ANTIPROTON-PROTON AND PROTON-PROTON TOTAL CROSS SECTIONS FROM 4 TO 20 Bev/c*

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(Received August 16, 1961)

Previous experiments have observed and compared the behavior of the $\bar{p}$-p total cross section[1,2] and the p-p total cross section[3,4] from low incident momenta (~3 Bev/c) to 10 Bev/c. Although the p-p cross section was slowly decreasing with increasing momentum from ≈44 mb to 40 mb, the $\bar{p}$-p cross section fell rapidly from ≈80 mb at 3 Bev/c to ≈50 mb at 10 Bev/c. The detailed behavior of the $\bar{p}$-p total cross section at even higher energies and comparison to the p-p total cross section was thought to be of considerable general interest, and also of specific interest due to a theorem of Pomeranchuk[5] which can be stated as follows: If one assumes that the total cross section of a particle β for a particle α becomes constant beyond an incident energy ϵ such that

$$\sigma_{\text{total}}(\alpha+\beta)=\text{const for energies} >\epsilon_1, \qquad (1)$$

$$\sigma_{\text{total}}(\bar{\alpha}+\beta)=\text{const for energies} >\epsilon_2, \qquad (2)$$

where $\bar{\alpha}$ is the antiparticle of α, then one can demonstrate on the basis of the forward dispersion relations that

$$\sigma_{\text{total}}(\bar{\alpha}+\beta)=\sigma_{\text{total}}(\alpha+\beta) \text{ for energies} >\epsilon, \qquad (3)$$

where $\epsilon >$ both ϵ_1 and ϵ_2. Although the basic assumption of constant total cross sections at high energy which is made by Pomeranchuk's theorem represents reasonable physical intuition, there is of course no compelling reason to believe that this is necessarily so, and of course no good reason to believe that, even if an ϵ exists, it is in the 10-20 Bev energy region.

The p-p total cross section has previously been shown to be constant within the errors (~5%) from 10 to 28 Bev/c and appears to satisfy the basic assumption of Pomeranchuk's theorem provided it remains constant at higher energies. As previously mentioned, the $\bar{p}$-p total cross section was still decreasing up to 10.5 Bev/c, the highest momentum previously reported, where $\sigma_{\text{total}}(\bar{p}\text{-}p) - \sigma_{\text{total}}(p\text{-}p) \approx 10\pm 3$ mb, so that Pomeranchuk's assumption was not yet satisfied.

Using the Brookhaven 33-Bev alternating gradient synchrotron the present investigation has determined the $\bar{p}$-p and p-p total cross sections at ~1-Bev/c intervals (except for two points) from 4 Bev/c to 20.3 Bev/c. It is found that Pomeranchuk's theorem is still not verified.

The experimental arrangement used for momenta above 9 Bev/c is shown in Fig. 1. Except for small corrections to the angle due to the synchrotron fringing field, the beam consists of particles emitted from the synchrotron target at 4.5°. The magnets Q_1, Q_2, B, Q_3, and Q_4 focus a beam of the desired momentum on scintillator S_3, 1 in. in diameter. The momentum of the system is defined to ~±2.5% by the proton beam size on the synchrotron target and S_3; the absolute scale of the momentum is uncertain by 2%. The particle compositions of these beams are given in a previous publication.[6] Typical $\bar{p}/\pi^-$ ratios were ~1% at low momenta, dropping to 0.2% at 20.3 Bev/c. Particles in the beam are identified by the focussing gas Čerenkov counter $\check{C}$. A schematic diagram of the optics of the counter is shown in Fig.

