1 Introduction

CP violation and quark mixing are among the most important outstanding issues in the study of elementary particle physics, with profound implications on the relationship between the fundamental constituents of matter, and the origin of the apparent matter anti-matter asymmetry in the universe. While CP symmetry violation had only been observed in K meson decays, during the past years, great international efforts involving several thousand researchers and new accelerators and detectors have uncovered similar effects using the heavier B meson.

Nevertheless, it is clear that two of the most incisive measurements in the study of CP symmetry violation and quark mixing are the branching ratios (or rate of decay) of charged and neutral K mesons decaying to a π meson and a neutrino anti-neutrino pair: $K^+ \to \pi^+ \nu\overline{\nu}$ and $K^\circ_L \to \pi^\circ \nu\overline{\nu}$. Discovery and study of these reactions are the main focus of the E949 (and its precursor E787) and KOPIO experiments at Brookhaven National Laboratory (BNL). These decay modes share a uniquely small theoretical uncertainty, allowing unambiguous extraction of the crucial quark mixing and CP violation parameters. Measurement of the branching ratios will provide the standard against which all other measures of CP violation will be compared, and even small deviations from the expectation derived from Standard Model (SM) predictions or from other measurements, e.g. in the B-meson sector, will unambiguously signal the presence of new physics.

The importance of these measurements is related to the extreme precision with which the SM can predict the branching ratios given the fundamental Cabibbo-Kobayashi-Maskawa quark-mixing matrix (CKM) parameters[1]. Although the reactions are extremely rare, the experiments have been designed with sufficient sensitivity to have the capability of discovering entirely unanticipated phenomena, or of inferring discrepancies in existing theory by comparison with B and K meson experiments. In the history of science, such transformations in our understanding have often followed the introduction of new instruments with greatly improved sensitivities — E949 and KOPIO are just such instruments and opportunities since KOPIO provides a direct measurement of the area of the unitarity triangle and E949 provides a direct measurement of of the mixing between t and d quarks $|V_{td}|$. Together they provide a complete determination of the unitarity triangle, one of the central goals of high energy physics today.

The E787 experiment presented evidence for the $K^+ \to \pi^+ \nu\overline{\nu}$ decay based on the observation of two clean events consistent with the SM expectation although the central experimental value $\mathrm{B}(K^+ \to \pi^+ \nu\overline{\nu}) = 1.57^{+1.75}_{-0.82} \times 10^{-10}$ exceeds it by a factor of two. E949 encompasses many improvements to the E787 apparatus which decrease backgrounds and allow for running at higher rates. The possibility of a larger than expected branching ratio gives strong impetus for E949 to fully explore the possibility of new physics, or alternatively to make a precise measurement of the magnitude of $|V_{td}|$. The experience of E787 provides a high level of confidence in projecting the sensitivity of E949, which has been borne out by first examination of the data from the first 12-week run in 2002. E949 employs the full intensity of the Alternating Gradient Synchrotron (AGS) proton beam, five times greater than available to E787, and runs concurrently with the Relativistic Heavy Ion Collider (RHIC). Two options for operation of E949, formulated with BNL management, are considered in this proposal. With Option A, at 12 weeks of operation per year, over a three year period E949 will achieve a sensitivity of (11–18)$\times 10^{-12}$. With Option B, at 18 weeks per year, E949 will achieve a sensitivity of (8–14)$\times 10^{-12}$. E949 will reach a sensitivity of approximately an order of magnitude below the SM prediction for this process and that achieved by E787. This will result in a determination of $|V_{td}|$ to better than 30% precision.

The physics opportunity presented by E949, and the national and international investment in it, has been placed in jeopardy due the funding exigencies which led the U.S. Department of Energy's Division of High Energy Physics (DOE DHEP) to terminate support of the HEP program at the AGS in FY2003. Previously, the DOE DHEP had committed to support E949 as a high priority activity (see Supplementary Document #4). We are proposing that the National Science Foundation (NSF) undertake to support the running and operation of E949 so that the goals of the experiment can be met before the start of KOPIO. The E949 measurement not only provides an important contribution to understanding quark mixing and the origin of CP violation in the SM, it enhances the RSVP program by allowing an independent determination of the parameters of the unitarity triangle and provides critical technological and analytical techniques to be transferred from E949 to KOPIO.

2 Theory

The $K^+ \to \pi^+ \nu\overline{\nu}$ decay is a flavor changing neutral current process which first arises at the one loop level[2] in the SM. The presence of the top quark in the loops[3] makes it very sensitive to the modulus of the elusive CKM coupling V_{td} [4]. This sensitivity can be fully exploited because of the hard Glashow-Iliopoulos-Maiani (GIM) suppression[5] and the relatively small QCD corrections, which have been calculated to next-to-leading-logarithmic order[6–8]. Moreover the normally problematic hadronic matrix element can be determined to a few percent from the rate of K_{e3} ($K^+ \to \pi^\circ e^+ \nu_e$) decay and corrections to the latter have been calculated, reducing this uncertainty even further[9]. Even the main higher order electroweak corrections have been shown to be very small[10]. Long-distance contributions that could in principle spoil the connection between the branching ratio B($K^+ \to \pi^+ \nu\overline{\nu}$) and $|V_{td}|$ have been shown to be negligible[11–16]. Taking account of all known contributions to the intrinsic theoretical uncertainty, the branching ratio can be calculated to 7%[4] given the SM input parameters such as $|V_{td}|$. Conversely, if B($K^+ \to \pi^+ \nu\overline{\nu}$), m_t, $|V_{cb}|$, etc. were well known, $|V_{td}|$, could be determined to <6%. QCD corrections to the charm contribution are the leading source of the residual theoretical uncertainty.

Thus not only can the effects of SM short-distance physics be clearly discerned in this process, but also the effects of possible non-SM physics. Most forms of new physics postulated to augment or supersede the SM have implications for B($K^+ \to \pi^+ \nu\overline{\nu}$)[17]. Recently, attention has focused on the possible effects of a fourth generation[18, 19], leptoquarks[20–22], a left-right symmetric model[23], technicolor[24–26], supersymmetry[27–37], two-Higgs models[38, 39], singlet quarks[40–42,19], extra dimensions[43] and assorted others[44–46,39]. It is notable that the effects of new physics upon the K and B system almost always turn out to be discernibly different. The surprisingly large value of ϵ'/ϵ reported by KTeV[47] and NA48[48] has excited speculation that new physics may be at work in the K system. In some models (*e.g.* supersymmetric ones), the same interactions that have the potential to raise ϵ'/ϵ, can have measurable effects on $K^+ \to \pi^+ \nu\overline{\nu}$ [34].

In the SM, using current data on m_t, m_c, V_{cb}, $|V_{ub}/V_{cb}|$, ϵ_K, B°—$\overline{B^\circ}$ mixing, and including estimates of the theoretical errors, the $K^+ \to \pi^+ \nu\overline{\nu}$ branching ratio has been calculated to be B($K^+ \to \pi^+ \nu\overline{\nu}$) $= (0.72 \pm 0.21) \times 10^{-10}$[8, 49, 50]. A measurement of B($K^+ \to \pi^+ \nu\overline{\nu}$) along with that for the neutral analog B($K_L^\circ \to \pi^\circ \nu\overline{\nu}$), to be undertaken by the KOPIO experiment[51] at BNL, completely determines the CKM triangle. (Fig. 1 shows the standard representation of this triangle.[1]) Measurements of these $K \to \pi\nu\overline{\nu}$ decays are among[2] the theoretically cleanest ways of

[1]This assumes that m_t and $|V_{cb}|$ are known.

