HIGH-ENERGY TOTAL CROSS SECTIONS FOR POSITIVE PIONS AND PROTONS ON HYDROGEN*

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On the basis of dispersion relations, Pomeranchuk has shown that if the (π^+,p) and (π^-,p) total cross sections approach constant values at high energies, these limits must be equal.[1] Considerable information is already available on the (π^-,p) total cross sections in the Bev range.[2-4] We present the results of an experiment at the Berkeley Bevatron in which (π^+,p) cross sections between 1.4 and 4.0 Bev/c were measured. Data on (p,p) total cross sections are also presented.

The experimental arrangement is shown in Fig. 1. Positive particles produced when the circulating proton beam strikes a target are bent inwards towards the center of the Bevatron by the magnetic field. In order to obtain positive pions with the highest possible momentum, the pion beam was brought out of the machine through a window on the inside radius. The beam is further deflected by bending magnets to keep it clear of the Bevatron structure and is focused by an 8-in.-bore doublet quadrupole.

Scintillation counters M_1, M_2, and M_3, each $1\frac{1}{2}$ in. in diameter, define the beam. Pions are distinguished from protons by requiring a coincidence with C, a gas Čerenkov counter[5] filled with sulfur hexafluoride to give an index of refraction of approximately 1.008. By putting C in anticoincidence with $M_1M_2M_3$, we obtained data on p-p scattering simultaneously with the (π^+,p) data.

After passing through the defining telescope, the beam impinged on a 4-ft-long liquid hydrogen target. The number of pions (and protons) transmitted was measured simultaneously at three different solid angles by means of counters S_1, S_2, and S_3. An extra coincidence in S_0 was added to reduce accidentals. The solid angles defined by S_1, S_2, and S_3 ranged from 0.6 to 4.3 millisteradians.

The coincidence circuits used were of the type described by Wenzel.[6] With the clipping lines employed, the resolving time was about 5×10^{-9} sec. The output of the monitor coincidence circuit was used as an input to a second circuit where a coincidence with S_0 and S_1 (for example) was required. Several species of accidentals were monitored throughout the experiments, and corrections to the data were made where necessary. Accidentals involving C were always less than 2% of the number of pions.

The momentum spread accepted by the counter telescope was approximately 2.5%, and the uncertainty in the momentum determination is estimated to be ±3%. Extensive magnetic shielding to reduce the Bevatron's leakage field was required along most of the beam line.

Data collection at each momentum involved series of runs with the H_2 target filled and empty; each series consisted of a full run preceded and followed by an empty run. The number of counts recorded in each series was usually sufficient to give a cross section with a statistical uncertainty of less than 1%. An analysis of the data from different measurements at the same momentum indicated that the probable error assigned to each measurement had to be increased to about 3%. The results given below are averages of two

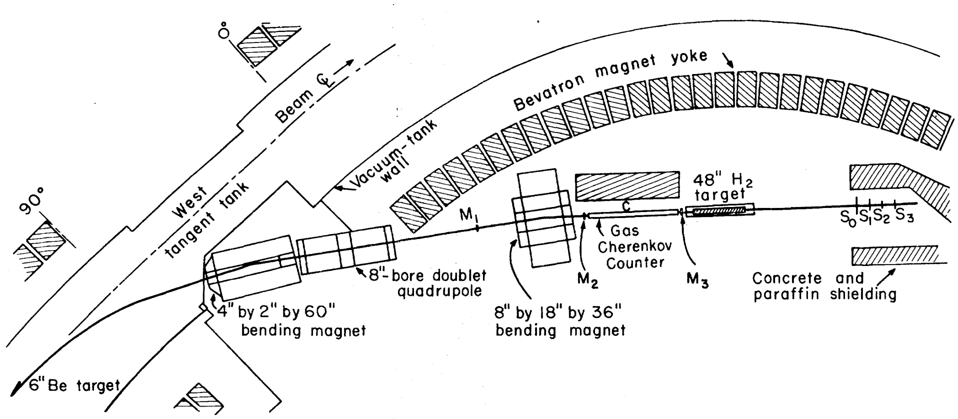

FIG. 1. Experimental arrangement.

