$K^{\pm}_{l3}$ FORM FACTOR MEASUREMENT AT NA48/2

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In 2003/2004 the NA48/2 experiment collected a large sample of $K^{\pm}$ decays. Using a run with minimal trigger conditions, samples of 2.5×10^6 $K^{\pm}_{\mu 3}$ and 4.0×10^6 $K^{\pm}_{e3}$ events were selected. These samples allow precise measurements of the form factors in various parametrizations. This report describes the event selections and the fitting procedure and gives a preliminary result.

1 Introduction

Semileptonic decays of the kaon ($K^{\pm}_{l3}$, $l = \mu, e$) provide the most accurate and theoretically cleanest way to measure the CKM matrix element $|V_{us}|$. In addition, stringent constraints 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. The form factors are important input parameters to the phase space integrals of those decays for the determination of $|V_{us}|$.

The $K^{\pm}_{l3}$ decays are usually described in terms of the vector form factor f_+ and the scalar form factor f_0 defined as [1]:

$$f_0(t) = f_+(t) + \frac{t}{m_k^2 - m_\pi^2} f_-(t). \tag{1}$$

The functions 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 K_{e3} decays. By construction, $f_0(0) = f_+(0)$. Since $f_+(0)$ is not directly measurable, it is customary to factor out $f_+(0)$ and to normalize to this quantity all the form factors, so that:

$$\bar{f}_+(t) = \frac{f_+(t)}{f_+(0)}, \; \bar{f}_0(t) = \frac{f_0(t)}{f_+(0)}. \tag{2}$$

To describe the form factors, two different parametrizations are used in this report. Widely known and most common is the Taylor expansion, called quadratic parametrization in the following:

$$\bar{f}_{+,0}(t) = 1 + \lambda'_{+,0} \frac{t}{m_\pi^2} + \frac{1}{2} \lambda''_{+,0} \frac{t^2}{m_\pi^4}, \tag{3}$$

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 the parameters and

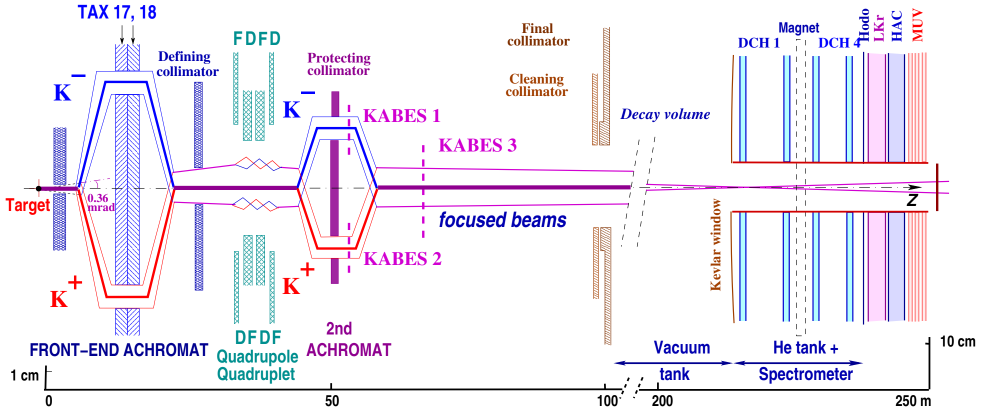

Figure 1: Schematic side view of the NA48/2 beam line, decay volume, and detectors.

the absence of a physical meaning. To reduce the parameters and to add a physical motivation, the pole parametrization is used:

$$\bar{f}_{+,0} = \frac{M^2_{V,S}}{M^2_{V,S} - t}. \tag{4}$$

In this parametrization, dominance of a single resonance is assumed and the corresponding pole masses $M_{V,S}$ are the only free parameters.

2 The NA48/2 Experiment

In the years 2003 and 2004, the NA48/2 experiment 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 selected 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 minimum bias trigger setup which required one or more tracks in the magnetic spectrometer and an energy deposit of at least 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 of four drift chambers and a dipole magnet deflecting the charged particles in the horizontal plane and providing a momentum resolution 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, a muon veto system (MUV) was essential to distinguish muons from pions. It consisted of three planes of scintillator strips with alternating horizontal and vertical orientation. Each plane was shielded by a 80 cm thick iron wall. The inefficiency of the system was at the level of one per-mil for muons with momenta greater than 10 GeV/c, and the time resolution was below 1 ns. The NA48 detector is described in detail elsewhere [2].

3 $K^\pm_{l3}$ event selection

The detector can measure only the charged lepton and the two photons 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 were required. The track had to be inside the geometrical acceptance of the detector, and needed a good reconstructed decay vertex, proper timing and a momentum $p > 5$ GeV/c in case of electrons. For muons, the momentum needed to be greater than 10 GeV/c to ensure proper efficiency of the MUV system. To identify the track as a muon, an associated hit in the MUV system and a ratio $E/p > 0.2$ was required, where E is the energy deposited in the calorimeter and p is the track momentum. For electrons, a range of $0.95 < E/p < 1.05$ and no associated hit in the MUV system were required. At least two photon clusters were needed to reconstruct the neutral pion. They were required 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 was applied, requiring the missing mass squared ($K^\pm_{l3}$ hypothesis) to satisfy $m^2_{\text{miss}} < (10 \text{ MeV}/\text{c}^2)^2$.

