RESULTS ON ϵ' AND CPV EFFECTS IN $K_L \to \pi^+\pi^-e^+e^-$ FROM NA48

J. P. NASSALSKI

Soltan Institute for Nuclear Studies
(Ul. Hoża 69, 05-816 Warszawa, Poland)

UDC 539.12.01

Results are presented on direct CP violation determined from the data collected in the year 2001 and from all the data of the NA48 experiment: $\mathrm{Re}(\epsilon'/\epsilon) = (14.7 \pm 2.2) \times 10^{-4}$. Also shown are results on $K_{L(S)} \to \pi^+\pi^-e^+e^-$ decays: branching fractions and the asymmetry in the distribution of the angle ϕ between the $\pi^+\pi^-$ and e^+e^- planes in the kaon rest system. This asymmetry is due to indirect CP violation and is expected to be large for K_L decays and negligible for K_S. Our results confirm these expectations: $A_\phi = (14.2 \pm 3.6)\%$ and $(-1.1 \pm 4.1)\%$ respectively.

Introduction

Neutral kaon decays have been widely used to study the CP violation since its discovery in the year 1964 [1]. The dominating and well established effect is the "indirect" CP violation due to mixing of CP eigenstates, which occurs on the level of $\epsilon \sim 10^{-3}$ [2]. On the other hand, CP violation can also occur in the transition from the initial to the final state in the decay due to interference of amplitudes of different isospin. This "direct" CP violation is represented by the parameter ϵ'. In the Standard Model, the CP violation is due to the complex phase of the quark mixing-matrix [3]. The predicted values of ϵ' are in the range $\epsilon'/\epsilon = (-0.001, 0.003)$.

In the experiments, the direct CP violation is determined from the double ratio R of the decay widths:

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} \approx$$

$$\approx 1 - 6 \times \mathrm{Re}(\epsilon'/\epsilon). \quad (1)$$

First mesurements of direct CP violation published in 1993 by NA31 [4] and by E731 [5] gave not consistent results. New results from NA48 data collected in 1997 [6] and in 1998—1999 [7] and from KTeV [8, 9] demonstrated the existence of direct CP violation. In this paper, we report on the measurements performed in 2001 at a 30% lower beam intensity and give our final result on $\mathrm{Re}(\epsilon'/\epsilon)$ [10]. The event sample from 2001 has 1.5M events in the least favourable channel $K_L \to 2\pi^0$. The total sample of events collected by NA48 in this channel is 5M events.

Recent theoretical analysis of $K_L \to \pi^+\pi^-e^+e^-$ decay [11, 12] show that the correlation in the angle ϕ between the $\pi^+\pi^-$ and e^+e^- planes in the kaon rest system contains a large term due to indirect CP violation. It arises because the amplitude of the underlying process, $K_\mathrm{L} \to \pi^+\pi^-\gamma^*$, has two dominating components arising from : 1. the CP-violating bremsstrahlung process in which the K_L decays into $\pi^+\pi^-$ where one of the pions radiates a virtual photon and 2. the CP conserving direct emission process associated with a magnetic dipole transition. The interference of these CP-even and CP-odd amplitudes produces a CP violating circular polarization of the virtual photon which gives rise to an asymmetry in the distribution of the angle ϕ,

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\phi} = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \sin\phi \cos\phi\,,$$

where the asymmetric term Γ_3 has the contribution from the interference. In the experiments, the asymmetry is calculated from the distribution of events in the $(\sin\phi\, \cos\phi)$ variable:

$$\mathcal{A}_\phi = \frac{\mathrm{N}_{\pi\pi\mathrm{ee}}(\sin\phi\cos\phi > 0) - \mathrm{N}_{\pi\pi\mathrm{ee}}(\sin\phi\cos\phi < 0)}{\mathrm{N}_{\pi\pi\mathrm{ee}}(\sin\phi\cos\phi > 0) + \mathrm{N}_{\pi\pi\mathrm{ee}}(\sin\phi\cos\phi < 0)}\,. \quad (2)$$

The predicted value for this asymmetry is as large as 14% and it is 3×10^{-7} for the branching ratio [11, 12].

The decay $K_S \to \pi^+\pi^-e^+e^-$ is dominated by the CP-even inner bremstrahlung amplitude and therefore no asymmetry is expected while the branching ratio is by two orders of magnitude larger.

The measurements of the branching ratio and of the asymmetry for $K_L \to \pi^+\pi^-e^+e^-$ decay come from KTeV E799 collaboration [13, 14] and from KEK experiment [15] where only the branching ratio was measured. Results on $K_S \to \pi^+\pi^-e^+e^-$ come only from NA48 where the branching ratio has beed determined [16].

In this paper, we show new results on the branching ratios and on the asymmetries for $K_{L,S} \to \pi^+\pi^-e^+e^-$ decays from the new high statistics data [17].

ISSN 0503-1265. Ukr. J. Phys. 2003. V. 48, N 11-12

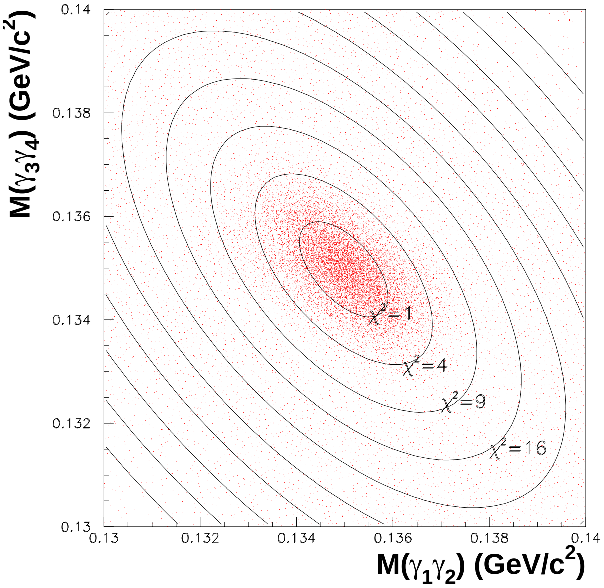

Fig.1. Invariant mass of one pair of photons vs. the other. Contours show the values of constant χ^2 (see text)

