KLOE results on kaon decays and summary status of V_{us}

T. Spadaro*
Laboratori Nazionali di Frascati dell'INFN
Via E. Fermi, 40 00044 Frascati (Roma) Italia

Recent KLOE measurements allowing the extraction of the V_{us} element of the CKM matrix are here briefly described. The status of the resulting value of V_{us} is summarized. The perspectives for the completion of ongoing analyses are discussed, with particular emphasis on the measurements of scalar form factor slopes from study of $K_{L\mu3}$ and of V_{us} from the decay width of $K_{l3}^{\pm}$.

I. V_{us} EXTRACTION FROM SEMILEPTONIC KAON DECAYS

The most precise test of the unitarity of the CKM matrix can be performed from its first row. Letting $\Delta = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1$, an accuracy of few parts in 10^{-4} on Δ can be reached. The contribution of $|V_{ub}|^2$ is negligible [1]; the determination of V_{ud} from super-allowed nuclear beta decays gives an uncertainty of 5×10^{-4} on Δ (see Hardy's contribution in this volume), and a similar accuracy can be reached by extracting $|V_{us}|$ from the rates Γ for semileptonic kaon decays:

$$\begin{aligned}\Gamma^i(K_{e3(\gamma),\,\mu3(\gamma)}) \;=\; & |V_{us}|^2 \frac{C_i^2 G^2 M^5}{128\pi^3} S_{\rm EW}\, |f_+^{K^0}(0)|^2 \\ & I^i_{e3,\,\mu3}\,(1+\delta^i_{e3,\,\mu3}),\end{aligned}$$

where i indexes $K^0 \to \pi^-$ and $K^+ \to \pi^0$ transitions for which $C_i^2 = 1$ and $1/2$, respectively, G is the Fermi constant, M is the appropriate kaon mass, and $S_{\rm EW}$ is a universal short-distance electroweak correction [2]. The δ^i term accounts for long-distance radiative corrections depending on the meson charges and lepton masses and, for $K^\pm$, for isospin-breaking effects. These corrections are presently known at the few-per-mil level [3]. The $f_+^{K^0}(0)$ form factor parametrizes the vector-current transition $K^0 \to \pi^-$ at zero momentum transfer t, while the dependence of vector and scalar form factors on t enter into the determination of the integrals $I_{e3,\,\mu3}$ of the Dalitz-plot density over the physical region. Since f_+ is dominated by the vector $K\pi$ resonances, the closest being the $K^*(892)$, the natural form for its dependence on t is:

$$f_+(t) \propto \frac{M_V^2}{M_V^2 - t}, \qquad (1)$$

but it is also customary to expand the form factor in powers of t up to first or second orders, as

$$f_+(t) \propto 1 + \lambda_+ \frac{t}{m^2_{\pi^+}} \text{ or } 1 + \lambda'_+ \frac{t}{m^2_{\pi^+}} + \frac{\lambda''_+}{2}\left(\frac{t}{m^2_{\pi^+}}\right)^2. \qquad (2)$$

For the scalar form factor a linear parametrization is typically used:

$$f_0(t) \propto 1 + \lambda_0 \frac{t}{m^2_{\pi^+}}. \qquad (3)$$

The difference of $f_+(0)$ from unity reflects $SU(3)$- and $SU(2)$-breaking corrections and is evaluated from purely theoretical calculations. The reader can refer to Sachrajda's and Portolés's contributions in this volume for recent updates, while we will use the old Leutwyler and Roos evaluation,

$$f_+(0) = 0.961(8), \qquad (4)$$

in the following. The experimental inputs in the above formulae are the semileptonic decay widths, evaluated from the γ-inclusive BR's and from the lifetimes, and the parameters describing the t-dependence of the vector and scalar form factors. Results from KLOE measurements of all these inputs are reported in the following.

