TOTAL CROSS SECTIONS FOR PIONS ON PROTONS IN THE MOMENTUM RANGE 4.5 TO 10 Gev/c

G. von Dardel, R. Mermod, P. A. Piroué,* M. Vivargent, G. Weber, and K. Winter
CERN, Geneva, Switzerland
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In a previous paper[1] we reported on measurements of total cross sections for p, $\bar{p}$, $K^{\pm}$, and $\pi^{\pm}$ on protons at high energy. According to a theorem given by Pomeranchuk,[2] the total cross sections for a particle and its antiparticle must become equal if they approach constant values at high energy. For pions, the conditions of this theorem are thought to be fulfilled at lower energies than for the other particles. In our previous paper, a large uncertainty on the muon contamination did not allow us to draw any significant conclusion concerning the validity of the Pomeranchuk theorem.

The present paper reports on a more accurate measurement of the $(\pi^{\pm}, p)$ total cross sections in the momentum range 4.5 to 10 Gev/c; the experimental method used eliminated the effect of muon contamination on the cross sections.

The layout of the experiment is shown in Fig. 1. A beam of secondary particles enters the experimental hall and comes to a focus at the center of a velocity-selective gas Čerenkov counter $\check{C}$, after having traversed a system of two quadrupole lenses and a bending magnet located in the target area. The beam spot at the Čerenkov counter is imaged by another doublet of quadrupole lenses, Q_3, Q_4, onto transmission counters, S_4, S_5, S_6, which are located behind a 312-cm long liquid hydrogen target. Bending magnet B_2 provides a second momentum analysis eliminating secondaries from reactions produced in the collimator walls, in the Čerenkov counter, and in the air, and also eliminating part of the decay muons. The beam incident on the hydrogen target is defined by scintillation counters, S_1, S_2, and S_3, 2, 5, and 2 cm in diameter, respectively, operated in coincidence with the Čerenkov counter, which is set to count pions, but does not discriminate against muons and electrons. After traversing the transmission counters S_4, S_5, and S_6, having diameters of 10, 15, and 20 cm, respectively, the beam is intercepted by a 1-mm long iron absorber in which strongly interacting particles and electrons are lost, whereas more than 99% of the muons are transmitted into counter S_7 (30 cm in diameter). The pions transmitted into counters S_4, S_5, and S_6 are signalled by the coincidences $(S_1S_2S_3\check{C}S_4\bar{S}_7)$, $(S_1S_2S_3\check{C}S_5\bar{S}_7)$, and $(S_1S_2S_3\check{C}S_6\bar{S}_7)$, respectively. These rates, normalized to the incident rate $(S_1S_2S_3\check{C})$, were measured for both target "full" and target "empty." Two steel plates of appropriate thickness simulated the empty target. The coincidence logics was arranged such that the time resolution in all channels was determined by threefold coincidence units of 5-nsec resolution. The accidental rates were negligibly small.

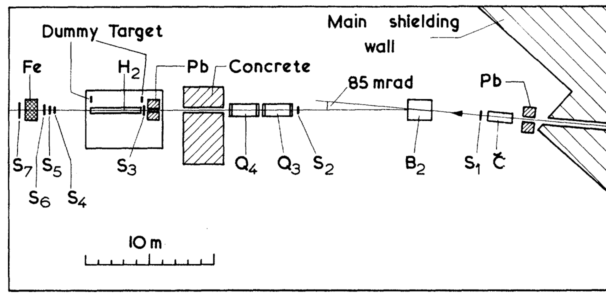

FIG. 1. Experimental layout. The first doublet of quadrupoles and the first bending magnet are in the target area (not shown). Lead collimators shown are 2.5 ×2.5 cm^2, S_1-S_7 scintillators, Q_{3-4} quadrupole lenses, B_2 second bending magnet.

The electron contamination in the negative beam was estimated to 0.6% at 6 Gev/c from a measurement using a threshold Čerenkov counter in a similar beam, and a calculation of the effect of radiation losses in the material in the actual beam used in the experiment. All sources of positron contamination are expected to yield a smaller fraction in the positive beam. In both beams, the contamination is decreasing with increasing energy. The correction to the cross section and to the difference $\sigma(\pi^-, p) - \sigma(\pi^+, p)$ will be less than 0.2 mb.

Earlier measurements of the transmission in hydrogen of negative pions had shown that there is no structure within 3% of the cross section for either isospin state in the momentum range 5-10 Gev/c. Therefore, it was sufficient in the present work to measure cross sections at a few momenta only (4.5, 5.75, 7.0, and 10.0 Gev/c).

Total cross sections were obtained by extrapolating to zero solid angle the cross sections measured with counters S_4, S_5, and S_6, subtending solid angles averaged over the target length of 0.469, 0.826, and 1.315 msr, respectively.

Table I. Total cross sections for negative and positive pions on protons and their difference.

Momentum (Gev/c)	$\sigma(\pi^-,p)$ (mb)	$\sigma(\pi^+,p)$ (mb)	$\sigma(\pi^-,p)-\sigma(\pi^+,p)$ (mb)
4.5	30.2 ± 0.4	27.6 ± 0.3	2.6 ± 0.5
5.75	29.1 ± 0.4	26.9 ± 0.4	2.2 ± 0.6
7.0	28.4 ± 0.4	26.1 ± 0.3	2.3 ± 0.5
10.0	27.0 ± 0.4	25.2 ± 0.4	1.8 ± 0.6

For the lowest momentum, a correction for multiple scattering of 1.3% was applied to $\sigma(S_4)$. The cross sections plotted versus solid angle form a straight line at all momenta, and consequently, linear extrapolation to zero solid angle was used to derive the total cross section. The results are given in Table I.