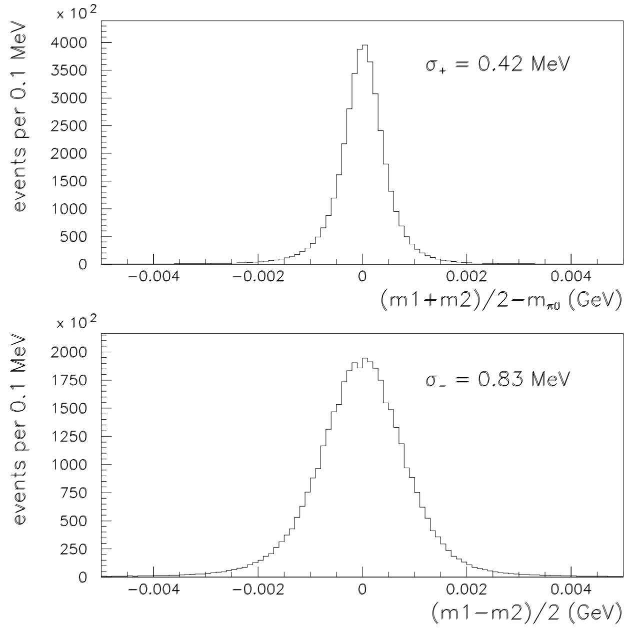

Fig.2. Distribution of the deviation of the average invariant mass of photon pairs from the m_{π^0} (upper plot) and of the difference of the invariant masses of photon pairs (lower plot)

The detailed description of the NA48 apparatus and of the data analysis can be found in [7, 16].

1. Determination of Re(ϵ'/ϵ)

In NA48 experiment, the four decay modes which enter Eq.(1) are measured simultaneously using K_L and K_S beams of similar momentum spectra in the range 70 - 170 GeV, displaced verticaly by 72 mm at the begining of the decay region and converging to the center of the main detector. For both charged and neutral decay modes, K_L and K_S are distinguished by coincidence between decay time and and the time of protons producing K_S beam seen in the tagger. In order to minimize acceptance corrections due to the differences in K_L and K_S decay lengths, K_L decays are weghted as a function of their proper liftime, such that the K_L and K_S distributions become very similar. In this way, most of the systematic effects cancel in the ratio R. The value of Re(ϵ'/ϵ) is extracted from the measurements of R made in bins of kaon energies.

1.1. Reconstruction and Selection of Neutral Decays

$K_{L(S)} \to \pi^0\pi^0 \to 4\gamma$ events are selected using data from a LKr calorimeter [7, 18]. The energy resolution of the calorimeter is $\sigma(E)/E = (3.2 \pm 0.2)\%/\sqrt{E} \oplus (9 \pm 1)\%/E \oplus (0.42 \pm 0.05)\%$ with E in GeV [19]. The time and space resolutions for 20 GeV photons are 300 ps and 1.3 mm, respectively. Using the measured energies and impact point positions of four photons and assuming that their invariant mass is equal to the kaon mass, the distance D from the decay vertex to the calorimeter is be calculated. In the next step, the distance D is used to compute the invariant masses of photon pairs, m_1 and m_2. Finally these masses are compared to the nominal π^0 mass using χ^2 defined as:

$$\chi^2 = \left[\frac{(m_1+m_2)/2 - m_{\pi^0}}{\sigma_+}\right]^2 + \left[\frac{(m_1-m_2)/2}{\sigma_-}\right]^2 .$$

Fig.1 shows the distribution of the invariant masses of two photon pairs and contours of constant values of χ^2. The distribution of each of the two terms in the definition of χ^2 is shown in Fig.2. There are three possible photon pairings and the one with the lowest χ^2 value is kept. Good neutral decays are further selected requiring $\chi^2 < 13.5$.

$K_S \to 2\pi^0$ decays are background free, while K_L mode contains a residual background from $K_L \to 3\pi^0$ decays. From Monte Carlo studies, this background is known to have a flat χ^2 distribution. Its contribution is estimated in the region $36 < \chi^2 < 135$ and extrapolated to the signal region defined as $\chi^2 < 13.5$ (see Fig.3).

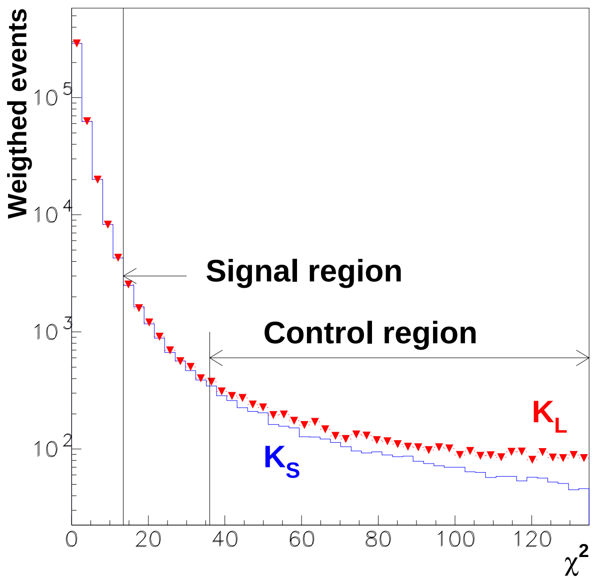

Fig.3. Distribution of χ^2 in the neutral decay mode: for the weighted K_L candidates (red points) and the background free K_S decays. Background in K_L is estimated in the control region and extrapolated to the signal region.

