TOTAL CROSS SECTIONS FOR INTERACTIONS OF 4.75- *AND* 3.7-Bev/c K^+ *AND* π^+ *MESONS WITH PROTONS AND NUCLEI*

M. F. LIKHACHEV, V. S. STAVINSKII, HSÜ YÜN-CH'ANG and CHANG NAI-SEN

Joint Institute for Nuclear Research

Submitted to JETP editor January 24, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **41**, 38-41 (July, 1961)

The total cross sections for interactions of K^+ and π^+ mesons with protons were measured. The following values were obtained: 21.3 ± 4.6 mb and 21 ± 4.3 mb for 4.75 ± 0.15 Bev/c and 3.7 ± 0.1 Bev/c K^+ mesons, respectively; the corresponding values for π^+ mesons of the same momenta were 33.3 ± 1.3 mb and 30 ± 1.2 mb. Data on the cross sections for inelastic collisions of K^+ and π^+ mesons with various nuclei have also been obtained.

According to bevatron measurements,[1] the total cross section for interactions between K^+ mesons and protons attains a maximum of ~ 19 mb at a K^+-meson momentum of ~ 1.2 Bev/c and then drops to 13 mb at 2.4 Bev/c. In this connection, it is important to obtain data on the total cross sections for interactions between K^+ mesons and hydrogen at higher energies.

We carried out two series of measurements with the proton synchrotron of the High Energy Laboratory of the Joint Institute for Nuclear Research. The momentum of the particles bombarding a target-absorber was 4.75 ± 0.15 Bev/c in one case and 3.7 ± 0.1 Bev/c in the other. A diagram of the experimental layout is shown in Fig. 1.

As the source of K^+ mesons and other positive particles, we used a beryllium plate 20 × 2 × 4 cm bombarded by protons accelerated to ~ 10 Bev in the first series and to ~ 8 Bev in the second.

The K^+ and π^+ mesons of given momentum were deflected by the magnetic field of the proton synchrotron by an angle of ~ 18° relative to the primary proton direction. They passed through two quadrupole magnetic lenses focusing the particles in the vertical plane and defocusing them in the horizontal plane. After undergoing another deflection of ~ 8°, the particles passed through a system of scintillation and Cerenkov counters.[2]

The signals from the scintillator and Cerenkov radiator of each counter were picked up by a single photomultiplier tube (FÉU-33 or FÉU-24) and the pulses were applied to the electronic circuit. The basic block diagram of the electronic equipment used to measure the total cross section for interactions between K^+ mesons and hydrogen is shown in Fig. 2. This figure also shows the path of the signal from the photomultiplier, through the branching circuit, to the input of "fast" coincidence and anticoincidence circuits ($\tau \approx 5 \times 10^{-9}$ sec). The K^+ mesons were separated and recorded by two scintillation counters S_1 and S_2 and two gas Cerenkov counters Y_1 and Y_2 set to record K^+ mesons of a given momentum; these counters were connected in anticoincidence with a threshold gas Cerenkov counter P, which recorded π^+ and μ^+ mesons. In the separated K^+ meson beam (K^+ mesons constituted ~ 1% of all positive beam particles), π^+ and μ^+ mesons, positrons and random coincidences totaled no more than 0.5% of the K^+ mesons.

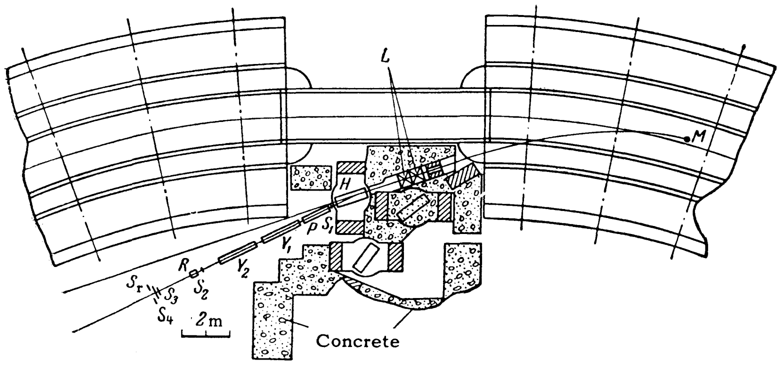

FIG. 1. Experimental layout: M – target; R – scatterer; H – magnet; L – magnetic lens; S – scintillation counters of diameter 9 cm (S_1), 6 cm (S_2), 14.5 cm (S_3), 16 and 30 cm (S_r); Y and P – Cerenkov counters.

