OG 1020

XXIV International Conf. on High Energy Physics
Aug. 4-19, 1988 Munich, W. Germany

BNL-41496

CONF-880867--2

Search for the Decay $K^+ \to \pi^+\mu^+e^-$ *

The E777 Collaboration

BNL--41496

DE88 015852

May 31, 1988

M.E. Zeller, C. Alliegro, C. Campagnari, N.J. Hadley, A.M. Lee
Department of Physics, Yale University, New Haven, Connecticut 06511

H.A. Gordon, D.M. Lazarus, P.Rehak
Brookhaven National Laboratory, Upton, New York 11973

P.S. Cooper
Fermi National Laboratory, Batavia, Illinois, 60510

J. Egger, W.D. Herold, H. Kaspar
Paul Sherrer Institute (SIN), CH-5234 Villigen, Switzerland

V. Chaloupka, E.A. Jagel, H.J. Lubatti
Department of Physics, University of Washington, Seattle, Washington 98195

Abstract

A search for the lepton-flavor violating decay $K^+ \to \pi^+\mu^+e^-$ has been performed. Measurements have also been made of the branching ratio and decay particle distributions foe the decay $K^+ \to \pi^+e^+e^-$. A description of the measurement technique, and preliminary results are presented.

The level to which lepton flavor is conserved is one of the outstanding issues in particle physics. While this apparent law has been known since 1961[1], it was in the early 1980's when theoretical models were created to elucidate the mechanisms of spontaneous symmetry breaking[2] that attention to this area was re-stimulated. The decays $K^+ \to \pi^+\mu^+e^-$ and $K^0 \to \mu e$ took on particular interest because these models predicted that such decay modes might occur at rates observable with present technology[3]. We are reporting results of a search for the former mode, $K^+ \to \pi^+\mu^+e^-$. During this experiment we accumulated several hundred events of the mode $K^+ \to \pi^+e^+e^-$ which are also described in this paper.

The experiment, performed at the Brookhaven National Laboratory's Alternating Gradient Synchrotron, employed a two magnet spectrometer system situated in a 6 GeV/c unseperated beam of approximately $5\times10^6 K^+$ and $10^8 \pi^+$ and protons per machine pulse. The detector, previously described in Ref. 4, is shown in Fig. 1. Also shown are the trajectories from a decay $K^+ \to \pi^+\mu^+e^-$ originating from the 5 m long, evacuated decay volume upstream of the magnet M1. This magnet deflected positively charged particles to the right and negatively charged particles to the left for purposes of removing them from the beam region and directing them to the sides of the apparatus specifically designed for the respective particle identification. Momentum measurement was accomplished by the four proportional wire chamber packages, P1-P4, situated around the spectrometer magnet M2. The momentum resolution of this configuration, measured in GeV/c, was $0.01 \times P^2$, where P, the momentum of the decay products, ranged from 0.6 to 5 GeV/c.

Correct particle identification of electrons on the left side of the apparatus and pions and muons on the right was critical in reducing backgrounds. On the left, threshold Cerenkov counters C1L and C2L were filled with Hydrogen gas at atmospheric pressure. For electron detection they had an average yield of 2.2 photoelectrons, while for muon detection their threshold was 6.3 GeV. By measuring their response to particles of known species originating from $K^+ \to \pi^+\pi^+\pi^-$ (τ decays) and $K^+ \to \pi^+\pi^0$, $\pi^0 \to e^+e^-\gamma$ (Dalitz decays) it was determined that the probability of misidentifying a π^- as an e^- by the pair of counters was $< 6 \times 10^{-7}$.

Following the P4 proportional chamber was a Pb-scintillator shower counter[5]. It contained a total of 11 radiation lengths and was segmented vertically in half, horizontally by 24, and longitudinally into three sections. With the pulse height of each cell recorded for each event, the shower evolution for each track could be observed. In the analysis of the data discussed here only the total energy deposited was examined, resulting in the probability for identifying pions as electrons to be <0.14 for momenta ranging from 0.6 to 5. GeV/c.

Particle identification on the right side was performed in a similar fashion, except the Cerenkov counters C1R and C2R contained CO_2 giving them an expected yield of six photoelectrons for electrons, and a threshold of 3.7 GeV/c for muons.

