NA48 RESULTS ON RARE K^0 DECAYS

GIUSEPPINA ANZIVINO
(on behalf of the NA48 Collaboration [a])
Dipartimento di Fisica, Università di Perugia
Via A. Pascoli, 06124 Perugia, Italy

The main purpose of the NA48 experiment is the determination of the direct CP violation parameter Re$(\varepsilon'/\varepsilon)$ from simultaneous measurement of the $\mathrm{K_{L,S}} \rightarrow \pi^0\pi^0,\ \pi^+\pi^-$ decay modes. At the same time, however, others kaon decay modes are being recorded. In the following I will report on preliminary new results on the decays $\mathrm{K_S} \rightarrow \gamma\gamma$, $\mathrm{K_S} \rightarrow \pi^0\mathrm{e^+e^-}$, $\mathrm{K_S} \rightarrow \pi^+\pi^-\mathrm{e^+e^-}$ and $\mathrm{K_L} \rightarrow \mathrm{e^+e^-e^+e^-}$.

1 Experimental set-up and data taking

Two simultaneous and almost collinear neutral beams converge towards the NA48 detector. The $\mathrm{K_L}$ beam is produced from a 450 GeV/c SPS proton beam ($\sim 1.5 \times 10^{12}\,ppp$); the $\mathrm{K_S}$ beam is produced splitting off a small fraction of the primary proton beam using a bent crystal ($\sim 3 \times 10^7\,ppp$). The NA48 detector is described in detail elsewhere [1], its main components are recalled in the following. A liquid krypton electromagnetic calorimeter (LKr) used to measure energy, position and time of electromagnetic showers, with energy resolution of $\sigma(E)/E \simeq 0.100/E \oplus 0.032/\sqrt(E) \oplus 0.005$ (E in GeV) and position and time resolution for a single photon better than $1.3\,mm$ and $300\,ps$, respectively. A magnetic spectrometer (four drift chambers and a dipole magnet) with a momentum resolution of $\sigma_p/p \simeq [0.5 \oplus 0.009p]\%$ (p in GeV/c). A hodoscope of scintillating counters for triggering purpose with a time resolution of $\sim 150\,ps$. An iron-scintillator hadron calorimeter and a muon identification system.

The results presented are based on data recorded in 1998 and 1999 at different trigger and beam intensity conditions; the analysis of the decays $\mathrm{K_S} \rightarrow \gamma\gamma$ and $\mathrm{K_S} \rightarrow \pi^0\mathrm{e^+e^-}$ is based on data collected during a 2-day test run in 1999 using a $\mathrm{K_S}$ beam only at high intensity ($\sim 6 \times 10^9\,ppp$).

2 Measurement of the Branching Ratio $\mathrm{K_S} \rightarrow \gamma\gamma$

The study of the decay $\mathrm{K_S} \rightarrow \gamma\gamma$ is interesting for the understanding of the low energy hadronic dynamics in Chiral Perturbation Theory (χPT), since it is sensitive to higher order loop effects.

[a] Cagliari-Cambridge-CERN-Dubna-Edinburgh-Ferrara-Firenze-Mainz-Orsay-Perugia-Pisa-Saclay-Siegen-Torino-Warsaw-Wien

There are no short distance contributions and theoretical predictions for the branching ratio are finite and unambiguous (2.25×10^{-6} with an error of less than 10 %); the measured value [2] is $(2.4 \pm 0.9) \times 10^{-6}$.

The kaon energy and decay vertex are reconstructed from the energies and the positions of the electromagnetic showers, measured in the LKr. In order to select $\mathrm{K} \to \gamma\gamma$ candidates, the data sample is restricted to events with ≥ 2 energy clusters. Pairs of clusters that are in time within $5\,ns$ are then selected, with the additional requirement that no other cluster with energy $\geq 1.5\,GeV$ is in time with the event in a window of $3\,ns$.

