Summary of the Experiments with Charged Kaons Working Group

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Conveners:
P.S. Cooper, Fermilab; J. Ritchie, Univ. Texas-Austin

Members:
G. Buchalla, SLAC; M. Diwan, BNL; J. Engelfried, Fermilab:;
V. Kubarovski, IHEP Serpukhov; L. Littenberg, BNL, H. Ma, BNL;
C. Milstene, Tel Aviv; M. Moinester, Tel Aviv; E. Ramberg, Fermilab;
T. Shinkawa, KEK; R. Tschirhart, Fermilab

INTRODUCTION

The working group focused on the opportunities for high sensitivity experiments using charged kaon beams. We looked in detail at the options for precision measurements and rare decay searches using the charge kaon decay in flight technique; particularly the CKM letter of intent. The initial concept for the CKM experiment was a non magnetic decay in flight spectrometer with the capability to run with at least 3MHz of kaon decays. It is based upon phototube ring imaging Cerenkov counters. The major goal of CKM is the measurement of the branching ratio of $K^+ \to \pi^+ \nu \bar{\nu}$.

The interest an in-flight measurement of $K^+ \to \pi^+ \nu \bar{\nu}$ at the Main Injector is motivated by the high kaon fluxes potentially available combined with the opportunity for long fixed-target runs in parallel with Collider running. The Brookhaven experiment focusing on this mode, E787, is currently limited by kaon flux and running time. That experiment has a good chance to observe $K^+ \to \pi^+ \nu \bar{\nu}$ for the first time, but in the best case scenario its measurement of the branching ratio is likely to be based on a handful of events. A Main Injector experiment should not be statistics limited. A sample of 100 events appears to be a plausible goal, permitting a 10% measurement of the branching ratio and a determination of the magnitude of the CKM matrix element V_{td} at a level where experimental and theoretical uncertainties are of similar size. The main challenge in such an experiment will be to reject backgrounds to the necessary level.

WORKING GROUP TALKS

The working group heard talks from its own members and held joint sessions with several other groups. These included:

Experiments with Charged Kaons Working Group Session

P. Cooper Overview of the CKM experiment
L. Littenberg BNL E787 Results and Lessons
M. Diwan T-violation in $K_{\mu 3}$ at BNL
C. Milstene Radiative $K_{\mu 2}$ with the CKM apparatus
J. Engelfried Selex Rich Design and Performance
Freewheeling Discussions

Joint session with the K0 group (Theory)

G. Buchalla Direct CP violation in Kaons
J. Donoghue Radiative Complex of Rare K_L Decays

Joint meeting with CPT working group (K^+ beams)

G. Thomson Design for an RF separated K^+ beam

Joint meeting with Beams working group

P. Cooper CKM requirements for debunched beams

Joint session with K° and detector groups (detectors)

A. Roodman CsI Calorimeter at KTeV
R. Tschirhart CsI Calorimeter readout at KAMI

R. Littenberg Photon veto at BNL787/BNL $\pi^\circ\nu\bar{\nu}$

T. Inagaki Photon veto at KEK $\pi^\circ\nu\bar{\nu}$
J. Jennings Photon veto at KTeV
K. Arisaka Photon veto at KAMI
A. Bross Fiber tracking

The discussions of the theory of CP violation by Wolfenstein in the plenary session and Buchalla and Donoghue in the parallel sessions all emphasized the importance of measuring the branching ratios of charged and neutral kaons to the $\pi\nu\bar{\nu}$ final state. These two decay modes are theoretically clean. A measurement of the charged mode to 10% would determine the magnitude of the CKM matrix element V_{td} to about 5%, with the theory error being of similar magnitude. A measurement of the neutral mode directly measures the Wolfenstein parameter η, upon which Standard Model CP violation depends. This class of measurement is complimentary to measurements of decay rate asymmetries in the ψK_S and $\pi^+\pi^-$ decay modes of the B meson which are the primary aims of the B factories and major goals of the upcoming Fermilab collider experiments. Ultimately the combination of measurements with K's and B's will provide a stringent test of the Standard Model; either all CP violation comes from the imaginary parts of V_{td} and V_{bu} or there is clear evidence for a non-Standard Model CP violating interaction. The values of V_{td} measured in the kaon and B sectors must not only have imaginary parts - they must be the same complex number for the Standard Model to adequately describe the violation of CP. Such agreement between the kaon and B sectors would be compelling confirmation of both the Standard Model as the sole source of CP violation and of the validity of the measurements.

