THE LIFETIME OF

THE D^0 CHARMED MESON

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of the Ohio State University

By

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* * * * * * * *

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ACKNOWLEDGMENTS

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INTRODUCTION

The discovery in 1974 of the J/Ψ (1-2) and the subsequent discovery of the D^0 in 1976 (3) provided the first experimental evidence for the existence of the flavor charm. Proposed ten years earlier as a simple mechanism for explaining the absence of a strangness changing neutral current (4), the flavor charm was predicted to decay weakly.

Several subsequent experiments have attempted to observe the production and decay of charmed particles. Decays of particles with masses greater than the stable strange particles have been observed in emulsion exposures to cosmic rays (5) and accelerator produced protons (6), in the streamer chamber (7), in two emulsion-spectrometer experiments at CERN (8-9), and also in the 15-ft bubble chamber at Fermilab (10).

Only one of the decays (8) seen in these experiments could be fully reconstructed while the others had decay times in the range 0.2 - 52.0 x 10^{-13} seconds.

The experiment described in this paper (E531 at Fermilab) attempts to resolve the ambiguities in the lifetimes of the charmed particles. (Partial results from

this experiment have been published previously. (11-12)) This experiment was designed as a hybrid emulsion-spectrometer with 23 liters of Fuji nuclear emulsion exposed to the single-horn focused neutrino beam at Fermilab. A total of 7.2 x 10^{+18} protons at 350 GeV/c were incident on the neutrino target resulting in 2355 reconstructed events of which 1821 were in the fiducial volume of the emulsion. A total of 1235 events have been found in the emulsion. As of March 1, 1981 all predicted events have been searched for and 90% of the found events have been searched for charm. After searching for decays we have found a total of 20 neutral charmed particle decay candidates.

CHAPTER 1

THEORY

A. GIM Model

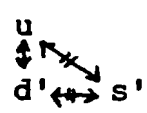
In the model proposed by Glashow, Iliopoulos and Maiani (GIM) (13), a new quark with the quantum number charm is postulated. Since the weak currents are components of an isovector current, the weak currents (before the introduction of charm) could be written as:

$$
\begin{aligned}
J^{+} &= \bar{d}'u \\
J^{-} &= \bar{u}\, d' \\
J^{0} &= \bar{u}\, u \;-\; \bar{d}'d',
\end{aligned}
\qquad (1)
$$

where u is the up quark and d' is a mixture of the down (d) and strange (s) quarks. These are mixed by the Cabibbo angle giving:

$$d' = d \cos\theta_c + s \sin\theta_c$$
$$s' = s \cos\theta_c - d \sin\theta_c. \tag{2}$$

The Cabibbo angle is measured to be approximately .22 radians. This model has two difficulties. First, as can easily be shown, s' is completely ignored by the weak interactions, i.e. there are no transitions between u and s' quarks and d' and s' quarks:



(3)

Second the neutral current J^0 has a strangeness-changing component:

$$\begin{aligned} J^0 &= \bar{u}\, u - \bar{d}'d' \\ &= \bar{u}\, u - \bar{d}\, d \cos^2\theta_c - \bar{d}\, s \cos\theta_c \sin\theta_c \\ &\qquad + \bar{s}\, d \sin\theta_c \cos\theta_c - \bar{s}\, s \sin^2\theta_c. \end{aligned} \tag{4}$$

This is in contradiction with experimental data such as BR($K_L^0 \to \mu^+ \mu^-$) = 9.1×10^{-9} and the small K_L^0 K_S^0 mass difference.

To remedy this situation the GIM model introduces the charmed quark which couples to the s'. Thus the weak currents become:

$$
\begin{aligned}
J^{+} &= \bar{d}'u + \bar{s}'c \\
J^{-} &= \bar{u}\,d' + \bar{c}\,s' \\
J^{0} &= \bar{u}\,u - \bar{d}'d' + \bar{c}\,c - \bar{s}'s' \\
J^{0} &= \bar{u}\,u - \bar{d}\,d + \bar{c}\,c - \bar{s}\,s
\end{aligned}
\tag{5}
$$

which has no strangeness-changing neutral component. The weak currents predict selection rules for charged current transitions which can be broken down into Cabibbo "favored" ($\cos\theta_c$) and "unfavored" ($\sin\theta_c$) modes as follows:

Charm non-changing:	$\Delta Q=1,\ \Delta I=1,\ \Delta S=0$	$\cos\theta_c$
	$\Delta Q=\Delta S=1,\ \Delta I=1/2$	$\sin\theta_c$
Charm changing:	$\Delta Q=\Delta C=\Delta S,\ \Delta I=0$	$\cos\theta_c$
	$\Delta Q=\Delta C,\ \Delta S=0,\ \Delta I=1/2$	$\sin\theta_c$

(6)

where ΔQ etc. refer to the change in the quantum numbers of the quark. The four quarks are now members of a fundamental quartet under the group SU(4) with the following quantum numbers: ($Y = B + S + C$)

	Q	C	S	B	Y	I_3
u	2/3	0	0	1/3	1/3	1/2
d	-1/3	0	0	1/3	1/3	-1/2
c	2/3	1	0	1/3	4/3	0
s	-1/3	0	-1	1/3	-2/3	0

Using this fundamental quartet of quarks one finds that under the group SU(4) the 0^- mesons become members of a singlet plus 15-plet as shown in figure 1. The central plane with C=0 represents the familiar singlet plus octet of SU(3) along with the new SU(4) singlet the η_c. Above these lie the charmed mesons the D^0, D^+ and F^+. At the bottom are the anti-charmed mesons. These particles are assumed to decay weakly if certain mass constraints ($M_D + M_K > M_F$, $M_F + M_K > M_D$) are satisfied.

The $1/2^+$ baryons form a 20-plet as shown in figure 2. The lowest lying of these (presumed to be the C_0^+ of Λ_c^+) will also decay weakly, while the others may decay weakly or strongly depending on the mass relationships between the baryons and mesons.

$J^P = 0^-$ MESONS

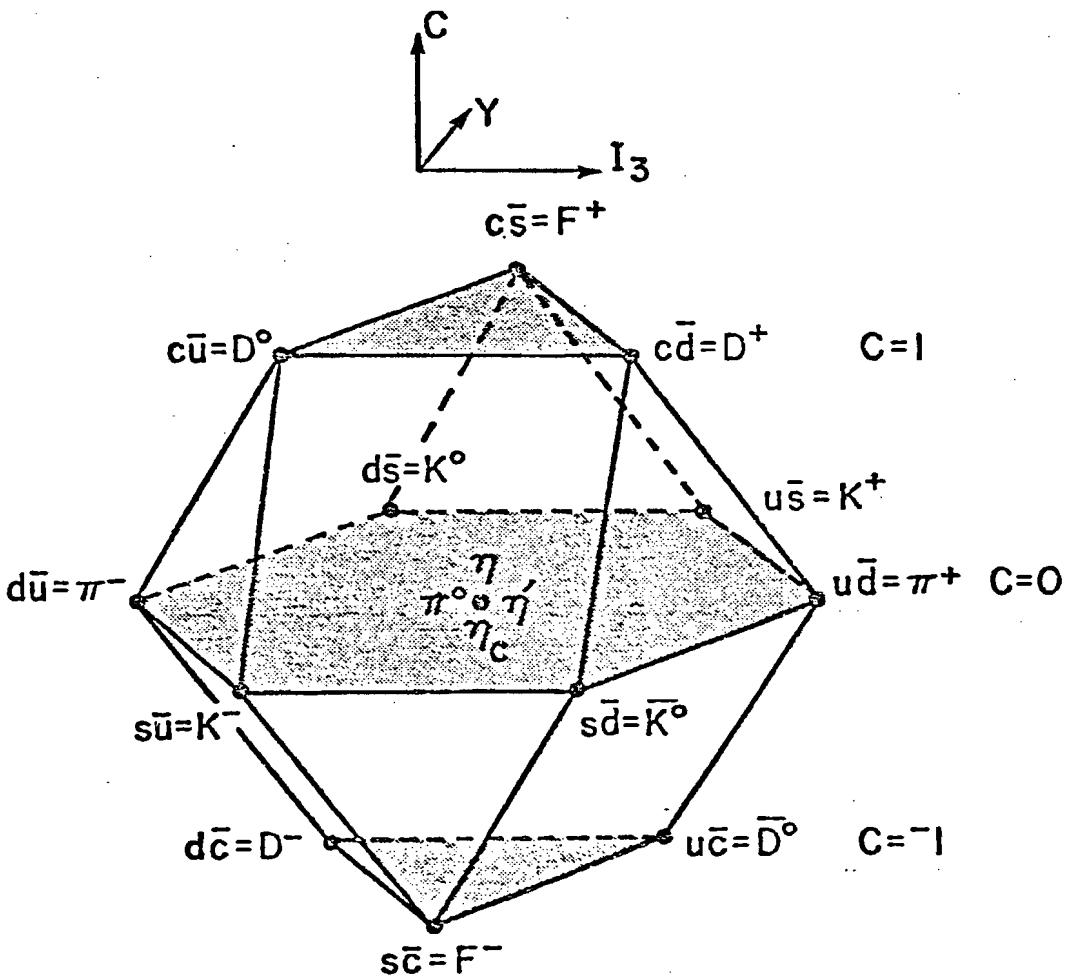


Figure 1. 0^- Mesons Under SU(4)

$J^P = \frac{1}{2}^+$ BARYONS 20_M

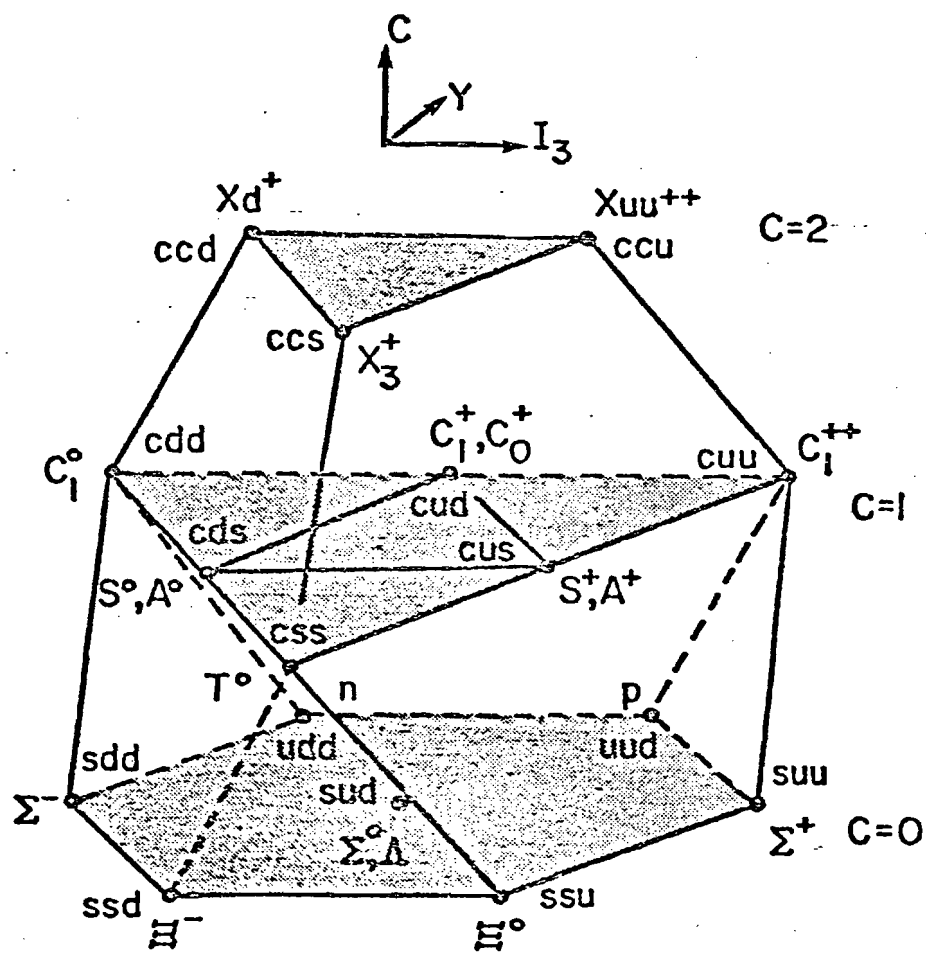


Figure 2. $1/2^+$ Baryons Under SU(4)

B. Charmed Particle Production

In the GIM model the production of charmed particles in a neutrino beam can be represented by the diagrams in figure 3. A target nucleon is a complicated object consisting of three real (or valence) quarks surrounded by a sea of virtual quarks and gluons. In the first process a Cabibbo unfavored ($\sin\theta_c$) current changes a valence d quark into a c quark. This process is open to neutrinos but not to anti-neutrinos. Since it is a Cabibbo unfavored process the rate is estimated to be lowered by a factor of $\sin^2\theta_c \simeq .05$ from the normal neutrino interaction rate. In the second process a virtual s quark is changed into a c quark. The contribution from this diagram is roughly equal to the valence quark contribution at Fermilab energies. Anti-neutrino production of charm proceeds similarly from the sea. There is little evidence for the diffractive process and its contribution is expected to be small.

Note that all the diagrams are charged current interactions. Neutral current interactions can produce charmed particles only through pair production.

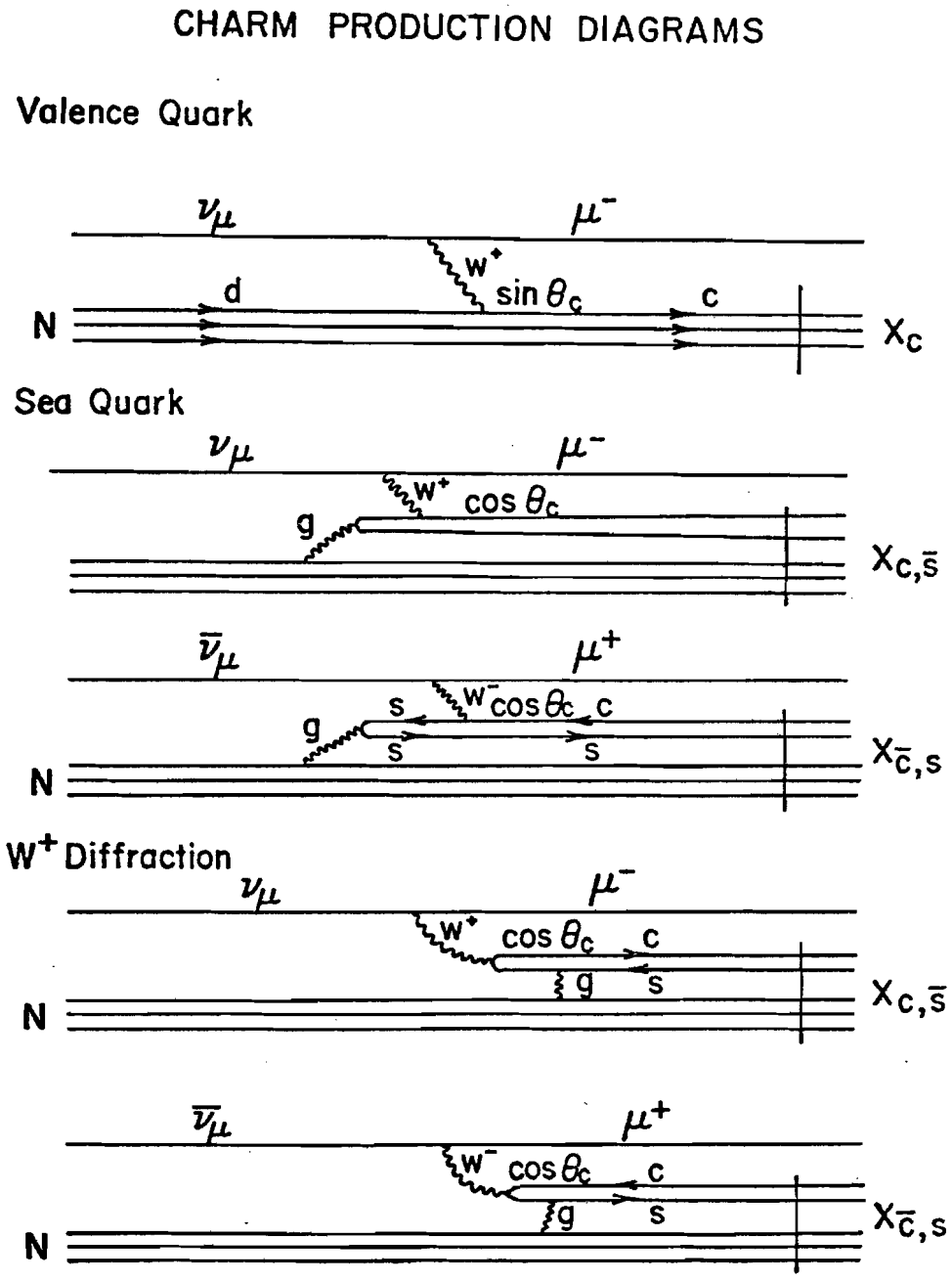


Figure 3. Neutrino Production of Charm

C. Charmed Particle Decay

In the simplest model for the decay of charmed particles, the decay can be viewed as the radiative weak decay of the charmed quark itself with no regard for the neighboring quarks or gluons (14). Thus in this model all the charmed particles which are stable with respect to the strong and electromagnetic forces should have the same lifetime, the lifetime of the charmed quark itself.

To calculate the charmed quark lifetime in this model we pattern the calculation after that for the decay of the muon. Making a direct substitution of a c quark for the muon and an s quark for the muon-neutrino we have (15):

$$\Gamma (c \rightarrow s\ e^{+}\ \nu_e) = \left(\frac{M_c}{M_\mu}\right)^5 \Gamma (\mu \rightarrow e\ \nu\ \bar{\nu}) \qquad (7)$$

The major cause of uncertainty in the rate is the uncertainty in the mass of the charmed quark, which can be estimated by the constituent mass model. In this model one takes a weighted average of the vector and pseudo-scalar meson masses and subtracts the mass of the up or down quark. Thus:

$$M_c = \frac{3*M_{D^*} + M_D}{4} - M_u \tag{8}$$

If we estimate the mass of the u quark in the same way we arrive at an estimate of 1.65 GeV for the mass of the charmed quark. The total decay rate for the charmed quark can be estimated by simple counting of diagrams. The semileptonic rate to muons is expected to be the same as that to electrons. The hadronic decay rate is expected to be three times (for three colors) the rate for electron semileptonic decay. Thus the total rate is expected to be 5x that of (1). Combining all this information we arrive at the estimate:

$$\Gamma\ (\ c \rightarrow \text{all}\ ) \approx 2.1 \times 10^{12}\ /\text{second} \tag{9}$$

This gives a lifetime of 5×10^{-13} seconds. This simple model can certainly stand some improvement. First of all it assumes that the mass of the strange quark is zero. If we use the constituent mass model again we get a mass of .5 GeV for the strange quark. This limits the phase space available to the decay and will lower the rate for all radiative weak decays. The total rate for radiative weak decays becomes:

$$\Gamma(c \rightarrow \text{all}) = g(\varepsilon) \text{ uncorrected rate} \tag{10}$$

where:

$$g(\varepsilon) = 1 - 8\varepsilon^2 - 24\varepsilon^4 \ln\varepsilon + 8\varepsilon^6 - \varepsilon^8 \tag{11}$$

and

$$\varepsilon = \frac{M_s}{M_c} \tag{12}$$

For the values stated above we get $g(\varepsilon) = .52$. The adjusted lifetime is correspondingly longer and comes out to approximately 9×10^{-13} seconds. It turns out that 9×10^{-13} seconds is a good estimate for the lifetime of the D^+ but is not a good estimate for the D^0.

The GIM model predicts the type of decay products that a charmed particle should produce. Cabibbo favored decays of a D^0 meson should be of the form (according to rule (3)):

$$D^0 \rightarrow \bar{K}^0 \ (m\pi)^0 \quad \text{or} \quad D^0 \rightarrow K^- \ (m\pi)^+ \tag{13}$$

while Cabibbo unfavored decays would be of the forms:

$$\begin{aligned} &D^0 \rightarrow \bar{K}^0 \ K^0 \ (m\pi)^0 \quad \text{or} \quad D^0 \rightarrow K^- \ K^+ \ (m\pi)^0 \\ &\text{or} \quad D^0 \rightarrow (m\pi)^0 \end{aligned} \tag{14}$$

CHAPTER 2

NEUTRINO BEAM

A. Proton Source

The source of high energy particles for this experiment was the proton synchrotron at Fermi National Accelerator Laboratory. During this experiment the accelerator produced an average of $2.0 \times 10^{+13}$ protons at 350 Gev per pulse with a cycle time between pulses of about 8 seconds. Of this usually $1.5 \times 10^{+13}$ protons per pulse were incident on the neutrino target. A plan view of the laboratory is shown in figure 4.

The proton accelerator at Fermilab actually consists of several accelerators in series. Protons are produced by ionizing hydrogen gas within the dome of a Cockcroft-Walton

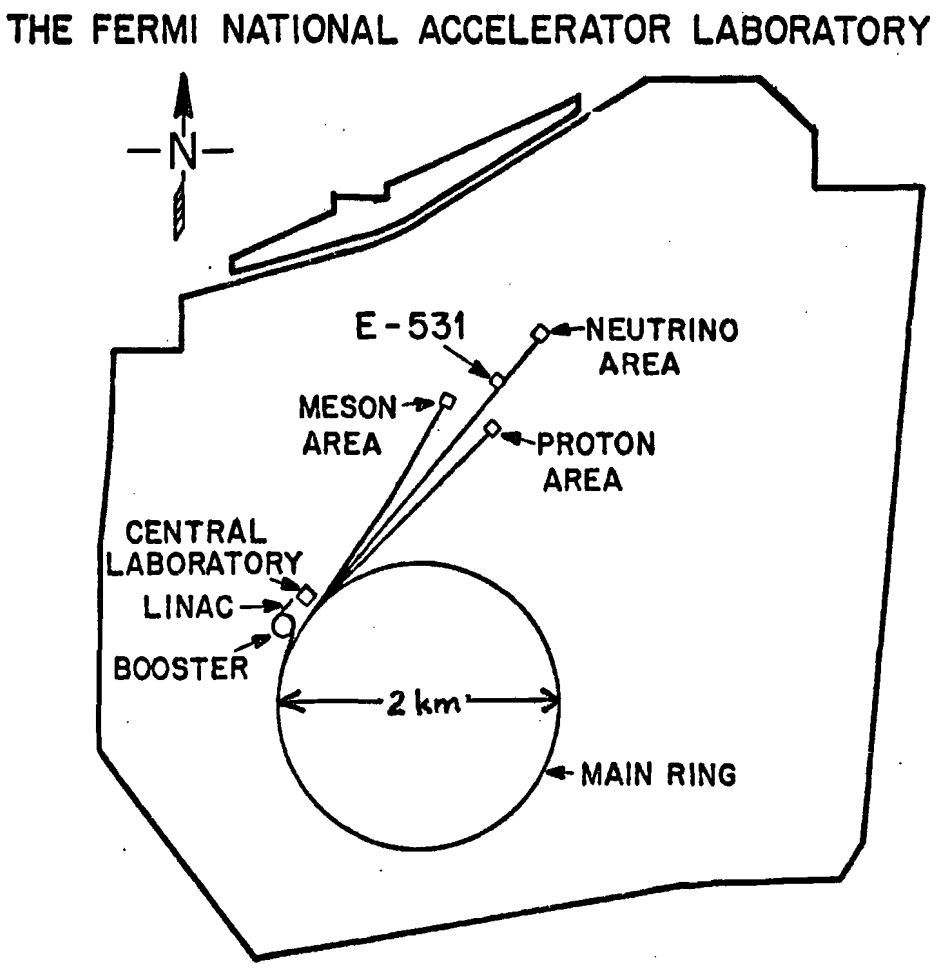


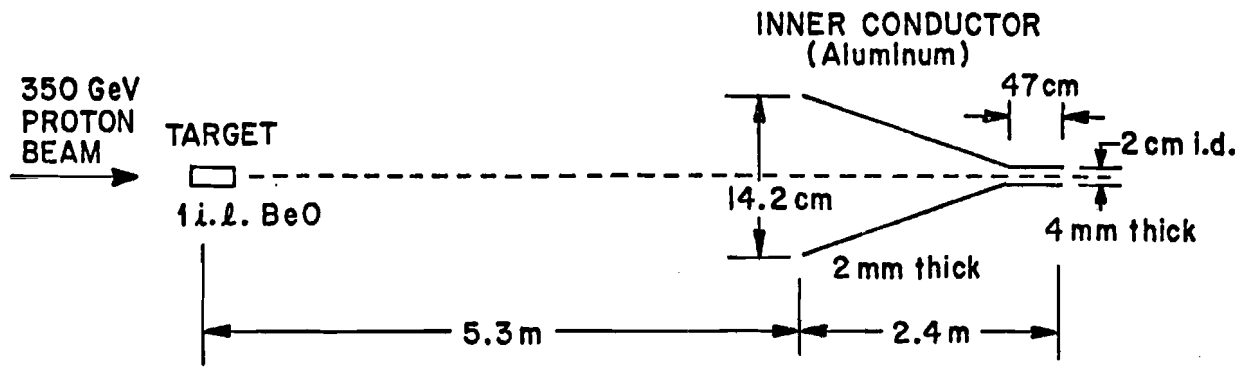
Figure 4. Plan View of Fermilab

pre-accelerator operating at 750,000 volts. These protons are then fed into a linear accelerator 175m long which brings the kinetic energy up to 200 MeV. At the end of the linear accelerator the protons are injected into an alternating gradient booster synchrotron, which takes the protons up to 8 GeV and injects them into the main ring. The main ring brings the protons up to their final energy (350 GeV for our experiment). After extraction from the main ring the protons are routed to the switchyard which sends the proton beam to the various experimental areas.

B. Single Horn Neutrino Beam

The switchyard provided a 1ms long pulse of protons to the neutrino target. For this experiment the neutrino beam was produced in the single horn neutrino target as shown in figure 5. Incident from the left are the 350 GeV protons from the switchyard. These interact in the one interaction length BeO target to produce secondary pions and kaons. Downstream (5.3 m) of the target the focusing horn increased the neutrino fluxes further downstream and selected a preferred neutrino type. A pulsed current of 80kA was forced along the inner conductor of the horn in the direction of the beam during the 1ms spill. Those secondary particles within 1.3 mr of the beam were unaffected since

Single Horn Neutrino Target



Operating Conditions:

$I = 80\ kA$

$\Delta p_T = 0.17\ GeV/c$

Figure 5. Single Horn Neutrino Target

they passed through the central hole. Particles produced between 1.3 mr and 1.8 mr passed through a long section of the horn which absorbed 50% of them. Those particles produced beyond 1.8 mr passed through a thin section of the horn (transmission 90%) and entered the magnetic field of the horn. Positively charged particles received a transverse momentum kick of .17 GeV/c back towards the beam thus providing a focusing effect. Negatively charged particles received a similar kick away from the beam and thus are defocused. The secondary pions and kaons are then allowed to travel unimpeded along the decay pipe as shown in figure 6. Approximately 15% of the pions and 30% of the kaons subsequently decay before reaching the end of the decay pipe. The hadrons and most of the muons in the beam are absorbed in the shielding consisting of 180m of steel and 280m of earth and concrete. Some muons managed to punch through to our apparatus or were able to avoid some of the shielding. (Gaps existed in parts of the shielding). As a result a significant number of muons passed through the apparatus with each neutrino pulse. This resulted in a large number of background muon tracks in the emulsion. (The number of minimum ionizing tracks with slopes within 20 degrees of the neutrino beam was measured to be $225/mm^2$).

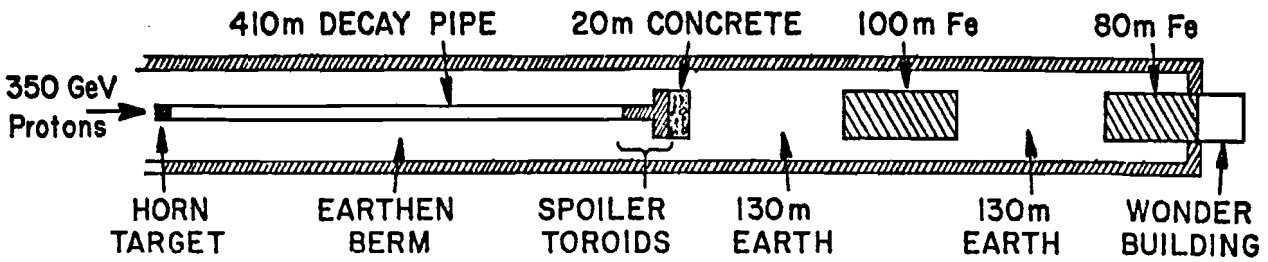


Figure 6. Neutrino Beam Line to Wonder Building

For the last 15% of data taking the muon spoilers were turned on. The purpose of the spoilers was to deflect muons away from the forward beam direction thus lowering the number of muons reaching the Wonder Building housing the experiment.

The neutrino beam consists primarily of muon neutrinos produced in the decays:

$$\pi^+ \rightarrow \mu^+ \nu_\mu \tag{1}$$

$$K^+ \rightarrow \mu^+ \nu_\mu \tag{2}$$

The major neutral "contaminants" to the muon neutrino beam are anti-muon neutrinos produced by the charged conjugation counterparts to (1) and (2). A small complement of electron and anti-electron neutrinos is produced by the processes:

$$K^+ \rightarrow \pi^0 e^+ \nu_e \tag{3}$$

$$K_L^0 \rightarrow \pi^+ e^- \bar{\nu}_e \tag{4}$$

$$K_L^0 \rightarrow \pi^- e^+ \nu_e \tag{5}$$

A monte-carlo program (16) investigated the energy spectrum of the neutrino beam producing the results shown in figure 7. As expected the beam consists primarily of muon neutrinos. The neutrino energy peaks at 20 GeV with a long tail going out to about 200 GeV. The anti-muon neutrino

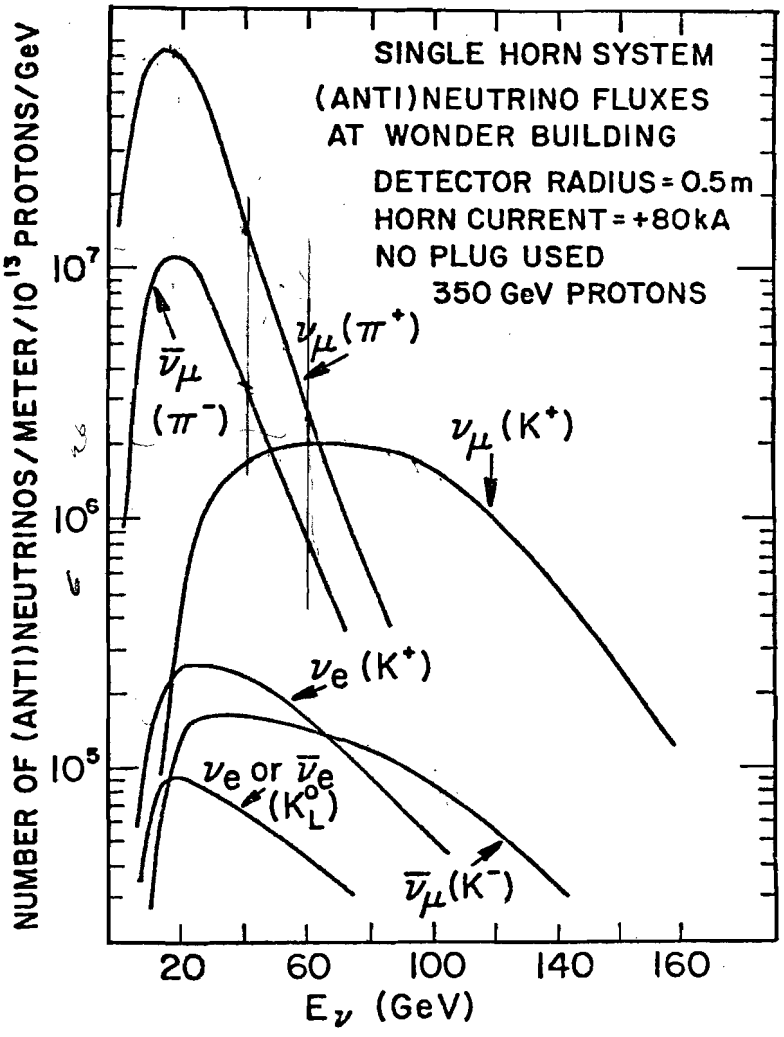


Figure 7. (Anti)Neutrino Fluxes at Wonder Building

component is predicted to be 10% while the electron and anti-electron neutrino component is predicted to be .4%. Both theses figures are consistent with our data.

CHAPTER 3

EXPERIMENTAL APPARATUS

A. General Overview

Two overriding concerns shaped the design of this experiment. First, since the lifetimes of the charmed particles were predicted to be on the order of 10^{-12} seconds, the experiment needed to measure small decay paths accurately. Second, since there are many types of charmed particles each having many decay channels, the experiment also needed to determine accurately the momentum, particle type, and angles of the decay products. To meet these requirements the experiment was designed as a hybrid emulsion-spectrometer apparatus as illustrated in figure 8.

