The NA48 measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$

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Abstract

The direct CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ has been measured from the decay rates of neutral kaons into two pions using the NA48 detector at the CERN SPS. During the 2001 running period, data have been collected under conditions different to those used in previous years. The result from 2001 data is $\mathrm{Re}(\varepsilon'/\varepsilon) = (13.7 \pm 3.1) \times 10^{-4}$. Combining this result with the previous one based on data collected in 1997-99, a final value of $\mathrm{Re}(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$ is obtained from the NA48 experiment.

1 Introduction

CP violation in the neutral kaon system can occour via the mixing of flavour eigenstates. This indirect CP violation was discovered in 1964 [1]. Its magnitude is characterised by the complex parameter ε. CP violation can also occur in the decay process through the interference of amplitudes with different isospins, and is characterised by the parameter ε'. The experimentally measured quantity is the double ratio R of the decay widths:

$$R = \frac{\Gamma(\mathrm{K}_L \to \pi^0\pi^0)/\Gamma(\mathrm{K}_S \to \pi^0\pi^0)}{\Gamma(\mathrm{K}_L \to \pi^+\pi^-)/\Gamma(\mathrm{K}_S \to \pi^+\pi-)} \approx 1 - 6 \times Re(\varepsilon'/\varepsilon)$$

Recently NA48 has published the result $\mathrm{Re}(\varepsilon'/\varepsilon) = (15.3 \pm 2.6) \times 10^{-4}$ based on the data collected in 1997-99 [2]. Using data accumulated between 1996-97, the KTeV collaboration presented the result $\mathrm{Re}(\varepsilon'/\varepsilon) = (20.7 \pm 2.8) \times 10^{-4}$ [3]. These results show the existence of direct CP violation in the neutral kaon system.

Data collected in 2001 were recorded under different conditions: the drift chambers were rebuilt after having been damaged in 1999, and the beam intensity was about 30% lower to allow intensity-related effects to be checked. The statistics accumulated during 2001 data taking are about half of the statistics accumulated during 1998-99. The details of this analysis can be found elsewhere [4].

2 Beam and detector

The experiment is designed to allow cancellation of systematic effects that contribute symmetrically to different components of the double ratio. Data are collected simultaneously in the four decay modes, cancelling the absolute fluxes and minimising the sensitivity of the measurement to beam intensity and variations of the detection efficiency. The K_S and K_L decays are provided by two almost collinear beams, with similar momentum spectra which converge at the centre of the main detector. In order to be insensitive to small residual differences in the momentum spectra, the analysis is performed in bins of energy. To minimise the difference in acceptance due to large difference in K_S and K_L decay lengths, only K_L decays occuring in the same decay region as K_S are used. In addition, K_L decays are weighted as a function of their proper lifetime. With this procedure the acceptance correction to the double ratio R cancels to first order, and only small remaining effects due to the beam geometry need to be corrected using a Monte Carlo simulation of the experiment.

During 2001, the SPS had a cycle time of 16.8 s (14.4 s in 1998-99) with a spill length of 5.2 s (2.38 s in 1998-99) and a proton momentum of 400 GeV (450 GeV in 1998-99). The ratio between K_L and K_S intensity was maintained stable in time within 10% of the nominal intensity. K_S and K_L decays are distinguished by the presence (K_S case) or the absence (K_L case) of a coincidence between the decay time recorded by the detector, and the time of the protons incident on the K_S target, detected by an array of scintillators (tagger). Because of the different decay lengths, two different targets are used to produce K_L and K_S, located respectively at 126 m and 6 m upstream of the beginning of the decay region. The K_S beam traverses an anti-counter detector (AKS) consisting of a photon converter and scintillators, that provides an accurate definition of the beginning of the decay region by vetoing K_S decays occurring upstream. The K_S enters the decay region 6.8 cm above the K_L beam line, and the axes of the two beams crosses at the position of the electromagnetic calorimeter.

