4 Rare Kaon Decays

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Experiment E-865 at Brookhaven AGS

The final long data taking run for experiment E865 at the Brookhaven AGS ended on December 31, 1998. Since then the analysis of the data taken in 1996, 1997 and 1998 with a broad band charged particle spectrometer equipped with a particle identification system on rare K^+ decays in-flight into multilepton final states has progressed and been finalised for some channels.

The flavour changing neutral current decays $K^+ \to \pi^+ e^+ e^-$ ($K_{\pi ee}$) and $K^+ \to \pi^+ \mu^+ \mu^-$ ($K_{\pi\mu\mu}$) are known to be dominated in the Standard Model by long-distance effects involving one-photon exchange. Our published results for these decays not only include precise branching ratios

$$\begin{array}{lll} B(K_{\pi ee}) & = (2.94 \pm 0.05(\mathrm{stat}) \pm 0.13(\mathrm{syst}) \pm 0.05(\mathrm{theor})) \times 10^{-7} & [1] \\ B(K_{\pi\mu\mu}) & = (9.22 \pm 0.60 \pm 0.49) \times 10^{-8} & [2] \end{array} ,$$

but also establish firmly the vector nature of the interaction, and resolve the discrepancy of the older data with $e\mu$ universality. Furthermore the form factor parameters ($f_V(z) = a + bz + w^{\pi\pi}(z)$, $z = M_{ee}^2/m_K^2$) have been determined with $a = -0.587 \pm 0.010$ and $b = -0.655 \pm 0.044$, a result which points to a small but important contribution from the pion loop term $w^{\pi\pi}$ calculated in next-to-leading order chiral perturbation theory.

Table 4.1: *Upper limits for lepton number violating decays established by experiment E865. For each mode the change in electron number L_e, muon number L_μ and total lepton number L are listed.*

Decay mode	ΔL_e	ΔL_μ	ΔL	Branching ratio	Data	Ref.
$K^+ \to \pi^+ \mu^+ e^-$	1	-1	0	$< 3.9 \cdot 10^{-11}$	$K_{\pi\mu e}$ (1996)	[3, 4]
				$< 2.1 \cdot 10^{-10}$	$K_{\pi\mu e}$ (1995)	[5, 6]
				$< 2.0 \cdot 10^{-10}$		[7]
				$< 2.8 \cdot 10^{-11}$	Combined	
$K^+ \to \pi^+ e^+ \mu^-$	-1	1	0	$< 7.0 \cdot 10^{-9}$		[9]
				$< 5.1 \cdot 10^{-10}$	K_{e4} (1997)	[8]
$\pi^0 \to \mu^+ e^-$	1	-1	0	$< 1.7 \cdot 10^{-8}$		[9]
				$< 3.8 \cdot 10^{-10}$	$K_{\pi\mu e}$ (1996)	[4]
$K^+ \to \mu^+ e^+ \pi^-$	-1	-1	2	$< 7.0 \cdot 10^{-9}$		[9]
				$< 4.9 \cdot 10^{-10}$	K_{e4} (1997)	[8]
$K^+ \to e^+ e^+ \pi^-$	-2	0	-2	$< 1.0 \cdot 10^{-8}$		[9]
				$< 6.3 \cdot 10^{-10}$	K_{e4} (1997)	[8]
$K^+ \to \mu^+ \mu^+ \pi^-$	0	-2	-2	$< 1.5 \cdot 10^{-4}$		[9]
				$< 3.0 \cdot 10^{-9}$	$K_{\pi\mu\mu}$ (1997)	[8]

For the lepton flavour conservation violating decay $K^+ \to \pi^+\mu^+e^-$ ($K_{\pi\mu e}$) the analysis of the 1996 data has been completed [3, 4]. It yielded an upper 90% confidence limit for the branching ratio of $3.9 \cdot 10^{-11}$, which combined with our 1995 data [5, 6] and those from earlier experiments [7] reduces to $2.8 \cdot 10^{-11}$ (see Table 4.1). From our 1998 run we expect a sensitivity level below 10^{-11}. The first analysis pass of the 600 tapes with about 2×10^8 events recorded has recently been finished. The second pass will further reduce the sample for the maximum likelihood method signal search. The analysis of these data is subject of the thesis of Aleksej Sher. Figure 4.1 shows the results of such an analysis for the 1996 data [3, 4], from which the quoted limit was extracted.

