SEARCH FOR THE DECAY $K_L \rightarrow \pi^0 e^+ e^-$

CERN-Edinburgh-Mainz-Orsay-Pisa-Siegen Collaboration

G.D. Barr, P. Clarke¹, D. Coward², D. Cundy, N. Doble, L. Gatignon, V. Gibson,
R. Hagelberg, G. Kessler, J. van der Lans, T. Miczaika³, H.N. Nelson,
J. Steinberger, H. Taureg, H. Wahl and C. Youngman⁴

CERN, Geneva, Switzerland

R. Black, D.J. Candlin, J. Muir, K.J. Peach, B. Pijlgroms⁵, I.P. Shipsey⁶
and W. Stephenson

Physics Department, University of Edinburgh, UK

H. Blümer, R. Heinz, M. Kasemann⁷, K. Kleinknecht, P. Mayer, B. Panzer,
B. Renk and H. Rohrer

Institut für Physik, Universität Mainz, Fed. Rep. Germany ^a

E. Augé, R.L. Chase, M. Corti, D. Fournier, P. Heusse, L. Iconomidou-Fayard,
I. Harrus, A.M. Lutz, H.G. Sander⁸ and A.C. Schaffer

Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud, Orsay, France ^b

Bertanza, A. Bigi, P. Calafiura, M. Calvetti⁹, R. Carosi, R. Casali, C. Cerri,
I. Mannelli¹⁰, A. Nappi and G.M. Pierazzini

Dipartimento di Fisica e Sezione INFN, Pisa, Italy

H. Burkhardt, M. Holder, G. Quast, M. Rost, W. Weihs and G. Zech

Fachbereich Physik, Universität Siegen, Fed. Rep. Germany ^c

(Submitted to Physics Letters B)

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- 1) Present address: Brunel, The University of West London, Uxbridge, UK
 - 2) On leave from SLAC, Stanford, Calif., USA (work supported in part by the U.S. Department of Energy contract DE-AC03-76SF00515).
 - 3) Present address: DFVLR, Cologne, Fed. Rep. Germany.
 - 4) Present address: II. Inst. f. Exp. Physik, Universität Hamburg, Fed. Rep. Germany.
 - 5) Present address: FWI, University of Amsterdam, The Netherlands.
 - 6) Present address: Syracuse University, NY, USA.
 - 7) Present address: CERN, Geneva, Switzerland.
 - 8) Present address: Fachbereich Physik, Universität Siegen, Fed. Rep. Germany.
 - 9) Present address: Dipartimento di Fisica e Sezione INFN, Perugia, Italy.
 - 10) Present address: Scuola Normale Superiore, Pisa, Italy.
 - a) Funded by the German Federal Minister for Research and Technology (BMFT) under contract 054MZ18.
 - b) Funded by Institut National de Physique des Particules et de Physique Nucléaire, France.
 - c) Funded by the German Federal Minister for Research and Technology (BMFT) under contract 054Si74.

ABSTRACT

A search for the decay $K_L \rightarrow \pi^0 e^+ e^-$ has been performed at the CERN SPS. One candidate event has been found, compatible with an expected background of 1.5 events. The corresponding upper limit for the branching ratio is $\Gamma(K_L \rightarrow \pi^0 e^+ e^-)/\Gamma(K_L \rightarrow \text{all}) < 4 \times 10^{-8}$ with 90% confidence.

I. Introduction

The search for rare decays of K mesons which are forbidden or suppressed in the standard model provides the opportunity of detecting unexpected phenomena. An interesting channel is the decay $K_L \rightarrow \pi^0 e^+ e^-$. The one photon exchange diagram of this decay is a CP-violating process [1] in which the contribution from direct CP violation is expected to dominate the effect due to state mixing [2]. Assuming that the CP conserving contribution through two-photon exchange is negligible, the branching ratio is calculated from the CP violating transition to be 3.7×10^{-12} [3]. Calculations including CP conserving contributions predict branching ratios in the range 2×10^{-11} to 3×10^{-10} [4-6]. These branching ratios are still below the sensitivity of the present generation of experiments. The present published experimental upper limit is 2.3×10^{-6} [7]. In addition to a candidate for $K_L \rightarrow \pi^0 \mu^+ \mu^-$ decay, one candidate event for $K^0 \rightarrow \pi^0 e^+ e^-$ has been reported recently [8] which has subsequently been found to be compatible with background corresponding to an experimental upper limit of 3.2×10^{-7} [9]. The aim of this analysis is to substantially improve the experimental limit.

