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KLOE measurement of the scalar Form-Factor slope for $K_L \to \pi\mu\nu$ decay.

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I present the KLOE measurement of the $K-\pi$ form-factor parameters for the decays $K_L \to \pi e\nu$ and $K_L \to \pi\mu\nu$. These measurements are based on ~ 300 pb^{-1} of data collected in 2001 and 2002, corresponding to ~ 2 million K_{e3} and $K_{\mu3}$ selected events.

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1. Introduction

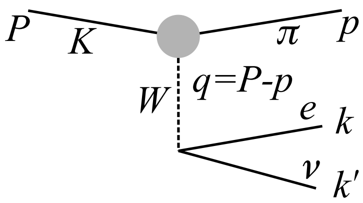


Figure 1: Amplitude for $K \to \pi l \nu$. The gray region indicates the $K \to \pi W$ vertex structure.

Semileptonic kaon decays offer the cleanest way to obtain the value of the Cabibbo angle θ_c. Following the notation of Fig. 1, the transition matrix element for K_{l3} decays is given by:

$$M = \frac{G}{\sqrt{2}} V_{us} \langle \pi(p) | j_\mu | K(P) \rangle \bar{l}(k) \gamma^\mu (1-\gamma_5) \nu(k') \tag{1.1}$$

where $V_{us} = \sin\theta_c$. The main uncertainty on the determination of V_{us}, comes from our knowledge of the matrix element $\langle \pi(p)|j_\mu|K(P)\rangle$. Using Lorentz invariance we can expand it in the following way:

$$\langle \pi(p)|j_\mu|K(P)\rangle = C_k[(P+p)_\mu f_+(t) + (P-p)_\mu f_-(t)] \tag{1.2}$$

where $t = (P-p)^2 = M_K^2 + m_\pi^2 - 2M_K E_\pi$. Eq. 1.2 defines the form factors $f_\pm(t)$. In K_{e3} decays, the form factor f_- is suppressed by a factor m_e/M_K and can be neglected. A new form factor is usually introduced:

$$f_0(t) = f_+(t) + \frac{t}{M_K^2 - m_\pi^2} f_-(t) \tag{1.3}$$

f_0 and f_+ are related to the transitions amplitudes 0^+ and 1^-, respectively, for the lepton pair in the final state. In the meson dominance approximation, the form factors can be expressed as (pole model):

$$f_{+,0}(t) = f_+(0)\frac{1}{1 - t/M_{V,S}^2} \tag{1.4}$$

A more general expression is obtained by using a power expansion:

$$f_{+,0} = f_+(0)(1 + \lambda'_{+,0}\frac{t}{m_{\pi^+}^2} + \frac{1}{2}\lambda''_{+,0}\left(\frac{t}{m_{\pi^+}^2}\right)^2 + \cdots) \tag{1.5}$$

This expansion reduces to the pole model expansion when $\lambda''_{+,0} = 2(\lambda'_{+,0})^2$.

The correct choice of the parametrization for the form factors has a crucial importance for a precise determination of $V_{us} \times f_+(0)$. For instance, the integral over the phase space of the squared amplitude for K_{e3} decays, changes by $\sim 0.5\%$ if we use the linear or quadratic expansion to measure the form-factor parameters from the same data sample. This leads to a systematic variation on $V_{us} \times f_+(0)$ of $\sim 0.25\%$, that is of the same order of the present fractional error.

2. Measurement of form-factor parameters in $K_L \to \pi e \nu$ decays

At KLOE neutral kaons are produced in the decay $\phi \to K_L K_S$. K_L decays are tagged by the presence of a $K_S \to \pi^+\pi^-$ decay. The K_L momentum is obtained from the kinematics of the two body decays $\phi \to K_S K_L$, using the reconstructed K_S direction and the known value of the ϕ momentum. The two tracks, not coming from the K_S decay, with minimum distance to the K_L line of flight are considered as belonging to the K_L decay products. Only events in a fiducial volume $35 < r_T < 150$ cm and $|z| < 120$ cm are retained. $K_L \to \pi^+\pi^-\pi^0$ and $K_L \to \pi^+\pi^-$ decays are rejected by requiring $E^2_{miss} - p^2_{miss} - m^2_{\pi^0} < -5000$ MeV^2 and $\sqrt{E^2_{miss} + p^2_{miss}} > 10$ MeV, respectively. E_{miss} and p_{miss} are the missing energy and momentum. The main background is due to $K_L \to \pi\mu\nu$ decays. A large fraction of it is rejected requiring $\Delta_{\pi\mu} > 10$ MeV, where $\Delta_{\pi\mu}$ is the lesser value of $|E_{miss} - p_{miss}|$ calculated in the two hypotheses, $\pi\mu$ and $\mu\pi$. Further background rejection and the particle identification are obtained by means of time of flight (ToF). The tracks are extrapolated to the calorimeter surface and associated to clusters. For each track the difference between measured and expected time of flight $\Delta t_{e,\pi} = t_{cl} - t_{e,\pi}$ is calculated. The expected time $t_{e,\pi}$ is obtained assuming the particle to be an electron or a pion, respectively. The mass assignment is obtained by choosing the lesser of $|\Delta t_{\pi^+} - \Delta t_{e^-}|$ and $|\Delta t_{\pi^-} - \Delta t_{e^+}|$. Then, K_{e3} events are selected by applying a 2σ cut ($\sigma \simeq 0.5$ ns) in the plane $(\Delta t_\pi, \Delta t_e)$ (Fig. 2). The final background contamination is $\sim 0.7\%$ mainly

