ORKA
Executive Summary
September 20, 2013

A high precision measurement of the ultra-rare $K^+ \to \pi^+ \nu\bar{\nu}$ decay at Fermilab would be one of the most incisive probes of quark flavor physics this decade. Its dramatic reach for uncovering new physics is due to several important factors:

1. The branching ratio is sensitive to many new physics models which extend the Standard Model to solve its considerable problems. Figure 1 shows a plot of the branching ratios of $K_L^0 \to \pi^0 \nu\bar{\nu}$ vs. $K^+ \to \pi^+ \nu\bar{\nu}$ in various new physics models. These rare K decays are potentially sensitive to new physics effects not accessible by other reactions.

2. The Standard Model predictions for the $K^+ \to \pi^+ \nu\bar{\nu}$ and $K_L^0 \to \pi^0 \nu\bar{\nu}$ branching fractions are broadly recognized to be theoretically robust at the 5% level. Only a precious few accessible loop-dominated quark processes can be predicted with this level of certainty.

3. The $K^+ \to \pi^+ \nu\bar{\nu}$ branching fraction is highly suppressed in the Standard Model to the level 10^{-10} .This suppression allows physics beyond the Standard Model to contribute dramatically to the branching fraction with enhancements of up to factors of five above the Standard Model level.

4. The certainty with which the Standard Model contribution to $K^+ \to \pi^+ \nu\bar{\nu}$ can be predicted will permit a 5σ discovery potential for new physics for enhancements of the branching fraction as small as 35%.

This sensitivity is unique in quark flavor physics and allows probing of essentially all models of new physics that couple to quarks within the reach of the LHC. Furthermore, a high precision measurement of $K^+ \to \pi^+ \nu\bar{\nu}$ is sensitive to many models of new physics with mass scales well beyond the direct reach of the LHC. If the LHC discovers new physics, $K^+ \to \pi^+ \nu\bar{\nu}$ and a few other cleanly interpretable processes will be essential for deciphering the flavor structure of the new effects. If no new physics is evident at the LHC, $K^+ \to \pi^+ \nu\bar{\nu}$ will extend the indirect search for higher mass scales.

The experimental challenge of suppressing backgrounds to enable measurement of $K^+ \to \pi^+ \nu\bar{\nu}$ at the 1 in 10 billion Standard Model rate has been met successfully. Several events of $K^+ \to \pi^+ \nu\bar{\nu}$ decay were clearly observed at BNL by using a carefully refined technique involving stopped low-energy kaons. The Fermilab Main Injector (MI) accelerator, running at about 95 GeV with a moderate duty factor to produce kaons, presents an outstanding opportunity to extend this approach by two orders of magnitude in sensitivity. The first order of magnitude improvement comes from the substantially brighter source of very low energy kaons, and the second arises from incremental improvements to the experimental techniques firmly established at BNL. ORKA shown schematically in figure 2 will use the CDF super-conducting magnet; the CDF hall is currently being prepared to allow installation of the experiment. ORKA will yield 1000 events at the SM level or a precision of <5% for the $K^+ \to \pi^+ \nu\bar{\nu}$ branching ratio measurement; this is comparable to the uncertainty of the Standard Model prediction and therefore represents the maximum reach for clearly revealing new physics with this process. ORKA will also study other important rare kaon and pion decays listed in table 1.

Although other measurements of $K \to \pi\nu\bar{\nu}$ are being initiated, ORKA will attain orders of magnitude higher sensitivity. At CERN, NA62 proposes to acquire O(100) events of $K^+ \to \pi^+\nu\bar{\nu}$ using 75 GeV kaon decay-in-flight, a new approach in this field. NA62 will begin after the current CERN shutdown ends. At JPARC, the KOTO experiment is aiming for sensitivity comparable to a few events of $K_L^0 \to \pi^0\nu\bar{\nu}$ at the SM level. If these experiments uncover deviations from the SM, ORKA will be ready to study the effects with $K^+ \to \pi^+\nu\bar{\nu}$ in much higher precision enabling, for instance, detailed study of the pion spectrum. If no new physics is indicated, ORKA will proceed to explore the possibilities of new physics with the ultimate sensitivity comparable to the SM precision. Opportunities for ORKA to attain even higher precision would be made possible by the advent of Project X and ORKA will represent an important training platform for future leaders in this field.

