Measurement of direct CP violation with the experiment NA48 at CERN

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Abstract. The subject of CP Violation in the neutral kaon system is introduced, and the technique used by the NA48 Collaboration in the measurement of the double ratio of two-pion decays is discussed. The most recent result is discussed and compared with previous ones and with the recent announcements from the KTEV Collaboration.

1 Introduction

The kaon mesons have been a particularly relevant subject throughout the history of elementary particle physics. Kaons carry the Strangeness (S) quantum number, and their decays are mediated by weak interactions. Two and three-pion final states are observed among the decay channels. On its own, this suggests that weak interactions violate the Parity symmetry, because, due the intrinsic negative parity of the pions, two and three-pion final states have opposite Parity quantum number. Other observations proved that the weak interactions do not conserve P-Symmetry, but the combination CP (Parity $\times$ Charge Conjugation) appeared to be conserved. At the same time, the time inversion T was supposed to be a good symmetry, since the global combination of symmetries CPT is believed to be rigorously conserved on general grounds of relativistic field theory.

CP conservation has a very noticeable effect in the decay of the neutral kaons K^0 and $\bar{K^0}$. Since the decay to two pions (CP=+1) is favored by phase space over the three-pion one, a kaon is described by the superposition of two states (K_S and K_L) with different lifetimes: K_S particles decay quickly and almost exclusively to two pions (lifetime $\tau_S = 0.89\times10^{-10}$ s), K_L's decay more slowly ($\tau_L = 5.2\times10^{-8}$ s), typically to three pions or pion-lepton-neutrino states.

If the symmetry CP would be conserved in kaon decays, then K_S and K_L would have defined ±1 CP value, and be described as $(K^0 \pm \bar{K^0})/\sqrt{2}$. However, the observation that two-pion states constitute 0.3 % of K_L decays proved that CP is violated in the decays of neutral kaons [1].

There can be two different kinds of CP Violation (CPV) in kaon decays. CPV can be due to an asymmetric proportion of K^0 and $\bar{K^0}$ in K_S and K_L, described by the complex parameter ε [2]. This small parameter can be generated by an interaction coupling K^0 and $\bar{K^0}$ (therefore a ΔS=2 interaction), which would not link them to a decay state, but would affect the mass matrix of the K^0–$\bar{K}^0$ system. In this case, we speak of Indirect CP violation. This model is successful in describing most of the CPV phenomena, such us the predicted and observed asymmetry in semileptonic K_L decays. K_L decays to two pions are due to the small component ($|\varepsilon| = 2.23 \times 10^{-3}$) with CP= +1 present in K_L. Since this component is the dominant one in K_S, the relative abundance of $\pi^0\pi^0$ and $\pi^+\pi^-$ is the same in K_L and K_S.

Is there another origin of CPV in kaon decays? This would be caused by the direct decay of the CP= −1 component into two-pion final states, and it is referred to as Direct CPV (DCPV), with ΔS=1.

In general, a process can show DCPV if its amplitude is formed by at least two complex components. In the square of the amplitude, the interference terms will be different between the direct and the CP conjugated process, since the phases in the fundamental couplings are opposite, while the phases in the wave function associated to (strong) interactions in the final states are CP invariant and do not change.

In the decay of K^0 (or $\bar{K}^0$) to two pions, we have indeed two amplitudes, since the pions can be in two different Isospin states (I=0 or 2, I=1 being excluded by particles exchange symmetry). So if the weak amplitudes A_0, A_2 have different phases, DCPV can arise. Furthermore, since $\pi^0\pi^0$ and $\pi^+\pi^-$ select different Isospin amplitudes, DCPV can be identified looking at differences in the relative rates between K_L and K_S [3]:

$$A(K_L \to \pi^0\pi^0)/A(K_S \to \pi^0\pi^0) = \varepsilon - 2\,\varepsilon'$$
$$A(K_L \to \pi^+\pi^-)/A(K_S \to \pi^+\pi^-) = \varepsilon + \varepsilon'$$

where DCPV is described by the parameter ε':

$$\varepsilon' = i\ \mathrm{e}^{i(\delta_2-\delta_0)}(\mathrm{Re}A_2/\mathrm{Re}A_0)(\mathrm{Im}A_2/\mathrm{Re}A_2 - \mathrm{Im}A_0/\mathrm{Re}A_0)/\sqrt{2}$$

A quantity directly accessible by experiments is the double ratio of decay rates:

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)/\,\Gamma(K_S \to \pi^0\pi^0)}{\Gamma(K_L \to \pi^+\pi^-)/\,\Gamma(K_S \to \pi^+\pi^-)} \simeq 1 - 6 \times \mathrm{Re}\,(\varepsilon'/\varepsilon)\,.$$

Here only terms at first order in $\mathrm{Re}\,(\varepsilon'/\varepsilon)$ are retained, in agreement with observations and with expectations, since $A_2 \ll A_0$ following the ΔI=1/2 rule of weak decays.

