Expression of Interest

Charged Kaons at the Main-Injector

An Experiment to Measure $K^+ \to \pi^+ \nu \bar{\nu}$

Peter S. Cooper, Michael B. Crisler, Robert S. Tschirhart
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

Jack L. Ritchie
University of Texas at Austin
Austin, Texas 78712

April 4, 1996

Summary

We are studying the feasibility of an experiment to measure the branching ratio of the rare decay $K^+ \to \pi^+ \nu \nu$ at the Main Injector. Our design goals are:

1. To be able to observe approximately 100 events for a 1×10^{-10} branching ratio in two years of running with the Main Injector,
2. to reduce all backgrounds to the level of a few events, and
3. to limit capital costs to less than 10M$.

A measurement of the rate of the rare kaon decay $K^+ \to \pi^+ \nu \bar{\nu}$ constitutes a direct and theoretically clean measurement of the magnitude of the V_{td} CKM matrix element. We are currently focusing on a high rate decay in flight experiment built around PMT based RICH detectors. We hope to be able to submit a proposal in the fall of this year, provided that we are convinced that our design goals can be substantially met.

Introduction

A measurement of $B(K^+ \to \pi^+ \nu \bar{\nu})$ with sufficient statistics to be limited by theoretical uncertainties would, by itself, put significant constraints on the remaining unknown parameters of the standard model. In combination with another independent measurement of the unknown CKM parameters ρ and η both the real and imaginary parts of V_{td} would be determined to within a quadratic ambiguity. This would conclusively resolve whether some, all or none of the CP violation observed in the neutral kaon system is the result of the standard model.

We are also studying the possibility of using the same apparatus to observe CP violation in the τ decay mode of the charge kaon ($K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$) through the rate asymmetry across the Dalitz plot between K^{+} and K^{-} decays. The branching ratio for $K^{+} \rightarrow \pi^{+}\nu\nu$ is sensitive mainly to ρ while the asymmetry in $K_{\tau}^{\pm}$ decay is sensitive mainly to η.

Were these measurements to be successfully completed in the first round of experiments at the Fermilab Main Injector we would have an independent determination of the parameters of the CKM matrix from the kaon system at a time just before the planned Fermilab Collider and B factory experiments could yield complementary results from the B system. A stronger test of the hypothesis that all CP violation is due to the phase in the CKM matrix is hard to imagine. We will discuss the $K^{+} \rightarrow \pi^{+}\nu\nu$ measurement here in order to illustrate the ideas. The $K_{\tau}^{\pm}$ decay asymmetry measurement has not been sufficiently well developed at this time.

Theory

The branching ratio for the $K^{+} \rightarrow \pi^{+}\nu\bar{\nu}$ decay was first calculated by Inami and Lim [1], as an isospin rotation from K_{e3} ($K^{+} \rightarrow \pi^{0}e^{+}\nu$) decay. The result of that calculation using the Wolfenstein parameterization of the Cabibbo Kobayashi Maskawa (CKM) matrix [2] , $V_{us} = \lambda = 0.2205(18)$ [3], A = 0.82(10) [3], and present values for the charmed and top quark masses; 1.3 (3)[GeV] [3], and 174(16) [GeV] [3], respectively is:

$$B(K^{+} \rightarrow \pi^{+}\nu\bar{\nu}) = [(0.52 \pm 0.14) \times 10^{-10}]\left[(1.30-\rho)^{2} + \eta^{2}\right]$$

The QCD and long distance corrections for this decay are well calculated and relatively small [4-7]. A measurement of $B(K^{+} \rightarrow \pi^{+}\nu\nu)$ defines an annulus in the (ρ,η) plane centered about the point

$(\rho,\eta)=(1.30, 0)$. The shift of the center from $\rho=1$ is due to the contribution of the charmed quark to the decay. If $B(K^+\rightarrow \pi^+\nu\nu)$ is measured to 10% with 100 events then the radius of the annulus is statistically determined to 5%. Such a measurement yields ρ with a precision of ±18% dominated by the present experimental uncertainties in the other Standard Model parameters.

Beam and Apparatus

The present upper limit for the branching ratio of $K^+\rightarrow \pi^+\nu\bar{\nu}$ is $<2.4 \times 10^{-9}$ at 90% CL [8]. This result is from the E787 experiment at Brookhaven which is the only one actively searching for this decay at this time. E787 is a stopped kaon experiment with an overall acceptance of 0.55% for the $K^+\rightarrow \pi^+\nu\nu$ decay mode [8]. The E787 experimenters have improved both their acceptance and rate capability. They project a sensitivity of 5×10^{-11} by 1998.

