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Pion-Nucleon Total Cross Sections from 0.4 to 0.90 GeV/c*

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The total cross sections of $\pi^{\pm}$ on protons in the momentum interval from 0.40 to 0.90 GeV/c have been measured with high relative precision. In this interval the statistical error varies between 10 and 20 μb. No new structure is observed.

A number of investigations of π^+p and π^-p total cross sections have been made over the past several years which include the range of incident momenta measured in the present experiment.[1-4] Recent experiments[5,6] with improved statistical accuracy in the region of incident momentum from 0.4 to 0.9 GeV/c have revealed no new structure although knowledge of the heights, widths, and positions of established structure has been gradually refined. The present experiment, a subsidiary experiment to one previously reported,[7] was designed to cover this momentum interval with higher precision than previously obtained in order to search for possible structure and to provide data with the high relative precision necessary for an adequate check of theoretical models formulated for this region.

The experiment was performed at the Lawrence Berkeley Laboratory using a secondary pion beam of the Bevatron. Incident beam pions were selected by a counter telescope π, consisting of four scintillation counters (S_1, S_2, $\overline{G}$, and S_3), a Plexiglas Čerenkov counter (C_0), and a high-pressure gas Čerenkov counter (C_1) as shown in Fig. 1. The 32.1-ft flight path between S_1, S_2, both located downstream from C_0, and S_3, located at the upstream end of the hydrogen target, was used to reject protons and kaons by time-of-flight differences. C_0 was operated as a threshold detector to provide further rejection of protons and kaons in the incident beam. Electrons and positrons accompanying beam pions were rejected by a factor of 50 : 1 by the high-pressure Čerenkov counter C_1 which was operated at 65 psia of carbon dioxide. Correction for muon contamination and determination of thresholds for pions and muons was obtained from curves of counting rate versus pressure for C_1 made during the tuning phase of the experiment.

The beam momentum was determined by measuring the difference in time of flight for pions and protons along the 32.1-ft flight path corrected for the momentum loss of pions and protons in the remainder of the incident beam path. The error in such measurements was estimated to be ±0.5%.

The liquid-hydrogen target flask was 6 in. in diameter and 12 in. in length with convex Mylar end caps. Its effective length was determined by measuring the profile of these caps at liquid-nitrogen temperature and averaging its length over the measured spatial distribution of the incident pion beam. The target flask and an identical but evacuated flask could be remotely positioned on the beam axis by means of a pneumatic device in order to provide a periodic check of background during the experimental runs.

The transmission counters $T_1, \ldots, T_5$ were placed on a movable stand downstream from the liquid-hydrogen target. These counters were used to measure the flux transmitted through the target.

These were disks of $\frac{3}{8}$- and $\frac{1}{2}$-in.-thick NE 102 plastic scintillator having a radius of $7\sqrt{n}$ in., $n=1, \ldots, 5$, in order to give uniform increments in the solid angle subtended by successive counters. The counters were repositioned according to beam momentum so that the 4-momentum transfer intercepted by the largest counter remained constant. Finally, a 2×3-in. efficiency counter E was placed 10 ft downstream from S_3 at the final focus.

The electronics circuitry made use of the technique of providing two separate 200-MHz discriminators for certain counters, one set at a low threshold level to provide jitter-free, leading edge timing signals (called "fast") and the other set at a high threshold to provide a high level of discrimination against background signals (called "slow"). Circuits were included to eliminate signals from events occurring within 30 nsec of each other which helped to eliminate dead-time effects in the electronics.

The cross section σ_i observed for the ith transmission counter may be written as

$$\sigma_i = \frac{M}{\rho N L}\log_e(R_{ie}/R_{if}),$$

where ρ is the hydrogen density, L is the effective length of the hydrogen target, N is Avogadro's number, M is the atomic weight of hydrogen, and R_{if} and R_{ie} are the transmission rates for full and empty target, respectively. Pions that are scattered at angles small enough to intercept the detectors are subtracted in order to arrive at a true value of the cross section:

$$\sigma_i = \sigma - \int_0^{\Omega_i} (d\sigma/d\Omega)d\Omega,$$

where σ is the total cross section to be measured, Ω_i is the solid angle subtended by detector i at the target center, and $d\sigma/d\Omega$ is the differential cross section. If we further assume that $d\sigma/d\Omega$ is constant over the angular region subtended by all the detectors, then we have

$$\sigma_i = \sigma - (d\sigma/d\Omega)\Omega_i .$$

If this assumption is good, a plot of the cross section obtained for each counter as a function of the corresponding solid angle subtended at the target should yield a straight line, and an extrapolation of this line to zero solid angle gives the desired total cross section.

