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# NEW RESULTS ON $K_L$ and $K_S$ RARE DECAYS BY NA48

AUGUSTO CECCUCCI*
*CERN, EP Division*
*1211 Genève 23, Switzerland*

New measurements of the branching ratios $K_L \to e^+e^-e^+e^-$ and $K_L \to \pi^0\gamma\gamma$ are presented. The use of a target placed nearby the beginning of the decay region allows sensitive $K_S$ rare decay searches: we report a new measurement of $BR(K_S \to \gamma\gamma)$ and a new upper limit for the decay $K_S \to \pi^0e^+e^-$.

## 1. Introduction

While designed to measure direct CP violation via the $\mathrm{Re}(\varepsilon'/\varepsilon)$ parameter, the NA48 experiment at the CERN-SPS also offers a competitive program on rare $K_L$ and $K_S$ decays. The $K_L$ ($K_S$) particle is created aiming 450 GeV/c protons onto a beryllium target placed 126 (6) m upstream of the decay region. References and details on the experimental apparatus can be found elsewhere [1]. A competitive $K_S$ rare decay program can be carried out removing the upstream target and aiming the protons directly to the target placed nearby the decay region ($K_S$ target). Results from $K_S$ decays presented in this paper are based on a short two day run that took place in 1999.

## 2. $K_L \to e^+e^-l^+l^-$

The $K_L \to e^+e^-l^+l^-$ decays proceed mainly via the double internal photon conversion, hence probing the $K-\gamma^*\gamma^*$ vertex. The theoretical prediction[2] are $3.7\times10^{-8}$ for $l = e$, and $(1.30 \pm 0.15) \times 10^{-9}$ for $l = \mu$. The data sample presented here was accumulated during the 1999 SPS proton run. The trigger algorithm imposes the reconstruction of at least two vertexes displaced by no more than 6 m. The offline selection requires the closest distance of approach to be smaller than 15 cm. In order to identify the electrons, the ratio E/P between the energy (E) and the momentum (P) of each track has to be between 0.9 and 1.2. The transverse momentum must be smaller than $5 \times 10^{-4}(\mathrm{GeV/c})^2$ and the reconstructed invariant mass of the four tracks has to be within 0.475 and 0.525 GeV/c$^2$. The vertex of the decayed kaon is required to lie within 700 and 9000 cm from the $K_S$ target. The background coming from $K_L \to \gamma e^+e^-(K_L \to \gamma\gamma)$, with one (two) photons converted, is rejected requiring a distance of at least 2 cm between the two tracks

*On behalf of the NA48 Collaboration: Cagliari Cambridge CERN Dubna Edinburgh Ferrara Firenze Mainz Orsay Perugia Pisa Saclay Siegen Torino Vienna Warsaw of opposite charge in the first drift chamber. After the selection, 132 events remain in the signal region with negligible background. To normalize the kaon flux, the $K_{\rm L} \rightarrow \pi^0\pi^0_D\pi^0_D$ and $K_{\rm L} \rightarrow \pi^+\pi^-\pi^0_D$ ($\pi^0_D \equiv \gamma e^+e^-$) decay modes are used. The preliminary NA48 result is:

$$\mathrm{BR}(K_{\rm L} \rightarrow e^+e^-e^+e^-) = (3.67 \pm 0.32_{stat} \pm 0.23_{syst} \pm 0.08_{norm}) \times 10^{-8}, \qquad (1)$$

in agreement with the theoretical prediction. The $K_{\rm L} \rightarrow e^+e^-\mu^+\mu^-$ mode is more sensitive to a non-trivial form factor. So far only one event has been published [3]. NA48 sees a clear signal in the kaon region of the $m_{e^+e^-\mu^+\mu^-}$ distribution (Fig. 1).

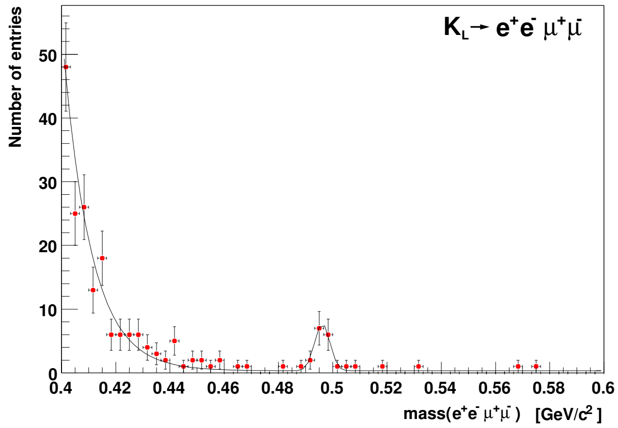


Fig. 1. Invariant mass distribution for the four tracks under the $e^+e^-\mu^+\mu^-$ hypothesis.

