SSC Detector Muon Sub-System Beam Tests

R. Downing, S. Errede, A. Gauthier, M. Haney,
I. Karliner, T. Liss, T. O'Halloran, P. Sheldon, V. Simiatis, J. Thaler, J. Wiss
Physics Department, University of Illinois, Urbana, IL 61801

D. Green, P. Martin, J. Morfin
Fermi National Accelerator Laboratory, Batavia, IL 60510

S. Kunori, A. Skuja
Department of Physics & Astronomy, University of Maryland, College Park, MD 20742

T. Okusawa, T. Takahashi, Y. Teramoto, T. Yoshida
Physics Department, Osaka City University, Sumiyoshi-ku, Osaka 558 Japan

Y. Asano
Institute of Physics, University of Tsukuba, Sakura-mura, Niihari-gun, Ibaraki-ken 305 Japan

T. Mann
Tufts University

R. Davisson, G. Liang, H. Lubatti, R. Wilkes, T. Zhao
Physics Department, University of Washington, Seattle, WA 98195

D. Carlsmith
Physics Department, University of Wisconsin, Madison WI 53706

CONTACT PERSON: H. Lubatti
Bitnet HENRY@UWAPHAST
Phone (206) 543-8964
FAX (206) 685-0635

We propose to start a test-beam experiment at Fermilab studying the problems associated with tracking extremely high energy muons through absorbers. We anticipate that in this energy range the observation of the muons will be complicated by associated electromagnetic radiation Monte Carlo simulations of this background need to be tuned by direct observations. These beam tests are essential to determine important design parameters of a SSC muon detector, such as the choice of the tracking geometry, hardware triggering schemes, the number of measuring stations, the amount of iron between measuring stations, etc.

We intend to begin the first phase of this program in November of 1990 utilizing the Tevatron muon beam. We plan to measure the multiplicity, direction, and separation of secondary particles (mainly electrons) associated with the primary muon track as it emerges from an absorber. The second phase of beam test in 1992 or later (depending upon the Fermilab schedule) will be a full scale test for the final design chosen in our muon subsystem proposal.

1 Muon Measurement Simulations

High energy muons exiting steel toroid magnets are often accompanied by delta rays and electromagnetic shower remnants.[1] The fraction of clean muons decreases with energy as the processes of muon bremstrallung and direct pair production become more important (Fig. 1). Confidence in the Monte Carlo predictions of the spectra of these particles and of the multiparticle capabilities of the muon chambers is crucial to the design of the muon system.

The problem we are addressing is well illustrated by Figure 2 which shows a GEANT simulation of 100 GeV muons exiting an iron magnet and entering a set of argon-ethane chambers having aluminum walls. At the energies typical of SSC muons the problem of associated electrons cannot be ignored. We must be prepared to identify and characterize the muons in the presence of such electrons. The muons are seen to proceed along straight paths regardless of the intervening aluminum chamber walls. Because of absorption and scattering in the walls, the electrons on one side of a wall appear almost unrelated to those on the other side. As shown in Figure 3, background particles exiting the steel absorber typically consist of low multiplicity penetrating knockons and pairs of several MeV in energy with a broad angular distribution, accompanied by a fair number of X-rays and gamma rays. The electrons originate largely in the last few millimeters of the steel while the photons arrive from larger depths. Typically three quarters of the events containing background have only one or two excess charged particles. A chamber system able to distinguish several wide angle tracks from the muon track may effectively recover a large fraction of contaminated measurements, significantly reducing the number of required decoupled measurements.

The observed background track rate depends on the details of the chamber system. An energy deposition in the gas of only 1 KeV generates a hit, so careful attention must be paid to simulation thresholds in predicting these background rates. The spectrum and thickness dependance of the rate of knockons generated in an aluminum wall typical of extruded proportional tubes are shown in Figures 4 and 5. Electrons below about 100 KeV do not make it out of the wall. In the gas itself (Fig. 6), there is about a 1% probability per cm of a knockon with range exceeding 1 mm. The Compton and photoelectric effect play an insignificant role in depositing energy in the gas of a typical chamber. The chamber system is largely transparent to the large soft photon component of the EM shower. Thus, the threshold may be typically as high as 500 KeV in the absorber, decreasing to 100 KeV in the wall and to 10 KeV in the gas itself.