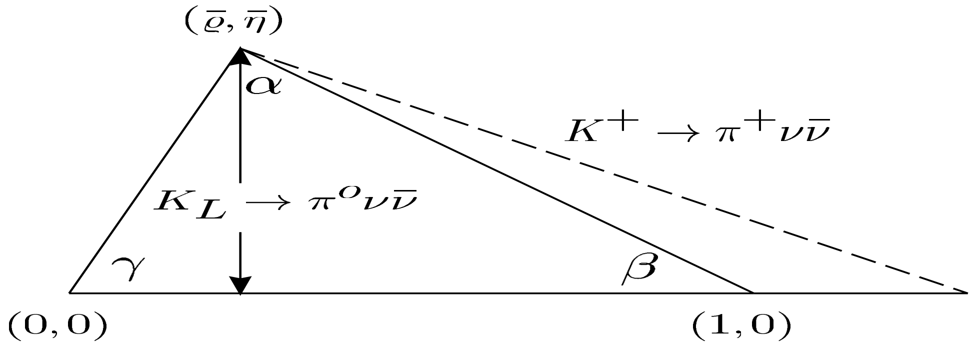

Figure 1: *Standard CKM triangle determination from the K system.*

determining the CKM parameters $\overline{\rho}$ and $\overline{\eta}$[52]. In order to confront the SM explanation for CP violation, determination of these parameters from the K system is essential.

The $K^+ \to \pi^+ \nu \overline{\nu}$ measurements are timely and important and complementary to those obtained from the B system. Any discrepancies in the values found in the K and B systems would be unambiguous indicators of new physics. Measurement of $K^+ \to \pi^+ \nu \overline{\nu}$ will directly complement the results expected soon on B_s mixing from the CDF and D0 experiments presently collecting data at the Fermilab Tevatron, since the ratio $\Delta M_{B_s}/\Delta M_{B_d}$ also gives a clean determination of $|V_{td}|$. The comparison between these results is one of the best testing grounds in the search for physics beyond the Standard Model.

3 History

The decay $K^+ \to \pi^+ \nu \overline{\nu}$ has been sought since the early 1960s as an indication of the existence of flavor changing neutral currents. E949 grew out of the successful precursor experiment, E787, which took data from 1995–98 and improved the sensitivity to $K^+ \to \pi^+ \nu \overline{\nu}$ by four orders of magnitude beyond previous attempts (see Supplementary Document #2). E787 discovered the first two $K^+ \to \pi^+ \nu \overline{\nu}$ events as well as several other important rare K decays and performed many non-SM searches.

A new proposal to upgrade E787 and extend the sensitivity of $K^+ \to \pi^+ \nu \overline{\nu}$ to an order of magnitude below the SM was given scientific approval by BNL in 1998 as E949. The DOE DHEP approved E949 in 1999 as a high priority activity. The approval of E949 cited the significance of the E949 measurement in furthering the understanding of CP violation, the importance of exploiting the large investment in the detector and the value of the experience and expertise developed by E949 to be transferred to the CKM experiment (see Supplementary Document #4). [The DOE/NSF High Energy Physics Advisory Panel's (HEPAP) sub-panel, Particle Physics Project Prioritization Panel (P5), has recommended not to go forward with CKM (September 30, 2003).] The E949 experiment is the next step to fully exploit the $K^+ \to \pi^+ \nu \overline{\nu}$ process and CKM would have been the culminating experiment, advancing the sensitivity to the limit of theoretical uncertainties. E949 will collect 10 events at the SM level in the next few years using a stopped kaon beam. CKM, using a new technique with a high energy separated beam, $K^+ \to \pi^+ \nu \overline{\nu}$ decays in flight in vacuum

[2] The only comparably clean modes are $B_d^\circ \to \psi K_S^\circ$ and perhaps the ratio of B_s to B_d mixing frequencies $\Delta M_{B_s}/\Delta M_{B_d}$

and redundant magnetic and velocity spectrometers, would have reached an order of magnitude beyond E949 to collect 100 events at the SM level in the next decade. E949 and CKM are natural components of a national program to fully exploit the study of the $K^+ \to \pi^+ \nu\overline{\nu}$ decay, building on the successful observation of this mode by E787. The diminished prospects for CKM to be realized makes the determination of $\mathrm{B}(K^+ \to \pi^+ \nu\overline{\nu})$ from the completion of E949 all the more critical.

E949 had an engineering run in 2001 and a successful first data collection run of 12 weeks in 2002. However, funding for operations of the AGS for HEP in support of the E949 experiment was omitted from the President's budget for DOE in FY2003 and the future of E949 is uncertain. In addition to the possible loss of a timely scientific opportunity, the present situation compromises the integrity of international commitments and the careers of 60 scientists including eight graduate students and five post-doctoral scholars.

Predicated in part on the success of E787, KOPIO was proposed to measure $K^\circ_L \to \pi^\circ \nu\overline{\nu}$, and was approved as part of a NSF-supported MRE project, RSVP. RSVP has been extensively reviewed and endorsed by national, laboratory and internal NSF panels. A complete plan for funding RSVP (KOPIO and MECO) was laid out in the FY2004 Presidential Budget Proposal for the NSF, including preoperations during the construction period of FY2006–FY2010. The NSF will operate the AGS for these experiments and the AGS will be upgraded to increase its intensity by 40% (see Section 6). If this intensity increase is available to E949 the sensitivity of this proposal will likewise be increased. The RSVP MRE funding plan includes $144.9M in capital and an asymptotic level of operations support of almost $15M per year (providing for AGS operations and support for both of the experiments). Funding of this proposal, as a transition into the RSVP era, would effectively allow the NSF to reap physics benefits from an AGS HEP program many years earlier than RSVP. This proposal utilizes proposed NSF support for the AGS base program during RSVP preoperations, making completion of E949 very cost effective. This proposal has the strong support of BNL management (see Supplementary Document #5).

The opportunity to support E949 now, poised to produce outstanding physics, provides not only a highly visible and rapid scientific return, but also many tangible benefits to the RSVP program. The KOPIO photon veto inefficiency is difficult to calculate *ab initio* especially due to complexities of photo-nuclear effects. Early operation of E949 already demonstrated a factor of three improvement in π° inefficiency, critical for the success of KOPIO. Crucial E949 studies are planned to explore further improvements suggested by measurements on similar Pb-scintillator detectors at KEK. E949 is a test bed for many other planned KOPIO techniques. These include photo-multiplier gain monitoring studies (an LED-based system has been under continuous development); advanced techniques for detecting signals overlaid by early accidentals (via transient digitizer and other instrumentation); intensive studies of possible background correlations arising from kinematic and photon veto constraints; and, highly sophisticated analysis techniques to meet the challenge of attaining increased acceptance at ultra-low sensitivity. In other tests, E949 will be used to measure the effects of ambient neutrons on detectors similar to those in KOPIO, and provide effective means of reducing backgrounds and dealing with high induced rates.

4 E787 Results

The E787 strategy for detecting $K^+ \to \pi^+ \nu\overline{\nu}$ decay from kaons at rest requires an identified π^+ and no other observable activity in the detector to suppress backgrounds below the signal sensitivity. Major background sources include the two-body decays $K^+ \to \mu^+ \nu_\mu$ ($K_{\mu 2}$) and $K^+ \to \pi^+ \pi^\circ$ ($K_{\pi 2}$), scattered pions in the beam, and K^+ charge exchange (CEX) reactions resulting in decays $K_L^0 \rightarrow \pi^+ l^- \overline{\nu}_l$, where $l = e$ or μ. A plot of the center of mass momentum spectrum of the π^+ from $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ is shown in Fig. 2. The primary search region is above the $K_{\pi 2}$ peak at 205 MeV/c.

