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NEW RESULTS IN KAON PHYSICS FROM NA48 AND KTEV

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ABSTRACT

In the recent year many new results from kaon decays have been reported from both the NA48 experiment at CERN and the KTeV experiment at Fermilab. Both experiments have new and improved measurements of the parameter $\mathrm{Re}(\epsilon'/\epsilon)$ of direct CP violation in the neutral kaon system. Also several new results on rare and very rare K_L decays were reported. In addition, the NA48 collaboration has performed special high-intensity K_S run periods, with the first results now being available.

1 Introduction

Kaon physics has been a very fruitful field in particle physics since a long time. This has been true in particular for the investigation of CP violation, but also for the precise determination of fundamental parameters such as the Cabibbo angle V_{us} or for the understanding of low energy meson dynamics, for which perturbative QCD cannot be used and instead effective theories as Chiral Perturbation Theory have to be applied.

Even though many results stem from experiments made in the 1970's, thirty years later the field of kaon decays is still of considerable interest for physics. The reason for this is the huge amount of statistics accumulated by the main players NA48 at CERN and KTeV at Fermilab, which makes it possible to do precision measurements — as e.g. for the determination of direct CP violation — as well as to search for extremely rare decays.

Both the NA48 and KTeV experiments were built for the precise determination of $\mathrm{Re}(\epsilon'/\epsilon)$, which is a measure of the amount of direct CP violation in kaon decays. The two experiments derive the beams of neutral kaons from interactions of protons with 400 GeV (NA48) or 800 GeV (KTeV) energy on a fixed target. Charged particles in the kaon beam are deflected by sweeping magnets. To ensure pure K_L beams, the neutral particles have to travel more than 100 m before reaching the fiducial decay volume of similar length. To create a beam of short-lived K_S mesons the NA48 experiment uses a second target, positioned slightly above the K_L beam-line and shortly before the decay volume. KTeV on the other hand uses a regenerator placed in front of one of its two K_L beam lines to produce K_S mesons.

The measurement of direct CP violation, described in the next section, has been the original purpose of the two experiments. However, either with the same data or with data from special data taking periods, also the investigation of many rare K_L and K_S decays has been possible. The most recent results are reported in the sections 3 and 4. In the last section an outlook on measurements of $K^{\pm}$ decays with the NA48/2 experiment is given.

2 Measurement of direct CP violation

In 1964 Christenson, Cronin, Fitch, and Turlay discovered CP violation in the decay of the long-lived kaon K_L to two pions [1]. It is explained by the small admixture of the eigenstates with opposite CP to the mass eigenstates: $|K_L\rangle \propto |K_2\rangle + \epsilon\,|K_1\rangle$ and $|K_S\rangle \propto |K_1\rangle + \epsilon\,|K_2\rangle$, with the CP eigenstates $|K_1\rangle$ and $|K_2\rangle$ for $CP = +1$ and -1,

resp., and the parameter ϵ measured to $|\epsilon| = (2.28 \pm 0.02) \times 10^{-3}$. In the Standard Model, this so-called indirect CP violation is explained by the complex phase of the CKM matrix and mediated by $K^0\overline{K^0}$ oscillations via box diagrams.

A second possibility of CP violation is the direct decay of the K_2 state to two pions. In contrast to indirect CP violation it leads to different partial widths of the decays of K^0 and $\overline{K^0}$ to two pions. Its strength is given by the parameter ϵ', which is of the order 10^{-6} and can be measured by the amplitude ratios

$$\eta_{+-} \;=\; \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} \;\simeq\; \epsilon + \epsilon' \quad \text{and} \quad \eta_{00} \;=\; \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} \;\simeq\; \epsilon - 2\,\epsilon'. \quad (1)$$

Within the Standard Model direct CP violation proceeds via penguin diagrams and is in general non-vanishing, while for other theories — as e.g. a hypothetical superweak interaction — ϵ' has to be zero.

Both experiments NA48 and KTeV measure direct CP violation via the double ratio

$$R \;\equiv\; \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} \;\approx\; 1 - 6 \times \mathrm{Re}\left(\frac{\epsilon'}{\epsilon}\right). \quad (2)$$

This method has the advantage of the cancellation of many systematic uncertainties, when all four decay modes are measured simultaneously.

The NA48 collaboration has recently finished the analysis on their complete data set, which contains data from the years 1997–99 and 2001. The data sample contains about 5×10^6 recorded events of the statistically limiting decay $K_L \to \pi^0\pi^0$. The KTeV collaboration has so far published results from their 1996 and 97 data sets, which correspond to a total of 3.4×10^6 reconstructed $K_L \to \pi^0\pi^0$ decays. The 1999 KTeV data are still being analyzed.

