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CP and *T* Violation with *K* Mesons

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Abstract: Recent measurements of charge-conjugation parity and time-reversal symmetry violations in the kaon system are reviewed and discussed, and ongoing and future activities in the field are briefly described.

Introduction

Since its discovery in 1964 [1] the investigation of *CP* violation was always high on the agenda of fundamental research in particle physics, although it is only in the last decade that the unceasing experimental efforts actually led to the gathering of qualitatively new pieces of information. Still, however, the deep meaning and origin of this subtle effect remains unclear, although the recognition of the importance of its rôle in Nature grew steadily.

This paper will try to give a broad and shallow, but fairly complete, overview of the investigations performed on *CP* violation (and its close counterpart, *T* violation) using the system of *K* mesons, which is uniquely attractive for this purpose. In the spirit of the Time and Matter conference, the review is addressed to interested non-specialists; the interested reader can find many more details e.g. in [2].

Kaons: some history

K mesons (kaons) are the lightest form of "flavoured" matter, as they contain a quark or an anti-quark from one of the heavier families which are not present in ordinary matter, namely the strange quark. For this very reason they played a central role in shaping what we now know as the Standard

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Model (SM) of particle physics: one should just recall the Cabibbo angle, the fall of parity, the prediction of the existence of the charm quark and of course CP violation. Arguably, no other particle extended our understanding of the structure of Nature at the fundamental level more than the kaon, as it opened the field of flavour physics.

The tiny violation of the combined parity and charge-conjugation symmetries (CP violation) first manifested itself in a not-so-straightforward way as the evidence of two-pion decay of the long-lived neutral K meson, a physical state which was known to decay copiously to the three-pion state of opposite CP-parity.

The importance of CP violation needs not being recalled here: let us just note that it is the tiniest observed violation of a discrete symmetry and, as a required ingredient in any (not-too-weird) cosmological baryogenesis recipe, it is deeply related to the observed matter-antimatter asymmetry of the Universe, and (through the "sacred" CPT theorem) to microscopic time reversal violation. The involvement of charge conjugation implies that the study of CP symmetry is only accessible to high-energy physics experiments.

The importance of the kaon system for CP violation does not stem only from it being the one in which such phenomenon was originally discovered, but also from the fact that it displays all the features of flavour physics, and in particular all the (known) kinds of CP violation (of the same magnitude as in other systems, e.g. B mesons), and moreover it is a rather simple system, easily accessible from an experimental point of view; in this sense kaons can be considered as the *minimal flavour laboratory*. Their main downside is related to their theoretical understanding: as it is often the case at low (with respect to the QCD scale) energies, the link from the observed properties to the fundamental parameters of the underlying theory is marred from nightmarish QCD difficulties in the theoretical treatments, which so far resulted in precise computations not being available for kaons.

All possible ways in which CP and T violation can manifest themselves can be and have been investigated with kaons: the existence of physical states which are not CP eigenstates (the aforementioned decay of the long-lived state to $K_L \to 2\pi$, showing it has a $CP = +1$ component), the transition between states with different CP eigenvalues ($K_2 \to 2\pi$, direct CP violation), the time asymmetry of virtual transition probablilities $P(K^0 \to \overline{K}^0) \neq P(\overline{K}^0 \to K^0)$, the differences in the behaviour of CP-conjugate states (charge asymmetries in $K^{\pm}$ decays), and the search for non-zero T-odd quantities (transverse lepton polarization in $K_{\ell 3}$ decays). In the following all the above signatures will be briefly discussed.

