PHYSICS HIGHLIGHTS FROM KLOE*

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(Received July 2, 2007)

The KLOE experiment has successfully completed its data taking in March, 2006, with a total integrated luminosity of about 2.5 fb^{-1}. The analyses of 20% of the whole data sample have been mostly finalized and new results relevant, among other issues, for improving the sensitivity on the $\mathcal{CP}$, $\mathcal{CPT}$ violation parameters and for testing unitarity in the first row of the CKM matrix have been recently published. This paper reviews the major achievements in kaon and hadron physics.

PACS numbers: 13.20.–v, 13.20.Eb, 13.66.Bc, 13.66.Jn

1. Introduction

During the last data taking period, started in May 2004, DAϕNE, the Frascati ϕ-factory, has delivered data with increasing performance reaching 200 pb^{-1} per month. The KLOE detector [1] has operated with excellent efficiency collecting more than 95% of the delivered luminosity, in steady conditions of detector performance, calibration quality as well as machine background and beam energy. More than 90% of the sample has been reconstructed and a challenging production of about 2 fb^{-1} of simulated events, including details of the running conditions (beam kinematics and machine background) is underway. KLOE, with the analysis of 450 pb^{-1} (20% of the whole sample), has been able to reach an accuracy of few per mil on the measurements of the absolute kaon branching ratios (BR) and on the kaon lifetimes, has studied the decays of the non-$q\bar{q}$ candidates, $f_0(980)$ and $a_0(980)$, and has obtained new measurements in the pseudoscalar sector. The results on hadronic cross section are the subject of a separate paper [2].

* Presented at The Final EURIDICE Meeting "Effective Theories of Colours and Flavours: from EURODAPHNE to EURIDICE", Kazimierz, Poland, 24–27 August, 2006.

2. Results in Kaon physics

For long lived neutral and charged kaons the semileptonic BRs and lifetimes have been measured. An almost background-free sample of 13,000 $K_\mathrm{S} \to \pi^\pm e^\mp \nu$ events has been isolated, and the $\pi^+ e^-$ and the $\pi^- e^+$ final states separately measured. The limit on $\mathrm{BR}(K_\mathrm{S} \to \pi^0\pi^0\pi^0)$ has been improved. For charged kaons $\mathrm{BR}(K^+_{\mu 2})$ has been also obtained to 0.3%. From these precise measurements a novel determination of the $\mathcal{CP}$, $\mathcal{CPT}$ violating parameters has been derived and the V_{us} element of the CKM matrix has been extracted with 0.9% fractional error.

2.1. The K_L main decay modes

The measurement of the absolute K_L BRs through the tagging technique is a unique possibility of the ϕ-factory. A pure sample of nearly monochromatic K_L's is selected by the identification of $K_\mathrm{S} \to \pi^+\pi^-$ decays and the K_L kinematics is fixed by reconstruction of the tagging decay. K_L charged decays are recognized by requiring a decay vertex along the K_L line-of-flight. K_L charged modes are separated by $\Delta_{\mu\pi} = |p_\mathrm{miss} - E_\mathrm{miss}|$, where p_miss and E_miss are missing momentum and energy evaluated using pion mass for one track and muon mass for the other, and $\Delta_{\mu\pi}$ is the minimum between the two possible values. The number of events is obtained by fitting the $\Delta_{\mu\pi}$ spectrum with a linear combination of four Monte Carlo-predicted shapes ($K_\mathrm{L} \to \pi e\nu, \pi\mu\nu, \pi^+\pi^-\pi^0, \pi^+\pi^-$). The $\Delta_{\mu\pi}$ spectrum is sensitive to the radiative corrections that are simulated by very accurate generators in the KLOE Monte Carlo (MC) [3]. For the $K_\mathrm{L} \to \pi^0\pi^0\pi^0$ events, the neutral vertex position is reconstructed exploiting the time-of-flight capability of the calorimeter (EMC). Arrival time of each photon gives an independent determination of the path-length of the K_L and its final value is obtained from a weighted average. The $K_\mathrm{L} \to \pi^0\pi^0\pi^0$ sample is used not only for the BR measurement, but also for determining the K_L lifetime (τ_{K_L}) [4], from a fit to the proper-time distribution. The result is $\tau_{K_\mathrm{L}} = (50.92 \pm 0.17 \pm 0.25)$ ns. The $K_\mathrm{L} \to \pi^+\pi^-\pi^0$ control sample has been used to derive and control the systematics errors. A total of about 13×10^6 tagged events have been analyzed for these measurements. Since the acceptance in the fiducial volume depends on the K_L lifetime, the sum of all of the decay modes has been set equal to unity, removing the dependence on τ_{K_L} and obtaining in fact also a precise determination of the K_L lifetime itself. Results [5] for the main BRs are:

$$\begin{aligned}
\mathrm{BR}(K_\mathrm{L} \to \pi e\nu) &= 0.4007 \pm 0.0005_\mathrm{stat} \pm 0.0004_\mathrm{syst-stat} \pm 0.0014_\mathrm{syst}\,,\\
\mathrm{BR}(K_\mathrm{L} \to \pi\mu\nu) &= 0.2698 \pm 0.0005_\mathrm{stat} \pm 0.0004_\mathrm{syst-stat} \pm 0.0014_\mathrm{syst}\,,\\
\mathrm{BR}(K_\mathrm{L} \to \pi^0\pi^0\pi^0) &= 0.1997 \pm 0.0003_\mathrm{stat} \pm 0.0004_\mathrm{syst-stat} \pm 0.0019_\mathrm{syst}\,,\\
\mathrm{BR}(K_\mathrm{L} \to \pi^+\pi^-\pi^0) &= 0.1263 \pm 0.0004_\mathrm{stat} \pm 0.0003_\mathrm{syst-stat} \pm 0.0011_\mathrm{syst}\,.
\end{aligned}$$

The corresponding lifetime is $\tau_{K_L} = (50.72 \pm 0.17_{\rm stat} \pm 0.33_{\rm syst})$ ns, in agreement with the direct measurement. Averaging the two, independent measurements we find: $\tau_{K_L} = (50.84 \pm 0.23)$ ns, with 0.45% fractional error.

2.2. Semileptonic form factor slope from K_L decays

In the matrix element of the semileptonic modes $K_{\rm L,S} \to \pi^{\pm} e^{\mp} \nu$ only the vector form factor $f_+(t)$ contributes. This form factor (*ff*) is parametrized as

$$f_+(t) = f_+(0) \left[1 + \lambda'_+ \frac{t}{m^2_{\pi^+}} + \frac{\lambda''_+}{2} \frac{t^2}{m^4_{\pi^+}} + ... \right] ,$$

where $f_+(0)$ is evaluated from theory and t is the $K \to \pi$ momentum transfer. About 2 million $K_L \to \pi e \nu$ decays have been used to measure the semileptonic *ff* slopes. Since the K_L momentum at the ϕ-factory is fixed by tag reconstruction, is possible to determine t, and to extract the slope-parameter(s) by fitting the spectrum with MC-predicted shapes. Results from the two lepton charges have been separately evaluated to control the reliability of the efficiency evaluation, different for the two charge states. The results are,

$$\lambda'_+ = (25.5 \pm 1.5_{\rm stat} \pm 1.0_{\rm syst}) \times 10^{-3} ,$$

$$\lambda''_+ = (1.4 \pm 0.7_{\rm stat} \pm 0.4_{\rm syst}) \times 10^{-3} ,$$

with $\chi^2/ndf = 325/362$ ($P(\chi^2) = 92\%$). The same data-set has been fit using the pole parametrization: $f_+(t)/f_+(0) = M_{\rm V}^2/(M_{\rm V}^2 - t)$, obtaining $M_{\rm V} = (870 \pm 6_{\rm stat} \pm 7_{\rm syst})\,{\rm MeV}$ ($\chi^2/ndf = 326/363$), in agreement with the quadratic parametrization that can be derived from the Taylor-expansion of the pole function, constraining $\lambda''_+ = 2\lambda'^2_+$. This is nicely satisfied by our results [6], competitive with other recent measurements [7, 8].