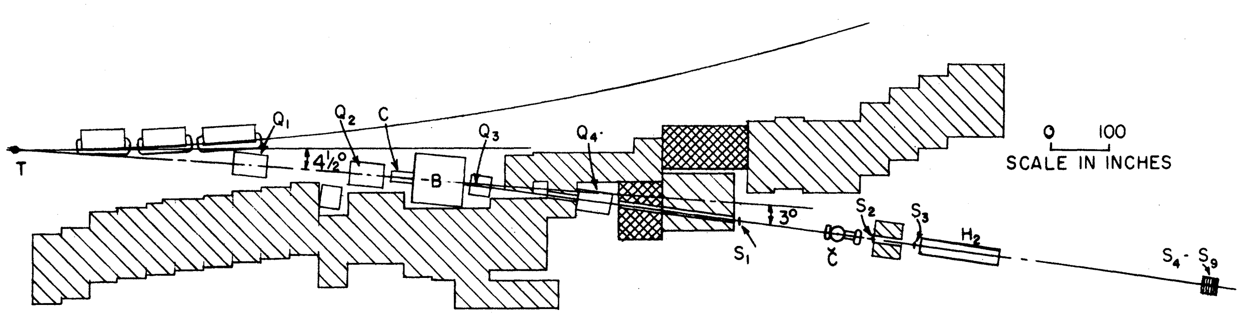

FIG. 1. Experimental arrangement. T, internal target; Q_{1-4}, Focussing magnets; C, collimator; B, analyzing magnet; S_{1-3}, beam-defining scintillators; $\check{C}$, velocity-selecting Čerenkov counter; H_2, liquid hydrogen target; S_{4-9}, scintillators for transmission measurement.

2(a). In Fig. 2(b) is shown a curve of the ratio $S_1S_2S_3\check{C}\bar{A}/S_1S_2S_3$ in the region of pressure corresponding to antiprotons at 16 Bev/c. As can be seen, there is a small background (~4%) at pressures at which the counter should not respond. It has been verified that these counts are due to incomplete rejection of pions and K mesons, and a correction of ~2% was made to the cross section for this effect. To measure the cross section alternate runs are made with a 10-foot long liquid-H_2-filled target and two Al plates which simulated the empty target. By requiring, in addition to the ($S_1S_2S_3\check{C}\bar{A}$) identification, a coincidence with one of the counters S_4 - S_9, ranging from 4 to 12 in. in diameter (see Fig. 1), simultaneous measurements are made of the transmission of the hydrogen for six different geometries. A seventh channel measured accidental coincidences with the 12-in. counter delayed. The transmissions thus measured, of course, include particles scattered through small angles as well as secondaries produced in inelastic collisions in the target.

