PROCEEDINGS OF SCIENCE

Kaon Session Summary

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Experimental results in the Kaon system have contributed greatly to establishing both the framework and the details of the Standard Model.
In the era of Higgs searches and heavy flavour decays, Kaon physics is still a very exciting field. Many old and new experiments continue to study rare decays and to produce precision measurements that are placing non-trivial bounds on theories.
At the conference new results in Kaon physics have been presented by KLOE, NA48/2 and NA62 experiments:
NA48/2 provides new competitive results on $K^{\pm}\mu 3$ form factors in the quadratic, dispersive and Pole parametrization for both K^{+} and K^{-} decays.
NA48/2 reported on kaon radiative decays precision measurements [1]. Particularly interesting is the final result on direct photon emission (DE) in the $K^{\pm} \to \pi^{+}\pi^{0}\gamma$ and its interference term (INT) with the inner bremsstrahlung [IB] amplitude, with INT being measured for the first time.
The high statistics measurements of $K^{\pm} \to \pi^{+}\pi^{-}e^{\pm}\nu$ (Ke4) [2] and $K^{\pm} \to \pi^{0}\pi^{0}\pi^{\pm}$ ($K3\pi$) [3] decays performed by the NA48/2 experiment allowes a model independent approach to the study of low energy $\pi-\pi$ scattering close to threshold, providing an accurate test of Chiral Perturbation Theory prediction. For the first time the experimental precision matches the one of the theoretical prediction and the agreement is outstanding.
KLOE and NA62 discussed preliminary results on the test of lepton universality from the measurement of the helicity suppressed ratio $R_K = \Gamma(Ke2)/\Gamma(K\mu 2)$.
KLOE reported on new accurate determinations of the K_L and K_S lifetime extracted from the proper time distributions of $K_L \to 3\pi^{0}$ and $K_S \to \pi^{+}\pi^{-}$ decays.
NA62 is undergoing a major upgrade of the detector with the goal to search for new physics beyond the Standard Model, by collecting of the order of 100 $K^{+} \to \pi^{+}\nu\overline{\nu}$ ultra rare decays with a 10% background level.

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1. Kaon Session Summary

Kaon physics has always played a crucial role for our understanding of fundamental interactions in the flavour sector. Together with B-physics, for which however precise experimental information has become available only recently, the study of kaon physics has allowed fundamental tests of the Standard Model (SM) and provides, at present, precise constraints on its possible new physics extensions.

Kaons remain a privileged observatory for flavour physics phenomena where all the features of flavour physics are present: kaons are a rather simple system of the lightest mesons containing a quark flavour of a generation beyond the first, they have rather long lifetimes, with a broad hierarchy between K_L and K_S, and they are produced in large quantity.

From a theoretical point of view while there are few selected processes in kaon physics, like the rare $K^0 \to \pi\nu\bar{\nu}$ decays, which can be studied with almost negligible theoretical uncertainties, in most of the cases the extraction of the physical results also relies on the capability of controlling the non-perturbative effects of the strong interactions. This is the case, for example, for the determination of the CKM matrix element V_{us} from the study of semileptonic and leptonic kaon decays, or the theoretical prediction of the ε_K parameter which determines the indirect CP violation in $K^0 - \overline{K^0}$ mixing.

Both kaon physics precision measurements and the search for and measurement of ultra-rare decays are powerful tools for investigation in the flavour sector and search for new physics contributions beyond the SM.

Several kaon experiments are providing precision tests of the flavour sector of the SM: E391a at KEK; E949 at BNL; KLOE at Frascati; KTeV at Fermilab; NA48/2 and NA62 at CERN.

The most accurate determinations of the CKM matrix element V_{us}, come from the study of semileptonic $K \to \pi l \nu$ (Kl3) and leptonic $K \to l\nu$ (Kl2) decays.

This precision measurement of V_{us} [4] enables an incisive test of first-row CKM unitarity which can probe the presence of 4th generations and other new physics. In contrast, assuming CKM unitarity, the effective Fermi coupling (G_F) determined from these quark decays can be compared with G_F determined from muon, tau, and W/Z decays. This comparison is thereby sensitive to physics beyond the SM, and is giving the second most precise determination of G_F after that from muon decay.

Contrary to lepton flavour violation which has recently been discovered in the neutrino sector, lepton universality in meson decays is strictly required in the SM. Violation of lepton universality would be an immediate indication of new physics and most theories beyond the SM predict lepton flavour violating transitions (LFV). Search for LFV in the semileptonic decays Kl3 is a test of the vector current of the weak interactions. Lepton flavour independent factors cancel in the ratio of the semileptonic decay rates $\Gamma(K\mu3)/\Gamma(Ke3)$. The experimental results from KTEV, NA48, KLOE, KEK-E246 are all [5] in agreement with the SM expectation and in good agreement with lepton universality.

The ratio $R_K = \Gamma(Ke2)/\Gamma(K\mu2)$ is precisely calculated in the SM. Any significant experimental deviation would immediately be evidence for new physics that violate lepton universality. Because of the strong helicity suppression of the $Ke2$ decay ($BR = 1.1 \times 10^{-5}$), its rate is particularly sensitive to new-physics. Recent works point out that sizable violations of lepton universality can be expected in Kl2 decays such as a tree-level contribution from the H^+ in two-Higgs-doublet models.

