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Measuring K_S and K_L lifetimes with the KLOE detector

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A ϕ-factory offers the possibility to select pure kaon beams. In $\phi \to K_S K_L$ decay the detection of a K_S (K_L) tags the presence of the K_L (K_S) and this allows to perform precise measurement of K_S-K_L properties. We are presently finalizing new determinations of the K_S and K_L lifetimes using the whole KLOE data set, about 2 fb^{-1}. Both determinations benefit from a precise knowledge of kaon momenta. The K_L lifetime, which has been already measured by KLOE with 0.6% accuracy using 20% of the total data sample, is obtained from a fit to the proper time distribution of $K_L \to \pi^0\pi^0\pi^0$ decays, tagged by the $K_S \to \pi^+\pi^-$ decay on the opposite hemisphere of the apparatus. The proper time distribution of a sample of $K_S \to \pi^+\pi^-$ decay events, selected with tighter cuts, is then used to get a competitive measurement of the K_S lifetime.

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DAΦNE [1] is an e^+e^- collider operating at a center of mass energy $\sqrt{s} \sim 1020$ MeV, the ϕ-meson mass (for a review of the experiments at DAΦNE see ref. [2]). Beams collide at an angle of π-0.025 rad. For each run we measure the CM energy $\sqrt{s}$, $\mathbf{p}_\phi$ and the average position of the beams interaction point P using Bhabha scattering events. For each run set, we generate a sample of Monte Carlo (MC) events with threefold equivalent statistics. We use a coordinate system with the z-axis along the bisector of the external angle of the e^+e^- beams, the so called beam axis, the y-axis pointing upwards and the x-axis toward the collider center. KLOE detector [3, 4, 5, 6] collected very large samples, $\sim 10^9$ events of slow K-mesons of well known momentum. Many properties of kaons such as masses and branching ratios have been already measured. While KLOE had not however attempted to measure the K_S lifetime, the K_L lifetime has already been measured, ref [7] (direct measure) and [8] (indirect measure using BR constraint). The ultimate motivation for the lifetime measurements is the determination of the quark mixing parameter V_{us}, see ref. [9], using as input only KLOE measurements.

1. K_S lifetime measurement.

$K_S \to \pi^+\pi^-$ decay events are selected requiring two opposite tracks intersecting at a point D with $r_{\rm D} < 10$ cm and $|z_{\rm D}| < 20$ cm, where $x = y = z = 0$ is the average e^+e^- collision point. The invariant mass of the two tracks, assumed to be pions, must satisfy $|M_{\pi\pi} - M_{K^0}| < 5$ MeV. The kaon momentum $\mathbf{p}_K$ can be obtained from the sum of the pion momenta and, with higher accuracy, from the kaon direction (always obtained from pions directions) and the knowledge of ϕ momentum and the center of mass energy, $\sqrt{s}$. We call the latter value $\mathbf{p}'_K$. The magnitude of the two values of the kaon momentum must agree to within 10 MeV. The above procedure selects a $K_S \to \pi^+\pi^-$ sample almost 100% pure. The ϕ decay point P lies on the beam axis and is known only roughly (~ 2 cm) in each run data period. For each event we evaluate $z_{\rm P}$ as the point of closest approach to the K_S direction as determined from the tracks. The transverse position of IP is assumed well known for each run. The resolution of $z_{\rm P}$ is about 2 mm. Events with $z_{\rm P} < 2$ cm are rejected. From the length of PD and p'_K we compute the K_S proper time. Its residual distribution is shown in fig. 1 left, histogram a, in units of the lifetime value used in our MC, τ_{MC}= 89.53 ps. The distribution has an rms spread of 0.86 τ_{MC} and is not symmetric. Time resolution can be improved discarding events with poor vertexing resolution. From MC we observe that bad vertex reconstruction is correlated with large values of $\Delta p = p_K - p'_K$, the difference in magnitude of $\mathbf{p}_K$ and $\mathbf{p}'_K$. Fig.1 right shows the Δp distribution for data and MC. In order to ensure good vertex reconstruction we apply analysis cuts on pion opening angle, pion polar angles and on the angle, in the transverse plane, between one pion and the kaon, in order to avoid large value of Δp. A further significant improvement in the time resolution is obtained performing a geometrical fit: event by evente we choose a new point P′ on the beam axis and a new decay point D′ on a line through P′, parallel to the kaon flight direction (assumed to be unbiased), so as to minimize $\chi^2 = |\mathbf{r}_{\rm D'} - \mathbf{r}_{\rm D}|^2/\sigma^2_{r_{\rm D}} + (z_{\rm P'} - z_{\rm P})^2/\sigma^2_z$. The proper time residual distribution, after all cuts and the geometrical fit, is shown in fig. 1 left, curve b. The rms spread in t is now 0.32 τ_{MC}, a factor of three lower than the initial value. After all these cuts survive about 20 million $K_S \to \pi^+\pi^-$ decay events (this analysis uses only the 2004 data sample, about 0.4 fb^{-1}). The final efficiency as a function of proper time is shown in fig. 2 left. To check the correctness of the K_S flight direction we use

