High precision measurement of the form factors of the charged kaon semileptonic decays $K_{l3}^{\pm}$

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Abstract

The NA48/2 experiment presents new measurements of the form factors of the semileptonic decays of charged kaons, based on 4.0 million $K_{e3}^{\pm}$ and 2.5 million $K_{\mu 3}^{\pm}$ decays, collected in 2003 and 2004. The result matches the precision of the current world average on the vector and scalar form factors and allows to significantly reduce the form factor uncertainty on $|V_{US}|$.

1 Introduction

Semileptonic kaon decays $K \rightarrow \pi l \nu$ offer the most precise determination of the CKM matrix element $|V_{US}|$. The hadronic matrix element of these decays is usually described in terms of two form factors (vector $f_+(t)$ and scalar $f_0(t)$ ones), which depend on $t = (p_K - p_\pi)^2$.

Since the measurement of the matrix element overall normalization is usually a separate experimental task, a normalized decay form factors $\bar{f}_{+,0}(t)$ are defined in such a way, that $\bar{f}_{+,0}(0) = 1$. Two parameterizations of these functions are most used [1]:

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

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

Quadratic parameterization (1) is the simplest one, but at the present experimental precisions it has a strong correlations between the parameters. Less parameters has the pole parameterization (2), that also adds a physical meaning, assuming a dominance of a single resonances with the masses $M_{V,S}$.

NA48/2 experiment with the charged kaon beams provides a largest events statistics for precision measurement of both $K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu$ ($K_{\mu 3}^{\pm}$) and $K^{\pm} \rightarrow \pi^0 e^{\pm} \nu$ ($K_{e3}^{\pm}$) semileptonic decay form factors.

2 NA48/2 beam and detectors

NA48/2 beamline is shown on the Fig. 1. Two simultaneous K^+ and K^- beams are produced by 400 GeV/c protons impinging on a beryllium target. Particles of opposite charge with a central momentum of 60 GeV/c and a momentum band of $\pm 3.8\%$ (rms) are selected by two

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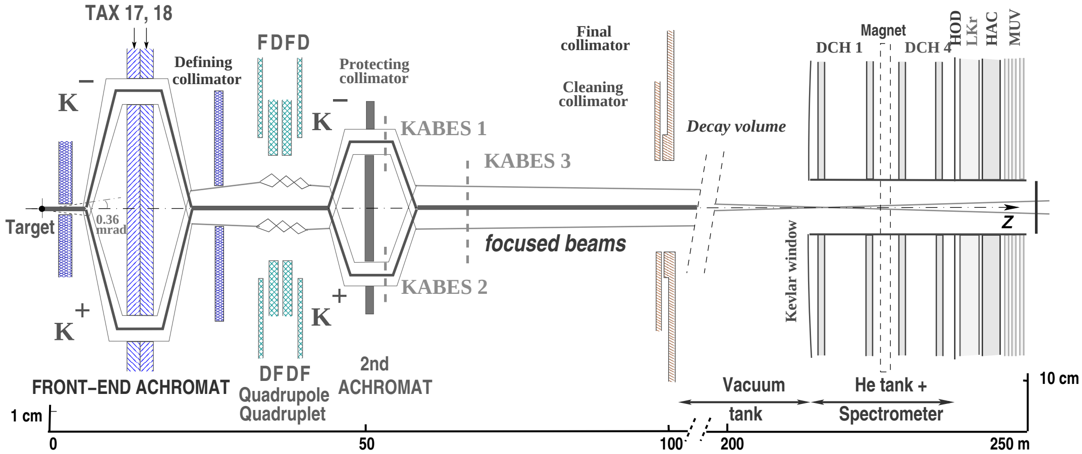

Figure 1: NA48/2 beamline and detector layout

systems of dipole magnets, focusing quadrupoles, muon sweepers and collimators. The decay volume is a 114 m long vacuum space.

A detailed description of the detector elements is available in [2]. Charged particles from $K^{\pm}$ decays are measured by a magnetic spectrometer consisting of four drift chambers (DCH1–DCH4) and a dipole magnet located between DCH2 and DCH3. The spectrometer is located in a tank filled with helium at atmospheric pressure and separated from the decay volume by a thin $Kevlar^{®}$ window. A 16 cm diameter aluminum vacuum tube centred on the beam axis runs the length of the spectrometer through central holes in the window, drift chambers and calorimeters. Charged particles are magnetically deflected in the horizontal plane by an angle corresponding to a transverse momentum kick of 120 MeV/c. The momentum resolution of the spectrometer is $\sigma(p)/p = 1.02\% \oplus 0.044\% p$ (p in GeV/c). The magnetic spectrometer is followed by a scintillator hodoscope.

