Cross sections and charged-particle multiplicities in $\pi^+ p$ and pp collisions at 60 GeV/c*

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We have measured charged-particle multiplicities and elastic and inelastic cross sections for $\pi^+ p$ and pp interactions at 60 GeV/c. The data are from a 30000-picture exposure of the 30-inch bubble chamber to a tagged but unseparated positive-particle beam at Fermilab. The low-order moments of the inelastic multiplicity distributions for all charged particles are $\langle n\rangle = 5.60 \pm 0.09$, $f_2 = 0.96 \pm 0.31$, and $\langle n\rangle/D = 2.19 \pm 0.06$ for pp reactions and $\langle n\rangle = 6.23 \pm 0.10$, $f_2 = 1.63 \pm 0.37$, and $\langle n\rangle/D = 2.22 \pm 0.06$ for $\pi^+ p$ collisions.

We report measurements of topological and elastic cross sections obtained in an investigation of $\pi^+ p$ and pp interactions at 60 GeV/c. The data are from a 30 000-picture exposure of the 30-inch Fermilab bubble chamber to an unseparated positive beam. The beam from the accelerator impinged upon a thin copper target; the secondary positive beam was taken at an angle of ~10 mrad with respect to the primary 300-GeV/c proton beam. Separation of π^+ mesons from protons was achieved using a differential Čerenkov counter. Muons in the beam were tagged using hadron filters located downstream of the bubble chamber.[1]

The film was scanned for all interactions observed in a restricted fiducial region; all two-pronged events found were measured, reconstructed in space, and fitted to an elastic-scattering hypothesis.[2] Assuming an exponential dependence of the elastic cross section on the square of the four-momentum transfer (t), we corrected this cross section for losses of events at small-t values[3] and normalized the sum of the total elastic and inelastic cross sections to previously determined precision measurements of total cross sections.[4]

Figure 1 presents our measured t depencence of the elastic cross section for both $\pi^+ p$ and pp data. (There are 174 events and 198 events in the $\pi^+ p$ and pp samples, respectively.) The smooth curves on the figures correspond to our best fits for $t > 0.05$ GeV^2 to simple exponential functions of the form

$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=0} e^{-At} . \tag{1}$$

The slopes (A values) appear to depend on the nature of the projectile and are in good agreement with previous measurements in this energy regime.[5] The extrapolated values of $(d\sigma/dt)_{t=0}$ are consistent with expectations of the optical theorem for purely imaginary elastic amplitudes. (See Fig. 1 for the parameters in question.)

In Tables I and II we present topological cross sections for $\pi^+ p$ and pp data, respectively. (Corrections have been made for Dalitz-decay modes of π^0 mesons.[2]) As indicated above, we have norm-

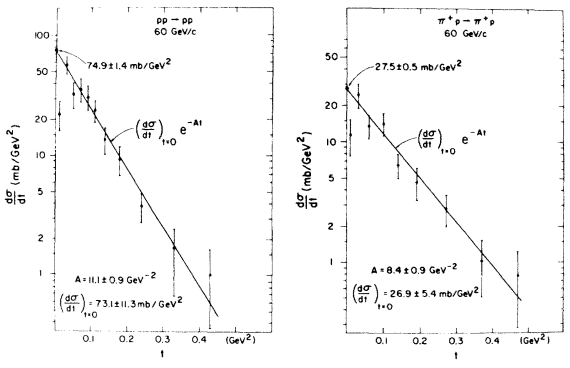

FIG. 1. Elastic-scattering distributions for $\pi^+ p$ and pp channels at 60 GeV/c. The stars at $t = 0$ indicate the values for $d\sigma/dt$ expected from the optical theorem. The values for A and $(d\sigma/dt)_{t=0}$ are from fits to the data.

TABLE I. Topological cross sections in pp collisions at 60 GeV/c.

Topology	Number observed	Corrected number [a]	Cross section [b] (mb)
2	305	193 [c]	6.6±0.7
		143 [d]	4.9±0.6
4	274	277	9.5±0.6
6	258	258	8.8±0.5
8	156	155	5.3±0.4
10	70	68	2.3±0.3
12	24	23	0.78±0.17
14	4	3	0.10±0.06
16	1	1	0.03±0.03
Total inelastic		928	31.7±0.8
Total		1121	38.3

[a] Corrections have been made for losses at small momentum transfers and for π^0 mesons (see Ref. 2).
[b] Total cross section has been normalized to previously determined values (see Ref. 4).
[c] Elastic.
[d] Inelastic.

