RESULTS ON *CP* VIOLATION FROM NA48*

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The main goal of the NA48 experiment at the CERN SPS accelerator is the measurement of the *direct* CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ in the $K^0 \to 2\pi$ decays, with an accuracy close to 2×10^{-4}. The preliminary result obtained from 1998 data is reviewed. The use of intense K^0_{S} and K^0_{L} beams allows in parallel the investigation of rare CP violating decays. The future project aiming to study *direct* CP violation with charged kaon beams is briefly discussed.

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1. Introduction

CP violation was discovered in 1964 by Christenson, Cronin, Fitch and Turlay [1], in the decay of the long-lived neutral kaon (called until then 'K^0_2') in two charged pions, with a branching ratio close to 2×10^{-3}: '**Evidence for the 2π-decay of the K^0_2 meson**'. This discovery showed that the long-lived neutral kaon could not be a pure CP eigenstate. As soon as 1964, Wu and Yang [2] introduced a new formalism to describe the neural kaon system, with K^0_{S} and K^0_{L} states, and the '*impurity parameter*' ε_K:

***CP* symmetry being not conserved**, the Hamiltonian eigenstates K^0_{S} (S=Short) and K^0_{L} (L=Long) are no more pure CP eigenstates (K^0_1 resp. K^0_2), but contain a small contribution of the opposite CP eigenstate (K^0_2

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resp. K_1^0), parametrized by ε_K (in the hypothesis of CPT invariance):

$$|K_S^0\rangle = \frac{1}{\sqrt{1+|\varepsilon_K|^2}}(|K_1^0\rangle + \varepsilon_K|K_2^0\rangle)\,,$$

$$|K_L^0\rangle = \frac{1}{\sqrt{1+|\varepsilon_K|^2}}(|K_2^0\rangle + \varepsilon_K|K_1^0\rangle)\,.$$

It then clearly appears that the parameter ε_K describes the CP violation resulting from an asymmetric mixing between the K^0 and $\overline{K^0}$ states, the decay process itself being CP conserving. This kind of CP violation in the **mixing** is called **indirect *CP* violation**.

CP violation can also arise as a consequence of the decay into two pions of the K_2^0 component of the K_L^0. This kind of CP violation in the **decay** is called **direct *CP* violation**. It is linked to the phase difference between weak transitions amplitudes of the $|K^0\rangle$ and $|\overline{K^0}\rangle$ to a two pions final state of defined isospin I, and the relevant parameter in the kaon system is ε' which can be written as:

$$\varepsilon' = \frac{\varepsilon_K}{\sqrt{2}}\left\{\frac{\langle\pi\pi_{I=2}|H|K_L^0\rangle}{\langle\pi\pi_{I=0}|H|K_L^0\rangle} - \frac{\langle\pi\pi_{I=2}|H|K_S^0\rangle}{\langle\pi\pi_{I=0}|H|K_S^0\rangle}\right\}.$$

This expression immediately shows the smallness of ε', since $\varepsilon = (2.28 \pm 0.02) \times 10^{-3}$ and because of the empirical $\Delta I = 1/2$ selection rule, and the value of $\mathrm{Re}(\varepsilon'/\varepsilon)$ is expected in the $\mathcal{O}(10^{-3})$ range. The smallness of *direct* CP violation effects created a tremendous experimental effort over the last 2 decades to establish whether or not ε' was different from zero as predicted by the *superweak* model [3]. The theoretical interest is twofold: *first* assert whether a CP_{odd} state can decay to a CP_{even} final state, which would immediately rule out the *superweak* model, and *second* put constraints on the parameters of the Cabibbo–Kobayashi–Maskawa V^{CKM} matrix [4] in the framework of the Standard Model (Fig. 1). A 'pedagogical' formula (Buras [5]) shows how ε'/ε is related to the V^{CKM} coefficients:

$$\frac{\varepsilon'}{\varepsilon} \approx \frac{\mathrm{Im}\,\lambda_t}{1.34} 18 \left(\frac{110\ \mathrm{MeV}}{M_S(M_C)}\right)^2 \left[0.75\,B_6 - 0.4 B_8 \left(\frac{M_T}{165\ \mathrm{GeV}}\right)^{2.5}\right] \frac{\Lambda_{\overline{\mathrm{MS}}}}{340\ \mathrm{MeV}}$$

with $\mathrm{Im}\,\lambda_t = |V_{ub}||V_{cb}|\sin\delta$. The theoretical uncertainties on the matrix element B_6 — reflecting the effect of the ElectroWeak penguins, and B_8 — corresponding to the *strong* penguins, are such that no quantitative estimate of $\mathrm{Im}\,\lambda_t$ can presently be extracted from the measurement of ε'/ε.

The ratio of the CP violating to the CP conserving kaon decay amplitudes to a $\pi\pi$ final state is different for final states $\pi^0\pi^0$ and $\pi^+\pi^-$, because

