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Search for direct CP-violation in $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays

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Abstract

A search for direct CP-violation in $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decay based on 47.14 million events has been performed by the NA48/2 experiment at the CERN SPS. The asymmetry in the Dalitz plot linear slopes $A_g = (g^{+} - g^{-}) / (g^{+} + g^{-})$ is measured to be $A_g = (1.8 \pm 2.6) \cdot 10^{-4}$. The design of the experiment and the method of analysis provide good control of instrumental charge asymmetries in this measurement. The precision of the result is limited by statistics and is almost one order of magnitude better than that of previous measurements by other experiments.

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1 Introduction

Studies of direct CP-violation play an important role in understanding the nature of weak interactions, and provide the opportunity to search for physics beyond the Standard Model (SM). More than three decades passed since the discovery of CP-violation in the mixing of neutral kaons [1], until direct CP-violation was definitively established in the neutral kaon system by the measurement of a non-zero ϵ'/ϵ parameter [2],[3]. More recently, direct CP violation has been also detected in B meson decays [4]. In order to explore possible non-SM enhancements to heavy-quark loops which are at the core of direct CP-violating processes, different systems must be studied. In kaons, besides the ϵ'/ϵ parameter in $K_L \to \pi\pi$ decays, promising complementary observables are the rates of GIM-suppressed rare kaon decays proceeding through neutral currents, and an asymmetry between K^+ and K^- decays to three pions. The $K^\pm \to 3\pi$ matrix element is usually parameterized by a polynomial expansion in two Lorentz-invariant variables u and v:

$$|M(u,v)|^2 \propto 1 + gu + hu^2 + kv^2 + ..., \tag{1}$$

where $|h|, |k| \ll |g|$ are parameters, and

$$u = \frac{s_3 - s_0}{m_\pi^2}, \quad v = \frac{s_1 - s_2}{m_\pi^2}, \tag{2}$$

where m_π is the charged pion mass, $s_i = (p_K - p_i)^2$, $s_0 = \sum s_i/3$ $(i = 1,2,3)$, p_K and p_i are kaon and i-th pion 4-momenta, respectively. The index $i = 3$ corresponds to the odd, i.e. charged pion (the other two pions have the same charge). Any difference in the slope parameters between K^+ and K^- indicates the presence of direct CP violation. SM predictions for the asymmetry in the linear slopes g^+ for K^+ and g^- for K^-:

$$A_g = \frac{g^+ - g^-}{g^+ + g^-} \tag{3}$$

vary from a few 10^{-6} to a few 10^{-5} [5]. Several experiments [6] have searched for such asymmetries with a precision at the level of 10^{-3} for both $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ decay modes, obtaining no evidence for direct CP violation. Existing theoretical calculations involving processes beyond the SM [7] do not exclude substantial enhancements of the asymmetry A_g which could be observed in the present experiment.

The NA48/2 experiment at the CERN SPS was designed to search for direct CP-violation in the decays of charged kaons to three pions, and collected data in 2003 and 2004. A result based on the analysis of $4.714 \cdot 10^7$ $K^\pm \to \pi^\pm\pi^0\pi^0$ decays accumulated during the 2003 run is presented in this paper. An asymmetry result for $K^\pm \to \pi^\pm\pi^+\pi^-$ decays recorded at the same time has recently been published [8].

2 Description of the Experiment

In order to reach a high accuracy in the measurement of the charge asymmetry parameter A_g, the highest possible level of charge symmetry between K^+ and K^- is a crucial requirement in the choice of beam, experimental apparatus, strategy of data taking and analysis. A novel beam line with two simultaneous charged beams of opposite charges was designed and built in the high intensity hall (ECN3) at the

