BNL-67850

Prospects for measuring $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L^0 \to \pi^0\nu\bar{\nu}$ at BNL

D. A. Bryman[a] and L. Littenberg[b]

[a]Department of Physics and Astronomy, University of British Columbia
6224 Agricultural Road, Vancouver, B.C. V6T 1Z1, Canada

[b]Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA

We report on current and future progress on measuring $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L^0 \to \pi^0\nu\bar{\nu}$ at the Brookhaven AGS.

1. INTRODUCTION

The rare kaon decays $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L^0 \to \pi^0\nu\bar{\nu}$ offer unique opportunities to probe higher order phenomena associated with quark mixing and the origin of CP non-invariance. E787 at the Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS) has presented evidence for the $K^+ \to \pi^+\nu\bar{\nu}$ decay[1] based on the observation of a single clean event. The branching ratio indicated by this observation is consistent with the Standard Model (SM) expectation. To fully explore the possibility of new physics or to make a precise measurement of the t-d quark coupling $|V_{td}|$ (assuming the SM level for $B(K^+ \to \pi^+\nu\bar{\nu})$), a new measurement is about to commence. E949 is designed to obtain a single event sensitivity of $(8\text{–}14)\times 10^{-12}$, roughly an order of magnitude below the SM prediction. In order to reach this sensitivity the present detector is being upgraded, and higher beam currents will be exploited. E949 is expected to begin in mid-2001 when the Relativistic Heavy Ion Collider (RHIC) begins full operation and continue for two years of data taking ending in 2003. With the completion of E949, the possibility of an inconsistency with the SM prediction of $K^+ \to \pi^+\nu\bar{\nu}$ will be fully explored or the important top-down quark mixing parameter will be determined to a precision 15 – 30% if the SM expectation is confirmed.

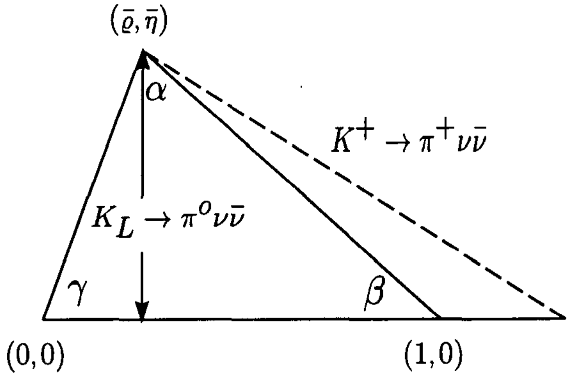

Figure 1. The unitarity triangle.

In addition, it has become evident that the K sector can yield the single most incisive measurement in the study of CP violation through a measurement of the branching ratio for $K_L^0 \to \pi^0\nu\bar{\nu}$ ($B(K_L^0 \to \pi^0\nu\bar{\nu})$), estimated to be about 3×10^{-11} . Within the SM this is a unique quantity which directly measures the area of the CKM unitarity triangles *i.e.* the physical parameter that characterizes all CP violation phenomena, or the height of the triangle shown in fig. 1. The quest to observe $K_L^0 \to \pi^0\nu\bar{\nu}$ is being taken up by the new KOPIO experiment at BNL discussed below.

The measurements of $B(K^+ \to \pi^+\nu\bar{\nu})$ and $B(K_L^0 \to \pi^0\nu\bar{\nu})$ will result in a complete picture of Standard Model CP-violation in the K system and a comparison with comparably precise measurements anticipated from the B sector will be possible.

2. THEORY OF $K \to \pi\nu\bar{\nu}$

$K^+ \to \pi^+\nu\bar{\nu}$ is a flavor-changing neutral current process, arising at the one loop level in the SM as shown in Fig. 2. The presence of the top quark in the loops makes this decay very sensitive to the modulus of the elusive CKM coupling V_{td}[2]. Moreover, this sensitivity can be fully exploited because of the hard GIM suppression, the relatively small QCD corrections (which have been calculated to next-to-leading-logarithmic order[4]), and the fact that the normally problematic hadronic matrix element can be determined to a few percent from the rate of $K \to \pi e\nu$ (K_{e3}) decay[3]. Taking account of all known contributions to the intrinsic theoretical uncertainty, the branching ratio can be calculated to a few percent[2], given the SM input parameters. QCD corrections to the charm contribution are the leading source of the residual theoretical uncertainty. Long distance contributions are known to be negligible so not only can the effects of SM short-distance physics be clearly discerned, but also the effects of possible non-SM physics. In the SM, using current data on m_t, m_c, V_{cb}, $|V_{ub}/V_{cb}|$, ϵ_K, $\bar{B}-B$ mixing, etc., the branching ratio is expected to be $B(K^+ \to \pi^+\nu\bar{\nu}) = (0.6\text{–}1.5)\times 10^{-10}$.