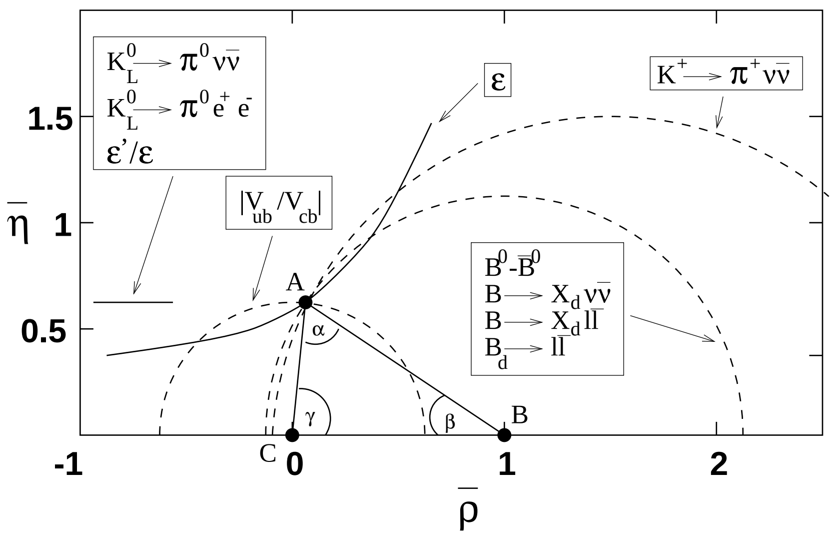

Fig. 1. Contributions to the determination of the unitarity triangle (from Buras).

of their different decomposition on isospin eigenstates of $I = 0$ and $I = 2$. In other words, the two CP violating neutral kaon decay amplitudes into two pions:

$$\eta^{+-} \equiv \frac{A(K^0_{\rm L} \to \pi^+\pi^-)}{A(K^0_{\rm S} \to \pi^+\pi^-)} \simeq \varepsilon + \varepsilon'$$

and

$$\eta^{00} \equiv \frac{A(K^0_{\rm L} \to \pi^0\pi^0)}{A(K^0_{\rm S} \to \pi^0\pi^0)} \simeq \varepsilon - 2\,\varepsilon'$$

contain different admixture of the two CP violating processes in charged and in neutral mode. This small difference is used by the fixed target experiments to search for *direct* CP violation in a significant difference from 1 of the double ratio of decay rates R:

$$R \equiv \frac{\frac{\Gamma(K^0_{\rm L}\to\pi^0\pi^0)}{\Gamma(K^0_{\rm S}\to\pi^0\pi^0)}}{\frac{\Gamma(K^0_{\rm L}\to\pi^+\pi^-)}{\Gamma(K^0_{\rm S}\to\pi^+\pi^-)}} = \left|\frac{\eta_{00}}{\eta_{+-}}\right|^2$$

and derive ε'/ε as:

$$\mathrm{Re}\left(\frac{\varepsilon'}{\varepsilon}\right) \simeq \frac{1-R}{6}\,.$$

Ten years ago, the NA31 experiment at CERN reported a first evidence of *direct CP* violation: $\mathrm{Re}(\varepsilon'/\varepsilon) = (23 \pm 6.5) \times 10^{-4}$ [6]. The result of the competitor experiment E731 at Fermilab was in marginal agreement: $\mathrm{Re}(\varepsilon'/\varepsilon) = (7.4 \pm 5.2 \pm 2.9) \times 10^{-4}$ [7]. Clarifying the situation with a much better accuracy was one of the main motivations of new experiments in both laboratories. The methods of NA31 and E731 were radically different, as well as their limitations. E731 was statistically limited, and therefore used at best the statistical power of K^0_{L} decays, at the price of a strong dependence upon the Monte Carlo simulation. On the other hand, the simultaneous collection of K^0_{L} and K^0_{S} decays allowed natural cancellations in single ratios of decay rates. NA31 appears more systematically limited, because of distinct K^0_{L} and K^0_{S} data taking periods, resulting in quite different accidental activities. Among the strong points of NA31, we have to quote the absence of backgrounds for K^0_{S} decay modes due to the use of a target unlike E731 which uses a regenerator, and the similarity of the energy and vertex position distributions, resulting in a very small differential acceptance correction and Monte Carlo dependence.

The NA48 experiment at CERN was primarily designed to measure $\mathrm{Re}(\varepsilon'/\varepsilon)$ with a precision of 2×10^{-4}, taking advantage of the experience acquired with the previous generation of experiments. The use of intense kaon beams allows this experiment to be sensitive to rare K^0_{L} and K^0_{S} decays. Its competitor, KTeV at Fermilab, aims at a similar accuracy on $\mathrm{Re}(\varepsilon'/\varepsilon)$ (E832 [8]) and has a dedicated experimental setup for rare kaon decay studies (E799-II).

2. The NA48 beams and detectors

The extraction on $\mathrm{Re}(\varepsilon'/\varepsilon)$ is based on the double ratio technique sketched in the previous section. The NA48 beam line was designed having in mind the minimization of the corrections to the double ratio of number of events from the four decay modes in a common fiducial region. Two quasi-colinear K^0_{L} and K^0_{S} beams are formed, and their 2π decays are collected simultaneously in order to maximize the cancellations of beam fluxes, efficiencies, experimental acceptances and losses due to accidental activity in the double ratio.

K^0_{L} are produced by the interaction of the SPS 450 GeV proton beam on a beryllium target located ~ 240 m from the detectors, with a 2.4 mrad targeting angle optimizing the kaon over neutron ratio in the neutral beam, and a typical intensity of 1.4×10^{12} protons per 2.5 s spill every 14.4 s. Part of the remaining protons are channeled by a bent silicon crystal and put back in the neutral beam, then directed to a second '*near*' target located ~ 120 m from the detectors. Typically, 3×10^{7} protons hit this so-called K^0_{S}