Charged particle momenta are measured by a magnetic spectrometer, composed of four drift chambers with a dipole magnet inducing a transverse-momentum kick of 265 MeV/c. The spatial resolution is 96μm, while the momentum resolution is $\sigma(p)/p = 0.48\% \oplus 0.009\% \times p$. A liquid-krypton calorimeter, 27 radiation lengths long, is used to measure energy deposits. It fully contains electromagnetic showers with energies up to 100 GeV, and has an energy resolution of $\sigma(E)/E = (3.2 \pm 0.2)\%/\sqrt{(E)} \oplus (9 \pm 1)\%/E \oplus (0.42 \pm 0.05)\%$ where E is measured in GeV. The two beam intensities are measured by beam counters located at the end of the K_L beam line (K_L monitor) and close to the K_S target (K_S monitor). During 2001 data taking, another K_L monitor with higher counting rate and a K_S monitor close to the tagger were added. A muon counter at the end of the detector is used to identify muons. The experimental layout is described in detail elsewhere [4].

3 Event reconstruction and selection

The details of the event reconstruction and selection can be found elsewhere [4]. Final states containing $\pi^0\pi^0$ are selected using only information from the electromagnetic calorimeter. From the measured energies and impact points of the photons, the decay vertex position along the beam line is reconstructed assuming the nominal kaon mass. A χ^2 is built from the invariant mass of the photon pairs, compared to the nominal π^0 mass. A cut on χ^2 is applied to reject the residual background from $3\pi^0$ decays in the K_L sample. The K_S sample is background free. The absolute energy scale is adjusted using $K_S \to \pi^0\pi^0$ decays and imposing the condition that the reconstructed AKS position matches the true value.

Final states containing $\pi^+\pi^-$ are reconstructed using information from the spectrometer. Both the longitudinal and the transverse position of the kaon decay vertex can be reconstructed. Since the beams are separated vertically by about 6 cm in the decay region, a clear identification of K_S and K_L is possible using the reconstructed vertex position. A cut on the ratio of the two track momenta is applied to remove asymmetric decays in which one track is close to the beam pipe, where the Monte Carlo modelling is more critical. To reject the background from semileptonic K_L decays, events with a track consistent with being an electron (high E/p ratio) or a muon (hits in the muon counter) are discarded. Kinematical cuts are also applied on the reconstructed $\pi^+\pi^-$ invariant mass and on the kaon transverse momentum.

The fiducial ranges used to count events are chosen to be: kaon energy between 70 and 170 GeV; proper time τ between 0 and $3.5\tau_s$, where $\tau = 0$ correspond to the position of the AKS counter and τ_s is the K_S lifetime. A decay is labelled K_S if there is a coincidence within ± 2 ns between the event time and the proton time measured by the tagger. Mis-identification probabilities are measured and a correction is applied to the data.

4 Intensity effects

The overlap of a good event with extra particles related to decays in the high-intensity K_L beam may result in the loss of the event. The effect on R is minimized thanks to the simultaneous data collection in the four decay modes. The possible residual effects can be separated into two components.

The first component is related to the difference in the beam intensity in K_S and K_L events, and is given by $\Delta R = \Delta\lambda \times \Delta I/I$. $\Delta\lambda$ is the difference between the mean losses in $\pi^+\pi^-$ and $\pi^0\pi^0$ modes and $\Delta I/I$ is the difference between the K_L beam intensity in K_L and K_S events. $\Delta\lambda$ is minimised by applying the same dead-time conditions to all modes. It is estimated by overlaying data and Monte Carlo events with the beam monitor triggers, and is found to be $(1.0 \pm 0.5)\%$. The hypothesis of linear dependence of the accidental losses as a function of the intensity is well satisfied by the data, as shown in Fig 1. $\Delta I/I$ is minimised by having simultaneous beams, and it is measured from the rate of out-of-time energy deposits and tracks in selected K_S and K_L decays. This is illustrated in Fig 2. The beam monitor data are also used as a cross-check. The uncertainty on R from the intensity difference effect is $\pm 1.1 \times 10^{-4}$, significantly better than the value found in 1998-99 data samples, because of the lower intensity and the improved beam monitors.

The second component is related to a difference in illumination between K_L and K_S decays coupled to a variation of the rate of event loss as a function of the impact points of the decay products. The effect is also computed using the overlay technique, and the uncertainty on R is evaluated to be $\pm 3.0 \times 10^{-4}$.

The effect on R of the additional detector activity generated by the same proton (in-time activity) has been evaluated to be 1.0×10^{-4}.