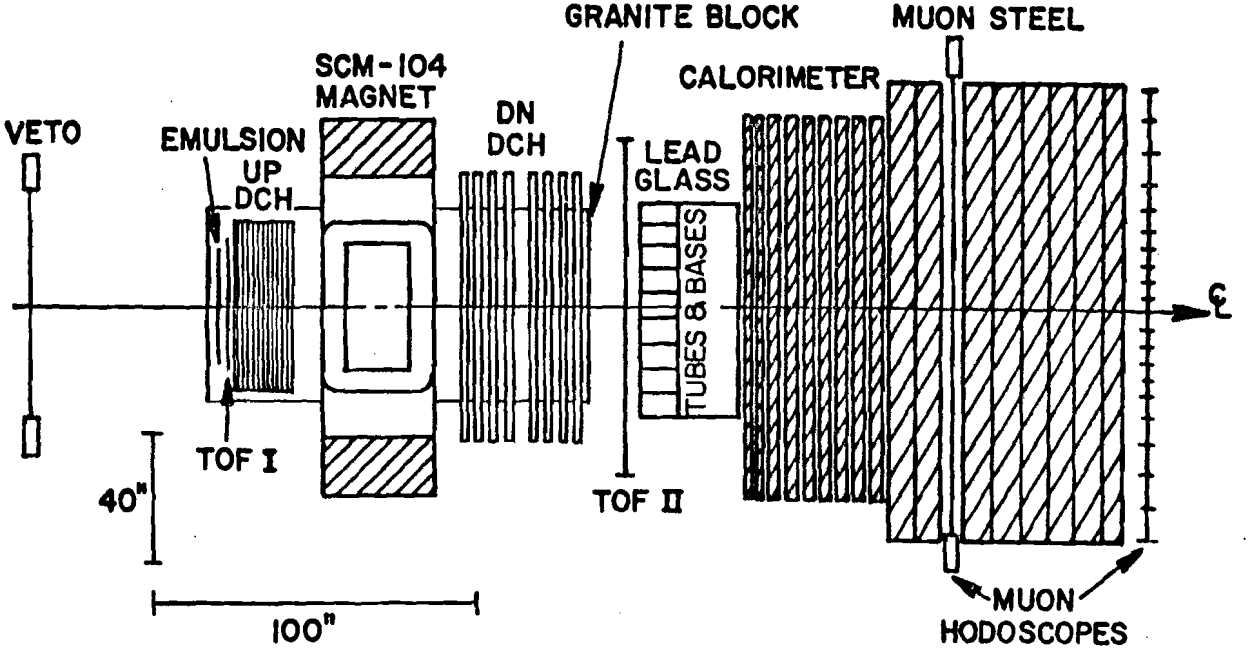


Figure 8. Plan View of Apparatus

Throughout this work reference will be made to a standard reference frame illustrated in figure 9. This is a right-handed system with the beam direction in the positive z direction, up in the positive y direction and x in the beam left direction.

The purpose of the spectrometer is two-fold. First the spectrometer accurately locates events in the emulsion stack. Without an accurate vertex prediction locating the events would take an unreasonable length of time (at least 25 years). Second the spectrometer determined the momentum of the charged particles and provided information on particle type from measurements of time-of-flight, energy deposited in the lead glass blocks and in the calorimeter, and the range in steel. In addition the spectrometer provided information on neutral particles such as the π^0, K^0, and neutron.

The emulsion also played two roles. The momentum of charged tracks could be measured in the emulsion from multiple scattering ensuring that tracks that miss the spectrometer have some measurement of momentum and slopes. Since the emulsion had such high resolution it enabled one to see decay distances as short as 5 μm and also made it posssible to measure parent particle's slopes.

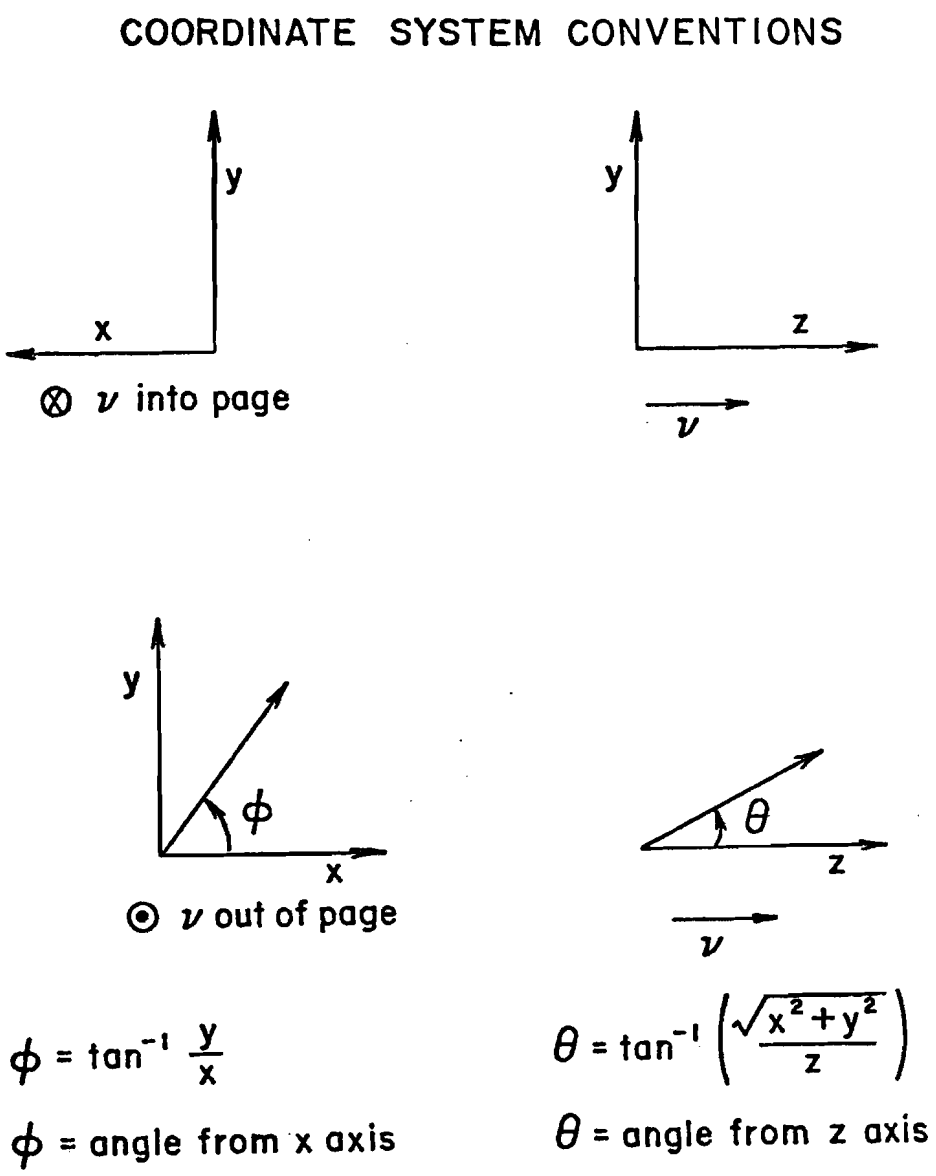


Figure 9. Standard Reference Frame

Since the decay vertex is visible it is possible to make constrained hypotheses for the decay. Conservation of four-momentum at the decay vertex provides four constraint equations. If the slopes and momenta of the decay products are known along with their masses, and the slopes of the parent particle are measured, then only 2 unknowns remain; the parent particle mass and momentum. This case gives us two remaining contraints that the decay must satisfy. This is commonly refered to as a 2-C fit. If we force the mass to that of a known particle we have one more constraint and thus a 3-C fit. If the parent particle's slopes are unknown, then forcing the mass still gives us a 1-C fit. If the parent's slopes are measurable but a missing neutral decay product is needed to balance transverse momentum, then forcing the mass gives us four unknowns for our four constraints. This is merely a calculation or 0-C "fit". In figure 10 a typical 0-C situation is shown. In this case a K^0 is needed to balance transverse momentum but is not seen in the spectrometer. From the figure it can be seen that in general there are two valid solutions for the momentum of the missing neutral particle giving two solutions for the momentum of the parent particle.

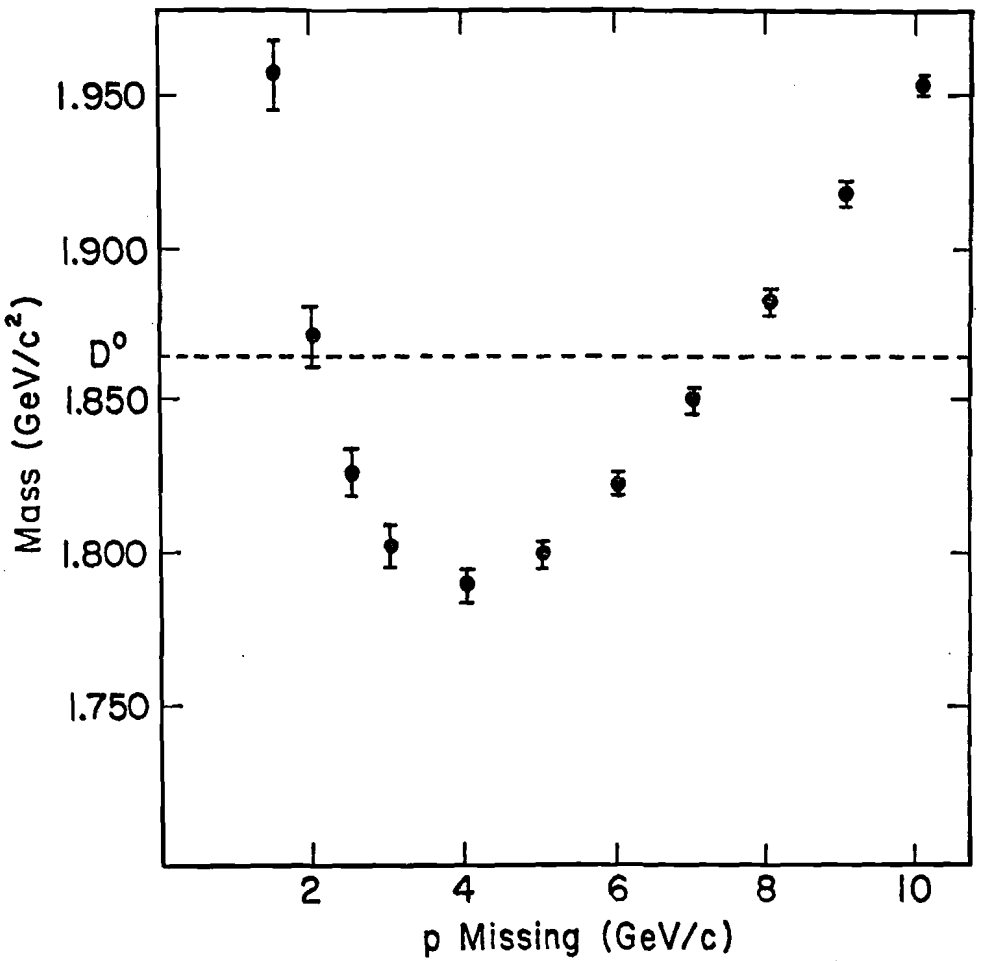


Figure 10. 0-C Fit to Event 577-5409

B. Emulsion Modules

The emulsion stack, shown in figure 11, consisted of 23 liters of Fuji nuclear emulsion divided into 39 modules. There were two distinct arrangements of the emulsion layers. The upper half of the emulsion stack consisted of modules which held pure emulsion pellicles oriented with the the plane of the pellicle parallel to the incident neutrino beam as illustrated in figure 12. Each module consisted of 177 pellicles 600 μm thick pressed between 2 G-10 blocks for rigidity. This "horizontal" arrangement of the emulsion pellicle presented an easily observable topology for the minimum ionizing tracks produced in an event.

The lower half of the emulsion stack consisted of 27 modules of emulsion each consisting of 68 films of emulsion oriented perpendicular to the incident neutrino beam. Each film consisted of a 70 μm thick plastic film coated on both sides by 330 μm of Fuji nuclear emulsion. This "vertical" orientation allowed easier following of tracks back into the emulsion from the spectrometer since distortion was limited to the edges of the emulsion.

For both module types a minimum ionizing track produced 28-30 grains per 100 μm in the developed emulsion. The

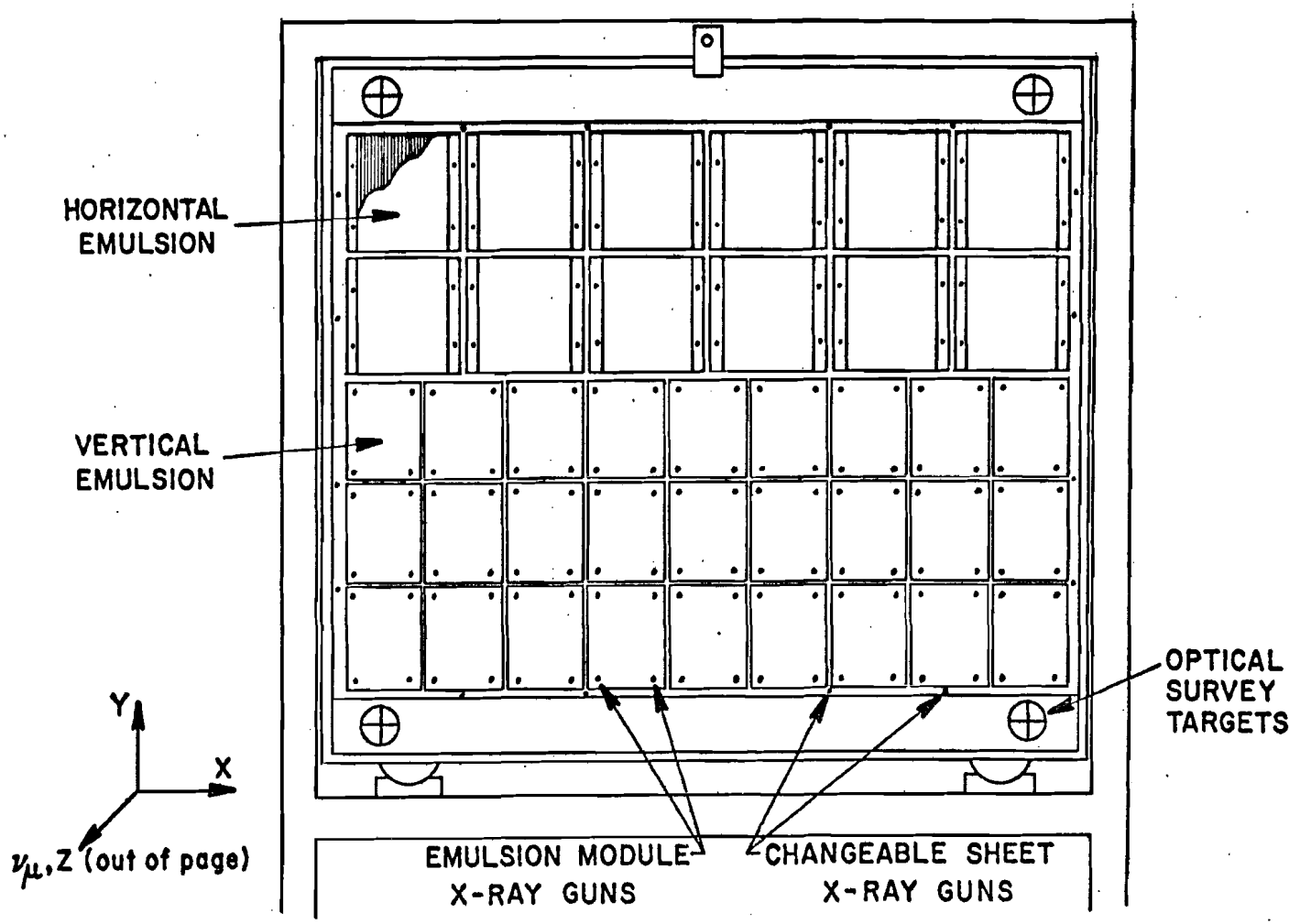


Figure 11. Emulsion Target

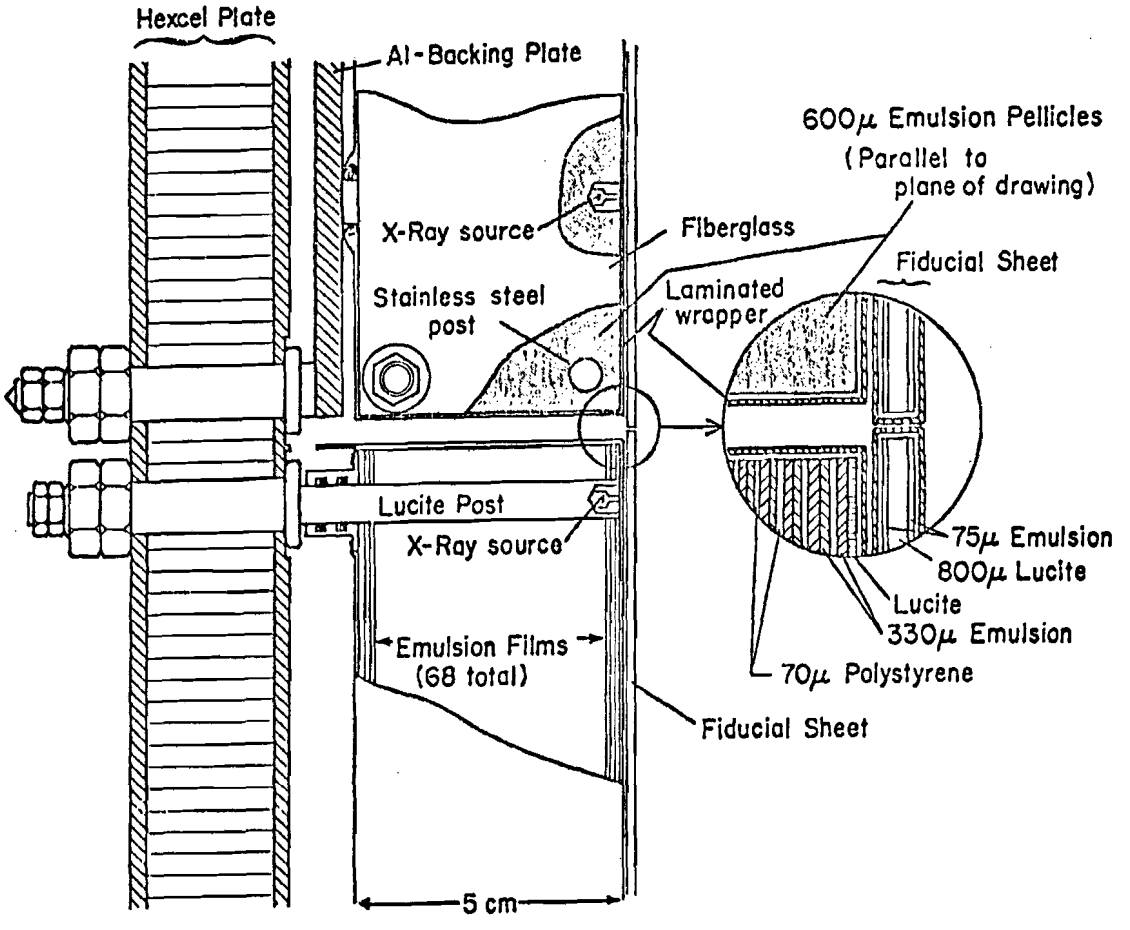


Figure 12. Cutaway of Emulsion Target

errors in measuring the position of a track in the emulsion were approximately 0.2μm in the plane of the emulsion and 2.0μm perpendicular to the emulsion plane. Limited particle identification could be done in the emulsion itself from ionization losses. In figure 13 the ionization loss in the emulsion is plotted as a function of Pβ for the charged tracks. For a typical track the error in measuring the relative ionization was 0.07. Particle identification by ionization loss was used for the neutral decays in only one case, for a pion with a momentum of .20 GeV/c.

The entire emulsion stack was mounted on a Hexcel aluminum plate located upstream of the emulsion. Providing a low mass but rigid support, the Hexcel plate contributed 25% to the total mass of the target. Immediately downstream of the emulsion stack was a large sheet of polystyrene 800 μm thick coated on both sides with 75 μm of emulsion. This large sheet was changed frequently (approximately every two or three days) in order to limit the total number of tracks that passed through it. Since the "changeable sheet" had a shorter exposure to both cosmic rays and background muon tracks from the neutrino beam, a track reconstructed in the spectrometer could be linked with a particular track in the emulsion with less chance of choosing the wrong track in the emulsion.

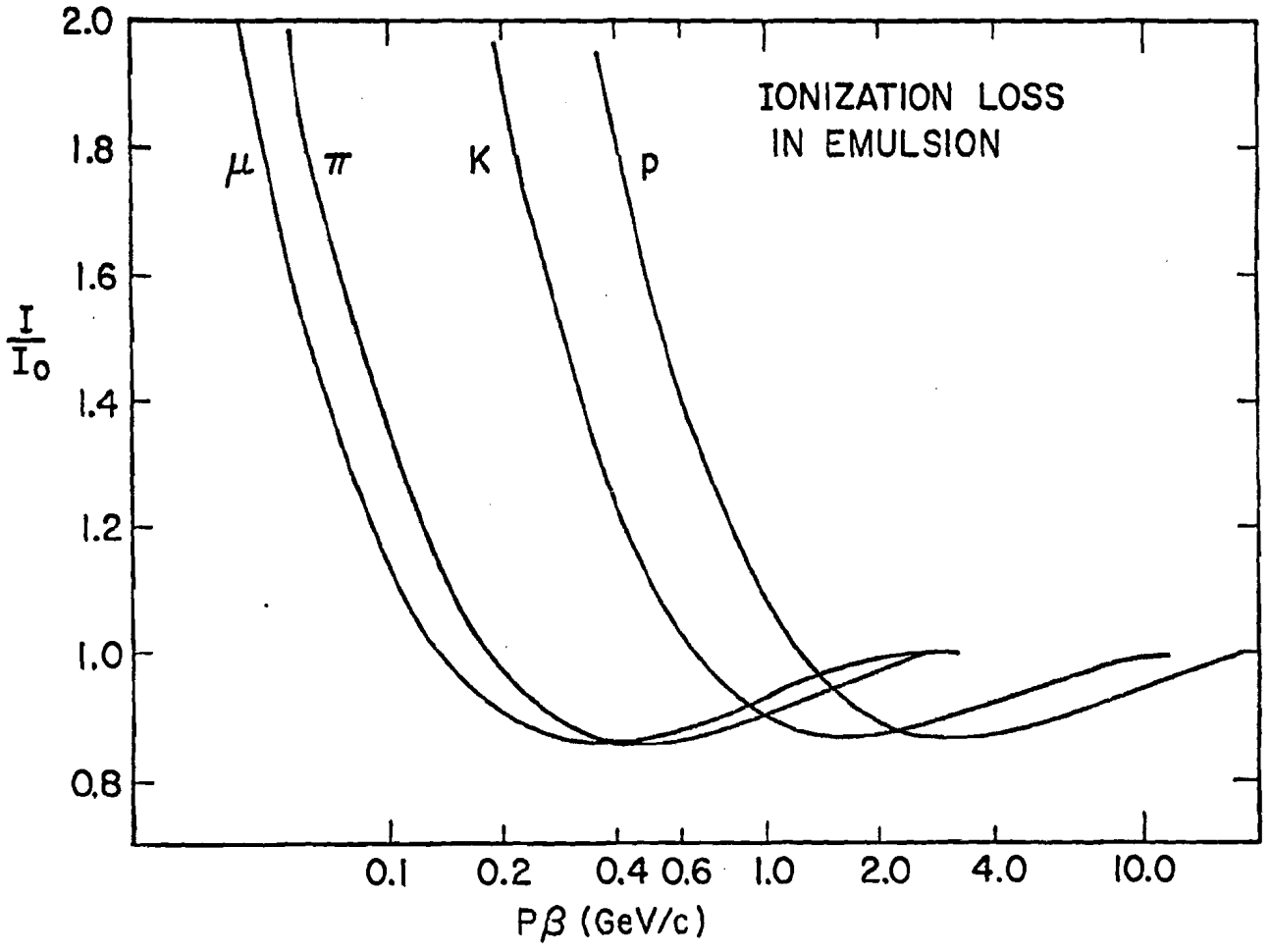


Figure 13. Ionization Loss in Emulsion

THE SPECTROMETER

The spectrometer consisted of the following devices:

1. Veto Counters
2. Time-Of-Flight Counter I.
3. Upstream Drift Chambers.
4. Analyzing Magnet.
5. Downstream Drift Chambers.
6. Time-Of-Flight Counters II.
7. Lead Glass Wall.
8. Steel and Scintillator Calorimeter.
9. Muon Counters.

C. Veto Counters

The veto counters were the most upstream portion of the apparatus. The purpose of the veto counters was to reject any interaction which may have been induced by a charged particle, and to reject events which mimic interactions such as two or more charged particles passing through the spectrometer within a small time interval. The veto counters were timed so that any real neutrino interaction which produced particles moving backwards in the laboratory did not veto the event.

It was possible for the veto counters to reject a real event if a background muon track triggered it when the real event took place. This "veto overkill" can be determined from the percentage of time that the veto counters were on which in this experiment was an average of 13%.

D. Time-Of-Flight Counter I.

The first time-of-flight counter (TOFI) consisted of a single rectangle of scintillator viewed by 12 phototubes as shown in figure 14. TOFI was intended to serve as the start for the measurement of the flight time of the charged particles. However, since the counter was 8 cm downstream of the emulsion target, wide angle tracks produced in the event caused a jitter in the start time measured by the counter. Therefore this counter saw limited use as a time-of-flight counter though its measurement of the start time was accurate enough for use by the analysis programs for start time "neighborhood" measurements. The one sigma error for the start time as measured by TOFI was 300 psec.

TOFI also served as part of the trigger for the apparatus. All twelve tubes were added to give a single trigger pulse. (See section 4-A for a description of the trigger requirements).

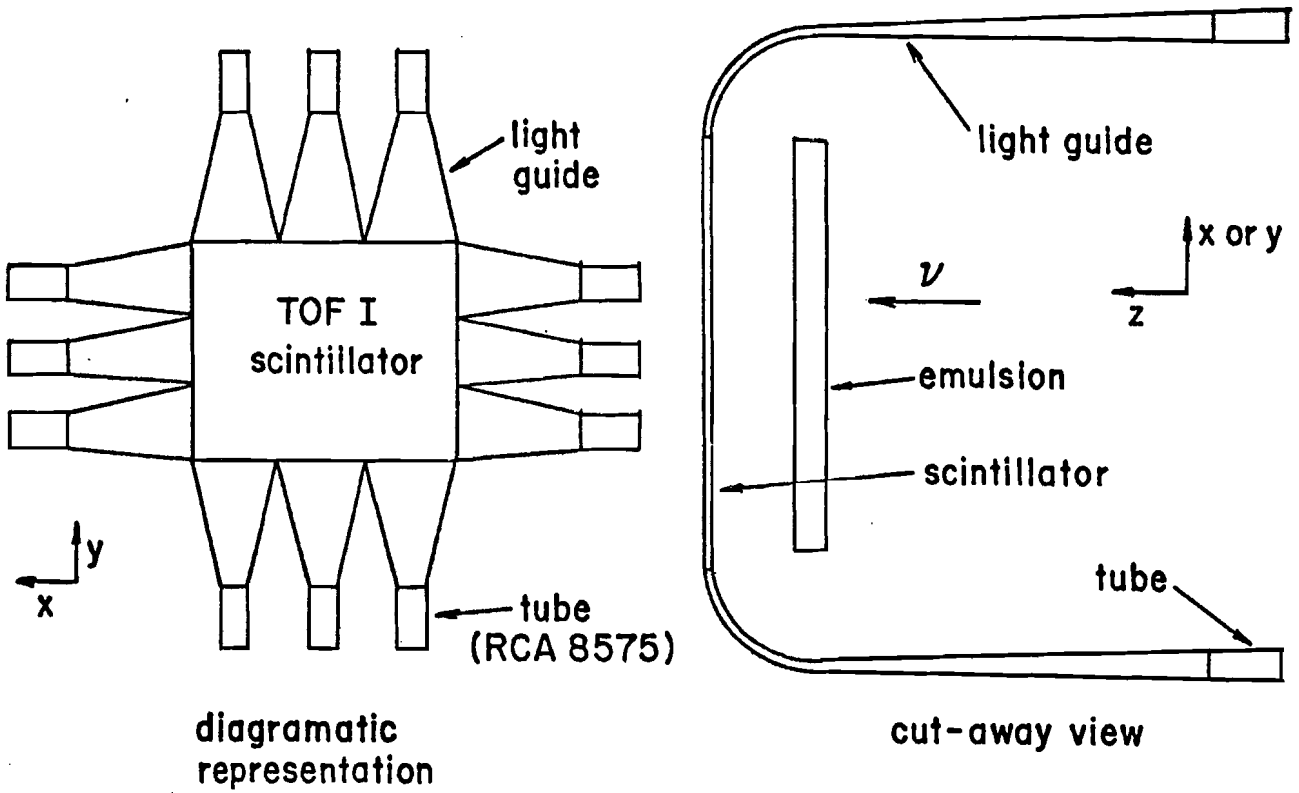


Figure 14. TOF I Counter

E. Drift Chambers and Analyzing Magnet.

The heart of the spectrometer consisted of the drift chambers and analyzing magnet. There were a total of 20 drift chambers, 12 upstream of the analyzing magnet and 8 downstream.

The upstream drift chambers pinpointed where in the emulsion the neutrino interaction took place and also provided part of the information necessary for momentum measurement. The upstream drift chambers came in 3 sets of 4 chambers with orientation angles 60 degrees apart as seen in figure 15. This orientation provided equal measurement accuracy of slopes and intercepts for tracks in any view.

Each of the upstream drift chambers consisted of 32 cells each containing one sense wire centered in 44 field shaping wires as shown in figure 16. The lines in the cell represent the equipotential curves within the cell. It can be seen that the field is roughly linear except near the sense wire. Each chamber was approximately square and had an active area of $1.5m^2$

The analyzing magnet (SCM-104 on loan from Argonne National Laboratory) is a thin, wide gap dipole. The gap is

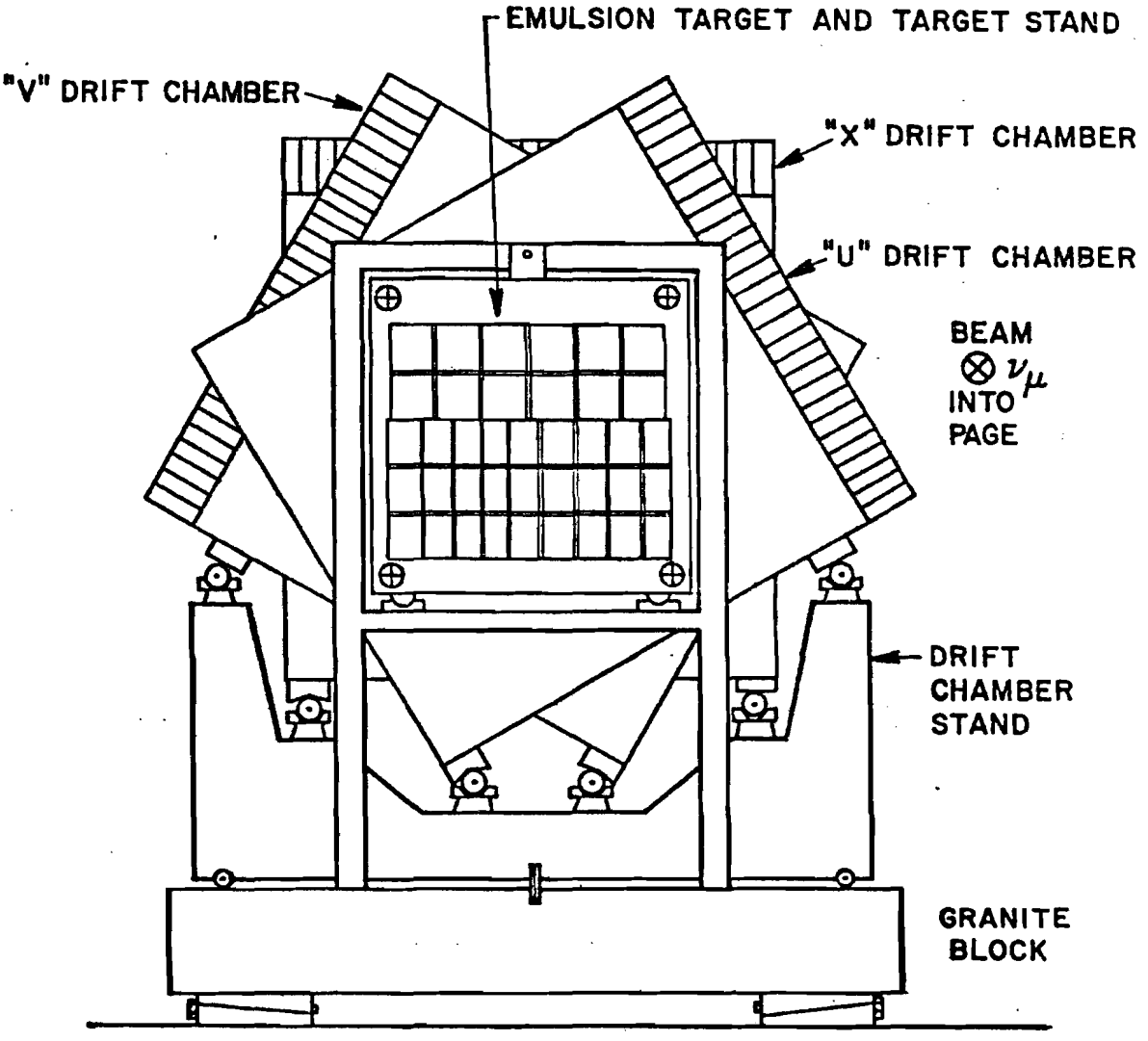
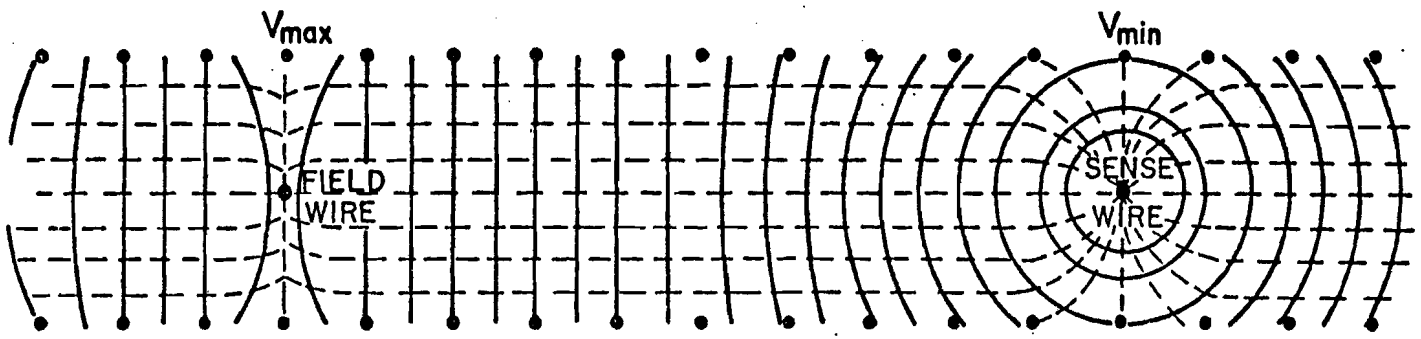


Figure 15. Upstream Drift Chambers

CELL CONFIGURATION AND
EQUIPOTENTIALS FOR UPSTREAM DRIFT CHAMBERS



Sense wire: 20μm dia. Au-W wire
Field wire & cathode plane wires: .75μm dia. Cu-Be wire
Cell size = 4.0 cm
2.0 mm cathode wire spacing
7.0 mm cathode plane spacing

V_{max} = 3.1 kV
V_{min} = 1.7 kV
E = 700 V/cm

Figure 16. Upstream Drift Chamber Cell

2.1 m wide by .9 m high by .9 m in depth giving it a solid angle acceptance as seen by the emulsion target of approximately 1.1 steradians. The central field of the magnet was 5.9 kgauss and the total integral Bdl was 6.5 kg-m. A plastic bag filled with helium was placed in the magnet gap to reduce multiple scattering of charged tracks.

