LEPCON-PITT 217

Study of Alexei's "BOX" Kpme Candidates

October 4, 2001

BASED UPON:

The Forbidden and Unexpected Decay of Kaon
$(K \rightarrow \pi \mu e)$

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1 Introduction

This paper is based upon the work of Ingrid Clay in the summer of 2001, working at SIUE with Julia Thompson and David Kraus. The results were obtained during her stay, and the bulk of the paper was written. The part before the midterms has only minor modifications from that paper, except for moving some figures from hard copy appendices into latex figures in the paper. In the section after the midterms, again, more tables and figures were put into latex format and included in the text, and some additional explanation and discussion was included.

1.1 Overview

Particle physics is the study of the properties of subatomic particles and of the interactions that occur among them [1, 2]. It is the branch of science that deals with the ultimate constituents of matter and the fundamental interactions that occur among them. The subject is known as high-energy physics or elementary particle physics. My project is part of an experiment to search for the rare, possibly forbidden (a process which hasn't been seen) decay $K^+ \to \pi^+ \mu^+ e^-$ of the particle Kaon, whose characteristics are shown in Table 1

Table 1: Properties of the kaon particle

Property	Value/Type
Mass:	1/2 proton mass
Lifetime:	K^+ and K^-: 10^{-8};K^0: 10^{-10} sec
Spin:	0
Particles:	K^+, K^-
Anti-Particles:	K^-, $\overline{K^0}$

The Kaon has several modes of decay. The main modes are shown in Table 2.

Mode	Frequency
$\mu^+\nu$	63%
$\pi^+\pi^0$	21.2%
$pi^+\pi^+\pi^-$	5.5%
$\pi^0 e^+\nu$	4.8%
$\pi^0\mu^+\nu$	3.2%
$\pi^+\pi^0\pi^0$	1.73%

Table 2: Main decay modes of the K^+

Some decay modes are easily confused with the decay sought, which implies a need for sophisticated methods of identifying the decays.. The most common decay is $K \to \mu\nu$, which occurs 63% of the time. This could act as a background decay known as an "accidental" if the muon traveled close in time and space to a separate decay vertex, which would confuse the interpretations of other decays. Two more common decays are $K^+ \to \pi^+\pi^+\pi^-$ (Tau) and $K^+ \to \pi^+\pi^+\pi^0$, with $\pi^0 \to e + e - \gamma$ (Kdal, so called because of the Dalitz decay, $pi^0 \to e + e\gamma$, of the pion). One must know all possible outcomes to minimize mistakes in identifying the found events correctly. The decay of $K_{\pi\mu e}$ also sheds light on one of the most perplexing problems with the Standard Model (SM: a model of six Quarks and six Leptons as fundamental entities), the origin of mass. The mass of fermions (quarks) is not determined in the SM. The SM of particle Physics forbids the decay; through the postulate of Lepton Flavor Number Conservation (LFN: Figure 3).

Understanding the postulate of LFN Conservation requires an understanding of at least some of the following topics: the existence of three generations of fermions (Figure 4), because it is only with multiple generations that mixing can occur at all; the origin of mass, which is problematic in the SM and is related to the assumed mass-less-ness and degeneracy of the neutrinos required for LFN Conservation; and the difference between the Quark and Lepton Sectors, because the mixing of generations is observed in the Quark Sector while it has not, to much lower levels, been observed in the Lepton Sector. My part in this experiment is to use the data collected to study possible backgrounds to this unexpected decay and perhaps even to find a possible candidate for the $K_{\pi\mu e}$ decay.

1.2 Apparatus

The description of the E865 apparatus in this section draws upon the theses of Douglas Bergman [4] and Stefan Pislak [5], as well as of an REU paper of Anne Smith in summer, 2001, in which she studied the magnetic fields in D5 and D6 [3]. The set up of E865 apparatus (Figure 1) helps to minimize particle decay accidentals. It begins with a beam of protons accelerated to a momentum of 6 GeV (1 eV = -e (1 Volt)) propelled into a copper target, hence releasing Kaons. The kaons then travel 100 ft. to the first magnet D5, decaying somewhere in this region. The decay products enter D5, which then deflects charged particle trajectories away from the center magnet. D5 also serves to direct positive and negative charged particles to opposite sides of the detector and to sweep decay products away from the beam region. They then pass two proportional wire chambers, PI and P2, which detect their position, by sensing the voltage created when the charged particles ionize methane. The next piece of the apparatus is the Cerenkov counter C I, which detects particles moving through a material (called a radiator) and will emit light if their speed in the radiator is greater than the speed of light in the radiator. The particles are bent as they enter the magnetic field D6. Their direction after D6 is measured in P3 and P4, which allows us to calculate precisely the momentum of the decay particles. C2, the second Cerenkov counter, is between P3 and P4. A calorimeter where e- and pions interact follows P4. The last piece is a muon detector, where muons, and those pions which passed through the calorimeter, interact. The calorimeter and muon detector identify the types of particles being detected and allow us to infer their "rest mass."

1.3 Kinematics

The obtaining of the rest mass brings us to "Special Relativity" (Einstein's' energy-mass relationship) Eo = $m_o c^2$. The mass of the decay products is found by hypothesizing the identity of the particle based on its charge and reaction to the detection devices. Using the conservation of energy (Eo = El + E2 + E3 +...) and Conservation of Momentum (Pxo = Pxl + Px2 + ...; Pyo = Pyl + Py2 + ...; Pzo = Pzl + Pz2+ ....). We can calculate the energy with the equation $Eo^2 = E^2 - (pc)^2$ thus $E^2 = (pc)^2 + (mc^2$. From the total energy and momentum of the decay product, both of which are conserved in decays, the effective mass of the Kaon can be calculated in the same way, and compared to the known value.

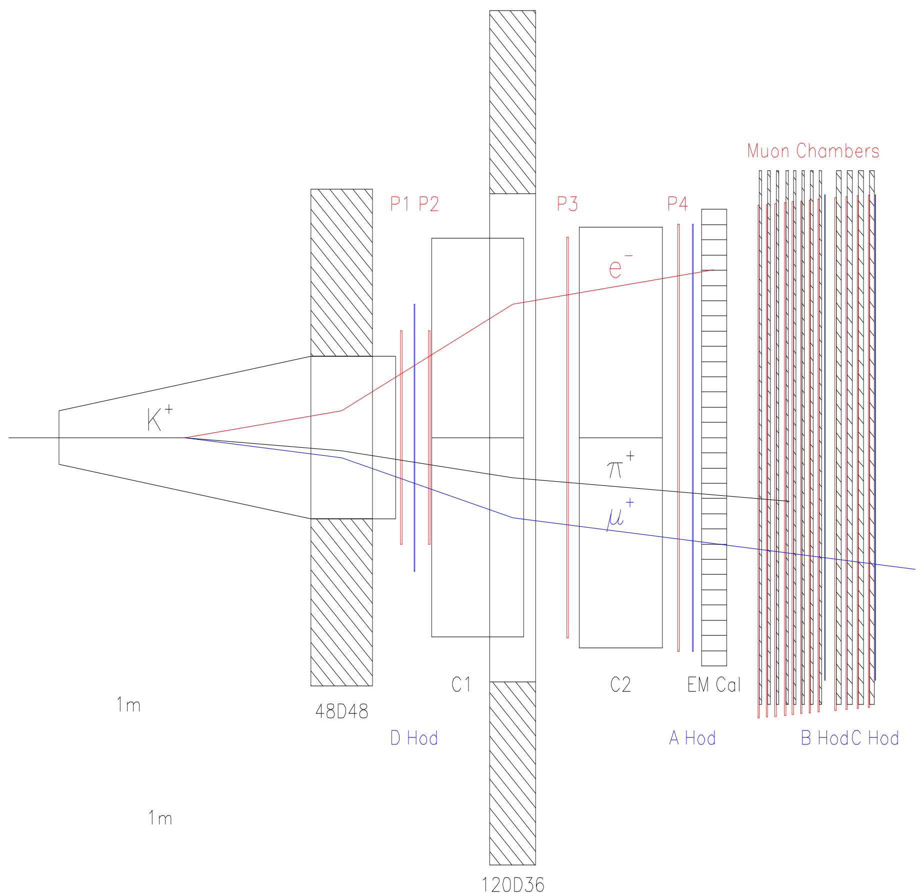

Figure 1: Plan View of Experiment E865

2 Decay Products and Their Interactions

2.1 Particle Identification

Searching for $K_{\pi\mu e}$ requires us to be quite sure of the correct particle type identification. One way to get a real pion, muon, and electron from Kaon Decay is via the chain: $K^+ \rightarrow \pi^+\pi^+\pi^-$, with $\pi^+ \rightarrow \mu\nu$ and $\pi^- \rightarrow e^-\nu_e$. This has a branching ratio of 6.9 X 10^{-6}, in order for the event to be seen as a $K^+ \rightarrow \pi^+\mu^+e^-$ candidate, the pion must decay within the apparatus, and the fact that momentum and energy carried off by the neutrinos makes it hard to reconstruct a vertex or to project the Kaon back to the target. According to Douglas Bergman, the two biggest backgrounds, for final state pi, mu, e, are $K^+ \rightarrow \pi + \pi + \pi^-$ (K3pi, or Ktau) where one pi+ is identified as a μ^+ and the pi- as an electron), and $K \rightarrow \pi^0\pi^+$, with $\pi^0 \rightarrow ee\gamma$ (Kdal) where the positron is identified as a pi+ and the pi+ is identified as a μ^+. It is difficult to get a good separation between pions and muons, since 7% of the pions decay to a muon within the detector and some pions that don't decay will still make it through the muon stack to mimic muons. Thus we must then discriminate between pions and electrons. Since our trigger selects decays with three charged tracks, The total rate in our apparatus is dominated by $K+ \rightarrow \pi^+\pi^+\pi^-$ decays. Electrons appear infrequently in three track Kaon decays. When they do appear it is often via the Dalitz decay where they are accompanied by a positron. Thus the efficient recognition of positrons is a powerful suppressor of background events.

To get a better understanding of this we will look at each particle in each part of our PID apparatus.

2.2 Electrons

Proportional Wire Chambers (PWC). Proportional chambers are particle detectors consisting essentially of a container of gas (argon) subject to an electric field. The PWCs in our detector are PI, P2, P3, and P4. They are used to reconstruct tracks of charged particles and determine their momentum. A trailing particle can leave a trail of electrons and ions in the gas. The charge particle debris are collected at the chamber electrodes and in the process provide an electric signal, indicating the passage of that particle.

Cerenkov Counter Cerenkov counters, like the Calorimeter, are used to separate the electrons from the pions. Cerenkov light occurs when the velocity of a charged particle traversing a dieletric medium exceeds the velocity of light in that given medium. There are two independent, atmospheric pressure, threshold Cerenkov counters (C1 and C2) in the detector. A threshold counter detects the presence of a particle whose velocity exceeds some minimum amount. In this apparatus decay products are usually detected to one side or the other based on their charges. The electron identification system is matched to the charge of the electron and positron, to reduce the Kdal background. The negative electron is sent to the left side of the detector. To reduce the Kdal background, the positron is sent to the right side, where there is an efficient positron veto. The photons are detected by photomultipliers, and the unit of collected light is a "photoelectron" (or p.e.). One photoelectron is the electrical charge output from the photomultiplier which corresponds to the conversion of one photon into an electron in the photocathode of the photomultiplier.

Figure 2 shows some distributions related to electrons: the low mee resulting from the neutral pion decay (part a), the ratio of deposited energy to momentum (of order 1 for an electron or positron, shown in part d), and the total number of photoelectrons in C1 and C2 for electrons (part b) and positrons (part c).

These figures are similar to those found in the theses of Bergman [4] and Pislak [5] , but were found from the final Kpme running in 1998.

Calorimeter The calorimeter is a device that measures the total energy deposited by a particle or group of particles used to measure the energy of electrons and positrons and to detect photons. Electron (positive and negative) is not a "strong" or "nuclear" reaction, but instead a very effective electromagnetic interaction. Electron and Positron's particle identification (PID) are made by comparing the energy given by the calorimeter with that of the momentum given by the spectrometer. This ratio (E/P) should be close to unity. One will see in Chapter 3. that the E/P values for our proposed electron are usually $\approx$-1, indicating that the electron energy is contained in the calorimeter. Thus it is highly unlikely that an electron will make it to the muon range detector, because of the energy loss.

2.3 Pions

Proportional Wire Chambers (PWC) As the pions move through these chambers the pions, being "ionizing" particles go straight through the ionized gas, and that is how they are detected. Typical distributions of pions (from Tau events) is shown in Figure 3. Of particular interest is the energy deposit itself in the calorimeter (EC3, part d) and the ratio of energy deposit in the calorimeter to momentum of the particle (EC3/EP3, part b)).

Cerenkov Counter Pions that do not shower are not likely to be identified as electrons, however, since they give no light in the Cerenkov counters.

Calorimeter Pions usually interact only electromagnetically, like muons, leaving about 250 MeV/c in the calorimeter and thus having a low E/P. But they can also shower hadronically and in this case have larger E/P ratios up to unity and beyond. (Ratios larger than unity would only occur if there were overlapping showers in the calorimeter, or due to imperfect calorimeter resolution.) This is not probable, but it does contribute to PID efficiency for pions. The calorimeter is not compensated for hadronic showers, and much visible energy of the showers leaks out of the back of the calorimeter. The result is that pions show a minimum ionizing peak at low E/P and a broad shower peak with a max of about .5.

2.4 Muons

Proportional Wire Chambers (PWC) Muons, like that of pions, are also-minimum ionizing particles, and they are read in the ionizing gas as are pions.

Cerenkov Counter Muons from kaon decays do not give significant light in the Cerenkov counter.

Calorimeter Muons are minimum ionizing particles in this momentum range and should thus leave a signal of about 250 Me V in the calorimeter. Muons are distinguished by the fact that they are too heavy to undergo bremsstrahlung radiation, and thus make a shower in the calorimeter, yet they do not interact hadronically like the pions do. Muons are much more penetrating than any of the other particle types, and are identified by looking for a track penetrating many interaction lengths of steel at the back of the detector.

Muon Detector The muon stack consists of thick plates of steel interspersed with proportional chambers. The muon planes of vertical and horizontal views, each consisting of a number I of modules each containing 32 wires. Muons are required to leave a track in the muon chambers to a depth consistent with their initial momentum. A muon of a given energy has an expected range in the steel of the range stack. This places a lower limit of about .8 GeV on our acceptance for muons. Muons above this momentum are required to reach their expected range, or exit the range stack out the back if they are energetic enough.

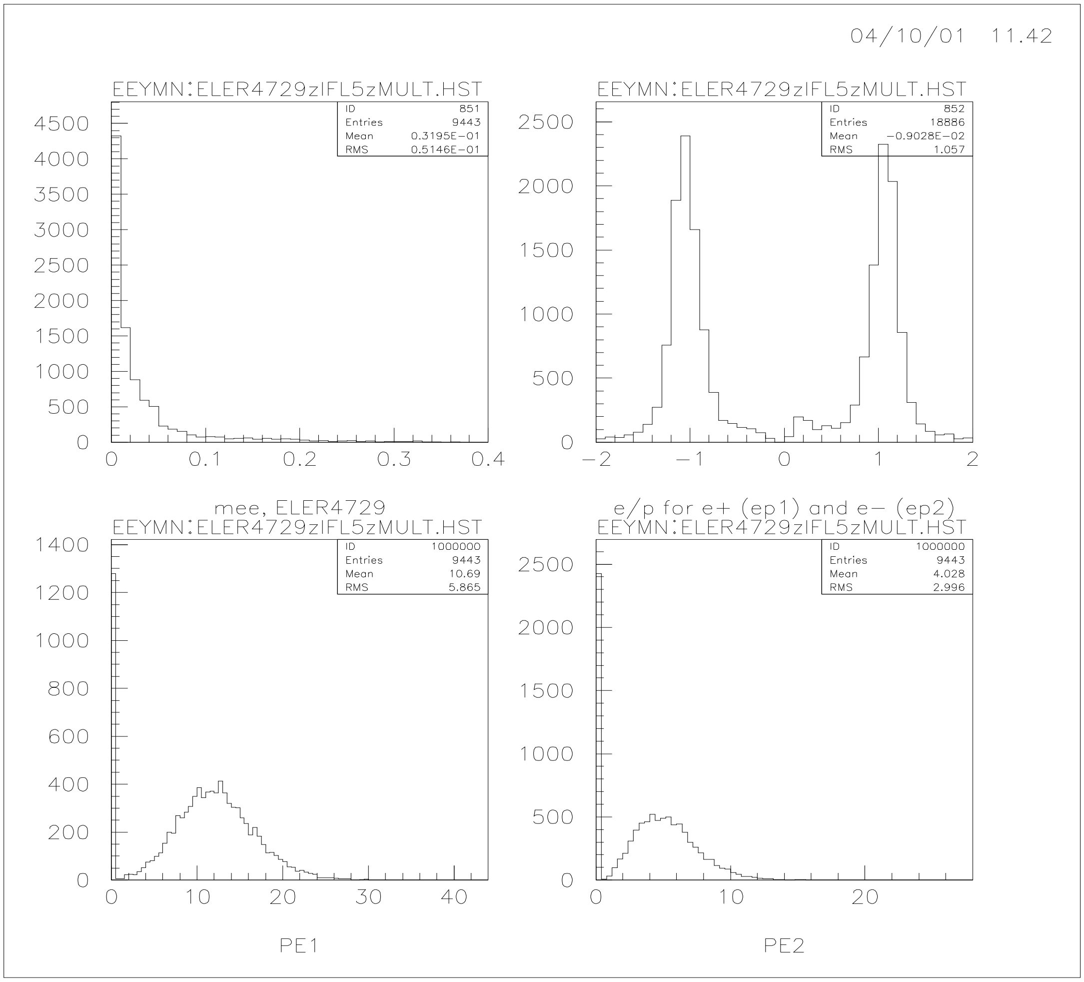

Figure 2: Mee, E/p and number of photoelectrons in C1 + C2 for members of selected ELER triggers, candidates for events arising from a neutral pion Dalitz decay to photon, e+ e-. PE1 is number of photoelectrons for the positron, and PE2 is number of photoelectrons for the electron. PE2 is less because hydrogen is used on the left (electron) side of the Cerenkov counters and methane is used on the right (positron) side.

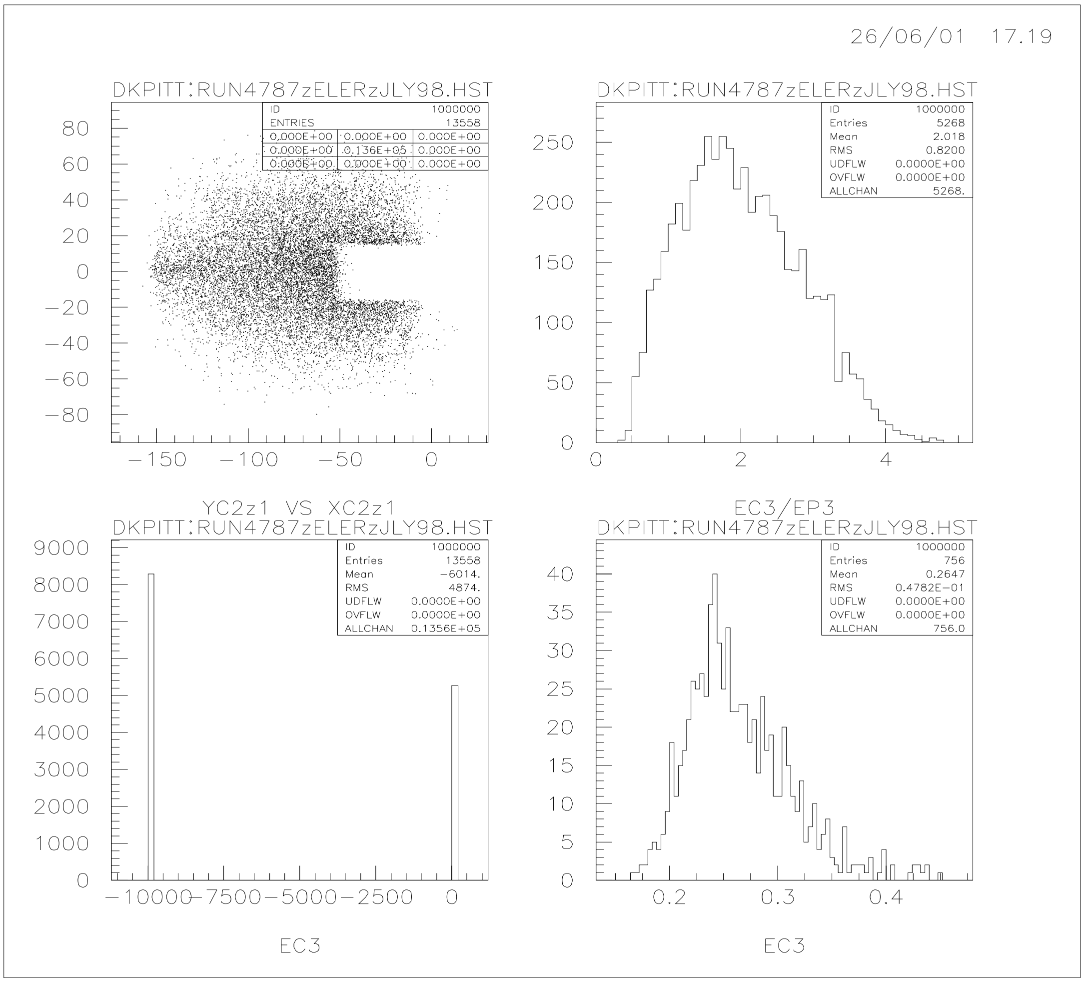

Figure 3: Various distributions related to pions and their energy deposit in the detector. a) E/p; b) Momentum ; c) EC3 (energy deposit in the calorimeter, but on a large scale, showing that not all 2-body vertices have found third tracks on the vertex; d) EC3, the energy deposit in the calorimeter, on a reasonable scale.

