# SEARCH FOR DIRECT CP VIOLATION IN CHARGED K DECAYS

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Abstract

The NA48/2 experiment at the CERN SPS collected an unprecedented statistics of charged Kaon decays with a unique double-beam technique, which allows high control of systematics, with the main goal of looking for direct CP violation asymmetries. A preliminary result is presented on the CP-violating Dalitz plot linear slope asymmetry in $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ decays, which corresponds to a ten-fold improvement in accuracy with respect to previous measurements.

## 1 Introduction

More than 40 years after its discovery [1], the phenomenon of CP violation still eludes a deep understanding, and holds a central role on the present and future agenda of high-energy physics experimental investigations. After a long hiatus during which this elusive effect seemed to be confined to a rather peculiar sector of particle physics, two recent breakthroughs were the experimental evidences for direct CP violation in neutral kaons (*i.e.* $\epsilon'/\epsilon$, [2] [3] [4]), and the evidence for CP violation effects in $B$ meson decays [5]. Direct CP violation, manifesting itself as an asymmetry in two CP-conjugate decay amplitudes (which was recently detected also for $B$ mesons [6]), is the most "straightforward" manifestation of CP violation, and while its importance cannot be overestimated, as a strong qualitative test of the way the Standard Model accommodates CP violation (*i.e.* the CKM paradigm), its quantitative exploitation to constrain fundamental parameters of the theory has been hampered so far by dire theoretical difficulties in providing accurate predictions in terms of the underlying fundamental parameters, due to the complexity of the hadronic environment. Still, an intense theoretical program is under way to devise new approaches to improve such predictions, to ultimately allow the experimental direct CP measurements to be used also as strong quantitative constraints to the Standard Model; lattice QCD appears to be the most promising candidate for this program.

After a successful program of investigations with neutral kaons, which culminated with the proof of direct CP violation [3], and after an experiment (NA48/1) devoted to the study of rare $K_S$ decays, the NA48 collaboration undertook a high-statistics investigation of charged K decays (NA48/2), with the main purpose [7] of looking for further CP violation effects, which for charged particles can only be of the direct type.

The relatively low mass of the $K^\pm$ in the hadron spectrum results in a limited number of decay modes with large branching fractions; the most common ones which are expected to possibly support CP violation are the $3\pi$ modes: $\pi^\pm\pi^+\pi^-$ and $\pi^\pm\pi^0\pi^0$, with branching fractions 5.6% and 1.7% respectively. The interest in these decay modes surged from the observation that they do not share some of the intrinsic *a priori* suppression factors which make direct CP violation effects small for neutral kaons (*i.e.* $|\epsilon'| \simeq 4 \cdot 10^{-6}$).

It turns out, however, that explicit predictions for CP violating asymmetries in the Standard Model, while being quite uncertain, are usually very small; while this fact likely precludes present experiments from detecting such effects, it opens up a large window of opportunity for challenging the Standard Model itself.

The usual phenomenological description of $K \to 3\pi$ decays is made in terms of the bi-dimensional Dalitz plot parameters [8] $u$ and $v$, related to the energy sharing to the "odd" pion (*i.e.* the one having opposite charge with respect to the two other ones), and among the two "even" pions respectively:

$$u = \frac{s_3 - s_0}{m_\pi^2} = 2m_K \frac{m_K/3 - E_3^*}{m_\pi^2} \qquad v = \frac{s_2 - s_1}{m_\pi^2} = 2m_K \frac{E_1^* - E_2^*}{m_\pi^2}$$

where $s_i = (p_K - p_i)^2$, $p_K$ being the four-momentum of the decaying kaon and $p_i$ $(i = 1, 2, 3)$ those of the pions (with index $i = 3$ for the odd one), and $s_0 = (s_1 + s_2 + s_3)/3$. After transforming to the kaon centre of mass frame, the pion centre of mass energies $E_i^*$ appear. The matrix element is naively expanded as

$$|M|^2 \propto 1 + gu + hu^2 + kv^2 + \cdots$$

where [8]:

$$g(\pi^\pm\pi^+\pi^-) = -0.2154 \pm 0.0035 \qquad g(\pi^\pm\pi^0\pi^0) = 0.652 \pm 0.031$$

and $|h|, |k| \ll |g|$ imply smaller quadratic terms. While other results from NA48/2 show that this simple parameterization around the centre of the Dalitz plot is not entirely adequate to describe the physics, it is the conventional one adopted so far.

