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RECENT RESULTS OF NA48 ON NEUTRAL KAON RARE DECAYS

MARCO CLEMENCIC
on behalf of the NA48 Collaboration

Dipartimento di Fisica Sperimentale and INFN, Torino, Italy

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Recent results obtained by the NA48 collaboration on neutral kaon rare decays are reported. A first observation of $K_S \to \pi^0\gamma\gamma$ and a detailed study of $K_{L,S} \to \pi^+\pi^-e^+e^-$ have been performed.

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1. Introduction

Rare decays of neutral kaons provide useful informations to test strong interaction effective theories, like chiral perturbation theory, needed to make predictions on branching ratios and other decay parameters. In this paper, some results on a few rare decay modes of the neutral kaons, obtained by the NA48 experiment at the CERN SPS, are reported.

2. The NA48 experiment

2.1. The beam setup

A primary proton beam from the CERN Super Proton Synchrotron is driven to a beryllium target (K_L target). After a sweeping magnet and some collimators, a neutral beam is formed. The last collimator exit is located 126 m downstream of the target (see Fig. 1).

The primary protons not interacting in the K_L target are deflected by a bent crystal, forming a secondary proton beam that is transported to a second target (K_S target, identical to the first one). After 6 m of sweeping and collimation, a second neutral beam, quasi-parallel to the first one, is sent to the decay region.

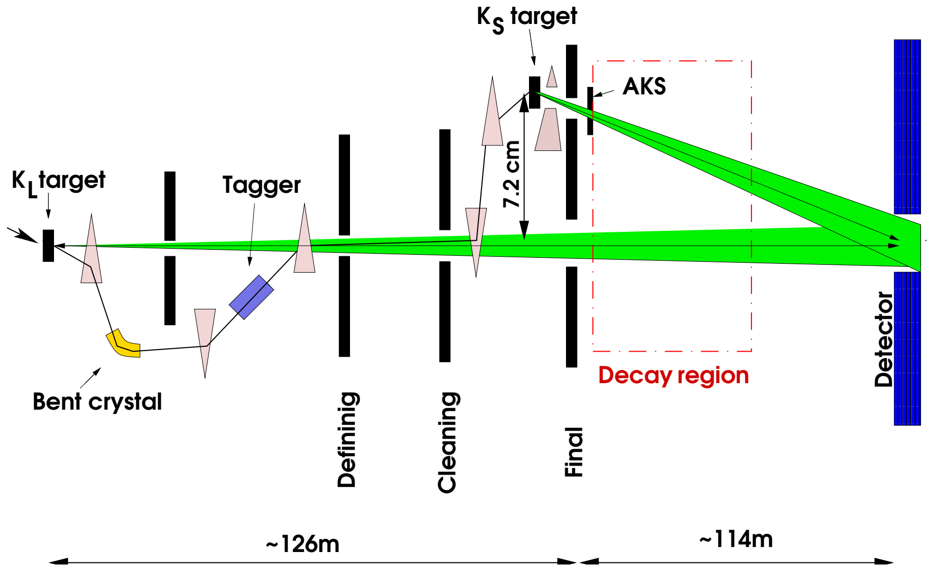


Fig. 1. The NA48 beam setup.

The two beams, K_L and K_S, can be present simultaneously, as in the data taking mode suited for ϵ'/ϵ measurement, or separately for other studies.

The secondary proton beam is normally much less intense than the primary ($\sim 10^{-5}$), but, for special "high intensity runs", the K_L target and the bent crystal can be removed, and the primary beam transported directly to the K_S target.

2.2. The detectors

The kaons decay inside a 90 m long, tapered vacuum tank, terminated by a kevlar window. Protruding from the window center, a 16 cm diameter beam pipe traverses all detectors to let the neutral beam pass across the detectors without interacting (see Fig. 2).

Charged particles are detected by a spectrometer consisting of four drift chambers and a dipole magnet, with a transverse momentum kick of 265 MeV/c, placed between the second and the third chamber. The spectrometer is enclosed by a gas-tight tank filled with helium. The momentum resolution is

$$\frac{\sigma_p}{p}(\%) = 0.48 \oplus 0.009\,p \qquad (p \text{ in GeV}/c). \tag{1}$$

where $\oplus$ indicates the sum in quadrature. The space resolution in each transverse coordinate is 90 μm and the average efficiency per plane is better than 99%.

For the detection of the photons, a quasi-homogeneous liquid krypton calorimeter is placed downstream the spectrometer. This detector has a 127 cm thick, projective tower structure. The surface is subdivided into 13212 2 cm × 2 cm cells. The energy resolution is

$$\frac{\sigma_E}{E}(\%) = \frac{3.2}{\sqrt{E}} \oplus \frac{10.0}{E} \oplus 0.5 \qquad (E \text{ in GeV}). \tag{2}$$

The time and space resolutions achieved for 20 GeV photons are better than 300 ps and 1.3 mm, respectively.