or more measurements at each momentum. The uncertainty in the extrapolation to the zero solid angle subtended by the last counter was considered in assigning the errors. Where necessary, the data at the smaller solid angles were corrected for multiple Coulomb scattering by a method similar to that of Sternheimer.[7] These corrections were assigned a probable error of ±20% and had little effect on the extrapolated cross sections. Other possible sources of error are discussed below.

(A) Sources of error in the (π, p) measurements. A curve of the ratio of $M_1M_2CM_3$ counts to $M_1M_2M_3$ counts as a function of gas pressure in the Čerenkov counter indicated less than 2% electron contamination and less than 1% muon contamination at 1.8 Bev/c. Such a curve gives only the fraction of muons with momentum equal to or greater than that of the pions. The total muon contamination for the geometries and momenta used was determined by calculation, and corrections were made. The maximum was 2%. Practically all of the muons came from pions decaying after M_2, where the calculation is relatively simple.

(B) Sources of error in the (p, p) measurements. The errors assigned to the (p, p) cross sections have been increased to allow for the uncertainty in the efficiency of the anticoincidence circuits and the Čerenkov counter. If these were not 100% efficient in eliminating pion counts, the measured (p, p) cross sections would be low. The assigned errors are based on an efficiency between 90% and 100%.

K-meson contamination in the "proton beam" is estimated to be less than 1% for the momenta and take-off angles used in this experiment.

Table I. Total (π^+, p) and (p, p) cross sections.

Momentum (Bev/c)	$\sigma(\pi^+, p)$ (mb)	$\sigma(p, p)$ (mb)
1.40	39.4 ± 0.6	$46.9^{+1.0}_{-0.6}$
1.46	39.1 ± 0.8	$47.5^{+2.2}_{-1.1}$
1.60	35.8 ± 0.9	$47.7^{+3.0}_{-1.1}$
1.73	30.1 ± 0.5	$46.5^{+2.0}_{-0.6}$
1.89	28.4 ± 0.6	$46.3^{+3.2}_{-0.8}$
2.05	27.8 ± 0.6	$45.0^{+3.0}_{-1.0}$
2.47	29.0 ± 0.6	$45.6^{+1.9}_{-0.7}$
2.97	29.2 ± 0.5	$45.1^{+0.9}_{-0.5}$
3.58	29.2 ± 0.4	$43.3^{+0.6}_{-0.5}$
4.00	29.3 ± 0.4	42.4 ± 0.6

Our cross sections are shown in Table I and Fig. 2 which also shows data of other experimenters.[2,8,9] Our data for $\sigma(\pi^+, p)$ indicate a maximum near 1.5 Bev/c and an essentially constant cross section above 2.4 Bev/c. Our value at 4.0 Bev/c is 29.3 ± 0.4 mb. The best high-energy values for $\sigma(\pi^-, p)$ to date are 28.7 ± 2.6 mb at 4.3 Bev/c,[3] and 29.1 ± 2.9 mb at 5.2 Bev/c.[4]