To design an optimized detector for this regime requires a good Monte Carlo representation of the low-energy electron components associated with high energy muons. This is a region of little intrinsic interest generally disposed of by imposing a low-energy cut-off on both both electrons and photons. Precisely because this region is commonly ignored it is important for us to confirm the detailed MC predictions by direct observations.

2 The Tevatron Muon Beam

The E665 Tevatron muon beam is normally tuned to a mean momentum of approximately $\overline{p}_\mu = 500\text{GeV/c}$. A measured muon momentum distribution is shown in Figure 7. The mean beam momentum can be tuned from 100 GeV/c to 700 GeV/c, which is the most interesting range for a SSC muon detector. Some of the parameters of the Tevatron muon beam used by E665 in 1987 are summarized in Tables 1 and 2.

Table 1. Tevatron Muon Beam (Typical)

typical $\overline{p}_\mu$	500 GeV/c
momentum spread (FWHM)	120 GeV/c
typical muon rate at 10^{12} proton/spill	0.5 MHz

Table 2. Beam Divergence

	horizontally	vertically
rms angular spread at $BT4^*$	0.8 mr	0.5 mr
rms spread at BT4	2 cm	1 cm
rms spread at end of E665	3 cm	2 cm

$^*BT4$ is the last beam tagging station at the entrance of the muon lab.

Although it is unnecessary to know the momentum of the muons on a particle by particle basis for this test, we plan to constrain the incoming muon trajectory through the E665 beam spectrometer system by using the beam hodoscope information from E665. The mean beam momentum will be known quite accurately after correcting the average energy loss of muons in the E665 spectrometer (3 meters of iron and 3 meters of concrete). We would set up our apparatus downstream of the E665 absorber where there is approximately 20 meters of lab space available. We can debug the system using halo muons while E665 is running.

3 Detector

Our detector system consists of scintillating trigger counters, 4 stations of small drift chambers and absorber. Lead and iron of different thickness will be tested. A possible arrangement of the detector is shown in Figure 8. It will be located downstream of the Fermilab E665 experiment but upstream of the muon beam dump magnets. We request that Fermilab install concrete blocks both inside and outside the downstream radiation fence of the Muon Lab to allow us to place the detector at beam height. In addition, we request that Fermilab move the beam dump magnets 10m downstream of their present location.

3.1 Tracking

Multihit capability and extremely good two track resolution are key factors since we want to measure closely spaced tracks: the muon exiting from the absorber and other charged particles which may accompany it. Such capability is also very desirable in a SSC muon detector in order to find true muon trajectories and reduce ambiguities.

We plan to use four stations of multisampling drift chambers (jet chambers) following the design used by E665 for the vertex drift chambers which they are currently installing. The Seattle group has been involved in the design and fabrication of the E665 vertex chambers and will modify the existing design and fabricate the five (one spare) chambers needed for these tests. The chamber parameters are given in Table 3.

Because of the small size of the muon beam, the active area of the tracking chambers need not be very large. We choose a cell width of 2.75 in. (1.375 in. drift distance), which is the same as the large cell width in the E665, VCZ vertex chambers and allows us to use existing designs. We will have three cells in each chamber module with 6 sense wires in each cell. The total number of readout channels will be 18 for each module. The active area of the chamber will be 11 in. x 8.25 in. The chambers will have Al/Kapton windows so that we can introduce various thicknesses of Al and other material to study the effect on the EM debris.

Of the four tracking stations shown in Figure 8. D1,2,4 define the muon trajectory and D3 measures the EM debris and our ability to sort out the muon track. Based on E665 vertex chamber performance we expect to achieve single wire resolution of 200 μm and double track resolution of <2 mm.

