Anomalous production of charged lepton pairs in experiments with neutral kaons

L. V. Sil'vestrov and G. G. Takhtamyshev
Joint Institute for Nuclear Research

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Analysis of data obtained in experiments with neutral kaons at the BIS installation indicates an anomalous production of e^+e^- and $\mu^+\mu^-$ pairs outside the target. This production cannot be explained by known background processes.

Several hypotheses suggest the existence of new light particles which might be observed on the basis of the presence of charged lepton pairs in the final state.[1] In this letter we report the results of an analysis of e^+e^- and $\mu^+\mu^-$ pairs (which we will refer to below as l^+l^- pairs) which were detected at the BIS installation in experiments on the regeneration of $K_L - K_S$ mesons in deuterium.[2] The installation detected pairs of charged particles emitted from a common point in the decay volume. The apparatus and the lepton detectors are described in Ref. 3. The analysis included the following steps.

1. A study was made of the processes which constitute the major background in the detection of l^+l^- pairs: the decays $K_{e3} \to \Pi^{\pm} \; e^{\mp} \nu_l$ and $K_{\mu 3} \to \Pi^{\pm} \; \mu^{\mp} \nu_\mu$ (which we denote collectively as K_{l3}) in which the pions are incorrectly identified as electrons or muons. If all of the l^+l^- pairs detected are part of this background, their geometric and kinematic distributions should be the same in the case of an identical normalization with corresponding distributions for Πl pairs from the K_{e3} and $K_{\mu 3}$ decays. In particular, the distributions in the invariant masses $M(l^+l^-)$ and $M(\Pi l)$ should be the same under the assumption that the pion has the rest mass of the corresponding lepton.

To test this assertion, we simulated l^+l^- pairs, working from the condition that all or part of the background came from K_{l3} decays. We used the experimental dependence of the coefficient of the incorrect identification of pions on their momentum. This procedure is described in detail in Ref. 4 for the e^+e^- pairs. No difference of any sort was found between the distributions of the l^+l^- and Πl pairs which were simulated.

Figure 1 shows experimental distributions of the invariant masses of the l^+l^- and Πl pairs. There is a discrepancy between the distribution $M(l^+l^-)$ (the histograms) and the distribution $M(\Pi l)$ (the points): There is deficiency of l^+l^- pairs with respect to the background on the right side of the distribution and an excess on the left side. A possible explanation is that the observed distribution $M(l^+l^-)$ is a superposition of two different distributions: one corresponding to the background from Πl pairs and the other of a nonbackground origin. In order to distinguish nonbackground (excess) l^+l^- pairs, we used a standard procedure: The background distribution was brought into coincidence with the experimental data in those bins in which no excess pairs were observed (as shown by the curve in the figure). We then constructed the difference

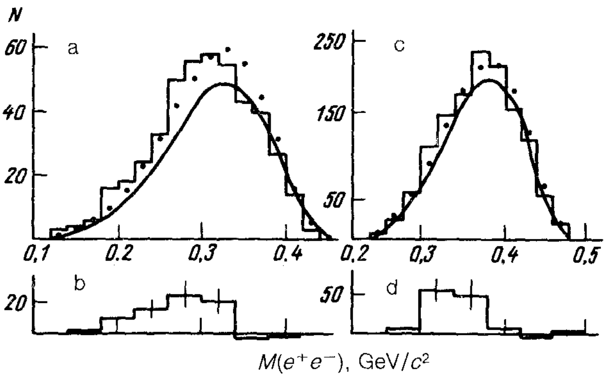

FIG. 1. a—Distribution of the invariant masses of e^+e^- and $\Pi^\pm e^\mp$ pairs; b—difference between the histogram and the solid curve; c, d—the same, for $\mu^+\mu^-$ and $\Pi^\pm\mu^\mp$ pairs.

between the experimental distribution $M(l^+l^-)$ and this curve (Fig. 1, b and d). We observed a signal from the excess l^+l^- pairs (at a level of approximately four times the error) in the mass regions $M(\Delta ee) \lesssim 0.34$ GeV/c^2 and $M(\Delta\mu\mu) \lesssim 0.38$ GeV/c^2. The number of excess l^+l^-pairs, $N(\Delta ll)$ is shown along with the total numbers of l^+l^- pairs, $N(l^+l^-)$ and K_{l3} decays, $N(K_{l3})$ in Table I.

2. Information of the $e^\pm\mu^\mp$ pairs detected by the apparatus was used. These pairs arise as a background process when the pion in K_{e3} decays is incorrectly identified as a muon or when a pion in $K_{\mu3}$ decays is identified as an electron. If all of the e^+e^-, $\mu^+\mu^-$ and $e^\pm\mu^\mp$ pairs detected by the apparatus are taken to be incorrectly identified pions, then the calculated number of $e^\pm\mu^\mp$ pairs would be given by

$$N(e\mu)_1 = N(K_{\mu3})\frac{N(ee)}{N(K_{e3})} + N(K_{e3})\frac{N(\mu\mu)}{N(K_{\mu3})}. \tag{1}$$

Here N is the number of events of the specified type.