Progress in the investigation of CP violation showed a rather long hiatus, since after the initial discovery not much qualitatively new information was obtained for about 36 years, and the phenomenon remained quite elusive and moreover apparently confined to the neutral kaon system, despite a rather aggressive worldwide experimental program. Such a situation allowed the survival of the super-weak *ansatz* [3], according to which the only known manifestation of CP violation could be attributed to a tiny new kind of interaction, which would be enhanced by the sensitivity linked to the small mass difference between the neutral K states, while remaining practically unobservable anywhere else. The big question was therefore whether CP violation was indeed an intrinsic property of weak interactions (as suggested by the CKM picture in the SM) or rather a more exotic phenomenon. The key in answering this question laid in the search for CP violation in the decay amplitudes, or *direct* CP violation, i.e. an effect which could not possibly be attributed to a property of the decaying system itself (the neutral K), in contrast to the known *indirect* CP violation, parameterized by the quantity

$$|\epsilon| \sim \left| \frac{A(K_L \to \pi\pi)}{A(K_S \to \pi\pi)} \right| \simeq 2 \cdot 10^{-3} \tag{1}$$

and related to the virtual $K^0 - \overline{K}^0$ oscillations. Only the latter effect could be accounted for by a super-weak model, while the CKM scheme predicts the existence of both (although not quantitatively). This second manifestation of CP violation, which turned out to be much smaller than the first for the K system, in general requires the presence of two interfering amplitudes with interacting hadrons in the final state.

The final clarification of this long-standing puzzle concerning the existence of direct CP violation in Nature had to wait 1999, when the first results from the latest round of dedicated neutral kaon experiments were announced; eventually both the E832 (KTeV) experiment at Fermilab [4] and the NA48 experiment at CERN [5] proved that direct CP violation exists, confirming a (disputed) earlier indication of the NA31 CERN experiment [6]. The above experiments showed that CP violation is indeed present in the decay amplitudes of the long-lived neutral kaon to two-pion final states, as quantified by the small but non-zero parameter ϵ',

$$\epsilon' \simeq \frac{1}{3} \left[\frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} - \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} \right]. \tag{2}$$

Averaging the most precise results on $\mathrm{Re}(\epsilon'/\epsilon)$ one obtains

$$\mathrm{Re}(\epsilon'/\epsilon) = (16.3 \pm 2.3) \cdot 10^{-4}. \tag{3}$$

A graphical depiction of the present data is shown in figure 1; the interested reader can find more details on this whole story for example in [7].

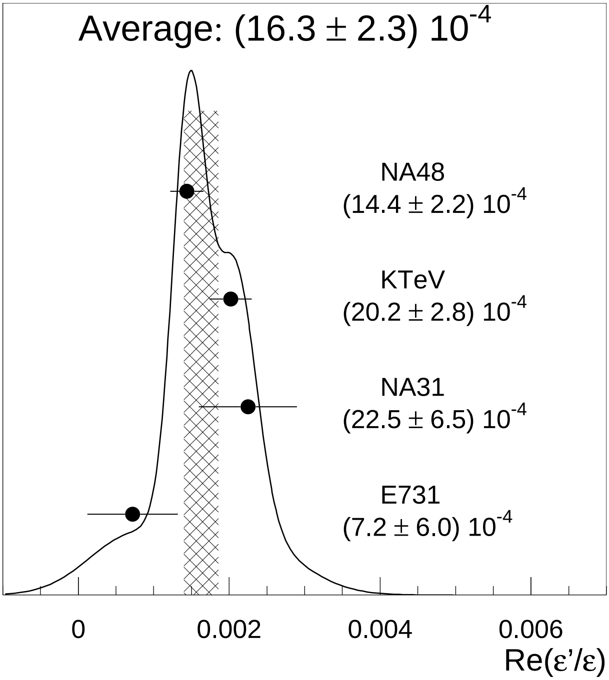

Figure 1: Ideogram of recent $\mathrm{Re}(\epsilon'/\epsilon)$ measurements. The curve shows the (unnormalized) probability distribution according to the PDG procedure [27]. The quoted error is inflated to reflect the unsatisfactory statistical consistency of the results.

