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## PHOTOPRODUCTION OF $K$ MESONS*

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We have studied the reaction $\gamma + p \to K^+ + \Lambda^0$ using the bremsstrahlung beam of the Cornell synchrotron. The reaction is observed by detecting the $K$ meson and measuring its laboratory angle and momentum. Since the reaction is 2-bodied, these measurements, together with the conservation laws, are sufficient to determine the energy of the incident photon responsible for the production of the $K$ meson. The experimental arrangement is shown in Fig. 1. The photon beam passes through a cylindrical liquid

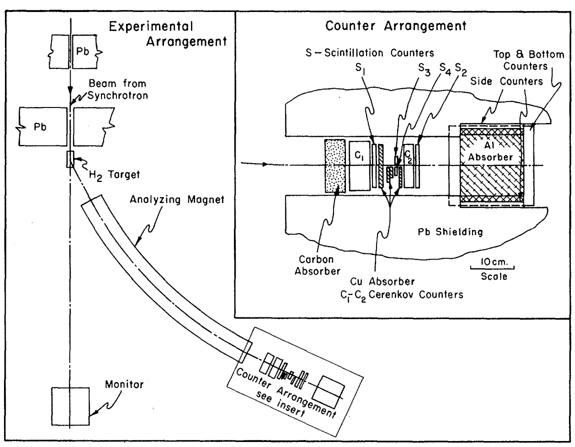


FIG. 1. Experimental arrangement for the detection of $K^+$ mesons.

hydrogen target (3 in. long and $1\frac{1}{2}$ in. diameter) and is monitored by a total-absorption ion chamber.[1] Positively charged particles emerging from the hydrogen target enter a two-lens strong-focusing analyzing magnet which selects a band of momenta. On emerging from the magnet, the particles pass through a series of counters designed to select the $K$ mesons from the other particles of the same momenta. $K$ mesons pass through the Cerenkov counters $C_1$ and $C_2$, the scintillation counters $S_1$, $S_2$, and either $S_3$ or $S_4$, and come to rest in the aluminum block as is shown in the insert in Fig. 1. They then decay with a mean life of $1.24 \times 10^{-8}$ sec. About 70% of these give rise to a secondary particle which is detected in one of the four scintillation counters which surround the aluminum block. These four counters are hereafter called "side" counters.

The counters $S_3$ and $S_4$ constitute the defining counters for two independent channels (designated 3 and 4) differing in momentum by approximately 13%. A particle is identified as a $K$ meson if it makes a prompt coincidence between counters $S_1$, $S_2$, $S_3$, or $S_4$, and at least one of the "side" counters. Suitable absorbers are provided so that the pulse heights required in counters $S_1$, $S_2$, $S_3$, and $S_4$ are about twice that of a relativistic particle. Light particles ($e$, $\mu$, $\pi$) are rejected both by the pulse-height requirement and by $C_1$ and $C_2$ in anticoincidence. The $K$-meson velocity is below the detection threshold in the Cerenkov counters. Particles of proton mass or heavier, of the proper momentum, will not have sufficient range to reach counter $S_2$. Without the side-counter requirement the background rate is approximately 5 to 10 times the $K$-meson rate. This background rate, which corresponds to about 0.5% of the $\pi$ mesons and protons traversing the magnet, probably arises from the particles of the wrong momentum which get through the analyzing magnet in some unorthodox manner, i.e., scattering from the pole tips, and so do not have the ranges and pulse heights predicted for particles of the proper momentum. The addition of the side-counter requirement reduces the background in most cases to less than 10%.

The prompt coincidences, $S_1$, $S_2$, $S_3$, or $S_4$, plus one of the side counters is made with a resolving time $\tau = 5 \times 10^{-7}$ sec. In addition, a coincidence is required between $S_2$ and the side counters with a resolving time $\tau = 5 \times 10^{-8}$ sec. With this resolving time the combined background from chance coincidences and electrons arising from $\pi$-$\mu$-$e$ decay is approximately 2%.

