# A NEW MEASUREMENT OF THE DIRECT CP VIOLATION PARAMETER $\mathrm{Re}(\epsilon'/\epsilon)$ BY THE NA48 EXPERIMENT AT CERN

MASSIMO LENTI
*CERN, EP Division, 1211 Geneva 23, Switzerland*
*On leave of absence from INFN, Sezione di Firenze, Italy*

A preliminary measurement of $\mathrm{Re}(\epsilon'/\epsilon)$ based on data collected in 1998 by the NA48 experiment at CERN is presented. The principles of the measurement, the data analysis and the main systematics are discussed. The preliminary result is: $\mathrm{Re}(\epsilon'/\epsilon) = (12.2 \pm 4.9) \times 10^{-4}$ which combined with the already published NA48 result based on data collected in 1997 becomes: $\mathrm{Re}(\epsilon'/\epsilon) = (14.0 \pm 4.3) \times 10^{-4}$.

## 1 Physics Motivation

CP violation has been discovered in the $K^0\overline{K^0}$ system a long time ago. The mass eigenstates, $K_S$ and $K_L$, are characterized by very different lifetimes and the short lifetime state decades mainly into two pions (CP=+1 state), while the long lifetime one decades into 3 pions (CP=$-1$) and semileptonically. In few per mille of the cases the $K_L$ also decades into two pions, thus violating CP conservation. The bulk of this violation is interpreted as an asymmetric mixing of $K^0\overline{K^0}$ and is parametrized by $\epsilon$. If, as predicted by the standard model of weak interaction, the CP violation happens also in the kaon decay, the decay amplitudes into two pions with isospin 0 or 2 for the $K^0$ are different from those of the $\overline{K^0}$. This difference is parametrized by $\epsilon'$ and is given by:

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

where R is the so-called double ratio. Previous measurements can be found in [1,2,3,4,5].

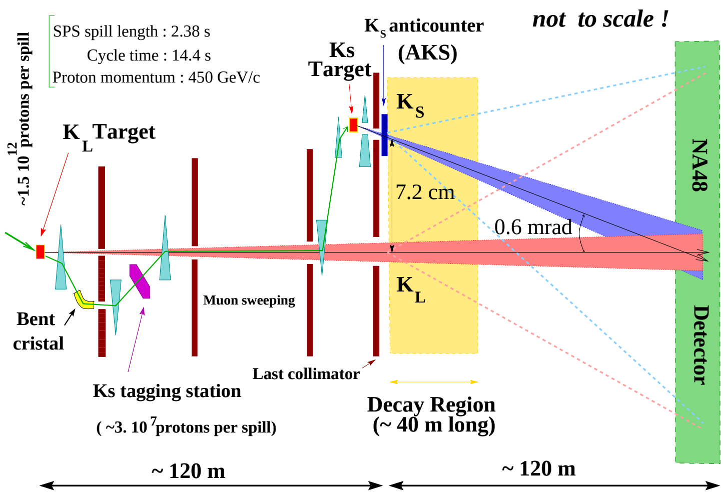


Figure 1: The two NA48 beams.

## 2 The NA48 experiment

The NA48 experiment collects the four modes at the same time and in the same fiducial volume so that the double ratio reduces to:

$$\mathrm{R} = \frac{\mathrm{N}(\mathrm{K_L} \rightarrow \pi^0\pi^0)}{\mathrm{N}(\mathrm{K_S} \rightarrow \pi^0\pi^0)} \Big/ \frac{\mathrm{N}(\mathrm{K_L} \rightarrow \pi^+\pi^-)}{\mathrm{N}(\mathrm{K_S} \rightarrow \pi^+\pi^-)} \tag{2}$$

### *2.1 The two beams system*

The 450 GeV/c proton beam from the SPS accelerator impinges on a primary target forming, after about 120 m of collimation and charged particles sweeping, the $K_L$ beam. A small part of the protons not interacting in the target are channelled through a bent silicon crystal forming a secondary proton beam which crosses a tagging station and impinges on a secondary target forming, after about 6 m of collimation and cleaning, the $K_S$ beam. At the last collimator exit the $K_S$ and $K_L$ beams are separated by 7 cm and converge, with a 0.6 mrad angle, at the detectors position.

