KLOE prospects and preliminary results for $K_{\ell 3}$ decay measurements

The KLOE Collaboration

The KLOE experiment has been running since April 1999 at the DAΦNE $e^+e^-$ collider at a center of mass energy centered around the $\phi$ meson mass. The luminosity integrated up to September 2002 is $\sim 500 \text{ pb}^{-1}$. Here we present the perspectives on the measurement of the $V_{us}$, CKM-matrix element with the KLOE detector, using both charged and neutral kaon semileptonic decays.

At present, determinations of $V_{us}$ and $V_{ud}$ provide the most precise constraints on the size of CKM matrix elements; in particular the most accurate determination of $V_{us}$ is obtained from semileptonic decays of both neutral and charged kaons ($K_{\ell 3}$). Concerning the steps necessary to extract $V_{us}$ from the experimental determination of $K_{\ell 3}$ decay rates, specifically the theoretical evaluation of $f_+(0)$ and the theoretical treatment of photonic radiative corrections, we refer the reader to the contribution to these proceedings by V. Cirigliano [1] and to the proceedings of the previous $CKM$ Workshop [2].

Measurements of the branching ratios and the momentum dependence of $f_+(0(t))$ ($\lambda_+ \text{ and } \lambda_0$) for the decays $K^+_{\ell 3}$, $K^0_{\ell 3}$, $K^+_0$, and $K^0_0$, together with the lifetimes $\tau_{K^+}$ and $\tau_{K^0}$, allows four independent determinations of the observable $|t_{K^+}f_+(0)| \cdot V_{us}$ to be obtained. At KLOE, we have the possibility of measuring the full set of kaon semileptonic decays using the same detector; moreover, in all channels we can use the tagging technique.

We will start with a summary of the characteristics of the KLOE detector and of the data set. We will then describe the status of the different contributions that the KLOE experiment can make in the field of $V_{us}$ determination.

The KLOE experiment at DAΦNE

KLOE [3] operates at DAΦNE [5], an $e^+e^-$ collider also known as the Frascati $\phi$ factory; $\phi$ mesons are produced in small angle (25 mrad) collisions of equal energy electrons and positrons, giving the $\phi$ a small transverse momentum component in the horizontal plane, $p_\phi \sim 13 \text{ MeV}/c$. The main advantage of studying kaons at a $\phi$ factory is that $\phi$ mesons decay $\sim 49\%$ of the time into charged kaons and $\sim 34\%$ of the time into neutral kaons. $K_L^+$’s and $K_S^+$’s (or $K^+$’s and $K^0$’s) are produced almost back-to-back in the laboratory, with mean decay paths $\lambda_L \sim 340 \text{ cm}$, $\lambda_S \sim 0.6 \text{ cm}$, and $\lambda_L \sim 90 \text{ cm}$, respectively. One of the features of a $\phi$ factory is the possibility to perform tagged measurements: the detection of a long-lived neutral kaon $K_L$ guarantees the presence of a $K_S$ of given momentum and direction and vice versa. The same holds for charged kaons.

The KLOE detector (fig. 1) consists of a large cylindri-
A calor dris chamber surrounded by a lead-scintillating fiber sampling calorimeter. A superconducting coil outside the calorimeter provides a 0.52 T field. The drift chamber [6], 4 m in diameter and 3.3 m long, has 12582 all-stereo sense wires and 37746 aluminium field wires. The chamber shell is made of carbon fiber-epoxy composite and the gas used is a 90% helium, 10% isobutane mixture. These features maximize transparency to photons and reduce $K_L \rightarrow K_S$ regeneration. The position resolutions are $\sigma_x \sim 150 \mu m$ and $\sigma_z \sim 2$ mm. The momentum resolution is $\sigma(p_\perp)/p_\perp \leq 0.4%$. Vertices are reconstructed with a spatial resolution of $\sim 3$ mm. The calorimeter [7] is divided into a barrel and two endcaps and covers 98% of the solid angle. The energy resolution is $\sigma_E/E = 5.7%/\sqrt{E(\text{GeV})}$ and the timing resolution is $\sigma_t = 54 ps/\sqrt{E(\text{GeV})} \oplus 50$ ps. The trigger [8] uses calorimeter and chamber information. For the work described here, the trigger relies entirely on calorimeter information. Two local energy deposits above threshold (50 MeV on the barrel, 150 MeV on the endcaps) are required. The trigger time has a large spread with respect to the bunch crossing time. However, it is synchronized with the machine RF divided by 4, $T_{\text{sync}} = 10.8$ ns, with an accuracy of 50 ps. The time $T_0$ of the bunch crossing producing an event is determined after event reconstruction.

