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Nuclear emulsions have been exposed to 114-, 135-, and 170-Mev positive heavy mesons produced at 90° by 5.7-Bev protons striking a copper target. The exposures were made using the strong-focusing spectrometer.[1]

1. The Strong-focusing Spectrometer

The principal features of this apparatus consist of a strong-focusing quadrupole-magnet lens system followed by a conventional momentum-analyzing magnet. The arrangement is shown in Fig. 1. It can be shown that the flux of heavy mesons at the stack position is

$$\frac{dN_k}{dA} = N_p N_t \frac{d^2\sigma}{d\Omega dE} \left(\frac{1}{\beta} \frac{dP}{dx} M_H L_H \right) \left(\frac{\theta_H \theta_V}{M_H L_H M_V L_V} \right) e^{-t/\tau}, \qquad (1)$$

where dN_k/dA is the number of heavy mesons per unit area, N_p is the total number of protons traversing the target, N_t is the number of target nuclei per cm^2 in the proton beam direction, $d^2\sigma/d\Omega dE$ is the cross section in cm^2 $ster^{-1}$ Mev^{-1}, βC is the velocity of the heavy mesons, dP/dx is the momentum dispersion of the analyzing magnet, M_H and M_V are the horizontal and vertical magnifications of the strong-focusing lens, L_H and L_V are the horizontal and vertical dimensions of the target, θ_H and θ_V are the effective horizontal and vertical angular apertures of the strong-focusing lens, and t and τ are the proper time of flight and the mean lifetime of the heavy mesons.

2. Mass Measurements

The mass of each heavy meson can be found by measuring the range of the meson in the nuclear emulsion stack and by following its track back to the point of entrance to determine its momentum. The momentum of the meson can then be determined by measurement of the ranges of the protons entering the stack at the same point. Ideally, the mass resolution should have a total width

$$\Delta M = \left(\partial M / \partial P \right)_R \Delta P, \quad \text{where } \Delta P = \left(dP/dx \right) M_H L_H .$$

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* National Science Foundation Predoctoral Fellow.

In practice this resolution is somewhat broadened by multiple scattering in the thin window and in the air, by aberrations of the strong-focusing lens, and by multiple scattering and range straggling in the nuclear emulsion. Systematic uncertainties can arise from energy loss in the air path through the analyzing magnet and from lack of precision in determination of the momentum-range relations. The resolution and yield of heavy mesons are sufficient so that systematic errors incurred in this method may be comparable to or larger than the statistical uncertainties.

3. Scanning

Scanning is done by searching for tracks several centimeters ahead of the region in which the heavy mesons are expected to stop. Each track having the appropriate grain density and direction is followed to the end of its range and is identified by its decay as a heavy meson. Because the heavy mesons have a spread in ranges, it is necessary to examine the selective bias caused at the point of scanning by light grain count for long-range particles and by large accumulated multiple scattering for short-range particles. The scanning region was chosen far enough from the stopping region to give negligible bias for masses between 800 and 1100 m_e. In the worst case for the figures shown, the extremes of grain count at the scanning point deviated by about 10%, and the largest accumulated rms multiple scattering angle was calculated to be less than 1.5° greater than the average.

4. Results

A. 135 Mev. The first stack of twelve pellicles, 2 in. by 3 in. by 600 microns, was exposed to 135-Mev K mesons produced in a copper target of dimensions $L_H = 1$ in., $L_V = 0.25$ in. Three K_L's had fortuitously flat secondary tracks more than 5 centimeters long before leaving the stack. The secondary masses were determined by grain count and multiple scattering to be 293 ± 29, 275 ± 33, and 259 ± 31 electron masses. The respective $P\beta$'s at the decay points were 138 ± 18, 134 ± 20 and 157 ± 19. An 8% uncertainty in the scattering constant is included. Grain-count calibrations were made by using the readily available pion tracks that came from the target and traversed the stack with selected momentum. These three decays, therefore, agree well with the established $K_{\pi 2}$ decay scheme.

B. 114 Mev. A stack of 107 pellicles 3.5 in. by 3.5 in. by 600 microns was exposed to 114-Mev K mesons produced in the same target as above. Preliminary results from this exposure are given in "Bevatron K-Mesons", by Birge et al., which is to appear as a Letter to the Editor in the Phys. Rev.