II. Experimental Set-up and Data Taking

The data were collected in the summer of 1986 while performing a measurement of the CP-violating parameter ϵ'/ϵ through a comparison of K_S and K_L decay rates into $2\pi^0$ and $\pi^+\pi^-$ final states respectively [10]. For the present analysis we use the fact that $\pi^0 e^+ e^-$ events are expected to appear the same as $\pi^0 \pi^0$ events in the electromagnetic and hadronic calorimeters. Two tracks will also be seen in the drift chambers pointing towards two electromagnetic showers in the calorimeter. The measurement of the $\pi^0 e^+ e^-$ branching ratio is made by comparing the number of $\pi^0 e^+ e^-$ and $\pi^0 \pi^0$ events observed, with small geometrical corrections.

The experimental setup of the detector and the beam layout have been described in detail elsewhere [11]. Long lived neutral kaons with energies around 100 GeV are produced by 450 GeV protons incident on a target 250 m in front of the detector.

The detector is based principally on track measurement and calorimetry. It is designed for good stability, high efficiency, large acceptance and fast data acquisition. It consists of:

- four ring-shaped anticounters surrounding the decay region,
- two wire chambers spaced 25 m apart each consisting of four planes, with ± 0.5 mm resolution in each projection,
- scintillator hodoscopes for trigger purposes,
- a liquid argon/lead sandwich calorimeter with strip readout to measure photons and electrons with ± 0.5 mm position and $\pm 7.5\%/\sqrt{E}$ (GeV) energy resolution,
- an iron/scintillator sandwich calorimeter to measure the energy of charged pions,
- two planes of scintillators, shielded by the equivalent of 3 m of iron to reject muons.

The wire chambers are used to measure the electron directions and the position of the decay vertex. The liquid argon calorimeter is used to measure the energies and positions of the electrons and photons. The iron calorimeter is used to reject events containing charged pions.

III. Event Reduction and Reconstruction

The trigger is based on the minimum total energy and the number of clusters in the liquid argon calorimeter. The $K_L \rightarrow \pi^0 e^+ e^-$ events fulfil the same trigger conditions that were required for $K_L \rightarrow \pi^0 \pi^0$ with four identified photons. The data sample of 2×10^7 such triggers is reduced by requiring the following conditions:

- less than 6 GeV of energy in the hadron calorimeter,
- two reconstructed space points in the first chamber,
- at least two space points in the second chamber which is located directly in front of the liquid argon calorimeter.

The 3 million remaining triggers are processed by a modified version of the reconstruction program for $2\pi^0$, $\pi^+\pi^-$ and $\pi^+\pi^-\pi^0$ events used for the ϵ'/ϵ analysis. A complete reconstruction of the tracks in the chambers and the corresponding showers is

performed. The information from the liquid argon calorimeter is used independently to search for electromagnetic showers. Events containing extra photons with more than 3 GeV of energy are rejected. 10^5 events with two tracks pointing to electromagnetic showers and at least two additional photons remain.

The normalization is obtained from a sample of the CP-violating decay $K_L \rightarrow \pi^0 \pi^0$, scaled down by a factor of 50 and written to the same output stream.

IV Analysis and Results

The two electromagnetic showers which are correlated with the tracks are assumed to be electrons. The other two are assumed to be photons. A common vertex is calculated from the energies and lateral positions of the showers in the calorimeter, using the K^0 mass as a constraint. The invariant mass of the photon pair is calculated using this vertex. This part of the reconstruction is identical to that used for the $\pi^0 \pi^0$ events. In addition, for the $\pi^0 e^+ e^-$ candidates, a four particle mass is obtained assuming the decay vertex to be the point where the electron tracks meet.