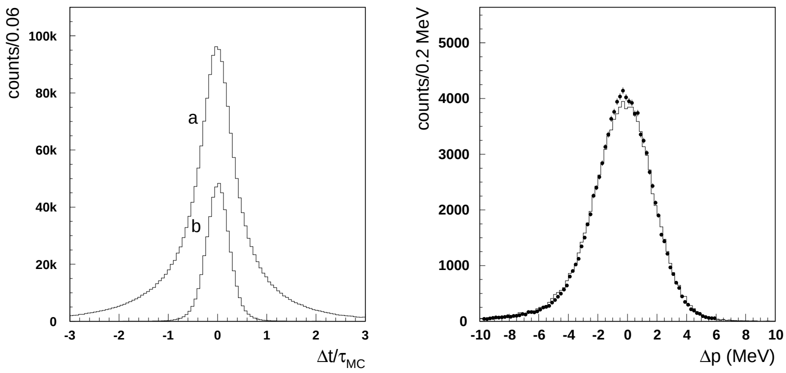

Figure 1: Left. Monte Carlo. Reconstructed time residual, histogram a, for the initial K_S sample (rms spread $\sim$0.86τ_{MC}) and after cuts and geometrical fit, b, (rms spread $\sim$ 0.32 τ_{MC}). Right. Distribution of Δp=$p_K - p'_K$ for data (dots), and Monte Carlo (line). The tail at left is due to the initial state radiation.

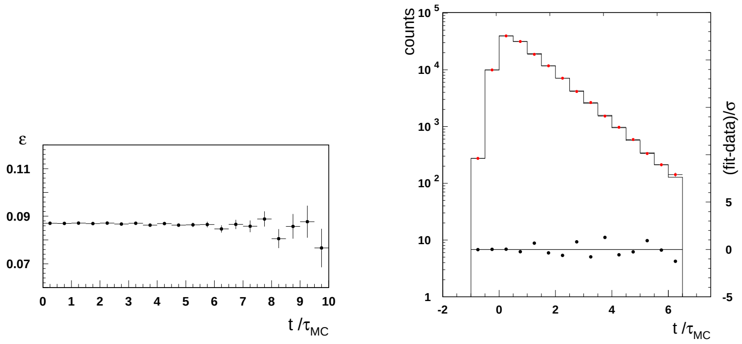

Figure 2: Left. Total efficiency as a function of proper time. Right. A fit example, dots are data, line is MC. The pull in visible below.

a sample of K_L-mesons reaching the calorimeter, where they are detected by nuclear interactions. The K_L interaction point in the calorimeter together with the known ϕ momentum gives the K_S direction with much better resolution. No bias is observed in the comparison with the K_S direction as obtained from pions. Errors in the reconstruction of the pion tracks can bias the position of P and D. If we divide our sample in the subsamples corresponding to the two possible di-pion 'V' topologies we find a difference of about 6% in the lifetime. We do correct for this effect. From MC we obtain the correction to be applied to the K_S decay length, as a function of Δp. The correction is applied event by event to the data. After applying this correction the difference is reduced to about 10^{-3}. To improve the result stability, we retain only events with $|\cos\theta_K| < 0.5$, discarding in this way only $\sim$8% of the events. Due to the different resolution of detector we divide the data in a 10$\times$18 grid in $\{\cos\theta_K, \phi_K\}$ and fit each data set for the lifetime τ. The other fit parameters are σ_1, σ_2 (the two-Gaussian resolutions), α (the weight of the first Gaussian), and δ. This last parameter takes into account for a possible difference of the transverse IP position with respect to the position assumed to be known in each run. We perform 180 independent fits. The fit range, -1 to 6.5 τ_{MC}, is divided in 15 time bins. A fit example is shown in Fig.2 right. Final result is obtained with a weighted average of the 180 fit results. The normalized pull of these 180 results has an rms of 1.1. Systematics evaluation have been obtained mainly with the cut variation method (Tab.1).

source	absolute value (ps)
analysis cuts	0.024
fit range	0.012
p'_K calibration	0.033
kaon mass	0.004
efficiency	0.005
total	0.043

Table 1: Systematic error contributions.

