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RARE K^+ DECAYS IN FLIGHT: LATEST RESULTS AND FUTURE PLANS*

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ABSTRACT

E777 at the Brookhaven AGS has published a final branching ratio limit for the lepton family violating decay $K^+ \to \pi^+\mu^+e^-$ of 2.1 x 10^{-10} (90% C.L.). New results based on approximately 500 events of the G.I.M. suppressed decay $K^+ \to \pi^+e^+e^-$ have yielded a branching ratio of $(2.75 \pm 0.23 \pm 0.13)$ x 10^{-7} assuming a vector interaction with, a form factor = $0.105 \pm 0.035 \pm 0.015$. The branching ratio times decay probability for $K^0 \to \pi^+X^0$, $X^0 \to e^+e^-$ was found to be less than 1.5 x 10^{-8} (99% C.L,) in the e^+e^- invariant mass range of 150 to 340 MeV/c. An approved second generation experiment sensitive to $K^+ \to \pi^+\mu^+e^-$ at the 10^{-12} level is discussed.

In addition to achieving a new upper bound on the forbidden decay $K^+ \to \pi^+\mu^+e^-$ [1] and a branching ratio limit of 4.5 x 10^{-7} for the decay process $K^+ \to \pi^+A^0$ where A^0 is any short lived neutral particle of mass less than 100 MeV/c^2 decaying into e^+e^- with lifetime shorter than 10^{-13} sec,[2] E777 has analyzed more than 500 $K^+ \to \pi^+e^+e^-$ decays, which being a flavor changing neutral current transition is rare decay, highly suppressed in the standard model. Although the literature indicates no experimental data beyond a first branching ratio measurement of (2.7 ± 0.5) x 10^{-7} based on 41 events,[3] there have been a number of calculations of the branching ratio and the e^+e^- invariant mass spectrum[4] which have remained untested due to the paucity of experimental data. Once the parameters describing this decay are determined it becomes possible to predict some properties of the decay $K^0_S \to \pi^0e^+e^-$.

The apparatus has been described in detail in the literature.[1] Figure 1 shows a band of $K_{\pi ee}$ events above the π^0 mass. The low mass region is dominated by $K_{\pi 2}$ followed by Dalitz decays, $K^+ \to \pi^+\pi^0$, $\pi^0 \to e^+e^-\gamma$ which has a branching ratio of 2.5 x 10^{-2}. In Fig. 2a, the $M_{\pi ee}$ spectrum of events with M_{ee} above 150 MeV/c^2 is presented with a Monte Carlo simulation of the data added to an estimated background indicated by the shaded region. The estimated background was obtained from the distribution of events within the $M_{\pi ee}$ signal region or 470 MeV/c^2 < $M_{\pi ee}$ < 512 MeV/c^2, whose reconstructed K^+ trajectories do not originate at the production target. The M_{ee} spectrum of events in the signal region with M_{ee} > 150 MeV/c^2 is displayed in Fig. 2b with our

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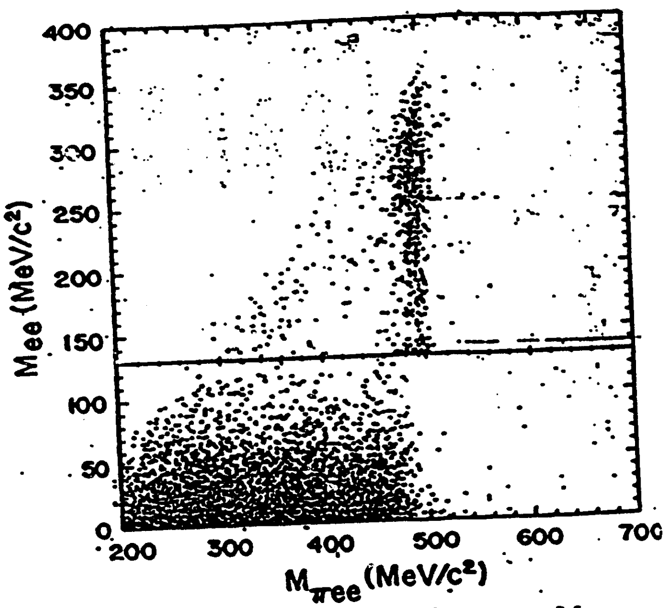


Fig. 1. Scatter plot of the e^+e^- invariant mass, M_{ee}, vs $\pi^+e^+e^-$ invariant mass, $M_{\pi ee}$, for selected events with a π^+, e^+, and e^- in the final state. The number of events with M_{ee} less than 130 MeV/c^2 is scaled down by 140.

simulation of this signal superimposed. The χ^2 per degree of freedom for the fit was 1.1. The simulation used the acceptance of our apparatus and the decay spectrum calculated for a vector interaction neglecting terms of order $(M_e/M_\pi)^2$; $d\Gamma/dM_{ee} = CM_{ee}p^3_\pi\,(1.0 + \lambda M^2_{ee}/M^2_\pi)^2$ where C is a normalization constant, p_π is the pion momentum in the K^+ center of mass frame and λ is a parameter determining the M_{ee} dependence of the form factor for the decay. The simulation was fitted to our data by performing a χ^2 minimization with respect to the branching ratio, B.R., and λ, with the overall normalization given by the Dalitz decays which are well understood and whose distribution is well fitted by our Monte Carlo simulation. Normalizing to the Dalitz decays eliminates most effects arising from uncertainties in detector acceptance and efficiencies. The result of this procedure is given in Fig. 3 where contours of branching ratio vs λ are shown for intervals of χ^2_{min} + n. The resultant values for the branching ratio and λ are B.R. = $(2.75 \pm 0.23 \pm 0.13) \times 10^{-7}$ and $\lambda = 0.105 \pm 0.035 \pm 0.015$). The first uncertainties are statistical and represent the 1σ contours. The second are systematic arising from uncertainties in detector efficiencies, acceptance and the uncertainty in branching ratio times decay probability for Dalitz decays added in quadrature.