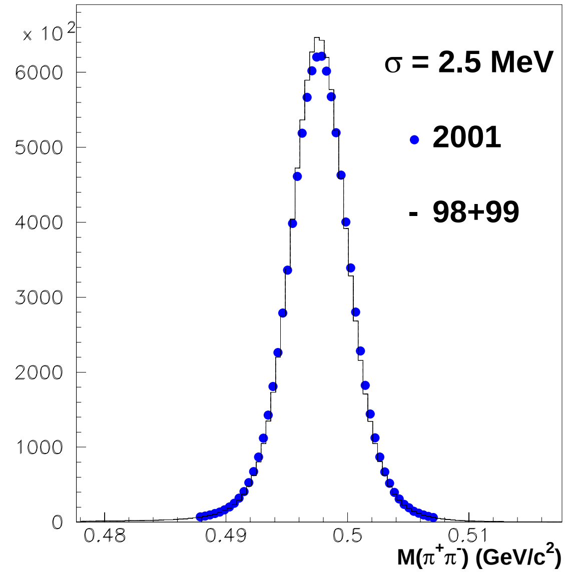

Fig.4. Distribution of the invariant masses of hadrons of positive and negative charges from selected events. The distributions obtained from 1998+1999 and from 2001 data are shown separately

1.2. Reconstruction and Selection of Chaged Decays

$K_{L(S)} \to \pi^+\pi^-$ events are reconstructed from pairs of tracks of opposite charge found in the drift chambers before and after the spectometer magnet. These tracks had to pass geometric and kinematic selection and were required to have a common vertex [7, 16]. The decay time, measured using a scintillation hodoscope, has a resolution of 150 ps. In order to reject background from semileptonic K_L decays, electrons were removed by a cut $E/p < 0.8$, where E is the energy of the corresponding LKr cluster and p is the reconstructed momentum. To reject muons, the muon chambers were required to have no hits close in space and time to the extrapolated tracks. In addition, it is required that the transverse component of the reconstructed kaon momentum be small. This component, p'_T, is calculated relative to the line passing through the production target and through the point where the kaon trajectory crosses the plane of the first drift chamber. Decays into $\pi^+\pi^-$ are required to have ${p'_T}^2 < 2 \times 10^{-4}\,\mathrm{GeV}^2$. The reconstructed invariant mass of candidate events is shown in Fig.4.

The selected events were required to be within $\pm 3\sigma_m$ from the nominal kaon mass.
The residual background from K_{e3} and $K_{\mu 3}$ decays in the K_L sample as well as the background from the scattering of the beam in the collimators is shown in Fig.5 as a function of ${p_T}'^2$. It is seen that their sum plus the background-free K_S well describes the measured distribution of K_L and therefore they have been correctly estimated.

1.3. Tagging of K_S Decays

A given neutral or charged decay is defined as K_S if it occurs within ± 2 ns to the nearest proton time in the tagger, otherwise it is defined as K_L.

Figure 6 shows the distribution of this time difference for K_S and K_S events decaying into $\pi^+\pi^-$, which are identified by their vertex position. A fraction of true K_S events is seen outside of the tagging window and they are wrongly taken as K_L. They are due to tagging inefficiency which, for the charged mode, is equal to $(1.12 \pm 0.03) \times 10^{-4}$. Similarly a fraction of true K_L events is seen inside the tagging window and they are wrongly taken as K_S. They are due to accidental coincidence with the proton in the tagger. In the charged

ISSN 0503-1265. Ukr. J. Phys. 2003. V. 48, N 11-12

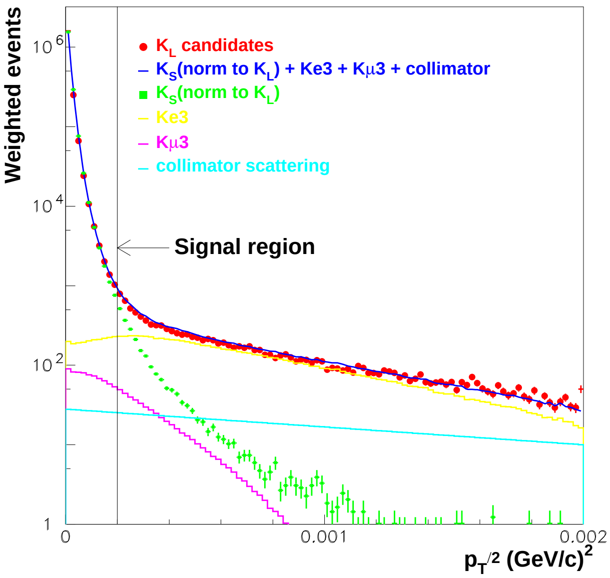

Fig.5. Distribution of ${p'_T}^2$ in the charged decay mode: for weighted K_L candidates (red), background free K_S normalized to K_L and for the backgrounds arising from K_{e3} and $K_{\mu 3}$ decays and from the scattering of a beam in the collimators

decay mode, this accidental tagging is equal to $(8.115 \pm 0.010) \times 10^{-2}$. Such direct measurements of the tagging inefficiency and accidental tagging are not possible for the neutral decay mode but the difference between charged and neutral decay modes must be precisely estimated in order to determine the unbiased ratio R. To estimate the difference in the tagging inefficiency, several methods were used, e.g. K_S and K_L decays into $2\pi^0$ and $3\pi^0$ where one of the photons converts to an electron-positron pair. The results show that the tagging inefficiencies for the neutral and charge modes agree within $\pm 0.5 \times 10^{-4}$. To estimate the difference in the accidental tagging, comparisons were made between vertex selected $K_L \to \pi^+\pi-$ and $K_L \to 3\pi^0$, because $3\pi^0$ comes exclusively from K_L. The difference between accidental tagging in neutral and charge modes was found to be $(+3.4 \pm 1.4) \times 10^{-4}$. This is due to different sensitivities to accidentals of $\pi^+\pi^-$ and $2\pi^0$ event selections.

