PION CHARGE EXCHANGE SCATTERING AT HIGH ENERGIES.
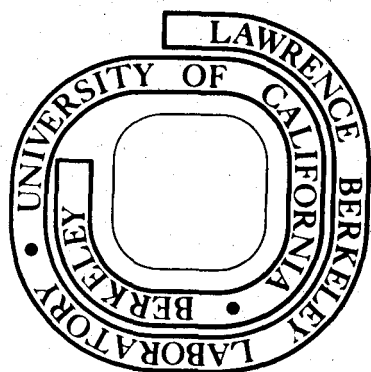
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DISCLAIMER

Pion Charge Exchange Scattering at High Energies[*]

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ABSTRACT

We report on a study of pion charge exchange scattering carried out at
Fermilab in the energy range 20 to 200 GeV. The results can be described
remarkably well by a simple Regge pole model. The charge exchange cross
sections in the forward direction lead to a prediction for the difference in
total cross sections of $\pi^- p$ and $\pi^+ p$ which is in satisfactory agreement with
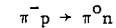direct measurements of this difference in another experiment at Fermilab.

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In the study of strong interaction dynamics, two reactions have a
special importance because of their simplicity from a theoretical point
of view. These are the pion charge exchange scattering

$$\pi^- p \to \pi^0 n$$

and the related reaction in which η mesons are produced,

$$\pi^- p \to \eta n.$$
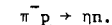
In Regge theory, the amplitude of each of these reactions is dominated by
a single Regge pole, (the ρ-pole in charge exchange and the A_2 in the η
reaction) so that the experimental data have a relatively direct theoretical
interpretation. In addition, the forward charge exchange cross section provides
a measure of the difference between $\pi^- p$ and $\pi^+ p$ total cross sections.

With these motivations we have carried out an experiment at Fermilab to
study these reactions over a large beam energy range extending from 20 to 200
GeV. A description of the apparatus and data analysis procedures is presented
in the following letter[1] along with the results for the η reaction. Results
for the π^0 reaction are presented here in Table 1 and in Figs. 1 and 2. Data
on the production of other particles such as η' and ω will be reported later.

According to Regge theory, if the charge exchange amplitude at high energies
is dominated by the ρ-pole, it is expected to have a simple power law energy
dependence at fixed t, giving a differential cross section of the form

$$\frac{d\sigma}{dt}(s,t) = \beta(t) \, \nu^{2\alpha(t)-2} \tag{1}$$

where $\nu = (s - u)/4M = \omega + t/4M$, ω is the π^- lab energy and s, t and u are the
usual energy and momentum transfer variables. The functions $\beta(t)$ and $\alpha(t)$ are
not predicted by the theory but it has been found from previous data[2,3,4] that
the "ρ trajectory," $\alpha(t)$, is approximately linear in t, the extrapolation of
$\alpha(t)$ as determined for negative t passing nearly through the points corresponding
to the observed spin and mass[2] of the ρ and g mesons.

Some deviation from the above simple power law behavior might be expected because of possible Regge cuts and because the observation of asymmetry in charge exchange scattering from polarized targets[5,6] indicates that the amplitudes must have other components besides the dominant pole, at least in the energy region below 10 GeV. Nevertheless, an excellent phenomenological description of our entire set of data is provided by the simple expression (1), with

$$\alpha(t) = \alpha_0 + \alpha_1 t + \alpha_2 t^2 , \quad -1.4 < t \leq 0 \text{ GeV}^2$$

$$\beta(t) = \beta_1 e^{b_1 t} - t(t - t_0)^2 (\beta_2 + \beta_3 t + \beta_4 t^2) e^{b_2 t}$$

Values of the parameters found from a fit to our data are

$$\alpha_0 = .481 \pm .004 \qquad \alpha_1 = .928 \pm .034 \qquad \alpha_2 = .205 \pm .055$$

$$b_1 = 5.20 \pm .21 \qquad b_2 = 6.16 \pm .61 \qquad t_0 = -.542 \pm .004$$

$$\beta_1 = 2340 \pm 80 \qquad \beta_2 = (2.34 \pm .10) \times 10^5$$

$$\beta_3 = (-.77 \pm 1.41) \times 10^5 \quad \beta_4 = (11.6 \pm 5.4) \times 10^5$$

The units are such that t is in GeV^2, ν in GeV, and $\frac{d\sigma}{dt}$ in $\mu b/\text{GeV}^2$. The fit gives a χ^2 of 107 for 128 degrees of freedom.

