# LATEST RESULTS ON DIRECT CP VIOLATION FROM THE NA48 EXPERIMENT

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The NA48 experiment, at CERN SPS, aims to search for direct CP violation through the measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$ with high accuracy. In order to achieve this, intense beams and a carefully designed detector architecture have been realized. The first result, from 1997 data sample, has been published last year. A preliminary analysis based on data collected in 1998 is presented here. The result for the $\mathrm{Re}(\varepsilon'/\varepsilon)$ parameter is $(12.2 \pm 4.9) \times 10^{-4}$.

## 1 Direct CP violation

The CP-violating decay of the long-lived neutral kaon, $\mathrm{K_L}$ , into two pions (first discovered in 1964 [1]), is interpreted to be mainly due to the CP-conserving decay of the $K_1$ ($CP = +1$) component (CP violation in the $\mathrm{K^0}$-$\mathrm{\bar{K}^0}$ mixing) and is parametrized by the $\varepsilon$ parameter ($|\varepsilon| = (2.28 \pm 0.02) \times 10^{-3}$).

The interference in the decay amplitudes of different final states isospin might induce a direct CP violation in the decay of the $K_2$ ($CP = -1$) component; this contribution to CP violation is quantified by the parameter $\varepsilon'$.

The Standard Model relates direct CP violation to the existence of three generations of quarks and of a complex phase of the CKM matrix. Theoretical predictions for the ratio $\mathrm{Re}(\varepsilon'/\varepsilon)$ are typically in the range $(0 - 25) \times 10^{-4}$ (see [2]).

Previous measurements of $\mathrm{Re}(\varepsilon'/\varepsilon)$, performed so far using the *double ratio* method, can be found in [3,4,5,6]. While E731 and NA31 were marginally consistent and could not assess a conclusive statement, first results from the second generation experiments KTeV and NA48, published during 1999, point to the existence of direct CP violation.

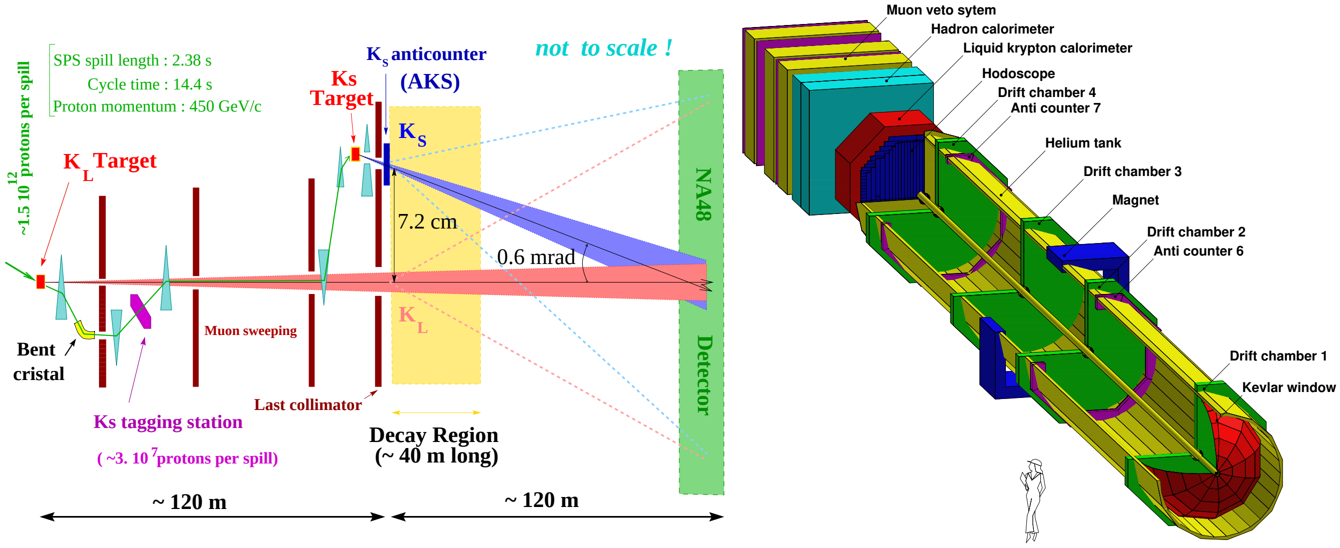


Figure 1: Schematic layout of NA48 beam (left) and detector (right)

## 2 The NA48 method and detector

The goal of the NA48 experiment is to evaluate $\mathrm{Re}(\varepsilon'/\varepsilon)$ with an accuracy $\simeq 2 \times 10^{-4}$, by measuring the double ratio

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

The required statistical error is reached by collecting $\sim$ 5 millions $\mathrm{K_L} \to \pi^0\pi^0$ (the limiting mode), with high rate and very efficient data taking.

