

# Results from the NA48 experiment on the semileptonic decays of charged kaons

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In the 2003 and 2004 years the NA48/2 experiment collected a large sample of  $K^\pm$  decays. Using a run with minimal trigger conditions a sample of  $2.5 \times 10^6$   $K^\pm \rightarrow \pi^0 \mu^\pm \nu_\mu$  ( $K_{\mu 3}^\pm$ ) events and  $4.0 \times 10^6$   $K^\pm \rightarrow \pi^0 e^\pm \nu_e$  ( $K_{e 3}^\pm$ ) were collected. These samples allow a precise measurement of the form factors according to various parameterisations. In this report the event selections and the fitting procedure are described and preliminary results are presented.

## 1 Introduction

Semileptonic decays of charged and neutral Kaons 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. These form factors are important input parameters to the phase space integral of those decays for the determination of  $|V_{us}|$ . The  $K_l^\pm$  ( $l = e, \mu$ ) decays are usually described in terms of the vector form factor  $f_+$  and the scalar form factor  $f_0$  defined as:

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

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  $K_{e 3}$  decays. By construction,  $f_0(0) = f_+(0)$  and, 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:

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

To describe the form factors, two different parameterisations are used in this study. The most used one is the Taylor expansion:

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

where  $\lambda'_{+,0}$  and  $\lambda''_{+,0}$  are the slope and the curvature of the form factors, respectively. The disadvantage of this parameterisation is related to the strong correlations between parameters

and the absence of physical constraints. To reduce the parameters and to add a physical motivation the pole parameterisation is also used:

$$\bar{f}_{+,0}(t) = \frac{M_{V,S}^2}{M_{V,S}^2 - t} \quad (4)$$

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

## 2 The NA48/II experiment: beam and detector

In the 2003 and 2004 years the NA48/2 experiment has collected data from charged kaon decays. Two simultaneous  $K^+$  and  $K^-$  beams were produced by a 400 GeV/c proton beam delivered by the CERN SPS and impinging on a berillium target. The layout of beams and detectors is shown in figure 1. The NA48/2 beamline was designed to select kaons with a momentum range of  $(60 \pm 3)$  GeV/c. The data used for the  $K_{l3}^{\pm}$  form factor analysis were collected in 2004 during a dedicated run with a special trigger setup which only 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 to obtain an acceptable rate of events to be recorded. The main components

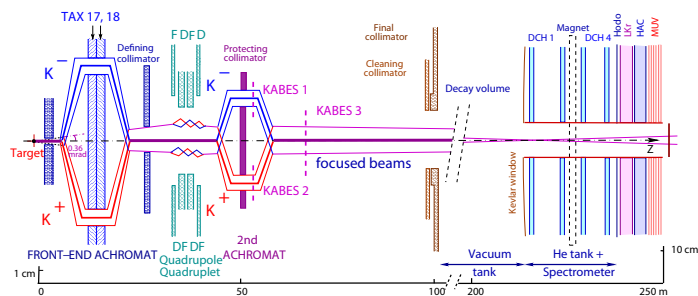


Figure 1: Schematic side view of the beam line, the decay volume and the detector of the NA48/II experiment.

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  $K_{\mu 3}^{\pm}$  decays, the muon veto system (MUV) was essential to distinguish muons from pions. It consisted 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 [1].

### 3 Event selection

The topology of the decays allowed the detector to measure only the lepton 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  $p > 5$  GeV/c for electrons. For muons the momentum need to be greater than 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 electromagnetic calorimeter and  $p$  the track momentum. For electrons a cut range between  $0.95 > E/p > 1.05$  is used. For the electron identification no associated hit in the MUV system is required. At least two photon clusters are needed to reconstruct 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 lepton mass hypothesis) to satisfy  $m_{miss}^2 < 10$  MeV<sup>2</sup>. For  $K_{\mu 3}^\pm$  the background from  $K^\pm \rightarrow \pi^\pm \pi^0$  events with charged  $\pi^\pm$  that decay in flight are suppressed by using a combined cut on the invariant mass  $m_{\pi^\pm \pi^0}^2$  and on the  $\pi^0$  transverse momentum. This cut reduces the contamination to 0.5% causing a loss of statistics of about 24%. Another source of background is due to  $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$  events with  $\pi^\pm$  decaying in flight and a  $\pi^0$  not reconstructed. The estimated contamination amounts to about 0.1% and no specific cut is applied. For  $K_{e 3}^\pm$  only the background from  $K^\pm \rightarrow \pi^\pm \pi^0$  significantly contributes to the signal. A cut in the transvers momentum of the event reduce this background to less than 0.1% by only lossing about 3% of signal events. The selected samples amount to  $2.5 \times 10^6$   $K_{\mu 3}^\pm$  events and  $4.0 \times 10^6$   $K_{e 3}^\pm$  events.