2.3. Measurement of BR*($K_L \to \pi^+\pi^-(\gamma)$)*

A measurement of the absolute BR for this decay is aimed at shedding light on the unclear experimental status: the old results differs by 6% (*i.e.* shows a $4 - \sigma$ discrepancy) with respect to a recent measurement to 0.6% from the KTeV experiment [9]. A precise measurement of BR($K_L \to \pi^+\pi^-(\gamma)$) has been obtained through the ratio $R = {\rm BR}(K_L \to \pi^+\pi^-(\gamma))/ {\rm BR}(K_L \to \pi\mu\nu)$ using the semileptonic BR from KLOE [5]. For selecting the $K_L \to \pi^+\pi^-(\gamma)$ events, the distribution of $\sqrt{E^2_{\rm miss} + |p_{\rm miss}|^2}$ has been used, where $E_{\rm miss}$ is the missing energy in the hypothesis of $K_L \to \pi^+\pi^-$ decay. A fit to the distribution with a linear combination of MC-predicted shapes for the signal and the $K_{\rm L} \to \pi\mu\nu$, $K_{\rm L} \to \pi e\nu$ background in the region $\sqrt{E^2_{\rm miss} + |p_{\rm miss}|^2} \leq 20$ MeV provides the event count. The analysis of the 2001–2002 data sample has been recently completed [10] and the result, fully inclusive of the final-state radiation, is

$$\mathrm{BR}(K_{\rm L} \to \pi^+\pi^-(\gamma)) = (1.963 \pm 0.012_{\rm stat} \pm 0.017_{\rm syst}) \times 10^{-3}\,,$$

confirming the KTeV measurement.

2.4. The $K_{\rm S}$ semileptonic decays

At the ϕ factory very large samples (about 6×10^8 per fb^{-1}) of tagged, monochromatic $K_{\rm S}$ mesons are studied. From the analysis of 450 pb^{-1} it has been possible to measure [11] for the first time the BRs of both charge states, $\mathrm{BR}(K_{\rm S} \to e^+\pi^-\nu)$, $\mathrm{BR}(K_{\rm S} \to e^-\pi^+\bar{\nu})$, and thus the electron charge asymmetry $A_{\rm S}$:

$$A_{\rm S} = \frac{\Gamma\,(\mathrm{K_S} \to \pi^-\mathrm{e}^+\nu) - \Gamma\,(\mathrm{K_S} \to \pi^+\mathrm{e}^-\bar{\nu})}{\Gamma\,(\mathrm{K_S} \to \pi^-\mathrm{e}^+\nu) + \Gamma\,(\mathrm{K_S} \to \pi^+\mathrm{e}^-\bar{\nu})}\,. \tag{1}$$

From the $K_{\rm S}$ semileptonic decays, a competitive measurement of V_{us} has been also obtained exploiting the very precise knowledge of the $K_{\rm S}$ lifetime. Event counting is performed from a fit of the $E_{\rm miss} - p_{\rm miss}$ spectrum with a combination of MC-predicted shapes for signal and background. For each charge state the ratio $\mathrm{BR}(K_{\rm S} \to \pi^\mp e^\pm\nu(\overline{\nu}))/\mathrm{BR}(K_{\rm S} \to \pi^+\pi^-(\gamma))$ has been determined, normalizing the signal to $K_{\rm S} \to \pi^+\pi^-(\gamma)$ events. In order to evaluate the absolute BRs for the semileptonic modes, the above ratios have been combined with the ratio $R^\pi_{\rm S}$ of the dominant $K_{\rm S}$ decays measured at KLOE to 0.2% [12], obtaining:

$$\begin{aligned}
\mathrm{BR}(K_{\rm S} \to \pi^-e^+\nu) &= (3.528 \pm 0.062) \times 10^{-4}\,,\\
\mathrm{BR}(K_{\rm S} \to \pi^+e^-\bar{\nu}) &= (3.517 \pm 0.058) \times 10^{-4}\,,\\
\mathrm{BR}(K_{\rm S} \to \pi e\nu) &= (7.046 \pm 0.091) \times 10^{-4}\,,\\
A_{\rm S} &= (1.5 \pm 10.0) \times 10^{-3}\,.
\end{aligned} \tag{2}$$