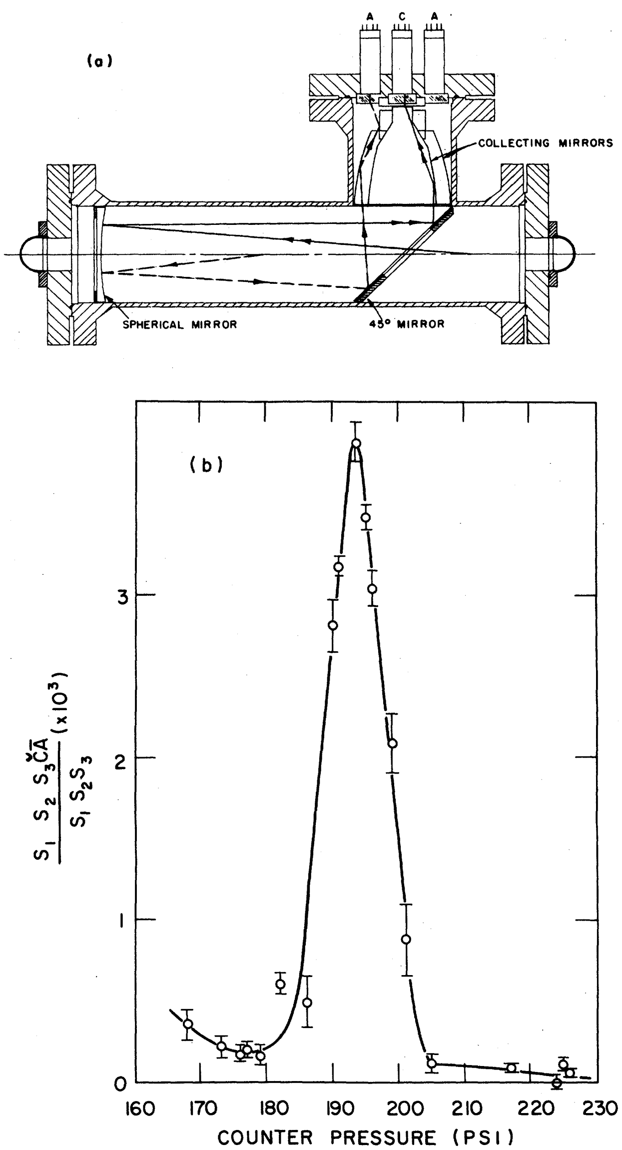

FIG. 2. (a) Velocity-selection Čerenkov counter. The solid ray is a typical ray from a particle with the desired velocity, and the broken ray is that from a particle with higher velocity. The first is counted in channel C, the second in channel A. (b) Čerenkov counter response in the region where 16-Bev/c antiprotons are expected to be detected.

By plotting the transmissions of the various counters S_4 - S_9 against their respective areas and extrapolating to zero area, one obtains the proper transmission which should result from an experiment having an ideal "good geometry."

Cross sections at 4-10 Bev/c were obtained with an arrangement similar to that shown in Fig. 1 except that the beam used leaves the synchrotron target at 9° and the angle of bending in magnet B is 5.5°. The momentum resolution of this beam is ±1.5%. The Čerenkov counter described above was used to measure 6-10 Bev/c while at 4, 5, and 6 Bev/c a pair of smaller counters capable of withstanding higher gas pressures were used in tandem in order to obtain a high rejection ratio for pions.

At the lower momenta the effects of multiple Coulomb scattering in the hydrogen target are not negligible. Sternheimer's method[7] of correcting for this effect was used. The smallest counter at low momenta requires an appreciable correction and was used only as a monitor on the beam size during runs with the hydrogen removed.

The cross sections shown in Fig. 3 were obtained by plotting the ratio of transmission with hydrogen in to transmission with hydrogen out versus counter area; each transmission was corrected for accidental coincidences first. These were small for the $\bar{p}$-p but were as much as a few percent for some cases of p-p at low momenta where the proton beam rates were high. The corrected ratios, as is expected, lie on a linear plot since the angles subtended by the counters S_4 - S_9 are small enough to be within the isotropic portion of the diffraction scattering peak. The smallest counter used in the extrapolation contains all but a negligible number of the singly Coulomb-scattered particles and hence no correction is required for this effect.

In Fig. 3 the errors shown are a combination of statistical errors and an estimated error on

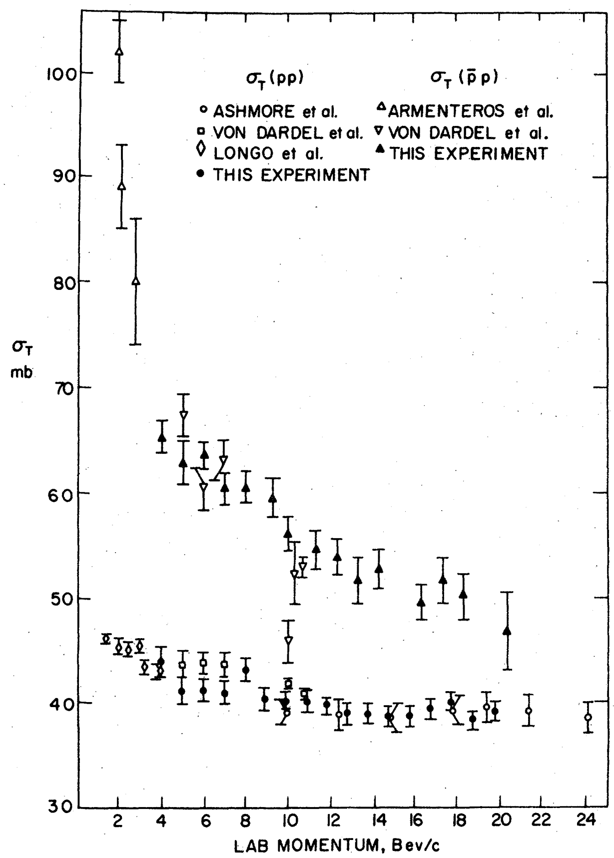

FIG. 3. Total $\bar{p}$-p and p-p cross sections.

