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RECENT RESULTS FROM KLOE AT DAΦNE

the KLOE collaboration

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Recent results obtained by the KLOE experiment operating at DAΦNE, the Frascati ϕ-factory, are presented. From a sample of about 10^9 ϕ-mesons produced at DAΦNE, we select K_L and K_S tagged mesons. We present the preliminary results on the search for $K_S \to 3\pi^0$, the branching ratio of the decay $K_S \to \pi e \nu$, and on the major K_L branching ratios, including the semileptonic decays relevant for the $|V_{us}|$ determination. A preliminary measurement of the K_L lifetime, using $K_L \to \pi^0\pi^0\pi^0$ decays, is also given.

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1 Introduction

DAΦNE [1], the Frascati ϕ factory, is an e^+e^- collider working at the center of mass energy $W \sim m_\phi \sim 1.02$ GeV, with a design luminosity of $5 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$.

The ϕ-mesons are produced in small angle (25 mrad) collisions of equal energy electrons and positrons, giving the ϕ a small transverse momentum component in the horizontal plane, $p_\phi \sim$ 13 MeV. The ϕ-mesons are produced with a visible cross section of $\sim 3.2\mu$b, and decay into

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K^+K^- (K_SK_L) pairs with a BR of $\sim 49\%$ ($\sim 34\%$). Kaons get a momentum of ~ 110 MeV/c ($\beta_K \sim 0.22$). K_S and K_L can be distinguished by their mean decay lengths: $\lambda_S \sim 0.6$ cm and $\lambda_L \sim 340$ cm.

The KLOE detector [2] consists of a 4 m diameter drift chamber surrounded by a lead-scintillating fiber electromagnetic calorimeter. A superconducting coil surrounding the barrel provides a 0.52 T magnetic field. Momentum resolution for tracks at large polar angle is $\sigma_p/p \leq 0.4\%$. Calorimeter energy resolution is $\sigma_E/E \sim 5.7\%/\sqrt{\mathrm{E(GeV)}}$ and the intrinsic time resolution is $\sigma_T = 54$ ps$/\sqrt{\mathrm{E(GeV)}} \oplus 50$ ps.

Data for an integrated luminosity of 450 pb^{-1} at the ϕ peak have been collected during years 2001 and 2002, corresponding to $\sim 1.4 \times 10^9$ ϕ-mesons produced. During 2002 data taking, the maximum luminosity reached by DAΦNE was 7.5×10^{31} cm^{-2}s^{-1}. Recently, after a long shutdown for machine improvements, KLOE has resumed its data taking in April 2004. Up to now (30^{th} October, 2004) $\sim$ 500 pb^{-1} have already been collected with a peak luminosity of 1.0×10^{32} cm^{-2}s^{-1}.

2 Kaon physics

Kaons are produced in pairs, so that the observation of a $K_S(K_L)$ guarantees the presence of a $K_L(K_S)$ with known momentum and direction in the opposite hemisphere (the same is true for charged kaons). This means that K's can be tagged, and highly pure and nearly monochromatic K_S, K_L, K^+ and K^- beams can be obtained.

The tagging of K_L and K_S is the basis of all the analysis concerning the neutral kaons.

About half of the K_L-mesons reach the calorimeter, where most interact,"K_L*-crash*". A K_L-crash is identified as a local energy deposit with energy above 100 MeV and a time of flight consistent with $\beta \sim 0.22$. The coordinates of the energy deposit determine the K_L's direction to ~ 20 mrad. K_S tagging efficiency is $\sim 30\%$.

K_L events are identified by the presence of a $K_S \to \pi^+\pi^-$ decay. We require a vertex with two opposite curvature tracks within a cylindrical FV of radius $r < 10$ cm and lenght $h < 20$ cm, around the IP. The two tracks, assumed to be pions, must have invariant mass within 5 MeV of m_{K_S}. The magnitude of the total momentum of the two tracks must be within 10 MeV of the value expected from the ϕ boost, $\vec{p}_\phi$. Tagging efficiency is ∼65%.