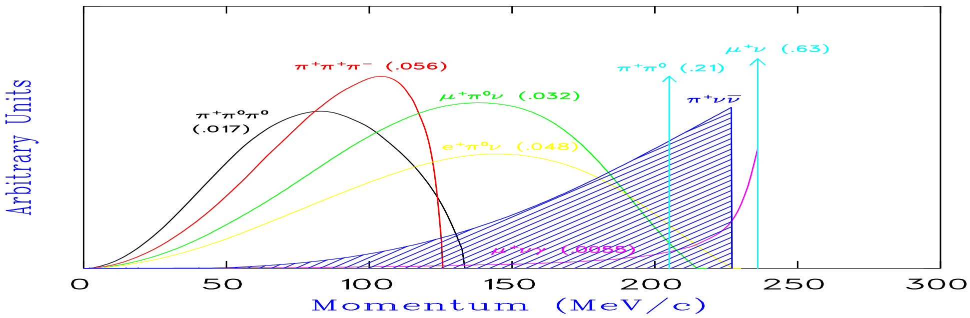

Figure 2: *Momentum in the center of mass of charged particles from the major K^+ decay modes and $K^+ \rightarrow \pi^+ \nu \overline{\nu}$. (Branching ratios in parentheses.)*

The main E787 data set was acquired during the period 1995–98. The set of conditions for E787 operations during the 1995 run will be used as a benchmark. These conditions included 13 Tp/spill (13×10^{12}/spill)[3], 5.3 MHz of incident kaons, a stopped kaon rate of 1.2 M/spill, a deadtime of 25%, and an acceptance of 0.16%. This acceptance is 60% of the acceptance at zero rate. Continuous improvements to the E787 system were implemented throughout its operation. For E949, additional upgrades and improvements in technique have substantially increased the sensitivity as will be discussed in Section 5 below.

The final results from E787[53–55] were based on observation of decays of 5.9×10^{12} kaons at rest. Measurement of the $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ decay involves only the π^+ track and its subsequent decay products and was accomplished with an overall efficiency of 2×10^{-3} to suppress background processes by up to 10 orders of magnitude. The sum of all backgrounds was suppressed to the level of 0.15 ± 0.05 events with the procedures and estimates subjected to extensive verification (see Section 5.4). The combined result for E787 data is shown in Fig. 3, with the distribution of range and kinetic energy of events surviving all other cuts.

The box represents the signal region in which two events appear. A likelihood ratio technique was used to determine the best estimate of the branching ratio. Based on two observed events and the expected background levels, $\mathrm{B}(K^+ \rightarrow \pi^+ \nu \overline{\nu}) = 1.57^{+1.75}_{-0.82} \times 10^{-10}$. This result is consistent with the SM prediction. The estimated probability for the observation to be due entirely to background is 0.02%. Even with these limited statistics, the E787 result has provided a non-trivial improvement in the determination of $\overline{\rho}$ and $\overline{\eta}$ from fits to all of the experimental data (e.g. D'Ambrosio and Isidori[49]).

Progress has also been made to access the region below the $K_{\pi 2}$ peak, deemphasized in the primary search for the decay $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ because of the low momentum tail of $K_{\pi 2}$ decays. It contains more phase space and suffers less from pion absorption; these factors can increase the acceptance by up to a factor of 3 compared to that above the $K_{\pi 2}$ peak. A complete analysis of the 1996 data set has been published (analysis of 1997 is nearing completion). One event was found with an expected background of 0.73 ± 0.18 events giving a limit $\mathrm{B}(K^+ \rightarrow \pi^+ \nu \overline{\nu}) < 4.2 \times 10^{-9}$ (90% CL) [56]. Substantial improvements to the detector have been made for E949, particularly in

[3] The proton beam spill typically lasted 1.6 s with a cycle time of 3.6s.

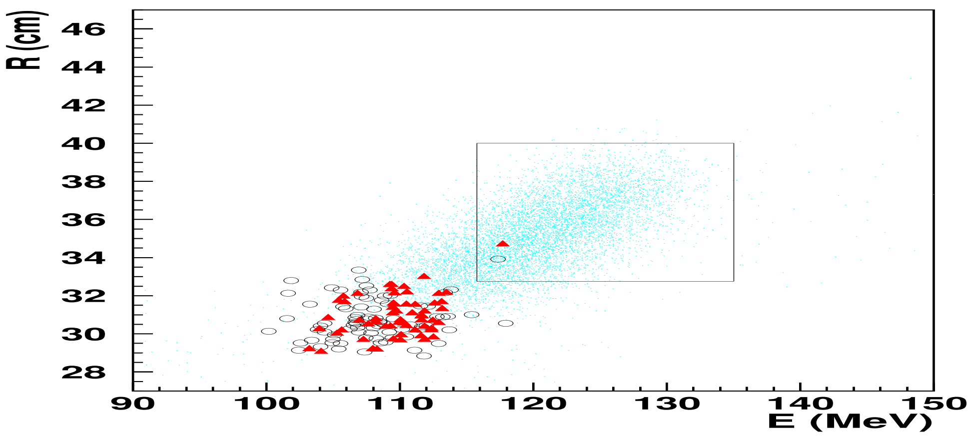

Figure 3: *Range vs. energy plot of the E787 final sample for* $K^+ \to \pi^+ \nu \overline{\nu}$ *. The circles are for the 1998 data and the triangles are for the 1995–97 data set. The group of events around* $E = 108$ *MeV is due to the* $K^+ \to \pi^+ \pi^\circ$ *background. The simulated distribution of expected events from* $K^+ \to \pi^+ \nu \overline{\nu}$ *is indicated by dots.*

the photon veto systems, which should allow E949 to further suppress the background and obtain significant additional sensitivity for B($K^+ \to \pi^+ \nu \overline{\nu}$).

E787 studied numerous other rare K and π decays and performed searches for many as-yet unobserved processes. In addition to $K^+ \to \pi^+ \nu \overline{\nu}$, the decays $K^+ \to \pi^+ \mu^+ \mu^-$, $K^+ \to \pi^+ \gamma \gamma$, and $K^+ \to \mu^+ \nu_\mu \gamma$ (SD) (Structure Dependent radiation) were discovered in E787 and many searches for other interesting processes were either performed for the first time or improved by many orders of magnitude. The first high statistics measurement of the direct emission component of the radiative decay $K^+ \to \pi^+ \pi^\circ \gamma$ was also reported[57]. The trigger for $K^+ \to \pi^+ \pi^\circ \gamma$ has been improved to accept a lower phase space region to enhance the acceptance for direct emission. In addition, searches for the decays $K^+ \to \pi^+ \gamma$ [58], $K \to \pi^+ \pi^\circ \nu \overline{\nu}$ [59] and $\pi^\circ \to \nu \overline{\nu}$ [60] have been performed. Substantial improvements in the limits on $K^+ \to \pi^+ X^\circ$ [56] were obtained recently as shown in Fig. 4. A more detailed list of physics topics from E787 and E949 is provided in Supplementary

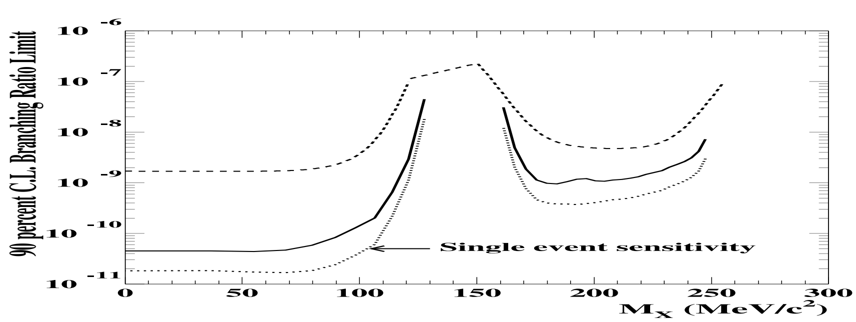

Figure 4: *E787 imits on* $K^+ \to \pi^+ X^\circ$ *for various values of the mass of the unknown particle,* m_X*.*

Document #3, and is summarized here in Table 1.