1.4. Acceptance Corrections

In order to minimize the acceptance corrections due to the differences in K_L and K_S decay lengths, K_L decays are weghted as a function of their proper lifetime. Figure 7 shows that, after weighting, K_L and K_S decay distributions are identical.

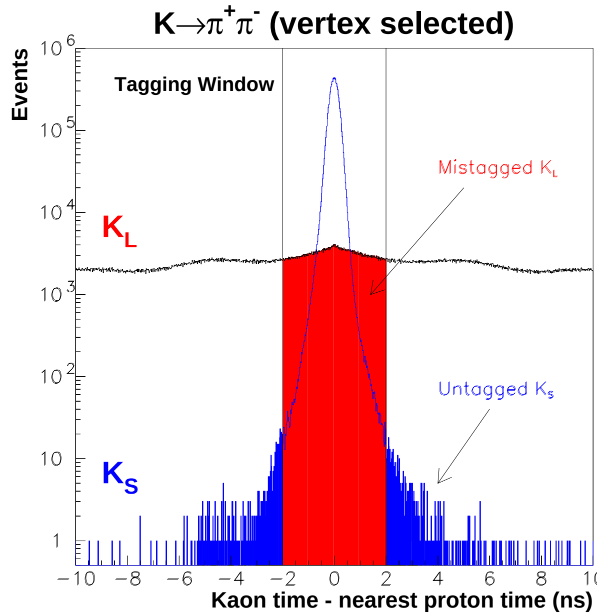

Fig.6. Distribution of the difference of the decay time of K_S (blue) and K_L (red) into charged pions and the nearest proton time measured in the tagger. K_S and K_L were identified using their vertex positions

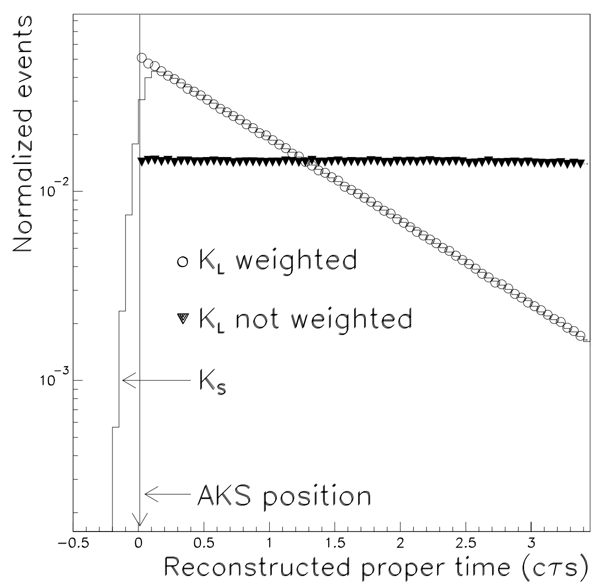

Fig.7. Reconstructed proper time of K_S decays (histogram) and of K_L decays (triangles) in units of K_S life time. Open points show the distribution of K_L after weighting (see text). Arrow shows the AKS position which defines the beginning of the decay region

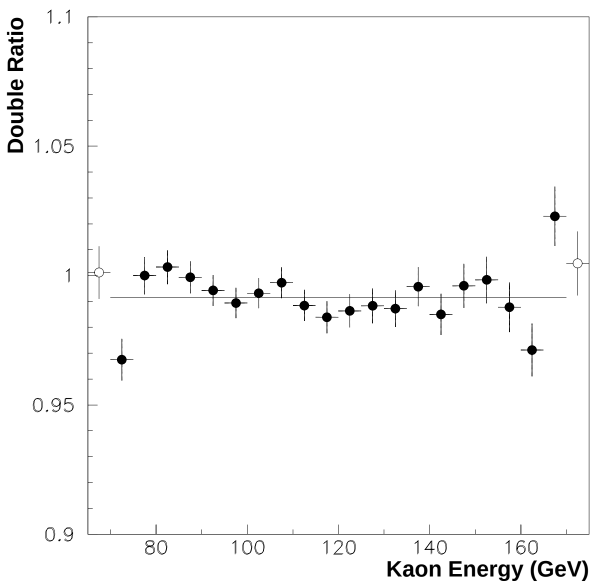

Fig.8. Results on the double ratio plotted as a function of kaon energy. The values given by open circles were not used in the calculation of the final result

The remaining small differences are due to different beam sizes and directions and they have been estimated using large-statistics Monte Carlo simulations.

For the selected events, their proper time τ was required to be $0 < \tau < 3.5\tau_s$, where $\tau = 0$ is defined at the position of the AKS counter. For K_S events, AKS was used to veto upstream decays and to define $\tau = 0$, while, for K_L events, a cut on the reconstructed τ was used.

1.5. Results

Various corrections were applied to the measured ratio R. The most important are (in units of 10^{-4}): acceptance $(+21.9 \pm 3.5_{\rm stat} \pm 4.0_{\rm syst})$, $\pi^+\pi^-$ background $(+14.2 \pm 3.0)$, beam scattering (-8.8 ± 2.0), accidental tagging $(+6.9 \pm 2.8_{\rm stat})$, $2\pi^0$ background (-5.6 ± 2.0) and $\pi^+\pi^-$ trigger inefficiency $(+5.2 \pm 3.6_{\rm stat})$. The overall correction is $(+35.0 \pm 11.0) \times 10^{-4}$. Figure 8 shows the ratio R after corrections as a function of the kaon energy.

The final result for the ratio from 2001 data is $R = 0.99181 \pm 0.00147_{\rm stat} \pm 0.00110_{\rm syst}$ and the corresponding value of the CP violation parameter is: $\mathrm{Re}(\epsilon'/\epsilon) = (13.7 \pm 2.5_{\rm stat} \pm 1.9_{\rm syst}) \times 10^{-4}$. By combining this result with the published one from 1997—1999 data, the final result from the NA48 is obtained: $\mathrm{Re}(\epsilon'/\epsilon) = (14.7 \pm 1.4_{\rm stat} \pm 1.7_{\rm syst}) \times 10^{-4} = (14.4 \pm 2.2) \times 10^{-4}$.