Direct *CP* violation actually represents the most straightforward matter-antimatter asymmetry effect, and when the above result is rewritten as a partial decay width difference both its physical meaning and its numerical significance are clearer,

$$\frac{\Gamma(K^0 \to \pi^+\pi^-) - \Gamma(\overline{K}^0 \to \pi^+\pi^-)}{\Gamma(K^0 \to \pi^+\pi^-) + \Gamma(\overline{K}^0 \to \pi^+\pi^-)} = (5.04 \pm 0.82) \cdot 10^{-6}. \tag{4}$$

While the main importance of the above result is expressed by the fact that $\epsilon' \neq 0$ (with a significance which at present exceeds 7 standard deviations), regardless of its exact value, one should not oversee the fact that this parameter is now measured at the $\sim$ 15% level, and improvements on the precision are expected when the final result from the full KTeV statistics will be available.

Right after the above results appeared, a steady flow of CP-violating measurements in the heavier system of neutral B mesons started emerging from B-factories [8] [9]: the main advantage of such system with respect to K is that among many more available decay modes some can be found which are better tractable theoretically, so that the experimental results can be used to extract information on the parameters of the underlying theory, namely the angles of the CKM unitarity triangles.

On the contrary, the theoretical difficulties (linked to strong interaction effects) in the computation of the ϵ and ϵ' parameters are formidable, and despite the good accuracy of the experimental results such parameters cannot yet be used as quantitative constraints on the Standard Model in a precise way, although progress is expected to come (since quite some years, actually) from lattice QCD simulation. What can be fairly said today concerning the comparison of ϵ' with the Standard Model is that the measured value is fully consistent with the theory, which indeed predicts such an effect to exist within an order of magnitude.

One point of interest in this respect is linked to the hypothesis of "antigravity", that is a possible difference in the gravitational interaction of matter and anti-matter, which periodically resurfaces in physics. The $K^0 - \overline{K}^0$ coupled system is a very precise interferometric system on which such hypothesis could be tested, as any difference in the gravitational coupling of the two particles would perturb the oscillation pattern; indeed the smallness of the experimental asymmetry was used to set limits on antigravity [10], but the same argument was later turned around to propose that the measured effect usually ascribed to CP violation might indeed be an (anti-)gravitational effect. The measurement of direct CP violation, not arising in particle-antiparticle oscillations, breaks the above connection, sending back the antigravity hypothesis to a limbo.

Another experimental approach for kaon experiments should be mentioned at this point, which is analogous to that of B meson factories: the KLOE experiment at the DAΦNE e^+e^- collider in Frascati, working from 1999 to 2006, produced entangled $K^0\overline{K}^0$ (and K^+K^-) pairs by running at the centre of mass energy of the ϕ resonance (1020 MeV). In this way several interesting measurements can be made with a technique which is quite complementary to the one used at hadron colliders. While a lack of luminosity was an obstacle to high-statistics measurements, and the original aim of measuring direct *CP* violation was not reached, KLOE provided many other interesting measurements, including the first evidence for QM interference in the kaon system.

An entangled-pair experiment as KLOE might in principle offer an alternative way of measuring direct *CP* violation parameters: by studying the correlated decay probability of the pair into two different hadronic states ($\pi^+\pi^-$ and $\pi^0\pi^0$) as a function of their time difference, both the real and imaginary part of ϵ'/ϵ (the latter quantity being linked to direct *CPT* violation) could be extracted [11], although much higher statistics is required than is available at KLOE.

More *CP* violation with neutral kaons

More traditional ways of measuring *CP* violation also saw a renaissance in recent years, as a byproduct of the high-statistics experiments discussed above. The $K_L \to \pi^+\pi^-$ decay amplitude was re-measured at KLOE, KTeV and NA48, reaching the 0.5% accuracy level, using different experimental approaches.

