PHYSICS WITH CHARGED KAONS: RECENT AND FUTURE EXPERIMENTS

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Abstract

This paper summarizes some recent progress and future perspectives in the experimental investigation of the Standard Model (SM) (and physics beyond it) using charged kaon decays, except for the important mode $K^\pm \rightarrow \pi^\pm \nu \bar{\nu}$ which is discussed in detail elsewhere [1].

INTRODUCTION

Kaons, being the minimal “flavour laboratory”, always had a leading role in the discovery and the study of fundamental physics issues which are related to flavour changing transitions induced by weak interactions. Their success as a physics probe is partly due to the mixed blessing of their relatively small mass (on the hadronic scale), and its experimental consequences.

Along the history from the discovery of CP violation [2] to the evidence of direct CP violation [3] [4] the peculiar system of neutral kaons was central, while charged kaons were deeply exploited for the search of very rare processes probing high energy scales [5].

The level of sensitivity at which rare kaon decay searches have been pushed is rather remarkable: several branching ratios at the $10^{-8}$ level have been measured (not to mention the smallest branching ratio ever measured, $BR(K_L \rightarrow e^+e^-) \simeq 9 \times 10^{-12}$), and limits down to $10^{-11}$ are available [6].

Today, great efforts are dedicated to testing the Standard Model by over-constraining the CKM mixing matrix, and it should be noted that also in this respect kaon decays might offer a very powerful probe, complementary and in some cases even superior to the one represented by $B$ mesons [7], for the decays which can be reliably described by the theory. We do not know where new physics will show up first, and even relatively well measured parameters such as the Cabibbo angle might reserve some surprise [8], so that more refined measurements of several kaon decays are now of great interest.

For what concerns CP violation searches, it should be noted that so far the only evidence of this phenomenon in Nature arises from somewhat subtle effects involving coupled neutral states. While after the discovery of direct CP violation we have no reason to doubt that CP asymmetries should be present also in charged particle decays, as predicted by our current paradigm for describing CP violation, such asymmetries - which would be indeed the simplest manifestations of CP violation from a conceptual point of view and entirely due to direct CP violation - have yet to be detected (although admittedly we might be close to this). T-odd correlations, being actively probed in charged K decays through polarization measurements, are also a complementary window on new physics through CP violation (also T violation has only been detected in the state mixing of neutral kaons so far).

One should also mention that precise kaon decay data is needed to further constrain the parameters of the effective theory we use to describe low-energy physics, namely chiral perturbation theory, and that measurements of branching ratios and decay form factors can offer stringent tests of anomalous couplings and universality.

LEPTON FLAVOUR NUMBER VIOLATION

Several experiments were devoted to searches for lepton flavour number violation (LFV) by searching for rare decays of charged kaons. These measurements allowed to dismiss several models of new physics thanks to their sensitivity to very high mass scales, and represent nowadays an important constraint to models of physics beyond the SM. The results achieved by several dedicated experiments, lately mainly by BNL experiment E865, are rather impressive (see table 1). The low limits reached make further progress difficult: kaon flux and physical backgrounds are the limiting factors, and no new dedicated experiments on LFV with kaons are in preparation at this time.

Table 1: Present limits on LFV charged kaon decays [6].

| Mode            | BR limit (90% CL) |
|-----------------|-------------------|
| $K^+ \rightarrow \pi^+ \mu^+ e^-$ | $2.8 \times 10^{-11}$ |
| $K^+ \rightarrow \pi^+ \mu^- e^+$ | $5.2 \times 10^{-10}$ |
| $K^+ \rightarrow \pi^- \mu^+ e^+$ | $5.0 \times 10^{-10}$ |
| $K^+ \rightarrow \pi^- e^+ e^+$    | $6.4 \times 10^{-10}$ |
| $K^+ \rightarrow \pi^- \mu^+ \mu^+$ | $3.0 \times 10^{-9}$ |

HADRONIC DECAYS AND CP VIOLATION

The decay amplitudes for $K^\pm \rightarrow 3\pi$ have been computed recently at next-to-leading order in the chiral perturbation expansion [9] [10], partially accounting for isospin-breaking effects. The corrections with respect to the leading order results are found to be of the order 30%, and the fitted values of the Dalitz plot slopes (see [6] for the definitions) agree rather well with the experimental data, as shown in table 2.