The analysis methods of the two experiments are fairly similar, with the exception of the treatment of K_S and K_L acceptances. NA48 weights the $K_L \to 2\pi$ events with the K_S life-time in order to reduce the K_S-K_L acceptance differences to pure beam geometry. This method however loses about 70% of the K_L statistics. The KTeV collaboration on the other hand uses a Monte Carlo simulation to account for the acceptance differences, which allows the use of the whole K_L statistics for the analysis, but results in an about 20 times larger correction on the result. Both experiments have made huge efforts to understand and possibly reduce systematic uncertainties. A list of the systematics is given in Tab. 1. The largest uncertainty comes from the energy scale and possible non-linearities of the electromagnetic calorimeters used to measure the $K^0 \to 2\pi^0$ decays.

	NA48 (2001)	KTeV (96/97)
Trigger efficiency	± 0.6	± 0.6
$\pi^+\pi^-$ reconstruction	± 0.5	± 0.3
$\pi^0\pi^0$ reconstruction	± 0.9	± 1.5
Background	± 0.7	± 1.1
Accidental activity	± 0.6	—
K_S tagging	± 0.7	—
Acceptance	± 0.7	± 0.9
MC statistics	± 0.6	± 0.6
Fit procedure	—	± 0.3
Total	± 1.8	± 2.4

Table 1: *Systematic uncertainties on* $\mathrm{Re}(\epsilon'/\epsilon)$ *for NA48 and KTeV.*

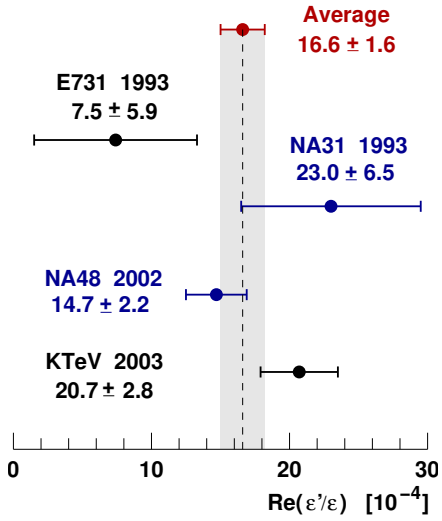

Figure 1: *Recent measurements and current world average for* $\mathrm{Re}(\epsilon'/\epsilon)$.

The final result of the NA48 experiment on the combined 1997–99 and 2001 data is $\mathrm{Re}(\epsilon'/\epsilon) = (14.7 \pm 1.4_{\mathrm{stat}} \pm 1.7_{\mathrm{syst}}) \times 10^{-4}$ [2]. The KTeV collaboration has published the measurement $\mathrm{Re}(\epsilon'/\epsilon) = (20.7 \pm 1.5_{\mathrm{stat}} \pm 2.4_{\mathrm{syst}}) \times 10^{-4}$ on the 1996 and 97 data [3]. The combined world average, including the results of the predecessor experiments NA31 at CERN and E731 at Fermilab as shown in Fig. 1, now is

$$\mathrm{Re}(\epsilon'/\epsilon) = (16.6 \pm 1.6) \times 10^{-4}. \tag{3}$$

This establishes a non-zero value of ϵ' and therewith the existence of direct CP violation in neutral kaon decays at a $10\,\sigma$ level.

However, the theoretical interpretation of the value of the result remains difficult, as long range contributions dominate and the QCD and electro-weak penguin amplitudes destructively interfere. Furthermore, a strong dependence on the strange quark mass exists. A large number of groups have tried to predict $\mathrm{Re}(\epsilon'/\epsilon)$, but results vary by more of an order of magnitude and still have large uncertainties.

3 Rare K_L decays

Apart from the measurement of direct CP violation, both experiments have accumulated large amounts of statistics of K_L decays. The KTeV collaboration has performed special data taking periods in 1997 and 1999 (experiment E799) for the investigation of rare K_L decays. This was not done in NA48, where rare K_L decays were recorded together with the $K \to 2\pi$ decays used for the $\mathrm{Re}(\epsilon'/\epsilon)$ measurement.

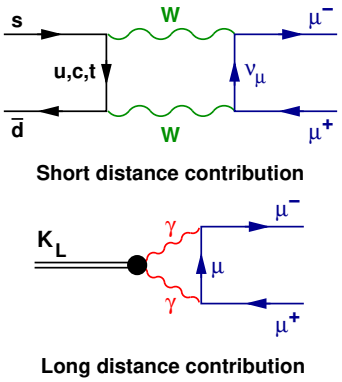

Figure 2: *Diagrams of short and long distance contributions to* $K_L \to \mu^+\mu^-$.

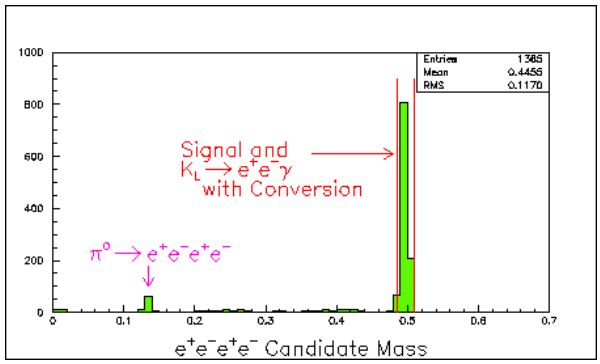

Figure 3: *Invariant mass distribution of the KTeV* $K_L \to e^+e^-e^+e^-$ *candidates.*

The KTeV experiment has for most K_L decays about $3-4$ times more statistics collected than NA48, they therefore dominate most of the rare K_L decay measurements.

