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For pub. Phys. Rev. Letters UCRL-8955

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

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

Michael J. Longo, Jerome A. Helland, Wilmot N. Hess,
Burton J. Moyer, and Victor Perez-Mendez

November 10, 1959

Printed for the U. S. Atomic Energy Commission

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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.[2,3,4] 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 1-1/2 in. diam, 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.

*Work done under auspices of U. S. Atomic Energy Commission.

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 experiment, 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 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.

Our cross sections are shown in Table I and Fig. 2 which also shows data of other experimenters. 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]

We wish to acknowledge our indebtedness to Ken Lou for handling the many engineering problems encountered in the experiment, to Thomas Devlin for his help in conducting the experiment, and to the Bevatron staff and crew.

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 ± .6	$46.9^{+1.0}_{-0.6}$
1.46	39.1 ± .8	$47.5^{+2.2}_{-1.1}$
1.60	35.8 ± .9	$47.7^{+3.0}_{-1.1}$
1.73	30.1 ± .5	$46.5^{+2.0}_{-0.6}$
1.89	28.4 ± .6	$46.3^{+3.2}_{-0.8}$
2.05	27.8 ± .6	$45.0^{+3.0}_{-1.0}$
2.47	29.0 ± .6	$45.6^{+1.9}_{-0.7}$
2.97	29.2 ± .5	$45.1^{+0.9}_{-0.5}$
3.58	29.2 ± .4	$43.3^{+0.6}_{-0.5}$
4.00	29.3 ± .4	42.4 ±0.6

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Figure legends

Fig. 1. Experimental arrangement.