In the analysis of the data, several factors were considered which could result in significant corrections to the raw data: contamination of the incident beam by particles other than pions, multiple scattering, direct Coulomb scattering, Coulomb-nuclear interference effects, decay corrections, and miscellaneous instrumental effects. Electrons or positrons comprised from 50% of the incident beam at the lowest momentum to 5% at the highest. Principle rejection of this beam component was by Čerenkov counter C_1, which, in conjunction with timing, gave a rejection ratio better than 0.995 over the entire momentum range with an uncertainty negligible compared with that in other major corrections. The only other important beam contamination was by muons. Necessary correction of the data for muons not vetoed by counter logic was evaluated during the tuning phase

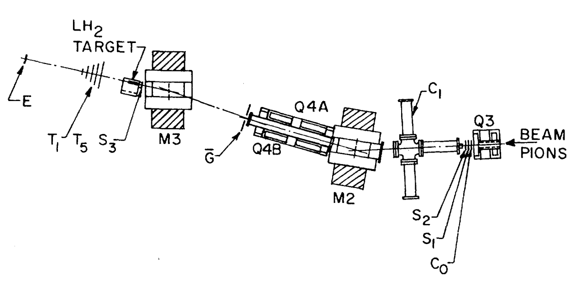

FIG. 1. Experimental configuration of counters and magnets using a secondary pion beam from the Lawrence Berkeley Laboratory Bevatron. Beam transport magnets $M2$, $M3$, $Q3$, $Q4A$, and $Q4B$ are described in Ref. 7.

TABLE I. $\pi^{\pm}p$ total cross sections.

Momentum (MeV/c)	π^+p (mb)	Error (mb)	π^-p (mb)	Error (mb)
415	64.31	0.18	30.83	0.20
435	55.86	0.20	28.19	0.17
455	46.63	0.14	26.73	0.15
475	40.81	0.16	26.18	0.17
495	35.92	0.16	26.50	0.14
515	31.90	0.13	26.70	0.11
535	29.02	0.09	27.19	0.18
555	26.25	0.07	27.88	0.13
575	23.33	0.11	28.81	0.11
595	21.30	0.19	29.26	0.17
614	19.75	0.10	30.19	0.10
632	18.11	0.07	32.14	0.14
650	16.93	0.08	34.02	0.15
668	15.96	0.08	37.56	0.16
687	14.95	0.10	41.59	0.13
705	14.46	0.16	44.58	0.09
723	14.12	0.09	45.46	0.14
741	14.10	0.15	44.59	0.12
760	14.35	0.08	41.60	0.14
778	14.62	0.11	38.63	0.16
791	14.86	0.11	36.63	0.09
815	15.41	0.12	35.58	0.07
833	16.42	0.09	35.12	0.12
851	17.50	0.09	36.09	0.12
870	18.64	0.05	38.64	0.08