The errors given are statistical only, including the error in extrapolation. The absolute values of the cross sections may have an additional error of about 0.5 mb due to uncertainties in the effective target length and the calibration of the steel plates simulating the empty target. This should affect neither the difference of cross sections for negative and positive pions, nor the momentum dependence.

The results are shown in Fig. 2 together with data of other authors.[3-7] Our value for the (π^+,p) cross section at 4.5 Gev/c is lower than values given by Longo et al.[3] and Chzan et al.[7]

Unlike the situation for (p,p) total cross sections[8] which have been shown to be constant between 5 and 28 Gev/c, a monotonic decrease is observed for both the (π^+,p) and (π^-,p) cross section with increasing energy. Hence, the condition for Pomeranchuk's theorem[2] that total cross sections tend asymptotically to constant values is not satisfied for the π-nucleon system up to 10 Gev/c.

The difference observed between the cross sections for negative and positive pions is outside the errors, and slowly decreasing with increasing energy. This difference may be due to elastic charge exchange of negative pions, but should vanish if the equality of the cross sections in different isotopic spin states, predicted by Pomeranchuk's theorem, were fulfilled. That it does not vanish confirms the conclusion of the preceding paragraph.

The monotonic decrease of the cross sections at high energies could, if it continued, be considered in connection with recent theories by Berestetsky and Pomeranchuk[9] and Gribov[10] which suggest a cross section decreasing to zero faster than $(\ln E)^{-1}$. Extrapolating our values according to the functional dependence $\sigma=\sigma_0[\ln(E/E_0)]^{-1}$ leads to cross sections of 20 mb at 100 Gev and 16 mb at 1000 Gev.

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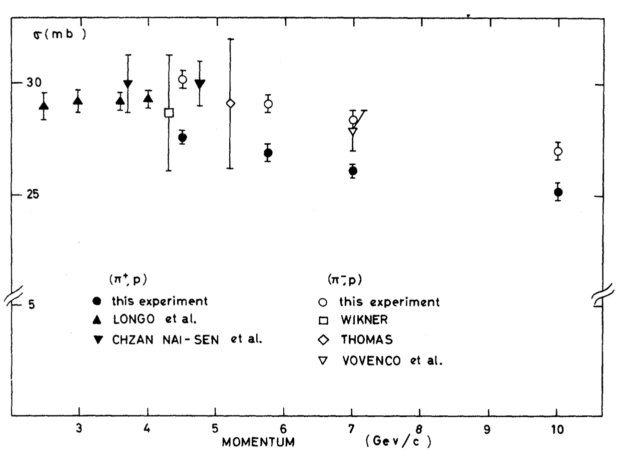

FIG. 2. Total cross sections for (π^-,p) and (π^+,p) versus momentum. Observe break in ordinate scale.

*Present address: Palmer Physical Laboratory, Princeton University, Princeton, New Jersey.

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MAGNETIC MOMENT OF POSITIVE AND NEGATIVE MUONS*

D. P. Hutchinson, J. Menes,† and G. Shapiro
Columbia University, New York, New York

A. M. Patlach
International Business Machines Watson Scientific Computing Laboratory, New York, New York

and

S. Penman‡
University of Chicago, Chicago, Illinois
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This Letter reports on the refinement of the technique for measuring muon magnetic moments and on its application to positive and (bound) negative muons in various materials. These refinements enable us to obtain a statistical accuracy of several parts per million in reasonably short runs. In addition to the absolute measurement of g_μ, this sensitivity permits the observation of environmental effects and thus has applications to nuclear and solid-state physics.

The magnetic moment of the μ meson, like that of the electron, is of theoretical importance because of the exact predictions that can be made of its magnitude. Quantum electrodynamics enables one to calculate the moment[1] in units of the muon magneton, $e\hbar/m_\mu c$. *TCP* invariance requires the positive and negative muon, as particle and antiparticle, to have equal magnetic moments.[2]

Since the discovery of parity nonconservation, there has been a succession of increasingly accurate measurements[3-5] of the muon magnetic moment, at this laboratory and elsewhere. These experiments, as well as the present one, generally express the muon moment in units of the proton magnetic moment, and depend on separate determinations of the muon mass[6] for comparison with theory. A direct measurement of the "anomalous part" of the magnetic moment, which does not depend strongly on the mass value for its interpretation, has also recently been made.[7] The accuracy of the present experiment so far exceeds that of any muon mass determination that it must await future experiments on the latter before its significance can be realized. Alternatively one can accept present theoretical[1] or experimental[7] estimates of the g factor, and combine them with the present results to obtain a "best" value for the muon mass.

The basic method of this experiment is similar to that of reference 5, to which the reader is referred for details. The increased sensitivity of the present experiment is due to numerous improvements in the apparatus, including a higher muon precession frequency, an extremely homogeneous magnetic field, and the transistorizing of all circuitry. Recent improvements in the beam facilities at Nevis, including the long-duty-cycle beam and a new low-energy muon beam, also contributed to the increased sensitivity. Figure 1 shows the experimental arrangement.

Figure 2 shows the results of typical runs with positive and negative muons stopping in HCl solution and graphite, respectively. Early-late phase shift is plotted against magnetic field, as measured by a proton magnetic resonance[8] at the monitor position. Experimental conditions were such that for a target material that does not depolarize positive muons (e.g., bromoform), running time of three hours was sufficient to reduce the statistical error to 12 ppm.

Results of the runs with positive muons stopping in various target materials are summarized in Table I, in chronological order. Statistical errors calculated from a priori considerations are indicated.

The accuracy of the experiment is such that diamagnetic shielding of the muon by atomic elec-