The KLOE data set

During 2002 data taking DAΦNE reached a peak luminosity of $\approx 8 \times 10^{30} \text{cm}^{-2}\text{s}^{-1}$. Since the start of data taking, we have collected an integrated luminosity of $\sim 500 \text{ pb}^{-1}$; considering only the $\sim 400 \text{ pb}^{-1}$ of data passing all quality cuts, with particular reference to machine-background conditions, and using a $\phi$ cross-section of $\sim 3 \mu b$, we can estimate that our data set contains $\sim 6 \times 10^8 K^+K^-$ pairs and $\sim 4 \times 10^8 K_LK_S$ pairs. Therefore, for $K_{\ell 3}$, taking selection efficiencies into account, we estimate that we have about a million events for each of the semileptonic channels, which translates into a statistical error of $\sim 10^{-3}$ on the branching ratio measurements. Moreover, these data give a statistical contribution to the absolute error on the slope of $f_{s, 0}(t)$ of $\sim 10^{-4}$ for both neutral and charged kaons; we note here that $\alpha_0$ must be measured with an absolute error of $\sim 10^{-3}$ to reach a 1% relative precision on the theoretical determination of $f_{s, 0}(t)$ [9].

Two peculiar characteristics of KLOE, are the tagging technique and the good resolution on kaon momentum. The tagging allows us to select clean kaon beams of $K^*$ or of $K_{\ell 3}$, and to measure absolute branching ratios. Thus the strategy for the selection of $K_{\ell 3}$ decays is to tag using one kaon of the pair, and to look for the desired semileptonic decay of the other.

The very clean signature of the decays $K^+ \rightarrow \pi^+\pi^0$ and $K^+ \rightarrow \mu^+\nu$ is exploited to tag charged kaons (fig.2 left); only drift chamber information is used to select these decays, so that the tagging efficiencies for different decays of $K^*$ and $K^+$ are determined after event reconstruction.

Tagging allows us to select clean kaon beams of $K^*$ or of $K_{\ell 3}$, and to measure absolute branching ratios. Thus the strategy for the selection of $K_{\ell 3}$ decays is to tag using one kaon of the pair, and to look for the desired semileptonic decay of the other.

The very clean signature of the decays $K^+ \rightarrow \pi^+\pi^0$ and $K^+ \rightarrow \mu^+\nu$ is exploited to tag charged kaons (fig.2 left); only drift chamber information is used to select these decays, so that the tagging efficiencies for different decays of $K^*$ and $K^+$ are determined after event reconstruction.

For neutral kaons, we use the $K_L \rightarrow \pi^+\pi^-$ decays to tag the $K_L$, while the sample of $K_L$ interacting in the calorimeter ($K_L$-crash) are used to tag the $K_S$ (fig.2 right). In these cases as well the tagging efficiencies are estimated directly from data. With the statistics of $\sim 400 \text{ pb}^{-1}$ we can reach a level of $O(0.1\%)$ accuracy on tagging efficiencies, both for charged and neutral kaons.

As already mentioned, the second peculiar characteristic of KLOE is the good resolution on the kaon momentum. For neutral kaons, the resolution on $K_L$ momentum ($p_L = p_S - p_S$) relies on the resolution of the $K_S$ momentum ($\approx 1 \text{ MeV}$, measured with the drift chamber using $K_L \rightarrow \pi^+\pi^-$ events), and on the fact that $p_S$ is measured run by run using Bhabha events and contributes a negligible error to the $K_L$ resolution. For charged kaons, the kaon momentum is measured directly by the drift chamber with a resolution of $\approx 1 \text{ MeV}$.