The downstream drift chambers, shown in figure 17, consisted of 4 chambers in the x view and 2 chambers each rotated ± 10 degrees. This orientation package provided the same resolving power in the x direction as the upstream chambers. The resolution in y was a factor of 6 worse than that of the upstream chambers but was good enough for pointing into counters downstream. Since the charged tracks were deflected mainly in the x direction, this orientation provided good momentum measurement.

Each chamber was filled with a 50% Argon-50% Ethane mix gas with the field shaping wires providing a drift field of 750V/cm producing an average drift velocity of 50μm/ns.

The timing clock for the drift chamber system consisted of a single 83MHz oscillator with a primary and 3 delayed phases enabling a timing resolution of 1.5ns. Thus with a drift velocity of 50μm/ns the clock could give a ±75μm

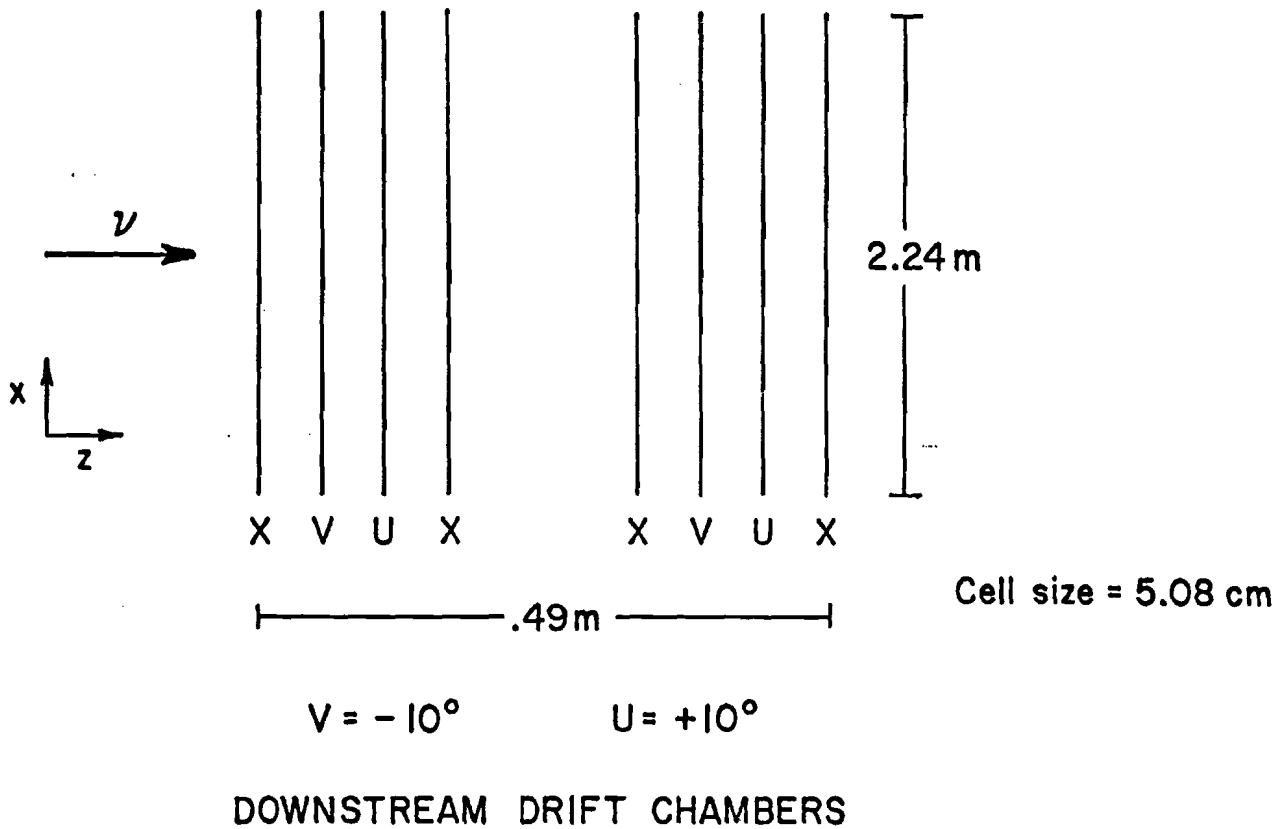


Figure 17. Downstream Drift Chambers

resolution of position. This was less than the intrinsic resolution of the drift chambers which was 125μm and 175μm sigma for the upstream and downstream chambers respectively as measured by residuals of fitted high momentum muon tracks.

In addition to accurate measurement of a single track, total reconstruction of an event requires good separation of different tracks. The electronics measuring the drift time could distinguish between two tracks as little as 1.8 mm apart in the chamber in the direction of the chamber measurement. As many as 32 hits in each chamber could be recorded.

F. Time-Of-Flight Counters II.

The second wall of time-of-flight counters consisted of 30 scintillators oriented vertically and viewed with a photo-tube at each end as shown in figure 18. The TOFII counters came in two sizes, the narrow counters were 2.5 inches wide and the wide counters were 4 inches wide. It is this wall which provided the flight time of the charged particles. The second time-of-flight counters (TOFII) also were part of the trigger system. (See section 4-A). The flight time resolution for a track depended upon the number

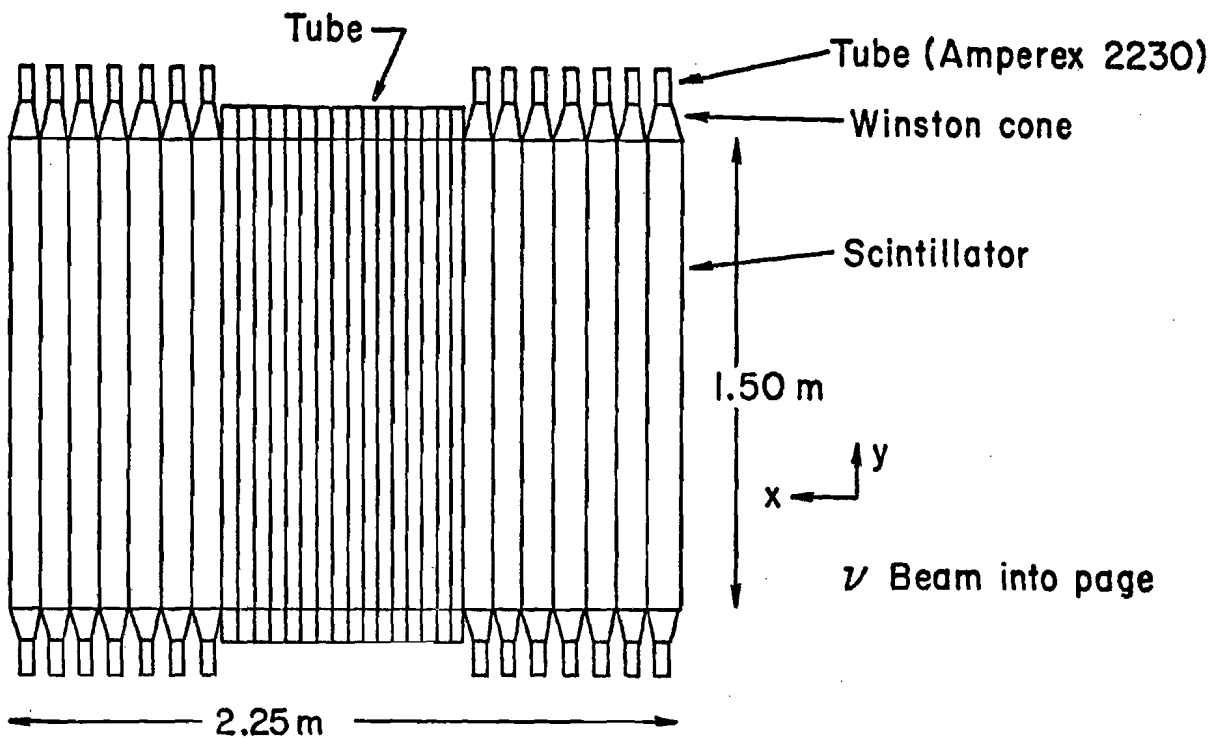


Figure 18. TOF II Counters

of tracks in the same counter and the size of the counter itself. For the narrow counters the difference in flight time between paddles with only one hit each had a resolution of 100ps. If a paddle had two hits then the difference in flight time had a resolution of 150ps. For the wide counters, the resolution was 1.5 times that of the narrow counters. If more than two tracks hit a counter then only the top and bottom tracks' flight time could be measured.

TOFII is 2.85m downstream of the emulsion target providing approximately 10ns of flight time for relativistic particles. One sigma flight time separations for single hit particles in the narrow counters occured at momenta of 3 GeV/c for pions versus kaons and 6 GeV/c for kaons versus protons.

G. The Lead Glass Wall

Immediately downstream of the second set of time-of-flight counters was a wall of lead glass blocks. Each block was 19 cm square by 30 cm in depth along the beam direction resulting in 10 radiation lengths of material. (Twelve blocks were slightly longer giving 13 radiation lengths). The wall consisted of 68 blocks in a 9 by 8 pattern with the corners unoccupied as shown in figure 19.

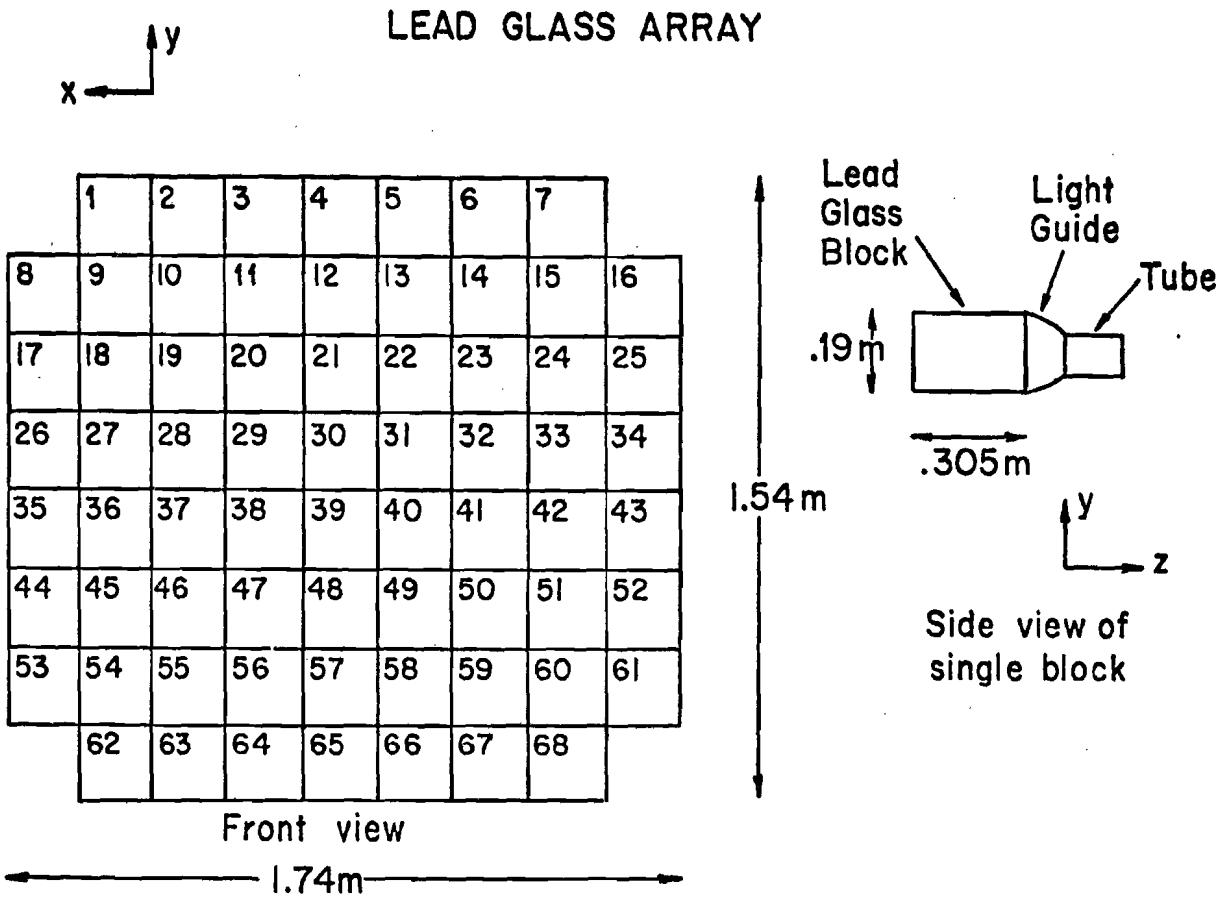


Figure 19. Lead Glass Wall

The lead glass array was useful in identifying electrons and photons. Electrons were identified from comparison of the energy deposited in the lead glass with the momentum measured by the spectrometer. If these two values were the same within measurement errors then the particle could be tentatively identified as an electron. Gammas were hypothesized any time there appeared to be excess energy (> .3 GeV) in a lead glass block that could not be associated with a charged track. The energy resolution of the lead glass was measured to be: (See section 5-A).

$$\sigma_E = .15 \cdot \sqrt{E} \text{ GeV} \tag{1}$$

H. The Calorimeter.

Downstream of the lead glass was a steel and scintillator sandwich calorimeter. Shown in figure 20 , the calorimeter measured the total hadronic energy of the charged and neutral particles which entered it. The calorimeter consisted of 5 planes of 4 scintillators sandwiched between 10 cm of steel. Past experiments (17) with the type of calorimeter used for this experiment showed that the energy resolution for this system is approximately given by:

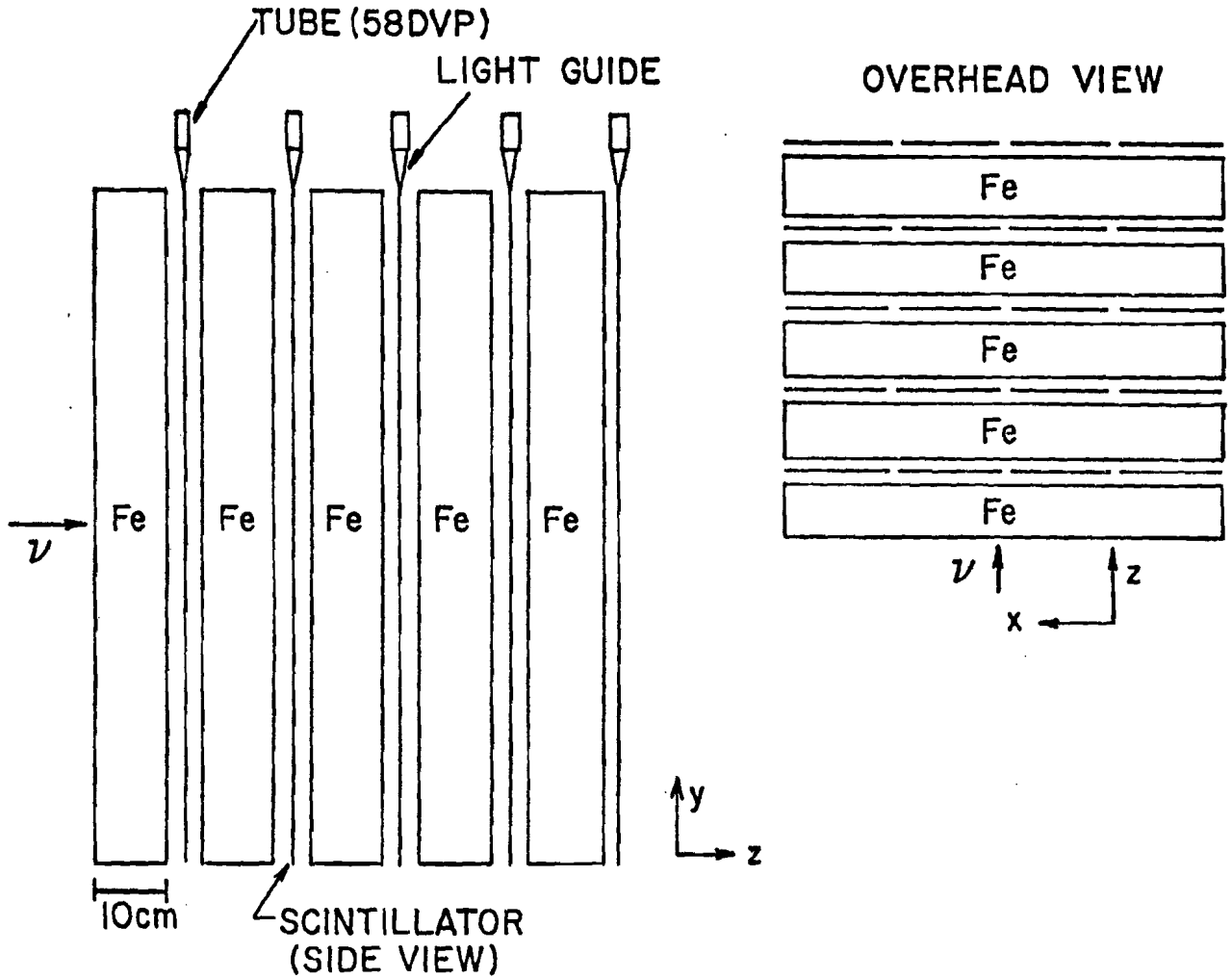


Figure 20. Calorimeter

$$\sigma_E = 1.1 \cdot \sqrt{E} \text{ GeV} \tag{2}$$

The calorimeter was useful for measuring the total hadronic energy of an event and for detecting long lived neutral hadrons such as the K_L^0 and neutron.

I. Muon Counters

The final detectors in the beam were the muon counters. These were two hodoscopes of scintillator counters behind 1.2 m and 2.3 m of steel respectively as shown in figure 21. The thickness of the steel was chosen to absorb the hadrons produced in an event while allowing muons of sufficient energy to penetrate to the scintillators. The energy required for a muon to reach the first counter wall was 1.5 GeV and was 2.8 GeV for the second wall. This includes the energy loss in the lead glass array ($\simeq$ .1 GEV). Position measurement was given by the counter position for the direction against the "grain" of the scintillator wall and by single ended timing along the counter. Position error by timing was 12 cm σ.

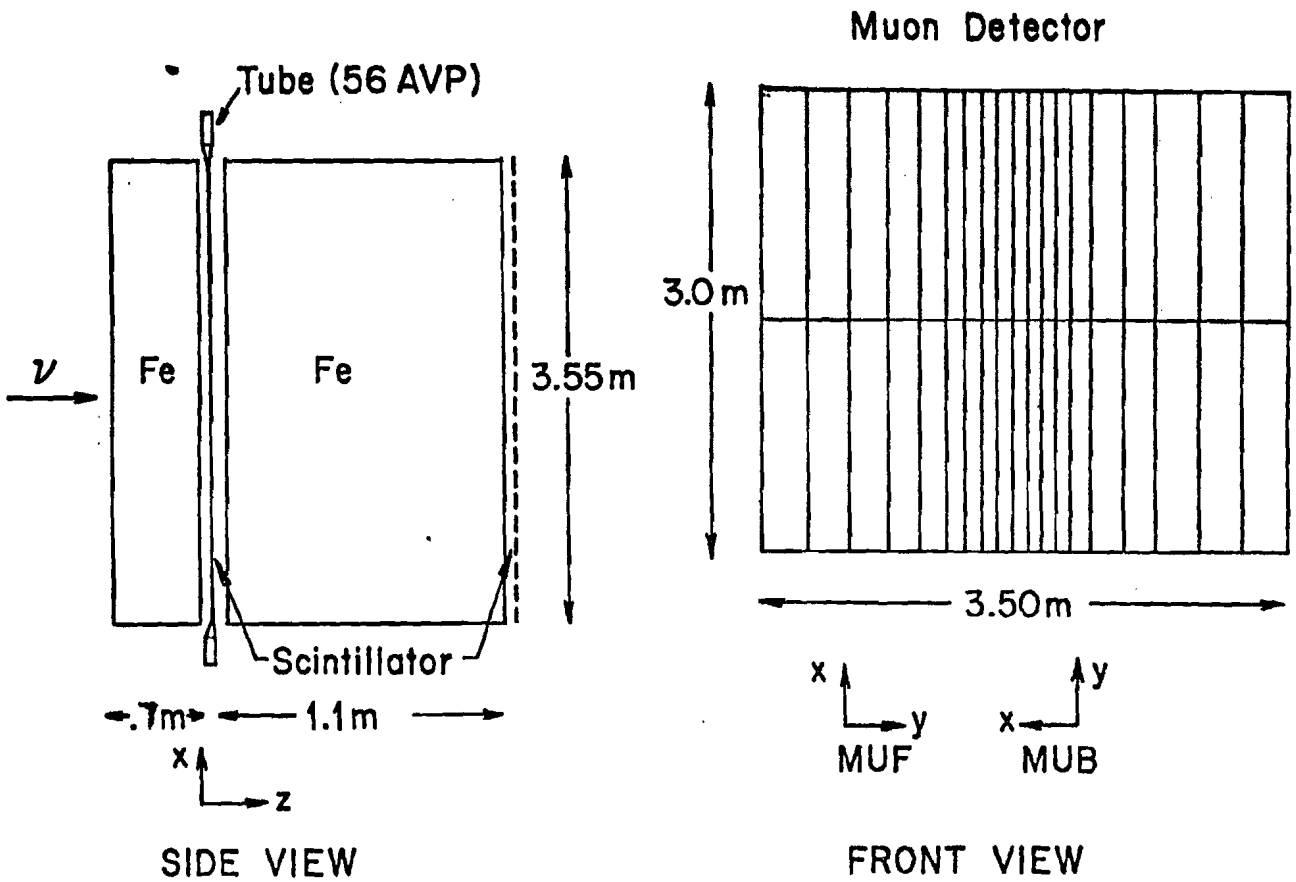


Figure 21. Muon Counters

J. Alignment

The success of the experiment depended very heavily on the accuracy with which an event seen in the spectrometer could be projected into the emulsion. This required that the alignment between the emulsion stand and the drift chambers be well known and stable throughout the several months of exposure time.

The emulsion stand, TOFI, and the upstream and downstream chambers were mounted on a single block of granite as shown in figure 22. If the floor beneath the magnet were then to settle, these instruments would behave as a single unit thus preserving the relative distances and angles between them.

Attached in several places on the emulsion and drift chamber stands were position transducers. The transducers (or sensors) consisted of a Linear Variable Differential Transformer (LVDT) which related the position of a nickel-iron movable core to an output voltage. Shown in a cutaway view in figure 23, the function of the sensors was to measure any movement of the emulsion stack or drift chambers relative to the granite block from thermal expansion, settling, etc. A survey of the positions of all

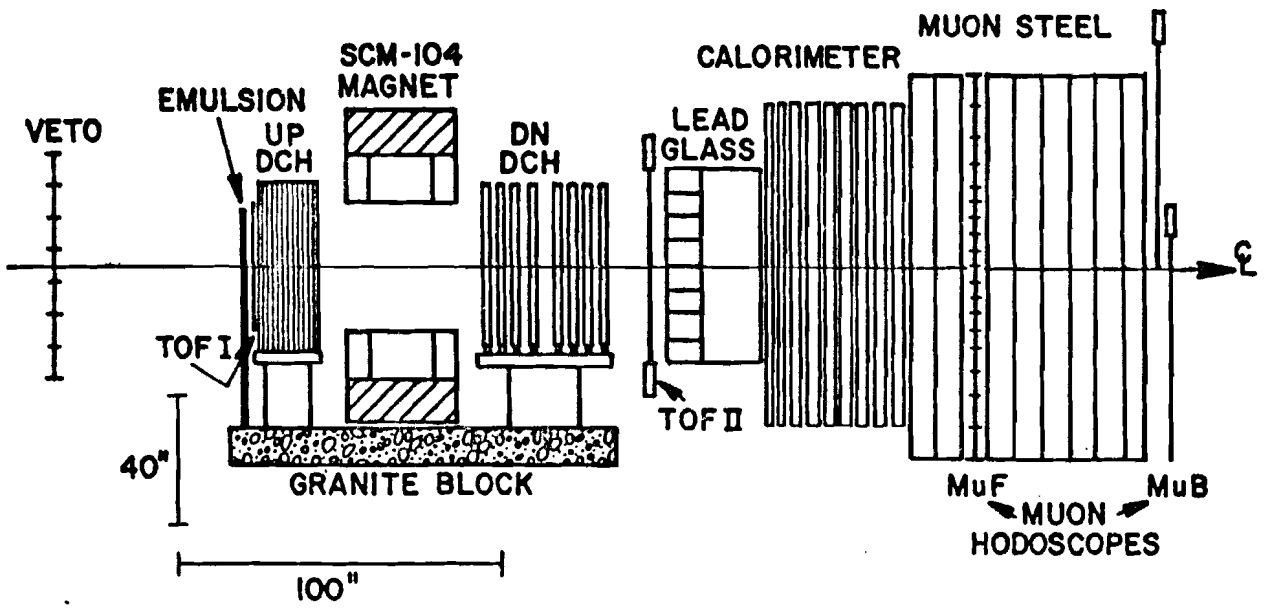


Figure 22. Granite Block and Support Stands

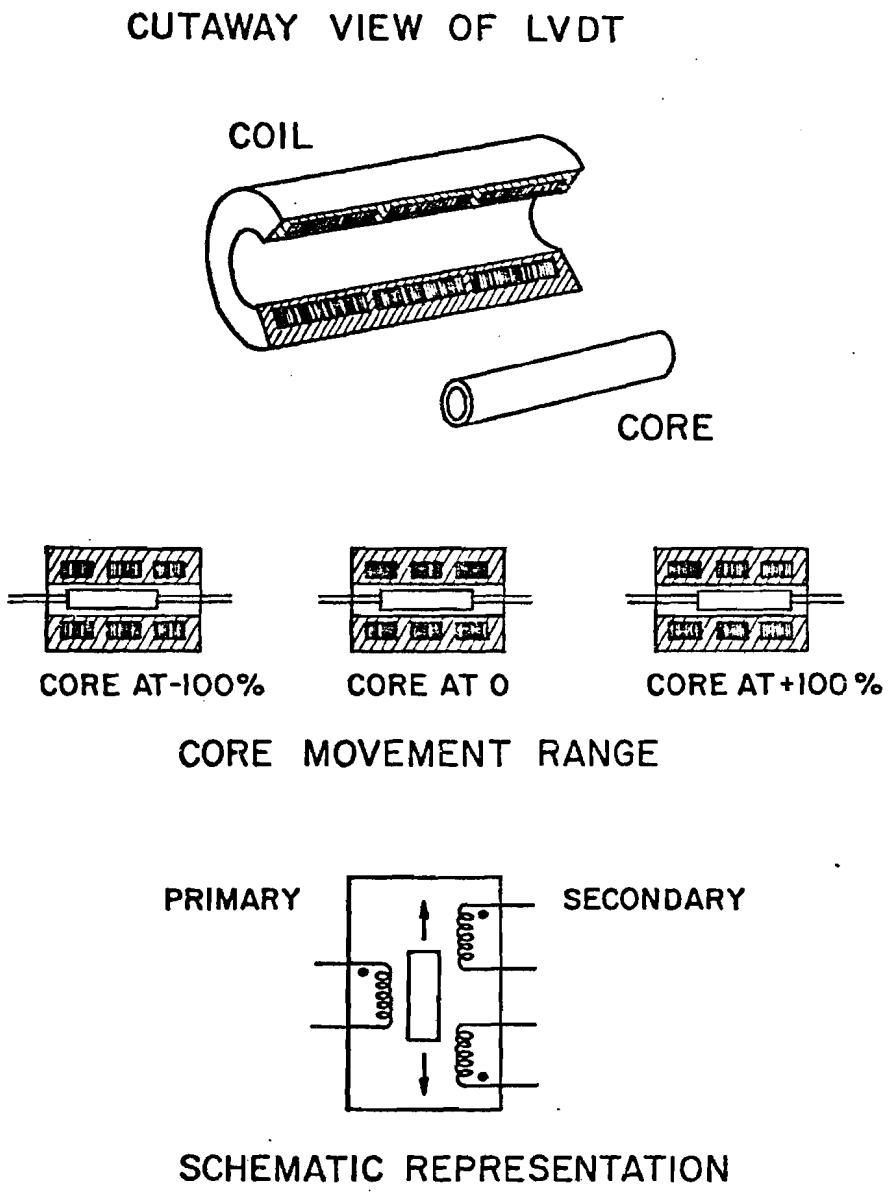


Figure 23. Cutaway of LVDT

apparatus in the experiment was made both before and after data taking. There were no significant changes in positions between these two surveys supporting the belief that the apparatus was positionally stable during the experiment. More evidence for this assumption comes from the tuned positions of the drift chambers. (See section 5-A for a definition of "tuned"). Over the entire duration of the experiment the average range in the tuned position of the first wire in the drift chambers was 125μm.

CHAPTER 4

DATA ACQUISITION

A. Triggers

A total of four different trigger types were taken during the experiment, two different data triggers and two different calibration triggers. The two data triggers were designated 1. neutrino and 2. muon. The requirements for the two data triggers are shown in table 1.

The requirements for the neutrino trigger were chosen to avoid any bias towards either charged or neutral currents and therefore do not involve the muon counters.

The purpose of the muon triggers was to calibrate the drift chambers, TOFI and TOFII, the lead glass array, the

TABLE 1: NEUTRINO AND MUON TRIGGER REQUIREMENTS

Neutrino Trigger:

f 2.5 minimum ionizing in TOF I

f 2 TOF II counters on

no anti counters on

Muon Trigger:

f 0.5 minimum ionizing in TOF I

only 1 TOF II counter on

calorimeter and the muon counters.

During each spill the muon trigger was gated off for the first 95% of the spill to allow the neutrino trigger full occupancy for that time. During the last 5% of the spill both the muon and neutrino triggers were active. This provided approximately 5 muon triggers per spill.

Between successive spills the two calibration triggers were taken. The laser-flasher trigger read in pulse height (ADC) and timing (TDC) information obtained from applying a common fast laser light pulse to all the TOF phototubes through fiber optics, and a slow common neon light flash to all the lead glass phototubes. The sensor trigger read DC levels from the LVDT's, counter and drift chamber high voltage monitors and a Hall-effect probe in the spectrometer magnet.

B. Electronics

Most of the electronics units employed in this experiment were standard devices used by many similar experiments. However, several devices were either not standard or are otherwise worth special mention.

To avoid calibration problems due to power supply voltage drifts, the TOF system high voltage was kept to within 1 volt of the nominal value by LRS HV4032 power supplies.

Jitter was removed from the anti counter signal by a Lecroy 624 octal mean timer to avoid vetoing events with backsplash from the emulsion target.

While most of the signals (ADC's and TDC's) were read through standard CAMAC interfaced modules, the drift chamber system was read out through a specially designed interface. Pulses from the sense wire were first amplified (100x) and then routed to a time recorder module. When a pulse reached the time recorder a time digitizer was started and continued to count until a stop pulse (a delayed data trigger) was received or the digitizing limit was reached. Up to 16 hits per wire could be accomodated by the system and multiple events could be stacked in local memory by controlling modules enabling information from several triggers to be stored during the 1ms spill. For a more detailed description of the drift chamber readout system see reference 21.

C. Data Acquisition

Actual data acquisition was performed through a Data General Eclipse computer with a CAMAC interface. During data taking a program running on the Eclipse read in the data associated with each trigger type and wrote the data immediately to magnetic tape. When not reading or writing data the program monitored several values in order to determine if incoming data were valid. Power supplies and the magnetic field were monitored and if any deviation from the nominal value was detected an alarm mechanism was triggered. Running averages and histograms could be generated allowing continuous monitoring of the apparatus.

In addition to data acquisition and storage, the Eclipse computer could simultaneously run analysis programs on previous data tapes. (A single run represented approximately 8 hours of data taking). Detailed histogramming of ADC and TDC values could be done as well as visual display of partially reconstructed events. In this way drift chamber efficiencies, noise levels and other similar effects could be more accurately monitored.

