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$\mathrm{K}_{\mu 3}^{\pm}$ Form Factors Measurement at NA48/2

Michele Veltri[1]

Università di Urbino and INFN Sezione Firenze
Via S. Chiara 27, I–61029 Urbino, Italy

We report here a measurement of form factors of $K_{\mu 3}^{\pm}$ decay by the NA48/2 experiment at CERN. Using a sample of 3.4×10^6 events we provide preliminary form factor values according to various parametrizations. The slope of the scalar form factor is in agreement with other measurements and theory predictions.

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[1] On behalf of the NA48/2 collaboration: Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Vienna.

1 Introduction

In recent years semileptonic kaon decays ($\mathrm{K}_{\ell 3}, \ell = \mathrm{e}, \mu$) have attracted renewed interest [1]. These decays provide the most accurate and theoretically cleanest way to measure $|V_{us}|$ and can give stringent constraints on new physics scenarios 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 $f_\pm(t)$ where $t = (p_K - p_\pi)^2$ is the four–momentum squared 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 $\mathrm{K}_{\mathrm{e}3}$ decays. $\mathrm{K}_{\mu 3}$ decays instead are usually described in terms of f_+ and the scalar form factor f_0 defined as:

$$f_0(t) = f_+(t) + t/(m_K^2 - m_\pi^2) f_-(t), \tag{1}$$

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 factor out $f_+^{K^0\pi^-}(0)$ and normalize to this quantity all the form factors so that:

$$\bar{f}_+(t) = \frac{f_+(t)}{f_+(0)},\ \bar{f}_0(t) = \frac{f_0(t)}{f_+(0)},\ \bar{f}_+(0) = \bar{f}_0(0) = 1. \tag{2}$$

There exist many parametrizations of the $\mathrm{K}_{\ell 3}$ form factors in the literature, a widely known and most used is the Taylor expansion:

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

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 [2] 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, applaying physical constraints, reduce to one the number of parameters used. A typical example is the pole one:

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

where the dominance of a single resonance is assumed and the corresponding pole mass $M_{V,S}$ is the only free parameter. More recently a parametrization based on dispersion techniques has been proposed [3]:

$$\bar{f}_+(t) = \exp\Big[\frac{t}{m_\pi^2}(\Lambda_+ + \mathrm{H(t)})\Big], \qquad \bar{f}_0(t) = \exp\Big[\frac{t}{\Delta_{K\pi}}(\mathrm{lnC} - \mathrm{G(t)})\Big].$$

The parameter C is the value of the scalar form factor at the Callan–Treiman point, $f_0(t_{CT})$, where $t_{CT} = \Delta_{K\pi} = m_K^2 - m_\pi^2$. It can be used to test the existence of right handed quark currents coupled to the standard W boson.

2 The NA48/2 experimental set–up

The NA48/2 experiment at CERN/SPS was primarily designed to measure the CP violating asymmetry in $K^{\pm} \to 3\pi$ decays. The layout of beams and detectors is shown on Fig. 1 Two simultaneous K^+ and K^- beams were produced by 400 GeV primary

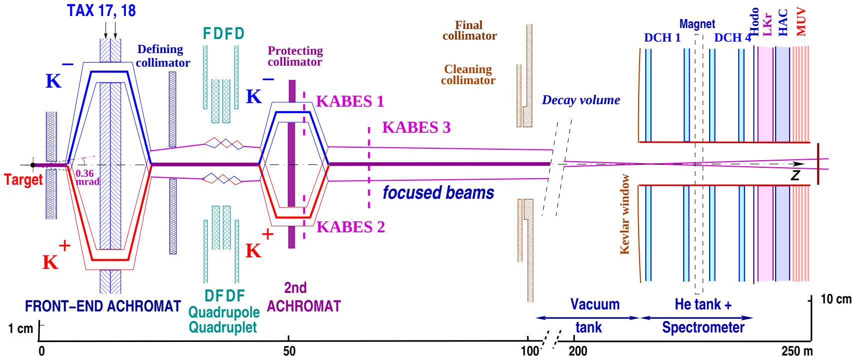

Figure 1: Schematic side view of the NA48/2 beam line, decay volume and detectors.

protons impinging on a beryllium target. A system of magnets and collimators selected particles, with average momentum of 60 GeV, of both positive and negative charge. At the entrance of the decay volume, a 114 m long vacuum tank, the K^+ flux was $\sim 2.3 \times 10^6$ per pulse of 4.5 s duration and the K^+/K^- ratio was about 1.8. The NA48 detector is described in detail elsewhere [4], the main component used in this analysis are:
– a magnetic spectrometer (DCH), designed to measure the momentum of charged particles, it consisted of a magnet dipole located between two sets of drift chambers. The obtained momentum resolution was $\sigma(p)/p(\%) = 1 \oplus 0.044\, p$ (p in GeV/c);
– a charged hodoscope (Hodo), made of two perpendicular segmented planes of scintillators, it triggered the detector readout. The time resolution was $\sim$ 150 ps;
– a liquid krypton electromagnetic calorimeter (LKr) of 27 radiation lengths and energy resolution of $\sigma(E)/E(\%) = 3.2/\sqrt{E} \oplus 9.0/E \oplus 0.42$ (E in GeV);
– a muon system (MUV) consisting 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 and the time resolution was below 1 ns. The data used for this analysis were collected in 2004 during a dedicated run with a special trigger setup, lower intensity and a reduced momentum spread.

