MUC-NOTE-COOL_EXP-304

MICE Upstream Cherenkov Detector

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1 Introduction

Cherenkov radiators can provide particle identification for the International Muon Ionization Cooling Experiment (MICE) [1]. MICE is designed as a section of an ionization cooling channel for a Neutrino Factory [2]. Upstream a simple C_6F_{14} radiator can provide $(\pi - \mu - e)$ separation for many momenta if pulse height information is used as well as thresholds [3]. This can beat down any backgrounds that might be left over from the time of flight detector.

The $(\mu - e)$ separation in the downstream detector provides a more challenging problem. Muon decay has a lot of phase space. Electrons are widely dispersed. Again a Cherenkov counter is used. The radiator is aerogel with an electron threshold of about 2 MeV/c and a muon threshold of about 400 MeV/c. The majority of electrons hit the aerogel, but a fair number miss. With a Belle style detector photomesh PMTs on each aerogel block, all hits register [4]. With a light guide some high angle hits are lost. In either case, one must rely on finding kinks in the tracking system to do some of the electron ID.

The strength of the Cherenkov detector is to veto forward decays. MICE must be able to tell the difference between forward decays that have almost the same momentum as the parent muon and muons that just did not get cooled properly. Some tracking may be needed near the Cherenkov detector, even if it is just a scintillator hodoscope.

If X-rays from the RF cavities are below 2 MeV they should not be lead to electrons that give Cherenkov light. A larger concern is RF noise pickup by photomultipler tubes. For 201 MHz, the skin depth ($SQRT(2./(2.*PI*FREQ*CONDUCT*U*U0))$) of pure aluminum is 6 microns. So 100 microns of aluminum (17 skin depths) might provide an adequate RF shield. This is the thickness of a Coca Cola can. Copper would be easier to solder to form a sealed container and has a skin depth of 5 microns.

2 Aerogel Cherenkov Detector

Mississippi proposes to work with the Universite Catholique de Louvain on Cherenkov particle ID. The task would be split between the two institutions.

For downstream ($\mu-e$) discrimination, we propose to use a particle ID system similar to that adopted by the Belle collaboration at KEK in Japan. It uses silica aerogel blocks with fine-mesh photomultiplier tubes (PMTs) to work in a magnetic field. For details of what the detector elements look like see Fig. 1 and Fig. 2 respectively.

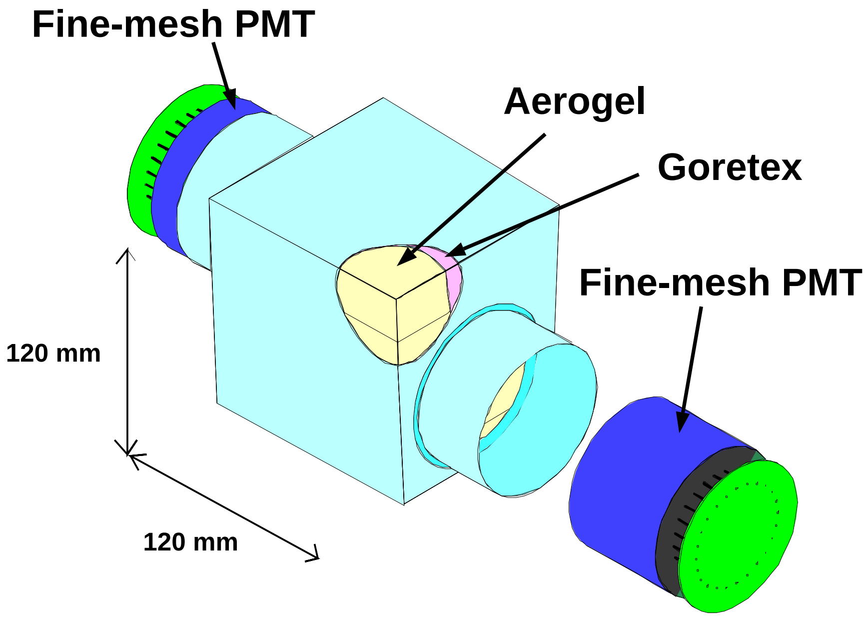

Figure 1: The aerogel Cherenkov counter design from Ref. [4].

We propose to use two PMTs per aerogel block. We have been making maps of the solenoidal fringe fields. The phototubes must be in a field less than 1.5 Tesla. The layout would be designed to make it difficult for a particle to pass through both PMTs. Rare cases of double passage could be excluded from analysis. The solenoid opening is large and tracks at the edges in fringe fields are not parallel to tracks in the center. Muon decay will give transverse kicks to some of the electrons. Proximity collection of light will work if a track passes though a silica aerogel block. Electrons give light, muons do not.