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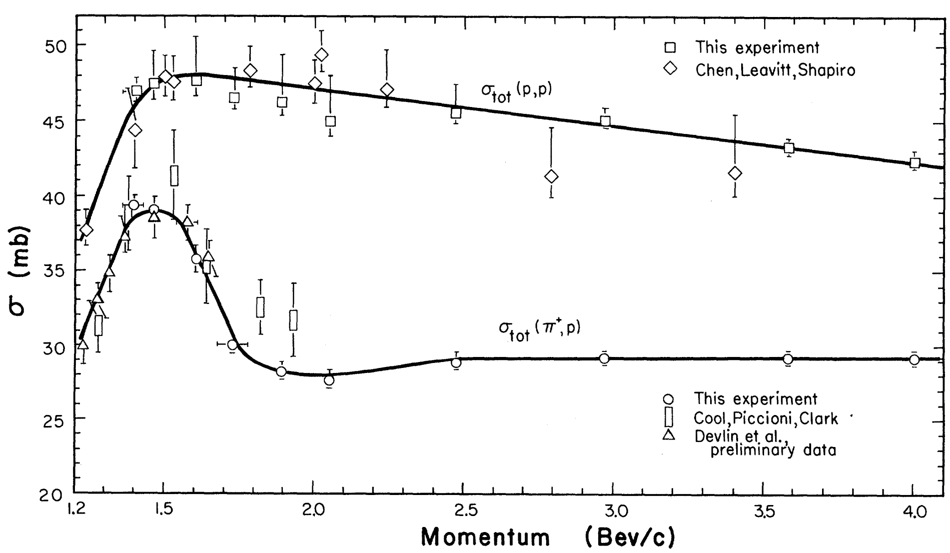

FIG. 2. Total (π^+, p) and (p, p) cross sections vs momentum.

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μ-MESON DECAY

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It was originally suggested by Yukawa[1] that the muon decay may be mediated by an unstable boson with weak couplings to lepton fields. More recently,[2,3] a charged, spin-one boson has been proposed in order to generate the V-A form of the weak decay interactions. It has already been pointed out[4] that a charged scalar intermediary can give rise to the desired couplings, providing an alternative but generally equivalent theory of the weak interactions. This applies when the first-order Kemmer formalism for spinless bosons is employed, but not with the use of the more conventional Klein-Gordon second-order theory.

The field equations in the Kemmer theory may be written

$$\varphi_\lambda = m^{-1}\partial_\lambda \varphi + m^{-2}(g_1^{(\mu)} J_\lambda^{(\mu)} + g_1^{(e)} J_\lambda^{(e)}),$$

$$\varphi = m^{-1}\partial_\lambda \varphi_\lambda + m^{-2}(g_2^{(\mu)} J^{(\mu)} + g_2^{(e)} J^{(e)}), \quad (1)$$

when both scalar and vector interactions are present, where

$$J_\lambda^{(e)} = \bar{\psi}_{(e)}\gamma_\lambda \frac{1-\gamma_5}{2}\psi_{(\nu)} + \text{c.c.},$$

$$J^{(e)} = \bar{\psi}_{(e)} \frac{1-\gamma_5}{2}\psi_{(\nu)} + \text{c.c.}$$

Only in the absence of any vector interaction is φ_μ simply proportional to $\partial_\mu \varphi$. The induced normal muon decay interaction, to lowest order in $g_1^{(e)}$ and $g_2^{(e)}$, is

$$m^{-2} g_1^{(\mu)} g_1^{(e)} \int d^4x\, J_\lambda^{(e)}(x) J_\lambda^{(\mu)}(x)$$

$$+ \left(g_2^{(\mu)} + g_1^{(\mu)}\frac{m^{(\mu)}}{m}\right)\left(g_2^{(e)} + g_1^{(e)}\frac{m^{(e)}}{m}\right)$$

$$\times \int d^4x\, d^4x'\, J^{(e)}(x) D_F(x-x', m) J^{(\mu)}(x'). \quad (2)$$

The first term is a purely local V-A interaction, the second a nonlocal S-P interaction. If $g_2^{(e)} = 0$, the scalar admixture for muon decay becomes $m^{(\mu)} m^{(e)}/m^2$ – less than 10^{-4} for nucleonic mass of the intermediary.[5] Alternatively, if either or both of the factors $[g_2^{(\mu)} + g_1^{(\mu)}(m^{(\mu)}/m)]$ and $[g_2^{(e)} + g_1^{(e)}(m^{(e)}/m)]$ are set equal to zero, the normal μ-decay interaction (to this order in g) becomes a purely local one.

Using the Klein-Gordon formalism, we obtain