Recent NA48 results on rare K decays

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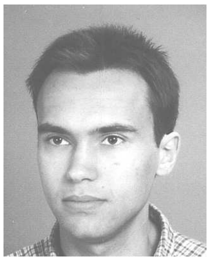

Recent NA48 results from detailed studies of $K_{L,S} \to \pi^+\pi^-e^+e^-$ and $K_S \to \pi^0\gamma\gamma$ decay modes are presented. The results are based on the data collected with the NA48 detector at the CERN SPS during the 1998-1999 and 2000 data taking periods, respectively. Prospects for future results on charged kaon decays are briefly described.

1 NA48 experiment

The NA48 experiment has been designed for a precise measurement of the CP-violation parameter $Re(\epsilon'/\epsilon)$. It makes use of simultaneous K_L and K_S beams produced at two different targets, situated 120m from each other. The main two elements of the setup are charged particle magnetic spectrometer and liquid krypton electromagnetic calorimeter (LKr). The spectrometer consists of a dipole magnet with a horizontal transverse momentum kick of 256 MeV/c and a set of four drift chambers (two upstream of the magnet and two downstream of it). The momentum resolution of the spectrometer is given by $\sigma_P/P(\%) = 0.48 \oplus 0.009 \times P$, where P is in GeV/c. LKr is a quasi-homogeneous detector, having projective tower structure which is formed by copper-beryllium ribbons extending between the front and the back of the calorimeter with a accordion geometry. The energy resolution of the calorimeter is $\sigma_E/E(\%) = 3.2\%/\sqrt{(E)} \oplus 10.0/E \oplus 0.5$, where E is given in units of GeV. A detailed description of the whole NA48 setup can be found elsewhere [1].

2 Data samples

The $K_L \to \pi^+\pi^-e^+e^-$ and a fraction of the $K_S \to \pi^+\pi^-e^+e^-$ data were taken using simultaneous K_L and K_S beams during the 1998 and 1999 SPS running periods dedicated to the measurement of $\mathrm{Re}(\epsilon'/\epsilon)$. The main part of the K_S data was collected from a short high intensity K_S run in 1999. In both cases $K_L \to \pi^+\pi^-\pi^0$ mode, followed by the Dalitz decay of π^0, was used as a normalization channel.

The data needed to observe and analyze the $K_S \to \pi^0\gamma\gamma$ decay mode was recorded during a part of the 2000 run with high intensity K_S beam and without the charged particle magnetic spectrometer. The corresponding branching ratio was determined relative to the $K_S \to \pi^0\pi^0$ channel.

In order to take into account the detector acceptance and the reconstruction efficiency, a detailed Monte Carlo program based on GEANT has been employed.

3 First observation of $K_S \to \pi^0\gamma\gamma$

As it was recognized in [2], the decay $K_S \to \pi^0\gamma\gamma$ can provide valuable test of the chiral structure of the weak vertex. The interest in this particular decay mode is also enhanced by the fact that it has not been observed so far (recently the NA48 experiment put the best upper limit for the decay branching ratio to 3.3×10^{-7} using the 1999 high intensity K_S data).

The most important issues in the analysis of $K_S \to \pi^0\gamma\gamma$ are the efficient rejection and the accurate estimation of the backgrounds. The following background sources have been identified and carefully studied:

- Accidental beam activity. This background has been rejected by series of timing cuts and using veto signals from anti-counters which surround the decay volume. The remaining contribution has been evaluated from the sidebands of the time distributions.

- $K_S \to \pi^0\pi^0$ and $K_S \to \pi^0\pi^0$ followed by Dalitz decay of one of the π^0s. The suppression of these contributions has been obtained by applying a set of kinematic cuts against Dalitz decays and $K_S \to \pi^0\pi^0$ decays with significant γ energy losses.

- $K_L \to \pi^0\gamma\gamma$. Due to the fact that this background source is irreducible, its contribution to the signal has been subtracted using Monte-Carlo generated decays and a value for the flux obtained from a study of $K_S \to \pi^0\pi^0$ data.

- $\Xi^0 \to \Lambda\pi^0$ followed by $\Lambda \to n\pi^0$. The background has been rejected by cuts on the asymmetries between the γ energies. The contribution which survive the cuts has been estimated by comparing the shower profiles in the LKr calorimeter for the $K \to \pi^0\gamma\gamma$ candidates and reconstructed Ξ^0 decays.

The π^0 invariant mass distribution for $K \to \pi^0\gamma\gamma$ candidates which passed the whole event selection is shown in Figure 1. Table 1 summarizes the number of events seen inside the signal region and the estimated contributions from background sources. The probability that the observed 17.4 signal events are consistent with background fluctuations is less that 9×10^{-4} and therefore one can claim for first observation of this decay mode. The corresponding branching ratio was found to be $BR(K_S \to \pi^0\gamma\gamma)|_{z>0.2} = (4.9 \pm 1.6_{stat} \pm 0.8_{syst}) \times 10^{-8}$, where $z = q^2/M_K^2$, fully consistent with the prediction in [2]. On the other hand, the available statistics does not allow to test the chiral structure of the weak vertex (Figure 1).