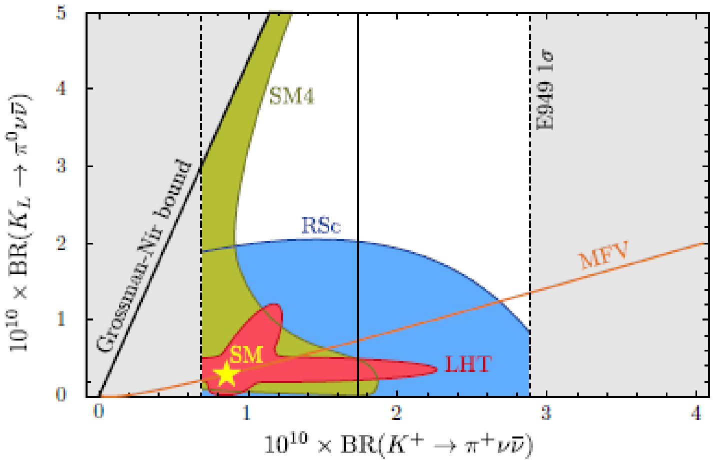


Figure 1: Predictions of different physics models for the branching ratios of the charged and neutral versions of $K \to \pi\nu\bar{\nu}$ .The SM prediction is indicated by a yellow star. The gray regions indicate the 68% CL limits from the BNL E787/949 experiments, and the exclusion from the Grossman-Nir bound. The orange line indicates the tight constraint of minimal flavor violation. (Other models predict similarly strong correlations between the two modes.) The red lobes show the region preferred by the Littlest Higgs model with T parity (LHT); the blue shoulder shows the region preferred by the Randall-Sundrum model with custodial protection (RSc); and the olive-green boomerang shows the region preferred by the Standard Model with a fourth sequential generation (SM4). The MSSM (with pre-LHC limits) populates most of the rest of the experimentally allowed region. (See references in the ORKA proposal.)

The ORKA collaboration (see fig. 3) consists of 60 collaborators representing 16 international institutions including five US universities, BNL, and FNAL. The ORKA proposal (P1021) was given Stage One approval by the Fermilab Director in December 2011. Recently, ORKA conducted a detailed cost evaluation indicating a base cost of $50M. In addition, modest scale

AIP projects relating to the beams would be required. The collaboration has identified several short term R&D issues related to detector and system technology including the use of multi-pixel photon counters, data acquisition systems, and extruded scintillators. The DOE OHEP subsequently initiated an R&D project funding several US institutions for ORKA R&D and indicated that CD0 could be realized as early as FY16.