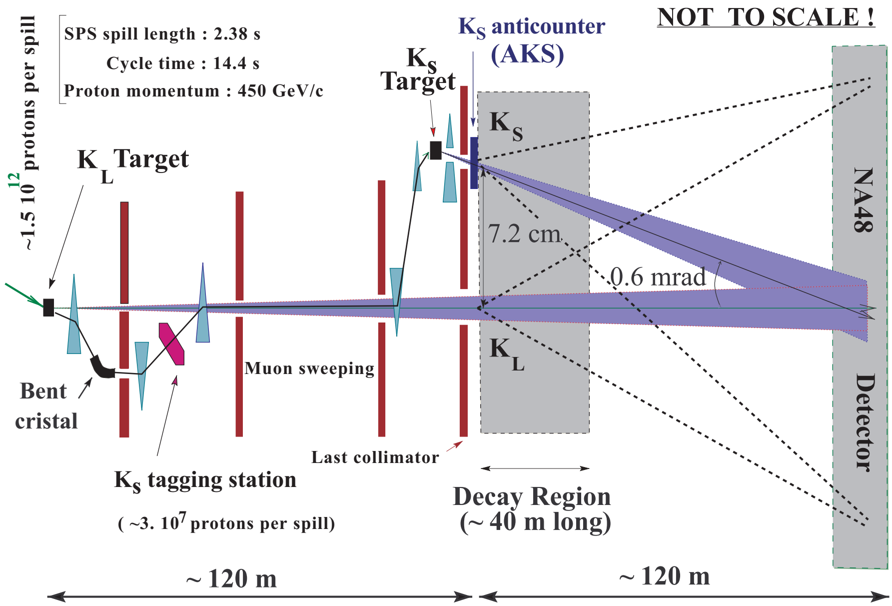

Fig. 2. The NA48 $K^0_{\rm L}$ and $K^0_{\rm S}$ beams.

target separated from the $K^0_{\rm L}$ beam axis by 7.2 cm in the vertical plane, with a targeting angle of 4.2 mrad which makes the $K^0_{\rm S}$ decay spectrum similar to the $K^0_{\rm L}$ one. The resulting neutral beam is directed to the NA48 detectors so that $K^0_{\rm L}$ and $K^0_{\rm S}$ beam are convergent at the electro-magnetic calorimeter 120 m upstream the $K^0_{\rm S}$ target (Fig. 2).

This convergence at the detectors makes it impossible to recognize the beam origin of $2\pi^0$ decays. Therefore a tagging counter is placed in the attenuated proton beam just after the bent crystal in order to identify the beam from which a decay originates by a time of flight technique between the protons and the kaon decay products.

The former CERN experiment NA31 mimicked the 'flat' $K^0_{\rm L}$ vertex distribution with a movable $K^0_{\rm S}$ target, to get similar energy and longitudinal vertex distributions, and therefore minimize the effect of the $K^0_{\rm L}$ *vs* $K^0_{\rm S}$ lifetime difference which populates quite differently the decay region. In the same spirit, NA48 applies lifetime weighting to the $K^0_{\rm L}$ events to make similar distributions and therefore minimize the differential acceptance correction in both neutral and charged modes. As a consequence, the decay region is limited to $3.5\,\tau_s$ from the $K^0_{\rm S}$ target corresponding to ~ 40 m, and about 2/3 of otherwise good $K^0_{\rm L}$ decays are rejected *online* by a lifetime cut. An additional increase of the statistical error of ~ 40 % is due to the weighting procedure, so that 3 years of high intensity proton beams are required to reach the aimed accuracy of $\sim 2\times10^{-4}$ on ε'/ε.

The main NA48 detectors are a magnetic spectrometer for the $\pi^+\pi^-$ mode, and an electromagnetic spectrometer for the $\pi^0\pi^0$ mode (Fig. 3). The spectrometer consists of four high resolution drift chambers placed on either sides of a dipole magnet with a $p_{\rm T}$ kick of 250 MeV/c, the space resolution is $\sigma_{X,Y} = 90$ μm and the $\pi^+\pi^-$ invariant mass resolution is 2.5 MeV/c^2. The $27X_0$ long liquid krypton electromagnetic calorimeter has a 2×2 cm^2 granularity, a position resolution better that 1.3 mm, and a good energy resolution resulting in a π^0 mass resolution of 1.1 MeV. These two detectors, as well as the charged trigger hodoscope and tagging detector, have time resolutions better than 1 ns to fulfill the $K^0_{\rm S}$ tagging requirements. Further details on the experimental setup will be found in [9].

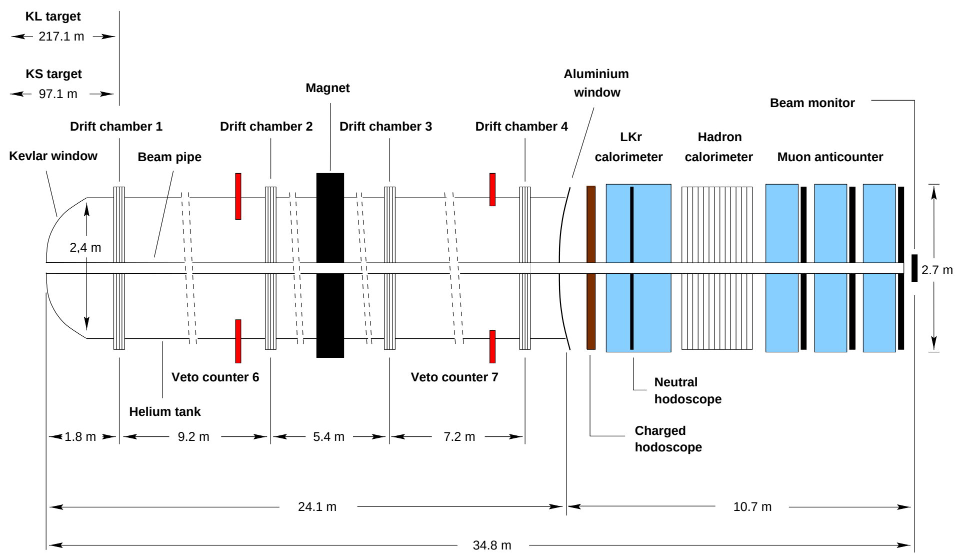

Fig. 3. The NA48 detectors.