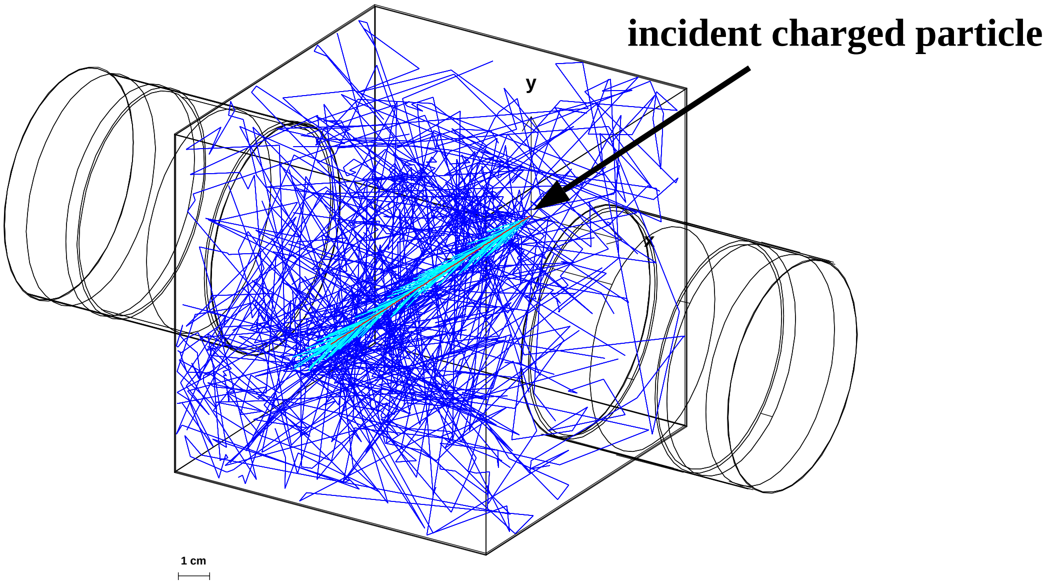

Figure 2: The aerogel Cherenkov simulation of light generation and collection for single event from Ref. [4].

Upstream, the beam is smaller and more parallel. We propose to use a single cell of C_6F_{14} liquid to do $(\pi - \mu - e)$ discrimination [5]. The PMTs would be mounted directly on the vessel holding the liquid. Pulse height informations used to aid in the discrimination. We have tested a C6-F14 Cherenkov detector with cosmic rays in Mississippi as noted in above reference. This is a fairly simple detector that would supplement the time of flight system to help beat systematic errors down to a low level. Table 1 shows the Cherenkov thresholds for electrons, muons, and pions.

The dimension of the Cherenkov detector is 90 x 90 x 15 cm^3 wall of the aerogel counters. The Cherenkov detector consist of 49 aerogel tiles and each tile is 15 x 15 x 15 cm^3 with two Fine Mesh PMTs (Hamamatsu). It includes 5 mil window of polyethylene as an entrance. The layout of the Cherenkov detector is shown in Fig. 3.

3 Beam Decays Spectrum

In order to understand the muon beam decay spectrum, we studied the decay of muons that may or may not fire the Cherenkov detector. In most of the time the 200 MeV/c muon beam could decays into electrons a long with both its neutrinos and muon neutrinos. The decay is $\mu^- \to e^- \bar{\nu}_e \nu_\nu$. (The charged conjugate modes are applied throughout this note).

The majority of the electrons decay into a small angle with respect to the beam direction, however 2% of such decays make an angle larger than 120° and about 5%