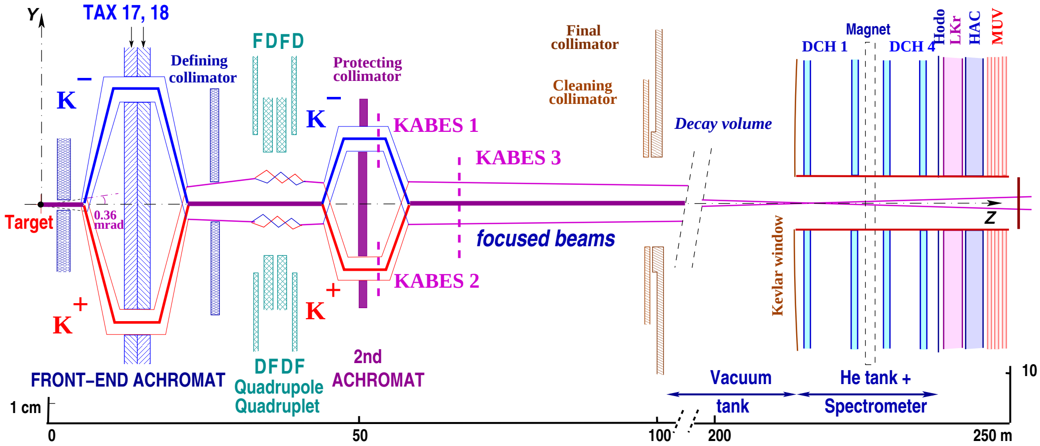

Figure 1: Schematic lateral view of the NA48/2 experiment. Region 1 (from target to decay volume): beam line (TAX17,18: motorized beam dump/collimators used to select the momentum of the K^+ and K^- beams; DFDF: focusing quadrupoles; KABES1-3: beam spectrometer stations). Region 2: decay volume and detector (DCH1-4: drift chambers; Hodo: hodoscope; LKr: electromagnetic calorimeter; HAC: hadron calorimeter; MUV: muon veto). The vertical scales for the two regions are different.

CERN SPS. The simultaneous recording of both K^+ and K^- decays and a frequent inversion of all magnetic field polarities provide a high level of intrinsic cancellation of the main possible systematic effects in the measurement of A_g.

A schematic view of the beam line and detectors is presented in Fig. 1. A right-handed coordinate system is used to describe the apparatus, with the z axis along the beam line direction, and the y axis directed vertically up (the field in the centre of the spectrometer magnet (see below) is alternatively parallel or anti-parallel to the y axis). The beam line and the set-up are designed to be symmetric with respect to $x = 0$. The charged particle beams are produced by 400 GeV protons from the SPS impinging at zero angle with respect to the z axis on a 40 cm long beryllium target with a diameter of 2 mm. The proton beam has an intensity of about 7×10^{11} protons per burst with a duty cycle of ~ 4.8 s / 16.8 s. Charged particles with a central momentum of 60 GeV/c and a momentum bite of ± 3 GeV/c (FWHM) are selected symmetrically by a first achromatic magnet system ('achromat') which separates the two beams in the vertical plane and recombines them again on the same axis. Both beams then pass through a series of focusing quadrupoles and are again split and cleaned in a second achromat. The second achromat together with the KABES detector [9] also serves as a beam spectrometer (not used in the present analysis). The K^+/K^- flux ratio is about 1.8, and is found to be stable during data taking.

Downstream of the second achromat both beams follow the same path and, after passing the cleaning and final collimators, enter a 114 m long evacuated decay region with a diameter of 1.92 m for the first 66 m, and 2.4 m for the rest. Here the two beams are collinear and superimposed within one millimetre, until they reach a spectrometer magnet where they are deflected horizontally in opposite directions by an angle of 2mrad.

The reconstruction of $K^\pm \to \pi^\pm\pi^0\pi^0$ decays is based on the information from a magnetic spectrometer and a liquid krypton calorimeter (LKr). The spectrometer is housed in a tank filled with helium at atmospheric pressure separated from the vacuum tank by a *kevlar* window with a thickness of 0.0031 radiation lengths (X_0). Surviving beam particles, as well as muons from $\pi \to \mu\nu$ decays, traverse the centre of the detectors inside an evacuated beam tube with a diameter of ~ 16 cm. Two drift chambers (DCH1,2) are located upstream and two (DCH3,4) downstream of a dipole magnet which deflects charged particles in the horizontal plane with a transverse momentum kick of 120 MeV/c. The DCHs have an octagonal shape with an area of 4.5 m^2. Each chamber has eight planes of sense wires, two horizontal, two vertical and two along each of two orthogonal 45° directions. The momentum resolution of the magnetic spectrometer is $\sigma(p)/p = 1.0\% \oplus 0.044\% p$ (p in GeV/c). The magnetic spectrometer is followed by a scintillator hodoscope consisting of two planes segmented into horizontal and vertical strips and arranged in four quadrants.

The LKr calorimeter [10] is an almost homogeneous ionization chamber with an active volume of 10 m^3 of liquid krypton, segmented transversally into 13248 projective cells, 2×2 cm^2 each, by a system of Cu−Be ribbon electrodes, and with no longitudinal segmentation. The calorimeter is 27 X_0 deep and has an energy resolution $\sigma(E)/E = 0.032/\sqrt{E} \oplus 0.09/E \oplus 0.0042$ (E in GeV). The space resolution for a single electromagnetic shower can be parameterized as $\sigma_x = \sigma_y = 0.42/\sqrt{E} \oplus 0.06$ cm for the transverse coordinates x and y. The LKr is used to reconstruct $\pi^0 \to \gamma\gamma$ decays.

The NA48 apparatus also includes a hadronic calorimeter and a muon detector. A description of these components can be found elsewhere [10].

