Future prospects for K experiments

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ABSTRACT: K decays still attract considerable experimental interest. This paper reviews ongoing programs and future projects and summarizes the physics issues addressed. Only programs not covered in individual contributions to this conference are included.

Kaon experiments in the immediate and longer term future address issues that can be classified in three broad areas. One is the study of rare decays occurring via effective flavor changing neutral currents. In the standard model[1] these processess are mediated by loop diagrams suppressed by the GIM mechanism and thus they provide enhanced sensitivity to possible new physics. The emphasis will be on measurements that can be related, with negligible theoretical uncertainty, to the parameters of the CKM matrix, describing generation mixing and CP violation in the standard model. The goal is to get an overconstrained picture together with similarly clean measurement from the B system.

In order to get short distance information from less 'golden' channels, non perturbative QCD effects have to be treated. For K decays, chiral perturbation theory[2] (ChPT) provides a workable theoretical framework. Tests of this approach and determination of its free parameters motivate continuing precision studies of rare decays.

Finally kaons remain a unique system where tests of discrete symmetries can be performed at unequalled levels of precision. Here the interest is twofold. On one side, new CP or T violating observables can be studied with increased experimental sensitivity, in some cases close to the expectations of the standard model, so that new physics could show up as unexpectedly large effects. On the other side the already stringent limits on possible effects of CPT violation can be further refined with new experimental information.

1. Selected physics issues

1.1 Flavor changing neutral current decays

The decays $K_L^0 \to \pi^0 \nu\overline{\nu}$ and $K^+ \to \pi^+ \nu\overline{\nu}$ are the theoretically cleanest cases. Long distance effects are negligible and the effective hamiltonian is dominated by a single operator whose matrix elements can be determined from the rate of K_{e3} decays.

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The first channel is CP violating; in the calculation of Wilson coefficients, top quark exchange dominates and QCD corrections can be computed reliably.The branching ratio is proportional to $|\Im(V_{ts}^* V_{td})|^2$ through a factor computed with theoretical uncertainties estimated of the order of 2%. In terms of the Wolfenstein parametrization[3] of the CKM matrix, this measures η^2. For $K^+ \to \pi^+ \nu\overline{\nu}$ there is a remaining non negligible contribution from charm quark exchange and a slightly larger theoretical uncertainty ($\sim$ 5%) is estimated. Again, in terms of the Wolfenstein parametrization, the branching ratio is proportional to $[(\rho_0 - \rho)^2 + \eta^2]$, with ρ_0 measuring the relative importance of c quark contribution. Thus ρ and η can be determined separately by these two measurements in the K sector and a non trivial relation with quantities measured in B decays, like, e.g., $\sin(2\beta)$, ensues (see figure 1).

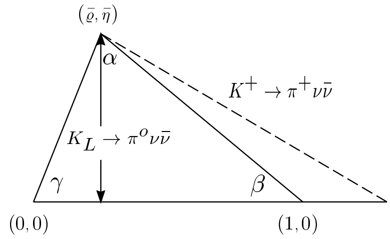

Figure 1: Unitarity triangle

Two more decay channels, $K_L^0 \to \mu^+\mu^-$ and $K_L^0 \to \pi^0 e^+ e^-$ are indicated as a potential source of information on CKM matrix and direct CP violation. They are not in the agenda of forthcoming experiments [1], but they motivate measurements of other decay channels that can be used to constrain their theoretical interpretation.

Short distance contributions to $K_L^0 \to \mu^+\mu^-$ are sensitive to ρ[4]. However the measured branching ratio[5] of $(7.18 \pm 0.17) \times 10^{-9}$ has been shown to be dominated by a more mundane absorptive contribution[6] from the $\gamma\gamma$ channel, estimated to be $(7.07 \pm 0.18) \times 10^{-9}$. In addition, long range dispersive contribution[7] from virtual photon intermediate states are expected. K_L^0 decays to photons or lepton pairs are indicated as necessary experimental input to subtract these effects and the refinement of existing measurements[8] will be in the agenda of future high rate experiments on K_L^0 decays.

Direct CP violation could dominate the $K_L^0 \to \pi^0 e^+ e^-$ channel[9]. This contribution has to be disentangled from two competing mechanisms: a CP conserving amplitude from two photon exchange and indirect CP violation, occurring through the small CP even component of the K_L^0 . These contributions can be related to experimental measurements of the decays $K_L^0 \to \pi^0\gamma\gamma$[10] and $K_S^0 \to \pi^0 e^+ e^-$[11] respectively.

