TOTAL CROSS SECTIONS FOR p, $\bar{p}$, $K^{\pm}$, AND $\pi^{\pm}$ ON HYDROGEN BETWEEN 3 AND 10 Gev/c

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Considerable information on the total cross section of hydrogen is available for particles having energies up to a few Gev. Pomeranchuk[1] and Amati, Fierz, and Glaser[2] have shown on the basis of dispersion relations that, if the total cross sections for a particle and its antiparticle on hydrogen approach constant values at high energies, then these limits must be equal. For these energies of a few Gev the total cross sections for a particle and its antiparticle are still quite different from each other, for both nucleons and K particles. Beams of higher-energy elementary particles have recently become available from the 25-Gev CERN proton synchrotron. We have used some of these beams for a first brief exploration of the elementary particle cross sections in the momentum range between 3 and 10 Gev/c.

The beam layout is shown in Fig. 1. Secondary particles from an internal target leave the fringing field of the synchrotron at an angle of 6°, are collimated and momentum-analyzed, and are defined as a beam by scintillators S_1, S_2, and S_3, each 5 cm in diameter. The various particles are identified and labelled electronically by putting in coincidence with $(S_1S_2S_3)$ a velocity-selective gas Čerenkov counter, $\check{C}$, having a resolution of $\Delta\beta = 0.001$.[3] A representative velocity spectrum at a fixed momentum of 8 Gev/c is shown in Fig. 2. The antiproton and K^- content of the negative beam and the K^+ content of the positive beam are in the range 0.5 to 2% over the momentum region covered. The momentum band accepted by the counter telescope was approximately 6%. The uncertainty in the momentum determination is estimated to be 3%.

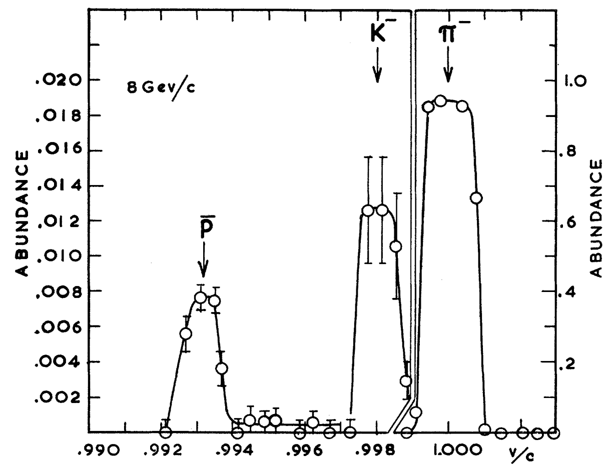

FIG. 2. Velocity spectrum of the negative beam of 8-Gev/c momentum.

The beam defined by a coincidence $(S_1S_2S_3\check{C})$ impinged on a 3.1-m long liquid hydrogen target, 20 cm in diameter, and alternatively on a steel plate calibrated to represent the empty target container. The transmission was measured simultaneously in counters S_4, S_5, and S_6 subtending solid angles of $(2.6,\ 4.5,\ \text{and}\ 9.0)\times10^{-4}$ sr, respectively, at the effective center of the target. Double coincidences $(S_1S_2S_3\check{C})S_4$, $(S_1S_2S_3\check{C})S_5$, and $(S_1S_2S_3\check{C})S_6$ were formed both with prompt timing appropriate to the particle velocity, and delayed with respect to the defining telescope to