For $K^\pm_{\mu 3}$, the background from $K^\pm \to \pi^\pm\pi^0$ events with a decay in flight of the charged pion was suppressed by using a combined requirement on the invariant mass $m_{\pi^\pm\pi^0}$ (under $\pi^\pm$ hypothesis) and on the π^0 transverse momentum. This cut reduces the contamination to 0.5%, 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 being reconstructed. The estimated contamination amounts to only about 0.1%, so no specific cut was applied. For $K^\pm_{e3}$, only the background from $K^\pm \to \pi^\pm\pi^0$ significantly contributes to the signal. A cut in the transverse momentum of the event reduced this background to less than 0.1%, while losing only about 3% of the signal. The selected samples amount to 2.5×10^6 $K^\pm_{\mu 3}$ and 4.0×10^6 $K^\pm_{e3}$ events.

4 Fitting procedure

To extract the form factors, a two-dimensional fit to the Dalitz plot density was performed. The reconstructed four-momenta of the pion and the lepton were boosted into the kaon rest frame. The calculation of the kaon energy was done by assuming no transverse component of the momentum of the kaon, which leaves only two solutions for the longitudinal component of the neutrino momentum. The solution which fits better to the designed kaon momentum of 60 GeV/c was used. In this way, the energy resolution in the Dalitz plot is improved, especially for high pion energies. The reconstructed Dalitz plot was then corrected for remaining background, detector acceptance and 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 was subdivided into 5 MeV × 5 MeV cells. Cells which do cross or are outside of the kinematical border were not used in the fit.

Table 1: Preliminary form factor fit results for the quadratic and the pole parametrization. The first error is statistical, the second systematic. For the combined result, statistical and systematic uncertainties were combined.

Quadratic ($\times 10^{-3}$)	λ'_+	λ''_+	λ_0
$K^\pm_{\mu 3}$	$26.3 \pm 3.0 \pm 2.2$	$1.2 \pm 1.1 \pm 1.1$	$15.7 \pm 1.4 \pm 1.0$
$K^\pm_{e3}$	$27.2 \pm 0.7 \pm 1.1$	$0.7 \pm 0.3 \pm 0.4$	
combined	27.0 ± 1.1	0.8 ± 0.5	16.2 ± 1.0
Pole (MeV/c^2)	m_V		m_S
$K^\pm_{\mu 3}$	$873 \pm 8 \pm 9$		$1183 \pm 31 \pm 16$
$K^\pm_{e3}$	$879 \pm 3 \pm 7$		
combined	877 ± 6		1176 ± 31

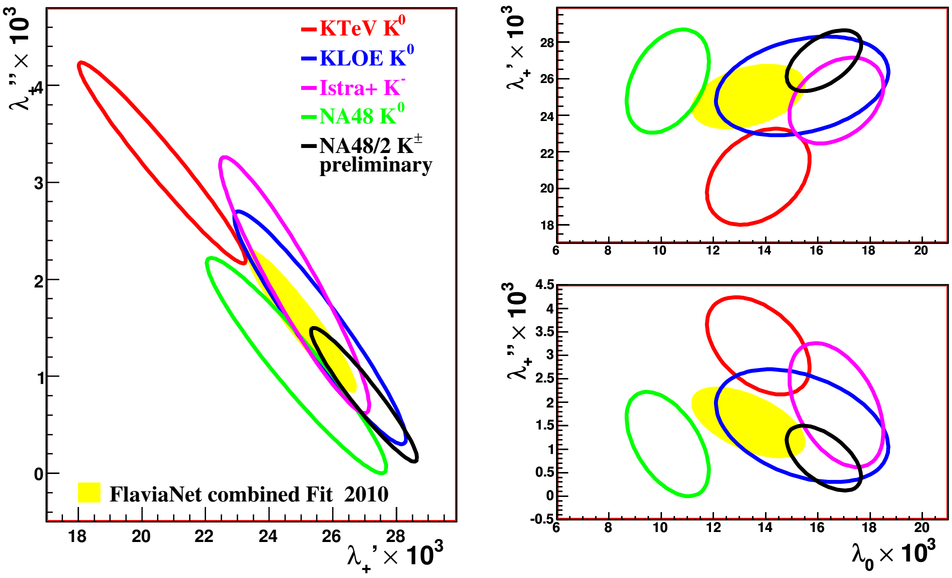

Figure 2: Combined quadratic fit results for K_{l3} decays. The ellipses are 68% confidence level contours. For comparison, the combined fit from the FlaviaNet kaon working group is shown[1].

5 Preliminary result

The fit results for the quadratic and the pole parametrization are listed in Table 1. The systematic uncertainty was 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 $\pi \to \mu$ background and took into account the differences in the results of two independent analyses that were performed in parallel.

For comparison, the combined $K_{l3}^{\pm}$ quadratic fit results as reported by recent experiments is shown in Fig. 2 [1]. The 68% confidence level contours are displayed for both neutral (KLOE, KTeV and NA48) and charged K_{l3} decays (ISTRA+ studied K^- only). The preliminary NA48/2 results presented here are the first high precision measurements done with both K^+ and K^- mesons. The form factors are in good agreement with most measurements done by the other experiments and compatible with the combined fit done by FlaviaNet [1].

6 Future perspectives for form factors at NA62

Using the beam line and detector of the NA48/2 experiment, the new NA62 collaboration collected data in 2007 for the measurement of $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$ and made tests for the future NA62 $K^+ \to \pi^+ \nu \bar{\nu}$ experiment. The collected data contain 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 $K_{\mu 3}^0$ samples of about 4×10^6 events. With these statistics, NA62 is able to realize high precision measurements of the form factors of all K_{l3} channels, providing important inputs to further reduce the uncertainty on $|V_{us}|$.

References

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