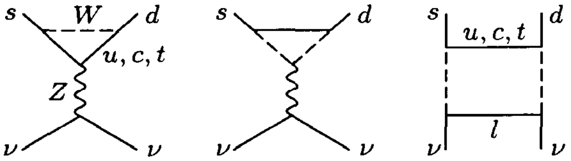

Figure 2. The leading electroweak diagrams inducing $K \to \pi\nu\bar{\nu}$ decays. For $K_L^0 \to \pi^0\nu\bar{\nu}$ only the top quark contributes.

The $K_L^0 \to \pi^0\nu\bar{\nu}$ decay mode is unique in that it is completely dominated by direct CP violation[5] due to the CP properties of K_L, π^0 and the relevant short-distance hadronic transition current. Since K_L^0 is predominantly a coherent, CP odd superposition of K^0 and $\bar{K}^0$, only the imaginary part of $V_{ts}^*V_{td}$ survives in the amplitude. The comments made above about the hadronic matrix element, QCD corrections, etc., in $K^+ \to \pi^+\nu\bar{\nu}$ also apply to $K_L^0 \to \pi^0\nu\bar{\nu}$ with the additional feature that the lack of a significant charm quark contribution reduces the intrinsic theoretical uncertainty to $\mathcal{O}(2\%)$. Since the value of the sine of the Cabibbo angle is well known ($|V_{us}| = \lambda = 0.2205$), $Im(V_{ts}^*V_{td})$ is equivalent to the Jarlskog invariant, $\mathcal{J} \equiv -Im(V_{ts}^*V_{td}V_{us}^*V_{ud}) = -\lambda(1-\frac{\lambda^2}{2})Im(V_{ts}^*V_{td})$. $\mathcal{J}$, in turn, is equal to twice the area of any of the six possible unitarity triangles[6]. Since theoretical uncertainties are extremely small, measurement of $B(K_L^0 \to \pi^0\nu\bar{\nu})$ will provide the standard against which all other measures of CP violation will be compared, and even small deviations from the expectation derived from SM predictions or from other measurements, *e.g.* in the B sector, will unambiguously signal the presence of new physics. In the Wolfenstein parameterization of the CKM matrix,

$$B(K_L^0 \to \pi^0\nu\bar{\nu}) = 1.8\cdot 10^{-10}\eta^2 A^4 X^2(x_t) \qquad (1)$$

Inserting the current estimates for SM parameters into Eqn. 1, the branching ratio for $K_L^0 \to \pi^0\nu\bar{\nu}$ is expected to lie in the range $(3.1 \pm 1.3)\cdot 10^{-11}$. A clean measure of the height of the unitary triangle, η, is provided by the $K_L^0 \to \pi^0\nu\bar{\nu}$ branching ratio. We note that, all other parameters being known, Eqn. 1 implies that the relative error of η is half that of $B(K_L^0 \to \pi^0\nu\bar{\nu})$. Thus, for example, a 15% measurement of $B(K_L^0 \to \pi^0\nu\bar{\nu})$ can, in principle, determine η to 7.5%.

Most forms of new physics[7,8] postulated to augment or supersede the SM have implications for B($K \to \pi\nu\bar{\nu}$). In minimal supersymmetry and in some multi-Higgs doublet models[9], the extraction of $\sin 2\alpha$ and $\sin 2\beta$ from CP asymmetries in B decays would be unaffected. Such effects might then show up in a comparison with