3.1 The decays $K_L \to \gamma^\star\gamma^\star$

Interest in the decays $K_L \to \gamma^\star\gamma^\star$ — with the virtual photons either becoming real photons or producing $e^+e^-/\mu^+\mu^-$ pairs — is high, as they determine the long distance contribution to the decay $K_L \to \mu^+\mu^-$ (Fig. 2). For this measurement the decays $K_L \to e^+e^-e^+e^-$ and $K_L \to \mu^+\mu^-e^+e^-$ are well suited, however, they also exhibit very small branching fractions.

The KTeV collaboration has recently analyzed their full 1997 and 99 data set for $K_L \to e^+e^-e^+e^-$ decays. They observe 1056 signal events, with a background expectation of only 5 events, which come from $K_L \to e^+e^-\gamma$ decays with an external γ conversion on detector material (Fig. 3). The preliminary result on the branching fraction is

$$\mathrm{Br(K_L \to e^+e^-e^+e^-)} = (4.07 \pm 0.12_{\mathrm{stat}} \pm 0.11_{\mathrm{syst}} \pm 0.16_{\mathrm{norm}}) \times 10^{-8}. \qquad (4)$$

The evaluation of the form factor is in progress.

KTeV has also published a measurement of $K_L \to \mu^+\mu^-e^+e^-$ decays based on their full data set. They find 132 events in the signal region with a background expectation of 0.8 events (Fig. 4), which results in a branching fraction measurement [4] of

$$\mathrm{Br(K_L \to \mu^+\mu^-e^+e^-)} = (2.69 \pm 0.24_{\mathrm{stat}} \pm 0.12_{\mathrm{syst}}) \times 10^{-9}. \qquad (5)$$

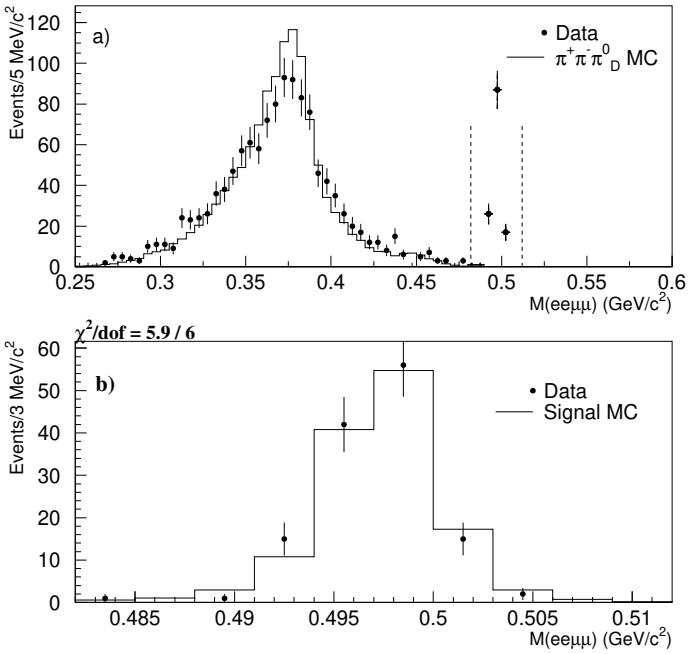

Figure 4: *Invariant mass distribution of the KTeV $K_L \to \mu^+\mu^-e^+e^-$ candidates.*

The measurement of the form factor agrees with measurements of the other $K_L \to \gamma^\star\gamma^{(\star)}$ modes, but suffers from the low statistics in this channel.

3.2 Search for the decay $K_L \to \pi^0 e^+e^-$

The very rare decay $K_L \to \pi^0 e^+e^-$ is expected to have a sizable direct CP violating amplitude from electro-weak penguin transitions (Fig. 5 top). This amplitude is directly proportional to $\mathrm{Im}(\lambda_t)$ $=\mathrm{Im}(V_{td}V_{ts}^\star) = \eta A^2\lambda^5$. and allows therefore the measurement of height η of the unitarity triangle. The corresponding contribution to the $K_L \to \pi^0 e^+e^-$ branching fraction has been estimated to a few 10^{-12}. However, also indirect CP violating and CP conserving amplitudes exist for $K_L \to \pi^0 e^+e^-$. The latter can be deduced from the measurement of $K_L \to \pi^0\gamma\gamma$ decays (see Fig. 5 bottom). Its contribution to $\mathrm{Br}(\mathrm{K_L} \to \pi^0\mathrm{e^+e^-})$ has been determined to $(0.5 \pm 0.2) \times 10^{-12}$ [5] and is small compared to the expected contribution from direct CP violation. The contribution from indirect CP violation can be fixed by the measurement of $K_S \to \pi^0 e^+e^-$, which is discussed in Sec. 4.1.