Among the possible CP asymmetries between $K^+$ and $K^-$ are those of partial decay widths (*i.e.* $|M|^2$): these are very highly suppressed in any model for symmetry reasons, and therefore not very promising for experimental detection. The experimental measurement of such rate asymmetries would require a precise knowledge of the relative kaon fluxes for both charge signs. On the other hand, the measurement of differences among the above parameters describing the decay distributions is independent on flux and can be performed just by comparing the Dalitz plot *shapes*. The main goal of the NA48/2 experiment is to measure the slope asymmetries

$$A_g = \frac{g_+ - g_-}{g_+ + g_-}$$

with a precision of $2.2 \cdot 10^{-4}$ for the $\pi^\pm\pi^+\pi^-$ decay mode and $3.5 \cdot 10^{-4}$ for $\pi^\pm\pi^0\pi^0$.

The above figures require collecting very large samples, and therefore intense beams, large acceptance and data acquisition bandwidths; these have to be matched with a careful control of systematics, which requires novel experimental approaches.

The available experimental information on $A_g$ is summarized in table 1, and some experimental predictions within the Standard Model and other models are shown in table 2 (where as usual some care must be taken with the

Table 1: Summary of experimental measurements on direct CP violating slope asymmetries in $K^{\pm}$ decays.

| **Asymmetry** | **Events** | **Experiment** |
|---|---|---|
| $A_g(\pi^{\pm}\pi^{+}\pi^{-}) = (-70 \pm 53) \cdot 10^{-4}$ | 3.2M | BNL AGS (1970) [9] |
| $A_g(\pi^{\pm}\pi^{0}\pi^{0}) = (19 \pm 125) \cdot 10^{-4}$ | 115K | CERN PS (1975) [10] |
| $A_g(\pi^{\pm}\pi^{+}\pi^{-}) = (22 \pm 15 \pm 37) \cdot 10^{-4}$ | 54M | HyperCP (2000) [11] prelim. |
| $A_g(\pi^{\pm}\pi^{0}\pi^{0}) = (2 \pm 19) \cdot 10^{-4}$ | 620K | Protvino IHEP (2005) [12] |

quoted “theoretical” errors, and central values could admittedly vary by up to an order of magnitude). One can see that NA48/2 has a great potential for closing the wide gap between experiments and theory, reaching the interesting region in which one could detect enhancements due to physics beyond the Standard Model, which were out of reach with lower experimental accuracy. Theoretical estimates are difficult and not far from being exhaustive, particularly for what concerns specific extensions of the Standard Model.

## 2 The NA48/2 experiment

The NA48/2 experiment largely exploits the existing NA48 detector and infrastructure, with some additional element and a completely new beam line, providing for the first time simultaneous and collinear $K^+$ and $K^-$ beams.

A hadron beam is produced by 400 GeV/$c$ protons from the SPS impinging on a beryllium target rod 40 cm long and 2 mm in diameter at zero degrees. The proton beam intensity is about $7 \cdot 10^{11}$ per pulse of 4.8 s duration. A first achromatic momentum selection stage collects charged particles of $(60 \pm 3)$ GeV/$c$ momentum and both charge signs for further transmission. After being recombined, the two hadron beams, containing about $6.4 \cdot 10^7$ particles per pulse (12 times more pions than kaons), with a kaon charge ratio $K^+/K^- \sim 1.8$, pass through magnetic focusing and muon sweeping stages, before being again split in the vertical plane by a second achromatic set of magnetic dipoles (see fig. 1). At this stage the vertical positions of individual beam particles are measured by MICROMEGA detectors (KABES), thus allowing a 1% momentum measurement of the incoming kaons.