$K_L^0 \to \pi^0\nu\bar{\nu}$, where, e.g., charged Higgs contributions modify the top quark dependent function in $B(K_L^0 \to \pi^0\nu\bar{\nu})$. In other new physics scenarios, such as supersymmetric flavor models[10], the effects in $K \to \pi\nu\bar{\nu}$ tend to be small, while there can be large effects in the B (and also the D) system. In these models the rare K decays are the only clean way to measure the true CKM parameters. Examples of new physics scenarios that show large deviations from the SM in $K \to \pi\nu\bar{\nu}$ are provided by some extended Higgs models, in topcolor-assisted technicolor models [11], in left-right symmetric models [12], in models with extra quarks in vector-like representations[8], leptoquark exchange [8], and in 4-generation models [13]. The confirmation of a relatively large value for ϵ'/ϵ has recently focussed attention on the contributions of flavor-changing Z-penguin diagrams in generic low-energy supersymmetric extensions of the SM[14]. Such diagrams can interfere with the weak penguins of the SM, and either raise or reduce the predicted $B(K_L^0 \to \pi^0\nu\bar{\nu})$ by considerable factors.

It is interesting that the effects of SUSY upon the K and B system generally turn out to be discernibly different.

3. RESULTS FROM E787

The E787 $K^+ \to \pi^+\nu\bar{\nu}$ event was observed in the 1995-97 data set where the estimated background from all sources was 0.08 ± 0.02 events (equivalent to a branching ratio of 3×10^{-11}). This event was in a particularly clean region where the expected background was only 0.008 ± 0.005 and which contained 36% of the acceptance of the full signal region. Fig. 3 shows the results of analysis of data in which the one event consistent with being due to $K^+ \to \pi^+\nu\bar{\nu}$ was observed. The branching ratio for $K^+ \to \pi^+\nu\bar{\nu}$ implied by this observation is $B(K^+ \to \pi^+\nu\bar{\nu}) = 1.5^{+3.4}_{-1.2} \times 10^{-10}$.[1] The E787 sensitivity for $K^+ \to \pi^+\nu\bar{\nu}$ should extend below the most probable SM level to less than 7×10^{-11}.

The results presented so far were obtained from data in the phase space region above the $K^+ \to \pi^+\pi^0$ ($K_{\pi2}$) peak. Progress is also being made to access the region below the $K_{\pi2}$ peak. The expected sensitivity in this region from the 1995-98 data is at the level of the SM prediction with S/N≈ 1. Substantial improvements will be made in E949.

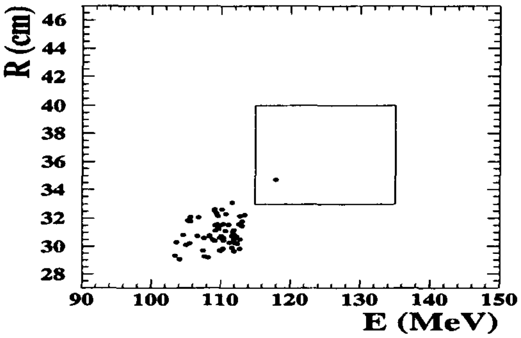

Figure 3. Range vs. Energy plot of E787 data taken in 1995-7. One event survived the analysis cuts indicated by the box.

E787(E949) also studies numerous other rare K and π decays and performs searches for many as-yet unobserved processes. Table 1 gives a partial list of E787 results. In addition to $K^+ \to \pi^+\nu\bar{\nu}$, the decays $K^+ \to \pi^+\mu\mu$, $K^+ \to \pi^+\gamma\gamma$, and $K^+ \to \mu^+\nu\gamma(SD)$ were discovered in E787 and many searches for other interesting processes were either done for the first time or improved by many orders of magnitude. Recently, the first high statistics measurement of the direct emission component of the radiative decay $K^+ \to \pi^+\pi^0\gamma$ was reported.[15] In addition, we are performing searches for decays like $K^+ \to \pi^+\gamma\gamma\gamma$, $K^+ \to \pi^+\pi^0\nu\bar{\nu}$, $K^+ \to \pi^+X$, and $\pi^0 \to \nu\bar{\nu}$, among others.

4. E949

E949 is based upon incremental upgrades to the techniques and technology of E787. The extensive analysis of E787 data has been used to project the sensitivity of E949. The detection of $K^+ \to \pi^+\nu\bar{\nu}$ (a single incident K^+ followed by the decay to a single π^+ of momentum $P < 227$ MeV/c and

Table 1
Some results from E787. The numbers in parentheses indicate the gain in sensitivity over previous work, if applicable.

