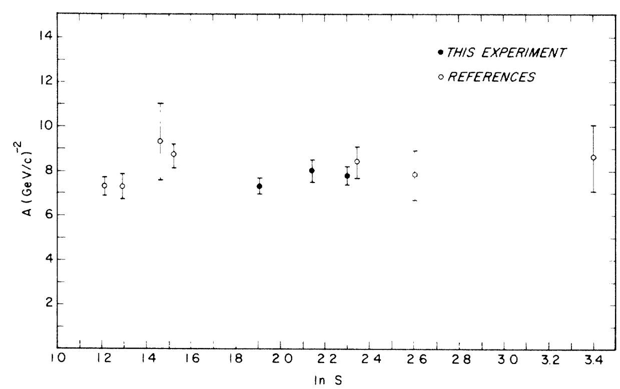

FIG. 2. The values of $A(s)$ (for $0<|t|<0.4$) as a function of ln$s$, derived by fitting the data to the expression $(d\sigma/dt)/(d\sigma/dt)_{t=0}=\exp[A(s)t]$. The reference points are taken from Table I.

In order to investigate the Regge prediction of the shrinkage of the diffraction peak with increasing energy, the $A(s)$ values for $0<|t|<0.4$ (GeV/c for our π^-+p data only (3 to 5 GeV/c) were fitted to the function $a+b\ln s$. The value of b is 1.5 ± 1.0 (GeV/c)$^{-2}$ where s is in (GeV)^2. Thus, while a shrinkage may exist it is certainly not of strong statistical significance. To examine the behavior of the $A(s)$ for π^-+p over a larger range of s than is available from this experiment, we have determined values of $A(s)$ from other published π^-+p data as listed in Table I. It is evident from Fig. 2 and Table I that the 15.9-GeV/c point is consistent with no shrinkage of the diffraction width, i.e., $A(s)$ constant, although the errors on that value of $A(s)$ are so large that some shrinking with energy above 3 GeV/c cannot be excluded.[10] At energies below 3 GeV/c, the asymptotic approximations in the deduction of (1) from Regge theory are less valid, and this simple description of diffraction widths is expected to be in error. It is noted from Fig. 2 that there could be a peak in the values of $A(s)$ (narrowing of the diffraction peak) near 2 GeV/c, although again poor statistics limit the possibility of establishing this from published data.

The π^++p diffraction peak cannot be compared absolutely with the π^-+p peak (Fig. 1) because of the π^+ normalization difficulty and the differences in incident pion momentum. However, Table I shows that the values of $A(s)$ for $0<|t|<0.4$ $(\text{GeV}/c)^2$ are similar, while for larger $|t|$ the π^++p seems to broaden more than the π^-+p.

Finally, comparing our π^-+p data with $p+p$ data of about the same range of momentum (3 to 6 GeV/c), it can be seen from Table I that the $p+p$ values of $A(s)$, 5.5 to 6, are consistently lower than the π^-+p values of $A(s)$, 7.3 to 8.0; i.e., the $p+p$ diffraction peaks are broader. On the other hand, at higher energies such as 16 GeV, an $A(s)$ of about 9 seems appropriate for both processes for $|t|<0.4$. Thus while $p+p$ shows a definite shrinkage in going from 3 to 16 GeV/c, we find that π^-+p shows little or possibly no shrinkage. If the $p+p$ and π^-+p diffraction peaks were due solely to the Pomeranchuk-Regge trajectory, then the shrinkage with increasing s would be the same in both cases.[2] Our conclusion, based on the work reported here plus other published data, is that the $p+p$ and π^-+p diffraction elastic scattering present different behaviors. This suggests that the influence of trajectories other than the Pomeranchuk trajectory, such as the P', ω, and ρ trajectories, must be considered if a complete understanding of diffraction scattering in this energy region is to be found in the Regge theory.

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*Atomic Energy Commission Predoctoral Fellow.

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[9]M. Longo and B. Moyer (private communication and to be published).

[10]In reference 3 there is a plot of $A(s)$ similar to Fig. 2 based on the π^-+p data of reference 3 at 15.9 GeV/c, reference d at 1.85 GeV/c, reference 4 at 5.17 GeV/c, and on $p+p$ data. The π^-+p points seem to indicate a definite shrinkage in the π^-+p diffraction peak similar to the $p+p$ shrinkage. However, it appears that in reference 3 the $A(s)$ corresponding to the 1.85-GeV/c data is plotted too low by roughly a factor of two relative to the other two π^-+p points for $A(s)$.