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Precision measurement of the form factors of the semileptonic decay $K^{\pm} \rightarrow \pi^{0} l^{\pm} \nu$ (Kl3)

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The NA48/2 experiment at CERN collected a very large sample of charged kaon decays into multiple final states. This data allow measurements related to QCD. We obtained our final measurement of the charged kaon semileptonic decays form factors based on 4.28 million Ke3 and 2.91 million Kmu3 selected decays, with the smallest uncertainty for Ke3 and a competitive result for Kmu3 and leading to the most precise combined Kl3 result coming from the Kaon sector that reduces the form factor uncertainty of $|V_{us}|$.

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Two simultaneous K^+ and K^- beams were produced by 400 GeV/c primary protons delivered by the CERN SPS. The NA48/2 beam line was designed to select kaons with a momentum range of (60 ± 3) GeV/c. These beams were dominated by $\pi^{\pm}$, the $K^{\pm}$ component was about 6%. The beam kaons were delivered to a fiducial decay region of about 114 m long contained in a cylindrical vacuum tank. The momenta of the charged decay products were measured in a magnetic spectrometer located downstream of the decay region. The spectrometer consisted of four drift chambers (DCH) and a dipole magnet between the second and third chambers. The spectrometer was followed by a plastic scintillator hodoscope (HOD), providing fast trigger signals and time measurement of charged particles with about 200 ps resolution for a single track. A 27 X_0 deep liquid Krypton electromagnetic calorimeter (LKr) located further downstream was used for charged particle identification and photon measurement. The identification of muons is performed with the MUon Veto system (MUV). It consists out of three planes of alternating horizontal and vertical scintillator strips. Each plane was shielded by a 80 cm thick iron wall. A detailed description of the whole setup can be found in [1].

1. The $K^{\pm} \to \mu^{\pm}\pi^0\nu_{\mu}$ and $K^{\pm} \to e^{\pm}\pi^0\nu_e$ form factors

The hadronic matrix element of semileptonic Kaon decays ($K^{\pm}l3$, $l = e, \mu$) is described by two dimensionless vector form factors $f_{\pm}(t)$, which depend on the squared four-momentum transferred to the lepton system, $t = (p_K - p_{\pi})^2$. In addition to the two vector form factors we can introduce also a scalar form factor (f_0). It is customary to normalize to $f_+(0)$ all the form factors so that:

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

There exist many parametrizations of the $Kl3$ form factors in the literature, a widely known and most used is the Taylor expansion [2]:

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

where $\lambda^{'}_{+,0}$ and $\lambda^{''}_{+,0}$ are the slope and the curvature of the form factors, respectively. As a second parametrizations we can use a model that, applying physical constraints, reduces to one the number of parameters used. A typical example is the pole one [3][4]:

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

where the dominance of a single resonance is assumed and the corresponding pole mass $M_{V,S}$ is the only free parameter. A third model exists, the Dispersive parametrization [5]

$$\bar{f}_+(t) = exp[(\Lambda_+ + H(t))t/m^2_{\pi}] \quad \bar{f}_0(t) = exp[(ln(C) - G(t))t/(m^2_K - m^2_{\pi})]$$

1.1 Event selection and final background rejection

The common part of data selection requires one charged track in the DCHs and a time coincidence with at least two clusters in the electromagnetic calorimeter (the two γ from the π^0 decay).

Process	Br (%)	Bkg(e)$\times 10^{-3}$	Bkg(μ)$\times 10^{-3}$
$K^{\pm} \to \pi^{\pm}\pi^0\pi^0; (\pi^0 \to \gamma\gamma)$	1.72	0.286	1.833
$K^{\pm} \to \pi^{\pm}\pi^0; (\pi^0 \to \gamma\gamma)$	20.43	0.270	0.264

Table 1: Summary of the main background contribution to $Ke3$ and $K\mu3$.