MODE	RESULT(E787 GAIN)	COMMENT
$K^+ \to \pi^+ \nu\bar{\nu}$	$(1.5^{+3.4}_{-1.2})10^{-10}$ (600)	Discovery
$K^+ \to \pi^+ \mu^+ \mu^-$	$(5.0 \pm 1.0)10^{-8}$ (4500)	Discovery
$K^+ \to \pi^+ \gamma\gamma$	$(1.1 \pm 0.3)10^{-6}$ (100)	Discovery
$K^+ \to \mu^+ \nu\gamma$	$(1.33 \pm 0.12)10^{-5}$ (1000)	Discovery
$K^+ \to \pi^+ \pi^0 \gamma$	$(4.72 \pm 0.77)10^{-6}$ (8)	Directly emitted radiation
$K^+ \to \pi^+ X$	$< 1.1 \times 10^{-10}$ (350)	Familon search
$K^+ \to \mu^+ \nu \mu^+ \mu^-$	$< 4.1 \times 10^{-7}$ (first limit)	Chiral Lagrangians
$K^+ \to e^+ \nu \mu^+ \mu^-$	$< 5 \times 10^{-7}$ (first limit)	Chiral Lagrangians
$\pi^0 \to \nu\bar{\nu}$	$< 8 \times 10^{-7}$ (10)	Sensitive to ν mass
$\pi^0 \to \gamma X$	$< 5.3 \times 10^{-4}$ (1900)	Search for new vector
$K^+ \to \pi^+ \pi^0 \nu\bar{\nu}$	$< 4.3 \times 10^{-5}$ (first limit)	Non-SM

no other observable products) requires suppression of all backgrounds to well below the sensitivity for the signal, preferably to the level of 10^{-11}. The two most significant backgrounds are the two body decays $K^+ \to \mu^+ \nu$ ($K_{\mu 2}$) and $K_{\pi 2}$. The other significant background comes from either a π^+ in the beam scattering into the detector or from K^+ charge exchange (CEX). Careful measurement and rejection of these backgrounds which can occur at levels 10^9 to 10^{10} greater than the signal is of paramount importance.

A drawing of the E787 detector upgraded for E949 is shown in Fig. 4. The AGS will be operated during the next several years in conjunction with RHIC which requires injection roughly twice per day leaving ≥ 20 hrs./day available for AGS slow extracted beam. E949 will be the primary (or only) AGS user during the 2001-2003 period.

The beam line, LESB3[16], transports $3 \times 10^6 K^+$/spill kaons at 700 MeV/c with a K/π ratio of 4:1 for 10^{13} protons on the production target. The K^+ are stopped in a scintillating fiber target in the center of the detector[17]. The fully hermetic detector is located in a 1-T solenoidal magnetic field. The incident kaons come to rest in a scintillating fiber target (TT). A low-mass central drift chamber[18] (UTC) measures the momentum of decay products. The energy, range, and decay sequence of charged particles are measured in the range stack (RS) array of scintillators. Two layers of straw tube detectors (RSSC) provide tracking within the RS. The entire range stack is instrumented with 500 MHz transient digitizers (TD)[19] to measure the $\pi \to \mu \to e$ decay chain. In addition, approximately 1000 transient digitizers based on GaAs CCD's[20] instrument other E787/E949 detector systems.

The photon veto system covers 4π sr. It consists of a barrel veto (BV), a barrel veto liner (BVL), two endcaps (EC) with pure-CsI crystals[21], two collar counters (CO) located outside of the EC's, a micro-collar (CM) located further downstream of the downstream CO, and an active degrader upstream of the target. The BV surrounds the RS. The total thickness of the BV is 14.3 radiation lengths ($X_\circ$). In E949, additional photon veto detectors will be installed.

The net increase in sensitivity per year of E949 over initial E787 running is a factor of 13 coming from improvements summarized in Table 2. After the proposed E949 running time of 6000 hours (~2 years or about 60 weeks), the expected $K^+ \to \pi^+ \nu\bar{\nu}$ sensitivity will be 1.7×10^{-11}. Combined with the E787 data, the result will reach 1.4×10^{-11} with 0.7 expected background events. With the added acceptance from the region below the $K^+ \to \pi^+ \pi^0$, the sensitivity may reach 7.6×10^{-12}. We would therefore expect to see 7–13 events if the branching ratio is equal to the central SM value of 10^{-10}.