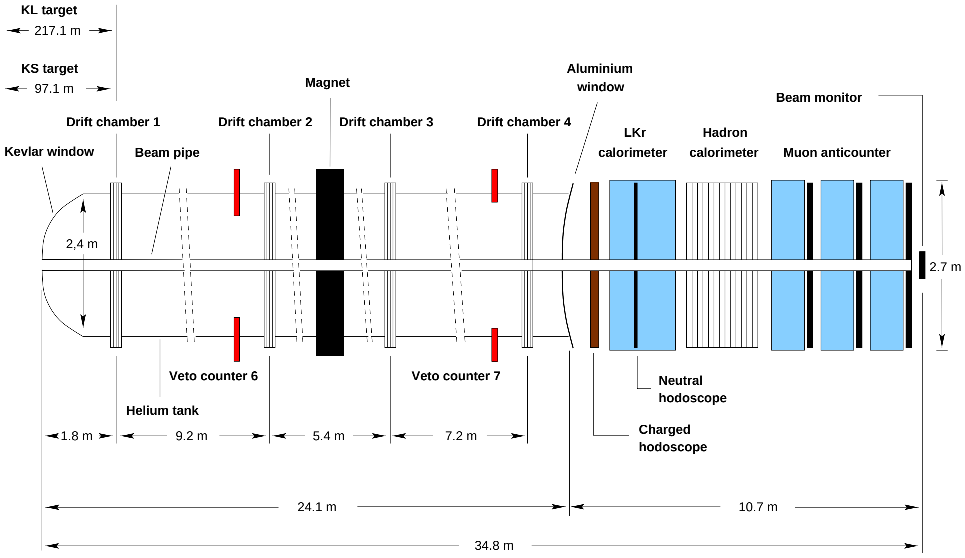


Fig. 2. The NA48 detectors.

A charged hodoscope, made of two planes of scintillators, segmented into horizontal and vertical slabs, is placed between the spectrometer and the calorimeter.

A hadron calorimeter and a muon detector are located after the electromagnetic calorimeter.

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

In the decay $K_S \to \pi^0\gamma\gamma$, the photon pair is produced by a pseudo-scalar meson pole (Fig. 3). According to the chiral perturbation theory (χPT), this pole is dominated by π^0 contribution, so the lowest order amplitude is non-vanishing, in contrast to the $K_L \to \gamma\gamma$ decay. The theoretical prediction for the branching ratio, limited to the kinematic region $z = m^2_{\gamma\gamma}/m^2_K > 0.2$ where the $\pi^0\pi^0$ background is minimum, yields 3.8×10^{-8}.

Using the data collected in the special high intensity K_S run of 2000, a sample of 31 $K_S \to \pi^0\gamma\gamma$ candidates pass all cuts applied. The background, estimated with

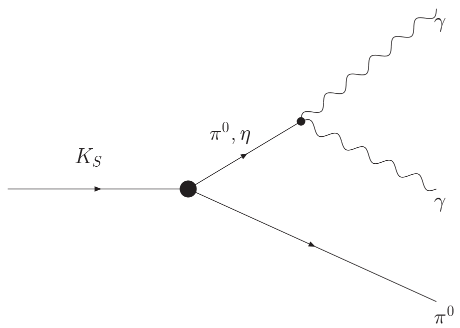


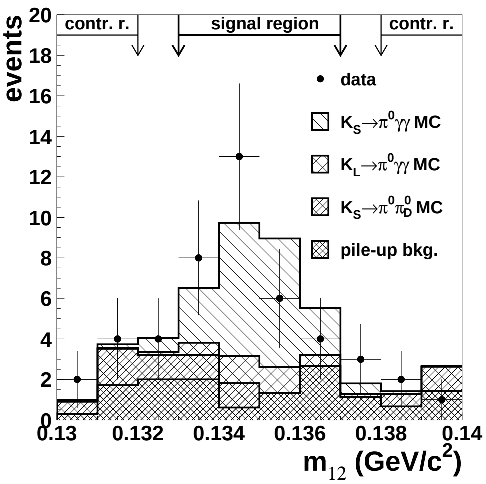
Fig. 3. Diagram for the $\mathrm{K_S} \to \pi^0\gamma\gamma$ *decay.*

Monte Carlo simulations of $\mathrm{K_L} \to \pi^0\gamma\gamma$ and $\mathrm{K_L} \to \pi^0\pi^0_\mathrm{D}$ plus study on accidental activity, is of 13.1 ± 3.1 events (Fig. 4). Normalizing to a $\mathrm{K_S} \to \pi^0\pi^0$ sample, and taking into account the different acceptances, one obtains

$$BR(\mathrm{K_S} \to \pi^0\gamma\gamma)_{z>0.2} = (5.1 \pm 1.6_{\mathrm{stat}} \pm 0.9_{\mathrm{syst}}) \times 10^{-8}\,, \tag{3}$$

in good agreement with the (χPT) predictions [1].