The KTeV collaboration has used both their 97 and 99 data sets to search for $K_L \to \pi^0 e^+e^-$ events. The main problem of the analysis is the rejection of the Greenlee background $K_L \to e^+e^-\gamma\gamma$, which has a branching fraction of 6×10^{-7} and may fake a $K_L \to \pi^0 e^+e^-$ decay if the photons accidentally have a π^0 invariant mass.

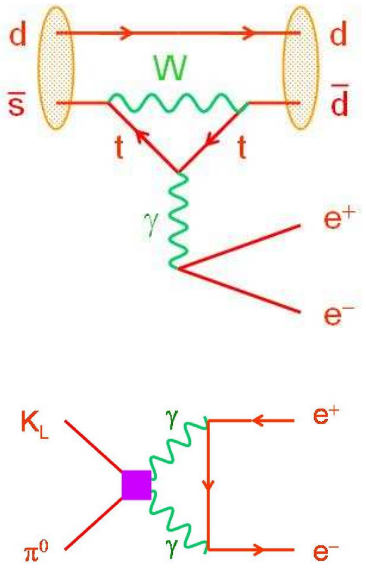

Figure 5: *Direct CP violating (top) and CP conserving amplitude (bottom) of* $K_L \to \pi^0 e^+ e^-$.

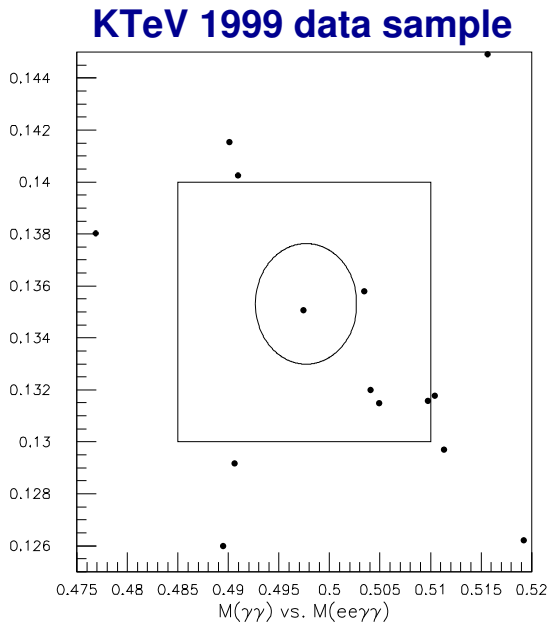

Figure 6: *Invariant* $\gamma\gamma$ *vs.* $e^+e^-\gamma\gamma$ *mass for* $K_L \to \pi^0 e^+ e^-$ *signal candidates in the KTeV 1999 data.*

This background is suppressed by using the topology of $K_L \to e^+e^-\gamma\gamma$ events, which arise from $K_L \to \gamma^\star\gamma \to e^+e^-\gamma$ decays with internal bremsstrahlung and therefore have one photon emitted close to an electron track.

Applying all selection criteria, KTeV observes one event in the signal box in the 99 data set (Fig. 6), consistent with the background expectation of 0.99 events from $K_L \to e^+e^-\gamma\gamma$ decays, which is converted into an upper limit of $\mathrm{Br(K_L \to \pi^0 e^+ e^-)} < 3.5 \times 10^{-10}$ at 90% confidence level [6]. Using also the published result on the 97 data set [7], this limit is improved to

$$\mathrm{Br(K_L \to \pi^0 e^+ e^-)} < 2.8 \times 10^{-10} \quad \text{at } 90\%\ \mathrm{CL}, \tag{6}$$

which is still about two orders of magnitude above the theoretical expectation for the direct CP violating amplitude.

4 Rare K_S decays

In ϵ' data taking, only moderate K_S intensity is needed, since the $K_L \to 2\pi$ decays limit the overall statistics, while the decay of K_S into 2π is dominant. The inves-