We have now recalculated the masses of the K mesons, using the position where the track was first picked up rather than the position of its ending (as was done in the preliminary report) to determine the momentum of the particle. The results of this mass determination plotted separately for K_L mesons and τ mesons are shown in Fig. 2. The distributions include 295 K_L mesons, 29 τ mesons, and 7 alternate decays of the τ into one charged pion.

The mass uncertainties given are $\sigma/\sqrt{N}$, where $\sigma = \sqrt{\overline{\Delta^2}}$ is the root-mean-square deviation from the average mass and N is the total number of events in the distribution. The average mass of the K_L mesons is $970.6 \pm 1.6\ m_e$, with $\sigma = 28.1$. For the τ mesons the average mass is $978 \pm 5.1\ m_e$, with $\sigma = 30$.

A comparison of the measured τ-meson mass of 978 ± 5 with the accepted value of 966 m_e indicates a possible systematic error. Only the relative masses are significant to the listed uncertainties.

The flux ratios as determined in this stack are

$$K_L/_\tau = 11 \pm 2, \qquad \pi/_{K_L} = 82 \pm 8.$$

Although the differential cross section uncorrected for decay in flight is estimated from Eq. (1) to be 2.4×10^{-32} cm^2 ster^{-1} Mev^{-1}, the quantity N_p is subject to large uncertainties. The ratios, however, are valid and an accurate determination of the cross section for K production awaits a measurement of the pion cross section.

C. <u>170 Mev.</u> A third stack consisting of fifty G.5 pellicles 3 in. by 6 in. by 600 microns was exposed to 170-Mev K mesons produced in a copper target of dimensions $L_H = 3/8$ in. and $L_V = 3/8$ in. This value of L_H gave a better momentum resolution than in the previous exposures. Results on the masses obtained from 165 K_L mesons and 15 τ mesons (among which are included three with alternative mode of decay) are plotted in Fig. 3.

The data yield an average mass for the K_L mesons of $953.2 \pm 2.0\ m_e$, with a root-mean-square deviation $\sigma = 25.6\ m_e$. For the τ mesons the average mass is $966.1 \pm 4.8\ m_e$ with $\sigma = 18.1\ m_e$.

The 12 : 1 ratio of K_L to τ mesons found in this stack remains about the same as that obtained at 114 Mev.

Scanning is still in progress, and at the present time an examination of the secondary tracks is also under way. Masses of the few mesons whose modes of decay have been identified are included in Table I.

5. Individual Masses

The mass resolution is not sufficiently narrow to give evidence for two different K_L mass values on the basis of the above data. Consequently, a number of fairly flat secondary tracks remaining in the stacks for distances greater than 5 centimeters have been followed. These were chosen without reference to the mass values and grain counted 5 centimeters or further from the decay point. At 5 centimeters the grain count for a $K_{\pi 2}$ secondary is about 1.27 times minimum and that for a $K_{\mu 2}$ is 1.04 times minimum. The pions of known momentum coming from the target were used for grain-count calibration. The measurements separated these K_L mesons into two groups: probable $K_{\pi 2}$ mesons and probable $K_{\mu 2}$ mesons. The average mass of each group relative to the τ mass is shown in Table I. Results from the 114-Mev stack and the 170-Mev stack are combined.

Three $K_{\mu 3}$ mesons have been found. The meson secondary ranges were 1.44, 1.5, and 4.7 cm. Two cases of three light noncoplanar secondaries (listed as K_{3L}) have been found and are under study. The average masses of these and of 9 τ' mesons are also listed in Table I.

6. τ Mesons

Thirty τ mesons have been found in regions of the 114-Mev stack, where at least two secondaries are certain to stop. To date, measurements have been made on the secondaries of 24 of these τ mesons. The range along the track was determined for each stopping pion secondary and the energy was computed by use of the range tables of Barkas.[2] The numbers of τ decays in the regions a, b, and c of the Fabri analysis[3] are 8, 8, and 8, respectively. The results are listed in Table II.

As a test for polarization of the τ mesons, direction cosines of each secondary were measured with respect to the axes of the emulsion stack. The projections of the normal to the decay plane on these axes were then calculated. (The normal to the production plane is one of these axes.) No significant difference from isotropy was observed.