The experiment was designed to be deadtimeless, all data being buffered for 204.8 μs, with synchronous neutral trigger and asynchonous level 2 charged trigger performing the online reconstruction of $\pi^+\pi^-$ candidates in less than 100 μs. The versatility of these programmable triggers and the high data acquisition capabilities allow the recording of large samples of control triggers as well as various trigger topologies for both the ε' analysis and the rare decays or hyperon decays studies.

3. The direct *CP* violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$

The first data taking for ε'/ε took place in 1997, with the collection of 0.5×10^6 $K^0_{\mathrm{L}}\to2\pi^0$ at a reduced beam intensity. This modest data sample allowed a first determination of $\mathrm{Re}(\varepsilon'/\varepsilon)$ with an accuracy of 7.3×10^{-4} [10]. A trigger/DAQ upgrade was performed before the 1998 data taking which provided a sample of 1.1×10^6 $K^0_{\mathrm{L}}\to2\pi^0$. This dataset was used for the preliminary result presented in this section [11]. The 1999 run, longer and more efficient owing to improved readout and overall DAQ/accelerator efficiency, allowed the recording of 2.0×10^6 $K^0_{\mathrm{L}}\to2\pi^0$. The implosion of the carbon-fiber beam-pipe during the winter shutdown damaged the four drift chambers of the spectrometer, and data taking with restrung drift chambers is foreseen to resume in July 2001 for 90 days at reduced proton intensity and longer spill in order to collect 1.5×10^6 $K^0_{\mathrm{L}}\to2\pi^0$. Altogether, $\sim5\times10^6$ of this more statistically limited mode will be collected, the statistics of any other 2π decay mode being at least four times higher.

Relying on events counting, the extraction of ε'/ε is in principal straightforward. The main difficulty is the precise definition of the decay volume, which requires an excellent knowledge of both neutral and charged energy scales. The high resolution detectors of the experiment allow a substantial reduction of the physics background which mainly affect the K^0_{L} decay modes: in charged mode the $Ke3+K\mu3$ background accounts for $(19\pm3)\times10^{-4}$, whereas the $K^0_{\mathrm{L}}\to3\pi^0$ background is estimated to $(7\pm2)\times10^{-4}$. We will simply emphasize two key points of the NA48 analysis method: the tagging and the events weighting.

The tagging constitutes the $K^0_{\mathrm{S}}/K^0_{\mathrm{L}}$ identification. In charged modes, the decay vertex spacial resolution in the transverse plane is such that decays originating from the K^0_{S} beam are easily identified from those of the K^0_{L} beam. Because of the convergence of the two beams at the calorimeter, the 4γ center of gravity distributions will be identical for K^0_{S} an K^0_{L} decays. Therefore the beam origin of the decay will be attributed on the basis of a time-of-flight coincidence between the event time of the decay and the (non-)occurrence of a proton in the tagging station, and this for both neutral and charged decays. The width of the coincidence window of ±2 ns (Fig. 4) has been chosen to minimize the systematic uncertainty coming from mistagging. Mistagging can occur from two sources: first the inefficiency of the tagging counters, which will cause K^0_{S} events to be identified as K^0_{L}. What really matters is the differential inefficiency between neutral and charged decays, and the tagging counters are highly symmetric to that respect. An inefficiency of $(1.97\pm0.05)\times10^{-4}$ is directly measured in charged mode, whereas using $2\pi^0$ and $3\pi^0$ events containing a conversion, the comparison of the charged hodoscope and electromagnetic calorimeter times allows to put

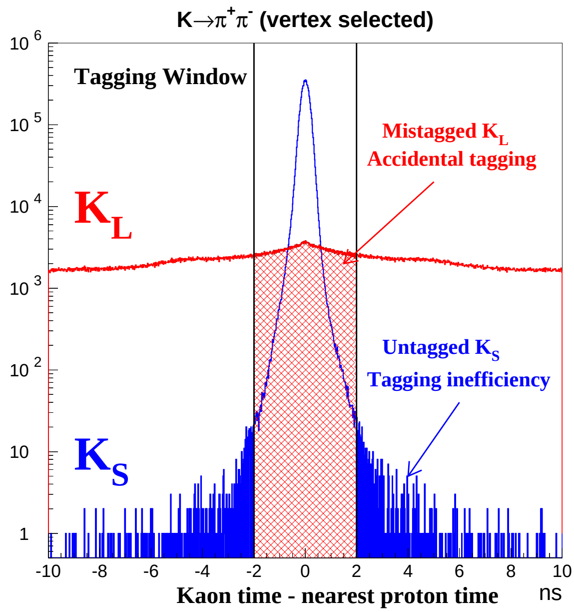

Fig. 4. Time distribution of the difference between $K^0_{\rm S,L}$ events and the time of the nearest proton seen by the tagging counter.

a bound of 0.5×10^{-4} on the differential inefficiency. The second mistagging effect is the accidental tagging of $K^0_{\rm L}$ as $K^0_{\rm S}$, due to accidental coincidences in the 4 ns wide window, and is as big as (11.05 ± 0.01) % directly measured in charged mode. Using $2\pi^0$ events in '*sides bands*' of the time of flight distribution to estimate the activity in the tagging window, as well as $3\pi^0$ events to determine the difference of activity between the tagging window and the sides bands, a charged-neutral differential effect of $(0.3 \pm 3.9) \times 10^{-4}$ is found and used to correct the double ratio R.