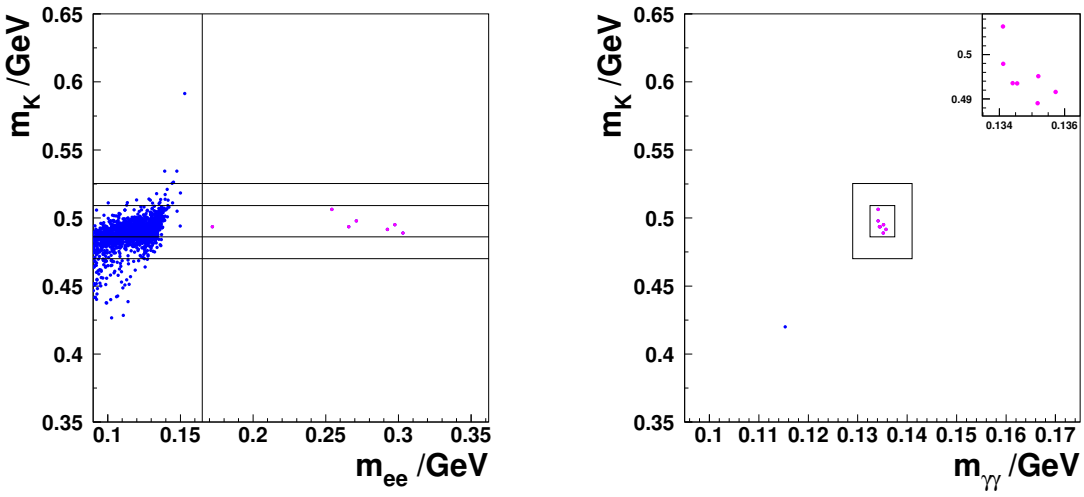

Figure 7: *Distributions of invariant $K_S \to \pi^0 e^+ e^-$ mass versus the e^+e^- invariant mass (left) and the two-photon invariant mass (right) in the NA48 data. Indicated are the borders of the signal and control regions and the cut at $m_{ee} > 165$ MeV/c^2.*

tigation of rare K_S decays therefore requires a different set-up as for the $\mathrm{Re}(\epsilon'/\epsilon)$ measurement.

In 2002, the NA48 successor experiment NA48/1 [8] has performed a special high-intensity run period with no K_L beam but with about 200 times increased proton intensity on the K_S target w.r.t. normal ϵ' data taking. While the detector itself had only to be slightly modified, the read-out had to be improved and partly re-done to deal with the much higher data rate.

In addition, the NA48 experiment has performed a high-intensity K_S run period in the year 2000. As the drift chambers were not operational in 2000, this run has been used for investigating K_S decays into neutral final states as $K_S \to 3\pi^0$, $K_S \to \gamma\gamma$, and $K_S \to \pi^0\gamma\gamma$.

4.1 First observation of $K_S \to \pi^0 e^+ e^-$

As described in the Section 3.2, the decay $K_S \to \pi^0 e^+ e^-$ directly measures the indirect CP violating part of the corresponding K_L transition. The decay had not yet been observed, the best upper limit was $\mathrm{Br(K_S \to \pi^0 e^+ e^-)} < 1.4 \times 10^{-7}$, determined by the NA48 experiment using a short test K_S data taking period in 1999 [9]. A similar analysis has now been performed on the much higher statistics of the 2002 NA48 data set. To suppress $K_S \to \pi^0 \pi^0_{\mathrm{Dalitz}}$ decays (with $\pi^0_{\mathrm{Dalitz}} \to e^+e^-\gamma$), an invariant e^+e^- mass above 165 MeV/c^2 was required for the signal candidates. The analysis was performed blind with both the signal and control region masked. After

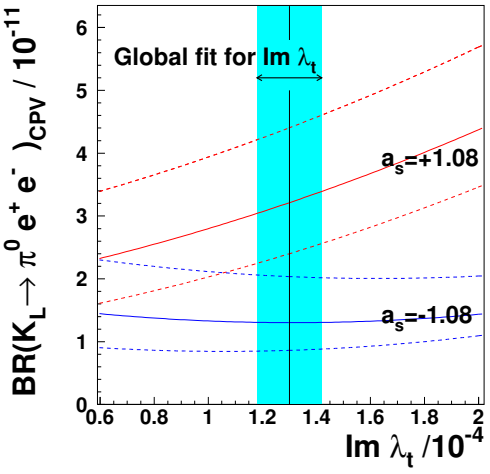

Figure 8: *Prediction for the CP violating fraction of the decay* $K_L \to \pi^0 e^+ e^-$ *as function of* $Im(\lambda_t)$.

opening the signal box, 7 signal candidates were found with an estimated background of 0.15 events from mainly $K_L \to e^+e^-\gamma\gamma$ and overlapping events (Fig. 7). This is the first observation of this decay, and corresponds to a (preliminary) branching fraction of

$$\mathrm{Br(K_S \to \pi^0 e^+ e^-)_{m_{ee}>165\,MeV}} = (3.0\ ^{+1.5}_{-1.2}{}_{\mathrm{stat}} \pm 0.2_{\mathrm{syst}}) \times 10^{-9}. \qquad (7)$$

Using the matrix element calculated by D'Ambrosio *et al.* [11] with the form factor set to 1, this turns into an overall branching fraction of $\mathrm{Br(K_S \to \pi^0 e^+ e^-)} = (5.8^{+2.8}_{-2.3\,\mathrm{stat}} \pm 0.3_{\mathrm{syst}} \pm 0.8_{\mathrm{theo}}) \times 10^{-9}$. Finally, using this result for the prediction of the CP violating $K_L \to \pi^0 e^+ e^-$ amplitudes, it follows

$$\mathrm{Br(K_L \to \pi^0 e^+ e^-)_{CPV}} = (17.7_{\mathrm{indirect\ CPV}} \pm 9.5_{\mathrm{interference}} + 4.7_{\mathrm{direct\ CPV}}) \times 10^{-12}, \qquad (8)$$

which shows the dominance of the indirect CP violating amplitude of $K_L \to \pi^0 e^+ e^-$ and the difficulty to extract $\mathrm{Im}\lambda_t$ from a future $K_L \to \pi^0 e^+ e^-$ measurement (Fig. 8).