The experimental situation dictates a much higher kaon decay rate. We believe this requires a decay in flight experiment with the minimum of material in the beam to reduce backgrounds from interactions. To achieve the 100 event level of sensitivity will require three orders of magnitude higher kaon decay rate at the same acceptance. A beam with ~10 MHz of decaying kaons will require a detector system with resolving times much less than 100 nsec and very high rate capabilities. The acceptance can be improved, thus lowering the rate required, by going to a high energy beam where the Lorentz boost folds the kaon decay products into a small forward cone. The major drawback in a decay in flight experiment is that the kaon as well as the pion must be identified and momentum analyzed with high precision. Similar experiments have been done in the past [9] and discussed for this decay mode in workshop studies [10]. In these cases the spectrometers are conventional magnetic spectrometers with either proportional wire chambers or drift chambers for charged particle tracking.

We are considering an apparatus which does the job of momentum measurement and particle identification for both the kaon and decay pion with a two low mass detectors; a pair of phototube ring imaging Cerenkov counters (RICH). These detectors would be based upon the experience gained with the phototube RICH in SELEX [11]. The other important detector systems are photon vetoes which can reject kaon decays with π°s at the 10^{-6} level. This estimate is based upon the KTEV photon veto design. Assuming the 4.7% acceptance given by a simple Monte Carlo simulation with basic sample defining cuts and Br = 1×10^{-10} the sensitivity is 150 events with missing neutral mass below M_{π° in 10^7 live seconds of beam. The cuts required to reduce the $K\pi 2$ background to the few event level retain about half of these events.

This measurement requires a high flux [>300 MHz] unseparated beam near 22 GeV/c . The rate of kaon decays, pion decays and interactions in the decay volume would each be about 3 MHz. Such a beam can be easily produced with 120 GeV/c protons from the Main Injector. We require the Main injector proton beam to be debunched so that accidental backgrounds are minimized. Accidentals are the largest potential source of background after $K\pi 2$ decays.

The work required to move from this stage to a full proposal is a more complete study of potential backgrounds from interactions, accidentals and decays. We have begun a full GEANT detector simulation. However, owing to on-going commitments to other fixed target experiments (SELEX, KTEV and BNL E871) we do not expect to complete this study until the fall.

Conclusion

While considerable work is required to demonstrate the feasibility of this experiment it is important to explore the full potential for experiments at the Main Injector. The prospect of cost-effective fixed target experiments running in parallel with the Collider program is a major attraction. BNL experiment 787 is expected to make a first observation of this decay mode by 1998. We do not believe that the BNL stopped kaon technique can be pushed to the sensitivity which is our design goal. The schedule we envision calls for tests and some engineering data for the detector in 1999, early in the life of the Main Injector. Physics running would take place in 2000 and 2001.

References

1. T. Inami and C.S. Lim, Prog.Theor. Phys. **65** (1981) 297.
2. L. Wolfenstein, PRL **51** (1983) 1945.
3. Particle Data Group: Phys. Rev. D **50**,1173 (1994).
4. J. Ellis and J.S.Hagelin, Physics Letters B **192** (1983) 201.

5. D. Rein and L.M. Sehgal, Phys. Rev. D **31** (1989) 3325.
6. G. Buchalla and A.J. Buras, Physics Letters B **333** (1994) 221.
7. G. Buchalla and A.J. Buras, Nuclear Physics B **412** (1994) 106.
8. Search for the Decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, S. Adler, et.al., PRL **76**,1421(1996), M.S. Atiya, et.al., PRL **70**,2521(1993), M.S. Atiya, et.al., NIM **A321**,129(1992), M.S. Atiya, et.al., Nucl. Phys. **A527**,727(1991), M.S. Atiya, et.al., PRL **64**,21(1990).
9. N.J. Baker, et.al., PRL 59,2382 (1987), *A Search for the Decay $K^+ \rightarrow \pi^+ \mu^+ e^-$*, C. Campagnari, et.al., PRL 61,2062 (1988), *An Improved Limit on the Branching Ration of $K^+ \rightarrow \pi^+ \mu^+ e^-$*, A.M. Lee, et.al., PRL **64**,165(1990), C. Alliegro, et.al., PRL 68,278 (1992)
10. *Report of the Working Group on K^+ Decay in Flight*, HS Collins, et.al., in the Proceedings of the Workshop on Physics at the Main Injector, S. Holmes and B. Winstein, Ed., Fermilab,p93, 1989.
11. *A Phototube RICH Detector*, By M. Pommot Maia .et.al. NIM **A326**(1993)496.