Both beams, whose transverse dimensions are about 5 mm RMS, are thereafter recombined along the experiment axis, and remain superimposed to within 1 mm while traveling through the $\sim$ 114 m long vacuum decay region towards a focus point at the detector. The detector itself has a central hole

Table 2: Some theoretical predictions for direct CP violating slope asymmetries in $K^{\pm}$ decays.

| **Asymmetry** | **Model** | **Reference** |
|---|---|---|
| $\lvert A_g(\pi^{\pm}\pi^{+}\pi^{-})\rvert \simeq 14 \cdot 10^{-4}$ | SM | Bel'kov *et al.* (1989) [13] |
| $\lvert A_g(\pi^{\pm}\pi^{0}\pi^{0})\rvert \simeq 14 \cdot 10^{-4}$ | SM | Bel'kov *et al.* (1989) [13] |
| $\lvert A_g(\pi^{\pm}\pi^{+}\pi^{-})\rvert \simeq (3.7 \pm 1.4) \cdot 10^{-4}$ | SM, NLO | Bel'kov *et al.* (1993) [14] |
| $\lvert A_g(\pi^{\pm}\pi^{0}\pi^{0})\rvert \simeq (3.1 \pm 1.4) \cdot 10^{-4}$ | SM, NLO | Bel'kov *et al.* (1993) [14] |
| $\lvert A_g(\pi^{\pm}\pi^{+}\pi^{-})\rvert \lesssim 0.45 \cdot 10^{-4}$ | SM, NLO | D'Ambrosio *et al.* (1991) [15] |
| $\lvert A_g(\pi^{\pm}\pi^{+}\pi^{-})\rvert \sim 2 \cdot 10^{-4}$ | 3HD | Shabalin (1998) [18] |
| $\lvert A_g(\pi^{\pm}\pi^{+}\pi^{-})\rvert \lesssim (0.5 \pm 0.2) \cdot 10^{-4}$ | SM, NLO | Shabalin (1993) [19] |
| $\lvert A_g(\pi^{\pm}\pi^{+}\pi^{-})\rvert \simeq (0.023 \pm 0.006) \cdot 10^{-4}$ | SM, NLO | Maiani *et al.* (1995) [16] |
| $\lvert A_g(\pi^{\pm}\pi^{0}\pi^{0})\rvert \simeq (0.013 \pm 0.004) \cdot 10^{-4}$ | SM, NLO | Maiani *et al.* (1995) [16] |
| $\lvert A_g(\pi^{\pm}\pi^{+}\pi^{-})\rvert \sim 10^{-5} \div 10^{-4}$ | SUSY | D'Ambrosio *et al.* (2000) [17] |
| $A_g(\pi^{\pm}\pi^{+}\pi^{-}) \simeq (-0.24 \pm 0.12) \cdot 10^{-4}$ | SM, NLO | Gamiz *et al.* (2003) [23] |
| $A_g(\pi^{\pm}\pi^{+}\pi^{-}) \simeq (-0.42 \pm 0.08) \cdot 10^{-4}$ | SM, NLO | Shabalin (2004) [20] |
| $A_g(\pi^{\pm}\pi^{+}\pi^{-}) \simeq (-0.2 \div -0.8) \cdot 10^{-4}$ | SM, NLO | Shabalin (2004) [21] |
| $A_g(\pi^{\pm}\pi^{+}\pi^{-}) \simeq 0.3 \cdot 10^{-4}$ | SM, NLO | Shabalin (2005) [22] |
| $A_g(\pi^{\pm}\pi^{0}\pi^{0}) \simeq 0.02 \cdot 10^{-4}$ | SM, NLO | Shabalin (2005) [22] |

for a vacuum pipe in which the undecayed charged particles of the beams keep traveling. Note that the decay products from charged pions in the beam, due to the limited transverse momentum available, are mostly confined to remain within such pipe, without illuminating the detector itself.

