6 Rare Kaon Decays

S. Pislak, P. Robmann and P. Truöl,
in collaboration with
J. Egger, W. D. Herold, H. Kaspar, and H. Weyer,
Paul–Scherrer–Institut, CH-5234 Villigen
Brookhaven National Laboratory, Upton, NY-11973, USA
University of New Mexico, Albuquerque, NM-87131, USA
University of Pittsburgh, Pittsburgh, PA-15260, USA
Yale University, Newhaven, CT-06511, USA
Institute for Nuclear Research, Academy of Sciences, 117 312 Moscow, Russia
Experiment E-865 at Brookhaven AGS

In Table 6.1 those rare K^+ decay modes are listed, for which we have accumulated a significant amount of data. For the lepton flavor conservation violating decay mode, which our experiment was primarily designed for, we have taken data mainly in 1995 and 1996, and will continue to do so during a final 24 week run from June 1998 to December 1998. The analysis of the 1995 data has been concluded [1, 2] and led to a lower limit for the branching ratio of 2×10^{-10}, similar to what was obtained previously [3]. The 1996 data, which are projected to give a factor of five improvement of this limit are still being analysed. The foreseen run could reach a single event sensitivity of 4×10^{-12} for the forbidden decay.

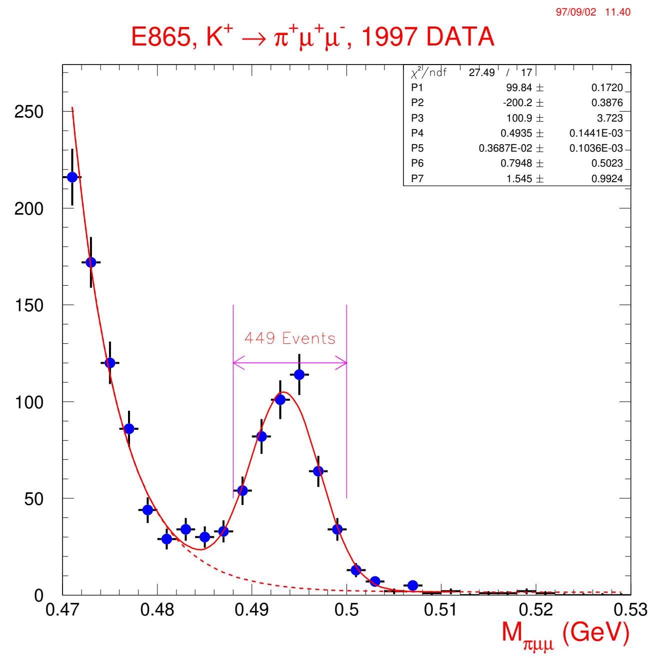

Figure 6.1: The $\pi^+\mu^+\mu^-$ invariant mass spectrum showing a peak at the K^+ mass containing approximately 400 events of the $K^+ \to \pi^+\mu^+\mu^-$ decay.

The data on the other rare decay modes were taken with our broad band K^+ spectrometer during last years run. A new scintillator pixel detector (15×25 pixels of 7×7 mm^2 area and 2 mm thickness viewed by phototubes through air light guides) was installed in the primary beam. This permitted to also look at decays with missing neutrinos or photons. As an example of the quality of this data, we show in Figure 6.1 a mass spectrum indicating a clear peak from about 400 $K^+ \to \pi^+\mu^+\mu^-$ events. As discussed in [4] this sample will provide an accurate test of predictions using chiral QCD Lagrangians. Measuring the branching ratio for the K_{e3} ($K^+ \to \pi^0 e^+ \nu_e$) channel is one of the means of improving our knowledge of the element V_{us} of the CKM-mixing matrix which connects the first and second generation of quarks. A factor of two in accuracy could be gained by comparing K_{e3} to $K_{\pi 2}$ ($K^+ \to \pi^+\pi^0$) decay. The statistical sample is large. Lastly the radiative decays $K^+ \to \mu^+\nu_\mu e^+e^-$ and $K^+ \to e^+\nu_e e^+e^-$ for which only a handful of events has been observed previously furnish information on the electromagnetic structure of the K^+.

Decay mode	**Branching ratio**	**Number of events**		**Comments**
		World data	**E865**	
$\pi^0 \to e^+e^-e^+e^-$	3.18×10^{-5}	146	2000	π^0 electromagnetic form factor
$\pi^0 \to e^+e^-$	7.5×10^{-8}	29	350	π^0 electromagnetic structure
$K^+_{e3}/K^+_{\pi 2}$	0.221 ± 0.012	3500	≈ 50000	V_{us}, needs $< 2\%$ accuracy
$K^+ \to \pi^+\pi^-e^+\nu_e$	3.7×10^{-5}	30000	≈ 300000	$\pi\pi$ scattering length, chiral QCD
$K^+ \to \mu^+\nu_\mu e^+e^-$	9.5×10^{-7}	27 ± 8	1600	K^+ electromagnetic structure
$K^+ \to e^+\nu_e e^+e^-$	2×10^{-8}	4	200	K^+ electromagnetic structure
$K^+ \to \pi^+e^+e^-$	2.7×10^{-7}	500	7000	branching ratio, chiral pert. theory
$K^+ \to \pi^+\mu^+\mu^-$	$< 2.3 \times 10^{-7}$	0	400	branching ratio, chiral pert. theory
$K^+ \to \pi^+\mu^+e^-$	$< 2 \times 10^{-10}$	0	$< 2 \times 10^{-10}$ (1995) $< 4 \times 10^{-11}$ (1996)	

Table 6.1: Results obtained by experiment E865, for which analysis is in progress.