In the Standard Model of the interactions between the fundamental constituents, the weak phases in the amplitudes come from the irreducible phase in the CKM matrix, and require Feynman diagrams containing loops including Up, Charm and Top quarks [4]. Theoretical predictions are uncertain due to difficulties in the computation of hadronic matrix elements, and the current predictions for $\mathrm{Re}\,(\varepsilon'/\varepsilon)$ are in the range of few 10^{-4} to $\approx 30\times10^{-4}$ [5].

2 Previous measurements

The results obtained up to last year are listed in Table 1. The collaboration NA31 at CERN [6] was the first to announce evidence for DCPV, not confirmed by E731 at Fermilab [7]. New experiments were set up both at Fermilab and CERN in the nineties, with first results published in 1999 [8,9].DCPV was confirmed, but the agreement among the different measurements was still poor. In 1999, NA48 announced a preliminary result from the sample of data collected in 1998 [10], consistent with the previous one.

New and more accurate results have been presented recently, and will be discussed in Section 7 and 8.

Table 1. Previous experimental results on $\mathrm{Re}\,(\varepsilon'/\varepsilon)$.

Experiment	Result$\times 10^4$
NA31 [6]	23.0 ± 6.5
E731 [7]	7.4 ± 5.9
KTEV - 96/97 data [8]	28.0 ± 2.4
NA48 - 97 data [9]	18.5 ± 7.3
NA48 - 98 data [10]	12.2 ± 4.9

3 NA48 Experimental technique

The determination of the double ratio R requires the measurement of four different rates. However, to achieve the required accuracy, it is crucial that the experiment is designed so that systematic effects contributes symmetrically to different components of R, and their effects cancel out to large extent in the final result.

In order to minimize the sensitivity to detector efficiency, to variations in beam intensity, and to accidental activity, the experiment is designed to collect data simultaneously in the four channels K_L, $K_S \rightarrow \pi^0\,\pi^0$, $\pi^+\pi^-$. Two neutral beams are used: (a) the K_L-beam, produced 126 m upstream of the nominal decay region (at a distance allowing the decay of the K_S component); (b) The K_S-beam, produced 6 m (corresponding on average to 1 τ_S) upstream of the decay region. The two beams are 68 mm apart as they pass the final collimator and enter the decay region, and are slightly convergent in order to virtually overlay at the position of the electromagnetic calorimeter, 115 m downstream. Contamination of the K_S-beam from K_L decay is negligible because of the difference in lifetime and branching ratios for $\pi\pi$ final states.

Figure 1 shows the layout of the decay region and the main components of the detector. In order to minimize the difference in acceptance between

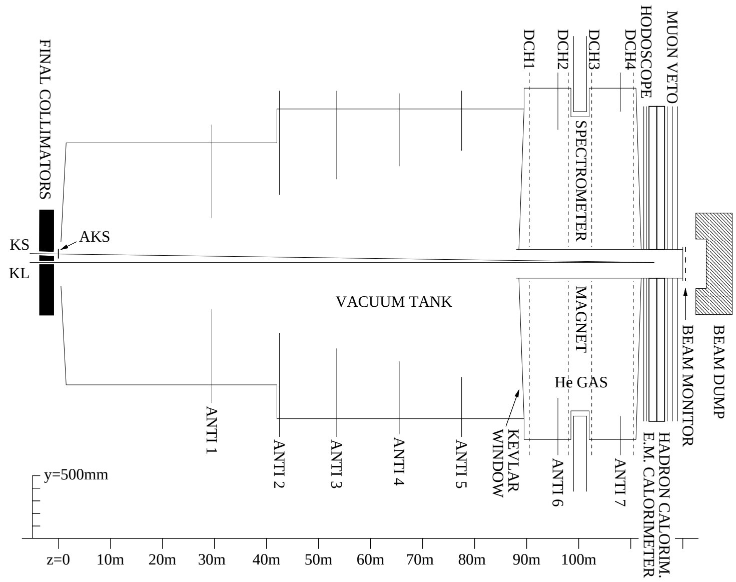

Fig. 1. Layout of the NA48 detector. The longitudinal and transverse scales are different.