A liquid Krypton calorimeter LKr is used to measure the energy of electrons and photons. It is an almost homogeneous ionization chamber with an active volume of ~ 10 m^3 of liquid krypton, segmented transversally into 2 cm $\times$ 2 cm projective cells by a system of Cu-Be ribbon electrodes. The calorimeter is 27 X_0 thick and has an energy resolution $\sigma(E)/E = 0.032/\sqrt{E} \oplus 0.09/E \oplus 0.0042$ (E in GeV). The space resolution for single electromagnetic showers can be parameterized as $\sigma_x = \sigma_y = 0.42/\sqrt{E} \oplus 0.06$ cm for each transverse coordinate x, y.

A muon veto system MUV is essential to separate muons from hadrons. It consisted out of 3 scintillator strip planes and 80 cm thick iron walls shielding each plane.

3 $K_{l3}^{\pm}$ events selection

At least one track in spectrometer and two clusters in the electromagnetic calorimeter were required by the event selection procedure. The track had to be in the geometrical acceptance of the relevant detector elements (DCH, LKr, MUV).

For electron tracks a proper timing and a momentum of $p > 5\ GeV/c$ were required. 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 a presence of associated hit in the MUV system and $E/p > 0.2$ were necessary (here E is the energy measured by LKr and p is the DCH track momentum). For electrons a range of $0.95 < E/p < 1.05$ and the absence of associated hit in

Table 1: Preliminary form factor results for the quadratic and the pole parametrizations

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

the MUV system were required.

Two LKr clusters with energies $E > 3\ GeV$ were regarded as a candidate to π^0 decay, if both of them were well isolated from any track hitting the calorimeter, and both were in time with the selected charged track. A missing mass of the reconstructed $K^\pm_{l3}$ event with an undetected neutrino was required to be less than 10 MeV/c^2.

For $K^\pm_{\mu 3}$ the background from $K^\pm \to \pi^\pm\pi^0$ events with the subsequent $\pi^\pm \to \mu^\pm\nu$ decay was suppressed by means of combined cut of the invariant mass $m_{\pi^\pm\pi^0}$ (under $\pi^\pm$ hypothesis) and π^0 transverse momentum. This cut reduces the background contamination to the level of 0.5% with a 24% loss of signal statistics.

Another source of background is due to $K^\pm \to \pi^\pm\pi^0\pi^0$ events with the $\pi^\pm$ decay and a lost π^0. The corresponding estimated contamination amounts to about 0.1%. It is a small contribution, but it introduces some slope in the Dalitz plot. So the corresponding correction has been applied on the final analysis stage.

For $K^\pm_{e3}$, only the background from $K^\pm \to \pi^\pm\pi^0$ with $\pi^\pm$ misidentified as electron significantly contributes to the signal. A cut in the transverse momentum of the event reduced this background to less than 0.1% with a loss of about 3% of the signal.

As a result, $2.5 \cdot 10^6$ $K^\pm_{\mu 3}$ and $4.0 \cdot 10^6$ $K^\pm_{e3}$ decays were selected.

4 Fitting

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. One of the two solutions which is closer to the kaon energy of 60 GeV/c was used.

The reconstructed Dalitz plot was then corrected for remaining background, detector acceptance (simulated by means of Monte Carlo program based on GEANT3 package [3]) and distortions induced by radiative effects. The radiative effects were simulated by using a special Monte Carlo generator developed by the KLOE collaboration [4].

The Dalitz plot was subdivided into 5 $MeV \times 5$ MeV cells in space of the lepton and pion energies in the kaon center-of-mass. Cells which are not completely inside the decay kinematical limits were not used in the fit.