II. EXPERIMENTAL SETUP

DAΦNE, the Frascati ϕ factory, is an e^+e^- collider working at $\sqrt{s} \sim m_\phi \sim 1.02$ GeV. ϕ mesons are produced, essentially at rest, with a visible cross section of ~ 3.1 μb and decay into $K_S K_L$ (K^+K^-) pairs with a BR of $\sim 34\%$ ($\sim 49\%$).

Kaons get a momentum of ~ 100 MeV/c which translates into a low speed, $\beta_K \sim 0.2$. K_S and K_L can therefore be distinguished by their mean decay lengths: $\lambda_S \sim 0.6$ cm and $\lambda_L \sim 340$ cm. K^+ and K^- decay with a mean length of $\lambda_\pm \sim 90$ cm and can be distinguished from their decays in flight to one of the two-body final states $\mu\nu$ or $\pi\pi^0$.

The kaon pairs from ϕ decay are produced in a pure $J^{PC} = 1^{--}$ quantum state, so that observation of a K_S (K^+) in an event signals, or tags, the presence of a K_L (K^-) and vice versa; highly pure and nearly monochromatic K_S, K_L, and $K^\pm$ beams can thus be obtained and exploited to achieve high precision in the measurement of absolute BR's.

The analysis of kaon decays is performed with the KLOE detector, consisting essentially of a drift chamber, DCH, surrounded by an electromagnetic calorimeter, EMC. A superconducting coil provides a 0.52 T mag-

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*Electronic address: tommaso.spadaro@lnf.infn.it

netic field. The DCH [4] is a cylinder of 4 m in diameter and 3.3 m in length, which constitutes a fiducial volume for K_L and $K^\pm$ decays extending for $\sim 0.4\lambda_L$ and $\sim 1\lambda_\pm$, respectively. The momentum resolution for tracks at large polar angle is $\sigma_p/p \leq 0.4\%$. The invariant mass reconstructed from the momenta of the two pion tracks of a $K_S \to \pi^+\pi^-$ decay peaks around m_K with a resolution of ∼800 keV, thus allowing clean K_L tagging. The c.m. momenta reconstructed from identification of 1-prong $K^\pm \to \mu\nu, \pi\pi^0$ decay vertices in the DC peak around the expected values with a resolution of 1–1.5 MeV, thus allowing clean and efficient $K^\mp$ tagging.

The EMC is a lead/scintillating-fiber sampling calorimeter [5] consisting of a barrel and two endcaps, with good energy resolution, $\sigma_E/E \sim 5.7\%/\sqrt{\mathrm{E(GeV)}}$, and excellent time resolution, $\sigma_T = 54$ ps$/\sqrt{\mathrm{E(GeV)}} \oplus 50$ ps. About 50% of the K_L's produced reach the EMC, where most interact. A signature of these interactions is the presence of an high-energy cluster not connected to any charged track, with a time corresponding to a low velocity: the resolution on β_K corresponds to a resolution of ~ 1 MeV on the K_L momentum. This allows clean K_S tagging. The timing capabilities of the EMC are also exploited to precisely reconstruct the position of decay vertices of K_L and $K^\pm$ to π^0's from the cluster times of the emitted photons, thus allowing precise measurements of the K_L and $K^\pm$ lifetimes.

In early 2006, the KLOE experiment completed data taking, having collected ~ 2.5 fb^{-1} of integrated luminosity at the ϕ peak, corresponding to ∼2.5 (3.6) billion K_SK_L (K^+K^-) pairs. The results presented here are based on the first 400 pb^{-1} collected and are based on analyses published in 2006.