The radiative decays $K \to \pi\pi\gamma$ offer a different way of probing *CP*-violating asymmetries. While for the most part dominated by *Bremsstrahlung* which (being an EM effect) is not expected to introduce any new feature, such decays also exhibit photon emission from the (weak) decay vertex, which can be accessed experimentally at the high end of the centre-of-mass photon energy distribution. Such "direct emission" contributions were measured both in $K_L \to \pi^+\pi^-\gamma$ [12] and in $K^\pm \to \pi^\pm\pi^0\gamma$, where recently NA48/2 also observed the interference term between the two terms [13], a potential source for observing *CP* violation effects, estimated at the $\mathcal{O}(10^{-4})$ level. It should also be mentioned that more than 10 years ago the E731 experiment at FNAL studied $K_L - K_S$ interference in radiative decays behind a regenerator, obtaining a result fully consistent (at modest accuracy) with the known *CP* violation in $\pi\pi$ decays, thus showing no new sources of asymmetry [14].

Another more recent use of radiative decays is linked to the detection of the rare decay $K_L \to \pi^+\pi^-e^+e^-$ in the '90s by KTeV and NA48 (BR $\simeq 3\cdot 10^{-7}$). Internal photon conversion allows the polarization analysis of the $\pi^+\pi^-\gamma$ decay, as the lepton plane orientation is correlated to the photon helicity; in this way a rather large asymmetry between the $\pi^+\pi^-$ and e^+e^- planes is expected to originate from *CP* violation (as polarization states are no longer summed over). Such asymmetry was indeed measured to be $\simeq$ 13%, consistent with indirect CP violation in $\pi\pi$ decay [15, 16] (see fig. 2).

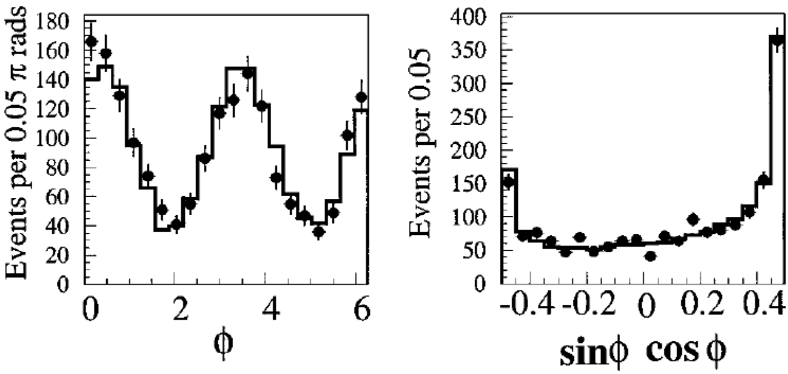

Figure 2: Distributions of the angle ϕ between the lepton and dipion planes in $K_L \to \pi^+\pi^-e^+e^-$ from KTeV.

A similar kind of measurement was also performed in the purely leptonic decays $K_L, K_S \to e^+e^-e^+e^-$ [17, 18], where no significant CP violation was detected, as expected.

Precise measurements of the charge asymmetry of semi-leptonic decay rates with several hundred millions K_L decays were obtained both by KTeV [19] and NA48 [20]. The results give

$$\delta_L^{(e)} \equiv \frac{\Gamma(K_L \to \pi^- l^+ \nu) - \Gamma(K_L \to \pi^+ l^- \overline{\nu})}{\Gamma(K_L \to \pi^- l^+ \nu) + \Gamma(K_L \to \pi^+ l^- \overline{\nu})} = (3.34 \pm 0.07) \cdot 10^{-3}, \tag{5}$$

which, assuming CPT conservation, provides a measurement of the (indirect) CP violation parameter ϵ which is fully consistent (and more precise) that the one obtained from hadronic decays (no direct CP violation is possible in this decay mode due to lack of interfering amplitudes). The corresponding quantity for the $K_L \to \pi\mu\nu$ decay is measured to be fully consistent with the above, as expected from $\mu - e$ universality.