The tagged K_S (K_L) momentum is obtained from the decay kinematics of $\phi \to K_SK_L$ using the reconstructed K_L (K_S) direction and the known value of $\vec{p}_\phi$ (the boost of the ϕ, as the IP are reconstructed run by run using Bhabha events). Techniques to tag charged kaon beams have been developed also.

Some analyses have been already published at KLOE ([3–5]), but we will discuss here only the most recent and advanced items.

Direct search for $K_S \to \pi^0\pi^0\pi^0$

The decay $K_S \to 3\pi^0$ is a pure CP violating process. The related CP violation parameter η_{000} [6] is defined as the ratio of K_S to K_L decay amplitudes. In the Standard Model we expect η_{000} to be similar to η_{00}. The expected branching ratio of this decay, BR($K_S \to 3\pi^0$) $= \frac{\Gamma_L^{000}}{\Gamma_S} \cdot |\eta_{000}|^2 \sim$ BR($K_L \to 3\pi^0$)$\cdot \frac{\tau_S}{\tau_L} \cdot |\eta_{00}|^2 \sim 2 \times 10^{-9}$, makes its direct observation really challenging. The best direct upper limit on the BR has been set to 1.5×10^{-5} at 90% C.L. by SND [7] where, similar to KLOE, it is possible to tag a K_S beam. Recently NA48 [8] derived the limit 7.4×10^{-7} at 90% C.L., detecting the interference term between $K_S K_L$ in the same final state, which depends on η_{000}. The study of this decay is also important because of the uncertainty on η_{000} limits the precision on CPT invariance test via the Bell-Steinberger relation [9]. This relation uses unitarity to connect the CP violating amplitudes of K_S and K_L decays with the CP violating parameter ε and the CPT violating parameter δ through:

$$(1 + i\tan(\phi_{sw}))(\Re(\varepsilon) - i\Im(\delta)) = \sum (A^*(K_S \to f) A(K_L \to f)/\Gamma_S)$$

where the sum runs over all the possible decay channels f, and $\tan(\phi_{sw}) = 2\Delta m_{S,L}/(\Gamma_S - \Gamma_L)$.

A K_L-crash tag and six neutral clusters coming from the IP are required in the search for $K_S \to \pi^0\pi^0\pi^0$. The major background is $K_S \to 2\pi^0$ +2 fake γ from shower fragments, machine background clusters in overlap with the events or both.

To reduce the background a kinematic fit has been performed. The K_S mass, K_L 4-momentum conservation and $\beta = 1$ for each γ, is imposed. We also define 2 pseudo-χ^2, $\chi^2_{3\pi}$ and $\chi^2_{2\pi}$. The $\chi^2_{3\pi}$ is based on the 3 best reconstructed pion masses, while the $\chi^2_{2\pi}$ selects 4 out of the 6 γ's providing the best kinematic agreement with the $\pi^0\pi^0$decay.

The residual contamination due to fake K_L-crash tags from $K_S \to \pi^+\pi^-$, $K_L \to 3\pi^0$ events is reduced to a negligible amount by vetoing events with tracks coming from the IP. To enforce the selection we add a cut on the variable $\Delta E = M_\phi/2 - \sum E_i$, where the sum runs over the four γ's chosen by the $\chi^2_{2\pi}$; for the signal events the missing π^0 implies $\Delta E \simeq M_{\pi^0}$.

An optimisation of the cuts was performed to obtain the best average upper limit following the $\bar{N}_{90}$ prescription [10]. The final cuts have been set to: $\chi^2_{fit} < 31$, $\Delta E >$ 37 MeV and we have defined the following signal box region ($14 < \chi^2_{2\pi} < 60$ and $\chi^2_{3\pi} <$ 3.7). In Fig. 1 the events surviving this selection for data and MC are reported.