K_L and K_S, only decays occurring in the upstream part are used, requiring $0 < \tau < 3.5\,\tau_S$, or $0 < z < 21$ m on average.

The upstream end of the fiducial decay volume, on the K_S beam, is defined by an anticounter formed by a monocrystal Iridium converter, and a set of plastic scintillation counters.

As discussed in more detail in Section 5, the identification K_L vs. K_S is done looking for a time coincidence between a kaon decay measured in the main detector, and the detection of a proton in the beam directed to the K_S production target. This is done by means of a finely segmented scintillation counter (tagger).

The main detector follows the 90 m evacuated decay tube. Charged pions are measured in a magnetic spectrometer formed by a dipole magnet and four drift chambers. The momentum resolution is equal to about 1 % for 100 GeV track momentum. A hodoscope of plastic scintillation counters is used for triggering and timing measurement for $\pi^+\pi^-$ decays.

The four photons from $\pi^0\,\pi^0$ decays are measured in a quasi-homogeneous liquid Krypton calorimeter. This detector uses a novel design, with longitudinal read-out cells (13,000 channels) formed by metal ribbons. The resolution in shower transverse position and energy are better than 1 mm and 2 % respectively, for shower energy above 25 GeV. Drifts in response are particularly small with this instrument, which is operated with controlled temperature, inherently stable cell gain, and accurately calibrated electronics. A uniformity of response of 0.4 % was achieved, together with a time resolution better than 200 ps for shower energy above 25 GeV.

Additional detectors in the NA48 set-up include a scintillating fiber hodoscope contained in the Krypton calorimeter, a hadronic calorimeter with iron blocks and scintillation counters, (used in the $\pi^+\pi^-$ trigger), a muon veto hodoscope, sets of anticounters placed around the decay region, and various beam intensity monitors.

4 Trigger, reconstruction and analysis

The trigger for $\pi^+\pi^-$ is formed by a first-level trigger based on the scintillation hodoscope, on the total energy measured by the calorimeters, and on the presence of hits in the drift chambers. A second-level trigger includes readout of the chambers and fast reconstruction from a farm of processors. The trigger had 1.6 % dead time and (97.90 ± 0.03) % efficiency, determined from comparison of different trigger elements and downscaled first-level triggers. Offline event-selection requires that the two tracks combine with an invariant mass compatible with the kaon (resolution: 2.5 MeV/c^2). Background due to $K_L \to \pi\,\mu\,\nu$ and $\pi\,e\,\nu$ is reduced in different ways: (a) requiring no hits in the muon veto matching reconstructed tracks; (b) on each track the momentum obtained from the spectrometer (P) and the energy measured by the Krypton calorimeter (E) should not match, in order to reject electrons; and (c) applying a cut on the component of the pair momentum transverse to the kaon direction. The final total background is equal to $(16.9 \pm 3.0) \times 10^{-4}$, with the error dominated by uncertainties in the background subtraction.

The trigger for $\pi^0\,\pi^0$ is entirely based on the Krypton calorimeter. Energy sums are used to analyse events in a pipeline processor free from dead time. The trigger efficiency was determined to be equal to (99.920 ± 0.009) %, with negligible difference between K_L and K_S events. The measurement of energy (E_i) and transverse distances ($d_{\rm ij}$) between the four showers are used to determine the longitudinal distance between the kaon decay vertex and the calorimeter, assuming that the total invariant mass of the four photons is equal to the kaon mass:

$$z_{\rm Kr} - z_{\rm decay} = \sqrt{\Sigma_{\rm ij} E_{\rm i} E_{\rm j} {d_{\rm ij}}^2} / M_{\rm K}\ .$$

Additional constraints are available, because the four photons must pair with an invariant mass equal to the neutral pion. The invariant mass of the pairs are measured with resolution of 0.9 MeV/c^2. The background is from to $K_L \to 3\pi^0$ decays, with two photons escaping the detector acceptance, and typically does not match the pion mass constraints. The residual background is $(9.6 \pm 2.0) \times 10^{-4}$ of the signal, with the uncertainty coming mainly from the interpolation below the signal region.

