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PROOF OF COMPARABLE K-PAIR AND π-PAIR PRODUCTION FROM TIME-LIKE PHOTONS OF 1.5, 1.6, AND 1.7 GeV AND DETERMINATION OF THE K-MESON ELECTROMAGNETIC FORM FACTOR*

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The observation of 21 K^+K^- pairs in 38 hadron pair events produced at 1.5, 1.6, and 1.7 GeV total centre-of-mass energies in e^+e^- annihilations, establishes that time-like photons produce K pairs and π pairs with comparable rates in this energy range. The K-meson electromagnetic form factor at a mean s-value of 2.4 GeV^2 is measured to be $|F_K| = 0.50 \pm 0.08$. The number of e^+e^- pairs observed in the same angular and energy range is 5148.

We have already reported [1] the observation of hadron pair production in the reaction

$$e^+ + e^- \to h^\pm + h^\mp \qquad (1)$$

(where $h^\pm$ stands for $\pi^\pm$ or $K^\pm$) at total colliding beam energies from 1400 to 2400 MeV, but proof of K-meson pair production in this energy range until now depended on the non-observation of a Čerenkov counter signal in one event [2] at 1500 MeV.

This paper shows how the K^+K^- pairs have been identified and how their yield compares with the total hadron pair production in reaction (1) at 1500, 1600, and 1700 MeV total centre-of-mass energies.

The principle of the method was simply to measure the ranges of the particles. When a two-body final state is produced in an (e^+e^-) colliding beam machine, the final-state particles have a very well defined energy, and as at the above beam energies in 93% of the events one or other of the K mesons will reach the end of their range without a strong interaction, K-meson pairs can be separated from pion pairs simply via range measurements.

When a K^+ meson stops it decays, and the decay products will make it look very like a pion scattering if the event is detected in a spark chamber system.

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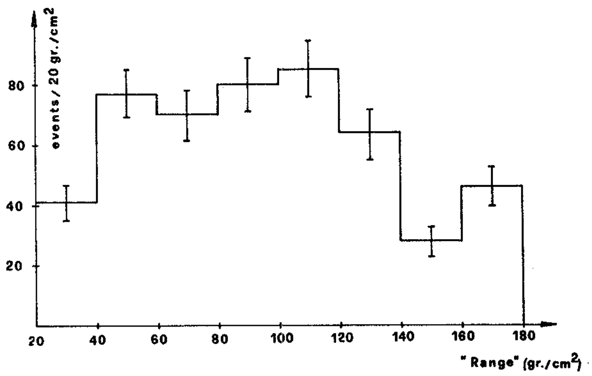

Fig. 1. The "range" distribution of interaction points in the heavy-plates range spark chambers, observed with known pion beams of momentum 760 MeV/c and 1000 MeV/c (summed together).

Similarly, a K^- meson reaching the end of its range will usually be captured so that either it will look like a scatter or like a track which stops with no long-range secondaries. Thus, K mesons may be detected with high efficiency as tracks which stop or appear to scatter when they have crossed an absorber thickness equal to the expected K-meson range.

In contrast to this, the distribution of the interaction points for pions spreads over the full available range of the apparatus as shown in fig. 1, obtained from data taken in special calibration runs [1].

The experimental apparatus consisted of two tele-

Fig. 2. Scatter diagrams of the ranges observed in the two telescopes: R_E against R_I. R is the absolute value of the observed "range" minus the K-meson range. One event corresponds to a rectangle in the diagram. The dimensions of the rectangle vary with the thickness of the spark chamber layer where the hadronic signature occurred: a) total energy = 1200, 1300, 1400, 1900, 1940, and 2100 MeV; b) total energy = 1500, 1600, and 1700 MeV. The grouping of events around $R_E = R_I = 0$, is the proof of (K^+K^-) pair production.

scopes placed at 90° relative to the colliding beams. One was external (E) and the other internal (I), relative to the storage ring.

Each telescope contained thin-plate spark chambers near the interaction region to establish the two-body (collinear) nature of the event, followed by a series of heavy-plate range spark chambers. Scintillation counters gave accurate time-of-flight measurements and fast trigger signals. Fuller details are given in ref. [1].

Hadronic events were defined as those which showed a clear hadronic signature (a scatter or a stopping track) in at least one of the telescopes. For such events, the ranges of the two tracks were measured taking as definition of "range" the depth in the chambers at which any hadronic feature (stop, scatter, interaction) was first seen. These values were corrected for the obliqueness of the tracks in the telescopes.

Figs. 2a, 2b show the results in the form of scatter diagrams in which are plotted the "range" R_I, observed in the internal telescope, against R_E in the external telescope. In order to combine results from several energies without losing resolution, and hence show up the K-meson signal more clearly, the quantity $R \equiv |R_0 - R_K|$ has been plotted; R_0 is the observed "range" of the event and R_K is the mean range of K mesons at the appropriate beam energy. The use of a scatter diagram is important because events with a K-like track in one of the telescopes should also look like K mesons in the other for genuine K^+K^- pairs. These pairs must group near $R_E = R_I =$ zero in a scatter diagram.