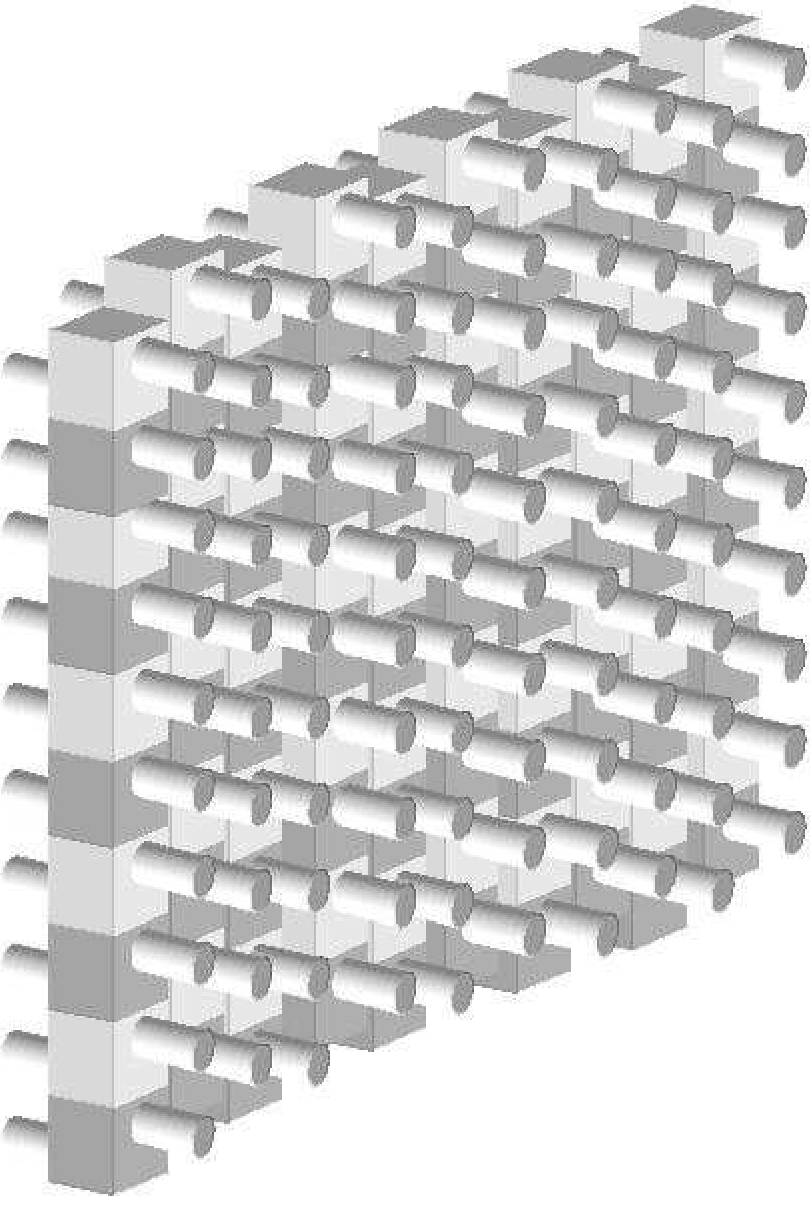

Figure 3: Possible layout of a downstream Cherenkov detector.

Material	Boiling Point ^{0}K	Density g/cm^3	X$_0$ mm	Length mm/15pe	Refractive Index n	Electron MeV/c	Muon MeV/c	Pion MeV/c
Polystyrene		1.03	424	4	1.581	0.42	86	114
Quartz	2500	2.20	123	4	1.458	0.48	99	132
Water	373	1.00	361	5	1.33	0.58	120	159
C_6F_{14}	329	1.68	206	6	1.244	0.69	143	189
C_2F_6	195	1.61	~200	7	1.222	0.73	150	199
LN$_2$	77	0.81	471	7	1.205	0.76	157	208
LD$_2$	24	0.18	7540	10	1.128	0.98	202	267
LH$_2$	20	0.071	8900	12	1.112	1.05	217	287
LNe	27	1.206	240	14	1.092	1.16	241	318
Aerogel	2500	0.30	995	16	1.075	1.30	268	354
Aerogel	2500	0.20	1490	24	1.050	1.60	330	436
Aerogel	2500	0.15	1990	31	1.038	1.84	379	501
Aerogel	2500	0.10	2985	46	1.025	2.27	470	620
Isobutane	261	0.0027	169300	581	1.0019	8.29	1710	2260

Table 1: Cherenkov thresholds ($p = \gamma\beta m$; $\beta = 1/n$) for electrons, muons, and pions. The refractive indices for C_6F_{14} and C_2F_6 are for 350 nm and are approximations based on linear extrapolations [6]. DELPHI [7] and SLD [8] use C_6F_{14} as a liquid Cherenkov radiator. BELLE at KEK uses silica aerogel [4].

of the them make an angle larger than 90° shown in Fig. 4.

We also studied the total momentum of electrons versus its cosine angle distribution. Most of the electrons which have a low total momentum make a larger angle as we expected. Fig. 5 shows the corresponding of the total momentum of the electrons versus its cosine angle with respect to the beam direction. The electrons that made an angle larger than 90° have a total momentum about 30 MeV/c.

4 Cherenkov Detector in GEANT4 Simulation

We have coded the aerogel Cherenkov detector into MICE software simulation package. CKOVTrackerGeom class is coded for the description of the Cherenkov geometry and materials. The logical and the physical volume of the Cherenkov detector described by CKOVTracker and CKOVSD classes respectively. We use CKOVHitBank class as an interface for recording the hits information of the photons into the Cherenkov system. It records the position and time of each step, the energy deposition of each step, the momentum and energy of each track as well as its step length.

