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Precision Kaon Physics with KLOE

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A ϕ-factory offers the possibility to select pure kaon beams: neutral kaons from $\phi \to K_S K_L$ are in fact produced in pairs and the detection of a K_S (K_L) tags the presence of a K_L (K_S),the same holds for charged kaons. This allows us to perform precise measurement of kaon properties. The KLOE collaboration has measured most decay branching ratios of K_S, K_L and $K^\pm$ mesons together with the K_L and the $K^\pm$ lifetime, and the shape of the form factors involved in kaon semileptonic decays. These results provide the basis for the determination of the CKM parameter V_{US} and the most precise test of the unitarity of the quark flavor mixing matrix.
Bounds on new physics extensions of the standard model with lepton flavor violation have been set using the KLOE result on $R_K = \Gamma(Ke2)/\Gamma(K\mu 2)$ based on the complete data set of 2.2 fb^{-1}. The final 1.3% accuracy on the ratio R_K has been achieved measuring 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.
We are presently finalizing new determinations of the K_L and K_S lifetimes using the whole KLOE data set, consisting of more than 10^9 $\phi \to K_S K_L$ decays.

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Introduction The KLOE experiment collected $\sim 2.5\,\mathrm{fb}^{-1}$ of integrated luminosity at DAΦNE, the Frascati ϕ-factory [1]. DAΦNE is an e^+e^- collider that operates at the ϕ-meson mass. A ϕ-factory offers the possibility to select pure kaon beams, the kaon pair is in an antisymmetric state so that the final state is always $K_S K_L$. Therefore, the detection of a K_L signals the presence of a K_S of known momentum and direction, independently of its decay mode. The same holds for charged kaons. The KLOE detector consists of a large cylindrical drift chamber, surrounded by a lead/scintillating-fiber sampling calorimeter. A superconducting coil surrounding the calorimeter provides a 0.52 T magnetic field.

CKM unitarity The most precise test of CKM unitarity is given by $|V_{\mathrm{ud}}|^2+|V_{\mathrm{us}}|^2+|V_{\mathrm{ub}}|^2=1$ where $|V_{\mathrm{ud}}|$ is measured from superallowed $0^+\to 0^+$ nuclear β decay, $|V_{\mathrm{us}}|$ extracted from kaon semileptonic decay and $|V_{\mathrm{ub}}|$ being negligible. The kaon semileptonic decay rate is given by $\mathrm{BR}(K\to\pi\ell\nu(\gamma))/\tau = G^2 m_K^5/(768\pi^3)C_K^2|V_{\mathrm{us}}|^2|f_+(0)|^2 I_K^\ell S_{\mathrm{ew}}[1+\delta_{\mathrm{SU(2)}}+\delta_{\mathrm{em}}]$, where the branching rations and the lifetimes are obtained experimentally from semileptonic decays inclusive of radiation. The theoretical inputs are: the universal short distance electroweak correction S_{ew}, the hadronic form factor at zero momentum transfer $f_+(0)$, the form factor correction for strong SU(2) breaking $\delta_{\mathrm{SU(2)}}$ and the long distance electromagnetic effects δ_{ew}. KLOE has measured all relevant inputs for charged and neutral kaons: all the branching ratios, lifetimes and form factors. The measured values of $V_{\mathrm{us}}f_+(0)$ are [2]: 0.2155(7) for K_Le3, 0.2167(9) for $K_L\mu3$, 0.2153(14) for K_Se3, 0.2152(13) for $K^\pm e3$, and 0.2132(15) for $K^\pm\mu3$ decays. Their average yields $V_{\mathrm{us}}f_+(0)=0.2157(6)$ ($\chi^2/\mathrm{ndf}=7.0/4$, $\mathrm{Prob}=13\%$), with 0.28% accuracy to be compared with the 0.23% of the world average $V_{\mathrm{us}}f_+(0)=0.2166(5)$ [3]. Defining $r_{\mu e}=|V_{\mathrm{us}}f_+(0)|^2_{\mu3}/|V_{\mathrm{us}}f_+(0)|^2_{e3}=g_\mu^2/g_e^2$, where g_ℓ is the coupling strength at the $W\to\ell\nu$ vertex, lepton universality can be tested comparing the measured value with the Standard Model prediction $r_{\mu e}^{SM}=1$. KLOE obtained $r_{\mu e}=1.000(8)$, averaging between charged and neutral modes, to be compared with $(r_{\mu e})_\pi=1.0042(33)$ from leptonic pion decays [4], and $(r_{\mu e})_\tau=1.0005(41)$ from leptonic τ decays [5]. Using $V_{\mathrm{us}}f_+(0)$ from $K_{\ell3}$ decays and $f_+(0)=0.964(5)$ [6], we obtain $V_{\mathrm{us}}=0.2237(13)$. Moreover $V_{\mathrm{us}}/V_{\mathrm{ud}}$ can be measured using the ratio of the radiative inclusive decay rates of $K^\pm\to\mu^\pm\nu(\gamma)$ and $\pi^\pm\to\mu^\pm\nu(\gamma)$, combined with the lattice calculation of f_K/f_π [7]. Using $\mathrm{BR}(K^\pm\to\mu^\pm\nu)=0.6366(17)$ from KLOE [8] and $f_K/f_\pi=1.189(7)$ [9], we get $V_{\mathrm{us}}/V_{\mathrm{ud}}=0.2323(15)$. Combining this result with V_{us} from $K_{\ell3}$ decays and $V_{\mathrm{ud}}=0.97418(26)$ [10], CKM unitary has been tested to a $0.6\,\sigma$ level: $1-|V_{\mathrm{ud}}|^2+|V_{\mathrm{us}}|^2+|V_{\mathrm{ub}}|^2=4(7)\times10^{-4}$. We then obtained $G_{\mathrm{CKM}}=G_{\mathrm{F}}\sqrt{|V_{\mathrm{ud}}|^2+|V_{\mathrm{us}}|^2+|V_{\mathrm{ub}}|^2}=1.16633(35)\times10^{-5}\ \mathrm{GeV}^{-2}$, with $G_F=1.166371(35)\times10^{-5}\ \mathrm{GeV}^{-2}$. At present, this result is more accurate than what obtained from τ decays and electroweak precision tests.