Curves computed with the above parameters are shown in Figs. 1 and 2. The data points shown in these figures and also the cross sections given in Table 1 have been corrected for the effects of experimental t-resolution and finite bin widths. This correction (or unfolding) has been made as follows: the fitting function (1) has been folded with the t-resolution and integrated over the finite bin widths in order to obtain "smeared" cross sections to be compared with the measured data in minimizing χ^2. The ratios of unsmeared to smeared fitting cross sections are then used as the correction factors applied to the measured data.

Separate fits at each energy were also made to investigate the energy dependence of the parameter t_0. The values of t_0 fluctuate by ± 0.02 GeV^2 but no systematic variation with energy is apparent.

The trajectory $\alpha(t)$ obtained from the overall fit is shown by the solid curve in Fig. 3, together with "data points," $\alpha^*(t)$, obtained in the conventional manner by fitting the data at each value of t separately, using the form (1). As may be seen in this figure, the observed values of $\alpha(t)$ in the t range from 0 to -0.3 GeV^2 fall remarkably close to a straight line drawn through the points corresponding to the ρ and g mesons.

Although the parameterization given above fits our data remarkably well, it agrees only qualitatively with previous data[2,3,4] as shown by an example at 5.9 GeV in Fig. 1. Effective trajectories obtained from the lower energy data have had a significantly larger intercept α_0.

We next consider a comparison between our data and the difference in total cross sections for $\pi^- p$ and $\pi^+ p$ interactions, $\Delta\sigma = \sigma_{tot}(\pi^- p) - \sigma_{tot}(\pi^+ p)$. As is well known, isospin invariance and the optical theorem relate this difference to the imaginary part of the forward charge exchange amplitude. Expressed in terms of cross sections, this relation is

$$\frac{d\sigma}{dt} (t=0) = \frac{\pi}{p_{lab}^2} (1 + R^2) [\text{Im}A(0)]^2 = 25.54 (1 + R^2) (\Delta\sigma)^2$$

where R is the ratio of real to imaginary parts of the forward charge exchange amplitude A(0), p_{lab} is the incident beam momentum in GeV, and $\frac{d\sigma}{dt}$ is the charge exchange cross section in $\mu b/\text{GeV}^2$ if $\Delta\sigma$ is in mb. Furthermore, if we assume that the observed power law dependence of $\frac{d\sigma}{dt}(t=0)$ extends to higher energies, dispersion relations give a relation between the ratio R and the exponent $\alpha(0)$; $R = \tan \frac{\pi\alpha(0)}{2}$.

We are thus able to predict the difference $\Delta\sigma$ from the charge exchange data. The result is shown in Fig. 4 where it is compared with direct measurements of this difference in three experiments[7,8,9]. Our prediction agrees very well with the results of Carroll et al.[9] obtained at Fermilab in the energy range 23 to 240 GeV.

We wish to express our appreciation to the many people at the Fermilab, at LBL and at Caltech, who have contributed much to this experiment. A powerful system for on-line analysis of data was created by J. F. Bartlett. The charged particle and gamma veto system was designed by M. A. Wahlig. D. Hermeyer helped build and maintain much of the electronics and also helped take some of the data. Others to whom we are particularly indebted are D. Eartley, P. Koehler, R. Lundy, H. Haggerty, G. C. Fox, R. D. Field, and P. R. Stevens.

References and Footnotes

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Captions

Table 1. Differential cross sections in $\mu b/GeV^2$ and other results

for $\pi^- p \to \pi^0 n$. These data have been corrected for the effects

of experimental t-resolution and finite bin widths. Only statis-

tical errors and errors in t-dependent corrections are given for

$\frac{d\sigma}{dt}$ but all systematic errors are included in the integral cross

sections σ_I. The right-hand column, $\alpha^*(t)$, contains values of the

trajectory obtained by fitting the data for each value of t

separately.

Figure 1. Differential cross sections at 20.8, 64.4, and 199.3 GeV from this

experiment, and at 5.9 GeV from Ref. 2. The curves are the result

of a fit described in the text.

Figure 2. Differential cross sections in the region of small t. The curves

are the result of a fit described in the text.

Figure 3. The effective trajectory $\alpha(t)$.

Figure 4. Data from three experiments (Refs. 7, 8, 9) on the difference $\Delta\sigma$

of $\pi^- p$ and $\pi^+ p$ total cross sections, compared to the prediction

(solid line) from our data on charge exchange scattering. This

prediction is obtained from the parameters of the fit described in

the text.