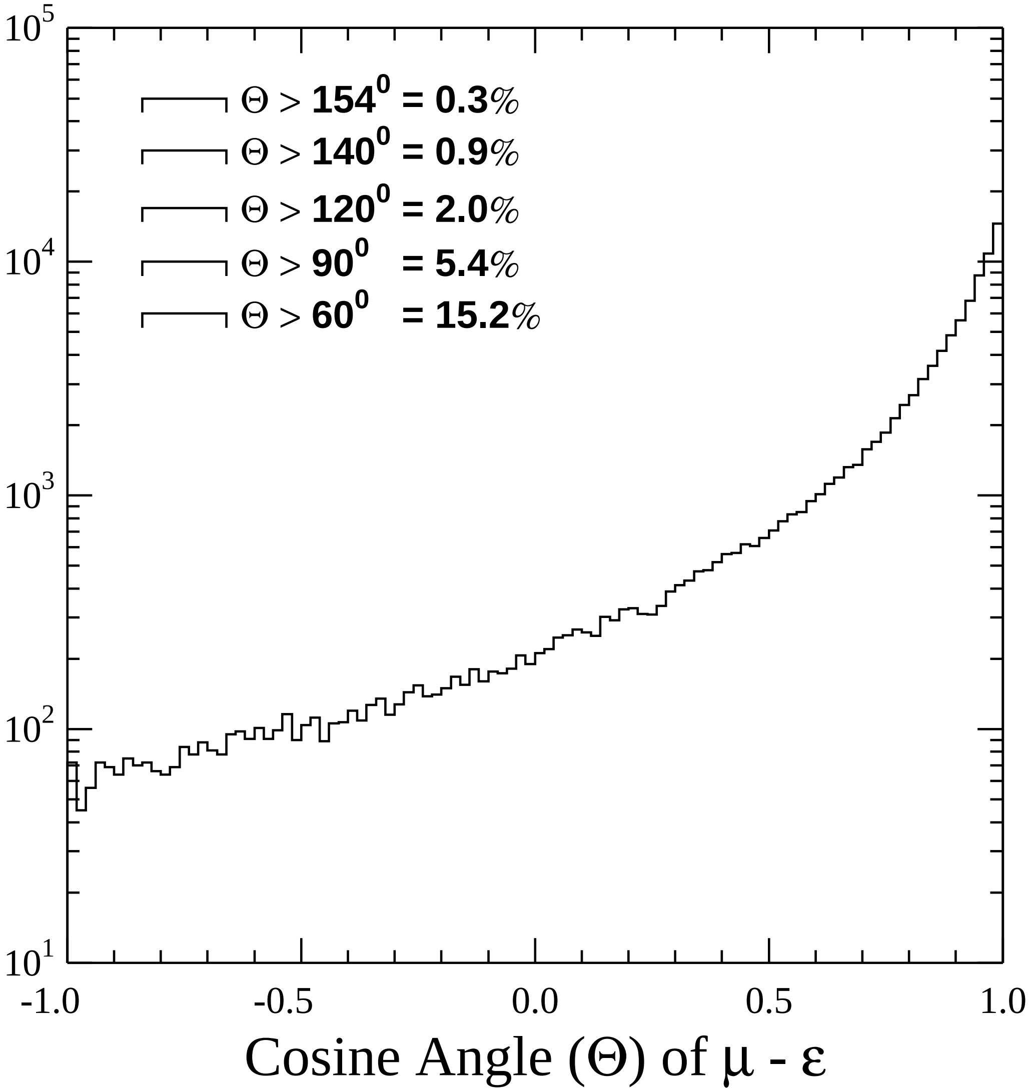

Figure 4: 200 MeV/c muon beam cosine angle decay distribution.