The main contribution to the background comes from $\mathrm{K_S} \to \pi^0\pi^0$ (also used as normalization channel) with two photons lost. This background can be removed using an appropriate definition of the decay region. Kinematically, the maximum value of the $\gamma\gamma$ mass from $\mathrm{K_S} \to \pi^0\pi^0$ decay is 458 MeV, which tanslates in a minimum value of the vertex position of $9\,m$. A decay region of $5\,m$ downstream of the last collimator is almost background free. After this cut, the sample of observed $\mathrm{K} \to \gamma\gamma$ events has three components: $\mathrm{K_S} \to \gamma\gamma$ decays, $\mathrm{K_L} \to \gamma\gamma$ and residual background. The vertex distribution of those events is shown in Fig. 1: open circle are $\mathrm{K_S} \to \pi^0\pi^0$ events, closed squares are $\mathrm{K} \to \gamma\gamma$. The solid line shows the $\gamma\gamma$ background from MC simulated $\mathrm{K_S} \to \pi^0\pi^0$ decays. The peak at z = -1250 cm is due to η mesons produced in the AKS (a set of scintillating counters used to precisely define the beginning of the fiducial region).

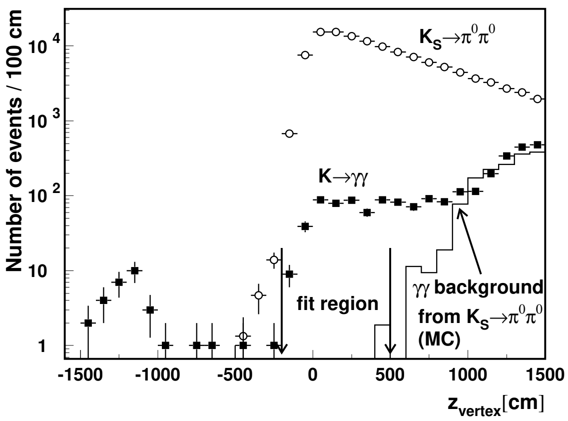

Figure 1 *z_v distribution for data and MC.*

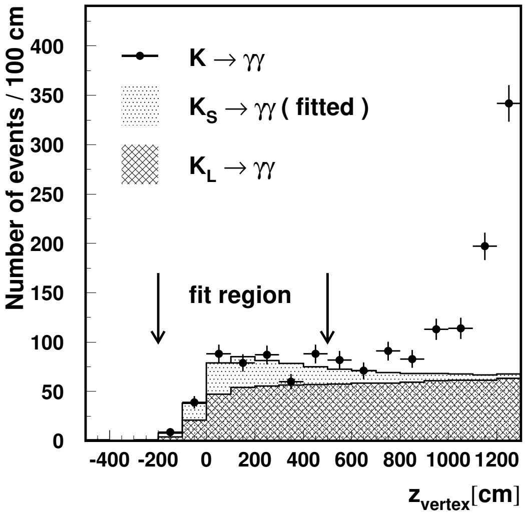

Figure 2 *Fitted* $\mathrm{K_S} \to \gamma\gamma$ *signal.*

Knowing the $\mathrm{K_L} \to \gamma\gamma$ branching ratio, the $\mathrm{K_L} \to \gamma\gamma$ contribution can be estimated from the $\mathrm{K_L}$ flux at the target; this can be determined using the observed $\mathrm{K_S} \to \pi^0\pi^0$ events since the $\mathrm{K_L}$ and $\mathrm{K_S}$ fluxes are equal at the production target. The number of $\mathrm{K_S}$ in the 5 m decay region, at a given energy E, can be evaluated from the number of $\mathrm{K_S} \to \pi^0\pi^0$ in the fiducial region, corrected for detector acceptance and trigger efficiency, and from the branching ratio $\mathrm{K_S} \to \pi^0\pi^0$. The number of decays is then extrapolated back to the production target, using the $\mathrm{K_S}$ lifetime, to determine the $\mathrm{K_S}$ and hence the $\mathrm{K_L}$ flux. Residual background has been evaluated using a full simulation of the detector.