MODE	RESULT	GAIN	COMMENT
$K^+ \to \pi^+ \nu\overline{\nu}$	$(1.57^{+1.75}_{-0.82})10^{-10}$	775	Discovery
$K^+ \to \pi^+ \gamma\gamma$	$(1.1 \pm 0.3)10^{-6}$	100	Discovery
$K^+ \to \pi^+ \mu^+ \mu^-$	$(5.0 \pm 1.0)10^{-8}$	4500	Discovery
$K^+ \to \mu^+ \nu_\mu \gamma$ (SD)	$(1.33 \pm 0.12)10^{-5}$	1000	Discovery
$K^+ \to \pi^+ \pi^\circ \gamma$ (DE)	$(4.72 \pm 0.77)10^{-6}$	8	Direct Emission Radiation
$K^+ \to \pi^+ X^\circ$	$< 5.9 \times 10^{-11}$	645	Familon Search
$K^+ \to \mu^+ \nu \mu^+ \mu^-$	$< 4.1 \times 10^{-7}$	2.4M	Light Higgs Search
$K^+ \to e^+ \nu \mu^+ \mu^-$	$< 5 \times 10^{-7}$	2M	Light Higgs Search
$\pi^\circ \to \nu\overline{\nu}$	$< 8 \times 10^{-7}$	10	Non-SM Search
$\pi^\circ \to \gamma X^\circ$	$< 5.3 \times 10^{-4}$	1900	Vector Particle Search
$K \to \pi^+ \pi^\circ \nu\overline{\nu}$	$< 4.3 \times 10^{-5}$	new	Non-SM Search
$K^+ \to \pi^+ \gamma$	$< 3.6 \times 10^{-7}$	4	Angular Momentum Violation

Table 1: *E787 published results, including the improvement (GAIN) over pre-E787 measurements.*

E787 has also developed a number of new technologies and techniques. These include large systems of 500 MHz transient digitizers based on high speed flash analog-to-digital converters (ADCs)[61] and unique GaAs CCDs[62], scintillating fiber detectors, undoped CsI crystals[63–65], inflated-foil drift chambers[66], and an advanced separated kaon beam[67]. The 'blind analysis' approach developed to a high degree by E787 also been adopted by numerous other high energy physics collaborations to avoid biases in data analysis and background estimation.

5 E949

The E787 detector[68] and technique provide a firm basis for projecting the sensitivity of E949. The primary improvement for E949 comes from stopping more K^+ near the center of the detector, without significantly increasing the instantaneous rates in the detector. At significantly higher flux from the AGS, increasing the duty factor and lowering the kaon momentum leaves the instantaneous rate of incident kaons essentially unchanged. At lower kaon momentum the fraction of kaons that stop increases, so the sensitivity increases. Additional improvement arises from the longer running time envisioned while the AGS is serving as an injector to RHIC and from increased trigger, data acquisition (DAQ) and running efficiency. The E949 upgrades to the E787 detector and DAQ have increased the background rejection, especially important in the region below the $K_{\pi 2}$ peak, and the DAQ bandwidth to handle the increased sensitivity.

5.1 The E949 Detector

The E949 detector as upgraded is shown in Fig. 5. The detector is located in the C4 beam line at the AGS. The C4 beam line, or Low Energy Separated Beam (LESB3)[67], transports kaons of up to 830 MeV/c. At 690 MeV/c it can transmit more than $3 \times 10^6 K^+$/spill with a K^+/π^+ ratio of 3:1 for 10^{13} protons on the production target. The K^+ are stopped in a scintillating fiber target in the center of the detector. The detector, which for vetoing purposes is hermetic, is located in a 1 T, solenoidal magnetic field.

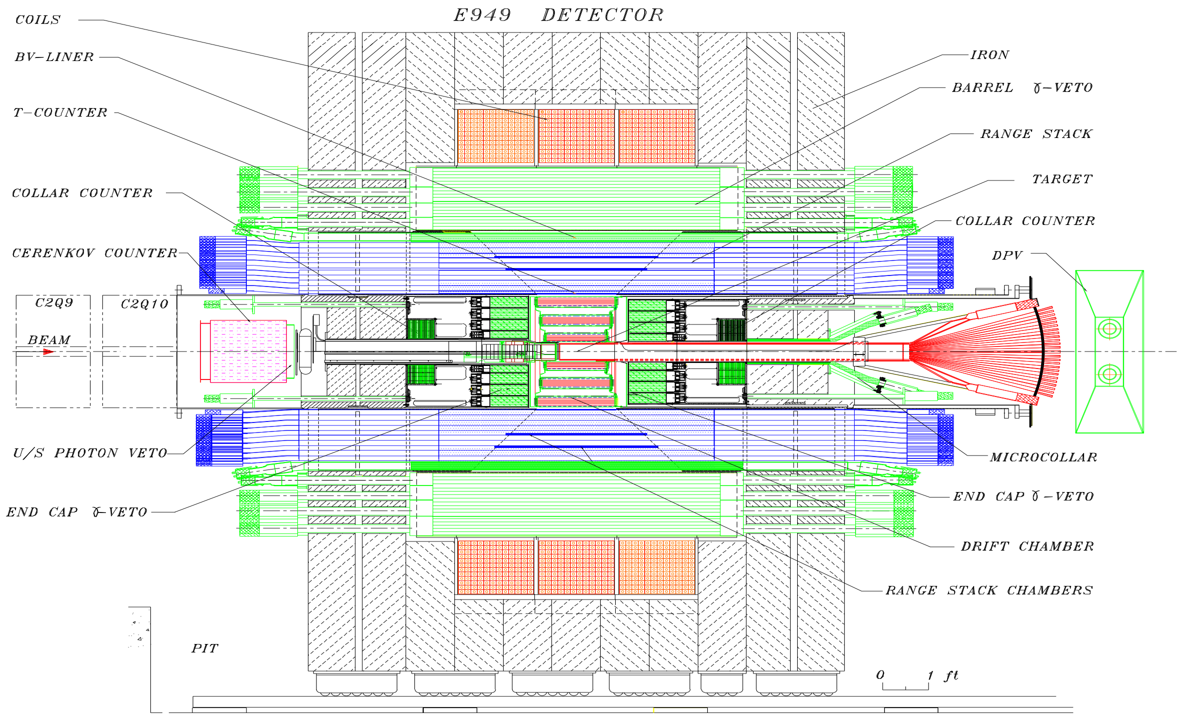

Figure 5: *The E949 detector.*

The incident kaons are identified in a Cherenkov counter, two tracking chambers and then, after slowing down in an active degrader, an energy loss (dE/dx) counter before coming to rest in the central target.

The scintillating fiber target (TT) consists of 413 5-mm square fibers. Each fiber is 3.1 m long and read out by a single PMT. The target is surrounded by 6 scintillators (IC), whose 241 mm length determines the fiducial region of the target.

The central drift chamber[66] (UTC) is a cylindrical, low-mass chamber that consists of 12 layers of axial wire cells and six layers of thin cathode strip foils supported by differential gas pressure. The momentum resolution for muons and pions in the range 150–250 MeV/c is <1% and the z-resolution is <1 mm.