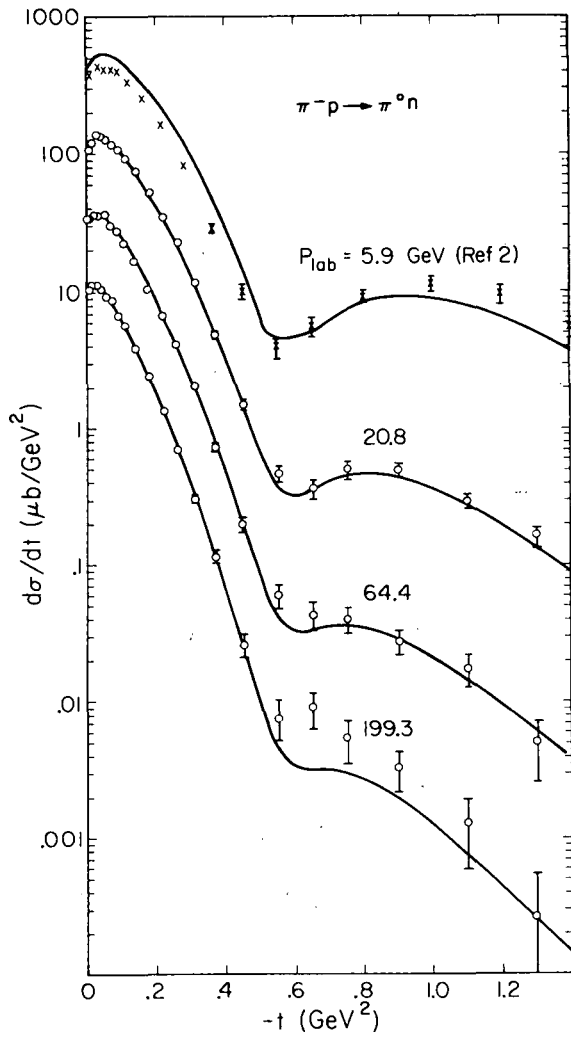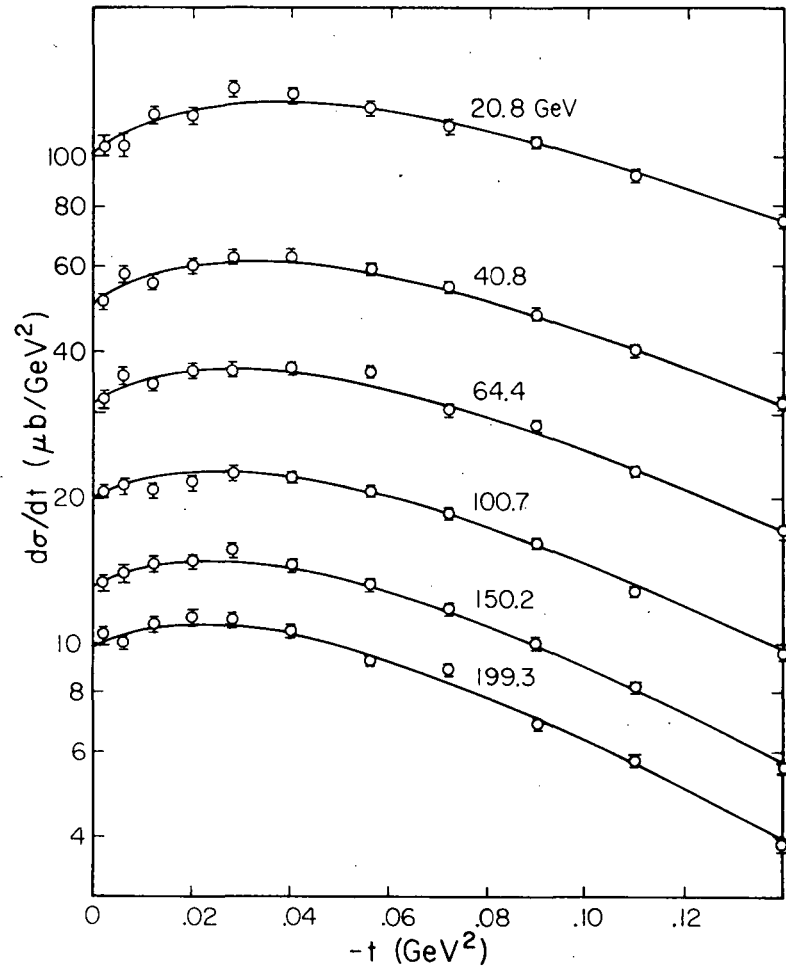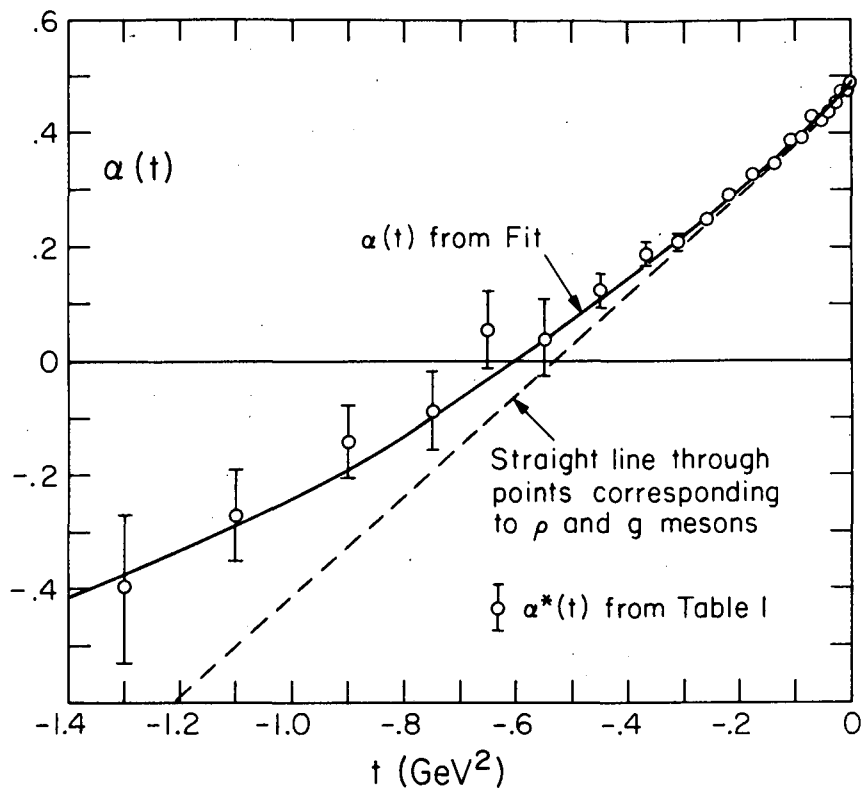| -t (GeV²)	Bin Width (GeV²)	Beam Momentum GeV						$\alpha^*(t)$
		20.8	40.8	64.4	100.7	150.2	199.3	
0.002	0.004	104 ± 5	50.6 ± 2.1	32.0 ± 1.3	20.3 ± 0.8	13.4 ± 0.5	10.4 ± 0.4	0.491 ± 0.012
0.006	0.004	105 ± 5	57.8 ± 2.3	35.9 ± 1.4	21.1 ± 0.8	14.0 ± 0.6	10.1 ± 0.4	0.474 ± 0.011
0.012	0.008	121 ± 5	55.2 ± 1.8	34.5 ± 1.1	20.8 ± 0.7	14.6 ± 0.5	11.0 ± 0.4	0.474 ± 0.010
0.020	0.008	120 ± 5	59.9 ± 1.9	36.8 ± 1.2	21.5 ± 0.7	14.8 ± 0.5	11.3 ± 0.4	0.471 ± 0.009
0.028	0.008	137 ± 5	62.1 ± 1.9	36.9 ± 1.2	22.6 ± 0.7	15.6 ± 0.5	11.3 ± 0.4	0.453 ± 0.009
0.040	0.016	134 ± 4	62.1 ± 1.6	37.0 ± 1.0	22.1 ± 0.6	14.5 ± 0.4	10.6 ± 0.3	0.439 ± 0.008
0.056	0.016	126 ± 4	59.0 ± 1.6	36.5 ± 1.0	20.5 ± 0.6	13.2 ± 0.4	9.3 ± 0.3	0.422 ± 0.008
0.072	0.016	116 ± 4	54.2 ± 1.5	30.7 ± 0.9	18.6 ± 0.5	11.9 ± 0.3	8.84 ± 0.26	0.427 ± 0.008
0.090	0.020	108 ± 3	48.0 ± 1.2	28.4 ± 0.8	16.1 ± 0.4	10.0 ± 0.3	6.86 ± 0.20	0.393 ± 0.007