## 3. $K_{\rm L} \rightarrow \pi^0\gamma\gamma$

The decay rate is finite at one loop in Chiral Perturbation Theory (CHPT). The $O(p^4)$ CHPT calculation predicts only 1/3 of the measured rate [5]. Calculations[6] performed to $O(p^6)$ and including a Vector Meson Dominance (VMD) contribution, parameterized by $a_{\rm V}$, predict a tail at low $m_{\gamma\gamma}$. The VMD contribution is important because it leads to a CP conserving component in $K_{\rm L} \rightarrow \pi^0e^+e^-$. This decay mode was first measured by NA31[4]. The best measurement was published by KTEV[7]. Data presented here comes from the 1999 and part of the 1998 sample. The candidates are triggered by a deposit of at least 50 GeV in the Liquid Krypton Calorimeter (LKr), a center of gravity smaller than 15 cm, a proper time smaller than 5.5 $K_{\rm S}$ lifetimes and less than 6 energy peaks in each of the two neutral trigger projections. Only events with four photon candidates ontime and no hits in the drift chambers or in the $K_{\rm L}$ vetoes were retained for further analysis. The main experimental background comes from $K_{\rm L} \rightarrow 3\pi^0$ decays with photons either lost or overlapping in the calorimeter. A decay region of only 20 m is used to reduce the background which tend to accumulate closer to the calorimeter in case of lost energy. If the combination of two (three) photon candidates is compatible with the reconstruction of one (two) $\pi^0$ originating more than 6 m upstream of the reconstructed kaon vertex and in the collimator region, the event is rejected. In addition, the width of the photon candidate must be compatible with that of electromagnetic showers. The NA48 signal for small $m_{\gamma\gamma}$ (Fig. 2) gives a clear evidence for contributions beyond $O(p^4)$. The preliminary branching ratio, normalized to

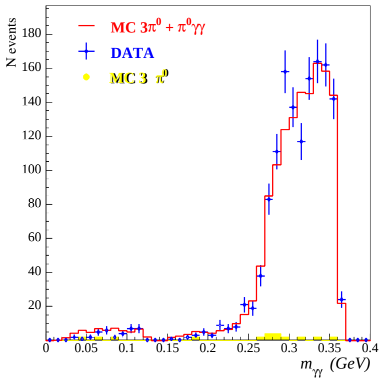


Fig. 2. Distribution of the $m_{\gamma\gamma}$ for the $K_{\rm L} \rightarrow \pi^0\gamma\gamma$ candidates.

$K_{\rm S} \rightarrow 2\pi^0$ and assuming a value of $a_{\rm V} = -0.45$, is:

$$BR(K_{\rm L} \rightarrow \pi^0\gamma\gamma, {\rm a_V} = -0.45) = (1.51 \pm 0.05({\rm stat}) \pm 0.20({\rm syst})) \times 10^{-6}. \qquad (2)$$

## 4. $K_{\rm S} \rightarrow \gamma\gamma$

This decay is interesting because it is calculable in CHPT with no counter-terms and it is sensitive to loops. The theory predicts the branching ratio with a small error [8]. The first measurement of $K_{\rm S} \rightarrow \gamma\gamma$ was carried out by NA31 [9]. The same number of $K_{\rm S}$ and $K_{\rm L}$ is produced in the target. The $K_{\rm L} \rightarrow \gamma\gamma$ component must therefore be subtracted. The highest $m_{\gamma\gamma}$ that can be formed by odd pairing of photons from the reaction $K_{\rm S} \rightarrow \pi^0\pi^0$, amounts to 458 MeV/c$^2$. This figure translates into a downstream vertex displacement of at least 9 m if a $K_{\rm S} \rightarrow 2\pi^0$ event is analyzed under the $K_{\rm S} \rightarrow \gamma\gamma$ hypothesis. Therefore, the choice of a short decay region allows to keep the daunting background $K_{\rm S} \rightarrow 2\pi^0$ with two lost photons under control. The flux is measured using $K_{\rm S} \rightarrow 2\,\pi^0$ and $K_{\rm L} \rightarrow 3\,\pi^0$ decays. To evaluate the remaining background from $2\pi^0$, $10^8$ events have been simulated. The overlap of photons reduces the background free region to 5 m. The vertex distribution for the candidate events is shown in Fig. 3. The branching ratio is fitted maximizing a likelihood function binned in energy and decay vertex position. The contribution of $K_{\rm L} \rightarrow \gamma\gamma$ is computed making use of the measured [10] branching ratio for this process. The result is:

$$BR(K_{\rm S} \rightarrow \gamma\gamma) = (2.58 \pm 0.36(stat) \pm 0.22(syst)) \times 10^{-6}, \qquad (3)$$