Kaon decays are selected by a two-level trigger. The first level requires a signal in at least one quadrant of both scintillator hodoscope planes in coincidence with the presence of energy deposition in the LKr consistent with at least two photons. At the second level, a fast processor receiving the DCH information reconstructs the charged particle momentum and calculates the missing mass under the assumption that the particle is a $\pi^\pm$ originating from the decay of a 60 GeV/c $K^\pm$ travelling along the nominal beam axis. The requirement that the missing mass is not consistent with a π^0 mass rejects most $K^\pm \to \pi^\pm\pi^0$ events. The typical rate of this trigger is ∼15,000 per burst.

3 Event selection and reconstruction

After rejecting data affected by the malfunctioning of some detector components, nearly 110 million events are selected for further analysis, containing at least one charged particle with momentum above 5 GeV/c and at least four energy clusters in the LKr, each consistent with a photon and above an energy threshold of 3 GeV. In order to exclude events with overlapping electromagnetic showers in the LKr, the distance between any two photons in the LKr is required to be larger than 10 cm, and the distance between each photon and the impact point of the charged particle on the LKr plane must exceed 15 cm. Fiducial cuts on the distance of each photon from the LKr edges and the central hole are also applied in order to ensure full containment of the electromagnetic showers. In order to symmetrize the geometrical acceptance to particles of opposite charges, radial cuts are applied around the average beam position, which is continuously monitored for K^+ and K^- separately using the large sample of simultaneously recorded $K^\pm \to \pi^\pm\pi^+\pi^-$ decays [8]. In particular, to eliminate effects associated with the drop of DCH efficiency near the central beam hole, the distance between the charged pion and

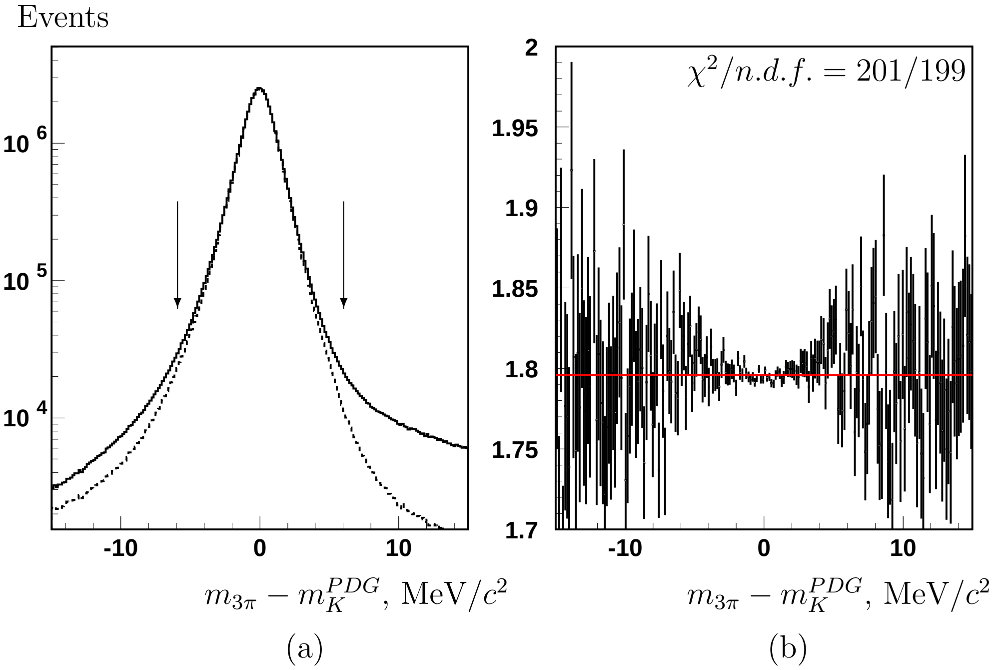

Figure 2: (a) Difference between the invariant $\pi^\pm\pi^0\pi^0$ mass and the PDG kaon mass [11]. The selected interval is indicated by the arrows. The dashed histogram shows the same distribution for events with no hit in the muon detector. (b) Ratio of invariant mass distributions for $\pi^+\pi^0\pi^0$ and $\pi^-\pi^0\pi^0$ fitted with a constant function.

the average beam position on DCH1 (DCH4) is required to be larger than 12.5 cm (16.5 cm). Around 70 million events pass these requirements.

For each selected event, the $K^\pm \to \pi^\pm\pi^0\pi^0$ decay is reconstructed as follows. Assuming that each pair i, k of LKr clusters (i, k =1,2,3,4) originates from a $\pi^0 \to \gamma\gamma$ decay, the distance D_{ik} between the π^0 decay vertex position along the z axis and the front plane of the LKr is calculated:

$$D_{ik} = \frac{\sqrt{E_i E_k \left[(x_i - x_k)^2 + (y_i - y_k)^2\right]}}{m_{\pi^0}}, \tag{4}$$

where E_i and E_k are the energies of the i-th and k-th photon, respectively, x_i, y_i, x_k, y_k are the coordinates of their impact points on the LKr front plane, and m_{π^0} is the π^0 mass [11].