Fig. 2a shows the results at 1200, 1300, and 1400 MeV total energy, where K-meson pairs are not energetic enough to cause a trigger, combined with the results at 1900, 1940, and 2100 MeV, where K-meson pairs stop outside the fiducial region of the chambers. This diagram thus shows the experimental "range" distributions, characteristic of hadronic interactions, as opposed to stopping particles.

Fig. 2b shows the results for energies of 1500, 1600, and 1700 MeV, where K-meson pairs stop in the fiducial volume of the telescope. There are 38 hadron pair events in the scatter diagram. There is a clear grouping of events near the K range in both telescopes, i.e.

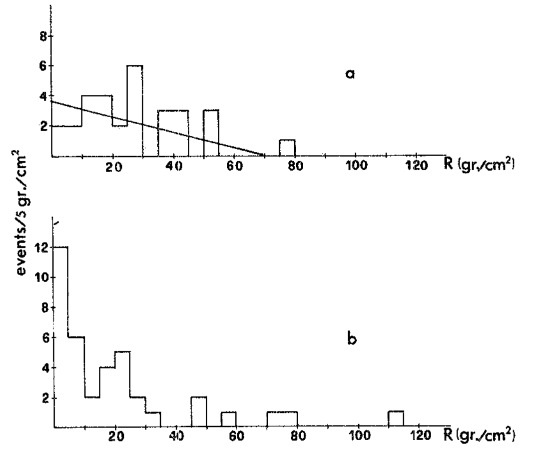

Fig. 3. Histograms of least-ranges. For each event the smaller of the two "ranges" R_E or R_I is plotted: a) total energy = 1200, 1300, and 1400 MeV. The line shows the distribution calculated from the calibration measurements of fig. 1. b) total energy = 1500, 1600, and 1700 MeV, showing the peak due to (K^+K^-) pair events.

near $R_E = R_I$ = zero. This is the proof for (K^+K^-) pair production.

To estimate the fraction of events which are K mesons, the observed ranges were plotted in histogram form by using from each event only that track which gave the range nearest to the expected K-meson range. This method ensures that the stopping rather than the interacting K mesons are used. Fig. 3a contains the data of the 1200 to 1400 MeV sample, and shows how the pion distribution is distorted by this selective plotting technique. The line is the expected shape calculated using just the calibration data of fig. 1. Fig. 3b shows the data of the 1500 to 1700 MeV sample. The K-meson peak in the K-π mixture is clearly visible. The π component can easily be estimated from the number of events with a range greater than 35 g/cm^2 in fig. 3b. These events, whose range differs from the K range by more than 35 g/cm^2, must be pions. Therefore the data of fig. 3a can be used to estimate the total pion component and hence the true number of observed K^+K^- pairs. Thus in a total number of 38 hadron pair events (21 ± 6) turn out to be K^+K^- pairs. After correcting for the efficiencies, for background events from multiple pion production, and for the small fraction of K mesons which simulate pions, the ratio

$$\left(\frac{K}{h}\right) = \frac{\text{number of } K^+K^- \text{ pairs}}{\text{number of } (K^+K^- + \pi^+\pi^-) \text{ pairs}}$$

is found to be (K/h) = 0.64 ± 0.20.

As a cross-check of the method, events which could be positively identified as pions in the 1500 to 1700 MeV sample were used to estimate the total number of pions present. From calibration data it was calculated that 0.45 of all pion events will have one track which penetrates the fiducial volume of the chambers without interacting or scattering. This pattern can be simulated by only a small fraction (< 5%) of K mesons which decay with a penetrating secondary at a decay angle of less than 10°. Thus penetration is a clear pion signal. Notice that, as mentioned above, for a hadron pair event at least one side has to show a clear hadronic signature. This requirement eliminates cosmic rays and beamgas background.

In the sample of 38 hadron pair events, there were 10 penetrating pionic tracks which, after corrections for efficiencies and multiple pion contamination, gave the value (K/h) = 0.41 ± 0.16.

Thus, the mean result of these two methods of identifying K pairs and π pairs is

$$\left(\frac{K}{h}\right) = 0.53 \pm 0.13 .$$

This value of (K/h) shows that, even at these low energies, time-like photons produce K pairs and π pairs almost equal rates.

The observed sample of K^+K^- pairs allows the determination of the charged K-meson electromagnetic form factor $|F_K|$ at a mean value of $s = (2E_{beam})^2$, equal to $s = 2.4$ GeV^2. This turns out to be

$$|F_K| = 0.50 \pm 0.08$$

to be compared with the theoretical value $|F_K|_{th} = 0.48$, expected [3] on the basis of SU_3 and simple ρ, ω, ϕ dominance of the K-meson electromagnetic form factor. The number of (e^+e^-) pairs observed in the same experimental conditions is 5148.

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[2] G. Barbiellini et al., INFN Report No. 420, December 1972. At lower energies V.E. Balakin et al., Phys. Lett. 41B (1972) 205 have observed: one event at 1.18 GeV, one event at 1.26 GeV, and two events at 1.34 GeV.

[3] N. Cabibbo, private communication.