Three new recent and preliminary measurements were reported by NA48/2, KLOE [6] and NA62. The NA62 experiment has collected a sample of more than 100,000 $K^+ \to e^+\nu_e$ decays and presented results on the ratio R, at the 0.5% level, that is consistent with the SM expectation. A combination of the three results with the current PDG value yields a new world average of R_K result in very good agreement with SM expectations. contributing substantially to constraining further on charged Higgs couplings within the context of SUSY.

The investigation of CP violation (CPV) is of major importance in particle physics as it addresses fundamental questions linked to the observed matter-antimatter asymmetry in the Universe. The Kaon system was the first playground for the violation of CP symmetry and all three types of CPV have been observed in the Kaon system.

CP violation was discovered in $K_L^0 \to \pi\pi$ decays in 1964. The phenomenon of neutral kaon mixing accounts for the indirect CP violation measured with the parameter Re(ε), where ε represents the asymmetric mixing of the CP eigenstates into the mass eigenstates. Direct CP violation is due to an asymmetry in the amplitude of K^0 decays into two pions, with different isospin values. This effect is quantified by the parameter Re(ε'). A non-zero value of ε' arises naturally in the SM from the complex phase of the CKM matrix. The violation of CP symmetry takes also place in the interference between decays with and without mixing, represented in terms of the parameters Im(ε) and Im(ε').

The NA48 Collaboration at CERN and the KTEV Collaboration at FNAL have carried out over the last decade an extensive physics programme dedicated to the study of CP violation (and rare processes) using K_L and K_S. The final results [7] [8] clearly established the existence of direct CPV in the neutral kaon system.

Only direct CP violation effects occur in the charged kaon sector, since mixing is not allowed. Direct CP violation is expected to induce different amplitudes for K^+ and K^- decays into the same three-pion final states. NA48 experiment at CERN SPS has achieved an accuracy one order of magnitude better than previous measurements [9]. The result is compatible with SM and does not show any evidence of CPV.

World data on K_S and K_L decay amplitudes can be combined to obtain refined values for the CP and CPT violation parameters Re(ε) and Im(δ) using the Bell-Steinberger unitarity relation. Such an analysis was performed in 2001 by the CPLEAR collaboration. The phases of the $K_L - to - K_S$ amplitude ratios $\eta_{+-} = (K_L \to \pi^+\pi^-)/(K_S \to \pi^+\pi^-)$ and $\eta_{00} = (K_L \to \pi^0\pi^0)/(K_S \to \pi^0\pi^0)$ measured by KTEV [10], KLOE [11]and NA48 [12] are all in good agreement.

An extension of the KLOE program has been proposed to pursue new, higher-statistics measurements of many (if not all) of the observables discussed above.

Four very rare kaon decays $K \to \pi\nu\bar{\nu}$, flavour-changing neutral current processes dominated by Z penguin and box diagrams, provide information on the unitarity triangle. Their rates can be calculated with minimal intrinsic uncertainty in the SM, because there are no contributions from long-distance processes with intermediate photons, and because the hadronic matrix elements can be obtained from $Kl3$ rate and form factor measurements.

The following experiments and initiatives are preparing or considering major upgrades: E14 at JPARC; NA62 at CERN; K-initiative at Fermilab.

A high precision measurement of the ultra-rare $K^+ \to \pi^+ \nu\overline{\nu}$ decay would be one of the most incisive probes of quark flavour physics in the coming decade. E787/949 at Brookhaven has actually measured this BR obtaining $1.73^{+1.15}_{-1.05} \times 10^{-10}$.

The new CERN experiment, NA62, is a major upgrade of the existing detector and beam-line systems and proposes a sensitivity of about 100 SM events. An initiative at Fermilab is studying experiment concepts with a sensitivity goal of 1000 SM events.

The E14 experiment at JPARC in Tokai Japan is pursuing sensitivity of the $K_L \to \pi^0 \nu\overline{\nu}$ process at the single SM event level, which would be sensitive to several models beyond the SM. This nearly x100 increase in sensitivity is achieved though upgrading the existing E391 detector and a new high intensity beam-line at the JPARC accelerator complex.

Experimental efforts in the kaon sector will thus continue for some time.

2. Kaon Session Summary Conclusion

Measurements in the kaon system have contributed greatly to establishing both the framework and the details of the SM. The broad sweep of consistency of all flavour physics phenomena today within the SM has led us to the tension between the expectations of TeV-scale new physics and the apparent absence of corresponding quantum corrections that should affect quark flavour measurements at the current state of the art. The next round of experiments in kaon physics are aimed at the $K^+ \to \pi^+ \nu\overline{\nu}$ and $K_L \to \pi^0 \nu\overline{\nu}$ processes, which are particularly promising tools to crack the flavour Problem. Proton beam facilities exist world-wide today to mount these experiments which have the potential to deliver these incisive measurements within the coming decade.

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