Among all photon pairs, the two with the smallest D_{ik} difference are selected as the best combination consistent with the hypothesis of two π^0 mesons originating from $K^\pm \to \pi^\pm\pi^0\pi^0$ decay. The arithmetic average of the two D_{ik} values is used to define the distance of the reconstructed $K^\pm$ decay vertex from the LKr (this choice gives a $\pi^0\pi^0$ invariant mass equal to $2m_{\pi^0}$ at threshold, corresponding to the best possible resolution).

Fig. 2 (a) shows the invariant mass distribution for two π^0s and a reconstructed charged particle track, assumed to be π^+ or π^-. A clear signal from $K^\pm \to \pi^\pm\pi^0\pi^0$ decays is seen, as expected, with a mass resolution of $\sim$0.9 MeV/c^2. The tails originate from wrong photon pairing (the fraction of these events is 0.23%, as estimated by a Monte Carlo simulation) and $\pi \to \mu\nu$ decays. No charge asymmetry is seen in this distribution, as shown in Fig. 2 (b).

Further event selection requires the $\pi^\pm\pi^0\pi^0$ invariant mass to differ from the nominal $K^\pm$ mass [11] by less than 6 MeV/c^2, and the reconstructed kaon momentum to be between 54 and 66 GeV/c. In addition, the times of the track ($t^\pm$) and of the photons (t^γ) must be consistent with a single event within the experimental resolution: $|\langle t^\gamma\rangle - t_i^\gamma| < 5$ ns and $|\langle t^\gamma\rangle - t^\pm| < 20$ ns, where $\langle t^\gamma\rangle$ is the average time of the four photons. These requirements are satisfied by 47.14×10^6 events.

The presence of magnetic fields in the spectrometer and to a lesser extent in the beam line (achromats, focusing quadrupoles, etc.) introduces a small but unavoidable charge asymmetry in the apparatus acceptance. In order to effectively eliminate differences between the K^+ and K^- beams, the polarities of all magnets in the beam line ('achromat polarities') are reversed weekly during data taking, while the polarity of the spectrometer magnet is reversed daily. All magnet currents are carefully monitored and kept at their nominal value at the level of 10^{-4}. A set of data which contains at least two periods with different achromat polarities is called a 'super-sample' and is treated in the analysis as an independent, self-consistent data unit. During the 2003 running period three super-samples were collected (see Table 1)[1]. Each super-sample contains four $K^+ \to \pi^+\pi^0\pi^0$ and four $K^- \to \pi^-\pi^0\pi^0$ samples with different combinations of the beam line and spectrometer magnet polarities.

Super-samples	Sub-samples	Achromat A+		Achromat A-	
		K^+	K^-	K^+	K^-
I	22	8.53	4.63	7.87	4.51
II	16	6.17	3.44	4.00	2.22
III	4	1.84	1.02	1.87	1.04
Total	42	47.14			

Table 1: Number of selected $K^+ \to \pi^+\pi^0\pi^0$ and $K^- \to \pi^-\pi^0\pi^0$ decays (in millions). A sub-sample is a set of events taken in a run with a given configuration of beam and spectrometer magnet polarities.

4 Asymmetry measurement method

The variable u is defined as:

$$u = \frac{M_{00}^2 - s_0}{m_\pi^2}, \tag{5}$$

where $s_0 = (m_K^2 + m_\pi^2 + 2m_{\pi^0}^2)/3$, m_K, m_π, m_{π^0} are the kaon, charged pion, neutral pion masses, respectively, and M_{00} is the invariant mass of two neutral pions evaluated using only information from the LKr (a charge-blind detector). The Dalitz plot of the selected events is shown in Fig. 3 (a). The events at large u are affected most by the detector acceptance because for these the charged pion trajectory is very close to the beam pipe. Fig. 3 (b) shows the u spectrum (the projection of the Dalitz plot onto the u-axis) for these events.

[1]The super-sample (SS) notation used in this paper differs from that of [8]: SS I and SS III correspond to SS 0 and SS 3 of [8], respectively, while SS II contains data from both SS 1 and SS 2 corresponding to running conditions for which the first-level trigger described in Section 2 was fully operational.

