PROCEEDINGS OF SCIENCE

$K^{\pm}_{\mu3}$ Form Factor Measurement at NA48/2

Manuel Hita-Hochgesand*
Institut für Physik, Universität Mainz
E-mail: hitahoch@uni-mainz.de

In the year 2003/2004 the NA48/2 experiment collected a large sample of $K^{\pm}$ decays. Using a run with minimal trigger conditions a sample of 3.4×10^6 $K^{\pm}_{\mu3}$ events were accumulated. This sample allows a precise measurement of the form factors according to various parametrizations. In this report the event selection and the fitting procedure are described and a preliminary result is given.

The Xth Nicola Cabibbo International Conference on Heavy Quarks and Leptons,
October 11-15, 2010
Frascati (Rome) Italy

*Speaker.

1. Introduction

Semileptonic decays of the Kaon ($K_{l3}^{\pm}$, $l = \mu, e$) provide the most accurate and theoretically cleanest way to measure the CKM matrix element $|V_{us}|$. In addition, also a stringent constraint on new physics can be given by testing lepton universality. The hadronic matrix element of these decays is described by two dimensionless form factors $f_{\pm}(t)$, which depend on the squared four-momentum $t = (p_K - p_\pi)^2$ transferred to the lepton system. Thes form factors are important input parameters to the phase space integral of those decays for the determination of $|V_{us}|$.

The $K_{l3}^{\pm}$ decays are usually described in terms of the vector form factor f_+ and the scalar form factor f_0 defined as:

$$f_0(t) = f_+(t) + \frac{t}{m_k^2 - m_\pi^2} f_-(t). \tag{1.1}$$

The function f_+ and f_0 are related to the vector (1^-) and scalar (0^+) exchange to the lepton system, respectively. Being proportional to the lepton mass squared, the contribution of f_- can be neglected in Ke3 decays. By construction $f_0(0) = f_+(0)$ and since $f_+(0)$ is not directly measurable it is customary to factor out $f_+^{K^0\pi^-}(0)$ and to normalize to this quantity all the form factors, so that:

$$\bar{f}_+(t) = \frac{f_+(t)}{f_+(0)},\ \bar{f}_0(t) = \frac{f_0(t)}{f_+(0)},\ \bar{f}_+(0) = \bar{f}_0(0). \tag{1.2}$$

To describe the form factors, three different parametrizations are used in this report. The widely known and most used one is the Taylor expansion:

$$\bar{f}_{+,0}(t) = 1 + \lambda'_{+,0}\frac{t}{m_\pi^2} + \lambda''_{+,0}\frac{t^2}{m_\pi^4}, \tag{1.3}$$

where $\lambda'_{+,0}$ and $\lambda''_{+,0}$ are the slope and the curvature of the form factors, respectively. The disadvantage of this parametrization is related to the strong correlations between parameters and the absence of physical constraints. To reduce the parameters and add a physical motivation the pole parametization is used:

$$\bar{f}_{+,0} = \frac{M_{V,S}^2}{M_{V,S}^2 - t}. \tag{1.4}$$

In this parametrization the dominance of a single resonance is assumed and the corresponding pole masses $M_{V,S}$ are the only free parameters. More recently, a parametrization based on dispersion techniques has been proposed [1]:

$$\bar{f}_+(t) = \exp\left(\frac{t}{m_\pi^2}(\Lambda_+ + H(t))\right), \quad \bar{f}_0(t) = \exp\left(\frac{t}{\Delta_{K\pi}}(\ln C - G(t))\right). \tag{1.5}$$

The parameter $\ln C = \ln[f_0(m_K^2 - m_\pi^2)]$ is the logarithm of the value of the scalar form factor at the Callan–Treiman point. This value can be used to test the existence of right handed quark currents coupled to the standard W boson [1].