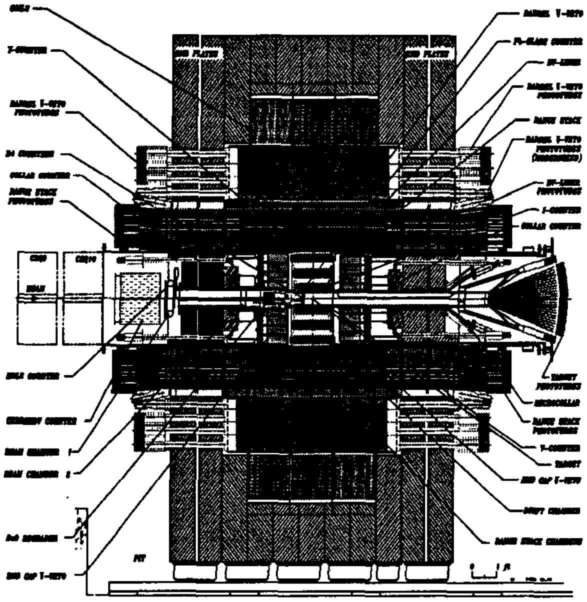

Figure 4. The E949 detector.

Fig 5 is a plot of the progress in sensitivity for $K^+ \to \pi^+\nu\bar{\nu}$ experiments. Included are experiments that set 90% CL limits (earlier E787 results and previous experiments), as well as the single event sensitivities for E787 and E949.

Reliable estimation of backgrounds is one of the most important aspects of the measurement of $K^+ \to \pi^+\nu\bar{\nu}$ at the 10^{-10} level and the techniques established by E787 appear to be robust. The very large amounts of data written to tape are used directly to estimate the background levels in the signal region using a technique designed to avoid biases. The only background calculation that relies considerably on Monte Carlo simulation is that from CEX. In the E787 1995-7 data set, the estimated background level in the signal region with the final analysis cuts was $b = 0.08 \pm 0.02$ background events as indicated in the second column of Table 3. The third column in Table 3 shows the background levels anticipated for E949.

Upgrade	Imprvmnt. factor
Lower momentum	1.44
Higher duty factor	1.53
E787 improvements	1.54
Addtl. efficiency improvements	1.9
Rate effects & below $K_{\pi 2}$	2
Total	13

Table 2
Sensitivity/hr. improvement factors for E949 compared to the published E787 result.

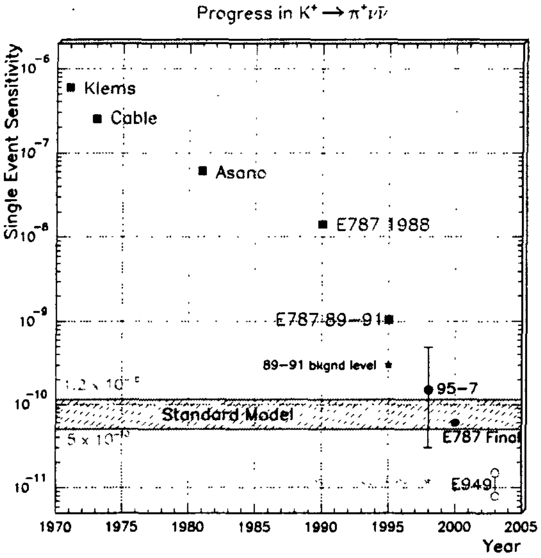

Figure 5. History of progress in the search for and measurement of $K^+ \to \pi^+\nu\bar{\nu}$. The solid squares represent single event sensitivities for experiments that set limits on the branching ratio. The solid circles represent the measured and expected sensitivities for the E787 observation of this decay. The open circles represent the expected sensitivity for E949.

Background	E787 1995	E949
$K_{\pi 2}$	0.03 ± 0.02	0.23
$K_{\mu 2}$	0.02 ± 0.02	0.16
Single beam	0.012 ± 0.009	0.09
Double beam	0.007 ± 0.007	0.05
CEX	0.01 ± 0.01	0.07
Total background	0.08 ± 0.02	0.6
SM signal level	0.25	7

Table 3
Background levels (events) measured for the E787 1995 data set and expected for E949 for the region above the $K_{\pi 2}$. The SM signal levels are also shown.

