PROCEEDINGS OF SCIENCE

High precision measurement of the form factors of the semileptonic decays $K^{\pm} \to \pi^{0} l^{\pm} \nu$ (Kl3)

Roberto Piandani[*]
University and INFN of Perugia
E-mail: `roberto.piandani@cern.ch`

I report here a preliminary high precision measurement of the form factors of the semileptonic kaon dekay $K^{\pm} \to \pi^{0} l^{\pm} \nu$ by the NA48/2 experiment at CERN. Using a run with minimal trigger condition in 2004 a sample of 2.5×10^{6} $K^{\pm}_{\mu 3}$ and 4×10^{6} $K^{\pm}_{e3}$ events has been collected and used to obtain the form factors with different parametrizations.

Sixth International Conference on Quarks and Nuclear Physics,
April 16-20, 2012
Ecole Polytechnique, Palaiseau, Paris

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[*] Speaker.

PoS(QNP2012)111

1. Physical Motivation

Semileptonic Kaon decays ($K^{\pm}_{l3}$, $l = e,\mu$) can provide with great accuracy $|V_{us}|$, giving also a stringent constraint on new physics by testing for possible violations of CKM unitarity and 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 one of the input (through the phase space integral) needed to determine $|V_{us}|$. In the matrix element f_- is multiplied by the lepton mass and therefore its contribution can be neglected in K_{e3} decays. In addition to the two vector form factors ($f_{\pm}(t)$), also a scalar form factor exists related to f_+ and f_- in the following way:

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

The function f_+ and f_0 are related to the vector (1^-) and scalar (0^+) exchange to the lepton system, respectively. By construction $f_0(0) = f_+(0)$ and since $f_+(0)$ is not directly measurable it is customary to normalize to this quantity all the form factors so that:

$$\bar{f}_+(t) = \frac{f_+(t)}{f_+(0)},\ \bar{f}_0(t) = \frac{f_0(t)}{f_+(0)},\ \bar{f}_+(0) = \bar{f}_0(0) = 1.$$

There exist many parametrizations of the K_{l3} form factors in the literature, a widely known and most used is the Taylor expansion:

$$\bar{f}_{+,0}(t) = 1 + \lambda'_{+,0}\frac{t}{m^2_{\pi^\pm}} + \frac{1}{2}\lambda''_{+,0}\left(\frac{t}{m^2_{\pi^\pm}}\right)^2,$$

where $\lambda'_{+,0}$ and $\lambda''_{+,0}$ are the slope and the curvature of the form factors, respectively. The disadvantage of such kind of parametrization is related to the strong correlations that arise between parameters. These forbid the experimental determination of λ''_0 experimentally, although, at least a quadratic expansion would be needed to correctly describe the form factors. This problem is avoided by parametrizations which, applying physical constraints, reduce to one the number of parameters used. A typical example is the pole one:

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

where the dominance of a single resonance is assumed and the corresponding pole mass $M_{V,S}$ is the only free parameter.

2. The NA48/2 experiment

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 figure 1. The NA48/2 beam line was designed to select kaons with a momentum range of (60 ± 3) GeV/c. The data used for the 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 an energy deposit

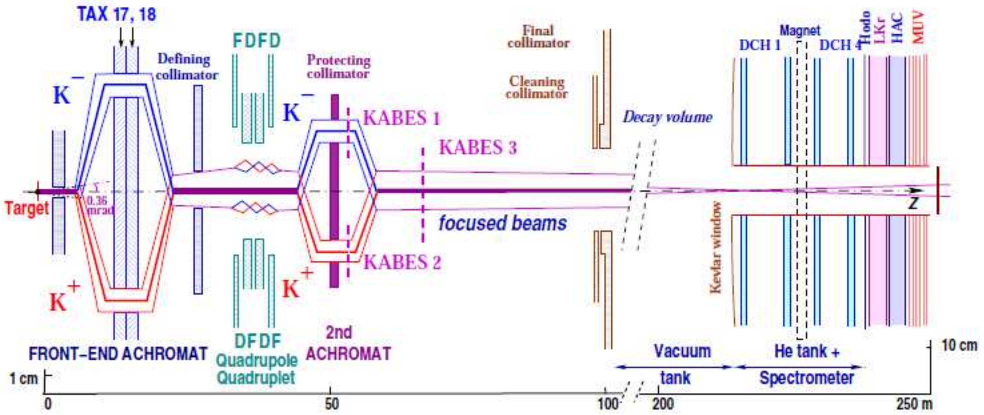

Figure 1: Schematic side view of the NA48/2 beam line, decay volume and detector.

of 10 GeV/c in the electromagnetic calorimeter. 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 $K_{\mu 3}$ 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 mille for muons with momentum greater than 10 GeV/c and the time resolution was below 1 ns. A detailed description of the NA48/2 beam line and detectors can be found here [1].