2.5. Direct search for the $K_{\rm S} \to \pi^0\pi^0\pi^0$ decay

Observation of the decay $K_{\rm S} \to \pi^0\pi^0\pi^0$ signals $\mathcal{CP}$ violation in kaon mixing and/or decay. The parameter η_{000}, the ratio of $K_{\rm S}$ to $K_{\rm L}$ decay amplitudes, can be written as: $\eta_{000} = A(K_{\rm S} \to \pi^0\pi^0\pi^0)/A(K_{\rm L} \to \pi^0\pi^0\pi^0) = \varepsilon + \varepsilon'_{000}$, where ε quantifies the $K_{\rm S}$ $\mathcal{CP}$-impurity and ε'_{000} is due to a direct $\mathcal{CP}$-violating term. The Standard Model prediction for this decay is $\mathrm{BR}(K_{\rm S} \to \pi^0\pi^0\pi^0) \sim 1.9 \times 10^{-9}$ to an accuracy of a few %. Besides the interest in confirming the SM prediction, η_{000} enters the $\mathcal{CPT}$ test through the unitarity requirement [13]. With the 2001–2002 data sample a sensitivity to $\sim 10^{-7}$ [14] has been reached. At the end of the selection procedure, 2 events have been found, with an expected background of $N_{\rm b} = 3.13 \pm 0.82_{\rm stat} \pm 0.37_{\rm syst}$ and a total efficiency $\varepsilon_{3\pi^0} = (24.36 \pm 0.11_{\rm stat} \pm 0.57_{\rm syst})\%$. Folding the counting and background uncertainties we find $N(K_{\rm S} \to \pi^0\pi^0\pi^0) \leq 3.45$ at 90% C.L. The same sample contains 37.8×10^6 $K_{\rm S} \to \pi^0\pi^0$ events, used for normalization, so that:

$$\mathrm{BR}(K_{\rm S} \to \pi^0\pi^0\pi^0) \leq 1.2\times 10^{-7}, \qquad \text{at 90\% C.L.},$$

~ 6 times better than the previous upper limit [15]. The ongoing analysis on the whole data sample aims at a factor of ten improvement in sensitivity.

2.6. $\mathcal{CP}$ and $\mathcal{CPT}$ violating parameters

The KLOE results have been used also to improve the precision on the phenomenological parameters related to $\mathcal{CP}$ and $\mathcal{CPT}$ violation, *i.e.* $\mathrm{Re}(\varepsilon)$ and $\mathrm{Im}(\delta)$ [16]. The improvement has been obtained using the requirement on unitarity from which Bell and Steinberger have derived the relation (BSR) between $\mathcal{CPT}$-violating parameters and $\mathcal{CP}$-violating interference of $K_{\rm L}$ and $K_{\rm S}$ decays to the same final state,

$$\left(\frac{\Gamma_{\rm S}+\Gamma_{\rm L}}{\Gamma_{\rm S}-\Gamma_{\rm L}}+i\tan\phi_{\rm SW}\right)\left(\frac{Re(\varepsilon)}{1+|\varepsilon|^2}-i\mathrm{Im}(\delta)\right)=\frac{1}{\Gamma_{\rm S}-\Gamma_{\rm L}}\sum_f A_{\rm L}(f)A^\star_{\rm S}(f)\,. \quad (3)$$

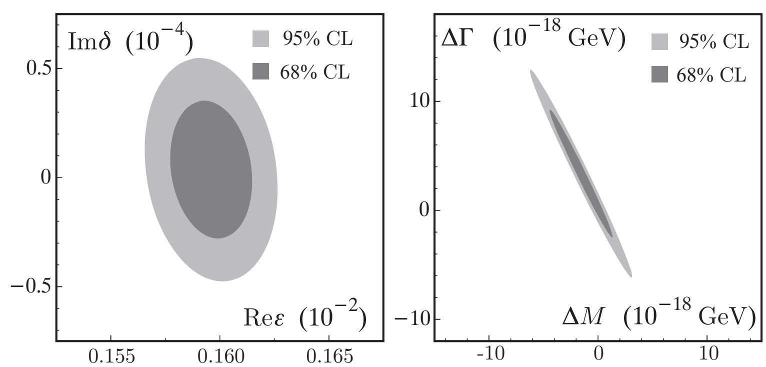

Fig. 1. Left: allowed region at 68% and 95% C.L. in the $\mathrm{Re}(\varepsilon)$, $\mathrm{Im}(\delta)$ plane. Right: allowed regions in the ΔM, $\Delta\Gamma$ plane.