Behind the shower detector on the right side was a muon identifier consisting of eight packages of proportional tubes interspersed between 9 cm thick steel plates. Each package contained one vertically and one horizontally oriented plane of tubes with an effective wire spacing of 0.65 cm. Muons of momentum 0.6 Gev/c, the minimum momentum expected for our decay mode, penetrated the first four plates before reaching the end of their range, while muons with momentum above 1.1 GeV/c passed through the entire array.

Trajectories which yielded no light in C1R and C2R, showed energy consistent with minimum ionization in the shower counter, and had agreement between measured momentum and range were associated with muons. Those which showed no light but stopped before reaching their appropriate range were associated with pions, and those with light in either counter or an appropriate distribution of energy in the shower detector were associated with electrons. Again, quantitative determination of the probabilities of misidentification and efficiencies was made with particles of known identities in the running environment.

For the decay mode $K^+ \to \pi^+\mu^+e^-$ the detector was triggered by a coincidence between two scintillation counters on the right side of the F array behind P4, (this array consisted of 48 counters with the same horizontal segmentation as the shower detector), a potential muon track at least four plates deep into the muon array, and observation of at least 0.4 photoelectrons in both C1L and C2L. For calibration a τ trigger was implemented in which the left side requirement was a single F counter, and the right a pair of F counters. Because of the large number of τ triggers, typically 10^4 per machine pulse, this trigger was pre-scaled by a factor of 8192. A πee trigger was created in which the right side requirement was two F counters in coincidence with both C1R and C2R, and the left side requirement was a C1L, C2L coincidence. This trigger was pre-scaled by a factor of 8. Finally, a high mass πee trigger was constructed which in addition required that the e^+ and e^- be above and below, or below and above, the median plane of the apparatus.

With the these triggers enabled simultaneously, the apparatus was triggered approximately 120 times per machine pulse. The efficiency of the triggers was studied by a series of runs with various trigger elements removed from being required.

Data analysis proceeded in a tiered fashion with successively more stringent kinematic and particle identification requirements imposed at each layer. Potential events were first selected as those which had only one reconstructed track on the left and at least two on the right side of the apparatus. These were required to emanate from a common vertex where the squere root of the sum of the squares of the distances of the tracks, S, to a common point was less than 10 cm. Variables describing the kinematics of the parent particle were calculated, and loose cuts applied to the horizontal and vertical angles and momentum of its trajectory, and to the position of the decay point. Loose cuts were also imposed on the calculated origin of the parent particle at the production target. Particle identification then proceeded as described above.

For all of these cuts, indeed for every stage of the analysis, comparison was made with data from τ decays and from Monte Carlo calculations to yield understanding of efficiencies and possible biases.

With τ events used as a template, distributions of the several quantities described above could be formed. For this purpose the events were required to have S<2.0 cm, unambiguous identification of all three particles as pions, and reconstructed invariant mass as $M_K \pm 10\text{MeV}/c^2$. These distributions were then employed as liklihood functions for the subsequent analysis. For each event the log of the liklihood was calculated as the sum of the logs of the liklihoods of the several parameters. A final cut was made at that value of the log of the liklihood below which 90% of the τ events were accepted.

Our results are displayed as scatter plots of S *vs.* the invariant mass of the reconstructed final state, M. Fig. 2 shows such a plot for τ's with designations of a signal region for both parameters. The corresponding plot for $K^+ \to \pi^+\mu^+e^-$ candidates is shown in Fig. 3. The signal region in M has been expanded to account for the increased Q of this mode compared to τ's. As can be seen, there are no events in the signal region. The nearest event consistent with a good vertex has an invariant mass of 467 MeV/c^2, 4.5 standard deviations from the K^+ mass. Those events with mass near 400 MeV/c^2 are consistent in number and distribution with misidentified τ's and τ's with subsequent decay of one or more pions. Those at higher mass and large S are due to similar processes with decay of secondary products and to random association of tracks in an event.

To compute a limit for the branching ratio of $K^+ \to \pi^+\mu^+e^-$ we normalize to Dalitz decays. This mode was chosen because the trigger requirement of light in C1L and C2L was commmon to it and the $\pi\mu e$ decay. For data obtained in our 1987 run the branching ratio for $K^+ \to \pi^+\mu^+e^-$ was determined to be $< 1.1\times 10^{-9}$ (90%CL). This is an improvement of a factor of 4.4 from the published limit[6]. We have subsequently obtained approximately eight times more data and new results will be forthcoming.

