# Recent results of the NA48/2 experiment

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**Abstract.** The main goals of the NA48/2 experiment are a search for direct CP - violation in the charged kaon decays, a measurement of the pion scattering lengths using Ke4 decays and an investigation of some rare decays. By using large samples of $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays, the asymmetries in the linear Dalitz plot slopes $A_g = (g^+ - g^-)/(g^+ + g^-)$ were measured with high accuracy for both decay modes. The design of the experiment and the method of analysis provide good control of instrumental charge asymmetries in this measurement. Investigating the two neutral pion effective mass distribution in the $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays, we observed cusp-like anomaly . This anomaly, never observed before, can be interpreted as an effect due to the final state charge exchange process $\pi^{+}\pi^{-} \to \pi^{0}\pi^{0}$ in the $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ decay. Comparison with theoretical models allowed to obtain a measurement of the pion-pion scattering length with a new technique which has a high precision.

**Keywords:** CP - violation, kaons, asymmetry, pion scattering lengths
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## INTRODUCTION

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[7] are the $3\pi$ modes: $\pi^{\pm}\pi^{+}\pi^{-}$ and $\pi^{\pm}\pi^{0}\pi^{0}$, with branching fractions 5.6% and 1.8% respectively. The NA48 collaboration undertook a high - statistics investigation of charged K decays (NA48/2), with the main purpose of looking for CP - violation effects.

## INVESTIGATION OF THE $K^{\pm} \to 3\pi$ DECAYS WITH THE NA48/2 SETUP

Data have been collected in 2003 - 04, providing samples of $3.11 \times 10^9$ fully reconstructed $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ and $91 \times 10^6$ $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays. A beam line transporting simultaneously the $K^+$ and $K^-$ beams was designed as a major element leading to cancellation of main systematic uncertainties, allowing the decays of $K^+$ and $K^-$ to be recorded at the same time. The two charged beams of opposite signs and momentum of $60 GeV/c \pm 3.8\%$ are selected by a system of "achromat" magnets and collimators. The frequent inversion of all magnetic field polarities leads to symmetric acceptance for the two beams. The two beams enter in a 114 m long decay volume and the $K^{\pm} \to 3\pi$ final state is reconstructed by combining the signals coming from a spectrometer and from a liquid Krypton calorimeter(LKr)[1]. The spectrometer, consisting of four drift chambers [2] and a dipole magnet, located between the second and the third chamber allows to track and measure the momentum of the charged pions. The resolution of the spectrometer is $\sigma(p)/p = 1.02\% \bigoplus 0.044\% p$ (p in GeV/c). The LKr is used to reconstruct $\pi^0 \to \gamma\gamma$ decays. The resolution on the $\gamma$ energy is $\sigma(E)/E = 0.032/\sqrt{E} \bigoplus 0.09/E \bigoplus 0.0042$ (E in GeV) .

The usual phenomenological description of $K \to 3\pi$ decays is made in terms of the bi-dimensional Dalitz plot parameters [3] `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: $u = (s_3 - s_0)/m_{\pi}^2$, $v = (s_2 - s_1)/m_{\pi}^2$, where $s_i = (p_K - p_i)^2$, $p_K$ is the four-momentum of the decaying kaon, $p_i$ (i=1,2,3) are those of the pions (i=3 corresponds to the odd pion) and $s_0 = (s_1 + s_2 + s_3)/3$. The matrix element is conventionally parametrized by a polynomial expansion[3]: $|M(u,v)|^2 \propto 1 + gu + hu^2 + kv^2$, where g,h,k are the so called linear and quadratic Dalitz plot slope parameters. A difference of slope parameters $g^+$ and $g^-$, describing positive and negative kaon decays respectively, is a manifestation of direct CP - violation usually defined by the corresponding slope asymmetry

$$A_g = (g^+ - g^-)/(g^+ + g^-) \approx \Delta g/(2g), \qquad (1)$$

where $\Delta g$ is the slope difference and $g$ is the average slope. The SM predictions for $A_g$ [4] vary from a few $10^{-6}$ to a few $10^{-5}$.