The measurement of the $\mathrm{BR}(K_L \to \pi^+\pi^-)$ is relevant for $\mathrm{Re}(\varepsilon)$, while the new upper limit on $\mathrm{BR}(K_{\rm S} \to \pi^0\pi^0\pi^0)$ improves the accuracy on $\mathrm{Im}(\delta)$, and the first measurement of the $K_{\rm S}$ semileptonic charge asymmetry decreases the uncertainty from semileptonic decays making it also independent from the unitarity assumption. The results, $\mathrm{Re}(\varepsilon) = (159.6\pm1.3)\times10^{-5}$ and $\mathrm{Im}(\delta) = (0.4\pm2.1)\times10^{-5}$ are significantly better than the previous one, $\mathrm{Re}(\varepsilon) = (164.9\pm2.5)\times10^{-5}$ and $\mathrm{Im}(\delta) = (2.4\pm5.0)\times10^{-5}$ [13]. The contours of the allowed region for the $\mathcal{CP}$, $\mathcal{CPT}$-violating parameters are shown in Fig. 1. The limits on $\mathrm{Im}(\delta)$ and $\mathrm{Re}(\delta)$ have been also translated into limits on ΔM and $\Delta\Gamma$, the K^0–$\bar{K}^0$ mass and decay-width difference. In particular, assuming $\Gamma_{K^0} = \Gamma_{\bar{K}^0}$, $-5.3\times10^{-19} \leq \Delta M \leq 6.3\times10^{-19}$ has been derived at 95% C.L.

2.7. The $K^\pm$ semileptonic decay and lifetime

The ϕ-meson decays ∼49% of the time into quasi anti-collinear $K^\pm$ pairs: the detection of a $K^\pm$ tags the presence of a $K^\mp$ of known momentum and direction. The decay chains of the $K^\pm$ pair define two spatially well separated regions called the tag and the signal hemispheres. The measurement of the BRs for the $K^\pm$ semileptonic decays is based on four independent samples tagged by the following kaon decays: $K^+_{\mu2}$, $K^+_{\pi2}$, $K^-_{\mu2}$, and $K^-_{\pi2}$. To select a semileptonic decay on the signal side a decay vertex in the drift chamber (DC) and an energy deposit in the EMC connected to the charged track coming from the decay vertex, have been required. Two-body decays have been rejected by a cut on the momentum of the charged particle coming from the decay vertex, computed in the kaon rest frame assuming pion mass. The lepton mass, m^2_{lept}, has been determined from the velocity of the lepton obtained from time-of-flight. The number of K_{e3} and $K_{\mu3}$ has been then extracted by fitting the m^2_{lept} distribution using the MC-predicted shapes for the semileptonic modes and for all the associated background sources. The BRs have been separately evaluated for each tag sample, dividing by the number of tag counts and correcting for acceptances. The acceptances have been obtained from MC simulation. Corrections have been applied to account for data-MC discrepancies in tracking and clustering. About 190 000 $K^\pm_{e3}$ and 100 000 $K^\pm_{\mu3}$ decays have been selected. The results, obtained for each channel averaging over the four different tag samples carefully accounting for the correlations, are:

$$\mathrm{BR}(K^\pm_{e3}) = (5.047 \pm 0.043_{\mathrm{stat}} \pm 0.080_{\mathrm{syst}})\,,$$

$$\mathrm{BR}(K^\pm_{\mu3}) = (3.310 \pm 0.048_{\mathrm{stat}} \pm 0.065_{\mathrm{syst}})\%\,.$$

The error is dominated by the uncertainty on data-MC efficiency corrections. The evaluation of systematics coming from signal selection efficiency is still preliminary.

The $K^\pm$ lifetime, $\tau_{K^\pm}$, is an experimental input to the determination of V_{us}, and affects, through the evaluation of the geometrical acceptance, also the BR measurements. The present fractional uncertainty is about 0.2%;

however available data show large discrepancies between "in-flight" [17] and "at-rest" [18] measurements. Two different methods have been developed: one based on the measurement of the decay length, using charged decay vertices reconstructed in the DC, and the other based on the decay time of the kaons, exploiting EMC time reconstruction of the photons from π^0's produced in $K^\pm \to X^\pm\pi^0$ decays. Both methods reach accuracies of a few per mil. They are independent and their comparison can be used to assess part of the systematic uncertainty. The signal events are tagged by $K^-_{\mu 2}$ decays. With the first method, by fitting the proper-time distribution after the evaluation on data of the vertex-reconstruction efficiency and the resolution effects, the preliminary result,

$$\tau_{K^+} = (12.367 \pm 0.044_{\text{stat}} \pm 0.065_{\text{syst}})\ \text{ns}\,,$$

has been obtained with $\chi^2/\text{dof} = 17.7/15$.