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1. L. T. Kerth, D. H. Stork, R. W. Birge, R. P. Haddock, and M. N. Whitehead, Bull. Am. Phys. Soc., Vol. 30, No. 3.

2. Walter H. Barkas and D. M. Young, University of California Radiation Laboratory Report No. UCRL-2579 Rev.

3. E. Fabri, Il Nuovo Cimento 11, 479 (1954).

ACKNOWLEDGMENT

The help of the Bevatron staff made the direction of Dr. Edward J. Lofgren is greatly appreciated.

Table I $\left[M_K - M_\tau\right]$

τ (Alt. mode of decay)	= 2.4	±	9.8
$K_{\mu 2}$	= 12	±	16.2
$K_{\mu 3}$	= 1.8	±	10.3
$K_{\pi 2}$	= 9	±	13
K_{L3}	= 38	±	20.7

Table II

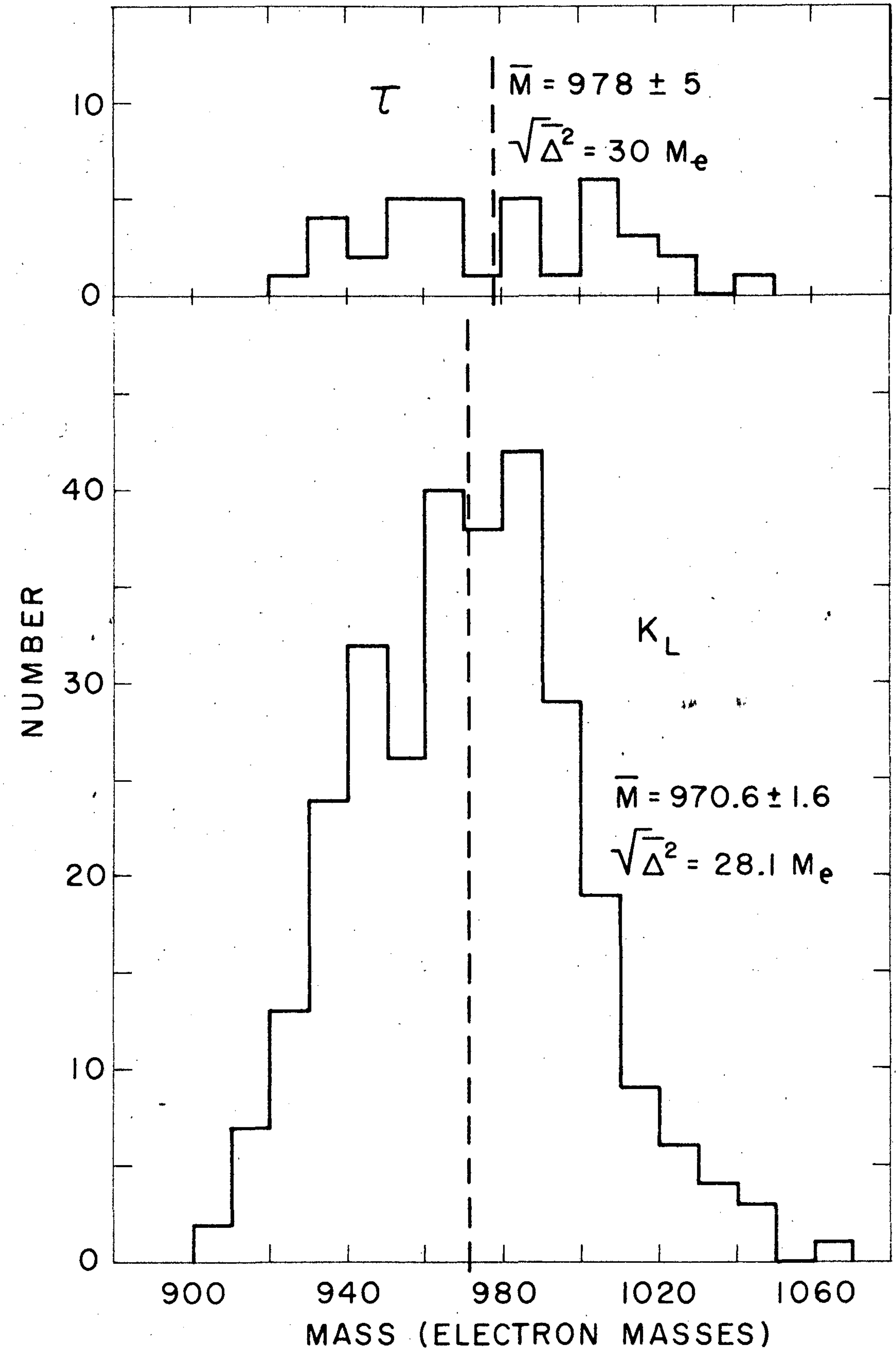
Event		Range (m.m)	Energy (Mev)
5	π^+	2.890	11.8
	π^- (star)	6.668	17.4
	π^+	31.39	46.1
			75.3
7	π^+	3.375	12.4
	π^- (star)	15.29	30.0
	π^+	18.03	33.1
			75.5
36	π^- (ρ)	2.11	9.6
	π^+	6.18	17.6
	by cons. of mom		
	π^+	27.4	44.4
			71.6
40	π^- (star)	3.620	13.0
	π^+	15.56	30.2
	π^+	16.07	30.9
			74.1
51	π^+	4.53	14.7
	π^- (star)	12.00	25.9
	by cons. of mom.		
	π^+	17.10	32.3
			72.9
103	π^+	.721	5.4
	π^+	13.57	27.9
	by cons. of mom.		
	π^-	25.20	40.2
			73.5
85	π^+	2.883	11.4
	π^+	5.774	16.8
	π^- (star)	29.50	44.4
			72.6
86	π^+	3.007	11.6
	π^- (ρ)	9.253	21.5
	π^+	27.04	42.2
			75.3
123	π^+	6.454	18.0
	π^+	7.432	19.6
	π^- (star)	23.47	38.7
			76.3