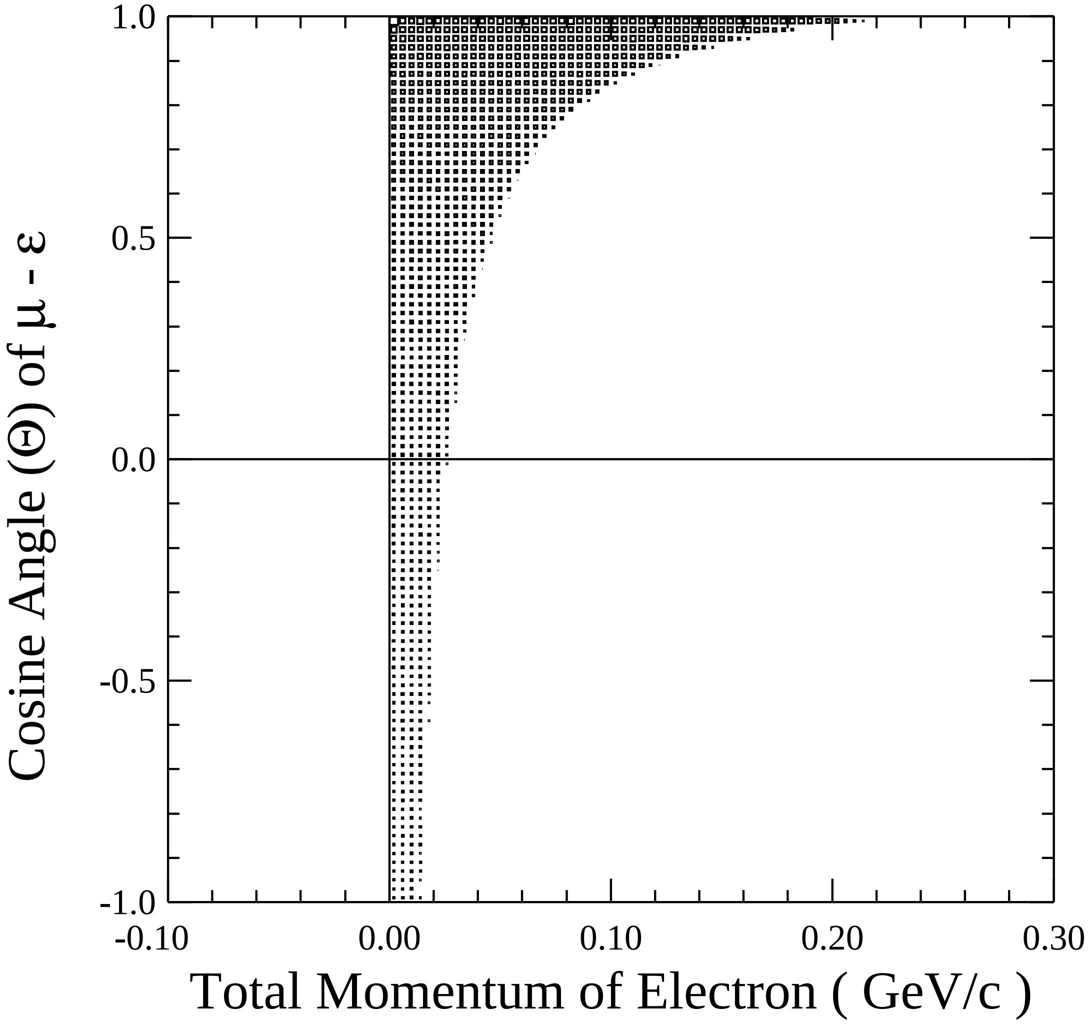

Figure 5: Total momentum of the electron versus its cosine angle distribution with respect to the beam direction.

All the classes have been coded into the CVS MICE repository. We also tested the code in order to integrated them with the other subdetector system. The code has a flexibility on using some of the aerogel mixture that consist of 62.5% of quartz and 37.5% of water with corresponding to its index of refraction as well as its density. A detail description of the MICE Cherenkov detector and the algorithms used for track reconstruction and particle identification is provided elsewhere [9]. Parameters of the aerogel are given in Table 2.

TYPE	$\rho\ (g/cm^3)$	n
Aerogel101	0.04	1.01
Aerogel102	0.08	1.02
Aerogel103	0.12	1.03
Aerogel104	0.16	1.04
Aerogel105	0.20	1.05

Table 2: The aerogel parameters coded into CVS MICE repository.

5 Advanced Model of the Rear Analysis Solenoid

In order to advance our study we have modeled the rear analysis solenoid with a length of 1.8 meters and central field value of B_0=4 Tesla. We have implemented a full field calculation to help us understand the particle trajectories and pattern recognition problems involving muons and decayed electrons in the rear Cherenkov detector. Muons are injected into the solenoid entrance with a σ_R=10 cm and σ_θ=0.15 spread as a starting point. A longitudinal momentum of P_l=230 MeV/c and spread σ_{P_t}=30 MeV/c was used. See Fig. 6.

6 Particle Tracking Simulation

In our simulation four tracking stations are located in the final solenoid at z=0.15 m, 0.65 m, 1.15 m, and 1.65 m. At each tracker location we record the x and y space point. For muon without decays these hits form a tight spiral of order a few cm [P_t=0.3 q B(T) R(m)]. Electrons from decay will exhibit a pulled hit and may be easily vetoed by the tracker in most cases.