5. THE KOPIO EXPERIMENT

The experimental aspects of measuring $B(K_L^0 \to \pi^0 \nu\bar{\nu})$ are quite challenging. Observing a decay mode with a branching ratio on the order of 3×10^{-11} requires a prodigious number of kaons in order to achieve the desired sensitivity. Moreover this is a three body decay where only a π^0 can be observed. There are competing decays that also yield π^0s but with branching ratios that are millions of times larger, *e.g.* $K_L \to \pi^0\pi^0$. Compounding the difficulty, interactions between neutrons and kaons in the neutral beam with residual gas in the decay volume can also result in emission of single π^0s, as can the decays of hyperons which might occur in the decay region, *e.g.* $\Lambda \to \pi^0 n$. The current experimental limit $B(K_L^0 \to \pi^0\nu\bar{\nu}) < 5.9 \times 10^{-7}$[22] is a by-product of the KTeV experiment at Fermilab. It employed the Dalitz decay $\pi^0 \to \gamma e^+ e^-$. Further improvement in sensitivity by perhaps an order of magnitude may be expected during the next few years. An experimental improvement in sensitivity of more than four orders of magnitude is therefore required to obtain the signal for $K_L^0 \to \pi^0\nu\bar{\nu}$ at the SM level of $B(K_L^0 \to \pi^0\nu\bar{\nu}) = 3 \times 10^{-11}$.

Thus, a detection technique must be developed that provides maximum possible redundancy for this kinematically unconstrained decay, that has an optimum system for insuring that the observed π^0 is the only detectable particle emanating from the K_L^0 decay, and that has multiple handles for identifying possible small backgrounds that might simulate the desired mode. It is with these issues in mind that the KOPIO experiment has been designed. KOPIO employs a low energy, time-structured K_L^0 beam to allow determination of the incident kaon momentum. This intense beam, with its special characteristics, can be provided only by the BNL Alternating Gradient Synchrotron (AGS)[23]. Utilizing low momentum also permits a detection system for the π^0 decay photons that yields a fully constrained reconstruction of the π^0's mass, energy, and, momentum. The system for vetoing extra particles is well understood. These features which are similar to those employed successfully in the E787 measurement of $K^+ \to \pi^+\nu\bar{\nu}$ provide the necessary redundancy and checks.

The beam and detectors for KOPIO employ well known technologies. Important aspects of the system are based on previously established measurement techniques and new aspects have been studied in beam measurements and with prototypes and simulations. Figure 6 shows a simplified representation of the beam and detector concept. The 24 GeV primary proton beam impinges on the kaon production target in 200 ps wide pulses at a rate of 25 MHz giving a microbunch separation of 40 ns. A 500 μsr solid angle neutral beam is extracted at $\sim 40^o$ to produce a "soft" K_L spectrum peaked at 0.65 GeV/c; kaons in the range from about 0.4 GeV/c to 1.3 GeV/c are used. The vertical acceptance of the beam (0.005 r) is kept much smaller than the horizontal acceptance (0.100 r) so that effective collimation can be obtained to severely limit beam halos and to obtain an additional constraint on the decay vertex position. Downstream of the final beam collimator is a 4 m long decay region which is surrounded by the main detector. Approximately 16% of the kaons decay yielding a decay rate of about 14 MHz. The beam region is evacuated to a level of 10^{-7} Torr to suppress neutron-induced π^0 production. The decay region is surrounded by an efficient Pb/scintillator photon veto detector ("barrel veto"). In order to simplify triggering and offline analysis, only events with the signature of a single kaon decay