Candidate events for the decay $K^+ \to \pi^+e^+e^-$ underwent a similar analysis and were chosen to be those with correct particle identification and S< 2. cm. For events with ee invariant mass less than 150 MeV/c^2 this sample is dominated by Dalitz decays. We thus show in Fig. 4 the πee invariant mass distribution for events with $M_{ee} > 160$ MeV/c^2. In Fig. 5 we display the M_{ee} distribution for events with $470 < M_{\pi ee} < 515$ MeV/c^2; superimposed are distributions for scalar and vector matrix elements. While the vector is obviously preferred, the fit may be improved using a more complex interaction once the details of the Dalitz plot are studied. The data shown represent approximately half of the complete sample, and further analysis is proceeding.

This research was supported in part by the Department of Energy under contracts No. DE-AC02-76CH000016 and No. DE-AC02-76ER03075, and by the National Science Foundation Grant No. PHY-861 3003.

References

* Contributed paper to the XXIV International Conference on High Energy Physics.

1. G. Feinberg and S. Weinberg, Phys. Rev. Lett. **6**, 381 (1961).
2. L. Suskind, Phys. Rev. **D 20**, 2619 (1978).
3. e. g. S. Dimopoulos and J. Ellis, Nucl. Phys. **B182**, 505 (1981).
4. N. J. Baker *et al.* , Phys. Rev. Lett. **59**, 2832 (1987).
5. G. Abshire *et al.* , Nucl. Inst. and Meth. **164**, 67 (1979).
6. A. M. Daimant-Berger *et al.* , Phys. Lett. **62B**, 485 (1976).

Figure Captions

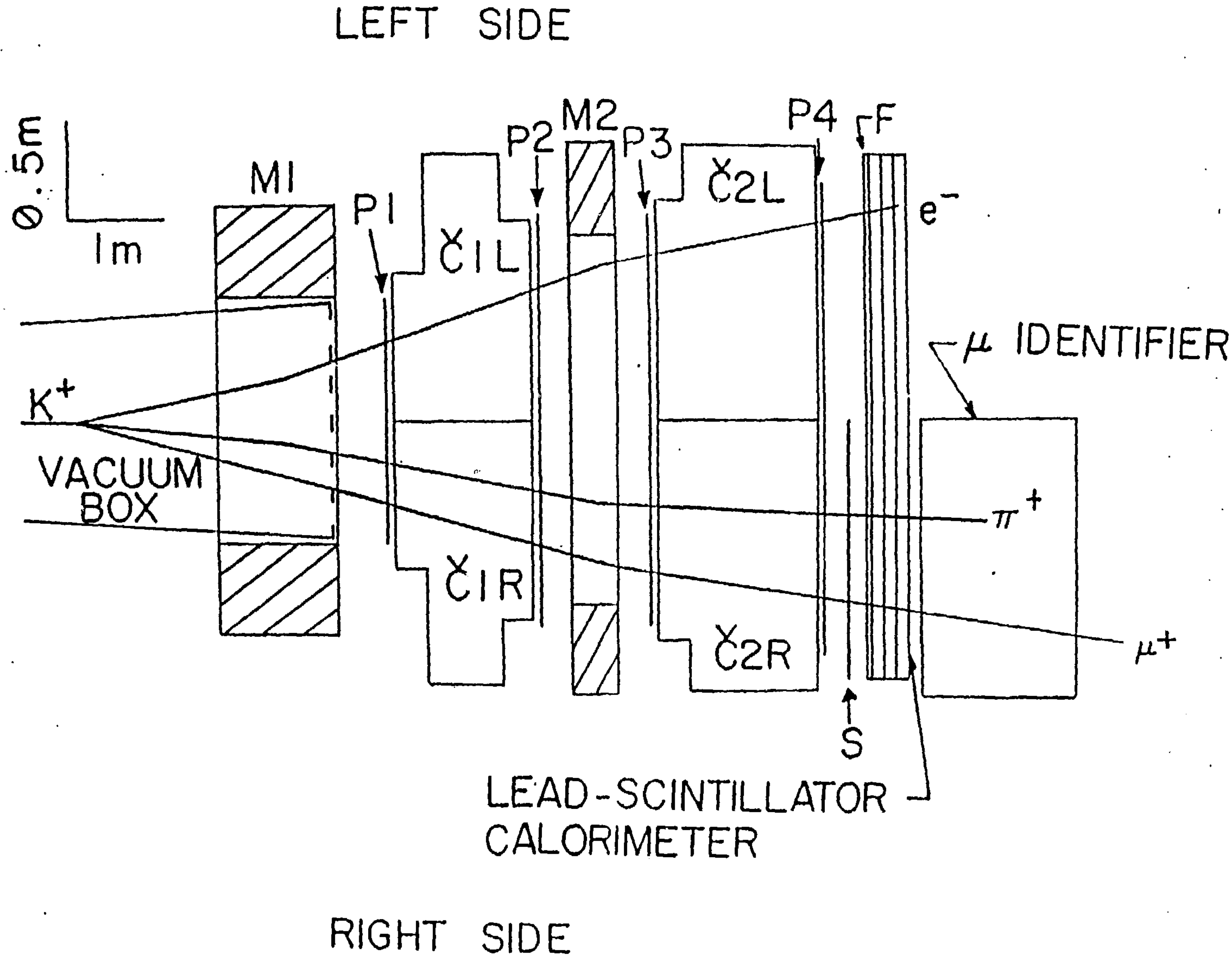
1. Plan view of the apparatus. M1 and M2 are spectrometer magnets, P1-P4 are proportional wire chamber packages, C1L-C2R are Cerenkov counters.