K_{e4} ($K^+ \to \pi^+\pi^-e^+\nu_e$) decay is the only available source of clean information on $\pi\pi$ $S-$wave scattering near threshold and has for this and other reasons some special significance in the theory of chiral symmetry. The latter theory allows the description of the couplings of pions and kaons using a set of nonlinear Lagrangians, with coefficients, which are to be determined phenomenologically. K_{e4} decay is the simplest process in which predictions can be tested which follow in the limit of large number of colors (N_c) of quantum chromodynamics (QCD) (see Figure 6.2). The tools for a complete analysis of K_{e4} within the spirit of these models exist [5, 6]. The only previous experiment [7] is statistically limited, as e. g. evidenced by the value for the scattering length obtained $a_0^0 = 0.26 \pm 0.05$ (exp.), compared to $a_0^0 = 0.20 \pm 0.01$ (theor.). We have been able to take 3×10^5 events, ten times the present world data, with good phase space coverage. We demonstrate this e. g. with the di-pion mass and angular distributions in Figure 6.3, which show how the shape of the theoretical predictions [6] is hardly modified when the matrix elements are used as input to the Monte Carlo simulation of the experiment [1]. The kinematical variables are indicated in Figure 6.2.

In standard weak interaction theory, the data can be described by a set of model independent form factors, which are functions of the di-pion mass and angle, and the di-lepton mass. The di-lepton angle, and the angle between the lepton and the hadron plane do not enter. The di-pion mass spectrum (from only 4 % of the data) is shown in Figure 6.3, as well as the reconstructed mass of the missing neutrino. The data has undergone various cuts against background sources. The present sample contains less 2 % background events mainly from $K^+ \to \pi^+\pi^-\pi^+$ decay with a pion misidentified as a positron. The di-pion

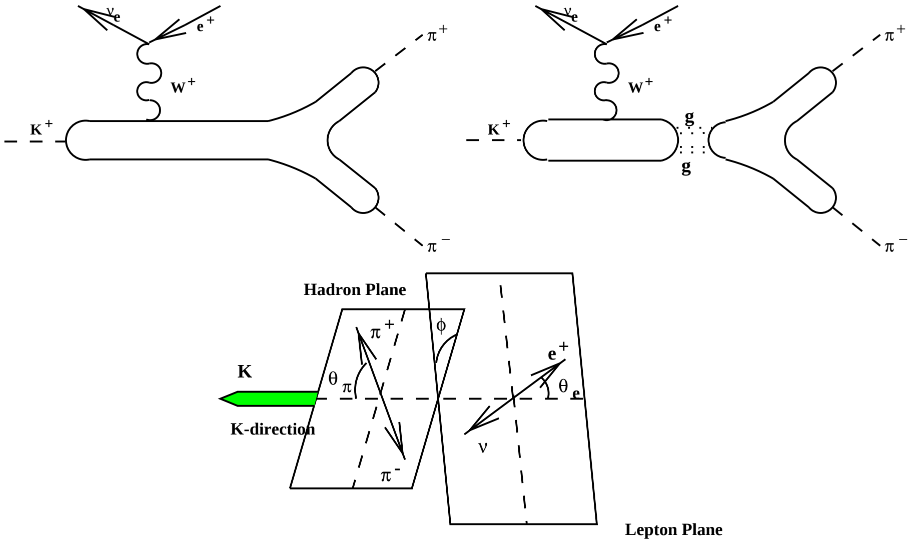

Figure 6.2: Top: two diagrams are shown, which are considered in theoretical treatment of K_{e4} decays using chiral perturbation theory in the limit of large number of colors; the right diagram with the two gluon exchange is of higher order and therefore of reduced importance. Bottom: the kinematical variables which are used in the description of $K^+ \to \pi^+\pi^-e^+\nu_e$ (K_{e4}) decay. θ_π is the angle in $\pi\pi$ center of mass between the π^+ and the $\pi\pi$ recoil direction, θ_e similarly the angle in the $e\nu$ center of mass system between the e^+ and $e\nu$ recoil direction and lastly ϕ is the angle between the dipion and the dilepton decay planes.

spectrum peaks near the low mass kinematical limit of $2m_\pi$, which explains why this data is sensitive to threshold $\pi\pi$ scattering. Some fine tuning of the data analysis is still required, before preliminary values for the scattering length and other form factor parameters can be extracted.

References

[1] S. Pislak, Experiment E865 at BNL: a search for the decay $K^+ \to \pi^+\mu^+e^-$, Thesis, University of Zürich (1997).