The method for the measurement of the asymmetry in the Dalitz plot slopes is based on comparing the reconstructed $u$ spectra of $K^+$ and $K^-$ decays: $N^+(u)$ and $N^-(u)$. The ratio of the $u$ spectra $R(u) = N^+(u)/N^-(u) \propto (1 + (g + \Delta g)u + hu^2)/(1 + gu + hu^2)$, so $\Delta g$ can be extracted from a fit to the ratio $R(u)$ and $A_g = \Delta g/2g$ can be evaluated. The presence of magnetic fields in both the beam line(achromatic magnets) and the magnetic spectrometer, combined with some asymmetries in detector performance, introduces residual charge asymmetries. In order to equalize the local effects on the acceptance the polarities of all the magnets in the beam line were reversed during the data taking on an approximately weekly basis, while the polarity of the spectrometer was alternated on a more frequent basis (approximately once per day in 2003 and once in 3 hours in 2004). The actual ratio $R(u)$ to be fit is obtained as a quadruple ratio of $K^+/K^-$: $R(u) = R_{US}R_{UJ}R_{DS}R_{DJ} = R(1+\frac{\Delta g.u}{1+gu+hu^2})^4$. Here the subscript U(D) relates to the beam line magnets' polarities, denoting whether $K^+$ travel along the upper (lower) beam path in the achromatic magnets. 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 Saleve (Jura) mountains respectively). The preliminary result for the difference in the linear slope parameter of the Dalitz plot for $K^\pm \to \pi^\pm\pi^+\pi^-$ decays, measured with full NA48/2 data sample, is

$$\Delta g = g^+ - g^- = (0.6 \pm 0.7_{stat.} \pm 0.4_{trig.} \pm 0.6_{syst.}) \times 10^{-4} \quad (2)$$

Converted to the direct CP - violating asymmetry in $K^\pm \to 3\pi^\pm$ decays using the PDG value of the Dalitz plot slope $g = -0.2154 \pm 0.0035$[3], this leads to

$$A_g = (-1.3 \pm 1.5_{stat.} \pm 0.9_{trig.} \pm 1.4_{syst.}) \times 10^{-4} \quad (3)$$

The preliminary results obtained with the full data sample for the $K^\pm \to \pi^\pm\pi^0\pi^0$ decay mode are

$$\Delta g = g^+ - g^- = (2.7 \pm 2.0_{stat.} \pm 1.2_{syst.} \pm 0.3_{ext.}) \times 10^{-4} \quad (4)$$

$$A_g = (2.1 \pm 1.6_{stat.} \pm 1.0_{syst.} \pm 0.2_{ext.}) \times 10^{-4} \quad (5)$$

Further investigation of the two neutral pions invariant squared mass $M_{00}^2$ spectra shows a sudden change in the slope (cusp) near $M_{00} = 2m_{\pi^+}$(Fig.1). Such an anomaly has not been seen in previous experiments. The sudden change of the slope suggests the presence of a threshold "cusp" effect from the decay $K^\pm \to \pi^\pm\pi^+\pi^-$ contributing to the $K^\pm \to \pi^\pm\pi^0\pi^0$ amplitude through the charge exchange reaction $\pi^+\pi^- \to \pi^0\pi^0$. This phenomenon has been recently discussed by Cabibbo[5]. The PDG parametrization for the $K^\pm \to \pi^\pm\pi^0\pi^0$ decay amplitude $M_0$ is given by $M_0 = ((1+1/2gu)^2 + h'u^2)^{1/2}$. In the Cabibbo theory a new term in the amplitude is added : $M_1 \propto (a_0 - a_2)J$ proportional to the difference between the $I=0$ and $I=2$ S - wave scattering lengths. The term $J$ changes from real to imaginary at $M_{00} = 2m_{\pi^+}$

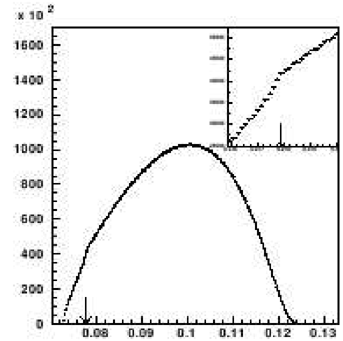


**FIGURE 1.** Neutral pions invariant squared mass

The destructive interference of $M_0$ and $M_1$ is responsible for the cusp. The most recent theoretical prediction of Cabibbo and Isidori[6] for the $\pi\pi$ scattering lengths is $(a_0 - a_2)m_{\pi^+} = 0.265 \pm 0.0004$. Using $23 \times 10^6$of $K^\pm \to \pi^\pm\pi^0\pi^0$ decays and performing a fit according to the re-scattering Cabibbo -Isidori model[6], we determine

$$(a_0 - a_2)m_{\pi^+} = 0.268 \pm 0.010_{stat.} \pm 0.004_{syst.} \pm 0.013_{theo.}. \quad (6)$$

## SUMMARY AND CONCLUSIONS

The asymmetries of the Dalitz plot slopes in the $K^\pm \to \pi^\pm\pi^0\pi^0$ and $K^\pm \to \pi^\pm\pi^+\pi^-$ decays have been measured with 10 times better precision than the previous experiments. A cusp - like structure has been observed for the first time in the two $\pi_0$ coming from $K^\pm \to \pi^\pm\pi^0\pi^0$ invariant mass. The $\pi\pi$ scattering lengths difference has been extracted with high precision. The final results for the CP - violating asymmetries and for the pion scattering lengths obtained using only the data collected during 2003 have been published[8].

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