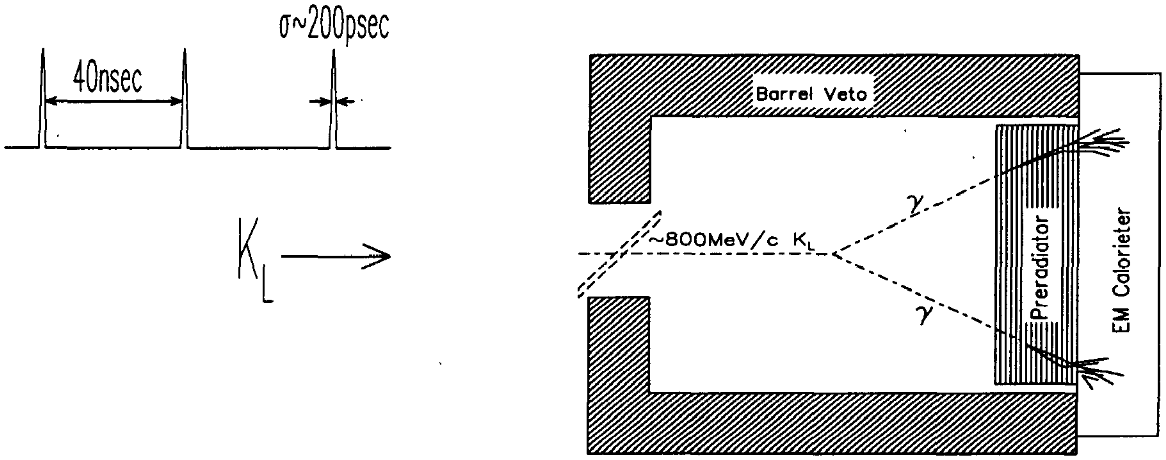

Figure 6. Elements of the KOPIO concept : a pulsed primary beam produces low energy kaons whose time-of-flight reveals their momentum when the π^0 from $K^0_L \to \pi^0\nu\bar{\nu}$ decay is reconstructed.

producing two photons occurring within the period between microbunches are accepted.

Photons from $K^0_L \to \pi^0\nu\bar{\nu}$ decay are observed in a two-stage endcap detector comprised of a fine-grained preradiator followed by an 18 radiation length (X_0) electromagnetic calorimeter. The preradiator obtains the times, positions and angles of the interacting photons from π^0 decay by determining the initial trajectories of the first e^+e^- pairs. The preradiator consists of 64 0.034 X_0-thick layers, each with plastic scintillator, converter and dual coordinate drift chamber. The preradiator has a total effective thickness of 2 X_0 and functions to measure the photon positions and directions accurately in order to allow reconstruction of the K_L decay vertex while also contributing to the achievement of sufficient energy resolution.

The calorimeter located behind the preradiator consists of "Shashlyk" tower modules, 11 cm by 11 cm in cross section and 18 X_0 in depth. A Shashlyk calorimeter module consists of a stack of square tiles with alternating layers of Pb and plastic scintillator read out by penetrating WLS fibers. The preradiator-calorimeter combination is expected to have an energy resolution of $\sigma_E/E \simeq 0.033/\sqrt{E}$. Shashlyk is a proven technique which has been used effectively in BNL experiment E865 and is presently the main element in the PHENIX calorimeter at RHIC.

Suppression of most backgrounds is provided by a hermetic high efficiency charged particle and photon detector system surrounding the decay volume. The system includes scintillators inside the vacuum chamber, decay volume photon veto detectors and detectors downstream of the main decay volume. The barrel veto detectors are constructed as Pb/scintillator sandwiches providing about 18 X_0 for photon conversion and detection. The detection efficiency for photons has been extensively studied with a similar system in BNL experiment E787. The downstream section of the veto system is needed to reject events where photons or charged particles leave the decay volume through the beam hole. It consists of a sweeping magnet with a horizontal field, scintillators to detect charged particles deflected out of the beam, and photon veto modules. A special group of counters - collectively, the "catcher" - vetoes particles that leave the decay volume but remain in the beam phase space. This system takes advantage of the low energy nature of our environment to provide the requisite veto efficiency while being blind to the vast majority of neutrons and K^0s in the beam. The catcher uses aerogel Cerenkov radiators read out with phototubes.

The goal of KOPIO is to obtain about 60 events with a signal to background ratio of greater than 2:1. This will yield a statistical uncertainty in the measurement of the area of the CKM unitarity triangle of less than 10%. While $K_L^0 \to \pi^0\nu\bar{\nu}$ is clearly the focus of KOPIO, many other radiative K decays of significant interest to the study of low energy QCD will be measured and numerous searches for non-SM processes will also be conducted simultaneously.

The KOPIO collaboration includes UBC, BNL, Cincinnati, Kyoto, Moscow (INR), New Mexico, TJNAF, TRIUMF, Virginia, VPI, Yale, and Zurich, and we are actively seeking additional collaborators. Construction of the detector and beamline is expected to begin in 2002, and the experiment is scheduled to begin operation in 2005-6.