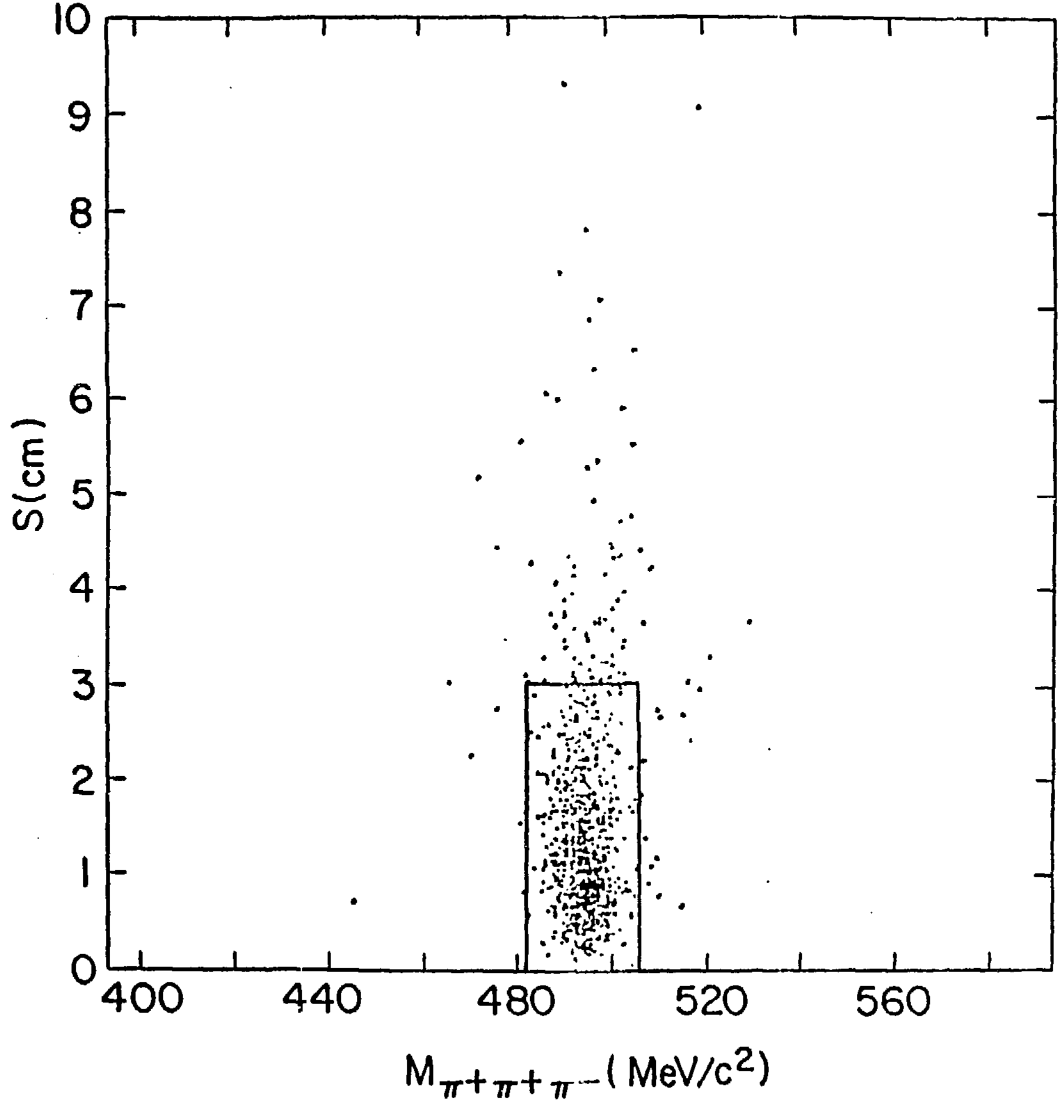
2. S vs. $M_{\pi\pi\pi}$ plot for τ decays. The rectangular outline is considered the signal region.