0.110	0.020	92.1 ± 3	40.1 ± 1.1	22.9 ± 0.6	12.9 ± 0.4	8.2 ± 0.2	5.79 ± 0.18	0.387 ± 0.008
0.140	0.040	74.3 ± 2.1	31.4 ± 0.8	17.0 ± 0.4	9.5 ± 0.2	5.54 ± 0.15	3.88 ± 0.11	0.344 ± 0.007
0.180	0.040	50.9 ± 1.5	20.2 ± 0.5	10.6 ± 0.3	5.87 ± 0.17	3.54 ± 0.11	2.40 ± 0.08	0.326 ± 0.008
0.220	0.040	33.7 ± 1.2	13.1 ± 0.4	6.8 ± 0.2	3.64 ± 0.13	2.10 ± 0.08	1.36 ± 0.06	0.294 ± 0.010
0.260	0.040	22.0 ± 0.9	7.6 ± 0.3	4.20 ± 0.18	1.93 ± 0.09	1.15 ± 0.06	0.709 ± 0.040	0.248 ± 0.012
0.310	0.060	11.6 ± 0.5	4.24 ± 0.18	2.09 ± 0.10	0.99 ± 0.05	0.53 ± 0.03	0.311 ± 0.022	0.208 ± 0.013
0.370	0.060	4.8 ± 0.3	1.73 ± 0.11	0.75 ± 0.06	0.37 ± 0.03	0.204 ± 0.019	0.117 ± 0.013	0.184 ± 0.020
0.450	0.100	1.44 ± 0.13	0.50 ± 0.04	0.199 ± 0.023	0.088 ± 0.011	0.050 ± 0.007	0.026 ± 0.005	0.123 ± 0.031
0.550	0.100	0.44 ± 0.07	0.090 ± 0.018	0.058 ± 0.012	0.022 ± 0.006	0.0067 ± 0.0027	0.0071 ± 0.0026	0.040 ± 0.067
0.650	0.100	0.36 ± 0.06	0.103 ± 0.018	0.044 ± 0.010	0.015 ± 0.004	0.0067 ± 0.0024	0.0091 ± 0.0026	0.052 ± 0.064
0.750	0.100	0.51 ± 0.07	0.080 ± 0.016	0.041 ± 0.009	0.022 ± 0.005	0.0044 ± 0.0019	0.0055 ± 0.0019	-0.087 ± 0.071