The energy, range, and decay sequence of charged particles are measured in the range stack (RS). They are stopped in this cylindrical array of 19 layers and 24 azimuthal sectors of plastic scintillator. Each counter is read out with a PMT on each end. The innermost layer, 24 T-counters, are 0.52 m long to define the acceptance. The remaining layers are 1.82 m long. Two layers of straw tube detectors (RSSC) are located after layers 10 and 14, to provide fine resolution tracking within the RS. The entire range stack is instrumented with transient digitizers (TD)[61] to measure the $\pi^+ \to \mu^+ \to e^+$ decay chain.

The photon veto system consists of: a barrel veto (BV), two endcaps (EC), 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 consists of 4 layers of Pb-scintillator sandwich, read out by a PMT on each end. The BV surrounds the RS, 2π in azimuth and 1.9 m axially. The total thickness of the BV is in radiation lengths ($X_\circ$) is 14.3 $X_\circ$. The barrel veto liner (BVL), part of the E949 upgrade, between the RS and the BV added 2.3 $X_\circ$ of critical live material in a thin region of the E787 detector near 45°, and thus is expected to significantly improve the photon vetoing power of the entire detector. It will be especially effective in reducing the $K_{\pi 2}$ background in the region below the $K_{\pi 2}$ peak.

The endcaps[63–65] consist of 143 crystals of pure-CsI, arranged in four concentric rings. The CO and CM systems are both Pb-scintillator and provide coverage of photons at small angles. The number of radiation lengths provided by the CO has been doubled, by increasing the Pb thickness to 2 mm. In addition, the K^+ degrader was increased from 4 $X_\circ$ to 7 $X_\circ$ by replacing the PbG with a Cu-scintillator sandwich. A new upstream photon veto (UPV) was added to the downstream face of the Cerenkov counter with 3 $X_\circ$ of Pb-scintillator. A new downstream photon veto (DPV) with 7 $X_\circ$ of Pb-scintillator was added behind the target. In addition to the photon veto detectors listed above, the entire detector is used to veto energy that is not associated with the charged track.

Approximately 1,000 channels of 500 MHz 8-bit transient digitizers based on GaAs CCD's[62] have been instrumented on the TT, EC and beam systems. They have improved the timing resolution and the double pulse (pile-up) resolution for these systems.

The trigger consists of 2 levels. The first, Level 0, requires a kaon stopping in the target, a decay at least 1.5 ns later, no photons in the BV, BVL, EC or RS, a range longer than the $K^+ \to \pi^+\pi^+\pi^-$ and shorter than the $K_{\mu 2}$. The second level trigger, Level 1, has two components: Level 1.1 requires a $\pi^+ \to \mu^+$ decay in the stopping counter, Level 1.2, requires that no energy is deposited in counters adjacent to the stopping counter.

The DAQ[69–73] is Fastbus based, with front-end readout into SLAC Scanner Processors. The E949 data transfer capability was demonstrated to be >25 Mbytes/sec. The deadtime, which is dominated by the readout of the front-end modules into the SSP's, was ~17% per MHz of stopped kaons (KB) (down from 28%).

5.2 Initial E949 Running and Sensitivity Improvements

E949 had a short initial running period in 2002 in which approximately 2×10^{12} kaons were stopped (roughly one third of the number collected by E787). Problems with high voltage breakdown in the electro-magneto-static separators forced E949 to run with a larger pion contamination and with 35% fewer kaons per proton. The primary motor generator set for the AGS had been damaged, necessitating the use of the backup set, which required running at the reduced duty factor of 41% and with lowered primary proton beam momentum. These problems will be corrected before future running of E949, with an expected increase in sensitivity of more than 50%.

In spite of these difficulties many of the projected improvements for E949 were confirmed. The net increase in sensitivity per year from these improvements is approximately thirteen[4] and is summarized in Table 2. In order to achieve this increase in sensitivity for E949 the number of protons on target needed will be 65 Tp/spill. The AGS intensity has increased significantly, to more than 70 Tp and the AGS duty factor has simultaneously increased, from 37% in early 1995 to 49% in 1998. It is expected that there should be no problems in increasing this to 65% or more[74]. The cooling requirements for the production target for this experiment (with 16 Tp/sec) are less than has already been demonstrated for the E787 target[75]. In fact, E949 has already run with more than 31 Tp/sec on target.

[4]We have conservatively estimated that the overall improvement will be a factor of two less than the combined factors discussed.

Upgrade	Improvement factor
Lower momentum	1.4
Higher duty factor	1.6
Hardware improvements	1.7
Analysis improvements	1.8
Phase space below $K^+ \to \pi^+ \pi^\circ$	2
Optimization at higher rate	2
Total	13

Table 2: *Sensitivity improvement factors for E949, compared to the baseline running conditions described in the text.*

5.3 Running Conditions and Expected Sensitivity

A reliable calculation of the sensitivity of E949 in the region above the $K_{\pi 2}$ is possible due to the large amounts of data available from E787 and the initial run of E949 in 2002. Measurements of the K^+ production and the fraction of kaons that stop in the scintillating fiber target have been made as a function of K^+ momentum. The deadtime of the trigger and DAQ, the acceptance of the offline analysis cuts and online trigger have been measured as a function of rate for E787 data. Some significant new information is already available from E949 data. The anticipated sensitivity of E949, as a function of spill length, kaon momentum, and protons on target has been studied. Contour plots of the sensitivity are shown for E787's 1995 baseline conditions (13 Tp) and for E949 (65 Tp) in Fig. 6a–b.[5] The baseline sensitivity is 1.46×10^6/hr at 780 MeV/c and a 1.7 sec spill

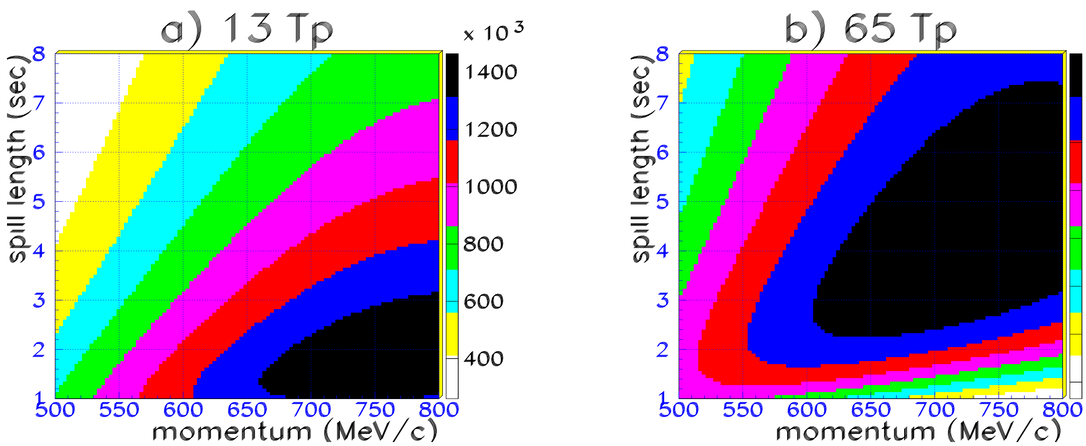

Figure 6: *Contours of constant sensitivity/hr for E787 as run in 1995 (13 Tp) and for E949 at 65 Tp (for the region above the $K_{\pi 2}$).*

(see Fig. 6a). The proposed E949 sensitivity at 65 Tp (see Fig. 6b) is 8.9×10^6/hr at 730 MeV/c and 4.1 sec spill every 6.4 sec, which is 5 times larger than the baseline. Improvements to the AGS intensity are planned to enable delivery of 100 Tp (as discussed below in Section 6). Once the AGS is able to deliver 100 Tp to the C-target, E949 could be re-optimized for higher intensity.

[5] Neither calculation includes AGS or experimental running inefficiencies.