According to Buchalla, the predicted Standard Model branching ratio of the $K^+\rightarrow \pi^+\nu\bar{\nu}$ decay mode is $[0.9\pm0.3]\times10^{-10}$ where the uncertainty is mainly a reflection of the uncertainties in our knowledge of other standard model parameters which enter the calculation. The decay is dominated by diagrams involving top quark loops. The largest theoretical error in extracting the magnitude of V_{td} from the $K^+\rightarrow \pi^+\nu\bar{\nu}$ branching ratio comes from the uncertainty in the small contribution from charm quark loops, owing to the uncertain charm quark mass. The cost of this theoretical "purity" an experiment of extraordinary difficulty.

This kaon decay modes has di-neutrinos in the final state which make the best conceivable measurement kinematically under-constrained. A successful experiment must eliminate or control all background processes to well below the 10^{-11} level in branching ratio in order to demonstrate a convincing signal. The most promising region of decay phase space for controlling backgrounds is the range of center-of-mass momenta between the peaks from the $K_{\pi2}$ and $K_{\mu2}$ decays. All efforts thus far have been focused on a measurement of $K^+ \to \pi^+\nu\bar{\nu}$ in this region.

Experimental progress to date in the search for the $K^+ \to \pi^+\nu\bar{\nu}$ decay mode has been exclusively via the stopped kaon technique. This work has spanned more than 30 years. For the last half of this period the flagship experiment was and is E787 at BNL. The status and plans for this experiment were reviewed by Laurie Littenberg. E787 published in 1995 an upper limit of 2.4×10^{-9} at 90% CL for this decay mode based upon data taken before 1991. The experiment has had a major upgrade and has taken new data. They hope that with data in hand plus significant running in the next two years they should be able to make a first observation of this decay. Under optimal circumstances E787 may achieve a single event sensitivity of about 2×10^{-11}, permitting the observation of about 5 events.

Littenberg reported that they have pushed the sensitivity of BNL787 up to a useful K+ stopping rate above 1 MHz. The experiment features an active scintillating fiber target surrounded by hermetic photon vetos, high precision tracking with redundant measurements of energy, momentum and range for the π^+. Identification of the π^+ is accomplished by observing the $\pi \to \mu \to e$ decay chain. The beam is a separated, high purity, low energy, K^+ beam with $K^+/\pi^+ \sim 3$ driven with $2\text{-}3\times10^{13}$ protons/spill. The experiment represents an investment of more than 10 years and 20M$ with a team of physicists who are now the world experts in this type of physics.

The experiment's acceptance after all necessary cuts is ~0.2%. This is nearly an order of magnitude below design goals. This loss came about in a traditional way; a large number of factors of 0.8-0.9 relative to the design. The major backgrounds which they needed to control are $K^+ \to \pi^+\pi^\circ$ [$K_{\pi 2}$] with the π° unrecognized due to photon veto inefficiencies and $K^+ \to \mu^+\nu$ [$K_{\mu 2}$] with the μ^+ mis-identified as a π^+. The limitations of the present experiment are available kaon flux and running time. The experiment is statistically limited and has pushed the stopped kaon technique to such a level that it will be a very hard act to follow.

In another talk Milind Diwan described the recently approved BNL E923 experiment to improve the measurement of the T violating component of the muon polarization in $K_{\mu 3}$ decay. The goal is to improve the limit on the out of plane component of the muon polarization to the 1.5×10^{-4} level; 30 times better than the previous measurements. There are model predictions at the 1×10^{-3} level, an order of magnitude higher than the proposed sensitivity. The experiment is done by decay in flight in a high intensity (2×10^7 K^+/spill) 2 GeV/c separated charged kaon beam. The decay muons are stopped in a precision polarimeter based upon the muon spin precession technique. This appears to be a promising and elegant experiment which approaches the questions of CP violation in the Standard Model from a rather different observable.

THE CKM EXPERIMENT

The rationale for a decay in flight experiment at the Fermilab Main Injector is to lift the flux (statistics) limitations. The separated K^+ beam discussed in this workshop would provide 15 MHz of K^+, 3 MHz of decays and ~100 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events detected in 2 years of running. The required input of protons to drive this beamline is 2×10^{12}/spill; less than 10% of the MI design intensity. The ability to run in parallel with the Fermilab collider program should allow adequate running time.

The goals set forth in the CKM expression of interest which was submitted to Fermilab in April 1996 are:

1. To be able to observe approximately 100 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events for a 1×10^{-10} branching ratio in two years of running with the Main Injector.
2. To reduce all background to the level of a few events.
3. To limit capital cost to less than 10M$.

