NEW RESULTS OF KAON RARE DECAYS FROM NA48

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The decay $K_L \to \pi^0\gamma\gamma$ has been analyzed using 1999 and parts of 1998 NA48 data. 1397 candidates have been found above a background of about 30 events giving a preliminary branching ratio of $\mathrm{Br}(K_L \to \pi^0\gamma\gamma, a_v = -0.45) = (1.51 \pm 0.05_{stat} \pm 0.20_{sys}) \cdot 10^{-6}$. A preliminary result on the decay $K_L \to \pi^+\pi^-e^+e^-$ has been obtained for the 1998 data. The branching ratio based on 458 events is $\mathrm{Br}(K_L \to \pi^+\pi^-e^+e^-) = (2.90 \pm 0.15_{stat}) \cdot 10^{-7}$. The CP asymmetry observed in the angular distribution between the $\pi\pi$ and the ee plane is $(20 \pm 5)\%$. The decay $K_S \to \pi^+\pi^-e^+e^-$ has been observed for the first time with a branching ratio in the order of $4 \cdot 10^{-5}$. The CP asymmetry for this decay is consistent with zero as expected.

1 The Decay $\mathbf{K}_L \to \pi^0\gamma\gamma$

1.1 Theory

Rare meson decays like $K_L \to \pi^0\gamma\gamma$ play an important role as a test for chiral perturbation theory. Recent calculations have been performed up to the order of p^6, where p ist the momentum of the pion in the kaon rest frame. These calculations include vector meson exchange contributions. The decay $K_L \to \pi^0\gamma\gamma$ has a second point of interest: it is a CP conserving intermediate state in the decay $K_L \to \pi^0e^+e^-$ (which consists of a direct and a indirect CP violating and a CP conserving amplitude). With the known parameters of the decay $K_L \to \pi^0\gamma\gamma$ it is possible to predict whether $K_L \to \pi^0e^+e^-$ is dominated by CP conserving or CP violating contributions.

The decay $K_L \to \pi^0\gamma\gamma$ has no $\mathcal{O}(p^2)$ tree level contribution because the external particles are neutral. Furthermore, the only $\mathcal{O}(p^4)$ contributions are chiral meson loops which are finite, since no $\mathcal{O}(p^4)$ counterterms and therefore no cut-off ambiguity exist. First calculations of the order of p^4 have been done using 1-loop diagrams [1] (Figure 1a). The expected branching ratio was $\mathrm{Br}(K_L \to \pi^0\gamma\gamma) = 6.8 \cdot 10^{-6}$ with a characteristic two photon invariant mass distribution. The first measurements demonstrated that the two photon mass distribution favours the shape

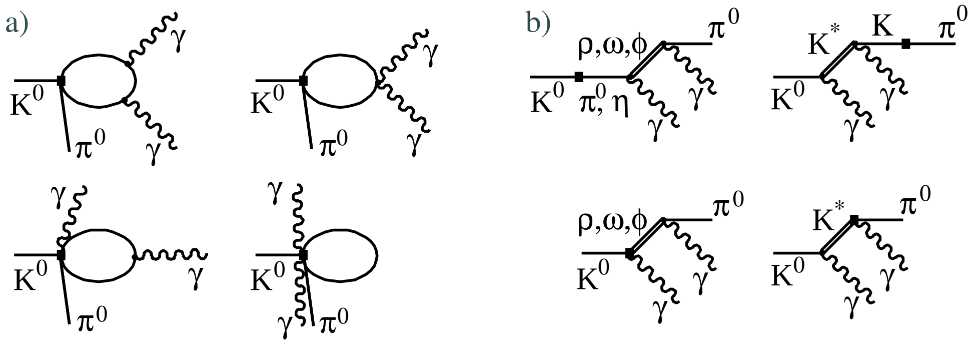

Figure 1: a) 1-loop diagrams to calculate $K_L \to \pi^0\gamma\gamma$ in chiral perturbation theory ($\mathcal{O}(p^4)$).
b) Vector meson exchange contribution to the decay $K_L \to \pi^0\gamma\gamma$.

given by the meson loop contribution, but gave a branching ratio larger than predicted by chiral perturbation theory ($(1.7\pm0.3)\cdot10^{-6}$ by NA31 [2,3] and $(1.86\pm0.6)\cdot10^{-6}$ by E731 [4], respectively).

Because of this discrepancy the calculations have been extended to the next to leading order of (p^6) [5,6,7,8]. The two dominant mechanisms at this order are the two pion intermediate state and the vector meson exchange (Figure 1b). For non-vanishing vector meson exchange the two photon invariant mass spectrum differs significantly from the one obtained with $\mathcal{O}(p^4)$ calculations in the mass region below 240 MeV (Figure 2).