III. V_{us} FROM SEMILEPTONIC K_L DECAYS

A. Measurements of K_{Le3} and $K_{L\mu3}$ BR's

The analysis of K_L decays starts with the identification of $K_S \to \pi^+\pi^-$ decays, which gives a pure K_L "beam" of known momentum and direction. In a fiducial volume extending for $\sim 0.4\lambda_L$, two-track decay vertices are selected around the K_L line of flight and the number of events for each of the decay modes $K_L \to \pi e\nu$, $\pi\mu\nu$, and $\pi^+\pi^-\pi^0$ are obtained from the distribution of the difference $E_{\rm miss} - P_{\rm miss}$ of missing momentum and missing energy in the hypotheses of pion and muon daughter particles. Photon vertices from $K_L \to 3\pi^0$ decays are reconstructed on the K_L line of flight from the times of at least 3 photon clusters. Since the geometrical acceptance of these selections depends on the value of the K_L lifetime, the output values of the BR's are expressed as a function of τ_L [6]:

$$\begin{aligned}
\mathrm{BR}(K_L \to \pi e\nu) &= \frac{40.49(10)_{\rm st}(18)_{\rm sy}\%}{1+k\Delta\tau} && (5)\\
\mathrm{BR}(K_L \to \pi\mu\nu) &= \frac{27.26(9)_{\rm st}(14)_{\rm sy}\%}{1+k\Delta\tau} && (6)\\
\mathrm{BR}(K_L \to \pi^0\pi^0\pi^0) &= \frac{20.18(5)_{\rm st}(23)_{\rm sy}\%}{1+k\Delta\tau} && (7)\\
\mathrm{BR}(K_L \to \pi^+\pi^-\pi^0) &= \frac{12.76(6)_{\rm st}(14)_{\rm sy}\%}{1+k\Delta\tau}, && (8)
\end{aligned}$$

where $\Delta\tau = 51.7$ ns $- \tau_L$, $k = 0.0128$ ns^{-1}, and the uncertainties on the above results are correlated with the following coefficients:

$$\begin{pmatrix} 1 & 0.09 & 0.07 & 0.49 \\ & 1 & -0.03 & 0.27 \\ & & 1 & 0.07 \\ & & & 1 \end{pmatrix} \qquad (9)$$

The above inputs are to be used for the evaluation of world-average K_L BR's. Imposing the unitarity of the above ratios, $\sum_i BR_i = 1 - \mathrm{BR}(K_L \to \pi\pi) - \mathrm{BR}(K_L \to \gamma\gamma) = 1 - 0.36\%$, we can extract both the four main BR's and τ_L. This calculation is handled by performing a fit to the above measurements, together with the direct KLOE measurement of τ_L from the $K_L \to \pi^0\pi^0\pi^0$ decay distribution, $\tau_L = 50.92(17)_{\rm st}(25)_{\rm sy}$ ns [7]. The results are

$$\begin{aligned}
\mathrm{BR}(K_L \to \pi e\nu) &= 40.08(6)_{\rm st}(14)_{\rm sy}\% && (10)\\
\mathrm{BR}(K_L \to \pi\mu\nu) &= 26.99(6)_{\rm st}(13)_{\rm sy}\% && (11)\\
\mathrm{BR}(K_L \to \pi^0\pi^0\pi^0) &= 19.96(5)_{\rm st}(19)_{\rm sy}\% && (12)\\
\mathrm{BR}(K_L \to \pi^+\pi^-\pi^0) &= 12.61(5)_{\rm st}(10)_{\rm sy}\% && (13)\\
\tau_L &= 50.84(14)_{\rm st}(18)_{\rm sy}\ \mathrm{ns}, && (14)
\end{aligned}$$

with correlation matrix

$$\begin{pmatrix} 1 & -0.31 & -0.55 & -0.01 & 0.16 \\ & 1 & -0.41 & -0.14 & 0.22 \\ & & 1 & -0.47 & -0.14 \\ & & & 1 & -0.26 \\ & & & & 1 \end{pmatrix}. \qquad (15)$$