A new result was obtained by the KLOE experiment, which detected for the first time the semi-leptonic decays of K_S and measured their (indirect CP-violating) charge asymmetry in the $\pi e \nu$ mode to be [22],

$$\delta_S^{(e)} = (1.5 \pm 9.6 \pm 2.9) \cdot 10^{-3}. \tag{6}$$

The equality of the above asymmetry with the precisely-measured one of K_L ($\delta_L(e)$) provides in principle a test of CPT violation, which is however still far from being statistically significant.

Besides the usual CP violation in $K_L \to 2\pi$ decays, searches were performed also in $K_S \to 3\pi$ decays (K_S would be expected to be a pure $CP = +1$ state if CP were conserved, while 3π states are dominantly $CP = -1$), where any effect is expected to be much smaller due to the large $K_S \to 2\pi$ decay rate. Interference of K_S and K_L decays into 3π final states was searched for at hadron machines (NA48/1 experiment) [24], while by exploiting pure tagged K_S decays the best current limit was set by KLOE [25],

$$\mathrm{BR}(K_S \to 3\pi^0) < 1.2 \cdot 10^{-7} \quad (90\%\,\mathrm{CL}), \tag{7}$$

still far from the expected figure $\approx 10^{-9}$.

Unitarity imposes a relation linking the (indirect) $CP-$ and $CPT-$ violating parameters to all the physical decay amplitudes: for the kaon system, with a limited number of decay modes, such Bell-Steinberger relation [21] is useful to obtain information on the symmetry-violating parameters.

The analysis of the consequences of the above relation is periodically repeated as new data becomes available; using the last experimental input this gives [26],

$$\mathrm{Re}(\epsilon) = (160.2 \pm 1.3) \cdot 10^{-5}, \qquad \mathrm{Im}(\delta) = (1.2 \pm 1.9) \cdot 10^{-5}, \tag{8}$$

where δ is the phenomenological parameter describing (indirect) CPT violation, linked to differences in mass and decay widths between K^0 and $\overline{K}^0$.

In this respect an older CERN experiment should also be mentioned, which provided a wealth of measurements on the kaon system with a different technique, akin to that used to study CP violation in B mesons at hadronic colliders. CPLEAR [23] exploited low-energy $\overline{p}p$ collisions to produce tagged $K^0, \overline{K}^0$ mesons and to study their time evolution. While unable to pursue the initial goal of (what else?) measuring direct CP violation, from 1990 to 1996 this experiment measured several quantities, some of them unique, greatly contributing to the knowledge of the strange flavour sector.

CP violation with charged kaons

Charged particles are free from mixing effects, and any CP asymmetry there would be necessarily of the direct kind. Again, theoretical predictions of direct CP-violating effects are quite difficult, and only order of magnitude estimates are usually available; the smallness of strong rescattering phases leads in general to tiny values for the asymmetries in the SM (below the 10^{-4} level).

While several asymmetry measurements were performed with charged kaons in the past, all with null results, until recently a large gap still remained between the ballpark values expected in the Standard Model and the experimental results, which allowed for possible large enhancements, actually predicted for some parameter values of new physics models, such as SUSY.

A great improvement in the accuracy of the measurement was achieved by the NA48/2 experiment, which studied the most copious charged kaon decay modes in which CP violation might be expected, namely $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^0\pi^0$ (with BR in the percent range).

Since decay rate asymmetries are expected to be suppressed and are also more difficult to measure experimentally, the experiment focused on the search for $K^\pm$ differences in the shapes of Dalitz plots, which for such 3-body decays are parameterized by slope parameters with respect to two Lorentz-invariant kinematical variables [27]. Control of systematics is of paramount importance for such kind of measurement, and NA48/2 exploited a unique configuration with two simultaneous, superimposed, narrow momentum spectra ($60 \pm 3\,\mathrm{GeV}/c$) K^+ and K^- beams (see fig. 3), and extracted asymmetries on the linear slope parameters g for the dependence of the decay rate on the kinematical variable corresponding to the CM energy of the odd-sign pion. These were obtained from the measured ratios of normalized kinematical distributions, equalizing acceptance differences mostly linked to the presence of an analyzing magnetic field by frequently reversing its polarity. In this way a robust measurement was obtained in two years of data-taking (2003-04), in which first-order instrumental asymmetries were eliminated and systematics from second-order effects were kept low enough to match the statistical precision obtained by collecting more than $3{\cdot}10^9$ $K^\pm$ decays.