5 Kaon identification

The identification K_L vs. K_S is done by comparing the decay time (measured by the hodoscope and the Krypton calorimeter respectively for $\pi^+\pi^-$ and $\pi^0\pi^0$ decay modes) with the pulses detected on the tagger counter placed on the proton beam-line directed to the K_S production target. If a coincidence within a 4 ns wide interval is found, the event is labeled as K_S, otherwise as K_L. This method is affected, *a priori*, by two limitations: (a) accidental coincidences with protons not associated with the decaying kaon, which generates fake K_S out of real K_L events, and (b) tagging inefficiencies, where missing the coincidence produces instead a fake K_L.

The measurement of the double ratio is affected significantly only if the two kinds of errors are different in the two modes $\pi^+\pi^-$ and $\pi^0\pi^0$. Therefore, taking data simultaneously in the four decays with a detector scarcely sensitive to beam intensity assures that accidental tagging will be substantially symmetric in the two modes. Inefficiency in the tagger counter is also void of consequences, being symmetric between the two modes.

In the $\pi^+\pi^-$ mode, the decay vertex reconstruction achieved by the tracking chambers is sufficient to separate the two beams, and therefore the frequency of tagging errors can be measured directly. On the other hand, The differences in tagging errors between $\pi^0\pi^0$ and $\pi^+\pi^-$ can be determined accurately: for type (a), accidental coincidences in side bands of the tagging time-window are used; for type (b), differences in timing resolution are determined for events where both the hodoscope and the calorimeter measurements are present, which occur in case of Dalitz decays ($\pi^0 \to \gamma\, e^+e^-$), or in case of photon conversions into e^+e^- pairs in the thin Kevlar window delimiting the vacuum decay tube. Fig. 2 shows the distributions of time differences used for tagging and tagging studies, and Table 2 provides the values of the tagging errors.

Table 2. Tagging errors.

Accidental tagging rate in $\pi^+\pi^-$	10.649×10^{-2}
Accidental tagging difference $\pi^+\pi^-$ - $\pi^0\pi^0$	$(4.6 \pm 1.7) \times 10^{-4}$
Tagging inefficiency rate in $\pi^+\pi^-$	1.6×10^{-4}
Inefficiency difference $\pi^+\pi^-$ - $\pi^0\pi^0$	$(0.0 \pm 0.5) \times 10^{-4}$

6 Additional systematic effects and acceptance correction

The measurement of the double ratio requires an accurate definition of the intervals in kaon energy and in decay path over which the measurement is

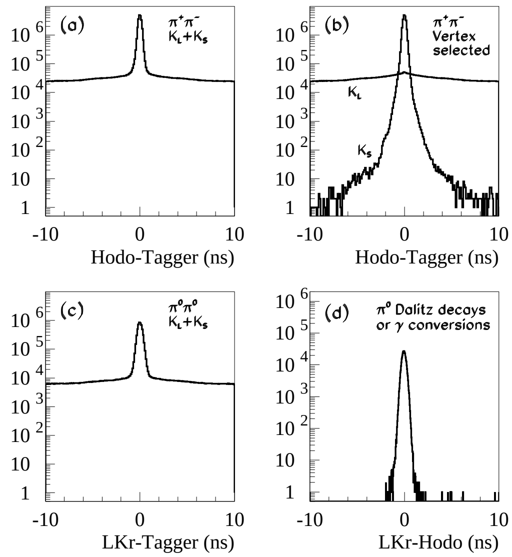

Fig. 2. Kaon identification: (a) distribution of the minimum difference between tagger and track times for $\pi^+\pi^-$ decays; (b) the same, separating K_S and K_L events from the reconstructed decay vertex; (c) as (a) for $\pi^0\pi^0$ decays; (d) difference in time measurement between calorimeter and hodoscope for events with electrons.

performed. The spectra of the K_L and K_S beams are similar and the accepted range is designed to balance gains and losses due to an energy scale offset. The reconstructed kaon mass value and the upstream edge of the K_S decays (at the K_S-anticounter) provide checks on the absolute scale and linearity of reconstruction in the $\pi^+\pi^-$ mode.