The main part of the NA48 detector used for the measurement of the CP-violating asymmetry in $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ decays is the magnetic spectrometer [24], composed of four large drift chambers and a dipole magnet (120 MeV/$c$ horizontal magnetic kick) enclosed in a helium-filled tank. Each octagonal chamber has four double planes of sense wires with 1 cm spacing, aligned along four directions oriented at 45° with respect to each other. The momentum resolution is $\sigma(p)/p = 1.0\% \oplus 0.044\%\, p$ ($p$ in GeV/$c$).

The trigger to select $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ decays is a two-level one. At the first level a two-layer scintillator hodoscope provides a fast coincidence signal consistent with a minimum track multiplicity of two, and such signal starts a

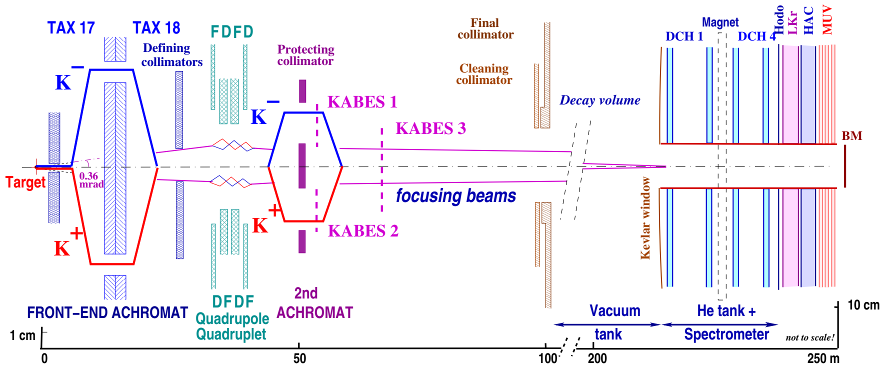


Figure 1: Sketch of the NA48/2 beam setup. Note that two beams are superimposed to within $\sim$ 1 mm all along the decay region.

farm of fast processors [25] which performs track reconstruction based on three drift chambers' data. Events with at least two tracks consistent with being originated in the decay volume are kept, giving a rate of about 30K in 4.8 s. For part of the 2003 run and all of the 2004 run events which were not selected by the above condition were also kept if one track consistent with having originated in the decay volume was reconstructed and the missing mass (assuming it to be a charged pion originating from a 60 GeV$/c$ nominal momentum kaon traveling along the beam axis) was incompatible with the kinematics of $K^\pm \to \pi^\pm\pi^0$ decay.

## 3 Principle of the measurement

The presence of the two oppositely charged beams, being spatially superimposed and present at the same time plays an important role in enforcing by design large cancellations of detector acceptance effects and response drifts on the measured asymmetries, therefore leading to robust cancellations of possible systematic errors.

The density of $K^\pm$ events in the Dalitz plot is projected onto the $u$ axis to obtain one-dimensional distributions $N^\pm(u)$. The ratio $R(u) = N^+(u)/N^-(u)$ of such distributions is to first order independent on the distortions induced by the variation of the detector acceptance over the Dalitz plot, and can be fit to a linear function $\overline{R}(1 + \Delta g u)$ to extract $\Delta g = g_+ - g_- = A_g 2g$ to sufficient accuracy.

Clearly, any instrumental effect has to be both charge-asymmetric and

$u$-dependent, in order to potentially bias the measurement.