Our preliminary result

$$\tau(K_S) = (89.562 \pm 0.029_{\text{stat}} \pm 0.043_{\text{syst}})\,\text{ps} \tag{1.1}$$

is in agreement with recent measurements, ref. [11, 12, 13].

In KLOE we can measure the lifetime for kaons traveling in different galactic directions. We choose three orthogonal directions, the first being the direction of the dipole anisotropy of the cosmic microwave background (CMB), $\{\ell_1,\, b_1\}$ = {264°, 48°} in galactic coordinates, ref. [14]. The other two directions are taken as $\{\ell_2,\, b_2\}$ = {174°, 0°} and $\{\ell_3,\, b_3\}$ = {264°, -42°}. After transforming K_S momentum from local to galactic coordinate system, we retain only events with K_S momentum inside a cone of 30° opening angle, parallel (+) and antiparallel (-) to the chosen directions and evaluate the kaon lifetime. The 6 results are consistent with eq. 1.1. Defining the asymmetry $\mathscr{A} = (\tau_S^+ - \tau_S^-)/(\tau_S^+ + \tau_S^-)$, we obtain the results of tab. 2. Systematic errors are strongly reduced when

$\{\ell,\, b\}$	$\mathscr{A} \times 10^3$
$\{264°, 48°\}$	-0.2±1.0
$\{174°, 0°\}$	0.2±1.0
$\{264°, -42°\}$	0.0±0.9

Table 2: Observed asymmetry. Errors are dominated by statistics.

evaluating the asymmetry. Results in tab. 2 show all the asymmetries values are well consistent with zero.

2. K_L lifetime measurement

Before recent KLOE measurements [7, 8], present knowledge of K_L lifetime goes back to a single measurement performed about 40 years ago [10]. The KLOE detector is large enough, r=200 cm, so that about 50% of the K_L decay inside it. This analysis uses the 2004 and 2005 data sample, corresponding to an integrated luminosity of $\sim$ 2 fb^{-1}. We have measured the K_L lifetime using $K_L \to \pi^0\pi^0\pi^0$ decay events tagged by $K_S \to \pi^+\pi^-$ decay. This choice maximizes the number of usable events and minimize the disturbance of the K_L decay on the detection of the tagging K_S decay and therefore the systematic uncertainty. The selection of $K_S \to \pi^+\pi^-$ sample is the same as described in the K_S lifetime analysis (initial sample). The $K_L \to \pi^0\pi^0\pi^0$ decay vertex is reconstructed along the opposite direction to that of the K_S in the ϕ rest frame. The photon

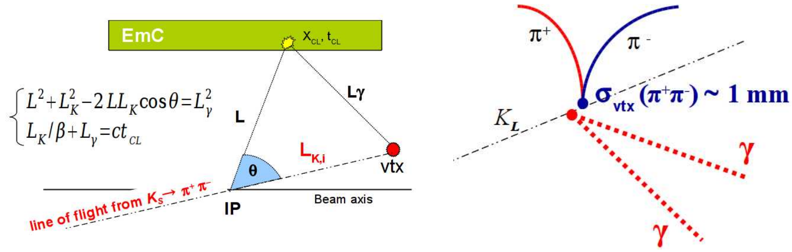

Figure 3: Left. Layout of the method used to determine the K_L decay lenght path, L_K, from EmC informations. Right. $K_L \to \pi^+\pi^-\pi^0$ control sample is used to calibrate vertex reconstruction.

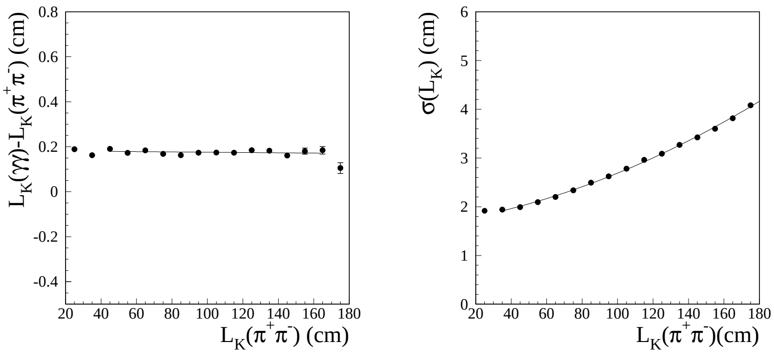

Figure 4: Left. Comparison of L_K determination from photons and from the position of the charged vertex in the $K_L \to \pi^+\pi^-\pi^0$ decay events. Right. Vertex resolution versus L_K.