The selection efficiency is $\varepsilon_{3\pi^0} = (22.6 \pm 0.8)$%, and the expected background is $N_b = 3.2 \pm 1.4_{MCstat} \pm 0.5_{syst}$. The systematic error on the background is evaluated by comparing data and MC expectations in control boxes around the signal in the $\chi^2_{3\pi}$–$\chi^2_{2\pi}$ plane.

Four events are found in the data sample, in agreement with the background expectation. We set an upper limit on the number of $K_S \to \pi^0\pi^0\pi^0$ events to 5.8 at 90% C.L. In the same tagged sample we count 3.8×10^7 $K_S \to \pi^0\pi^0$ events, used for signal normalization.

We finally derive $\mathrm{BR}(\mathrm{K_S} \to 3\pi^0) \leq 2.1 \times 10^{-7}$ at 90% C.L. This result can also be translated into a limit $|\eta_{000}| \leq 0.024$ at 90% C.L., which greatly reduces the contribution of this decay to the error on $\Im(\delta)$.

BR($K_S \to \pi e \nu$) measurement

Discrete symmetries can be tested through the measurement of the charge asymmetries for K_L and K_S semileptonic decays, $A_{L,S}$, defined as

$$A_{L,S} = \frac{\Gamma\left(\mathrm{K_{L,S}} \to \pi^- \mathrm{e}^+ \nu\right) - \Gamma\left(\mathrm{K_{L,S}} \to \pi^+ \mathrm{e}^- \bar{\nu}\right)}{\Gamma\left(\mathrm{K_{L,S}} \to \pi^- \mathrm{e}^+ \nu\right) + \Gamma\left(\mathrm{K_{L,S}} \to \pi^+ \mathrm{e}^- \bar{\nu}\right)}.$$

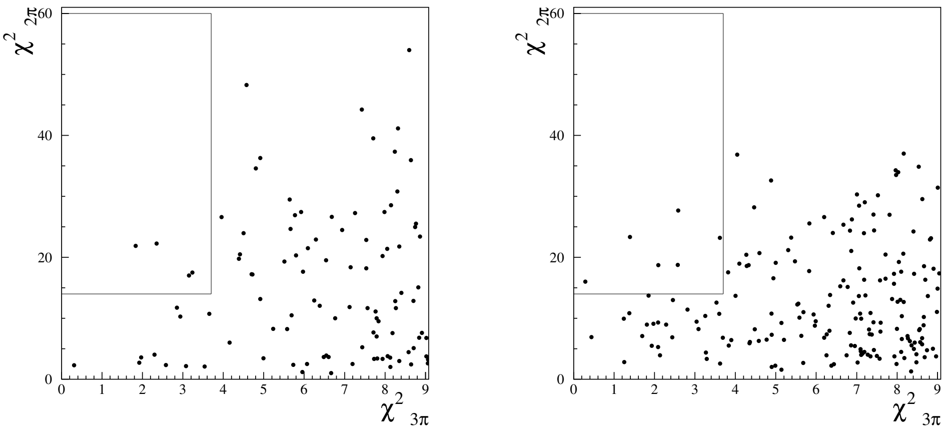

Fig. 1. $\chi^2_{2\pi}$ versus $\chi^2_{3\pi}$ for our sample at the end of the analysis chain: data (left) and Monte Carlo (right). The rectangular regions represent the signal box.

If CPT invariance holds and the rule $\Delta S = \Delta Q$ holds [2], each of the two charge asymmetries are expected to be equal to $2 \times Re(\epsilon) \simeq 3 \times 10^{-3}$, where ϵ is the parameter describing CP violation in the $K^0 - \bar{K}^0$ mass matrix. If $\Delta S = \Delta Q$ holds, a difference between A_S and A_L signals CPT violation either in the mass matrix, or in the decay amplitudes. The value of A_L is known at present with a precision of 10^{-4} [12, 13], while A_S has never yet been measured. At present, the most precise test of CPT conservation in the mixing has been performed using interferometry technique at the CPLEAR experiment [14] and has a precision of 3×10^{-4}. The KLOE collaboration has already published the BR for the K_{e3} decay of the K_S with a relative error of 5%, using 17 pb^{-1} collected in 2000 [4]. A new measurement with the whole 2001-2002 statistics gives a first determination of A_S.