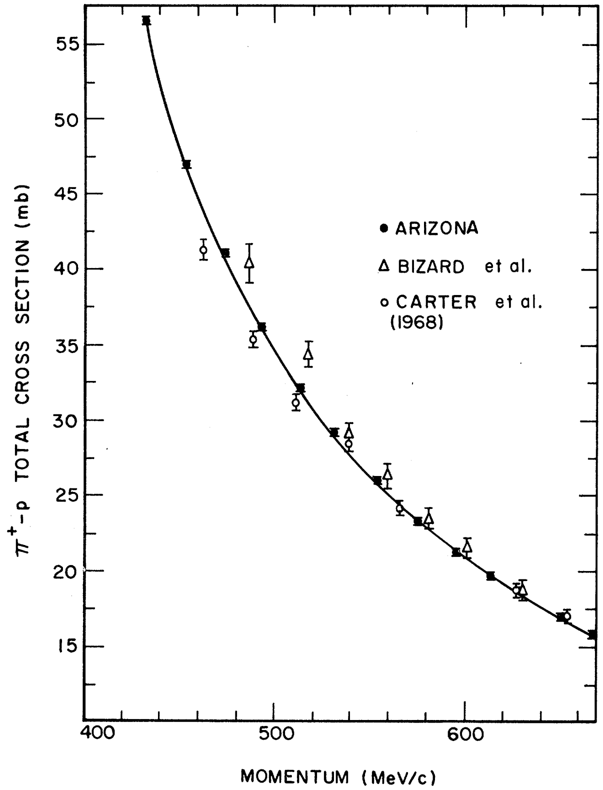

FIG. 2. π^+-p total cross sections together with the results of other experiments. The symbols correspond to the following references: ○ (Carter *et al.*, Ref. 5); △ (Bizard *et al.*, Ref. 1); ● (present experiment). The curve is drawn to aid in identifying the present results.

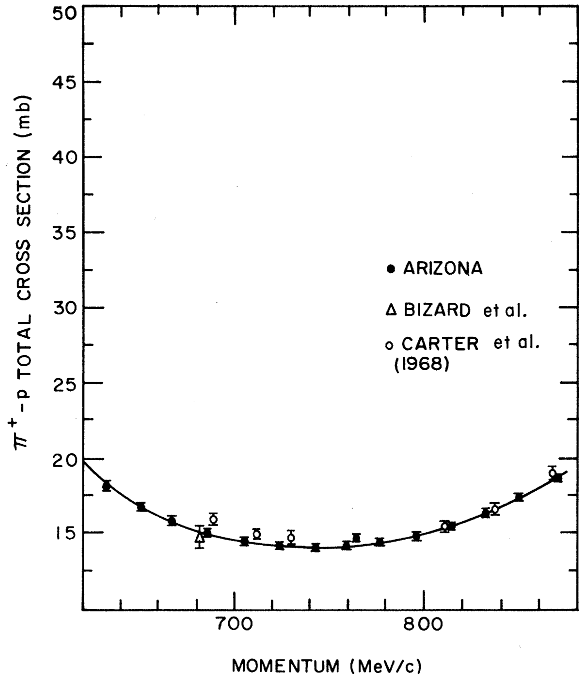

FIG. 3. π^+-p total cross sections together with the results of other experiments. The symbols correspond to the following references: ○ (Carter *et al.*, Ref. 5); △ (Bizard *et al.*, Ref. 1); ● (present experiment). The curve is drawn to aid in identifying the present results.

of the experiment by determining the dependence of event rate on the pressure in the gas Čerenkov counter C_1 and was found to be typically 2% with an uncertainty of ±0.2%.

Multiple-Coulomb scattering effects were not included in the error analysis since the transmission counters were large enough to intercept all particles multiply-scattered by electrons in the matter of the transport system. Direct Coulomb scattering by target protons was determined from the Rutherford scattering formula, and the Coulomb-nuclear interference correction was obtained by finding an explicit expression for the following equation in terms of scattering amplitudes:

$$|f(\theta)_{\text{measured}}|^2 = |f(\theta)_{\text{nuclear}} + f(\theta)_{\text{Coulomb}}|^2 .$$

This was evaluated numerically, using existing phase-shift data, and integrated numerically over the solid angles subtended by the transmission counters. These two Coulomb effects gave corrections which were typically 3% with uncertainties of ±0.3% at most.

Other factors were found to contribute to corrections and uncertainties which were negligible compared with the effects mentioned above. These included decay corrections, the effect on empty-target rates of the different energy-loss by pions in full and empty targets, uncertainty in the density of liquid hydrogen in the target, and uncertainty in the effective target length. The results of the total cross section measurements are shown in Table I, together with errors resulting from statistics and correction uncertainties.

Figures 2 and 3 show the measured π^+p total cross sections along with those of Carter *et al.*[5,6] and Bizard *et al.*[1] The agreement in the region from 560 to 860 MeV/c is excellent. From 460 to 560 MeV/c a small systematic deviation between the data of the three experiments is observed. However, the results of Carter *et al.*[6] taken at momenta ranging from 150 to 400 MeV/c connect smoothly with the present data.