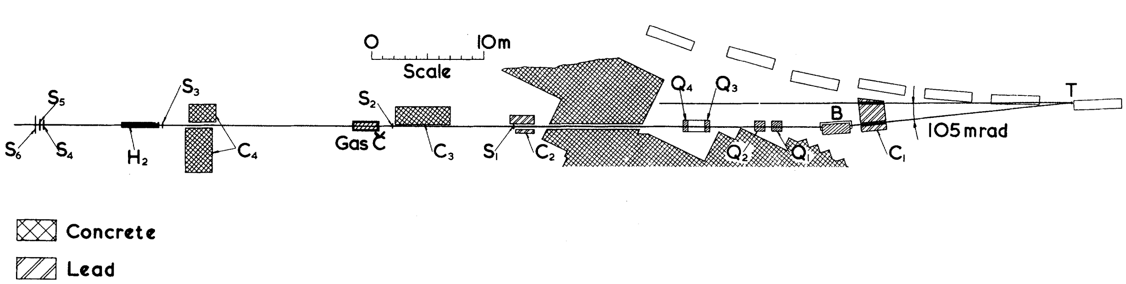

FIG. 1. Experimental layout. C_{1-4}, collimators; B, bending magnet; Q_{1-4}, quadrupole lenses; $\check{C}$, gas Čerenkov counter; S_{1-6}, scintillators; T, internal target.

measure accidental rates. The coincidence rates with target full and empty were corrected separately for accidental counts and the cross section obtained for each counter was plotted as a function of the solid angle subtended. The cross sections were corrected for multiple scattering using the graphs of Sternheimer.[4] This correction was negligible at high momenta for all three counters. At lower momenta it affects first S_4 and then S_5. Since our three geometries are all contained within the flat portion of the expected diffraction peak, the cross sections, corrected for multiple scattering, were fitted to a linear dependence on subtended solid angle and extrapolated to zero solid angle to obtain the total cross section.

The errors of the extrapolated cross sections were calculated from the statistical errors of the measured transmissions combined with the uncertainty in the multiple scattering correction, which latter was assumed to be ±100%, due to incomplete knowledge of the beam structure. With this assumption the best extrapolated value at lower momenta, where the multiple scattering correction to data from S_4 was large, was obtained by using only the data from S_5 and S_6 in the extrapolation to zero solid angle.

The p-p cross sections together with earlier data are shown in Fig. 3. Our data join on well to the results of measurements of Longo et al.[5] at lower energies and fall slowly in the range from 5 to 10 Gev/c. Our values at 10 and 10.7 Gev/c are considerably higher than earlier data at 9.4 Gev/c on free protons in emulsions.[6]

The $\bar{p}$-p cross section, also shown in Fig. 3, continues to diminish with increasing momentum from the high values previously measured at low momenta[7] to a value approximately 10 mb higher than the p-p cross section at 10.7 Gev/c.

The cross sections for positive and negative K mesons are shown in Fig. 4, together with the results of other investigators.[8-11] Our K^--p cross sections do not disagree with the more accurate measurements of Cook et al.[8] at low momentum. Taken together with their results, our point at 8 Gev/c indicates an almost constant cross section of 25 mb from 3 to 8 Gev/c. Our K^+-p cross sections at low momenta may be compared with the measurements of Burrowes et al.[9] Although the errors of our low-momentum points are large, it is difficult to fit a curve to the data without assuming some structure in the cross section. However, the data of Burrowes et al. were not corrected for diffraction scattering. Further research is clearly needed in this energy region. At 8 Gev/c the K^--p cross section is 5±2 mb higher than the K^+-p cross section.

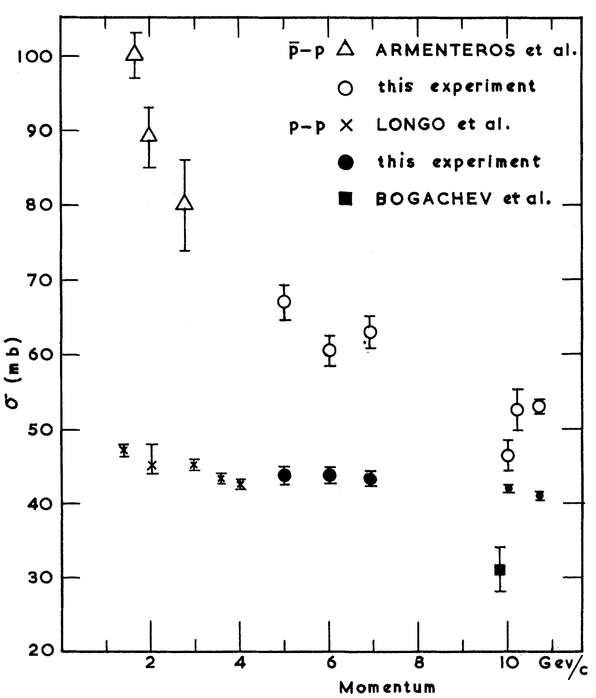

FIG. 3. Total $(\bar{p},p)$ and (p,p) cross sections versus momentum.