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

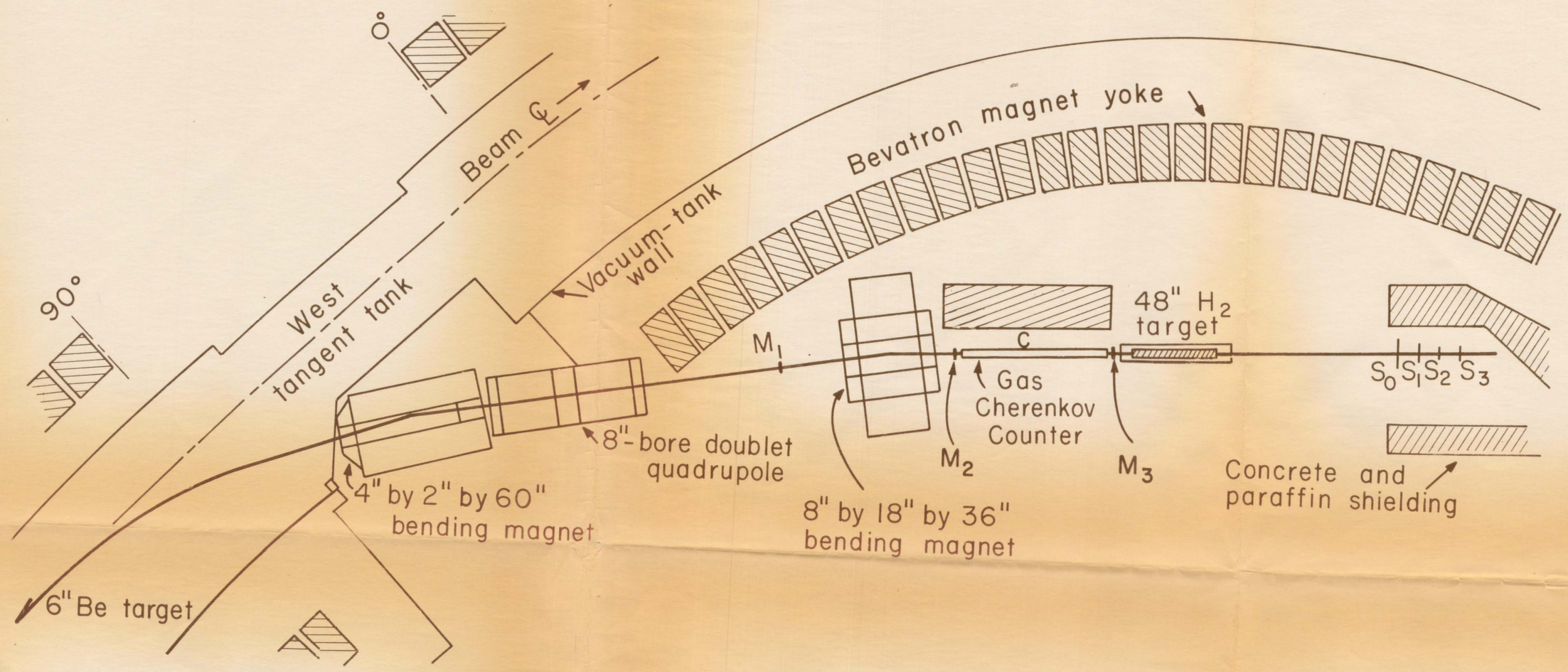
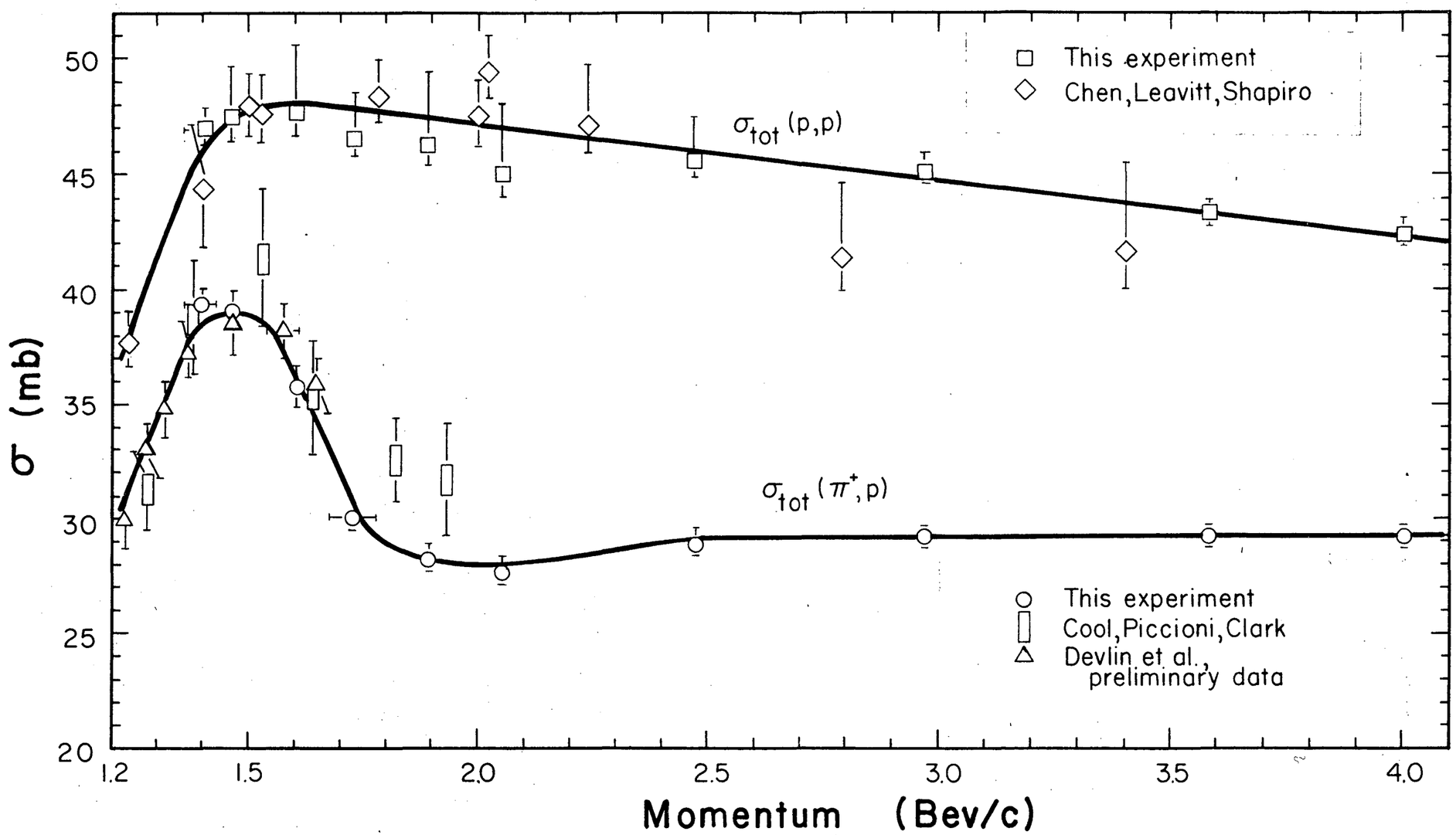

0°
Beam ℄
West
tangent tank
90°
Vacuum-tank
wall
Bevatron magnet yoke
48" H_2
target
M_1
C
Gas
Cherenkov
Counter
M_2
M_3
S_0 S_1 S_2 S_3
8"-bore doublet
quadrupole
4" by 2" by 60"
bending magnet
8" by 18" by 36"
bending magnet
Concrete and
paraffin shielding
6" Be target

Fig. 1


This experiment
Chen, Leavitt, Shapiro
σ_{tot} (p,p)
σ_{tot} (π^+,p)
This experiment
Cool, Piccioni, Clark
Devlin et al., preliminary data
σ (mb)
50
45
40
35
30
25
20
1.2
1.5
2.0
2.5
3.0
3.5
4.0
Momentum (Bev/c)

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