Table II (continued)

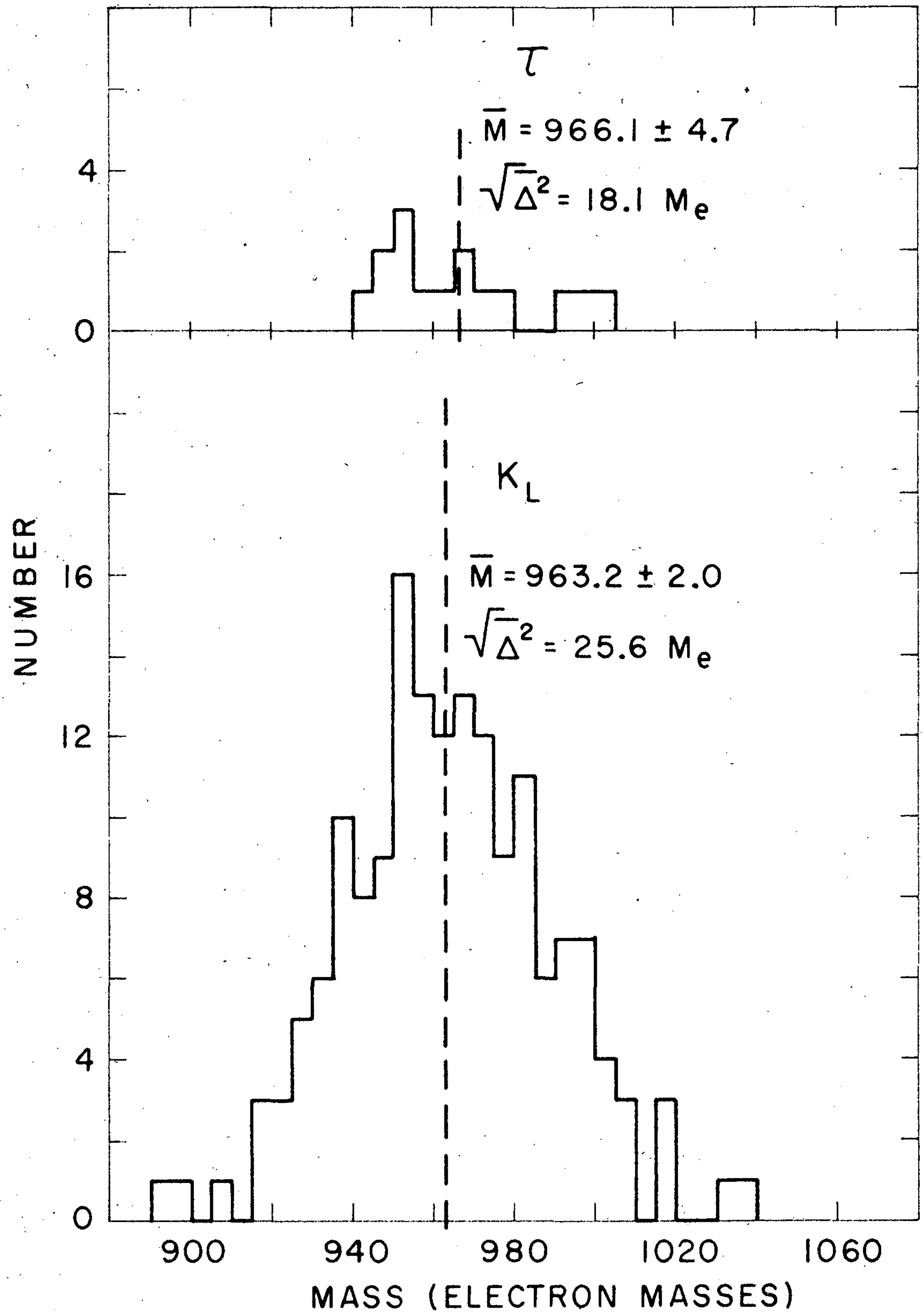
		Range (m.m.)	Energy Mev
131	π^- (p)	1.885	8.9
	π^+	9.925	19.9
	by cons. of mom.		
	π^+	29.80	45.0
			73.6
163	π^- (Star)	4.433	14.65
	π^+	7.387	19.45
	by cons. of mom.		
	π^+	24.95	40.0
			74.1
181	π^+	3.844	13.5
	π^+	4.513	14.7
	π^- (Star)	32.21	47.0
			75.2
203	π^+	6.170	17.5
	π^- (Star)	6.599	18.25
	π^+	24.33	39.6
			75.3
219	π^+	1.893	8.95
	by cons of mom		
	π^-	15.20	29.8
	π^+	19.89	35.0
			73.8
236	π^+	4.069	14.2
	π^+	9.539	22.5
	π^- (Star)	24.05	39.3
			76.0
248	π^- (p)	3.310	12.3
	by cons. of mom.		
	π^+	8.50	21.1
	π^+	29.33	42.4
			75.8
297	π^+	3.305	12.3
	π^+	15.80	30.5
	π^- (Star)	16.96	31.5
			74.3
273	π^- (p)	8.936	21.4
	π	16.31	23.6
	π^+	16.59	31.3
			76.3

Table II (continued)

		Range (mm)	Energy (Mev)