1.2 CPT tests

K^0 $\overline{K}^0$ mixing provides high sensitivity to a possible difference of mass and/or mean life between K^0 and $\overline{K}^0$, implying CPT violation. These effects are characterized by the complex parameter

$$\Delta = \frac{\Lambda_{\overline{K}^0\overline{K}^0} - \Lambda_{K^0K^0}}{2(\lambda_L - \lambda_S)},$$

where $\Lambda_{\overline{K}^0\overline{K}^0}$, $\Lambda_{K^0K^0}$ are the diagonal elements of the $K^0\overline{K}^0$ mass matrix $[\Lambda] = [M] - i\frac{[\Gamma]}{2}$ and λ_L,λ_S its eigenvalues, related to the mass and mean life of K_S^0,K_L^0 .

Information on Δ comes from several sources[12]: semileptonic decays of flavor tagged K^0 and $\overline{K}^0$, comparison of the phases of the CP violating parameters η_{+-} and η_{00} with the

[1] In the first case a remarkably precise measurement of the branching ratio exists, in the second the measurement requires the suppression of an overwhelming physical background from $K_L^0 \to \gamma\gamma e^+ e^-$

"superweak" phase defined by $\tan(\phi_{SW}) = 2\Delta m_{S,L}/\Delta\gamma_{S,L}$, comparison of the semileptonic charge asymmetries with the real parts of η_{+-} and η_{00}. If the possibility of CPT violation in the decay amplitudes is not disregarded, the best limits are $\sim 3\times 10^{-4}$ for $\Re(\Delta)$ and $\sim 5\times 10^{-5}$ for $\Im(\Delta)$[13], translating to a few 10^{-18} GeV for both the mass and width differences. Tighter limits can be obtained assuming CPT conservation in the decay.

The extraction of $\Im(\Delta)$ without assumptions about CPT conservation in the decay, relies on the Bell-Steinberger sum rule[14], a statement of the conservation of probability in the decay of K^0's . This sum rule relates the elements of the $K^0\ \overline{K}^0$ mass matrix with a combination of products of K_L^0 and K_S^0 decay amplitudes to the same final states

$$(1+i\frac{2\Delta m_{S,L}}{\Delta\gamma_{S,L}})(\Re(\epsilon)-i\Im(\Delta)) = \frac{1}{\Gamma_S}\sum_f A^*(K_S\to f)A(K_L\to f).$$

The present precision in the calculation of the sum rule is limited by the measurement of η_{000} , the CP violation parameter characterizing the $K_S^0\to 3\pi^0$ decay.

I will mention finally that a new input for the determination of $\Re(\Delta)$ could come from a measurement of the charge asymmetry in K_S^0 semileptonic decays

$$\delta_S = \frac{\Gamma(K_S^0\to\pi^-e^+\nu)-\Gamma(K_S^0\to\pi^+e^-\overline{\nu})}{\Gamma(K_S^0\to\pi^-e^+\nu)+\Gamma(K_S^0\to\pi^+e^-\overline{\nu})}$$

and its comparison with the corresponding asymmetry in K_L^0 decays[15]. The difference $\delta_S-\delta_L$ would be proportional to $\Re(\Delta)$ if the ratio of the $\Delta S=-\Delta Q$ CPT violating semileptonic amplitude to the $\Delta S=\Delta Q$ CPT conserving one can be neglected.

2. Ongoing experiments (except $K\to\pi\nu\overline{\nu}$)

2.1 Kloe

The experiment Kloe[16] will study decays of tagged K_L^0 and K_S^0 produced at the $DA\Phi NE$ Φ factory in Frascati. The peak luminosity achieved at the time of the conference falls short of the design luminosity of $5\times 10^{32}cm^{-2}s^{-1}$ by about a factor 20. Although this does not allow yet significant measurements of direct CP violation in K_L^0 decays, interesting measurements can be made with tagged K_S^0 and K_L^0 decays. Absolute branching ratios can be measured and, for some rare K_S^0 decays, tagging allows better signal to background ratio, compared with data from hadron machines where K_S^0 beams have a large component of K_L^0's.

