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 $K^\pm \to \pi^\pm\pi^0\pi^0$ decays and from the $K^\pm \to \pi^+\pi^-e^\pm\nu$ phase shift δ. Branching ratios and form factors have been measured for $K^\pm \to \pi^\pm\gamma\gamma$, $K^\pm \to \pi^\pm\gamma\, e^+e^-$ and $K^\pm \to \pi^\pm e^+e^-$ 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 ± 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 $K^\pm \to \pi^\pm\pi^0\pi^0$ events (neutral trigger).

[a] On behalf of the NA48/2 Collaboration.

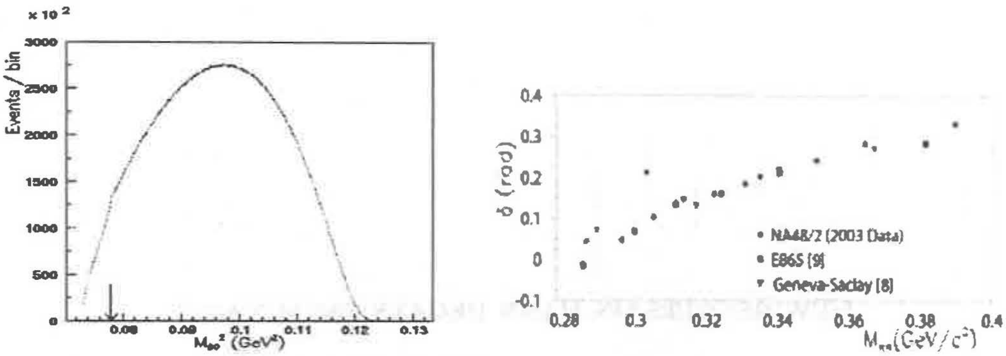

Figure 1: (Left) Invariant $\pi^0\pi^0$ mass squared of $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ candidates. Note the presence of a cusp for $M_{00}^2 = 4m_{\pi^-}^2$ (arrow). (Right) Variation of phase shift in $K^{\pm} \to \pi^+\pi^- e^{\pm}\nu$ decays with $\pi^+\pi^-$ invariant mass.

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 $M_{00}^2 = 4m_{\pi^{\pm}}^2$ (Fig. 1 (left)) can be explained by $\pi^+\pi^-$ re-scattering terms [3,4] and provides a measurement of a_0^0 and a_0^2 from a fit of the M_{00}^2 distribution around the cusp discontinuity. A sample of about 59.6×10^6 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:

$$\begin{aligned}(a_0^0 - a_0^2)m_{\pi^+} &= 0.261 \pm 0.006_{stat} \pm 0.003_{syst} \pm 0.001_{ext} \pm 0.013_{theory},\\ a_0^2 m_{\pi^+} &= -0.037 \pm 0.013_{stat} \pm 0.009_{syst} \pm 0.002_{ext},\end{aligned} \quad (1)$$

where the theoretical uncertainty is due to neglected $O(a_i^3)$ 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 δ_0 and δ_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_0^2 is related to a_0^0. A one paramater fit gives $a_0^0 = 0.256 \pm 0.006_{stat} \pm 0.002_{syst}{}^{+0.018}_{-0.017}{}_{ext}$, which implies $a_0^2 = -0.0312 \pm 0.0011_{stat} \pm 0.0004_{syst}{}^{-0.0129}_{-0.0122}{}_{ext}$. The external error reflects the width of the Universal Band. From a two parameters fit, the results are:

$$\begin{aligned}a_0^0 m_{\pi^+} &= 0.233 \pm 0.016_{stat} \pm 0.007_{syst},\\ a_0^2 m_{\pi^+} &= -0.047 \pm 0.011_{stat} \pm 0.004_{syst},\end{aligned} \quad (2)$$