2.8. The $K^+ \to \mu^+\nu(\gamma)$ decays

The precise measurement of the $\text{BR}(K^+ \to \mu^+\nu(\gamma))$, through the ratio of the partial decay widths of $K^+ \to \mu^+\nu(\gamma)$ and $\pi^+ \to \mu^+\nu(\gamma)$, allows an independent and competitive estimate of $|V_{us}|$ (or, to be more precise, of $|V_{us}/V_{ud}|$) compared with the traditional extraction of $|V_{us}|$ from $K_{\ell 3}$ decays [19]. We have measured the fully inclusive $\text{BR}(K^+ \to \mu^+\nu(\gamma))$ using about 175 pb^{-1} of integrated luminosity. The measurement is based on $K^- \to \mu^-\nu$ decays for event tagging, searching for the signal among all the K^+ decays [20]. The tagging selection is based on the presence of one two-tracks vertex in the DC which signals the K^- decay. The number of $K^+ \to \mu^+\nu(\gamma)$ is obtained from the p^* distribution, *i.e.* the momentum of the charged particle from the decay vertex computed in the kaon rest frame assuming pion mass. The background is made up of events with one π^0 in the final state, and its contribution to the p^* distribution has been directly obtained from data studying the sample with one π^0 selected from cluster reconstruction in the EMC. The efficiency has been determined using a control sample of $K \to \mu\nu(\gamma)$ events selected exploiting their typical signature in the EMC.

From some 865,283 $K^+ \to \mu^+\nu(\gamma)$ decays in a sample of $\sim 5.2 \times 10^8$ ϕ-mesons, we find

$$\text{BR}(K^+ \to \mu^+\nu_\mu(\gamma)) = 0.6366 \pm 0.0009_{\text{stat}} \pm 0.0015_{\text{syst}}\,,$$

with fractional error of 0.27%. The CKM mixing matrix element has been obtained combining our result with lattice QCD calculations of the ratio of the decay constants of the pseudoscalar mesons, f_K/f_π=1.210(4)(13) [21] and using the radiative corrections of Ref. [19],

$$|V_{us}/V_{ud}|^2 = 0.05211 \pm 0.00016 \pm 0.00019 \pm 0.00117\,,$$

where the errors refer, respectively, to the experimental measurements, radiative corrections, and lattice QCD calculations.

2.9. Extraction of V_{us}

The most precise test of unitarity of the CKM matrix, to one part per mil, comes from the first row: $1 - \Delta = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2$ using the V_{us} value from the measurement of the semileptonic decay widths ($\Gamma = \mathrm{BR}/\tau$) and V_{ud} from nuclear beta decays, V_{ub} contributing only at 10^{-5} level. A new determination of V_{us} has been obtained by KLOE using the results on semileptonic decays [5], on τ_{K_L} [4], on the semileptonic *ff* slopes [6], and the measurement of the $\mathrm{BR}(K_\mathrm{S} \to \pi e \nu)$ [11]. V_{us} is proportional to the square root of the partial width of semileptonic kaon decays:

$$|V_{us}| \times f_+(0) = \left[\frac{128\pi^3 \Gamma}{G_\mu^2 M_K^5 C_K^2 S_\mathrm{ew} I_K^l(\lambda'_+, \lambda''_+, \lambda_0, 0)}\right]^{1/2} \frac{1}{1 + \delta_\mathrm{em} + \delta^K_{\mathrm{SU}(2)}}\,, \quad (4)$$

where $f_+(0)$ is the vector *ff* at zero momentum transfer, C_K^2 is 1 (1/2) for neutral (charged) kaons and the short-distance electroweak corrections are included in the parameter $S_\mathrm{ew} = 1.0232(3)$ [22]. $I_K^l(\lambda'_+, \lambda''_+, \lambda_0, 0)$ is the result of the phase space integration after factorizing out $f_+(0)$. λ'_+ and λ''_+ are the linear and quadratic slopes of the vector *ff*, and λ_0 is the slope of the scalar *ff*. In the above expression, long-distance radiative corrections for both the form factor $f_+(0)$ and the phase space integral have been factorized out and included in the parameter δ_em [23,24], while $\delta^K_{\mathrm{SU}(2)}$ is the strong isospin breaking correction. Using all the semileptonic BRs measured at KLOE, the values $\lambda'_+ = 0.02542 \pm 0.0003$, $\lambda''_+ = 0.00129 \pm 0.00003$ (from the average of KLOE, NA48 and KTeV results of the pole-function fit), $\lambda_0 = 0.0159 \pm 0.0009$ (from the average of KTeV and ISTRA+ measurements [25]), the K_L lifetime from KLOE, $\tau_{K_\mathrm{S}} = (0.08953 \pm 0.00005)$ ns (from the world average), and $\tau_{K^\pm} = (12.385 \pm 0.024)$ ns (from the old experiments [17, 18]),