3. S vs. $M_{\pi\mu e}$ plot for $K \rightarrow \pi\mu e$ candidates.

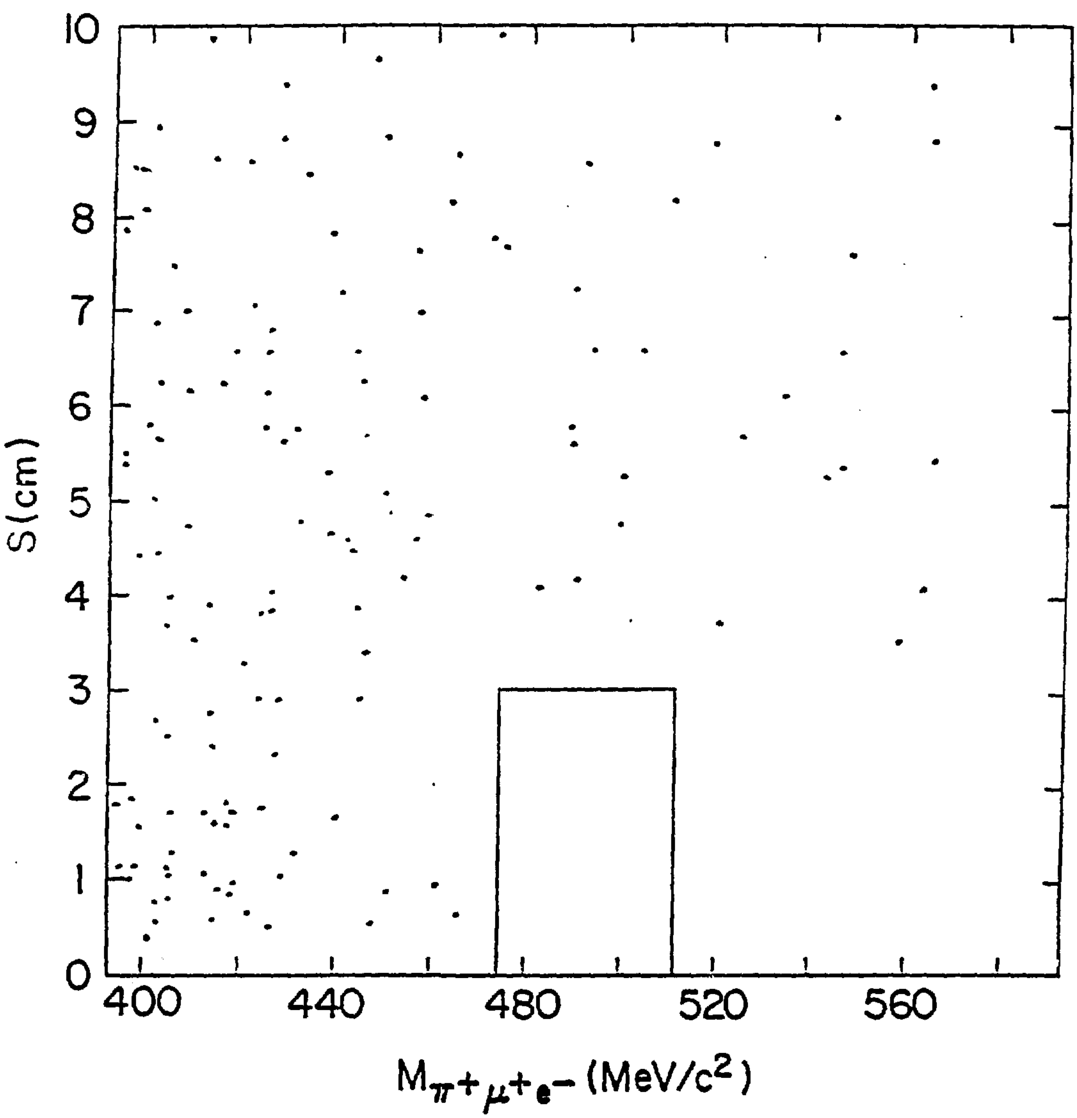
4. Distribution of $M_{\pi ee}$ for $K^+ \rightarrow \pi^+ e^+ e^-$ candidates with $M_{ee} > 160\,\mathrm{MeV/c^2}$.