[2] D. Bergman, A search for the decay $K^+ \to \pi^+\mu^+e^-$, Thesis, Yale University, Newhaven (1997).

[3] A. M. Lee et al., Phys. Rev. Let. **64** (1990), 165.

[4] R. Appel et al., Experimental studies of rare K^+ decays, Proc. 28-th Int. Conf. on High-Energy Physics, Warsaw, Poland (1996), (World Scientific, Singapore 1997) p. 1188.

[5] C. Riggenbach, J. Gasser, J. F. Donoghue, and B. R. Holstein, Phys. Rev. **D43** (1991), 127.

[6] J. Bijnens, G. Ecker and J. Gasser, CERN-Report TH.6504/92; J. Gasser, private communication.

[7] L. Rosselet et al., Phys. Rev. **D15** (1977), 574.

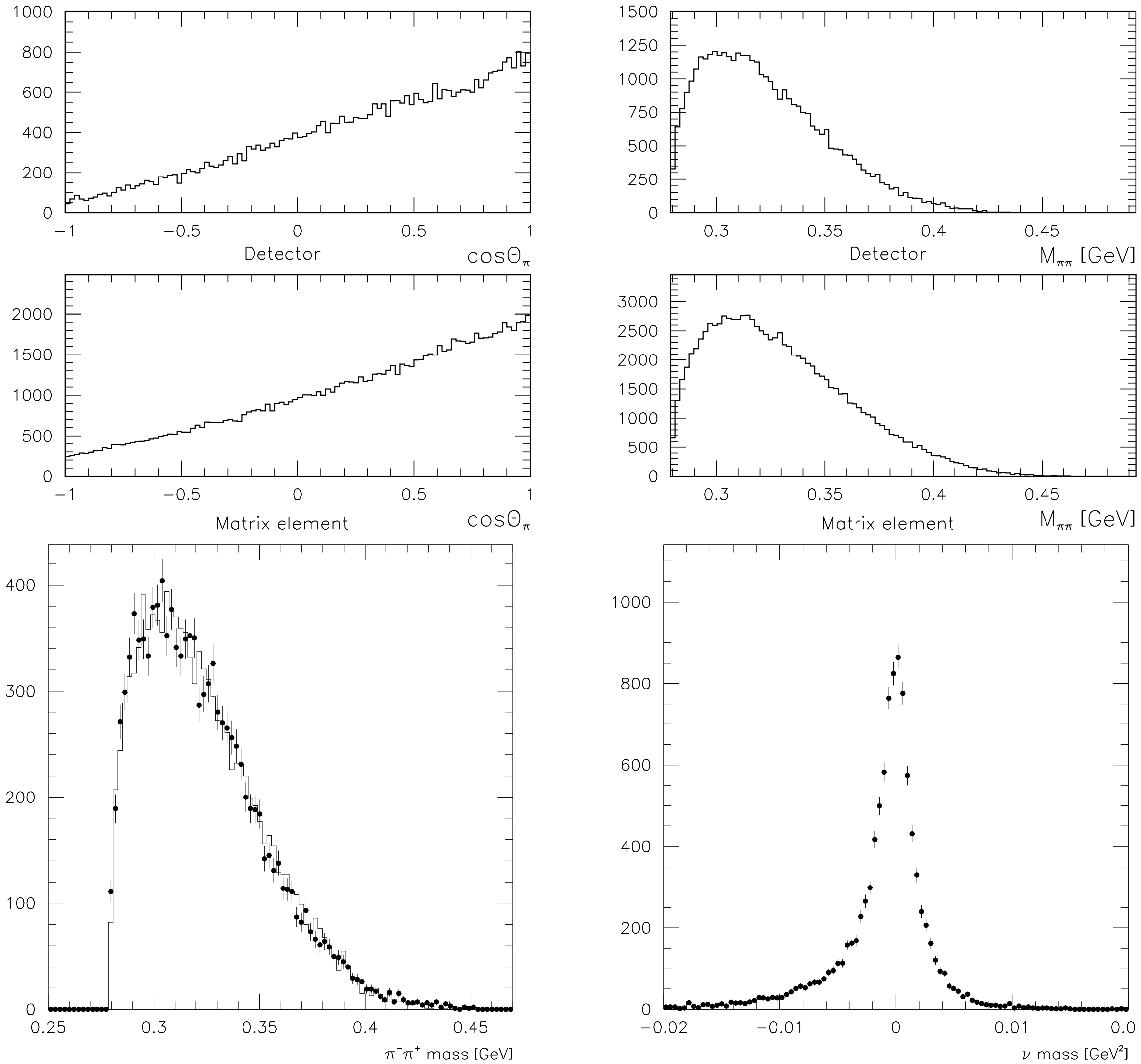

Figure 6.3: Kinematical distributions for K_{e4} decay. Top: theoretically predicted [6] di-pion decay angle and invariant mass distributions without and with detector acceptance folded in. Bottom: di-pion invariant mass and missing neutrino mass distribution for 4 % of the E865 data compared to predictions folded with the experimental acceptance and efficiencies (solid histogram).