$$f_+(0) \times |V_{us}| = 0.2159 \pm 0.0005\,,$$

has been obtained in agreement with the expected value from unitarity,

$$f_+(0) \times |V_{us}| = f_+(0) \times \sqrt{1 - |V_{ud}|^2} = 0.2187 \pm 0.0028\,,$$

where $|V_{ud}| = 0.97377 \pm 0.0027$ from Ref. [26] and $f_+(0) = 0.961 \pm 0.008$ from Ref. [27] have been used; the accuracy on $f_+(0)$ is the dominant contribution to the test sensitivity. All the results on the first row of the CKM matrix are summarized in Fig. 2 where the allowed region from the combined measurements is also shown.

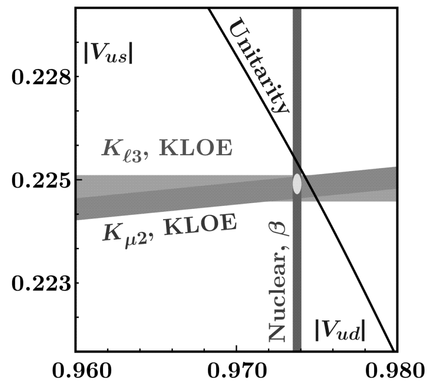

Fig. 2. Results on V_{us} and V_{ud} from KLOE measurements and superallowed nuclear β decays.The ellipse close to the unitarity circle is the 1σ allowed region from the combined results.

3. Results in hadron physics

The program on the light scalars at KLOE includes the measurements of the decay rates of $f_0(980)$, $a_0(980)$, sensitive to the structure of the isoscalar and isovector states. At present, KLOE is also the experiment with the highest statistics of η and η' decays, relevant for testing χPT. Several decay modes and the ratio $\mathrm{BR}(\phi \to \eta'\gamma)/\mathrm{BR}(\phi \to \eta\gamma)$ have been studied.

3.1. $f_0(980) \to \pi\pi$

The nature of the light scalar mesons has been investigated through ϕ radiative decays, analyzing the decay chains $\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma$ and $\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$ [28]. The charged, $\pi^+\pi^-\gamma$, and the neutral, $\pi^0\pi^0\gamma$ final states are dominated, respectively, by $e^+e^- \to \pi^+\pi^-\gamma$ with a photon from initial (ISR) or final state (FSR) radiation, and by $e^+e^- \to \omega\pi^0$ with $\omega \to \pi^0\gamma$ decay. A clear contribution from the intermediate $\phi \to f_0(980)\gamma$ process has been observed in both final states. The kaon-loop (KL) [29] and no-structure (NS) [30] model have been used to extract the f_0 mass and its coupling to $\pi\pi$, KK and to the ϕ. Both models have been found to provide an acceptable description of the experimental measurements.

The analysis of the $\pi^+\pi^-\gamma$ final state requires events with two charged tracks and missing momentum at large polar angle, matching an energy-cluster in the EMC, to suppress ISR contribution. The event kinematics, together with the time-of-flight signature, allow the rejection of the background processes, $e^+e^- \to e^+e^-\gamma/\mu^+\mu^-\gamma$ and $\phi \to \pi^+\pi^-\pi^0$. The f_0 parameters have been extracted by fitting the $\pi^+\pi^-$ invariant mass in the region $420 \le M_{\pi\pi} \le 1010$ MeV. The uncertainty on the results, shown in Table I, has been determined studying several systematic effects related to the photon efficiency and background evaluation.

TABLE I

Intervals of maximal variation of the f_0 parameters for both kaon-loop and no-structure models for charged and neutral final states.