Table 3. Chamber Parameters

Number of sense wires per cell	6
Sense wire staggering	0.250 mm
Wire length	11"
Maximum drift distance	1.375"
Cell width	2.75"
Number of cells per module	3
Number of sense wires per module	18
Sense wire diameter	0.025 mm
Sense wire high voltage	1.0 kV
Sense wire tension	30-50 g
Cathode wire diameter	0.16 mm
Cathode wire high voltage	4.1 kV
Cathode wire tension	200 g
Chamber gas: Argon/Ethane	50/50

Table 4. ASIC Preamplifier Parameters

Number of channels per chip	4
Number of channels per board	16
Gain	1.5 V/pC
Bandwidth	30 MHz

Table 5. Hybrid Shaping Amplifiers

Number of channels per mother board	48
Signals return to base line:	25 ns

3.2 Electronics and Data Aquisition

We plan to use the E665 vertex drift chamber front end electronics. This system uses specially designed high gain/low noise ASIC preamplifier chips mounted on the chamber frame. Signals from the preamplifiers are sent to shaping amplifiers and discriminators and eventually readout by LeCroy fastbus TDC's.

The DaQ system for the SSC Muon Sub-System test beam studies in the E-665 muon beam at Fermilab will be provided by the experimenters.

The DaQ system for the SSC muon test stand will probably be located out on the floor of the new Muon Lab (outside the radiation fence) but as near to the test stand as possible, in order to minimize cable runs. Space will be needed for the relay racks and associated equipment, as well as table/work space/terminal area, file cabinets, book shelves, etc.

The trigger for the initial muon studies will be formed simply from a multiplicity coincidence of several scintillation counters in the muon beam and the absence of signals from beam halo veto counters. Data-taking will NOT be interrupt driven for simplicity, and will thus be relatively slow. Once a trigger is generated, a common stop/inhibit will be generated for the FASTBUS TDC's, ADC's, Scalers, etc. The data will then be read out and packed into a specified event record format, most likely being written initially to a file on disk (and then copied to 8mm cassette tape after a run), or written directly to 8mm tape. Copies of the data taken in these muon studies will then be made locally using the 8mm dual cassette tape drive and distributed to all interested members of the collaboration for their own data analysis, along with code to read and unpack the events into a suitable format.

The DaQ system for the muon beam test stand will initially be debugged using cosmic ray muons and then with real beam. Once the DaQ system has stabilized and the beam-on operating environment in the Muon Lab is better understood, more sophisticated triggering schemes (e.g. using prompt hit information from the drift chambers) could be attempted for additional and more detailed studies, e.g. of the trigger efficiency for various hardware triggering schemes.

3.3 What Can We Study?

The prioritized goals of our 1990 test are:

1. Studying the number, energy and angular distribution of charged particles emerging from the absorbers along with muons and their dependence on muon energy, the type of material, material thickness, etc. This allows us to tune the Monte Carlo which we will use for designing the SSC muon system.

2. Studying the efficiency of muon track reconstruction and the smearing of the resolution due to secondary, accompanying charged particles for different types of tracking devices.

3. Testing prototype trigger schemes and their implementation. With this apparatus we can test both "bend angle" triggers which make a cut on the muon bend angle and "saggita triggers" which make a cut on the saggita of muons in a magnetic field. The latter requires a minimum of three measurements.

4. Test Čerenkov Triggers (lucite, gas, etc.)

References

[1] C. Zupanicic, 'Physics and Statistical Foundations of TeV Muon Spectroscopy', CERN-EP/85-144;
W. Lohmann et al., CERN-EP/85-03;
'Report of the Task Force on Detector R&D for the SSC', SSC-SR-1021;
A. Van Ginneken, Fermilab-Pub-86/33;
'SSC Muon Detector Group Report', proceedings of the 1986 Snowmass Summer Study;
'Muon Energy Loss at High Energy and Implications for Detector Design', J. Eastman and S. Loken, Proceedings of the 1987 Berkeley Workshop.

List of Figures

5. Probability that a 100 GeV muon knocks out an electron exceeding 1 KeV in kinetic energy from an aluminum wall as a function of wall thickness.
6. Integral probability for the production of knockons exceeding an energy threshold by muons in traversing 1 cm of Argon-Ethane gas.
7. Measured momentum distribution of E665 muon beam.
8. Arrangement of the detector.
   - **a)** Possible arrangement of our detector downstream of E665 absorber.
   - **b)** Enlarged view of set-up.

