$K^+ \to \pi^+\mu^+\mu^-$ IN E865 AT BNL

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Preliminary values for the $K^+ \to \pi^+\mu^+\mu^-$ branching ratio and form factor are reported, based on 400 events, a factor of 2 more in total events and 100 times the present world sample of fully reconstructed events. The results are consistent with previous results on the $\pi^+e^+e^-$ mode. However, the relatively large slope of the form factor in q^2, $\lambda = 0.182 \pm 0.01 \pm 0.007$, required to fit the $\pi^+e^+e^-$data and to give consistency between the $\pi^+e^+e^-$ and $\pi^+\mu^+\mu^-$ branching ratios, is larger than expected in simple models of the decays. The $K^+ \to \pi^+\mu^+\mu^-$ branching ratio we find, $(9.23 \pm 0.6_{stat} \pm 0.58_{syst.}) \times 10^{-8}$ is the most precise measurement of this mode and is $\approx 3.2\sigma$ larger than the previous measurement. These πll results are inconsistent with $O(p^4)$ Chiral Perturbation Theory but compatible with $O(p^6)$. Systematic studies for both modes are still in progress.

Introduction and Theoretical Background

The primary interest of E865 is the forbidden decay $K^+ \to \pi^+\mu^+e^-$. Results from two independent analyses [3,14] have yielded a limit of 2×10^{-10} for a preliminary 1995 data set, data from 1996 and 1998 has a statistical reach of order 10^{-11}. However, an important by-product of this experiment has been that E865 has significantly increased world sample sizes for several other

K^+ decay modes with 3 charged particles in the final state. (Final states containing a π^0 are included, since the π^0 is detected through $\pi^0 \to \gamma e^+ e^-$). A detailed understanding of the K decays, among them $\pi^+ e^+ e^-$ and $\pi^+ \mu^+ \mu^-$, tests models of the weak interaction and low energy QCD.

The focus of this paper is a new measurement of the branching fraction for $K^+ \to \pi^+ \mu^+ \mu^-$. The previous best measurement, from E787 [1], based on a small number of fully reconstructed events and about 200 partially reconstructed events, is $(5.0 \pm 1.0) \times 10^{-8}$; they did not make a form factor measurement, because of limited acceptance and incomplete event information. With specific assumptions about the form of the interaction (typically, vector, with a linear q^2 dependence, as in Ke3), the expected $\pi^+ \mu^+ \mu^- / \pi^+ e^+ e^-$ ratio can be calculated from the E865 results, and from theory, and compared with the experimental observation. For the $\pi^+ e^+ e^-$ we use the most precise results, a branching fraction of $(2.82 \pm 0.04 \pm 0.15) 10^{-7}$ and λ of $0.182 \pm 0.01 \pm 0.007$, based on our 10000 events [10].

Short distance contributions [11] to $K \to \pi ll$ are only of order 10^{-9}. Long distance contributions [4,12,9,15] come close to the observed $\pi^+ e^+ e^-$ rate and give a $\pi^+ \mu^+ \mu^-$ to $\pi^+ e^+ e^-$ ratio of about 0.22-0.24. Vector and a1 meson dominance [12] is an example of a simple model with a parameter free prediction for the branching fractions but small form factor dependence on q^2, similar to Ke3. Chiral Perturbation theory parameters allow a range of predictions for the form factor. In $O(p^4)$ [8,7], the form factor and its q^2 dependence are tightly correlated with the branching ratio. Using an $O(p^6)$ calculation of an explicit "pion loop term" [6] with a polynomial of the expected Chiral Perturbation behavior at $O(p^6)$ gives additional parameters and flexibility.

The E787 $\pi^+ \mu^+ \mu^- / \pi^+ e^+ e^-$ ratio, 0.18 ± 0.04, is about 1.5 σ below predictions.

Experimental Apparatus

E865 at BNL [13] is a magnetic spectrometer illuminated by an intense unseparated 6 GeV/c beam, of $\approx 10^8 K^+$ and $\approx 2 \times 10^9 \pi^+$ per 1.6 sec AGS pulse. Momentum measured in the spectrometer is compared with energy deposit in the 600 module 15 r.l. deep "Shashlik" calorimeter. Electron and positron identification is done by two threshold Cerenkov counters with H_2 on the left (primarily negative particles) and CH_4 on the right (primarily positive particles). A 24 plane proportional tube - iron plate range stack identifies muons. The $\pi^+ e^+ e^-$ data were taken parasitically in 1995 and 1996, and $\pi^+ \mu^+ \mu^-$ data in a 1997 reduced intensity run.

Event Selection and Analysis

The $\pi^+\mu^+\mu^-$ events are normalized to the $\pi^+\pi^+\pi^-$ final state, with similar kinematics. The trigger for all modes [13] requires three particles in a kinematically plausible configuration in hodoscope counters and the calorimeter. The analysis required: a good reconstructed vertex; reasonable vector momentum; and two electrons or two muons, one negatively charged on the left and one positively charged on the right. For the $\pi^+e^+e^-$ events, Cerenkov counter light is required both in the trigger and in the analysis; and for the $\pi^+\mu^+\mu^-$ events, muon chamber signals were. Cuts in track chisquare help eliminate the primary background for the $\pi^+\mu^+\mu^-$ events, secondary decays ($\pi \to \mu\nu$) from $K^+ \to \pi^+\pi^+\pi^-$.