CHAPTER 5

ANALYSIS

A. Calibration

A large effort was needed to properly calibrate the various components of the apparatus. Two distinct methods of calibration were used in this experiment, (1) reconstructed background muons were projected throughout the apparatus and (2) laser and flasher pulses which were routed to certain counters between neutrino spills were analyzed.

The background muon gate was active for the last 5% of each neutrino spill providing over the course of the experiment four hundred thousand muon events. These tracks were used in calibrating the drift chambers and all counter systems.

Drift Chamber Calibration

The drift chamber calibration proceeded through several steps. Each drift chamber position and orientation was surveyed before and after the emulsion exposure.

The drift chamber parameters were "tuned" by reconstructing the background muon tracks. The tuned parameters were:

1. ZCHAM (the position along the beam direction)
2. FWIRE (the position of the first wire in the chamber)
3. ORIEN (the orientation angle of the chamber relative to the x axis)
4. STOPT (the absolute electronic stop time)
5. DRIFT (the individual chamber drift velocity)
6. CUBIC (a nonlinear correction to the drift velocity near the sense wires)
7. STOPD (the individual chamber stop time correction)

These parameters were tuned by perfoming a linear least-squares regression analysis on the residual errors from the reconstructed tracks in each chamber. These parameters were updated approximately 25 times throughout the exposure to correct for variations due to temperature changes and other causes.

Time of Flight Calibration

The time of flight counters were calibrated mainly on the background muon events. Since the particle types were known, the true flight time could be calculated and compared with the flight time measured by the TOF counter and adjustments made.

To check the calibration of the TOF system, each track in the neutrino events had its TOF measured and a corresponding mass calculated if the track was slow enough for accurate mass measurement ($P < 2.0$ Gev/c). As seen in figure 24, the protons produced from the complex nuclei in the target show clearly in the plot. There are symmetric peaks for the K^+ and K^- with a central smear for the pions, muons and electrons. The mass at the center of the proton peak is 939 ± 4 MeV/c^2.

Momentum Resolution and Calibration

The momentum of each track that passed through the spectrometer was obtained by a quintic spline fit to the hits used by the track. This method fitted a smooth curve through the points forcing the second derivatives of the curve to reflect the field strength along the particle path.

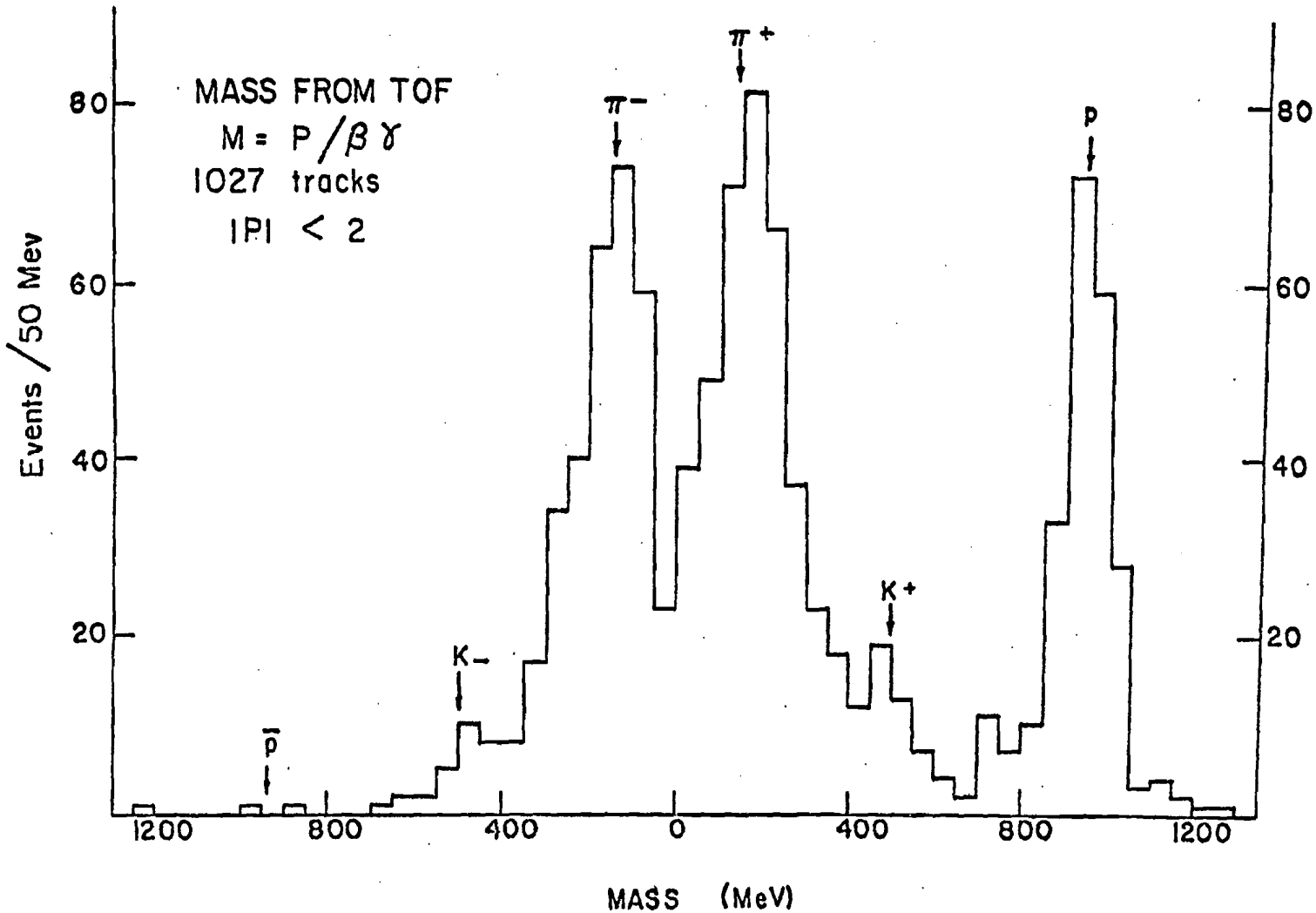


Figure 24. Particle Mass by TOF

For tracks that pass through the spectrometer the momentum resolution is restricted by two processes. For high momentum tracks, the resolution is limited by the ability of the chambers to measure the change in the slope of the particle as it passes through the magnet. With the arrangement of the chambers in this experiment, the upstream chambers could measure the slope in x to ±.0005 while the downstream chambers could measure it to ±.00075. For low momentum particles the resolution was limited by multiple scattering in the drift chambers and the helium bag in the magnet gap.

The momentum resolution can be calculated by using the thin lens approximation. For this method the momentum is given by:

$$P = \frac{.03 \int Bdl}{\theta} \qquad (1)$$

Where θ is the angle between the upstream and downstream slopes, P is the momentum in GeV/c and $\int Bdl$ is in kg-m. In our experiment the magnetic field was in the y direction making the angle θ equal the change in the x slope for small angles. Using our value of $\int Bdl$ we get:

$$P = \frac{.19}{x'_{up} - x'_{down}} \tag{2}$$

Since the resolution in the change of slopes was .001 then the error in P due to the finite resolution can be calculated as:

$$\sigma_P = .005\ P^2 \tag{3}$$

Multiple scattering also contributed to the momentum error. The total radiation length of the upstream drift chambers, the helium bag and helium in the magnet gap and the downstream chambers was .031 radiation lengths. This would cause a change in slope of:

$$\sigma x' = .0027/P \tag{4}$$

This would imply a contribution to the momentum error of:

$$\sigma P = .014P \tag{5}$$

This is actually an overestimate since the measurement of the slopes is done while the track is scattering. A Monte-Carlo program investigated the actual contribution from multiple scattering and found it to be:

$$\sigma P = .009P \tag{6}$$

The magnetic field strength is known absolutely to 1% giving a contribution of:

$$\sigma P = .010P \tag{7}$$

Taking (3), (6) and (7) in quadrature we have:

$$\sigma P = ((.005P^2)^2 + (.013P)^2)^{1/2} \tag{8}$$

Tracks which did not pass through the magnet gap but which did pass through the upstream drift chambers could still have their momentum measured. In Appendix A a complete description of the calibration method is given. For these upstream-only tracks the momentum resolution was found to be:

$$\sigma P = .35P^2 \tag{9}$$

Lead Glass Resolution and Calibration

The lead glass array was calibrated in two steps. Sample blocks were placed in an electron test beam. By varying the momentum of the beam, several calibration points were taken. In figure 25 the energy resolution of a block is plotted versus beam energy, E, in GeV. From the figure it is seen that the resolution can be parameterized as:

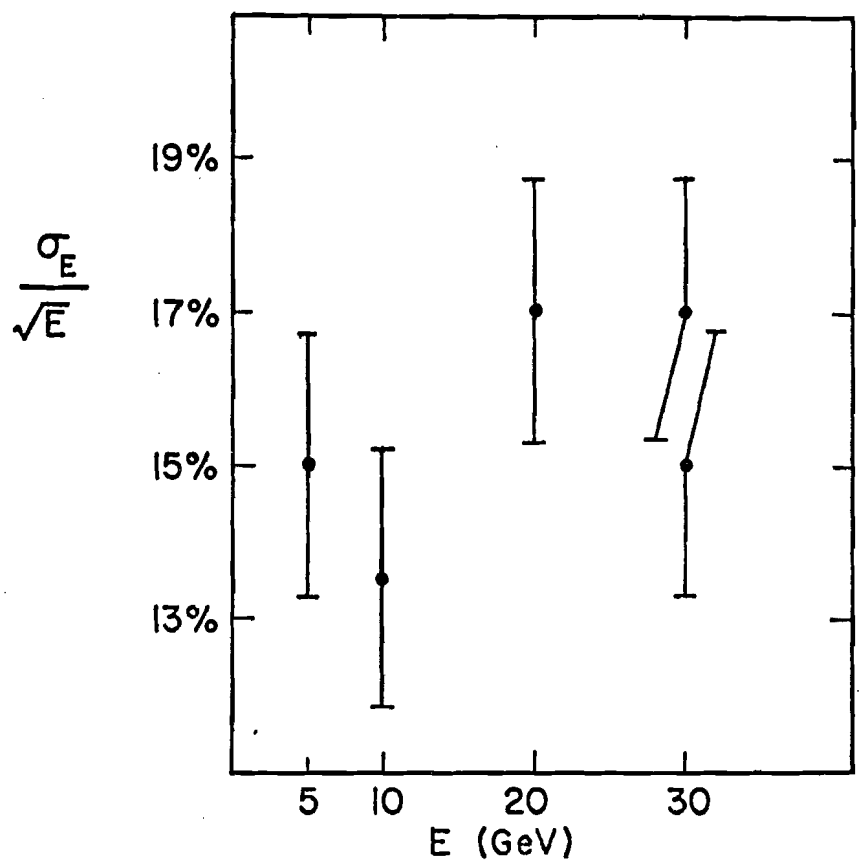


Figure 25. Energy Resolution of Lead Glass Blocks

$$\sigma_E = .15 \cdot \sqrt{E} \tag{10}$$

If a linear component exists its contribution is smaller than .015 E. In addition to the resolution measurement it was also necessary to calibrate the blocks. This was accomplished by relating the pulse height from electrons to the minimum ionizing peak due to hadrons. Thus an effective energy for a minimum ionizing particle could be calculated.

For the actual lead glass array the calibration was done by finding the pulse height for minimum ionizing tracks due to the background muons in each particular block over a small set of runs. The energy associated with any pulse height seen in the blocks for neutrino events could be calculated by using the effective energy of a minimum ionizing track in that block. Thus the energy would be calculated as:

$$E = E_{min} \cdot \frac{\text{Pulse height}}{\text{Pulse height}_{min}} \tag{11}$$

Calorimeter Calibration

The calorimeter was not calibrated directly since it could not be transported to any test beam and since there were not a sufficient number of hadrons of known energy in the neutrino data. Since our calorimeter was similar to well tested versions (17), we used the calibration data from these experiments. These experiments determined that the resolution of their calorimeter was:

$$\sigma E = 1.1 \sqrt{E} \tag{12}$$

Where E is the energy of the hadron in GeV. These experiments relate the energy of the incoming hadrons to the number of minimum ionizing tracks seen in the scintillators. Thus to calibrate our calorimeter we merely needed to relate the pulse height in the scintillator to the number of minimum ionizing tracks it represents as we did for the lead glass. The background muons were used to find this ratio. The response of the calorimeter to the muon tracks is shown in figure 26.

B. Vertex Prediction

The first step in the analysis of the acquired data was the initial reconstruction from the data tapes of the neutrino events, thereby predicting where in the emulsion

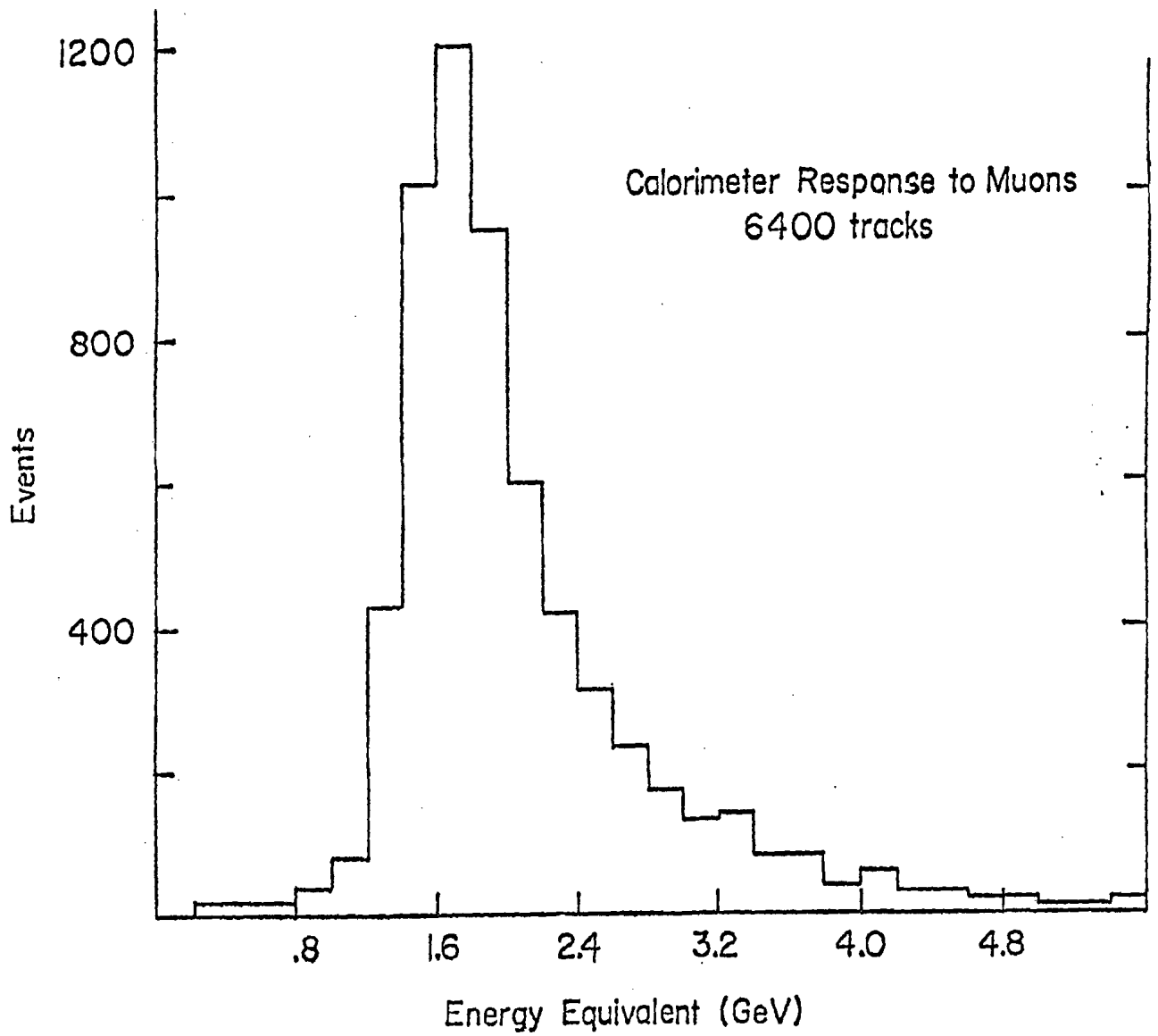


Figure 26. Response of Calorimeter to Muons

the event took place. This process was performed by two independent programs at two institutions. After partial analyses, done at Toronto University and Ohio State University, a final analysis of the entire data sample was done at Ohio State University with an improved reconstruction algorithm. Briefly the algorithm attempted to project either muon or high momentum hadron tracks from the downstream chambers into the upstream chambers towards an estimated vertex. This lent a small bias in the recontructed events towards charged current interactions, but reconstruction efficiency was high enough (> 80%) that this bias was fairly weak.

A total of 2355 events were reconstructed with a vertex in the emulsion target.

C. Event Location

Once a prediction had been made by a reconstruction program for the position of the neutrino interaction and the exit positions of the tracks, the production vertex in the emulsion was located by one of two methods. The first method involved scanning a volume surrounding the predicted location of the production vertex. This volume was a region 4 mm on a side perpendicular to the beam direction and 20 mm

parallel to the beam direction. This method was efficient only for those neutrino interactions that produced a relatively large number of heavily ionizing tracks. The other method used was first to locate a candidate for a track seen in the spectrometer in either the changeable sheet or in the downstream end of a pellicle. Usually several candidates were found this way and each was followed upstream until either the production vertex was found or the particle left the emulsion stack. This method was insensitive to the production characteristics of the event and depended only on the accuracy of the exit position measurements by the spectrometer system.

D. Decay Location

After the production vertex was found a search for decay candidates was done. Neutral decays were looked for in a cylinder with a radius of 300 μm and 1000 μm long in the beam direction. Decays were also located by following any track with momentum greater than .7 GeV/c that the primary analysis program reconstructed and which had no match at the production vertex yet which pointed back to the production vertex to within 2mm. This method was called the backscan method.

The efficiency for finding a decay (or scanning efficiency) is a function of the distance from the production vertex to the decay vertex. The scanning efficiency for neutral decays is shown in figure 27. There are some losses near the vertex due to vertex clutter. Heavily ionizing tracks and a finite grain count for minimum ionizing tracks make the observation of a decay within a few microns of the production vertex difficult. Within about 30 μm however the scanning efficiency is at its maximum value. The efficiency remains at this maximum value until 400 μm. It falls beyond this distance because it is difficult to find a decay vertex since it has no heavily ionizing tracks that show up easily in a microscope's field of view. At 1000 μm the efficiency drops to the value that corresponds to the probability of locating the decay solely by the backscan method. The backscan method is a highly efficient method (> 90%) but can be easily used only in the vertical emulsion modules. The value of 60% is the weighted mean for those found events which could and could not be backscanned. The maximum decay distance allowed is the full length of the emulsion which was 5cm.

Not all found decay candidates are D^0 decays. Some background events from neutral strange particle decays and neutral particle interactions are expected. The number of

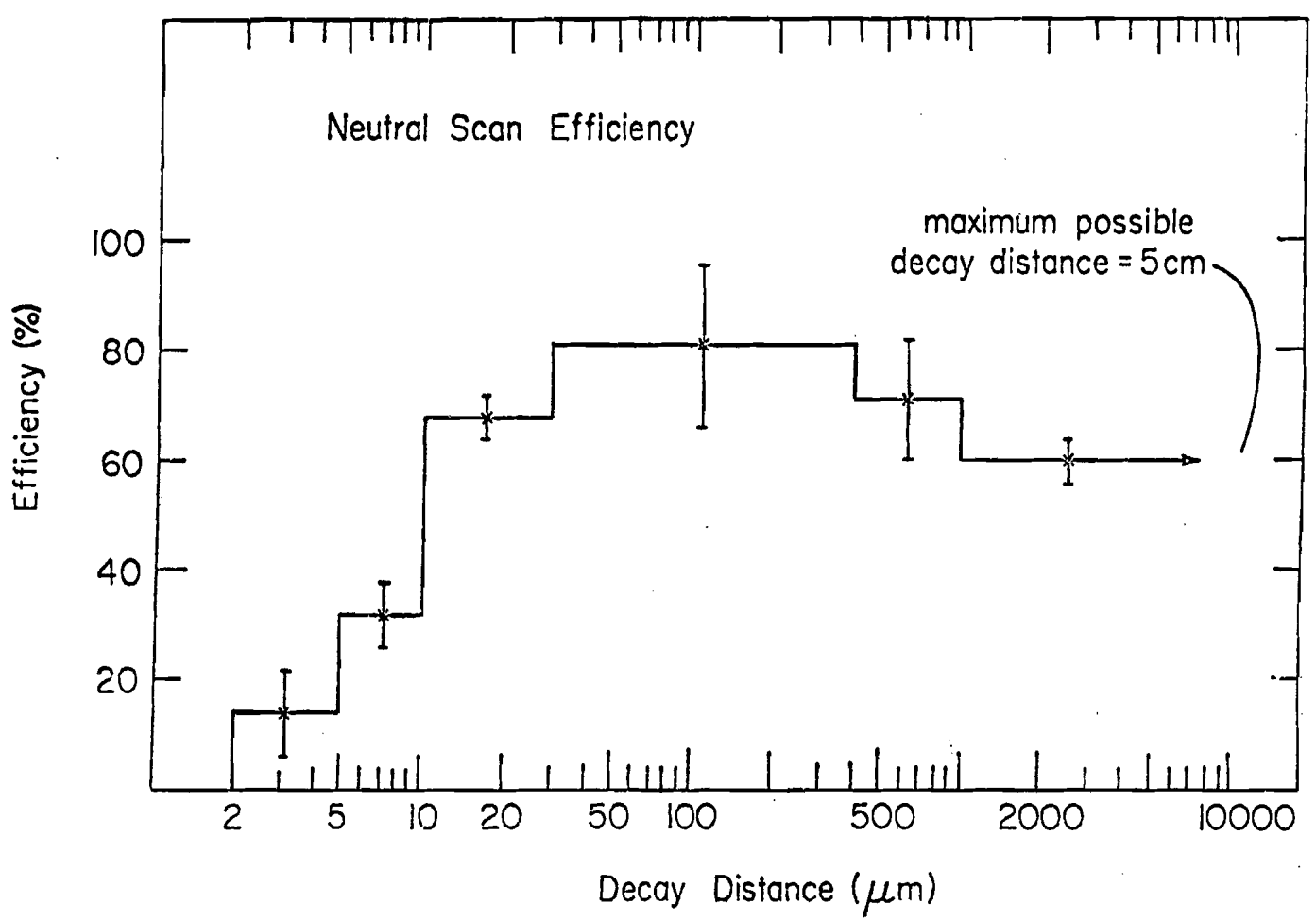


Figure 27. Neutral Decay Scanning Efficiency

neutral particle interactions can be calculated. Previous studies (18) have shown that a neutral strange particle is produced in .14 of the events. In addition a neutron with momentum greater than 2 GeV/c is produced in .21 of the events. The length of emulsion remaining downstream of the primary vertex is 2.3 cm on the average. Using the interaction length for our emulsion (23 cm) we calculate that a total of 41.5 neutral interactions should have occurred in the emulsion for the 1235 found events. Most of these interactions will produce either nuclear breakup at the interaction or an odd number of minimum ionizing tracks. Only 3.5% (19) of the interactions will mimic a decay with no heavily ionizing tracks and an even number of shower tracks. Folding in an average scanning efficiency of 65% for neutral decays we predict that we should see .94 neutral interactions which mimic a neutral decay. In addition interactions and neutral strange particle decays can be eliminated on the basis of the fitted mass of the D^0 decay candidate.

E. Event Reanalysis

After a charmed decay candidate had been identified in the emulsion, a series of programs and calculations were performed on the event to determine if the event indeed was

a charmed particle decay and if so what type of charmed particle decayed and what its proper decay time was.

A secondary reconstruction program attempted to find all minimum ionizing tracks seen in the emulsion including any that might have been missed in the original reconstruction. Each track was projected into the upstream drift chambers and an attempt was made to reconstruct a track using hits near the predicted coordinates. If an upstream-only track was sucessfully reconstructed a search was made for downstream continuation of this track. After these tracks were found the program then attempted to reconstruct independent tracks using drift chamber hits not used by the previous tracks. Each found track was then analyzed for TOF, muon identification, electro-magnetic energy in the associated lead glass block, and hadronic energy in the associated calorimeter row.

At this point an attempt was made at particle identification to guide the decay reconstruction. All probable decay hypotheses were attempted in order to arrive at a unique 3 constraint fit to the decay. If no hypothesis made a good (confidence level greater than 5%) fit then the decay was approached as a 0-C event.

The method of event reanalysis can be best illustrated by following the entire process for a single event. Choosing the event RUN 493 RECORD 177 as our example, the results from the primary reconstruction program are shown in table 2.

A total of four tracks were found by the primary analysis program. For each of the tracks the following information is given: first are the θ, ϕ, x, and y coordinates of the track at the changeable sheet, used to identify track candidates on the changeable sheet. The P column contains the momentum of the track in GeV/c. The χ^2 and number of drift chamber hits used from the track fitting programs are displayed, as are the fitted x and y slopes for each track. The IDENT column is for the muon identification of the track. The MUFB for track four is a mnemonic which indicates that the track points to muon counter hits in both the front and back planes. The VRTX# column indicates which of the "improved vertices" (from a second program pass) the track points back to. The 0 for track 2 indicates it does not point back accurately to any of the vertices. The final two pieces of data are the distance by which a track misses its associated vertex in mm in x and y respectively. In the case of track 2 the distance is from the improved vertex 1.

TABLE 2: PRIMARY EVENT RECONSTRUCTION FOR 493-177 77

RUN 493 RECORD 177 TUNE FROM RUN 494

ORIGINAL TRIAL VERTEX (MM): X,Y,Z= -348.95 -192.36 35.96
ESTIMATED ERRORS 1.19 1.14 3.91

CALORIMETER ENERGY (GEV): 30.43

4 TRACKS FOUND PROCESSING TIME (SEC) 10.88

TRK	THETACS(RAD)	PHICS(DEG)	XCS(MM)	YCS(MM)	P(GEV)	CHISQ
1	0.0878	113.7	-351.49	-191.05	-0.748	0.29
2	0.1038	110.1	-351.59	-195.68	-0.751	2.39
3	0.0971	128.5	-350.36	-190.92	6.564	1.62
4	0.0731	-44.8	-347.53	-193.26	-18.698	0.79

NPU	NPD	DX/DZ	DY/DZ	IDENT	VRTX#	X,Y DIST FROM VERTEX	
11	7	-0.0354	0.0806		1	-1.57	-0.50
10	4	-0.0358	0.0978		0	-1.66	-5.52
12	8	-0.0606	0.0763		1	0.14	-0.27
11	7	0.0520	-0.0516	MUFB	1	0.41	0.29

LIST OF IMPROVED VERTICES

VERTEX# 1 X,Y,Z(MM): -349.12 -192.38 34.47
EST. ERRORS 0.72 0.75 3.47

A glance at the table shows that tracks one and two are nearly identical in slopes and momenta. Track two has a higher χ^2 and uses fewer drift chamber hits leading one to believe that it is merely a poorer solution to the same track that track one represents. Thus it would seem that a total of three independent tracks have been found, all pointing back to the same vertex.

The x, y, and z of this vertex indicates that the event took place in one of the vertical emulsion modules and was thus searched for. When this event was found by the emulsion scanners in Japan, they also found a possible charmed particle decay. When this happens, the usual procedure is to telex the emulsion information from Japan to Fermilab in order to start the event reanalysis.

The contents of the telex for this event are given in table 3.

As we can see from the telex, only track four went back to the primary vertex. No candidate for counter track three was found at either the primary vertex, the decay vertex or on the changeable sheet. No candidate for tracks one and two were found at either the primary or decay vertex. The fact that the primary vertex was found so near to the

FOR DR. RON SIDWELL

FROM PROF. K. NIU 80/5/15

NEW VEE

NGY450 493- 177 MOD=11 FILM=24 NH=0 NS=3

AT VERTEX			COUNTER				
TRK	DX/DZ	DY/DZ	TRK	DX/DZ	DY/DZ	P	
EM1	0.052	-0.051	4	0.052	-0.051	-18.7	REF
EM2	-0.057	-0.018					
EM3	-0.037	1.374					
V-1	0.101	-0.170					
V-2	-0.211	0.251					
0-V	-0.031	0.019					
			1	-0.035	0.081	-0.7	
			2	-0.036	0.098	-0.8	
			3	-0.061	0.076	6.6	

DECAY POINT

DX,DY,DZ= -10.1, +6.3, 326 MICRON

FLIGHT LENGTH=326 MICRON

VERTEX COORDINATE

X,Y,Z= -348.09, -191.24, 39.16 MM

PLEASE FIND TRKS V-1,V-2, AND EM-2. THESE EXITED MODULE WITHOUT APPRECIABLE ANGLE CHANGES.

NO CANDIDATE FOUND FOR COUNTER TRK 3.

BEST REGARDS

predicted vertex is surprising since only one track went back to it. The fact that there were no heavy ionizing tracks (NH=0) at the primary vertex indicates that the followback method was the only method reasonably sure to find this event.

The slopes listed after the O-V entry are the slopes of the neutral decaying particle.

In order to reconstruct the decay vertex it was necessary to find at least the tracks V-1 and V-2 in the spectrometer. The next step in the analysis was to reanalyze the event using the emulsion information provided by the telex as a guide for the track finding routines.

In table 4 the results from the reanalysis program are shown. The primary vertex is now given in inches and the matchup between the tracks seen in the emulsion and computer or counter tracks are given.

The first three tracks match tracks seen in the emulsion. Track one is the muon track previously seen while the matches to V-1 and V-2 are new tracks found by the reanalysis program. Track V-1 is an upstream-only track as evidenced by the 0 under the PTS DN column. An up and

TABLE 4: EVENT REANALYSIS FOR 493-177

RESULTS OF CHARM CANDIDATE REFIT FOR:

RUN 493 RECORD 177

DONE ON 81/03/30. AT 18.17.02.

VERTEX IS AT X,Y,Z= -13.732 -7.563 1.511

	EMULSION		COMPUTER					
TRACK	DX/DZ	DY/DZ	DX/DZ	DY/DZ	P	PTS UP	DN	CHI-SQ
1	.052	-.051	.052	-.052	-18.87	11	7	.704
V-1	.101	-.170	.102	-.174	3.13	11	0	.321
V-2	-.211	.251	-.219	.251	-.52	12	7	.507
U-1	NO MATCH		-.035	.082	-.76	12	6	.312
U-2	NO MATCH		.688	-.078	.62	7	8	1.507
U-3	NO MATCH		-.060	.076	6.37	12	8	.953

MUID	EPBG	BETA	DBETA	XMISS	YMISS	XCHS	YCHS
MUFB	.285	.006	.012	.010	-.001	-347.46	-193.18
	0.000	0.000	1.000	.010	.011	-346.44	-195.40
	.219	.046	.028	.022	-.003	-352.76	-187.00
	.299	.011	.016	-.082	-.021	-351.60	-190.95
	0.000	.434	.014	-3.675	.818	-427.95	-172.94
	.360	-.023	.028	-.023	-.003	-350.61	-190.62

TOTAL CALORIMETER ENERGY IS 30.43 GEV
4.40 2.18 12.79 11.06 IN COLUMNS 1,2,3,4

TOTAL LEAD GLASS ENERGY IS 1.16 GEV

downstream track candidate has been found for V-2. The three tracks U-1, U-2, and U-3 are at this point unidentified tracks that do not match any track seen in the emulsion. U-1 and U-3 are tracks one and three found by the primary reconstruction program while U-2 is new.

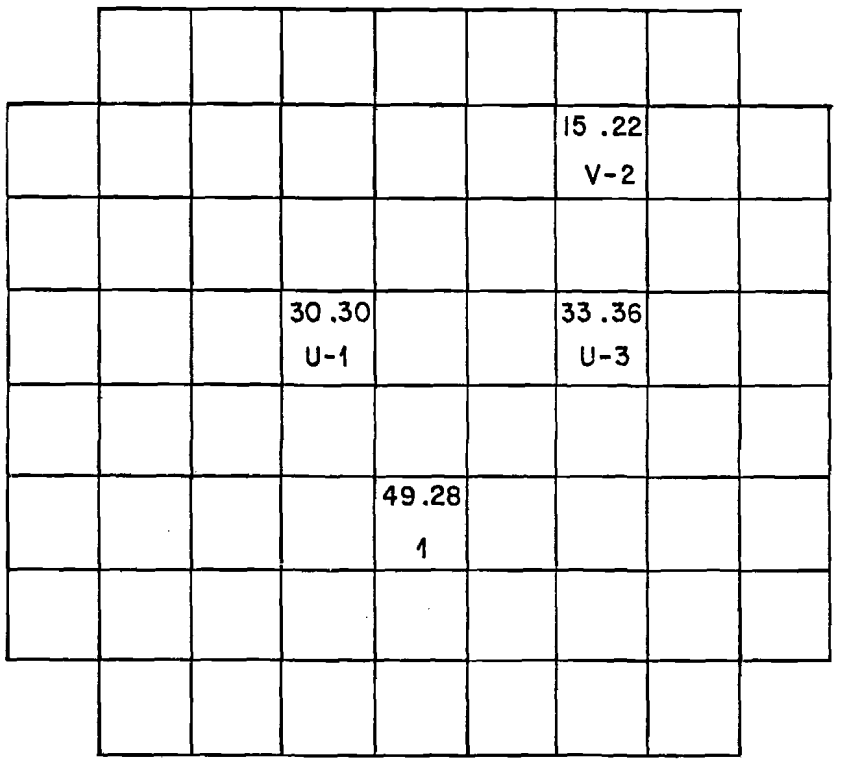
Additional counter information is now available for the tracks found by the computer program. EPBG is the energy in the lead glass array near the entry point of the charged track. Comparing these energies with the momenta of the tracks we find that there are no candidates for electrons in this event. MUID serves the same purpose as the IDENT of the primary analysis program and once again emulsion track 1 is identified as a muon. BETA and DBETA are respectively $1-\beta$ and its error as measured by the TOF system. The TOF for track 1 is consistent with a muon. Tracks V-2 and U-1 are consistent with either muons or pions. Track U-2 is a well identified proton and track U-3 is inconsistent only with a proton. Lastly the x and y misses in inches at the vertex, and coordinates at the changeable sheet in mm are listed. The mystery of the good prediction of the primary vertex is seen to be result of the fact that tracks 1, U-1, and U-3 all point back to the primary vertex quite well. V-1 and V-2 also point back to the primary vertex quite well as is expected since the decay vertex is so close (326 μm).

