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V_{us} and lepton universality from kaon decays at KLOE

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Precise measurements of semileptonic kaon decay rates at KLOE provide the measurement of the CKM mixing matrix element $V_{\rm us}$ and information about lepton universality. Leptonic kaon decays provide an independent measurement of $|V_{\rm us}|^2\,/\,|V_{\rm ud}|^2$, through the ratio $\Gamma(K\to\mu\nu)/\Gamma(\pi\to\mu\nu)$. These measurements, together with the result of $|V_{\rm ud}|$ from nuclear β transitions, provide the most precise test of CKM unitarity, allowing the universality of lepton and quark weak couplings to be tested. Bounds on new physics extensions of the standard model with lepton flavor violation can be set using the final KLOE result on $R_{\rm K}=\Gamma(K_{e2})/\Gamma(K_{\mu2})=2.493\pm0.025_{\rm stat}\pm0.019_{\rm syst}$, based on the measurement of the differential width $d\Gamma(K\to e\nu\gamma)/dE_\gamma/\Gamma(K\to\mu\nu)$ for photon energies $10<E_\gamma<250$ MeV.

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1. INTRODUCTION

The KLOE experiment [1] collected an integrated luminosity $\int \mathscr{L} \mathrm{d}t\ \sim$2.5fb^{-1} at the Frascati $\phi-$factory DAΦNE, an e^+e^- collider operated at the energy of 1020 MeV, the ϕ-meson mass. With its general purpose detector, consisting of a large cylindrical drift chamber surrounded by a lead-scintillating fiber electromagnetic calorimeter entirely immersed in an axial magnetic field, KLOE produced the most comprehensive set of results on kaon physics from a single experiment using the unique availability of pure K_S ,K_L and $K^{\pm}$ beams at a $\phi-$factory .

An overview of KLOE results for K_L, K_S and $K^{\pm}$ used to extract $V_{\rm us}$ is presented (sec. 2), together with the measurement of $R_{\rm K}$ (sec. 3) and future perspectives (sec. 4).

2. $V_{\rm us}$ from kaon decays: unitarity and universality

The most precise test of CKM unitarity is given by the constraint on its first row $|V_{\rm ud}|^2 + |V_{\rm us}|^2 + |V_{\rm ub}|^2 = 1$ with $|V_{\rm ud}|$ measured from superallowed $0^+ \to 0^+$ nuclear β transitions, $|V_{\rm us}|$ from semileptonic kaon decays and $|V_{\rm ub}|^2$ being negligible. The kaon semileptonic decay rate is given by:

$$\Gamma(K_{l3}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{\rm us}|^2 |f_+(0)|^2 I_{K,l}(\lambda)(1 + 2\Delta_K^{SU(2)} + 2\Delta_{K,l}^{EM}) \tag{2.1}$$

where $K = K^0, K^{\pm}$, $l = e, \mu$ and C_K is a Clebsch-Gordan coefficient, equal to $1/2$ and 1 for $K^{\pm}$ and K^0, respectively. The decay width $\Gamma(K_{l3})$ is experimentally determined by measuring the kaon lifetime and the semileptonic BRs, inclusive of radiation.

Branching ratios	
$K_L \to \pi e \nu$	0.4008 ± 0.0015
$K_L \to \pi \mu \nu$	0.2699 ± 0.0014
$K_S \to \pi^+\pi^-$	0.60196 ± 0.00051
$K_S \to \pi^0\pi^0$	0.30687 ± 0.00051
$K_S \to \pi e \nu$	$(7.05 \pm 0.09)\times 10^{-4}$
$K^+ \to \mu^+\nu(\gamma)$	0.6366 ± 0.0017
$K^+ \to \pi^+\pi^0(\gamma)$	0.2067 ± 0.0012
$K^+ \to \pi^0 e^+ \nu(\gamma)$	0.04972 ± 0.00053
$K^+ \to \pi^0 \mu^+ \nu(\gamma)$	0.03237 ± 0.00039
Lifetimes	
τ_L	50.84 ± 0.23
$\tau_{\pm}$	12.347 ± 0.030
Form factors (dispersive approach)	
λ_+	$25.7(0.6)\times 10^{-3}$
λ_0	$14.0(2.1)\times 10^{-3}$

Table 1: Summary of KLOE results useful for $V_{\rm us}$ measurement [1].

