RECENT RESULTS FROM NA48/2 ON K_{e4} AND K3π DECAYS, INTERPRETATION IN TERMS OF $\pi\pi$ SCATTERING LENGTHS

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Recent results from the NA48/2 experiment at the CERN/SPS are presented. Large samples of K_{e4} decays have been collected in 2003 and 2004 in the charged ($K^{\pm} \to \pi^{+}\pi^{-}e^{\pm}\nu$) and neutral ($K^{\pm} \to \pi^{0}\pi^{0}e^{\pm}\nu$) modes. Form factors and branching fraction measurements are reported. The $\pi\pi$ scattering lengths a_0^0 and a_0^2 can be extracted from the charged K_{e4} phase shift δ and also from the cusp in the M^2_{00} distribution of $K^{\pm} \to \pi^{0}\pi^{0}\pi^{\pm}$ decays.

1 Introduction

Charged K_{e4} data are of particular interest as they give access to the $\pi\pi$ phase shift $\delta = \delta_0^0 - \delta_1^1$ in absence of any other hadron. The measured variation of the phase shift with the invariant mass $M_{\pi\pi}$ near threshold can be related to the scattering lengths a_0^0 and a_0^2 using dispersion relations and data at intermediate energies [1,2,3]. More constrained predictions using two-loop Chiral perturbation theory [2] can be compared to the measurement. The neutral K_{e4} mode does not address the same question as the two π^0s cannot exhibit a phase difference. However, the measurement of the single form factor F_s in the neutral mode can be compared to the one measured in the charged Ke4 mode. The cusp observed in the $M_{\pi^0\pi^0}$ distribution of the $K^{\pm} \to \pi^{0}\pi^{0}\pi^{\pm}$ decays at $M_{00} = 2m_{\pi^+}$ can be explained by $\pi^{+}\pi^{-}$ rescattering terms and provides another measurement of the a_0^0 and a_0^2 scattering lengths.

2 Experimental setup

Two simultaneous $K^{\pm}$ beams were produced by 400 GeV protons from the CERN/SPS, impinging on a beryllium target. The beams were then deflected in a front-end achromat to select momenta in the range (60$\pm$3) GeV/c and focused $\sim$ 200 m downstream at the first spectrometer chamber. A schematic view of the beam line can be found in [4]. The NA48/2 detector main components are: a magnetic spectrometer consisting of a dipole magnet surrounded by two sets

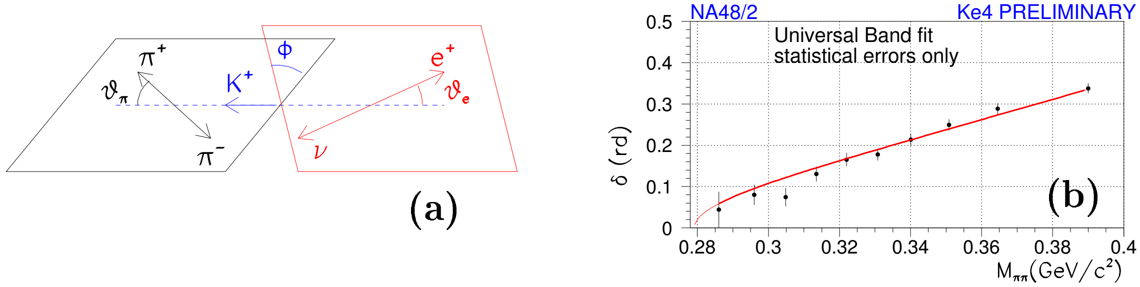

Figure 1: (a): Topology of the charged K_{e4} decay, (b): Variation of the phase shift with $M_{\pi\pi}$.

of drift chambers (the momentum of charged decay products is measured with a relative precision of $\sim$ 1% for 10 GeV/c tracks) and a 27 radiation length liquid krypton calorimeter used to measure electromagnetic deposits and identify electrons through their E/p ratio (the energy and position resolutions are $\sim$ 1% and $\sim$ 1.5 mm (resp.) for 10 GeV showers).

More than $4{\cdot}10^9$ $K^\pm \to \pi^+\pi^-\pi^\pm$ decays, $\sim 10^8$ $K^\pm \to \pi^0\pi^0\pi^\pm$ decays, $\sim 10^6$ $K^\pm \to \pi^+\pi^- e^\pm \nu$ and $\sim 4 \cdot 10^4$ $K^\pm \to \pi^0\pi^0 e^\pm\nu$ decays have been collected in 2003 and 2004. Preliminary results from the analysis of partial statistics are reported here.