Track U-2 is the only track which does not point back to the primary vertex well, missing it by over 3.5 inches.

In figure 28 the lead glass array hits are shown for this event. All blocks which are on are at the minimum ionizing energy for that block and all have a reconstructed charged track entering it. Therefore there are no γ or π^0 candidates for this event.

The task before us now is to reconstruct the decay vertex to ascertain if this is indeed a candidate for a charmed particle decay.

The first possibility to eliminate is the decay of a neutral strange particle. A 2 constraint fit to the decay vertex shows that the decay can not be a 2 body decay. The three body decays of neutral strange particles that could considered candidates for this event are either too unlikely (BR $\Lambda^0 \rightarrow p\ e^-\ \nu = .81 \times 10^{-3}$) or are associated with a lifetime too long to be considered likely for a 326μm decay ($\tau(K_L^0) = 5.2 \times 10^{-8}$ sec.) or are eliminated on the basis of mass. Since the decay is at least three body, one or more neutral particles must be found to balance transverse momentum at the decay vertex. As we have seen before there are no π^0 or γ candidates in this event, thus if one exists



ENERGY DEPOSITED
IN LEAD GLASS
ARRAY FOR
EVENT
493-177

Figure 28. Lead Glass Hits for 493-177

it must either be very low energy or wide angle to miss the spectrometer.

Tracks U-1, U-2, and U-3 however make a good vertex at the TOFI counter. Assuming they come from the interaction of a neutral particle, we then have a candidate for the sought after neutral particle from the decay. The first question that must be addressed is whether any of the tracks in the alleged interaction are false combinations of hits used by other tracks in the event. These tracks have no hits or mates in common with the tracks from the emulsion, and also the χ^2 of these tracks and the TOF identifications are quite good, leading one to believe that the tracks are real.

We now need to determine what type of neutral particle from the decay in the emulsion initiated the interaction. The three possible candidates are the K^0, the Λ^0 and the neutron. An interaction by a K^0 seems quite plausible and can not be easily eliminated. The visible momentum from the interaction (greater than 7 GeV/c) is quite high for a baryon making either a neutron or Λ^0 interaction less likely. In addition a Λ^0 interaction would usually produce a stange baryon among the decay products. Since no strange baryon decay is seen a Λ^0 interaction is even less likely.

We must now calculate the slopes and momentum for the interacting neutral particle. The slopes are calculated by using the differences in x, y, and z between the decay and interaction vertices. This gives $-.060 \pm .006$ and $.079 \pm .006$ for x and y respectively. The calculation of the momentum is a bit more nebulous. The sum of the momenta of U-1 and U-3 would represent a good measurement of the incoming neutral particle's momentum if we considered the interaction to be a charge-exchange interaction and assumed that U-2 is a recoil proton. Track U-3 would then be a typical leading particle with slopes nearly that of the incoming neutral and relatively high momentum. The measurement error of the momentum of U-3 is approximately .20 GeV/c while that of U-1 is less than .003 GeV/c. Adding a .30 Gev/c contribution from Fermi momentum of the target nucleus, we get $7.13 \pm .50$ GeV/c as the momentum of the incoming neutral particle. If the interaction was not a charge-exchange interaction then the momentum would be raised by the momentum of the outgoing neutral particle. This case was not considered since (as we shall see momentarily) the momentum solution for a charge-exchange interaction balences transverse momentum at the decay vertex quite well. In table 5 we list the possible hypotheses for the neutral charmed particle decay. Only Cabibbo favored decays are listed. Also listed is the K_S^0 decay hypothesis for later comparison.

TABLE 5: POSSIBLE HYPOTHESES FOR EVENT 493-177

	Hypothesis	Assumed Mass
1.	$K^0 \rightarrow \pi^+ \pi^-$	.494 GeV
2.	$D^0 \rightarrow K^0 \pi^+ \pi^-$	1.863 GeV
3.	$\Sigma_c^0 \rightarrow \Lambda^0 \pi^+ \pi^-$	2.425 GeV
4.	$A^0 \rightarrow \Lambda^0 K^+ \pi^-$	2.500 GeV
5.	$A^0 \rightarrow n \pi^+ \pi^-$	2.500 GeV

The assumed masses for the K^0 and the D^0 are standard. The Σ_c^0 is assumed to decay strongly but for our purposes we put the mass at the $\Lambda_c^+ \pi^-$ threshold. Since the A^0 has not been seen the mass represents only an educated guess.

The results of the 2 and 3 constraint fits to the decay for all the hypotheses are shown in table 6 and table 7 respectively. NHYP is the corresponding hypothesis number from the previous table. CHI2 and C.L. are the χ^2 and confidence level for the fit. Iter is the number of iterations the fitting program performed to arrive at the solution. MASS and M-SIG are the fitted mass and error in GeV/c^2. P-GEV and P-SIG are the fitted momentum and error in GeV/c for the parent particle. TAU and T-SIG are the fitted decay time and error. DELPX and DELPY are the initial momentum imbalances in x and y at the decay vertex and DX/DZ, X-SIG, DY/DZ, and Y-SIG are the fitted slopes and errors in x and y for the parent particle.

As related before the two body solution for the decay is untenable. In the 2-C fits the three body solutions are quite good giving a confidence level near 60% indicating that the neutral particle is indeed from the decay. The fitted masses for the various three body solutions are in the right neighborhood though with large errors. The 3-C

TABLE 6: 2 CONSTRAINT FITS FOR 493-177

NHYP	CHI2	C.L.	ITER	MASS	M-SIG	P-GEV	P-SIG	DELPX	DELPY
1	14.26	.001	6	.404	.005	1.122	.029	-.320	.469
2	1.06	.589	3	1.733	.104	10.251	.651	-.112	.042
3	1.06	.589	3	2.109	.091	10.251	.651	-.112	.042
4	1.06	.589	3	2.304	.073	10.251	.651	-.112	.042
5	1.06	.589	3	1.981	.095	10.251	.651	-.112	.042

TAU	T-SIG	DX/DZ	X-SIG	DY/DZ	Y-SIG
.3916E-12	.1306E-13	-.034	.003	.013	.004
.1837E-12	.7404E-14	-.028	.004	.021	.005
.2235E-12	.1010E-13	-.028	.004	.021	.005
.2442E-12	.1156E-13	-.028	.004	.021	.005
.2100E-12	.9070E-14	-.028	.004	.021	.005

TABLE 7: 3 CONSTRAINT FITS FOR 493-177

NHYP	CHI2	C.L.	ITER	MASS	P-GEV	P-SIG	DELPX	DELPY
1	180.93	0.000	4	.498	1.624	.010	-.320	.469
2	2.46	.483	2	1.863	11.011	.282	-.112	.042
3	9.66	.022	3	2.425	12.327	.360	-.112	.042
4	6.06	.109	3	2.500	11.801	.298	-.112	.042
5	18.98	0.000	4	2.500	13.626	.377	-.112	.042

TAU	T-SIG	DX/DZ	X-SIG	DY/DZ	Y-SIG
.3331E-12	.1043E-13	-.002	.002	-.029	.002
.1839E-12	.7347E-14	-.026	.004	.019	.004
.2138E-12	.9058E-14	-.024	.004	.016	.004
.2302E-12	.9143E-14	-.025	.004	.017	.004
.1994E-12	.8234E-14	-.023	.004	.014	.004

solutions indicate that all but the first and final hypotheses are at least tenable (remember that the assumed masses for the last three hypotheses are quite loose) with the D^0 hypothesis having the best confidence level at nearly 50%. Remember though that hypotheses three and four use a Λ^0 interaction which would be difficult to explain in the present topology.

Thus the hypothesis with the best confidence level is also the most simple. The decay can be considered as:

$$D^0 \rightarrow K^0 \pi^+ \pi^-$$

The fitted proper decay time becomes: $t = 1.84 \pm .07 \times 10^{-13}$ seconds.

F. Found Events

The primary analysis program reconstructed a total of 2355 neutrino events over the entire data run. However, all of these events did not originate in the emulsion target. The distribution of the reconstructed events is shown in figure 29. Events within the limits of the emulsion stack as shown in the figure are not all accessible, however, as many of these are in support posts and G-10 support blocks in the emulsion modules. A breakdown of the events is shown in table 8.

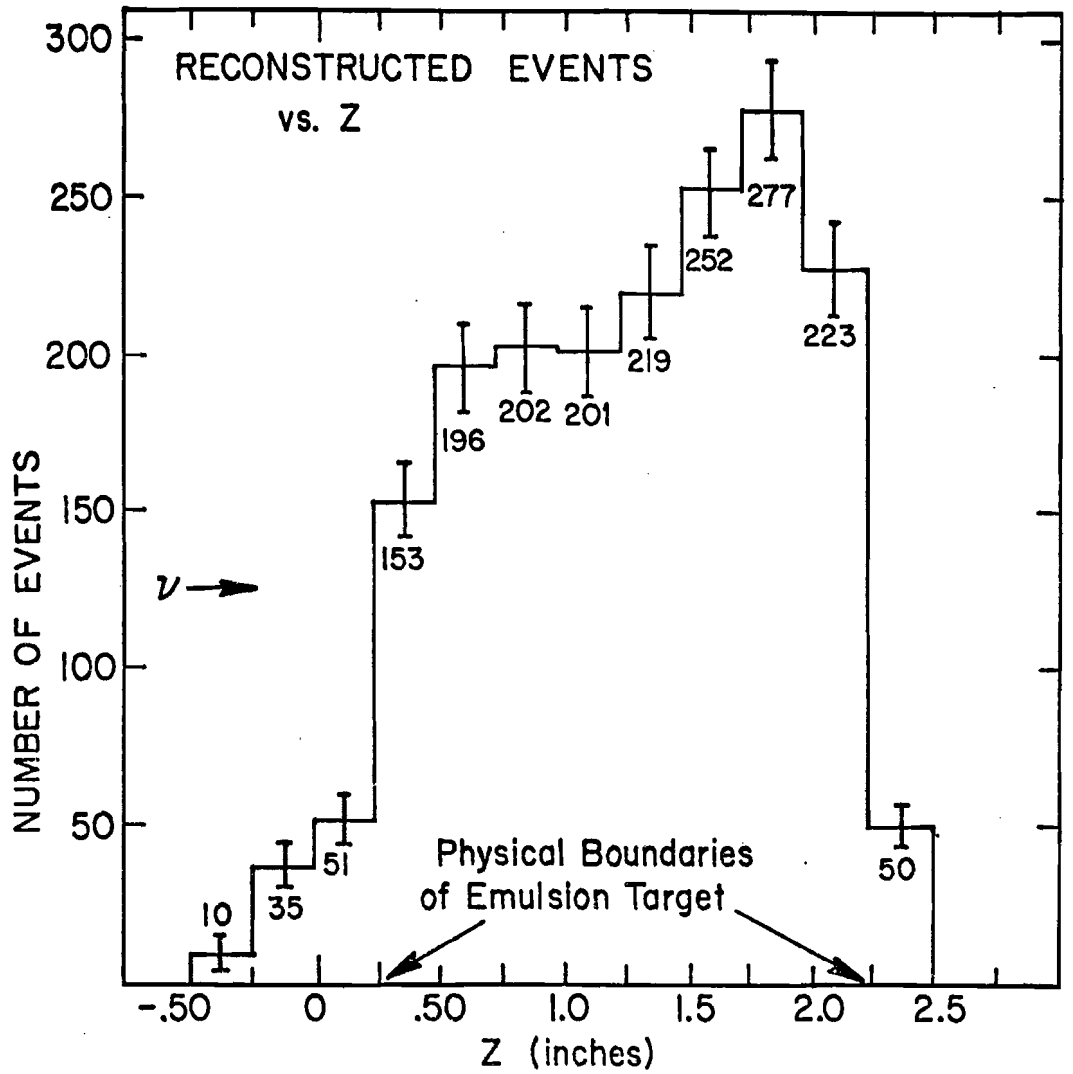


Figure 29. Reconstructed Events vs. Z

TABLE 8: RECONSTRUCTED EVENTS

RECONSTRUCTED EVENTS	2355
IN FIDUCIAL VOLUME OF EMULSION	1877
FOUND EVENTS	1235
CHARM DECAY CANDIDATES	43

Thus a total of 1821 events are in the fiducial volume of the emulsion. All of these events have been searched for with the results shown in table 9. The event location efficiency of 76% is a significant improvement over previous experiments. A large part of the increase is due to the followback method of event location which is able to locate events with no heavily ionizing tracks at the primary vertex.

In figure 30 the distribution of the number of heavily ionizing tracks (NH) at the primary vertex is plotted for the events found by the followback method. Approximately 28% of these events have NH = 0. In contrast figure 31 is the distribution of the NH of those events found by the volume search method. Only 10% of these events have NH = 0. The discrepency in the number of events with NH > 13 can be explained by the differing definitions of "grey" versus "black" tracks at a primary vertex by the different institutions using the different methods. (A minimum ionizing track is called a "white" track) Thus for events with many non-minimum ionizing tracks, the NH count would be different for a single interaction.

The distribution of the number of minimum ionizing tracks (NS for number of "shower" tracks) at the primary

TABLE 9: FOUND EVENTS

Search Method	Volume	Followback
Predicted Events	1411	944
In Fiducial Volume	877	822
Searched For	877	822
Found	509	726
Charm Search Done	477	617
Multiprong Decay Candidates:		
Charged	8	14
Neutral	3	18
Interactions		
Hadronic:		
Charged	51	22
Neutral	1	0
Electron pairs	40	65

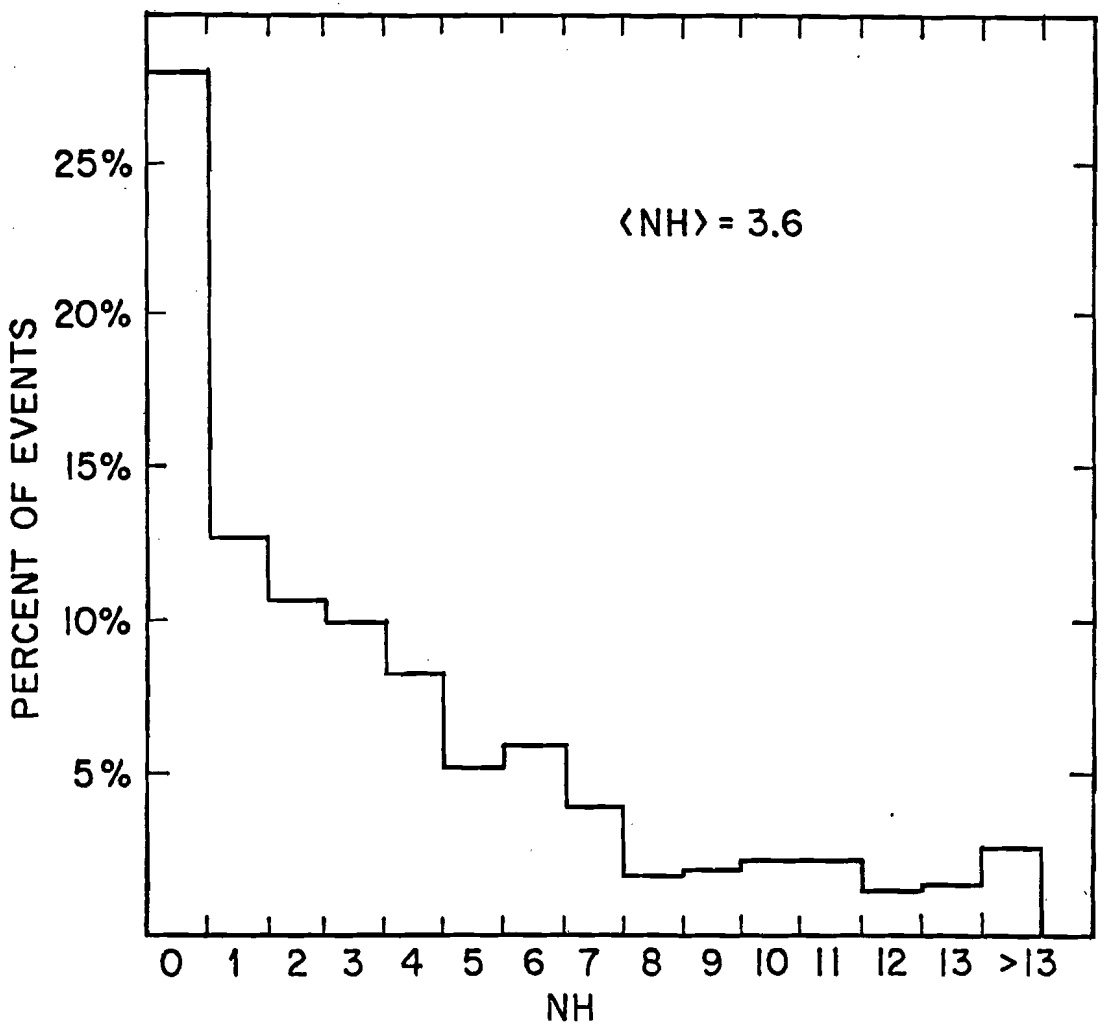


Figure 30. NH Distribution for Followback Method

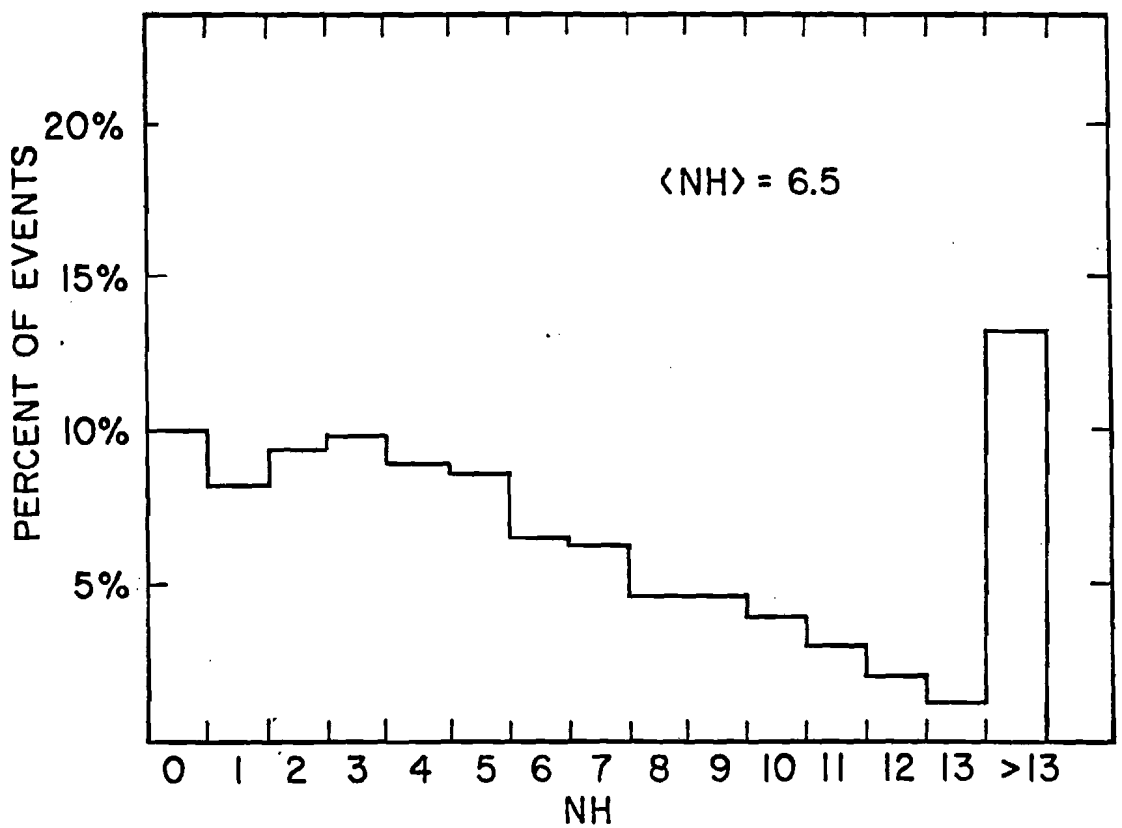


Figure 31. NH Distribution for Volume Seach Method

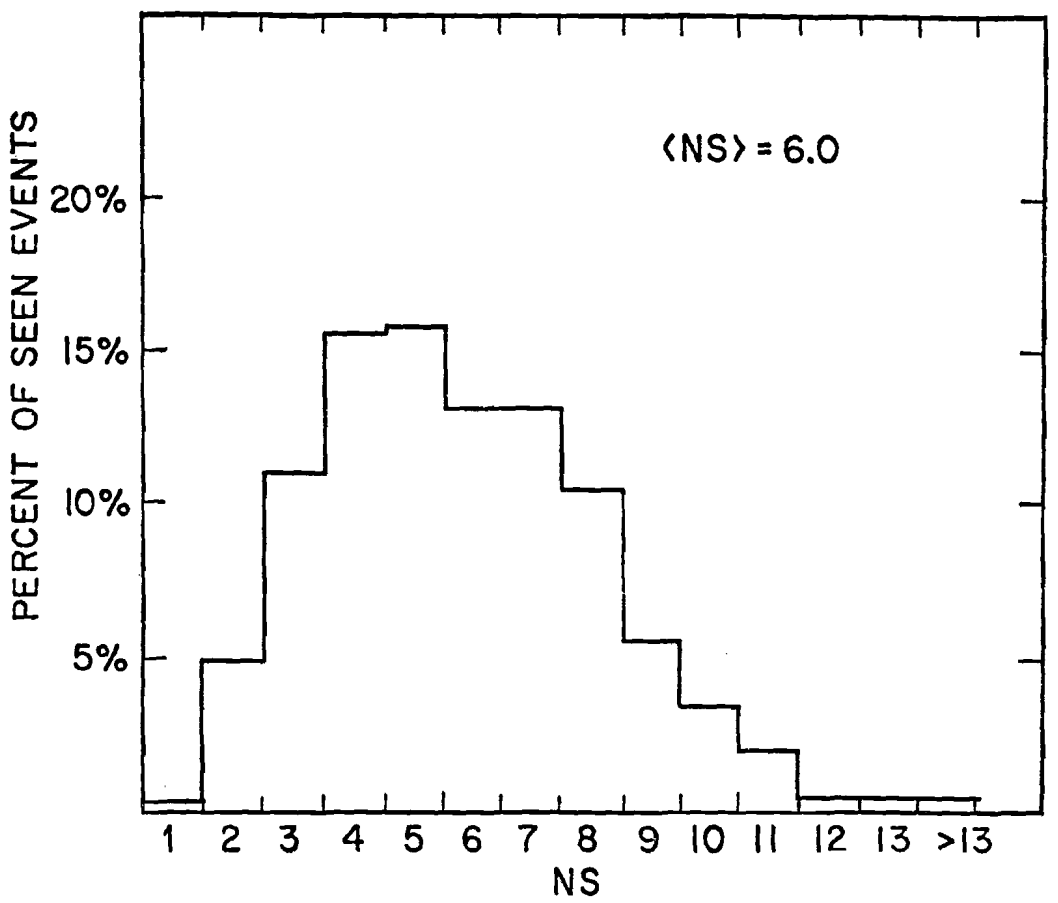


Figure 32. NS Distribution for All Events

vertex is shown in figure 32. The distribution of NS makes a very good fit to a Poisson distribution with an expectation value of 6 minimum ionizing tracks.

G. Found Decay Candidates

The search for decays of D^0 mesons associated with the events found in the emulsion has yielded the results shown in table 10. A total of 22 neutral decay candidates are seen in the emulsion in a total of 20 events. The long decay seen in event 11 is probably the decay of a Λ^0 to p π^- though the Λ^0 does not point back to the vertex well. Event 14 is the decay of another neutral baryon (2l). In event 13 the analyzing magnet's power supply had tripped thus giving us no momentum information on this event, making analysis too difficult for further interpretation. Event 19 is too jetlike (six tracks within 30mr) for accurate reconstruction of the event. The remaining 18 decays are consistent with the decay of a D^0 meson and are usable for lifetime analysis. Event 7 seems to be an associated production of charm in a neutral current event though this is only a preliminary analysis of this event. Of the remaining 18 usable events, three are semileptonic decays. The decay lengths ranged over three orders of magnitude from 6μm to 5471μm. Of the 20 candidates, 2 have 6 charged daughter

TABLE 10: FOUND DECAYS

EVENT	RUN	RECORD	DECAY LENGTH	NUMBER OF PRONGS	COMMENTS
1	478	2638	126	6	
2	486	6857	256	4	
3	493	177	326	2	
4	513	8010	27	4	
5	518	4935	116	2	
6	522	3061	5471	4	μ^- μ^+ EVENT
7	529	3013	590	2	ASSOCIATED
			3170	2	PRODUCTION
8	547	2197	4052	4	
9	547	3705	749	4	
10	556	152	41	4	
11	577	5409	67	2	
			32850	2	Λ^0 DECAY
12	597	6914	4374	2	μ^- e^+ EVENT
13	609	1768	449	2	MAGNET OFF
14	635	4949	4352	2	NEUTRAL BARYON
15	638	5640	184	2	
16	654	3711	6	6	
17	661	2729	702	2	
18	661	6517	2640	2	μ^- μ^+ EVENT
19	666	5294	653	4	
20	670	7870	187	2	

tracks, 7 have 4 and 11 are two prong events. All 18 usable events are inconsistent with any known strange particle decay.

H. Fitted Decays

With the exception of the 6μm decay, the parent particle's slopes have been measured for each decay making it possible to perform a three constraint fit to the decay of a D^0 meson. In most events however one or more neutral particles are needed to balance momentum at the decay vertex. After the secondary analysis program searched for neutral particles that could be associated with the decay, all possible hypotheses were tried to make a good 3-C fit. Those events with at least one hypothesis with a confidence level greater than or equal to 5% are listed in table 11. A total of 11 events fit this criterion. Only the best 3-C fit for each decay is given. It can be seen that only three events could be fit without recourse to neutral particles seen in the spectrometer. Those particles which are underlined are identified at the 90% confidence level.

In table 12 we have the fitted 2-C mass associated with the hypothesis in the previous table. The error in the mass varied widely depending on whether or not upstream-only

TABLE 11: 3-CONSTRAINT HYPOTHESES

RUN	RECORD	CONFIDENCE LEVEL	HYPOTHESIS
486	6857	.12	$D^0 \rightarrow \pi^- \underline{\pi}^+ K^- \pi^+$
493	177	.48	$D^0 \rightarrow \pi^+ \underline{\pi}^- K^0$
513	8010	.05	$\bar{D}^0 \rightarrow \pi^+ K^+ \underline{\pi}^- \pi^- \underline{\pi}^0$
518	4935	.88	$D^0 \rightarrow \pi^+ K^- \underline{\pi}^0 \underline{\pi}^0$
529	3013(V1)	.61	$D^0 \rightarrow \pi^+ K^- \underline{\pi}^0$
529	3013(V2)	.90	$\bar{D}^0 \rightarrow \pi^- K^+$
547	2197	.46	$D^0 \rightarrow \pi^+ \pi^- \underline{\pi}^+ K^- \underline{\pi}^0$
547	3705	.78	$D^0 \rightarrow K^- \pi^- \underline{\pi}^+ \pi^+$
556	152	.99	$D^0 \rightarrow \pi^- K^- \underline{\pi}^+ \underline{\pi}^+ \underline{\pi}^0$
638	5640	.99	$\bar{D}^0 \rightarrow K^+ \pi^- \underline{\pi}^0 \underline{\pi}^0$
661	2729	.30	$D^0 \rightarrow \underline{\pi}^- \pi^+ \underline{K}^0_S \underline{\pi}^0$

TABLE 12: FITTED 2-C MASSES

RUN	RECORD	FITTED MASS (MeV/c^2)	ERROR	MOMENTUM (GeV/c)
486	6857	1816	40	12.30
493	177	1733	104	11.01
513	8010	1766	48	9.18
518	4935	1939	117	30.07
529	3013(V1)	2000	130	13.23
529	3013(V2)	1823	137	47.60
547	2197	1859	38	23.58
547	3705	1961	117	13.53
556	152	1855	43	15.43
638	5640	1857	76	21.85
661	2729	1859	34	12.33

WEIGHTED TOTAL FITTED MASS = 1842 ± 16 MeV/c^2

tracks or π^0's were used in the fit. The total weighted mass is a bit low but is within 1.5 σ of the accepted value.

In table 13 the remaining events are listed. The one 1-C fit is the 6μm decay which is too short to measure the parent particle slopes thus leaving only one constaint (force to D^0 mass). The six events in the lower table are unable to be fit since one or more missing neutral particles are needed to balance transverse momentum at the decay vertex. In general this generates two solutions to the parent particle's momentum. The first event is the exception to the rule since the minimum mass is at the mass of the D^0. The third and sixth events have a preferred solution. In the third event the high momentum solution for the K^0 is not allowed by the energy seen in the calorimeter and the high momentum solution to the missing π^0 in the sixth event is not supported by the lead glass array. For the lifetime fit the average or preferred momenta from the 0-C fits are used.

Taking the average or preferred solution from the 0-C fits, the 3-C fits and a 1-C fit to the 6μm decay we combine them into 18 "fitted" decays in table 14.

TABLE 13: 0 AND 1-CONSTRAINT HYPOTHESES

1-C HYPOTHESIS

RUN	RECORD	CONFIDENCE LEVEL	HYPOTHESIS
654	3711	.06	$D^0 \rightarrow \pi^+ \pi^+ K^- \pi^- \pi^- \pi^+$

0-C HYPOTHESES

RUN	RECORD	MOMENTA	HYPOTHESES
478	2638	8.6	$D^0 \rightarrow \underline{\pi}^- \pi^- \underline{\pi}^+ \underline{\pi}^+ \pi^- \pi^+ (\pi^0)$
522	3061	36.0 65.0	$D^0 \rightarrow \pi^- \pi^+ \underline{\mu}^+ K^- (\nu_\mu)$
577	5409	11.9* 17.4	$D^0 \rightarrow \pi^+ \pi^- (K^0)$
597	6914	25.0 67.0	$D^0 \rightarrow \underline{e}^+ K^- (\nu_e)$
661	6517	21.2 40.0	$D^0 \rightarrow \underline{\mu}^+ K^- (\nu_\mu)$
670	7870	6.8* 9.2	$D^0 \rightarrow K^+ \pi^- (\pi^0)$

* Indicates Preferred Solution

TABLE 14: ALL FITTED DECAY CANDIDATES

EVENT	RUN	RECORD	MUON MOMENTUM	PROPER DECAY TIME	CHARM MOMENTUM	Z OF PRODUCTION
1	478	2638	-4.52	.90E-13	8.60	1.80
2	486	6857	-----	1.29E-13	12.30	.77
3	493	177	-18.70	1.84E-13	11.01	1.54
4	513	8010	11.11	.18E-13	9.18	1.54
5	518	4935	-3.98	.24E-13	30.07	1.39
6	522	3061	-5.18	7.34E-13	50.50	.83
7	529	3013	-----	2.77E-13	13.23	1.98
8			-----	4.14E-13	47.60	1.98
9	547	2197	-46.86	10.68E-13	23.58	1.33
10	547	3705	-186.00	3.44E-13	13.53	2.14
11	556	152	-10.30	.17E-13	15.43	1.62
12	577	5409	-30.30	.35E-13	11.90	.33
13	597	6914	-63.33	7.46E-13	46.00	.99
14	638	5640	27.03	.52E-13	21.85	1.83
15	654	3711	-4.42	.02E-13	19.20	1.87
16	661	2729	-26.32	3.54E-13	12.33	1.56
17	661	6517	-25.64	5.91E-13	30.60	.79
18	670	7870	34.00	1.92E-13	6.80	1.37

Of the 17 events only two have no identified muon associated with the event. In both cases however there are charged tracks at the primary vertex which do not traverse the muon counters. Three of the events have an associated positive muon indicating that these events were induced by anti-neutrinos. This is not inconsistent with the 10% anti-neutrino component of the beam.

CHAPTER 6

RESULTS AND CONCLUSIONS

A. Calculation of the Lifetime

Once all the decays consistent with the decay of a D^0 had been identified, a maximum likelihood estimate of the lifetime was performed. The maximum likelihood method was chosen since it had been shown that it provided an efficient and unbiased estimator for exponential distributions (20).