6. CONCLUSIONS

Rare kaon decay experiments underway or planned for the BNL AGS will yield new and independent determinations of $V_{ts}^*V_{td}$. A measurement of $B(K_L^0 \to \pi^0\nu\bar{\nu})$ allows a determination of the imaginary part of this quantity, which is the fundamental CP-violating parameter of the Standard Model, in a uniquely clean manner. Since the measurement of $B(K^+ \to \pi^+\nu\bar{\nu})$ determines $|V_{ts}^*V_{td}|$, a complete derivation of the unitarity triangle is facilitated. These results can be compared to high precision data expected to come from the B sector in a number of ways, allowing for unique tests of new physics.

7. ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC02-98CH10886 and by the Natural Sciences and Engineering Research Council and the National Research Council of Canada.

REFERENCES

1. S.Adler *et al. Phys. Rev. Lett.* **84**, 3768 (2000)and *Phys. Rev. Lett.* **79**, 2204 (1997).
2. A.J. Buras and R. Fleischer, in *Heavy Flavours II*, World Scientific, eds. A.J. Buras and M. Linder, 65-238 (1997);G. Buchalla and A.J. Buras, *Nucl. Phys.* **B400**, 225 (1993); G. Buchalla and A.J. Buras, *Nucl. Phys.* **B548**, 309 (1999).
3. W.J. Marciano and Z. Parsa, *Phys. Rev.* **D53**, R1 (1996).
4. G. Buchalla and A.J. Buras, *Nucl. Phys.* **B412**, 106 (1994).
5. L. Littenberg, *Phys. Rev.* **D39**, 3322 (1989).
6. C. Jarlskog and R. Stora, *Phys. Lett.* **B 208**, 268 (1988).
7. M. Leurer, *Phys. Rev. Lett.* **71**, 1324 (1993). S. Davidson, D. Bailey, and B. Campbell, *Z. Phys.* **C61**, 613 (1994). A.J. Buras, A. Romanino, and L.Silvestrini, *Nucl. Phys.* **B520**, 3 (1998). G-C. Cho, hep-ph/9804327, KEK-TH-568, Apr 1998. T. Goto, Y. Okada, and Y. Shimizu, hep-ph/9804294, KEK-TH-567, Apr 1998. G. Couture and H. König, *Z. Phys.* **C69**, 167 (1996).
8. Y. Grossman and Y. Nir, *Phys. Lett.* **B398**, 163 (1997).
9. G. Bélanger, C.G. Geng and P. Turcotte, *Phys. Rev.* **D46**, 2950 (1992); C.E. Carlson, G.D. Dorata and M. Sher, *Phys. Rev.* **D54**, 4393 (1996) hep-ph/9606269.
10. Y. Nir and M. Worah, *Phys. Lett.* **B423**, 319 (1998).
11. Z. Xiao, C. Li and K. Chao, *Eur. Phys. J.* **C10**, 51 (1999).
12. Y. Kiyo, T. Morozumi, P. Parada, M.N. Rebelo, and M. Tanimoto, *Prog. Theor. Phys.* **101**, 671 (1999).
13. T. Hattori, T. Hasuike, and S. Wakaizumi, *Phys. Rev.* **D60**, 113008 (1999).
14. A.J. Buras, G. Colangelo, G. Isidori, A. Romanino and L. Silvestrini, *Nucl. Phys.* **B566**, 3 (2000); A. J. Buras, P. Gambino, M. Gorbahn, S. Jager, and L. Silvestrini, hep-ph/0007313.
15. S. Adler *et al.*, *Phys. Rev. Lett.*, in press, hep-ex/0007021 (2000).
16. J. Dornboos *et al.*, *Nucl. Instr. Meth.* **A444**, 546 (2000).
17. M. Atiya *et al.*, *Nucl. Instr. Meth.* **A321**, 129

(1992).
18. E.W. Blackmore *et al.*, *Nucl. Instr. Meth.* **A404**, 295 (1998).
19. M. Atiya *et al.*, *Nucl. Instr. Meth.* **A279**, 180 (1989).
20. D.A. Bryman *et al.*, *Nucl. Instr. Meth.* **A396**, 394 (1997).
21. T. Komatsubara *et al.*, *Nucl. Instr. Meth.* **A404**, 315 (1998).
22. A. Alavi-Harati *et al.*, *Phys.Rev.***D61**, 072006 (2000).
23. J. W. Glenn, AGS/AD Technote 426 (1996); J. W. Glenn, *et al.*, **Proc. Particle Accelerator Conference** (in press), BNL-63890, May 1997.