Decays near the rear of the solenoid or present the greatest danger of misidentification. In the figure show forced muon decay at z=1.5 m, just before the rear station. In some cases the hit on the final tracker plane will lie within the chi-square of fit limit and escape the particle id system undetected, possibly signaling an emittance increase. Fig. 7 shows the x and y projection of tracker hits for muon track. Note the small cluster size. and Fig. 8 shows the x and y projection of tracker hits for electrons

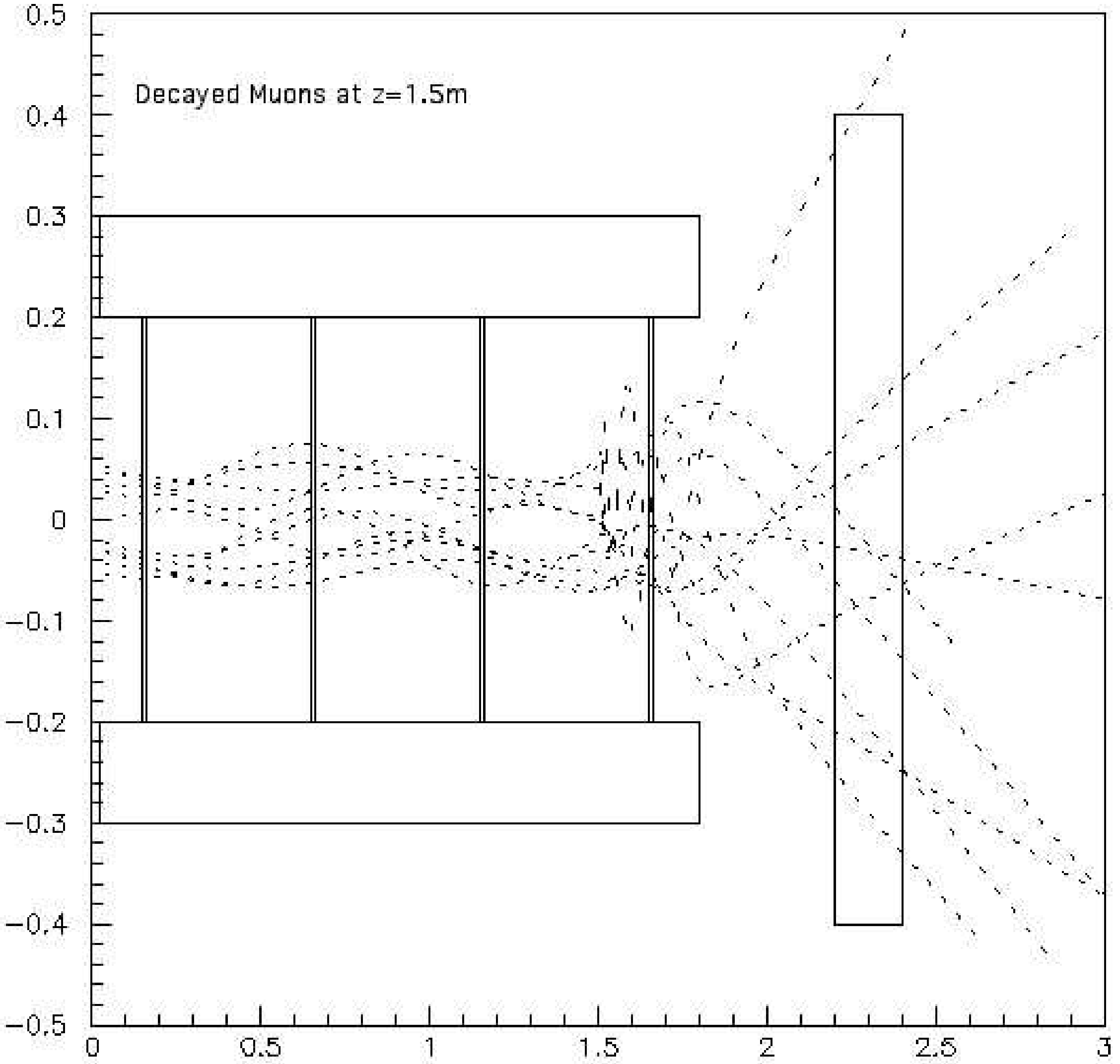

Figure 6: Model of rear solenoid and aerogel counter. Muons are shown decaying at z=1.5 m near the last tracker plane.