In general the maximum likelihood function takes the following form:

$$L(x) = \prod_{i=1}^{N} pdf(y_i : x) \tag{1}$$

where x is the parameter whose value is to be estimated; the y_i's are the measured values whose probability distribution function (pdf) is dependent on the value of x and for which there are N measurements. If there were no inefficiencies in finding the decays of the charmed particles then the probability distribution function for a decay of proper time t_i would be:

$$pdf(t_i : \tau) = \frac{1}{\tau} e^{-t_i/\tau} \tag{2}$$

However, since there are inefficiencies in finding the decays the probability distribution function must be modified in order to take these into account. The scanning efficiency as described in section D then enters into the probability distribution function which now becomes:

$$pdf(t_i : \tau) = \frac{1}{\tau} \frac{\varepsilon(z_i)\ e^{-t_i/\tau}}{A(P_i : \tau)} \tag{3}$$

where $\varepsilon(z_i)$ is the scanning efficiency at distance z_i and P_i is the momentum of the i'th particle. $A(p_i : \tau)$ is a normalization factor given by:

$$A(P_i:\tau) = \int_0^\infty \frac{1}{\tau}\, \varepsilon(z')\, e^{-t'/\tau}\, dt' \tag{4}$$

$$z' = \gamma_i\, \beta_i\, c\, t' = \frac{p_i}{m}\, c\, t' \tag{5}$$

In practice the log of the likelihood function is used and takes the following form:

$$\ln(L(\tau)) = \sum_{i=1}^{N} \left\{ \ln(\varepsilon(z_i)) - \ln(\tau \cdot A(P_i:\tau)) - \frac{t_i}{\tau} \right\} \tag{6}$$

The most probable lifetime is that value of τ which maximizes the log-likelihood function. An estimate of the variance in the estimate of the lifetime can be made by observing which values of τ lower the log-likelihood function by 1/2 and 2 for the 1 and 2 sigma intervals repectively (20).

In order to elucidate this complicated function of τ, a short digression is in order. The maximum likelihood function becomes much more tractable if we ignore any scanning biases (it turns out that in our case the scanning efficiencies are nearly constant over the critical region and this is not a bad approximation. All calculations of the actual lifetimes and errors however make use of the full

equation (6)).

If there were no scanning biases then the maximum-likelihood function would take the form:

$$L(\tau) = \prod_{i=1}^{N} \frac{1}{\tau} e^{-t_i/\tau} \tag{7}$$

This can be rewritten as:

$$L(\tau) = \left\{ \frac{1}{\tau} e^{-t_{avg}/\tau} \right\}^{N} \tag{8}$$

Where t_{avg} is the simple arithmetic average of the proper decay times. Since the log of the maximum-likelihood function is used to calculate the errors we have:

$$\ln(L(\tau)) = -N \left\{ \tau_{avg}/\tau + \ln(\tau) \right\} \tag{9}$$

The condition for the maximum for equation 9 is simple to calculate and gives $\tau_{max} = t_{avg}$. The value of the likelihood function becomes:

$$\ln(L(\tau_{max})) = -N \left\{ 1 + \ln(t_{avg}) \right\} \tag{10}$$

The 1σ or 68% confidence level limits are obtained by finding which values of τ bring the value of the log-likelihood function down by 1/2 from the value at the maximum. Thus:

$$\ln(L(\tau_{1\sigma})) = -N \{ 1 + 1/2N + \ln(t_{avg}) \} \tag{11}$$

but:

$$\ln(L(\tau_{1\sigma})) = -N \{ t_{avg}/\tau_{1\sigma} + \ln(\tau_{1\sigma}) \} \tag{12}$$

Combining (11) and (12) and rearranging terms we get:

$$1 + 1/2N + \ln(t_{avg}/\tau_{1\sigma}) - t_{avg}/\tau_{1\sigma} = 0 \tag{13}$$

One can solve this transcendental equation numerically but if one is interested (as we are) in the region where $t_{avg} \simeq \tau_{1\sigma}$ we can approximate the log term to second order as:

$$\ln(x) \simeq (x-1) - \frac{1}{2}(x-1)^2 \tag{14}$$

Substituting (14) into (13) we arrive at:

$$1/N - \{ t_{avg}/\tau_{1\sigma} - 1 \}^2 = 0 \tag{15}$$

Solving (15) for $\tau_{1\sigma}$ we get:

$$\tau_{1\sigma} = \{ (1 \pm \sqrt{1/N})/(1-1/N) \} \cdot t_{avg} \qquad (16)$$

Thus the error improves with the square root of the number of decays as expected and confidence level is offset from the maximum, giving a larger range above the maximum than below it. This offset decreases in significance as the number of decays increases. We also see that any of the statistics depend only on the average decay time and thus will not tell us anything about the consistency of the data with the hypothesis of one exponential distribution.

The actual implementation of the maximum likelihood calculation was a computer program which took into account the scanning efficiencies' contribution. The likelihood function was computed for 100 values of τ in the region of t_{avg}. Actual calculation of τ_{max} was done by a parabolic interpolation about the maximum value in the likelihood array while calculations of the 1σ limits was done by linear interpolation at the -1/2 region.

B. Lifetime Fits

For those decays for which a good 3-C fit has been found, the maximum likelihood lifetime is found to be:

$$\tau_{3-C} = 2.91^{+1.24}_{-0.78} \times 10^{-13} \text{ seconds} \quad (1)$$

The errors represent the 68% confidence level limits. When the preferred or average solutions for the missing neutrals are added into the data set the most likely lifetime becomes:

$$\tau_{all} = 3.23^{+0.98}_{-0.70} \times 10^{-13} \text{ seconds} \quad (2)$$

Other charmed particle lifetimes (21) are listed in table 15 for comparison with the lifetime of the D^0. From this table it is seen that the charmed particles are not consistent with only one lifetime for all species. In particular the D+ is significantly longer lived than the D^0. The F^+ and Λ_c^+ both have lifetimes on the same order as the D^0 meson.

C. One Lifetime Test

In addition to determining the most likely lifetime for the data set, we also made a test to determine if the decay times were consistent with the assumption of one exponential distribution. This test would provide information on three

TABLE 15: COMPARISON OF CHARMED PARTICLE LIFETIMES 115

PARTICLE	LIFETIME	NUMBER OF DECAYS
D^0	$3.23^{+0.99}_{-0.70} \times 10^{-13}$ seconds	18
D^+	$10.30^{+10.32}_{-4.21} \times 10^{-13}$ seconds	5
F^+	$1.98^{+1.77}_{-0.81} \times 10^{-13}$ seconds	3
Λ_c^+	$1.39^{+0.76}_{-0.44} \times 10^{-13}$ seconds	6

areas of interest. Since this test would depend on the comparison of observed and expected decay spectra, an error in our knowledge of the scanning efficiency could cause the test to fail. Also if we were mis-identifying particle types and therefore mixing decay times, the test could also fail. Finally, if the D^0 had two distinct lifetimes with a larger difference than expected by theory, the test again could fail. Two distinct lifetimes with a large seperation for the D^0 could indicate large mixing between charmed quarks and other quarks occurs, or could be interpreted as evidence for charm changing neutral currents. Both these effects are predicted to be quite small for the D^0 and therefore any difference seen would be of great interest.

In order to determine if the data set in question was a consistent set we generated a test statistic T which was calculated as follows:

$$T = \int_0^\infty \{ F(t)-F'(t) \}^2 \, dt \qquad (1)$$

where: F is the observed integral decay spectrum

F' is the expected integral decay spectrum for a lifetime equal to the lifetime calculated by the maximum likelihood method.

The question we needed to answer then was: What fraction of the time do we expect to measure a lifetime equal to the one we did see and simultaneously measure a test statistic T greater than T for the true data set for any real single lifetime?

To answer this question we generated a large number of fake data sets with a Monte-Carlo program taking into account the scanning efficiencies and allowing the generating lifetime to range near the most likely lifetime for the real data. A complete description of the Monte-Carlo program is given in appendix B. A confidence level was then given by the fraction of the fake data sets that had a T value greater than the T value for the real data set.

D. One Lifetime Test Results

A semi-log plot of the integral decay spectrum for all the events is shown in figure 33. Superimposed on this is the predicted number of events from the maximum likelihood fit to the data. It can be seen that there is no large disagreement with the experimental data implying that the one lifetime test should give a good confidence level.

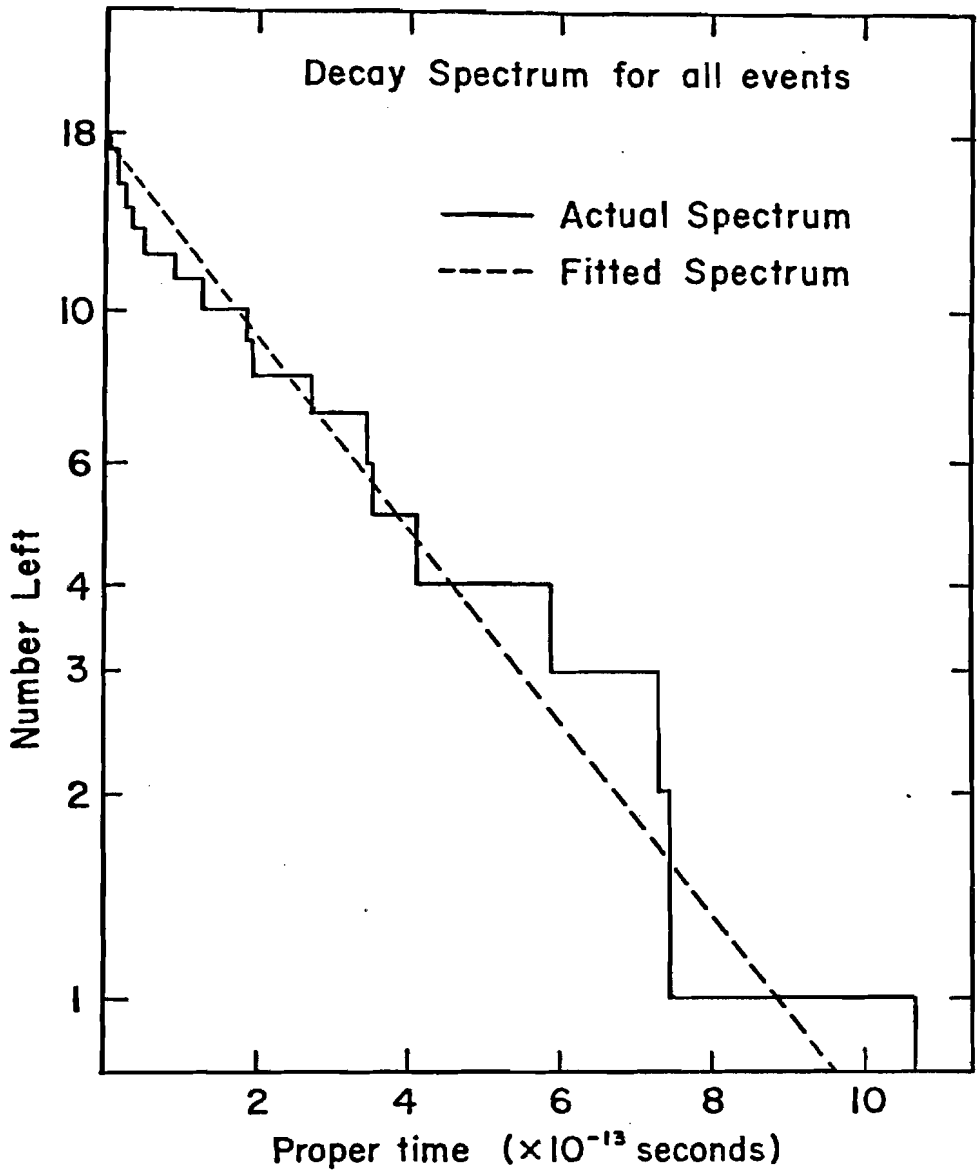


Figure 33. Integral Decay Spectrum

The results of the one lifetime test are shown in table 16. The computed confidence level for the data is 56% indicating that the data set is completely consistent with only one lifetime. A total of 741 comparison sets were generated by the program thus giving sufficient accuracy to the confidence level determiniation. Once the confidence level has been calculated we can say something about the possibility of there are actually two lifetimes in our sample which have not been resolved. The calculation of the power of the one lifetime test is based on the assumption that the alternative is two lifetimes with equal probability of production though not equal probability of observation in the emulsion. A calculation of the power of the one lifetime test with a cut at the confidence level for the total sample gives us the powers shown in figure 34. Thus we can reasonably say that if there were two lifetimes for the D^0 then they could not be more than a factor of 8 apart at the 90% confidence level provided that the two lifetimes were equally populated.

E. Conclusions

The data from this experiment indicates that the naive model of charmed particle decay is insufficient to describe the lifetimes of the charmed particles. The simple

TABLE 16: RESULTS OF ONE LIFETIME TEST

SCANNING EFFICIENCIES ARE:

FROM	TO	EFFICIENCY
0	2	.00
2	5	.14
5	10	.32
10	30	.68
30	400	.81
400	1000	.71
1000	60000	.60

THE MONTE-CARLO GENERATING LIFTIME RANGED

FROM 2.55 to 4.21 WITH THE FITTED LIFETIME

FORCED TO BE 3.24 +- 20%

TEST VALUE FOR REAL DATA = 9.3748

COMPUTED CONFIDENCE LEVEL IS .557

WITH 413 EVENTS WITH HIGHER TEST VALUES AND

WITH 328 EVENTS WITH LOWER TEST VALUES

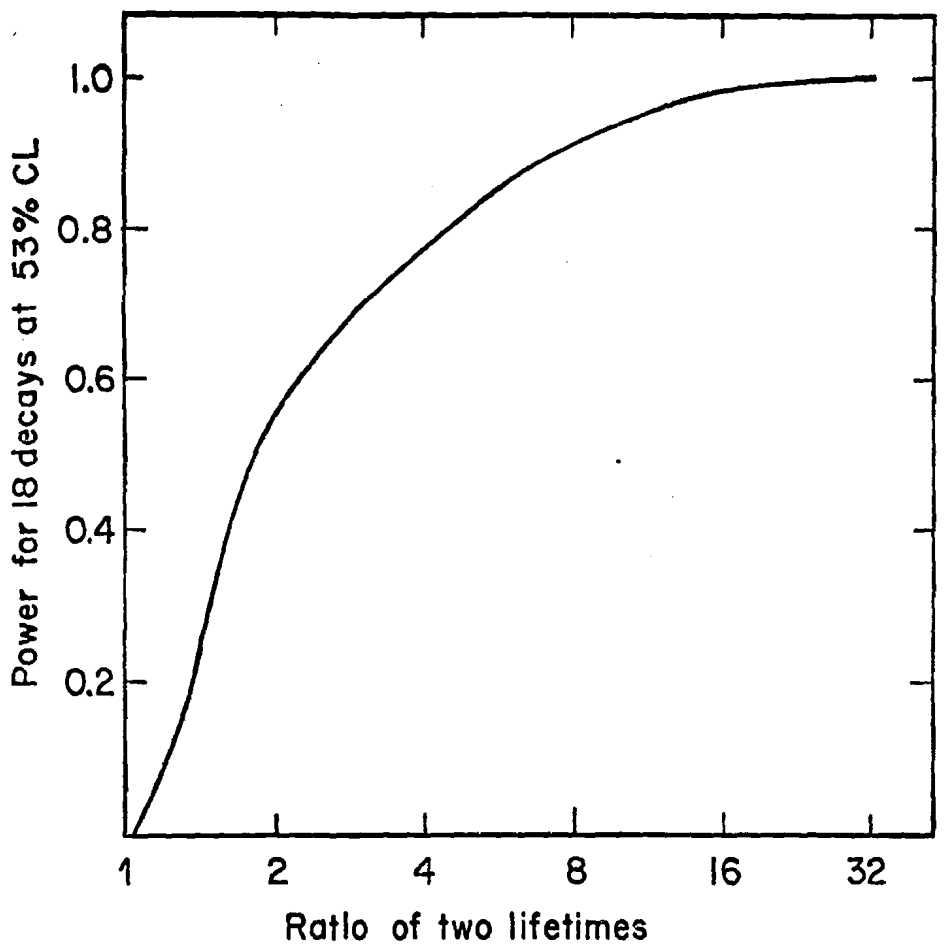


Figure 34. Power of the One Lifetime Test

radiative weak decay of a charmed quark makes a good estimate of the lifetime only for the D^+ meson. Errors on the ratio of the lifetimes of the D+ to the D0 show that a 1σ confidence interval gives the ratio of the lifetimes to be:

$$R = 3.19 \begin{matrix} +3.01 \\ -1.49 \end{matrix} \qquad (1)$$

To determine if the lifetimes could be equal, a test was made (see Appendix C) to compute the probability that a single lifetime could generate the ratio of lifetimes we see or worse. For the D^+/D^0 this probability is 2.2%.

In addition the other charmed particles have lifetimes shorter than that of the D^+.

The one lifetime test seems to indicate that there is only one lifetime for the D^0 yet there remain interesting questions. Of the four longest decays, three are semileptonic. Such an occurrence should happen only 1.5% of the time based on binomial statistics. The power of the one lifetime test is insufficient to tell us much more than that the data does not belong to two obviously different lifetimes. Another method is open to us however which may

be of more value. If there were two lifetimes for the D^0 then one would expect the semileptonic branching ratio to be larger for the longer lived species since the semileptonic rates should be the same. If we split the data into hadronic and semileptonic decays we could expect that the semileptonic decays would be enriched with the longer-lived species while the hadonic decays would be an enriched sample of the short-lived species. This method could be sensitive enough to provide some information when the one lifetime test becomes relatively powerless.

If we divide the data sample into 15 hadronic and 3 semileptonic decays we immediately run into a problem. While the hadronic decays all have either a single or a preferred solution, the semileptonic decays are all ambiguous between fast and slow solutions. The calculated lifetime for the hadronic decays is:

$$\tau_{hadronic} = 2.30^{+.79}_{-.54} \times 10^{-13} \text{ seconds} \qquad (2)$$

For the semileptonic decays however there are 8 different combinations of momenta and lifetimes. Using the average solutions in such a small sample size is hazardous. We need to look at the the extreme case and see if we can draw any conclusions for the total sample. The case of most interest

is the one where all the solutions used are fast thus giving us the smallest proper time. For this case we find:

$$\tau_{\substack{\text{semileptonic}\\ \text{all fast}}} = 5.39 \begin{matrix} +5.55 \\ -2.25 \end{matrix} \times 10^{-13} \text{ seconds} \qquad (3)$$

The large asymmetry in the errors is due to the small statistics for the semileptonic decays. It can be seen that the lifetimes for the hadronic and semileptonic modes differ by large amounts. The probility that a single lifetime could be responsible for a ratio this large or larger is 5.9%. If we assign equal probabilities to the high and low momentum solutions then this represents only 1/8 of the possible solutions with all the others having lower probabilities of the same lifetime.

If we use the average lifetimes for the semileptonic decays we get:

$$\tau_{\substack{\text{semileptonic}\\ \text{average}}} = 8.53 \begin{matrix} +9.21 \\ -3.60 \end{matrix} \times 10^{-13} \text{ seconds} \qquad (4)$$

This is comparable to the lifetime of the D^+. We find the ratio of the average semileptonic to hadronic lifetimes to be:

$$R = 3.71 \begin{matrix} +3.50 \\ -1.80 \end{matrix} \qquad (5)$$

This ratio is small enough that the negative findings of the one lifetime test are no hindrance. The probability that a single lifetime could be responsible for this ratio or larger is only 0.8%. The total confidence level for the semileptonic and the hadronic lifetimes being the same is on the order of 2%. While this is not conclusive evidence for two lifetimes it at least points to a worthwhile project to pursue. The second run of this experiment is expected to generate another 50 D^0 decays thus giving enough statistics to resolve this very interesting question.

Upstream Only Momentum Measurement

Since the SCM-104 magnet had a large fringe field, it was possible to measure the momentum of charged tracks using only the upstream drift chambers. Therefore a track that did not pass through the magnet gap could still have its momentum measured.

After the drift chamber hits for a track candidate had been chosen, a quintic spline fit to the hits was performed. For those points along the track for which there was no measured value for the magnetic field, a polynomial approximation was used. This method depended heavily on the last three drift chambers participating in the track since they were the closest to the magnet. Fortunately, the tracks had usually separated enough for the electronics to distinguish between them accurately.

To measure how accurately the momentum of these "up only" tracks had been measured, up only momentum measurements were performed on tracks which did traverse the gap and consequently whose momentum was well known.

In order to interpret the results of the above test we need to know what we expect the accuracy of the measurement to depend on. The situation can be modelled by the approximation that the incident particle experiences an increasing magnetic field in the y direction (out of the paper as shown in figure 35). Thus a positively charged particle travelling in the positive z direction will have its trajectory bent in the negative x direction. If we assume that the amount of bend is small (a safe assumption in the small fringe field) then we can consider the momentum in the z direction to be constant and equal to the total momentum. The change in momentum in the x direction is given then by:

$$P_x(z) = \frac{-q}{c} \int_0^z B_y(z)\, dz \qquad (1)$$

In this approximation then the x slope is given by:

$$\frac{dx}{dz} = \frac{-q}{Pc} B'(z) \qquad (2)$$

where:

$$B'(z) = \int_0^z B_y(z)\, dz \qquad (3)$$

Integrating (2) we find the x position as a function of z to be:

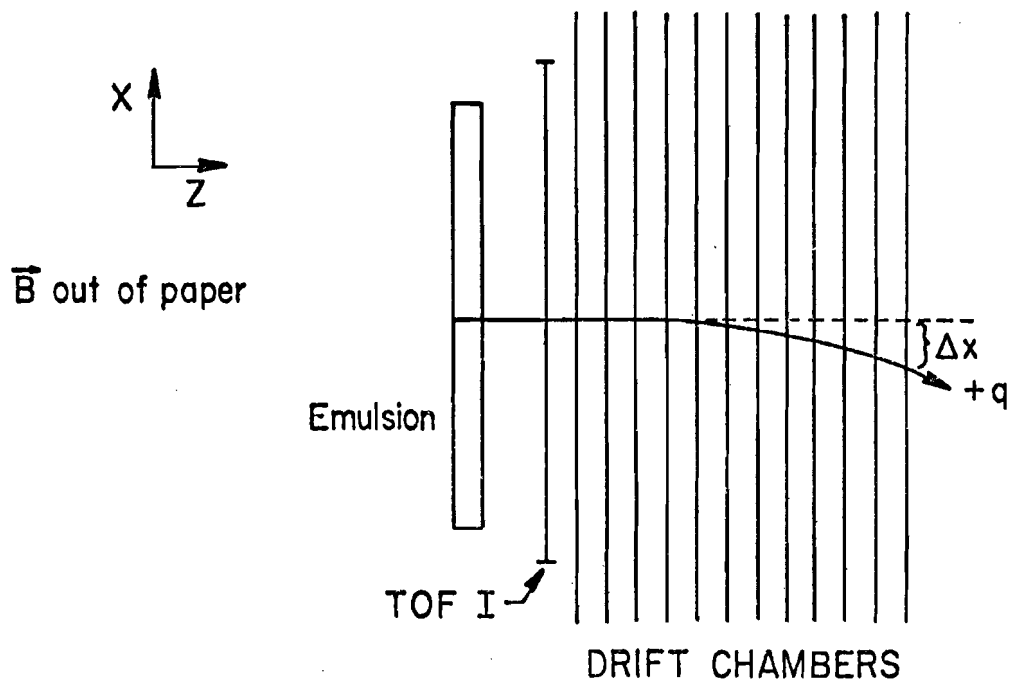


Figure 35. Upstream Only Particle Path

$$x = \frac{-q}{Pc} B''(z) \tag{4}$$

where:

$$B''(z) = \int_0^z B'(z)\, dz \tag{5}$$

Where z=0 is defined as that the position along the z axis at which the x slope is 0. If we make the approximation that the magnetic field grows linearly with z and starts at 0 when z=0 we then get $B_y(z) = Bz$ and:

$$B''(z) = \frac{B}{6} z^3 \tag{6}$$

therefore the x position is given by:

$$x = \frac{-q}{Pc} \frac{B z^3}{6} \tag{7}$$

Thus the largest deviations (which are the most critical to the momentum measurement) occur in the last few chambers upstream of the magnet. Solving (7) for P we get:

$$\frac{1}{P} = \frac{-x\, c}{q\, B''} \tag{8}$$

Since the error in the position is approximately gaussian the measurement of Q=1/P should also be gaussian and the measurement error for the reciprocal of the momentum should be a constant.

The results of the measurement errors for up only measurements of up and down tracks is shown in figure 36. As expected the shape of the curve is approximately gaussian and the seperate binnings for high and low momentum tracks show no significant change in structure. The curves imply that the error constant is approximately .35/GEV thus a 1.0 GeV track would have 1 sigma error limits of 1.54 and .74 GeV.

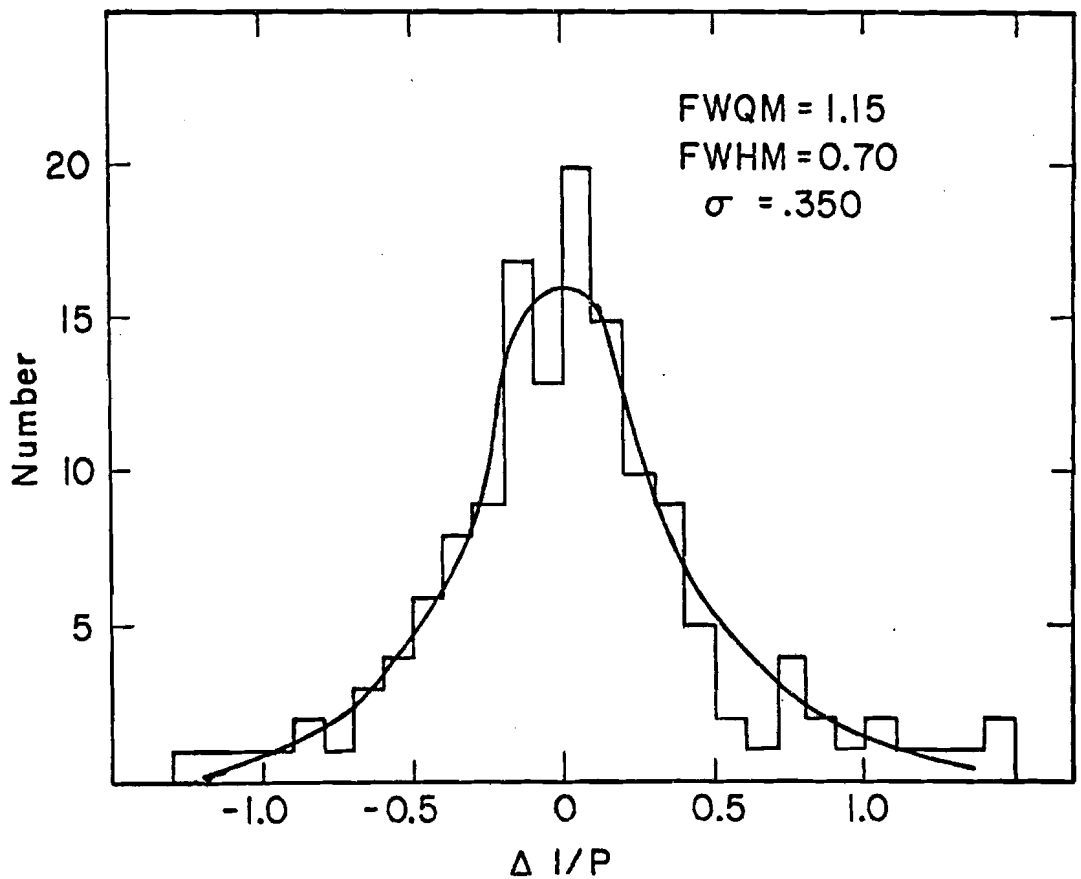


Figure 36. Upstream Only Momentum Resolution

One Lifetime Fit Program

In order to determine if the set of decays of a single particle type were self consistent, the one lifetime test was performed. The test consisted of two parts, first a test variable was generated which measured the goodness of fit to the expected decay spectrum and second this test value was compared with the expected range of values for similar decay sets which were self consistent.

Obtaining a test variable was a fairly straightforward problem which was solved by integrating the difference squared between the observed and expected integral decay spectra as explained earlier in the text. To make the test statistic a meaningful number however involved generating a large number of test statistics from data that was known to be self consistent. This was accomplished through the use of a Monte Carlo program.

The basic premise behind the Monte Carlo program was the random generation of decay times from a generating lifetime and comparing the test statistics calculated from these sets with the test statistic calculated with the true data set. Care had to be taken to insure that the scanning

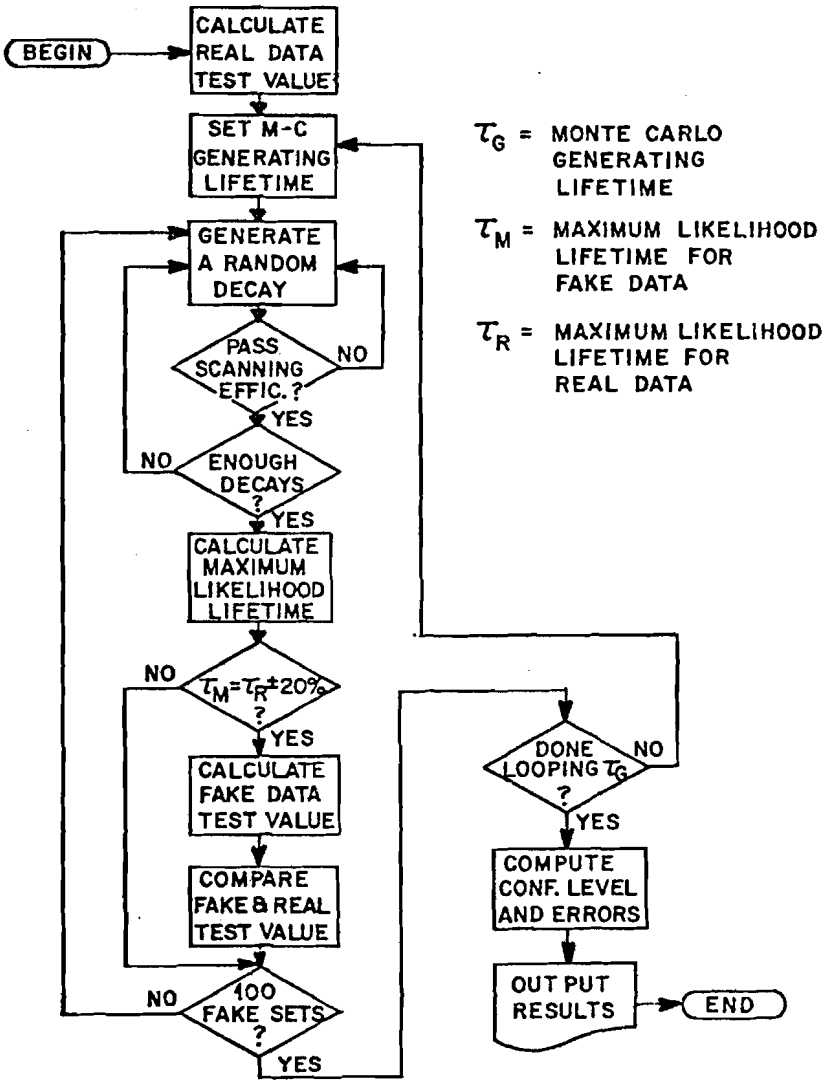
efficiencies were properly included and that "unusual" combinations (such as true lifetime shorter than measured but with one or more long decays giving a longer calculated lifetime) were included in the sample.

The general flow of the Monte Carlo program is given in table 17. The generating lifetime ranged within the one sigma limits of the maximum lifetime calculations so that unusual combinations were included but the resulting set had to produce its own maximum likelihood lifetime close to that of the real data set.

After the program finished generating its fake test statistics a confidence level was determined from the percentage of events having a worse test statistic.

A poor test statistic does not automatically imply that there is more than one lifetime for a particular particle type, it could also mean that an error had been made in either particle type assignment for one or more particles in the sample or that the scanning efficiencies were not what we used in the equation. Errors in scanning efficiencies could be checked by varying the efficiencies that are input into the program. Particle type assignment errors are more difficult to check.

Table 17: ONE LIFETIME TEST PROGRAM FLOW CHART



ONE LIFETIME TEST PROGRAM FLOW CHART

Another useful number to know is the power of the test. The power of the test was measured against the most likely physical alternative to one lifetime, that being two lifetimes with equal particle populations. The power of the one lifetime test was calculated by generating decays randomly from two lifetimes. Any decay had an equal probability of being generated from either the short or long lifetime subject only to scanning biases.

Same Lifetime Test

To determine if two calculated lifetimes could actually be the same, the following test was done. First the "true" lifetime was assumed to be the weighted average of the two maximum likelihood lifetimes. For example the weighted average of the D^+ and D^0 decays would be:

$$\tau_{true} = (18 \cdot 3.23 + 5 \cdot 10.30) / 23 = 4.77 \times 10^{-13} s \quad (1)$$

Next two sets of fake decays were generated by a Monte-Carlo program using this "true" lifetime, one with 18 decays the other with 5. The maximum likelihood lifetime for each fake set was calculated and a ratio taken.

This routine was performed many times building a histogram of ratios. The probability of a ratio as large or larger than the actual ratio could then be calculated by finding the percentage of fake ratios equal to or higher than the real ratio.

Data Summary Sheets

On the following pages are listed the raw data information for all the D^0 candidates. These forms represent the contents of a disk file generated by the event reanalysis program and subsequently modified by hand as was deemed necessary. The listings follow a fixed format readable by a FORTRAN program. Since this is a printed listing, the first character is a carriage control and thus does not appear. The formats given below are those used to read the disk file and thus contain room for these control characters.

HEADER INFORMATION

1. Run and Record
   4X,I5,7X,I7
2. Institution and Scan Number, NH, NS
   1X,A3,I5,3X,I3,3X,I3
3. Last Revision Date, Yr., Mo., Day
   15X,I2,1X,I2,1X,I2

VERTEX INFORMATION

The vertices are classified into two types. Type 1 is a vertex measured by the computer programs and is measured in inches. The primary vertex is always type 1. Type 2

vertices are those measured in the emulsion and distances are listed in microns from the primary vertex. All charm decay vertices are listed as type 2.