### *2.2 The $K_S$ tagging*

$K_S$ decays are distinguished by $K_L$ decays with a time of flight technique: $K_S$ decays are in coincidence with a proton crossing the tagging station (made of a stack of thin scintillators) while $K_L$ decays are not; the chosen coincidence window is 4 ns wide. For charged decays the vertex position is well reconstructed and the tagging performances are directly tested. The tagging inefficiency (i.e. the probability that a $K_S$ decay is out of coincidence) is measured to be $(1.95 \pm 0.05) \times 10^{-4}$, while the accidental tagging probability (i.e. the probability that a $K_L$ is tagged as $K_S$ due to an accidental coincidence) is $(11.05 \pm 0.01)\%$.

For neutral decays indirect methods have to be used to test the tagging performances. The tagging inefficiency difference between neutral and charged decays is less than $3 \times 10^{-4}$; the accidental tagging difference between neutral and charged decays is measured to be $(0.5 \pm 4) \times 10^{-4}$. The induced correction on R are $(0 \pm 3) \times 10^{-4}$ and $(+1 \pm 8) \times 10^{-4}$ respectively.

### 2.3 The detectors

Charged decays are reconstructed by a magnetic spectrometer with an invariant mass resolution of 2.5 Mev/c$^2$ at the kaon mass. A hodoscope made of two planes of scintillators is used for triggering and for the time measurement used for the $K_S$ tagging.

The neutral decays are reconstructed by a quasi-homogeneous liquid Krypton calorimeter, which measures energy, impact position and time of the photons from $\pi^0$'s decay.

A hadron calorimeter, a muon veto and a system of anti counters are also included.

### 2.4 The backgrounds

The backgrounds in charged decays are due to $K_L$ semileptonic decays and are measured to be $(19 \pm 3) \times 10^{-4}$. $K_L$ scattering and regeneration in the collimator are removed in charged decays by a transverse momentum cut needed to suppress the $K_{l3}$ background. Such a cut is not applied in neutral events and the $(10 \pm 3) \times 10^{-4}$ scattered/regenerated events have to be corrected for.

The background in neutral decays is due to $K_L \to 3\pi^0$ decays with two lost or not reconstructed photons and is measured to be $(7 \pm 2) \times 10^{-4}$.

### 2.5 The energy scale

The decay position of $K_{S,L} \to \pi^0\pi^0$ is reconstructed by the energies and impact positions of the four photons, imposing the kaon mass. The beginning of the $K_S$ decay region is defined by an anti-counter (AKS). The overall distance/energy scale is set by matching the reconstructed position of the AKS (as given by neutral decays) with the geometrical one.

### 2.6 The $K_L$ proper time weighting

The distributions of $K_L$ and $K_S$ decays are very different due to their lifetimes. They are made similar by giving a weight to each $K_L$ decay based on its proper time, with the penalty of the increase of the statistical error on the double ratio of 35%. The acceptance correction reduces in this way to $(31 \pm 6(stat) \pm 6(syst)) \times 10^{-4}$.

### 2.7 Analysis cuts

The selected kaon energy range is between 70 and 170 GeV, where $K_S$ and $K_L$ spectra are similar. The fiducial volume starts at the AKS position for $K_L$ and is 3.5 $K_S$ lifetimes long for both $K_S$ and $K_L$ to minimize energy scale sensitivity. The dead time induced by the drift chamber readout (about 25%) and by the charged trigger (about 5%) is applied to neutral events to simmetrize any induced effect. All corrections are applied in bins of energy (20 bins, each 5 GeV wide, have been chosen) to account for the slight difference in $K_S$ and $K_L$ spectra (which in this way cancels in the double ratio).

### 2.8 Accidental activity

Accidental activity can induce asymmetric losses or gains in $K_S$ and $K_L$, which are estimated overlaying good $\pi^+\pi^-$ and $\pi^0\pi^0$ decays with events collected proportionally to the beam intensity. The measured correction to R is $(2 \pm 6) \times 10^{-4}$.

