Measuring $K^+ \to \pi^+ \nu\bar{\nu}$ at Fermilab

D. Bryman, R. Tschirhart for the P996 Collaboration

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A reexamination of the operating conditions for proposed Experiment P996 has led to the conclusion that a sensitivity of 1000 Standard Model events of the rare decay $K^+ \to \pi^+ \nu\bar{\nu}$ can be achieved using the Fermilab Main Injector beam. This is a goal strongly endorsed by P5 and HEPAP.

Operating P996 with the Main Injector

P996 originally proposed operation of the Tevatron as a stretcher for Main Injector (MI) injected beams in order to achieve optimum high duty factor conditions for the measurement of $K^+ \to \pi^+ \nu\bar{\nu}$**.** A more cost-effective approach involves kaon production driven directly from the MI which was designed to sustain up to a 33% slow-spill fraction at 150 GeV. The MI can flexibly interlace fast (NuMI) cycles with slow-spill cycles. For instance, a 6-second "flat-top" slow-extraction spill could be interlaced with 8 NuMI pulses in a 24-second cycle. This scenario would provide an average beam power of 40 kW to P996 with a 33% duty factor (d.f.) (120kW instantaneous power). In this scenario 33% of the MI time-line would be used, starting after 2-3 years of nominal NOvA running which mitigates the impact on NOvA sensitivity as a function of time. Eventual P996 operations with the Main Injector would directly benefit the 8 GeV program, which could receive additional Booster beam during the MI slow spill. Assuming a constant MI time-line fraction, the MI beam intensity, energy, and duty factor can be further optimized to obtain the most favorable operating conditions for slow spill operation of P996.

Similarly, the choice of kaon momentum for P996 can be further optimized. For example, the fraction of the incident kaon beam that stops in the experimental target is higher for lower beam momentum (e.g. p_k= 550 MeV/c compared to 710 MeV/c as in E949) reducing the instantaneous rates in the experiment due to extraneous processes. However, at lower momentum, a larger fraction of kaons is lost in transport due to the 12 ns lifetime.

A preliminary optimization of the beam conditions appears to favor the MI running at 125 GeV with a 40% d.f. using p_k =600 MeV/c. With these conditions, a 7 year run of the experiment would yield 1000 $K^+ \to \pi^+ \nu\bar{\nu}$ events at the SM level**,** and the $K^+ \to \pi^+ \nu\bar{\nu}$ branching ratio would be measured with precision of <3.7%. At this level, all the many approaches to non-SM physics predicted for $K^+ \to \pi^+ \nu\bar{\nu}$ will be explored at the level of the SM theoretical uncertainty opening the possibility of a major discovery. If initiated promptly, P996 would compete

very favorably with CERN NA-62 slated to begin in 2013-14 aiming at 40 events per year using a new untested technique. .

A staged approach to measuring $K^+ \to \pi^+ \nu \bar{\nu}$ culminating at Project X

P996 would be a natural Day-1 experiment at Project X due to the solid physics case and the well established technique which would undergo further refinement. By operating P996 for some period prior to the inception of Project X beams e.g. 1-3 years using the MI beam, the fully debugged experiment with possible improvements (based on initial running) would be capable of producing a substantial physics result very early in the lifetime of Project X, if it is initiated on a compatible time scale. We estimate that a sensitivity of approximately 340 events/yr at the SM level would be achieved with the Project X beam power. The growing national and international interest in P996 would spur the development of a Project X kaon community and open the door for early development of the neutral K channel measurement of $K_L^0 \to \pi^0 \nu \bar{\nu}$ which is sensitive to additional new physics effects, particularly in the CP violating sphere. We estimate that approximately 200 SM level events/yr could be achieved for $K_L^0 \to \pi^0 \nu \bar{\nu}$ which would share the production target with P996 at Project X.

Driving P996 with the Main Injector would represent an incisive first stage of the experiment with 1000-event sensitivity. As such P996 would be a relatively low-cost "Day-1" experiment in the Project-X research program. The current P996 experiment total project cost (TPC) estimate presented to OHEP on March 12th 2010 is $40M then-year dollars with the experiment located in the CDF collision hall. Adjusting this then-year TPC to include beam transport from the Main Injector (F0) to the CDF collision hall (B0), and removing Tevatron stretcher capital costs from the TPC reduces the P996 then-year cost estimate to less than $50M. It is also possible to site the experiment in the KTeV/Seaquest hall following operation of the Seaquest experiment which currently is driven by slow-extracted MI beam. When Project X beams and experimental areas and targets are ready, P996 could then be relocated to the Project-X 3 GeV campus.