4 Detailed study of $K_{L,S} \to \pi^+\pi^-e^+e^-$

The matrix element of $K_L \to \pi^+\pi^-e^+e^-$ decay receives contributions from CP-violating inner bremsstrahlung, CP-conserving emission of M1 photon, CP-violating emission of E1 photon and CP-conserving K^0 charge radius processes [3,4]. The interference between two first terms leads to an observable CP-violating polarization of the virtual γ. This observable can be analyzed

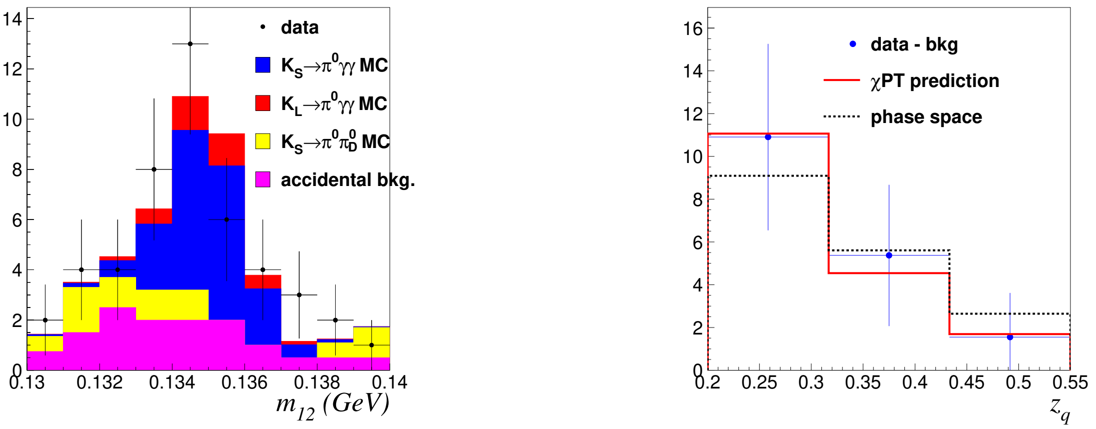

Figure 1: $K_S \to \pi^0\gamma\gamma$ candidates: the invariant mass of two photons which form π^0 (left); the $z = q^2/M_K^2$ distribution (right).

Table 1: $K_S \to \pi^0\gamma\gamma$. Summary of the number of events in the signal region and the expected contributions from background sources.

Number of events in signal region	31.0	$\pm$	5.6
Beam activity	-7.4	$\pm$	2.4
$K_S \to \pi^0\pi^0_D$	-2.4	$\pm$	1.2
$K_L \to \pi^0\gamma\gamma$	-3.8	$\pm$	0.0
Acceptance		$\pm$	0.7
Number of events after background subtraction	17.4	$\pm$	6.2

in terms of asymmetry $A_\phi = (N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0})/(N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0})$, where N represents the number of observed events and ϕ is the angle between the planes formed by $\pi^+\pi^-$ and e^+e^-. Contrary to the K_L case, in the $K_S \to \pi^+\pi^-e^+e^-$ decay the only contribution is the inner bremsstrahlung.

During the analysis of $K_L \to \pi^+\pi^-e^+e^-$ two main background sources have been identified:

- $K_L \to \pi^+\pi^-\pi^0$ followed by Dalitz decay of π^0. The background has been suppressed by strong kinematical cuts against events with missing particle.

- Two overlapping in time K^0e3 decays. Both the vertex quality cut and the cut on time difference between π^+e^- and π^-e^+ pairs have been applied in order to reduce this kind of background. The remaining contribution in the signal region has been estimated using accidental events in which the two pions and two leptons have the same charge.

Figure 2 shows the distribution of the invariant mass for the selected $K_L \to \pi^+\pi^-e^+e^-$ candidates. As one can see the background contamination is small enough allowing an unbiased analysis of the decay parameters. In the K_S case the background from $K_L \to \pi^+\pi^-\pi^0_D$ is significantly lower, but at the same time two new contributions arise - the irreducible contamination from $K_L \to \pi^+\pi^-e^+e^-$ and the $\Xi^0 \to \lambda\pi^0_D$ decay.

In order to extract the parameters of the M1 emission and K^0 charged radius processes, the selected $K_L \to \pi^+\pi^-e^+e^-$ candidates have been fitted to Monte Carlo generated events by a maximum likelihood method. Similar analysis of the K_S data has confirmed that it is consistent with pure inner bremsstrahlung contribution.