The detector described in the CKM EOI consists of two phototube ring imaging Cerenkov counters separated by a vacuum decay volume with a surrounding photon veto system. The beam envisioned in the EOI was an unseparated 300MHz beam which yielded 3MHz of K^+ decays in the decay volume. The two RICHs are each velocity spectrometers which measure the vector velocity of the kaon and pion respectively from the center and radius of each observed ring. Both counters can be blinded to the Cerenkov light from beam pions by not instrumenting the small region illuminated by beam pion rings. The intrinsic fast time response of photomultipliers gives this design very high rate capabilities. In a simple simulation the proposed CKM detector was able to maintain ~2% acceptance while controlling the background from the $K_{\pi 2}$ mode to the level of a few events.

The choice of phototube RICHs was based upon the experience with this technique in the Selex(E781) experiment. Jurgen Engelfried presented a detailed report of the design, performance and experience with the present Selex RICH. The Selex RICH appears to have met its major design criteria. Detailed offline alignment and calibrations have not yet been done because data taking is still underway in Selex and the present performance is more than good enough for the preliminary charm analyses now underway. The Selex RICH has a readout with a 160 nsec time gate. The intrinsic time resolution of phototube RICHs is unexplored and the random noise level is much higher in the Selex RICH than is proposed for CKM.

The most valuable portions of the workshop were the unstructured (freewheeling) discussions. The experience in kaon rare decay experiments of the working group members sitting around the table approached 100 years. Particular areas of concern were various scattering and interaction processes which could corrupt events and the lack of redundant measurements. Milind Diwan raised the possibility of a background source from K+ charge exchange scattering in the kaon RICH gas followed by a $K^\circ \rightarrow \pi^+ e^- \nu$ decay with the electron unobserved. Stan Wojcicki expressed concern about all the bad things which can happen in 3% of a radiation length of Nitrogen. He also questioned how the experiment could be triggered. Thus far little thinking has gone into triggering CKM so no satisfying answer to this question was given. There was consensus that too much rejection was being required of the RICH velocity spectrometers. This is consistent with the view that π° rejection needs to be improved over what was assumed in the CKM EOI. The requirements on the muon veto system seems to be a rejection of about 10^{-3}.

There was discussion on other physics measurements which might be possible in the CKM apparatus. It was felt that a program broader than just one measurement was important for the health and sociology of a CKM collaboration. This is particularly important for students and younger member of the collaboration. The list identified includes:

High statistics studies:

$K^+ \rightarrow \mu^+ \nu \gamma$ - Kaon structure dependent form factors

$K^+ \rightarrow \pi^+ \mu^+\mu^-$, $\pi^+ e^+ e^-$, $\pi^+ \gamma \gamma$

Precision measurements:

K^+_{e3}, $K^+_{\mu 3}$ - V_{us} to ~0.1%

Lepton flavor violation:

$K^+ \rightarrow \pi^+ \mu^+ e^-$

Caroline Milstene reported on the possibilities to measure the Kaon structure dependent form factors in the kaon radiative decay $K^+ \rightarrow \mu^+ \nu$. In a dedicated one week run with a small high precision photon calorimeter 10^7 events are accepted. This should yield ~10^5 events in the region of the Dalitz plot sensitive to the F_v+F_a and F_v-F_a form factors. The present best measurement is as yet unpublished from BNL787. Laurie Littenberg showed, privately, a measurement of abs(F_v+F_a) from 2500 $K_{\mu 3}$ events obtained in a one week dedicated run of BNL787.