5 Result and conclusion

A summary of the corrections and of the systematic uncertainties applied to R for 2001 data is shown in table 1. The residual acceptance correction is mostly due to beam geometry effects. Some systematic uncertainties are determined by the statistical significance of the control samples used. The result on the 2001 data, which consists of 1.55×10^6 events in the limiting mode $K_L \to \pi^0\pi^0$, is $\mathrm{Re}(\varepsilon'/\varepsilon) = (13.7 \pm 2.5_{stat} \pm 1.8_{syst}) \times 10^{-4}$. The agreement between this result and that published previously demonstrates the stability of the measurement at different average beam intensities. Taking into account the correlated systematic uncertainty of $\pm 1.4 \times 10^{-4}$, the combined result from NA48 experiment is $\mathrm{Re}(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$.

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3. A.Alavi-Harati *et al.*, hep-ex/0208007, submitted to Phys.Rev.D
4. R.Batley *et al*, *Phys.Lett.*B **544**, 97 (2002)

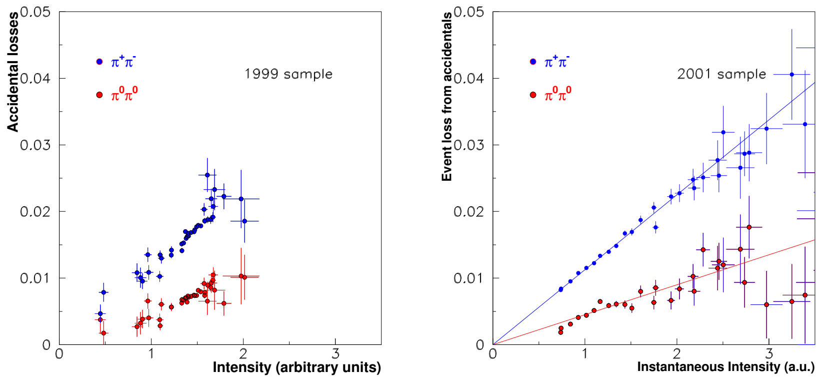

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Figure 1: Losses in selected events due to accidental activity as a function of the beam intensity, for K_S and K_L 1999 sample (left), and 2001 sample (right).

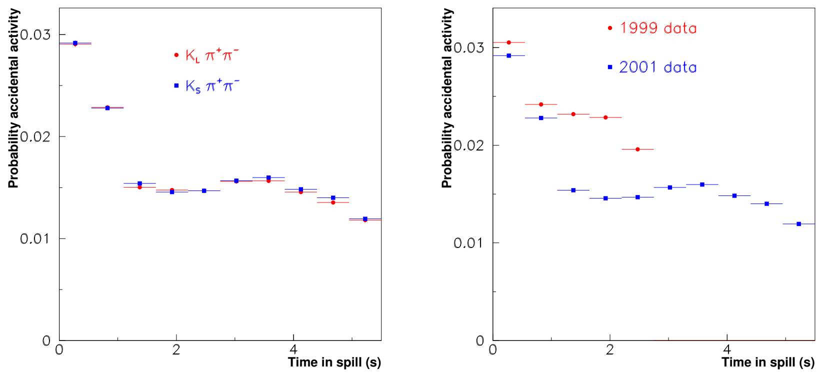

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Figure 2: Probability of accidental activity in the electromagnetic calorimeter inside the readout window as a function of the time during the spill, for K_S and K_L decay to $\pi^+\pi^-$ (left). Comparison of the same probability for 1999 and 2001 data (right).

Table 1: Correction and systematic uncertainty on R (units 10^{-4}) for 2001 data.

$\pi^+\pi^-$ trigger	+5.2	$\pm$3.6 (stat)
AKS inefficiency	+1.2	$\pm$0.3
Reconstruc. of $\pi^0\pi^0$	-	$\pm$5.3
Reconstruc. of $\pi^+\pi^-$	-	$\pm$2.8
Backgroung to $\pi^0\pi^0$	-5.6	$\pm$2.0
Backgroung to $\pi^+\pi^-$	+14.2	$\pm$3.0
Beam scattering	-8.8	$\pm$2.0
Accidental tagging	+6.9	$\pm$2.8 (stat)
Tagging ineffic.	-	$\pm$3.0
Acceptance statist.	-	$\pm$3.5 (stat)
Acceptance systemat.	+21.9	$\pm$4.0
Intensity	-	$\pm$1.1 (stat)
Illumination	-	$\pm$3.0
K_S in-time activity	-	$\pm$1.0
Total	+35.0	$\pm$11.0