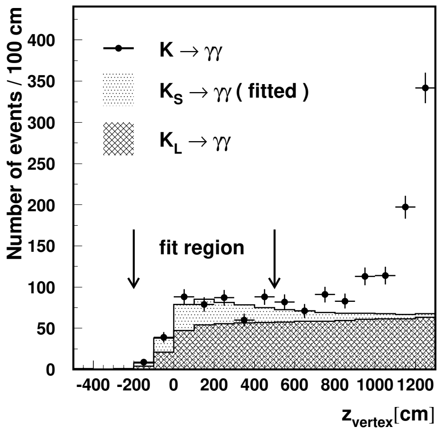


Fig. 3. Reconstructed decay vertex for the $K \to \gamma\gamma$ and background events.

$$R = \frac{\Gamma(K_S \to \gamma\gamma)}{\Gamma(K_L \to \gamma\gamma)} = 2.53 \pm 0.35(stat) \pm 0.22(syst). \tag{4}$$

The result is in agreement with the theoretical predictions.

## 5. $K_S \to \pi^0 e^+ e^-$

The main interest in $K_S \to \pi^0 e^+ e^-$ is to bound the indirect CP violation component of the $K_L \to \pi^0 e^+ e^-$ decay due to mixing:

$$BR(K_L \to \pi^0 e^+ e^-)_{\mathrm{CPVind}} \sim 1/330 \times BR(K_S \to \pi^0 e^+ e^-). \tag{5}$$

The $K_S \to \pi^0 e^+ e^-$ mode cannot be reliably predicted and it is not well bound experimentally[11]. The trigger requires no hits in drift chamber 1, less than 8 GeV in the hadronic calorimeter, at least 50 GeV in the LKr, a center of gravity smaller than 10 cm and a proper time smaller than 5 $K_S$ lifetimes. The offline event selection requires four showers and two tracks. The E/P for each track has to be between 0.9 and 1.1. Background from $K_S$ , $K_L \to e^+ e^- \gamma\gamma$ is negligible given the smallness of the branching ratio for these reactions. A cut on $m_{ee} > 0.165$ GeV/c$^2$ reduces the background expected from $K_S \to \pi^0 \pi^0_D \to \gamma\gamma e^+ e^- \gamma$, with one photon lost, to less than 0.03 events. To keep the background from $K_S \to 2\pi^0_D \to e^+ e^- \gamma e^+ e^- \gamma$, with an electron (positron) lost from each Dalitz $\pi^0$ decay, to less than 0.03 events the cut $|m_{e\gamma} - m_{\pi^0}| < 0.03$ GeV/c$^2$ is applied. Cuts are tuned on a large MC sample. The decay $K_S \to \pi^0_D \pi^0$ is used as normalization channel. The $m_{e^+e^-}$ distribution for the normalization channel (data and Monte Carlo) and the $m_{e^+e^-}$ distribution expected for the signal are shown in Fig. 4. After the selection no events are found in the signal region. This leads to the upper limit:

$$BR(K_S \to \pi^0 e^+ e^-, m_{e^+e^-} > 165 \text{ MeV/c}^2) < 8.3 \times 10^{-8} \; 90 \;\% \; CL. \tag{6}$$

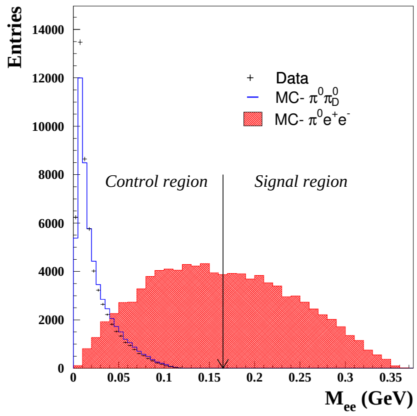


Fig. 4. $K_S \to \pi^0_D\pi^0$ and $K_S \to \pi^0e^+e^-$ (Data and Monte Carlo).

Using a specific form for the matrix element[12], the extrapolated result for the full branching ratio is:

$$BR(K_S \to \pi^0e^+e^-) < 1.6 \times 10^{-7} \; 90 \; \% \; CL. \tag{7}$$

This result represent an improvement by one order of magnitude over the previous experimental bound.

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