BEAM ISSUES

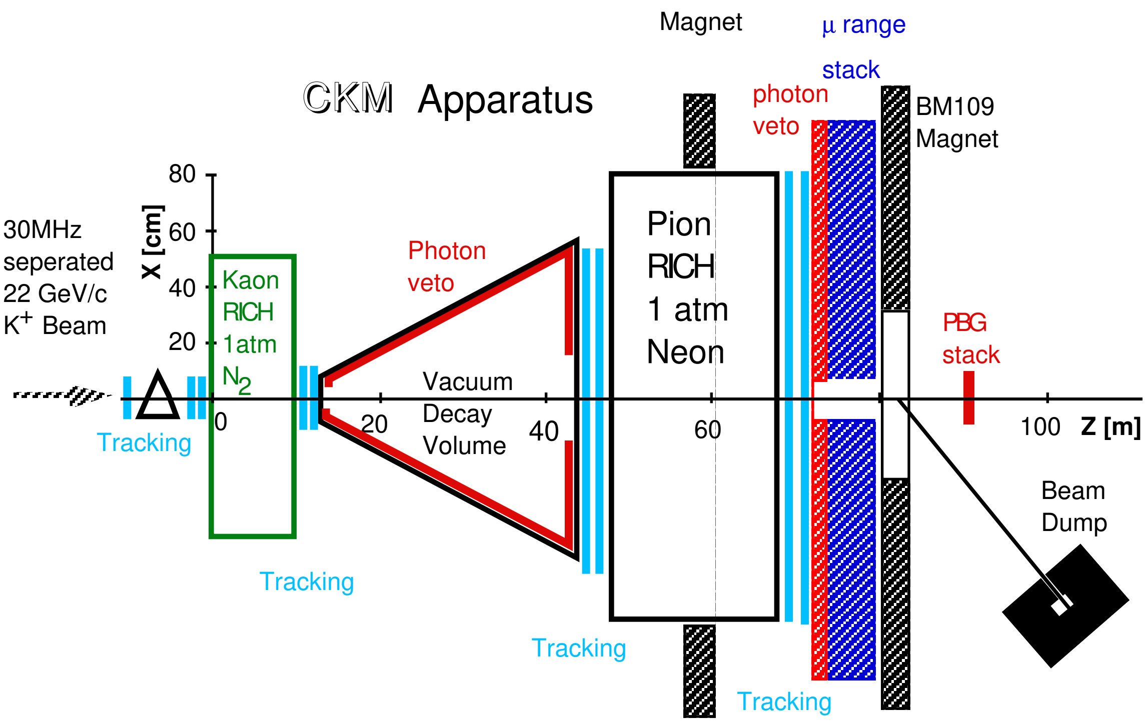
An important improvement in the prospects for a rare kaon decay in flight experiment has been provided by Gordon Thomson and co-workers. They have designed an RF separated K+ beam. The impetus for this work has been the CPT experiment, described elsewhere in these proceedings. However, such a beam is needed for CKM as well. The present design accommodates both CPT and CKM. This beam can provide 30 MHz of K^+ with a contamination of less than 10% π^+ in a beam with less than 100 μrad divergence and a 1% momentum bite to the CKM experiment for about $5x10^{12}$ protons per spill incident on the kaon production target.

The availability of such a beam will make it practical for CKM to place tracking detectors in the beam. Several indications point to this as a requirement. The previously discussed need to determine the decay angle free of multiple scattering in the RICH gas is one. Also, chromatic dispersion in nitrogen, which is planned for the beam RICH, probably degrades the ring resolution to the point where this measurement alone is insufficient to determine the beam momenta. Finally, beam kaons which decay upstream of the beam RICH will produce pions and muons at lower than beam energies which can fake a kaon at the beam energy. These last two effects point to a need for a magnetic determination of beam particle energy, which of course requires tracking in the beam."

Another beam issue is the spill structure. In 300 MHz unseparated beam the idea was to request debunched protons with enough 53 MHz RF ripple remaining to allow the Beams Division to control the beam. The question was raised by Milind Diwan whether a debunched beam is really advantageous. In a 30 MHz separated kaon beam there may be significant advantages to having zero rate in a $\pm$18.8 nsec window around a particular kaon. There is some loss if RF buckets with more than one beam particle are rejected. The RF bucket occupancy will be recorded and can be analyzed after the fact to keep as much beam as possibly consistent with the requirements of controlling the background levels. This issue requires further study.

CONCLUSIONS

By the last meeting of the working group on Saturday afternoon a revised CKM apparatus was written on the blackboard by Cooper. This figure is reproduced below. It contains charged particle tracking around each element of the original CKM apparatus plus tracking upstream in the beamline to given an independent magnetic measurement of the kaon momentum. The "straw man" proposal for these tracking stations were two multi view (xyuv) strawtube chambers spaced by 2m for a total of 8 planes. This suggestion is based upon similar chambers which were used in BNL871. The angular resolution would be ~100 μrad. The material introduced into the beam would be about 2×10^{-3} radiation lengths per station. There was also a magnet with ~100 MeV/c p_t kick and ~1m length added in the middle of the pion RICH. This will produce two rings for each decay pion. The angular separation of the two rings is an independent measure of the momentum of the pion. The field also provides charge determination. This option needs careful study, since it will probably make it harder to veto photons which convert inside the pion RICH.



This revised detector considerably increases CKM's redundancy and addresses some of the known problems with the initial version of CKM. For instance, the measurements of the tracks just before and after the vacuum decay volume decouples the decay reconstruction and background rejection from scattering in the radiator gas in either RICH.

Several members of the working group expressed interest in doing real work in the near future in order to bring the CKM ideas to the level of a real proposal. The next step is to simulate the revised apparatus and start to address the background issues at a level appropriate for a proposal. The revised CKM apparatus addresses the issues of redundant measurements and control of scattering at the conceptual level. The question now is how much these additions improve the background rejections at the level of serious simulations.

While observing 100 $K^+ \to \pi^+ \nu \bar{\nu}$ decays with low background is a daunting task, we believe it is a very exciting prospect. It would be a strong addition to the Main Injector fixed-target physics program.