The main originality of the NA48 analysis is the $K^0_{\rm L}$ weighting. It aims to compensate for the large $K^0_{\rm S}$ to $K^0_{\rm L}$ lifetime difference which populates quite differently the longitudinal decay volume. In fact, $K^0_{\rm L}$ and $K^0_{\rm S}$ decays are detected in different transverse positions of the experimental setup, which create a strong differential dependence on the experimental acceptance and local inefficiencies. In order to avoid a large correction to the double ratio, $K^0_{\rm L}$ events are weighted roughly speaking by the ratio of $K^0_{\rm S}$ to $K^0_{\rm L}$ decay rates as a function of their proper time τ:

$$\mathrm{Weight}(\tau) = \frac{\Gamma_{2\pi}(\tau \text{ from } K^0_{\rm S} \text{ target})}{\Gamma_{2\pi}(\tau \text{ from } K^0_{\rm L} \text{ target})} \sim \exp\left(-\tau\left(\frac{1}{\tau_{\rm S}} - \frac{1}{\tau_{\rm L}}\right)\right) .$$

The beginning of the decay region is defined by the $K^0_{\rm S}$ anti-counter position, 6 m from the $K^0_{\rm S}$ target. A cut on the reconstructed $Z_{\rm vertex}$ position is applied on $K^0_{\rm L}$ events, whereas the anti-counter itself is used for $K^0_{\rm S}$ events. The cost of the weighting procedure is an increase of the statistical uncertainty by 36 %, and the gain is that all $K^0_{\rm L}$ distributions become quite similar to the $K^0_{\rm S}$, up to small irreducible residual differences showing the difference between the $K^0_{\rm S}$ and $K^0_{\rm L}$ beams. A full Monte Carlo simulation is then necessary to estimate the differential acceptance correction to the double ratio, which accounts for $(31 \pm 8.5) \times 10^{-4}$ with this weighting procedure although it would be as high as $\sim 200 \times 10^{-4}$ otherwise (Fig. 5). This acceptance correction is the largest contribution to the overall correction of $(37 \pm 24) \times 10^{-4}$ applied on the double ratio of raw number of events, the effect on ε'/ε being 6 times smaller, and illustrates the robustness of the NA48 analysis method.

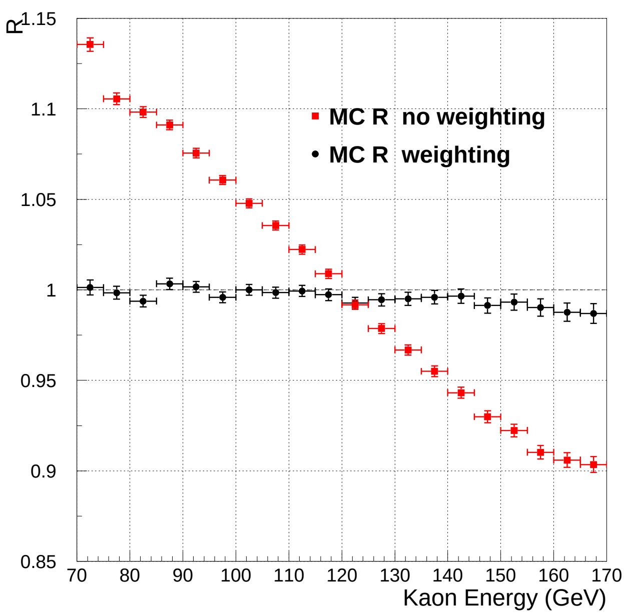

Fig. 5. Acceptance correction *vs* kaon energy with and without $K^0_{\rm L}$ weighting.

For the $\sim 1 \times 10^6$ $K^0_{\rm L} \to 2\pi^0$ collected in 1998 by NA48, the preliminary result reads:

$$\mathrm{Re}\left(\frac{\varepsilon'}{\varepsilon}\right) = (12.2 \pm 2.9_{\rm stat} \pm 4.0_{\rm syst}) \times 10^{-4} .$$

It is quite compatible with the earlier result on 1997 data [10], and constitutes in itself a $2.5\,\sigma$ signal of *direct CP* violation. The agreement with the

KTeV result is not quite perfect, but one has to wait for final results of both collaborations before drawing conclusions on the exact level of *direct* CP violation and its compatibility with the Standard Model prediction which requires an improvement of the theoretical uncertainties. The analysis of both 1998 and 1999 NA48 data is being finalized with a threefold increase in data statistics, while the systematic uncertainty goes below the 3×10^{-4} level, and will be in shape for the summer 2001 conferences.

4. *CP* violating rare kaon decays

Unlike its KTeV competitor, the hyperons and rare kaon decay studies in NA48 were performed during the standard ε' running, with the parasitic recording of events satisfying a wide variety of trigger conditions. Among those, we will concentrate here on the decays closely related to CP violation.

4.1. $K_{\rm S,L} \to \pi^+\pi^-e^+e^-$

The decay $K_{\rm L}^0 \to \pi^+\pi^-e^+e^-$ is expected to proceed mainly through a $\pi^+\pi^-\gamma^*$ state. Two dominant components contribute to the amplitude: an indirect CP-violating $K_{\rm L}^0 \to \pi^+\pi^-$ with inner bremsstrahlung, and a CP-conserving photon M1 direct emission followed by internal conversion. The interference of these two amplitudes results in a CP-violating circular polarization of the γ^*, which can be probed by studying the correlation of the e^+e^- plane relative to the $\pi^+\pi^-$ plane: the ϕ angle between these planes is a T odd variable. In the model of Sehgal and Wanniger [12], a non-zero value of the Γ_3 term of the ϕ angular distribution:

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

constitutes an unambiguous sign of *indirect* CP violation. The effect is then particularly visible in the CP-violating asymmetry defined as:

$$\mathcal{A}_\phi = \frac{N_{\cos\phi\sin\phi>0} - N_{\cos\phi\sin\phi<0}}{N_{\cos\phi\sin\phi>0} + N_{\cos\phi\sin\phi<0}}$$

for which the theoretical prediction of [12] is 14.4 %.