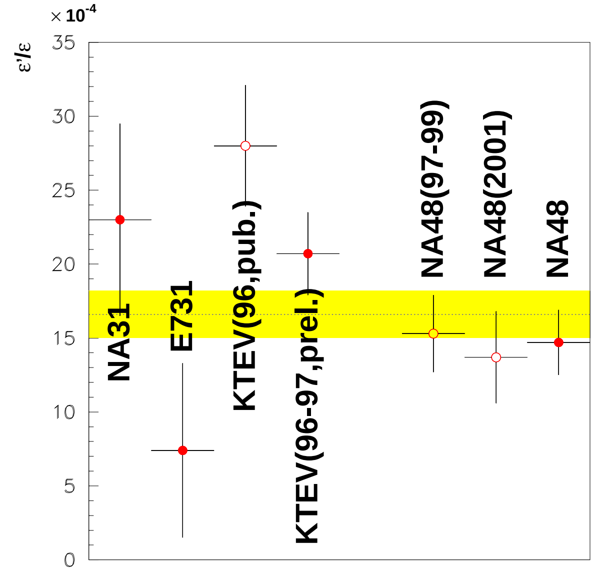

Fig. 9. Values of $\mathrm{Re}(\epsilon'/\epsilon)$ obtained from all experiments

Fig. 9 presents all the published data on $\mathrm{Re}(\epsilon'/\epsilon)$. Clearly there is strong evidence that direct CP violation occurs in Nature.

2. Results on $K_{L(S)} \to \pi^+\pi^-e^+e^-$

$K_{L(S)} \to \pi^+\pi^-e^+e^-$ data were taken in 1998 and 1999 with a dedicated 4-track trigger using the same apparatus. All K_L data and part of K_S data were collected concurrently to $\mathrm{Re}(\epsilon'/\epsilon)$ measurements. In total 600M triggers were collected. In addition, a dedicated test run with high intensity K_S beam only provided 27M triggers and most of $K_S \to \pi^+\pi^-e^+e^-$ events in 1999.

The branching ratios are obtained by normalizing to reconstructed $K_L \to \pi^+\pi^-e^+e^-\gamma$ Dalitz decays which have the same topology and the known branching ratio.

2.1. Reconstruction and Selection of Events

Events are reconstructed using a magnetic spectrometer and an LKr calorimeter described before. Electrons (pions) are identified by the condition $E/p > 0.85$ $(E/p < 0.85)$. The tracks were required to pass geometric and kinematic cuts similar to those used for $\mathrm{Re}(\epsilon'/\epsilon)$ measurements. All six combinations of pairs of tracks were required to have a common vertex. The reconstructed kaon momentum was extrapolated

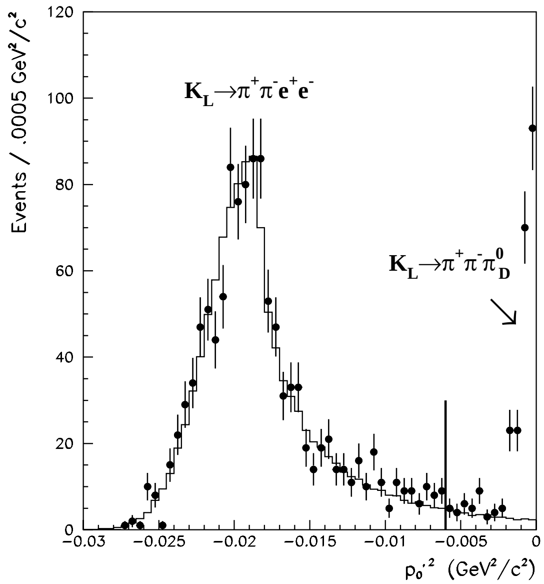

Fig. 10. Distribution of the ${p'_0}^2$ variable for the selected $K_L \to \pi^+\pi^-e^+e^-$ candidates (points). The histogram shows the distribution obtained from the $K_L \to \pi^+\pi^-e^+e^-$ Monte Carlo events normalized to the number of observed candidates. The enhancement at ${p'_0}^2 \sim 0$ is due to $K_L \to \pi^+\pi^-\pi^0_D$ decays. The signal region is defined to the left from the vertical line

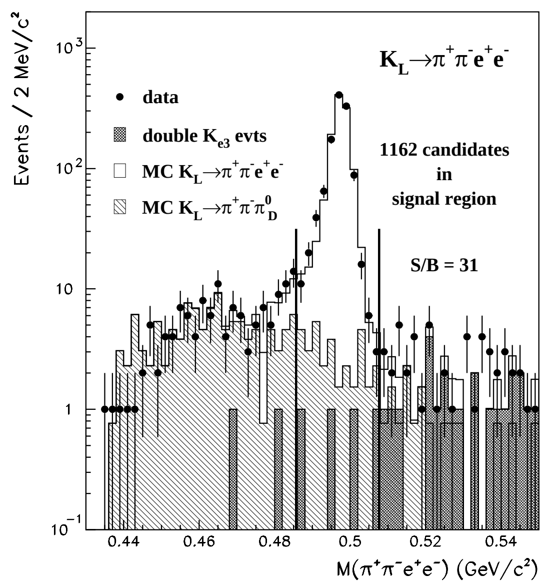

Fig. 11. Invariant mass distribution $M_{\pi\pi ee}$ for $K_L \to \pi^+\pi^-e^+e^-$ candidates. Data are represented by points while the different histograms show the shape expected from Monte Carlo for good events and the background components due to $K_L \to \pi^+\pi^-\pi^0_D$ and overlapping K_{e3} decays. The signal region is indicated by vertical lines

upstream to identify their origin, i.e. K_L or K_S production target. For the data from the simultaneous K_L and K_S running, tagger information was used to reduce the backgound in the K_S sample.