4.2 Search for CP violation in $K_S \to 3\pi^0$

The decay $K_S \to 3\pi^0$ is purely CP violating in complete analogy, but with reversed CP values, to $K_L \to \pi^0\pi^0$. The amplitude ratio compared to the corresponding K_L decay is expected to be

$$\eta_{000} \equiv \frac{A(K_S \to 3\pi^0)}{A(K_L \to 3\pi^0)} = \epsilon + i\,\frac{\mathrm{Im}(A_1)}{\mathrm{Re}(A_1)}. \qquad (9)$$

While the real part is fixed by CPT conservation the imaginary part depends on the isospin 1 amplitude A_1 and may differ from $\mathrm{Im}(\epsilon)$. Experimentally, $K_S \to 3\pi^0$ has never been observed. The parameter η_{000} has been measured to $\mathrm{Re}(\eta_{000}) = 0.18 \pm 0.15$ and $\mathrm{Im}(\eta_{000}) = 0.15 \pm 0.20$ by CPLEAR [12]. In addition, the SND experiment has set a limit on the branching fraction of 1.4×10^{-5} at 90% confidence level [13].

In NA48 K_L and K_S mesons are produced in equal amounts at the target. The dependence of the $K^0/\overline{K^0} \to 3\pi^0$ intensity as function of proper time therefore is given by

$$\begin{aligned} I_{3\pi^0}(t) \;\propto\; & \underbrace{e^{-\Gamma_L t}}_{K_L \text{ decay}} + \underbrace{|\eta_{000}|^2\, e^{-\Gamma_S t}}_{K_S \text{ decay}} \\ & + \underbrace{2\,D(p)\,(\mathrm{Re}(\eta_{000})\cos\Delta m t - \mathrm{Im}(\eta_{000})\sin\Delta m t)\; e^{-\frac{1}{2}(\Gamma_S+\Gamma_L)\,t}}_{K_L\text{-}K_S \text{ interference}} \end{aligned} \tag{10}$$

with the momentum dependent dilution $D(p) = (N(K^0) - N(\overline{K^0})/(N(K^0) - N(\overline{K^0})$. In NA48, this production asymmetry is on average about 0.35 with an almost linear dependency from the kaon momentum. While it is hopeless to observe the pure K_S contribution above the K_L decay, the $K_L K_S$ interference is suppressed by only the first order in η_{000}.

For the η_{000} measurement data from the 2000 near-target run period were used. From these data about 6.5×10^6 $3\pi^0$ events were selected with practically negligible background. To be as independent from Monte Carlo simulation as possible data from the far-target run period of the same year were used for normalization to $K_L \to 3\pi^0$. In this way, due to the almost identical geometry of near- and far-target beams, only residual effects had to be corrected for by Monte Carlo simulation (see Fig. 9 left). To also be independent of the correct modeling of the different kaon energy spectra in the simulation, the fit to the proper time distribution of the $3\pi^0$ events was performed in bins of energy, leaving all normalizations free in the fit. The fit result is $\mathrm{Re}(\eta_{000}) = -0.026 \pm 0.010$ and $\mathrm{Im}(\eta_{000}) = -0.034 \pm 0.010$ with a correlation coefficient of 0.8. The systematic uncertainties are dominated by uncertainties in the detector acceptance, the accidental activity, and the $K^0\overline{K^0}$ dilution (see Tab. 2). The complete result, which is still preliminary, then is

$$\begin{aligned} \mathrm{Re}(\eta_{000}) &= -0.026 \pm 0.010_{\mathrm{stat}} \pm 0.005_{\mathrm{syst}} \quad \text{and} \\ \mathrm{Im}(\eta_{000}) &= -0.034 \pm 0.010_{\mathrm{stat}} \pm 0.011_{\mathrm{syst}}. \end{aligned} \tag{11}$$

The corresponding confidence limits are shown in Fig. 10. The result is consistent with 0 with roughly 5% probability. Turning this result into an upper