The π^-p data are shown in Figs. 4 and 5. Here a definite systematic difference is observed between the data of Carter *et al.* and those of both the present experiment and Bizard *et al.*, which agree well with each other. No new structure has been observed in this work.

One aspect of the experimental technique em-

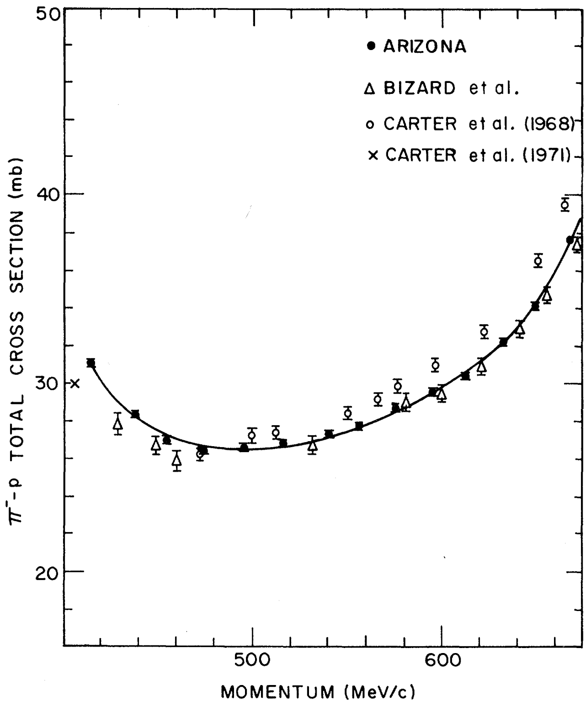

FIG. 4. π^--p total cross sections together with the results of other experiments. The symbols correspond to the following references: ○ (Carter *et al.*, Ref. 5); △ (Bizard *et al.*, Ref. 1); × (Carter *et al.*, Ref. 6) ● (present experiment). The curve is drawn to aid in identifying the present results.

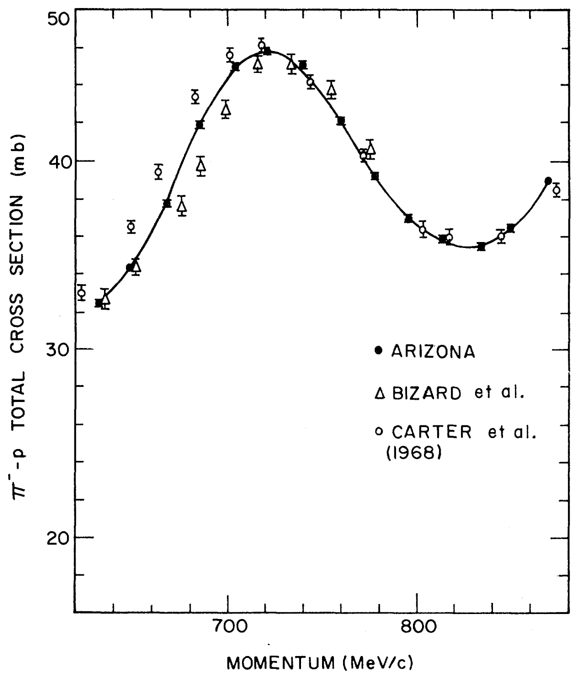

FIG. 5. π^--p total cross sections together with the results of other experiments. The symbols correspond to the following references: ○ (Carter *et al.*, Ref. 5); △ (Bizard *et al.*, Ref. 1); ● (present experiment). The curve is drawn to aid in identifying the present results.

ployed which could explain the discrepancies noted above has to do with the orientation of the transmission counters: In the present experiment, the smallest-diameter counter is furthest downstream while in the experiments of Carter *et al.*[5,6] the reverse is true. It is believed that this, combined with the effects of the charge-exchange reaction in the transmission counters which is possible in the π^-p case, could provide a possible explanation. This possibility will be investigated in further total cross-section measurements which are currently in progress.

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