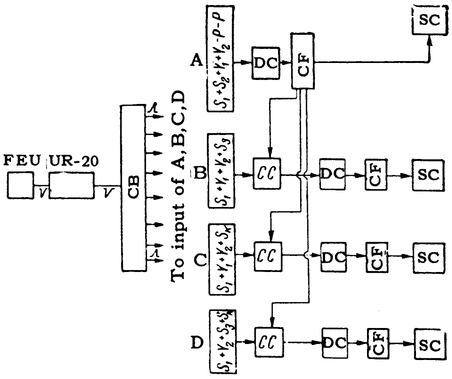

FIG. 2. Block diagram of the electronic equipment: A – four-channel coincidence circuit ($\tau \approx 5 \times 10^{-9}$ sec) with two anticoincidence channels; B, C, D – four-channel coincidence circuits ($\tau \approx 5 \times 10^{-9}$ sec); CC – two-channel coincidence circuits ($\tau \approx 5 \times 10^{-7}$ sec); DC – discriminators; CF – cathode followers; SC – scaler circuits. The path of the signal from the FÉU photomultiplier to the coincidence circuits is shown on the left: UR – amplifier with a mean amplification factor of 18 and bandwidth of 180 Mc; CB – clipper-branching circuit.

The π^+ mesons were separated by a threshold gas Cerenkov counter in coincidence with S_1 and S_2. The μ^+-meson and positron contamination in the π^+-meson beam was $(3 \pm 1)\%$ and $< 0.1\%$, respectively.

Liquid hydrogen (2.13 g/cm^2) in a foamed polysterene container was used as the target-absorber R in the experiments with hydrogen. In this case, the particles scattered out of the beam were measured at angles $\theta > 2.3°$ (in the laboratory system), where $\theta = \tan^{-1}(r/\rho)$; r is the radius of counter S_3 and ρ is the distance between S_3 and the center of the target.

In order to find the total interaction cross section, it is also necessary to take into account the particles scattered by angles $\leq 2.3°$. To do this at 3.7 Bev/c, we used a ring counter S_r located 1.9 m from the center of the target (see Fig. 1). The ring counter was connected in coincidence with counters S_1, S_2, Y_1, Y_2 and with S_1, S_2, Y_1, Y_2, S_3 in the measurements of K^+ mesons scattered out of the beam and with counters S_1, S_2, P and S_1, S_2, P, S_3 in the case of π^+ mesons (see Fig. 2).

Assuming an isotropic distribution (for small angles) for the secondary particles not recorded simultaneously by S_3 and S_r but recorded only by S_r, and knowing the probabilities that the secondary particles pass through only counter S_r and (owing to the multiplicity) simultaneously through both counters S_r and S_3, we found the cross-section correction $\Delta\sigma$ ($\leq 2.3°$) for processes in which at least one secondary particle traverses counter S_3. We call this cross section correction the "forward-scattering" correction. This correction was 0.3 ± 0.3 mb for K^+ mesons and 3 $\pm$ 0.3 mb for π^+ mesons (of momentum 3.7 Bev/c).

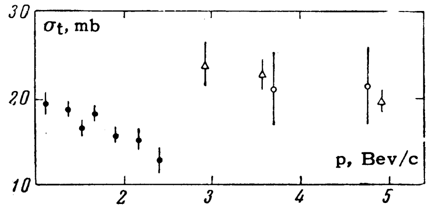

FIG. 3. Total cross sections for the interaction between K^+ mesons and hydrogen as a function of the K^+ momentum (in the laboratory system): ○ – present experiment, ● – data from,[1] Δ – data from[5]

The total cross sections for the interaction of K^+ mesons with hydrogen corrected for forward scattering were 21 ± 4.3 mb and 21.3 ± 4.6 mb at 3.7 and 4.75 Bev/c, respectively. For π^+ mesons, the corresponding values of the cross sections, corrected for forward scattering and the μ^+-meson contamination of the beam were 30 ± 1.2 and 33.3 ± 1.3 mb. Here we used the same forward scattering correction at 4.75 Bev/c as at 3.7 Bev/c.