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

$K^{\pm}_{\mu 3}$ events are selected by requiring a track in DCH and at least two clusters (photons) in LKr that are consistent with a π^0 decay. The track has to be inside the geometrical acceptance of the detector, satisfy vertex and timing cuts and have $p > 10$ GeV/c to ensure proper efficiency of MUV system. In order to be identified as a muon the track has to be associated in space and time to a MUV hit and have $E/p < 0.2$, where E is the energy deposited in the calorimeter and p the track momentum. Finally a kinematical constraint is applied requiring the missing mass squared (in the μ hypothesis) to satisfy: $|m_\nu| < 10$ MeV^2. Background from $\mathrm{K}^\pm \to \pi^\pm\pi^0$ events with charged π that decays 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 to 0.6% the contamination but causes a loss of statistics of about 24%. Another source of background is due to $\mathrm{K}^\pm \to \pi^\pm\pi^0\pi^0$ events with π 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 $\mathrm{K}^\pm_{\mu 3}$ sample amounts to about 3.4×10^6 events.

4 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 5×5 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 results of the fit for quadratic, pole and dispersive parametrizations, are listed in Table 1. The comparison with the results of $\mathrm{K}_{\mu 3}$ quadratic fit as reported by recent experiments [1] is shown in Fig. 2. The 1σ contour plots are displayed both for $\mathrm{K}^0_{\mu 3}$ decays (KLOE, KTeV and NA48) and charged K (ISTRA studied $\mathrm{K}^-_{\mu 3}$ only), our high precision measurement is the first to use both K^+ and K^- particles. We find a quadratic term in the expansion of the vector form factor compatible with zero and a slope of the scalar form factor larger with respect to NA48 case [5] and in agreement with other measurements. For this preliminary evaluation of systematic uncertainty we have changed by small amounts the cuts defining the vertex quality and the geometrical acceptance, we applyed variations to the values of pion and muon energies in the kaon cms, we increased $\pi \to \mu$ background and took into account the differences in the results of two independent analyses that are realized in parallel.

Quadratic ($\times10^3$)	$\lambda_+^{'}$	$\lambda_+^{''}$	λ_0
	30.3±2.7±1.4	1.0±1.0±0.7	15.6±1.2±0.9
Pole (MeV/c^2)	m_V	m_S	
	$836\pm7\pm9$	1210±25±10	
Dispersive ($\times10^3$)	Λ_+	$\ln C$	
	28.5±0.6±0.7±0.5	188.8±7.1±3.7±5.0	

Table 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 [3] has been evaluated and added to dispersive results.

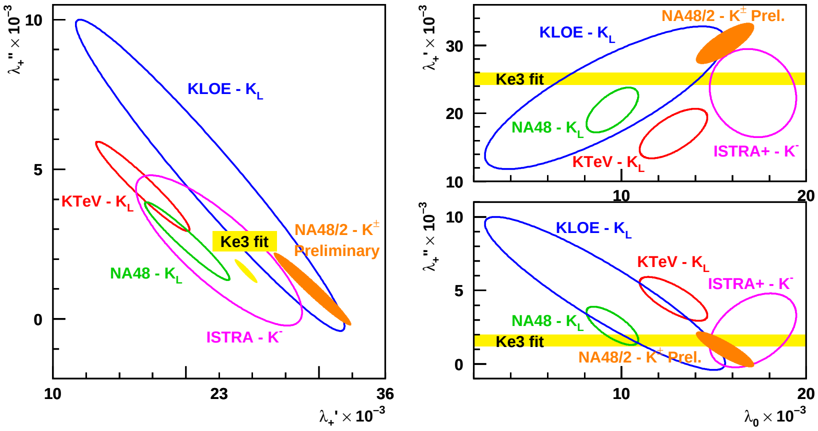

Figure 2: Quadratic fit results for $\mathrm{K}_{\mu 3}$ ($\mathrm{K_L}$ for neutral and $\mathrm{K}^{\pm}$ for charged) decays. The ellipses are the 1 σ contour plot. For comparison also the K_{e3} fit from FlaviaNet WG1 is shown.

5 $\mathrm{K}^{\pm}_{e3}$ form factors and future perspectives at NA62

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

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

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