The background from $K_{L(S)} \to \pi^+\pi^-$ overlapping with the accidental photon conversion was suppressed by requiring that the $\pi^+\pi^-$ invariant mass is outside ± 7 MeV window centered on the nominal kaon mass and that pion time and lepton time are equal within 1.5 ns. The background from two accidental K_{e3} decays of opposite charges in the K_L beam was reduced by requiring that π^-e^+ and π^+e^- times are equal within ± 1.5 ns.

2.2. Selection of $K_L \to \pi^+\pi^-e^+e^-$ Events

The most important background comes from the K_L Dalitz decay with the photon not seen in the detectors. This decay occurs at a rate of four order of magnitude larger than the signal.

Two additional cuts were used to suppress it: (1) on the transverse momentum of the kaon relative to the line passing through its decay point and the K_L target, $p_t^2 < 5 \times 10^{-4}$, (2) on the ${p'_0}^2$ variable [20] defined in a frame where the momentum of $\pi^+\pi^-$ is perpendicular to the kaon momentum. For the $K_L \to \pi^+\pi^-\pi^0$ events, it is equal to the square of the longitudinal momentum of the π^0 and therefore positive, whereas for $K_L \to \pi^+\pi^-e^+e^-$ it is mostly negative, as seen in Fig.10. The cut ${p'_0}^2 < -6 \times 10^{-3}\,\mathrm{GeV}^2$ is very effective in removing this background. The invariant mass distribution of $\pi^+\pi^-e^+e^-$ after all cuts is shown in Fig.11.

The signal region, defined as $485.7 < M_{\pi\pi ee} < 507.7$ MeV, contains 1162 events. Residual background due to Dalitz decays has been estimated by Monte Carlo simulation to be equal to 33.2 ± 5.0 events. The background due to double K_{e3} decays has been estimated from data using samples of accidental $\pi^+\pi^+e^-e^-$ and $\pi^-\pi^-e^+e^+$ events to be 4.0 ± 2.0.

2.3. Selection of $K_S \to \pi^+\pi^-e^+e^-$ Events

In this decay channel, the background from K_L Dalitz decay is expected to be much smaller and therefore less strigent cuts were used on ${p'_0}^2 < 5 \times 10^{-3}\,\mathrm{GeV}^2$ and $477.7 < M_{\pi\pi ee} < 512.7$ MeV. Also a looser cut on p_t^2

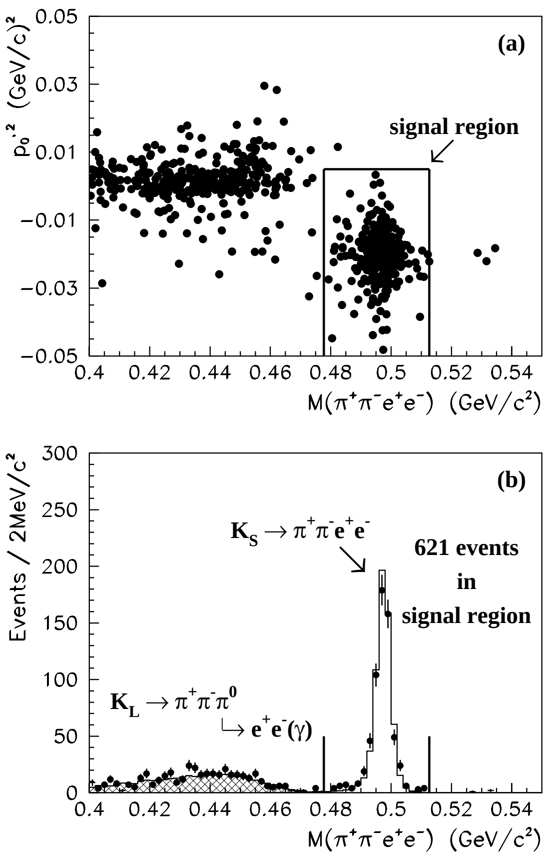

Fig. 12. a — $p_0'^2$ vs. $M_{\pi\pi ee}$ for $K_S \to \pi^+\pi^-e^+e^-$ candidates. The box indicates the signal region. b — invariant mass $M_{\pi\pi ee}$ of events above (dots) and the MC predictions for the signal (plain histogram) and the $K_L \to \pi^+\pi^-\pi^0_D$ background hatched histogram)

was used because, due to a smaller distance between the target and the decay point, it is less well determined: $p_t^2 < 5 \times 10^{-4}$. The invariant mass distributions of the selected events are shown in Fig. 12.

There are 621 events in the signal region. The background from Dalitz decays has been estimated from the Monte Carlo to be $0.7^{+1.4}_{-0.7}$ events.

2.4. Results on the Branching Ratios

The branching ratios (BR) were obtained by normalizing the number of selected $K_{L(S)} \to \pi^+\pi^-e^+e^-$ events (N) to the number of reconstructed Dalitz decays (N_D) $K_L \to \pi^+\pi^-e^+e^-\gamma$ in the same sample:

$$\mathrm{BR} = \mathrm{BR}_D \frac{N}{N_D}\frac{A_D}{A} R_{\mathrm{trig}} R_{\mathrm{flux}}.$$

Here $\mathrm{BR}_D = (1.505 \pm 0.047) \times 10^{-3}$ [2], A and A_D are corresponding acceptances, R_{trig} is the ratio of trigger efficiencies for Dalitz and signal events and R_{flux} is the ratio of fluxes of kaons decaying in the fiducial region for Dalitz and signal events.

Selection procedure of Dalitz events was similar to that for the signal. In addition, an isolated in time cluster in LKr (γ) was required such that the invariant mass of $e^+e^-\gamma$ was consistent with the mass of π^0. 2.8M such events originated from K_L target and 1.4k from K_S. The acceptances for the signal and the normalization channels were obtained from the Monte Carlo; for different event samples, they were in the range (3.49-3.70)% for the signal events and (1.56-1.85)% for the normalization channel.The ratios of trigger efficiencies were equal within less than 1% error. The flux ratio for the K_L mode was equal to unity and for the K_S mode it was calculated from the Monte Carlo using kaon production spectra to be 0.133 ± 0.002.