1. Number of Vertices
   1X,I3

2. Description Line
   1X

3. Vertex Number, Vertex Type, Vertex Position in X, Y, and Z
   1X,I4,I6,1X,3F8.3 (for type 1)
   1X,I4,I6,1X,3F8.1 (for type 2)

ENERGY INFORMATION

1. Total Calorimeter Energy
   28X,F7.2

2. Calorimeter Energy in Columns 1,2,3,4
   1x,4F7.2

3. Total Lead Glass Energy
   27X,F7.2

EMULSION INFORMATION

This section contains information on tracks seen in the emulsion or deduced from decays or interactions in the spectrometer. first we have:

1. Number of "Emulsion" Tracks
   1X,I3

2. Header Line 1
   1X

3. Header Line 2
   1X

For each of these tracks the following information is given:

1. Track Identifier, Production Slopes in X and Y, Emulsion Exit Slopes, Relative Ionization, $1/P_\beta$ as Measured in the Emulsion, Vertex at which Track Ends
   1X,A7,4F7.3,F7.2,F9.3,I3

2. The Second Line Gives the Associated Error for the Value Above it in the Same Format
   1X,7X,4F7.3,F7.2,F9.3,I3

The track identifier follows the following conventions (m and n are numbers):

1.	n	Track n from the primary vertex.
2.	n-m	Charged decay track m from track n.
3.	0V	Neutral Decaying Particle.
4.	V-m	Charged track m from neutral decay.
5.	In-m	Charged track m from interaction of track n.
6.	0I	Neutral Interacting Particle.
7.	U-m	Unmatched track m.
8.	En-m	Electron m from pair conversion n.
9.	G-m	Gamma m from lead glass block.
10.	L-m	Lambda decay track m.
11.	K-m	Kaon decay track m.

SPECTROMETER INFORMATION

1. Total Number of Tracks
   1X,I2

2. Header Line
1X

For each track the following information is given: in the format:

1X,A7,3F7.3,3I3,F6.3,1x,O6,F6.2,F6.3,I2,2F6.3,I2

TRACK Track identifier.

DX/DZ X slope.

DY/DZ Y slope.

1/P 1/momentum as measured by the spectrometer or
1/momentum as fitted by decay fitting program for particles or
1/block energy for gammas.

Q Particle charge.

UP Number of upstream drift chamber hits used

DN Number of downstream drift chamber hits used or
Associated lead glass block for gammas.

CHISQ Chi-squared for fitted track or
Chi-squared of 3-C fit for decaying tracks.

ID Octal formatted binary code for possible particle types. Assignments are:

1.	000001	Gamma
2.	000002	Electron
3.	000004	Muon
4.	000010	Pion
5.	000020	Kaon
6.	000040	Eta
7.	000100	Proton
8.	000200	Lambda

9.	000400	Sigma
10.	010000	D
11.	020000	F
12.	040000	Lambda-c

EPBG	Lead glass energy associated with track
BETA	$1-_{\beta}$ from TOF
V	Vertex at which track begins
XMISS	Amount by which track misses vertex 1 in X
YMISS	Amount by which track misses vertex 1 in Y
F	Fit flag = 1/0 if track is used to fit decay vertex

AUXILLIARY INFORMATION

No present use at this time. Reserved for future information.

COMMENTS

General comments on event.

```
RUN  478 RECORD   2638
NGY  430 NH  1 NS  3
LAST DONE ON  81/04/30.
  2 VERTICES
NUMBER TYPE    X        Y        Z
   1     1   15.257  -1.607   1.801
   2     2     17.0    -3.0   125.0
TOTAL CALORIMETER ENERGY IS   4.55 GEV
   2.19   1.74    .36    .27 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   1.04 GEV
 10 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1     -.059   .157  -.059   .157
          .003   .003   .003   .003
   2      .226   .884   .226   .884
          .011   .011   .011   .011
   3     -.514  -.546  -.514  -.546
          .009   .009   .009   .009
  OV      .136  -.024                              2
          .008   .008
  V-1    -.123  -.065  -.134  -.053
          .003   .003   .003   .003
  V-2    -.066  -.156  -.066  -.157
          .003   .003   .003   .003
  V-3     .002  -.071   .012  -.084
          .002   .002   .002   .002
  V-4     .103   .020   .110   .022
          .003   .003   .003   .003
  V-5     .187  -.030   .187  -.025   0.99
          .003   .003   .003   .003   0.05
  V-6     .211   .075   .219   .070   0.99
          .004   .004   .004   .004   0.05
 11 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1     -.059   .157   .221 -1  9  7 1.255 000130   .52  .007 1  .007 -.001 0
                        .006                                .013
   2                                         000136            1

   3                                         000136            1

  OV      .136  -.024   .116  0             010000            1
          .008   .008    003
  V-1    -.129  -.096  2.695 -1 12  6  .684 000014  0.00  .074 2  .078 -.167 1
                        .035                                .026
  V-2    -.068  -.155   .548 -1 11  8 1.035 000030  0.00 -.038 2  .057  .001 1
                        .009                                .075
  V-3     .006  -.080   .875  1 12  6  .777 000014  0.00  .012 2  .019  .012 1
                        .012                                .015
  V-4     .109   .024  1.537  1 12  8  .142 000010  0.00  .028 2  .004 -.011 1
                        .021                                .040
  V-5     .196  -.024   .671 -1 12  8  .512 000036  0.00  .045 2  .006 -.026 1
                        .010                                .034
  V-6     .215   .075   .821  1 12  8 1.100 000136  0.00  .046 2  .027 -.043 1
                        .012                               1.000
 U-1      .296   .033  8.048  1 12  6  .503 000002  0.00  .046 1 -.207  .061 0
                        .105                                .195
  0 LINES OF AUXILLARY TRACK INFORMATION
  1 LINES OF COMMENTS
TOF ERRORS PER DB
```

```
RUN  486 RECORD   6857
NGY  440 NH  1 NS  4
LAST DONE ON  81/04/30.
  2 VERTICES
NUMBER TYPE     X        Y        Z
   1     1   15.170   -6.710    .770
   2     2     -3.9    -10.2   256.0
TOTAL CALORIMETER ENERGY IS  19.65 GEV
   1.07   6.82   1.65  10.12 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   3.78 GEV
  9 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1      .024  -.041   .024  -.041
          .002   .002   .002   .002
   2      .252  -.111   .252  -.111
          .004   .004   .004   .004
   3      .306  -.166   .306  -.166
          .005   .005   .005   .005
   4      .574   .091   .574   .091
          .007   .007   .007   .007
  0V     -.015  -.040                              2
          .004   .004
  V-1    -.077   .019  -.077   .019
          .002   .002   .002   .002
  V-2    -.052  -.116  -.052  -.116
          .003   .003   .003   .003
  V-3     .028  -.144   .028  -.144
          .003   .003   .003   .003
  V-4     .088  -.015   .088  -.015
          .002   .002   .002   .002
 14 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID    EPBG  BETA V XMISS YMISS F
   1                                         000136            1

   2                                         000136            1

   3                                         000136            1

   4                                         000136            1

  0V     -.015  -.022   .081  0       5.900 010000            1             0
          .002   .002   .003        /
  V-1    -.077   .018   .158 -1 11  8 1.241 000130  2.39  .014 2  .004 -.012 1
                        .005                                .014
  V-2    -.057  -.117  1.212  1 12  8  .972 000014   .05 -.000 2 -.034  .034 1
                        .017                                .017
  V-3     .039  -.121  1.111 -1 10  0 1.000 000136            2             1
                        .350
  V-4     .081  -.013   .299  1 11  8 1.578 000130   .37 -.153 2 -.053  .005 1
                        .006                                .165
 U-1     -.042  -.148  4.801 -1  8  0  .545 000136  0.00 0.000 1  .177  .002 0
                        .350                               1.000
 U-2     -.009  -.090  1.137  1 12  8  .293 000014   .33 -.007 1 -.106  .043 0
                        .016                                .018
 U-3      .338  -.254  2.025  1 10  0 3.784 000136  0.00 0.000 1 -.068 -.023 0
                        .350                               1.000
 G-1     -.073   .031   .520  0     38       000001  1.92       1 0.000 0.000 0
          .015   .015   .052                             .19
 G-2     -.197  -.155  2.001  0     66       000001   .50       1 0.000 0.000 0
          .015   .015   .396                             .10
  0 LINES OF AUXILLARY TRACK INFORMATION
  0 LINES OF COMMENTS
```

```
RUN  493 RECORD    177
NGY  450 NH  0 NS  3
LAST DONE ON  81/04/30.
  3 VERTICES
NUMBER TYPE    X        Y        Z
   1     1  -13.732  -7.563   1.511
   2     2    -10.1     6.3   326.0
   3     1  -14.016  -7.172   6.452
TOTAL CALORIMETER ENERGY IS  30.43 GEV
   4.40   2.18  12.79  11.06 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   1.29 GEV
  7 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1      .052  -.051   .052  -.051
          .002   .002   .002   .002
   2     -.057  -.018  -.057  -.018
          .002   .002   .002   .002
   3     -.037  1.374  -.037  1.374
          .015   .015   .015   .015
  0V     -.031   .019                              2
          .005   .005
  V-1     .101  -.170   .101  -.170
          .003   .003   .003   .003
  V-2    -.211   .251  -.211   .251
          .005   .005   .005   .005
  0I      .060   .079                              3
          .006   .006
 10 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1      .052  -.052   .053 -1 11  7  .704 000004   .28  .006 1  .010 -.001 0
                        .005                                .012
   2                                           000136          1

   3                                           000136          1

  0V     -.026   .019   .091          2.460 010000            1             0
          .004   .004   .002
  V-1     .102  -.174   .320  1 11  0  .321 000136  0.00 0.000 2  .010  .011 1
                        .350                                1.000
  V-2    -.219   .251  1.926 -1 12  7  .507 000014   .22  .046 2  .022 -.003 1
                        .026                                .028
 0I       .060   .079  0.140  0              000260            2             1
          .006   .006   .009
I0-1     -.035   .082  1.315 -1 12  6  .312 000014   .30  .011 3 -.082 -.021 0
                        .018                                .016
I0-2      .688  -.078  1.616  1  7  8 1.507 000100  0.00  .434 3-3.675  .818 0
                        .022                                .014
I0-3     -.060   .076   .157  1 12  8  .953 000130   .36 -.023 3 -.023 -.003 0
                        .005                                .028
  0 LINES OF AUXILLARY TRACK INFORMATION
  0 LINES OF COMMENTS
```

```
RUN  513 RECORD   8010
NGY   25 NH  0 NS  5
LAST DONE ON  81/05/08.
  2 VERTICES
NUMBER TYPE    X       Y       Z
   1     1   -1.612  -1.813   1.595
   2     2     -2.4    -2.4    27.0
TOTAL CALORIMETER ENERGY IS  24.67 GEV
  10.92   2.29  10.33   1.14 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS  12.01 GEV
 10 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1       .045  -.020   .045  -.020
          .002   .002   .002   .002
  2       .164  -.035   .164  -.035
          .003   .003   .003   .003
  3       .247   .247   .247   .247
          .005   .005   .005   .005
  4      -.442   .276  -.442   .276
          .007   .007   .007   .007
  5       .658  -.087   .658  -.087
          .008   .008   .008   .008
 0V      -.089  -.089                              2
          .015   .015
 V-1     -.015  -.096  -.015  -.096
          .002   .002   .002   .002
 V-2     -.006  -.124  -.006  -.124
          .003   .003   .003   .003
 V-3     -.261   .004  -.261   .004
          .004   .004   .004   .004
 V-4     -.072  -.685  -.072  -.685
          .008   .008   .008   .008
 15 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1       .043  -.013   .087  1 11  7  .607 000004  4.51 -.029 1  .020 -.007 0
                        .005                                 1.000
  2       .156  -.030  1.213  1 12  8  .816 000016  3.47  .023 1 -.006 -.018 0
                        .017                                  .015
  3       .227   .253   .409 -1 11  7  .297 000032  0.00 -.002 1  .034 -.002 0
                        .007                                  .015
  4      -.447   .279  1.987 -1 12  0  .305 000136  0.00 0.000 1  .001 -.054 0
                        .350                                 1.000
  5       .656  -.021  1.099  1 11  0 1.661 000136  0.00 0.000 1  .176 -.127 0
                        .350                                 1.000
 0V      -.057  -.108   .109  0       7.950 010000            1             0
          .002   .004   .002
 V-1     -.025  -.091   .312  1 11  8  .171 000130  1.96 -.706 2  .001  .005 1
                        .006                                 1.000
 V-2     -.017  -.119   .352  1 12  8 1.886 000130   .69 -.010 2 -.043  .008 1
                        .007                                 1.000
 V-3     -.274   .013  1.090 -1 12  8  .253 000014   .29 -.012 2  .004  .050 1
                        .015                                  .020
 V-4     -.049  -.623   .250 -1 11  0 1.918 000136  0.00 0.000 2 -.012  .017 1
                        .350                                 1.000
 G-1     -.061   .115  1.157  0    22       000001   .86       1 0.000 0.000 0
          .015   .015   .174                             .13
 G-2     -.061   .053   .273  0    31       000001  3.67       1 0.000 0.000 0
          .015   .015   .020                             .27
 G-3      .063  -.009  1.735  0    38       000001   .58       1 0.000 0.000 0
          .015   .015   .320                             .11
 G-4      .001  -.009   .394  0    39       000001  2.54       1 0.000 0.000 0
          .015   .015   .035                             .22
 G-5     -.061  -.071  2.077  0    49       000001   .48       1 0.000 0.000 0
          .015   .015   .419                             .10
  0 LINES OF AUXILLARY TRACK INFORMATION
```

EVENT SUMMARY

0 LINES OF COMMENTS

```
RUN  518 RECORD   4935
NGY  193 NH  0 NS  2
LAST DONE ON  81/05/08.
  3 VERTICES
NUMBER TYPE    X        Y        Z
   1     1   -4.008   -3.668   1.388
   2     2     -4.4      4.4   124.0
   3     2   -517.0   670.0  6820.0
TOTAL CALORIMETER ENERGY IS  20.64 GEV
   7.98   1.16   7.44   4.06 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS  24.20 GEV
  9 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1      .272   .207   .266   .180
          .005   .005   .005   .005
   2      .269  -.1998  .268  -.200
          .005   .005   .005   .005
  0V     -.035   .035                              2
          .004   .004
  V-1    -.032   .042  -.032   .042
          .002   .002   .002   .002
  V-2    -.078   .100                              3
          .003   .003
IV-2-1   -.309   .778  -.309   .778
          .010   .010   .010   .010
IV-2-2   -.495   .823  -.495   .823
          .011   .011   .011   .011
IV-2-3   -.156  -.208  -.164  -.209
          .004   .004   .004   .004
IV-2-4    .181   .169   .163   .171
          .004   .004   .004   .004
 16 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID    EPBG  BETA V XMISS YMISS F
   1      .269   .193   .661  1 12  7 1.832 000100   .30  .137 1  .060 -.134 0
                         .010                                .010
   2      .268  -.200   .251 -1 12  0 1.000 000004  0.00 0.000 1             0
                         .010                              1.000
  0V     -.029   .043   .033  0       0.680 010000            1             0
          .003   .003   .001
  V-1    -.031   .041   .153  1 10  7 1.009 000120 11.22  .017 2 -.024  .017 1
                         .005                                .009
  V-2    -.078   .100   .285 -1       1.000 000134            2             1
          .003   .003   .011                                 .009
IV-2-1                                         000136            3

IV-2-2                                         000136            3

IV-2-3   -.164  -.206  1.799 -1 12  6  .767 000016   .49  .025 3  .106  .033 0
                         .024                                .018
IV-2-4    .171   .172   .705 -1 12  6  .507 000000   .14 -.093 3 -.019 -.044 0
                         .010                                .025
El-1     -.004  -.014  1.054  1 11  6 1.116 000016  1.10  .016 1 -.299 -.042 0
                         .015                                .014
El-2     -.008  -.020   .235 -1  8  6 1.088 000032  7.68 -.004 1 -.272  .029 0
                         .006                                .009
 G-1     -.041   .068   .109  0    31        000001  9.21       1 0.000 0.000 0
          .015   .015   .005                          .42
 G-2      .021   .006   .143  0    39        000001  6.99       1 0.000 0.000 0
          .015   .015   .008                          .37
 G-3     -.041   .006   .930  0    40        000001  1.08       1 0.000 0.000 0
          .015   .015   .126                          .15
 G-4     -.103   .006  2.419  0    41        000001   .41       1 0.000 0.000 0
          .015   .015   .527                          .09
 G-5     -.103  -.180   .474  0    67        000001  2.11       1 0.000 0.000 0
          .015   .015   .046                          .20
```

0 LINES OF AUXILLARY TRACK INFORMATION
0 LINES OF COMMENTS

```
RUN  522 RECORD   3061
OSK  167 NH  2 NS  8
LAST DONE ON  81/05/08.
  3 VERTICES
NUMBER TYPE     X        Y        Z
   1     1    7.031    2.952    .830
   2     2   -63.0   -410.0   6050.0
   3     2   -90.0   -290.0   5460.0
TOTAL CALORIMETER ENERGY IS  59.13 GEV
   8.90  22.04  24.53   3.65 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS  15.29 GEV
 16 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1       .014 -1.698   .014 -1.698
          .040   .020   .040   .020
  2       .241  -.464   .241  -.464
          .020   .010   .020   .010
  3      -.597  -.305  -.580  -.305
          .022   .010   .022   .010
  4      -.034  -.031  -.017  -.031
          .008   .004   .008   .004
  5       .011   .051   .028   .051
          .009   .004   .009   .004
  6       .012   .063   .029   .063
          .009   .004   .009   .004
 0I      -.016  -.054                              3
          .009   .004
 I0-1     .518   .150   .518   .150
          .019   .009   .019   .009
 I0-2    -.033   .111  -.033   .111
          .010   .004   .010   .004
 I0-3    -.097  -.005  -.097  -.005
          .009   .004   .009   .004
 I0-4     .058  -.051   .058  -.051
          .009   .004   .009   .004
 0V      -.010  -.068                              2
          .009   .004
 V-1      .023  -.034   .023  -.034
          .008   .004   .008   .004
 V-2      .022  -.047   .022  -.047
          .008   .004   .008   .004
 V-3     -.027  -.057  -.027  -.057
          .009   .004   .009   .004
 V-4     -.011  -.065  -.011  -.065
          .009   .004   .009   .004
 27 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1                                          000136             1

  2                                          000136             1

  3                                          000136             1

  4      -.011  -.059  1.968  1 12  6  .818 000136  0.00 0.000 1 -.049 -.134
                        .026                                1.000
  5                                          000136             1

  6       .029   .062   .014 -1  9  7 2.023 000004  6.83 -.031 1  .032 -.008 0
                        .005                                1.000
 0I                                          000136             1

 I0-1     .559   .152  3.924  1 12  6  .475 000010  0.00  .113 1 -.626  .271
                        .051                                 .058
 I0-2    -.022   .103   .647  1 11  8 1.342 000134   .28  .016 3 -.166 -.090 0
                        .010                                1.000
```

IO-3	-.089	.005	1.237	-1	11	6	1.603	000014	.13	-.031	3	.202	-.102	0
			.017							.031				
IO-4	.060	-.051	.193	-1	10	8	.601	000130	3.30	.025	3	.029	-.025	0
			.006							.029				
0V								010000			1			
V-1	.021	-.036	.095	-1	7	6	2.183	000130	8.20	.015	2	.050	.027	1
			.005							.023				
V-2	.013	-.050	.233	1	11	8	1.736	000130	6.34	-.012	2	.028	-.005	1
			.006							1.000				
V-3	-.027	-.058	.109	1	7	8	2.343	000004	7.93	-.024	2	-.039	-.001	1
			.005							.018				
V-4	-.015	-.067	.091	-1	9	8	1.840	000004	6.34	-.010	2	.022	-.007	1
			.005							1.000				
U-1	.087	-.062	3.153	1	12	7	.787	000006	.28	-.046	1	-.054	.113	0
			.041							.079				
U-2	.110	-.031	1.129	1	12	8	.840	000136	6.83	.001	1	-.315	-.088	0
			.016							1.000				
U-3	.051	-.097	1.039	1	12	6	.677	000134	.52	0.000	1	-.055	-.104	0
			.014							1.000				
U-4	-.045	.878	1.343	1	11	0	1.436	000136	0.00	0.000	1	-.200	-.003	0
			.350							1.000				
U-5	.139	-.023	1.983	1	12	6	.588	000136	1.65	0.000	1	.016	.026	0
			.026							1.000				
G-1	.116	-.048	.694	0		36		000001	1.44		1	0.000	0.000	0
	.015	.015	.081						.17					
G-2	.055	-.048	.717	0		37		000001	1.39		1	0.000	0.000	0
	.015	.015	.085						.17					
G-3	-.007	-.048	.185	0		38		000001	5.41		1	0.000	0.000	0
	.015	.015	.011						.33					
G-4	-.069	-.048	.628	0		39		000001	1.59		1	0.000	0.000	0
	.015	.015	.070						.18					
G-5	.055	-.171	3.061	0		55		000001	.33		1	0.000	0.000	0
	.015	.015	.750						.08					
G-6	-.069	-.233	1.696	0		65		000001	.59		1	0.000	0.000	0
	.015	.015	.309						.11					

0 LINES OF AUXILLARY TRACK INFORMATION
1 LINES OF COMMENTS
THERE SEEMS TO BE SOME CONFUSION ABOUT THE DECAY COORDINATES FOR 0V

```
RUN   529 RECORD    3013
NGY   574 NH   0 NS   8
LAST DONE ON   81/05/20.
  4 VERTICES
NUMBER TYPE     X        Y        Z
   1     1  -16.317   -6.026    1.982
   2     2    -33.3    -25.0    640.0
   3     2     -8.5    -65.9   3139.0
   4     1  -15.317   -5.721    6.280
TOTAL CALORIMETER ENERGY IS   50.13 GEV
   3.30     .74   36.46    9.63 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   17.68 GEV
 19 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ   DY/DZ   DX/DZ   DY/DZ    I/I0   1/PBETA   V
  1       .053   -.231    .052   -.229
          .004    .004    .004    .004
  2       .220   -.053    .219   -.049
          .004    .004    .004    .004
  3       .130    .064    .127    .064    1.05             4
          .003    .003    .003    .003     .06
 I3-1     .325    .126    .325    .126
          .002    .002    .002    .002
 I3-2    -.044   -.045   -.044   -.045
          .002    .002    .002    .002
 I3-3     .342    .123    .342    .123
          .002    .002    .002    .002
  4       .181    .348    .181    .348
          .005    .005    .005    .005
  5       .025    .062    .021    .061
          .002    .002    .002    .002
  6      -.011    .284   -.014    .275
          .004    .004    .004    .004
  7      -.673   -.319   -.673   -.319    0.99
          .002    .002    .002    .002     .05
  8       .300   -.800    .300   -.800
          .050    .050    .050    .050
  0V1    -.037   -.054                             2
          .007    .008
 V1-1    -.069   -.214   -.065   -.214    1.06
          .004    .004    .004    .004     .06
 V1-2    -.002    .087   -.002    .087
          .002    .002    .002    .002
  0V2    -.011   -.019                             3
          .002    .004
 V2-1    -.031    .002   -.029    .001
          .002    .002    .002    .002
 V2-2     .019   -.059    .021   -.056
          .002    .002    .002    .002
 E1-1    -.033   -.036   -.033   -.036
          .002    .002    .002    .002
 E1-2    -.027   -.008   -.027   -.008
          .002    .002    .002    .002
 28 TOTAL TRACKS
 TRACK   DX/DZ   DY/DZ    1/P    Q UP DN CHISQ    ID     EPBG  BETA V XMISS YMISS F
  1       .044   -.237   2.247 -1 11  0 1.613 000136  0.00 0.000 1  .097  .048 0
                          .350                                 1.000
  2       .214   -.059    .736 -1 12  7  .558 000014   .16  .005 1  .189  .156 0
                          .011                                  .014
  3                                                 000136            1

 I3-1    -.044   -.045    .737  1 10  7 1.654 000014   .71  .002 4  .003  .005 1
                          .011                                  .018
 I3-2     .342    .123   4.386  1 12  6  .279 000016  0.00  .161 4 -.039  .019 1
                          .057                                  .156
 I3-3     .325    .126   1.616  1 12  8  .163 000014   .26  .011 4  .044 -.014 1
```

			.022							.018				
.4	.177	.348	.937	1	11	0	.459	000136	0.00	0.000	1	.071	.031	0
			.350							1.000				
5	.025	.059	1.134	1	9	0	.381	000136	0.00	0.000	1	-.030	.048	0
			.350							1.000				
6	-.014	.283	.835	1	11	8	1.162	000014	.06	-.003	1	-.024	-.072	0
			.012							.026				
7								000136			1			0
8								000136			1			0
0V1				0				010000			1			0
V1-1	-.069	-.222	.421	1	9	0	.230	000136	0.00	0.000	2	-.010	.032	1
			.350							1.000				
V1-2	-.002	.086	.185	-1	11	6	.638	000034	2 71	-.038	2	.015	.018	1
			.006							.024				
0V2				0				010000			1			0
V2-1	-.029	.000	.025	-1	9	8	.881	000130	5.25	-.045	3	.003	.005	1
			.005							.027				
V2-2	.019	-.062	.112	1	8	8	.611	000130	2.21	-.016	3	.016	.028	1
			.005							.022				
E1-1	-.033	-.036	1.031	1	10	0	.252	000002	0.00	0.000	1	-.031	.011	1
			.350							1.000				
E1-2	-.035	.030	7.669	-1	10	0	2.640	000136	0.00	0.000	1	.441	-.405	0
			.350							1.000				
U-1	.236	-.055	3.084	1	12	7	.700	000016	.71	-.040	1	-.110	-.009	0
			.040							.112				
U-2	.271	.125	1.103	1	12	8	1.594	000014	.28	.011	1	-.267	.011	0
			.015							.017				
G-1	-.003	.087	.369	0		32		000001	2.21		1	0.000	0.000	0
	.015	.015	.031						.23					
G-2	-.003	.025	.190	0		41		000001	4.75		1	0.000	0.000	0
	.015	.015	.012						.32					
G-3	-.065	.025	1.276	0		42		000001	.78		1	0.000	0.000	0
	.015	.015	.202						.12					
G-4	-.003	-.037	.632	0		50		000001	1.58		1	0.000	0.000	0
	.015	.015	.070						.18					
G-5	-.065	-.037	.448	0		51		000001	2.23		1	0.000	0.000	0
	.015	.015	.042						.21					
G-6	-.065	-.099	.463	0		60		000001	2.16		1	0.000	0.000	0
	.015	.015	.044						.21					
G-7	-.127	-.099	1.972	0		61		000001	.51		1	0.000	0.000	0
	.015	.015	.388						.10					

0 LINES OF AUXILLARY TRACK INFORMATION
0 LINES OF COMMENTS

```
RUN   547 RECORD    2197
NGY   542 NH   4 NS   2
LAST DONE ON   81/05/20.
  2 VERTICES
NUMBER TYPE     X        Y        Z
   1     1    -5.244 -11.455    1.326
   2     2     130.0    74.0   4050.0
TOTAL CALORIMETER ENERGY IS  26.39 GEV
    .21  14.93  10.86    .39 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   6.92 GEV
  7 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/IO  1/PBETA  V
  1      -.017  -.001  -.017  -.001
          .002   .002   .002   .002
  2      -.063   .035  -.063   .035
          .002   .002   .002   .002
 0V       .032   .018                              2
          .002   .002
 V-1      .005  -.006   .005  -.006
          .002   .002   .002   .002
 V-2      .057   .001   .057   .001
          .002   .002   .002   .002
 V-3      .095   .013   .095   .013
          .002   .002   .002   .002
 V-4      .076   .054   .076   .054
          .002   .002   .002   .002
 13 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1      -.017  -.001   .022 -1 11  7 2.657 000004  1.22 -.021 1  .003 -.003 0
                        .005                                 1.000
  2      -.064   .039   .287  1  9  8 2.421 000130  1.30  .057 1  .063  .044 0
                        .006                                 1.000
 0V                                              01000              1            0

 V-1      .009  -.006   .113  1 11  6 1.028 000130  1.23 -.072 1 -.006  .012 0
                        .005                                 1.000
 V-2      .058   .004   .165 -1  9  7 1.360 000130   .51 -.003 1  .023  .027 0
                        .005                                  .012
 V-3      .092   .002   .747  1 12  7 1.603 000036  1.23 -.033 1  .178  .161 0
                        .011                                  .060
 V-4      .078   .054   .192 -1 11  6 1.122 000130   .85 -.002 1  .044  .024 0
                        .006                                  .019
 U-1     -.058   .072   .942 -1 11  6 1.405 000016  1.42  .019 1 -.017 -.000 0
                        .013                                  .015
 U-2      .018  -.029   .990  1 11  7  .970 000016  1.09 -.004 1  .038 -.087 0
                        .014                                  .013
 U-3      .137   .061  1.873  1 12  6  .807 000136  1.32  .198 1 -.093  .054 0
                        .025                                 1.000
 U-4     -.055   .065  1.434  1 12  8  .590 000014   .48 -.004 1 -.068  .069 0
                        .019                                  .020
 G-1      .093   .131  2.267  0    29        000001   .44       1 0.000 0.000 0
          .015   .015   .478                             .09
 G-2     -.155  -.055  1.468  0    60        000001   .68       1 0.000 0.000 0
          .015   .015   .249                             .12
  0 LINES OF AUXILLARY TRACK INFORMATION
  0 LINES OF COMMENTS
```

EVENT SUMMARY

```
RUN  547 RECORD   3705
NGY  534 NH  0 NS  3
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE    X        Y        Z
   1     1    4.630 -12.480   2.140
   2     2     49.0    77.0   740.0
TOTAL CALORIMETER ENERGY IS  17.33 GEV
   1.44  14.57   1.32   0.00 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   2.25 GEV
  8 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ   DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1      -.026  -.026   -.026  -.026
          .002   .002    .002   .002
  2       .084   .128    .084   .128
          .003   .003    .003   .003
  3       .180   .456    .180   .456
          .006   .006    .006   .006
 0V       .066   .105                                2
          .007   .010
 V-1      .100   .113    .100   .113
          .003   .003    .003   .003
 V-2     -.077   .191   -.077   .191
          .004   .004    .004   .004
 V-3      .033  -.047    .033  -.047
          .002   .002    .002   .002
 V-4      .067  -.162    .067  -.162   1.09
          .003   .003    .003   .003    .07
  9 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ    1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1      -.026  -.026    .004 -1 11  8  .617 000004   .29  .012 1 -.024  .003 0
                         .005                                .020
  2       .086   .127    .741  1 12  8  .635 000014   .56 -.002 1 -.015 -.027 0
                         .011                                .015
  3       .190   .474   1.202  1 10  0  .184 000136  0.00 0.000 1  .008  .010 0
                         .350                              1.000
 0V       .065   .111    .074  0        1.070 010000            1              0
          .003   .005    .003
 V-1      .105   .115    .067 -1  8  6 1.773 000130   .40  .001 2 -.047 -.018 1
                         .005                                .013
 V-2     -.077   .191    .363 -1 11  7  .468 000030   .57  .004 2 -.016  .006 1
                         .007                                .022
 V-3      .045  -.050   1.737  1 12  7  .100 000134   .25  .057 2 -.044  .043 1
                         .023                              1.000
 V-4      .070  -.164    .995  1 11  0 2.359 000136  0.00 0.000 2 -.009  .033 1
                         .350                              1.000
 U-1      .145   .063   2.660  1 12  6 1.371 000134  0.00  .156 1 -.108  .056 0
                         .035                              1.000
  0 LINES OF AUXILLARY TRACK INFORMATION
  1 LINES OF COMMENTS
THE Y SLOPE OF 0V HAS BEEN ADJUSTED FOR INCORRECT REFERENCE TRACK ADJUSTMENT
```

```
RUN  556 RECORD    152
NGY  156 NH  3 NS  2
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE     X        Y        Z
   1     1  -10.807  -9.302   1.617
   2     2      2.7     0.0    40.0
TOTAL CALORIMETER ENERGY IS   6.99 GEV
    .69    .65   1.85   3.79 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   8.99 GEV
  8 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1      -.164   .022  -.164   .022
          .003   .003   .003   .003
  2       .084   .021   .084   .021
          .002   .002   .002   .002
 0V       .068   .000                              2
          .020   .012
 V-1      .068  -.073   .068  -.073
          .002   .002   .002   .002
 V-2      .133   .030   .133   .030
          .003   .003   .003   .003
 V-3     -.063   .173  -.063   .173
          .003   .003   .003   .003
 V-4      .199  -.024   .199  -.024
          .004   .004   .004   .004
 E1-1    -.026  -.067  -.026  -.067
          .002   .002   .002   .002
 14 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1      -.164   .030   .099 -1 11  8 1.154 000004   .40 -.015 1  .005  .019 0
                         .005                                .017
  2       .083   .019   .800  1  8  8 1.311 000030   .27  .022 1
                         .012
 0V       .060  -.014   .065  0        .130 010000            1             0
          .003   .003   .001
 V-1      .069  -.073   .268 -1 11  7  .734 000130  1.04  .013 2  .017  .027 1
                         .006                                .013
 V-2      .133   .031   .210 -1  9  7  .648 000130  1.46  .016 2 -.003  .010 1
                         .006                                .010
 V-3     -.062   .173  1.514  1 12  7  .035 000014  0.00  .014 2  .012  .050 1
                         .020                                .020
 V-4      .198  -.026  1.311  1 12  8  .389 000014  4.45  .033 2  .039  .010 1
                         .018                                .014
 E1-1    -.026  -.068  1.017 -1 12  7  .421 000016  2.10  .001 1 -.026  .050 0
                         .014                                .013
 U-1      .138   .022  1.401  1 12  8  .968 000016  4.72  .018 1 -.046  .094 0
                         .019                                .015
 U-2     -.116   .145  2.869 -1 12  6 1.303 000134   .09  .103 1  .013  .088 0
                         .038                              1.000
 G-1      .139  -.010  1.231  0    47       000001   .81       1 0.000 0.000 0
          .015   .015   .191                             .13
 G-2      .014  -.010   .273  0    49       000001  3.67       1 0.000 0.000 0
          .015   .015   .020                             .27
 G-3      .139  -.072  2.934  0    56       000001   .34       1 0.000 0.000 0
          .015   .015   .703                             .08
 G-4     -.048  -.072  1.103  0    59       000001   .91       1 0.000 0.000 0
          .015   .015   .162                             .13
  0 LINES OF AUXILLARY TRACK INFORMATION
  0 LINES OF COMMENTS
```