A further test on (χPT) could be done by measuring the z-dependence of the *BR*. Figure 5 shows that the statistical and background uncertainties do not allow for an unambiguous conclusion.



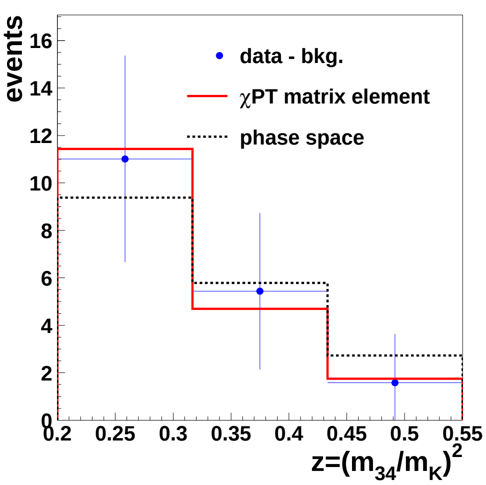


Fig. 4 (left). Invariant-mass distribution of the photon pair assigned to the π^0*. The data in the control region are accounted for by background, while the signal region contains a conspicuous excess, consistent with a* $\mathrm{K_S} \to \pi^0\gamma\gamma$ *signal.*

Fig. 5. The z*-distribution of data after background subtraction, compared to Monte Carlo* $\mathrm{K_S} \to \pi^0\gamma\gamma$ *simulation, using phase space (dashed) and (χPT) matrix element (continuous).*

4. *Study of* $\mathrm{K_{L,S}} \to \pi^+\pi^-\mathrm{e^+e^-}$

The $\mathrm{K_L} \to \pi^+\pi^-\mathrm{e^+e^-}$ decay is dominated by the CP-violating inner bremsstrahlung term (IB) and by the CP-conserving direct emission M1 amplitude (DE) (Fig. 6). The interference between the IB (CP = +1) and the DE (CP = −1) amplitudes induces a CP-violating, circular polarization of the γ^*.

If ϕ is the angle between the $\mathrm{e^+e^-}$ and $\pi^+\pi^-$ planes, the following asymmetry can be measured

$$A^{\mathrm{L}}_{\phi} = \frac{N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}}{N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}}. \tag{4}$$

A calculation from Heiliger and Sehgal [2] gives $A^{\mathrm{L}}_{\phi} \approx 14\%$.

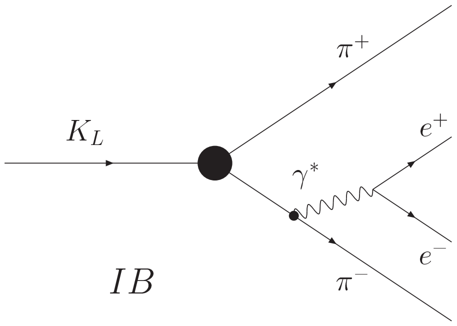


Fig. 6. Diagrams for $\mathrm{K_L} \to \pi^+\pi^-\mathrm{e^+e^-}$*, with inner bremsstrahlung (IB) and direct emission (DE).*

The $\mathrm{K_S} \to \pi^+\pi^-\mathrm{e^+e^-}$ decay is dominated by the CP-conserving IB, with no expected angular asymmetry. Therefore this decay can be used to cross check the $\mathrm{K_L}$ analysis.

From the data collected in 1998 and 1999, a sample of 1162 $\mathrm{K_L} \to \pi^+\pi^-\mathrm{e^+e^-}$ candidates was selected. The angular asymmetry, before any acceptance correction, is $(24.9\pm2.9_{\mathrm{stat}})\%$. The corrected A^{L}_{ϕ}, obtained in a model-dependent way by taking into account the acceptance distribution, is [3]

$$A^{\mathrm{L}}_{\phi} = (14.2 \pm 3.0_{\mathrm{stat}} \pm 1.9_{\mathrm{syst}})\%\,, \tag{5}$$

showing a clear signature of indirect CP violation.