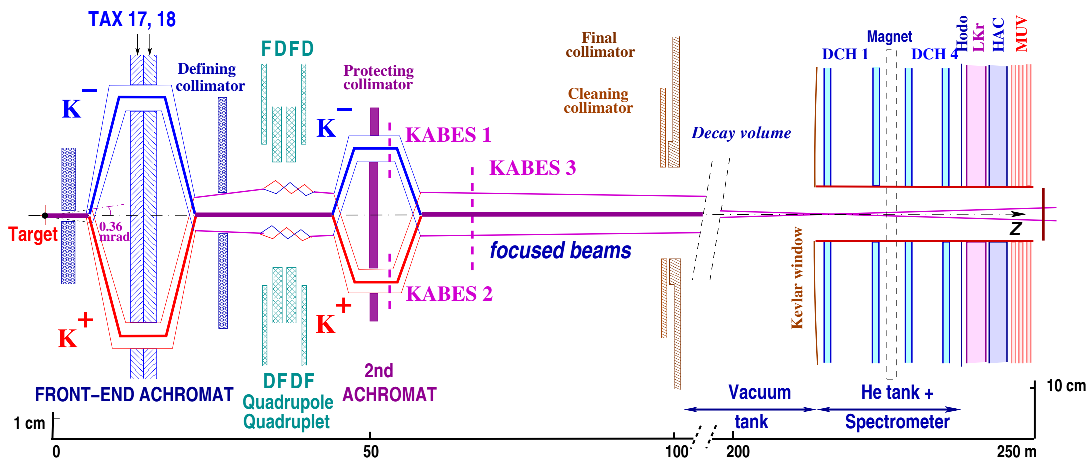

Abbildung 1: Schematic side view of the NA48/2 beam line, decay volume, and detectors.

2. The NA48/2 Experiment

In the years 2003 and 2004 the NA48/2 experiment has collected data from charged kaon decays. Two simultaneous K^+ and K^- beams were produced by 400 GeV/c primary protons delivered by the CERN SPS. The layout of beams and detectors is shown in Fig. 1. The NA48/2 beamline was designed to select kaons with a momentum range of (60 ± 3) GeV/c. The data used for the $K^{\pm}_{\mu 3}$ form factor analysis were collected in 2004 during a dedicated run with a special trigger setup which requires one or more tracks in the magnetic spectrometer and at least a energy deposit of 10 GeV/c in the electromagnetic calorimeter. Also the intensity of the beam was lowered and the momentum spread was reduced.

The main components of the NA48/2 detector were a magnetic spectrometer, composed by four drift chambers and a dipole magnet deflecting the charged particles in the horizontal plane, providing a resolution on the momentum measurement of 1.4% for 20 GeV/c charged tracks, and a liquid krypton electromagnetic calorimeter (LKr) with an energy resolution of about 1% for 20 GeV photons and electrons. For the selection of $K^{\pm}_{\mu 3}$ decays, the muon veto system (MUV) is essential to distinguish muons from pions. It consists out of three planes of alternating horizontal and vertical scintillator strips. Each plane was shielded by a 80 cm thick iron wall. The inefficiency of the system was at the level of one per mill for muons with momentum greater than 10 GeV/c and the time resolution was below 1 ns. The NA48 detector is described in detail elsewhere [2].

3. $K^{\pm}_{\mu 3}$ event selection

The topologic of the decay allows the detector to measure only the muon and the two photons coming from the instant decay of the neutral pion, the neutrino leaves the detector unseen. To select the decay, one track in the magnetic spectrometer and at least two clusters in the electromagnetic calorimeter are necessary. The track has to be inside the geometrical acceptance of the detector, need a good reconstructed decay vertex, proper timing cuts and a momentum $p > 10$ GeV/c to ensure proper efficiency of MUV system. To identify the track as a muon an associated hit in the

MUV system and $E/p > 0.2$ is required, where E is the energy deposited in the calorimeter and p the track momentum. At least two photon clusters are needed to calculate the neutral pion. They need to be well isolated from any track hitting the calorimeter, to have an energy $E_\gamma > 3$ GeV/c, and to be in time with the track in the spectrometer. Finally a kinematical constraint is applied, requiring the missing mass squared (in the μ hypothesis) to satisfy $m^2_{\text{miss}} < 10$ MeV^2.