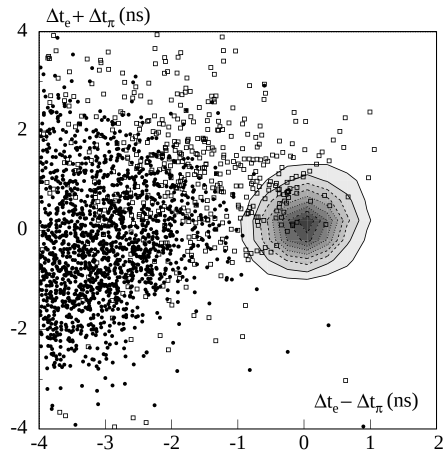
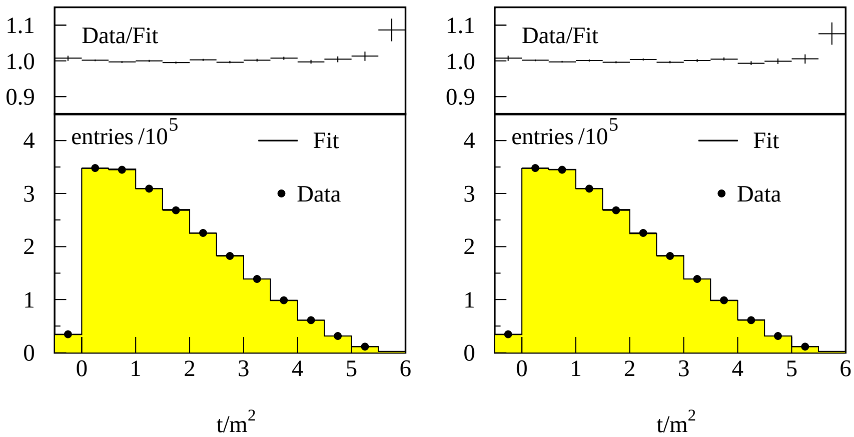


Figure 2: Monte Carlo distribution of $\Delta t_e - \Delta t_\pi$ versus $\Delta t_\pi - \Delta t_e$. Signal (gray scale), background from $K_L \to \pi e \nu$ with wrong $\pi - e$ identifi cation (black dot), background from $K_L \to \pi\mu\nu$ (empty box).

due to $K_L \to \pi\mu\nu$ decays. Using an integrated luminosity of ~ 300 pb^{-1} of data collected in 2001 and 2002, 2 million K_{e3} decays are selected [1]. The form-factor parameters are measured by fitting the distribution of the selected events in $t/m^2_{\pi^+}$. The fitting function is obtained by a convolution of the theoretical spectrum with the experimental efficiency and resolution effects. The radiative corrections are taken into account in the Monte Carlo simulation as described in [2]. The fit results obtained using the linear and quadratic expansions for the form factor are shown in Fig. 3. Both linear and quadratic fits have good probability, $P(\chi^2) = 89\%$ and $P(\chi^2) = 92\%$, respectively, with a small improvement in the second case. The fits are performed independently for the two charge modes, and for different data periods, in order to check systematic effects on the cluster efficiency



Linear Fit Quadratic Fit

Figure 3: K_{e3} fit results: data (dots) are superimposed on the fit function (histogram). The data/Fit ratio is also shown.

(different for low energy pions) and the stability over the data-taking time. Taking into account all systematic errors and combining the result for the two charge modes, KLOE finds for the quadratic fit:

$$\begin{aligned} \lambda'_+ &= (25.5 \pm 1.5_{stat.} \pm 1.0_{syst.}) \times 10^{-3} \\ \lambda''_+ &= (1.4 \pm 0.7_{stat.} \pm 0.4_{syst.}) \times 10^{-3} \end{aligned} \tag{2.1}$$

with a correlation of ~ -0.95. For the pole-model fit KLOE measures:

$$M_V = (870 \pm 6) \text{ MeV} \tag{2.2}$$

with probability $P(\chi^2) = 92.4\%$.