B. K_L form factor slopes

From the sample of charged K_L decays, additional loose cuts on kinematics and improved particle identification from the time of flight (TOF) of daughter particles (evaluated from connected EMC clusters) allow the selection of a high-purity 2×10^6-event sample of $K_L \to \pi^\mp e^\pm \nu(\overline{\nu})$ decays. Within this sample, the probability of misidentifying an electron as a pion is negligible, so that the momentum tranfer t can be safely evaluated from the K_L momentum and from the momenta of the daughter tracks. The vector form factor slopes are extracted through binned log-likelihood fits of t distributions to the parametrizations of Eqs. 1 and 2. The results are [8]:

$$\begin{aligned} M_V &= (870 \pm 6_{\rm st} \pm 7_{\rm sy})\ \text{MeV}, \qquad (16)\\ \lambda_+ &= (28.6 \pm 0.5_{\rm st} \pm 0.4_{\rm sy}) \times 10^{-3}, \qquad (17)\end{aligned}$$

and

$$\begin{aligned} \lambda'_+ &= (25.5 \pm 1.5_{\rm st} \pm 1.0_{\rm sy}) \times 10^{-3}\\ \lambda''_+ &= (1.4 \pm 0.7_{\rm st} \pm 0.4_{\rm sy}) \times 10^{-3} \qquad (18)\\ \rho(\lambda'_+, \lambda''_+) &= -0.95\end{aligned}$$

The KLOE inputs from K_{Le3} decays allow the evaluation of $f_+(0) \times |V_{us}| = 0.21561(69)$, i.e., with an accuracy of 0.32%.

The analysis of a $K_{L\mu3}$ sample for the measurement of the scalar form factor slope, Eq. 3, is more complicated than for K_{Le3} because pure and efficient π-μ separation is much more difficult to achieve. In order to overcome this problem, an analysis presently in progress aims at measuring λ_0 through a fit to the distribution of the neutrino energy E_ν, which can be evaluated simply through a Lorentz transform of $P_{\rm miss}$ in the K_L frame. As a side effect, the sensitivity on λ_+ (λ_0) from a E_ν fit is reduced by a factor of ~2 (1.25) with respect to that achieved from a t fit. The relative statistical accuracy on λ_0 will be in the range of 5–10% after analysis of the entire data set.

The results from quadratic fits of K_{Le3} can be compared to and combined with the measurements from K_{Le3} decays from NA48 [9], and from K_{Le3} and $K_{L\mu3}$ decays from KTeV [10], and ISTRA+[11]. This comparison has to be performed with correlations taken into account. Using the method of [12], the values obtained are (see Fig. 1):

$$\begin{aligned} \lambda'_+ &= (24.92 \pm 0.83) \times 10^{-3}\\ \lambda''_+ &= (1.59 \pm 0.36) \times 10^{-3} \qquad (19)\\ \lambda_0 &= (16.07 \pm 0.82) \times 10^{-3},\end{aligned}$$

with $\chi^2/\text{dof} = 11.9/9$ (21.7%) and correlation matrix

$$\begin{aligned} \rho(\lambda'_+, \lambda''_+) &= -0.94\\ \rho(\lambda'_+, \lambda_0) &= 0.24 \qquad (20)\\ \rho(\lambda''_+, \lambda_0) &= -0.34.\end{aligned}$$

The above result, together with the KLOE measurements of $\text{BR}(K_L \to \pi\mu\nu)$ and τ_L, gives $f_+(0) \times |V_{us}| = 0.21633(78)$, i.e., with an accuracy of 0.36%.

IV. V_{us} FROM SEMILEPTONIC K_S DECAYS

The analysis of K_S decays starts with the identification of K_L interactions in the EMC, which gives a K_S "beam" of known momentum and direction. Two-track decay vertices close to the interaction point are selected; in order to reject the background from $K_S \to \pi^+\pi^-$ decays, we apply a PID technique exploiting the time of the clusters connected to the K_S daughter tracks. After this selection, pion and electron tracks are precisely identified. About 10 000 events for each of the $K_S \to \pi^+ e \overline{\nu}$ and $\pi^- e^+ \nu$ decay modes are obtained from the distribution of the difference $E_{\rm miss} - P_{\rm miss}$ of missing momentum and missing energy. By normalizing the number of K_{e3} counts to the number of $K_S \to \pi^+\pi^-$ counts in the same date set and correcting for the efficiency ratio for each charge state, we obtain [13]:

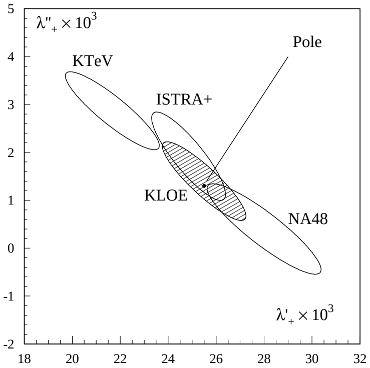

FIG. 1: Measurements of λ'_+ and λ''_+: 1-σ contours are shown for each experiment. The dot shows (λ'_+, λ''_+) values corresponding to the pole-fit result of KLOE data.

$$\begin{aligned} R_+ &= \tfrac{\Gamma(K_S \to \pi^- e^+ \nu)}{\Gamma(K_S \to \pi^+\pi^-)} = 5.099(82)_{\rm st}(39)_{\rm sy} \times 10^{-3}\\ R_- &= \tfrac{\Gamma(K_S \to \pi^+ e^- \overline{\nu})}{\Gamma(K_S \to \pi^+\pi^-)} = 5.083(73)_{\rm st}(42)_{\rm sy} \times 10^{-3}\end{aligned} \qquad (21)$$

The total errors are ~ 1% and are dominated by the statistics for signal events and background subtraction. Combining $R_\pm$ with the precise KLOE measurement of the ratio [14],

$$R = \frac{\Gamma(K_S \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^0\pi^0)} = 2.2549 \pm 0.0054, \qquad (22)$$

and imposing e-μ universality, we obtain the main K_S BR's:

$$\begin{aligned} \text{BR}(K_S \to \pi^+\pi^-) &= (69.196 \pm 0.051) \times 10^{-2} \quad (23)\\ \text{BR}(K_S \to \pi^0\pi^0) &= (30.687 \pm 0.051) \times 10^{-2} \quad (24)\\ \text{BR}(K_S \to \pi^- e^+ \nu) &= (3.528 \pm 0.062) \times 10^{-4} \quad (25)\\ \text{BR}(K_S \to \pi^+ e^- \overline{\nu}) &= (3.517 \pm 0.058) \times 10^{-4}, \quad (26)\end{aligned}$$

from which we obtain $\text{BR}(K_S \to \pi e \nu) = (7.046 \pm 0.091) \times 10^{-4}$. These are by far the most precise measurements of these BR's and allow a substantial improvement in the accuracy of the determination of CP and CPT parameters of the K^0 system using the Bell-Steinberger relation [15]. An enriched sample of ~10 000 K_{Se3} events with a 0.7% overall contamination can be obtained by tightening the kinematic cuts. From this, a linear fit to the t-distribution yields the first measurement ever made of the vector form factor slope λ_+ for K_{Se3}:

$$\lambda_+ = (33.9 \pm 4.1) \times 10^{-3}. \tag{27}$$

Using the much more precise determination of the slopes from K_{Le3} decays and the precise average value of τ_S from the PDG [1], our value for BR($K_S \to \pi e \nu$) gives $f_+(0) \times |V_{us}| = 0.2154(14)$, i.e., with an accuracy of 0.67%. This determination is unique to KLOE.

The event sensitivity at KLOE to $K_{S\mu3}$ decays is lower than that for K_{Se3}. The reasons are similar to those presented for the analysis of the $K_{L\mu3}$ form factor slopes. In addition, in this case the background is dominated by events having the same particles as the signal: in $K_S \to \pi^+\pi^-$ decays, a π may decay to $\mu\nu$ before entering the DCH. The BR for $K_{S\mu3}$ decay has never been measured before. The analysis is in progress and a total accuracy of 3% on the BR should be obtained after the entire data set is analyzed.