Tagged K_S^0	0.6×10^8
$K_S^0\to\pi^+\pi^-$	2×10^7
$K_S^0\to\pi^0\pi^0$	1×10^7
$K_S^0\to\pi^+e\nu$	6700
$K_S^0\to\gamma\gamma$	70
Tagged K_L^0	0.9×10^8
$K_L^0\to\pi^+\pi^-$	2.7×10^4
$K_L^0\to\pi^0\pi^0$	1.0×10^4
$K_L^0\to\gamma\gamma$	0.5×10^4

Table 1: KLOE exptected data yield for $200pb^{-1}$

The experiment is running with the goal of collecting, in the present year, an integrated luminosity of $200pb^{-1}$. Examples of the statistics expected for some channels of interest is shown in table 1. The possibilities of the experiment are demonstrated by preliminary data on the $K_S^0\to\pi e\nu$ decay[17]. In $17pb^{-1}$ analyzed, 627 events of this channel have been identified. This is already much more than the previous world statistics dominated by 75 events collected in the experiment CMD-2[18]. A significant measurement of the charge asymmetry in this decay, δ_S, would be possible if the design luminosity is reached.

2.2 NA48

The CERN experiment NA48, designed for the measurement of the $\Re(\epsilon'/\epsilon)$ parameter, will conclude the data collection for this program in the present year. The apparatus will be used for a study of rare decays of the K^0_S (experiment NA48/1[21]) and for an experiment on charged K decays (NA48/2[22]).

NA48/1 will take data in 2002 to collect a statistics corresponding to $\sim 3 \times 10^{10}$ K^0_S decays. For $K^0_S \to \pi^0 e^+ e^-$ the expected sensitivity is $\sim 6 \times 10^{-10}$/event. The rather wide range of theoretical expectations for the branching ratio is centered at values that will lead to a positive observation of the decay with ~ 10 events. In any case, the experiment will put tight constraints on the contribution of indirect CP violation to $K^0_L \to \pi^0 e^+ e^-$. Even a measurement at the level of the single event sensitivity would, in fact, constrain this contribution, through

$$\frac{BR_{CPindir}(K^0_L \to \pi^0 e^+ e^-)}{BR(K^0_S \to \pi^0 e^+ e^-)} \simeq |\eta_{+-}|^2 \frac{\tau_L}{\tau_S} \simeq 3 \times 10^{-3},$$

to a value close to the lower end of the interval of theoretical expectations for the contribution of direct CP violation to the branching ratio

$$1.5 \times 10^{-12} < BR_{CPdir}(K^0_L \to \pi^0 e^+ e^-) < 5 \times 10^{-12}.$$

Another ambitious goal of NA48/1 is an improvement of the experimental bound on the parameter η_{000} characterizing CP violation in the decay $K^0_S \to \pi^0\pi^0\pi^0$. The experiment will look for modulation of the decay time distribution from the interference between K^0_L and K^0_S amplitudes. With $\sim 8\times 10^6$ events in a region of proper decay times $1.2\tau_S < t_0 < 4.7\tau_S$ and a control of the acceptance slope with a precision of the order of $10^{-3}/c\tau_S$ the experiment aims at setting a bound on $|\eta_{000}|$ of the order of 10^{-2}, about an order of magnitude better than the previous best limits[20]. This will reduce the error in the calculation of the Bell-Steinberger sum rule by more than a factor 2 with a corresponding improvement of the precision of the CPT violation parameter $\Im(\Delta)$.

Other decay channels of interest for ChPT phenomenology can be studied with large statistics. I will quote $K^0_S \to \gamma\gamma$ (~ 24000 events , with an expected background of 25000 $K^0_L \to \gamma\gamma$) , and $K^0_S \to \pi^0\gamma\gamma$ (~ 110 events).

NA48/2 is expected to run in 2003 on a beam of $\sim 60 GeV/c$ charged K. The main goal is a measurement of a possible CP violating asymmetry in the decay $K^\pm \to 3\pi$. If the matrix element is parametrized as $|M(u,v)|^2 \propto 1 + gu + hu^2 + kv^2$, with u related to the CM energy of the odd pion by $u = [2M(M - 3E^*_\pi)]/(3m^2)$, the asymmetry sought for is defined as

$$A_g = \frac{g^+ - g^-}{g^+ + g^-},$$

where the superscript of g refers to the charge of the decaying kaon. The existence of an asymmetry requires not only direct CP violation but also amplitudes with different phase shifts of final state interactions. Theoretical expectations range[19] from $\sim 10^{-4}$ to $\sim 10^{-6}$. NA48 aims at an improvement of two orders of magnitude of the present best experimental limit[23], $A_g = (-7 \pm 5) \times 10^{-3}$, dating back to 1970. To this end $\sim 10^{10}$ decays to 3 pions will be collected and special measures will be taken to symmetrize detection efficiencies between positive and negative kaon decays. A unique feature of this experiment is the use of concurrent K^+ and K^- beams, produced by a system of acromats shown in figure 2. This will cancel time or intensity dependent effects, whereas geometrical asymmetries of the apparatus will be symmetrized by frequent reversals of the magnetic field. A combined statistical and systematic error at the level of 1×10^{-4} on the measurement of A_g will be achieved.