3. $K^{\pm}_{\mu 3}$ and $K^{\pm}_{e3}$ event selection

The two samples are selected requiring a good track in the spectrometer, the track has to be in geometrical acceptance of the detector, satisfy vertex and timing conditions. The muon is identified requiring the association between a hit in the MUV and the track and requiring an $E/p < 0.2$, where E is the energy deposited in the calorimeter and p the track momentum. The electron is identified requiring the association of the track to a cluster in the LKr and requiring $0.95 < E/p < 1.05$. In addition to the good track also a good pair of photons compatible with the $\pi^0 \to \gamma\gamma$ decay is requested. Finally a kinematical constraint is applied, requiring the missing mass squared (in the lepton mass hypothesis) to satisfy $m^2_{miss} < 10\ (MeV/c^2)^2$. For $K^{\pm}_{\mu 3}$ the background from $K^{\pm} \to \pi^{\pm}\pi^0$ events with $\pi^{\pm} \to \mu^{\pm}\nu_{\mu}$ in flight are suppressed by using a combined cut on the invariant mass $m^2_{\pi^{\pm}\pi^0}$ and on the π^0 transverse momentum. This cut reduces the contamination to 0.5% causing a loss of statistics of about 24%. 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 reduces this background to less than 0.1% by only lossing about 3% of signal events. The selected samples amount to 2.5×10^6 $K^{\pm}_{\mu 3}$ events and 4.0×10^6 $K^{\pm}_{e3}$ events.

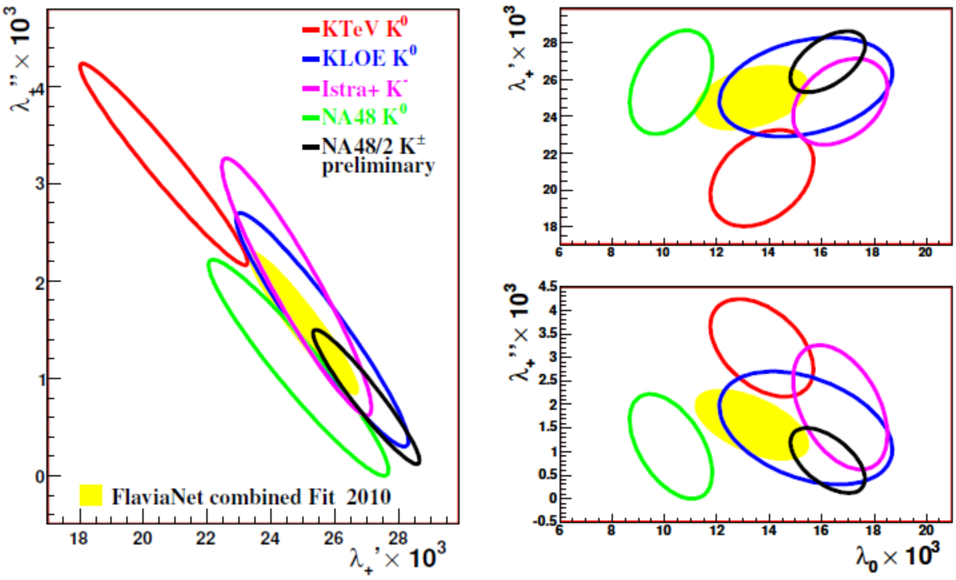

Figure 2: Quadratic fit results for $K_{\mu 3}$ decays. The ellipses are 68% confidence level contours. For comparison also the combined fit from FlaviaNet WG1 is shown.

4. The fitting procedure and preliminary results

To extract the form factors a fit is performed to the Dalitz plot density. The Dalitz plot is subdivided into $5 \times 5\ MeV^2$ cells, those crossed by the kinematical border are not used for the fit. The raw density must be corrected for acceptance and resolution, residual background, 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]. The preliminary results of the fit for quadratic and pole parametrizations 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^0_{l3} (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 parameters of the vector form factor λ'_+ and λ''_+ are compatible with the combined fit done by FlaviaNet [3] (also shown in Figure 2) and a slope parameter λ_0 of the scalar form factor larger with respect to the NA48 K_L result [4]. 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 definition for 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 $\pi \to \mu$ decays. The systematic error also took into account for the differences in the results of two independent analyses that were realized in parallel.

Quadratic ($\times 10^{-3}$)	λ_+'	λ_+''	λ_0
$K^\pm_{\mu 3}$	$26.3 \pm 3.0_{stat} \pm 2.2_{sys}$	$1.2 \pm 1.1_{stat} \pm 1.1_{sys}$	$15.7 \pm 1.4_{stat} \pm 1.0_{sys}$
$K^\pm_{e3}$	$27.2 \pm 0.7_{stat} \pm 1.1_{sys}$	$0.7 \pm 0.3_{stat} \pm 0.4_{sys}$	
Combined	26.98 ± 1.11	0.81 ± 0.46	16.23 ± 0.95
Pole (MeV/c^2)	M_V		M_S
$K^\pm_{\mu 3}$	$873 \pm 8_{stat} \pm 9_{sys}$		$1183 \pm 31_{stat} \pm 16_{sys}$
$K^\pm_{e3}$	$879 \pm 3_{stat} \pm 7_{sys}$		
Combined	877 ± 6		1176 ± 31

Table 1: NA48/2 preliminary form factors fit results for quadratic and pole parametrizations. The first error is statistical, the second systematical. In the combined result the statistical and systematical uncertainties has been combined.

5. Form factors and NA62

The NA62 experiment, using the same beam line and detector of NA48/2, collected data in 2007 and 2008 for the measurement of $R_K = \frac{\Gamma(K_{e2})}{\Gamma(K_{\mu 2})}$ and made tests for the future $K^+ \to \pi^+ \nu \bar{\nu}$ experiment. The data collected contain also huge K^+_{e3} and $K^+_{\mu 3}$ samples of $\sim$ 40 and 20 $\times 10^6$ events, respectively. A special K_L run was also taken: it provides K^0_{e3} and $K^0_{\mu 3}$ samples 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 $|V_{us}|$.

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