NEW RESULTS ON KAON DECAYS FROM NA48/2

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Recent results from the NA48/2 experiment are presented. The $\pi\pi$ scattering lengths $a_0^0$ and $a_0^2$ have been extracted from the cusp in the $M_{00}^2$ distribution of $K^+ \rightarrow \pi^+\pi^0\pi^0$ decays and from the $K^\pm \rightarrow \pi^\mp e^\pm \nu$ phase shift $\delta$. Branching ratios and form factors have been measured for $K^\pm \rightarrow \pi^\pm \gamma\gamma$, $K^\pm \rightarrow \pi^\pm \gamma e^+e^-$ and $K^\pm \rightarrow \pi^\pm e^+e^-$ decays and are also summarized here.

1 Introduction

During 2003 and 2004, the NA48/2 experiment at CERN SPS has collected the world largest amount of charged kaon decays. The main goal of NA48/2 was the search for direct CP violation in $K^\pm$ decays into three pions. However, given the high statistics achieved, many other physics topics were also covered including the study of the $\pi\pi$ interaction at low energy, radiative decays, the measurement of $V_{us}$ from semileptonic decays, etc.. In the following sections, recent results on ChPT parameters obtained by the NA48/2 Collaboration will be presented.

2 The NA48/2 experiment

Simultaneous $K^+$ and $K^-$ beams were produced by 400 GeV protons from the CERN SPS, impinging on a Be target. Kaons were deflected in a front-end achromat to select a momentum band of $60 \pm 3$ GeV/$c$ and then focused such that they converge about 200 m downstream at the beginning of the detector. A description of the detector can be found in [1]. For the measurements presented here, the most important detector components are the magnet spectrometer, consisting of two drift chambers before and two after a dipole magnet, and the quasi-homogeneous liquid krypton calorimeter. The momentum of the charged particles and the energy of the photons are measured with a relative uncertainty of 1% at 20 GeV. The trigger was mainly designed to select events with three charged tracks (charged trigger) and $K^\pm \rightarrow \pi^\pm \pi^0\pi^0$ events (neutral trigger).

*aOn behalf of the NA48/2 Collaboration.*
3 Measurement of $\pi\pi$ scattering lengths

The quark condensate $\langle 0 | \bar{q} q | 0 \rangle$ is a fundamental parameter of ChPT. Its value must be determined experimentally, e.g. by measuring the $\pi\pi$ scattering lengths $a_0^0$ and $a_0^2$, which are predicted very precisely within the framework of ChPT[2].

NA48/2 has reported two new measurements of the $\pi\pi$ scattering lengths using $K^\pm \to \pi^\pm \pi^0 \pi^0$ and $K^\pm \to \pi^+ \pi^- e^\pm \nu$ decays. A cusp observed in the $M_{\pi^0\pi^0}$ distribution of $K^\pm \to \pi^\pm \pi^0 \pi^0$ decays at $M_{200}^2 = 4m_{\pi^\pm}^2$ (Fig. 1 (left)) can be explained by $\pi^+ \pi^-$ re-scattering terms[9,10] and provides a measurement of $a_0^0$ and $a_0^2$ from a fit of the $M_{200}^2$ distribution around the cusp discontinuity. A sample of about $59.6 \times 10^6$ decays from 2003 and 2004 data has been used for this analysis, and the preliminary results from the fit of the Cabibbo-Isidori model[5] are:

\[
(a_0^0 - a_0^2)m_{\pi^+} = 0.261 \pm 0.006_{\text{stat}} \pm 0.003_{\text{syst}} \pm 0.001_{\text{ext}} \pm 0.013_{\text{theory}},
\]

\[
a_0^2m_{\pi^+} = -0.037 \pm 0.013_{\text{stat}} \pm 0.009_{\text{syst}} \pm 0.002_{\text{ext}},
\]

where the theoretical uncertainty is due to neglected $O(a_s^2)$ and radiative corrections. Alternative fits are being performed following the approach by[6].

In $K^\pm \to \pi^+ \pi^- e^\pm \nu$ decays, the pions are produced close to threshold. The decay amplitude depends on the complex phases $\delta_0$ and $\delta_1$ (the $S$ and $P$ waves $\pi\pi$ phase shifts for isospin $I = 0$). The difference $\delta = \delta_0 - \delta_1$ can be measured as a function of the invariant mass of the two pions, $M_{\pi\pi}$. NA48/2 has performed a combined fit to the decay form factors and the phase shift difference as a function of $M_{\pi\pi}$ in a sample of 670000 signal candidates with 0.5% background[7]. The results are shown in Fig. 1 (right) together with two earlier experiments[8,9]. From the phase shift measurements, the $\pi\pi$ scattering lengths can be extracted using dispersion relations[10]. At the center of the Universal Band[11] $a_2^2$ is related to $a_0^0$. A one parameter fit gives $a_0^0 = 0.256 \pm 0.006_{\text{stat}} \pm 0.002_{\text{syst}} \pm 0.018_{\text{ext}}$, which implies $a_0^2 = -0.0312 \pm 0.0011_{\text{stat}} \pm 0.0004_{\text{syst}} \pm 0.0129_{\text{ext}}$. The external error reflects the width of the Universal Band. From a two parameters fit, the results are:

\[
a_0^0m_{\pi^+} = 0.233 \pm 0.016_{\text{stat}} \pm 0.007_{\text{syst}},
\]

\[
a_0^2m_{\pi^+} = -0.047 \pm 0.011_{\text{stat}} \pm 0.004_{\text{syst}},
\]

with $\rho = 0.967$. Theoretical work including isospin symmetry breaking effects[12] suggests that $a_0^0$ could decrease by $\approx 0.02$ for and $a_0^2$ by $\approx 0.004$, bringing this measurement in agreement with other measurements and ChPT predictions[7].