3 My Contribution

3.1 Events and Runs

I am working with data file BOX.DAT, prepared by Aleksey Sher, of possible Kpme candidates. Here are the data and the corresponding graphs I have compiled together . From the data collected I was able also to figure out which of the tracks were muons, electrons or pions. I also studied the data and came to a conclusion about possible backgrounds. In studying these events, we have characterized them by high momenta of one track, indicating that that particle may be a muon from a beam particle (pion or kaon) decay ("beam muon"). We looked at muons which weren't strong muons. We also took into consideration the timing between the different tracks, how far or near in time they were to each other. We also looked at the vertex Chi-square in these events, whether they were too high, to produce reliable data.

3.2 Event 1272799 (Run 4168), No. 1 in Box.dat

This event is shown in Figure 4 and and Table 3.2.

We see that track number 1 is a muon, due to the muon flag. We are also certain this to be true due to the low energy in the calorimeter and the E/P (comparison of the energy deposited in the calorimeter to the momentum found by the track fit); muons do not interact strongly and therefore always are minimum ionizing particles and have small E/P ratios. Track 1 is also said to be a "beam muon" because of its high momentum (see appendix 1 for calculations), higher than most three-body decay products. Track 2, we have reason to believe is a pion, because the pion flag reads true. Track 3 is an electron because of the E/P value is -1, and the electron flag is true.

The timing of the tracks in the vertex (tracks 1, 2, and 3) are pretty far apart. Tk 1: -.474, 2:-6.287, and 3:1.44.

Table 3: Run: 4168 Event: 1272799 No. ?? in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1	C2
1 (μ)	-0.04	-0.11	4.4	0.21	0.05	T	0.6	O.O
2 (π?)	0.05	0.06	0.8	0.22	0.28	F	O.O	O.O
3 (e^-)	-0.01	0.03	0.8	0.78	-1	F	3.1	0.6

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	mee
1	-25.4	-15.2	-27.877	-22.313	0.127
2	-13.5	27.3	-49.97	48.631	0.067
3	109.5	16.4	106.219	23.535	

Summary: This Event is probably a decay from Kmunu or πmunu decay (Track 1) overlaid on a piece of another decay. Tracks 2 and 3 make an effective mee mass of 0.067, just above the typical limit of 0.050, and track 2 is in a relatively inefficient region of C1, and may split its light between two mirrors in C2.

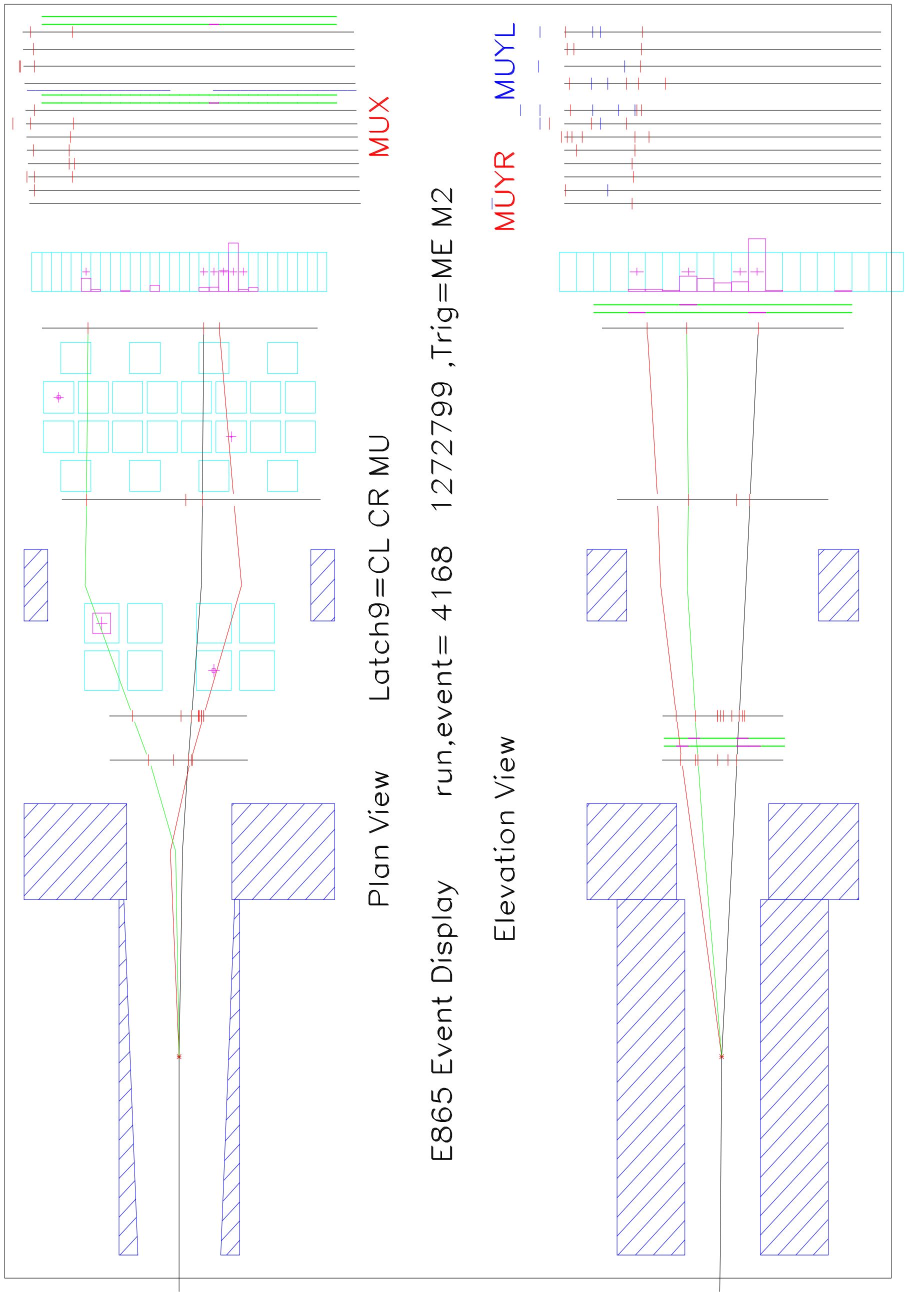

Figure 4: View of event 1272799, early Kpme candidate, in the detector

3.3 Event 59808 (Run 4324) No. 2 in Box.dat

Event 59808 is shown in Figure 5 amd Table 3.3.

Track 1 may be a pion due to the low energy and low E/P (.09); and the pion flag is true. Track 2 is an electron the E/P is close to -1; and the electron flag is true. The 2nd and the 3rd tracks have low XMEE of. 078, which indicates a low mass pair. And this can be seen from the position II in the Cerenkov counter. Thus we cannot tell if there is any electron activity or not. Because of the high E/P there may also be two electrons, tracks 3 and 4 may be positrons, (has the same mass an spin as an electron but opposite charge; anti- electron) or a type of shower. However, th pion flag is true for both Tracks 3 and 4. In track 3, the muon flag is also true, but the position shows that this would be a marginal muon, thus not a "good" muon.

Table 4: Run: 4324 Event: 59808 No. 2 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1	C2
1 (μ)	-0.19	0.01	2.6	0.25	0.09	F	3.1	0.64
2 (e^+)	0.08	-0.04	1.5	1.97	-1.3	F	7.34	5.04
3 (e^-)	0.11	0.041	1.65	2.27	1.37	F	0.0	0.0
4			0.6	0.89	1.48	F	0.	0.

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	xmee
1	-84.5	3	-104.67	4.46	.268
2	92.8	-17.5	107.46	-22.28	
3	-12.9	14.3	9.3	21.4	.077
4 *$\chi^2$98	-	-	-12.3	27.7	

Summary: The timing of the tracks in the vertex (1,2 and 3) are pretty close the are set apart by nano sec. Tracks 1:4.3; 2:4.8;3:3.4. This is most likely a Dalitz Decay, because of the relatively low xmee of track three with track 2, and because track 3 is on the edge of the fiducial volume in C1 and crosses to the left side of the beam line and so is out of the fiducial volume in C2.

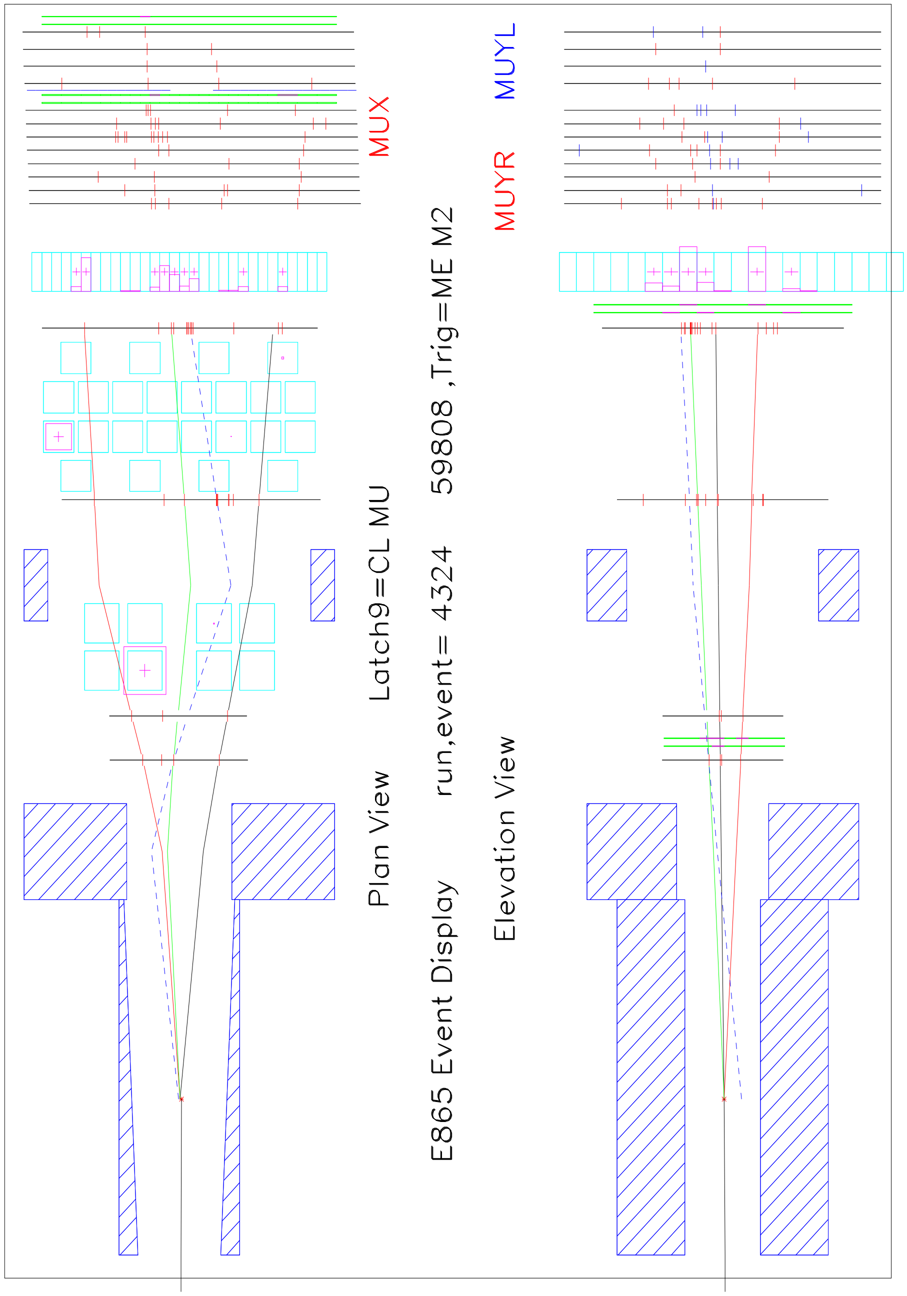

Figure 5: View of event 59808, early Kpme candidate, in the detector

3.4 Event 11060694 (Run 4415)

Event 11060694 is shown in Figure 6 and Table 3.4.

Track 1 looks like a positron because of the E/P .It is also marginal for Cl and C2 detection (In Figure 3, we can see C2 and the hole indicating where a particle may be or marginal or not seen at all), and its XMEE is .053; however, the pion flag is true. Track 2 is a pion (the pion flag is true) or an "accidental source". Track 3 is an electron because of the E/P 2, and the electron flag. This event has good timing track 1:1.15;2:1.825;3:2.048.

Table 5: Run: 4415 Event: 11060694 No. 3 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1p.e.	C2 p.e.
1	0.09	-0.04	1.86	2.32	1.25	F	O.O	0.376
2	-0.20	0.05	2.31	0.21	0.09	F	O.O	O.O
3 (e^-)	0.09	0.01	1.60	1.65	-1.04	F	2.00935	0.82142

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	mee
1	-22.21	-11.63	-8.95	-17.074	0.053
2	-81.48	11.65	-104.75	17.59	0.279
3	87.29	2.70	104.44	4.289	

Summary: This event is most likely a Dalitz Decay, because of the relatively low mee (0.053) of track one with the electron, and because track one is on the edge of the fiducial volume in both C1 and C2.

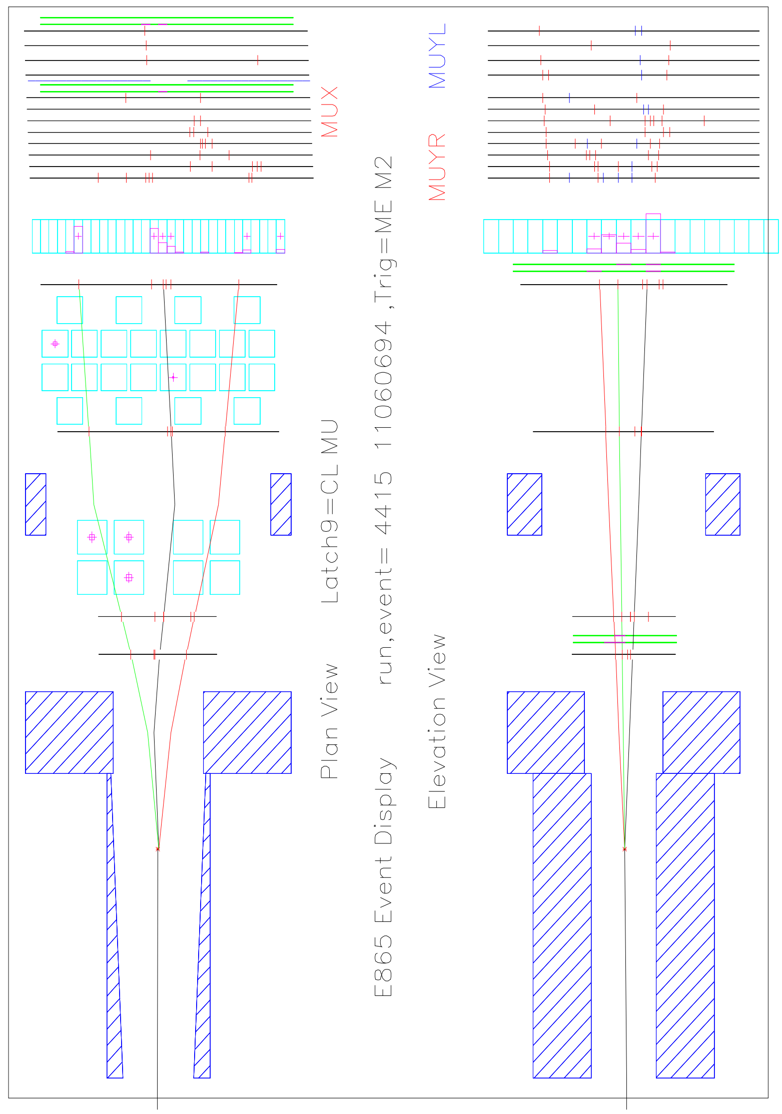

Figure 6: View of event 11060694, early Kpme candidate, in the detector

3.5 Event 547782

This event did not produce any data. The reason being may be because of the bad "chi-square" for the vertex.

3.6 Event 318302 (Run 4499)

Event 318302 is shown in Figure 7 and Table 6.

Track number 4, (Figure 7) is considered an "accidental source", because it has a high momentum of 4.74. Track 3 we also consider to be an electron, the E/P value is - 1.06; there were no flags indicated in this event, therefore there is not a "solid electron". No light was given off in the C2 and it was in time with track 2. Track 2 is a muon because of the muon flag, and the hits in the muon detector (MUX: 12; MUY:11). There was no data on track one. This event had more than three tracks.

Table 6: Run: 4499 Event: 318302 No. 5 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1 p.e.	C2 p.e.
1	-0.06	-0.02	2.74	0.73	0.27	F	0.	0.
2	-0.06	0.12	1.41	0.24	0.17	T	0.	0.
3	0.12	-0.08	1.64	1.75	-1.06	F	2.24	0.
4			1.52	0.94	.62	F	0.	0.
5			0.44	0.63	1.45	F	0.	0.
6			4.74	2.67	0.57	F	2.24	0.

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	mee
1	-42.9102	-2.95868	-42.416	-4.342	0.225
2	-84.9398	44.00331	-94.516	62.844	0.273
3	91.87349	-23.7986	111.791	-34.516	
4			-28.20	-40.80	
5			-98.23	-9.15	
6			45.03	1.77	

Summary: The timing was also off in this event. This event may be a Dalitz Decay, because of the high E/P of track 5. the high number of extra tracks makes the event hard to interpret.

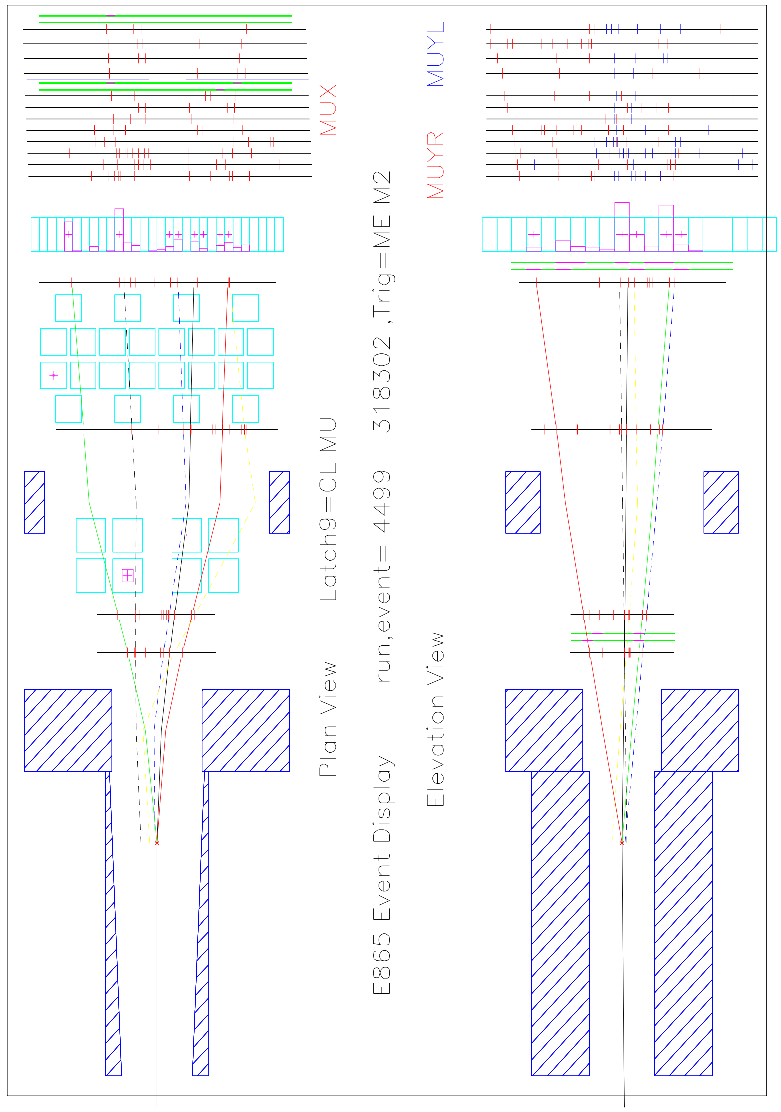

Figure 7: View of event 318302, early Kpme candidate, in the detector

3.7 Event 2089873 (Run 4559)

Event 2089873 is shown in Figure 8 and Table 7.

Track 1 is a muon, a beam muon, because of the high momentum (3.71). Track 2 is a pion, due to the pion flag. Track 3 is considered an electron. The E/P of 4 is very low (-.18). Electrons are required to have an E/P with in .2 of unity (Figure 2). This event also has extra tracks. They are also out of time.

Table 7: Run: 4559 Event: 2089873 No. 6 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1p.e.	C2p.e.
1	-0.11	-0.08	3.21	0.28	0.09	T	0.	0.
2	0.02	0.02	1.27	0.36	0.28	T	0.	0.
3	0.12	0.12	1.47	1.57	-1.06	F	3.02	5.44
4			1.20	1.15	0.97	F	0.	0.
5			1.45	.27	-0.18	T	0.	0.

