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New results from KLOE

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1 Introduction

The most precise determination of V_{us} comes from semileptonic kaon decays. We have measured with the KLOE detector at DAΦNE, the Frascati ϕ-factory, all the experimental inputs to V_{us} for both neutral and charged kaons. Using our results we extract the value of V_{us} with 0.9% fractional error, which is dominated by the theoretical error on the form factor, $f_+(0)$. A new determination of the ratio V_{us}/V_{ud} is also presented, based on our precise measurement of the absolute branching ratio for the decay $K \to \mu\nu(\gamma)$, combined with lattice results for the ratio f_K/f_π. New results on CPT symmetry and quantum mechanics test have also been achieved, which are based on the first measurement of the charged asymmetry for $K_S \to \pi e \nu$ decay and on interferometry studies using the $\phi \to K_L K_S \to \pi^+\pi^-\pi^+\pi^-$.

2 DAΦNE and KLOE

The DAΦNE e^+e^- collider operates at a total energy $\sqrt{s} = 1020$ MeV, the mass of the $\phi(1020)$-meson.

Since 2001, KLOE has collected an integrated luminosity of about 2.5 fb^{-1}. Results presented below are based on 2001-02 data for about 450 pb^{-1}.

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The KLOE detector consists of a large cylindrical drift chamber surrounded by a lead/scintillating-fiber electromagnetic calorimeter. The drift chamber [1], is 4 m in diameter and 3.3 m long. The momentum resolution is $\sigma(p_T)/p_T \sim 0.4\%$. Two track vertices are reconstructed with a spatial resolution of $\sim$ 3 mm. The calorimeter [2], composed of a barrel and two endcaps, covers 98% of the solid angle. Energy and time resolution are $\sigma(E)/E = 5.7\%/\sqrt{E[\mathrm{GeV}]}$ and $\sigma(t) = 57$ ps$/\sqrt{E[\mathrm{GeV}]} \oplus 100$ ps. A superconducting coil around the detector provides a 0.52 T magnetic field.

The KLOE trigger [3], uses calorimeter and drift chamber information. For the present analyses only the calorimeter triggers have been used. Two energy deposits above threshold, $E > 50$ MeV for the barrel and $E > 150$ MeV for the endcaps, have been required.

3 The tag mechanism

In the rest frame ϕ-mesons decay into anti-collinear $K\overline{K}$ pairs (with branching ratios BR($\phi \to K^+K^- \simeq$ 49%) and BR($\phi \to K_S K_L \simeq$ 34%) [4]). In the laboratory this remains approximately true because of the small crossing angle of the e^+e^- beams.

The decay products of the K and $\overline{K}$ define, event by event, two spatially well separated regions called the tag and the signal hemispeheres. Identified $\overline{K}(K)$ decays tag a $K(\overline{K})$ beam and provide an absolute count, using the total number of tags as normalization. This procedure is a unique feature of a ϕ-factory and provides the means for measuring absolute branching ratios.

Charged kaons are tagged using the two body decays $K^\pm \to \mu^\pm\nu_\mu$ and $K^\pm \to \pi^\pm\pi^0$. K_S are tagged by K_L interacting in the calorimeter (K_L-crash); K_L are tagged detecting $K_S \to \pi^+\pi^-$. For all of cases it is possible to precisely measure the tagged kaon momentum from the knowledge of the ϕ and the tagging kaon momentum.

4 K_L physics

As already stated, a pure sample of K_L mesons is selected by the identification of $K_S \to \pi^+\pi^-$ decays. K_L can either decay in the detector volume or interact in the calorimeter or escape the detector.

Branching ratios of K_L main decays

Starting from this sample, the K_L branching ratios are evaluated by counting the number of decays to each channel in the fiducial volume FV and correcting for the geometrical acceptance, the reconstruction efficiency and the background contamination.

K_L decays in charged particles are identified by selecting a decay vertex within the FV along the expected K_L flight direction, as defined by the tag. In order to discriminate among the different K_L charged modes the variable $\Delta_{\mu\pi} = |p_{miss} - E_{miss}|$ is used, where p_{miss} and E_{miss} are the missing momentum and the missing energy at the K_L decay vertex, evaluated by assigning to one track the pion mass and to the other one the muon mass. Signal counting is thus achieved by fitting the $\Delta_{\mu\pi}$ spectrum with a linear combination of four Monte Carlo shapes ($K_L \to \pi e \nu_e$, $K_L \to \pi \mu \nu_\mu$, $K_L \to \pi^+\pi^-\pi^0$, $K_L \to \pi^+\pi^-$).