3 Charged K_{e4} decays analysis

From part of the 2003 data, 370000 candidates were selected for three charged tracks topologies, requiring two opposite sign pions, one electron ($E/p > 0.9$) and missing energy and p_t (neutrino). The background contamination was estimated from "wrong sign" events ($\pi^\pm\pi^\pm e^\mp\nu$), which can only be background if one assumes the validity of the $\Delta S = \Delta Q$ rule.

The background sources are $K^\pm \to \pi^+\pi^-\pi^\pm$ decays with subsequent $\pi \to e\nu$ decay or a pion misidentified as an electron and $K^\pm \to \pi^\pm\pi^0(\pi^0)$ decays with subsequent Dalitz decay of a π^0 with an electron misidentifed as a pion and photon(s) undetected. The relative level of background to signal is $\sim$ 0.5% and has been cross-checked using Monte Carlo simulated events.

The K_{e4} decay is fully described by the five kinematic Cabibbo-Maksymowicz variables [5]: two invariant masses $M_{\pi\pi}$ and $M_{e\nu}$ and three angles θ_π, θ_e and Φ as shown in Figure 1a. Two axial (F,G) and one vector (H) form factors contribute to the transition amplitude and can be developed in a partial wave expansion of s, p, d waves [6].

$$F = F_s\, e^{i\delta_s} + \ F_p\, e^{i\delta_p} cos\theta_\pi + .., \quad G = G_p\, e^{i\delta_g} + .., \quad H = H_p\, e^{i\delta_h} + ..$$

Neglecting d wave terms and assuming the same phase for F_p, G_p, H_p, only one phase ($\delta(q^2) = \delta_s - \delta_p$) and four form factors are left, which are expanded further [7] in powers of $q^2 = ({M_{\pi\pi}}^2/4m_\pi^2) - 1$:

$$F_s = (f_s + f_s'\, q^2 + f_s''\, q^4), \ F_p = (f_p + ..), \ G_p = (g_p + g_p'\, q^2), \ H_p = (h_p + ..)$$

From the data sample, a total of 15000 equi-populated bins are defined (ten along $M_{\pi\pi}$, five along $M_{e\nu}$, five along $cos\theta_\pi$, five along $cos\theta_e$ and twelve along Φ). Ten independent four-parameter fits are performed, one for each bin in $M_{\pi\pi}$. Then a second fit determines the variation of each form factor with q^2 as shown in Figures 1b and 2.

In the case of the phase δ, the variation was fitted using a one parameter function, corresponding to the center line of the Universal Band [2]. A rather loose constraint between the $\pi\pi$ scattering lengths a_0^0 and a_0^2 is then imposed.

Systematic uncertainties were assessed comparing two independent analyses using different event selections, kaon reconstructions, detector corrections and fit methods. Uncertainties from acceptance, background contamination, electron identification, radiative corrections and possible unknown $M_{e\nu}$ dependence of the form factors have been investigated. The results are given

