Search for CP violation in $K^{\pm} \to 3\pi$ decays by the NA48/2 experiment at CERN

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Abstract. A preliminary measurement of the CP-violating charge asymmetry in $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ decays is presented by the NA48/2 collaboration. From the data collected in 2003, the asymmetry parameter A_g is found to be $(0.5 \pm 3.8) \times 10^{-4}$, consistent with Standard Model predictions.

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INTRODUCTION

CP violation in $K^{\pm} \to 3\pi$ decays can be investigated by comparing the Dalitz plot distributions for K^{+} and K^{-}. The matrix element for such decays is parametrized by

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

where u and v are kinematical variables which are related, in the kaon centre-of-mass system, to the odd pion energy and to the energy difference between the two even pions, respectively. If CP invariance holds, the parameters g, h and k are identical for K^{+} and K^{-} decays. Since h and k are much smaller than g, the charge asymmetry parameter

$$A_g = \frac{g^{+} - g^{-}}{g^{+} + g^{-}} = \frac{\Delta g}{2g} \quad (2)$$

where g^{+} and g^{-} are the linear slope parameters for K^{+} and K^{-} decays, respectively, provides a measure of CP violation that can be accessible to experiments. Present measurements of A_g [1] have uncertainties that are one to two orders of magnitude larger than Standard Model (SM) calculations ($A_g^{SM} < 10^{-4}$) [2]. Some extensions to the SM predict, however, larger asymmetry values which can reach a few 10^{-4} [3].

THE NA48/2 APPROACH

The design goal of the NA48/2 experiment is to measure the linear slope asymmetries for $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays with accuracies $\delta A_g < 2.2 \times 10^{-4}$ and $\delta A_g^0 < 3.5 \times 10^{-4}$, respectively. In order to reach such precisions, more than 2×10^9 $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and 10^8 $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ reconstructed events are needed.

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The experimental method is based on the use of intense and simultaneous $K^{\pm}$ beams, superimposed in space, with narrow momentum spectra (P_K = 60 $\pm$ 3 GeV/c). To keep systematic uncertainties at the required level, averaged K^+ and K^- acceptances are equalized by frequently alternating the magnet polarities of the kaon beam lines and the spectrometer. The measurement of charge asymmetries is obtained from slopes of normalized u-distribution ratios: $R(u) = N^+(u)/N^-(u) \propto (1 + \Delta g\, u)$. In this way, induced instrumental asymmetries can originate only from time-varying charge asymmetric and u-dependent effects.

Charged kaon beams are produced at the CERN 400 GeV/c SPS. The momentum selection and cleaning of the charged beams is performed by two achromats which allow particles of both charges to travel simultaneously. The charged beams are focused towards the NA48 detector located downstream of a 114 m decay volume contained in vacuum. The instantaneous rate of beam particles (mainly pions) is about 20 MHz for a proton intensity of 7×10^{11} per SPS pulse.

The NA48 detector is composed of a high-resolution magnetic spectrometer and a quasi-homogeneous liquid krypton electromagnetic calorimeter (LKr). A scintillator hodoscope, placed between the spectrometer and the calorimeter, is used for fast triggering purposes. The LKr calorimeter is followed by a hadronic calorimeter and a muon veto.

ASYMMETRY MEASUREMENT IN $K^{\pm} \to \pi^{\pm}\pi^+\pi^-$ DECAYS

The selection of $K^{\pm} \to \pi^{\pm}\pi^+\pi^-$ events is based only on hodoscope and magnetic spectrometer information. At the trigger level, fast signals from the scintillator hodoscope and hits from the spectrometer drift chambers are used to identify kaon decays. In the offline analysis, good events are selected by reconstructing 3-track vertices in the decay volume. The geometrical acceptance for $K^{\pm} \to 3\pi^{\pm}$ is limited mostly by the beam pipe traversing the drift chambers. About 1.6×10^9 events are reconstructed in the 2003 data sample with negligible background due to $\pi \to \mu\nu$ decays . The ratio of K^+ to K^- decays is about 1.8.

In order to equalize acceptances for K^+ and K^- decays, the quadruple product of K^+ to K^- ratios is performed:

$$R(u) = R_{UR}(u) \times R_{UL}(u) \times R_{DR}(u) \times R_{DL}(u) \propto (1 + 4\Delta g\, u) \qquad (3)$$

where U and D denote the positions (up or down) of the K^+ beam in the achromats while R and L correspond to the deflections (right or left) of positive particles in the magnetic spectrometer. The slope difference Δg is obtained by fitting the $R(u)$ distribution which is sensitive only to the time variation of asymmetries in experimental conditions with caracteristic time smaller than the corresponding field alternation periods. In 2003, field polarities of the achromats and magnetic spectrometer were alternated on week and day bases, respectively. Data were collected in four samples (SS0 to SS3). Time variation of acceptance due to slight transverse displacements (< 2 mm) of the kaon beams is reduced by applying as a function of time, kaon charge and momentum, geometrical cuts around the beam pipe, centered on averaged beam positions. Moreover, a fine tuning of the calibration of the spectrometer momentum scale and of the relative drift chambers alignment is obtained by imposing the nominal kaon mass value to reconstructed events.

TABLE 1. 2003 statistics and result

Sample	$K^+ \to \pi^+\pi^+\pi^-$ **(10^6)**	$K^- \to \pi^-\pi^-\pi^+$ **(10^6)**	Δ**g** **(10^{-4})**
SS0	431	240	0.5 ± 2.4
SS1	258	144	2.2 ± 2.2
SS2	253	141	-3.0 ± 2.5
SS3	95	53	-2.6 ± 3.9
Total	1036	577	-0.2 ± 1.3

Table 1 summarizes, for each sample, the event statistics together with the corresponding fitted value Δg. The uncertainties shown are purely statistical and include contributions from trigger efficiency measurements obtained from downscaled control events. The systematic uncertainty on Δg is estimated to be 0.9×10^{-4} with contributions coming from acceptance and beam geometry, spectrometer alignment and magnetic field, accidental activity and background as well as from the fit method and u-resolution. Using the value $g = -0.2154 \pm 0.0035$ [4], the 2003 preliminary result obtained for the asymmetry parameter is: $A_g = (0.5 \pm 2.4_{stat.} \pm 2.1_{stat.(trig.)} \pm 2.1_{syst.}) \times 10^{-4} = (0.5 \pm 3.8) \times 10^{-4}$, consistent with no observation of CP violation.

CONCLUSION

Based on the 2003 data, the NA48/2 experiment has obtained a preliminary measurement of the CP-violating charge asymmetry A_g in $K^\pm \to \pi^\pm\pi^+\pi^-$ decays which is one order of magnitude more precise than previous experiments. This result is consistent with SM predictions. The inclusion of 2004 data will increase by at least a factor two the available statistics, allowing the design accuracy on A_g to be reached. Moreover, about 10^8 $K^\pm \to \pi^\pm\pi^0\pi^0$ events have been collected during the 2003 and 2004 runs. The measurement of the asymmetry parameter A_g^0 is expected to have a sensitivity comparable to the one obtained for purely charged decay modes.

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