In the neutral mode, the energy scale is coupled to the distance scale by the formula for z_{decay} given above in Section 4. An energy scale offset or a non-linearity in the energy reconstruction would bias the measurement of the double ratio. However, the resulting effects are very small because of different reasons: (a) the linearity and the stability of the Krypton calorimeter are very satisfactory, (b) the boundary of the fiducial decay volume can be designed to minimize biases. For K_L decays, an energy offset causes an offset in the reconstructed proper decay time; given the long K_L decay path and the small variation of detector acceptance over the limited fiducial volume being considered, gains and losses of events compensate to large extent, and the resulting systematic uncertainty is small. For K_S decay, the downstream end of the accepted region is not critical because few events populate the region near the boundary set at 3.5 K_S lifetimes. The critical upstream end is accurately defined by the K_S-anticounter.

Accidental activity overlaid with kaon decays can affect the measurement by reducing the detection efficiency in any of the four channels. Accidental hits originate mainly from the K_L beam, and their effects cancel if they affect symmetrically K_L and K_S decays (in each decay mode), or, conversely, if the losses are symmetric between $\pi^0\pi^0$ and $\pi^+\pi^-$ decays (for both beams). In particular, the rate of accidental can be made symmetric by collecting K_L and K_S events simultaneously, and taking care that the ratio of the intensities of the two beams does not vary significantly. The data show that the rates of accidental activity in proximity of K_L and K_S events are equal within 1 %.

As explained below, the detector illumination can be made effectively similar between K_L and K_S decays, and this makes them equally sensitive to accidental hits.

The bias to the double ratio is reduced further if the sensitivity to accidental effects is made similar in $\pi^+\pi^-$ and $\pi^0\pi^0$ decays. This is achieved by defining fiducial cuts related to accidental activity, and by applying them symmetrically in both modes. In general, it is very useful to use a detector designed for high efficiency at high rate, and scarcely affected by accidental hits. Overall, we have determined that out of losses in the range of few per cent in the individual channels, the bias in the measurement of the double ratio can be reduced to be smaller than 5×10^{-4}.

In each of the decay modes, the detector acceptance depends smoothly on the decay position z (or decay time τ). Because of the difference in lifetimes, the averaged acceptances in $0 < \tau < 3.5\,\tau_S$ are different for K_L and K_S, and corrections up to about ±10 % would be needed across the momentum range 70–170 GeV. Rather than relying on a very accurate determination of the acceptance, we have chosen a different approach, which minimizes the difference in acceptance between K_L and K_S. The K_L decays are used in the double ratio weighted by a factor $w_L(z)$:[1]

$$w_L(z) \simeq exp[-z/(\beta\gamma c) \times (1/\tau_S - 1/\tau_L)]$$

In this way the z (or τ) distribution of the decays is equal for K_L and K_S, and the overall acceptance correction is equal to 0.27 % only, without exceeding 1.3 % at any kaon energy. The residual effect is related to differences in size and divergence between the two beams.

The distribution of showers and tracks in the detector is very similar for K_S and K_L-weighted events, hence minimizing the effects of non-uniformities, of localized reduction in efficiencies, and of accidental hits. As an example, Fig. 3 and 4 show comparisons for events with kaon energy between 100 and 110 GeV.

[1] The formula used in the analysis includes small terms due to K_S decays and K_S-K_L interference in the K_L-beam, not negligible for the highest kaon energy values.

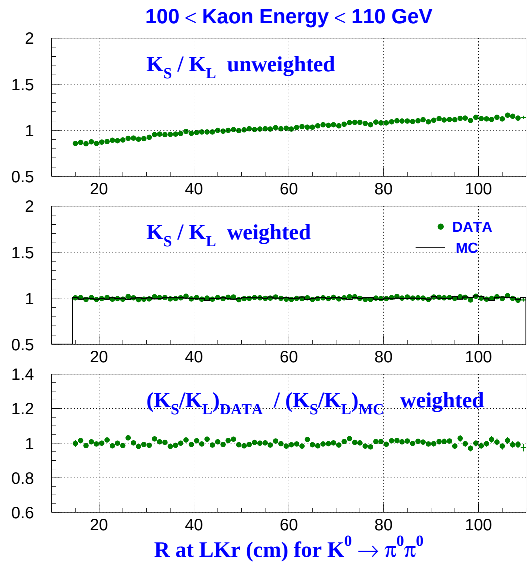

Fig. 3. Comparison of radial distribution of showers on the Krypton calorimeter, for $100 < E_K < 110$ GeV, for K_S, K_L, and K_L-weighted events, and for Monte Carlo predictions.

