New Measurement of Direct CP Violation Parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ by the NA48 Experiment at CERN

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Abstract. The NA48 experiment at CERN detects concurrently the four decay modes of the long and short lived neutral kaons. During 1998 data taking, statistics in each mode was increased by at least a factor two, with respect to the 1997 published data. A new measurement of the double ratio of the four modes has been obtained from these data. The new preliminary result on the direct CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ is $(12.2 \pm 4.9) \times 10^{-4}$ which, combined with the NA48 published result gives $\mathrm{Re}(\varepsilon'/\varepsilon) = (14.0 \pm 4.3) \times 10^{-4}$

DIRECT CP VIOLATION.

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

The interference of the amplitudes for final states with different isospin could also induce a direct CP violation in the decay of the $K_2(CP = -1)$ component; this contribution to CP violation is quantified by parameter ε' . Previous mesurements can be found in [1–4].

In the Standard Model, a value of ε' different from zero arises naturally from the complex phase of the CKM matrix. Theoretical predictions for the ratio $\mathrm{Re}(\varepsilon'/\varepsilon)$are typically in the range $(0 - 20) \times 10^{-4}$. The difficulty of the theoretical calculations come from QCD penguin diagrams and interactions in the final state [5].

[1] Cagliari, Cambridge, CERN, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Vienna, Warsaw

NA48 METHOD AND DETECTOR.

The aim of the NA48 experiment is to evaluate $\mathrm{Re}(\varepsilon'/\varepsilon)$, the direct CP violation parameter, with an accuracy $\simeq 2\times10^{-4}$, by measuring the double ratio

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

As the $\mathrm{K_L}$ CP-violating decays are suppressed $\simeq 200$ times compared to 3-body decays, **high rate** is required.

To minimize corrections to the ratio, the four modes are measured:

- **simultanously** so that effects due to fluxes, inefficiencies, dead time, accidental activities cancel.
- from the **same fiducial volume**: lifetime $< 3.5\times\tau_s$. To equalize longitudinal distribution between $\mathrm{K_S}$ and $\mathrm{K_L}$, a weight, function of lifetime, is applied so that the acceptance correction is minimum.
- with **high resolution**: magnetic spectrometer for $\pi^+\pi^-$ with uniform magnetic field and homogenous liquid Krypton calorimeter for $\pi^0\pi^0$ to reject backgrounds.
- in **bins of Kaon energy** to account for differences of $\mathrm{K_S}$ and $\mathrm{K_L}$ energy spectra (20 bins between 70 and 170 GeV).

The NA48 beam line was designed to fulfil these requirements; a schematic view is presented on figure 1.

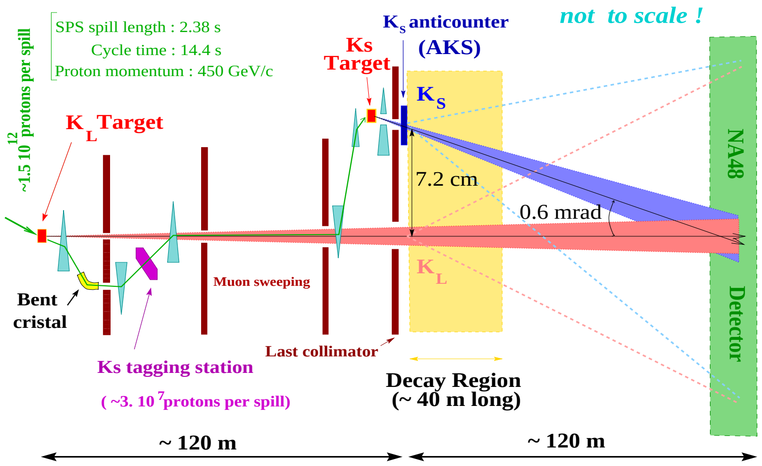

FIGURE 1. Schematic layout of the simultaneous $\mathrm{K_S}$ and $\mathrm{K_L}$ beams used by NA48

$\mathrm{K_S}$ and $\mathrm{K_L}$ decays are distinguished by time of flight: the fraction of protons directed to the $\mathrm{K_S}$ target cross the tagging station which measures the proton time with a resolution better than 200 ps. Events with a coincidence inside $\pm 2ns$ are labelled $\mathrm{K_S}$. In charged decays, the vertex position allows to identify vertices coming from the $\mathrm{K_S}$ and $\mathrm{K_L}$ targets and therefore to measure:

- The **tagging inefficiency**, the probability that a K_S decay is not in coincidence with a proton: $(1.95 \pm 0.05) \times 10^{-4}$.
- The **accidental tagging probability**, the probability that a K_L decay is in coincidence with a proton: $(11.05 \pm 0.01\%)$.

