6 Rare kaon decays

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The 1996 beam period turned out to be quite successful. Data were acquired about a week into the run and no major problems occured during the following 16 weeks. Compared to 1995 the efficiencies were improved for the large multiwire proportional chambers P_3 and P_4, a fourth trigger counter set (D, see Figure 6.1) was installed and the timing tightened at various points. This allowed a reduced trigger and a higher data taking rate giving a sensitivity to the branching ratio for $K^+ \to \pi^+\mu^+e^-$ of about 10^{-11}. In parallel the analysis of the 1995 data with respect to this lepton flavor conservation violating decay progressed. Preliminary results were presented at several conferences [1, 2, 3], and the thesis of Stefan Pislak [4] contains the final result, which we discuss briefly below.

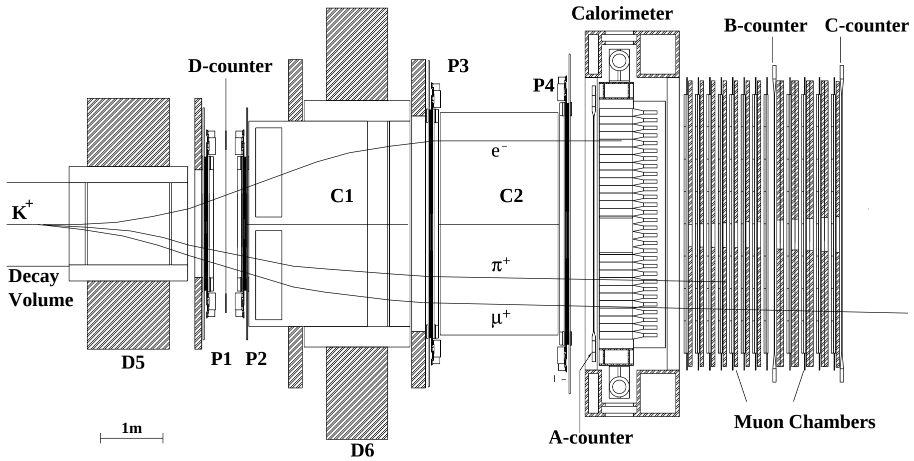

Figure 6.1: Plan view of the E865 detector.

With the beam time granted for 1997 we will examine other rare decays with our broad band K^+ spectrometer. Since we developed a new pixel detector last year for the primary beam we can now look also at decays with missing neutrinos or photons. For example running at about 2/3 of our normal beam intensity we can accumulate ~ 1000 K_{e4} events per hour while still taking $\pi\mu e$ data. We would like to run in this mode for about three weeks, to acquire about 3×10^5 events - ten times the present world's supply. This is an interesting mode with which to study $\pi\pi$ phase shifts and to look for CP violation, albeit not in a way that would be sensitive to standard model physics. We have also shown [2] that we can accumulate two $K^+ \rightarrow \pi^+\mu^+\mu^-$ events per hour with reduced beam, increasing the existing statistical sample by a factor of ten within a week, and sufficient to test of chiral Lagrangian calculations. Further plans aim at remeasuring the branching ratio for K_{e3} as a means of improving our knowledge of the element V_{us} of the CKM-mixing matrix which connects the first and second generation of quarks. A factor of two in accuracy could be gained by comparing K_{e3} to $K_{\pi 2}$ decay.

The 1995 data comprised 200 raw data tapes containing 3×10^6 events each. This is the data volume left after the four hardware trigger levels and the on-line event processor, which checks for correct timing, the presence of a muon candidate and hits in the Čerenkov counters. In the first off-line analysis step we divided the events into four basic classes, namely K_τ candidates (5%), cosmics for calorimeter calibration (15%), five track events (0.5%) and three track events (80%), and applied loose cuts on the reconstructed K^+ momentum ($p < 8$ GeV/c) and the distance of closest approach to a common vertex of each track ($s < 10$ cm). The first pass consumed a lot of computer time and reduced the data to 6×10^7 events. Hits in the proportional chambers are combined to space points and these to tracks, which are then related to energy deposits in the calorimeter. The high particle density (5×10^7 s^{-1} in the spectrometer outside the beam region) generates a large number of possible combinations which have to be scanned to find the final tracks. Though the momentum reconstruction uses a hard edge approximation for the field only it takes about 15 μs per event. The second pass improved the momentum fit for each track using the measured field map and applied particle identification criteria to define four new event classes, those containing a low-mass (1) or a high-mass (2) electron-positron pair, three charged tracks plus two photons with an invariant mass near that of the π^0 (3) and $K_{\pi\mu e}$ candidates (4). Class (4) events (2.1×10^6) have an identified pion, muon and electron with a reconstructed K^+ momentum between 5 and 7 GeV/c. Class (1) contains $K^+ \rightarrow \pi^+\pi^0; \pi^0 \rightarrow e^+e^-\gamma$ (K_{Dal}) events, which are used for normalisation. The particle identification used the signals from the Čerenkov counters, muon detector and calorimeter and compared the track measured track momentum with the energy in the calorimeter. The efficiencies can be determined from the data directly and are well above 90%.