5. Distribution of M_{ee} for $K^+ \rightarrow \pi^+ e^+ e^-$ candidates with $470 < M_{\pi ee} < 515\,\mathrm{MeV/c^2}$. The dashed histograms are Monte Carlo distributions with a scalar and vector interaction, for the left and right plots, respectively.

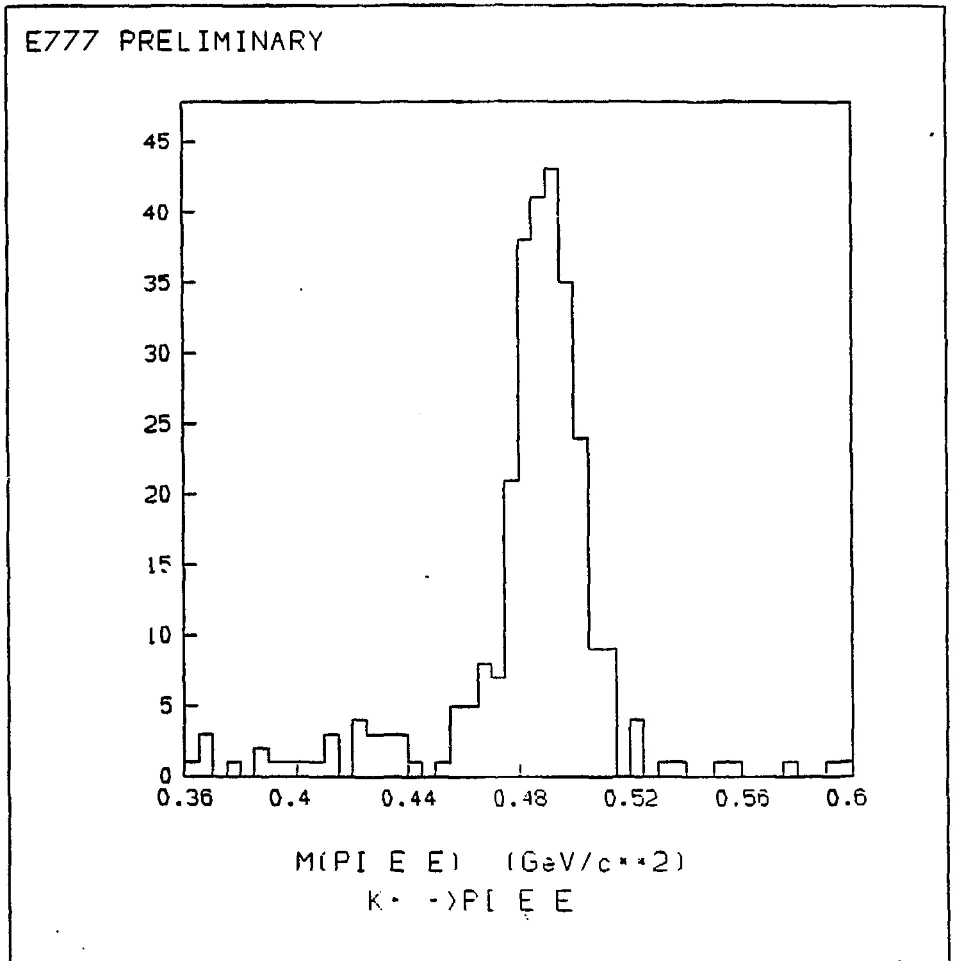

LEFT SIDE
0.5m
1m
M1
P1
Č1L
P2
M2
P3
Č2L
P4
F
e⁻
μ IDENTIFIER
K⁺
VACUUM BOX
π⁺
Č1R
Č2R
μ⁺
S
LEAD-SCINTILLATOR CALORIMETER
RIGHT SIDE