The $\mathrm{K_S} \to \gamma\gamma$ branching ratio has been measured using a binned maximum likelihood method by comparing the data (divided in 11 kaon energy and 7 longitudinal vertex position bins) to the expected rates, leaving the branching ratio as a free parameter. The result is shown in Fig. 2 where the dotted area represents the fitted $\mathrm{K_S} \to \gamma\gamma$ events and the hatched area the $\mathrm{K_L} \to \gamma\gamma$ component. The closed circles show the data and the arrows identify the fitted region. We found 147 ± 21 $\mathrm{K_S} \to \gamma\gamma$ events and a value for the branching ratio of

$$BR(\mathrm{K_S} \to \gamma\gamma) = (2.58 \pm 0.36(stat) \pm 0.22(sys)) \times 10^{-6}$$

This measurement is in good agrement with the theoretical predictions and has an error a factor 2 better than the previously published result. The main contributions to the systematic error are: uncertainty on BR($K_L \to \gamma\gamma$) (5%), selection cuts (4%), background (5%), acceptance (2%) and trigger efficiency (2%).

3 Search for $K_S \to \pi^0 e^+ e^-$

The study of $K_S \to \pi^0 e^+ e^-$ is interesting because of its connection to the companion decay $K_L \to \pi^0 e^+ e^-$, in which conserving and non conserving CP amplitudes contribute. Whilst the CP conserving contribution can be obtained by measuring the low $m_{\gamma\gamma}$ component for the $K_L \to \pi^0\gamma\gamma$ decay, the study of $K_S \to \pi^0 e^+ e^-$ can set bounds on the indirect CP violation term. The predictions of χPT on the branching ratio are at the level of 10^{-9}, while the experimental limit [3] is $BR(K_S \to \pi^0 e^+ e^-) < 1.1 \times 10^{-6}$ at 90% confidence level.

$K_S \to \pi^0 e^+ e^-$ candidates were selected by requiring events with at least four clusters, two tracks and one vertex. Then groups of four clusters have to pass additional cuts on individual and total energy and on relative distance between them. The selected clusters must be within $3\,ns$ from the event time. The electron candidates were identified by requiring that cluster centers in the LKr are within $1.5\,cm$ from the extrapolation of each track. Candidate π^0's were formed from pairs of clusters with no associated track and an invariant mass within 3 MeV/c^2 with respect to the nominal π^0 mass ($\sim 3\sigma$). K^0 candidates were formed from the clusters associated to the pion and the clusters associated to the electron tracks and the invariant mass of the $\pi^0 e^+ e^-$ candidates was required to be within 6 MeV/c^2 with respect to the nominal K^0 mass ($\sim 3\sigma$).

The main background to $K_S \to \pi^0 e^+ e^-$ decay comes from $K_S \to \pi^0 \pi^0_D$ (also used as normalization channel) with $\pi^0_D \to e^+ e^- \gamma$ and one photon lost. This background is rejected by requiring the invariant mass $m_{\gamma\gamma}$ to be greater than 165 MeV/c^2; based on a simulation of 10^8 $K_S \to \pi^0 \pi^0_D$ decays, less than 0.3 events were expected in the data sample. Other sources of background are negligible.

After applying all the selection criteria, no $K_S \to \pi^0 e^+ e^-$ candidate remained in the data sample. In Fig. 3 it is shown a comparison of the electron-positron invariant mass (M_{ee}) obtained for the normalization channel with the one predicted [4] for $K_S \to \pi^0 e^+ e^-$. No event has been found in the region $M_{ee} > 165$ MeV/c^2: this allows to calculate a model independent upper limit of

$$BR(K_S \to \pi^0 e^+ e^-, M_{ee} > 165\ MeV/c^2) < 8.3 \times 10^{-8} \text{ (at 90\% CL)}$$

Extrapolating this limit to the full phase-space, assuming matrix element from model [4], we find an upper limit of

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

This result is an order of magnitude better than the previously published limit.

4 Observation of the decay $K_S \to \pi^+ \pi^- e^+ e^-$

The main production process for $K_S \to \pi^+ \pi^- e^+ e^-$ is the CP conserving inner bremsstrahlung; no asymmetry is expected contrary to the $K_L \to \pi^+ \pi^- e^+ e^-$ decay where an asymmetry is generated by the interference between CP conserving and CP violating amplitudes. In Fig. 4 it is shown the first observation of $K_S \to \pi^+ \pi^- e^+ e^-$ based on data collected in 1998: candidate events (dots) are compared to MC; lines indicate the accepted mass region for good events. A clean sample of 56 events was identified with negligible background contamination. Using $K_L \to \pi^+ \pi^- \pi^0_D$ decays as normalization channel, the branching ratio is measured to be

$$BR(\mathrm{K_S} \to \pi^+\pi^-\mathrm{e^+e^-}) = (5.1 \pm 0.9(stat) \pm 0.3(sys)) \times 10^{-5}$$

Using a larger data sample (1998 and 1999) a preliminary result for the asymmetry consistent with zero has been measured, in agreement with theoretical predictions.