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	mee
1	-42.73	-10.47	-51.67	-16.75	.346
2	-59.61	6.85	-54.06	9.14	.132
3	103.67	42.09	124.88	59.06	
4			14.5	-28.98	
5			19.48	36.94	

Summary: The momentum of track 1 (3.2 GeV/c) makes it a candidate from a decay from πmunu. The high E/P of track 4 makes it a possible positron candidate, and it is very near the edge of the fiducial volume in C2, and may cross over between C1 and C2 (did not have the C1 information handily available). the large number of tracks makes the event hard to interpret,

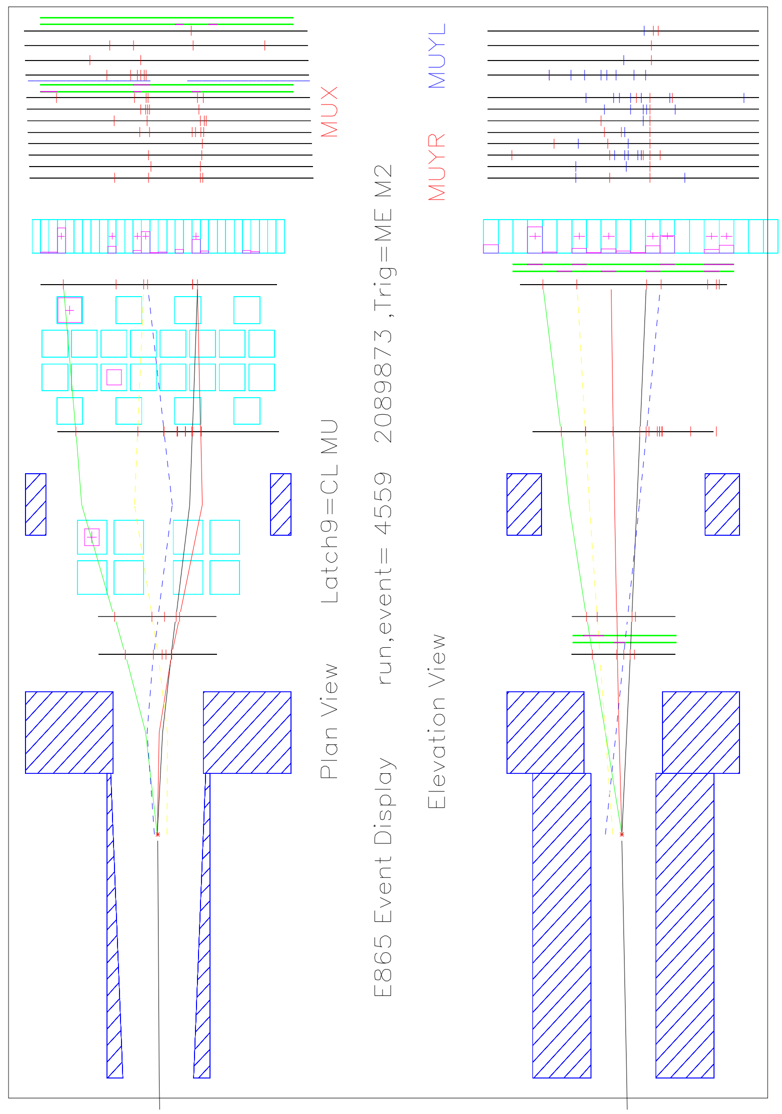

Figure 8: View of event 2089873, early Kpme candidate, in the detector

3.8 Event 1308914 (Run 4648)

This Event did not produce any data. We figure the reason being is because of the bad "chi-square" and associated probability at the vertex (Figure 19).

3.9 Event 40515 (Run 4678)

Event 40515 is shown in Figure 9 and Table 8.

Track 1 is a pion due to the pion flag. Track 2 may be a pion, however it is out of C2 mirrors and marginal in C1. Tack 3, is an electron based on its E/P value, and electron flag. Track 4 has a low E/P and a XMEl of.0171; it may be a low mass pair with Track 2 (Figure 9). Track 4 doesn't have a flag. This event had more than three tracks.

Table 8: Run: 4678 Event: 40515 No. 7 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1p.e.	C2p.e
1	-0.19	-0.05	2.16	0.24	0.11	F	0.	0.
2	0.08	0.03	1.24	0.26	0.21	T	0.	0.
3	0.07	0.03	2.62	2.93	-1.12	F	6.87	1.12
4			0.60	0.52	0.92	F	0.	10.29
5			2.17	0.21	0.09	F	6.87	1.12

Position of the Particle					
Tracks	XC1	YC1	XC2/P4	YC2/P4	mee
1	-100.93	-17.95	-125.293	-22.993	.285
2	-28.	14.7	-4.64	20.32	.071
3	50.52	6.98	57.34	10.39	
4			-115.05	8.09	
5			36.40	44.73	

Summary: Track 2 is in a region not able to be viewed in C2 and near the beam hole in C1. It makes a rather low mass mee pair (0.071) with track 3. The event seems likely to be part of a Dalitz decay.

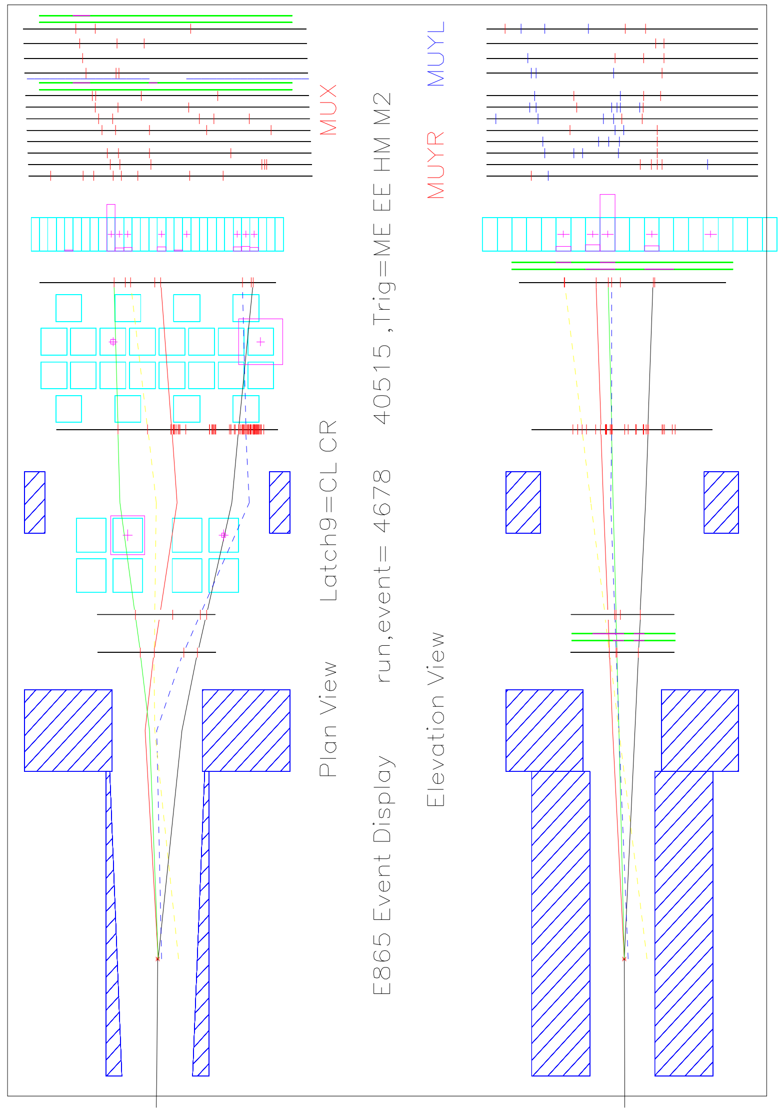

Figure 9: View of event 40515, early Kpme candidate, in the detector

3.10 Event 403280 (Run 3847)

Event 403280 is shown in Figure 10 and Table 9.

Track 3 is an electron due to the E/P value, and the electron flag is true. Track 1 is flagged as a pion, but makes a relatively low mass pair (0.085 MeV/c^2) with track 3. Track 2 is a muon, a beam particle muon, because of the high momentum (4.27 GeV/c) and the muon flag.

Table 9: Run: 3847 Event: 403280 No. 8 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1p.e.	C2p.e.
1	0.06	-0.08	0.83	0.37	0.44	F	0.	0.
2	0.01	0.13	4.3	0.27	0.06	T	0.	0.38
3	-0.01	-0.02	0.77	0.8	-1.04	F	1.25	3.64

Position of the Particles					
Tracks	XC1	YC1	XC2	YC2	mee
1	-73.39	-44.703	-49.95	-59.05	0.085
2	-19.50	17.21	-18.20	25.57	0.106
3	108.8702	-10.7396	106.235	-12.371	

Summary: The high momentum of track 2 suggests that is is a muon from a beam particle (kaon or pion) decay. Tracks 1 and 3 have a relatively small mee, but track 1 is not in a particularly poor area of either C1 or C2.

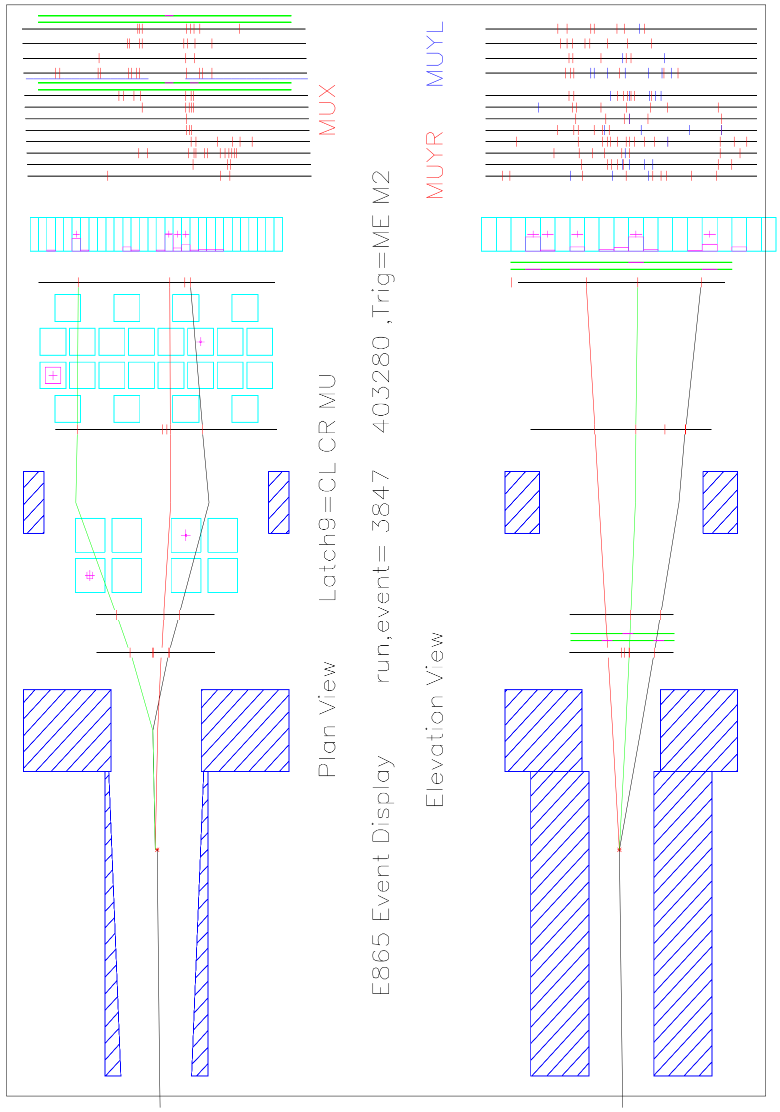

Figure 10: View of event 403280, early Kpme candidate, in the detector

3.11 Event 178066 (Run)

Event 178066 is shown in Figure 11 and Table 3.11.

Track 1 is a pion because of the E/P, and pion flag. Track 2, on other hand is a muon, based on the muon flag. Track 3 is an electron. Track 3 is an electron due to the electron flag and the energy deposition. There is a large light yield in C2 for track 3. Track 4 is a pion because of the pion flag. The event looks like an "accidental", because of the high vertex chisquare (10.84, which for 3 degrees of freedom is less than 1 % probable).

Table 10: Run: Event: 178066 No. 5 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1p.e.	C2p.e
1	0.01	0.08	2.66	0.86	0.32	F	0.	0.
2	0.03	0.13	1.33	0.4	0.3	T	0.	0.
3	0.00	-0.14	-1.94	2.07	-1.07	F	3.74	6.12
4			1.19	1.10	0.94	F	0.	0.

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	mee
1	-37.77	13.79	-38.76	22.19	.233
2	-57.78	45.81	-49.70	68.22	.279
3	42.51	-34.70	41.76	-53.13	
4			-55.30	-37.49	

Summary: This may be an accidental combination because of the high vertex Chi-square. Or an overlap of decays.

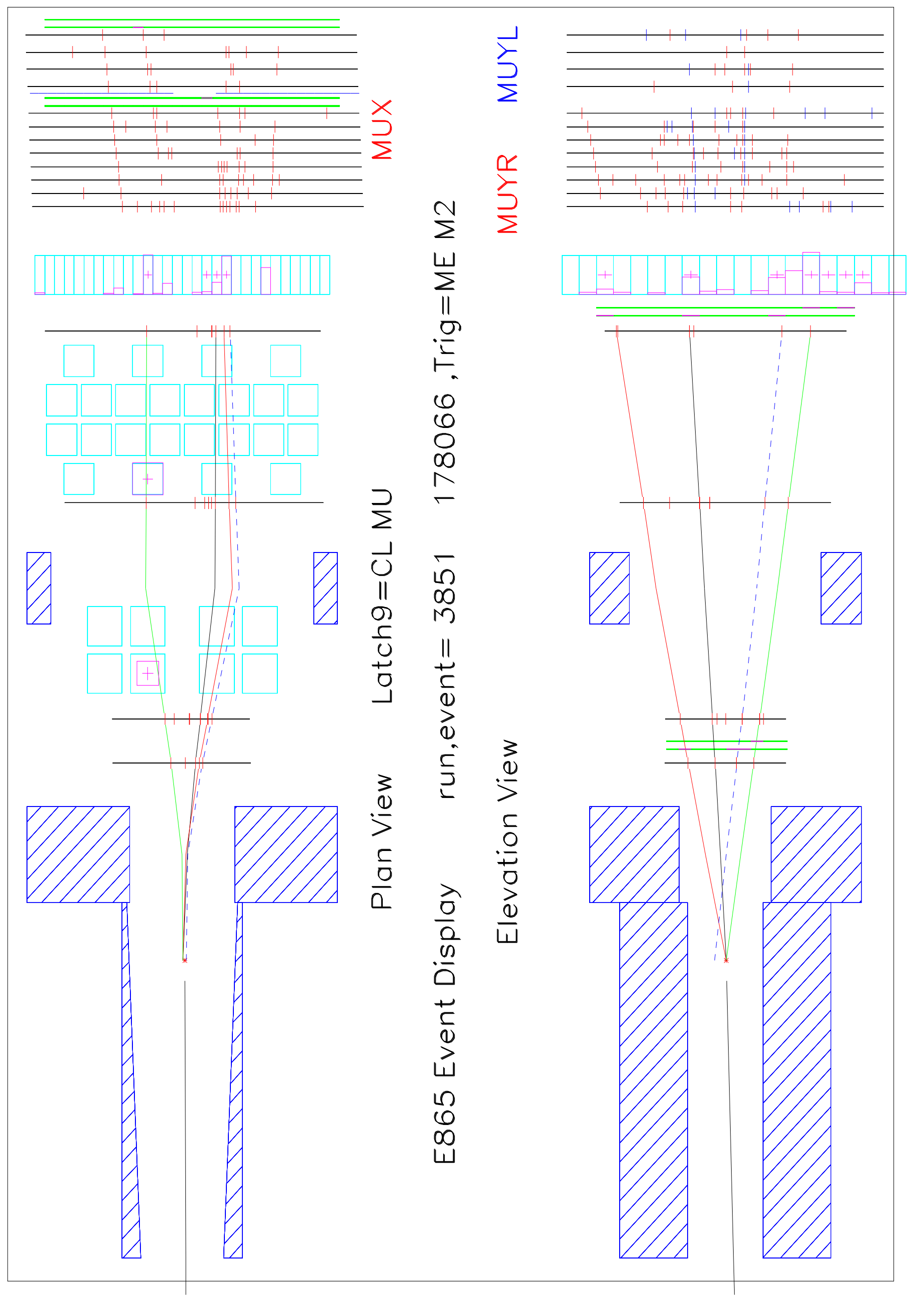

Figure 11: View of event 178066, early Kpme candidate, in the detector

3.12 Event 10265512

Event 10265512 is shown in Figure 12 and Table 11.

Track 1, is a muon, it also has a low-energy deposition. It also has low hits in MUY (4) of the muon detector. Track 2 is a pion, due to the high-energy deposition. Track 3 is an electron due to the electron flag and E/P, as well as track 4.

Table 11: Run: Event: 10265512 No. 9 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1p.e.	C2p.e.
1	0.01	-0.17	1.68	0.24	0.14	T	0.0	0.
2	-0.07	0,01	2.38	0.69	0.29	F	0.	0.
3	0.06	0.12	1.73	1.79	-1.03	F	1.38	2.03
4			1.99	2.77	-1.4	F	1.38	0.27

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	mee
1	-47.57	-43.38	-42.88	-72.63	.185
2	-46.90	1.82	-54.43	3.23	.288
3	65.77	29.62	75.72	48.52	
4			-11.68	22.74	

Summary: This event is complicated, because of the additional track 4, which again looks like an electron. The muon is a little marginal.

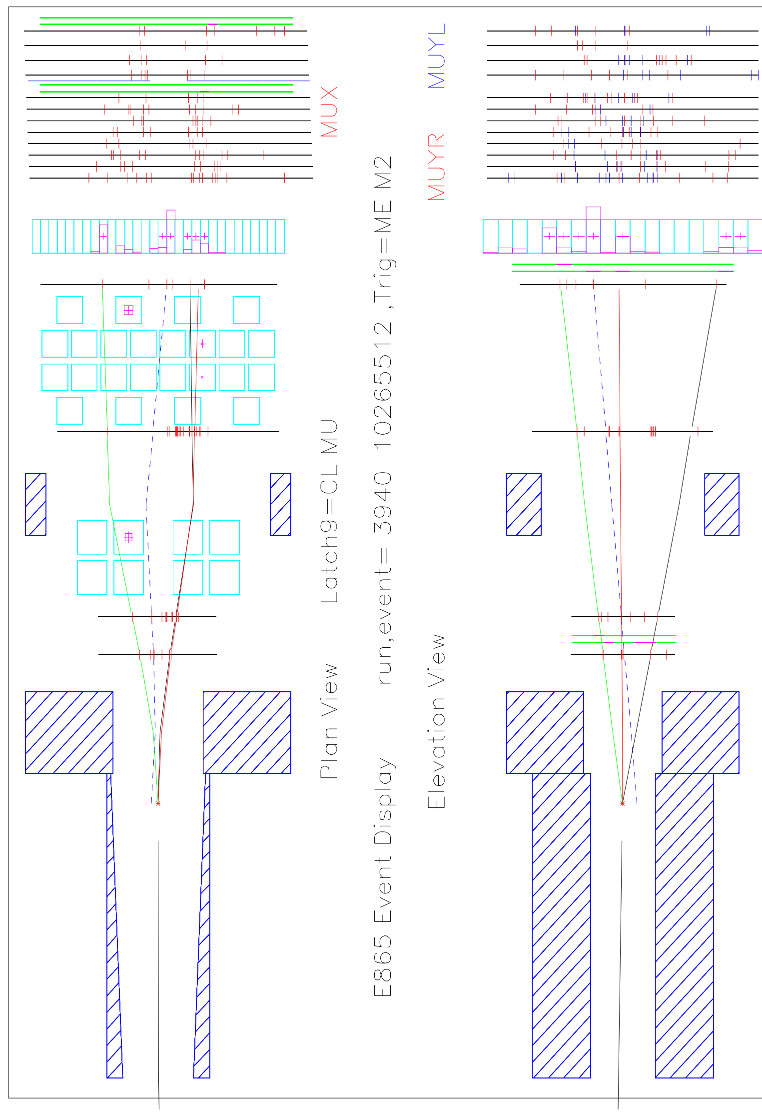

Figure 12: View of event 10265512, early Kpme candidate, in the detector

3.13 Event 974863

Event 974863 is shown in Figure 13 and Table 12.

Track 1, is most probably a pion, due to the pion flag. However it is somewhat marginal, and may not be seen in the Cerenkov counter. Track 2 is a muon, because of the muon flag. Track 3 is an electron because of the E/P value and the electron flag. Track 4, due to the high-energy value is most likely to be an "accidental source", because it isn't on the vertex. Its pion flag is true though.

Table 12: Run: Event: 974863 No. 10 in Box.dat

Track No.	Px	Py	Pz	Energy	E/P	Muon flag	C1p.e.	C2p.e.
1	-0.02	-0.02	1.81	0.96	0.53	F	1.38	0.27
2	-0.18	0.01	1.75	0.22	0.12	T	0.0	0.0
3	0.12	0.03	2.30	2.41	-1.05	F	0.61	8.28
4			3.25	0.86	0.26	F	0.	0.