The information described qualitatively above was combined quantitatively into an "event likelihood". The stability of the branching fraction as a function of event likelihood is shown in the plot on the left in Figure 1, where the quantity R (proportional to the branching fraction) is plotted against the event likelihood cut. R is defined as: $r_\mu/r_{3\pi}$ where $r_{\mu\ (or\ 3\pi)} = Ndata_{\mu(or\ 3\pi)}/Nmc_{mu(or\ 3\pi)}$ and Ndata and Nmc are respectively the accepted data (simulated) events. While R is relatively stable, the number of signal events (not shown because of space constraints) drops from 700 to 200 as the event likelihood moves from -19 to -10. This drop in signal is accompanied by a drop in background to signal from $\approx 40\%$ to $\approx 2\%$, reflecting the large admixture of background at the large negative value of the event likehood, and loss of signal as the event likelihood approaches -10. For our final result, we use an event likelihood cut of -13, which gives ≈ 400 signal events.

The effective mass of the $\pi^+\mu^+\mu^-$ final state is shown in the right hand side of Figure 1. Background from $K^+ \to \pi^+\pi^+\pi^-$, with two pions decaying to muons, is shown by the dark-shaded curve at low effective masses. The systematic error is estimated as $\approx 7\%$, dominated by $\approx 3\%$ from selection criteria and background subtraction, and $\approx 4\%$ from normalization uncertainties.

Results and Discussion

The $\mu\mu$ effective mass distribution (q^2) and the $\cos\theta_{\pi\mu^+}$ distribution (where $\theta_{\pi\mu^+}$ is the angle between the π^+ and μ^+ in the $\mu\mu$ center of mass frame) are not shown but are consistent with a vector interaction in the decay, with a form factor ≈ 0.2, as seen in the $\pi^+e^+e^-$ events [13,10]. Fit contours for the branching fraction and λ (the form factor q^2 dependence) are shown in Figure 2, assuming a linear q^2 dependence as in Ke3. The $\pi^+\mu^+\mu^-$ branching fraction and λ are larger than expected in a simple meson dominance model but agree with expectations from $\pi^+e^+e^-$. Our present understanding is that our πll

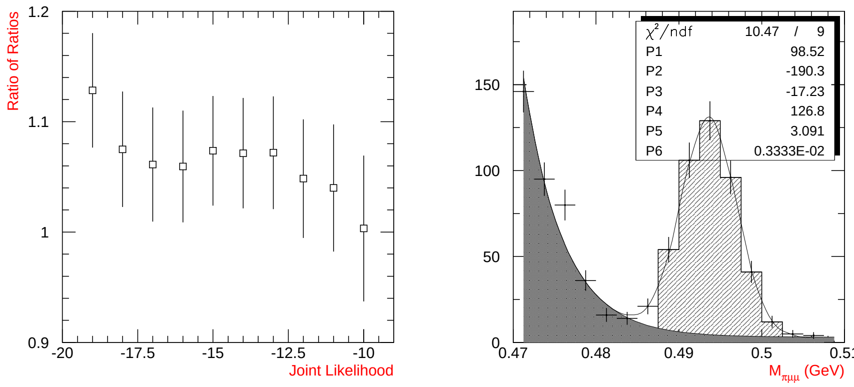

Figure 1: Left: R as a function of the joint likelihood cut, and track χ^2 cut. Right:$\pi^+\mu^+\mu^-$ invariant mass distribution for joint likelihood cut of -13.

data (branching ratios, and q^2 dependence, taken together, Ref. [13,10] and from this paper) are inconsistent with Chiral Perturbation theory at $O(p^4)$ [8,7], but, due to the additional parameters available, are consistent with an $O(p^6)$ calculation [6]. Detailed systematic studies and comparison with Chiral Perturbation theory are in progress.

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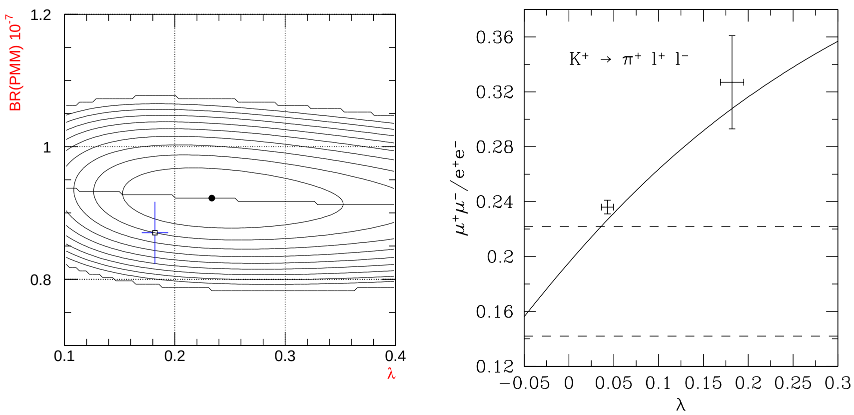

Figure 2: Left: χ^2 contour of Br vs λ. Each contour is one unit of χ^2. The solid point is the χ^2 minimum, and the open point with error bars is the prediction from the $\pi^+e^+e^-$ measurement. Right:Relative branching ratios of the $\pi^+\mu^+\mu^-$ and $\pi^+e^+e^-$ decay modes vs λ, assuming a linear dependence of the form factor on q^2. The previous result is shown as a band, while the point at low λ is from Lichard's meson dominance model, as representative of simple long distance models. The point at high λ is the result presented in this paper, using the λ and the $\pi^+e^+e^-$ branching fraction from the thesis of Scott Eilerts, the most precise determination of these parameters.

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