Background from $K^\pm \to \pi^\pm\pi^0$ events with charged $\pi^\pm$ that decay in flight are suppressed by using a combined cut on the invariant mass $m_{\pi^\pm\pi^0}$ and the π^0 transverse momentum. This cut reduces the contamination to 0.6% but causes a loss of statistics of about 24%. Another source of background is due to $K^\pm \to \pi^\pm\pi^0\pi^0$ events with $\pi^\pm$ decaying in flight and a π^0 not reconstructed. The estimated contamination amounts to about 0.1% and no specific cut is applied. The selected $K^\pm_{\mu 3}$ sample amounts to about 3.4×10^6 events.

4. Fitting procedure

To extract the form factors a two dimensional fit is performed to the Dalitz plot density. The reconstructed four-momentum of the pion and the muon where boosted into the kaon rest frame by using the calculated energy of the charged kaon. The calculation is done by assuming no transverse component of the momentum of the kaon. This leaves only two solution for the longitudinal component of the momentum of the neutrino. In this way the energy resolution in the Dalitz plot was improved, especially in the high energy region of the pion. The reconstructed data Dalitz plot is corrected for the remaining background, the acceptance and the distortions induced by radiative effects. The radiative effects were simulated by using a special Monte Carlo generator developed by the KLOE collaboration [3]. For the fit, the Dalitz plot is subdivided into 5×5 MeV^2 cells. Cells which cross or are outside of the kinematical border are not used in the fit.

5. Preliminary result

The results of the fit for quadratic, pole, and dispersive parametrizations, are listed in Table 1.

Quadratic ($\times 10^{-3}$)	λ'_+	λ''_+	λ_0
	$30.3 \pm 2.7 \pm 1.4$	$1.0 \pm 1.0 \pm 0.7$	$15.6 \pm 1.2 \pm 0.9$
Pole (MeV/c^2)	m_V		m_S
	$836 \pm 7 \pm 9$		$1210 \pm 25 \pm 10$
Dispersive ($\times 10^{-3}$)	Λ_+		lnC
	$28.5 \pm 0.6 \pm 0.7 \pm 0.5$		$188.8 \pm 7.1 \pm 3.7 \pm 5.0$

Tabelle 1: NA48/2 preliminary form factors fit results for quadratic, pole, and dispersive parametrizations. The first error is statistical, the second systematical. The theoretical uncertainty [1] has been evaluated and added to the dispersive results.

The comparison of the $K_{\mu 3}$ quadratic fit result as reported by recent experiments [4] is shown in Fig. 2. The 1 σ contours are displayed for both $K^0_{\mu 3}$ decays (KLOE, KTeV and NA48) and charged K (ISTRA+ studied $K^-_{\mu 3}$ only). The results presented here are the first high precision measurements done with both K^+ and K^- mesons. They show a quadratic term in the expansion of the vector