TABLE II. Topological cross sections in π^+p collisions at 60 GeV/c.

Topology	Number observed	Corrected number [a]	Cross section [b] (mb)
2	198	122 [c]	3.1±0.3
		89 [d]	2.3±0.3
4	199	201	5.2±0.4
6	210	211	5.4±0.4
8	148	147	3.8±0.3
10	90	89	2.3±0.2
12	34	33	0.85±0.14
14	11	10	0.26±0.08
16	1	1	0.03±0.03
Total inelastic		781	20.1±0.4
Total		903	23.2

[a] Corrections have been made for losses at small momentum transfers and for π^0 mesons (see Ref. 2).

[b] Total cross section has been normalized to previously determined values (see Ref. 4).

[c] Elastic.

[d] Inelastic.

alized the separate sets of data to their known respective total cross sections. As a check on the reliability of the π^+/p Čerenkov-counter separation procedure, we have also determined the ratio of the measured π^+p and pp total cross sections. This was done by calculating the ratio of π^+-induced interactions to proton-induced interactions, each interaction rate normalized by its measured beam flux.[6] We obtain 0.58 ± 0.03 for this ratio, a value consistent with the expected result of 0.61 ± 0.01.[4]

Table III provides a summary of the low-order moments of the multiplicity distributions for π^+p and pp data at 60 GeV/c. No unusual variations are detected relative to data at similar energies.[7]

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TABLE III. Low-order moments of multiplicity distributions at 60 GeV/c.

	π^+p		pp	
	All charges	Negative charges	All charges	Negative charges
$\langle n\rangle$	6.23±0.10	2.11±0.05	5.60±0.09	1.80±0.05
D	2.80±0.07	1.40±0.03	2.56±0.06	1.28±0.03
$\langle n\rangle/D$	2.22±0.06	1.51±0.04	2.19±0.06	1.40±0.05
$\langle(n-\langle n\rangle^3\rangle/D^3$ [a]	0.50±0.07		0.59±0.07	
$\langle(n-\langle n\rangle^4\rangle/D^4$ [a]	2.8±0.2		3.1±0.2	
f_2	1.63±0.37	−0.15±0.10	0.96±0.31	−0.16±0.08
f_3	−0.1±1.4	−0.29±0.21	1.4±1.2	−0.09±0.17

[a] These quantities are the same for all charges as for negative particles only.

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[1]D. C. Fong *et al.*, Nucl. Phys. B102, 386 (1976). We thank T. Ludlam and R. Yamamoto for helpful discussions concerning the tagging system.

[2]See C. Bromberg *et al.*, Phys. Rev. Lett. 31, 1563 (1973).

[3]We also corrected the inelastic cross section for losses at $t<0.05$ GeV^2. In doing this we assumed that the losses as a function of t were the same as those found for elastic scattering. See Ref. 2, and C. Bromberg Ph.D. thesis, University of Rochester, 1974 (unpublished), for more details on these procedures.

[4]We used 23.2 mb and 38.3 mb for π^+p and pp total cross sections, respectively. See the compilation of V. Barger, in *Proceedings of the XVII International Conference on High Energy Physics, London, 1974*, edited by J. R. Smith (Rutherford Laboratory, Chilton, Didcot, Berkshire, England, 1974), p. I-193.

[5]J. Lach, Fermilab Report No. Conf-76/15-EXP 2000.000, 1976 (unpublished).

[6]Interactions induced by beam protons were distinguished from those induced by positive pions by matching spatially reconstructed bubble-chamber beam trajectories to those obtained using the proportional-wire tagging system (Ref. 1).

[7]See, for example, J. Erwin *et al.*, Phys. Rev. Lett. 32, 254 (1974); T. Ferbel, in proceedings of the SLAC Summer Institute, 1974, edited by M. Zipf [SLAC Report No. SLAC-179 (unpublished)]; V. V. Amasov *et al.*, Phys. Lett. 42B, 519 (1972); G. A. Akopdzhanov *et al.*, Nucl. Phys. B75, 401 (1974).