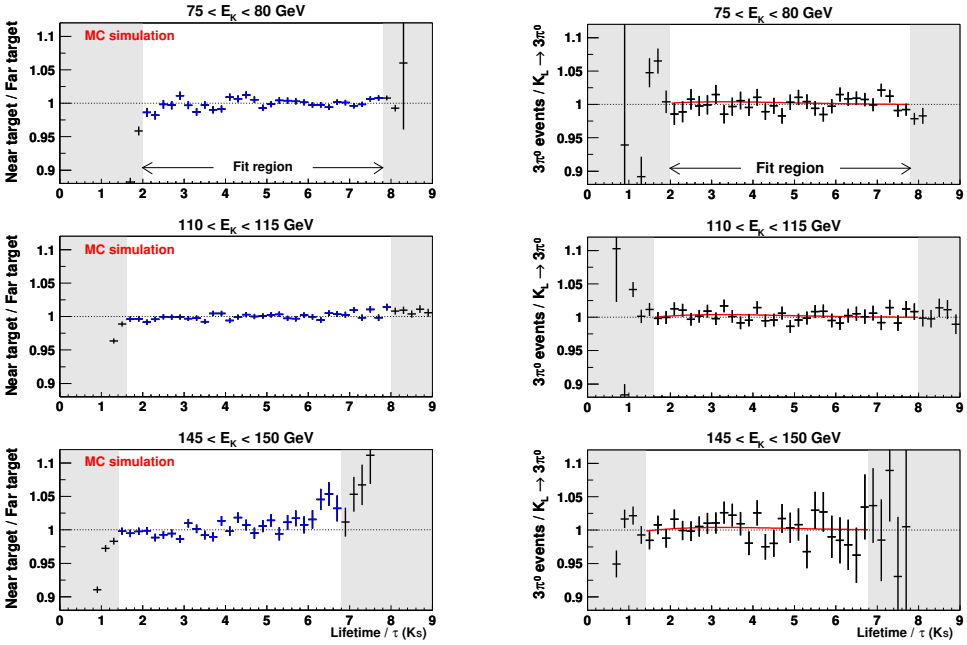

Figure 9: *Ratios of $3\pi^0$ events for different energy bins. Left: $K_L \to 3\pi^0$ Monte Carlo simulation from near and far target. Right: Near-target data normalized to geometry-corrected far-target $K_L \to 3\pi^0$ data.*

limit on the branching fraction, one gets

$$\mathrm{Br}(\mathrm{K_S} \to 3\pi^0) < 1.4 \times 10^{-6} \quad \text{at } 90\%\ \mathrm{CL}, \tag{12}$$

which is one order of magnitude below the previous best limit.

Assuming CPT conservation, which fixes $\mathrm{Re}(\eta_{000})$ to $\mathrm{Re}(\epsilon) = 1.6 \times 10^{-3}$, one receives

$$\mathrm{Im}(\eta_{000})|_{\mathrm{Re}(\eta_{000})=\mathrm{Re}(\epsilon)} = -0.012 \pm 0.007_{\mathrm{stat}} \pm 0.011_{\mathrm{syst}} \tag{13}$$

and $\mathrm{Br}(\mathrm{K_S} \to 3\pi^0)|_{\mathrm{Re}(\eta_{000})=\mathrm{Re}(\epsilon)} < 3.0 \times 10^{-7}$ at 90% CL.

Finally, this result improves the limit on CPT violation via the Bell-Steinberger relation. Using unitarity, this relation connects the CPT violating phase δ with the CP violating amplitudes of the various K_L and K_S decays [14]. So far, the limiting quantity has been the precision of η_{000}. This new result, added to the measurements of the other η parameters [15, 16, 17], improves the accuracy on $\mathrm{Im}(\delta)$ by about 40% to $\mathrm{Im}(\delta) = (-1.2 \pm 3.0) \times 10^{-5}$, now limited by the knowledge of η_{+-}. Assuming CPT conservation in the decay, this can be converted to a new limit on the $K^0\overline{K^0}$ mass difference of $m_{K^0} - m_{\overline{K^0}} = (-1.7 \pm 4.2) \times 10^{-19}$ GeV/c^2.

	$\mathrm{Re}(\eta_{000})$	$\mathrm{Im}(\eta_{000})$
Acceptance	± 0.003	± 0.008
Accidental activity	± 0.001	± 0.006
Energy scale	± 0.001	± 0.001
$K^0\overline{K^0}$ dilution	± 0.003	± 0.004
Fit	± 0.001	± 0.002
Total:	± 0.005	± 0.011

Table 2: *Systematic uncertainties on* η_{000}.

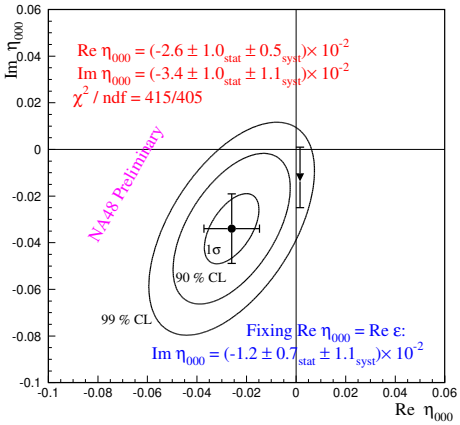

Figure 10: *Fit result for* η_{000} *(prel).*

4.3 Tests of Chiral Perturbation Theory in $K_S \to \gamma\gamma$ and $K_S \to \pi^0\gamma\gamma$

The neutral K_S decays into the $\gamma\gamma$ and $\pi^0\gamma\gamma$ final states are suited for investigating higher order predictions of Chiral Perturbation Theory (ChPT), as contributions from lowest order $\mathcal{O}(p^2)$ do not exist. For the decay $K_S \to \gamma\gamma$ an exact $\mathcal{O}(p^4)$ calculation predicts the branching fraction to be 2.1×10^{-6} [18].