Position of the Particle					
Tracks	XC1	YC1	XC2	YC2	mee
1	-53.44	-5.65	-55.4	-7.7	.135
2	-99.9	1.2	-128.5	2.6	.310
3	62.9	4.02	76.3	6.9	
4			-11.68	22.74	

Summary:Track 4 may be a complicating track from a beam muon decay, because of its relatively high momentum. Track 1 however, does show Cerenkov light, even though its E/P is only 0.53. So, although the xmee of tracks 1 and 3 is rather high (0.135), track 1 does look rather like an electron, and therefore the event might be part of a Dalitz decay.

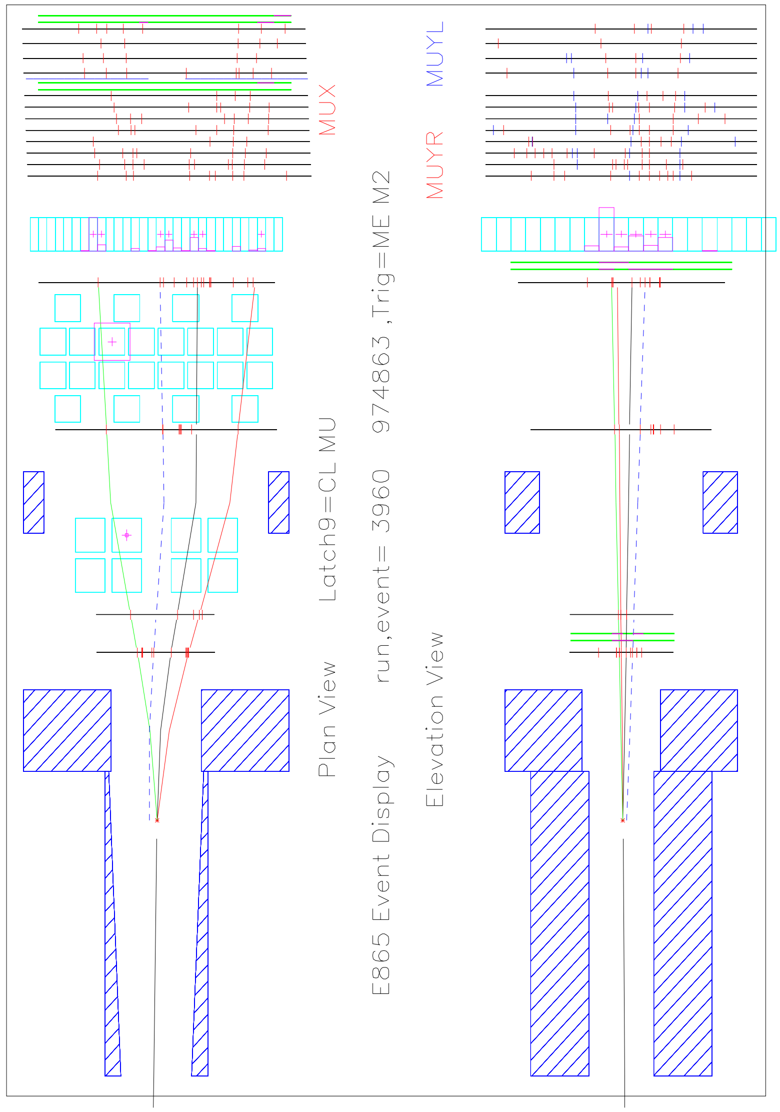

Figure 13: View of event 974863, early Kpme candidate, in the detector

4 After Midterms – Background Suppression Techniques: "Cuts"

4.1 Smaller sample – Refining intuition

This file, BOX.dat was prepared by Alexei Sher, with rather strict cuts, but also requiring that the tracks not be well timed:

1. $T_{rms} > 10.$
2. $S_{norm} < 2.35$
3. Tgtlik >-20.
4. Sum of track chisquares $< 15.$
5. $S_{2tk} < 5.$
6. M$_{ee} > 0.050 GeV/c^2$
7. Nphot $= 0$
8. Electron on left at shower counter.
9. Pion on right at shower counter.
10. Kpme effective mass within 12 MeV/c^2 of the kaon mass (494 GeV/c^2)

The results, according to our programs, are shown in Table 4.1.

I looked at the smaller samples first and decided to make cuts in them first. There were 12 events in the small data sample. One event made such a bad vertex chisquare that no further information was available about it. Of the 11 remaining, events were required to have only one flagged muon. with momentum less than 4 GeV/c, and not more than 3 tracks. A cut on the vertex chisquare would also have removed a large number of these events. As shown in Table 4.1, four of the eleven events were eliminated by removing events with either zero or two positive tracks identified as muons. From the flow chart one can see the swift decline in events with the cuts made. Of the seven events with only one flagged muon, two had muon momentum greater than 4 GeV/c. Of the remaining 5 events, all had more than 3 tracks in the event, and 3 of the 5 have vertex probability greater than 0.99. The characteristics of the small sample and cuts made in this sample were used as a strategy for the bigger sample of events.

Table 13: Summary of obvious undesirable characteristics in the original small sample of events provided by Alexei Sher.

No Muons	Extra Muons	1 muon
59808	1308914	127299
11060694	2089873	403280
		318302
		10265512
		178066
		40515
		974863

Table 14: Now look at events with one identified muon

tk3 < 4 GeV/c	tk3 > 4 GeV/c
318302	127299 (4.4 GeV/c)
10265512	403280 (4.3 GeV/c)
178066	
40515	
974863	

Table 15: Now look at events with track 3 momentum < 4 GeV/c

3 tks	> 3 tks	vtx chisquare	vtx chiprob
	318302	11.2	1.
	10265512	19.	1.
	178066	10.8	0.99
	40515	2.83	0.58
	974863	1.25	0.26

4.2 Larger Sample – Developing Possible "Cut" Set

A larger file of events was also prepared, relaxing the target likelihood cut and the cut on the sum of track chisquares:

1. $T_{rms} > 10.$
2. $S_{norm} < 2.35$
3. $S_{2tk} < 5.$
4. $M_{ee} > 0.050 GeV/c^2$
5. Nphot = 0
6. Electron on left at shower counter.
7. Pion on right at shower counter.
8. K3pi effective mass more than 20 MeV/c^2 of the kaon mass (494 GeV/c^2)
9. P_{sum} of the three charged tracks within 0.3 GeV/c of 5.95 GeV/c (the central value of the beam momentum).

In looking at this bigger data file of events and the FORTRAN program, "pass1-jt" (See Appendix 3 for Flow Chart), I studied the following characteristics: poor muon information, beam muons, poor timing agreement between tracks, and poor vertex fit. Together with jt, I also changed the "ntuple" file adding 13 new names to the file (Appendix 4). After some study, on each event sample I looked at, the Dalitz (Eler4729), the Tau, and Kpme simulated events and candidates from the data, I made appropriate cuts to select those events. The cuts were based on:

1. the number of tracks in the event identified as muons (or having "muon flags";
2. momentum of the positive tracks (requiring that it be less than 3 GeV/c). The reason for this cut is to require that positive tracks be below the Cerenkov threshold on the right.
3. the probability of the vertex chi-square.

The quantities XME1, XMEE, (the effective masses of each of the two postive tracks with the negative track) may also be very useful in discriminating against backgrounds, but are not included in this series of cuts.

Note that while the timing is expected to be very effective in removing backgrounds generally, applying it in the Kpme sample would be deceptive, since this sample has been chosen to have poor timing among the three events. Figure 14 shows timing distributions for a) Tau, b) ELER, and c), d) Kpme candidates. The poor timing for the Kpme candidates is most clearly shown in a scatterplot of the timing differences for the two sets of tracks, as shown in Figure 4.2, which clearly shows that most events have poor timing for one of the pairs.

These losses, as cuts on the muon flag, number of total tracks, momentum of the third track, and goodness of vertex fit, are shown in Table 4.2.

Table 16: Effect of "Cuts" on Event Samples. In each case below the number corresponding to a given cut is the number remaining after that cut is applied.

Cut	N_{TAU}	N_{ELER}	$N_{Kpmesim}$	$N_{Kpmecand}$
In File	1954	9443	4785	1478
Muon flag:				
Ktau: no μ flag	1517			
Eler: no μ flag		9146		
Pme: 1 μ flag			3674	1047
Ntrack $\leq$ 3	1199	7281	3693	473
P3 and P1 $\leq$ 3.	1129	6237	2865	232
probvtx<0.98	858	4825	2390	125
Mee > 0.075	543	-	2073	83
$XC1_{postks}$ < -10.	483	2825	1396	47

4.3 Results

From the table, it is clear that the Kpme sample is cut by more (a factor of 31!) than the normalizing samples (Ktau: 4.0; ELER: 3.3; and Kpme sim: 3.4). We have not yet studied the remaining sample of 47 to see what else may be odd about them.

Not surprisingly, if one requires that all three tracks be within 4 nsec of each other, no events remain. We were initially pleased at the effectiveness of the timing cuts before we realized that the Kpme sample events were chosen out of time.

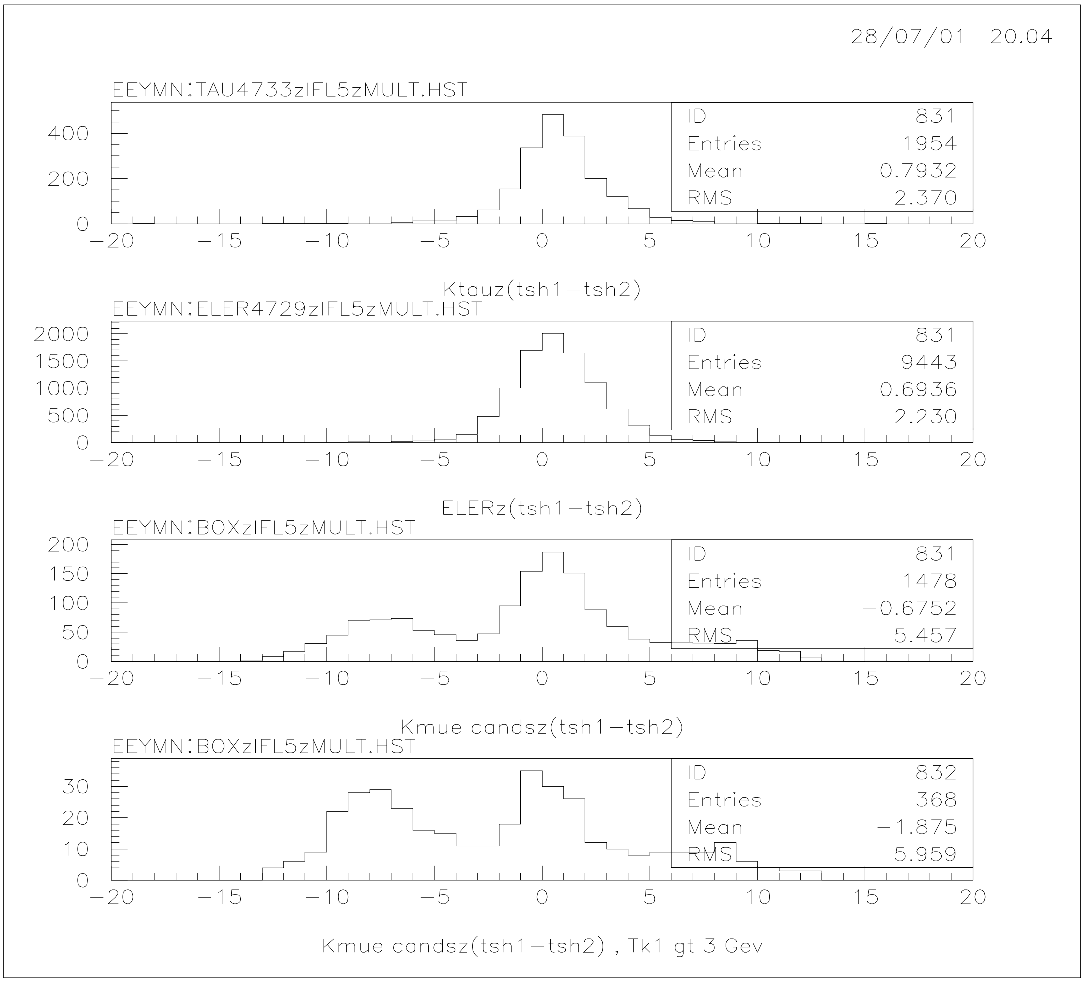

Figure 14: Time differences of the two pairs formed from the three charged tracks in the vertex of the event. a) Top: Tau events; b) Middle: ELER events (from π^0 Dalitz decays); c,d) bottom: Kpme candidates.

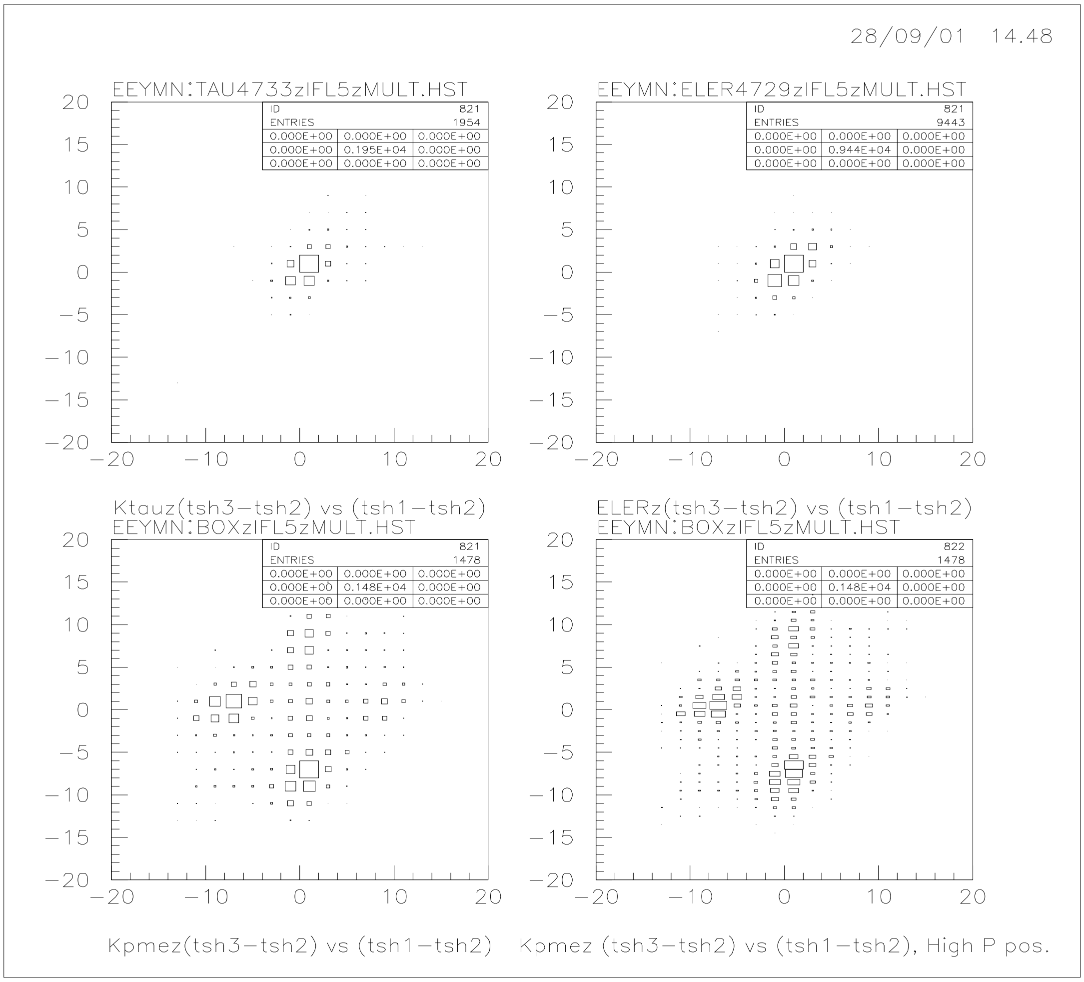

Figure 15: Various distributions from Kpme candidates. a) Scatterplot of the two possible Mee combinations; b) Number of photoelectrons for non-electron tracks, for events with good vertices; c) Scatterplot of timing differences for the two possible positive track combinations with the electron; d) "muon probability": 0 means no muon was found; the events with probability approximately 0.1 is for events with two tracks with a muon flag, for which one pion apparently has decayed (for a Kpme real event), for which the probability is about 10%.

5 After Midterms – Probability

We decided to try to use probability distributions based on the above quantities which discriminate against backgrounds, instead of the cuts, in hopes of avoiding such large losses. If the distributions were completely independent, the probability approach would not be any better than the cut approach. However, we suppose that the predominant composition of the Kpme sample is background events ("accidental" tracks overlapped with part of another kaon decay, or events with some other peculiarity such as scatters or decays of the individual tracks). These background events would generally fail one or more of the cuts, and if the probability approach is used, with the event probability the product of various individual probabilities, the true events will have disproportionately lower overall "event" probabilities, since several of the individual properties will be unlikely (have low probability for occurrence).

From the Dalitz and the Tau events and the simulated Kpme we evaluated the components of the probability, and applied them to all events to see the effect. In general, all the components of the probability show relatively more improbable Kpme candidate events than improbable Tau, Dalitz or Kpme simulated decays.

The components of the probability are:

1. number of tracks showing a muon flag, shown in Figure 16. There is about an 8% chance that a pion in our apparatus will decay to a muon. Therefore, there is approximately a 16% chance that one of the two positive tau tracks will be identified as a muon, and approximately an 8% change that the third track in an ELER event will be identified as a muon (except for the fact that there are some events from the Kmu3 decay, which could be accounted for in a more thorough treatment);

2. number of tracks, shown in Figure 17. At least three tracks on a vertex are required for all events. The three track events in the tau events would not be used in the analysis;

3. the vertex quality, shown in Figure 19. (from the vertex chisquare (for three degrees of freedom),the probability of the chisquare belonging to a real vertex is found);

4. "pbusy" (measure of accidental background activity in the detector), "Pbusy", shown in Figure 18 is the number of PWC hits * clusters in cal * number of A counter hits * number of B counter hits * number of C counter hits * number of D counter hits; it is the product of rates, and becomes large when several of the rate indicators are large. At high rates it is harder to reconstruct things, and therefore, it is reasonable to get rid of things that have high rates;

5. mee (effective mass of the two closest-lying particles, each taken as electrons; mee, shown in Figure 21, is small for real Dalitz decays of the π^0.

6. momentum of positive tracks.

5.1 The muon probability

came from the Taus, as shown in Figure 16: 22% that either positive track has a muon flag, and therefore 22% that a given pion will have a muon flag.

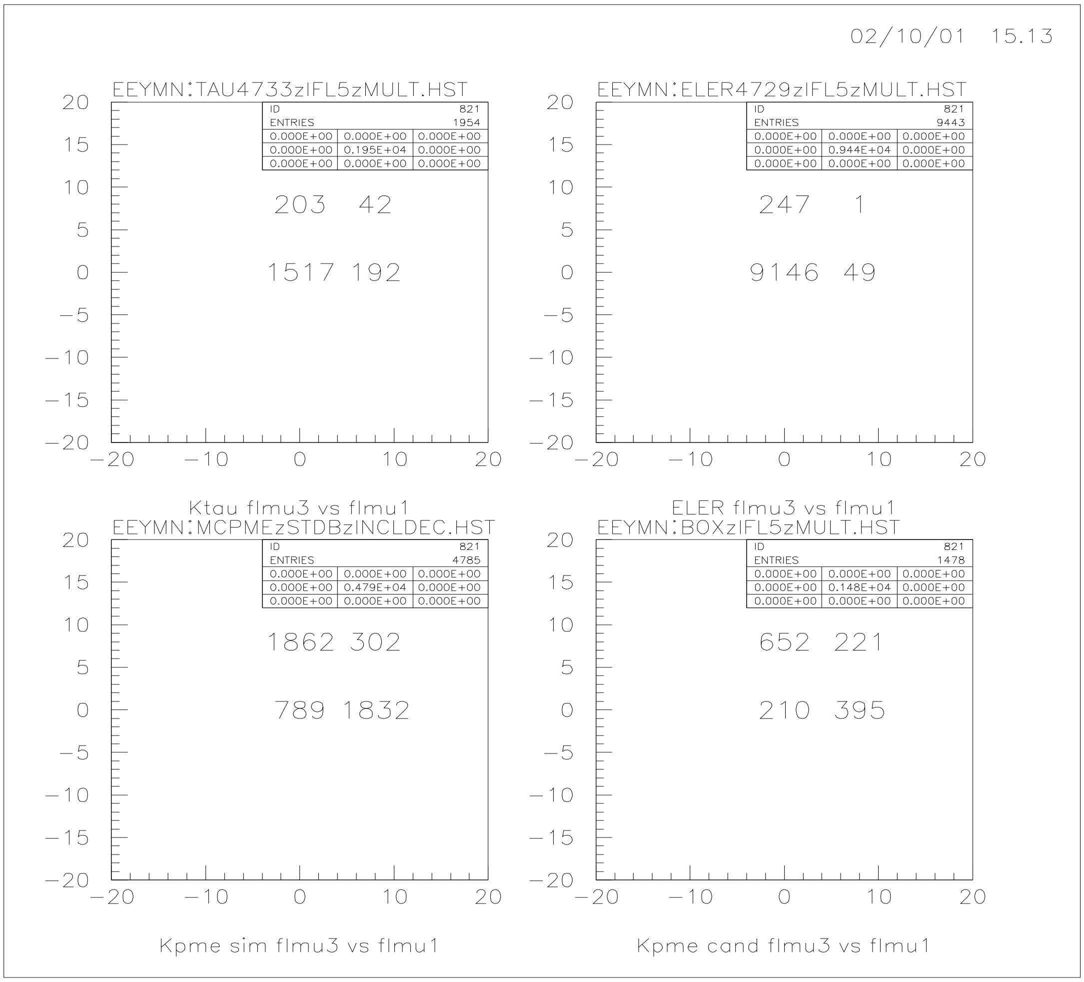

Figure 16: Scatterplot of number of events with first (FLMU1) or second (FLMU3) positive track showing a muon "flag", or identification. a)Top left: Tau; b) Top right: ELER; c) Bottom left: Kpme simulated events; d) Bottom right: Kpme candidates from data.

