CP Violation in the rare decay $K_L^0 \to \pi^0 \nu \bar{\nu}$

J-Parc Experiment E14 Collaboration
Submitted by J. R. Comfort, Arizona State University

The discovery of CP violation in neutral kaon decays in 1964 has led to considerable theoretical and experimental efforts to understand its origin. This violation is believe to be responsible for the very large matter/antimatter asymmetry in the universe. A small degree of CP violation is incorporated in the Standard Model (SM) through the parameter η in the CKM matrix. Numerous other possibilities have also been proposed, many of which involve new physics beyond the Standard Maodel.

CP violation continues to have intense interest, primarily with experiments in the B sector. However, the matrix elements for the rare kaon decays $K^+ \to \pi^+ \nu \bar{\nu}$ and $K^+ \to \pi^+ \nu \bar{\nu}$ are believed to have the smallest theoretical uncertainties. The branching ratio for the latter decay is considered to be the single most incisive measurement in the study of CP violation in the quark sector, because it provides a direct measure of the η parameter in the SM and the theoretical uncertainties are extremely small. The decay rate is directly proportional to η^2, and provides a direct measurement of the height of the CKM unitarity triangle. The SM estimate for the branching ratio is $(3.1 \pm 1.3) \times 10^{-11}$. Several models involving new physics yield larger values between the SM estimate and the Grossman-Nir limit of 1.4×10^{-9}. The current experimental upper limit, from a preliminary analysis of a portion of the data from the E391a experiment at KEK, is $< 2.1 \times 10^{-7}$.

Prior to its cancellation, the KOPIO collaboration at BNL was preparing to mount an experiment to measure the branching ratio. The decay remains an important one to study because of its very high discovery potential. The experiments in the B sector are primarily sensitive to the angles of the unitarity triangle, while the K_L^0 decay measures its size. The K_L^0 decay and the B system provide complementary information on the underlying contributions (matrix elements and diagrams) involved in the processes. Sensitivity to new physics beyond the SM can come, for example, from either the K_L^0 decay rate itself or from clear inconsistencies between the two unitary triangles constructed from B physics or kaon decays. Indeed such discrepancies might be the only indications of new physics available in the area of quark flavor physics.

The very small branching ratio, the neutral nature of the final state, and the very large competing backgrounds make an experiment very challenging. The signal for the K_L^0 decay is detection of exactly two photons with an invariant mass of a π^0, and nothing else. Kinematic constraints are applied to ensure that the π^0 comes from a K_L^0. The primary background decay mode of concern is $K_L^0 \to \pi^0 \pi^0$, with a $\sim 0.1\%$ branching ratio. Other backgrounds come for additional decay modes, including hadronic interactions of the products of these decays, or from neutrons in the beam. The photon detection efficiency of the components of the detector must also be thoroughly understood.

The KEK E391a experiment has completed data acquisition, but it will not achieve the necessary sensitivity. A new experiment to measure the branching ratio was very recently proposed and approved with high priority as a 'Day 1' experiment at the J-Parc laboratory. It is planned to have two stages. In the first phase, the E391a detector will be modified for much higher sensitivity at J-Parc. The goal is to make the first observation of the decay, and obtain about 3.5 SM events. In the second stage, the beam line and the detector will be upgraded, and the expectation is to obtain more than 100 SM events with a S/N ratio of 4.8. Equipment preparation for experiment E14 has begun. Most of the installation will occur during 2008, with shake-down and tune-up in 2009. Data acquisition for the first phase will begin in 2010 and can last up to 3 years. The second phase will require a new beam line.