The use of quadruple ratios of decay distributions, in which configurations with opposite magnetic fields orientations entered, allowed the cancellation of beam-related differential effects and global time instabilities, only leaving a sensitivity to small residual time differences of left-right instrumental asymmetries on short (few hours) timescale, whose effect was bounded by measurements of the possible corresponding sources and Monte Carlo estimates of the sensitivities.

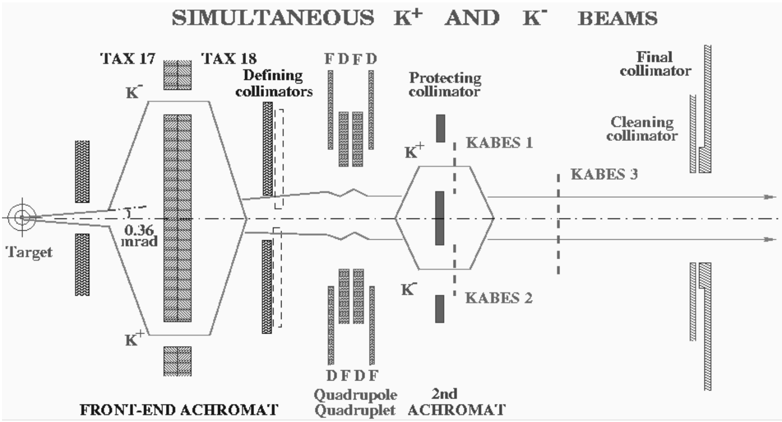

Figure 3: Schematic drawing of the beam configuration for the NA48/2 charged kaon experiment.

While the measurement for the decay mode with three charged pions only involved the magnetic spectrometer, that for the mode with two π^0 used only the electro-magnetic calorimeter, thus resulting in a completely indipendent measurement which, despite the lower branching ratio and acceptance, could match the former in precision thanks to the more favourable kinematical configuration.

The statistically-dominated final results from the experiment are consistent with no direct *CP* violation effects [28],

$$\frac{g_+ - g_-}{g_+ + g_-}(K^\pm \to \pi^\pm\pi^+\pi^-) = (-1.5 \pm 2.2)\cdot 10^{-4}, \tag{9}$$

$$\frac{g_+ - g_-}{g_+ + g_-}(K^\pm \to \pi^\pm\pi^0\pi^0) = (1.8 \pm 1.8)\cdot 10^{-4}, \tag{10}$$

and represent a ten-fold improvement on earlier results (see fig. 4), closing the gap for possible non-SM enhancements of direct *CP*-violation in these modes.

CPT conservation, or *T* violation

Since the early measurements of *CP* violation, tests were performed to check whether such phenomenon was accompanied by time-reversal vi-

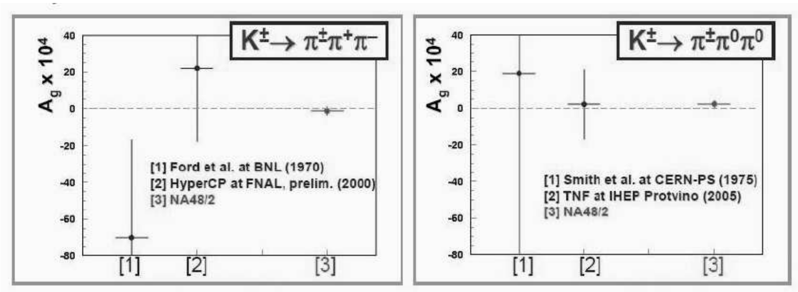

Figure 4: Results on Dalitz plot slope asymmetries in $K^{\pm} \to 3\pi$ decays.