A dedicated 4-tracks trigger was implemented in the course of the 1998 NA48 ε' data taking. A total of 1337 signal events was selected from 1998 and 1999 data, with 35 background events coming mainly from $K_{\rm L}^0 \to \pi^+\pi^-\gamma$ with conversion $\gamma \to e^+e^-$, overlayed $K_{\rm L}^0 \to \pi^-e^+\nu_e$ and $K_{\rm L}^0 \to \pi^+e^-\bar{\nu}_e$, and $K_{\rm L}^0 \to \pi^+\pi^-\pi^0_{\rm D}$ with $\pi^0_{\rm D} \to e^+e^-\gamma$. The main $K_{\rm L}^0 \to \pi^+\pi^-\pi^0_{\rm D}$ background is suppressed cutting on the $P_0'^2$ kinematic variable:

$$P_0'^2 \equiv \frac{\left(M_K^2 - M_{\pi^0}^2 - M_{\pi\pi}^2\right)^2 - 4M_{\pi^0}^2M_{\pi\pi}^2 - 4M_K^2(P_T^2)_{\pi\pi}}{4\left[(P_T^2)_{\pi\pi} + M_{\pi\pi}^2\right]}$$

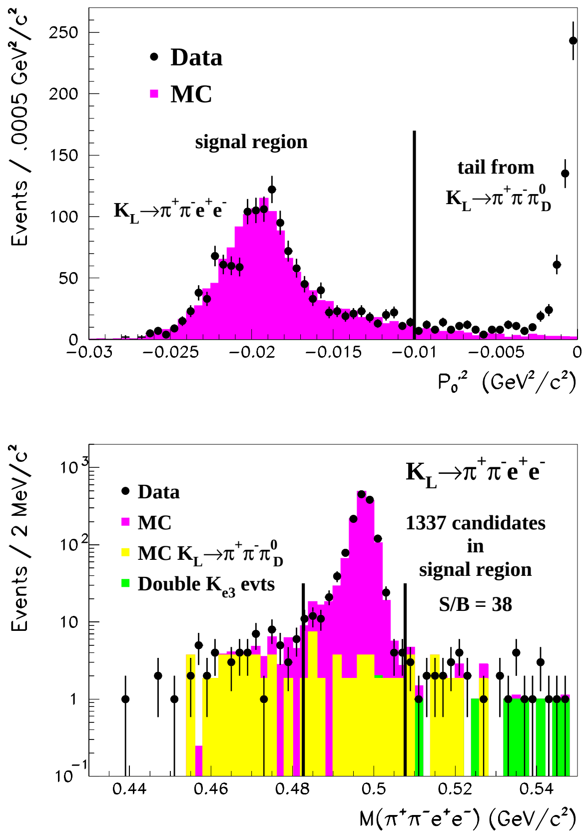

Fig. 6. Top: distribution of the $P_0'^2$ discriminating variable; bottom: $\pi^+\pi^-e^+e^-$ invariant mass distribution, where the solid lines delimit the signal region.

which is positive for background and negative for $\pi^+\pi^-e^+e^-$ events. Fig. 6 shows the $P_0'^2$ distribution and the $\pi^+\pi^-e^+e^-$ invariant mass distribution. The Monte Carlo used to compute the acceptance correction includes a form factor F in the M1 direct emission term:

$$F = \tilde{g}_{\rm M1}\left[1 + \frac{a_1/a_2}{(M_\rho^2 - M_K^2) + 2M_K E_\gamma^*}\right],$$

where we borrowed the values $\tilde{g}_{\rm M1} = 1.35^{+0.20}_{-0.17}$ and $a_1/a_2 = -0.720 \pm 0.029$ GeV$^2/c^2$ from KTeV [13] to allow easier comparisons. The preliminary branching ratio is:

$$\mathrm{BR}(K_{\rm L}^0 \to \pi^+\pi^-e^+e^-) = (3.1 \pm 0.1 \pm 0.2) \times 10^{-7}$$

using $K_L^0 \to \pi^+\pi^-\pi_D^0$ as normalization channel, which is in good agreement with the theoretical prediction of $\sim 3 \times 10^{-7}$ (Sehgal and Wanniger) and in fair agreement with the similar number from KTeV [14].

The CP-violating asymmetry is maximal where the interference of the M1 direct emission and the inner bremsstrahlung is the biggest. The experimentally observed asymmetry is the convolution of this interference with the detector acceptance, which enhance the observed effect. On the other hand, full simulation of the detector shows that in the absence of interference the observed asymmetry is zero, and that no asymmetry is generated by apparatus effects. Fig. 7 shows the observed angular distribution together with the Monte Carlo simulation before and after unfolding of the experimental acceptance. The asymmetry is found to be

$$\mathcal{A}_L = (13.9 \pm 2.7 \pm 2.0)\ \%$$

in agreement with the recently published value from KTeV [13] as well as with the theoretical prediction of [12].