5 Preliminary results

The preliminary fit results for the quadratic and the pole parametrization are shown in Table 1. The systematic uncertainty was evaluated by changing the analysis cuts and the geometrical acceptance. Additionally, the uncertainty of resolutions of the pion and muon energy in the

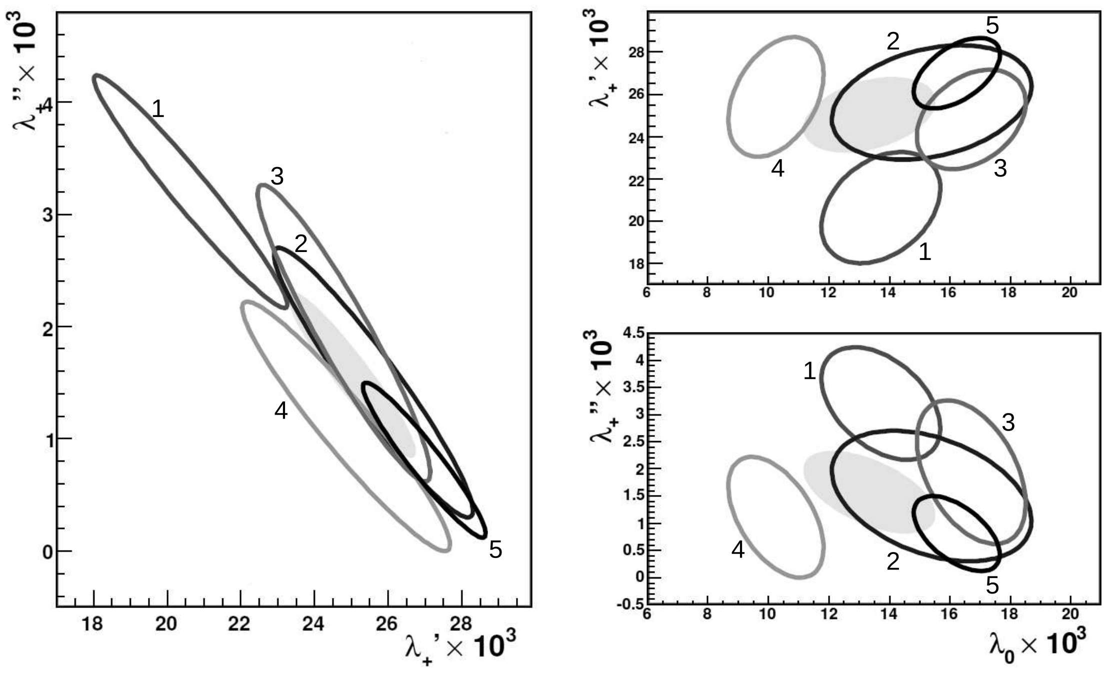

Figure 2: 68% confidence level contours for the K_{l3} combined quadratic fit results: 1 - KTeV (K^0, [5]); 2 - KLOE (K^0, [6]); 3 - Istra+ (K^-, [7, 8]); 4 - NA48 (K^0, [9]); 5 - NA48/2 ($K^\pm$, the present preliminary results). The **FlaviaNet** group fit results [1] are shown as a gray areas.

kaon center of mass, background contribution uncertainty and difference in two independent analyses were taken into account.

The K_{l3} quadratic parameterization fit combined results of recent experiments are shown in Fig. 2. The 68% condence level contours are plotted for both neutral K^0_{l3} (KLOE, KTeV and NA48) and charged $K^\pm_{l3}$ 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 obtained form factors are in good agreement with the other measurements (except $K^0_{\mu 3}$ one from NA48 [9]) and compatible with the FlaviaNet combined fit [1].

6 Summary and future prospects

NA48/2 provides new preliminary results for the charged kaon $K^\pm_{l3}$ formfactors based on few millions events. For the first time both K^+ and K^- $K^\pm_{e3}$ decays were studied together. Preliminary results for the quadratic and pole parametrizations have been obtained, that are competitive for K_{e3} and most precise for $K_{\mu 3}$. The combined results are the most precise measurements so far.

The NA62 experiment [10] data, collected in 2007 with the same beam line and detector of NA48/2, are available. Nearly 10^7 charged kaon $K^\pm_{l3}$ decays and 10^6 neutral kaon K^0_{l3} events were collected. With these statistics NA62 is able to perform a high precision measurements of the form factors of all K_{l3} channels, providing important inputs to further reduce the uncertainty on V_{US}. In addition, the comparison of both channels will set tight constraints on lepton flavor violation and other possible new physics (see, for example, [11]).

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