To count $K_L \to \pi^0\pi^0\pi^0$ events, we exploit the time of flight capability of the calorimeter to reconstruct the neutral vertex position. Such a vertex is assumed to be along the K_L line of flight. The arrival time of each photon detected in the calorimeter is thus used to give an independent determination of L_K, the path length of the K_L. Its final value is obtained from a weighted average of the different measurements. This decay has been used also to measure the K_L lifetime, $\tau_K = 50.92 \pm 0.17 \pm 0.25$ ns, from a fit to the proper time distribution of neutral decay vertexes [5].

Since the geometrical efficiency of the FV depends on τ_K, the branching ratios measured by KLOE have been renormalized by imposing their sum plus the remaining ones ($\approx 0.86\%$ from PDG) to be equal to one. This removes the uncertainty due to τ_K, while giving at the same time a precise determination of the K_L lifetime itself. The measured branching ratios are [6]:

$$\mathrm{BR}(K_L \to \pi e \nu_e(\gamma)) = 0.4007 \pm 0.0005 \pm 0.0004 \pm 0.0014 \quad (1)$$
$$\mathrm{BR}(K_L \to \pi \mu \nu_\mu(\gamma)) = 0.2698 \pm 0.0005 \pm 0.0004 \pm 0.0014 \quad (2)$$
$$\mathrm{BR}(K_L \to \pi^+\pi^-\pi^0(\gamma)) = 0.1263 \pm 0.0004 \pm 0.0003 \pm 0.0011 \quad (3)$$
$$\mathrm{BR}(K_L \to \pi^0\pi^0\pi^0(\gamma)) = 0.1997 \pm 0.0003 \pm 0.0003 \pm 0.0019 \quad (4)$$

The corresponding lifetime is: $\tau_{K_L} = 50.72 \pm 0.11 \pm 0.13 \pm 0.33$ ns. It is in agreement with KLOE's previous measurement. The two measurements are uncorrelated and can be averaged: $\tau_{K_L} = 50.84 \pm 0.23$ ns.

$K_L \to \pi e \nu_e$ decay: branching ratio and form factor

From the K_Le3 semileptonic decays it is possible to extract the shape of the vector form factor $f_+(t)$, since extra terms in the matrix element depend on the lepton mass. The form factor is usually parametrized as

$$f_+(t) = f_+(0)\left[1 + \lambda'_+ \frac{t}{m^2_{\pi^+}} + \frac{\lambda''_+}{2}\left(\frac{t}{m^2_{\pi^+}}\right)^2 + \dots\right] \quad (5)$$

where $f_+(0)$ is evaluated from theory and t is the $K \to \pi$ four momentum transfer squared of the lepton pair invariant mass. The parameters λ',λ'' are obtained by fitting the spectrum of $t/m^2_{\pi^+}$ K_{e3} events. The fit procedure takes into account the efficiency of the selection cuts, the resolution effects and the background contamination as a function of t. We find for a fit to $1 + \lambda'_+ t/m^2_{\pi^+}$ [7]:

$$\lambda_+ = (28.6 \pm 0.5 \pm 0.4) \times 10^{-3} \tag{6}$$

with $\chi^2/\mathrm{dof} = 330/363$ ($P(\chi^2) = 0.89$); for the quadratic term:

$$\lambda'_+ = (25.5 \pm 1.5 \pm 1.0) \times 10^{-3} \tag{7}$$

$$\lambda''_+ = (1.4 \pm 0.7 \pm 0.4) \times 10^{-3} \tag{8}$$

with $\chi^2/\mathrm{dof} = 325/362$ ($P(\chi^2) = 0.92$).

We also fit the data using a pole parametrization shape, $f_+(t)/f_+(0) = M_V^2/(M_V^2 - t)$. We obtain $M_V = (870 \pm 6 \pm 7)$ MeV ($\chi^2/\mathrm{dof} = 326/363$ with $P(\chi^2) = 0.924$).