Charge-related beam and detector differences can induce spurious asymmetries, the most obvious one being that due to imperfect left-right detector symmetry when coupled with the lateral deflecting effect of the spectrometer dipole magnet. While the beam is carefully aligned along the detector axis, any unavoidable local imperfection of the spectrometer can introduce an acceptance asymmetry. This effect is canceled to first order by periodically reversing (each day[1]) the polarity of the spectrometer magnetic field, therefore effectively equalizing the time-averaged acceptance for $K^+$ and $K^-$.

The largest instrumental effect on the event density in the Dalitz plot occurs at large $u$ values, where a steep drop in acceptance corresponds to the "odd" pion being lost into the central beam pipe hole for any spatial decay orientation. Similar cuts occurs at large $-(u \pm v)/2$ values, where one of the "even" pions is lost, but these are mapped onto wider $u$ regions after projecting. The most critical region is therefore the high $u$ edge, where any difference in the way the acceptance-defining central hole is seen by the two beams, due *e.g.* to an asymmetric relative mismatch between a beam axis, (which can drift by $\sim 1$ mm) and the detector axis, can directly induce a $u$ asymmetry, which is moreover magnified by the large lever arm due to the distortion occurring at the edge of the distribution. For this reason software acceptance cuts are enforced, which are centered on the effective beam axis, independently for $K^+$ and $K^-$: the momentum-weighted average of the three tracks' impact points at the first and last drift chambers are continuously monitored to high precision from the data, and all tracks are required to cross the first (last) drift chamber at a radial distance larger than 11.5 (13.5) cm from the average measured centre of the beam from which they originate. The larger cut at the last drift chamber accounts for the additional $\sim 2$ cm lateral displacement due to the magnetic deflection. On top of the tracking of the time-dependent variations of the beam axis' positions, the coupling of such positions to the value of kaon momentum and their dependence on the spill extraction time, due to the residual chromaticity of the beam line, are also factored out. The above acceptance cuts are always larger than the physical dimensions of the beam pipe hole and properly symmetrize the acceptance without resorting to MonteCarlo simulation and correction. A conservative limit of $\delta(\Delta g) = 0.5 \cdot 10^{-4}$ on the residual systematic effects is set by studying the result sensitivity to different acceptance cuts.

The coupling of resolution effects to acceptance variations are minimized by using a definition of $u$ in terms of the odd pion energy in the centre of mass frame, which has the best possible resolution in the critical region at large $u$.

The effects of small residual differences between the "upper" and "lower" beam paths in the achromats are canceled by periodically reversing (once per

[1] During the 2004 data-taking period the period was reduced to a few hours.

week) also all the magnetic fields along the beam lines, so that the paths of $K^\pm$ are exchanged. Note that the rather large intensity difference for the positive and negative beams is irrelevant for the measurement; also, accidental rate effects affect both $K^\pm$ events in the same way, since both beams are obtained simultaneously from the same target.

A complete independent data set ("supersample") therefore corresponded usually to a two-week long data-taking period, comprises four $K^+$ and four $K^-$ samples with all combinations of beam-line and spectrometer magnet polarities. The actual ratio $R(u)$ to be fit is obtained as a quadruple ratio of $K^+/K^-$:

$$R(u) = R_{US} R_{UJ} R_{DS} R_{DJ} \simeq \overline{R}(1 + 4\Delta g u)$$

where the subscript $U(D)$ relates to the beam line magnets' polarities, denoting a sample in which $K^+$ travel along the upper (lower) beam path in the achromatic magnet sets, while the subscript $S(J)$ relates to the spectrometer magnet polarity, denoting a sample in which particles with the same charge as the beam from which they originate are deflected to the right (left) in the spectrometer (*i.e.* towards the Salève (Jura) mountains respectively).

The above ratio exploits several cancellations: beam line differences - by comparing $K^+$ and $K^-$ traveling along the same paths, detector asymmetries - by comparing $K^+$ and $K^-$ illuminating the detector in the same way, while global time-dependent effects are canceled by the simultaneous detection of $K^+$ and $K^-$ events. The only residual effects which can induce a spurious asymmetry are therefore detector left-right asymmetries which vary in time on a time-scale shorter than that corresponding to a single magnet polarity configuration.