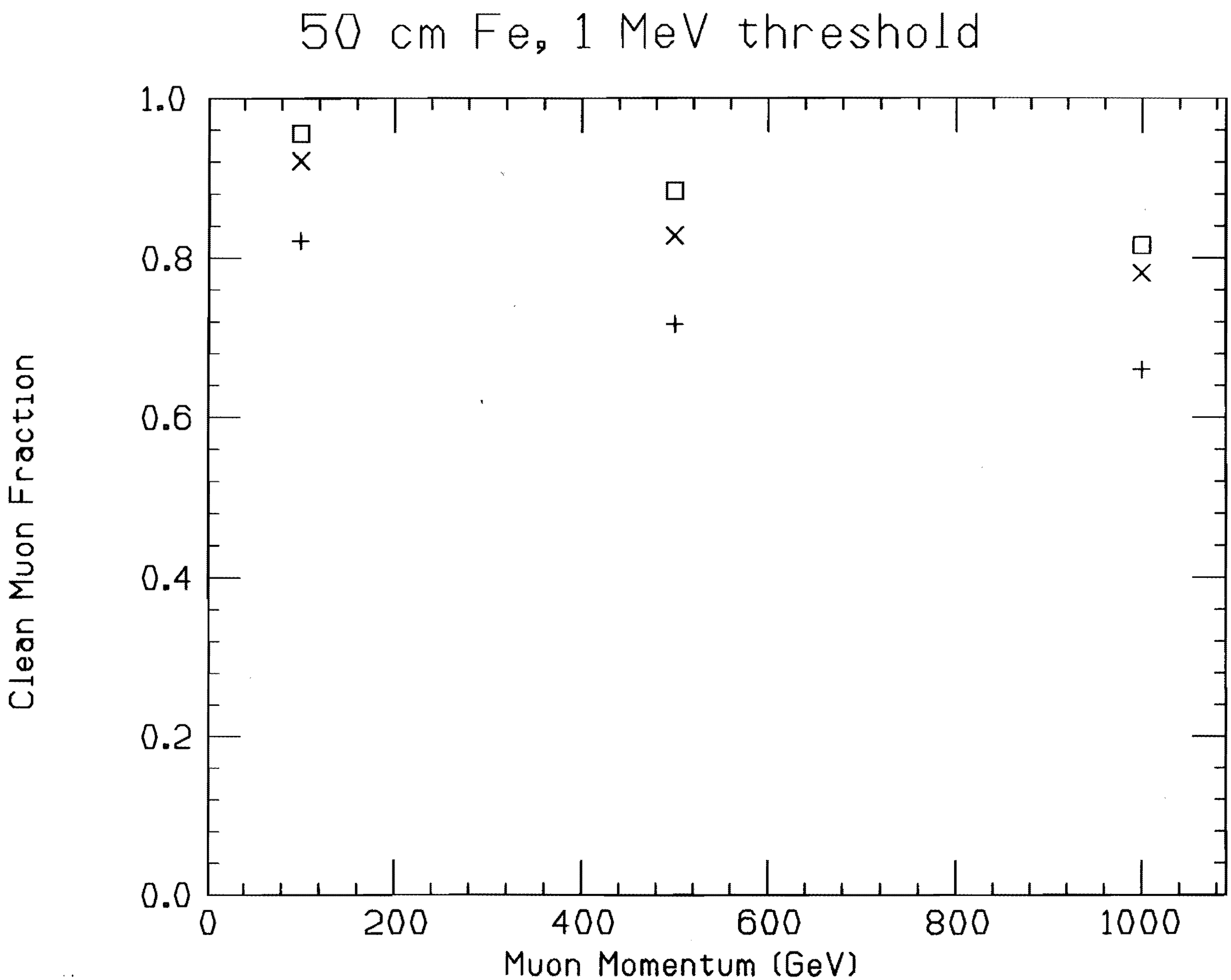
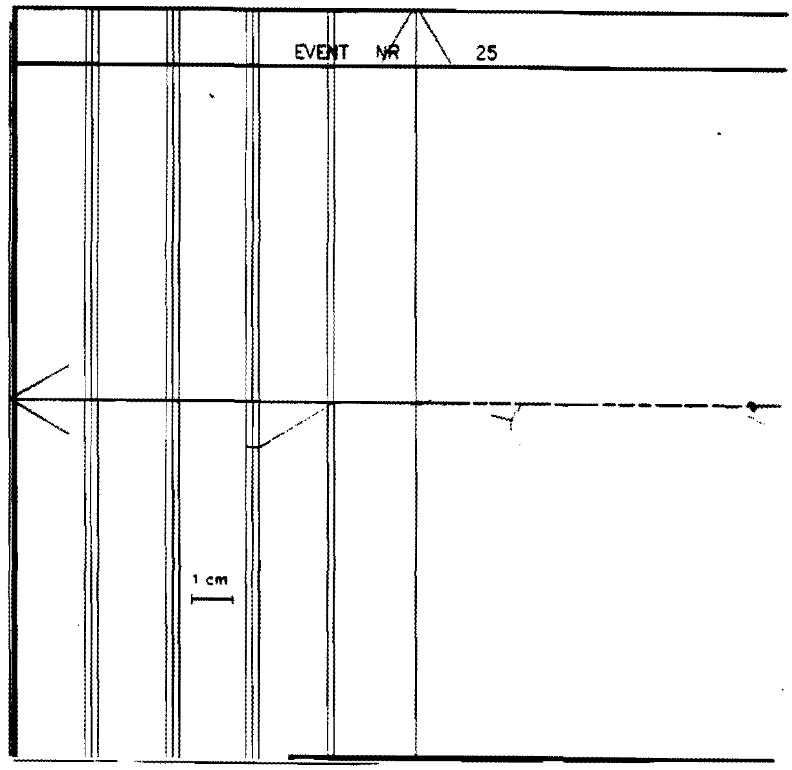

