Measurements of the charge asymmetry of the Dalitz plot parameters for $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ decays


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Abstract. The charge asymmetry of the $g$, $h$, and $k$ Dalitz plot parameters for $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ decays has been measured with 35 GeV/c hadron beams at the 70 GeV IHEP accelerator. The $g$, $h$, and $k$ values obtained appear to be identical for $K^{\pm}$ decays within the errors quoted. In particular, the charge asymmetry $A_g = (g^+ - g^-)/(g^+ + g^-)$ of the slope $g$ is equal to $(0.2 \pm 1.9) \times 10^{-3}$.

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1 Introduction

The observation of direct CP violation in neutral kaon decays [1–3] motivates a search for a similar effect in charged kaon decays. CP violation, for example, could manifest itself as a charge asymmetry of the Dalitz plot parameters in $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ decays. These parameters are coefficients in a series expansion of the squared module of the matrix element [4]:

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

where $u$ and $v$ are the invariant Mandelstam variables.

Theoretical estimates of the charge asymmetry of the Dalitz plot slope for $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ decays are uncertain and range from $10^{-6}$ to $10^{-3}$ [5–8]. In the majority of the experiments, only $g^+$ or $g^-$ was measured [4,9]. From these studies it follows that $\Delta g = g^+ - g^- = 0.066 \pm 0.017$. It is very unlikely to expect direct CP violation at this level, and one can assume that the above mentioned difference is due to the underestimation of the systematic uncertainties.

$K \rightarrow 3\pi$ decays have been studied simultaneously for both $K^+$ and $K^-$ mesons in [10–12]. Ford et al. [10] found $A_g = -0.0070 \pm 0.0053$ for $K^+ \rightarrow \pi^+\pi^0\pi^+$ decays. Smith et al. [11] determined $A_g = 0.0019 \pm 0.0012$ for $K^+ \rightarrow \pi^+\pi^0\pi^+$ decays. Preliminary analysis of our experimental data [12] based on a fraction of statistics yielded $A_g = -0.0003$ with a statistical error of 0.0025 and a systematic uncertainty below 0.0015. In this paper we report our final results on the charge asymmetry of the Dalitz plot parameter measurements.

2 Experimental setup

The experiment was carried out with the TNF-IHEP facility [13] (Fig. 1) at the 70 GeV IHEP accelerator. Unseparated positive and negative hadron beams with 35 GeV/c momentum are produced by 70 GeV protons in the external 30 cm Al target. The scintillation counters S1-S4 and the beam hodoscopes H1-H3 [14] and the GEPARD electromagnetic calorimeter are used to monitor the beam intensity and to measure particle trajectories and beam profiles. The typical particle flux was $4 \times 10^9$ per 1.7 second spill.

Kaons are selected with three threshold (C1-C3) and two differential (D1,D2) gas Čerenkov counters (Fig. 1). The admixture of unwanted particles under the kaon peak was substantially below 1%. The threshold counters are also used to select 10 GeV/c electrons to calibrate the GEPARD calorimeter.

About 20% of kaons decay in the 58.5 m long vacuum pipe located downstream of the BH4 hodoscope. The flanges of the vacuum pipe have thin Mylar windows in the path of beam particles. The 3.6 m diameter exit flange is made of 4 mm thick (0.23 $X_0$) stainless steel. The probability of a high-energy photon to convert into an $e^+e^-$ pair in this flange is equal to 0.16.

Kaons which pass through the decay pipe are detected by the anticoincidence counter AC. The BH5 beam hodoscope placed behind the calorimeter is used for a high precision measurement of the beam position at the setup end. The BH5 hodoscope operates in the counting mode and hence detects all beam particles.

The products of kaon decays are detected by three scintillation hodoscopes H1-H3 [14] and the GEPARD electromagnetic calorimeter. Each hodoscope is made of two $X,Y$...
octagonal planes with 3.85 m distance between the opposite octagonal sides. The plane is divided into half-planes with 256 elements each. The cross section of the hodoscope elements is \(14 \times 12\) mm\(^2\) and their length varies from 0.7 to 1.8 m. Scintillation light is detected by FEU-84-3 photomultiplier tubes.