Based on the observed number of $K_{L,S} \to \pi^+\pi^-e^+e^-$ events, the corresponding branching

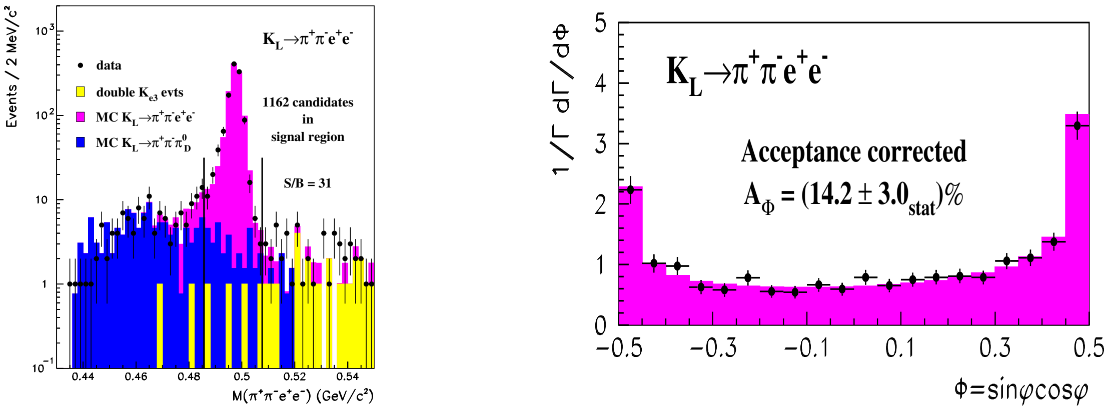

Figure 2: $K_L \to \pi^+\pi^-e^+e^-$: the invariant mass distribution (left); the angular distribution after acceptance correction (right).

ratios has been determined to be $BR(K_L \to \pi^+\pi^-e^+e^-) = (3.08 \pm 0.09_{stat} \pm 0.15_{syst} \pm 0.10_{norm}) \times 10^{-7}$ and $BR(K_S \to \pi^+\pi^-e^+e^-) = (4.71 \pm 0.23_{stat} \pm 0.16_{syst} \pm 0.15_{norm}) \times 10^{-5}$, respectively.

Figure 2 represents the angular distribution of $K_L \to \pi^+\pi^-e^+e^-$ after a correction for the detector acceptance. A numerical analysis of this distribution has shown that the asymmetry $A_\phi = (14.2 \pm 3.0_{stat} \pm 1.9_{syst})\%$. The observed 4σ effect is a clear indication of CP violation and is in agreement with the theoretical predictions [3,4]. As expected the corresponding K_S asymmetry is compatible with 0.

A detailed description of the $K_{L,S} \to \pi^+\pi^-e^+e^-$ analysis and results can be found in [5].

5 Run 2003

In 2003 the NA48 collaboration continues its experimental program by moving to charged kaon sector [6]. The main goal of the run will be a precise measurement of the CP-violation in the asymmetry of the Dalitz plots for $K^+ \to (3\pi)^+$ and $K^- \to (3\pi)^-$ decays. Another important aim of the experiment is to measure the scattering length a_0^0 by collecting about 10^6 $K^\pm e4$ events. As a by-product it is planned to study also some rare decay channels like $K^\pm \to \pi^\pm\pi^0\gamma$, $K^\pm \to \pi^\pm\gamma\gamma$, $K^\pm \to \pi^\pm e^+e^-$ and $K^\pm \to \pi^\pm\pi^0 e^+e^-$. Another interesting possibility will be to extract the CKM matrix element V_{US} from an analysis of high statistics samples of $K^\pm e3$ and $K^\pm\mu3$.

The experimental setup is basically the same with two major upgrades. The first one is a new beamline configuration which will provide simultaneous and focused 60 GeV/c $K^\pm$ beams. The second upgrade is a new beam spectrometer based on MICROMEGAS TPCs. The spectrometer will be able to work in the extremely high intensity beam environment and will measure the momentum of the decaying kaons with a precision of 1%.

References

1. A. Lai *et al*, *Eur. Phys. J.* C **22**, 231 (2001).
2. G. Ecker, A. Pich and E. De Rafael, *Phys. Lett.* B **189**, 363 (1987).
3. L. Sehgal and M. Wanninger, *Phys. Rev.* D **46**, 1035 (1992).
4. P. Heiliger and L. Sehgal, *Phys. Rev.* D **48**, 4146 (1993).
5. A. Lai *et al*, *CERN-EP-2003-006*(2003). Submitted to *Eur. Phys. J.* C.
6. R. Batley *et al*, *CERN-SPSC-P-253-ADD-3*(1999).