The disadvantage of this approach is that the statistical value of the samples of K_L events is reduced: the final statistical error is increased by about 35 % compared to an unweighted analysis.

7 NA48 result

The final correction and systematic uncertainties in the measurement of the double ratio, for data collected in 1998 and 1999, are given in Table 3. The value of R is obtained measuring the double ratio in 5 GeV wide bins in kaon energy, in order to cancel the effects of the small difference in spectra between K_L and K_S beams. Averaged in the 70–170 GeV interval, the result is $R = 0.99098 \pm 0.00101_{\mathrm{stat}} \pm 0.00126_{\mathrm{syst}}$, with the statistical error from the four samples and the total systematic error shown separately. The deviation from unity, scaled by the factor 1/6, gives the DCPV parameter: $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (15.1 \pm 2.7) \times 10^{-4}$, with the errors combined in quadrature. The value is consistent with the previous result from 1997 and 1998 data, and the current best result of NA48 (1997-1999) is [11]:

$$\mathrm{Re}\,(\varepsilon'/\varepsilon) = (15.3 \pm 2.6) \times 10^{-4}\,.$$ [2]

[2] Note added in proof. A new value $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (13.7 \pm 3.1) \times 10^{-4}$ from the last run of NA48 in 2001 has recently been published [12]. The final average of all data samples is $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$, fully consistent with the result above.

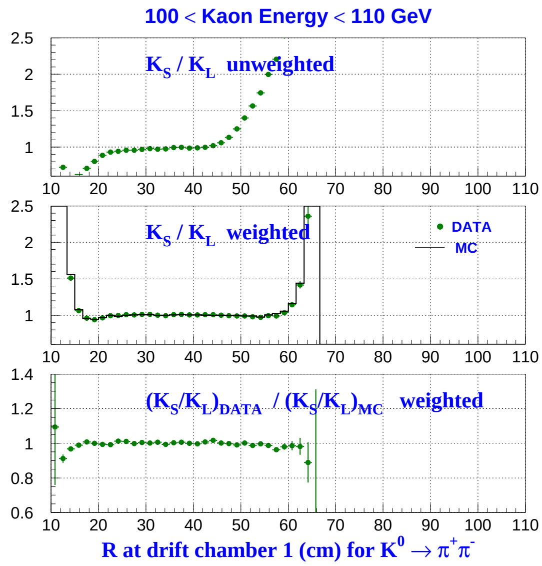

Fig. 4. Comparison of radial distribution tracks on the first drift chamber (for the track with smaller radius), for $100 < E_K < 110$ GeV, for K_S, K_L, and K_L-weighted events, and for Monte Carlo predictions.

Table 3. NA48 corrections and systematic uncertainties on R, in 10^{-4} units.

backgrounds	1.4 ± 4.1
tagging errors	8.3 ± 4.5
geometrical and energy scales, linearities	2.0 ± 6.4
trigger, AKS efficiency	-2.5 ± 5.2
acceptance correction	26.7 ± 5.7
accidental losses	0 ± 4.4
Total	35.9 ± 12.6

8 The KTEV experiment

There are several similarities between the CERN (NA48) and the Fermilab (KTEV) experiments on Re $(\varepsilon'/\varepsilon)$. They include the simultaneous detection of the four channels, the use of a magnetic spectrometer and of a high performance (although very different) electromagnetic calorimetry. The main differences include the design of the neutral beams, the K_L–K_S identification, and the acceptance corrections.

In KTEV, two identical neutral beams are used, well separated and nearly parallel as they enter the decay region. A kaon regenerator, made of plastic scintillator, is placed on either of the two beams, alternatively on each accelerator cycle. A fraction of the K_L crossing the regenerator undergoes forward coherent elastic scattering. In this process, the beam particle is effectively undeflected, but since the "strong" interaction with the regenerator is different for K^0 and $\bar{K^0}$, the superposition of states defining the impinging K_L is replaced by a superposition of K_L and K_S, in the process known as K_S regeneration.