The beginning of the fiducial region is precisely defined by an anticounter in the K_S line.

Charged decays are measured by a magnetic spectrometer made of four large drift chambers; the 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 π^0 invariant mass resolution is $\simeq 1$ MeV/c^2 and the time resolution around 270 ps.

1998 DATA ANALYSIS

Analysis consists in counting events in each mode to evaluate the double ratio R. Table 1 summarizes the statistics accumulated in 1998 (and 1997 for comparison). Corrections are then applied (table 2 summarizes the corrections applied on R_{raw}):

- **Trigger inefficiencies**: if K_S-K_L asymetric they can induce a bias on R. The neutral trigger is a fully pipelined system with a negligible dead time and an efficiency of $(99.93 \pm 0.02)\%$. No correction is applied. The charged trigger inefficiencies induce a correction on R of $(-1 \pm 11) \times 10^{-4}$.
- **Backgrounds** come from K_L three-body decays. To reject $K_L \to \pi^\pm \mu^\mp \nu_\mu$, $K_L \to \pi^\pm e^\mp \nu_e$ and K_L scattered on collimators, mass and transverse momentum cuts are applied; the charged background level after these cuts is $(19 \pm 3) \times 10^{-4}$. Scattered events are not rejected in neutral decays; the correction for this effect is $(10 \pm 3) \times 10^{-4}$. To reject $K_L \to 3\pi^0$ with two lost γ, a cut on a χ^2, computed comparing the $\gamma\gamma$ masses and the π^0 mass (*Relli*), is applied; the remaining background is at a level of $(7 \pm 2) \times 10^{-4}$.
- The **acceptance** correction is reduced by K_L weighting technique to a level (measured from Monte-Carlo) of $(31 \pm 6(stat) \pm 6(syst)) \times 10^{-4}$.
- The **neutral energy scale** is constrained by the reconstruction of the begining of the decay region to an accuracy of $\pm 10 \times 10^{-4}$.
- The **accidental activity** can induce asymetric losses and gains in K_S and K_L; we measure an effect on R of $(2 \pm 6) \times 10^{-4}$, by superimposing events triggered proportionally to the beam intensity, to good $\pi^+\pi^-$ and $\pi^0\pi^0$ events. The uncertainty on accidental effects is estimated by studying differential activities in K_S and K_L events, to a level of $(\pm 10) \times 10^{-4}$.

Statistics (millions)	1997	1998
$K_L \to \pi^0\pi^0$	0.49	1.14
$K_S \to \pi^0\pi^0$	0.98	1.80
$K_L \to \pi^+\pi^-$	1.07	4.87
$K_S \to \pi^+\pi^-$	2.09	7.46

Table 1: 1998 statistics.

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

Table 2: Corrections to R (10^{-4}).

RESULTS

The preliminary measured value of $\mathrm{Re}(\varepsilon'/\varepsilon)$based on data presented here is

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

where the first error is statistical, the second systematic. Figure 2 shows R as a funtion of Kaon energy. Combining this preliminary result with the final NA48 result based on data collected during 1997 [4] gives:

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

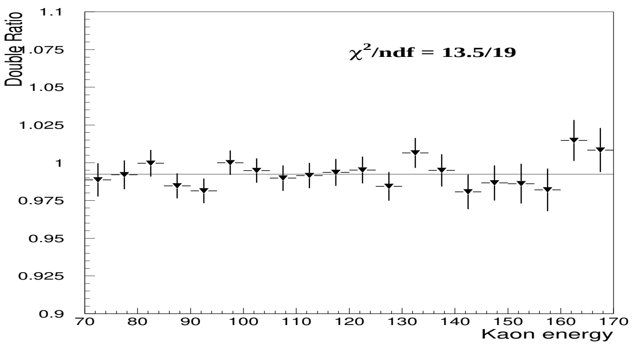

FIGURE 2. Double Ratio R as a function of Kaon Energy (GeV)

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