1.2 Event Selection

The decay investigated as well as the decay used for normalization $K_L \to 2\pi^0$ are triggered by the normal ε'/ε neutral trigger and have the same signature in the detector: 4 showers in the liquid Krypton calorimeter and no activity in the drift chambers. Almost the same selection criteria are applied for both channels. We distinguish between both decays using the χ^2 of the two best invariant pion masses, which has to be greater than 100 for $K_L \to \pi^0\gamma\gamma$ and less than 4.5 for $K_L \to 2\pi^0$.

The main background are $K_L \to 3\pi^0$ decays (whose branching ratio is $5\cdot10^5$ times higher than the expected signal branching ratio) with missing and/or overlapping photons. Because of missing photon energy the longitudinal (z-)vertex of the kaon decay is shifted by the reconstruction algorithm to a position downstream of its true value. Therefore, a large amount of

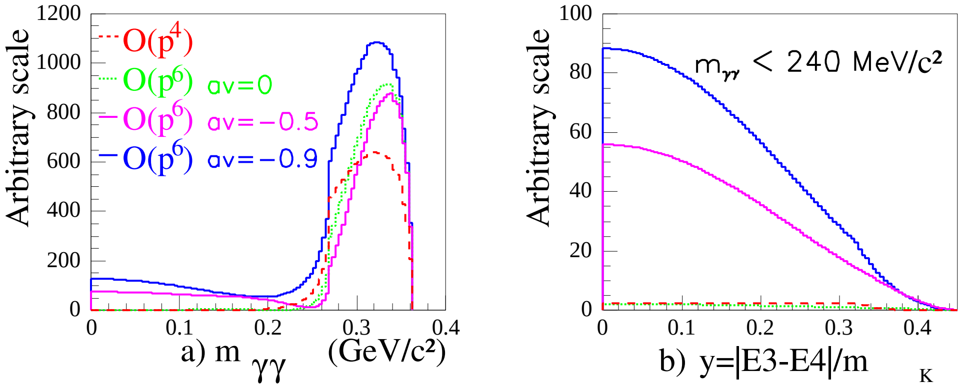

Figure 2: a) Theoretical predictions of the invariant diphoton mass for $K_L \to \pi^0\gamma\gamma$.
b) Difference between the energies of the two photons in the kaon rest frame.

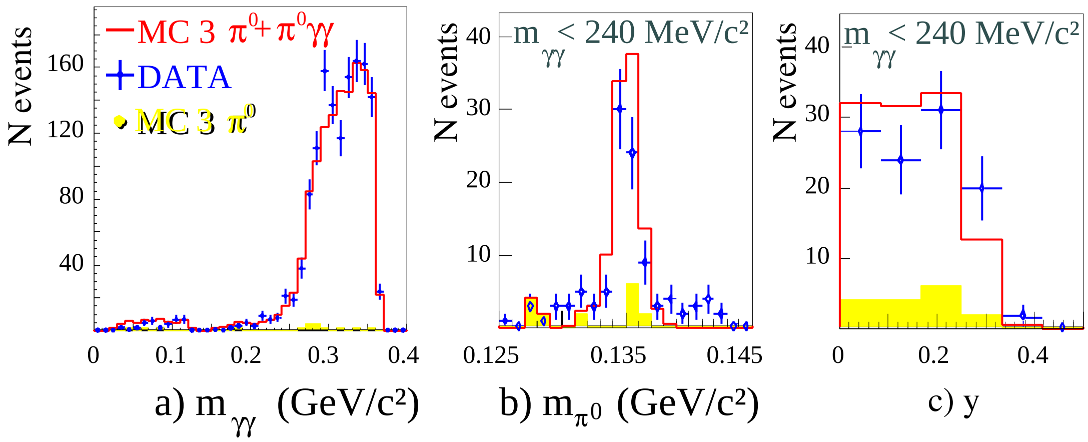

Figure 3: a) Invariant diphoton mass for $K_L \to \pi^0\gamma\gamma$ candidates.
b) Signal for lower diphoton mass region ($m_{\gamma\gamma} < 240$ MeV/c^2).
c) Difference between the energies of the two photons ($m_{\gamma\gamma} < 240$ MeV/c^2).

background events is rejected by a hard vertex requirement. Surviving background events are removed by cutting on the difference between the reconstructed kaon and pion vertices, calculated for all different scenarios of shower overlapping, and by requiring a small cluster width consistent with one electro-magnetic shower.