$K_L \to \pi^+\pi^-$

KLOE has also measured the BR of the $K_L \to \pi^+\pi^-$ decay. This has been done measuring the ratio $R = \mathrm{BR}(K_L \to \pi^+\pi^-(\gamma))/\mathrm{BR}(K_L \to \pi\mu\nu_\mu(\gamma))$ and taking the value of the semileptonic branching ratio previously measured, since the tagging efficiency are very similar. The number of events has been obtained fitting the spectrum of the quantity $\sqrt{E^2_{miss} + p^2_{miss}}$ with a linear combination of the Monte Carlo shapes for signal and backgrounds corrected for the data/Monte Carlo ratio. Thus the result obtained is [8]:

$$\frac{\mathrm{BR}(K_L \to \pi^+\pi^-(\gamma)}{\mathrm{BR}(K_L \to \pi\mu\nu_\mu(\gamma))} = (0.7275 \pm 0.0042 \pm 0.0054) \times 10^{-2} \tag{9}$$

using the BR from the semileptonic decay:

$$\mathrm{BR}(K_L \to \pi^+\pi^-(\gamma)) = (1.963 \pm 0.0012 \pm 0.0017) \times 10^{-3} \tag{10}$$

This measurement, together with the measurements of the $\mathrm{BR}(K_S \to \pi^+\pi^-)$, the K_L and K_S lifetimes, can be used to determine $|\eta_{+-}|$ and $|\epsilon|$:

$$|\eta_{+-}| = (2.219 \pm 0.013) \times 10^{-3} \tag{11}$$

$$|\epsilon| = (2.216 \pm 0.013) \times 10^{-3} \tag{12}$$

where for $|\epsilon|$ we have used the world average for $Re(\epsilon'/\epsilon) = (1.67 \pm 0.26) \times 10^{-3}$ and assumed $\arg \epsilon' = \arg \epsilon$.

5 K_S decays

As already stated, a pure sample of K_S is selected by the detection of a K_L interaction in the calorimeter (K_L-crash).

$R_S^\pi = BR(K_S \to \pi^+\pi^-(\gamma))/BR(K_S \to \pi^0\pi^0)$

The ratio R_S^π is a fundamental parameter of the K_S meson. It enters into the double ratio that quantifies direct CP violation in $K \to \pi\pi$ transitions: $R_S^\pi/R_L^\pi = 1-6\Re(\epsilon'/\epsilon)$. The most precise measurement was performed by KLOE using data collected in 2000 for an integrated luminosity of 17 pb^{-1}: $R_S^\pi = 2.236 \pm 0.003 \pm 0.015$ [9]. This result was limited by systematic uncertainties. A new measurement has been performed using 410 pb^{-1} data collected in 2001 and 2002, inproving on the total error by a factor three. The K_S decays into two neutral pions are selected by requiring the presence of at least three EMC clusters with a timing compatible with the hypothesis of being due to prompt photons (within 5 $\sigma's$) and energy larger than 20 MeV. The selection of charged decays requires for two oppositely charged tracks coming from the IP. The result obtained is: $R_S^\pi = 2.2555 \pm 0.0056$ [10]. This result can be compared and averaged with the old one; weighting each by its independent errors and calculating the average systematic error with the same weigths gives [10]:

$$R_S^\pi = 2.2549 \pm 0.0054 \tag{13}$$

The result can be combined with the KLOE measurement of $\Gamma(K_S \to \pi^\mp e^\pm \nu(\overline{\nu})/\Gamma(K_S \to \pi^+\pi^-(\gamma))$ to extract the dominant K_S BRs. For the $\pi\pi$ mode we find [10]:

$$\mathrm{BR}(K_S \to \pi^+\pi^-(\gamma)) = (69.196 \pm 0.051) \times 10^{-2} \tag{14}$$

$$\mathrm{BR}(K_S \to \pi^0\pi^0) = (30.687 \pm 0.051) \times 10^{-2} \tag{15}$$

BR($K_S \to \pi e \nu$) and charge asymmetry

The measurement of the BR is an improvement (factor 4 on the total error) of KLOE's previous result [11]. It has been obtained by measuring the ratio $\mathrm{BR}(K_S \to \pi e\nu(\gamma))/\mathrm{BR}(K_S \to \pi^+\pi^-(\gamma))$ and using the KLOE's BR for the two bodies decay as normalization. The event counting is performed by fitting the $E_{miss} - p_{miss}$ spectrum with a combination of MC shapes for signal and background [12]:

$$\mathrm{BR}(K_S \to \pi^- e^+ \nu) = (3.528 \pm 0.062) \times 10^{-4} \tag{16}$$

$$\mathrm{BR}(K_S \to \pi^+ e^- \nu) = (3.517 \pm 0.058) \times 10^{-4} \tag{17}$$

$$\mathrm{BR}(K_S \to \pi e \nu) = (7.046 \pm 0.091) \times 10^{-4} \tag{18}$$

Fitting the ratio of data and MC $t/m^2_{\pi^+}$ distributions we have measured the form factor slope. The fit has been performed using only a linear parametrization, since the available statistics does not allow to be sensitive to a quadratic one. The result obtained is in agreement with the corresponding value for the linear slope of the semileptonic K_L form factor. The slope obtained is $\lambda_+ = (33.9 \pm 4.1) \times 10^{-3}$. The charge asymmetry measured is [12]:

$$A_S = \frac{\Gamma(K_S \to \pi^- e^+ \nu) - \Gamma(K_S \to \pi^+ e^- \nu)}{\Gamma(K_S \to \pi^- e^+ \nu) + \Gamma(K_S \to \pi^+ e^- \nu)} = (1.5 \pm 9.6 \pm 2.9) \times 10^{-3}. \tag{19}$$

The comparison of A_S with the corresponding for K_L allows precision tests of CP and CPT symmetries. The difference between the charge asymmetries $A_S - A_L = 4(Re\ \delta + Re\ x_-)$ signals CPT violation either in the mass matrix (δ term) or in the decay amplitudes with $\Delta S \neq \Delta Q$ (x_- term). The sum of the asymmetries $A_S + A_L = 4(Re\ \epsilon + Re\ y)$ is related to CP violation in the mass matrix (ϵ term) and to CPT violation in the decay amplitude (y term). K_S and K_L decay amplitudes allow test of the $\Delta S = \Delta Q$ rule through the quantity:

$$Re\ x_+ = \frac{1}{2}\frac{\Gamma(K_S \to \pi e \nu) - \Gamma(K_L \to \pi e \nu)}{\Gamma(K_S \to \pi e \nu) + \Gamma(K_L \to \pi e \nu)}. \tag{20}$$

The results obtained (using other quantities when needed either from KLOE when available or from PDG) are:

$$Re\ x_+ = (-0.5 \pm 3.6) \times 10^{-3} \tag{21}$$

$$Re\ x_- = (-0.8 \pm 2.5) \times 10^{-3} \tag{22}$$

$$Re\ y = (0.4 \pm 2.5) \times 10^{-3} \tag{23}$$

they are all compatible with zero. KLOE has a disposal of a statistic five time bigger, using all the data available the uncertainty on A_S can be reduced by more than a factor 5.

BR($K_S \to \pi^0\pi^0\pi^0$)

This decay is a pure CP violating process. The related CP violation parameter η_{000} is defined as the ratio of decay amplitudes: $|\eta_{000}| = A(K_S \to 3\pi^0)/A(K_L \to 3\pi^0) = \epsilon + \epsilon'_{000}$ where ϵ describes the CP violation in the mixing matrix and ϵ'_{000} is a direct CP violating term. The signal selection requires six neutral clusters coming from the interaction point. Background coming from $K_S \to \pi^0\pi^0$ + fake γ is rejected applying a kinematic fit imposing as constraints the K_S mass, the K_L four momentum and $\beta = 1$ for each photon. Two pseudo χ^2 variables are then built, ζ_3 which is based on the best 6 γ combination into 3 π^0 and ζ_2 which select four out of six γ providing the best agreement with the $K_S \to \pi^0\pi^0$ decay. Events with two charged tracks coming from the interaction point are vetoed. Using the $K_S \to \pi^0\pi^0$ branching ratio as normalization sample we obtained a 90% C.L. upper limit [13]:

$$\mathrm{BR}(K_S \to \pi^0\pi^0\pi^0) < 1.2 \times 10^{-7}. \tag{24}$$

The corresponding 90% C.L. upper limit on η_{000} is:

$$|\eta_{000}| = \frac{|A(K_S \to 3\pi^0)|}{|A(K_L \to 3\pi^0)|} < 0.018. \tag{25}$$