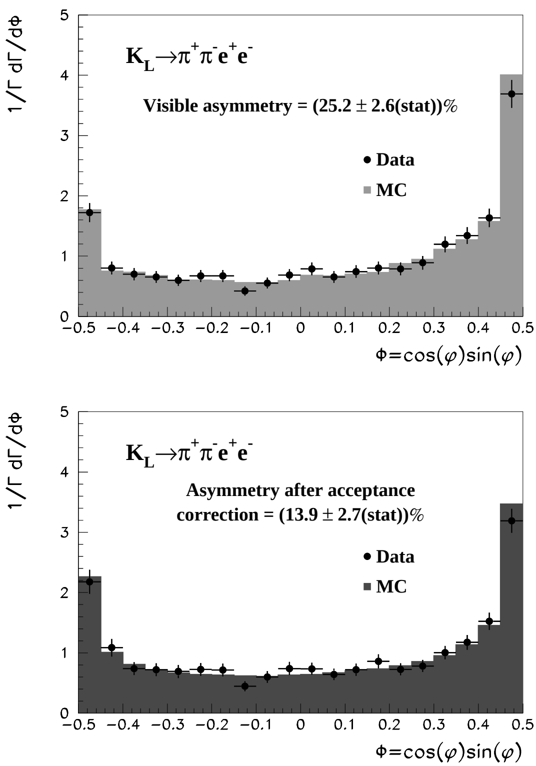

Fig. 7. $\cos\phi \sin\phi$ distributions. Top: observed in the data; bottom: after acceptance unfolding.

NA48 offers the unique opportunity of exploiting an almost pure $K^0_{\rm S}$ beam from the near target. The $K^0_{\rm S} \to \pi^+\pi^-e^+e^-$ channel was looked for, because the decay amplitude is dominated by the $CP_{\rm even}$ inner bremsstrahlung component and the expected asymmetry of the ϕ angular distribution is $\mathcal{A}_{\rm S} = 0$.

The first observation of $K^0_{\rm S} \to \pi^+\pi^-e^+e^-$ was recently reported [15] based on 56 events normalized to 105 fully reconstructed $K^0_{\rm L} \to \pi^+\pi^-\pi^0_{\rm D}$ events originating from the $K^0_{\rm S}$ target. The analysis of this decay mode relies both on the good vertex resolution for $K^0_{\rm S}/K^0_{\rm L}$ identification and on the use of the tagging counter to provide an extra factor 20 in rejecting background from the $K^0_{\rm L}$ beam.

At the end of the 1999 ε' data taking period, 2 days were devoted to a high intensity $K^0_{\rm S}$ test in order to estimate the rates for the future NA48 program [16]. The proton beam intensity was increased by a factor ~ 200, yielding a sensitivity equivalent to several years of operation with the standard $K^0_{\rm L} + K^0_{\rm S}$ beam setup. In particular, 724 $K^0_{\rm S} \to \pi^+\pi^-e^+e^-$ signal events were collected, which add up to 921 events when combined with 1998 and 1999 data. Fig. 8 shows the $\pi^+\pi^-e^+e^-$ invariant mass distribution of the candidates for the complete sample. The branching ratio:

$$\mathrm{BR}(K^0_{\rm S} \to \pi^+\pi^-e^+e^-) = (4.3 \pm 0.2 \pm 0.3) \times 10^{-5}$$

translates to the inner bremmstrahlung component part of $K^0_{\rm L} \to \pi^+\pi^-e^+e^-$: $\mathrm{BR}(K^{0IB}_{\rm L} \to \pi^+\pi^-e^+e^-) = (1.3 \pm 0.1) \times 10^{-7}$ in good agreement with theoretical expectations. The ϕ angular asymmetry can also be accurately measured: $\mathcal{A}_{\rm S} = (-0.2 \pm 3.4 \pm 1.4)\%$, compatible with zero, which confirms that the CP violating asymmetry $\mathcal{A}_{\rm L}$ observed in $K^0_{\rm L} \to \pi^+\pi^-e^+e^-$ is not an artefact of either apparatus or final state interactions.

4.2. $K_{\rm S,L} \to \pi^0e^+e^-$ *and* $K^0_{\rm S} \to 3\pi^0$

The high intensity $K^0_{\rm S}$ test described in the previous section was also used to search for $K^0_{\rm S} \to \pi^0e^+e^-$, whose branching ratio can be related to the *indirect* CP violation contribution to the $K^0_{\rm L} \to \pi^0e^+e^-$ decay. *Indirect* CP violation was also looked for in the $K^0_{\rm S} \to 3\pi^0$ decay during a dedicated 2000 running period. These two decays are among the main goals for the future 2002 physics program [16] recently accepted at CERN and are described in more details in these proceedings [17]