For the $\mathrm{K_S} \to \pi^+\pi^-\mathrm{e^+e^-}$ decay the measured asymmetry is

$$A^{\mathrm{S}}_{\phi} = (0.5 \pm 4.0_{\mathrm{stat}} \pm 1.9_{\mathrm{syst}})\%\,, \tag{6}$$

showing that detector systematics are small.

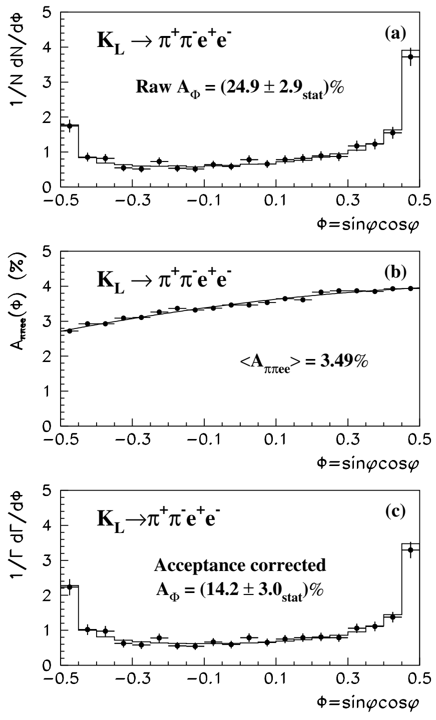


Fig. 7. Distribution of $K_L \to \pi^+\pi^-e^+e^-$ *events in the angular variable* $\sin\phi\cos\phi$ *before (a) and after (c) acceptance corrections. The histograms are Monte Carlo predictions. (b) Acceptance as a function of* $\sin\phi\cos\phi$*. The solid line is a polynomial fit of the Monte Carlo calculation.*

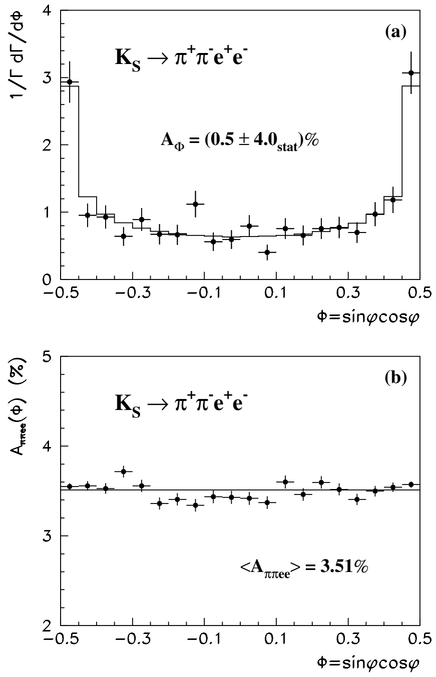


Fig. 8. Distribution of events (a) and acceptance (b) for $K_S \to \pi^+\pi^-e^+e^-$ *decays as a function of* $\sin\phi\cos\phi$*. The histogram in (a) is Monte Carlo prediction. In (b) a solid line represents the average value of the acceptance.*

The measured branching ratios are

$$BR(\mathrm{K_L} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-) = (3.08 \pm 0.20) \times 10^{-7}, \tag{7}$$

$$BR(\mathrm{K_S} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-) = (4.71 \pm 0.32) \times 10^{-5}. \tag{8}$$

By combining this result with the value already published for $\mathrm{K_S}$ [4], one obtains

$$BR(\mathrm{K_S} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-) = (4.69 \pm 0.30) \times 10^{-5}. \tag{9}$$

5. *Conclusions*

For the first time the $\mathrm{K_S} \to \pi^0\gamma\gamma$ decay mode was observed by NA48, with a BR in agreement with (χPT) predictions. A study of $\mathrm{K_{L,S}} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-$ decays yielded measurements of both branching ratios and angular asymmetries, also in good agrement with theoretical predictions.

References

[1] G. Ecker, A. Pich and E. de Rafael, Phys. Lett. B **189** (1987) 363.

[2] P. Heiliger and L. M. Sehgal, Phys. Rev. D **48** 4146 (1993); (Erratum) **60** (1999) 079902.

[3] A. Lai et al., NA48 Collaboration, CERN-EP-2003-006, submitted to EPJ.

[4] A. Lai et al., NA48 Collaboration, Phys. Lett. B **496** (2000) 137.

NOVI ISHODI SURADNJE NA48 O RIJETKIM RASPADIMA NEUTRALNIH KAONA

Izvješćujemo o nedavnim ishodima suradnje NA48 o rijetkim raspadima neutralnih kaona. Načinili smo prvo opažanje $K_S \to \pi^0\gamma\gamma$ i podrobno proučili raspad $K_{L,S} \to \pi^+\pi^-e^+e^-$.