V. V_{us} FROM SEMILEPTONIC K^+ DECAYS

A. Measurements of $K^{\pm}_{e3,\mu3}$ BR's

The analysis of $K^{\pm}$ decays starts with the identification of $K^{\mp}$ decays to $\mu^{\mp}\overline{\nu}(\nu)$ or $\pi^{\mp}\pi^0$ final states, which gives a pure sample of $K^{\pm}$-tagged events. One-prong decay vertices of $K^{\pm}$ are then selected in the DCH and the photons coming from π^0 decay are identified from TOF using the associated clusters in the EMC. In order to reject the background for $K^{\pm}_{e3,\mu3}$ identification, which is dominated by $\pi^+\pi^0$ and τ' decays, the lepton TOF is evaluated exploiting the time of the cluster connected to the K^+ daughter track. The number of events for each of the $K^+ \to \pi e \nu$ and $\pi\mu\nu$ decay modes are obtained from the distribution of the squared lepton mass evaluated from TOF. By normalizing to the number of tagged events and correcting for the selection efficiency, we obtain the following preliminary results [16]:

$$\begin{aligned} \mathrm{BR}(K^{\pm} \to e^{\pm}\pi^0\nu(\overline{\nu})) &= 5.047(39)_{\mathrm{st}}(81)_{\mathrm{sy}}\% & (28)\\ \mathrm{BR}(K^{\pm} \to \mu^{\pm}\pi^0\nu(\overline{\nu})) &= 3.310(45)_{\mathrm{st}}(65)_{\mathrm{sy}}\% & (29)\\ \rho(\mathrm{BR}(K^{\pm}_{e3}), \mathrm{BR}(K^{\pm}_{\mu3})) &= 0.42. & (30)\end{aligned}$$

B. Measurements of $K^{\pm}$ lifetime

The experimental status of τ_+ is unclear: the PDG quotes an average of $\tau_+ = 12.385(25)$ ns [1] with a relative accuracy of 0.2% and a confidence level of 0.2%. At KLOE there are two methods to perform a direct measurement of τ_+ from the distribution of the proper decay times t^*. One can obtain t^* from the $K^{\pm}$ track length in 1-prong kaon decays, properly accounting for kaon energy loss in each track segment L_i: $t^* = \sum_i L_i/(\beta_i\gamma_i c)$. An independent determination of t^* can be obtained from $K^{\pm}$ decays to final states containing π^0's, by using the photon TOF's. While this second method is still under development, a preliminary result from the first approach has been obtained using a sample of ~ 175 pb^{-1}:

$$\tau_+ \;=\; 12.367 \pm 0.044_{\mathrm{st}} \pm 0.065_{\mathrm{sy}}\ \mathrm{ns}, \tag{31}$$

where the systematic uncertainty has been conservatively evaluated. After the analysis of the entire data set, KLOE results are expected to clarify the experimental situation concerning τ_+. In the following, we will use the PDG value of τ_+.

VI. KLOE SUMMARY OF $f_0 \times |V_{us}|$

Using the form factor slopes (FF) from Eq. 18 for K_{e3} and the averages of Eq. 19 for $K_{\mu3}$ modes, the values of $f_+ \times |V_{us}|$ from KLOE measurements are:

			Input	
Mode	$f_+ \times \vert V_{us}\vert$	Error,%	KLOE	External
K_{Le3}	0.21561(69)	0.32	FF, BR, τ_L	
$K_{L\mu3}$	0.21633(78)	0.36	FF, BR, τ_L	FF
K_{Se3}	0.2154(14)	0.67	FF, BR	τ_S
$K^{\pm}_{e3}$	0.2170(21)	0.96	FF, BR	τ_+
$K^{\pm}_{\mu3}$	0.2150(28)	1.3	FF, BR, τ_L	FF, τ_+

(32)

The best accuracy is obtained from K_L modes, with errors dominated by τ_L; intermediate accuracy is obtained from K_{Se3}, with error dominated by the BR measurement. If the average FF's are used for each mode, the following results are obtained:

			Input	
Mode	$f_+ \times \vert V_{us}\vert$	Error,%	KLOE	External
K_{Le3}	0.21572(64)	0.30	FF, BR, τ_L	FF
$K_{L\mu3}$	0.21633(78)	0.36	FF, BR, τ_L	FF
K_{Se3}	0.2155(14)	0.66	FF, BR	FF, τ_S
$K^{\pm}_{e3}$	0.2171(21)	0.96	FF, BR	FF, τ_+
$K^{\pm}_{\mu3}$	0.2150(28)	1.3	FF, BR, τ_L	FF, τ_+
Average	0.21595(50)	0.23		

(33)

The average in the last line is evaluated taking correlations into account and has a 86% χ^2 probability. Using the Leutwyler-Roos value for $f_+(0)$ gives

$$|V_{us}| = 0.2247(19). \tag{34}$$

Using the world-average value of $V_{ud} = 0.97377(27)$ as obtained from $0^+ \to 0^+$ nuclear beta decays [17], we get $\Delta = (-13 \pm 10) \times 10^{-4}$. At the time of the 2004 PDG compilation [18], the world-average value was $\Delta = (-35 \pm 15) \times 10^{-4}$, i.e., $\sim 2.3\sigma$ away from zero.

The universality of e and μ couplings to the W demands that the values of V_{us} obtained from K_{e3} and $K_{\mu3}$ decays be the same. The KLOE data satisfy the e/μ universality test: unlike at the time of 2004 PDG [18], the ratios of effective Fermi constants are now compatible with unity:

Source	$G^2(\mu 3)/G^2(e3)$	
K_L	1.0059(83)	1.047(14)
$K^\pm$	0.981(25)	1.004(16)
	KLOE 06	PDG 04

(35)

VII. KLOE CONTRIBUTION TO $|V_{us}/V_{ud}|$

By comparing radiation-inclusive kaon and pion widths for $\mu\nu$ decays, one can extract the ratio $|V_{us}/V_{ud}|$ from the following relation [19]:

$$\frac{\Gamma(K\to\mu\nu)}{\Gamma(\pi\to\mu\nu)} = \frac{m_K\left(1-m_\mu^2/m_K^2\right)^2}{m_\pi\left(1-m_\mu^2/m_\pi^2\right)^2}\left|\frac{V_{us}}{V_{ud}}\right|^2\frac{f_K^2}{f_\pi^2}C \quad (36)$$

The theoretical inputs are the form-factor ratio f_K/f_π and the radiative corrections are described by the factor C. We use $f_K/f_\pi = 1.208(2)(^{+7}_{-14})$ from lattice calculations by the MILC collaboration [20], and $C = 0.9930(35)$ from [19].

From the precise KLOE measurement [21] BR$(K^+\to\pi^+\nu) = 63.66(9)_{\rm st}(15)_{\rm sy}\%$, and using the PDG values [1] for the other experimental inputs, we get $|V_{us}/V_{ud}| = 0.2286(^{+27}_{-15})$. This result can be fit together with the world-average value $V_{ud} = 0.97377(27)$ and the $|V_{us}|$ evaluation from KLOE results, Eq. 34. The fit is shown in fig. 2. It yields $V_{us} = 0.2240(16)$ and $\Delta = 1.60(89)\times10^{-3}$ with a χ^2 probability of 53%, demonstrating the consistency of the KLOE measurements, and giving no indication of any violation of CKM unitarity.

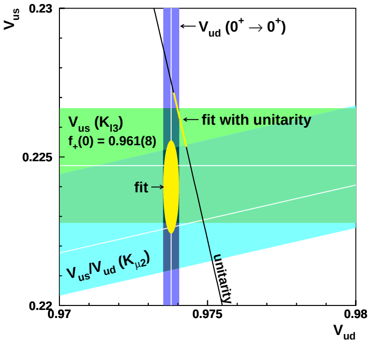

FIG. 2: The result of a fit combining the world-average value of V_{ud} with the KLOE measurements of V_{us} and V_{us}/V_{ud} is shown in the V_{us}-V_{ud} plane by the solid ellipse, which corresponds to a 1-σ contour. The unitarity constraint is also shown by the solid line. The segment highlighted on it represents the result of a fit assuming unitarity as a constraint.

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