International Journal of Modern Physics A

E865 RESULT: AN IMPROVED UPPER LIMIT ON THE DECAY $K^+ \to \pi^+\mu^+e^-$

ALEKSEY SHER for E865 collaboration

TRIUMF, 4004 Wesbrook Mall,
Vancouver, BC V6T2A3, Canada

Received (31 October 2004)
Revised (Day Month Year)

Based on results of a search for the lepton-family-number-violating decay $K^+ \to \pi^+\mu^+e^-$ with data collected by experiment E865 in 1998 at the Alternating Gradient Synchrotron of Brookhaven National Laboratory we report an upper limit on the branching ratio at 2.2×10^{-11} (90% C.L.). In combination with results based on the data collected in 1995, 1996, and a previous experiment, E777, an upper limit on the branching ratio of 1.2×10^{-11} (90% C.L.) is obtained.

Keywords: Lepton Flavor Violation; Rare K^+ decays

1. Introduction

The lepton-family-number-violating (LFNV) decays are strictly forbidden in the Standard Model (SM) with massless neutrinos. However, extensions of the SM such as Extended Gauge theories[1,2], Technicolor[3] and Supersymmetry[4] do allow LFNV processes. Moreover, because of the growing evidence for the lepton family transformations in the neutrino sector[5], even the SM, extended to incorporate massive neutrinos, predicts LFNV kaon decays at an unobservably low level[6]. Thus, an observation of a LFNV process like the decay $K^+ \to \pi^+\mu^+e^-$ ($K_{\pi\mu e}$) would serve as a clear indication of physics beyond the SM. A null search result, on the other hand, can put constrains on the parameters of the existing extension models, that allow LFNV, or even rule them out.

We have searched for the $K_{\pi\mu e}$ decay based on data recorded with the E865 detector at the Alternating Gradient Synchrotron (AGS) of Brookhaven National Laboratory.

2. E865 Detector

E865 detector, extensively discussed elsewhere[7], is a magnetic spectrometer illuminated by an intense unseparated 6 GeV/c beam of approximately $2{\times}10^8$ K^+, 4×10^9 π^+, and 2×10^9 protons per 2.8 sec AGS spill. Momentum, measured in the spectrometer, was compared with energy deposited in the 600 module 15 r. l. deep

"Shashlyk" calorimeter. Electrons and positrons were identified by two atmospheric pressure threshold Cerenkov counters, filled with hydrogen on the left side of the apparatus and with methane on the right side. A 24 plane proportional tube - iron plate range stack was used to identify muons.

3. Data Analysis

The analysis outlined here is based on data collected during a five month run in 1998. Basic requirements for $K_{\pi\mu e}$ events selection included the presence of a reconstructed three-charged-track vertex within the decay region of the acceptable quality. The invariant mass $M_{\pi\mu e}$, calculated using the daughter particles masses (m_π, m_μ, m_e) and their measured momenta, was required to be consistent with the K^+ mass, within the experimental resolution. Finally we required an unambiguous identification of e^-, π^+ and μ^+.

Backgrounds for $K_{\pi\mu e}$ were classified into two types. The first type consisted of rather common K^+ decays. The $K^+ \to \pi^+\pi^+\pi^-$ (K_τ) decay would mimic the $K_{\pi\mu e}$ if a π^- was misidentified as e^- and π^+ was either misidentified as μ^+ or underwent an in-flight decay ($\pi^+ \to \mu^+\nu$). Another background of this type was caused by kaon decays: $K^+ \to \pi^0\pi^+$, with a π^+ misidentified as μ^+, and $K^+ \to \pi^0\mu^+\nu$, Both decays would mimic $K_{\pi\mu e}$ if the π^0 underwent a Dalitz decay ($\pi^0 \to e^+e^-\gamma$) and the e^+ was misidentified as π^+. The suppression of the these type of backgrounds, to the level of (0.1 $\pm$ 0.1) events, was achieved by utilizing an excellent particle identification capability of the E865 detector (P(π^- as e^-)=$(2.4\pm1.4)\times10^{-6}$, P(e^+ as π^+)=$(2.5\pm0.3)\times10^{-6}$). The second type of background consisted of accidental combinations of the π^+, μ^+ and e^- tracks, originating from separate kaon decays, that would satisfy kinematic requirements for $K_{\pi\mu e}$. Such accidental events were usually characterized by uncorrelated track timing and poor kinematic quality. The number of accidental background events was estimated using the number of observed out-of-time $K_{\pi\mu e}$ candidates which otherwise satisfied all $K_{\pi\mu e}$ cuts. To extrapolate such events into the acceptable in-time signal region, the timing distribution of the high momentum ($P > 6.9$ GeV/c) $K_{\pi\mu e}$ candidates was used. From that timing distribution we determined the projection factor R (the ratio between the number of high momentum $K_{\pi\mu e}$ candidates which are in time and the ones which are out of time). The expected level of accidental background in the signal region was determined to be 8.2 ± 1.9 events. Rather than imposing additional or tighter cuts, the likelihood function was chosen to suppress this background. The general $K_{\pi\mu e}$ likelihood was constructed using the kinematic and timing variables which showed the most difference in their response for signal and accidental events.