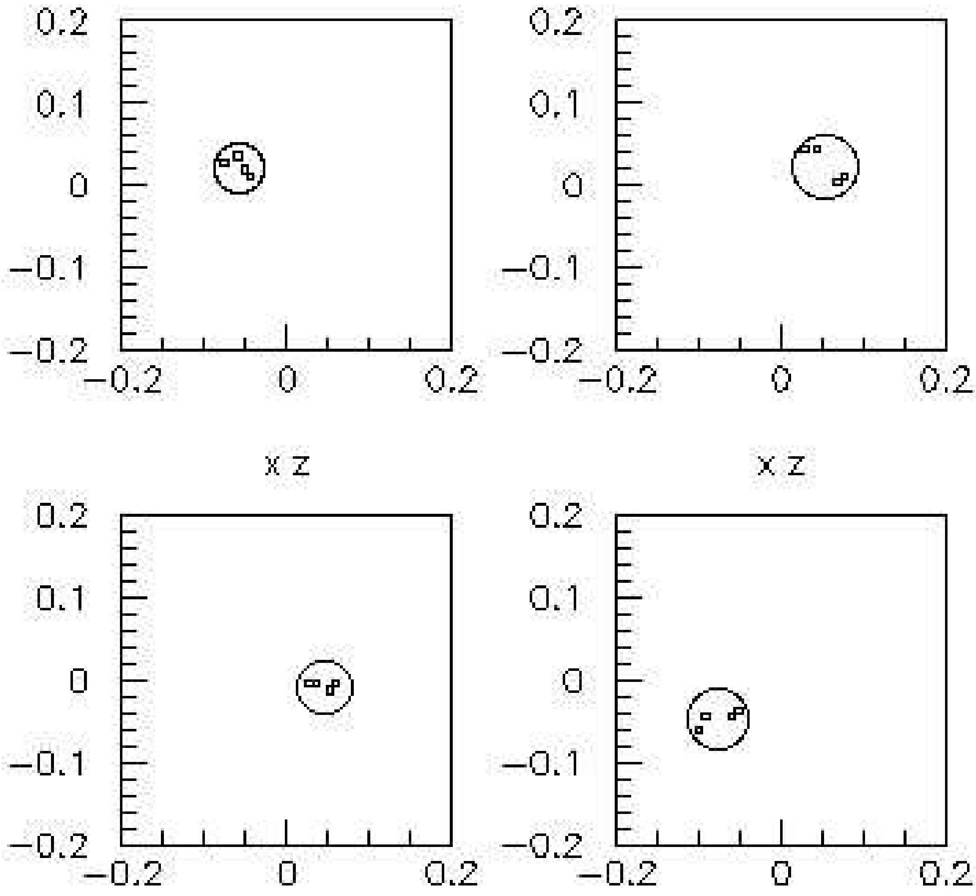

Figure 7: X-Y projection of tracker hits for muon tracks. Circles indicate tight reconstruction patterns.

from decay near the final tracking plane. The cluster pattern is pulled by the decay electrons in some cases but not all.