6 Quantum interference in kaons

KLOE at a ϕ-factory has the unique possibility for testing QM and CPT simmetry studying interference in the $\phi \to K_L K_S \to \pi^+\pi^-\pi^+\pi^-$ channel. Deviation from QM can be parametrized introducing a decoherence parameter ζ in the formula for the decay intensity [14, 15]:

$$I(|\Delta t|) \propto e^{-|\Delta t|\Gamma_L} + e^{-|\Delta t|\Gamma_S} - 2(1-\zeta)cos(\Delta m|\Delta t|)e^{\frac{\Gamma_S+\Gamma_L}{2}|\Delta t|} \tag{26}$$

The meaning and value of ζ depends on the basis used for the initial state (i.e. ζ_{SL} for $K_S K_L$ and $\zeta_{0\overline{0}}$ for $K^0\overline{K^0}$). The results have been obtained performing a fit of the Δt distribution. For the decoherence parameter we find [16]:

$$\zeta_{SL} = \quad 0.018 \pm 0.040 \pm 0.007 \qquad \chi^2/\text{dof} = 29.7/32 \tag{27}$$

$$\zeta_{0\overline{0}} = \quad (0.10 \pm 0.21 \pm 0.04) \times 10^{-5} \qquad \chi^2/\text{dof} = 29.6/32. \tag{28}$$

The results are consistent with zero, therefore there is not evidence for QM violation. Space-time fluctuactions at the Planck scale might induce a pure state to become mixed [17]. This results in QM and CPT violation, changing therefore the decay time distribution of the $K^0\overline{K^0}$ pair from ϕ decays. In some theoretical framework this violation can be parametrized with the quantities γ [18] or ω [19]. Again the values obtained are compatible with zero. There is no evidence for QM violation [16]:

$$\gamma = \quad (1.3^{+2.8}_{-2.4} \pm 0.4) \times 10^{-21} GeV \qquad \chi^2/dof = 33/32 \tag{29}$$

$$\Re\omega = \quad (1.1^{+8.7}_{-5.7} \pm 0.9) \times 10^{-4} \qquad \chi^2/dof = 29/31 \tag{30}$$

$$\Im\omega = \quad (3.4^{+4.8}_{-5.0} \pm 0.6) \times 10^{-4}. \tag{31}$$

Another test of CPT invariance can be performed via the Bell-Steinberger relation (BSR) [20]:

$$\left(\frac{\Gamma_S + \Gamma_L}{\Gamma_S - \Gamma_L} + i\ \tan\phi_{SW}\right)\left(\frac{Re(\epsilon)}{1+|\epsilon|^2} - i\ Im(\delta)\right) = \frac{1}{\Gamma_S - \Gamma_L}\sum_f A_L(f)A_S^*(f) \tag{32}$$

where $\phi_{SW} = \arctan(2(m_L - m_S)/(\Gamma_S - \Gamma_L))$. The Bell-Steinberger relation links a possible violation of CPT invariance ($m_{K^0} \neq m_{\overline{K^0}}$ or $\Gamma_{K^0} \neq \Gamma_{\overline{K^0}}$) in the time evolution of the $K^0\overline{K^0}$ system to the observable CP violating interference of K_L and K_S decays into the same final state f. Any evidence for a non vanishing $Im(\delta)$ can only be due to violation of: i) CPT invariance; ii) unitarity; iii) the time independence of M and Γ in the equation which describes the time evolution of the neutral kaon system within the Wigner-Weisskopf approximation:

$$i\frac{\partial}{\partial t}\Psi(t) = H\Psi(t) = \left(M - \frac{i}{2}\Gamma\right)\Psi(t), \tag{33}$$

where M and Γ are 2×2 time-independent Hermitian matrices and $\Psi(t)$ is a two-component state vector in the $K^0 - \overline{K^0}$ space. The result we have obtained (using all experimental inputs from KLOE where available) are [21]:

$$Re(\epsilon) = (159.6 \pm 1.3) \times 10^{-5} \tag{34}$$

$$Im(\delta) = (0.4 \pm 2.1) \times 10^{-5}. \tag{35}$$

The limits on $Im(\delta)$ and $Re(\delta)$ can be used to constrain the mass and width difference between the neutral kaons via the relation:

$$\delta = \frac{i(m_{K^0} - m_{\overline{K}^0}) + \frac{1}{2}(\Gamma_{K^0} - \Gamma_{\overline{K}^0})}{\Gamma_S - \Gamma_L} \cos \phi_{SW} e^{i\phi_{SW}} [1 + O(\epsilon)]. \tag{36}$$