50 cm Fe, 1 MeV threshold
Clean Muon Fraction
Muon Momentum (GeV)
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000

Figure 1



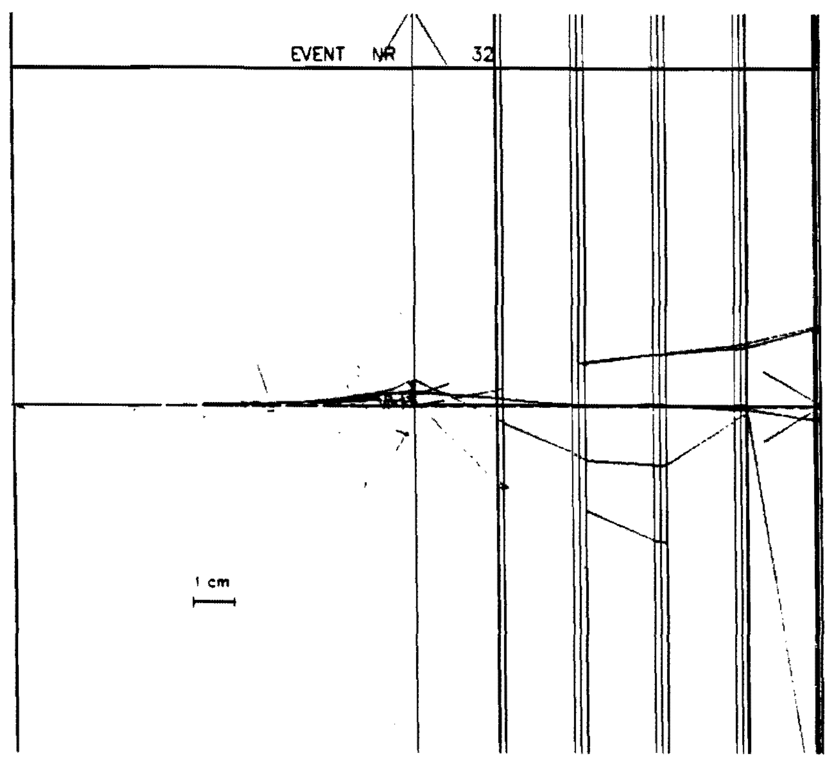
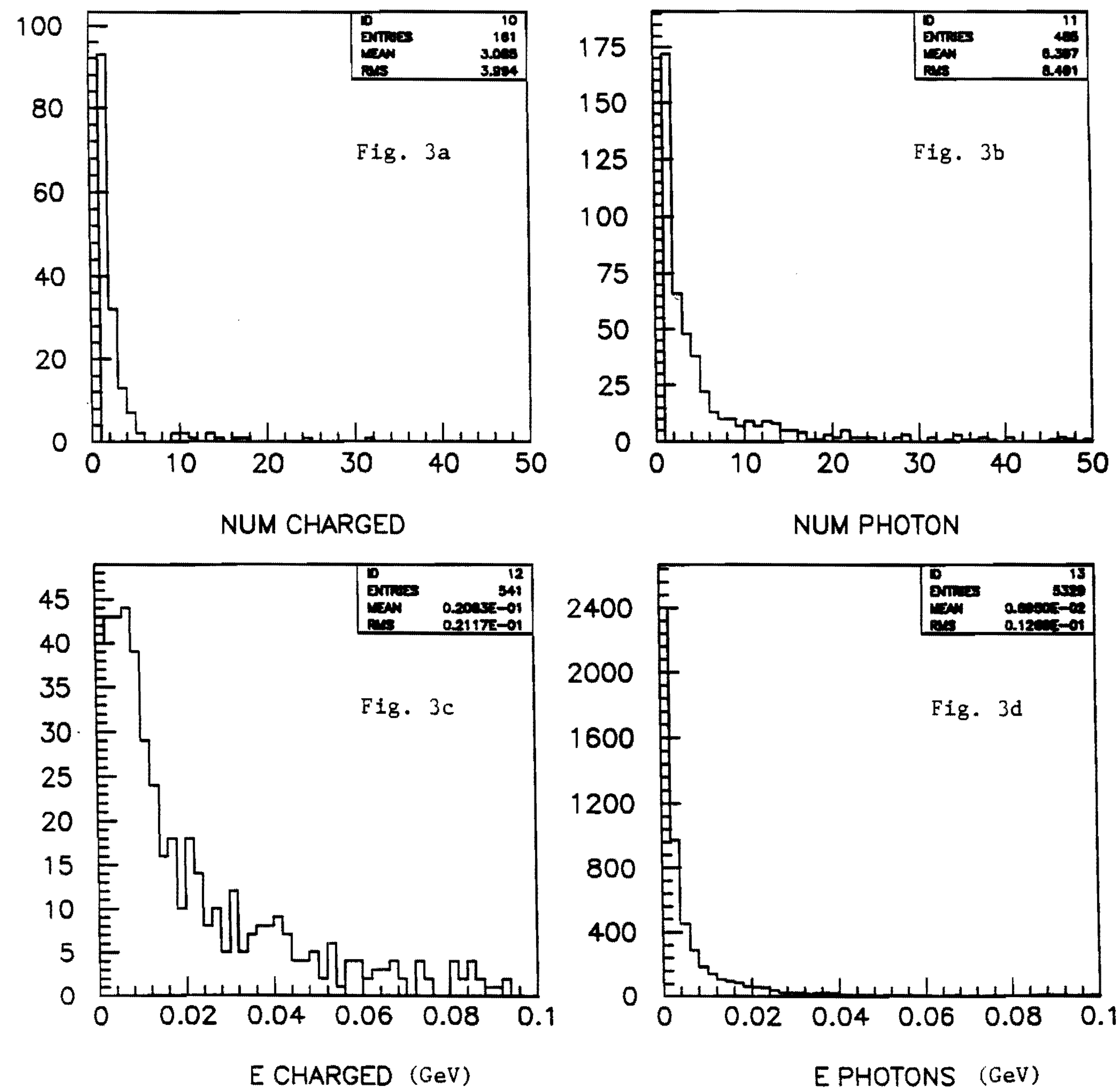