olation – as CPT conservation would require – or CPT symmetry was actually violated. First indications that the former scenario is favoured came from the measurement of the phase difference of the $K_L, K_S \to 2\pi$ amplitudes in interference experiments: since CPT symmetry requires such phase difference to be close to a value dictated by the mass and decay width differences of the two physical states, which turns out to be close to $\pi/2$, while in the opposite case of T conservation (and CPT violation) such difference should be $\approx \pi$. The data, including the most recent measurements by KTeV [4] confirm that the usual indirect CP violation is not accompanied by (indirect) CPT violation,

$$\phi_{+-} = 43.4 \pm 0.7^{\circ}, \qquad \phi_{00} = 43.7 \pm 0.8^{\circ}, \tag{11}$$

but rather by T violation.

A direct test of time reversal symmetry was proposed long ago by P. Kabir, namely the comparison of the forward and backward probabilities of $K^0 - \overline{K}^0$ virtual transitions,

$$A_T = \frac{\Gamma(\overline{K}^0 \to K^0) - \Gamma(K^0 \to \overline{K}^0)}{\Gamma(\overline{K}^0 \to K^0) + \Gamma(K^0 \to \overline{K}^0)}. \tag{12}$$

Exploiting semi-leptonic decays of neutral kaons, the CPLEAR experiment could actually perform the first (and so far sole) measurement of time-reversal violation [29],

$$A_T = (6.6 \pm 1.3 \pm 1.0) \cdot 10^{-3}, \tag{13}$$

which is fully consistent with the value expected from the known mixing (indirect) CP-violation parameter ϵ, assuming CPT conservation.

Other approaches have been used in searching for T violation effects, such as the measurement of T-odd correlations in multi-body decays. In a 3-body final state a T-odd quantity involving spin can be built; the classic example, with a long history, is the lepton polarization transverse to the decay plane in $K \to \pi\ell\nu$ decays (ℓ being a lepton),

$$P_T^{(\ell)} = \frac{\boldsymbol{p}_\pi \times \boldsymbol{p}_\ell \cdot \boldsymbol{S}_\ell}{|\boldsymbol{p}_\pi \times \boldsymbol{p}_\ell||\boldsymbol{S}_\ell|}, \tag{14}$$

where $\boldsymbol{p}$ are momenta and $\boldsymbol{S}$ is spin. The above parameter can be non-zero due to the interference of two decay amplitudes with different phases (CP violation), which are only sizable in the case $\ell = \mu$. Experiments in the '70s reached the final-state interaction limit for K_L decays, while experiments continued on $K^+ \to \pi^0\mu^+\nu$ decay: E246 at KEK, an elegant third-generation precision experiment (see fig. 5), recently published its final result [30],

$$P_T^{(\mu)}(K^+ \to \pi^0\mu^+\nu) = (-1.7 \pm 2.3 \pm 1.1) \cdot 10^{-3}, \tag{15}$$

based on the analysis of 12 million decays of stopped K^+.

A planned experiment at the new Japanese proton facility J-PARC is expected to push further this technique to achieve a tenfold improvement in accuracy, approaching the final-state interaction limit.

T-odd quantities involving only momenta can be formed in 4-body decays, an example being

$$\xi = \frac{\boldsymbol{p}_\pi \times \boldsymbol{p}_\ell \cdot \boldsymbol{p}_\gamma}{|\boldsymbol{p}_\pi \times \boldsymbol{p}_\ell \cdot \boldsymbol{p}_\gamma|} \tag{16}$$

in $K \to \pi\ell\nu\gamma$ decays, in which final-state interaction effects are estimated to be at the 10^{-4} level. A null result with modest accuracy for the above quantity was obtained on a thousand events by the ISTRA experiment [31] and a measurement is underway by NA48/2 with ten times more data and a better control of systematics.