	KB_L (10^{12})	$\lvert\vec{p_K}\rvert$	DF (%)	sf (%)	$(S.E.S.)^{-1}$ (10^{10})	bck events
E787(1995–98)	5.9	670–790	47	24	1.2	0.15
E949(2002)	1.7	710	41	27	∼0.4	∼0.1
E949(Option A)	11	730	64	26	3.2	0.5

Table 3: *Comparative Sensitivities. The reduction of the incident kaon momentum (p_K) has led to an increase the fraction of stopping kaons (sf). The AGS duty factor (DF) has increased over the same time period. The expected sensitivity (S.E.S.$^{-1}$) and number of background events (bck) for the region above the $K_{\pi 2}$ peak are scaled from E787 results, including online trigger and offline acceptance improvements.*

This proposal presents two options for AGS accelerator operations, although information is provided in the Budget Justification to cost any number of weeks of AGS operations. Under Option A, the AGS is operated for 12 weeks of E949 running per year (1200 hours/year); whereas, under Option B, the AGS is operated for 18 weeks per year (1800 hours/year). After the total E949 running time of 4,800(6,600) hours in Option A(Option B), the expected sensitivity for $K^+ \to \pi^+ \nu\overline{\nu}$ would be $2.3 \times 10^{-11}(1.7 \times 10^{-11})$. Combined with the E787 result, the sensitivity should reach $1.8 \times 10^{-11}(1.4 \times 10^{-11})$ with 0.6(0.8) expected background events. With the added acceptance from the region below the $K^+ \to \pi^+ \pi^\circ$, the sensitivity should reach $10.1 \times 10^{-12}(7.6 \times 10^{-12})$. Therefore the number of events is expected to be as high as 15(20) for a branching ratio of 1.5×10^{-10} or 7(10) events at the SM level. The sensitivity of E949 compared to E787 is shown in Table 3.

A plot showing progress in sensitivity to $K^+ \to \pi^+ \nu\overline{\nu}$ is shown in Fig 7. Included are experiments that set 90% CL limits (earlier E787 results[76–79] and previous experiments[80–82]), as well as the branching ratio measurements of E787 and a projection to this proposal assuming the current branching ratio.

5.4 Background Estimates

Reliable estimation of backgrounds is one of the most important aspects of the E949 measurement of $K^+ \to \pi^+ \nu\overline{\nu}$ at the 10^{-10} level. The techniques to do this have been fully proven in E787. An identified K^+ is required to stop in the target followed, after a delay of at least 2 nsec, by a single charged-particle track that is unaccompanied by any other decay product or beam particle. This particle must be identified as a π^+ with momentum, energy and range between the $K_{\pi 2}$ and $K_{\mu 2}$ peaks for the high energy phase space region or well below the $K_{\pi 2}$ peak for the lower energy region. To elude rejection, $K_{\mu 2}$ and $K_{\pi 2}$ events have to be reconstructed incorrectly in momentum, range and energy. In addition, any event with a muon has to have its track misidentified as a pion — the most effective weapon here is the measurement of the $\pi^+ \to \mu^+ \to e^+$ decay sequence which provides a suppression factor 10^{-5}. Events with photons, such as $K_{\pi 2}$ decays, are eliminated by exploiting the full calorimeter coverage. The inefficiency for detecting events with π° 's was 10^{-6} in E787. A significant improvement in π° detection efficiency is expected in E949. A scattered beam pion can survive the analysis only if misidentified as a K^+ and if the track is mismeasured as delayed, or if the track is missed entirely by the beam counters after a valid K^+ stopped in the target. Kaon charge exchange (CEX) background events can survive only if the K°_L is produced at

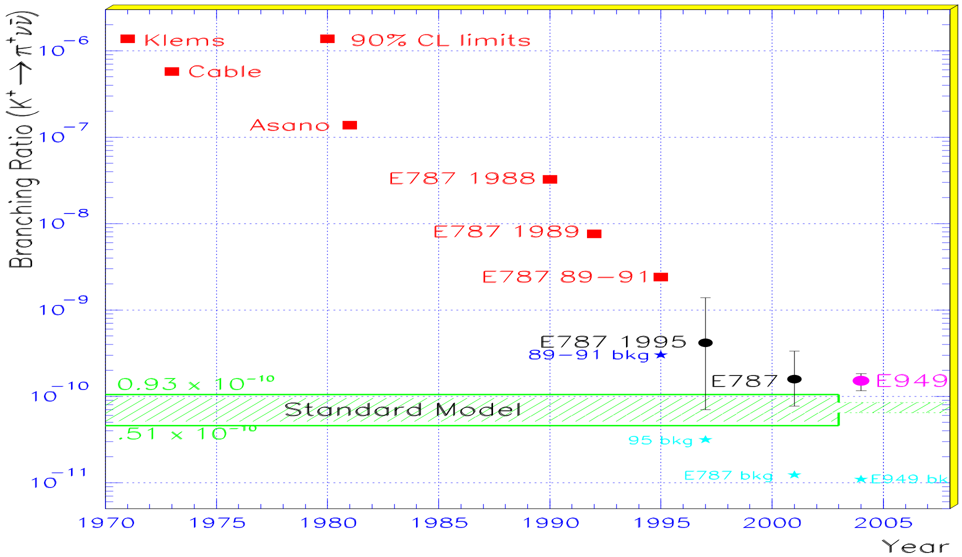

Figure 7: *History of progress in the search for $K^+ \to \pi^+ \nu\overline{\nu}$. The solid squares represent 90% CL upper limits from experiments that did not see any events. The solid circles represent the measured branching ratios from the E787 observation of this decay and the expected sensitivity after the completion of E949, assuming the branching ratio as measured by E787. The SM prediction of the branching ratio is shown with significantly reduced errors based on an assumed observation of B_s mixing. The equivalent branching ratio for the background is shown with stars.*

low enough energy to remain in the target for at least 2 ns, and if there is no visible gap between the beam track and the observed π^+ track, and if the additional charged lepton went unobserved.

In developing the required rejection criteria (cuts), the redundant and independent constraints available on each source of background are used to establish two independent sets of cuts. One set of cuts is relaxed or inverted to enhance the background (by up to three orders of magnitude) so that the other group can be evaluated to determine its power for rejection. For example, $K_{\mu 2}$ (including $K^+ \to \mu^+ \nu_\mu \gamma$) are to be studied by separately measuring the rejections of the TD particle identification and the kinematic cuts. Small correlations in the separate groups of cuts are investigated for each background source and corrected.

In the E787 data set, the total background level in the signal region with the final analysis cuts was $b = 0.15 \pm 0.05$ background events. As can be seen in Table 4, the estimated number of background events above the $K_{\pi 2}$ peak for E949 is 0.6(0.8) under Option A(B).

5.5 Sensitivity to $|V_{td}|$

Based on the estimated 10% systematic uncertainty, $|V_{td}|$ would be determined to 35%(30%) if the central value of the SM prediction is measured[83] (assuming a 5% uncertainty on $|V_{cb}|$). With the added sensitivity from the region below the $K^+ \to \pi^+ \pi^\circ$, the uncertainty on $|V_{td}|$ would be 30%(25% in Option B). This precision is comparable to that obtained from measurements of B_d°—$\overline{B_d^\circ}$ mixing. In the latter case the limit on the precision is less reliable since it comes from the

Background	Option A	Option B
$K_{\pi2}$	0.18	0.14
$K_{\mu2}$	0.35	0.26
Single beam	0.05	0.04
Double beam	0.08	0.06
CEX	0.15	0.11
Total	0.8	0.6

Table 4: *Background levels (events) measured from E787 and projected for the combined E787+E949 sensitivity above the $K_{\pi2}$ peak.*

theoretical difficulty in calculating the hadronic matrix element[84]. This proposed experiment is free of such difficulties. Eventually measurements of $|V_{td}|$ from the B sector with lower theoretical uncertainty are expected (e.g. from measuring B_s°—$\overline{B_s^\circ}$ as well as B_d°—$\overline{B_d^\circ}$ mixing) and the comparison with the $K^+ \to \pi^+ \nu\overline{\nu}$ result will become very interesting from the point of view of probing beyond the SM[18, 27, 28, 30] using only theoretically unambiguous quantities.