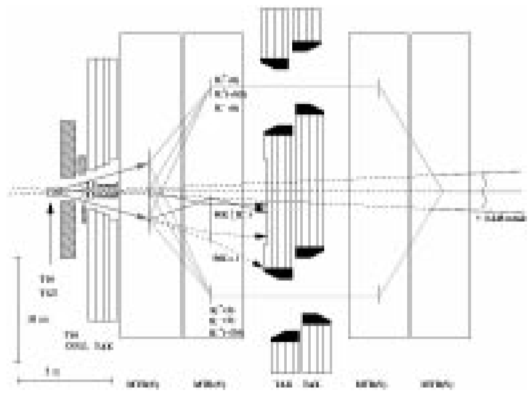

Figure 2: The first stage of the K^+K^-beams for NA48/2. The beams produced at 0^o are first separated in charge by a pair of bending magnets, go through collimators for broad momentum selection and are then redirected onto a common line by a second pair of magnets.

NA48/2 has a broad program, including study of asymmetries in different decay channels (e.g. $K^\pm \to \pi^\pm\pi^0\pi^0$), study of rare decays, especially radiative, and finally a high statistics analysis of the K_{e4} decay. About 1 million events of this decay will be collected for a measurement of a_0^0, the S-wave $\pi\pi$ scattering length, with an error better than 0.01. Together with the recent results of BNL E865[24] ($a_0^0 = 0.220 \pm 0.015$) , this will allow a precise test of the predictions of the standard ChPT. In fact a_0^0 is related to the value of the quark condensate $< 0|\overline{u}u|0 >$[26], which measures the spontaneous breaking of chiral symmetry and is assumed to be "large" [2] in the standard formulation of ChPT.

3. Measurements of $K^+ \to \pi^+\nu\overline{\nu}$

The present knowledge on the decay $K^+ \to \pi^+\nu\overline{\nu}$ comes from BNL experiment E787[27], which has seen 1 event with negligible background in K decays at rest, corresponding to $BR(K^+ \to \pi^+\nu\overline{\nu}) = (1.5^{+3.4}_{-1.2}) \times 10^{-10}$.

In addition to hermetic veto coverage, the experiment is characterized by redundant kinematic information on the π^+ for efficient rejection of the dominant background $K^+ \to \pi^+\pi^0$, producing a monochromatic π^+. Only π^+ momenta above the value expected for this decay are accepted in the analysis. E787 is completing the analysis of a sample of data collected in 1998, of size comparable to the one used for the published result.

[2]In connection with the Gell-Mann, Oakes and Renner formula[25], large means that in the expression $M_\pi^2 \simeq \frac{(m_u+m_d)\times|<0|\overline{u}u|0>|}{F_\pi^2}$ contributions from terms of higher order in the quark masses are negligible

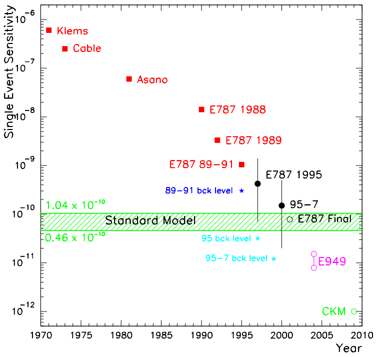

Figure 3: The progress in single event sensitivity for $K^+ \to \pi^+\nu\overline{\nu}$ (courtesy of L.Littenberg)