3. Measurement of form-factor parameters in $K_L \to \pi\mu\nu$ decays

The tag and preselection of $K_{\mu3}$ events are similar to those for K_{e3} decays described in the previous section. Two tracks are selected and associated to calorimeter clusters. $\pi\pi$ and $\pi\pi\pi$ events are rejected using kinematical cuts. A cut is applied on the plane of the variables $(\Delta_{\pi\mu}, \Delta_{\mu\pi})$, defined in the previous paragraph, to select $K_{\mu3}$ decays (left panel of Fig. 4). The 4% residual contamination from K_{e3} decays is reduced to 2% by applying a loose cut on a neural network variable (NN), based on E/p and shower shape, and on a ToF-based variable (rtof) (right panel of Fig. 4).

Since at low momenta the $\pi - \mu$ separation with ToF is difficult, due to the small mass difference, the form-factor parameters are measured from a fit to the neutrino energy (E_ν) spectrum. Infact, in this case there is no need to distinguish π from μ. Although in this case the errors on the slope parameters are 2-3 times bigger and the correlations are higher, the error on λ_0 is only 30% bigger if the fit is performed simultaneously to K_{e3} and $K_{\mu3}$. From 1.8 million selected events

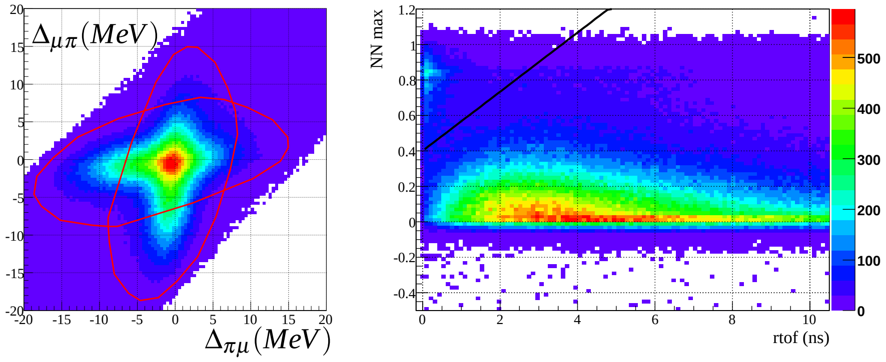


Figure 4: Selection cuts for $K_{\mu 3}$ events. Left: Elliptic cuts on the plane $(\Delta_{\pi\mu}, \Delta_{\mu\pi})$ are superimposed to the Monte Carlo distribution of signal events. Right: The neural network variable (NN) used to identify electrons is shown as a function of a ToF variable (rtof) for signal and background events. K_{e3} events have NN ~ 1 and rtof ~ 0. Selected events are below the shown cut.

KLOE finds as preliminary result:

$$\lambda_0 = (15.6 \pm 1.8_{stat.} \pm 1.9_{syst.}) \times 10^{-3} \tag{3.1}$$

The fit is shown in Fig. 5, where $\chi^2/\text{ndf} = 21/31$. The correlations of λ_0 with λ'_+ and λ''_+ are -0.95

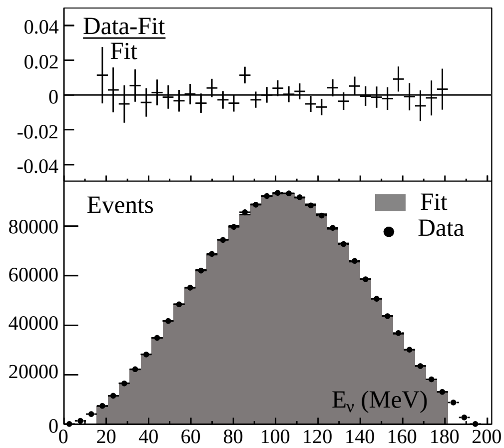


Figure 5: $K_{\mu 3}$ fi t (gray) to the E_ν distribution of the selected events (black dot). The upper plot shows the fi t residuals.

and 0.31, respectively.

Further improvements on λ_0 are expected. KLOE still has to analyze 2 fb^{-1} of data. With these data the relative error on λ_0 can be reduced to 5-10%.

References

[1] F. Ambrosino *et al.* [KLOE Collaboration], Phys. Lett. B **636** (2006) 166 [arXiv:hep-ex/0601038].

[2] C. Gatti, Eur. Phys. J. C **45** (2006) 417 [arXiv:hep-ph/0507280].