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Table 2: Dalitz plot slopes for $K^\pm \to 3\pi$ decays, from [6], [11] and [12] (the errors are inflated according to the PDG recipe to account for the poor consistency).

| Parameter                      | Experiment | $\chi^2$/dof | Theory fit |
|--------------------------------|------------|--------------|------------|
| $g(\pi^+\pi^0\pi^-)$         | $-0.2160 \pm 0.0029$ | 2.6          | $-0.22 \pm 0.02$ |
| $h(\pi^+\pi^0\pi^-)$         | $0.011 \pm 0.004$    | 1.3          | $0.012 \pm 0.005$ |
| $k(\pi^+\pi^0\pi^-)$         | $-0.0093 \pm 0.0022$ | 3.2          | $0.0054 \pm 0.0015$ |
| $g(\pi^0\pi^0\pi^0)$         | $0.628 \pm 0.019$    | 6.8          | $0.61 \pm 0.05$   |
| $h(\pi^0\pi^0\pi^0)$         | $0.045 \pm 0.011$    | 1.8          | $0.069 \pm 0.018$ |
| $k(\pi^0\pi^0\pi^0)$         | $0.003 \pm 0.006$    | 5.6          | $0.004 \pm 0.002$ |

New results were obtained recently for the $\pi^+\pi^0\pi^0$ decay mode: a preliminary branching ratio measurement at 1% with small background was obtained by KLOE at DAΦNE [11]:

$$BR(K^\pm \to \pi^+\pi^0\pi^0) = (1.781 \pm 0.013 \pm 0.016)\%$$

from 440 pb$^{-1}$ of integrated luminosity. The constrained kinematics with high-purity pion and muon tagging (obtained from $\pi^+\pi^0$ and $\mu^+\mu$ decays respectively) are strong points for this experiment, which has good prospects for improving our knowledge of the charged kaon decay parameters. The $8 \cdot 10^{31}$ cm$^{-2}$ s$^{-1}$ peak luminosity obtained in 2002 (leading to a total of 500 pb$^{-1}$ integrated luminosity) is less than an order of magnitude below the design one, which is expected to be reached with steady improvements on the machine.

New results on the Dalitz plot slopes [11] [12] helped improving the experimental determination of some parameters, although the consistency of the data remains rather poor, as seen from table 2, particularly for what concerns the linear slope of $\pi^+\pi^0\pi^0$ (see also [13]).

The 30-year long quest for direct CP violation [4] recently resulted in the definitive experimental evidence of this phenomenon [3], ruling out the super-weak ansatz. The $e'/\epsilon$ parameter describing direct CP violation in neutral kaon decays, however, is still under poor theoretical control (to the extent that the experimental value could still be saturated by new physics), so that more measurement of CP violation in different systems is required to really test the present paradigm. Long ago it was suggested that charge asymmetries in $K^\pm$ hadronic decays, such as for the linear Dalitz plot slope parameter $g$ in the decay to 3 charged pions, related to the kinetic energy distribution of the odd pion

$$A_g(\pi^+\pi^0\pi^-) = \frac{g(\pi^+\pi^0\pi^-) - g(\pi^-\pi^+\pi^+)}{g(\pi^+\pi^0\pi^-) + g(\pi^-\pi^+\pi^+)}$$

being in principle free from the amplitude suppression due to the $\Delta I = 1/2$ rule, could be a valid alternative to $e'/\epsilon$ as a measure of direct CP violation.

From a theoretical point of view, several predictions for the asymmetries in charged kaon decay parameters are available in the literature (see [10] [14] and references therein), spanning a rather wide range of values. At this time, however, the common understanding is that in the SM such asymmetries, although not fully under theoretical control, are rather tiny for accidental reasons generally below $10^{-4}$ (i.e. $A_g(\pi^+\pi^0\pi^-) \sim 0.5 \cdot 10^{-4}$ at most [10]); searches focus on common decay modes. In some extensions of the Standard Model somewhat larger values, above $10^{-4}$ could be reached [15] [16].

For 3$\pi$ decays the partial decay width asymmetries are suppressed with respect to the ones for the Dalitz plot slopes. Asymmetries are not expected to be significantly suppressed with respect to the ones for the Dalitz plot (in the decay to $\pi^+\pi^0\pi^0$), which would be a sign of direct CP violation, is rather poor at present, as shown in table 3.