4. Results and Conslusion

Eight events were observed in the signal region, which was consistent with our background prediction. Examination of the likelihood distribution of the surviving events demonstrate that they are more consistent with the background hypothesis

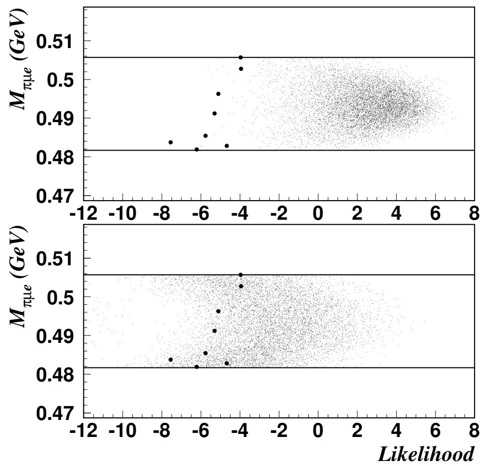

Fig. 1. Scatter plot of $K_{\pi\mu e}$ data (bold dots) and simulated signal(top) and background (bottom). The abscissa is the log-likelihood of the reconstructed events, the ordinate is the invariant mass ($M_{\pi\mu e}$) of the detected particles. The horizontal lines demark the 3σ mass region.

than that for the signal (see Fig. 1). The upper limit on the number of signal events ($N_{sig} < 2.4$ at 90% C.L.) was determined using the Likelihood distribution of observed events and the Bayesian approach [8]. Using the K_τ decay as a normalization mode, the upper limit on the $K_{\pi\mu e}$ branching ratio was set at[9]:

$$B(K^+ \to \pi^+\mu^+e^-) < 2.2 \times 10^{-11} \text{ (90\% C.L.)} \tag{1}$$

Our result can be combined with the previously established upper limit, $B(K_{\pi\mu e}) < 2.8 \times 10^{-11}$ (90 %C.L.) [10], yielding the new upper limit on the $K_{\pi\mu e}$ branching ratio:

$$B(K^+ \to \pi^+\mu^+e^-) < 1.2 \times 10^{-11} \text{ (90\% C.L.)} \tag{2}$$

Although no evidence of new physics was found, the parameter space of the existing extension theories that allow LFNV was reduced.

References

1. R. N. Cahn and H. Harari, Nucl. Phys. B **176**, 135 (1980).
2. O. Shanker, Nucl. Phys. B **185**, 382 (1981).
3. E. Farhi and L. Susskind, Phys. Rept. **74**, 277 (1981).
4. H. E. Haber and G. L. Kane, Phys. Rept. **117**, 75 (1985).
5. A. B. McDonald *et al.* [SNO Collaboration], AIP Conf. Proc. **646**, 43 (2003).
6. P. Langacker, S. Uma Sankar and K. Schilcher, Phys. Rev. D **38**, 2841 (1988).
7. R. Appel ,*et al.*, Nucl. Instr. and Meth. A **479**, 349 (2002).
8. K. Hagiwara *et al.* [Particle Data Group Collaboration], Phys. Rev. D **66** (2002).
9. A.Sher. *An Improved Limit on the Decay* $K^+ \to \pi^+\mu^+e^-$. PhD thesis, Univerisity of Zürich, (2004).
10. R. Appel, *et al.* Phys. Rev. Lett.:**85**, 2450 (2000).