We selected events in which each particle falls within the aperture of both the electron detector and the muon detector, and we calculated the number $N(e\mu)_1$ for these events. We found that this number exceeds the number of $e^\pm\mu^\pm$ pairs detected

TABLE I.

Lepton	$N(K_{l3})$	$N(l^+l^-)$	$N(\Delta l^+l^-)$	$N(l^+l^-)_b$
e	$27.5\cdot10^3$	451	66 ± 14	$\leqslant 10$
μ	$78\cdot10^3$	1362	109 ± 28	$\leqslant 9$

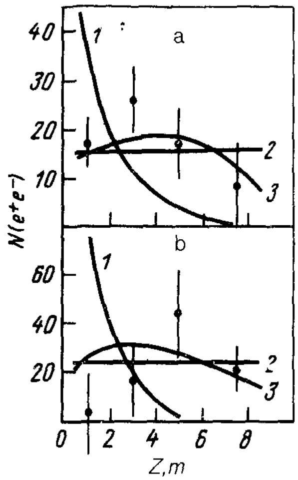

FIG. 2. a—Distribution of the Z coordinates of the vertices of the excess e^+e^- pairs (points) and that of the simulated pairs (curves); b—the same, for $\mu^+\mu^-$ pairs.

by the apparatus: $N(e\mu)_1 - N(e\mu)_{\text{expt}} = 205 \pm 46$. This discrepancy can be explained (as in Sec. I) on the basis that some of the e^+e^- and $\mu^+\mu^-$ pairs do not belong to the background from K_{l3} decays. Relation (1) can then be written

$$N(e\mu)_2 = N(K_{\mu 3})\,\frac{N(ee) - N(\Delta ee)}{N(K_{e3})} + N(K_{e3})\,\frac{N(\mu\mu) - N(\Delta\mu\mu)}{N(K_{\mu 3})}\,.$$

Substituting the numbers $N(\Delta ee)$ and $N(\Delta\mu\mu)$ for events in which the particles enter both lepton detectors, we find $N(e\mu)_2 - N(e\mu)_{\text{expt}} = 74 \pm 44$. In other words, the theoretical and experimental numbers of $e^\pm\mu^\mp$ pairs agree within twice the error. Consequently, this method provides an independent confirmation of the existence of excess l^+l^- pairs which do not belong to a background from K_{l3} decays.

3. Other sources of a background which might produce l^+l^- pairs in the final state were also simulated: a) decays of $K_{S,L}$ mesons resulting in the production of Π^0 mesons, with a subsequent conversion of the photons into e^+e^- pairs, both in the material of the apparatus and as a result of internal conversion (Dalitz pairs); b) the same processes, for Π^0 mesons produced in interactions of the neutrons of the beam with gaseous helium in the decay volume (n + He); c) the incorrect identification of pairs of $\Pi^+\Pi^-$ mesons from the decays of $K_{S,L}$ mesons; d) an incorrect identification of pairs of $\Pi^+\Pi^-$ mesons from n + He interactions; e) the direct production of lepton pairs in n + He interactions. The number of background pairs found as a result, $N(l^+l^-)_b$, is listed in Table I. This number does not exceed 15% of the observed effect.

Figure 2 shows the distribution of Z coordinates of the vertices of the excess l^+l^- pairs along the decay volume (the points), along with corresponding distributions for the simulated l^+l^- pairs, found under the assumption that these pairs belong to decays of K_S mesons (curve 1), to decays of K_L mesons (curve 3), or to n + He interactions (curve 2). The experimental points agree with curves 2 and 3 within the errors. Estimates of the number of l^+l^- pairs from the n + He interactions yield $N(e^+e^-)_b \leqslant 1.5$ and $N(\mu^+\mu^-)_b \leqslant 5$, so we are left with the assumption that the excess l^+l^- pairs result from either the decay of a new long-lived particle or a previously unobserved decay of K_L mesons. To estimate the relative probability for the latter possibility, we carried out a simulation of several schemes for such decays involving the production of l^+l^- pairs and massless neutral particles in the final state. We assumed that both charged and neutral particles with a mass on the order of or greater than that of the pion could appear in an intermediate state. For this simulation we required that the distribution in the invariant masses of the l^+l^- pairs agree with the observed distribution for the excess pairs. We found that the relative probability depends only weakly on the particular decay scheme; the values are

$$\Gamma(K_L \to e^+e^- + \ldots) / \Gamma(K_L)_{\text{all}} \cong (2 \div 5) \times 10^{-3},$$

$$\Gamma(K_L \to \mu^+\mu^- + \ldots) / \Gamma(K_L)_{\text{all}} \cong (0.6 - 1.2) \times 10^{-3}.$$

These figures are consistent with the existing uncertainty in the measurements of the partial widths of the basic decay modes of K_L mesons.[5] The results of the simulation of the l^+l^- pairs also agree with the possibility that there exists a long-lived neutral particle which decays into an e^+e^- pair or a $\mu^+\mu^-$ pair and one or two massless neutral particles.

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