The K_L-crash tagged event sample is used for this measurement. Two tracks of opposite curvature forming a vertex close to the IP are required. The invariant mass of the pair, calculated assuming both tracks are pions, must be smaller than 490 MeV. This rejects $\sim 95\%$ of the $\pi^+\pi^-$ decays.

We take advantage of the good timing performances of our electromagnetic calorimeter to discrimitate between electrons and pions by time of flight (TOF) measurements. Tracks are therefore required to be associated with calorimeter energy clusters.

In order to avoid uncertainties due to the determination of t0 (the time of the bunch crossing producing the event), we make cuts on the two-track time difference.

After the TOF requirements, particle types and charges for signal events can be assigned very precisely: the probability of misidentification is less than 10^{-4}.

[2] At present, the most precise test of the $\Delta S = \Delta Q$ rule comes from analysis of the time distribution of semileptonic strangeness-tagged kaon decays at CPLEAR [11]. The CPLEAR collaboration finds $Re(x_+)$ to be compatible with zero with an error of 6×10^{-3}.

Finally, for events passing all of the above criteria, we compute the missing energy and momentum $E_{\rm miss}$, $p_{\rm miss}$. For $\pi^{\pm}e^{\mp}\bar{\nu}(\nu)$ decays, these variables are the neutrino energy and momentum, and satisfy $E_{\rm miss} = cp_{\rm miss}$. The distribution of $E_{\rm miss} - cp_{\rm miss}$ is shown in Fig. 2, for $\pi^+e^-\bar{\nu}$ (left panel) and for $\pi^-e^+\nu$ (right panel) candidate events.

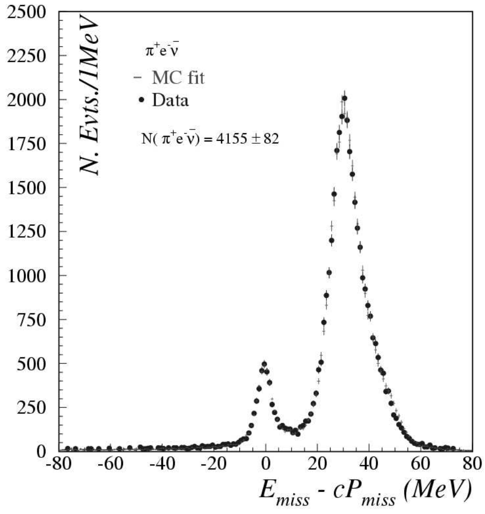

Fig. 2. $E_{\rm miss} - cp_{\rm miss}$ spectrum for $\pi^-e^+\nu$ (left panel) and for $\pi^+e^-\bar{\nu}$ (right panel) candidate events. Filled dots represent data; the crosses are the result of a fit varying the normalization of MC distributions for signal and background.

A clear peak at $E_{\rm miss} - cp_{\rm miss} = 0$ is evident and corresponds to the $K_S \rightarrow \pi e \nu$ signal. Events with $E_{\rm miss} - cp_{\rm miss} > 10$ MeV are mostly due to $K_S \rightarrow \pi^+\pi^-$ decays in which a pion decays to a muon before reaching the tracking volume or in which one of the two pion tracks is badly reconstructed.

The fit of the data to the sum of the signal and background spectra simulated using the Monte Carlo (MC) is also shown. The free fit parameters are the signal and background normalizations. Three independent fits are performed: one for each charge state and one in which we do not distinguish by charge.