The GEPARD is a sampling lead-scintillator calorimeter. It contains 1968 cells with \(76 \times 76\) mm\(^2\) cross section. Each cell consists of 40 alternating layers of 3 mm Pb and 5 mm scintillator. The total radiation length is 21 \(X_0\). Scintillation light is collected onto FEU-84-3 photomultiplier tubes using wavelength shifting light guides. The GEPARD calorimeter was calibrated by irradiating each cell with 10 GeV/c electrons at the beginning of data taking and by using \(K^\pm \to \pi^\pm \pi^0\) reconstructed events collected during the experiment. Both methods yielded consistent results. The \(\pi^0\) mass resolution is equal to 12.3 MeV/c\(^2\).

The Level 1 trigger is formed according to the logic formula

\[
T_1 = S_1 \cdot S_2 \cdot S_3 \cdot S_4 \cdot (D_1 + D_2) \cdot C_1 \cdot C_2 \cdot C_3 \cdot AC. 
\]

The Level 2 trigger uses information about the energy deposition in the GEPARD calorimeter [15]. For this purpose, the calorimeter is divided into 16 trigger elements. The Level 2 trigger is formed if the energy deposition exceeds 0.8 GeV in at least three trigger channels.

The stability of the beam and detector parameters was carefully monitored during the data collection. To reduce the systematic uncertainty in the measurement of the charge asymmetry of the Dalitz plot parameters, the beam polarity was reversed every day.

### 3 Event reconstruction and selection criteria

The \(K^\pm \to \pi^\pm \pi^0\pi^0\) event selection starts by finding energy clusters in the GEPARD calorimeter. The coordinates of the cluster and the \(X\) and \(Y\) coordinates measured by the H1–H3 hodoscopes are used in track reconstruction. To reduce the combinatorial background, only tracks with three or four hits in each \(X\) and \(Y\) projection are selected. Then the vertex position of the \(K^\pm\) decay is calculated using the reconstructed tracks. A track is considered to be associated with a kaon decay if the hypothesis of its intersection with the beam axis has a confidence level of 5% or more and the decay vertex position is inside the fiducial volume of the decay pipe. In addition, selected events have to satisfy one of the following criteria:

- five clusters with energies above 1 GeV are found and each track is associated with one of these clusters;
- four clusters with energies above 1 GeV are found and one of the tracks is not associated with these clusters.

These criteria are applied because there is a substantial probability for a gamma from \(\pi^0\) decays to convert into an \(e^+e^-\) pair in the exit flange of the decay pipe (see Sect. 2), and charged pion energy depositions in the calorimeter could exceed the threshold value of 1 GeV.

Events passing this preliminary selection are subjected to a kinematic fit that allows one to resolve ambiguities due to the combinatorial background (for example in the association of one of the tracks with the charged pion) and to calculate the Dalitz plot variables. Altogether 21 measured parameters are used in the fitting procedure: the energies and the coordinates of four clusters associated with gammas, the kaon mean energy and the parameters of the kaon and pion tracks. The parameters of the clusters are corrected for the transverse profile of the electromagnetic shower and for the spatial nonuniformity of the calorimeter. The energy of the charged pion is the only unknown parameter.

Seven constraints are imposed on the fitted parameters: four equations of the energy-momentum conservation, two equations for the effective masses of the gamma pairs and a required intersection of kaon and charged pion trajectories. The decay vertex coordinates are not fixed. The parameters are found by an iterative minimization of the functional using the method of Lagrange multipliers for incorporating constraints. The iterations are stopped when the relative changes of all fitted parameters at the last iteration are less than \(10^{-5}\). For each event all possibilities to associate one of the tracks with charged pion and \(\gamma\) pairs with \(\pi^0\)'s are considered. The combination with the lowest \(\chi^2\) is used. Figure 2 shows the \(\chi^2\) distributions for the data and simulated events. Events with \(\chi^2 > 20\) are rejected, since in this region the data exceeds the number of the simulated events due to the high background level. A simulation shows that this \(\chi^2\) cut decreases the background by a factor of 5, at the expense of a 28% reduced signal sample.