Results from the NA48 experiment on rare neutral kaon decays

Andrew Maier[*] [‡]
University of Siegen, Fachbereich Physik, Walter-Flex Straße 3, D-57068 Siegen, Germany
E-mail: `Andrew.Maier@cern.ch`

Abstract: New and recent measurements of the branching ratios of rare decays of neutral $K_{\rm S}$ and $K_{\rm L}$ mesons are presented. The results have been extracted from data collected during the NA48 ϵ'/ϵ runs as well as in a special high intensity $K_{\rm S}$ and hyperon run. In particular the presentation focuses on the decay of $K_{\rm L} \to \pi^0\gamma\gamma$, $K_{\rm S} \to \pi^0 e^+e^-$ and $K_{\rm S} \to \gamma\gamma$. The prospects of future programs aiming to study direct CP violation in charged kaons and to search for rare $K_{\rm S}$ decays are given using the example of $K_{\rm S} \to \pi^0 e^+e^-$.

1. Introduction

The NA48 experiment has been designed to measure the direct CP-violation parameter ϵ'/ϵ [1, 2] to a precision of 2×10^{-4} using simultaneous almost collinear K_S and K_L beams [3]. The design of the experiment, its good understanding of the systematics necessary for the measurement of ϵ'/ϵ and the high kaon flux make NA48 an excellent tool for the investigation of rare neutral kaon decays.

This paper reviews a small selection of the rare results from data taken during the 1998/1999 ϵ' run, as well as results from a two day high intensity K_S run, taken in 1999.

2. $K_L \to \pi^0\gamma\gamma$

The decay of $K_L \to \pi^0\gamma\gamma$ is interesting in two ways. Firstly, it is related to the CP conserving amplitude of the decay of $K_L \to \pi^0 e^+e^-$, which has a direct CP violating component. Secondly, it is a good test for Chiral Perturbation Theory (χPT), since at one loop calculations the rate is finite, yet the O(4) χPT calculations only predict about 1/2 to 1/3 of the measured rate. Calculations of O(6) including a Vector Meson Dominance (VMD) contribution which is parameterised by the parameter a_v, can accommodate the observed rate. The VMD contribution predicts a mass tail at low $m_{\gamma\gamma}$.

[*]Speaker.
[†]on behalf of the NA48 collaboration: Cagliari, Cambridge, CERN, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Vienna, Warsaw.
[‡]Address for correspondence:CERN/EP,CH-1211 Genève 23, Switzerland

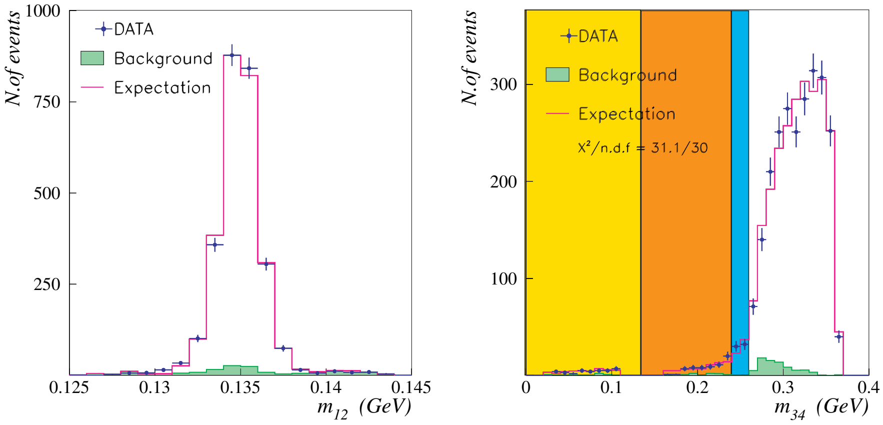

Figure 1: Invariant mass distribution of the photons resulting from the π^0 and the $\gamma\gamma$. The photons associated to the π^0 are labelled 1 and 2, while the $\gamma\gamma$ pair is labelled 3 and 4. The coloured areas represent three different regions used in Figure 2.

The data sample used for this measurement was taken from the 98/99 ϵ' data set, with a large number of $K_L \to 2\pi^0$ which have a similar topology as $K_L \to \pi^0\gamma\gamma$. $K_L \to 2\pi^0$ has also been used as a normalisation channel. Since both data and normalisation channel are taken under the same trigger conditions, trigger efficiencies cancel.