Figure 1: (Left) Invariant $\pi^0\pi^0$ mass squared of $K^\pm \to \pi^\pm \pi^0\pi^0$ candidates. Note the presence of a cusp for $M_{200}^2 = 4m_{\pi^\pm}^2$ (arrow). (Right) Variation of phase shift in $K^\pm \to \pi^+ \pi^- e^\pm \nu$ decays with $\pi^+ \pi^-$ invariant mass.
Data

O M has been determined in a model independent way to be $BR = (1.8 \pm 0.4 \text{ (stat) } \pm 0.0 \text{ (syst)}) \times 10^{-6}$. The preliminary result is $BR(K^{\pm} \to \pi^{\pm} \gamma \gamma) = (1.07 \pm 0.04 \text{ stat } \pm 0.08 \text{ syst}) \times 10^{-6}$. A model independent BR measurement is in preparation, together with the extraction of $\hat{c}$ from a fit to $M_{\gamma \gamma}$ and BR.

4 $K^{\pm} \to \pi^{\pm} \gamma \gamma$ analysis

The contributions of the chiral lagrangian to this decay appear at $O(p^4)$. At this order, only the $\Delta I = 1/2$ invariant amplitudes $A(z)$ and $C(z)$ with $z = M_{\gamma \gamma}^2/M_{K^{\pm}}^2$ contribute. $A(z)$ contains the $O(p^4)$ loop diagram contributions and the tree level counterterms absorbed in unknown parameter $\hat{c}$ predicted to be positive and of $O(1)$. The loop leads to a characteristic signature in the invariant mass $M_{\gamma \gamma}$ distribution, which is favoured to be above $2m_{\pi^\pm}$ and exhibits a cusp at $2m_{\pi^\pm}$ threshold. The parameter $\hat{c}$ fixes the value of the branching ratio and the $M_{\gamma \gamma}$ spectrum shape. $C(z)$ contains poles and tadpoles effects. $O(p^6)$ studies concluded that unitarity correction effects could increase the BR between 30% – 40%, while vector meson exchange contributions would be negligible.

NA48/2 has analyzed about 40% of its data, finding 1164 signal candidates with 3.3% background (40 times more statistics than previous experiments). This decay and its normalization channel ($K^{\pm} \to \pi^{\pm} \pi^0$) were collected through the neutral trigger chain intended for the collection of $K^{\pm} \to \pi^{\pm} \pi^0 \pi^0$ decays and therefore suffered from a very low trigger efficiency ($\approx 50\%$). Elaborate studies were performed to measure these efficiencies and correct for them (see Fig. 2 (left)). The reconstructed $M_{\gamma \gamma}$ spectrum can be seen in Fig. 2 for selected candidates (crosses), signal MC (yellow) and background (red).

The model dependent branching ratio of $K^{\pm} \to \pi^{\pm} \gamma \gamma$ has been measured, assuming the validity of the $O(p^6)$ ChPT as presented in and taking $\hat{c} = 2.4$. The preliminary result is $BR(K^{\pm} \to \pi^{\pm} \gamma \gamma) = (1.07 \pm 0.04 \text{ stat } \pm 0.08 \text{ syst}) \times 10^{-6}$. A model independent BR measurement is in preparation, together with the extraction of $\hat{c}$ from a fit to $M_{\gamma \gamma}$ and BR.

5 $K^{\pm} \to \pi^{\pm} \gamma e^+e^-$ analysis

This decay is similar to $K^{\pm} \to \pi^{\pm} \gamma$ with one photon internally converting into a pair of electrons. NA48/2 has reported the first observation of the decay $K^{\pm} \to \pi^{\pm} \gamma e^+e^-$ using the full 2003 and 2004 data samples. 120 candidates with $7.3 \pm 1.7$ estimated background events have been selected in the accessible region with $M_{\gamma ee} > 0.26 \text{ GeV}/c^2$ invariant mass. The candidates are shown in Fig. 5 (left). Using $K^{\pm} \to \pi^{\pm} \pi^0_D$ as normalization channel, the branching ratio has been determined in a model independent way to be $BR = (1.19 \pm 0.12 \text{ stat } \pm 0.04 \text{ syst}) \times 10^{-8}$ for $M_{\gamma ee} > 0.26 \text{ GeV}/c^2$. The parameter $\hat{c}$ has also been measured assuming the validity of $O(p^6)$ and found to be $\hat{c} = 0.90 \pm 0.45$.

*aThis is a realistic assumption based on previous results by which obtained $\hat{c} = 1.8 \pm 0.6.
6 $K^\pm \to \pi^\pm e^+e^-$ analysis

The FCNC process $K^\pm \to \pi^\pm e^+e^-$ can be described in ChPT. NA48/2 has collected 7146 candidates with 0.6% background. The decay rate has been measured using $K^\pm \to \pi^\pm \pi_0^0$ as normalization. A preliminary model independent measurement for $z = M_{e^+e^-}^2 / M_{K^\pm}^2 > 0.08$ gave $BR = (2.26 \pm 0.03_{stat} \pm 0.03_{syst} \pm 0.06_{ext}) \times 10^{-7}$. Model dependent fits to the $z$-spectrum have been performed (Fig. 3 (right)), obtaining the corresponding form factors and BR. The preliminary average BR in the full kinematic range is: $BR = (3.08 \pm 0.04_{stat} \pm 0.08_{ext} \pm 0.07_{model}) \times 10^{-7}$. Comparison of results with previous experiments and theoretical predictions can be found in.

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