The branching ratio for the $K_{L(S)} \to \pi^+\pi^-e^+e^-$ decay mode obtained from the 1998 and 1999 data is $\mathrm{BR}(K_L \to \pi^+\pi^-e^+e^-) = (3.08 \pm 0.09_{\mathrm{stat}} \pm 0.15_{\mathrm{syst}} \pm 0.10_{\mathrm{norm}}) \times 10^{-7}$. The dominant contribution to the systematic error comes from the model used in the Monte Carlo calculations and from the acceptance. Summing in quadrature the uncertainties, we have:

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

in agreement with the predictions [11, 12].

The branching ratio for the $K_S \to \pi^+\pi^-e^+e^-$ mode from 1999 data samples is $\mathrm{BR}(K_S \to \pi^+\pi^-e^+e^-) = (4.71 \pm 0.23_{\mathrm{stat}} \pm 0.16_{\mathrm{syst}} \pm 0.15_{\mathrm{norm}}) \times 10^{-5}$. Here the dominant contribution to the systematic error comes from the acceptance. Combining this result with the published value [16] obtained from the data collected in 1998, we obtain:

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

2.5. Results on the Asymmetries

Distribution of $K_L \to \pi^+\pi^-e^+e^-$ events as a function of the $\sin\phi\cos\phi$ variable is shown in Fig. 13,a. Figure 13,b shows the corresponding acceptance variation and Fig. 13,c distribution of events after acceptance correction.

Using Eq(2), we obtain the asymmetry $\mathcal{A}^{\mathrm{L}}_{\phi} = (14.2 \pm 3.0_{\mathrm{stat}} \pm 1.9_{\mathrm{syst}})\%$. The dominant sources of the systematic error are the same as for the branching ratio. Adding errors in quadrature, we obtain

$$\mathcal{A}^{\mathrm{L}}_{\phi} = (14.2 \pm 3.6)\%,$$

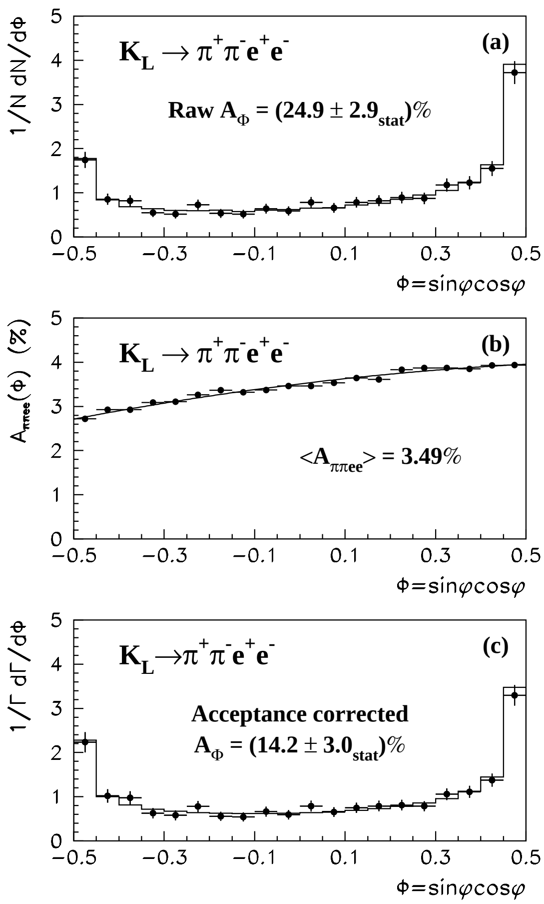

Fig. 13. *a* — distribution of the variable sinϕcosϕ for $K_L \to \pi^+\pi^-e^+e^-$ events. *b* — acceptance as a function of sinϕ cosϕ. The line is a polynomial fit. *c* — distribution of the variable sinϕcosϕ for $K_L \to \pi^+\pi^-e^+e^-$ events after acceptance correction. In *a* and *c* histograms are Monte Carlo predictions

in agreement with results from KTeV experiment [14] and with the predictions [11, 12]. Clearly very large CP violation effects are observed in $K_L \to \pi^+\pi^-e^+e^-$ decay.

Fig. 14 shows the distribution of $K_S \to \pi^+\pi^-e^+e^-$ events and the acceptance as a function of the sinϕcosϕ variable.

As expected, no asymmetry is seen in this decay channel. This result also shows that the asymmetry seen in K_L decay is a genuine effect. From the 1999 data sample, we obtain $\mathcal{A}_\phi^{\rm L} = (0.5\pm\, 4.0_{\rm stat} \pm 1.6_{\rm syst})\%$ or