In the limit $\Gamma_{K^0} = \Gamma_{\overline{K}^0}$ (i.e. neglecting CPT-violating effects in the decay amplitudes) we obtain the following bound at 95% C.L. on the mass difference [21]:

$$-5.3 \times 10^{-19}\ GeV < m_{K^0} - m_{\overline{K}^0} < 6.3 \times 10^{-19}\ GeV \tag{37}$$

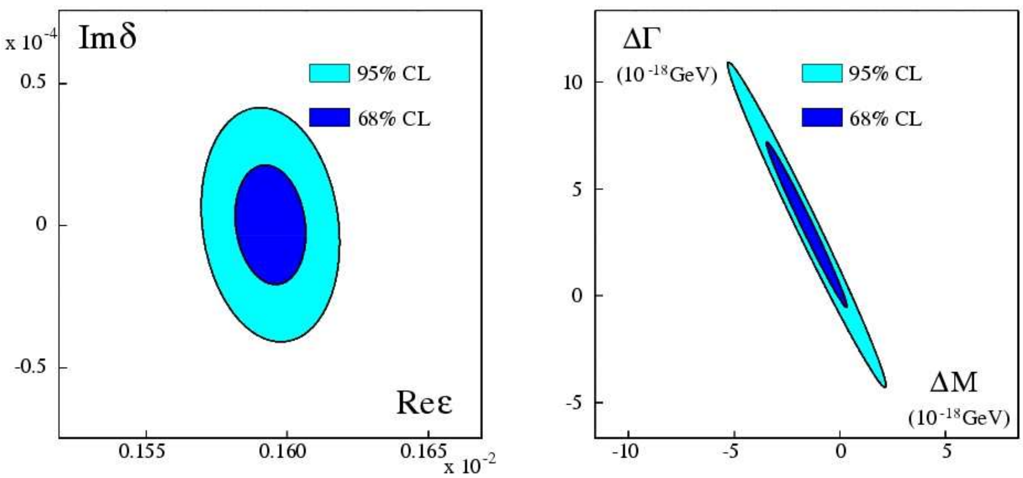

Figure 1: Left: allowed region at 68% and 95% CL in the Re(ϵ), Im(δ) plane. Right: allowed region at 68% and 95% CL in ΔM, $\Delta\Gamma$ plane.

7 Charged kaons decays

As already stated, a pure sample of $K^{\pm}$ is selected by the identification of a $K^{\mp}$ two bodies decay in the drift chamber.

Charged kaon lifetime

Together with the branching ratios of the semileptonic decays, the lifetime is one of the fundamental experimental inputs for the evaluation of V_{us}. There are two methods available for the measurement: the kaon decay length and the kaon decay time. The two methods allow cross checks and studies of systematics; their resolutions are comparable. The first requires a kaon decay vertex in the fiducial volume, then the kaon is extrapolated backward to the IP taking into account the dE/dx to evaluate its velocity. The proper time can be obtained fitting the distribution of

$$\tau^* = \sum_i \Delta T_i = \sum_i \frac{\sqrt{1-\beta_i^2}}{\beta_i c}\Delta l_i \tag{38}$$

The preliminary result we have obtained for the K^+ is:

$$\tau^+ = (12.377 \pm 0.044 \pm 0.065) ns \tag{39}$$

with $\chi^2/\text{dof} = 17.7/15$. The analysis with the second method is still in progress.

Branching ratio of the charged kaon semileptonic decays

The BRs for the two semileptonic decays are obtained performing a fit of the mass squared of the charged secondary decay product (m^2_{lept}), using the MC distributions for signal and background. The mass is obtaind via a TOF measurement. Background from $\mu\nu_\mu$ decay is rejected applying a cut on the momentum of the charged secondary in the decaying kaon rest frame. The BRs have been evaluated separately for each tag sample and each charge; corrections have been applied in order to account for data-MC differences. The preliminary branching ratios obtained are:

$$\text{BR}(K^\pm \to \pi^0 e^\pm \nu_e(\gamma) = (5.047 \pm 0.019 \pm 0.039) \times 10^{-2} \tag{40}$$

$$\text{BR}(K^\pm \to \pi^0 \mu^\pm \nu_\mu(\gamma) = (3.310 \pm 0.016 \pm 0.045) \times 10^{-2}. \tag{41}$$