By normalising to the number of $K_S \rightarrow \pi^+\pi^-$ events counted in the same tagged sample, we get the following preliminary values:

$$BR(K_S \rightarrow \pi^-e^+\nu) = (3.54 \pm 0.05_{\rm stat} \pm 0.05_{\rm syst}) \times 10^{-4},$$

$$BR(K_S \rightarrow \pi^+e^-\bar{\nu}) = (3.54 \pm 0.05_{\rm stat} \pm 0.04_{\rm syst}) \times 10^{-4},$$

$$BR(K_S \rightarrow \pi^{\pm}e^{\mp}\bar{\nu}(\nu)) = (7.09 \pm 0.07_{\rm stat} \pm 0.08_{\rm syst}) \times 10^{-4}.$$

On the basis of this results, we derive also the first measurement ever done of the charge asimmetry for the K_S :

$$A_S = (-2 \pm 9_{\rm stat} \pm 6_{\rm syst}) \times 10^{-3}.$$

This value is consistent with the much more precise A_L evaluations.

K_L Branching Ratios and $\tau(K_L)$

The measurement of the K_L absolute Branching Ratios is an unique possibility of the ϕ-factory, where a pure sample of almost monochromatic K_L can be selected by the identification of the $K_S \to \pi^+\pi^-$decays. The K_L absolute BRs can be determined on a tagged K_L events sample by counting the fraction of K_L decays in each channel, correcting for acceptances, reconstruction efficiencies and background. However, the tagging procedure is not perfect, because the tagging efficiency depends slightly on the K_L evolution[3]. The difference in tagging efficiency depends on the tagging algorithm and its minimization is used to optimize the tagging criteria. The tag bias is defined as the ratio of the tagging efficiency of each channel and the overall tagging efficiency.

The main source of tag bias is due to the dependence of the trigger efficiency on the K_L behavior. The hardware calorimeter trigger, which requires two local energy deposits above some threshold (50 MeV on the barrel and 150 MeV on the end caps), is used for the present analysis. The trigger efficiency is essentially 100% for $\pi^0\pi^0\pi^0$, between 95-85% for charged decays and lower for K_L interacting in the calorimeter or escaping. A tighter tag using $K_S \to \pi^+\pi^-$ events that provide themself the trigger of the event, has been used. In this case the overall tagging efficiency become $\simeq 20\%$. The average tag bias is .985, 0.99 and 1.02 for $\pi^\pm e^\mp \nu$ or $\pi^\pm \mu^\mp \nu$, $\pi^+\pi^-\pi^0$ and $\pi^0\pi^0\pi^0$ decays, respectively.

The FV used for the analysis is defined inside the drift chamber by $35 < \sqrt{x^2+y^2} < 150$ cm and $|z| < 120$ cm, where (x, y, z) are the K_L decay vertex position coordinates.

We require two good K_L decay tracks forming a vertex to improve the momentum resolution of the K_L decay products. The average tracking efficiency is 60.5% for K_{e3} 58.5% for $K_{\mu 3}$ and 43.0% for $\pi^+\pi^-\pi^0$ as evaluated from Monte Carlo simulation.

From Monte Carlo studies we found that the best discriminant amongst the K_L charged decay modes is the smallest of the two values of $\Delta_{\mu\pi}$=$|\vec{p}_{\rm miss}| - E_{\rm miss}$, where $\vec{p}_{\rm miss}$ is the missing momentum and $E_{\rm miss}$ is the missing energy evaluated assigning to the two particles the pion and muon masses.

The position of the K_L vertex for decays to neutrals is obtained from the photon time of arrival at the EMC. Each photon determines the K_L decay length L_K. The best value of L_K is the energy weighted average of each measurement. At least three photons with energy greater than 20 MeV originating from the K_L decay are required for the $K_L \to \pi^0\pi^0\pi^0$ event selection. The selection efficiency is about 99% with a residual contamination of 1.3% mainly due to $\pi^+\pi^-\pi^0$.

Systematic errors due to the still limited statistics in the evaluation of corrections, data Monte Carlo consistency, signal extraction stability, and limited knowledge of the K_L lifetime have been studied. They amount to 0.9-1 % depending on the decay mode, and are dominated by the knowledge of the $\tau(K_L)$ value and by the uncertainties on the tag bias evaluation.