The background for this channel is mainly due to $2\pi^0$ and $3\pi^0$ decays. The background from $2\pi^0$ is rejected using an invariant mass constraint and by building a χ^2 like variable with a π^0 mass hypothesis in order to reject $2\pi^0$ events. The background from $3\pi^0$ originates from missing or overlapping photons in the electro-magnetic calorimeter. This background is rejected using combinatorial cuts which make use of the fact that the vertex is correctly calculated for the π^0, but not for the K_L. Finally, cuts on the shower width of the photon clusters are made.

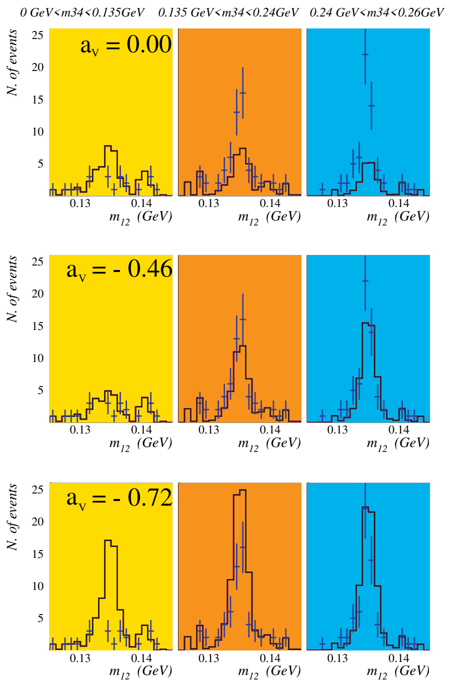

Figure 2: Distribution of the low mass tail for the di-γ system for different values of a_v for data and Monte Carlo.

Figure 1 shows the invariant mass distribution for the two photons associated to the π^0 and the two remaining photons, respectively. A low mass tail in the two γ distribution can be seen, which leads to the interpretation of a non vanishing value of a_v.

To get an understanding of the value of a_v it is illustrative to select different mass regions of the $\gamma\gamma$ mass distribution and to compare the expected number of events for various values of a_v from Monte Carlo simulation. This can be seen from Figure 2 where the invariant mass of the π^0 is compared with simulation for values of a_v of 0.0, -0.46 and -0.72, respectively. While the expectation of a vanishing a_v underestimates the events in the higher mass region, the large value of $a_v = -0.72$ overestimates the number of events in the low mass region. The final value of a_v found in the NA48 data is $a_v = -0.46 \pm 0.03_{(stat)} \pm 0.03_{(syst)} \pm 0.02_{(theo)}$. The branching ratio of $K_L \to \pi^0\gamma\gamma$ is determined to be $BR(K_L \to \pi^0\gamma\gamma) = (1.36 \pm 0.03_{(stat)} \pm 0.03_{(syst)} \pm 0.03_{(norm)}) \times 10^{-6}$.

A publication of this result is in preparation.

3. $K_S \to \pi^0 e^+ e^-$

The decays of K_L into $\pi^0 l^+ l^-$ are of considerable interest due to their sensitivity to direct CP violation [4]. However, in $\pi^0 e^+ e^-$ decay, both CP conserving and indirect CP violating amplitudes contribute. The CP conserving component can be measured from the decay $K_L \to \pi^0\gamma\gamma$, while the indirect CP violating part can be measured from the decay $K_S \to \pi^0 e^+ e^-$. The K_S decay is expected to be of the order of $BR(K_S \to \pi^0 e^+ e^-) = 5.2 a_s^2 \times 10^{-9}$, where a_s is expected to be of O(1), but is not well bounded theoretically. The decay has so far not been observed and the best limit to date for its branching ratio has been determined to be $BR(K_S \to \pi^0 e^+ e^-) < 1.1 \times 10^{-6}$ at the 90% confidence level by NA31 [5].

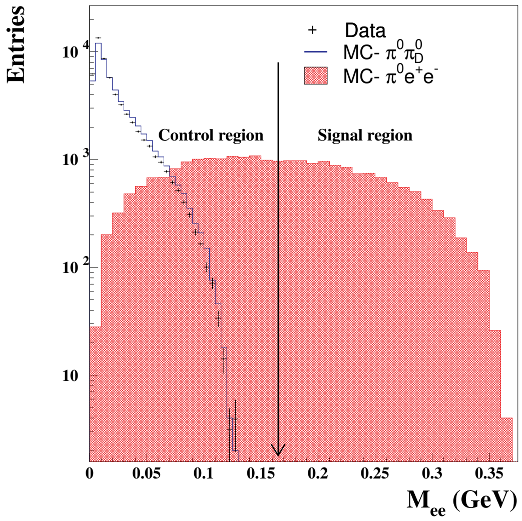

Figure 3: $K_S \to \pi^0\pi^0_D$ and $K_S \to \pi^0 e^+ e^-$ for data and Monte Carlo.