The experiment looks at $\pi\pi$ decays downstream of the regenerator, dominated by the K_S component, and compares the relative abundance of $\pi^0\,\pi^0$ and $\pi^+\pi^-$, with those observed in the "vacuum" beam, which does not cross the regenerator and is dominated by K_L decays. Parent identification is done from direct reconstruction of the decay vertex for $\pi^+\pi^-$, and from the transverse position of the center of gravity of energy deposition in the calorimeter for $\pi^0\,\pi^0$. Each characteristic specific of this experiment, and substantially different in NA48, carries a balance of advantages and disadvantages, which would deserve a detailed discussion not possible here.

It is relevant to mention that in order to use the largest possible statistical samples, in the main analysis KTEV does not apply event weighting like NA48, and actually includes in the K_L samples also decays upstream of the regenerator. The resulting acceptance correction is relatively large (several per cent), and is modeled by an accurate Monte Carlo, checked studying in detail K_L decays to $3\pi^0$ and $\pi\, e\, \nu$.

The KTEV collaboration published in 1999 [8] a result from samples of events collected in 1996 ($\pi^0\,\pi^0$ decays) and 1997 ($\pi^+\pi^-$). The value obtained was $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (28.0 \pm 4.1) \times 10^{-4}$, implying strong evidence for DCPV, but scarcely consistent with the previous result from E731. Recently, new results have been announced [13], including a revised value for the 1996/97 sample, now quoted as $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (23.2 \pm 4.4) \times 10^{-4}$, and a result from an independent sample collected in 1997: $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (19.8 \pm 2.9) \times 10^{-4}$. The change in the value obtained with the first samples of data is in part due to more accurate computations of the corrections, and in part to a recognized error in background subtraction. The overall KTEV result is $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (20.7 \pm 1.5_{\mathrm{stat}} \pm 2.4_{\mathrm{syst}} \pm 0.5_{\mathrm{MCstat}}) \times 10^{-4}$, where statistical, systematic and Monte Carlo statistical error are quoted separately; adding in quadrature:

$$\mathrm{Re}\,(\varepsilon'/\varepsilon) = (20.7 \pm 2.8) \times 10^{-4}\,.$$

The systematic errors include major contributions from energy scale and linearity in calorimetric measurements, from background due to scattering in the regenerator, and from the acceptance correction.

9 Conclusions

Fig. 5 shows the chronological sequence of the experimental results. Bands corresponding to $\pm 1\,\sigma$ (from nominal weighted averages) are provided for data as available in 1993, 1998, and for the current situation.

The current average of the results on DCPV in neutral kaon decays is $\mathrm{Re}\,(\varepsilon'/\varepsilon) = (17.3 \pm 1.8) \times 10^{-4}$; the average is obtained from the final results of NA31 and E731, and the last, comprehensive results from NA48 and KTEV. Compared to two or eight years ago, this value represents significant improvements in accuracy, which now approaches 10 %, and in consistency between the different measurements ($\chi^2/\mathrm{ndf} = 5.7/3$).

In a moment when measurements of CP Violation in the sector of the B mesons are becoming available [14], the results from the neutral kaon system are still most remarkable, since they remain the only evidence of direct violation of CP symmetry, occurring in the decay process rather than in the mixing of meson-antimeson states.

In the near future, new results are expected from the complete data samples collected by E731 and NA48. However, already now the situation is such that the most desirable advancements would be on the side of the theory: only a significant improvement in the accuracy of the prediction can establish or deny the compatibility between the measured value for DCPV in the kaon system and the Standard Model of fundamental interactions.

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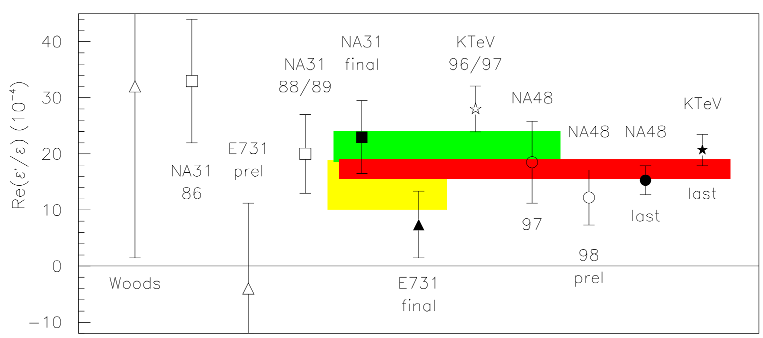

Fig. 5. Time evolution of results on $\mathrm{Re}\,(\varepsilon'/\varepsilon)$, with $\pm 1\sigma$ bands. The current average include the four data points with full symbols.

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