	$\pi^+\pi^-$		$\pi^0\pi^0$	
Parameter	KL	NS	KL	NS
M_{f_0} (MeV)	980−987	973−981	976−987	981−987
$g_{f_0 K^+K^-}$ (GeV)	5.0−6.3	1.6−2.3	3.3−5.0	0.1−1.0
$g_{f_0\pi^+\pi^-}$ (GeV)	3.0−4.2	0.9−1.1	1.4−2.0	1.3−1.4
$R = g^2_{f_0 K^+K^-}/g^2_{f_0\pi^+\pi^-}$	2.2−2.8	2.6−4.4	3.0−7.3	0.01−0.5
$g_{\phi f_0 \gamma}$ (GeV^{-1})	—	1.2−2.0	—	2.5−2.7

The analysis of the $\pi^0\pi^0\gamma$ final state requires events with five neutral clusters, imposes total 4-momentum conservation to the photons, selects the best combination of photon pairs to be associated to the pion decays, and constraints the invariant mass of the photon pairs to the π^0 mass. Cuts on the $M_{\gamma\gamma}$ value before the last kinematic fit and on the quality of the fit itself insure suppression of the background coming from $\phi \to \eta\gamma$ and $\phi \to \pi^0\gamma$ decays. The event distribution in the $M_{\pi\pi}$–$M_{\pi\gamma}$ plane has been fit to extract the f_0 parameters, shown in Table I.

The KL model provides a good description of data for both final states with a large coupling of $f_0(980)$ to kaons supporting the hypothesis of its 4-quark structure. On the other hand the interpretation of the NS model results is unclear due to the weak f_0 coupling to kaons from the neutral-mode analysis.

3.2. The η and η' pseudoscalars

From the ratio $R_\phi = \mathrm{BR}(\phi \to \eta'\gamma)/\mathrm{BR}(\phi \to \eta\gamma)$, the η-η' mixing angle in the flavour-basis [31] and information on the gluonic content of the η' meson [32] can be extracted. R$_\phi$ has been measured [33] selecting the final state with two pions, $\pi^+\pi^-$, and seven γ's, normalized to the sample with seven γ's only. These correspond, respectively, to the decays $\eta' \to \eta\pi\pi$ with $\eta \to \pi\pi\pi$, and $\eta \to \pi^0\pi^0\pi^0$. Moreover, given the final states, the η' decays to neutral pions are required to have η decays to $\pi^+\pi^-\pi^0$ and *vice versa*, the η' decays to charged pions must have eta decays to neutral pions only. A kinematic fit imposing 4-momentum conservation has been applied to improve the energy resolution for neutral clusters. Residual background to the η' channel is due to $K_\mathrm{S}K_\mathrm{L}$ events with the K_L decay near the interaction region and is largely reduced by a cut on the neutral cluster energies, $E_\gamma \geq 20$ MeV. The sample of η decays used for normalization is practically background-free. A sample of 3750 ± 61 $\phi \to \eta'\gamma$ events has been selected, with a contamination of $N_\mathrm{bck} = 345 \pm 6$ and an efficiency $\varepsilon_{\eta'} = 0.2345 \pm$

0.0016, evaluated from Monte Carlo simulation. Using the world-average for the intermediate η' and η decays, $R_\phi = (4.77 \pm 0.09_{\rm stat} \pm 0.19_{\rm syst}) \times 10^{-3}$, and $\varphi_{\rm P} = (41.4 \pm 0.3_{\rm stat} \pm 0.7_{\rm syst} \pm 0.6_{\rm th})^\circ$ from the parametrization of Ref. [31], have been obtained.

4. Conclusion

Some of the new measurements in kaon and hadron physics, based on 20% of the data collected at the ϕ-peak with the KLOE experiment, have been summarized. Other results not discussed in this paper include the analysis of the quantum mechanics (QM) interference in the time-evolution of the $K_{\rm L}$–$K_{\rm S}$ pairs to the $\pi^+\pi^-\pi^+\pi^-$ final state [34], and the Dalitz-plot study of the $\eta \to \pi\pi\pi$ channel [35]. The ongoing analyses on the entire statistics aim, among other topics, to improve the sensitivity on $K_{\rm S}$ rare decays ($K_{\rm S}\to \pi l\nu$, $K_{\rm S}\to \pi\pi\pi$, $K_{\rm S}\to \pi$ e e, $K_{\rm S}\to \pi\mu\mu$), on $K^\pm \to e\nu$, and on the QM interference patterns in the time-evolution of various $K_{\rm L}$–$K_{\rm S}$ final states.

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