Table 3: Experimental data on CP-violating asymmetries for $K^\pm$ decay rates ($A_F$) and Dalitz plot slope parameters ($A_g, A_h, A_k$), from [6], [17], [28]. In the third column “meas” indicates measurements, and “PDG” naive asymmetries evaluated from PDG values (using inflated errors) when no measurements are available.

| Mode                  | Asymmetry | Notes |
|-----------------------|-----------|-------|
| $A_F(\pi^+\pi^+\pi^-)$| $(0.07 \pm 0.12)%$ | meas  |
| $A_g(\pi^0\pi^0\pi^0)$ | $(-0.11 \pm 0.34)%$ | meas  |
| $A_h(\pi^0\pi^0\pi^0)$ | $(9 \pm 44)%$ | PDG |
| $A_k(\pi^0\pi^0\pi^0)$ | $(9 \pm 20)%$ | PDG |
| $A_g(\pi^+\pi^0\pi')$ | $(0.0 \pm 0.6)%$ | meas  |
| $A_g(\pi^0\pi^0\pi^0)$ | $(5.2 \pm 2.8)%$ | PDG |
| $A_h(\pi^0\pi^0\pi^0)$ | $(20 \pm 21)%$ | PDG |
| $A_k(\pi^0\pi^0\pi^0)$ | $(90 \pm 16)%$ | PDG |
| $A_F(\mu^+\nu)$       | $(-0.54 \pm 0.41)%$ | meas  |
| $A_F(\pi^0\pi^0\pi^0)$ | $(0.8 \pm 1.2)%$ | meas  |
| $A_F(\pi^0\pi^0\pi^0)$ | $(0.9 \pm 3.3)%$ | meas  |
| $A_F(\pi^0\pi^0\pi^0)$ | $(-2 \pm 12)%$ | meas  |
Dalitz plot slope asymmetries have been directly measured only for the $\pi^+\pi^0\pi^-$ mode. A preliminary result was recently obtained, as a byproduct, by the HyperCP experiment at FNAL, devoted to the search for CP violation in hyperon decays. With the 1997 data sample (about $4.2 \cdot 10^7 K^+ \text{ and } 1.2 \cdot 10^7 K^- \text{ decays, corresponding to 20\% of the total collected statistics}$) the preliminary result \[17\]

$$A_g(\pi^+\pi^-) = (-0.22 \pm 0.15 \pm 0.37)\%$$

was obtained (the first error being statistical and the second systematic). The largest systematics (expected to be improved in a full analysis) are given by the effect of residual uncontrolled magnetic fields and Monte Carlo corrections.

Other large differences between the measured parameters for $K^+$ and $K^-$ in different experiments hint at problems in the data; removing a single out-liwer measurement all the slope asymmetries become consistent with zero. Clearly, new experiments measuring both kaon charge partners, to better keep systematics under control, are required to improve the situation.

The small SM predictions for direct CP violating asymmetries in charged kaon decays allow for a large window of opportunity in searching for new physics. Two major experimental programs are being carried on to search for direct CP violation by measuring a charge asymmetry in the linear Dalitz plot slopes $g$ of $K^\pm \to 3\pi$ decays.

The NA48/2 experiment at the CERN SPS \[18\] uses a new beam line delivering simultaneous positive and negative unseparated hadron beams of 60 GeV/c average momentum (with a $\pm 5\%$ spread) to the improved NA48 detector. The beams (see fig. 1), produced at zero degrees by $7 \cdot 10^{11}$ protons per 4.8 s pulse from the SPS every 16.8 s, contain about 5\% $K^\pm$, resulting in $2.2(1.3) \cdot 10^6 K^+(K^-)$ entering the decay volume per pulse.

A high-rate beam spectrometer based on MICROMEGA chambers ("KABES") allows the measurement of the incoming particle charge, momentum and direction, complementing the magnetic spectrometer downstream; most of the flux from beam pion decays remains in the beam pipe crossing all detectors. By frequently switching the polarity of the analyzing and beam-line magnets, the experiment can cancel most of the systematics linked to asymmetries of the apparatus. NA48/2 took data for the first time in 2003, and a second run in 2004 will largely increase the statistics, to allow reaching the design error of $1.7 \cdot 10^{-4}$ on $A_g(\pi^+\pi^-)$. The experiment also collects a large amount of $K^\pm \to \pi^\pm\pi^0\nu\bar{\nu}$ decays, to reach a similar level of accuracy on the corresponding slope asymmetry.