### 4 Fitting procedure

To extract the form factors a two dimensional fit is performed to the Dalitz plot density. The reconstructed four-momenta of the pion and the lepton are 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 is improved, especially for high pion energies. 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 [2]. For the fit, the Dalitz plot is subdivided into  $5 \times 5$  MeV<sup>2</sup> cells. Cells which cross or are outside of the kinematical border are not used in the fit.

### 5 Preliminary results

The results of the fits for quadratic and pole parameterisations are listed in Table 1. The comparison between  $K_{l3}$  quadratic fit results by recent experiments is shown in Figure 2. The 68% confidence level contours are displayed for both  $K_{l3}^0$  (KLOE, KTeV and NA48) and charged K decays (ISTRA+ studied  $K_{l3}^-$  only). The preliminary NA48/2 results presented here are the first high precision measurements done with both  $K^+$  and  $K^-$  decays. The values of the

Quadratic ( $\times 10^{-3}$ )	$\lambda'_+$	$\lambda''_+$	$\lambda_0$
$K_{\mu 3}^{\pm}$	$26.3 \pm 3.0_{stat} \pm 2.2_{sys}$	$1.2 \pm 1.1_{stat} \pm 1.1_{sys}$	$15.7 \pm 1.4_{stat} \pm 1.0_{sys}$
$K_{e3}^{\pm}$	$27.2 \pm 0.7_{stat} \pm 1.1_{sys}$	$0.7 \pm 0.3_{stat} \pm 0.4_{sys}$	
Combined	$26.98 \pm 1.11$	$0.81 \pm 0.46$	$16.23 \pm 0.95$
Pole ( $MeV/c^2$ )	$M_V$		$M_S$
$K_{\mu 3}^{\pm}$	$873 \pm 8_{stat} \pm 9_{sys}$		$1183 \pm 31_{stat} \pm 16_{sys}$
$K_{e3}^{\pm}$	$879 \pm 3_{stat} \pm 7_{sys}$		
Combined	$877 \pm 6$		$1176 \pm 31$

Table 1: NA48/2 preliminary form factors fit results for quadratic and pole parameterisations. In the combined results the statistical and systematic uncertainties are combined.

parameters of the vector form factor  $\lambda'_+$  and  $\lambda''_+$  are compatible with the combined fit done by FlaviaNet[3] (also shown in figure 2). All the measured parameters 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, variations are applied to the resolutions of pion and muon energies in the kaon center of mass system, and to the cuts applied to reject backgrounds related to  $\pi \rightarrow \mu$  decays. The systematic error also took into account for the differences in the results of two independent analyses that were realized in parallel.

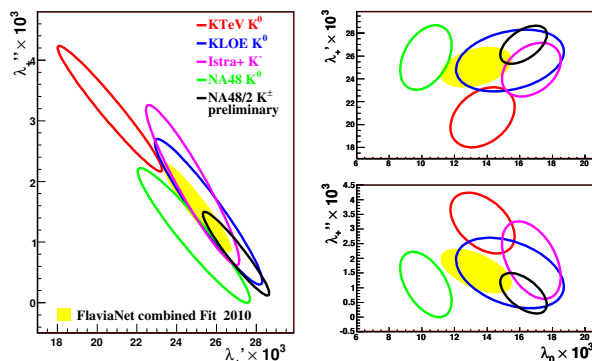


Figure 2: Quadratic fit results for  $K_{l3}$  decays. The ellipses are the 68% confidence level contours. For comparison the combined fit from FlaviaNet Working Group 1 is also shown.

## 6 Bibliography

### References

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