1.3 Result

Using a part of the 1998 and the full 1999 data sample we find 1397 candidates above a background of about 30 events. Using a Monte Carlo sample with an effective vector coupling of -0.45 to determine the acceptance we obtain a preliminary branching ratio:

$$\mathrm{Br}(K_L \to \pi^0\gamma\gamma, a_v = -0.45) = (1.51 \pm 0.05_{stat} \pm 0.20_{sys}) \cdot 10^{-6}.$$

The signal in the lower invariant diphoton mass region gives clear evidence for a contribution beyond the order of p^4 (Figure 3b).

2 The Decay $K_L \to \pi^+\pi^-e^+e^-$

2.1 Theory

The decay $K_L \to \pi^+\pi^-e^+e^-$ consists of two major amplitudes which interfere: CP violating $K_L \to \pi^+\pi^-$ decay with internal bremsstrahlung and CP conserving direct photon emission (figure 4). Because of this interference the virtual photon has a CP violating polarization which gives rise to a large asymmetry in the angle between the $\pi\pi$ and the ee plane. From theoretical predictions[9, 10] we expect an asymmetry of the order of 14%.

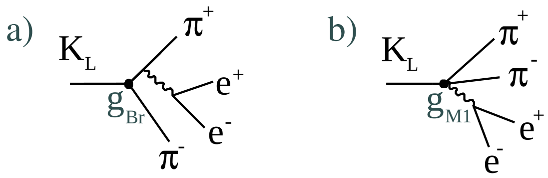

Figure 4: Contributions for the decay $K_L \to \pi^+\pi^-e^+e^-$:
a) CP violating bremsstrahlung.
b) CP conserving direct photon emission.

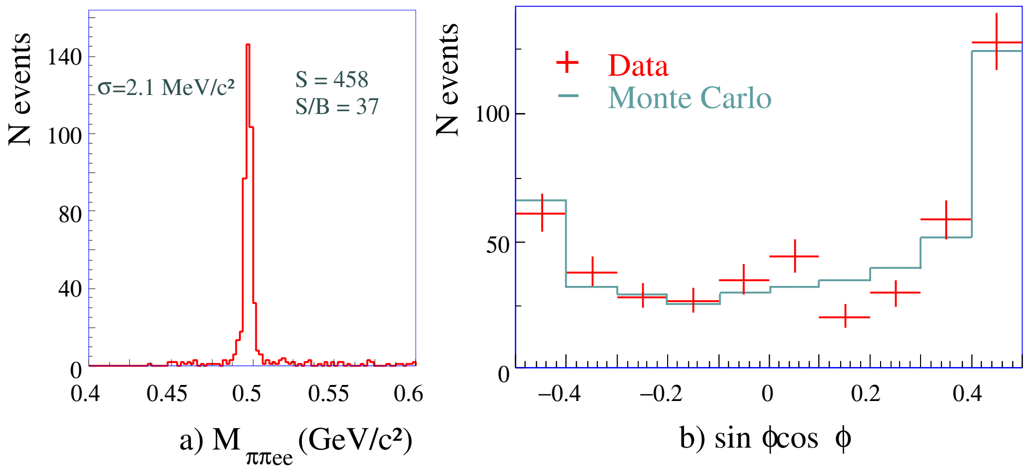

Figure 5: a) Signal for $K_L \to \pi^+\pi^-e^+e^-$ candidates.
b) Asymmetry in the angle between the $\pi\pi$ and the ee plane .

2.2 Result

Using the 1998 data we find 458 events with a signal to background ratio of 37±3 (figure 5a). The preliminary branching ratio is $\mathrm{Br}(K_L \to \pi^+\pi^-e^+e^-) = (2.90 \pm 0.15_{stat}) \cdot 10^{-7}$ not including systematic uncertainties. Analyzing Monte Carlo events generated with no theoretical asymmetry we find no asymmetry, while we see an asymmetry of 22% when we generate 14%. The data show an asymmetry of $(20 \pm 5_{stat})\%$ which is in good agreement with the theoretical predictions (Figure 5b).

3 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 $K_S \to \pi^+\pi^-$ decay with inner bremsstrahlung. Because we have only one process here we do not expect any asymmetry in the angle between the $\pi\pi$ and the ee plane. Besides a test of this theory it is an excellent opportunity to test a possible detector induced asymmetry.

Using the 1998 data we find 58 signal events and calculate a preliminary branching ratio of the order of $4 \cdot 10^{-5}$. From two days of high intensity K_S run in 1999 we extracted 731 candidate events and an asymmetry which is consistent with zero within a few percent. We therefore conclude that the detector does not produce any asymmetry in the decay $K_L \to \pi^+\pi^-e^+e^-$.

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