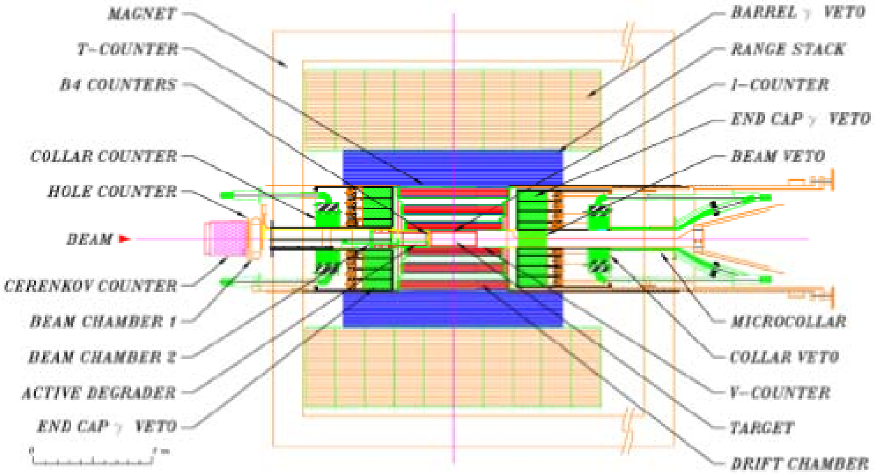
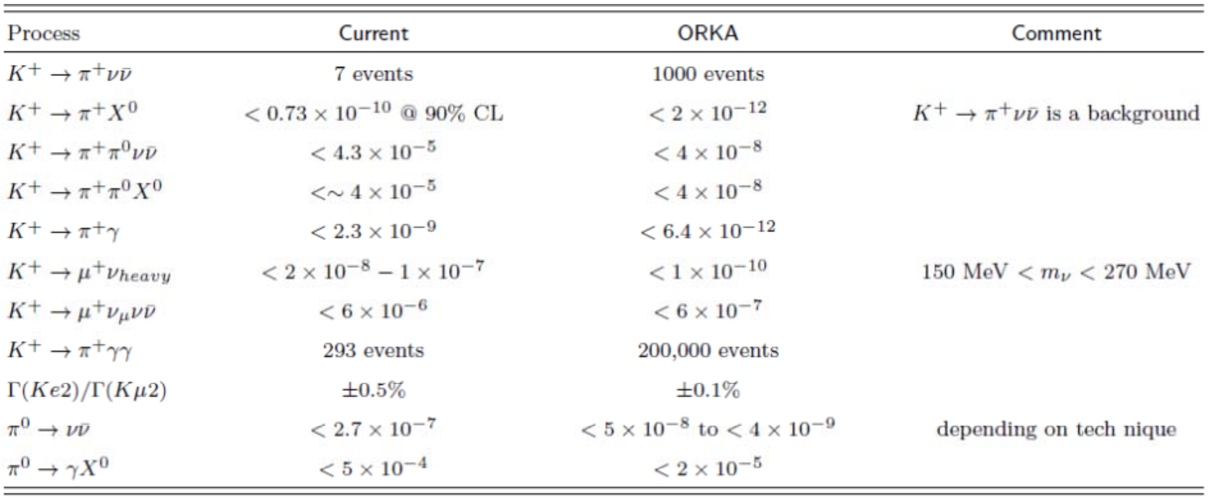


Figure 2: Elevation view of the proposed ORKA detector. The 600 MeV/c separtated K beam enters from the left. Several key components are labeled. The experiment will be contained within the CDF magnet.



Process	Current	ORKA	Comment
$K^+ \to \pi^+ \nu\bar{\nu}$	7 events	1000 events	
$K^+ \to \pi^+ X^0$	$< 0.73 \times 10^{-10}$ @ 90% CL	$< 2 \times 10^{-12}$	$K^+ \to \pi^+ \nu\bar{\nu}$ is a background
$K^+ \to \pi^+ \pi^0 \nu\bar{\nu}$	$< 4.3 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \to \pi^+ \pi^0 X^0$	$<\sim 4 \times 10^{-5}$	$< 4 \times 10^{-8}$	
$K^+ \to \pi^+ \gamma$	$< 2.3 \times 10^{-9}$	$< 6.4 \times 10^{-12}$	
$K^+ \to \mu^+ \nu_{heavy}$	$< 2 \times 10^{-8} - 1 \times 10^{-7}$	$< 1 \times 10^{-10}$	150 MeV $< m_\nu <$ 270 MeV
$K^+ \to \mu^+ \nu_\mu \nu\bar{\nu}$	$< 6 \times 10^{-6}$	$< 6 \times 10^{-7}$	
$K^+ \to \pi^+ \gamma\gamma$	293 events	200,000 events	
$\Gamma(Ke2)/\Gamma(K\mu2)$	±0.5%	±0.1%	
$\pi^0 \to \nu\bar{\nu}$	$< 2.7 \times 10^{-7}$	$< 5 \times 10^{-8}$ to $< 4 \times 10^{-9}$	depending on tech nique
$\pi^0 \to \gamma X^0$	$< 5 \times 10^{-4}$	$< 2 \times 10^{-5}$	

Table 1. Examples of physics processes accessible to ORKA.

Figure 3. ORKA Institutions.