5.2 Prob TK

Data that has to do with extra tracks, and hits have to come from the data because we have no way of simulating them, The track probability comes from the track distributions in Ktau and Dalitz events (Figure 17 and Table 17. To find the probability that an event has more than a given number of tracks, the number of events with more than that number is divided by the total number of events. The same process described above for Tau was done for the Dalitz, and the results were averaged in finding the final track probability.

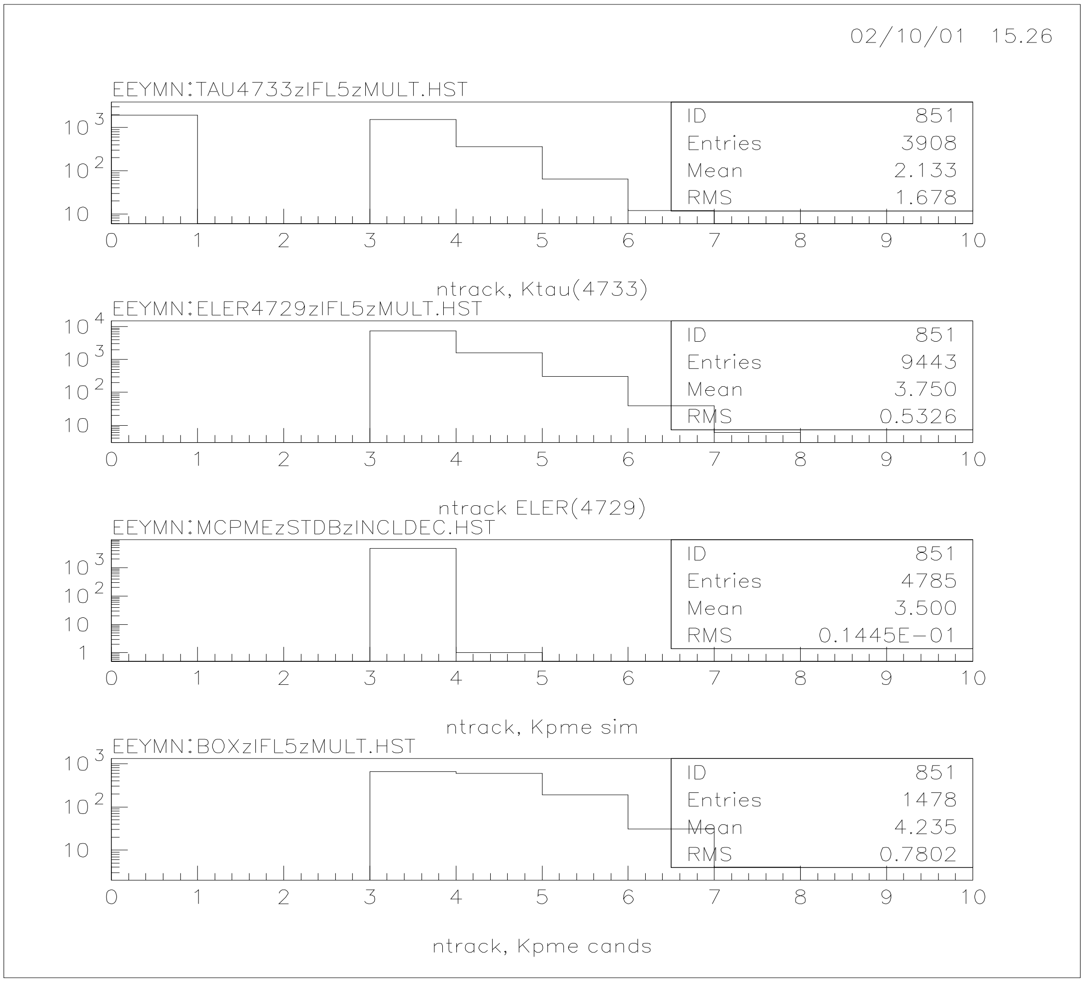

Figure 17: Number of tracks reconstructed. The events with 0 tracks are not used. From top to bottom: a) Tau; b) ELER; c) Kpme, simulated; d) Kpme candidates, data.

The numbers for the Dalitz and the Tau are very close, and an average of the results is used in finding the probabilities. Table 5.2 shows the corresponding numbers for the Kpme candidate events, which have noticeably more extra tracks.

Table 17: Number of events with different number of tracks found in 9146 Ktau events.

Track No.	Number of events	Number Divided by Tot.
3	796	.796
4	1541	.169
5	285	.0311
6	34	.00372
7	5	.00055

Table 18: Number of tracks, and inferred probabilities of extra tracks, from a sample of 1517 Dalitz events.

Track No.	Number of events	Number Divided by Tot.
3	1199	.790
4	260	.171
5	51	.03362
6	7	.00461

Table 19: Distribution of Number of Tracks found in 1047 (sum is 1027?) Kpme candidate events.

Track No.	Number of events	Number Divided by Tot.
3	473	.45177
4	427	.40783
5	125	.11939
6	2	.00191

5.3 The Pbusy probability

is again taken from the Ktau and Kdal events, as seen in Figure 18, in a similar fashion to the Probtk probability. "Pbusy" is seen to drop less fast for the Kpme data candidates (which we

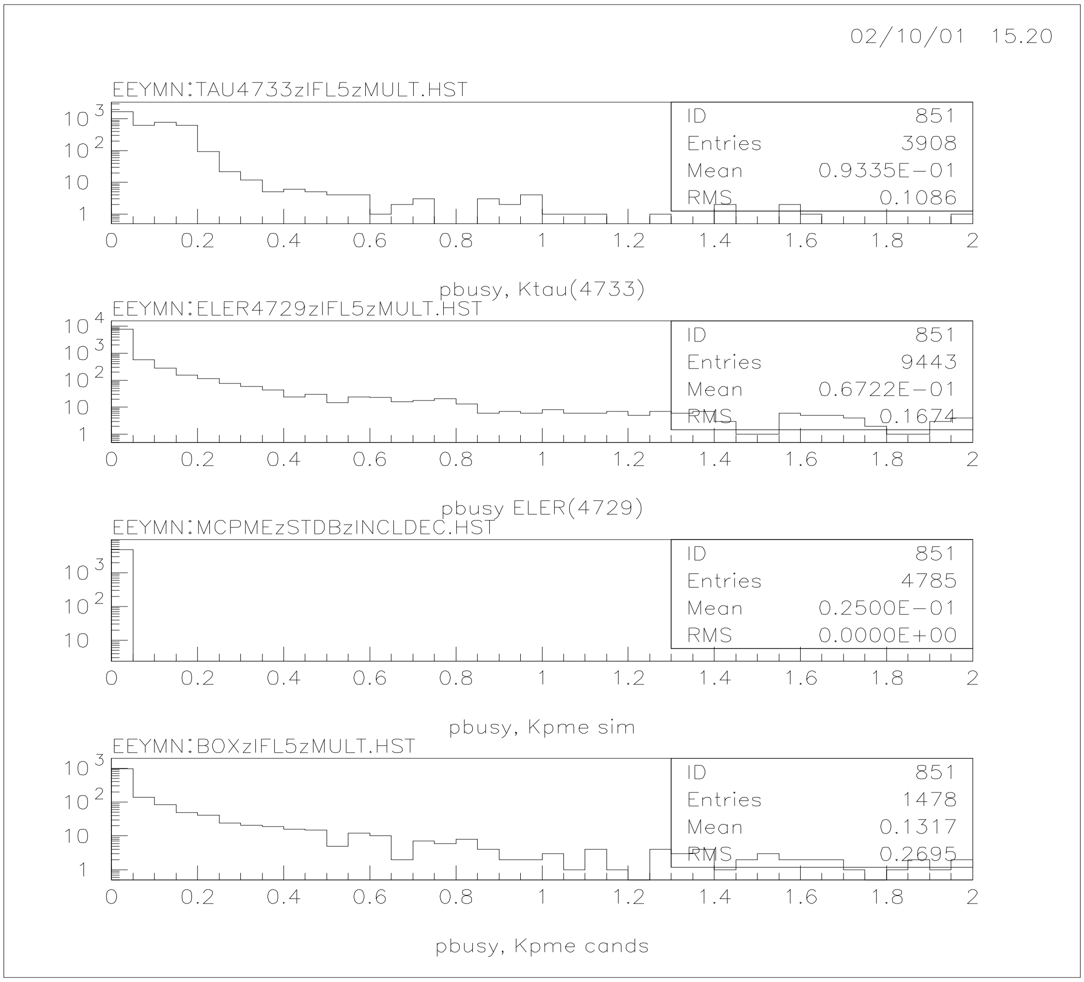

Figure 18: Pbusy. From top to bottom: a) Tau; b) ELER; c) Kpme, simulated; d) Kpme, candidates, data.

expect to contain disproportionately many background events) than any other decay.

5.4 The vertex probability

is taken from the CHI-PROB distributions in Figure 19. (The vertex probability was found by taking 1- CHI-PROB). We see that for all the modes, there are events with improbable vertices (large CHI-PROB, so low probability of that vertex being a well-measured significant physical vertex). But the Kpme candidates clearly have many more of these events than are found in the Tau and ELER events. For our present purposes, we suppose that the poor vertex probabilities in the Tau and ELER events really correspond to scattered tracks, decayed tracks, or some other physical process which has spoiled the vertex fit. In order to have good kinematic rejection of poor events which might fake the Kpme events, we are willing to lose all the poorly measured vertices, and we see that we will disproportionately lose more of the Kpme candidates than of the ELER and Tau events. [Note added in proof: More careful studies of the vertex probability indicate that most of the large vertex probability losses would also be lost with the usual "snorm" cut on closing distance for tracks in the vertex.

From these we find the topographical probability, the kinematic probability, and the event probability.

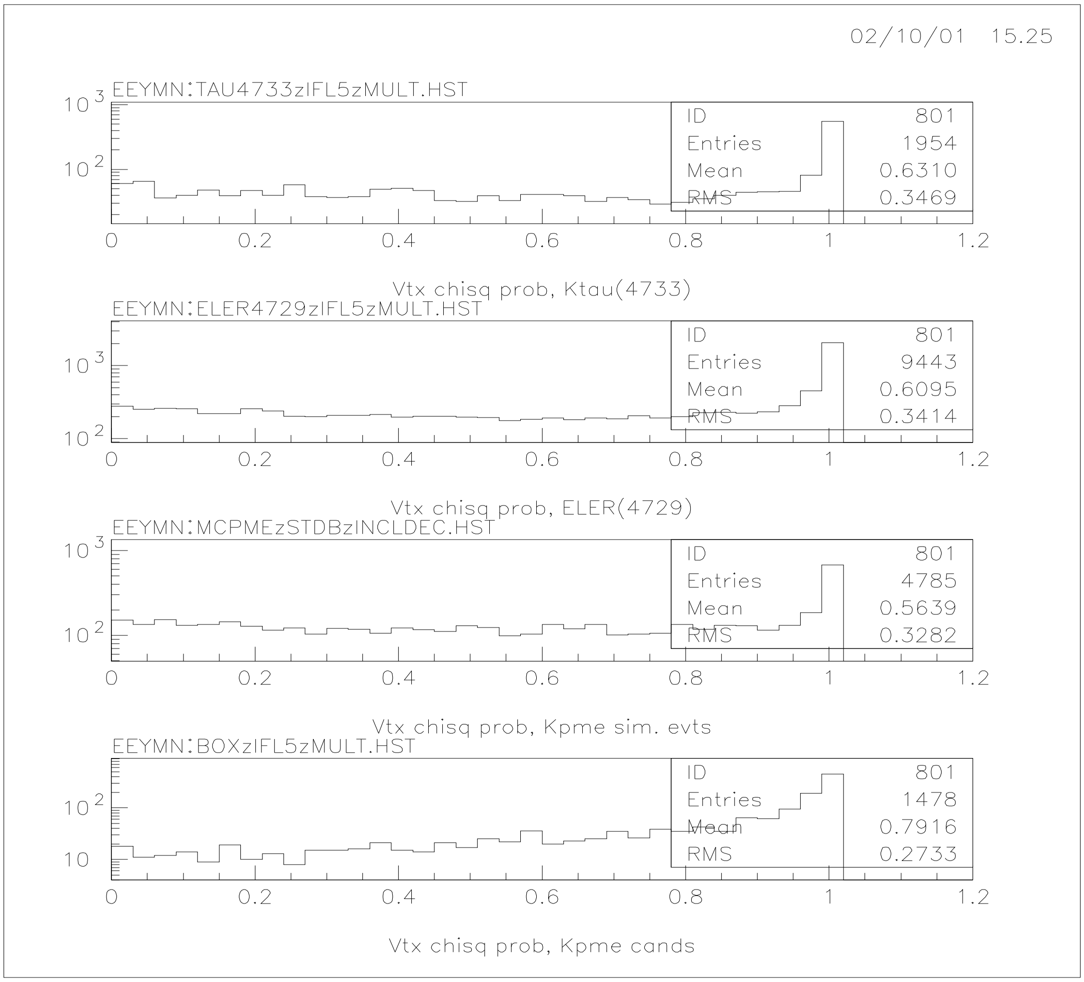

Figure 19: CHI-PROB. The vertex probability, 1-CHIPROB, will have a large spike at 0 probability, and such events will be rejected, or will have a low overall event probability. From top to bottom: a) Tau; b) ELER; c) Kpme, simulated; d) Kpme, candidates, data.

5.5 The topograpical probability

, which tests whether the topology of the event is correct, is the product of the muon probability, track probability, pbusy probability, and vertex probability, and is shown in Figure 20.

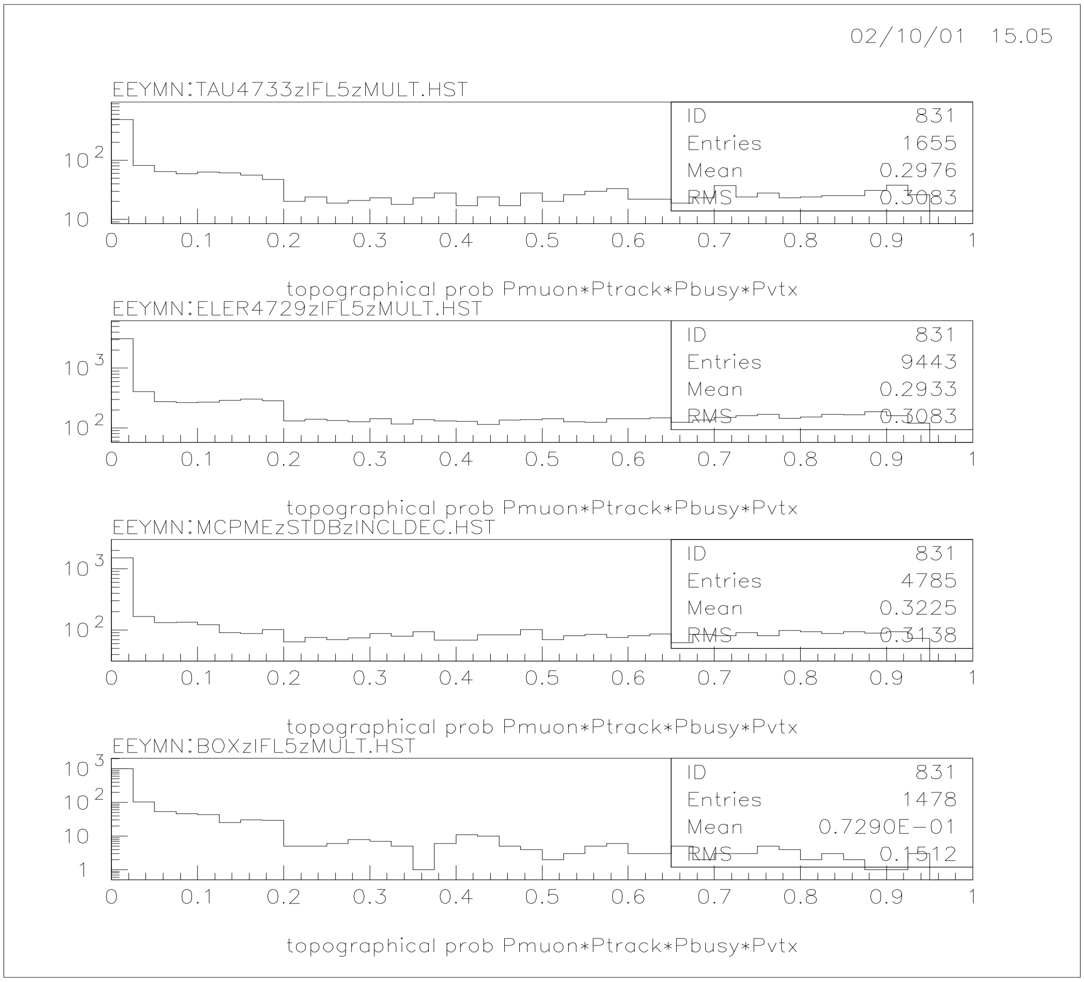

Figure 20: Probtop (Topographical Probability). From top to bottom: a) Tau; b) ELER; c) Kpme, simulated; d) Kpme, candidates from data.

5.6 Kinematic Probability, from Ktau, Kdal, and Kpme simulated events.

The kinematics probability is Pmee * Pmom. Distributions for these quantities are shown in Figures 21 and 22.

The Monte Carlo momentum and MEE distributions are those we would expect from real Kpme events. For event quantities which have to do with kinematics of decays, we can use data for recognized Tau and Kdal events, but to see how Kpme would look, we use simulated events.

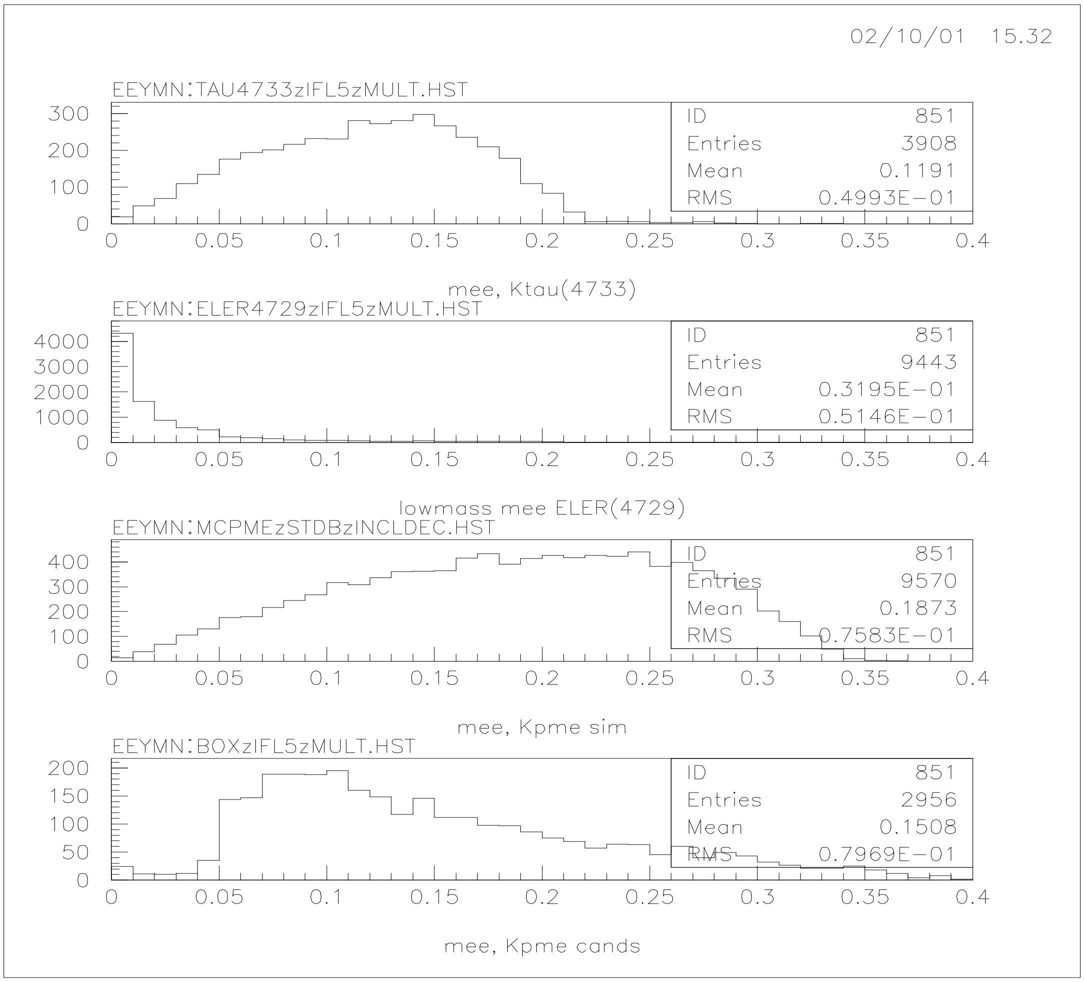

Figure 21: The mee (effective mass of two particles, each taken as electrons) distribution for different classes of events. From top to bottom: a) Tau; b) ELER events (from π^0 Dalitz decays); c) Kpme, simulated; and d) Kpme candidates from the data.