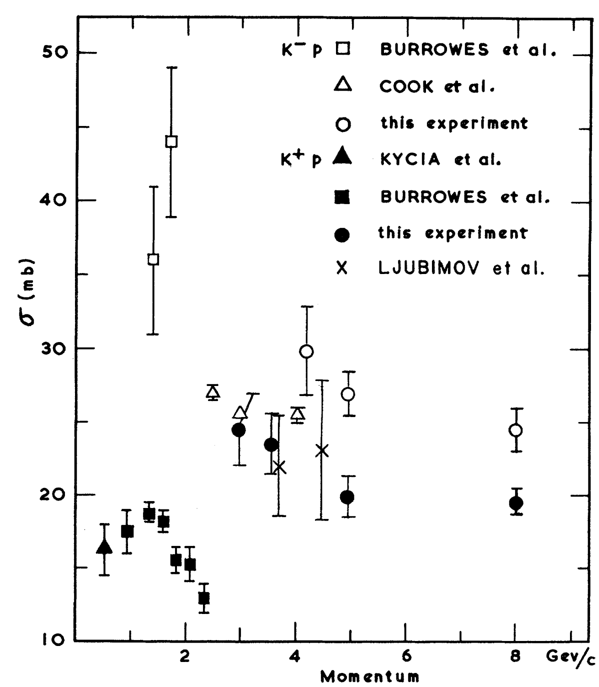

FIG. 4. Total (K^-,p) and (K^+,p) cross sections versus momentum.

In Fig. 5 are shown total cross sections for charged pions. The square symbols at 5 and 10 Gev/c denote cross sections for which the Čerenkov counter was adjusted to accept light mesons. At our energies muons and pions cannot be resolved by the Čerenkov counter so the cross sections refer to a mixture of these two particles. The round symbols represent total cross sections measured in the negative beam without the use of the Čerenkov counter. The contamination of K mesons and antiprotons in this beam is less than 3% at all energies and should not affect the results appreciably. The smooth energy dependence of the total cross sections in the negative beam indicates the absence of pronounced resonances in the π-p system in either the $T=\frac{1}{2}$ or $T=\frac{3}{2}$ isotopic spin states.

There is an apparent difference between the π^--p and π^+-p cross sections of 1.8 ± 0.8 mb at 5 Gev/c and 2.0 ± 0.6 mb at 10 Gev/c. Although outside the statistical errors, these differences may be the result of unequal muon contaminations in the two beams. Such an inequality may come about because of an excess of K^+ mesons undergoing $K_{\mu 2}$ decay in the positive beam, or because of asymmetry in the behavior of positive and negative beams in the fringing field of the accelerator. Below 6 Gev/c we expect the muon contamination in the negative beam to decrease rapidly due to the focusing effect of this fringing field upon undecayed pions. We estimate this effect to be sufficient to cause the apparent rise in the measured negative cross section at low energies.

Also shown in Fig. 5 are the π^+-p cross sections of Longo et al.[5] up to 4 Gev/c and the π^--p cross sections of Wikner[12] and Thomas.[13] Using transmission through carbon absorbers at 6 and 10 Gev/c we have estimated the muon contamination to lie between 9 and 15% in the negative beam. For purpose of comparison of our measured values with the earlier data, we have drawn in Fig. 5 points showing the negative pion cross sections we would infer assuming the muon contamination to be an arbitrary 10%.