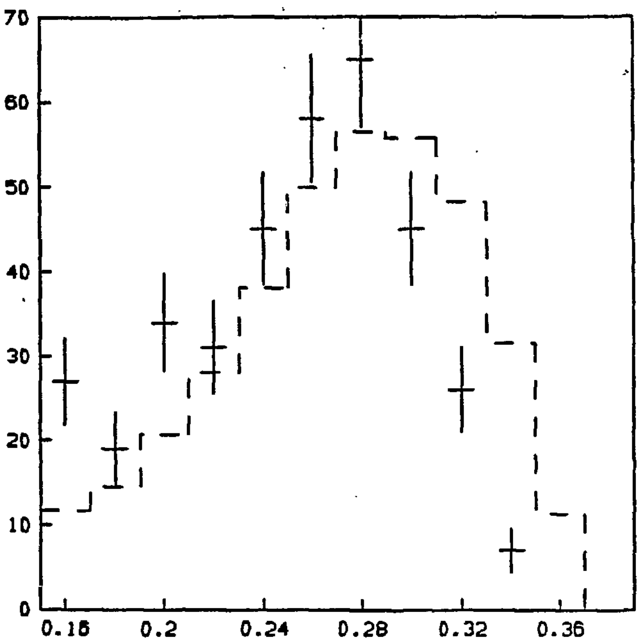
S(cm)
0
1
2
3
4
5
6
7
8
9
10
400
440
480
520
560
M π+π+π− (MeV/c2)



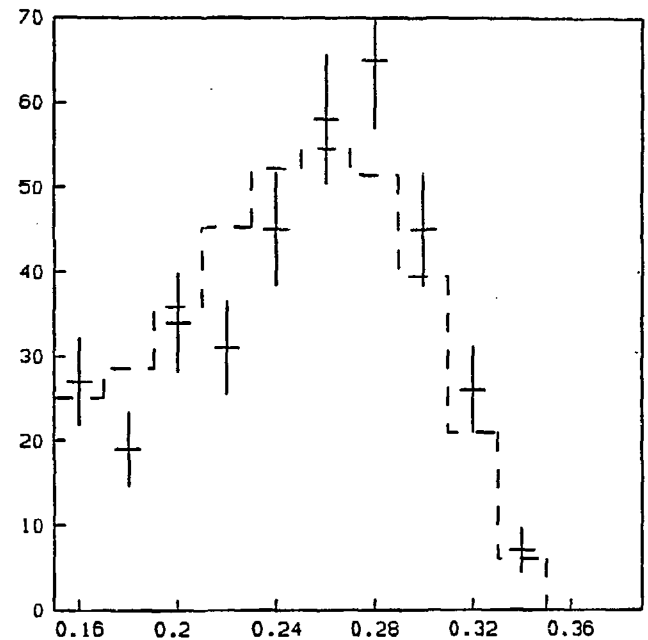
S(cm)
0
1
2
3
4
5
6
7
8
9
10
400
440
480
520
560
$M_{\pi^+\mu^+e^-}$ (MeV/c^2)



E777 PRELIMINARY
45
40
35
30
25
20
15
10
5
0
0.36
0.4
0.44
0.48
0.52
0.56
0.6
M(PI E E) (GeV/c**2)
K+ ->PI E E



E+E- MASS (357 EVENTS)
SCALAR MATRIX ELEMENT



E+E- MASS (357 EVENTS)
VECTOR MATRIX ELEMENT

DISCLAIMER