It is also useful to fit our data to the parameterization of Ecker, Pich, and de Raphael[5] based on a model employing a chiral Lagrangian. Incorporating our results into their parameterization leads to the prediction of 4.5×10^{-10} as an upper limit on the branching ratio for $K_s^0 \to \pi^0e^+e^-$ which in turn implies a branching ratio of less than 1.6 $\times 10^{-12}$ for $K_L^0 \to \pi^0e^+e^-$ if the decay were to proceed only through the CP violating part of the K^0-$\bar{K}^0$ mass matrix.

We have also searched our data for evidence of a decay $K^+ \to \pi^+X^0$, followed by $X^0 \to e^+e^-$. The result of this analysis is an upper limit on the branching ratio times decay probability of 1.5×10^{-8} (99% C.L.) over an X^0 mass range of 150 to 340 MeV/c^2.

E865 is the successor to E777, with the primary goal of pushing the sensitivity of the search for $K^+ \to \pi^+\mu^+e^-$ to the 3×10^{-12} level. As in E777 we expect to acquire a large sample of $K^+ \to \pi^+e^+e^-$ decays, accumulating some 50,000 in this case. In addition we plan to search for CP violation in the charged kaon sector by searching for asymmetries in $K^\pm \to \pi^\pm \pi^\pm\pi^\mp$ decays. The anticipated factor of 70 improvement in sensitivity over E777 arises from several enhancements based upon the experience gained in the earlier experiment.

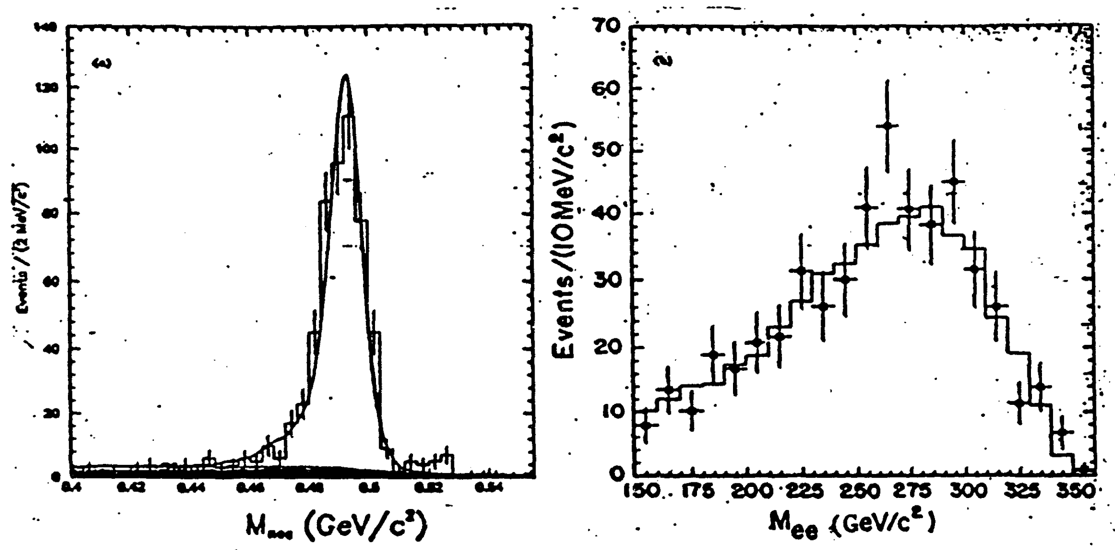
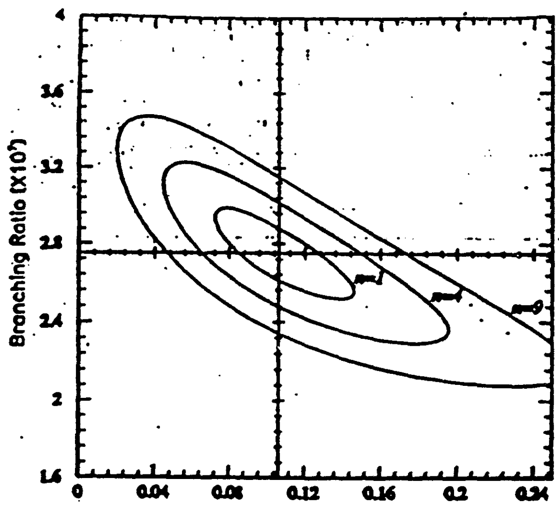


Fig. 2(a) $M_{\pi ee}$ invariant mass distribution for events with $M_{ee} > 150$ MeV/c^2. Histogram, with error bars, is experimental data; solid curve is the result of the Monte Carlo calculation of $K^+_{\pi ee}$ decays; shaded region is the estimated background. 1(b) M_e invariant mass spectrum for high mass events with ($470 < M_{\pi ee} < 512$) MeV/c^2. Solid line is the result of the Monte Carlo Calculation with $\lambda = 0.105$.



Although it is easy to propose improvements to a future experiment, our experience in E777, where we became all too familiar with the problems inherent in making precision measurements in a difficult environment, gives us confidence that we now understand how to deal with them while retaining those features that produced the successes of E777.

Fig. 3. $K^+\pi ee$ branching ratio vs. λ for constant values of χ^2 equal to χ^2_{min} + n, with n as indicated, for a decay hypothesis described in the text.

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