The theoretical inputs are: the universal short-distance electroweak correction S_{EW}=1.0232, the $SU(2)$-breaking $\Delta_K^{SU(2)}$ and the long-distance electromagnetic corrections $\Delta_{K,l}^{EM}$, and the form factor $f_+(0) \equiv f_+^{K^0\pi^-}(0)$ evaluated at zero momentum transfer. The form factor dependence on the momentum transfer can be described by one or more slope parameters λ, measured from the decay spectra, and enters in the phase space integral $I_{K,l}(\lambda)$.

All the relevant inputs to extract $V_{\rm us}$ from K_{l3} decay rates have been measured at KLOE [1]: BRs, lifetimes and form factors (Table 1). Complementary to K_{l3} decays, the measurement of BR$(K^{\pm} \to \mu^{\pm}\nu)$ allowed us to extract $V_{\rm us}/V_{\rm ud}$ and the result of BR$(K^+ \to \pi^+\pi^0(\gamma))$ improved the accuracy in the comparison of BR(K_{l3}) from absolute and relative measurements. A preliminary update of the K_L lifetime together with a preliminary result on the K_S lifetime have been presented at this conference[3]. To extract $V_{\rm us} f_+(0)$ we use eq.2.1 together with the $SU(2)$-breaking and long distance EM corrections to the full inclusive decay rate [4]. The measured values of $V_{\rm us} f_+(0)$ are [5]: 0.2155(7) for $K_L e3$, 0.2167(9) for $K_L\mu 3$, 0.2153(14) for $K_S e3$, 0.2152(13) for $K^{\pm}e3$, and 0.2132(15) for $K^{\pm}\mu 3$ decays. Their average

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is $V_{\rm us} f_+(0)$ = 0.2157(6) (χ^2/ndf = 7.0/4,Prob=13%), with 0.28% accuracy to be compared with the 0.23% of the world average $V_{\rm us} f_+(0)$ = 0.2166(5) [6].

Defining $r_{\mu e} = |f_+(0)V_{us}|^2_{\mu 3}/|f_+(0)V_{us}|^2_{e3} = g^2_\mu/g^2_e$, with g_ℓ the coupling strength at the $W \to \ell\nu$ vertex, lepton universality can be tested comparing the measured value with its Standard Model (SM) prediction $r^{SM}_{\mu e} = 1$. We obtain $r_{\mu e} = 1.000(8)$, averaging between charged and neutral modes, to be compared with $(r_{\mu e})_\pi = 1.0042(33)$ from leptonic pion decays [7], and $(r_{\mu e})_\tau = 1.0005(41)$ from leptonic τ decays [8]. Using $V_{\rm us} f_+(0)$ from K_{l3} decays and $f_+(0) = 0.964(5)$ [9], we get $V_{\rm us} = 0.2237(13)$. Furthermore $V_{\rm us}/V_{\rm ud}$ can be measured using the radiative inclusive decay rates of $K^\pm \to \mu^\pm\nu(\gamma)$ and $\pi^\pm \to \mu^\pm\nu(\gamma)$, combined with a lattice calculation of f_K/f_π [11]. Using BR$(K^\pm \to \mu^\pm\nu) = 0.6366(17)$ from KLOE [2] and $f_K/f_\pi = 1.189(7)$ [12], we get $V_{\rm us}/V_{\rm ud} = 0.2323(15)$. Combining this result with $V_{\rm us}$ from K_{l3} decays and $V_{\rm ud} = 0.97418(26)$ [13], CKM unitarity has been tested to a 0.6σ level: $1 - V^2_{\rm ud} + V^2_{\rm us} + V^2_{\rm ub} = 4(7)\times 10^{-4}$. We then obtained $G_{\rm CKM} = G_{\rm F}(V^2_{\rm ud} + V^2_{\rm us} + V^2_{\rm ub})^{1/2} = 1.16614(40)\times 10^{-5}$ GeV^{-2}, in perfect agreement with the measurement from the muon lifetime $G_{\rm F} = 1.166371(6)\times 10^{-5}$ GeV^{-2} and the most accurate compared to the measurements from tau-lepton decays and electroweak precision tests.