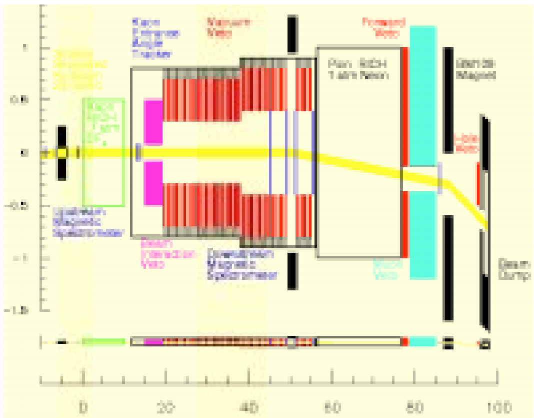

Figure 4: Layout of the CKM experiment

E949[28], an upgrade of the previous experiment, will collect data for two additional years with a sensitivity improved by a factor 14 with respect to E787. This factor comes not only from improvements in the beam, trigger and data acquisition, but also from a reoptimization of the analysis techniques, that should allow to accept events with π^+ momenta below the value expected for $\pi^+\pi^0$. A sensitivity of 10^{-11}/event should be reached by 2004, with an expectation of 7 events for the preferred standard model prediction.

Figure 3 shows the progress in sensitivity for this decay. The figure also includes the expectations of a more ambitious project, CKM[29], proposed to run at the Fermilab main injector in a more distant future.

A schematic of the CKM experiment is shown in figure 4. It aims at collecting 100 events for the standard model prediction, with an expected background of 10 events and it will be the first one to search for this channel in K^+ decays in flight. Veto efficiency is emphasized in the design and additional rejection against the dominant $\pi^+\pi^0$ background is given by the momentum-angle correlation expected for the two body decay. The momentum will be measured both in a magnetic spectrometer and from the Cherenkov angle in a RICH detector. Redundant magnetic and Cherenkov measurement is used also for the 22GeV/c beam particles. The beam is separated by superconducting RF, in order to get a hadron purity in the beam better than 70% and suppress background from pion interactions and decays.

4. Measurements of $K^0_L \to \pi^0\nu\overline{\nu}$

The study of this channel is an experimental challenge. The only measurable particles are two photons in the final state, the expected branching ratio is $\sim 3 \times 10^{-11}$ in the standard model, while the fraction of K^0_L decays with a π^0 in the final state is 34% . The primary handle for background rejection is a fully efficient veto, but kinematics can be used to select regions where background contributions are depleted.

Three groups have been addressing this experimental problem lately.

E391a[30], approved to run at KEK, is a ground breaking experiment for this measurement. The group has been addressing experimental issues in a systematic way. Veto efficiency is one of the key points. This has motivated a series of measurements[31] to clarify the limitations to the efficiency coming from the existence of physical processes yielding undetectable energy. The experiment is in the construction phase and should start data taking at the end of 2003. The expected sensitivity, $\sim 1 \times 10^{-10}/event$, is still above the standard model prediction, but the group hopes to build on the experience gained, to propose a later measurement at the future JHF KEK facility.

The KOPIO proposal[32] for the AGS at BNL advocates a different approach, complementing a very efficient veto with the use of as many kinematical constraints as possible. For photons, a 64 layers tracking preradiator, of $2X_0$ total depth, will provide angle and time measurement, in addition to the energy measured in a calorimeter. Geometrical reconstruction of the decay vertex will thus be possible. The momentum of the incoming K^0 will be determined by a measurement of the time of flight, made possible by the development of a low momentum microbunched beam structured in packets of 200ps rms separated by 40ns. The concept of the experiment is illustrated schematically in figure 5. The additional information allows

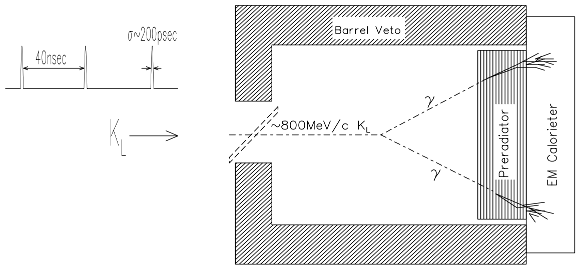

Figure 5: Schematics of the KOPIO concept

- use of the π^0 mass constraint;
- calculation of the π^0 momentum in the K^0 rest frame for rejection of the monocromatic π^0's coming from the dominant $K_L^0 \to \pi^0\pi^0$ background;
- rejection of particles produced by beam halo interactions in material around the beam;
- exclusion of kinematic regions where veto efficiencies are expected to be low.

Many critical parameters of the experiment have been established by test measurements.