While the principle of the experiment is such that MonteCarlo simulation is not required nor used to correct the measurement, a detailed GEANT-based MonteCarlo program with full detector simulation, including time-varying local drift chamber inefficiency and alignment maps and beam line geometry variations, is used to check the sensitivity of the result to various systematic effects.

## 4 Data analysis

The experiment took data in 2003 (50 days) and 2004 (60 days), collecting the unprecedented sample of $\sim 4 \cdot 10^9$ $K^\pm \to \pi^\pm\pi^+\pi^-$ decays, out of a total of about 200 TBytes of data written to tape.

Apart from the magnetic spectrometer and the scintillator hodoscope, no other sub-detector is involved in this analysis.

The spectrometer internal alignment was periodically calibrated by using data from special runs with no magnetic field, in which only beam halo muons are illuminating the detector Track reconstruction combines hit information from all four drift chambers, using the measured magnetic field maps scaled for the measured dipole magnet current, and correcting for the small magnetic fields due to the vacuum tank magnetization and the Earth's field, which were measured before the run.

The vertex-constrained track parameters are used to compute the three-pion invariant mass with a resolution of about 1.7 MeV$/c^2$. Small non-Gaussian invariant mass tails arise from kink tracks in which a charged pion decayed; in order to avoid introducing potential instrumental asymmetries from other sub-detectors, no muon rejection is applied, which is possible because background is entirely negligible. The charge symmetry of the muon decay invariant mass tails has been tested with MonteCarlo to a level corresponding to $\delta(\Delta g) = 0.4 \cdot 10^{-4}$.

A fine control on the spectrometer internal alignment is obtained by continuously monitoring the difference in the reconstructed three-pion invariant masses for $K^+$ and $K^-$ (equal by CPT), which can be induced by a residual horizontal misalignment between chambers before and after the spectrometer magnet, at the level of $\sim 1.5$ keV$/\mu$m. Tiny relative drifts of the drift chambers' positions, as small as a few $\mu$m per day up to 200 $\mu$m were detected in this way, and the reconstructed momenta were corrected accordingly as $p \to p(1 + \beta q p)$, where $p$ is the measured track momentum (in GeV$/c$), $q$ its charge sign and $\beta$ a parameter of order $10^{-5}$ GeV$^{-1}$ related to the measured mass difference for positive and negative events.

While each spectrometer magnetic field reversal was preceded by a full degaussing procedure, the reproducibility of the absolute magnitude of the field integral, and its equality for both polarities, can be controlled online only to within $\sim 10^{-3}$. Effects induced by smaller magnitude differences are canceled by the fact that geometric acceptance cuts were defined with respect to the average beam positions (both before and after magnetic deflection) and by a continuous momentum recalibration procedure which constrains the reconstructed three-pion invariant masses to its nominal (PDG) value with $\sim 10^{-5}$ precision. This recalibration affects both $K^\pm$ events which are collected at the same time.

The trigger as a potential source of bias due to charge-asymmetric inefficiencies is studied directly from the data, by using downscaled control samples collected with alternative trigger conditions uncorrelated to the elements under scrutiny. Only those parts of the inefficiencies which are correlated to spatial positions are potentially dangerous, since rate-dependent effects cancel due to the simultaneous beam scheme. The first level trigger inefficiency is measured to be small, $\sim 7 \cdot 10^{-4}$, charge-symmetric and flat in $u$ to good accuracy and constant in time, leading to no correction and an uncertainty of $\delta(\Delta g) = 0.4 \cdot 10^{-4}$ reflecting the statistical size of the control sample. For the second level trigger (online track/vertex reconstruction) inefficiencies are larger (0.2 to 1.8%) and do change in time, being largely related to drift chambers' wire inefficiencies, to which the online reconstruction is more sensitive. While no statistically significant charge asymmetry or $u$ dependence of the asymmetry was measured, the size of the collected control sample is not sufficient to exclude such effects to a high precision, so that a conservative approach is adopted by correcting each sample by the measured $u$-dependent trigger efficiencies, and therefore introducing a significant error due to the statistical power of the above sample. This turns out to be the largest systematic uncertainty at this stage of the analysis, although it could be reduced by further study.