The background of the experiment is measured primarily by operating with the peak beam energy 25 to 50 Mev below that necessary to produce the $K$ mesons under observation. At the laboratory angle of 24.5°, a curve was taken of counting rate as a function of peak beam energy. The momentum for channel 4 was 451 Mev/$c$ and for

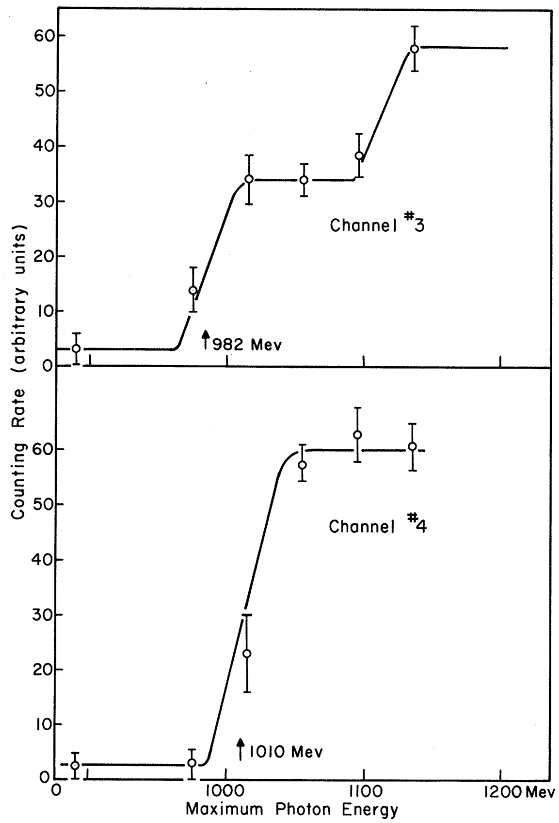


FIG. 2. $K^+$-meson counting rate as a function of the maximum photon energy of the bremsstrahlung spectrum at the laboratory angle of 24.5 degrees. The two momentum channels were held fixed and sensitive to $K$ mesons produced by photons of 982 and 1010 Mev for channels 3 and 4, respectively.

channel 3 was 398 Mev/$c$ corresponding to $K$ mesons produced by 1010-Mev and 982-Mev photons, respectively. The results are shown for both channels in Fig. 2. The curves drawn are the calculated relative counting rates as a function of peak beam energy, folding in the bremsstrahlung spectrum with the momentum and angular resolution of the magnet. The curves are normalized to the plateau counting rates. In channel 4, one sees a background rate of approximately 5%. The observed relative rates are in good agreement with those calculated. In channel 3, one sees approximately the same behavior except that the point at 1136 Mev lies much higher than the plateau region between 1000 and 1100 Mev. We attribute this increase to $K$ mesons produced in association with $\Sigma^0$ hyperons in the reaction $\gamma + p \rightarrow K^+ + \Sigma^0$. The expected relative counting rate for this reaction was calculated in a manner similar to that for the $(K^+, \Lambda^0)$ reaction. The point at 1136 Mev lies on the plateau of the expected counting rate. The curve in the figure is the calculated rate including the increased $K$-meson yield resulting from the $(K^+, \Sigma^0)$ reaction. The background at the lower energies is taken to be a measure of the non-$K$-particle background. There is also a 3% background of $K$ particles contributed by the walls of the hydrogen target.

The results of the measurement to date are shown in Figs. 3 and 4. Figure 3 shows the cross section, $d\sigma(\theta)/d\Omega$, as a function of the center-of-mass angle, $\bar{\theta}_{c.m.}$, for photons of

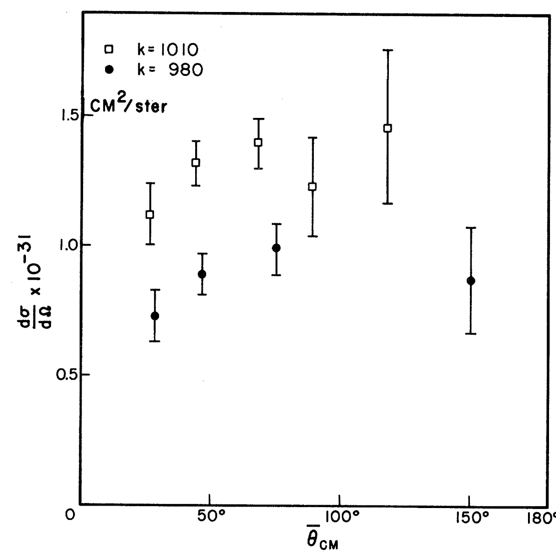


FIG. 3. The cross section for $K^+$-meson production from hydrogen as a function of center-of-mass angle for photon energies of 1010 and 980 Mev.