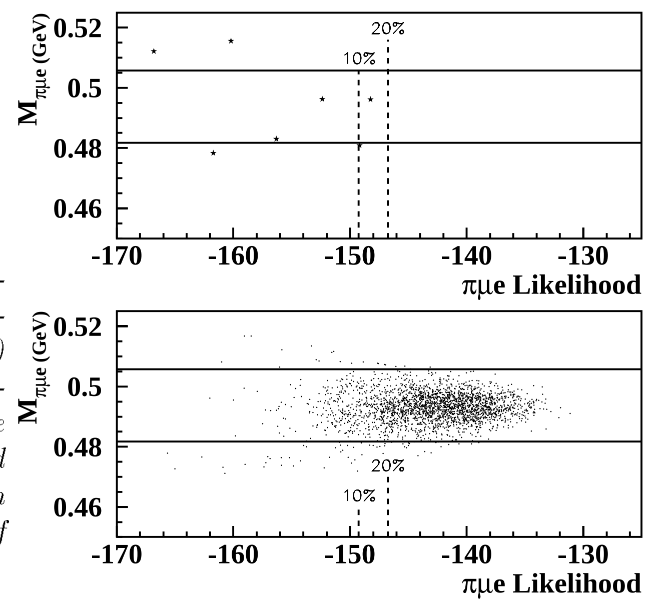

Figure 4.1: *Scatter plot of the $\pi\mu e$ log-likelihood function versus the $\pi\mu e$ invariant mass for data (total 1996 sample, top) and Monte Carlo (expected signal, bottom). The horizontal lines indicate the acceptance in $\pi\mu e$ mass, while the dashed vertical lines mark the boundaries for an event having a 10% or 20% probability of being a signal event [3, 4].*

As a by-product of our main analysis we have also reduced by at least an order of magnitude the limits on the following decays: $\pi^0 \to \mu^+e^-$, $K^+ \to \mu^+\mu^+\pi^-$ ($K_{\mu\mu\pi}$), $K^+ \to e^+\mu^+\pi^-$ ($K_{e\mu\pi}$), $K^+ \to e^+e^+\pi^-$ ($K_{ee\pi}$) and $K^+ \to \pi^+e^+\mu^-$ ($K_{\pi e\mu}$) (see Table 4.1). The limit for the unobserved π^0-decay was deduced from the $K_{\pi\mu e}$ data [4], for the $K_{\mu\mu\pi}$ decay from the dedicated $K_{\pi\mu\mu}$ trigger run in 1997, while the other three decays could in principle be contained in the K_{e4} sample.

The $K^+ \to \pi^+\pi^-e^+\nu_e$ (K_{e4}) sample was also taken in 1997 with a dedicated trigger. $4.4 \cdot 10^5$ nearly background free (after appropiate cuts) events were recorded for this decay with a measured branching ratio of $3.91 \cdot 10^{-5}$ [9]. These data represent a 14-fold increase in statistics compared to previous experiments [10]. Figure 4.2 shows the reconstructed $\pi\pi$ mass from these data compared to Monte Carlo simulations, one of the many control plots demonstrating our good understanding of the data and the detector. These data were then used to fit to $\pi\pi$ scattering phase shift differences and form factor as a function of $\pi\pi$ mass. A preliminary result of this analysis, without radiative corrections, which was presented at a 1999 conference [11], is shown in Fig. 4.2. In this first analysis the method described by Rosselet et al. [10] was used. A more sophisticated treatment based on chiral QCD perturbation theory is in preparation. Since a large number of theoretical calculations within this theoretical frame exist, our final results are eagerly awaited.

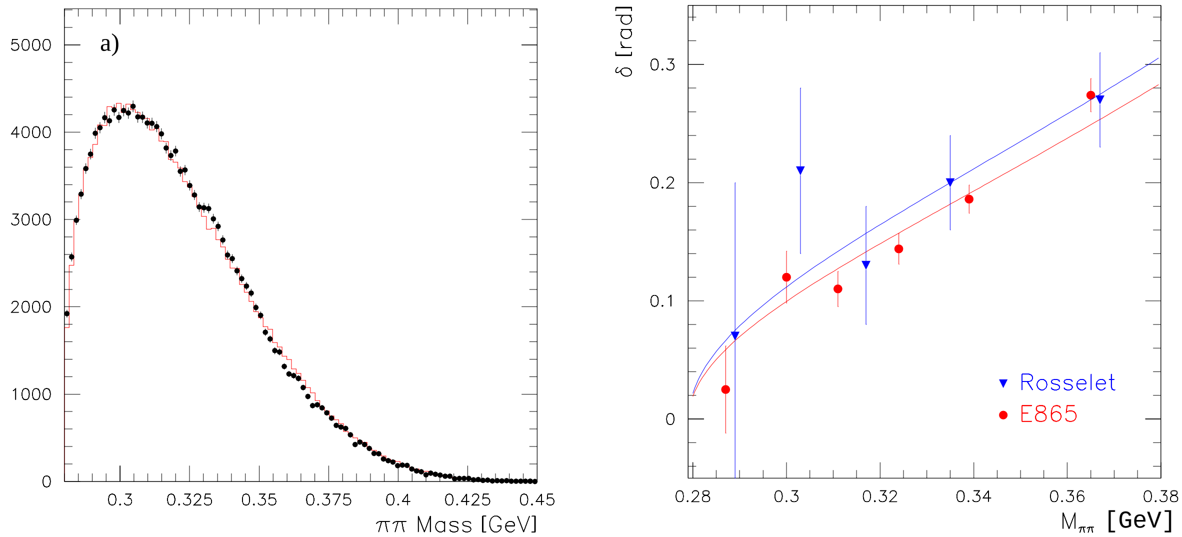

Figure 4.2: *a) Reconstructed $\pi\pi$ mass distribution for K_{e4} events. The dots represent the data, the histogramm shows the Monte Carlo simulation. b) Dependence of the s-wave phase shift parameter $\delta \equiv \delta_0^0 - \delta_1^1$ on the $\pi\pi$ mass [11]. The triangles are from an older experiment with fewer events, where also the fitting method is described [10].*

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