The $K_{\pi\mu e}$ candidates can be attributed to three classes, K_τ events with misidentified pions appearing with a low $\pi\mu e$ invariant mass, K_{Dal} events and accidentials. All these events can be removed in the final analysis step. Here all timing cuts are refined by correcting for energy and position dependence and the momentum reconstruction is optimized by decreasing the stepsize of the integration in the field, recollecting hits and adjusting the alignment. Fiducial volumes for the decay region, the K^+ production target and Čerenkov counter passage are defined, and photon and additional track vetos are implemented. 1555 events survive this selection, nearly all of them have invariant masses around 405 MeV. The signal region is defined in a twodimensional plot of s versus invariant mass M as $s < 2$ cm and $|M - M_K| < 12$ MeV. Figure 6.2 shows that 95 % of the K_τ events are contained within these limits and that the signal region is void of $K_{\pi\mu e}$ events. The observed spatial and mass resolution (σ_M = 2.3 MeV) agree well with Monte Carlo predictions. All events close to the signal region have been inspected and were identified as background events [4].

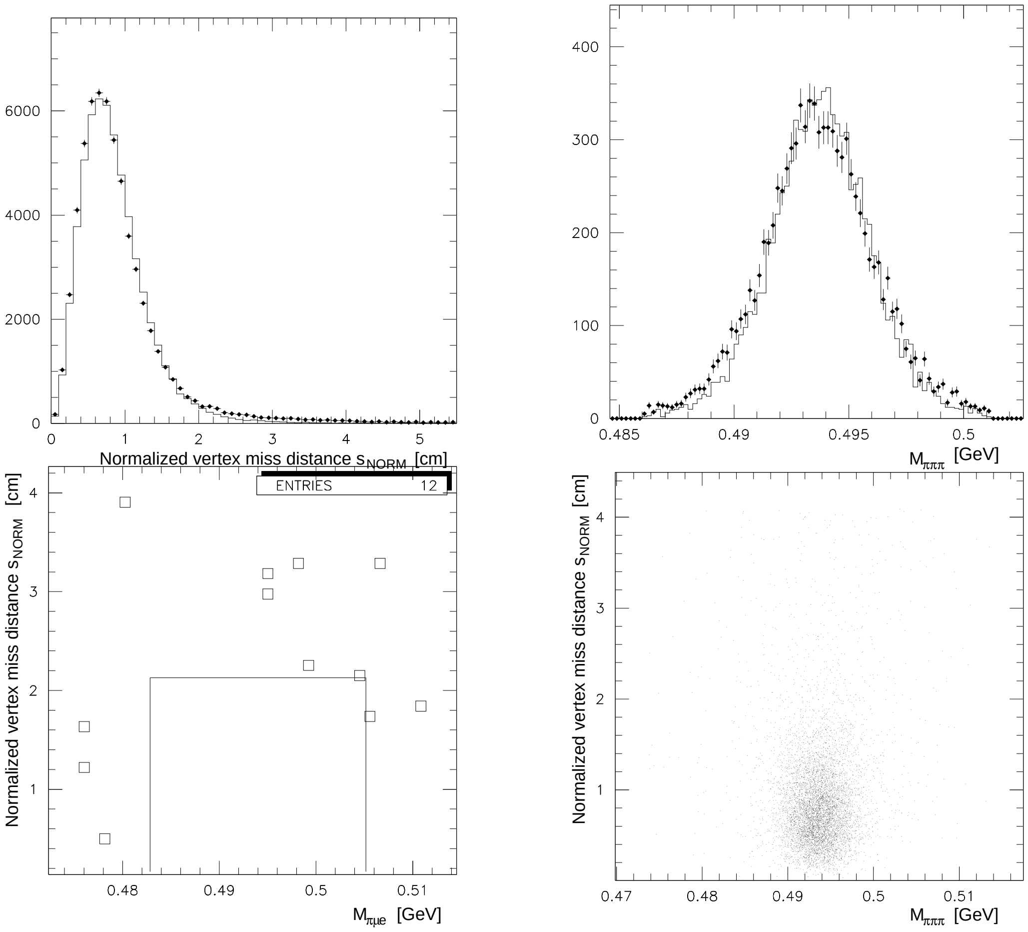

Figure 6.2: Top: Distribution of the distance of closest approach s (left) and of the invariant mass (right) for K_τ events: Monte Carlo (circles) and data (histogram). Bottom: Scatter plot of invariant mass versus s for $K_{\pi\mu e}$ (left) and K_τ (right) events.

For the normalization channel K_{Dal} most of the selection criteria are identical except that no production target cut is applied, since the K^+ reconstruction is incomplete due to the missing photon and obviously no photon veto is used. The reconstructed invariant mass $M_{\pi ee}$ is required to be at least 380 MeV to reduce contaminations from decays with missing neutrino and more than one π^0. The upper limit on $K^+ \to \pi^+\mu^+e^-$ branching ratio is then determined to

$$BR_{\pi\mu e} < BR_{Dal}\frac{N_{\pi\mu e}}{N_{Dal}}\frac{A_{Dal}}{A_{\pi\mu e}}C < 2.0 \times 10^{-10}$$

Here BR_{Dal} denotes the Dalitz-decay branching ratio (2.53×10^{-3}), N_{Dal} the number of observed decays (1.4×10^7), $A_{\pi\mu e}$ (0.0019) and A_{Dal} (0.0065) the acceptances calculated with the help of the Monte Carlo simulation for the two decays, and C (1.39) takes the differences in the event selection into account. For the upper limit quoted one inserts $N_{\pi\mu e} = 2.3$, the 90 % confidence level for a null experiment. This result matches the existing limit [5], and indicates, that no dangerous backgrounds are to be expected for the analysis of the 1996 run with roughly five times as much data.

References

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