Future and conclusions

After having contributed in such a significant way to the shaping of the Standard Model of particle physics, the kaon system still appears to be an endless source of opportunities for investigating the mysteries of flavour physics, and new horizons are being opened.

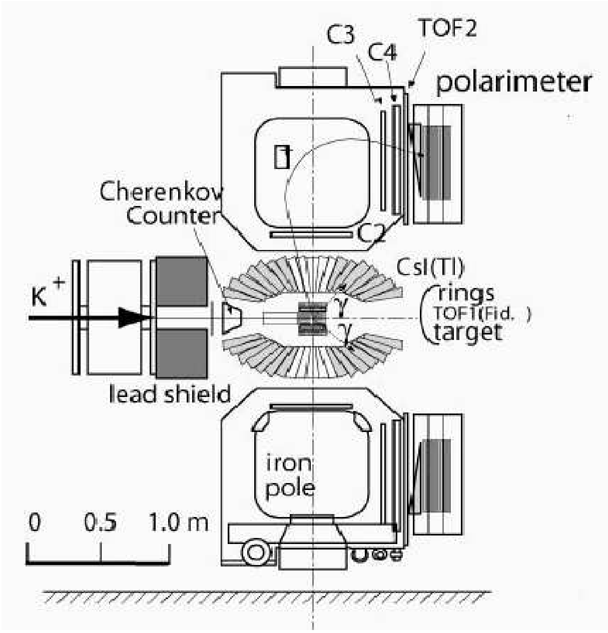

Figure 5: Schematic drawing of the principle of the KEK E246 experiment for measuring the transverse polarization of muons in $K^+ \to \pi^0\mu^+\nu$ decays.

It was realized that a class of flavour-changing neutral-current induced kaon decays holds a great potential as precision probe of the current picture of particle physics: these are decays of the kind $K \to \pi\ell\overline{\ell}$, in which strong-interaction effects are confined to one neutral-current vertex, which is accurately known from experiment, so that precise theoretical predictions can be made. Due to a well-known correlation in physics, unfortunately the expected branching ratios for these theoretically clean decays are in the 10^{-11} range, making their detection somewhat hard from an experimental point of view.

While $K^\pm \to \pi^\pm\ell^+\ell^-$ are dominated by long-distance physics and thus useless for precision measurements, $K_L \to \pi^0\ell^+\ell^-$ are interesting, in that their short-distance part can be precisely computed; in this case, however, in order to isolate the interesting CP-violating short-distance contribution an indirect CP-violating and a CP-conserving part have to be measured (using ancillary decay modes) and subtracted. Experimental limits are available on these modes at the few 10^{-10} level, but further progress would require dedicated experiments.

Even more interesting are the decays with two neutrinos in the final state, in which no EM corrections are involved: $K^{\pm} \rightarrow \pi^{\pm}\nu\overline{\nu}$ and $K_L \rightarrow \pi^0\nu\overline{\nu}$. The former was detected (3 events) by the dedicated BNL experiment E787 [32], while only upper limits exist for the latter, which is *CP*-violating. For these two decay modes the theoretical predictions have the astounding non-parametric uncertainties of only a few percent, and thus they represent very powerful probes for testing the SM at very high precision.

The experimental challenges to be overcome in order to measure kinematically unconstrained decays with backgrounds 9-10 order of magnitudes larger than the signal are clearly formidable, but the high potential of such investigations deserves the efforts. Two new projects are underway to measure both the above "golden" decay modes in flight: NA62 at CERN [33] plans to collect ~ 80 K^+ decays in two years, and the follow-up to E391a at KEK [34], to be carried on at J-PARC, targets the K_L decays. Such experiments are really complementary to those at the energy frontier: when (if) LHC will eventually reveal the existence of new particles beyond the SM, their nature and flavour properties will only be acessible to experiments at the precision frontier, of which those mentioned above are the prime examples.

Acknowledgments

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