A total of about 13×10^6 tagged K_L events are used for the measurement of the branching fractions. Almost twice as many additional events provide calibration. The number of signal events is obtained from a fit to the $|\vec{p}_{\rm miss}| - E_{\rm miss}$ distribution from data to a linear combination of Monte Carlo distributions for $K_L \to \pi^\pm e^\mp \nu$, $K_L \to \pi^\pm \mu^\mp \nu$ and $K_L \to \pi^+\pi^-\pi^0$(see Fig. 3).

[3] We include events with the K_L interacting in the calorimeter, escaping the detector and all K_L decays.

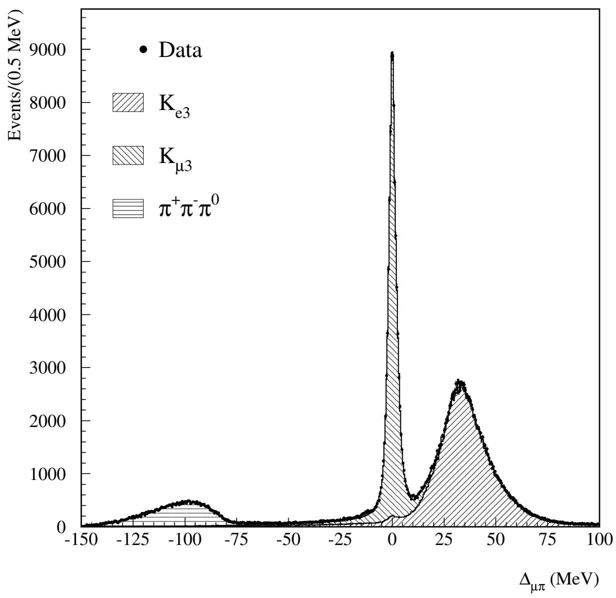

Fig. 3. $\Delta_{\mu\pi}$ distribution for one data sample and Monte Carlo. The contributions from different channels is also given.

The results of the measurement of the absolute branching fractions obtained using for the lifetime our result, reported later, are:

$$BR(K_L \to \pi^\pm e^\mp \nu) = \quad 0.3994 \pm 0.0006_{\,\rm stat} \pm 0.0034_{\,\rm syst},$$

$$BR(K_L \to \pi^\pm \mu^\mp \nu) = \quad 0.2708 \pm 0.0005_{\,\rm stat} \pm 0.0025_{\,\rm syst},$$

$$BR(K_L \to \pi^0 \pi^0 \pi^0) = \quad 0.2014 \pm 0.0003_{\,\rm stat} \pm 0.0022_{\,\rm syst},$$

$$BR(K_L \to \pi^+ \pi^- \pi^0) = \quad 0.1271 \pm 0.0004_{\,\rm stat} \pm 0.0010_{\,\rm syst}.$$

The sum of all measured BR's above, plus the PDG value for the remaining rare decays (0.0036), is $\sum$BR$_i$=1.0023±0.0009±0.0077, where the result, as remarked earlier depends on K_L lifetime. Turning the argument around, by renormalizing the sum to 1.0 we obtain the K_L lifetime:

$$\tau(K_L) = 51.35 \pm 0.05_{\,\rm stat} \pm 0.26_{\,\rm syst} \text{ ns}$$

The K_L proper time distribution has been obtained with $\sim 15 \times 10^6$ $K_L \to \pi^0\pi^0\pi^0$ decays, selected as in ref. [5]. The distribution is fitted with an exponential inside the FV, ranging over K_L decay lengths from 50 to 160 cm. In this interval the decay reconstruction efficiency is flat to ∼0.3 %. Variations of the fit result vs the FV choice are well within the statistical accuracy of the fit itself. Our preliminary result is:

$$\tau(K_L) = 51.15 \pm 0.20_{\rm stat} \pm 0.40_{\rm syst}\ {\rm ns}$$

The systematic error is at present dominated by the Monte Carlo statistics.