The systematic error on $R$ is minimized by measuring the four decay modes *simultaneously*, to cancel out effects due to fluxes, inefficiencies, dead time and accidental losses; from the *same fiducial volume* (lifetime $< 3.5\tau_s \;\; \to 20$ m) with two *quasi collinear beams*, to have similar geometrical acceptance; with *high resolution detectors*, to have powerful background rejection. The quite different vertex distribution along the z-axis for $\mathrm{K_S}$ and $\mathrm{K_L}$ decays, responsible for sizeable differential acceptance correction, is equalized offline by applying a *weight function* to $\mathrm{K_L}$ events (see fig. 2). The remaining $\mathrm{K_S}$–$\mathrm{K_L}$ differences in energy spectra are minimized by performing the *analysis in energy bins* (20 bins between 70 and 170 GeV).

The NA48 beam line, sketched in fig 1, has been designed to fulfil these requirements.

$\mathrm{K_S}$ and $\mathrm{K_L}$ decays are distinguished by *measuring the parent proton* passage through a $\mathrm{K_S}$ tagging station (upstream the target): events with a time coincidence between detector and tagger inside $\pm 2$ ns are labelled $\mathrm{K_S}$. The beginning of the fiducial region is defined by an anti-counter ($AKS$) positioned in the $\mathrm{K_S}$ line.

Charged decays are measured with a magnetic spectrometer composed by four large drift chambers; the $K$ invariant mass resolution is 2.5 MeV/c$^2$. The time measured with a plastic scintillator hodoscope has a resolution better than 200 ps. Neutral decays are reconstructed by a quasi-homogeneous Liquid Krypton calorimeter; the $\pi^0$ invariant mass resolution is $\simeq 1$ MeV/c$^2$, while the time resolution is $\sim 250$ ps.

## 3 Systematic Effects on 1998 data analysis

The 1998 data sample has been collected during 135 days of run at $1.4 \times 10^{12}$ protons per pulse on $\mathrm{K_L}$ target.

The analysis strategy consists in identify $\pi^0\pi^0$ and $\pi^+\pi^-$ events in the proper energy range, subtracting the 3-body background; tag $\mathrm{K_S}$ and $\mathrm{K_L}$ events, correcting for the mistagging probabilities; select the proper fiducial region to count neutral and charged events, through the global energy scale definition; weight $\mathrm{K_L}$ events and correct for the residual acceptance, trigger efficiency and accidental activity $\mathrm{K_S}$–$\mathrm{K_L}$ difference. All this is done in each energy bin.

The most important systematics are briefly described hereafter. Table 1 summarizes all the corrections which have been applied to $R$.

- The *mistagging probabilities* are due to *tagger inefficiency* (the $\mathrm{K_S}$ decay has no coincident proton), or to *accidental unwanted tagging* (the $\mathrm{K_L}$ decay has an accidental proton in time). The first case has a probability of $(1.97 \pm 0.05) \times 10^{-4}$, its bias being carefully studied with $\mathrm{K_S}$–only run and $\pi^0$–Dalitz decays. The second case happens in the $(11.05 \pm 0.01)\%$ of the times, while its differential L/S effect, studied by comparing accidental proton rate in charged and neutral decays, stays at the level of $10^{-4}$.
- The *acceptance* correction is reduced by the $\mathrm{K_L}$ weighting technique to a very small level. It is based on Monte-Carlo simulation of a $R = 1$ experiment (see fig. 2).
- The *background* levels after subtractions are $(19 \pm 3) \times 10^{-4}$ for charged events (mass and transverse momentum cuts are applied to reject $\mathrm{K_L} \to \pi^\pm\mu^\mp\nu_\mu$ and $\mathrm{K_L} \to \pi^\pm e^\mp\nu_e$ events); $(7 \pm 2) \times 10^{-4}$ for neutral events (cut on a $\chi^2$ variable, computed comparing the $\gamma\gamma$ masses and the $\pi^0$ mass, is applied to reject $\mathrm{K_L} \to 3\pi^0$ with two lost $\gamma$).
- *Trigger inefficiencies*: while the neutral trigger gives no bias on $R$ (negligible dead time, efficiency of $(99.93 \pm 0.02)\%$), the charged trigger system, much more complex, induces a correction on $R$, whose accuracy is mainly statistically limited.
- The *neutral energy scale* is constrained by the reconstruction of the beginning of the decay region ($AKS$ position).
- The *accidental activity* effects are checked by superimposing random pedestal events to good $\pi^+\pi^-$ and $\pi^0\pi^0$ events, and by studing the beams' correlation at small and large time scale.