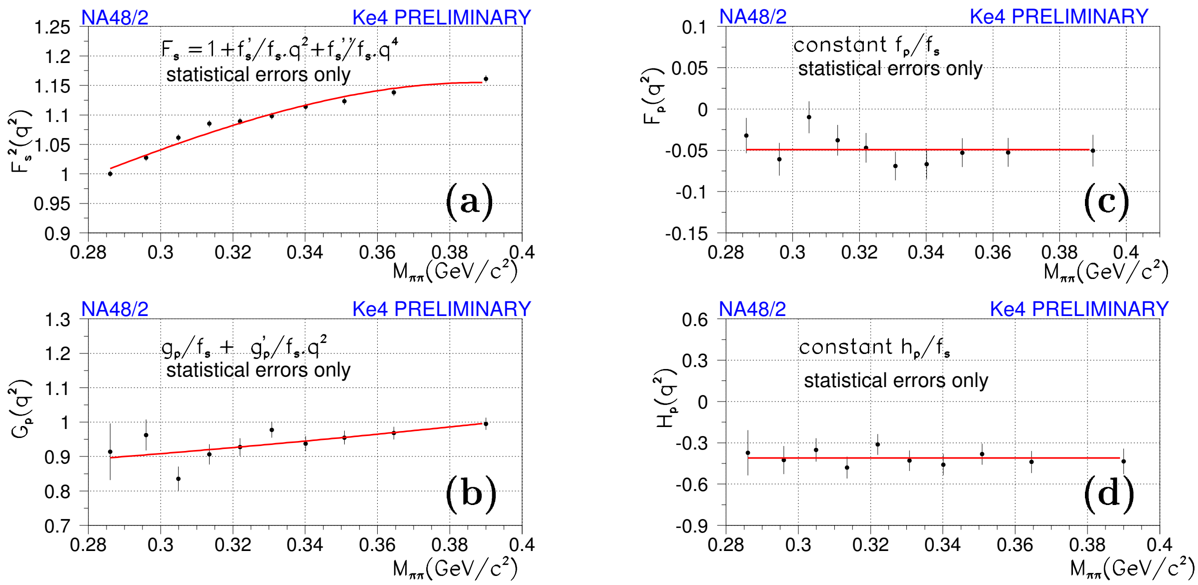

Figure 2: Variation of the form factors with $M_{\pi\pi}$ as measured in 10 independent bins. The line is the result of (a): a quadratic fit in q^2 for F_s, (b): a linear fit in q^2 for G_p and (c),(d): constant fits for F_p and H_p.

relative to f_s, as absolute values can only be obtained through the measurement of the decay rate:

$$
\begin{aligned}
f_s'/f_s &= 0.169 \pm 0.009_{\rm stat} \pm 0.034_{\rm syst} & f_s''/f_s &= -0.091 \pm 0.009_{\rm stat} \pm 0.031_{\rm syst} \\
g_p/f_s &= 0.891 \pm 0.019_{\rm stat} \pm 0.020_{\rm syst} & g_p'/f_s &= 0.111 \pm 0.031_{\rm stat} \pm 0.032_{\rm syst} \\
f_p/f_s &= -0.047 \pm 0.006_{\rm stat} \pm 0.008_{\rm syst} & h_p/f_s &= -0.411 \pm 0.027_{\rm stat} \pm 0.038_{\rm syst} \\
a_0^0 &= 0.256 \pm 0.008_{\rm stat} \pm 0.007_{\rm syst} \pm 0.018_{theo}
\end{aligned}
$$

A comparison with a_0^0 values obtained by previous $\mathrm{K_{e4}}$ experiments [8,9] and using the same Universal band center line constrain shows consistency within the measurement errors.

4 Neutral $\mathrm{K_{e4}}$ decays analysis

From 2003 (2004) data, $\sim$ 10000 (30000) events were selected requiring one charged track (identified as electron), two neutral pions (reconstructed from four $\gamma's$ in the calorimeter) and missing energy and p_t (neutrino). The background contamination was estimated from data by reversing some of the selection requirements. It is mainly due to $\mathrm{K}^\pm \to \pi^0\pi^0\pi^\pm$ events where the $\pi^\pm$ is misidentified as an electron. Another contribution comes from radiative K_{e3} decays and an accidental extra photon, the two photons faking a π^0. The relative background to signal level was 3% in 2003 and 2% in 2004. The reconstructed kaon mass is shown in Figure 3a.

The branching fraction is measured from 2003 data only. The preliminary value, normalized to $\mathrm{K}^\pm \to \pi^0\pi^0\pi^\pm$ is: $BR(K_{e4}^{00}) = (2.587 \pm 0.026_{\rm stat} \pm 0.019_{\rm syst} \pm 0.029_{ext}) \cdot 10^{-5}$, where the external error comes from the uncertainty on the normalization mode branching ratio. As there are two identical π^0s in the decay, one form factor describes the decay in the s-wave. This form factor and its q^2 dependence have been measured from the full statistics : $f_s'/f_s = 0.129 \pm 0.036_{\rm stat} \pm 0.020_{\rm syst}$ and $f_s''/f_s = -0.040 \pm 0.034_{\rm stat} \pm 0.020_{\rm syst}$. While measured with a smaller precision than in the charged $\mathrm{K_{e4}}$ mode, the values are in good agreement.