The OKA experiment \[19\] is in preparation at Protvino and will be installed on a new RF separated kaon beam line of 15 GeV/c ($\pi$ contamination <50\%) at the U-70 PS. Only one charge at the time will be available, but the high statistics ($3 \cdot 10^{13}$ protons per pulse giving a flux of $4(1.3) \cdot 10^6 K^+(K^-)$ entering the decay volume) is expected to allow reaching an error of $1 \cdot 10^{-4}$ on $A_g(\pi^+\pi^-)$.

The magnetic detector which will be used is an evolution of the ISTRA+ and GAMS ones. Several rare decays will also be studied with this setup. Half of the beam line is now ready and the first run is expected in November 2004.

The KLOE experiment, with its source of correlated $K^+K^-$ pairs, is also expected to contribute to the measurement of charge asymmetries when enough statistics will be available, and its results will be affected by rather different systematics.

### SEMI-LEPTONIC DECAYS

The interest in the measurement of semi-leptonic decays of kaons was revived recently due to the present unsatisfactory agreement of experimental data with one of the unitarity constraints on the CKM mixing matrix. The constraint relation $|V_{ud}|^2 + |V_{us}|^2 + |V_{td}|^2 = 1$ is violated at the 2.2 standard deviation level using the 2002 PDG data \[6\]. Half of the error is due to the knowledge of the $|V_{us}|$ matrix element, which is extracted from hyperon and kaon semi-leptonic decays. A new measurement of the $K^+ \to \pi^0e^+\nu$ ($K^+\nu$) branching ratio, obtained in a 1 week special run of experiment E865 at Brookhaven \[21\], gives a value for $|V_{us}|$ which disagrees with the previous measurements, but is in agreement with the unitarity constraint. Preliminary results from KLOE (with 78 pb$^{-1}$) \[22\] instead confirm previous results and the unitarity problem (see fig. 2).

New results are expected by the KLOE, NA48/2 and KTeV experiments, which should clarify the situation.

Another issue in semi-leptonic kaon decays concerns the experimental hints of the presence of scalar and/or tensor anomalous couplings in the form factors of $K_{\ell 3}$ decays, which arose several years ago. A recent high statistics ($5.5 \cdot 10^5 K_{\ell 3}$ decays) measurement by the ISTRAP+ experiment at Protvino \[23\] gave:

$$f_S/f_+(0) = 0.002^{+0.020}_{-0.022} \pm 0.003$$

$$f_T/f_+(0) = 0.021^{+0.064}_{-0.075} \pm 0.026$$

further supporting the conclusion of the E246 experiment at KEK \[24\] which denied the existence of such anomalous couplings.

![Figure 2: Recent determinations of the $|V_{us}|$ element of the CKM mixing matrix from semi-leptonic kaon decays.](image-url)
The E246 experiment also performed an interesting $\mu/e$ universality test by comparing the $\lambda_0$ form factor slope measurement with the value obtained by the $K_{\mu3}/K_{e3}$ branching fraction ratio.

**T-ODD CORRELATIONS**

A long standing field of investigation is the search for T-odd correlations, such as the transverse muon polarization $P_T(\mu)$ in $K_{\mu3}$ decays. While for the $K_L$ decay the limit due to SM final state interaction effects was reached in the 70’s, the investigation with $K^+$ decays is still away from such a limit, and the tiny ($< 10^{-5}$) SM effects allow these searches to be a good probe for new physics. The E246 experiment at KEK exploits the semi-muonic decays of stopped $K^+$ and forms a double ratio of events with opposite decay plane orientation to reduce the systematic sensitivity to spurious asymmetries. They recently published a new (null) result [25] based on the full collected statistics ($8.3 \cdot 10^6 K_{\mu3}$ stopped decays):

$$P_T(\mu) = (-1.12 \pm 2.17 \pm 0.90) \cdot 10^{-3}$$

and for the first time also a result for the $\mu^+\nu\gamma$ decay [26], which are complementary to the former mode for discriminating physics beyond the SM:

$$P_T(\mu) = (-0.64 \pm 1.85 \pm 0.10) \cdot 10^{-2}$$

The experiment is now completed: its final sensitivity (for the $K_{\mu3}^+$ mode) is expected to be around $1.5 \cdot 10^{-3}$ in the transverse polarization; the main systematics arise from residual detector misalignments, asymmetric spurious magnetic fields and the large in-plane muon polarization.