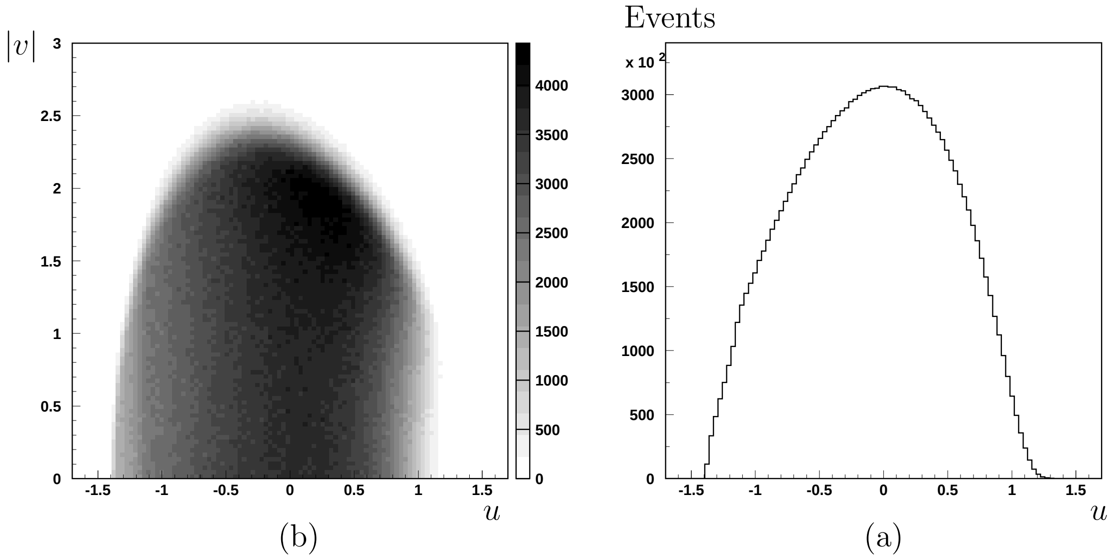

Figure 3: (a) Dalitz plot folded around $v = 0$; (b) u-spectrum for the selected events.

The asymmetry measurement is based on the comparison of the u spectra for K^+ and K^- decays, $N^+(u)$ and $N^-(u)$, respectively. For $K^\pm \to \pi^\pm\pi^0\pi^0$ decays the ratio of the u spectra $N^+(u)/N^-(u)$ is proportional to

$$\frac{N^+(u)}{N^-(u)} \propto \frac{1 + (g + \Delta g)u + hu^2}{1 + gu + hu^2}, \tag{6}$$

where $g = (0.638 \pm 0.020)$ and $h = (0.051 \pm 0.013)$ [11]. The possible presence of a direct CP violating difference between the linear slopes of K^+ and K^-, $\Delta g = g^+ - g^-$, can be extracted from a fit to this ratio. The measured asymmetry is then given by $A_g = \Delta g/2g$.

In order to minimize the effect of beam and detector asymmetries we use the ratio $R_4(u)$, defined as the product of four $N^+(u)/N^-(u)$ ratios:

$$R_4(u) = R_{US} \cdot R_{UJ} \cdot R_{DS} \cdot R_{DJ} = R\left(1 + \frac{\Delta g \cdot u}{1 + gu + hu^2}\right)^4, \tag{7}$$

where the first subscript U (D) denotes a configuration of the beam magnet polarities which corresponds to the positive beam traversing the upper (lower) path in the achromats; the second subscript S denotes the spectrometer magnet polarities (opposite for the events in the numerator and in the denominator of each ratio) deflecting the charged pions to negative x (towards the Salève mountain, given the topographical situation of the experiment in relation to the mountains surrounding CERN) and J corresponds to the deflection of the charged pions in the opposite direction (towards the Jura mountain chain). The spectra $N^+(u)$ and $N^-(u)$ for each of the four individual ratios in (7) are obtained from successive runs taken with the same beam magnet polarities and with the $\pi^\pm$ deflected in the same direction by the spectrometer magnet. The parameter Δg and the normalization R are extracted from a fit to the measured quadruple ratio $R_4(u)$ using the function in eq. (7). The measured slope difference Δg is insensitive to the normalization parameter R, which reflects the ratio of K^+ and K^- fluxes.

The quadruple ratio method complements the procedure of magnet polarity reversal. It allows a three-fold cancellation of systematic biases:

- beam line biases cancel between K^+ and K^- samples in which the beams follow the same path;
- the effect of local non-uniformities of the detector cancel between K^+ and K^- samples in which charged pions illuminate the same parts of the detectors;
- as a consequence of using simultaneous K^+ and K^- beams, global, time dependent, instrumental charge asymmetries cancel between K^+ and K^- samples.

A reduction of possible systematic biases due to the presence of stray permanent magnetic fields (Earth field, vacuum tank magnetization) is achieved by the radial cuts around the average beam position (see Section 3), which make the geometrical acceptance to charged pions azimuthally symmetric. The only residual sensitivity to instrumental charge asymmetries is associated with time variations of any acceptance asymmetries occurring on a time scale shorter than the magnetic field alternation period. However, their occurrence would have been detected by a number of monitors recorded throughout data taking.