Selection of $K_{\ell 3}$ samples

For charged kaons, the sample of $K_{\ell 3}$ events is selected by asking for a tag on one side, and for a decay vertex in the drift chamber and one $\pi^0$ in the electromagnetic calorimeter on the other. The time of flight information can be used to separate charged pions, muons, and electrons, exploiting the excellent timing resolution of the detector (fig.3). Most of the selection efficiencies can be evaluated directly from data using control samples: the momentum range of the lepton in $K_L$ is covered by $K^+ \rightarrow \pi^+\pi^0$, $K^+ \rightarrow \mu^+\nu$ and $K^+ \rightarrow \pi^+\pi^0\pi^0$ decays, while the energy range of $K_{\ell 3}$ $\pi^0$ clusters is covered by $\phi^0$ clusters from $K^+ \rightarrow \pi^+\pi^0$ and $K^+ \rightarrow \pi^+\pi^0\pi^0$ decays.

A sample of semileptonic $K_L$ decays has been selected from 78 pb$^{-1}$ of ‘02 data by looking for a $K_L$-tag on one side and asking for a vertex in the drift chamber fiducial volume. The separation of the various $K_L$ decays is evident in the plot (fig.4) of $P_{\text{miss}} - E_{\text{miss}}$ in the $\mu\pi$ or $\pi\mu$ mass (the mass assignment used is that which gives the smaller value of $E_{\text{miss}}$).
Figure 3. MC distribution of the $m^2$ of the charged daughter of the kaon, measured with a ToF technique: the $K^\pm e^\pm \nu$ and $K^\pm \mu^\pm \nu$ peaks are clearly separated while a background from $K^+ \to \pi^+ \pi^0 \pi^0$ and $K^\pm \to \pi^\pm \pi^0 \pi^0$ is still present.

Figure 4. Distribution of the difference between missing momentum and missing energy (MeV) for $K_L$ decays to charged product in the kaon rest frame.

Figure 5. Proper time distribution of decays $K_L \to \pi^0 \pi^0 \pi^0$ events.
Measuring $V_{us}$

Using experimental inputs from the PDG [10], four evaluations of the physical observable $|f_{K^\pi}^+(0) \cdot V_{us}|$ can be made (black points in fig. 6). KLOE preliminary branching ratio measurements of $K_\pi^0$ and $K_\mu^0$ confirm the previous value for $|f_{K^\pi}^+(0) \cdot V_{us}|$ (red open points in fig. 6). Also the KLOE preliminary branching ratio measurement of $K_S \rightarrow \pi e$ $= (6.81 \pm 0.12 \pm 0.10) \times 10^{-4}$ (upgrade with 2001 data of the 2000 result [12]) gives a $|f_{K^\pi}^+(0) \cdot V_{us}|$ value in agreement with the KLOE $K_L$ and PDG estimations (red point in fig. 6). It must be noted that each KLOE point in fig 6 has a statistical precision comparable to the PDG one which represents the fit or average of several experiments. Moreover, for most of the branching ratio measurements in the PDG it is not clear if these correspond to photon inclusive widths.

Conclusions

The KLOE preliminary measurements of $K_L$ charged decays and of $K_S \rightarrow \pi e$ branching ratios are currently at 2% level, while the $\tau_{K_S}$ is measured with a precision of 1%. Working is in progress for the other measurements involved in $V_{us}$. By measuring with the same detector the absolute branching ratios and the form factors momentum dependence both for charged and neutral kaon semileptonic decays, KLOE can improve the situation of the CKM-matrix element $V_{us}$.

References

1. V. Cirigliano, these proceedings
2. M Battaglia, AJ Buras, P Gambino and A Stocchi, eds. Proceedings of the First Workshop on the CKM Unitarity Triangle, CERN, Feb 2002, hep-ph/0303103
3. The KLOE Collaboration, A general purpose detector for DAΦNE, LNF-92-019 (1992).
4. The KLOE Collaboration, The KLOE detector, Technical Proposal, LNF-93/002 (1993).
5. S.Guiducci et al., Proc. of the 2001 Particle Accelerator Conference (Chicago, Illinois, USA), P. Lucas S. Weber ed., 353, (2001)
6. The KLOE Collaboration, Nucl. Inst. Meth. A 482 363 (2002)
7. The KLOE Collaboration, Nucl. Inst. Meth. A 488 (2002), 51-73
8. The KLOE Collaboration, Nucl. Inst. Meth. A 492 (2002), 134-146
9. J. Bijnens and P. Talavera, hep-ph/0303103
10. Particle Data Group 2002, K. Hagiwara et al., Phys. Rev. D 66 (2002)
11. The KLOE Collaboration, Phys. Lett. B 566 (2003), 61-69
12. The KLOE Collaboration, Phys. Lett. B 535/1 (2002), 37-42