Other possible sources of bias were studied, such as the dependence on the $u$ computation or the fitting limits ($-1 \leq u \leq 1$ for this result), the effects due to the uncertainty on the knowledge of the stray magnetic fields, pile-up effects, inhomogeneities in the spectrometer misalignment, the accuracy of time-tracking of various changes in the beam geometry and those due to charge-asymmetric pion interactions. All contributions to the systematic uncertainty are summarized in table 3.

Table 3: Summary of systematic uncertainties on $\Delta g = A_g 2g$ in units of $10^{-4}$.

| | |
|---|---|
| Acceptance, beam geometry | 0.5 |
| Spectrometer alignment | 0.1 |
| Spectrometer magnet | 0.1 |
| Pion decay | 0.4 |
| $u$ computation and fitting | 0.5 |
| Accidental activity | 0.3 |
| Total systematic uncertainty | 0.9 |
| Trigger efficiency: level 1 | 0.4 |
| Trigger efficiency: level 2 | 0.8 |
| Total trigger uncertainty | 0.9 |
| Total systematic error | 1.3 |

## 5 Preliminary result

The final 2003 sample of $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ after all cuts contains $1.6 \cdot 10^{9}$ events. The preliminary result is obtained as the average of three independent analysis, all of them giving consistent results. The results for each of the four super-samples of 2003 are averaged after trigger efficiency corrections; the results from all four super-samples are statistically consistent with each other ($\chi^2$/ndf = 3.2/3), as shown in figure 2.

The result stability was checked with respect to several variables, such as kaon energy and decay position, without finding any significant dependence

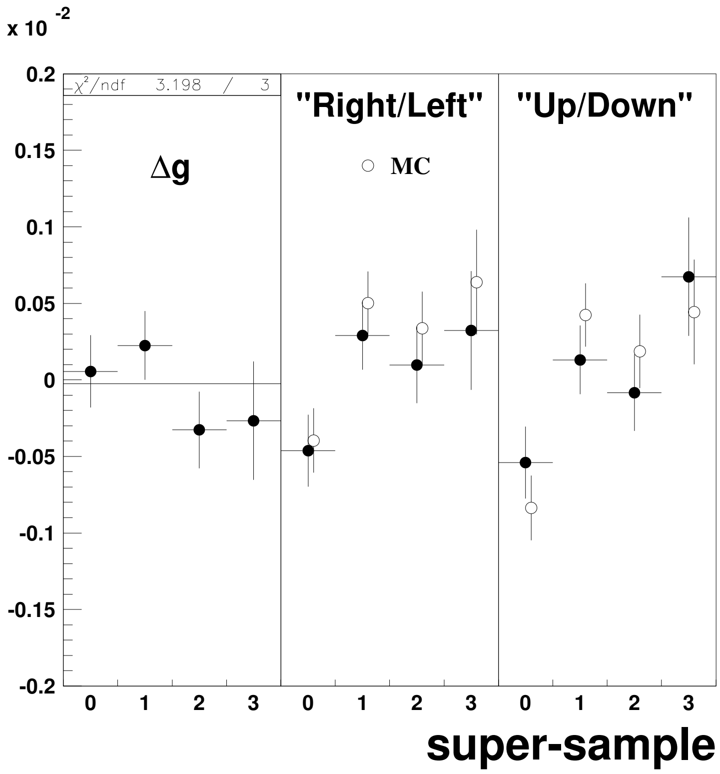


Figure 2: Stability of the preliminary result (in terms of $\Delta g$) and of null asymmetries as a function of supersample.