$$\mathcal{A}_\phi^{\rm S} = (0.5 \pm 4.3)\%\,.$$

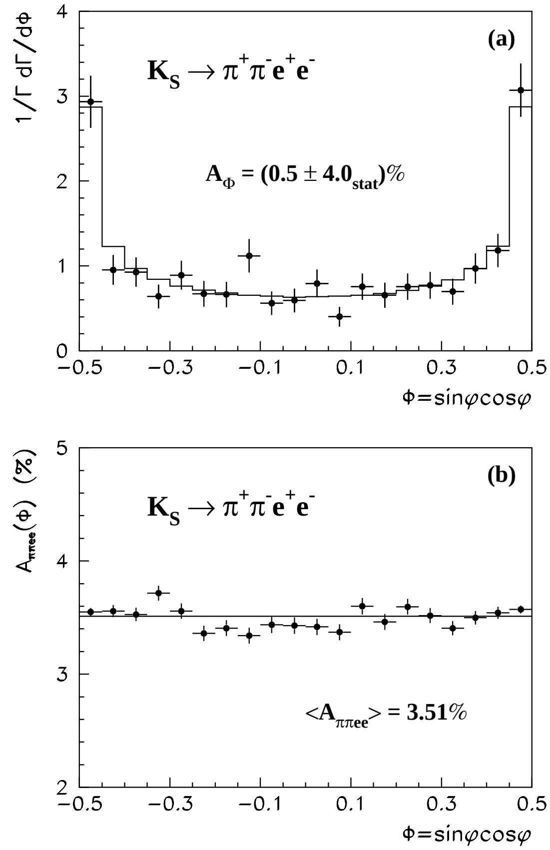

Fig. 14. *a* — distribution of the variable sinϕcosϕ for $K_S \to \pi^+\pi^-e^+e^-$ events. The histogram is the Monte Carlo prediction. *b* — acceptance as a function of sinϕcosϕ. The line shows the average value of the acceptance

Combining present and published sample (56 events) [16], we obtain

$$\mathcal{A}_\phi^{\rm S} = (-1.1 \pm 4.1)\%\,.$$

1. *Christenson J.H. et al.*//Phys. Rev. Lett.– 1964.– **13**.– P.138.
2. *Particle* Data Group // Phys. Rev. – 2002. – **D 66**.
3. *Kobayashi M. and Maskawa K.* // Prog. Theor. Phys. – 1973.– **49**. – P. 652.
4. *Barr G. et al.* // Phys. Lett. – 1993. – **B 317**. P. 233.
5. *Gibbons L.K. et al.*//Phys. Rev. Lett.– 1993.– **70**.– P.1203.
6. *Fanti V. et al.* // Phys. Lett. – 1999. – **B 465**. – P. 335.
7. *Lai A. et al.* // Europ. Phys. J. – 2001. –**C 22**.– P. 231.
8. *Alavi-Harati A. et al.* // Phys. Rev. Lett. – 1999. – **83**. P. 22.
9. *Glazov A.* for the KTeV Collaboration // Proc. Intern. Conf. on Kaon Physics/ Ed. by F. Costantini et. al. – Frascati Physics Serie 26, 2001, P.115.
10. *Batley J.R. et al.* // Phys. Lett. – 2002. – **B 544**. – P. 97.
11. *Sehgal L.M. and Wanninger M.* // Phys. Rev. – 1992.– **D 46**. – P. 1035-1041.// *Erratum:* Phys. Rev. – 1992. – **D 46**. – P. 5209.

12. *Heiliger P. and Sehgal L.M.* Phys. Rev. – 1993. – **D 48**. – P. 4146-4154.// *Erratum:* Phys. Rev. – 1999. – **D 60**. – P. 079902.
13. *Adams J. et al.* // Phys. Rev. Lett. – 1998. – **80**. – P. 4123.
14. *Alavi-Harati A. et al.* // Phys. Rev. Lett. – 2000. – **84**. – P. 408.
15. *Takeuchi Y. et al.* // Phys. Lett. – 1998. – **B 443**. – P. 409.
16. *Lai A. et al.* // Phys. Lett. – 2000. – **B 496**. – P. 137.
17. *Lai A. et al.* // to be published in Europ. Phys. J.
18. *Lai A. et al.* // Phys. Lett. – 2002. – **B 533**. – P. 196.
19. *Unal G.* for the NA48 Collaboration // Proc. IX Intern. Conf. on Calorimetry in HEP /Ed. by B.Aubert et al. – Frascati Physics Serie 21, 2001 p.361
20. *Luers D. et al.* // Phys. Rev. – 1964.– **133 B**. – P. 1276-1289.

РЕЗУЛЬТАТИ ВИМІРЮВАННЯ ϵ' ТА CPV-ЕФЕКТИ В РОЗПАДАХ $K_L \to \pi^+\pi^-e^+e^-$, З NA48-ЕКСПЕРИМЕНТУ

Я.П. Насальськi

Р е з ю м е

Представлено результати вимірювань CP-порушення з використанням даних, зібранних в 2001 р., та повних даних експерименту NA48: Re $(\epsilon'/\epsilon) = (14.7 \pm 2.2) \times 10^{-4}$. Представлено також результати вимірювань розпадів $K_{L(S)} \to \pi^+\pi^-e^+e^-$: частки каналів розпаду і асиметрії в розподілі кута ϕ між площинами $\pi^+\pi^-$ і e^+e^- в системі спокою K-мезона. Ця асиметрія можлива завдяки непрямому CP-порушенню і передбачується великою для K_L-розпадів та і нехтовно малою для K_S-розпадів. Наші результати підтверджують передбачення: $A_\phi = (14.2 \pm 3.6)$ і $(-1.1 \pm 4.1)\%$ відповідно.

РЕЗУЛЬТАТЫ ИЗМЕРЕНИЙ ϵ' И CPV-ЭФФЕКТЫ В РАСПАДАХ $K_L \to \pi^+\pi^-e^+e^-$ ИЗ NA48-ЭКСПЕРИМЕНТА

Я.П. Насальски

Р е з ю м е

Представлены результаты измерений CP-нарушения с использованием данных, собранных в 2001 г., и полные данные эксперимента NA48: Re $(\epsilon'/\epsilon) = (14.7 \pm 2.2) \times 10^{-4}$. Представлены также результаты измерений распадов $K_{L(S)} \to \pi^+\pi^-e^+e^-$: доли каналов распада и асимметрии в распределении угла ϕ между плоскостями $\pi^+\pi^-$ и e^+e^- в покоящейся ситеме K-мезона. Эта асимметрия возможна благодаря косвенному CP-нарушению и предполагается большой для K_L-распадов и пренебрежимо малой для K_S-распадов. Наши результаты подтверждают предположения: $A_\phi = (14.2 \pm 3.6)$ и $(-1.1 \pm 4.1)\%$ соответственно.