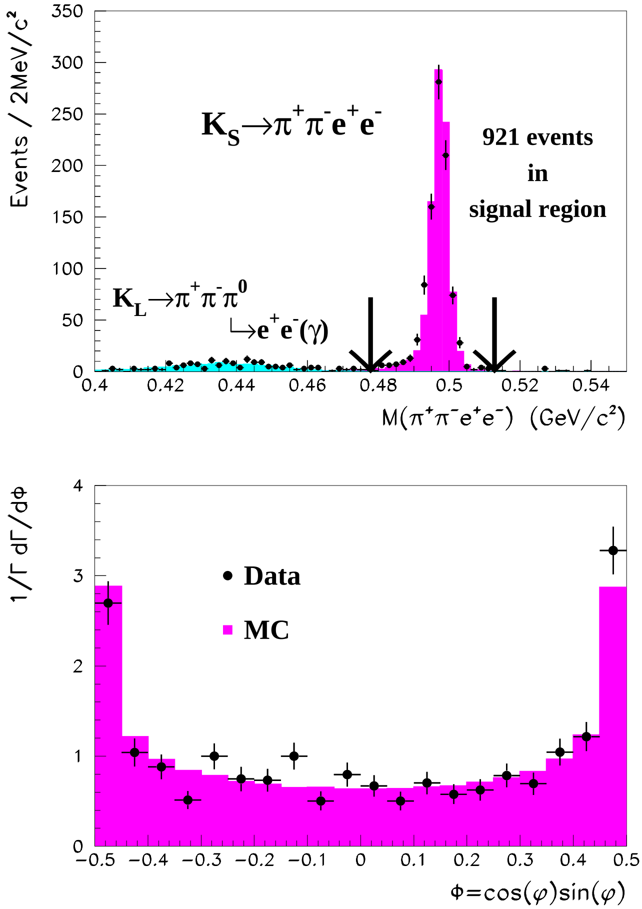

Fig. 8. Top: $\pi^+\pi^-e^+e^-$ invariant mass distribution; bottom: ϕ angular distribution, compared to $K^0_S \to \pi^+\pi^-e^+e^-$ Monte Carlo.

5. Direct CP violation in $K^\pm$ decays

Now that *Direct CP* violation is established in $K^0 \to 2\pi$ decays, measuring its emergence in other processes is of great importance in order to better understand the origin of this effect.

The NA48 collaboration has proposed to look for a manifestation of CP violation through the measurement of the Dalitz plot decay parameters in $K^\pm \to \pi^+\pi^-\pi^\pm$ using an extended NA48 setup [18] also accepted at CERN.

The matrix element for the decays $K^\pm \to \pi^+\pi^-\pi^\pm$ can be parametrized by:

$$|M(u,v)|^2 \propto 1 + gu + hu^2 + kv^2 \,,$$

where u=$(s_3$-$s_0)/m_\pi^2$, v=$(s_1$-$s_2)/m_\pi^2$, s_0=$(s_1+s_2+s_3)/3$ and $s_i = (P_K - P_i)^2$, P_K and P_i are the four-momenta of the kaon and of the pion ($i = 3$ for the odd pion).

If CP conservation holds, then the coefficients g, h and k are the same for K^+ and K^- decays. A measurement of *direct* CP violation can be obtained through the observation of a non-zero value for the asymmetry:

$$\mathcal{A}_g = (g^+ - g^-)/(g^+ + g^-)\,.$$

Theoretical predictions for $\mathcal{A}_g$ in the framework of the Standard Model are in the $\mathcal{O}(10^{-6} - 10^{-4})$. However, theoretical predictions in the framework of the Standard Model depend strongly on the value of ε'/ε, and some supersymmetric models could give a value as high as 10^{-4} [19]. The best measurement of $\mathcal{A}_g$ comes from an old experiment performed in 1970 [20] which obtained $\mathcal{A}_g = (-7.0 \pm 5.3) \times 10^{-3}$.

The proposed experiment will use simultaneous K^+ and K^- beams with a central momentum value of 60 GeV/c and a momentum bite $\Delta P/P$ = 20 %. Both charged beams would be selected with the same geometrical acceptance and directed along a common line pointing towards the NA48 detector. To accommodate these features, a modification of the present NA48 beam elements downstream of the present $K_{\rm L}^0$ target is necessary to implement two '*achromats*' and the collimators. A kaon beam spectrometer instrumenting the second achromat is under study, in order to allow the measurement of both the charged kaon sign and its momentum to $\sim 1\%$, and therefore put additional kinematical constraints on the decay. The foreseen kaon fluxes are 4.4×10^6 K^+ and 2.5×10^6 K^-/cycle, yielding 12.7×10^{10} K^+ and 7.1×10^{10} K^- decays/year for a decay region of 50m and 120 days running time per year at 50 % efficiency. This would allow NA48 to reach an accuracy of $\sim 1.4 \times 10^{-4}$ on $\mathcal{A}_g$ per year, where the limitation is of statistical nature.

6. Summary and outlook

Combining 1997 and 1998 preliminary result, the NA48 experiment has measured Re$(\varepsilon'/\varepsilon)$ = $(14.0 \pm 4.3) \times 10^{-4}$ more than 3 σ from zero, and together with KTeV establishes the existence of *direct* CP violation. The ε' program will be completed in 2001 with a rebuilt spectrometer, yielding a final statistics of $\sim 5 \times 10^6$ $K_{\rm L}^0 \to \pi^0\pi^0$. The improved systematics on the tagging, trigger efficiency, acceptance determination and accidentals will lead to a final uncertainty $\sim 2.5 \times 10^{-4}$, close to the design goal.

The investigation of rare decays concurrently with the measurement of ε'/ε allowed the measurement of the $K_{\rm L}^0 \to \pi^+\pi^-e^+e^-$ BR and CP violating angular asymmetry, as well as the first observation of $K_{\rm S}^0 \to \pi^+\pi^-e^+e^-$.

The NA48 approved future program will allow the investigation of *indirect* CP violation in $K_{\rm S}^0 \to \pi^0\pi^0\pi^0$ and $K_{\rm L}^0 \to \pi^0 e^+ e^-$ using a high intensity $K_{\rm S}^0$ beam in 2002, as well as to probe *direct* CP violation effects through the $\mathcal{A}_g$ asymmetry with better than 2×10^{-4} accuracy using charged kaon beams.

It is a pleasure for me to thank the organizers of the Cracow Epiphany Conference on b physics and CP violation, both for the physics content of the meeting and for their kind hospitality. This first conference of the new millennium is certainly one we will never forget.

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