(see fig. 3).

Null checks were performed by building ratios of events of the same charge, which are deflected in opposite directions in the spectrometer magnet or which are distinguished only by the upper or lower path of kaons along the beam line; any asymmetry in such ratios just reflects instrumental biases coupled to time variations. Such effects are seen to be at the $10^{-4}$ level and are fully reproduced by the MonteCarlo simulation as due to the time variation of the detector inefficiencies and beam optics (see fig. 2).

The preliminary result from the 2003 data for the asymmetry $A_g = \Delta g 2g$

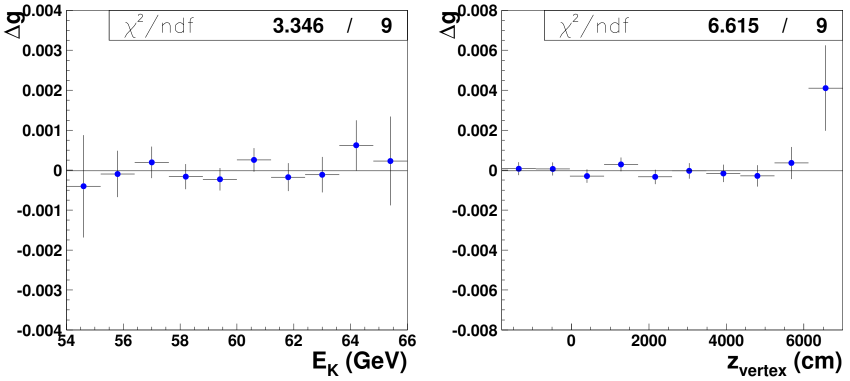


Figure 3: The linear slope difference $\Delta g$ as a function of kaon energy (left) and of longitudinal decay vertex position (right).

(using the average PDG [8]) value for the slope parameter $g$) is:

$$A_g = (0.5 \pm 2.4_{\rm stat} \pm 2.1_{\rm stat(trig)} \pm 2.1_{\rm syst}) \cdot 10^{-4} = (0.5 \pm 3.8) \cdot 10^{-4}$$

This result is consistent with no CP violation, and its precision is one order of magnitude better than earlier measurements. The systematic uncertainty can be reduced with further studies and using more data.

## 6 Further prospects

The 2004 data, which is presently being analyzed, contains more data than the 2003 one, of higher quality, so that the control of some systematic uncertainties is expected to be better, and the proposal goal seems within reach.

Other interesting possibilities being investigated to enhance the quality of the result include the use of the beam spectrometer information as an additional tool for systematic checks, and possibly as a means of allowing the measurement of the slope asymmetry also for events in which one of the pions is outside the detector acceptance, by using the measured $K$ momentum and direction to close kinematically the event: such sample, likely affected by different systematic effects, would be significantly larger and with a different $u$ spectrum, therefore being interesting as an alternative measurement.

NA48/2 also collected a large sample of $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays (about $2 \cdot 10^{8}$ in total), from which a measurement of the corresponding slope asymmetry will be extracted. Despite the lower branching ratio and acceptance for this mode, its larger Dalitz plot slope compensates, leading to a comparable statistical uncertainty on the slope asymmetry (*e.g.* $\sim 2.2 \cdot 10^{-4}$ for $28 \cdot 10^6$ events in a sub-sample of 2003 data). Systematic uncertainties will be different in this case, but it is interesting to notice that for this decay the asymmetry can be computed using practically only information from the electro-magnetic calorimeter, therefore leading to a rather complementary CP-violation measurement.

The slope asymmetries for the two $3\pi$ decay modes are expected to be strongly correlated in any given model (albeit such correlation is also affected by theoretical uncertainties), and the measurement of both would allow to constrain better the underlying parameters.

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