the extrapolation to zero solid angle, an error associated with the multiple Coulomb scattering correction, and background errors.

It is clear that our results generally agree with the early measurements[2] of $\sigma_{\text{total}}(\bar{p}\text{-}p)$ up to 10.5 Bev/c, and with the earlier $\sigma_{\text{total}}(p\text{-}p)$ up to 28 Bev/c[4] which used a C-CH_2 difference instead of a liquid hydrogen target. There is no evidence from our measurements for any appreciable structure in either $\sigma_{\text{total}}(\bar{p}\text{-}p)$ or $\sigma_{\text{total}}(p\text{-}p)$. In fact, we also find that $\sigma_{\text{total}}(p\text{-}p)$ is constant within the errors from 10-12 Bev/c to 20 Bev/c with a value $\sigma_{\text{total}}(p\text{-}p) = 39.5 \pm 1$ mb. On the other hand, $\sigma_{\text{total}}(\bar{p}\text{-}p)$ appears to decrease monotonically from 10 Bev/c [where $\sigma_{\text{total}}(\bar{p}\text{-}p) = 58 \pm 4$ mb] to 20.3 Bev/c [where $\sigma_{\text{total}}(\bar{p}\text{-}p) = 48 \pm 4$ mb].

Amati, Fierz, and Glaser have shown[8] that in order to assure constancy of the cross sections at high energies and convergence of the integral

$$\int^{t\to\infty} \frac{\sigma^-(E) - \sigma^+(E)}{E} dE, \tag{4}$$

in which the particle cross section is $\sigma^+(E)$ and the antiparticle cross section is $\sigma^-(E)$, one must require that

$$[\sigma^-(E) - \sigma^+(E)] \to 0 \tag{5}$$

faster than $1/\ln E$ as $E \to \infty$. The convergence of the above integral is necessary to give meaningful results for many dispersion relation treatments.

If we assume that the $\bar{p}$-p and p-p cross sections above 10 Bev/c have reached their limiting energy-dependence region, and if we assume the dependence to be $[\sigma^-(E) - \sigma^+(E)] \propto 1/\ln E$, then a fit of our data implies that $\sigma^-(E) - \sigma^+(E)$ may still be greater than 1 mb even for energies of several hundred Bev. Even if $\sigma^-(E) - \sigma^+(E)$ were to approach zero as fast as linearly with energy, it would appear from our data that the difference would not become zero before 35 Bev.

Von Dardel et al.[2] showed that $\sigma(K^-\text{-}p)$ was substantially larger than $\sigma(K^+\text{-}p)$ up to 8 Bev/c, where $\sigma_{\text{total}}(K^-\text{-}p) - \sigma_{\text{total}}(K^+\text{-}p) \approx 5 \pm 2$ mb. The results of their experiments as to whether $\sigma_{\text{total}}(\pi^-\text{-}p)$ and $\sigma_{\text{total}}(\pi^+\text{-}p)$ were the same or different up to 10 Bev/c were inconclusive due to possible experimental uncertainties. It was also not clear in these experiments that the cross sections at the higher energies were energy independent, but at least their energy variation appeared to be slow. Therefore, to date there has not been a clear demonstration of even a single case where Pomeranchuk's theorem was apparently applicable and verified.

The authors wish to acknowledge the cooperation of the AGS staff and the operating crew during these experiments. The authors also wish to acknowledge the assistance of J. Elias and C. Sinclair during these experiments.