Further cuts were applied to the event sample to select both $\pi^0 \pi^0$ events and possible $\pi^0 e^+ e^-$ candidates:

- total energy between 50 and 190 GeV,
- individual shower energies between 5 and 100 GeV,
- decay vertex less than 50 m downstream of the collimator,
- fiducial cuts on the positions of the electromagnetic showers.

In order to reject events with charged pions in the final state, the electron candidates are required to fulfil the following conditions:

- each shower has less than 2 GeV deposited in the hadron calorimeter,
- for each shower, the ratio of energy deposition in the first half of the liquid argon calorimeter (12 radiation lengths) to the total energy deposition must be >0.65 ,
- the distance between the impact point of the electron track and the corresponding electromagnetic shower must be smaller than 3 cm,
- the width of each shower must be between 1.5 and 3.0 cm.

The loss of events with electrons due to these conditions is 4%. Background from events with missing particles is suppressed using the following cuts:

- the centre of gravity of the electromagnetic energy is within 7 cm of the beam axis, (the beam profile at the liquid argon detector has a radius of 5 cm) and

- the transverse distance from the reconstructed K^0 trajectory to the target is less than 8 cm.

Figure 1 shows the distribution of the two photon mass versus the four particle mass for Monte Carlo $K^0 \rightarrow \pi^0 e^+ e^-$ events with uniform phase space population. The events cluster at the π^0 and the K^0 masses with resolutions of 2 MeV and 9 MeV respectively. Losses through radiative tails and identified Bremsstrahlung photons have been estimated to be small, and are neglected in the Monte Carlo calculation. The signal region is defined by a three standard deviation ellipse calculated from the experimental resolution.

Figure 2 shows the distribution of the remaining events in a scatter plot of the two photon mass versus the four particle mass. One event is found in the 3σ signal region shown on Figure 1. The invariant mass of the $e^+ e^-$ pair is 130 MeV, which is compatible with the mass of the neutral pion within experimental resolution. A source of background is from $K^0 \rightarrow \pi^0 \pi^0$ decays, where both photons from a single π^0 each convert into an $e^+ e^-$ pair in the 0.004 radiation lengths of material upstream of the first chamber. The $e^+ e^-$ pairs do not separate and each pair is recorded as one electron. The background from this process is estimated to be 1.5 events. The candidate is likely to be an event of this type. Background is also expected from several other sources, for example decays of the type $K^0 \rightarrow \pi^0 \pi^+ \pi^-$ and $K^0 \rightarrow \pi^0 \pi^+ e^- \nu$, Dalitz decays and accidental overlays.

Using Poisson statistics for one observed event and 1.5 expected background events we find an upper limit of 3.1 events with 90% confidence. The corresponding number of down scaled $\pi^0 \pi^0$ events is 1634 including 4% background. The acceptances for $\pi^0 \pi^0$ events and $\pi^0 e^+ e^-$ events have been determined by Monte Carlo (assuming uniform phase space for $\pi^0 e^+ e^-$) to be 14.3% and 13.1% respectively. Figure 3 shows the detection efficiency as a function of the $e^+ e^-$ mass. Using the measured branching ratio of 9.1×10^{-4} for $K_L \rightarrow \pi^0 \pi^0$ decays [10,12], we obtain an upper limit for the branching ratio of $\Gamma(K_L \rightarrow \pi^0 e^+ e^-) / \Gamma(K_L \rightarrow \text{all}) < 4 \times 10^{-8}$ with 90% confidence.

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Figure Captions

Figure 1: Invariant two photon mass versus the four particle mass after all cuts for 1230 Monte Carlo events. The ellipse is a three standard deviation contour around the signal.

Figure 2: Invariant two photon mass versus the four particle mass after all cuts. The ellipse indicates the signal region.

Figure 3: Detection efficiency as a function of e^+e^- mass.

Figure 1

Figure 2

Figure 3