Thanks to the symmetrical K^+ and K^- decay acceptances, the measurement does not require a Monte Carlo acceptance calculation. Nevertheless, a detailed GEANT-based [12] Monte Carlo simulation has been developed as a tool to study the sensitivity of the result to systematic effects. The Monte Carlo simulation includes an accurate mapping of the spectrometer magnetic field (as well as of the small stray permanent fields), full detector geometry and material description, run-by-run simulation of time variations of local DCH inefficiencies, and time variations of the beam properties.

5 Result

Since each super-sample listed in Table 1 allows an independent asymmetry measurement to be made according to the full procedure described above, Δg is obtained for each of these. The resulting fits for these data sets are shown in Fig. 4. The corresponding best fit values for Δg are presented in Table 2 with the statistical error only and are plotted in Fig. 5 (a).

Super-sample	$\Delta g \cdot 10^4$
I	4.3 ± 3.8
II	0.5 ± 5.0
III	-2.0 ± 8.2
Total χ^2/ndf: 0.7/2	2.3 ± 2.8

Table 2: Slope difference, Δg with its statistical error for each super-sample and the weighted average.

The final result is obtained as the weighted average of the Δg values for the three super-samples:

$$\Delta g = (2.3 \pm 2.8) \cdot 10^{-4}. \tag{8}$$

where the quoted error is only statistical.

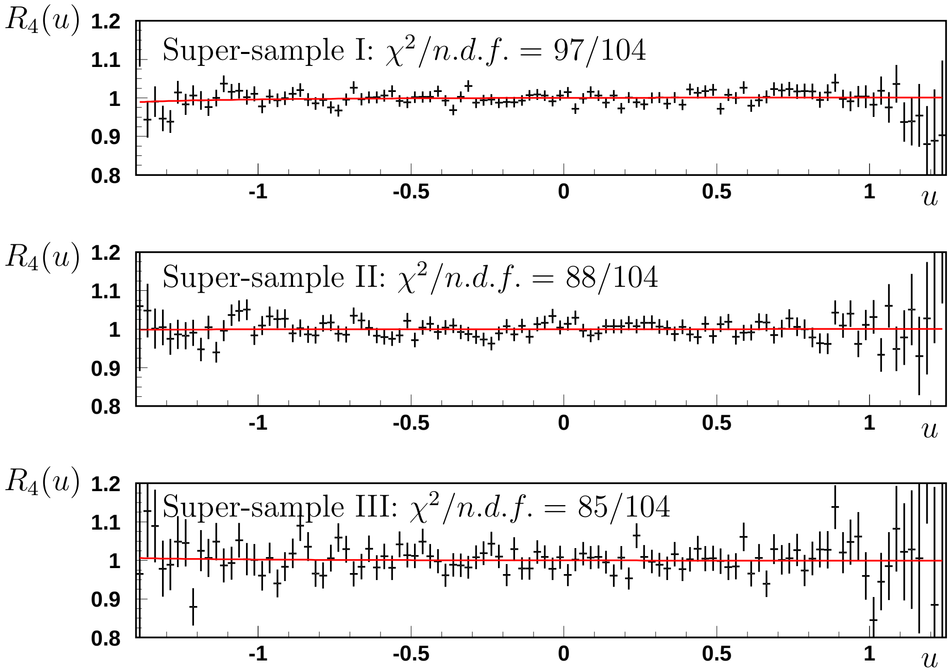

Figure 4: Fits of the normalized quadruple ratios for each super-sample.

Since the two π^0's are indistinguishable, a linear term in v cannot appear in the matrix element (1), and no asymmetry is expected for the linear $|v|$ slopes of K^+ and K^- decays. A measurement of the difference in these slopes should be considered, therefore, as a check of the cancellation of spurious charge asymmetries. A quadruple ratio of $|v|$ spectra is constructed and fitted with a linear function. The difference in slopes, averaged over the three super-samples, is found to be $(1.1 \pm 4.7) \cdot 10^{-4}$, which is consistent with zero.