Other requirements applied to the charged track are: a good reconstructed decay vertex inside the decay region and a proper timing. The selected track momentum region is different depending on the track type ($p > 5GeV/c$ for the electron, $p > 10GeV/c$ for the muon). The electron identification is performed asking $E/p > 0.9$, where E is the energy deposited in the LKr and p is the momentum measured in the spectrometer, and no signal in time in the MUV system. The muon identification is performed asking an associated hit in time in the MUV system and $E/p < 0.9$. The background contribution has been estimated using the NA48/2 Monte Carlo. For $Ke3$ the background from $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$, with $\pi^0 \to \gamma\gamma$, has a significant contribution. In order to remove this contribution from the final sample a cut in the $P_t(\nu) >= 0.03GeV/c$ of the event is applied, the final amount is less than 0.029%, table 1.1. For $K\mu3$ selection, essential background may come from $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ decays with the following $\pi^0 \to \gamma\gamma$. The final contamination is reduces to 0.183% cutting in $m(\pi^{\pm}\pi^0)$ and $m(\mu^{\pm}\nu)$, table 1.1. At the end of the two selection 2.91×10^6 $K\mu3$ and 4.28×10^6 $Ke3$ candidates have been reconstructed.

2. Form factors results

To extract the form factors an events-weighting fit is performed in $5 \times 5MeV$ cells in the Dalitz plot of E_{π^0} vs E_l energies, computed in the kaon rest frame.
Combining the $K\mu3$ and $Ke3$ samples the results for the parameters of the parametrization based on Taylor expansion are:

$$\lambda_+^{'} = (23.35 \pm 0.75(stat) \pm 1.23(syst)) \times 10^{-3}$$

$$\lambda_+^{''} = (1.73 \pm 0.29(stat) \pm 0.41(syst)) \times 10^{-3}$$

$$\lambda_0^{'} = (14.90 \pm 0.55(stat) \pm 0.80(syst)) \times 10^{-3}$$

For the pole parametrization the results are:

$$M_V = 894.3 \pm 3.2(stat) \pm 5.4(syst) \qquad M_S = 1185.5 \pm 16.6(stat) \pm 35.5(syst)$$

For the dispersive parametrization are:

$$\Lambda_+ = (22.67 \pm 0.18(stat) \pm 0.55(syst)) \times 10^{-3} \qquad ln|C| = (189.12 \pm 4.91(stat) \pm 11.09(syst)) \times 10^{-3}$$

The comparison with other experiment for the parameters of the Taylor expansion obtained with the combined samples are shown in figure 1.

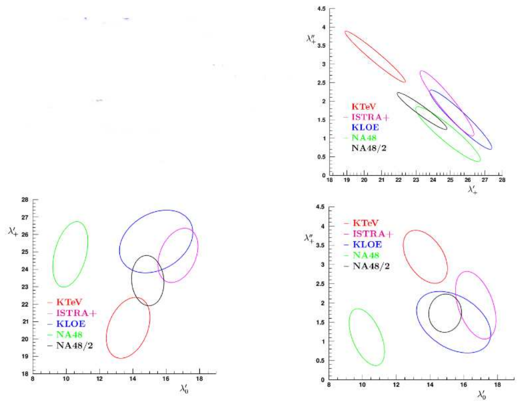

Figure 1: Comparison with other experiments of the form factors parameters in the Taylor expansion parametrization. KTeV [6],KLOE [7][8], NA48 [9][10] and ISTRA+ [11][12]. The values are multipled by a factor 10^3.

3. Conclusion

The NA48/2 collaboration performed the measurement of the $Kl3$ form factors using different parametrizations. The results for the $K\mu3$ sample is competitive with the other experiments. For the $Ke3$ sample the results have the smallest errors. Combaining the two samples the collaboration obtained the most precise results for the form factors of the semileptonic kaon decays. The present results are in agreement with the erlier values. The fianl result, with small differences with respect the one presented here has been published [13].

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