3. Lepton-flavor violation in $K_{\ell 2}$ decays

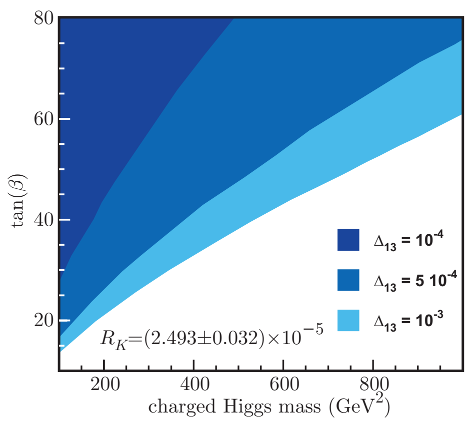

Figure 1: Excluded regions at 95% C.L. in the plane M_H–$\tan\beta$ for $\Delta^{31}_R = 10^{-4}, 5\times 10^{-3}, 10^{-3}$.

The Ke2 amplitude, helicity suppressed within the SM, is sensitive to contributions from new physics. Deviations of up to few percent from the SM value of $R_{\rm K} = \Gamma(K_{e2})/\Gamma(K_{\mu 2})$, calculated with very high precision, are expected within MSSM with lepton flavor violation by the charged Higgs [14]. $R_{\rm K}$ has been measured with a 1.3% accuracy, using the complete KLOE data set: $R_{\rm K} = (2.493 \pm 0.025_{\rm stat} \pm 0.019_{\rm syst})\times 10^{-5}$ [15]. The 0.8% fractional systematic uncertainty is dominated by the statistics of the control-sample used (0.6%) thus improvements with larger statistics are expected. Radiative corrections have been carefully taken into account. We have used KLOE measurement of $dR_\gamma/dE_\gamma = d\Gamma(K \to e\nu\gamma)/dE_\gamma/\Gamma(K \to \mu\nu)$ differential width integrated over for photon energies 10<E_γ<250 MeV: $R_\gamma = (1.483 \pm 0.066_{\rm stat} \pm 0.013_{\rm syst})\times 10^{-5}$ [15] in agreement with the Chiral Perturbation Theory prediction at $\mathcal{O}(e^2p^4)$. Our result on R$_{\rm K}$ gives strong constraints for $\tan\beta$ and $m_{H^\pm}$, as a function of the 1-3 slepton-mass matrix element Δ_{13}, as shown in fig.1.

4. Future perspectives

After the completion of the KLOE data taking [1], a proposal [16] has been presented for a physics program to be carried out with an upgraded KLOE detector, KLOE-2 [17, 18, 19], at an upgraded DAΦNE machine, which has been assumed to deliver an integrated luminosity $\mathcal{O}(20)$

fb^{-1}. The program will be focused on physics originating from the interaction region, where the ϕ-meson is produced: K_S decays, K_S-K_L interference, η and $K^{\pm}$ decays.

Using KLOE present data set together with the first 5 fb^{-1} of KLOE-2 data, we can improve the accuracy on the measurement of K_L and $K^{\pm}$ lifetimes and of K_Se3 branching ratio with respect to present world average [6]. The measurement of semileptonic decay rates, in particular of K_Se3, will strongly benefit from the insertion of an Inner Tracker [17], foreseen during the second phase of the KLOE-2 program. This upgrade will allow us to increase the acceptance for decays close to the interaction region with low momentum tracks and to improve the resolution on their track and vertex parameters. Therefore a significant reduction of the present experimental uncertainty on the measurement of $V_{\rm us} f_+(0)$ is expected. This, together with more precise measurements of $V_{\rm ud}$ and $f_+(0)$, would allow us to reach the level of precision of a few 10^{-4} in testing the unitarity relation thus improving the potential to investigate new physics within Standard Model extensions with gauge universality breaking.

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