As an additional cross-check of the method, quantities sensitive to instrumental left-right and up-down charge asymmetries, which cancel in the quadruple ratio (7), were evaluated. The asymmetry Δ_S between K^+ and K^- deflected towards the Salève mountain (no matter which way the beams travel in the achromats) can be extracted from a fit of the double ratio $R_{US} \cdot R_{DS}$ to the function $R_S[1+\Delta_S \cdot u/(1+gu+hu^2)]^2$, where R_S is a normalization parameter. Δ_S describes a combination of the physical CP-violating asymmetry between K^+ and K^- and the asymmetry of the apparatus response to particle of both charge signs deflected towards the Salève. An analogous asymmetry Δ_J can be defined for K^+ and K^- deflected towards the Jura mountains by fitting the double ratio $R_{UJ} \cdot R_{DJ}$. Then in the half-difference $\Delta_{SJ} = (\Delta_S - \Delta_J)/2$ any physical CP-violating asymmetry cancels, while the left-right instrumental asymmetry remains. Similarly, an up-down beam line asymmetry can be defined as $\Delta_{UD} = (\Delta_U - \Delta_D)/2$, where Δ_U and Δ_D are extracted from a fit to the double ratios $R_{US} \cdot R_{UJ}$ and $R_{DS} \cdot R_{DJ}$, respectively. These instrumental asymmetries are small, and are quantitatively well reproduced by the Monte Carlo simulation, as shown in Fig. 5 (b) and (c).

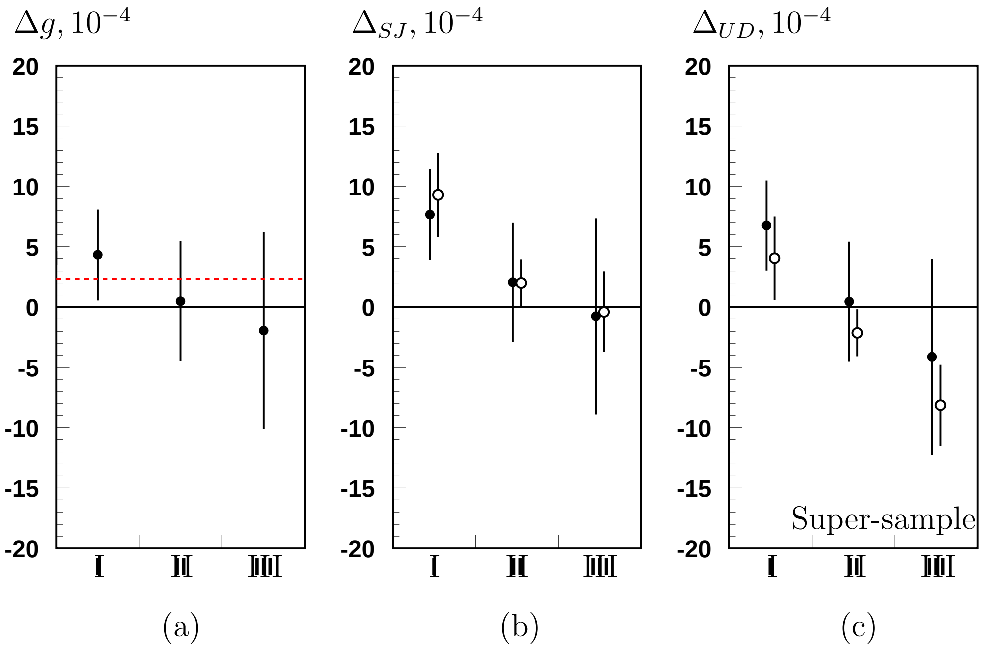

Figure 5: (a) Slope difference Δg for each super-sample; (b) left-right instrumental asymmetry and (c) up-down instrumental asymmetry for experimental data (full circles) and Monte Carlo events (open circles) (these instrumental asymmetries cancel in the quadruple ratio (6)).

6 Systematic uncertainties

The measured asymmetry (8) should be free from systematic biases thanks to the cancellation of instrumental asymmetries implemented in the detector design and data analysis. Nevertheless, a number of quantitative checks of possible systematic contributions to the measured Δg value have been performed.

Since only information on photon clusters is used for the u calculation, systematic uncertainties associated with the LKr response have been considered:

- Changes of the measured asymmetry are studied by varying the size of the u bins with respect to their nominal value of 0.025, including the use of bin sizes proportional to the u resolution (which vanishes at the lower u edge and reaches ± 0.04 at high u). The maximum observed difference, $\delta\Delta g = 0.4 \cdot 10^{-4}$, is taken as an upper limit for the systematic uncertainties associated with the u calculation.
- An uncertainty $\delta\Delta g = 0.1 \cdot 10^{-4}$ arises from the correction applied to the measured photon energies to account for uncertainties in the LKr non-linear response at low photon energies (typically 2% at 3 GeV and becoming negligible above 10 GeV).
- By varying the cut on the minimum allowed distance between LKr clusters the measured asymmetry is found to vary by less than $\delta\Delta g = 0.5 \cdot 10^{-4}$.
- The effect of wrong photon pairings in the reconstruction of the $\pi^0 - \pi^0$ pair is found to be negligible ($\delta\Delta g < 0.1 \cdot 10^{-4}$) from the study of a large sample of simulated events.

- The measured asymmetry is found to be insensitive to changes of the radial cut around the LKr central hole.