6 Support of E949 and AGS Operations

The opportunity to support E949 now, poised to produce outstanding physics, provides a highly visible and rapid scientific return. With the base cost of AGS accelerator operations by DOE-NP for RHIC and the base cost of slow extracted beams covered by NSF for RSVP, the operation of E949 is highly leveraged and very cost effective.

The costs to run E949 are shown in Table 5, and are broken out in significant detail in the Budget Justification section. The first year budget request includes a number of startup costs

year	Option A		Option B	
	Cost	Operations	Cost	Operations
FY2004	$0.8M beamline and detector preparation			
RSVP yr#1	$3.7M	12 weeks	$6.2M	18 weeks
RSVP yr#2	$3.7M	12 weeks	$6.2M	18 weeks
RSVP yr#3	$3.7M	12 weeks	$6.2M	18 weeks
Total	$11.8M	36 weeks	$19.3M	54 weeks

Table 5: *E949 Cost and Funding Proposal. All numbers are in FY2003 dollars. Funding for the first year includes beamline repair and upgrades and detector maintenance, along with some funds for beam tests during a proposed RSVP run. In subsequent years, base AGS labor costs for accelerator operations are being provided by DOE-NP as part of the RHIC program and for secondary beam operations by NSF as part of the RSVP program, providing very cost effective running for E949 with 10 weeks per year overlapping with RHIC. Additional running would be outside of RHIC and RSVP at a higher cost per week. The sensitivity represents the total world sensitivity from existing E787 and E949 data as well as from this proposal.*

necessary to bring the beamline into working order. This work needs to be started five months before the start of E949 operations with beam and includes repairs to one of the beam separators, replacements to the first two beam line elements, new beamline instrumentation, and modifications to the C-line to reduce the radiation exposure to LESB3. The total of these costs is $625K as discussed in the attached budget justification. An additional $175K is requested to prepare the detector for data taking. It is expected that funds received during the first year of this proposal would be applied to the preparations outlined above and would take 5 months to complete. Any additional funds would then be expended for running concurrently with RSVP. The funding in subsequent years, at a total cost of $3.7M($6.2M)/year under Option A(B), would be applied for 12(18) weeks of operations.

E949 (and E787) is a collaboration of universities and national labs in Canada, Japan, Russia and the United States (see Supplementary Document #1). The DOE DHEP has made a capital contribution estimated to be $30M. Canadian and Japanese agencies have contributed a comparable amount to this effort and continued operation of E949 is strongly supported. For operations of E949, the Japanese contingent is supported through the US-Japan Program for Cooperation in High Energy Physics at roughly $0.5M/yr and the Canadian group is supported by the National Science and Engineering Research Council of Canada (NSERC) and Canada's National Laboratory for Particle and Nuclear Physics (TRIUMF) at a similar level, in addition to staff costs and other laboratory support. Russian groups from the Institute for Nuclear Research in Troitsk (INR) and the Institute for High Energy Physics in Serpukhov (IHEP) are also committed to making substantial contributions.

Canada and Japan are also major contributors to RSVP-KOPIO. The Canadian Foundation for Innovation has agreed to provide $5M to upgrade the AGS intensity by 50% or more to approximately 100 Tp/spill, a development which could greatly benefit E949.

The E949 collaboration has demonstrated its readiness to exploit the $50M investment in the E787/E949 detector. The AGS is the highest intensity proton synchrotron in the world and will be available during RHIC operations for 20 hours per day for running E949. The analysis tools and personnel expertise are in place and the system has demonstrated sufficient background rejection to reach the E949 goals.

7 Education and Outreach

The E787 experiment has produced 13 PhD theses and 12 masters theses. Many of these students have gone on to leadership roles in high energy physics. E787 has also had a long tradition of outreach for younger students and over the years has worked with 29 Undergraduate Semester students, 2 Community College Honors Program (Summer) students, 7 High School Summer Science Program students, and 3 High School Science Teachers (Summer). More than 20% of these students came from underrepresented groups. E949 similarly provides an excellent opportunity to work on a state-of-the-art experiment in particle physics and yet not get lost within a large collaboration.

E949 has numerous interesting physics topics suitable for undergraduate and graduate student theses (see Section 4 and Supplementary Document #3). As a modest size fixed-target experiment, it is natural and incumbent on graduate students to become intimately familiar with all aspects of the experiment: from hardware through data analysis leading to their proficiency in advanced technologies. E787 and E949 have had a continual evolution of improvements in detector and electronics hardware; there is every reason to expect continued improvements and additional hardware opportunities for new E949 students.

8 E949 Collaboration and Principal Investigator

E949 is an international collaboration with 75 participants from Canada, Japan, the US, and Russia. The collaboration is managed by three co-spokesmen D. Bryman (University of British Columbia), S. Kettell (BNL), and S. Sugimoto (KEK).

The US E949 group is led by Steve Kettell who has worked intensively on rare K-decays at BNL for the last 14 years, including more than 10 years on E787. He is supported at BNL by an experienced group including Laurence Littenberg and others. BNL will be the principal subcontractor for this proposal.

Michael Marx, principal investigator of this proposal, has recently joined E949 and will be primarily involved in E949 data analysis. He has worked on a broad range of physics topics including rare K-decays, neutrino elastic scattering and oscillations, the D0 experiment, SSC experiments, and most recently the PHENIX experiment at RHIC before joining KOPIO as Project Director in 2001. An NSF-supported graduate student in his group at Stony Brook, Ms. Ilektra-atha Christidi, plans to analyze E949 data as a component of her thesis requirements. Marx has been concerned for many years with education outreach activities of high energy physics, and introduced an evening course for non-scientists 'Mystery of Matter', often referred to as 'Atom Smashing for Gym Teachers'.

9 Broader Impacts

The cutting-edge instrumentation, software, and experimental techniques essential for the success of groundbreaking experiments like E949 are often spurs to the concurrent advances in technology useful in other areas. For example, most radiation medicine techniques are based on original developments of high energy physics. The E949 and KOPIO collaborations will provide advances in accelerator, detector, electronics, and software technologies that will not only expand the research frontiers of sub-atomic physics but may also provide critical technological innovations applicable to many other fields.

In this context it is relevant to note that elements of the E949 and KOPIO designs for detecting gamma rays have already been shown to be potentially useful for several other applications and generated a patent. In 2000, a patent was granted to Prof. Bryman (E949 co-spokesman) for a gamma ray imaging system applicable to explosives imaging, based on an array of tracking chambers and plastic scintillators similar to the KOPIO preradiator which is an offshoot of E949 detector systems.

Approval of this proposal by NSF has benefits to international scientific cooperation, especially with Canada, Japan and Russia, whose capital and scientific investment in E949 is threatened by the premature termination of support by DOE.

References

[1] N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963); M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[2] M.K. Gaillard and B.W. Lee, Phys. Rev. D **10**, 897 (1974).

[3] T. Inami and C. S. Lim, Prog. Theor. Phys. **65**, 297 (1981).

[4] A.J. Buras and R. Fleischer, *Heavy Flavours II*, ed. Buras and Linder, p65 (World Scientific,1998).

[5] S.L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D **2**, 1285 (1970).

[6] G. Buchalla and A.J. Buras, Nucl. Phys. **B412**, 106 (1994).