In conclusion, the present results indicate that the total cross sections of charged nucleons, pions, and K mesons tend to approach constant values at high energies. For both the K mesons and the nucleons the difference between the particle and antiparticle cross sections on hydrogen and the weak dependence on energy of these cross sections suggest that the limiting equality predicted in reference 1 and 2 is reached, if at all, only at energies considerably higher than 10 Gev/c. On the other hand, the positive and negative pion cross sections are equal to within the systematic uncertainty.

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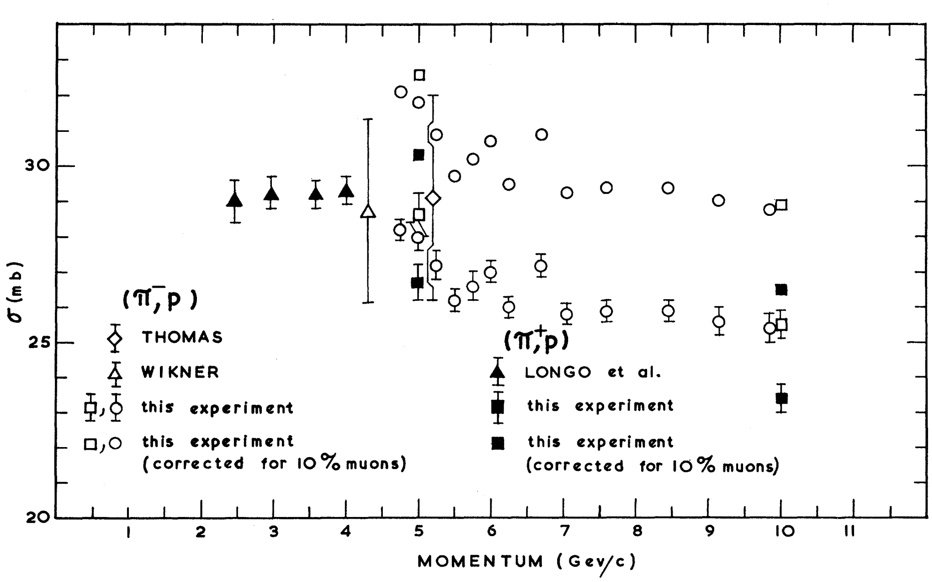

FIG. 5. Total (π^-,p) and (π^+,p) cross sections versus momentum. Square symbols represent measurements with the Čerenkov counter set for pions; circles represent measurements with the whole negative beam.

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PHOTOPRODUCTION OF CHARGED MESONS FROM DEUTERIUM AND THE π^-/π^+ RATIO

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We have used a 4-in. diameter deuterium bubble chamber at the Lawrence Radiation Laboratory electron synchrotron to observe the reactions

$$\gamma + d \to \pi^- + 2p, \tag{1}$$

and

$$\gamma + d \to \pi^+ + 2n \text{ (followed by } \pi^+ \to \mu^+ + \nu), \tag{2}$$

in the interval between threshold and 194-Mev photon energy (lab).[1] In Reaction (1), sufficient final-state information was obtained to determine the kinematical parameters required to calculate the final-state Coulomb effects. By correcting the observed ratio $R_d = (\sigma_{\gamma d \to \pi^-})/(\sigma_{\gamma d \to \pi^+})$ to account for the final-state Coulomb interactions, we obtained values of the ratio $R = (\sigma_{\gamma n \to \pi^-})/(\sigma_{\gamma p \to \pi^+})$ (see Table I), which involves the reaction of

Table I. σ^-/σ^+ as a function of photon energy and meson angle.

Bins	Spectator photon energy (Mev)[a]	θ^* pion c.m. angle, (deg)	σ^-/σ^+ Before (R_d) Coulomb correction	σ^-/σ^+ After (R) Coulomb correction
I	152 - 158	0 - 90	1.22 ± 0.16	1.08 ± 0.14
II	158 - 165	90 - 140	1.36 ± 0.19	1.27 ± 0.18
III	165 - 175	135 - 180	1.54 ± 0.21	1.44 ± 0.20

[a]The spectator photon energy (lab) and pion angle θ^* (lab) are from $(\gamma + p \to \pi^+ + n)$ two-body kinematics.