The beam bunching technique has been studied in a test performed with a 93MHz, 30kV RF cavity , in which an rms of 280ps for the microbunch has been achieved. Development of the final scheme, calling for a 25MHz, 150kV main cavity and an additional 100MHz harmonic cavity, is in progress.

For the tracking preradiator, measurements performed at the BNL LEGS facility on a small size prototype have demonstrated resolutions of the order of 25 mr for 250MeV photons. A design of an electromagnetic calorimeter based on the Shashlik technique has been prototyped and resolutions of 6.7% at 250MeV have been achieved. For low energy photons converting in the preradiator, the energy measurement will depend both on the Shashlik calorimeter and on the preradiator. For this reason, each preradiator layer will be equipped with 8mm thick scintillator plates. Although no combined test has been performed yet, Monte-Carlo simulations based on realistic light yields for the scintillators in the preradiator, indicate that the resolution achievable is $\sigma/E = 2.7\%/\sqrt{E_{GeV}}$. The experiment aims at collecting, for the standard model branching ratio, ~ 50 signal events, with a signal to background ratio of 2, in 4 years of data taking. Figure 6 illustrates the usefulness of the kinematical constraints, which identify a region free from the dominant $\pi^0\pi^0$ background.

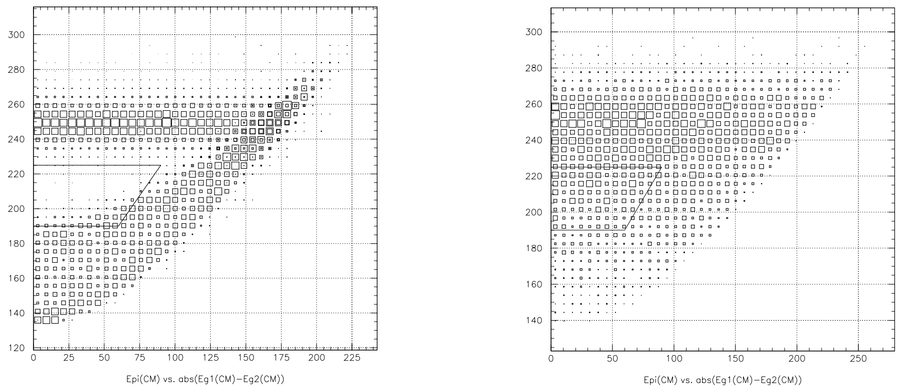

Figure 6: Scatter plots of $E^*_{\pi^0}$ versus $|E^*_{\gamma_1} - E^*_{\gamma_2}|$ for $K^0_L \to \pi^0\pi^0$ (left) and for $K^0_L \to \pi^0\nu\overline{\nu}$ (right) after the π^0 mass constraints. Veto conditions, not applied to the events in this figure, have a high efficiency at low $E^*_{\pi^0}$ and deplete the lower region in the $\pi^0\pi^0$ plot

The third possibility that has been considered is a measurement at the Fermilab main injector (KAMI[33]), in which background rejection is based primarily on the possibility to reach and maintain veto inefficiencies close to the physics limitations suggested by measurements performed at KEK. These limitations are less severe at higher energies. With veto inefficiencies for photons as low as $\sim 10^{-6}$ in some regions and the use of very fast detectors to veto photons also in the beam region (although with higher inefficiency) the experiment could collect ~ 100 events per year with a signal to background ratio of 4. Just before this conference we learned that this proposal has not been recommended by the Fermilab Program Advisory Committee.

5. Conclusions

The existence of direct CP violation in K decays has been demonstrated and the last measurements of $\Re(\epsilon'/\epsilon)$, also shown at this conference[34], finally indicate agreement on the magnitude of the parameter that describes it. With this phenomenon firmly established, in the next few years the presently active experiments will polish their results and provide a more complete phenomenological picture of K decays and CP violation. In some areas, the gap between present measurements and standard model predictions, leaves room for possible surprises.

In the longer term future, two new ambitious projects, CKM at Fermilab and KOPIO at BNL, will shift the emphasis towards quantitatively compelling tests of the standard model in the area of 'theoretically clean' flavor channel neutral current decays. Here it will be possible to make comparisons at a level of precision of 10%, in two a priory unrelated physical systems, the K and B mesons, of the parameters that describe the elusive phenomenon of CP violation in the standard model. The outcome will be interesting in any case. Maybe we will learn that the 'triumph' of the standard model extends also to the field of CP violation, but there is a possibility that a first window on new physics will be opened.

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