[7] M. Misiak and J. Urban, Phys. Lett. **B451**, 161 (1999).

[8] G. Buchalla and A.J. Buras, Nucl. Phys. **B548**, 309 (1999).

[9] W.J. Marciano and Z. Parsa, Phys. Rev. **D53**, R1 (1996).

[10] G. Buchalla and A.J. Buras, Phys. Rev. **D57**, 216 (1998).

[11] J.S. Hagelin and L.S. Littenberg, Prog. Part. Nucl. Phys. **23**, 1 (1989).

[12] D. Rein and L.M. Sehgal, Phys. Rev. **D39**, 3325 (1989).

[13] M. Lu and M.B. Wise, Phys. Lett. **B324**, 461 (1994).

[14] C.Q. Geng *et al.*, Phys. Lett. **B355**, 569 (1995).

[15] S. Faijfer, Nuovo. Cim. **110A**, 397 (1997).

[16] A.F. Falk *et al.*, Phys. Lett. **B505**, 107 (2001).

[17] I.I. Bigi and F. Gabbiani, Nucl. Phys. **B367**, 3 (1991).

[18] T. Hattori, T. Hasuike, and S. Wakaizumi, Phys. Rev. **D60**, 113008 (1999).

[19] T. Yanir, JHEP **0206**, 044 (2002).

[20] K. Agashe and M. Graesser, Phys. Rev. D **54**, 4445 (1996).

[21] M. Leurer, Phys. Rev. Lett. **71**, 1324 (1993).

[22] S. Davidson, D. Bailey, and B. Campbell, Z. Phys. **C61**, 613 (1994).

[23] Y. Kiyo *et al.*, Prog. Theor. Phys. **101**, 671 (1999).

[24] Z. Xiao, L. Lü, H. Guo and G. Lu, Eur. Phys. J. **C7**, 487 (1999).

[25] Z. Xiao, C. Li and K. Chao, Eur. Phys. J. **C10**, 51 (1999).

[26] G. Buchalla *et al.*, Phys. Rev. **D53**, 5185 (1996).

[27] A.J. Buras, A. Romanino, and L.Silvestrini, Nucl. Phys. **B520**, 3 (1998).

[28] G-C. Cho, hep-ph/9804327, KEK-TH-568, Apr 1998; G-C. Cho, Eur. Phys. J. **C5**, 525 (1998).

[29] G. Bhattacharyya and A. Raychaudhuri, Phys. Rev. **D57**, 3837 (1998).

[30] T. Goto, Y. Okada, and Y. Shimizu, Phys. Rev. **D58**, 094006 (1998), hep-ph/9804294.

[31] Y. Grossman and Y. Nir, Phys. Lett. **B398**, 163 (1997).

[32] G. Couture and H. König, Z. Phys. **C69**, 167 (1996).

[33] G. Colangelo and G. Isidori, JHEP-9809-009, hep-ph/9808487 (1998).

[34] A.J. Buras and L.Silvestrini, Nucl. Phys. **B546**, 299 (1999).

[35] A.J. Buras *et al.*, Nucl. Phys. **B566**, 3 (2000).

[36] A.J. Buras *et al.*, Phys. Lett. **B500**, 161 (2001).

[37] C-H. Chen, J. Phys. **G28**, L33 (2002).

[38] T. Barakat, Nuovo Cim. **A112**, 697 (1999).

[39] G. D'Ambrosio, *et al.*, Nucl. Phys. **B645**, 155 (2002).

[40] D. Silverman, Phys. Rev. **D58**, 095006 (1998).

[41] D. Hawkins and D. Silverman, Phys. Rev. **D66**, 016008 (2002).

[42] J.A. Aguilar-Saavedra, hep-ph/0210112.

[43] G. Burdman, Phys. Rev. **D66**, 076003 (2002).

[44] M.B. Popovic and E. Simmons, Phys. Rev. **D58**, 095007 (1998).

[45] M. Chanowitz, hep-ph/9905478.

[46] W. Chang and J.N. Ng, hep-ph/0210414.

[47] A. Alavi-Harati *et al.*, hep-ex/0208007.

[48] J.R. Batley *et al.*, Phys. Lett. **B544** 97 (2002).

[49] G. D'Ambrosio and G. Isidori, Phys. Lett. **B530**, 108 (2002).

[50] A. Höcker *et al.*, *Heavy Flavor Physics: Ninth International Symposium on Heavy Flavor Physics*, eds. A. Ryd and F.C. Porter, p 27 (AIP-618) hep-ph/0112295.

[51] D.A. Bryman and L. Littenberg, Nucl. Phys. Proc. Suppl. **99B**, 61 (2001).

[52] G. Buchalla *et al.*, Rev. Mod. Phys. **68**, 1125 (1996).

[53] S. Adler *et al.*, Phys. Rev. Lett. **79**, 2204 (1997).

[54] S. Adler *et al.*, Phys. Rev. Lett. **84**, 3768 (2000).

[55] S. Adler *et al.*, Phys. Rev. Lett. **88**, 041803 (2002)

[56] S. Adler *et al.*, Phys. Lett. **B537**, 211 (2002).

[57] S. Adler *et al.*, Phys. Rev. Lett. **85**, 4856 (2000).

[58] S. Adler *et al.*, submitted to Phys. Rev. **D** (2001).

[59] S. Adler *et al.*, Phys. Rev. **D63**, 032004 (2001).

[60] M.S. Atiya *et al.*, Phys.Rev.Lett. **66**, 2189 (1991).

[61] M.S. Atiya *et al.*, NIM **A279**, 180 (1989).

[62] D.A. Bryman *et al.*, NIM **A396**, 394 (1997).

[63] I.-H. Chiang *et al.*, IEEE Trans. Nucl. Sci. **NS–42**, 394 (1995).

[64] T.K. Komatsubara *et al.*, NIM **A404**, 315 (1998).

[65] M. Kobayashi *et al.*, NIM **A337**, 355 (1994).

[66] E.W. Blackmore *et al.*, NIM **A404**, 295 (1998).

[67] I.-H. Chiang *et al.*, NIM **A444** 546 (2000).

[68] M.S. Atiya *et al.*, NIM **A321**, 129 (1992).

[69] M. Burke *et al.*, IEEE Trans. Nucl. Sci. **NS–41**, 131 (1994).

[70] C. Witzig and S. Adler, Real-Time Comput. Appl., 123 (1993).

[71] S.S. Adler, Inter. Conf. Electr. Part. Phys., 133 (1997).

[72] C. Zein *et al.*, Real-Time Comput. Appl., 103 (1993).

[73] S.S. Adler *et al.*, to be submitted to IEEE.

[74] J. Sandberg and T. Roser, private communication.

[75] P. Pile and I-H. Chiang, private communication.

[76] M.S. Atiya *et al.*, Phys. Rev. Lett. **64**, 21 (1990).

[77] M.S. Atiya *et al.*, Nucl. Phys. **A527**, 727c (1991).

[78] M.S. Atiya *et al.*, Phys. Rev. Lett. **70**, 2521 (1993).

[79] S. Adler *et al.*, Phys. Rev. Lett. **76**, 1421 (1996).

[80] Y. Asano *et al.*, Phys. Lett. **107B**, 159 (1981).

[81] G.D. Cable *et al.*, Phys. Rev. **D8**, 3807 (1973).

[82] J.H. Klems *et al.*, Phys.Rev.Lett. **25**, 473 (1970); Phys. Rev. **D4**, 66 (1971).

[83] A.J. Buras, hep-ph/9806471, TUM-HEP-316-98, June 1998.

[84] C. Bernard, *Heavy Flavor Physics: Proceedings*, C. Campagnari, ed., Singapore World Scientific, 1999, 29 hep-ph/9709460.