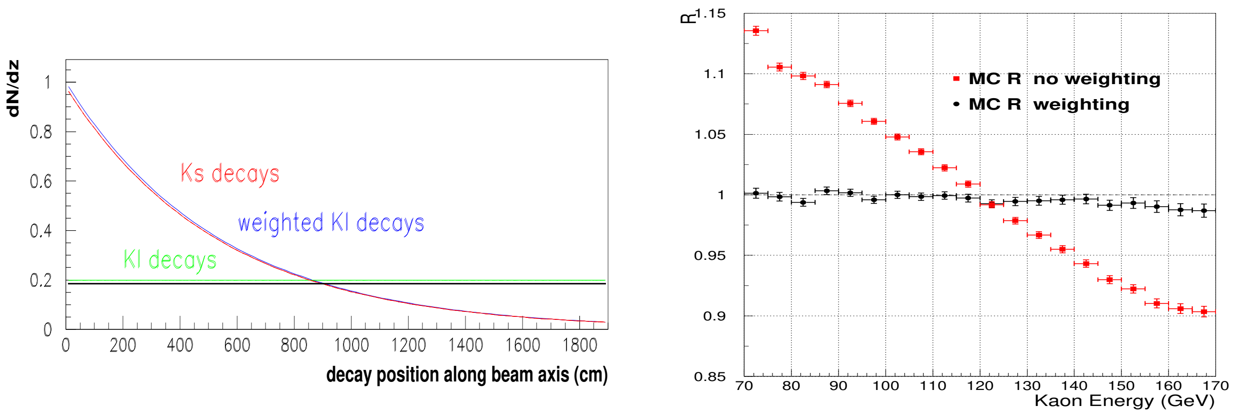


Figure 2: The weighting procedure on the $\mathrm{K_L}$ z-distribution (left) and its effect on the acceptance correction (right: in red, correction to apply on $R$ in case of unweighted analysis)

## 4 The result

The numbers of events collected during 1998 run, corrected for the mistagging probabilities, are listed in table 2. The statistical error on $R$, after the weighting procedure, is $17.3 \times 10^{-4}$.

Figure 3 shows the double ratio $R$ measured in each of the 20 energy bins. The average value, evaluated using an unbiased estimator of $log(R)$, is $0.99267 \pm 0.00173$, which leads to the preliminary result:

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 2.9(\mathrm{stat}) \pm 4.0(\mathrm{syst})) \times 10^{-4}.$$

Table 1: List of corrections to be applied to $R$ in the 1998 analysis (units of $10^{-4}$)

| Source | | | Source | | |
|---|---|---|---|---|---|
| Charged trigger | -1 | $\pm$ 11 | Acceptance | +31 | $\pm$ 9 |
| Accidental tagging | +1 | $\pm$ 8 | Neutral BKG | –7 | $\pm$ 2 |
| Tagging efficiency | – | $\pm$ 3 | Charged BKG | +19 | $\pm$ 3 |
| Neutral rec. systematics | – | $\pm$ 10 | Beam scattering | –10 | $\pm$ 3 |
| Charged vertex | +2 | $\pm$ 2 | Accid. activity | +2 | $\pm$ 12 |
| | | | Total | +37 | $\pm$ 24 |

Extensive checks have been performed on the stability of this result with respect to the various selection criteria.

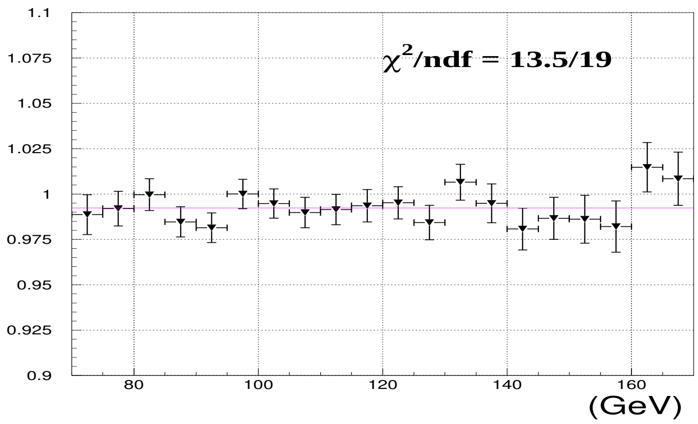


Figure 3: The double ratio as a function of Kaon energy

Table 2: Event statistics in 1998 (millions)

| | |
|---|---|
| $K_L \rightarrow \pi^0\pi^0$ | 1.14 |
| $K_S \rightarrow \pi^0\pi^0$ | 1.80 |
| $K_L \rightarrow \pi^+\pi^-$ | 4.87 |
| $K_S \rightarrow \pi^+\pi^-$ | 7.46 |

## 5 Conclusions and Prospects

This new preliminary result on $\mathrm{Re}(\varepsilon'/\varepsilon)$ based on data presented here confirms the occurrence of direct CP violation in the neutral Kaon system. The combination with the previously published NA48 result [6] gives:

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (14.0 \pm 4.3) \times 10^{-4}$$

where the correlation between systematic errors has been taken into account. More analysis work is in progress to reduce uncertainties due to accidental activity, accidental tagging and energy scale definition. The completion of the $\mathrm{Re}(\varepsilon'/\varepsilon)$ program will take place during the year 2001, delayed by one year because of the beam pipe implosion (Nov 1999). The 2001 run will be mostly devoted to investigate systematic effects intensity dependent. The 2000 run has been partly used to study systematics related to the global energy scale and to the kaon tagging technique, and partly to test the future $K_S$ decay program.

## References


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