5 Cusp in $\mathrm{K}^\pm \to \pi^0\pi^0\pi^\pm$ decays

Preliminary results using part of the data statistics have been already published [10]. However, some improvements in the analysis deserve to be mentionned. The invariant $\pi^0\pi^0$ mass squared distribution, M_{00}^2, shows a sudden change of slope at $M_{00}^2 = 2m_{\pi^+}^2$ as seen in Figure 3b. This effect has been explained and computed with a rescattering model [11] using the Dalitz plot

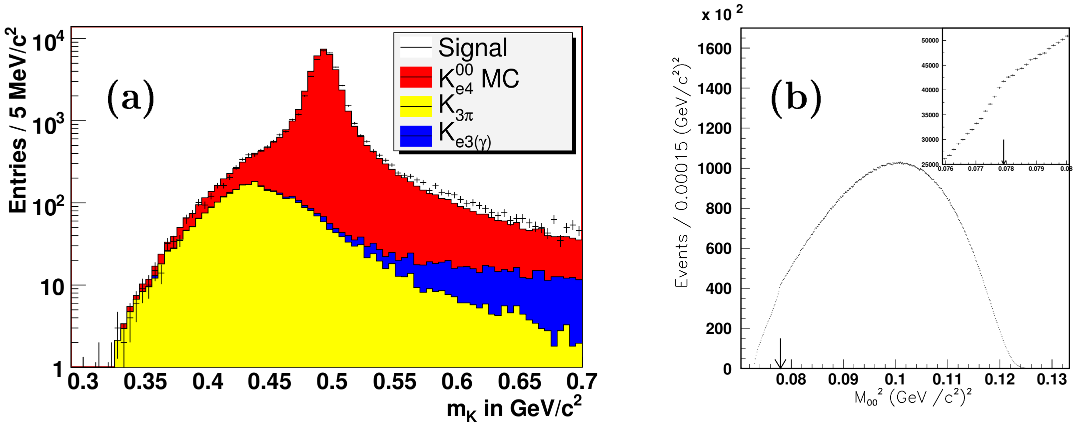

Figure 3: (a): Invariant mass distribution of the reconstructed kaon in the $K^\pm \to \pi^0\pi^0 e^\pm \nu$ mode (K_{e4}^{00}) and (b): Invariant $\pi^0\pi^0$ mass squared in the $K^\pm \to \pi^0\pi^0\pi^\pm$ mode. The insert is an enlargement of the narrow region around $M_{00}^2 = 4m_{\pi^+}^2$ (arrow).

formulation: $M_{\pm 00} \propto 1 + \frac{1}{2}g_0 u + \frac{1}{2}h'u^2 + \frac{1}{2}k'v^2$ where k' was set to zero, as suggested by [12]. A fit of the single mass distribution allows the simultaneous determination of g_0, h', a_0^2 and $(a_0^0 - a_0^2)$. Going to a 2D-fit requires to use both squared invariant masses M_{00}^2 and $M_{\pm 0}^2$. An alternative choice is M_{00}^2 and $cos\theta$, where θ is the angle between the charged $\pi^\pm$ and the π^0s direction in their rest frame. The following results were obtained, assuming a zero value for k':

$$g_0 = 0.645 \pm\ 0.004_{\rm stat} \pm\ 0.009_{\rm syst},\quad h' = -0.047 \pm\ 0.012_{\rm stat} \pm\ 0.011_{\rm syst}$$
$$a_0^2 = -0.041 \pm\ 0.022_{\rm stat} \pm\ 0.014_{\rm syst} \text{ and } a_0^0 - a_0^2 = 0.268 \pm\ 0.010_{\rm stat} \pm\ 0.004_{\rm syst} \pm\ 0.013_{ext}.$$

The systematic uncertainty includes acceptance and trigger efficiency. The external error corresponds to an estimate of the effect of the missing higher order terms and radiative corrections in the rescattering model. When fitting also the k' parameter in the 2D-fit, it is measured significantly away from zero: $k' = 0.0097 \pm\ 0.0003_{\rm stat} \pm\ 0.0008_{\rm syst}$. The corresponding changes for g_0 and h' are $\sim 2\%$ (resp.25%) but negligible for the scattering lengths.

6 Conclusion

Using part of the data recorded in 2003 and 2004, NA48/2 has improved measurements of the K_{e4} form factors in the charged and neutral modes. The neutral K_{e4} branching fraction has been measured. First evidence for a non-zero v^2 term in the $K^\pm \to \pi^0\pi^0\pi^\pm$ Dalitz plot has been reported. A preliminary value of the $\pi\pi$ scattering length a_0^0 has been obtained with 3% statistical and 3% systematic precision in the conservative approach of the Universal Band. A joint study of the K_{e4} and cusp analyses will provide stringent constraints in the (a_0^0, a_0^2) plane.

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