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

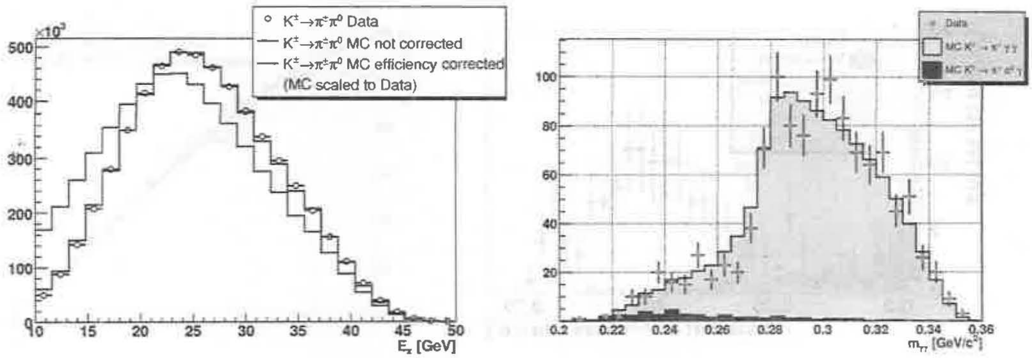

Figure 2: (Left) Pion track energy of $K^\pm \to \pi^\pm\pi^0$ normalization data (black) and MC events (red, blue) without and with trigger efficiency correction, respectively. (Right) $M_{\gamma\gamma}$ invariant mass of $K^\pm \to \pi^\pm\gamma\gamma$ candidates.

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

The contributions of the chiral lagrangian to this decay [13] appear at $O(p^4)$. At this order, only the $\Delta I = 1/2$ invariant amplitudes $A(z)$ and $C(z)$ with $z = M^2_{\gamma\gamma}/M^2_{K^+}$ 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 $O(1)$ [14]. The loop leads to a characteristic signature in the invariant mass $M_{\gamma\gamma}$ distribution, which is favoured to be above $2m_{\pi^+}$ and exhibits a cusp at $2m_{\pi^+}$ 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* [13,15] effects. $O(p^6)$ studies concluded [16] 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 [17]). 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 [16] and taking $\hat{c} = 2$ [a]. The preliminary result is $BR(K^\pm \to \pi^\pm\gamma\gamma) = (1.07 \pm 0.04_{stat} \pm 0.08_{syst}) \times 10^{-6}$. 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 $K^\pm \to \pi^\pm\gamma\gamma$ 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 sample[18]. 120 candidates with 7.3±1.7 estimated background events have been selected in the accessible region with $M_{\gamma ee} > 0.26$ GeV/c^2 invariant mass. The candidates are shown in Fig. 3 (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 $= (1.19 \pm 0.12_{stat} \pm 0.04_{syst}) \times 10^{-8}$ for $M_{\gamma ee} > 0.26$ GeV/c^2. The parameter $\hat{c}$ has also been measured assuming the validity of $O(p^6)$ [19] and found to be $\hat{c} = 0.90 \pm 0.45$.

[a] This is a realistic assumption based on previous results by [17] which obtained $\hat{c} = 1.8 \pm 0.6$.

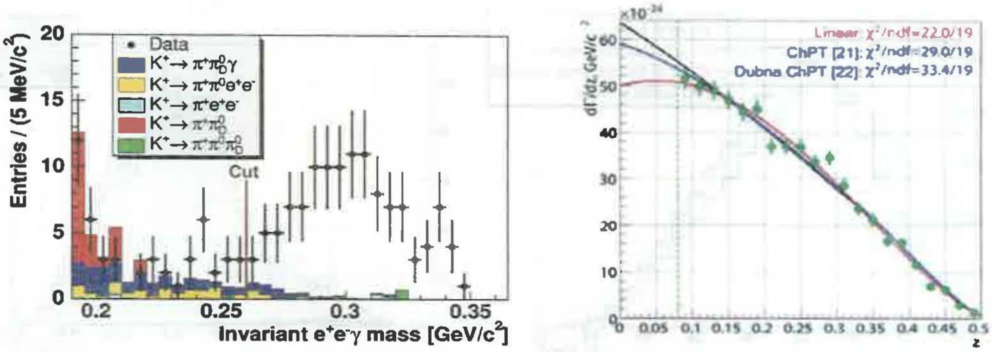

Figure 3: (Left) $M_{\gamma e^- e^-}$ invariant mass of $K^\pm \to \pi^\pm \gamma e^+ e^-$ candidates. Crosses are signal and colored histograms background. (Right) $K^\pm \to \pi^\pm e^+ e^-$ differential decay rate and different fit results from the considered models.

6 $K^\pm \to \pi^\pm e^+ e^-$ analysis

The FCNC process $K^\pm \to \pi^\pm e^- e^-$ can be described in ChPT[20]. NA48/2 has collected 7146 candidates with 0.6% background. The decay rate has been measured using $K^\pm \to \pi^\pm \pi^0_D$ as normalization. A preliminary model independent measurement for $z = M^2_{e^+e^-}/M^2_{K^\pm} > 0.08$ 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[23].

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