NA48 has used the data from its 2000 high-intensity K_S run period to investigate these decays. For $K_{L,S} \to \gamma\gamma$ about 20000 candidate events are observed in the signal region between -1 and 5 m from the final collimator (Fig. 11). About one third of these events originate from K_S decays. The corresponding branching fraction has been determined to [19]

$$\mathrm{Br}(\mathrm{K_S} \to \gamma\gamma) = (2.78 \pm 0.06_{\mathrm{stat}} \pm 0.04_{\mathrm{syst}}) \times 10^{-6}. \tag{14}$$

This can be compared to the $\mathcal{O}(p^4)$ ChPT prediction given above, showing a $\approx 30\%$ contribution from $\mathcal{O}(p^6)$ to the branching fraction.

For the decay $K_S \to \pi^0\gamma\gamma$ the theoretical prediction using ChPT is Br $= 3.8 \times 10^{-8}$ for $z = m^2_{\gamma\gamma}/m^2_K > 0.2$ to avoid the π^0 pole [20]. Analyzing its 2000 data set, the NA48 collaboration has found 31 signal candidates with an estimated background of 13.6 ± 2.8 events from various sources (Fig. 12). From this, the branching fraction was calculated to [21]

$$\mathrm{Br}(\mathrm{K_S} \to \pi^0\gamma\gamma)|_{z>0.2} = (4.9 \pm 1.6_{\mathrm{stat}} \pm 0.9_{\mathrm{syst}}) \times 10^{-8}. \tag{15}$$

This is the first observation of this decay. The measured branching fraction is in agreement with the theory prediction, albeit the statistical precision does not yet allow concrete conclusions.

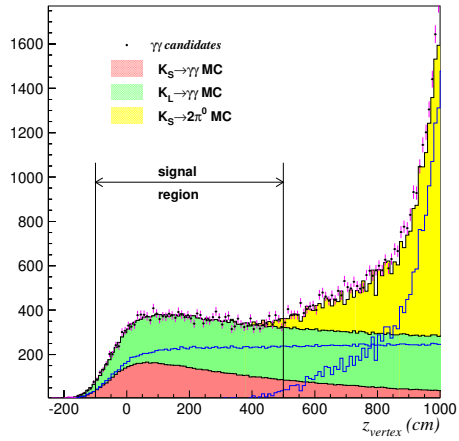

Figure 11: *Longitudinal vertex distribution of the NA48 $K_S \to \gamma\gamma$ candidates.*

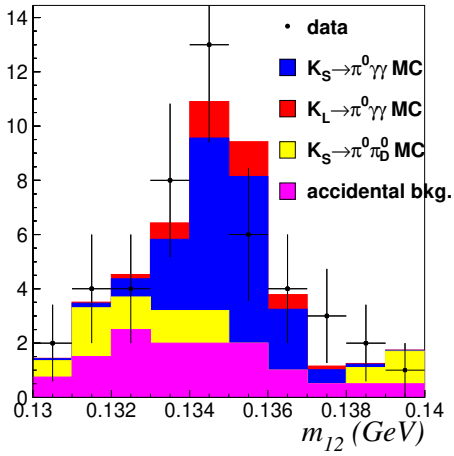

Figure 12: *Invariant $\pi^0 \to \gamma\gamma$ mass of the NA48 $K_S \to \pi^0\gamma\gamma$ candidates.*

5 Outlook on $K^\pm$ decays

In the year 2003 the NA48/2 experiment has performed a three month high intensity data taking period for the investigation of $K^\pm$ decays. For this special run the NA48 beam-line has been altered to simultaneously select K^+ and K^- mesons with a momentum of about 60 GeV/c. In addition, micro-mesh gas chambers have been installed as beam spectrometer to achieve a $K^\pm$ momentum resolution of $\sim 1\%$. Expected are about 3×10^{11} $K^\pm$ decays in the fiducial volume in the 2003 run period [22].

The main interest of this run is the search for direct CP violation in the slope of the $K^\pm \to \pi^+\pi^-\pi^\pm$ Dalitz plot. Theoretical predictions for CP violation lie between 10^{-4} and 10^{-6} for the difference of the slope parameter g between K^+ and K^- Dalitz plot. The sensitivity of NA48/2 is expected to be better than 10^{-4}.

Further goals of the NA48/2 experiment are the absolute measurement of $\mathrm{Br}(K^+ \to \pi^0 e^+ \nu)$ to determine the CKM matrix element V_{us}, a precise measurement of $K^+ \to \pi^+\pi^- e^+ \nu$ (K_{e4}) decays, and the investigation of various rare K^+ decays.

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