The distribution for their product (probkin), is shown in Figure 23.

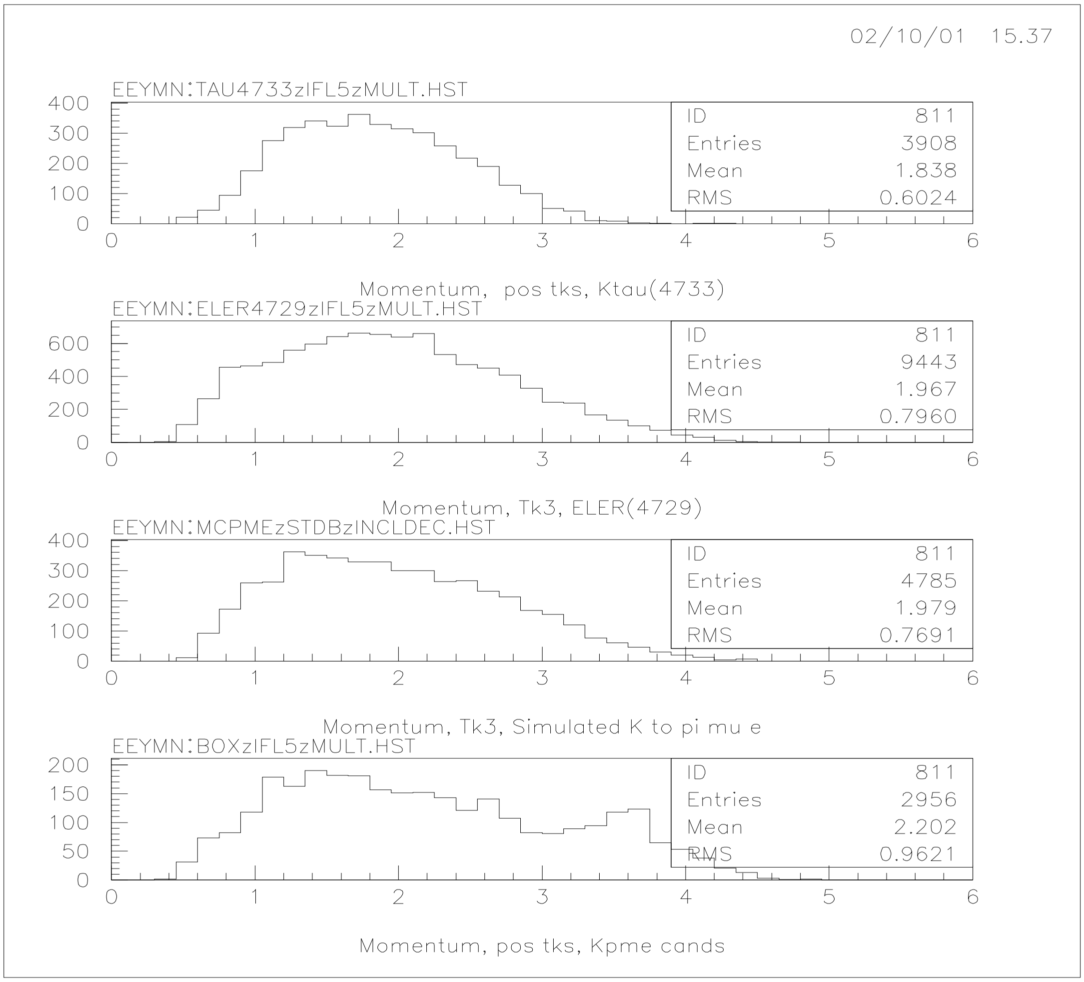

Figure 22: Momentum of the "third" track (the positive track least likely to be a member of a low-mass pair with the negative track in the vertex). From top to bottom: a) Tau; b) ELER events (from π^0 Dalitz decays); c) Kpme, simulated; and d) Kpme candidates from the data.

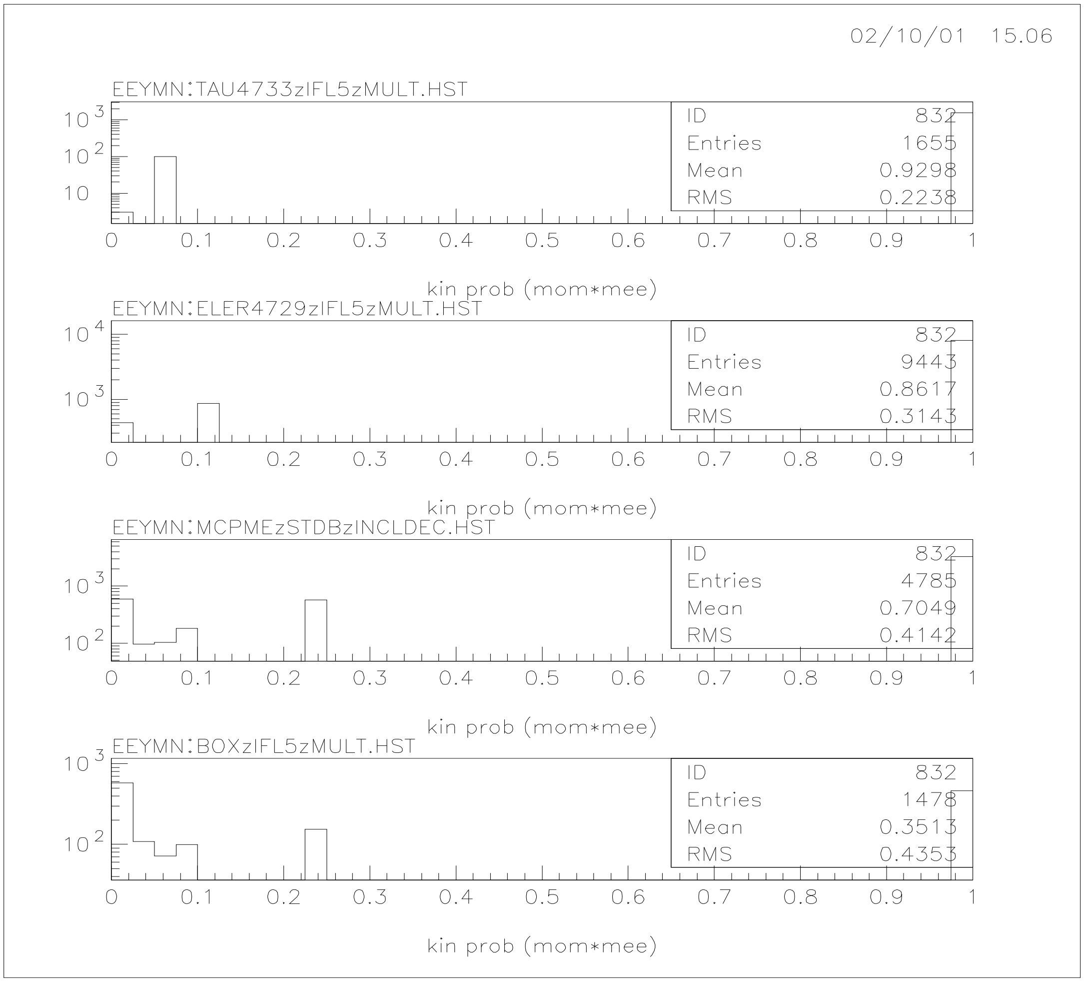

Figure 23: probkin (Kinematic Probability: Pmom*Pmee. From top to bottom: a) Tau; b) ELER events (from π^0 Dalitz decays); c) Kpme, simulated; and d) Kpme candidates from the data.

5.7 The event probability

is the $P_{topographical} * P_{kinematics}$. In figure 24 the event probability for each decay is placed side by side so they can be compared.

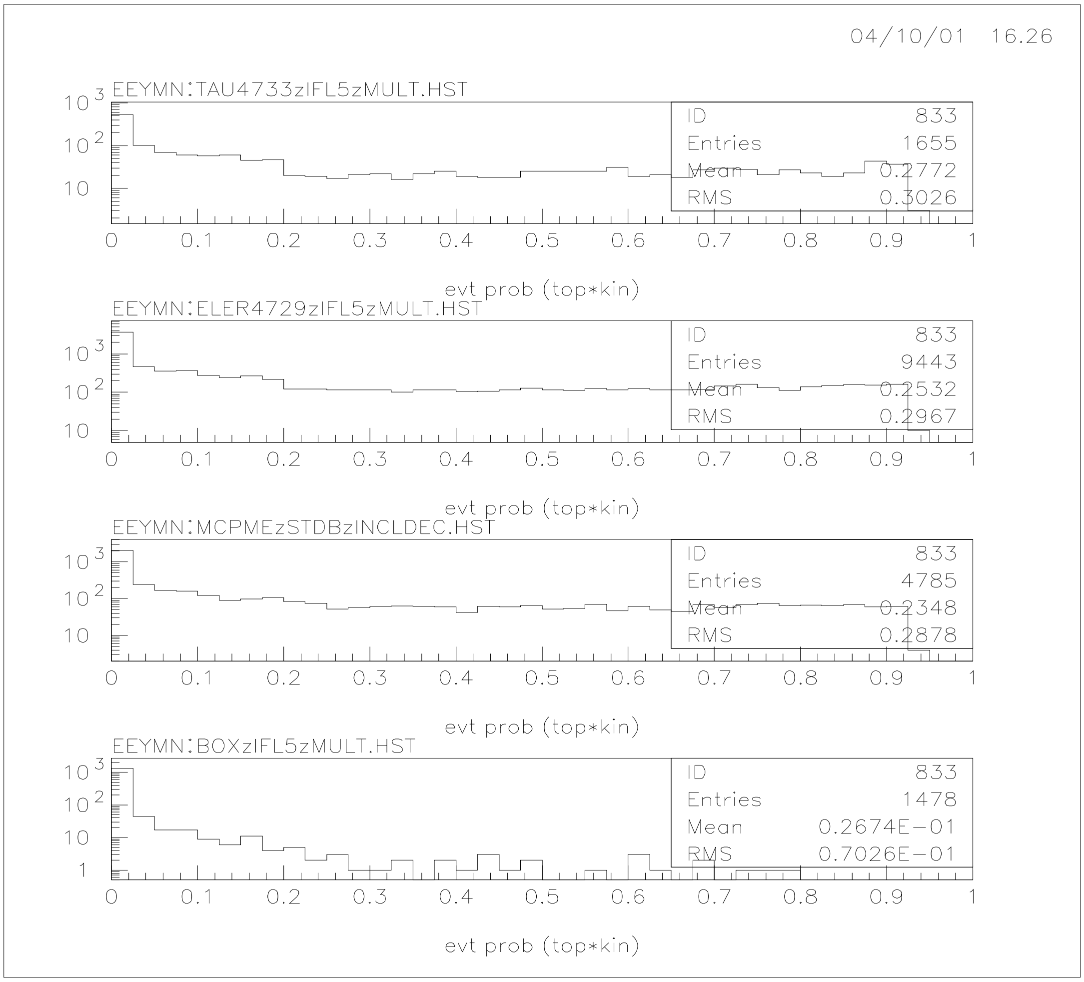

Figure 24: Probevt (Event Probability: Probtop*Probkin. From top to bottom: a) Tau; b) ELER events (from π^0 Dalitz decays); c) Kpme, simulated; and d) Kpme candidates from the data.

The Tau and Dalitz decays are similar; however the Kpme candidates are quite different.

5.8 Kpme Candidate Sample.

The probabilities prepared above were applied to the Kpme candidate sample.

After a cut on event probability, removing those with probability less than 0.2, we are left with 687 tau events (from a sample of 1954 selected with good Ktau mass and momentum) from run 4733, and 3642 ELER events (from an original sample of 9443 events)from run 4729. These two runs are comparable in their sequence, only by happenstance did we choose one for taus and one for ELER). Of the "BOX", or Kpme candidates, of the original 1478 events, only 33 remain.

The effects of the previous cutting method and the present probability method are compared in Table 5.8

Table 20: Comparison of the effect of "Cuts" on characteristics of event samples, with a cut on overall probability.

Cut	N_{TAU}	N_{ELER}	$N_{Kpmesim}$	$N_{Kpmecand}$
In File	1954	9443	4785	1478
Prev. cuts	483	2825	1396	47
Prob. > 0.2	687	3642	1777	33

We see that even this very rough probability treatment is more effective than simply cutting on event characteristics, keeping 30-40% more of the normalizing modes and only 70% as much of the Kpme candidates. It would seem useful to extend the technique by a more careful determination of the probabilities and by including the X-positions of the positive tracks in the probability.

5.9 Kinematic Interpretation of Selected Events

The scatterplots for the events interpreted as Ktau are shown in Figure 25, interpreted as Kdal in Figure 26, and interpreted as Kpme in Figure 27.

Table 5.9 gives some quantities of interest for the ten events which have probevt greater than 0.5.

Only one event (10444344) has momentum and effective pimue mass consistent with a beam kaon decay to this mode.

A picture of this event is shown in Figure 28 and a more detailed summary of this event is given in Appendix 8. Timing would remove this event, but we do not use timing information, since we are trying to assess the usefulness of other discriminators against false events. In this event, the muon candidate also goes close to the beam line. The spatial information should be used, and certainly can remove background events preferentially, but we have not yet made a systematic study of it.

We are able to see the particles as they move in our apparatus. The muon track appears to be in an area not covered by the Cerenkov counters, and such events should probably be removed, but we have not completed this study.

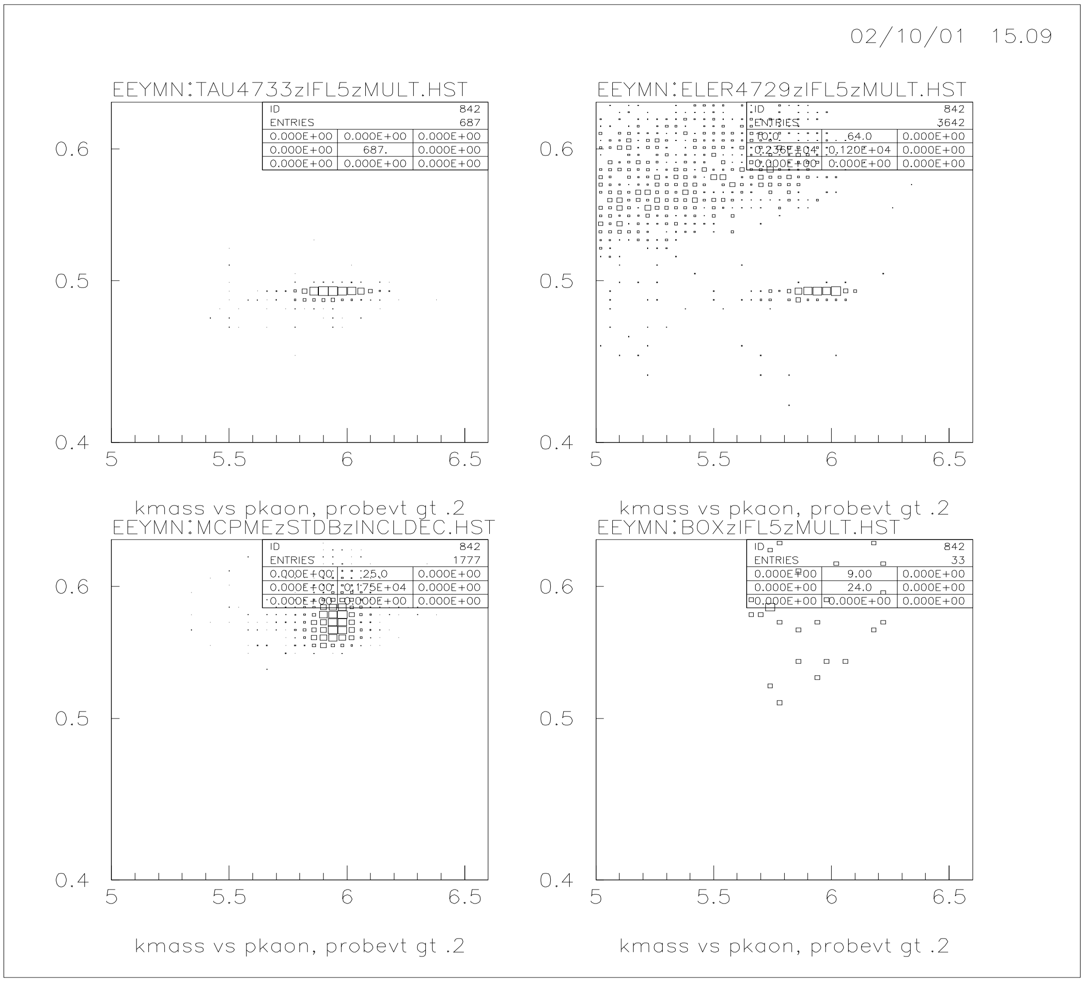

Figure 25: Events interpreted as the Ktau (K to $pi^+\pi^+\pi^-$), scatterplot of effective mass versus momentum of the three charged tracks. a) Top Left: Tau's ; b) Top right: Eler; c) Bottom left: Kpme, simulated; d) Bottom right: Kpme, candidates in the data.

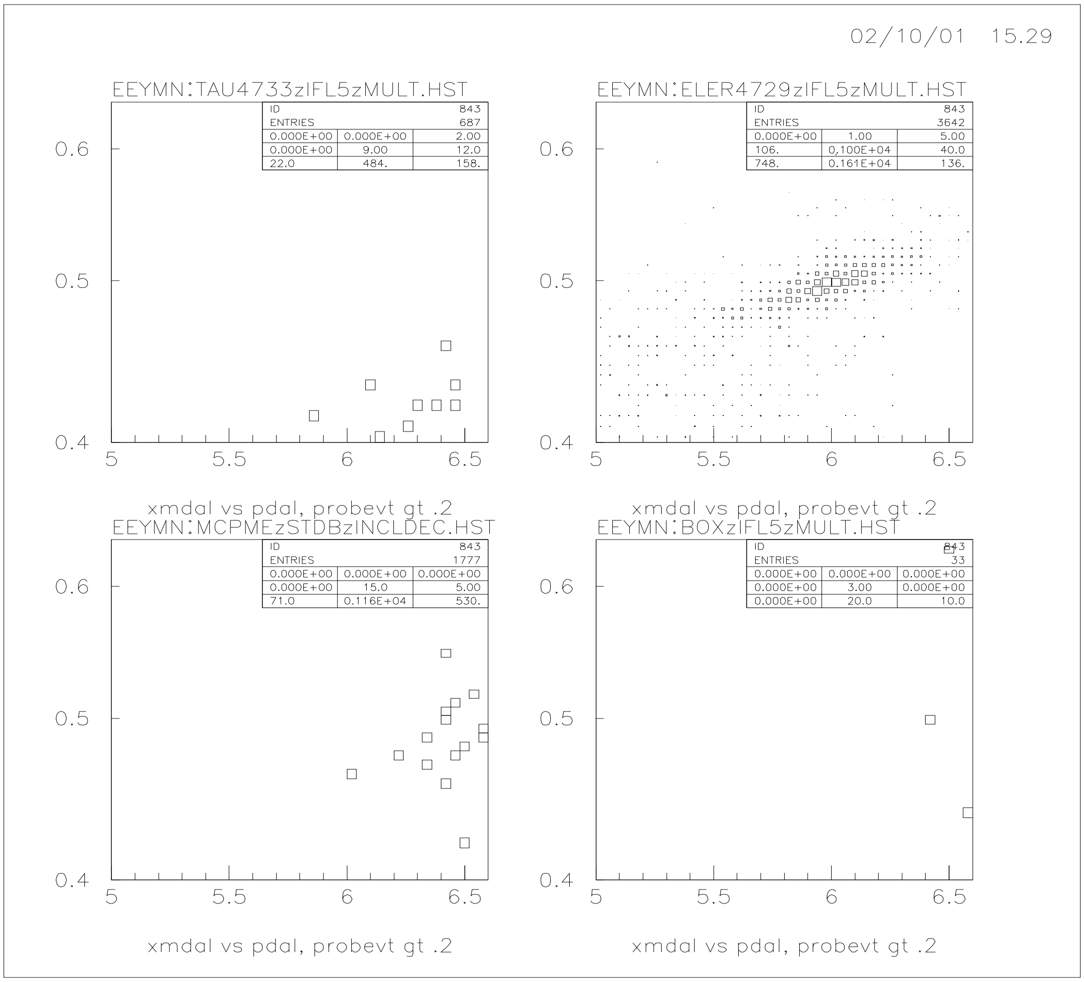

Figure 26: Events interpreted as the Kdal (K to $pi^+\pi^0$, with $\pi^0 \to \gamma e^+e^-$), scatterplot of effective mass versus momentum of the three charged particles and the photon from the π^0 decay. a) Top Left: Tau's ; b) Top right: Eler; c) Bottom left: Kpme, simulated; d) Bottom right: Kpme, candidates in the data.