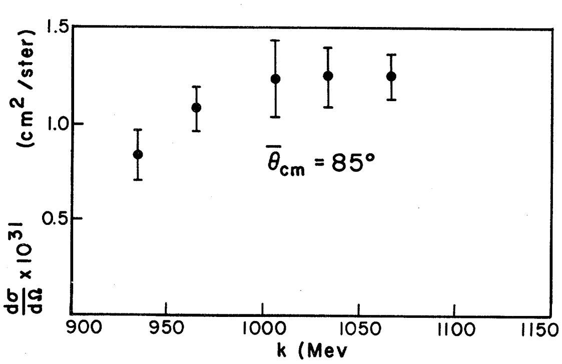


FIG. 4. The cross section for $K^+$-meson production from hydrogen as a function of photon energy for the angle of 85 degrees in the center of mass.

Table I. A tabulation of the cross sections obtained for the reaction $\gamma+p\to K^++\Lambda^0$. In addition, a single observation is given for the reaction $\gamma+p\to K^++\Sigma^0$. $d\sigma(\theta)/d\Omega$ is given in units of $10^{-31}$ cm²/sterad.

| $\gamma+p\to K^++\Lambda^0$ | | | | | |
|---|---|---|---|---|---|
| $k=1010$ Mev | | $k=980$ Mev | | $\bar{\theta}_{c.m.}=85°$ | |
| $\bar{\theta}_{c.m.}$ | $d\sigma(\theta)/d\Omega$ | $\bar{\theta}_{c.m.}$ | $d\sigma(\theta)/d\Omega$ | $k$ | $d\sigma(\theta)/d\Omega$ |
| 26° | 1.12 ± 0.12 | 28° | 0.73 ± 0.10 | 935 | 0.83 ± 0.16 |
| 44° | 1.32 ± 0.07 | 46° | 0.90 ± 0.09 | 963 | 1.08 ± 0.19 |
| 68° | 1.40 ± 0.10 | 75° | 0.99 ± 0.10 | 1006 | 1.23 ± 0.20 |
| 89° | 1.26 ± 0.19 | 150° | 0.87 ± 0.21 | 1032 | 1.25 ± 0.18 |
| 116° | 1.46 ± 0.29 | | | 1066 | 1.25 ± 0.14 |

| $\gamma+p\to K^++\Sigma^0$ | | |
|---|---|---|
| $k$ | $\bar{\theta}_{c.m.}$ | $d\sigma(\theta)/d\Omega$ |
| 1111 Mev | 85° | 0.61 ± 0.17 |

energy, $k$, of 1010 and 980 Mev. The point at 150° in the 980-Mev angular distribution is taken from a measurement previously reported.[2] The scarcity of data and the large probable errors for the measurement backward of 90° center-of-mass angle reflect the low counting rates due to unfavorable kinematical factors, as well as the relatively higher background. The errors shown are the standard statistical errors based entirely on the number of counts. In addition, one should add other uncertainties arising from corrections and possible systematic errors amounting to perhaps 10%. Figure 4 shows the cross section as a function of photon energy for a center-of-mass angle of 85°. Table I shows the numerical results for all measurements including the single measurement made for the associated production of $K^+$ and $\Sigma^0$. Results obtained at California Institute of Technology for the $(K^+, \Omega^0)$ reaction are in reasonable agreement with these.[3]

No attempt is made here to compare these results with theoretical calculations that have been published.[4–6] The calculated results for both the scalar and pseudoscalar $K$ mesons are very sensitive to the choice of the anomalous magnetic moments of the proton and the hyperon and it is at present unclear to us what choice is appropriate for these moments. There are a variety of choices of anomalous moments for both the scalar and pseudoscalar calculations which fit the data reasonably well.

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## MULTIPLE MESON PRODUCTION IN ELECTRON-PROTON COLLISIONS

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Recently there has been some interest in the possibility of obtaining information on the structure of the proton by observing meson production arising in electron-proton collisions.[1,2] In this note some calculations pertaining to multiple meson production obtained in this process are discussed. We consider the reaction

$$e+p\to e+p+\pi^{(+)}+\pi^{(-)}, \qquad (1)$$

since the measurement of negative pion production rates are most accessible to experimental