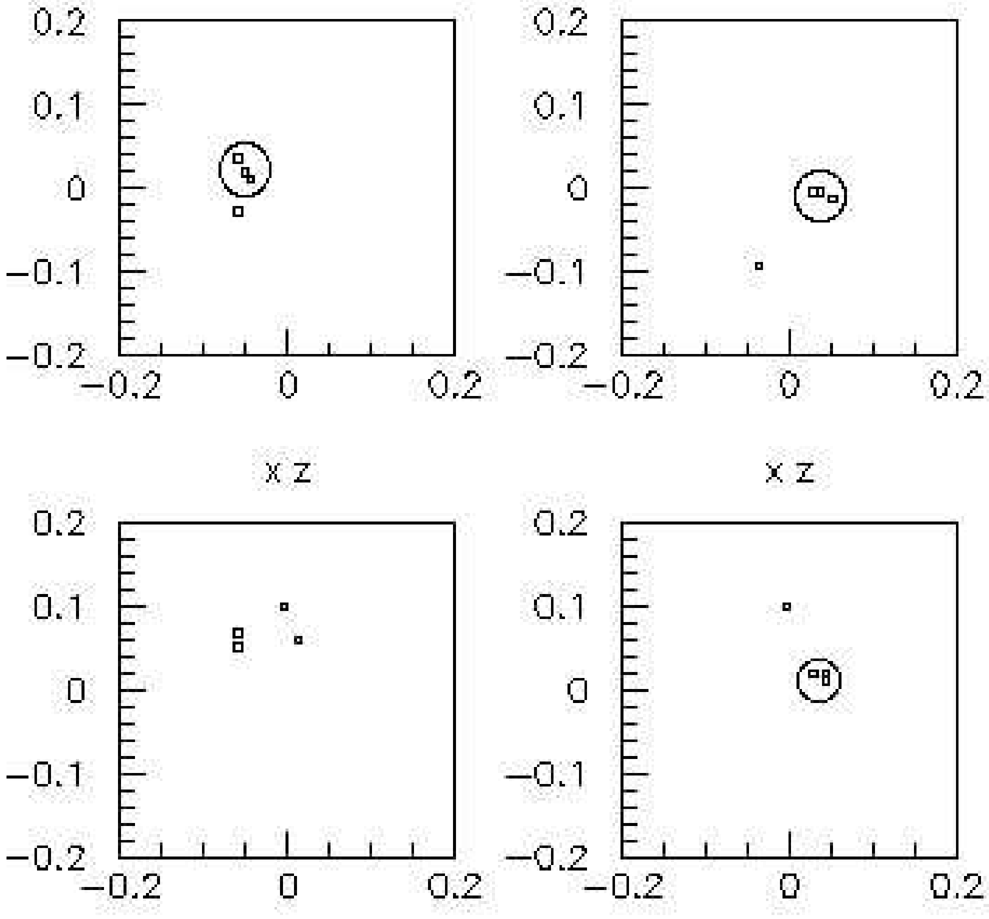

Figure 8: X-Y projection of tracker hits for electron tracks. In two of four cases well separated electron hit is recorded.

It may be advantageous to swim tracks from the final tracker station to the particle id entrance making a light yield prediction. Pixelation of the particle id system will give some advantage. The optimum level of pixelation is under study.

7 Response of 7 x 7 Aerogel Array

Response of the 7 x 7 aerogel array to electrons and muons has also been simulated. Aerogel of index n=1.05 with block lengths of 10 cm were used. Cherenkov wavelength spectrum, PMT quantum efficiency, and a 50% light collection efficiency are folded into the photoelectron count. A muon momentum distribution of average 230 MeV/c was used. The electrons and the muons are well separated in this case. (Fig. 9).

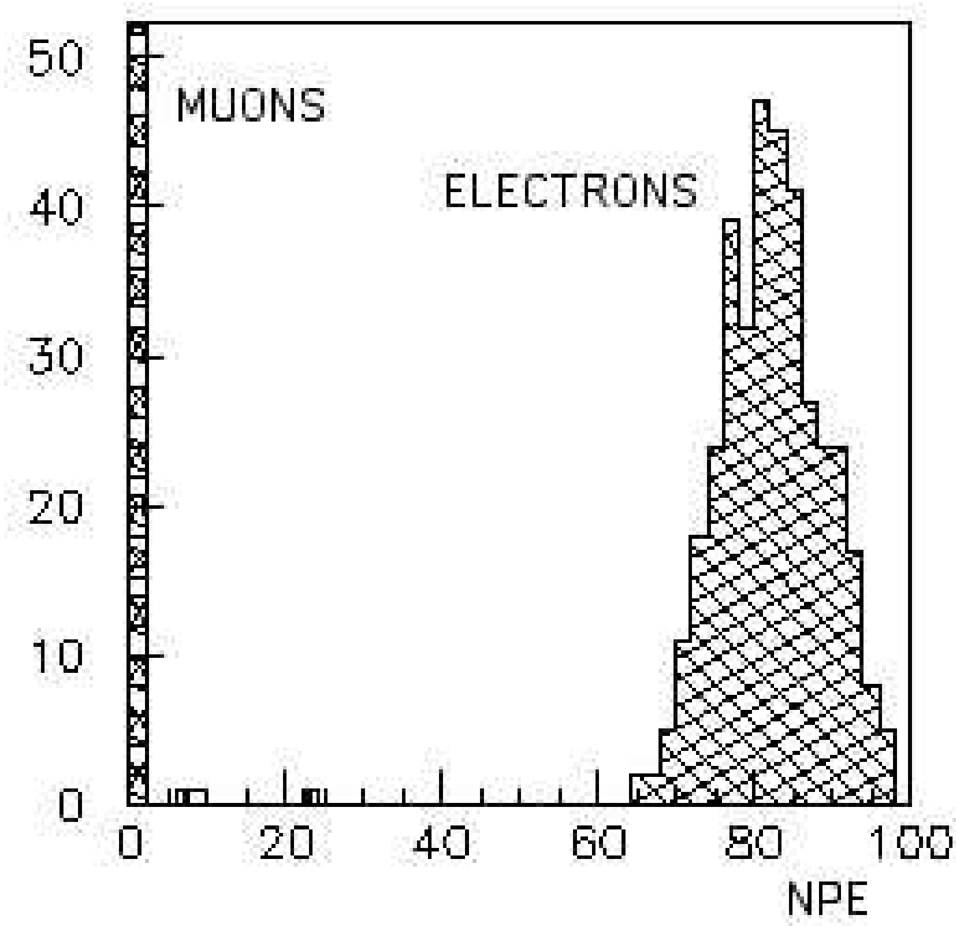

Figure 9: Photoelectron response of electron and muon tracks.

8 Acknowledgments

This work was supported in part by the U.S. Department of Energy contract DE-FG05-91ER40622.

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