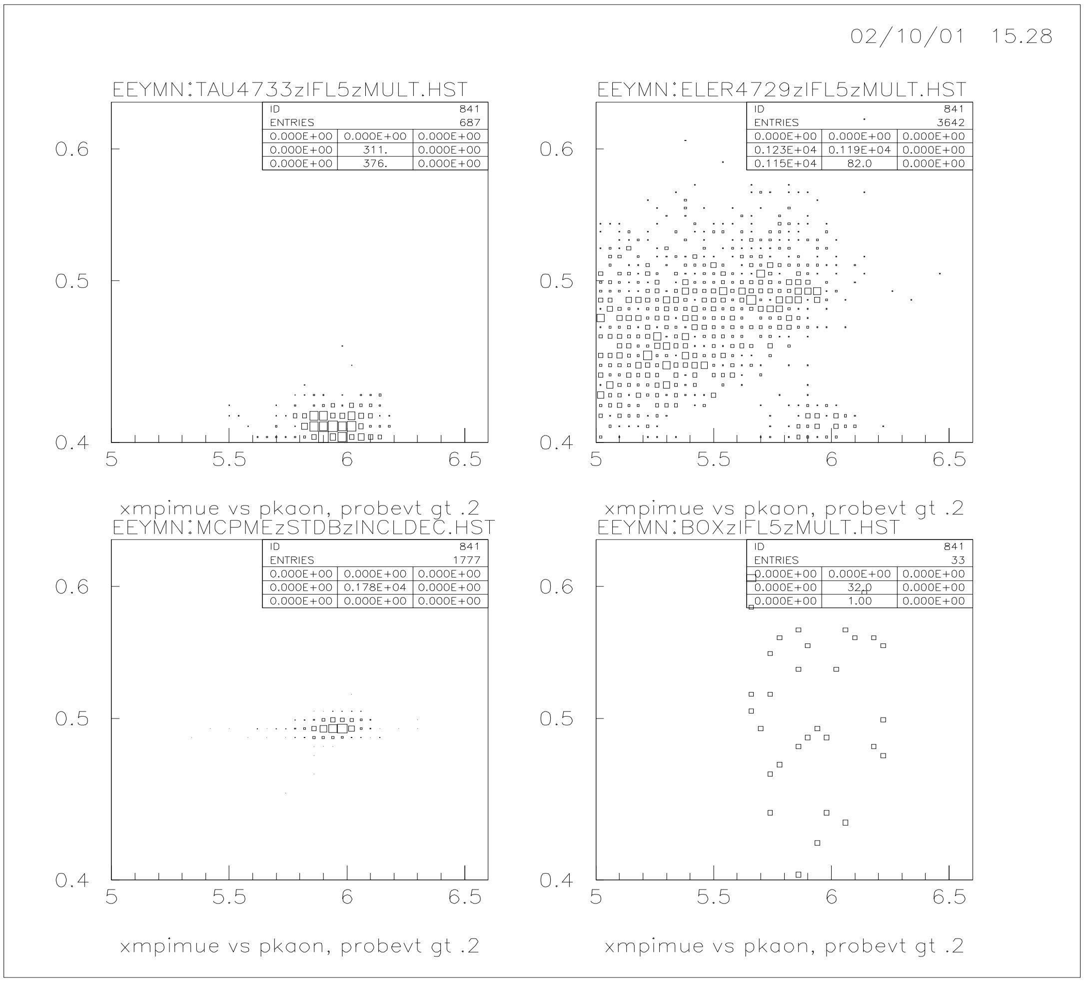

Figure 27: Events interpreted as the Kpme (K to $pi^{+}\mu^{+}e^{-}$), scatterplot of effective mass versus momentum of the three charged tracks. a) Top Left: Tau's ; b) Top right: Eler; c) Bottom left: Kpme, simulated; d) Bottom right: Kpme, candidates in the data.

Table 21: Information about out of time Kpme candidates with probevt greater than 0.5

```
   Out of time Kpme candidates with probevt greater than 0.50

pimue ?:run,event,probevt,top,kin: 4708.  619685. 0.690 0.701 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.745 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  5.66  0.606

pimue ?:run,event,probevt,top,kin: 4198. 3129467. 0.618 0.627 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.667 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  6.23  0.473

pimue ?:run,event,probevt,top,kin: 4227.  965893. 0.601 0.610 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.649 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  5.65  0.582

pimue ?:run,event,probevt,top,kin: 4562.  708947. 0.763 0.775 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.824 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  6.15  0.592

pimue ?:run,event,probevt,top,kin: 4582.   97180. 0.725 0.736 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.783 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  5.77  0.468

pimue ?:run,event,probevt,top,kin: 4633.10444344. 0.785 0.797 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.847 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  5.97  0.490

pimue ?:run,event,probevt,top,kin: 4708.  619685. 0.690 0.701 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.745 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  5.66  0.606

pimue ?:run,event,probevt,top,kin: 4730.10859125. 0.571 0.580 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.616 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  5.94  0.423

pimue ?:run,event,probevt,top,kin: 3977.10416412. 0.642 0.651 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.693 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  6.11  0.558

pimue ?:run,event,probevt,top,kin: 4006.    7972. 0.607 0.617 0.985
probmu,tk,vtx,busy:  0.950 1.000 0.656 0.990
probmom,mee,pkaon,xmpimue: 0.995 0.990  6.24  0.552
```

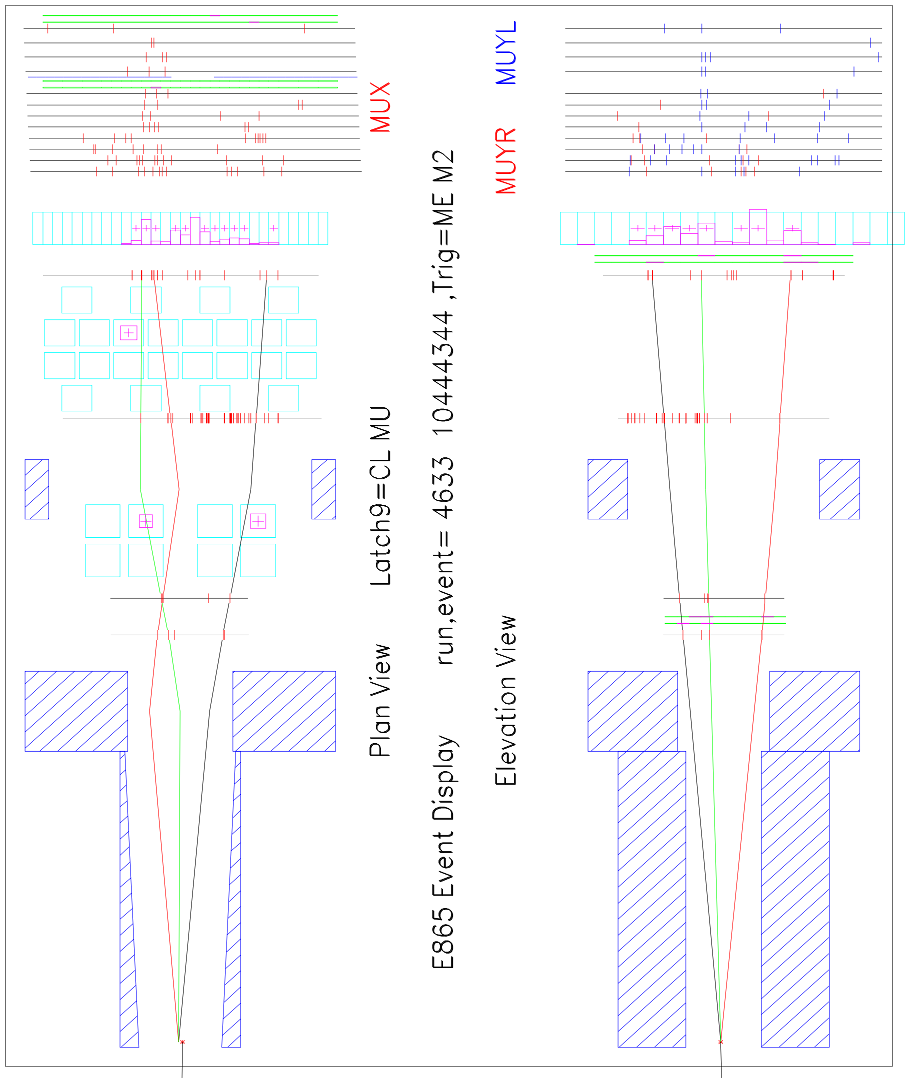

Figure 28: Picture of the Kpme candidate which satisfies all selection criteria except for timing (which had already been applied in these events).

References

[1] Fernow, Richard. **Introduction to Experimental Particle Physics**, Cambridge, University Press, 1986.

[2] Schwarz, Cindy. **A Tour of the Subatomic Zoo, A guide to Physics (Elementary Particle Physics?)**, 2nd. Ed. Library of Congress, New York, 1997.

[3] Smith, Anne J., **Magnetic Field Comparison of D6**, REUP-FOM Summer 2000. February 2001.

[4] D. Bergman. *A search for the decay* $K^+ \to \pi^+\mu^+e^-$. PhD thesis, Yale University, (1997).

[5] S. Pislak. *Experiment E865 at BNL: A search for the decay* $K^+ \to \pi^+\mu^+e^-$. PhD thesis, University of Zürich, (1997).

6 Appendix 1: Kinematics of Kaon decays

This appendix was not transcribed into latex.

7 Appendix 2: Characteristics of small Kpme candidate sample.

This information is now in Table 4.1.

8 Appendix 3: Flow Chart for Pass1-jt.for

This information was prepared in the process of extending the ntuple. This appendix was not transcribed into latex.

9 Appendix 4: Ntuple Contents

List of quantities (and their range in our Kpme candidate sample) available in the "ntuple" or compact data file from which we can make plots and carry out final analysis work. The quantities from 247 on were added in summer, 2001.

```
********************************************************
* NTUPLE ID=  100  ENTRIES=   1478    DALITZes
********************************************************
*  Var numb  *   Name    *    Lower     *    Upper     *
********************************************************
*      1     *  NWP1     * 0.200000E+01 * 0.140000E+03 *
*      2     *   NWP2    * 0.100000E+02 * 0.291000E+03 *
*      3     *  NWP3     * 0.150000E+02 * 0.614000E+03 *
*      4     *  NWp4     * 0.140000E+02 * 0.520000E+03 *
*      5     *   nsp14   * 0.704040E+05 * 0.992103E+08 *
```

6	runum	0.376400E+04	0.473300E+04
7	regi9	0.000000E+00	0.864000E+03
8	NSPp4	-.100000E+05	-.100000E+05
9	NCLMP	0.300000E+01	0.150000E+02
10	EC1	0.107094E+00	0.515517E+01
11	EC2	0.111241E+00	0.573468E+01
12	EC3	0.821328E-01	0.413553E+01
13	XC2_1	-.150876E+03	0.985623E+01
14	XC2_2	0.959794E+01	0.151628E+03
15	XC2_3	-.150379E+03	0.948925E+02
16	YC2_1	-.731076E+02	0.760833E+02
17	YC2_2	-.697756E+02	0.755229E+02
18	YC2_3	-.781871E+02	0.746367E+02
19	tsh1	-.992325E+01	0.988550E+01
20	tsh2	-.994425E+01	0.844175E+01
21	nelec	0.200000E+01	0.200000E+01
22	IQUAD1	0.100000E+01	0.300000E+01
23	IQUAD2	0.200000E+01	0.400000E+01
24	S	0.924320E-02	0.986114E+03
25	KMASS	0.420166E+00	0.745178E+00
26	ZK	-.576656E+03	0.610000E+02
27	ntrack	0.300000E+01	0.700000E+01
28	ninvtx	0.300000E+01	0.300000E+01
29	ep1	0.274451E-01	0.375412E+01
30	EP2	-.287981E+01	-.480335E-01
31	PE1	0.000000E+00	0.164993E+02
32	PE2	0.000000E+00	0.282996E+02
33	X1	-.645279E+02	-.133214E-01
34	X2	0.354408E+00	0.643673E+02
35	Y1	-.322702E+02	0.376013E+02
36	Y2	-.295545E+02	0.329899E+02
37	E1	0.107094E+00	0.515517E+01
38	E2	0.111241E+00	0.573468E+01
39	EVENT	0.970000E+02	0.126298E+08
40	C1LEFT	-.818130E+00	0.130404E+02
41	C1RIGHT	-.535014E+01	0.188648E+02
42	XM1	-.147095E+03	-.799268E+01
43	XM2	0.195852E+02	0.138367E+03
44	TXM1	-.239404E+00	0.148785E-01
45	TXM2	0.163650E-01	0.223542E+00
46	YM1	-.490704E+02	0.527452E+02
47	YM2	-.486244E+02	0.551794E+02
48	TYM1	-.981290E-01	0.103776E+00
49	TYM2	-.990742E-01	0.949550E-01
50	E24_1	0.525828E-01	0.105154E+01
51	E24_2	0.102381E+00	0.100257E+01
52	PKAON	0.243884E+01	0.649647E+01
53	C1f1adC	-.815150E+00	0.188648E+02

54	C1f2adC	-.171110E+01	0.669888E+01
55	C1f3adC	-.793500E-01	0.116787E+02
56	C1f4adC	-.919270E+00	0.115750E+02
57	C1f5adC	-.101456E+01	0.906249E+01
58	C1f6adC	-.180933E+01	0.106546E+02
59	C1f7adC	-.100768E+01	0.101523E+02
60	C1f8adC	-.805560E+00	0.685526E+01
61	C1f1tdC	-.163250E+02	0.999000E+03
62	C1f2tdC	-.182000E+02	0.999000E+03
63	C1f3tdC	-.540000E+01	0.999000E+03
64	C1f4tdC	-.437500E+01	0.999000E+03
65	C1f5tdC	-.156500E+02	0.999000E+03
66	C1f6tdC	-.190750E+02	0.999000E+03
67	C1f7tdC	-.467500E+01	0.999000E+03
68	C1f8tdC	-.770000E+01	0.999000E+03
69	C2A1ADC	-.125000E+01	0.936757E+01
70	C2A2ADC	-.104625E+01	0.303782E+01
71	C2A3ADC	-.992250E+00	0.128845E+02
72	C2A4ADC	-.114954E+01	0.704704E+01
73	C2A5ADC	-.950780E+00	0.582902E+01
74	C2A6ADC	-.714150E+00	0.540277E+01
75	C2B1ADC	-.126600E+00	0.842697E+01
76	C2B2ADC	-.919270E+00	0.745833E+01
77	C2B3ADC	-.540960E+00	0.672672E+01
78	C2B4ADC	-.658860E+00	0.203869E+02
79	C2B5ADC	-.761110E+00	0.894959E+01
80	C2B6ADC	-.867210E+00	0.714758E+01
81	C2C1ADC	-.157584E+01	0.879726E+01
82	C2C2ADC	-.857850E+00	0.232353E+02
83	C2C3ADC	-.112500E+01	0.221766E+02
84	C2C4ADC	-.118320E+01	0.770355E+01
85	C2C5ADC	-.850770E+00	0.292446E+01
86	C2C6ADC	-.103776E+01	0.128128E+02
87	C2D1ADC	-.181860E+01	0.210562E+02
88	C2D2ADC	-.770850E+00	0.783983E+01
89	C2D3ADC	-.815290E+00	0.806500E+01
90	C2D4ADC	-.731640E+00	0.804285E+01
91	C2D5ADC	-.113162E+01	0.139793E+02
92	C2D6ADC	-.107569E+01	0.956685E+01
93	C2A1TDC	-.201500E+02	0.999000E+03
94	C2A2TDC	-.187250E+02	0.999000E+03
95	C2A3TDC	-.200250E+02	0.999000E+03
96	C2A4TDC	-.185250E+02	0.999000E+03
97	C2A5TDC	-.168000E+02	0.999000E+03
98	C2A6TDC	-.122500E+02	0.999000E+03
99	C2B1TDC	-.199000E+02	0.999000E+03
100	C2B2TDC	-.133000E+02	0.999000E+03
101	C2B3TDC	-.737500E+01	0.999000E+03