Improved experiments on transverse muon polarization have been proposed, which could reach the $\sim 1 \cdot 10^{-4}$ sensitivity.

Another class of T-odd correlations is that involving only three-momenta in four-body final states, such as radiative semi-leptonic decays. As in the previous case, the small SM contributions from final state interactions leaves a large window of opportunity for searches of new physics. In particular, new sources of CP violation with vector or axial couplings are not constrained by the transverse muon polarization results [27], and will be searched for in the NA48/2 and OKA experiments.

**RARE DECAYS**

Apart from the very important $K \to \pi\nu\ell\bar{\nu}$ decays which are not discussed here, the class of FCNC loop-induced decays comprises also $K^\pm \to \pi^\pm \ell^+\ell^-$ (where $\ell$ is a charged lepton). These are less interesting than the previous ones (or even their $K_L$ counterparts) since long-distance physics dominates. Still, the value of the ratio of $K^+ \to \pi^+\mu^+\mu^-$ to $K^+ \to \pi^+\ell^+\ell^-$ decays is constrained in a model-independent way in the chiral perturbation expansion, and the experimental situation was unclear recently, with two incompatible experimental results (at 3.4 standard deviations) for the $K^+ \to \pi^+\mu^+\mu^-$ branching ratio, one of which would violate the constraint mentioned above. A new preliminary measurement by the HyperCP experiment [28]

$$BR(K^\pm \to \pi^\pm\mu^+\mu^-) = (9.8 \pm 1.0 \pm 0.5) \cdot 10^{-8}$$

seems to clarify the situation, bringing the experimental value of the above ratio within the limits allowed by the SM.
CP-violating asymmetries are expected to be tiny also in these modes, which makes them unattractive for such searches.

Among other interesting rare decay modes of charged kaons, \( \pi^\pm \gamma \) should be mentioned, with \( \sim 10^{-6} \) branching ratio. This channel is very interesting as a constraint on chiral perturbation theory, since in involves a free \( O(p^4) \) parameter and important \( O(p^6) \) contributions, complementing the information which can be extracted from the \( K_{L,S} \rightarrow \pi^0 \gamma \gamma \) decays. Due to the large \((\times 2 \cdot 10^5)\) irreducible background from \( \pi^\pm \pi^0 \), this mode is rather penalized from the experimental point of view, but high flux experiments are expected to improve its knowledge.

Similarly, the 4-lepton modes \( \ell^+\nu\ell^+\ell^- \), two of which were recently observed with much improved statistics and 10-20% background at BNL \([29]\):

\[
BR(K^+ \rightarrow e^+\nu e^+ e^-) = (2.48 \pm 0.14 \pm 0.14) \cdot 10^{-8}
\]

\[
BR(K^+ \rightarrow \mu^+\nu e^+ e^-) = (7.06 \pm 0.16 \pm 0.26) \cdot 10^{-8}
\]

(with \( m_{ee} > 150 \) and 145 MeV/c\(^2\) respectively), are also good probes of chiral perturbation predictions \([30]\). The modes with muon pairs have not been detected yet, but their branching ratios are predicted to be not far below the ones for the electron modes, so that they should be measurable in high flux experiments.

Some more exotic searches have been performed or are in the programs of future charged kaon experiments, such as for supersymmetric particles or \( K^+ \rightarrow \pi^+ \gamma \) decays (!).

\[\pi\pi\] INTERACTIONS

It is well known that \( K_{e4} \) decays are one of the best places to study low-energy \( \pi\pi \) interactions, thanks to the Fermi-Watson theorem; indeed, the asymmetry in the distribution of the angle between the di-pion and the di-lepton planes is sensitive to the \( \pi\pi \) scattering phase shifts. The value of the S-wave isoscalar scattering length parameter is a very precise prediction of chiral perturbation theory \([31]\): \( a_0^0 = 0.220 \pm 0.005 \). Low-energy \( \pi\pi \) scattering in the S-wave is particularly sensitive to the size of the \( \langle qT \rangle \) condensate breaking the chiral symmetry of QCD. The size of this condensate is a free parameter in chiral perturbation theory, and one of the assumptions (giving predictive power to the theory) is that it is large enough to make the lowest order term in the quark masses dominate the mass of light mesons.