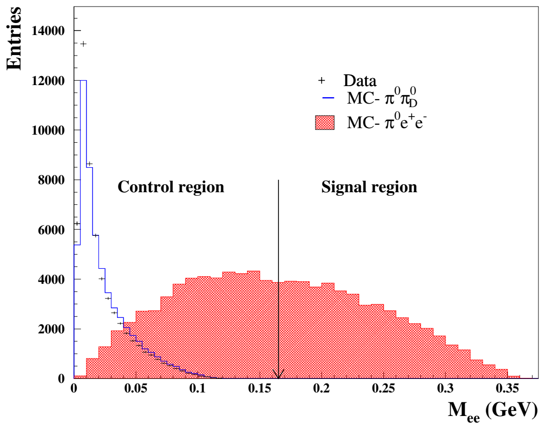

Figure 3 *M_{ee} spectra for signal and background*

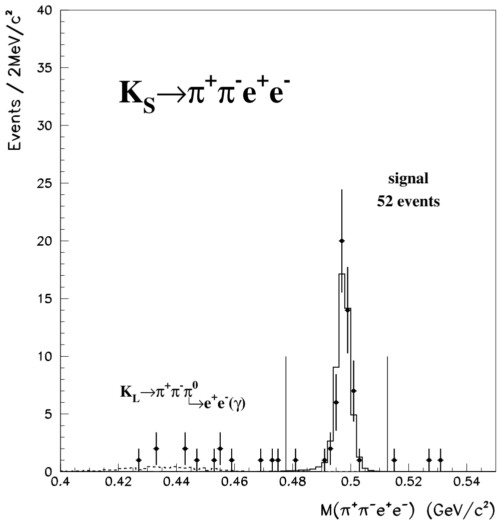

Figure 4 *Invariant mass distribution.*

5 Measurement of the branching ratio $\mathrm{K_L} \to \mathrm{e^+e^-e^+e^-}$

The analysis for this decay is based on data collected in 1999, during the normal $\mathrm{Re}(\varepsilon'/\varepsilon)$ data taking. Events were preselected requiring two positive and two negative tracks with distance of closest appoach to the vertex $< 15\,cm$. Electron candidates were identified by requiring that cluster centers in LKr be within $1.5\,cm$ from the extrapolation of each track. To reject pion showers, the ratio of cluster energy to track momentum E/p was required to be between 0.9 and 1.2.

Background coming from two coincident $\mathrm{K_L} \to \pi e \nu$ decays, with pions misidentified as electrons, is rejected requiring a good vertex quality; a cut on the invariant mass is used to reject $\mathrm{K_L} \to \pi^0\pi^0\pi^0$ decays, with at least one π^0 undergoing single or double Dalitz decay, and $\mathrm{K_L} \to \gamma\gamma$ and $\mathrm{K_L} \to \mathrm{e^+e^-}\gamma$ decays with conversion of the photons. The background from $\mathrm{K_L} \to \pi^+\pi^-\mathrm{e^+e^-}$ is negligible. After applying corrections for the acceptance and efficiencies, the obtained result is

$$BR(\mathrm{K_L} \to \mathrm{e^+e^-e^+e^-}) = (3.67 \pm 0.32(stat) \pm 0.23(sys) \pm 0.08(norm)) \times 10^{-6}$$

Acknowledgments

I am happy to thank the Organizing Commitee for the very interesting conference and also for the nice time I spent in Vietnam.

References

1. V. Fanti *et al. Phys. Lett.* B465 (1999) 335.
2. G. Barr *et al.*, *Phys. Lett.* B351 (1995) 579.
3. G. Barr *et al.*, *Phys. Lett.* B304 (1993) 381.
4. G. D'Ambrosio, G. Ecker, G. Isidori, and J. Portoles, hep-ph/9808289.