The values of the total cross sections for the interaction between π^+ mesons and hydrogen are in agreement with the results obtained by Longo et al [3] for π^+ mesons of momentum up to 4 Bev/c.

The basic results of the present experiment were reported by I. V. Chuvilo at the 1960 Rochester Conference,[4] at which data obtained at CERN on the total cross sections for the interaction between K^+ mesons and hydrogen at approximately the same energy were also reported.[5] Figure 3 shows the data on the total cross sections for the interaction of K^+ mesons with hydrogen obtained at the bevatron,[1] at CERN,[5] and in the present experiment. As seen from the figure, the total cross section rises appreciably in the interval 2.4 – 3.5 Bev/c. Such a behavior of the cross section seems understandable if it is assumed that some resonance or threshold effects, for example, the production of K-meson pairs, occurs in this momentum region. Using the data obtained with the ring counters, we can draw some qualitative conclusions on the angular distribution of the secondary particles (to 5° in the laboratory system) in the interaction of K^+ and π^+ mesons with protons. For K^+ mesons, the probability density is less, and depends more weakly on the angle than for π^+ mesons of the same momentum (3.7 Bev/c).

Until now, data have been entirely lacking on the absorption cross sections (i.e., inelastic cross sections) of π^+ and K^+ mesons by nuclei in the 3 — 5 Bev/c region. We measured the cross sections for the absorption of π^+ mesons by C, Al, Cu, Sn, and Pb nuclei and for K^+ mesons by C, Al, and Cu nuclei at 4.75 ± 0.15 Bev/c. The results are shown in the table.

Nucleus	Absorption cross section, mb	
	π^+ mesons	K^+ mesons
C	182 ± 8	136 ± 21
Al	344 ± 13	254 ± 33
Cu	689 ± 33	430 ± 120
Sn	1241 ± 190	—
Pb	1912 ± 161	—

In the experiment, we used absorbers of the following thicknesses: carbon — 21.15 g/cm^2, aluminum — 24.45 g/cm^2, copper — 13.30 g/cm^2, tin — 8.80 g/cm^2, and lead — 11.30 g/cm^2. Since the counter S_3 was seen from the center of the target-absorber at an angle of 3°, the absorption cross sections in the table have been corrected for Coulomb and diffraction scattering at angles ≤ 3° and for inelastic scattering at angles ≤ 3°. In the case of π^+ mesons, we also introduced corrections for the μ^+ meson contamination of the beam.

The authors express their gratitude to V. I. Veksler and A. A. Lyubimov for discussion and aid in the work. We express our gratitude to I. V. Chuvilo, who reported the basic results of this work at the 1960 Annual International Conference on High Energy Physics in Rochester. We consider it our pleasant duty to express our gratitude to the proton synchrotron crew for the proper functioning of the accelerator. We thank Yu. D. Prokoshkin for providing the liquid hydrogen target.

[1] Burrowes, Caldwell, Frisch, Hill, Ritson, and Schulter, Phys. Rev. Lett. **2**, 117 (1959).

[2] Likhachev, Lyubimov, Stavinskii, and Chang, Report at the Conference on Experimental Techniques, Berkeley, 1960; PTÉ (Instruments and Meas. Techn.), in press.

[3] Longo, Helland, Hess, Moyer, and Perez-Mendez, Phys. Rev. Lett. **3**, 568 (1959).

[4] Proceedings 1960 Annual Intern. Conf. on High Energy Physics at Rochester, Univ. of Rochester, 1961.

[5] von Dardel, Frisch, Mermod, Milburn, Piroue, Vivargent, Weber, and Winter, Phys. Rev. Lett. **5**, 333 (1960). (see also Proceedings 1960 Annual Intern. Conf. on High Energy Physics at Rochester, Univ. of Rochester, 1961.

Translated by E. Marquit
9