$|V_{us}|$ determination

The most precise check on the unitarity of the CKM mixing matrix is provided by measurements of $|V_{us}|$ and $|V_{ud}|$, the contribution of V_{ub} being at the level of 10^{-5}. $|V_{us}|$ is proportional to the square root of the kaon semileptonic partial width. Many factors are necessary for reaching the desired result [16]. In general we can write for $|V_{us}| \times f_+^{K^0}(0)$

$$\left[\frac{192\,\pi^3\Gamma}{G^2 M^2\, S_{\rm ew}\, I_i(\lambda'_+, \lambda''_+ \lambda_0)}\right]^{1/2} \frac{1}{1+\delta^i_{\rm em}+\Delta I_i/2}$$

where $f_+^{K^0}$ is the normalization of the form factors at zero momentum transfer and $I_i(\lambda'_+, \lambda''_+, \lambda_0)$ is the integral of the phase space density, factoring out $f_+^{K^0}$ and without radiative corrections. Short distance radiative corrections are in the universal term $S_{\rm ew}$ [17]. In addition long distance radiative corrections [18, 19] for form factor and phase space density are included as $\delta^i_{\rm em}$ and $\Delta I_i(\lambda)$. λ'_+ and λ''_+ are the slope and curvature of the vector form factor f_+. λ_0 is the slope of the scalar form factor. Using $\lambda'_+ = 0.0206 \pm 0.0018$, $\lambda''_+ = 0.00032 \pm 0.0007$ and $\lambda_0 = 0.0137 \pm 0.0013$ from KTeV [20] we obtain:

$$f_+^{K^0} \times |V_{us}| = 0.2147 \pm 0.0014 \text{ from } {\rm K_{Le3}}$$
$$f_+^{K^0} \times |V_{us}| = 0.2167 \pm 0.0015 \text{ from } {\rm K_{L\mu3}}$$
$$f_+^{K^0} \times |V_{us}| = 0.2171 \pm 0.0017 \text{ from } {\rm K_{Se3}}$$

A precise estimate $f_+^{K^0}(0) = 0.961 \pm 0.008$ was first given in 1984 [21]. Very recently lattice calculations [22] have given $f_+^{K^0}(0) = 0.960 \pm 0.009$, in excellent agreement with [21]. Using $V_{\rm ud} = 0.9740 \pm 0.0005$ from [23] the unitarity prediction is:

$$f_+^{K^0\pi^-}(0) \times |V_{us}| = 0.2177 \pm 0.0028$$

in agreement with the above quoted values. The possible violation of unitarity in the first row of the CKM matrix which followed from the value for BR(K_{e3}) given in the PDG particle listings is clearly no longer present. Our results are preliminary at the moment.

3 Non-kaon physics

Other than producing kaons, the ϕ meson decays $\sim$ 15% of the time in $\rho\pi$ and through radiative decays into pseudoscalar (η, η') and scalar (f_0, a_0) mesons. Although many interesting analyses have been published [24–27] on these items, and their findings are being improved with the larger statistical sample available, we discuss here only the study of the $f_0(980) \to \pi^+\pi^-$ decay.

3.1 Search for $\phi \to f_0(980)\gamma$ in $\pi^+\pi^-\gamma$ events

The ϕ radiative decays to scalar mesons give significant insight in the assessment of the nature of lower mass scalar mesons, in particular the scalar iso-scalar meson f_0 is searched in the $\pi^0\pi^0\gamma$ and $\pi^+\pi^-\gamma$ final states. KLOE has already published a study of the $\phi \to \pi^0\pi^0\gamma$ process based on 17 pb^{-1} of the 2000 data sample [25] where the f_0 signal is observed and analysed in the $M(\pi^0\pi^0)$ mass spectrum.