BR($K \to \mu\nu_\mu(\gamma)$)

The number of signal events has been obtained performing a fit of the momentum of the charged secondary in the decaying kaon rest frame. Background has been identified as any event having a π^0 in the final state. The efficiency has been evaluated directly on data using a sample selected only with calorimeter informations. The result obtained is [22]:

$$\text{BR}(K^+ \to \mu^+\nu_\mu(\gamma)) = 0.6366 \pm 0.0009 \pm 0.0015 \tag{42}$$

8 V_{us} summary

The KLOE results on semileptonic decays on both neutral and charged kaons, can be used together with results from other experiments in order to evaluate V_{us} and check the unitarity of the first row of the CKM matrix.
Averaging over all the available experimental inputs according to the procedure specified in [23], it is possible to extract the world average:

$$V_{us} \times f_+(0) = 0.2164 \pm 0.0004 \tag{43}$$

which can be compared with the value expected from unitarity of CKM matrix using V_{ud} from [24]:

$$V_{us} \times f_+(0) = 0.2187 \pm 0.0022. \tag{44}$$

We use $f_+(0) = 0.961 \pm 0.008$, computed by Leutwyler and Roos [25]. It is also possible

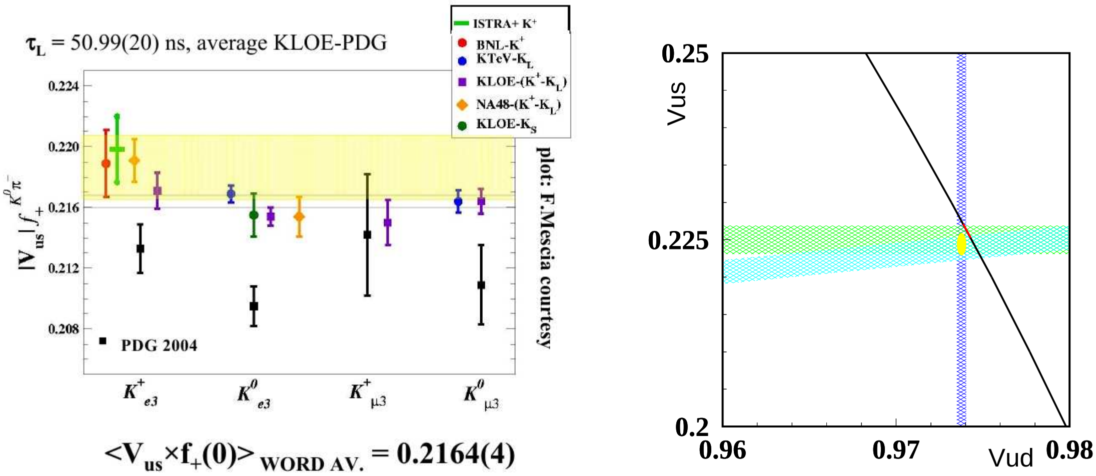

Figure 2: Left: $V_{us} \times f_+(0)$ world average. Right: $V_{us} - V_{ud}$ plane.

to use the charged kaon leptonic decay to evaluate V_{us} using lattice calculation of the ratio f_K/f_π as pointed out in [26]. Using the latest value from the MILC collaboration for the ratio of the decay constants [27] we find:

$$\frac{V_{us}}{V_{ud}} = 0.2286^{+0.0020}_{-0.0011}. \tag{45}$$

This value can be fitted together with V_{us} from kaon semileptonic decays and V_{ud} from nuclear beta decays, obtaining:

$$V_{us} = 0.2246^{+0.0009}_{-0.0013} \tag{46}$$

$$V_{ud} = 0.97377 \pm 0.00027 \tag{47}$$

with $\chi^2/dof = 0.046/2$, P$(\chi^2) = 0.97$. Imposing also the unitarity constraint (see the right panel of figure 2):

$$V_{us} = 0.2257 \pm 0.0007 \tag{48}$$
$$V_{ud} = 0.97420 \pm 0.00016 \tag{49}$$

with $\chi^2/dof = 3.94/1$, P$(\chi^2) = 0.05$.

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