The noise induced by the drift chambers readout doubles in the overlay procedure and has to be taken into account. The $K_S/K_L$ ratio is constant with a R.M.S. of 10% but the difference in accidental activity seen by $K_S$ and $K_L$ is about 1%: this allows to set an upper limit on induced effects on R by accidental activity of less than $10 \times 10^{-4}$.

### 2.9 Triggers

The neutral trigger is a fully pipelined system with a negligible dead time and an efficiency of $(99.93 \pm 0.02)\%$.

The charged trigger is divided into two levels. The first level is based on the total energy deposited in the calorimeters (with an efficiency of $(99.49 \pm 0.03)\%$) and a two tracks topology in the scintillators hodoscope ($(99.95 \pm 0.01)\%$ efficient). The second level is based on the on-line vertex and $\pi^+\pi^-$ invariant mass reconstruction, it has about 5% dead time and an efficiency of $(97.75 \pm 0.05)\%$ inducing a correction to R of $(-1 \pm 11) \times 10^{-4}$.

### 2.10 Result

In 1998 there were 138 days of data taking with an average of $1.4 \times 10^{12}$ protons per pulse on the primary target. The collected statistics include 7.46 millions of $K_S \to \pi^+\pi^-$, 4.87 millions of $K_L \to \pi^+\pi^-$, 1.80 millions of $K_S \to \pi^0\pi^0$ and 1.14 millions of $K_L \to \pi^0\pi^0$. Table 1 lists the corrections to be applied to the double ratio. In figure 2 the double ratio as a function of energy after the corrections is shown.

| Source | | |
|---|---|---|
| Charged Trigger | -1 | ± 11 |
| Accidental tagging | +1 | ± 8 |
| Tagging inefficiency | - | ± 3 |
| Energy scale | - | ± 10 |
| Charged vertex | +2 | ± 2 |
| Acceptance | +31 | ± 9 |
| Neutral background | -7 | ± 2 |
| Charged background | +19 | ± 3 |
| Beam scattering | -10 | ± 3 |
| Accidental activity | +2 | ± 12 |
| Total | +37 | ± 24 |

Table 1: Corrections to R ($10^{-4}$).

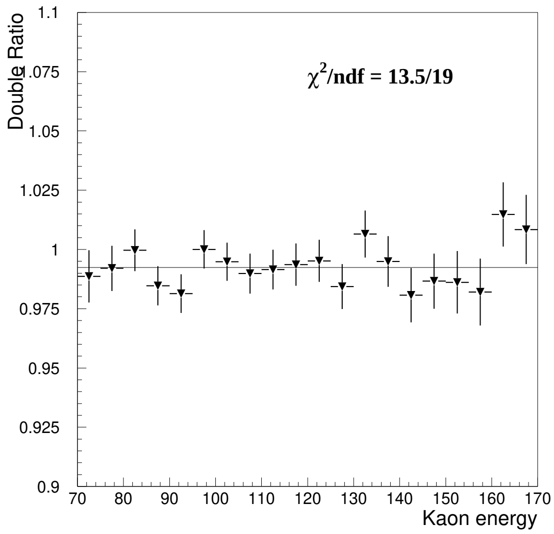


Figure 2: The Double Ratio vs Kaon energy.

The preliminary measured value of $\mathrm{Re}(\epsilon'/\epsilon)$ based on 1998 collected data is:

$$\mathrm{Re}(\epsilon'/\epsilon) = (12.2 \pm 2.9(\mathrm{stat}) \pm 4.0(\mathrm{syst})) \times 10^{-4} \tag{3}$$

where the first error is the statistical one, the second is the systematic one. Combining this preliminary result with the final NA48 result based on data collected during 1997 [5]:

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

## References


1. H. Burkhardt et al, *Phys. Lett.* B **206**, 169 (1988).
2. G. Barr et al, *Phys. Lett.* B **317**, 233 (1993).
3. L.K. Gibbons et al, *Phys. Rev. Lett.* **70**, 1203 (1993).
4. A. Alavi-Harati et al, *Phys. Rev. Lett.* **83**, 22 (1999).
5. V. Fanti et al, *Phys. Lett.* B **465**, 335 (1999).