The data for this analysis was taken in a two day high intensity test run after the end of the 1999 ϵ' data taking period. Events were selected to have at least 4 clusters in the electro-magnetic calorimeter and two tracks identified as electrons with an $0.9 < E/p < 1.1$ using the calorimeter and the spectrometer. The invariant mass of the event had to be compatible with the K^0 mass and the invariant mass of the two photons resulting from clusters not associated to tracks had to be compatible with the π^0-mass.

Background from the Dalitz decays $\pi^0\pi^0_D$ and $\pi^0_D\pi^0_D$ is removed by requiring that the mass of the $e\gamma$ system is at least 30 MeV larger or smaller than the π^0 mass. In addition, the mass of the ee system is required to be larger than 165 MeV/c^2. While this cut safely removes all background expected from the simulation, it also removes about 50% of the expected signal (see Figure 3).

After this selection, no events remain in the signal region. Using $K_S \to \pi^0\pi^0_D$ as normalisation channel, a new upper limit for the branching ratio can be given to be:

$BR(K_S \to \pi^0 e^+ e^-) < 1.4 \times 10^{-7}$ at the 90% confidence level [6]. This result includes a 7% systematic error and it improves the current best measurement by a factor of 8.

4. $K_S \to \gamma\gamma$

The interest for this decay arises from the fact that it is calculable in the framework of χPT with no counter-terms. It is also sensitive to loops. Therefore the branching ratio of this decay is predicted by theory with a small error to be $BR(K_S \to \gamma\gamma) = (2.3 \pm 0.2) \times 10^{-6}$ [7, 8, 9, 10]. Hence a precision measurement of this mode is an important test to Chiral Perturbation Theory.

The data collected originate from the same two day high intensity K_S run, which has been used to extract $K_S \to \pi^0 e^+ e^-$. Since the flux of K_S and K_L produced at the target are the same, it is important to subtract the number of the events originating from $K_L \to \gamma\gamma$ decays from the number of all $K \to \gamma\gamma$ events by measuring the flux of the K_L and using the measured branching ratio of $K_L \to \gamma\gamma$.

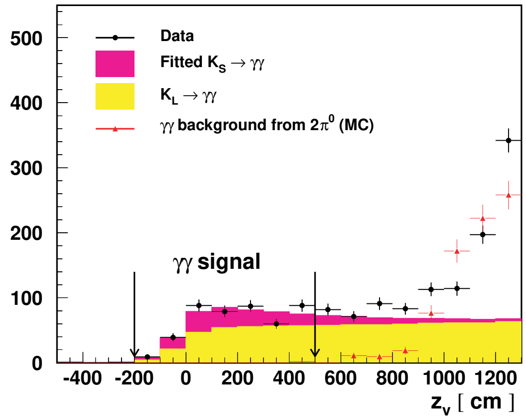

Figure 4: The vertex distribution for $K_S \to \gamma\gamma$, $K_L \to \gamma\gamma$ and the $\gamma\gamma$ background originating from $K_S \to 2\pi^0$.

Events were selected to have at least two clusters in the electro-magnetic calorimeter. The highest invariant mass $M_{\gamma\gamma}$ that can be formed by odd pairing photons from $K_S \to 2\pi^0$ decays, amounts to 458 MeV, which translates to into a vertex shift of 9 m, if such an event is analysed under the $K_S \to \gamma\gamma$ hypothesis. The choice of a short decay region, therefore allows to distinguish the signal from the background of $K_S \to 2\pi^0$ with 2 missed photons. Monte Carlo studies show, that taking into account also overlapping showers, a region of 5 m leads to an almost background free sample.

The vertex distribution for signal and background, both for data and Monte Carlo, is shown in Figure 4. The contribution from $K_L \to \gamma\gamma$ is removed and using $K_S \to 2\pi^0$ as a normalisation channel, a branching ratio of $BR(K_S \to \gamma\gamma) = (2.58 \pm 0.36_{(stat)} \pm 0.22_{(sys)}) \times 10^{-6}$ is measured [11], in good agreement with theoretical expectations.

5. Outlook

NA48 is involved in a rich program for the search of rare neutral kaon decays. A future run with a high intensity K_S beam, planned for 2002, will allow competitive physics in the area of rare K_S and hyperon decays. Already the two day high intensity K_S run in 1999 was able to improve the limit for the branching ratio for $K_S \to \pi^0 e^+ e^-$ by almost an order of magnitude. In addition to the K_S run, a special run of charged kaons is envisaged. This run is scheduled for 2003.

6. Acknowledgements

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