297	π^+	1.026	6.33
	π^- (p)	12.05	26.0
	π^+	28.22	43.2
			75.5
298	π^+	.332	2.71
	π^+	14.25	28.7
	π^- (star)	26.00	41.2
	π^- makes a ~150°		72.6
	scatter at ~ 27 Mev		
307	π^- (star)	6.221	17.7
	π^+	8.780	21.4
	π^+	20.27	35.4
			74.5
308	π^+	5.964	17.15
	π^- (star)	6.941	18.75
	π^+	23.66	39.0
			75.9
311	π^- (star)	8.253	20.7
	π^+	9.140	22.0
	π^+	16.41	31.8
			74.5
315	π^+	4.456	14.6
	π^+	6.934	19.5
	π^- (star)	25.88	41.1
			75.2


τ
$\bar{M} = 978 \pm 5$
$\sqrt{\bar{\Delta}^2} = 30\ M_e$
K_L
$\bar{M} = 970.6 \pm 1.6$
$\sqrt{\bar{\Delta}^2} = 28.1\ M_e$
NUMBER
MASS (ELECTRON MASSES)

23847-1


τ
M̄ = 966.1 ± 4.7
√Δ̄² = 18.1 Mₑ
K_L
M̄ = 963.2 ± 2.0
√Δ̄² = 25.6 Mₑ
NUMBER
0
4
8
12
16
900
940
980
1020
1060
MASS (ELECTRON MASSES)

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