energies and the K_L decay vertex position are obtained only with calorimetric informations. We require at least 3 clusters in the electromagnetic calorimeter (EmC) not associated to any track, each cluster with energy larger than 20 MeV. Distance between clusters must be at least 50 cm. The K_L polar angle is required to be within $40° \leq \theta_K \leq 140°$. After all these cuts a sample of about 45 million $K_L \to \pi^0\pi^0\pi^0$ decays is selected. The accuracy in the determination of the K_L direction is checked from $K_L \to \pi^+\pi^-\pi^0$ events, measuring the angle between $\vec{p}_{K_L}$ and the line joining the ϕ production point and the $K_L \to \pi^+\pi^-\pi^0$ decay vertex. The position of $K_L \to \pi^0\pi^0\pi^0$ vertex decay is obtained using the (photon) cluster time and position, according to the layout of Fig.3 left. The final K_L decay path lenght is obtained from the energy weighted average of the two closest (photon) clusters. A third cluster is required to be within 5σ. A control sample of $K_L \to \pi^+\pi^-\pi^0$ decay events, where both photons from π^0 decay are detected, is used to check the accuracy of the L_K determinations. The K_L lenght path as determined from the method described above, $L_K(\gamma\gamma)$, is compared with that obtained, with a much better accuracy, from the knowledge of the charge vertex position, $L_K(\pi^+\pi^-)$. An offset of 2 mm (Fig.4 left) results and must be corrected. Also the resolution $\sigma(L_K)$ is determined from $K_L \to \pi^+\pi^-\pi^0$ events by comparing $L_K(\gamma\gamma)$ and $L_K(\pi^+\pi^-)$. The residual distribution is shown in figure 4, right. The tagging efficiency for the $K_L \to \pi^0\pi^0\pi^0$ channel has a small linear dependence on L_K. We find the same linear dependence, with compatible slopes within their statistical uncertainties, for decay events $K_L \to \pi^+\pi^-\pi^0$ both

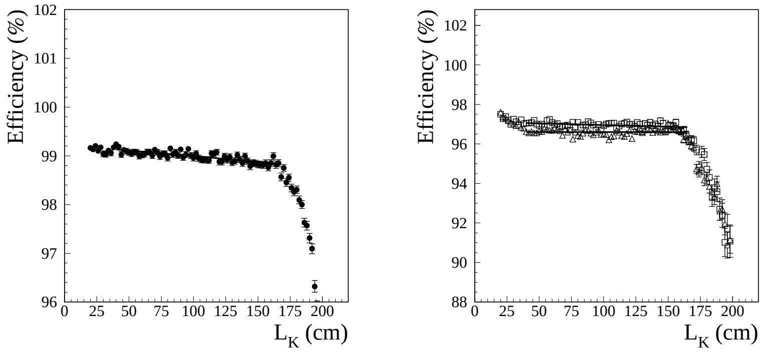

Figure 5: Left. Monte Carlo efficiency for $K_L \to \pi^0\pi^0\pi^0$ decay events. Right. Monte Carlo (triangle) and Data (box) efficiency for $K_L \to \pi^+\pi^-\pi^0$ decay events. A linear fit is superimposed.

for data and Monte Carlo. We use this data-Monte Carlo ratio efficiency to correct Monte Carlo efficiency for $K_L \to \pi^0\pi^0\pi^0$ decay events. A comparison between data and MC of the photon multiplicity and total energy distributions for $K_L \to \pi^0\pi^0\pi^0$ decays shows that only events with three and four clusters contain some background. Background, mostly to the three cluster events, is due to $K_L \to \pi^+\pi^-\pi^0$ decays where one or two charged pions produce a cluster not associated to a track and no track is associated to the K_L vertex. Other sources of background are $K_L \to \pi^0\pi^0$ decays and $K_S \to \pi^0\pi^0$ following $K_L \to K_S$ regeneration in the DC material. The $K_L \to \pi^+\pi^-\pi^0$ background and the other backgrounds in the three clusters sample are strongly reduced (from 5% to 1%) by requiring at least one cluster in the barrel with $E \geq$50 MeV and no tracks approaching the K_L line of flight by less than 20 cm. We perform a fit to proper time distribution with an exponential

source	absolute value (ns)
analysis cuts	0.08
time scale	0.06
bkg subtraction	0.08
tagging efficiency	0.17
total	0.21

Table 3: Systematic error contributions.

decay function convolute with a Gaussian resolution. Many effects distorting distribution have been corrected (efficiency and background subtraction). The preliminary result

$$\tau_{K_L} = (50.56 \pm 0.14_{stat} \pm 0.21_{syst})\,\mathrm{ns} \tag{2.1}$$

is in agreement with the previous KLOE direct measurement [8]. Efforts are still in progress in order to reduce both statistic and systematic error.

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