Measurement of $R_K=\Gamma(Ke2)/\Gamma(K\mu2)$ The decay $K^\pm\to e^\pm\nu$ is strongly suppressed in SM because of the helicity conservation and represents a powerful probe for new physics effects. Small deviations from SM value of R_K, evaluated with high precision, are expected within MSSM with lepton flavour violation by the charged Higgs [11]. R_K has been measured with a 1.3% accuracy, using the complete KLOE data set: $R_K=(2.493\pm0.025_{\mathrm{stat}}\pm0.019_{\mathrm{syst}})\times10^{-5}$ [12]. The effect of radiative corrections has been carefully evaluated in a dedicated measurement. The result of $(\mathrm{d}\Gamma(K\to e\nu\gamma)/\mathrm{d}E_\gamma)/\Gamma(K\to\mu\nu)$ integrated over $10<E_\gamma<200$ MeV is $R_\gamma=(1.483\pm0.066_{\mathrm{stat}}\pm0.013_{\mathrm{syst}})\times10^{-5}$ [12] in agreement with the χPt prediction at $\mathscr{O}(e^2p^4)$. Our result on R_K gives strong constraints for $\tan\beta$ and $m_{H^{\pm}}$, as a function of the 1-3 slepton-mass matrix element Δ_{13}.

K_L lifetime measurement The K_L lifetime (τ_L) uncertainty is the limiting factor on the accuracy of V_{us} measured from K_L semileptonic decays. To improve this accuracy the KLOE collaboration has decided to perform a new τ_L measurement with $\sim$ 46 million of $K_L \to 3\pi^0$ events. K_L mesons are tagged by detecting $K_S \to \pi^+\pi^-$ decays and the proper time distribution obtained with $K_L \to 3\pi^0$ decays is used to measure K_L lifetime, exploiting the high branching ratio of $3\pi^0$ decay mode and its high detection efficiency. The preliminary result is: $\tau_L = 50.56 \pm 0.14_{\text{stat}} \pm 0.21_{\text{syst}}$ ns [13] compatible with the previous KLOE measurement [14]. The expected statistical uncertainty with the whole data sample is $\sigma_{\text{stat}} \sim 0.1$ ns, and the systematic contribution, partially statistical in nature, is expected to decrease as well.

K_S lifetime measurement KLOE measures K_S lifetime (τ_S) with pure K_S beam and exploiting the event by event knowledge of K_S momentum. The lifetime is measured by fitting the proper time (t^*) distribution of $K_S \to \pi^+\pi^-$ decays. The t^* resolution is improved reconstructing the interaction point event-by-event using a geometrical fit, selecting events with pions decaying at large angle with respect to the K_S direction. The efficiency of the selection is $\sim$ 13%. Since the resolution depends on the K_S direction, we fit the proper time distribution from -1 to 6.5 τ_S in each of 180 bins in $\cos(\theta_K)$ and ϕ_K. The statistical error on τ_s is less than 0.1%. The final result has now been submitted for preliminary [15]: $\tau_S = (89.562 \pm 0.029_{\text{stat}} \pm 0.043_{\text{syst}})$ ps.

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