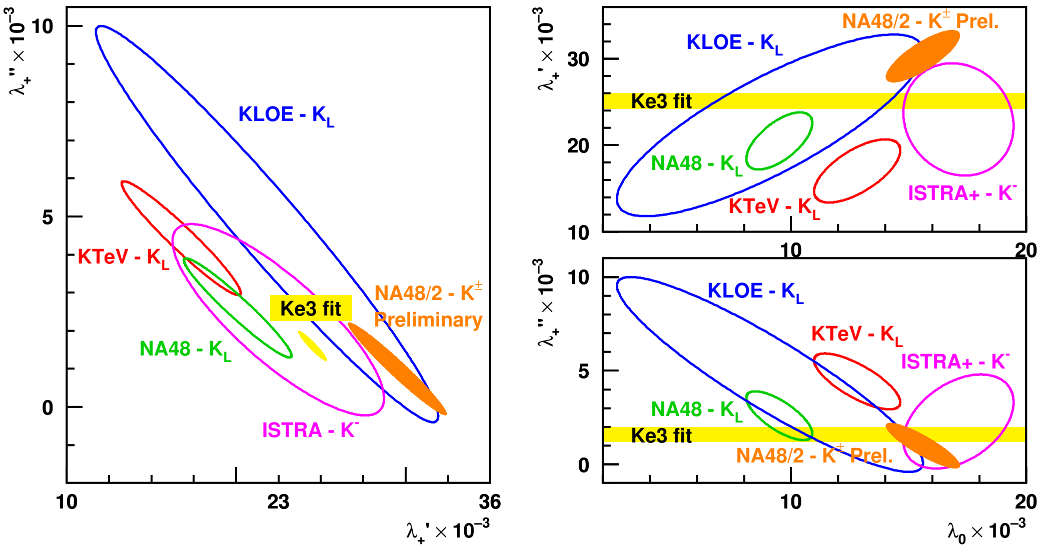

Abbildung 2: Quadratic fit results for $K_{\mu 3}$ (K_L for neutral and $K^{\pm}$ for charged) decays. The ellipses are the 1 σ contour plot. For comparison also the K_{e3} fit from FlaviaNet WG1 is shown.

form factor compatible with zero and a slope of the scalar form factor larger with respect to NA48 case [5] and are in good agreement with the measurements done by the other experiments. For this preliminary result, the systematic uncertainty has been evaluated by changing the cuts defining the vertex quality and the geometrical acceptance by small amounts. In addition, we applied variations to the resolutions of pion and muon energies in the kaon center of mass system, we varied the $\pi \rightarrow \mu$ background and took into account the differences in the results of two independent analyses that were realized in parallel.

6. $K_{e3}^{\pm}$ form factors and future perspectives at NA62

Using the same data sample, also $K_{e3}^{\pm}$ decays are under investigation. Their selection is similar to that of $K_{\mu 3}^{\pm}$, a track and a two clusters forming a good π^0 being required. The electron ID is achieved by demanding $0.95 < E/p < 1.05$, this results in a $K_{e3}^{\pm}$ sample of 4.2×10^6 events. Since these decays are described by only one form factor, problems related to correlations between parameters are greatly reduced. Furthermore background issues are less critical given that to fake these decays $K^{\pm} \rightarrow \pi^{\pm}\pi^0$ events with a $\pi^{\pm}$ having $E/p > 0.95$ are needed. For these reasons, results of higher precision with respect to $K_{\mu 3}^{\pm}$ analysis are expected from this measurement.

The NA62 experiment, using the same beam line and detector of NA48/2, collected data in 2007 for the measurement of $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ and made tests for the future $K^+ \rightarrow \pi^+ \nu\nu$ experiment. The data collected contain also huge K_{e3}^+ and $K_{\mu 3}^+$ samples of $\simeq 40$ and 20×10^6 events, respectively. A special K_L run was also taken: it provides K_{e3}^0 and $K_{\mu 3}^0$ sample of about 4×10^6 events. With these statistics NA62 will be able to realize high precision measurements of the form factors of all K_{l3} channels providing important inputs to further reduce the uncertainty on $|V_{us}|$.

Literatur

[1] V. Bernard, M. Oertel, E. Passemar, and J. Stern, Phys. Lett. **B638** (2006) 480, and Phys. Rev. **D80** (2009) 034034.

[2] V. Fanti et. al. [NA48Collaboration], Nucl. Instrum. Methods **A574** (2007) 433.

[3] C. Gatti, "Monte Carlo simulation for radiative kaon decays", Eur. Phys. J. **C45** (2006) 417.

[4] M. Antonelli et al., arXiv:1005.2323 [hep-ph].

[5] A. Lai et al. [NA48 Collaboration], Phys. Lett. **B647** (2007) 341.