The analysis of the $f_0 \to \pi^+\pi^-$ requires much more statistics due to the presence of irreducible backgrounds with rates larger respect to the signal. These backgrounds are $e^+e^- \to \pi^+\pi^-$ events accompained by initial (ISR) or final (FSR) state radiation. A further lower rate background is due to the decay chain $\phi \to \rho^\pm\pi^\mp$ with $\rho^\pm \to \pi^\pm\gamma$. Since the ISR cross-section is peaked at small photon angles respect to the beam line, the f_0 events are searched in the large photon angle region $45^o < \theta < 135^o$.

Although in this region the ISR is still the dominant process, the f_0 signal appears as a bump in the $\pi^+\pi^-$ invariant mass $M_{\pi\pi}$ spectrum around 980 MeV. The left panel of Fig. 4 shows the spectrum obtained from a 350 pb^{-1} data sample at $\sqrt{s} = M_\phi$.

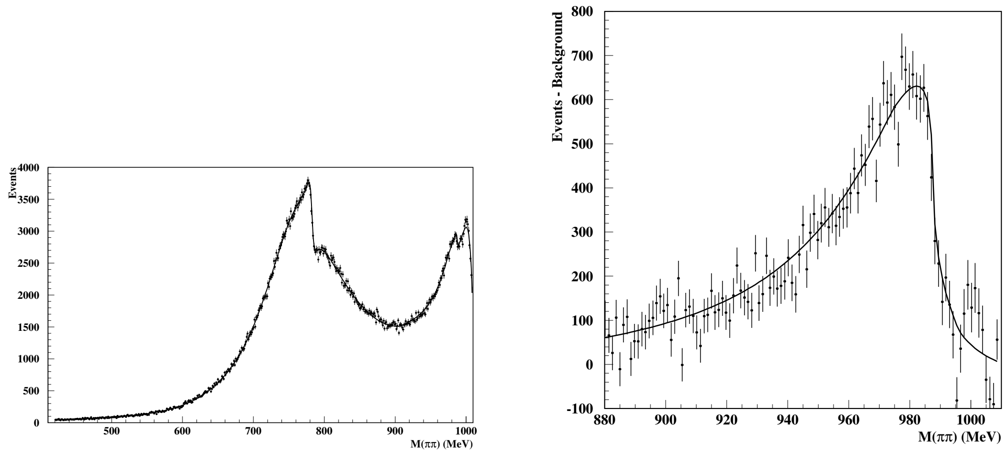

Fig. 4. (left panel) $M_{\pi\pi}$ spectrum of $\pi^+\pi^-\gamma$ events. (right panel) $M_{\pi\pi}$ spectrum of $\pi^+\pi^-\gamma$ events after background subtraction.The curve is the result of the fit described in the text.

The spectrum is dominated by the radiative return to the ρ^0. The f_0 bump is clearly evident close to the upper edge of the mass spectrum. An overall fit to the spectrum has been done applying the following formula:

$$\frac{dN}{dM_{\pi\pi}} = \left[(\frac{d\sigma}{dM_{\pi\pi}})_{ISR} + (\frac{d\sigma}{dM_{\pi\pi}})_{FSR+f_0} + (\frac{d\sigma}{dM_{\pi\pi}})_{\rho\pi} \right] \times L \times \epsilon(M_{\pi\pi})$$

with L the integrated luminosity and $\epsilon(M_{\pi\pi})$ the selection efficiency function of $M_{\pi\pi}$. The ISR and $\rho\pi$ contributions are parametrised according to [28–30]. The FSR and f_0 amplitudes give

rise to an interference term since the two pion state has the same quantum numbers in the two cases [31]. The f_0 amplitude is described assuming that the ϕ decays to $f_0\ \gamma$ through a charged kaon loop.
After subtracting the background as determined by the fit a clean peak for the $f_0 \to \pi^+\pi^-$ signal appears in the $M_{\pi\pi}$ spectrum (see the right panel of Fig. 4).

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