Recently, the BNL E865 experiment improved the experimental knowledge of the scattering length parameter with a statistics of \( 4 \cdot 10^6 \) \( K_{e4} \) decays \([32]\):

\[a_0^0 = 0.216 \pm 0.013 \pm 0.003\]

While this value is in good agreement with the theoretical one, its statistically-dominated precision is still quite larger than the theoretical error, and such an unusual situation in hadronic physics calls for improved experimental investigations.

The NA48/2 experiment at CERN plans to collect more than \( 1 \cdot 10^6 \) \( K_{e4} \) decays in order to be able to reach an error of \( \sim 0.01 \) on the \( a_0^0 \) parameter.

The DIRAC experiment at CERN \([33]\) investigates the formation of the electro-magnetically bound state of \( \pi^+\pi^- \) (“pionium”), and from the study of its lifetime expects to be able to measure \( |a_0^0 - a_0^0| \) to the 5% level.

Figure 3 summarizes the current knowledge of the scattering length parameters.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Recent experimental determinations of the \( \pi\pi \) S-wave scattering lengths, compared with theoretical predictions under different assumptions (see \([32]\) for details); the shaded bands are estimates of the expected errors from DIRAC and NA48/2, for illustrative purposes.}
\end{figure}

THE FUTURE

The present scenario indicates that the future of kaon physics will most likely be dominated by experimental efforts devoted to overconstrain the CKM unitarity triangle, by measuring the very rare decay modes which can be predicted in the cleanest way by the theory, \( i.e. \ K \rightarrow \pi\nu\pi \) modes \([1]\).

Among new facilities, one where a strong kaon physics program is foreseen is the J-PARC 50 GeV proton synchrotron in construction at Tokai in Japan \([34]\). This high-intensity machine \( (2 \cdot 10^{14} \) p/3.4 s \) is expected to deliver beam to experiments in 2008. Two beam lines are foreseen in the experimental hall (only one at startup), one of which with a low energy \( (\sim 600 \) MeV/c) separated \( K^+ \) beam \( (\sim 10^7 \) \( K^+ \)s\). Several letters of intent for charged kaon experiments have been submitted, including: an improved transverse muon polarization experiment to reach \( \sim 1 \cdot 10^{-4} \) sensitivity, an extensive program for the complete measurement of \( K^+ \) decay modes, a dedicated \( K_{e4}^+ \) branching ratio measurement, studies of pionium and \( \pi K \) atoms, and a \( K^+ \rightarrow \pi^+\nu\pi \) measurement. One can question which of these measurements will remain central in
kaon physics by 2008, and the answer clearly depends also on the success of the ongoing experimental efforts.

Considering the availability of charged kaons in the world, one is led to the picture depicted in Table 4: the sheer amount and quality of the ongoing and future activities, including the ones which were discussed at this workshop involving upgrades of existing machines and/or experiments, clearly indicate how the field is a very active one.

Playing the seer, one could guess the following possible scenario concerning physics with charged kaons at a time where the LHC is starting: all large branching ratios of the charged kaon will be known with high accuracy, with the universality tests which they imply, and including a consistent value of $|V_{us}|$ from the kaon sector; some CP-violating charge asymmetries will be measured at the $\sim 10^{-4}$ level (and several others at $10^{-3}$), chiral perturbation theory predictions for several rare decays will be put under stringent test, and the experimental results will be closer to the theoretical precision in $\pi\pi$ scattering lengths.

### CONCLUSIONS

After the impressive success of the first CP violation studies with $B$ mesons in recent years, also this heavier system is now reaching the stage in which challenging precision measurements are needed, requiring high statistics and a detailed understanding of several hard theoretical issues. It seems therefore worthy to look again with renewed interest at the relative advantages of experiments with kaons, which can offer an alternative and complementary view on some deep unanswered questions of physics.

It is a pleasure to thank the organizers of the workshop (and the conveners too) for the very pleasant and interesting time in the wonderful environment of Alghero.

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