102	C2B4TDC	-.111000E+02	0.999000E+03	
103	C2B5TDC	-.457500E+01	0.999000E+03	
104	C2B6TDC	-.106250E+02	0.999000E+03	
105	C2C1TDC	-.138000E+02	0.999000E+03	
106	C2C2TDC	-.101250E+02	0.999000E+03	
107	C2C3TDC	-.113500E+02	0.999000E+03	
108	C2C4TDC	-.307500E+01	0.999000E+03	
109	C2C5TDC	-.103000E+02	0.999000E+03	
110	C2C6TDC	-.132250E+02	0.999000E+03	
111	C2D1TDC	-.690000E+01	0.999000E+03	
112	C2D2TDC	-.862500E+01	0.999000E+03	
113	C2D3TDC	-.745000E+01	0.999000E+03	
114	C2D4TDC	-.622500E+01	0.999000E+03	
115	C2D5TDC	-.148250E+02	0.999000E+03	
116	C2D6TDC	-.602500E+01	0.999000E+03	
117	NBMUS	0.100000E+01	0.190000E+02	
118	NCMUS	0.100000E+01	0.220000E+02	
119	XM3	-.133446E+03	0.561165E+02	
120	YM3	-.552642E+02	0.617808E+02	
121	TXM3	-.213169E+00	0.618994E-01	
122	xmee	0.195313E-02	0.384652E+00	
123	XMPIZ	-.100000E+05	0.535719E+00	
124	PDAL	0.000000E+00	0.161064E+02	
125	XMDAL	-.100000E+05	0.718219E+00	
126	XGAM	-.100000E+05	0.152461E+03	
127	YGAM	-.100000E+05	0.844942E+02	
128	EGAM	-.100000E+05	0.104176E+02	
129	xmpimue	0.285270E+00	0.653757E+00	
130	FLMU1	0.000000E+00	0.110000E+02	
131	FLMU2	0.000000E+00	0.110000E+02	
132	FLMU3	0.000000E+00	0.110000E+02	
133	TRIGWD	0.514580E+05	0.647780E+05	
134	XMLEP	-.100000E+05	0.802173E+01	
135	CLOCK	-.352645E+06	0.238306E+07	
136	DCLOCK	0.000000E+00	0.163868E+07	
137	DSECDT	0.000000E+00	0.267427E-01	
138	DTZDT	-.718032E+02	0.263058E+01	
139	DA90DT	0.000000E+00	0.112275E+01	
140	DIONDT	0.000000E+00	0.670758E-01	
141	R1MHZCLK	0.000000E+00	0.100000E+01	
142	R2EOS	0.000000E+00	0.113547E+00	
143	R3LSEC	0.000000E+00	0.125128E+03	
144	R4A90	0.000000E+00	0.138992E+01	
145	R5CLAN	0.000000E+00	0.332925E+03	
146	R6C2LOR	0.000000E+00	0.525766E+02	
147	R7C2ROR	0.000000E+00	0.143003E+02	
148	R8C1LOR	0.000000E+00	0.100507E+03	
149	R9C1ROR	0.000000E+00	0.323499E+02	

```
*    150     * R10PME    * 0.000000E+00 * 0.529415E+00 *
*    151     * R11EEPS   * 0.000000E+00 * 0.562798E+00 *
*    152     * R12MT     * 0.000000E+00 * 0.223826E+02 *
*    153     * R13CLOR   * 0.000000E+00 * 0.399160E+04 *
*    154     * R14T1PR   * 0.000000E+00 * 0.201788E-02 *
*    155     * R15IONCH  * 0.000000E+00 * 0.742762E-02 *
*    156     * R16MHZCL  * 0.000000E+00 * 0.100000E+01 *
*    157     * R17CAM1   * 0.000000E+00 * 0.146760E+01 *
*    158     * R18CAM2   * 0.000000E+00 * 0.207916E+00 *
*    159     * R19CAM3   * 0.000000E+00 * 0.659657E-01 *
*    160     * R20CLAN   * 0.000000E+00 * 0.657588E-01 *
*    161     * R21CLOR   * 0.000000E+00 * 0.357715E+01 *
*    162     * R22CKAN   * 0.000000E+00 * 0.440387E+01 *
*    163     * R23A4SEC  * 0.000000E+00 * 0.173693E+01 *
*    164     * ta1       * -.998865E+01 * 0.985905E+01 *
*    165     * ta2       * -.991520E+01 * 0.971275E+01 *
*    166     * ptrans    * 0.238156E-02 * 0.421451E+00 *
*    167     * C1F1HTD   * -.131250E+02 * 0.999000E+03 *
*    168     * C1F2HTD   * -.121500E+02 * 0.999000E+03 *
*    169     * C1F5HTD   * -.147500E+01 * 0.999000E+03 *
*    170     * C1F6HTD   * -.131250E+02 * 0.999000E+03 *
*    171     * C2A1HTD   * -.151000E+02 * 0.999000E+03 *
*    172     * C2A2HTD   * -.992500E+01 * 0.999000E+03 *
*    173     * C2A3HTD   * -.957500E+01 * 0.999000E+03 *
*    174     * C2A4HTD   * -.532500E+01 * 0.999000E+03 *
*    175     * C2A5HTD   * -.167000E+02 * 0.999000E+03 *
*    176     * C2A6HTD   * -.827500E+01 * 0.999000E+03 *
*    177     * C2C1HTD   * -.164250E+02 * 0.999000E+03 *
*    178     * C2C2HTD   * -.110000E+01 * 0.999000E+03 *
*    179     * C2C3HTD   * -.850000E+01 * 0.999000E+03 *
*    180     * C2C4HTD   * -.850000E+00 * 0.999000E+03 *
*    181     * C2C5HTD   * -.362500E+01 * 0.999000E+03 *
*    182     * C2C6HTD   * 0.860000E+01 * 0.999000E+03 *
*    183     * C1F2iad   * 0.420000E+03 * 0.139300E+04 *
*    184     * C1F6iad   * 0.497000E+03 * 0.215600E+04 *
*    185     * C2A1iad   * 0.466000E+03 * 0.219300E+04 *
*    186     * C2A3iad   * 0.419000E+03 * 0.133000E+04 *
*    187     * C2B1iad   * 0.524000E+03 * 0.243700E+04 *
*    188     * C2C1iad   * 0.454000E+03 * 0.168400E+04 *
*    189     * C2C3iad   * 0.496000E+03 * 0.443900E+04 *
*    190     * C2D1iad   * 0.477000E+03 * 0.395200E+04 *
*    191     * C1F2ead   * 0.587000E+03 * 0.117400E+04 *
*    192     * C1F6ead   * 0.428000E+03 * 0.951000E+03 *
*    193     * C2A1ead   * 0.473000E+03 * 0.162000E+04 *
*    194     * C2A3ead   * 0.462000E+03 * 0.180700E+04 *
*    195     * C2B1ead   * 0.527000E+03 * 0.128900E+04 *
*    196     * C2C1ead   * 0.472000E+03 * 0.166500E+04 *
*    197     * C2C3ead   * 0.441000E+03 * 0.169600E+04 *
```

```
*    198     * C2D1ead   * 0.430000E+03 * 0.779000E+03 *
*    199     * chsq1     * 0.570450E-01 * 0.683540E+02 *
*    200     * chsq2     * 0.611021E-01 * 0.387889E+02 *
*    201     * chsq3     * 0.556340E-01 * 0.443555E+02 *
*    202     * chsq4     * -.100000E+05 * -.100000E+05 *
*    203     * ep3       * 0.246072E-01 * 0.783133E+01 *
*    204     * Ep4       * -.100000E+05 * 0.155562E+02 *
*    205     * XM4       * -.100000E+05 * 0.134385E+03 *
*    206     * YM4       * -.100000E+05 * 0.509854E+02 *
*    207     * TXM4      * -.100000E+05 * 0.116747E+00 *
*    208     * XC2_4     * -.100000E+05 * 0.147301E+03 *
*    209     * YC2_4     * -.100000E+05 * 0.794445E+02 *
*    210     * blank     * -.100000E+05 * -.100000E+05 *
*    211     * C1F22TD   * 0.000000E+00 * 0.108900E+04 *
*    212     * C1F62TD   * 0.000000E+00 * 0.112500E+04 *
*    213     * C2A12TD   * 0.000000E+00 * 0.131700E+04 *
*    214     * C2A32TD   * 0.000000E+00 * 0.113900E+04 *
*    215     * C2B12TD   * 0.000000E+00 * 0.113500E+04 *
*    216     * C2C12TD   * 0.000000E+00 * 0.103900E+04 *
*    217     * C2C32TD   * 0.000000E+00 * 0.103700E+04 *
*    218     * C2D12TD   * 0.000000E+00 * 0.409500E+04 *
*    219     *  Xmc      * -.100000E+05 * -.100000E+05 *
*    220     * Ymc       * -.100000E+05 * -.100000E+05 *
*    221     *  Zmc      * -.100000E+05 * -.100000E+05 *
*    222     *  Xvtx     * -.215576E+02 * 0.194110E+02 *
*    223     * Yvtx      * -.102679E+02 * 0.976701E+01 *
*    224     *  Zvtx     * -.576656E+03 * 0.610000E+02 *
*    225     *  txvr1    * -.110132E+00 * 0.144050E+00 *
*    226     *  tyvr1    * -.108283E+00 * 0.114389E+00 *
*    227     *  txvL2    * -.162263E+00 * 0.155954E+00 *
*    228     *  tyvL2    * -.101035E+00 * 0.114740E+00 *
*    229     *  txvr3    * -.112998E+00 * 0.143328E+00 *
*    230     *  tyvr3    * -.111906E+00 * 0.101246E+00 *
*    231     *  pxvmc1   * -.100000E+05 * -.100000E+05 *
*    232     *  pyvmc1   * -.100000E+05 * -.100000E+05 *
*    233     *  pzvmc1   * -.100000E+05 * -.100000E+05 *
*    234     *  pxvmc2   * -.100000E+05 * -.100000E+05 *
*    235     *  pyvmc2   * -.100000E+05 * -.100000E+05 *
*    236     *  pzvmc2   * -.100000E+05 * -.100000E+05 *
*    237     *  pxvmc3   * -.100000E+05 * -.100000E+05 *
*    238     *  pyvmc3   * -.100000E+05 * -.100000E+05 *
*    239     *  pzvmc3   * -.100000E+05 * -.100000E+05 *
*    240     *  chiprob  * 0.235677E-03 * 0.100000E+01 *
*    241     *  sumtxch  * 0.249825E-03 * 0.275171E+05 *
*    242     *  sumtych  * -.647397E+02 * 0.148721E+05 *
*    243     *  sumtpch  * -.166311E+04 * 0.399519E+04 *
*    244     *  xmcdec   * -.100000E+05 * -.100000E+05 *
*    245     * ymcdec    * -.100000E+05 * -.100000E+05 *
```

```
*    246     * zmcdec    * -.100000E+05 * -.100000E+05 *
*    247     *  xme1     * 0.138107E-02 * 0.427614E+00 *
*    248     *  tsh3     * -.995950E+01 * 0.961400E+01 *
*    249     *  tsh4     * -.100000E+05 * 0.987100E+01 *
*    250     *  ta3      * -.980105E+01 * 0.998090E+01 *
*    251     *  ta4      * -.100000E+05 * 0.987945E+01 *
*    252     * PEC1_1    * 0.000000E+00 * 0.827904E+01 *
*    253     * PEC1_2    * 0.000000E+00 * 0.116787E+02 *
*    254     * PEC1_3    * 0.000000E+00 * 0.106546E+02 *
*    255     * PEC1_4    * -.100000E+05 * 0.771375E+01 *
*    256     * pec2_1    * 0.000000E+00 * 0.117025E+02 *
*    257     * pec2_2    * 0.000000E+00 * 0.210562E+02 *
*    258     * pec2_3    * 0.000000E+00 * 0.686694E+01 *
*    259     * pec2_4    * -.100000E+05 * 0.139916E+02 *
*    260     * blank     * -.100000E+05 * -.100000E+05 *
*******************************************************
```

10 Appendices 5-7: Losses of Ktau, Eler, and Kpme Candidate Events to Cuts

This information is now given in Table 4.2

11 Appendix 8: Kpme candidate with Probevt > 0.5

Tables 11 - 11 give information about the Kpme candidate which passed all cuts. Table 11 gives

Table 22: Calorimeter information about the Kpme event which satisfies all Kpme criteria except for good timing.

```
RUN and EVENT 4633 10444344
 Shower Counter hits  (with some TDC timing signal)
   IX        IY       GEV       NS
        6        15    0.1147    7.8749
        9         9    0.1517    1.3570
        9        11    0.1002   26.4958
       10         9    0.1512    1.5851
       10        12    0.1090    2.8679
       10        13    0.0744   -1.0431
       11         9    0.1199    5.7914
       11        10    0.0844    4.6254
       11        15    0.0932    4.7241
       12        16    0.0883    2.7254
       13         7    0.2489   10.4572
       13         8    0.0987   20.2127
       13         9    0.1909   19.8512
       13        15    0.1631    2.5880
       14         8    0.1438   20.3979
       14         9    1.5048   20.6737
       15         7    0.3291   22.1163
       15        14    0.1857    2.7796
       16        14    0.8053    1.1229
       17        13    0.0802  -17.0370
       17        14    0.0885  -13.1920
       18        16    0.1274    1.7314
       19         7    0.2284   -1.1006
       19        12    1.0173   -0.9303
       19        13    0.2886   -0.6472
       20         6    0.0122  -18.3024
       20        12    0.1224   -4.1777
       20        13    0.1129    0.5006
```

information about clumps found in the calorimeter, and reconstructed tracks. Table 11 gives information about the scintillator counters again.

Table 26 gives informaiton about how the information above is combined.

Table 23: Formation about Event 1044... from scintillator arrays and Cerenkov counters C1 and C2.

IX	IY	GEV	NS
Scintillator counter A			
1	3	0.0000	-2.1705
1	4	0.0000	8.8968
1	6	0.0130	24.1098
1	9	0.0000	32.9060
1	12	0.0000	3.0247
2	4	0.0000	0.0962
2	9	0.0038	0.0887
Scintillator counter B			
16	1		-6.0108
16	2		31.3520
Scintillator counter C			
1	1		22.9730
6	1		2.3620
17	1		14.1342
10	2		-1.3100
11	2		24.8943
16	2		32.3693
19	2		43.8418
QUAD	TUBE	P.E.	NS
Cerenkov Counter 1			
3	1	2.7154	-1.3500
4	1	2.2786	-0.1750
Cerenkov Counter 2			
2	2	3.2605	-2.4500

Number of Eclumps, photon = 10 0

Table 24: Calorimeter clumps and tracks

```
clump   Eclump     x      y   E22/E33    SHTIM  ATIM  PHOTON
  1      0.335 -32.384  50.306   1.000   2.636   0.768 F
  2      0.175-100.841  49.162   1.000   7.875   6.161 F
  3      0.312 -43.531  50.208   0.606   3.752   2.345 F
  4      0.241  44.640 -49.645   0.949  -1.101  -1.973 F
  5      1.578  45.975  16.006   0.977  -1.030  -2.424 F
  6      1.248   5.710  30.507   0.837   1.433 999.000 F
  7      0.303 -66.573 -25.001   1.000   1.471  24.110 F
  8      0.136  33.382  58.656   1.000   1.731 999.000 F
  9      0.356 -54.673 -18.481   1.000   3.725  24.110 F
 10      0.378 -65.813   6.149   0.550   1.281  32.906 F
  Number of Space Tracks            3
Track flag cl. Spcpt1 Spcpt2 Spcpt3  Spcpt4 CHI2  DXYSH
  1    0    2     3       8     12    64   0.077  2.9
  2    0    4     4       7     14    65   0.881 107.5
  3    0    5     1       6     13    71   0.091  2.3
 Number of fitted tracks            3
Trk  WIRES  CLMP P(GEV)   P1X    P1Y     P4X    P4Y  chi2
  1    FF7F   2   2.96  -49.3   26.93  -100.01  47.4  1.1
  2    FFFF   4   1.30   26.4  -25.19    30.67 -44.3  2.4
  3    BFFF   5  -1.71   14.1    9.37    44.86  15.0  0.8
 Number tracks in vertex             3
  VTXTRK   SPTTRK     FITTRK
        1         1         1
        2         2         2
        3         3         3
  Vertex position=  -2.66       2.11      -444.83
  S              =  0.9893971
  Px,Py,Pz,Ptot  = -6.66E-02  7.87E-02   5.97       5.97
 Particle Id of tracks
TRACK   Bhit Chit MuX  MuY Mchi2 C1pe  C2pe  eop  ELEC MU  PI
  1  999.0  118.9   0   5 999.00  0.00  0.00  0.06 F    F  T
  2    7.2   77.3  12  10   6.13  0.00  0.00  0.19 F    T  T
  3  999.0   40.1  12  10   7.84  2.28  3.26 -0.92 T    F  F
     Xee    Xme    Xpe    Xem    Xmm    Xpm    Xep    Xmp    Xpp
eXX  0.386  0.447  0.488  0.433  0.489  0.526  0.465  0.518  0.553
mXX  0.414  0.472  0.511  0.458  0.511  0.547  0.489  0.539  0.573
pXX  0.434  0.489  0.527  0.476  0.528  0.563  0.506  0.554  0.588
 e+e- ms =   0.143      0.153
```

Table 25: More scintillator information.

```
a counters hit tdc:   3  4  6  9 12 19 24
a ctr values hit tdc:
999.0 999.0  -2.2   8.9 999.0  24.1 999.0 999.0  32.9 999.0
999.0   3.0 999.0 999.0 999.0 999.0 999.0 999.0   0.1 999.0
999.0 999.0 999.0   0.1 999.0 999.0 999.0 999.0 999.0 999.0
ctr,#hits a:adc,tdc, b,c,d tdc:    1   2   7   2  10   8
i,ictr,tdc,j,ictra,adc,yacnt:   1  3  -2.2  0  3    0.  -57.
i,ictr,tdc,j,ictra,adc,yacnt:   2  4   8.9  0  4    0.  -46.
i,ictr,tdc,j,ictra,adc,yacnt:   3  6  24.1  0  6 1091.  -23.
i,ictr,tdc,j,ictra,adc,yacnt:   4  9  32.9  0  9    0.   11.
i,ictr,tdc,j,ictra,adc,yacnt:   5 12   3.0  0 12    0.   46.
i,ictr,tdc,j,ictra,adc,yacnt:   6 19   0.1  0  4    0.  -46.
i,ictr,tdc,j,ictra,adc,yacnt:   7 24   0.1  0  9    0.   11.

d counters hit tdc:   7  9 12 15 16 17 18 19
d ctr tdc values:
999.0 999.0 999.0 999.0 999.0 999.0  -4.8 999.0   3.1 999.0
999.0  -1.3 999.0 999.0  80.7  21.9  -0.3   8.9  15.5 999.0

scdadc values:
  0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
  0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:     7    7  11.0  -4.8   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:     9    9  27.0   3.1   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:    12    2 -29.0  -1.3   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:    15    5  -5.0  80.7   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:    16    6   3.0  21.9   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:    17    7  11.0  -0.3   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:    18    8  19.0   8.9   0.0
d cntr: ictr,ictra,ydcnt,tdc,adc:    19    9  27.0  15.5   0.0

 pbusy,nclmp,ncal  1.33E-02          10           37
 run,event,nshok1         4633    10444344            0
 nshok1,nclump            0           10
```

Table 26: Information from the user routine, combining kinematic and particle id.

```
event,nvtxok,nfvtx,ninvtx:  10444344    0    3    3
 before pittuser, db_nevt,nshok1:            1            1
 IN certst, NEVT:           5
 ENTERING certst, NEVT,inew:            5          -1
 IN certst, NEVT:           6
 ENTERING certst, NEVT,inew:            6           1
 j,iquad,indst,adc           2           2           22   3.26
 nevt,RUN,EVT, bookING           1        4633    10444344
 #PTS P1    33.00000

nevt,icorr,ic,jc      1     1     1     1
adc: raw,corr; tdc: raw,corr:    565 -0.02     0 999.00
c1peds: 568.0  632.0  556.0  586.0  616.0  565.0  670.0  579.0
nevt,icorr,ic,jc      1     1     1     2
adc: raw,corr; tdc: raw,corr:    626 -0.07     0 999.00
nevt,icorr,ic,jc      1     1     2     1
adc: raw,corr; tdc: raw,corr:    554 -0.02     0 999.00
nevt,icorr,ic,jc      1     1     2     2
adc: raw,corr; tdc: raw,corr:    584 -0.01     0 999.00
nevt,icorr,ic,jc      1     1     3     1
adc: raw,corr; tdc: raw,corr:    980  2.72   927  -1.35
nevt,icorr,ic,jc      1     1     3     2
adc: raw,corr; tdc: raw,corr:    559 -0.09     0 999.00
nevt,icorr,ic,jc      1     1     4     1
adc: raw,corr; tdc: raw,corr:    973  2.28   900  -0.17
nevt,icorr,ic,jc      1     1     4     2
adc: raw,corr; tdc: raw,corr:    578 -0.01     0 999.00
```

Table 28 gives final information about the event.

Table 27: More information from the user routine about the event.

```
 nevt,event,iwnt            1    10444344           1
 I,ECLUMP,ethr            1  0.3353882      0.1000000
 I,ECLUMP,ethr            2  0.1749209      0.1000000
 I,ECLUMP,ethr            3  0.3124353      0.1000000
 I,ECLUMP,ethr            4  0.2405562      0.1000000
 I,ECLUMP,ethr            5   1.577650      0.1000000
 I,ECLUMP,ethr            6   1.247896      0.1000000
 I,ECLUMP,ethr            7  0.3029269      0.1000000
 I,ECLUMP,ethr            8  0.1359921      0.1000000
 I,ECLUMP,ethr            9  0.3555118      0.1000000
 I,ECLUMP,ethr           10  0.3782561      0.1000000
 nevt,ntrack           1           3
pittuser:event,ntrack,ninv,FTST   10444344  3  3    0.98
xyz vtx:   -3.   2.-445.
Opening new TGTLIK file, filename = OFLDAT:TGTLIK_97B.DAT
 TCUT,tcutlo   -26.77000      -400.0000
nevt,event,iwnt,ninvtx,S     110444344       1    3   0.98
 ninvtx            3
PX,PY,PZ,E0      -0.17      0.12      2.96      2.97
PX,PY,PZ,E0       0.11     -0.06      1.29      1.31
PX,PY,PZ,E0       0.00      0.02      1.72      1.72
PKAON,xms,,ptrans,PTOT 5.97 0.59 0.10 -0.07  0.08  5.97  6.00
 nevt,ninvtx,NHI, AT 152 LOOP       1         3           3
I,J,P,E,e_p,chisq:    1    2    2.96    0.17    0.06    1.08
I,J,P,E,e_p,chisq:    2    4    1.30    0.24    0.19    2.41
I,J,P,E,e_p,chisq:    3    5   -1.71    1.58   -0.92    0.84
 I,K,P,e_p,xd,yd,xcal,ycal 3  1 -1.7  0.9  18.2 5.1 44.6 15.4
tk:   3 xp1,xmc1,ymc1:    14.09   46.60   11.89
MUID: I,NGX,ngy,bdis:          3         2         11582955.
 il,muonfl            3 F
 tangents at vtx:  -1.3497E-03  1.171E-02
 IN certst, NEVT:           7
 ENTERING certst, NEVT,inew:            7           0
 NOW AT THE END OF certst, NEVT=:,           7
XY CAL,XY C2,PEC1,2   46.0   16.0   45.2   14.5    2.3    3.3
 I,K,P,e_p,xd,yd,xcal,ycal 1 2 3.0 0.1 -53.4  14.5 -102.6 49.1
tk:   1 xp1,xmc1,ymc1:   -49.33  -81.67   35.78
MUID: I,NGX,ngy,bdis:         1       0         04721098.00
 ir,muonfl            1 F
 tangents at vtx:  -5.835E-02  3.954E-02
 IN certst, NEVT:           8
 ENTERING certst, NEVT,inew:            8           0
 NOW AT THE END OF certst, NEVT=:,           8
XY CAL,XY C2,PEC1,2 -100.8   49.2  -97.2   45.6    0.0    0.0
nevt,IMEE,PX,PY,PZ,E0      1     0  -0.17   0.12   2.96   2.96
nevt,IMEE,PX,PY,PZ,E0      1     0   0.00   0.02   1.72   1.72
```

Table 28: Final information about the event.

```
EE PAir MOMENTUM AND MASS:      4.678    0.143
nev,ev,il,ir,xmee,ptot: 1 10444344 3  1  0.143 -0.2  0.1  4.7  4.7
 I,K,P,e_p,xd,yd,xcal,ycal  2  2 1.3  0.2 23.2  -13.8  34.9  -45.7
tk:   2 xp1,xmc1,ymc1:    26.38    1.58  -34.00
 nevt,n           1           2
nev,ev,il,ir,xmee,ptot:    1  10444344  3  1       0.143
ii,i,j,ipi,il,ir:     2    2    4    2    3    1
nevt,IMEE,PX,PY,PZ,E0      1     1   0.11  -0.06   1.29   1.30
nevt,IMEE,PX,PY,PZ,E0      1     1   0.00   0.02   1.72   1.72
EE PAir MOMENTUM AND MASS:      3.012     0.153
nevt,KMASS,PKAON,XMEE,ipi,XME1 1 0.586    5.968  0.143  2  0.153
 hi mass cand           1
HI MEE: EVNT,KMASS,PKAON,XMEE,XME1,PTOT 10444344      0.59      5.97
     0.14      0.15     -0.17      0.14      4.67      4.68
 NZERO,ninvtx           0           3
third tk: ipi,ngx,ngy,bdis     2    2    1      7.23
 muonfl  T
OTHER CH TK: PXYZ,E0  0.109    -0.058     1.294     1.307

noW before xmpme: il,ir,ipi:     3    1    2
ipme,i,ii,PX,PY,PZ,E0   0  1  1  -0.17   0.12   2.96   2.97
ipme,i,ii,PX,PY,PZ,E0   0  2  2   0.11  -0.06   1.29   1.30
ipme,i,ii,PX,PY,PZ,E0   0  3  3   0.00   0.02   1.72   1.72
pi mu e MOMENTUM AND MASS:      5.968     0.489
ipi,ipii,imu,il,ir,ptot: 2         1         2         3         1
     -0.1       0.1       6.0       6.0
POSITION OF POSITRON? AT C1,C2:  1.58    -34.00    -97.21     45.61
 IN certst, NEVT:           9
 ENTERING certst, NEVT,inew:           9           0
 NOW AT THE END OF certst, NEVT=:,           9
 ipi,NZERO           2           0
xmpimue,C1+C2 ON +, -. E-CAND,PI:  0.489   0.0    5.539      0.0
nevt,PTOT,PNU  1 -0.07  0.08  5.97  5.99  0.07 -0.08  0.00  0.10
XMEE,EPIZ,XMPIZ,PDAL,XMDAL   0.143     0.00 -10000. 0.0 -10000.0
ELEP,XMLEP,xmpimue       5.818 -10000.0      0.489
 ACCEPT: nevt,RUN,EVT:           1        4633    10444344
 status for event    10444344           0
```