EVENT SUMMARY


```
RUN  577 RECORD   5409
NGY   93 NH  6 NS  7
LAST DONE ON  81/05/31.
  3 VERTICES
NUMBER TYPE    X        Y        Z
   1     1   10.183   1.281    .327
   2     2     -2.7    -1.4    67.0
   3     2  -8970.0 -4880.0 32850.0
TOTAL CALORIMETER ENERGY IS  13.47 GEV
   1.66   7.21   4.04    .55 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   4.92 GEV
 13 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1       .062   .039   .062   .039
          .002   .002   .002   .002
  2      -.007  -.028  -.007  -.028
          .002   .002   .002   .002
  5      -.101   .364  -.101   .364
          .005   .005   .005   .005
  6      -.330  -.002  -.330  -.002
          .005   .005   .005   .005
  7      -.551   .311  -.551   .311
          .008   .008   .008   .008
  8      -.063  -.365  -.063  -.365
          .005   .005   .005   .005
  9       .115  -.517   .115  -.517
          .007   .007   .007   .007
 0V1     -.040  -.021                          2
          .010   .010
 V1-1    -.025  -.053  -.025  -.053
          .002   .002   .002   .002
 V1-2    -.182   .404  -.182   .404
          .006   .006   .006   .006
 0V2     -.273  -.149                          3
          .004   .004
 V2-1    -.284  -.198  -.284  -.198
          .005   .005   .005   .005
 V2-2    -.271  -.102  -.271  -.102
          .004   .004   .004   .004
 19 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1       .063   .039   .031 -1 10  8  .654 000004   .38 -.006 1 -.025 -.007 0
                        .005                                .015
  2      -.016  -.031   .951  1 12  8  .046 000016  1.37  .024 1  .014 -.002 0
                        .013                                .020
  5      -.120   .374   .877 -1 10  0 1.350 000136  0.00 0.000 1  .048 -.066 0
                        .350                               1.000
  6      -.319  -.034  2.234 -1 12  8  .150 000014  3.10  .049 1 -.049  .077 0
                        .029                                .021
  7                                          000136            1

  8      -.089  -.427  2.512 -1  9  0 1.204 000136  0.00 0.000 1  .044 -.103 0
                        .350                               1.000
  9       .148  -.548   .067 -1  9  0  .938 000136  0.00 0.000 1  .072  .094 0
                        .350                               1.000
 0V1     -.040  -.021   .084  0              010000            1             0
                        .007
 V1-1    -.028  -.057   .108  1  9  7  .678 000130  2.12  .018 2 -.010  .003 1
                        .005                                .023
 V1-2    -.184   .385  1.499 -1 10  0 2.077 000136  0.00 0.000 2 -.020  .037 1
                        .350                               1.000
 0V2     -.273  -.149   .714  0              000200            1             0
                        .014
 V2-1    -.270  -.187   .988  1 12  7  .652 000100  0.00  .247 3 -.002  .091 1
                        .014                                .014
```

```
 V2-2    -.292  -.105  2.564 -1 12  6  .663 000014  0.00  .056 3  .223  .066 1
                        .031                                .141
 U-1      .102   .014  2.594  1 12  6 1.147 000136   .32 0.000 1 -.457  .262 0
                        .034                               1.000
 U-2     -.021  -.084  1.095  1 10  7 2.607 000134   .00  .200 1 -.087 -.086 0
                        .015                               1.000
 U-3     -.388  -.232  2.909 -1 11  6 1.422 000134  0.00 0.000 1  .409 -.111 0
                        .038                               1.000
 U-4     -.287  -.290  1.520 -1  9  6 3.277 000134   .01  .295 1  .194 -.046 0
                        .020                               1.000
 G-1     -.033   .027  2.239  0    29       000001   .45       1 0.000 0.000 0
          .015   .015   .469                           .09
 G-2     -.033  -.034   .905  0    38       000001  1.10       1 0.000 0.000 0
          .015   .015   .121                           .15
  0 LINES OF AUXILLARY TRACK INFORMATION
  1 LINES OF COMMENTS
EMUSLSION TRACKS 3 AND 4 WERE PREVIOUS LABELS FOR V1-1 AND V1-2
```

```
RUN   597 RECORD    6914
NGY   540 NH   3 NS   5
LAST DONE ON   81/05/31.
  2 VERTICES
NUMBER TYPE     X        Y        Z
   1     1   -5.096 -10.192     .994
   2     2    196.0    157.0  4367.0
TOTAL CALORIMETER ENERGY IS   27.63 GEV
    .56  11.01  12.37   3.69 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   17.63 GEV
  8 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1      .019  -.011   .043  -.009
          .002   .002   .002   .002
   2      .005   .033   .015   .038
          .002   .002   .002   .002
   3     -.100  -.069  -.100  -.069
          .003   .003   .003   .003
   4     -.076  -.204  -.083  -.217
          .004   .004   .004   .004
   5     -.104  -.346  -.100  -.369
          .005   .005   .005   .005
  0V      .045   .036                              2
          .003   .003
  V-1     .039   .012   .042   .010
          .002   .002   .002   .002
  V-2     .080   .058   .086   .060
          .003   .003   .003   .003
 15 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1      .023  -.013   .113 -1  5  8 1.622 000032 10.64 -.029 1 -.001 -.008 0
                        .005                                .019
   2      .013   .034  1.764  1 10  0 1.699 000136  0.00 0.000 1 -.058  .020 0
                        .350                               1.000
   3     -.100  -.069   .017 -1 10  8  .734 000004   .37  .008 1 -.031 -.024 0
                        .005                                .011
   4                                          000136            1

   5     -.107  -.365  1.754  1 11  0  .490 000136  0.00 0.000 1  .027 -.001 0
                        .350                               1.000
  0V      .045   .036        0              010000             1              0

  V-1     .041   .012   .186  1 10  7  .893 000132 10.64  .007 1 -.049 -.041 0
                        .006                                .012
  V-2     .081   .060   .064 -1  8  7 1.468 000130  4.70 -.010 1 -.032 -.029 0
                        .005                                .011
 U-1      .079   .044  4.683  1  8  0 1.074 000136  0.00 0.000 1 -.134  .068 0
                        .350                               1.000
 U-2     -.041  -.009  9.547 -1 11  0 2.145 000136  0.00 0.000 1  .103 -.236 0
                        .350                               1.000
 U-3     -.012   .022  3.059 -1 10  0  .986 000136  0.00 0.000 1  .315 -.007 0
                        .350                               1.000
 G-1      .091   .059   .236  0    38        000001  4.24       1 0.000 0.000 0
          .015   .015   .016                             .29
 G-2      .030   .059  1.715  0    39        000001   .58       1 0.000 0.000 0
          .015   .015   .314                             .11
 G-3      .091  -.003  2.084  0    47        000001   .48       1 0.000 0.000 0
          .015   .015   .421                             .10
 G-4      .030  -.003   .103  0    48        000001  9.71       1 0.000 0.000 0
          .015   .015   .005                             .44
  0 LINES OF AUXILLARY TRACK INFORMATION
  0 LINES OF COMMENTS
```

```
RUN  609 RECORD   1768
KOB  000 NH  3 NS  2
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE     X        Y        Z
   1     1   -9.417   6.958    .800
   2     2     -6.3    20.9   442.4
TOTAL CALORIMETER ENERGY IS  28.44 GEV
    .39    .26  25.38   2.40 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS  10.08 GEV
  5 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1     -.005   .085  -.005   .085
          .009   .004   .009   .004
   2     -.009  -.105  -.009  -.105
          .010   .004   .010   .004
  0V     -.016   .045                              2
          .003   .006
  V-1     .134   .130   .134   .130
          .011   .005   .011   .005
  V-2    -.067   .035  -.067   .035
          .009   .004   .009   .004
  7 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1      .014   .079   .022  1 11  8 2.333 000130   .33  .014 1 -.020 -.033 0
                         .005                                .020
   2      .004  -.120   .013  1 11  8  .856 000004   .33  .011 1 -.021 -.030 0
                         .005                                .022
  0V                           0              010240            1              0

  V-1     .153   .106   .007  1 11  8  .917 000130  1.12 -.012 1 -.040 -.031 0
                         .005                                .013
  V-2    -.049   .023   .012  1  9  7  .428 000130  7.91  .017 1 -.015 -.032 0
                         .005                                .013
 G-1      .188   .105  1.266  0    10        000001   .79       1 0.000 0.000 0
          .015   .015   .199                             .12
 G-2     -.059   .043   .133  0    23        000001  7.51       1 0.000 0.000 0
          .015   .015   .007                             .38
  0 LINES OF AUXILLARY TRACK INFORMATION
  1 LINES OF COMMENTS
MAGNET TRIPPED OFF
```

EVENT SUMMARY


```
RUN  635 RECORD   4949
NGY  258 NH  1 NS  6
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE    X        Y        Z
   1     1   -2.858 -10.423   1.853
   2     2    680.7  -506.6  4304.0
   3     2  -1720.0  4470.0  9000.0
TOTAL CALORIMETER ENERGY IS  25.39 GEV
    .23  21.76   3.40   0.00 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   2.48 GEV
 10 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1     -.024   .044  -.023   .044
          .002   .002   .002   .002
   2     -.068   .044  -.066   .054
          .002   .002   .002   .002
   3      .063  -.069   .063  -.067
          .002   .002   .002   .002
   4     -.190   .497                 1.11           3
          .007   .007                  .06
  4-1    3.740   .544  3.740   .544
          .060   .060   .060   .060
   5     1.384  -.153  1.279  -.091   0.98
          .015   .015   .015   .015    .05
   6     -.407  -.498  -.411  -.154
          .008   .008   .008   .008
  0V      .158  -.118                          2
          .004   .004
  V-1     .099   .027   .088   .025
          .003   .003   .003   .003
  V-2    -.231  -.199  -.249  -.181   0.91
          .005   .005   .005   .005    .05
 13 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1     -.023   .044   .002 -1  9  7 1.795 000004   .52  .000 1 -.001 -.007 0
                         .005                                .014
   2     -.069   .048   .975  1 12  8  .616 000014   .16  .002 1 -.015  .026 0
                         .014                                .017
   3      .063  -.070   .048  1 10  7 1.124 000130  1.38  .024 1 -.006  .010 0
                         .005                            1.000
   4                                        000136            1

  4-1                                       000136            1

   5                                        000136            1

   6     -.408  -.160   .351 -1 12  0  .252 000136  0.00 0.000 1  .008  .008 0
                         .350                            1.000
  0V      .154  -.118   .209  0       10.510 100000            1            0
                         .001
  V-1     .090   .023   .362  1 11  8  .466 000100   .35  .055 2  .007 -.006 1
                         .007                                .015
  V-2    -.244  -.188  5.025 -1 11  0       000136  0.00 0.000 2            1
                         .350                            1.000
  0K      .984  -.513   .917  0              000040  0.00 0.000 2            1
                         .020                            1.000
 G-1     -.051   .061  2.273  0    40        000001   .44       1 0.000 0.000 0
          .015   .015   .480                            .09
 G-2      .074  -.063  1.010  0    56        000001   .99       1 0.000 0.000 0
          .015   .015   .142                            .14
  0 LINES OF AUXILLARY TRACK INFORMATION
  1 LINES OF COMMENTS
TRACK 4 UNDERGOES A NH=2, NS=1 INTERATION IN EMULSION PLATE 1
0K IS PER SE
```

```
RUN  638 RECORD   5640
NGY  490 NH 12 NS 19
LAST DONE ON  81/05/31.
  3 VERTICES
NUMBER TYPE    X        Y        Z
   1     1    4.376    1.013    1.830
   2     2    -12.0    16.0     183.0
   3     1    4.464    .821     2.560
TOTAL CALORIMETER ENERGY IS  13.40 GEV
   2.01   5.57   4.90    .91 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS  29.28 GEV
 23 EMULSION TRACKS
            PRODUCTION        EXIT
 TRACK    DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1       .049  -.067   .049  -.067
           .002   .002   .002   .002
   2      -.021   .128  -.021   .128
           .003   .003   .003   .003
   3      -.239   .249  -.239   .249
           .005   .005   .005   .005
   4      -.112   .053  -.112   .053
           .003   .003   .003   .003
   5      -.133   .023  -.133   .023
           .003   .003   .003   .003
   6      -.092  -.125  -.092  -.125
           .003   .003   .003   .003
   7      -.183  -.210  -.183  -.210
           .004   .004   .004   .004
   8       .013  -.281   .013  -.281
           .004   .004   .004   .004
   9       .143  -.022   .143  -.022
           .003   .003   .003   .003
  10       .254  -.031   .254  -.031
           .004   .004   .004   .004
  11     -1.026   .307 -1.026   .307
           .012   .012   .012   .012
  12      -.617   .097  -.617   .097
           .008   .008   .008   .008
  13      -.558  -.079  -.558  -.079
           .007   .007   .007   .007
  14       .470   .038   .470   .038
           .006   .006   .006   .006
  15       .703   .903   .703   .903
           .013   .013   .013   .013
  16       .306   .903   .306   .903
           .011   .011   .011   .011
  17       .092   .727   .092   .727
           .009   .009   .009   .009
 0V       -.066   .087                              2
           .009   .011
  V-1     -.029   .040  -.029   .040
           .002   .002   .002   .002
  V-2     -.037   .014  -.037   .014
           .002   .002   .002   .002
 0L        .120  -.264                              3
           .045   .045
  L-1      .153  -.266   .153  -.266
           .002   .002   .002   .002
  L-2     -.622  -.080  -.622  -.080
           .010   .010   .010   .010
 37 TOTAL TRACKS
 TRACK    DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1       .049  -.067   .037  1 10  7 1.565 000004   .03  .013 1 -.004  .001 0
                         .005                                .012
   2      -.038   .127   .947  1 11  8  .791 000000   .22  .063 1  .158  .038 0
                         .013                                .012
```

3	-.238	.251	.259	1	11	7	.273	000100	.00	.040	1	.002	.001	0
			.006							.014				
4	-.144	.021	2.059	-1	12	6	.361	000000	.30	.770	1	.135	-.024	1
			.027							.064				
5	-.133	.021	.189	-1	11	7	.895	000100	1.89	.030	1	.016	-.007	0
			.006							.013				
6	-.104	-.108	.809	1	12	7	1.326	000134	.08	.443	1	.002	-.054	0
			.012							1.000				
7								000136			1			
8	.012	-.296	.141	-1	11	0	1.849	000136	0.00	0.000	1	-.016	.008	0
			.350							1.000				
9								000136			1			
10								000136			1			
11								000136			1			
12								000136			1			
13	-.580	-.102	.044	-1	10	0	4.354	000136	0.00	0.000	1	.153	.052	0
14	.554	-.000	8.509	1	12	6	.853	000136	.18	.437	1	-.866	.242	0
			.111							1.000				
15								000136			1			
16								000136			1			
17								000136			1			
0V	-.017	.020	.037					010000			1			0
			.005											
V-1	-.028	.038	.074	-1	6	7	.691	000130	11.87	-.007	1	-.002	-.002	0
			.005							.013				
V-2	-.038	.017	.174	1	8	7	1.133	000132	9.34	.020	1	-.008	-.031	0
			.005							.013				
0L	.120	-.264	1.000	0				000200			1			0
			.016											
L-1	.153	-.266	1.155	1	12	7	.763	000100	.10	.324	1	-.022	.012	0
			.016							.011				
L-2	-.622	-.080	6.677	-1	12	6	1.101	000002	.63	-.078	1	.539	-.146	0
			.087							.126				
U-1	-.166	.056	1.661	-1	12	6	.897	000136	2.82	.511	1	.061	-.027	0
			.022							1.000				
U-2	-.005	.008	1.414	1	12	6	1.705	000000	.41	.432	1	.148	.126	0
			.019							.016				
U-3	-.003	.229	.602	1	11	7	.382	000100	.11	.133	1	.016	-.007	0
			.009							.018				
U-4	-.134	-.007	1.263	-1	12	6	1.220	000034	.04	.006	1	.298	.033	0
			.017							.167				
G-1	.201	.092	.962	0		17		000001	1.04		1	0.000	0.000	0
	.015	.015	.132						.14					
G-2	.139	.092	.356	0		18		000001	2.81		1	0.000	0.000	0
	.015	.015	.030						.23					
G-3	.077	.092	.455	0		19		000001	2.20		1	0.000	0.000	0
	.015	.015	.043						.21					
G-4	-.048	.092	.980	0		21		000001	1.02		1	0.000	0.000	0
	.015	.015	.136						.14					
G-5	.015	.030	.625	0		29		000001	1.60		1	0.000	0.000	0
	.015	.015	.069						.18					
G-6	-.048	.030	.119	0		30		000001	8.40		1	0.000	0.000	0
	.015	.015	.006						.41					
G-7	-.110	.030	.700	0		31		000001	1.43		1	0.000	0.000	0
	.015	.015	.082						.17					
G-8	-.048	-.032	.331	0		39		000001	3.02		1	0.000	0.000	0
	.015	.015	.027						.24					

```
G-9      -.048  -.095  1.278  0    48       000001   .78       1 0.000 0.000 0
          .015   .015   .202                          .12
G-10      .077  -.157  1.155  0    55       000001   .87       1 0.000 0.000 0
          .015   .015   .174                          .13
 0 LINES OF AUXILLARY TRACK INFORMATION
 0 LINES OF COMMENTS
```

EVENT SUMMARY


```
RUN  654 RECORD   3711
KOB  000 NH  1 NS  4
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE    X       Y       Z
   1     1    2.001  12.246   1.869
   2     2     0.0     0.0     6.5
TOTAL CALORIMETER ENERGY IS  17.89 GEV
   4.36   8.30   3.98   1.25 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS  28.43 GEV
 11 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/IO  1/PBETA  V
   1      .497   .283   .497   .283
          .020   .009   .020   .009
   2     -.217   .231  -.217   .231
          .014   .006   .014   .006
   3     -.390   .117  -.390   .117
          .016   .007   .016   .007
  10     -.056  -.253  -.056  -.253
          .013   .006   .013   .006
  0V      .000   .000                              2
          .100   .100
 V-1      .050   .005   .050   .005
          .008   .004   .008   .004
 V-2     -.034   .059  -.034   .059
          .009   .004   .009   .004
 V-3      .120  -.031   .120  -.031
          .010   .005   .010   .005
 V-4      .082  -.026   .082  -.026
          .009   .004   .009   .004
 V-5      .230  -.060   .230  -.060
          .012   .006   .012   .006
 V-6      .010  -.071   .010  -.071
          .009   .004   .009   .004
 25 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1      .477   .306  1.937  1 11  0 1.189 000136  0.00 0.000 1 -.033 -.084 0
                        .350                                1.000
   2     -.245   .233  2.556  1 11  0  .434 000136  0.00 0.000 1 -.005 -.045 0
                        .350                                1.000
   3     -.398   .091   .229 -1 11  8  .581 000012  0.00 -.029 1  .011 -.010 0
                        .006                                 .020
  10                                          000136            1

 V-1      .045  -.008  1.204  1 11  8 1.644 000000  1.65 -.028 1 -.107 -.021 0
                        .016                                 .016
 V-2                                          000136            1

 V-3      .097  -.022   .244 -1  9  7  .284 000030  1.74 -.001 1  .011 -.045 0
                        .006                                 .013
 V-4      .097  -.022   .244 -1  9  7  .284 000030  1.74 -.001 1  .011 -.045 0
                        .006                                 .013
 V-5      .219  -.069   .719 -1 12  8  .344 000016  0.00 -.002 1 -.012 -.038 0
                        .011                                 .019
 V-6     -.006  -.073   .198  1  8  7  .523 000000  6.32  .036 1  .017 -.019 0
                        .006                                 .010
 U-1      .017  -.043   .988  1 11  7 2.747 000016  2.24  .005 1 -.137 -.067 0
                        .014                                 .015
 U-2     -.029  -.060   .188  1 11  8  .872 000132  6.92  .010 1  .021 -.015 0
                        .006                                 .019
 U-3      .124  -.147  2.011  1 12  6  .753 000134   .01  .194 1 -.399  .149 0
                        .027                                1.000
 U-4      .044  -.024   .530 -1 11  8  .905 000130  1.43 -.027 1  .012 -.024 0
                        .009                                1.000
 U-5     -.034  -.008  2.530 -1 12  8  .641 000006  0.00  .001 1  .440 -.308 0
```

```
                          .033                                          .025
 U-6      -.019   -.077  1.093 -1 12   7 1.281 000136    .78 -.040 1  .190   .063 0
                          .015                                          1.000
 G-1       .034    .062   .390  0     11        000001  2.57       1 0.000 0.000 0
           .015    .015   .034                          .22
 G-2       .096    .000  1.558  0     19        000001   .64       1 0.000 0.000 0
           .015    .015   .272                          .11
 G-3       .034    .000   .085  0     20        000001 11.79       1 0.000 0.000 0
           .015    .015   .003                          .48
 G-4      -.028    .000   .723  0     21        000001  1.38       1 0.000 0.000 0
           .015    .015   .086                          .16
 G-5      -.090    .000  1.161  0     22        000001   .86       1 0.000 0.000 0
           .015    .015   .175                          .13
 G-6       .096   -.062  3.173  0     28        000001   .32       1 0.000 0.000 0
           .015    .015   .791                          .08
 G-7       .034   -.062  1.835  0     29        000001   .55       1 0.000 0.000 0
           .015    .015   .348                          .10
 G-8      -.028   -.062   .186  0     30        000001  5.39       1 0.000 0.000 0
           .015    .015   .011                          .32
 G-9      -.090   -.062  1.675  0     31        000001   .60       1 0.000 0.000 0
           .015    .015   .304                          .11
  0 LINES OF AUXILLARY TRACK INFORMATION
  3 LINES OF COMMENTS
TRACKS V-1 THROUGH V-2 USED TO BE 4-9
X AND Y SLOPES FOR 0V ARE NOT MEASURED, ERRORS REPRESENT REASONABLE
LIMITS ONLY.
```

```
RUN  661 RECORD   2729
NGY  609 NH  0 NS  2
LAST DONE ON  81/05/31.
  3 VERTICES
NUMBER TYPE    X       Y       Z
   1     1    3.506  -1.411   1.559
   2     2     50.4    30.8   700.0
   3     1    3.963  -1.057   8.116
TOTAL CALORIMETER ENERGY IS  15.91 GEV
    .71  10.84   4.35   0.00 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   4.63 GEV
  8 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1      -.047  -.041  -.047  -.041
          .002   .002   .002   .002
  2       .112   .045   .112   .045
          .003   .003   .003   .003
 0V       .072   .044                              2
          .007   .004
 V-1      .003   .245   .003   .245
          .004   .004   .004   .004
 V-2      .075   .246   .075   .246   1.45    2.778
          .004   .004   .004   .004    .07    1.340
 0K       .070   .054                              3
          .007   .007
 K-1      .100  0.000   .100  0.000
          .003   .003   .003   .003
 K-2      .043   .093   .043   .093
          .003   .003   .003   .003
 10 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1      -.047  -.040   .037 -1 10  8  .900 000004   .46  .005 1  .001 -.001 0
                        .005                                .013
  2       .124   .051  1.303  1 12  7 1.031 000014   .41  .003 1 -.111  .037 0
                        .018                                .014
 0V       .070   .046   .081  0             010000            1             0
                        .001
 V-1      .010   .242   .526 -1 11  8  .975 000010   .54  .004 2 -.040  .000 1
                        .008                                .012
 V-2      .180   .157  5.540  1 12  6  .537 000010  0.00 0.000 2  .062 -.151 1
                        .072                                1.000
 0K       .070   .054   .128  0             000040            2             1
                        .003
 K-1      .101   .005   .279 -1  9  7 1.962 000030   .35 -.010 3 -.221  .231 1
                        .006                                .013
 K-2      .043   .094   .234  1 10  8 1.260 000130   .40  .008 3  .175 -.260 1
                        .006                                .013
 G-1      .084  -.075   .588  0    46        000001  1.70       1 0.000 0.000 0
          .015   .015   .063                           .18
 G-2      .146  -.137  1.935  0    54        000001   .52       1 0.000 0.000 0
          .015   .015   .377                           .10
  0 LINES OF AUXILLARY TRACK INFORMATION
  1 LINES OF COMMENTS
V-2 IS IDENTIFIED AS A PION FROM I/I0
```

```
RUN  661 RECORD   6517
NGY  325 NH  3 NS  5
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE    X        Y        Z
   1     1    3.410  -5.633     .789
   2     2    147.8   -94.3  2460.0
TOTAL CALORIMETER ENERGY IS  21.79 GEV
   7.48  10.61   3.46    .23 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   8.42 GEV
  7 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
   1      .119  -.029   .119  -.029
          .003   .003   .003   .003
   2     -.092   .030  -.092   .030
          .002   .002   .002   .002
   3      .010   .085   .010   .085
          .003   .003   .003   .003
   4     -.251  -.199  -.251  -.199
          .005   .005   .005   .005
  0V      .056  -.036                              2
          .003   .003
  V-1     .018  0.000   .018  0.000
          .002   .002   .002   .002
  V-2     .065  -.092   .065  -.092
          .003   .003   .003   .003
 17 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
   1      .118  -.031   .156 -1 10  7  .675 000130   .79 -.005 1 -.008 -.001 0
                        .005                                .012
   2     -.091   .030   .049 -1  8  8 1.104 000004   .54  .002 1 -.002  .005 0
                        .005                                .011
   3                                          000136        1              0

   4     -.181  -.228   .858  1 11  0 1.142 000136  0.00 0.000 1 -.012 -.007 0
                        .350                               1.000
  0V     -.091   .030   .049 -1  8  8 1.104 000004   .54  .002 1 -.002  .005 0
                        .005                                .011
  V-1     .018   .001   .115  1 10  7 1.007 000004   .59  .010 1  .018  .027 0
                        .005                                .013
  V-2     .064  -.090   .096 -1  7  8 2.546 000130  4.12  .003 1 -.009  .048 0
                        .005                                .011
 U-1      .025  -.001  2.199  1 12  7  .391 000002   .41 -.011 1 -.028  .049 0
                        .029                                .022
 U-2      .007  -.085  2.053 -1 12  6  .611 000006  0.00 -.006 1  .165 -.061 0
                        .027                                .021
 U-3     -.044   .428   .732  1 12  0  .935 000136  0.00 0.000 1  .027 -.004 0
                        .350                               1.000
 U-4     -.001  -.013  2.273 -1 12  6  .853 000006  0.00 -.001 1  .184 -.340 0
                        .030                                .023
 G-1     -.101   .145  3.075  0    22        000001   .33       1 0.000 0.000 0
          .015   .015   .755                            .08
 G-2     -.286   .022  3.158  0    43        000001   .32       1 0.000 0.000 0
          .015   .015   .786                            .08
 G-3      .146  -.040  2.492  0    45        000001   .40       1 0.000 0.000 0
          .015   .015   .551                            .09
 G-4      .084  -.040  2.541  0    46        000001   .39       1 0.000 0.000 0
          .015   .015   .567                            .09
 G-5      .146  -.102  2.096  0    54        000001   .48       1 0.000 0.000 0
          .015   .015   .425                            .10
 G-6      .084  -.102   .268  0    55        000001  3.73       1 0.000 0.000 0
          .015   .015   .019                            .27
  0 LINES OF AUXILLARY TRACK INFORMATION
  0 LINES OF COMMENTS
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RUN  666 RECORD   5294
NGY  488 NH  2 NS  4
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE    X        Y        Z
   1     1   -5.067 -12.536   1.736
   2     2     16.7     6.1   653.0
TOTAL CALORIMETER ENERGY IS   1.72 GEV
   0.00   0.00   0.00   1.72 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS  17.99 GEV
  9 EMULSION TRACKS
          PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1      -.045  -.012  -.045  -.012
          .002   .002   .002   .002
  2       .014   .017   .014   .017
          .002   .002   .002   .002
  3       .026  -.005   .026  -.005
          .002   .002   .002   .002
  4       .031  -.004   .031  -.004
          .002   .002   .002   .002
 0V       .026   .009                              2
          .004   .003
 V-1      .024   .014   .024   .014
          .002   .002   .002   .002
 V-2      .030   .006   .030   .006
          .002   .002   .002   .002
 V-3      .039  -.022   .039  -.022          1.724
          .002   .002   .002   .002           .884
 V-4      .076   .085   .076   .085
          .003   .003   .003   .003
 14 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1      -.044  -.011   .001 -1  7  8 1.228 000004   .36  .001 1  .013 -.005 0
                        .005                                .015
  2       .014   .018   .029 -1  8  8 1.941 000130 16.03 -.082 1 -.011 -.003 0
                        .005                               1.000
  3       .025  -.006   .059  1  7  7  .857 000132 16.04 -.060 1  .017 -.010 0
                        .005                               1.000
  4       .031  -.004   .046  1  7  7 3.178 000000 16.03 -.076 1  .013  .001 0
                        .005                                .024
 0V                                          010000            1            0

 V-1                                         000136            2            0

 V-2                                         000136            2            0

 V-3      .035   .007  1.404  1 12  8  .725 000014  0.00 -.060 2 -.081 -.035 1
                        .019                                .113
 V-4      .073   .082   .464  1 12  7  .538 000130   .55 -.042 2 -.012  .004 1
                        .008                               1.000
 U-1     -.047  -.010   .717 -1 10  6  .444 000136 16.35 -.128 1  .043 -.031 0
                        .011                               1.000
 U-2      .054   .011   .320  1  9  7 2.410 000132 16.03 -.083 1 -.172 -.125 0
                        .007                               1.000
 G-1      .092   .016  3.147  0    47        000001   .32       1 0.000 0.000 0
          .015   .015   .782                             .08
 G-2      .030   .016   .073  0    48        000001 13.70       1 0.000 0.000 0
          .015   .015   .003                             .52
 G-3     -.219   .016  2.242  0    52        000001   .45       1 0.000 0.000 0
          .015   .015   .470                             .09
  0 LINES OF AUXILLARY TRACK INFORMATION
  0 LINES OF COMMENTS
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RUN  670 RECORD   7870
NGY  150 NH  0 NS  7
LAST DONE ON  81/05/31.
  2 VERTICES
NUMBER TYPE    X        Y        Z
   1     1    -.763   -8.930   1.366
   2     2     6.9      1.0    210.0
TOTAL CALORIMETER ENERGY IS   9.82 GEV
    .42   4.12   3.75   1.54 IN COLUMNS 1,2,3,4
TOTAL LEAD GLASS ENERGY IS   9.53 GEV
 10 EMULSION TRACKS
           PRODUCTION        EXIT
 TRACK   DX/DZ  DY/DZ  DX/DZ  DY/DZ   I/I0  1/PBETA  V
  1        .004   .015   .004   .015
           .002   .002   .002   .002
  2       -.004   .022  -.004   .022
           .002   .002   .002   .002
  3        .015  -.001   .015  -.001
           .002   .002   .002   .002
  4       -.142   .082  -.142   .082
           .003   .003   .003   .003
  5       -.207  -.059  -.207  -.059
           .004   .004   .004   .004
  6        .303  -.546   .303  -.546
           .008   .008   .008   .008
  7        .019  -.071   .019  -.071
           .002   .002   .002   .002
 0V        .033   .005                              2
           .004   .003
 V-1       .014  -.064   .014  -.064
           .002   .002   .002   .002
 V-2      -.187  1.180  -.187  1.180
           .013   .013   .013   .013
 15 TOTAL TRACKS
 TRACK   DX/DZ  DY/DZ   1/P   Q UP DN CHISQ   ID     EPBG  BETA V XMISS YMISS F
  1        .003   .013   .028  1 10  7  .606 000004  5.22  .049 1 -.000 -.003 0
                         .005                                1.000
  2       -.018   .033  1.313  1 12  8  .361 000014   .23  .029 1 -.068  .004 0
                         .018                                .020
  3                                            000136        1              0

  4       -.141   .085   .474 -1 11  8  .427 000020   .36  .025 1 -.029  .024 0
                         .008                                .014
  5       -.218  -.065   .338  1 11  7  .292 000100   .00  .059 1 -.012 -.002 0
                         .007                                .013
  6        .310  -.572   .483 -1 10  0 2.099 000136  0.00 0.000 1  .051  .135 0
                         .350                                1.000
  7        .030  -.083  1.857 -1 12  7  .596 000016  0.00  .017 1  .032 -.009 0
                         .025                                .018
 0V        .033   .005   .147  0           4 010000          4 1              0
                         .021
 V-1       .021  -.076   .165  1 11  8 1.624 000130  1.16  .004 2 -.014  .001 1
                         .005                                1.000
 V-2      -.077  1.258  3.797 -1 12  0  .296 000136  0.00 0.000 2 -.070  .101 1
                         .350                                1.000
 U-1       .406  -.058  1.461  1 12  7  .333 000000   .38 -.025 1  .064 -.051 0
                         .020                                .017
 G-1      -.006   .049  2.133  0    39       000001   .47       1 0.000 0.000 0
           .015   .015   .436                           .10
 G-2       .056  -.013   .941  0    47       000001  1.06       1 0.000 0.000 0
           .015   .015   .128                           .14
 G-3      -.006  -.013   .234  0    48       000001  4.28       1 0.000 0.000 0
           .015   .015   .016                           .29
 G-4      -.006  -.075  1.296  0    57       000001   .77       1 0.000 0.000 0
           .015   .015   .207                           .12
  0 LINES OF AUXILLARY TRACK INFORMATION
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0 LINES OF COMMENTS

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