Effects related to the magnetic spectrometer do not affect the result directly, since the charged track is only used for tagging, and not for the u calculation. Upper limits from effects such as spectrometer alignment and momentum scale are found to be negligible ($\delta\Delta g < 0.1 \cdot 10^{-4}$). The total systematic uncertainty associated with the charged track geometrical acceptance and with beam geometry is found to be $\delta\Delta g < 0.3 \cdot 10^{-4}$ by varying the radial cuts which define the acceptance around the beam tube. An estimate of a possible bias from the contamination of $\pi \to \mu\nu$ decays is obtained from a Monte Carlo simulation and does not exceed $\delta\Delta g = 0.5 \cdot 10^{-4}$. An upper limit $\delta\Delta g = 0.1 \cdot 10^{-4}$ is obtained from the uncertainties on the permanent magnetic fields in the $K^\pm$ decay region by artificially varying their map in the event reconstruction. In addition, it is checked that the result is stable with respect to wide variations of the accepted $\pi^\pm\pi^0\pi^0$ invariant mass interval.

Systematic uncertainties associated with the presence of accidental tracks and LKr clusters are found to be $\delta\Delta g = 0.2 \cdot 10^{-4}$ by varying the allowed number of additional particles in the event and by checking the stability of the result with different timing cuts.

The trigger inefficiency, if it depends on u and on the pion charge and if it is not stable in time, could bias the measured asymmetry. Each component of the trigger logic is studied separately for possible systematic biases:

- The inefficiency ($\sim 0.25\%$) to charged tracks of the level 1 trigger is measured for each sub-sample as a function of the x and y coordinates of the charged track impact point on the hodoscope plane for each sub-sample. This is done by studying all one-track events in control samples recorded by triggers which do not use the charged hodoscope. Any effect of this inefficiency on Δg is corrected by reweighting the $K^\pm \to \pi^\pm\pi^0\pi^0$ events and the result is found to change by $\delta\Delta g = (0.1 \pm 0.1) \cdot 10^{-4}$ from the nominal value. A similar result is obtained from the Monte Carlo simulation.

- The largest systematic uncertainty ($\delta\Delta g = 1.3 \cdot 10^{-4}$) in the present analysis is conservatively estimated as an upper limit due to any unknown effect associated with the inefficiency of the level 1 neutral trigger based on a requirement on the number of LKr clusters. This inefficiency is found to vary from 0.7% at the beginning of the data-taking period, to 3% at the end of the run, as measured using a control sample. This estimation is limited by the statistics of the control sample and further analysis is expected to reduce this error.

- The average level 2 inefficiency is $\sim 5.7\%$. The main part ($\sim 70\%$ of it) is due to local inefficiencies in the DCHs, which could affect the asymmetry measurement if they are not stable in time. The DCH wire inefficiency is properly simulated by the Monte Carlo and a shift $(0.1 \pm 0.2) \cdot 10^{-4}$ is measured between the result obtained from the total sample of Monte Carlo events and the sample containing only events satisfying the level 2 trigger. The total uncertainty from the level 2 inefficiency, including other possible sources (timing effects between detectors, data buffer overflows, inefficiency of the level 2 algorithm) is found to be less than $\delta\Delta g = 0.4 \cdot 10^{-4}$.

All systematic uncertainties are summarized in Table 3. The overall uncertainty, obtained by summing all contributions in quadrature, is conservatively taken to be

LKr related effects	0.7
Beam geometry and charged track acceptance	0.3
$\pi \to \mu$ decay	0.5
Accidentals	0.2
Trigger Level 1	1.3
Trigger Level 2	0.4
Total systematics uncertainty	1.6
External uncertainty	0.3

Table 3: Systematic uncertainties to the measured Δg value (in units of 10^{-4}).

$1.6 \cdot 10^{-4}$. An additional external uncertainty of $0.3 \cdot 10^{-4}$ arises from the known precision on g and h [11][2].

7 Conclusion

By studying $4.714 \cdot 10^7$ $K^\pm \to \pi^\pm\pi^0\pi^0$ decays the difference between the slope parameters in the Dalitz plots of K^+ and K^- decays has been measured:

$$\Delta g = (2.3 \pm 2.8_{stat.} \pm 1.3_{trig.(stat.)} \pm 1.0_{syst.} \pm 0.3_{ext.}) \cdot 10^{-4}. \tag{9}$$

The corresponding asymmetry parameter A_g, which describes a possible direct CP-violation in these decays, is found to be[3]:

$$A_g = (1.8 \pm 2.2_{stat.} \pm 1.0_{trig.(stat.)} \pm 0.8_{syst.} \pm 0.2_{ext.}) \cdot 10^{-4} = (1.8 \pm 2.6) \cdot 10^{-4}. \tag{10}$$

This result is almost one order of magnitude more precise than previous measurements and is consistent with the predictions of the Standard Model.

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