0.900	0.200	0.50 ± 0.05	0.069 ± 0.011	0.028 ± 0.006	0.0155 ± 0.0031	0.0064 ± 0.0017	0.0034 ± 0.0011	-0.141 ± 0.064
1.100	0.200	0.30 ± 0.04	0.042 ± 0.008	0.018 ± 0.004	0.0041 ± 0.0016	0.0025 ± 0.0010	0.0013 ± 0.0007	-0.270 ± 0.080
1.300	0.200	0.16 ± 0.03	0.020 ± 0.006	0.005 ± 0.002	0.0023 ± 0.0012	0.0012 ± 0.0007	0.0003 ± 0.0003	-0.398 ± 0.128
$\frac{d\sigma}{dt}(t=0)$ from fit		100.3	49.8	30.9	19.51	12.88	9.61	
$\sigma_I(\mu b) = \int_{-1.5}^{0} \frac{d\sigma}{dt} dt$		22.6 ± 1.1	9.8 ± 0.5	5.61 ± 0.25	3.20 ± 0.14	2.02 ± 0.09	1.44 ± 0.06	
Number of Events		26,700	36,500	29,900	30,700	26,100	23,400	

Table 1

$\pi^- p \longrightarrow \pi^\circ n$

$P_{lab} = 5.9$ GeV (Ref 2)

20.8

64.4

199.3

$d\sigma/dt$ ($\mu b/GeV^2$)

$-t$ (GeV^2)

Fig. 1

20.8 GeV

40.8

64.4

100.7

150.2

199.3

$d\sigma/dt$ ($\mu b/GeV^2$)

$-t$ (GeV^2)

Fig. 2

α(t)

α(t) from Fit

Straight line through
points corresponding
to ρ and g mesons

Q α*(t) from Table I

t (GeV²)

Fig. 3

Foley et al.   1967
Denisov et al. 1971
Carroll et al. 1976

Δσ (mb)

P_lab (GeV)

Fig. 4