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*This work was performed under the auspicies of the U. S. Atomic Energy Commission.

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K^+-p INTERACTION AT 455 Mev*

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(Received July 31, 1961)

We have undertaken a systematic study of the interaction of positive K mesons with hydrogen and deuterium in the energy interval from 0 to 455 Mev. Some preliminary results have already been reported.[1] In this note we present the results obtained for the elastic and inelastic K^+-p interaction at 455 Mev.

Previous investigations of K^+ interactions in nuclear emulsion[2] and propane[3] have yielded measurements of differential and total cross sections for the process $K^+ + p \rightarrow K^+ + p$ in the energy interval 40 to 300 Mev. The differential cross section at 225 Mev,[4] as well as the total cross sections in the range 175 Mev $< E_K <$ 8 Bev, have been measured by counter techniques.[5,6] The features of the K^+-p scattering from 80 to 300 Mev are that (a) the total cross section is approximately 14 mb, varying little, if at all, with energy; and (b) the angular distribution is isotropic.

The Lawrence Radiation Laboratory 15-inch hydrogen bubble chamber was exposed to a separated beam of K^+ mesons produced by the 6-Bev circulating protons of the Bevatron (Fig. 1). The system was designed for a momentum of 645 Mev/c. With adjustment of the magnet parameters it was possible to obtain the higher momentum of 810 Mev/c ($T_K \approx 455$ Mev). A mass-resolution curve at 810 Mev/c for the separation system is shown in Fig. 2. The background of light particles (pions, muons, and electrons) was approximately 10%; the pion component is analyzed in more detail below.

The initial sample of events, chosen to satisfy geometric and incident-momentum criteria, contained both inelastic and elastic K^+ interactions and also a background of π^+ interactions. Kine-

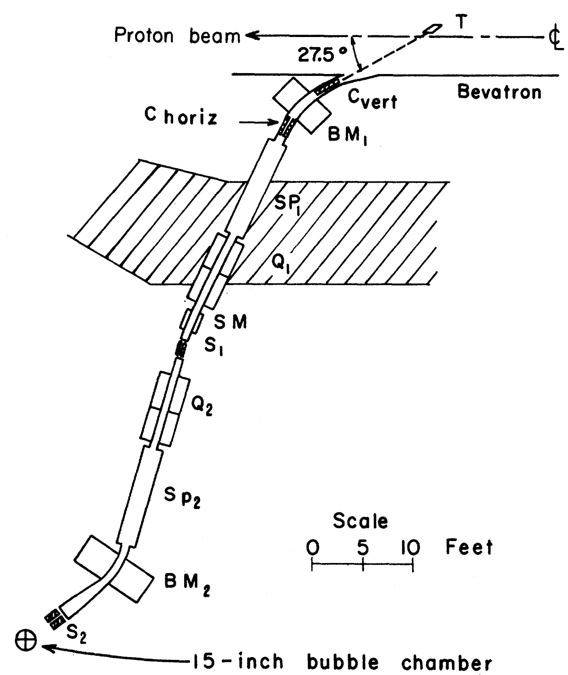

FIG. 1. Layout of the separated K^+ beam. The beam design was similar to a separated K^- beam designed earlier [P. Eberhard, M. Good, and H. K. Ticho, Rev. Sci. Instr. 31, 1054 (1960)], and is described in detail in G. Goldhaber, S. Goldhaber, J. Kadyk, T. Stubbs, D. H. Stork, and H. K. Ticho, Lawrence Radiation Laboratory Internal Report Bev-483, February 26, 1960 (unpublished). The K^+ beam from the target (T) is focused by the quadrupole Q_1 onto slit S_1. The momentum selection is effected by bending magnet BM_1, and the subsequent mass separation by the crossed electric and magnetic field in spectrometer Sp_1. The second state is essentially a mirror image of the first. The steering magnet SM was introduced for additional freedom in the horizontal plane. C_{horiz} and C_{vert} are horizontal and vertical collimators, respectively.