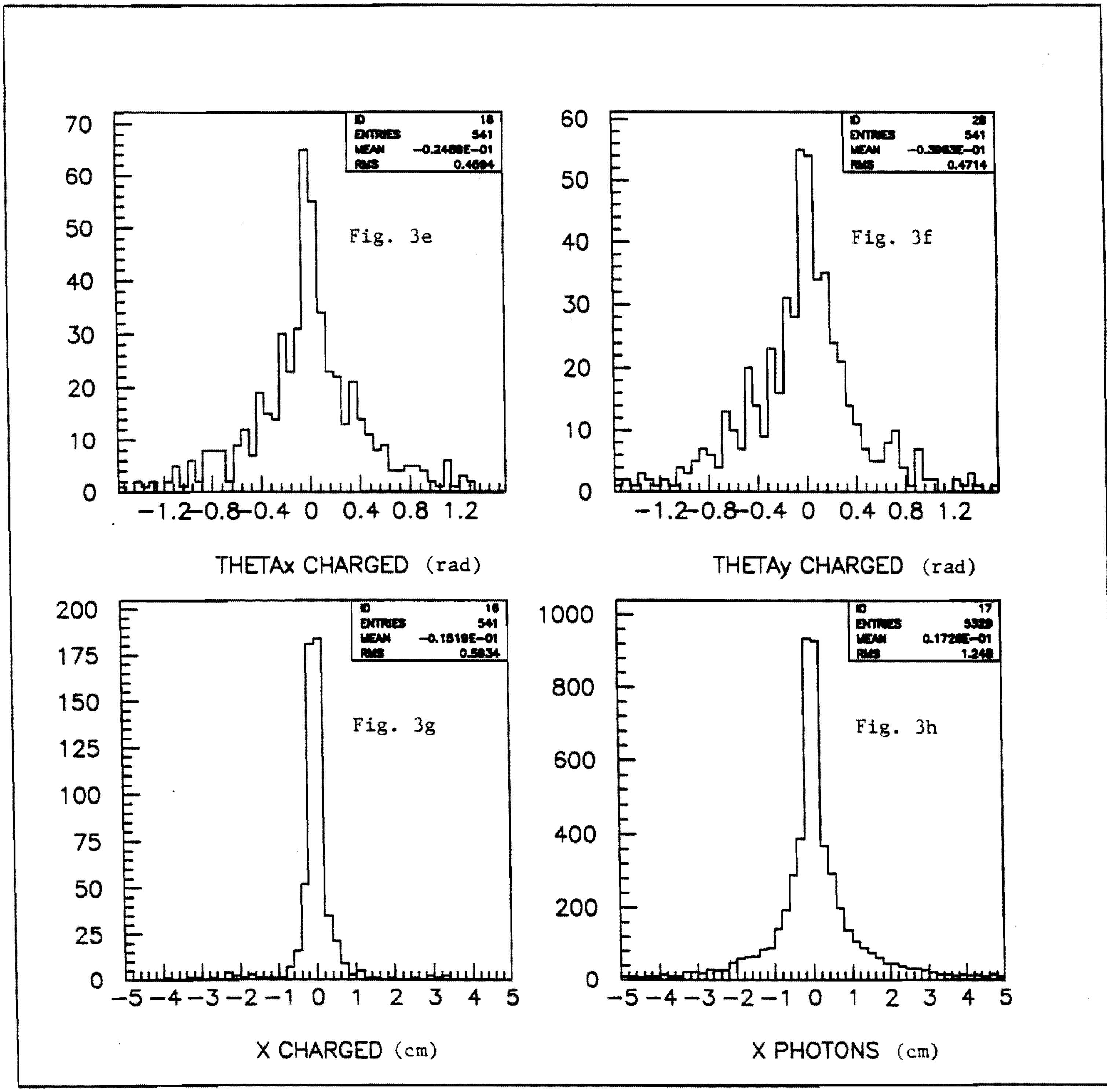
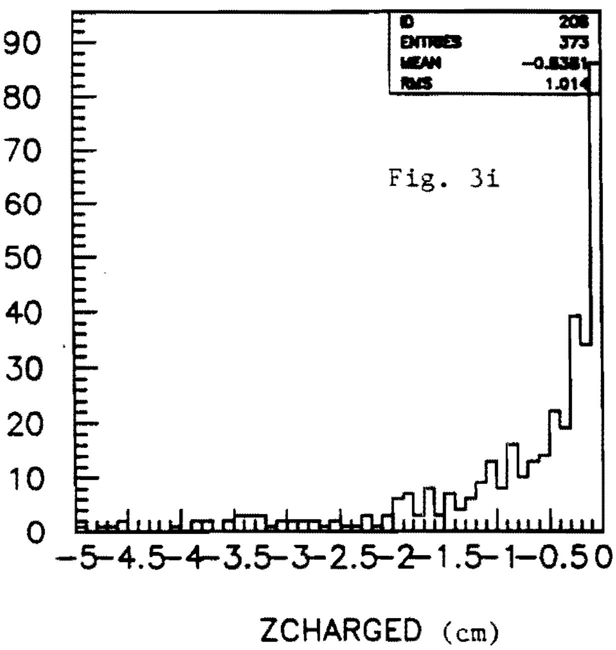
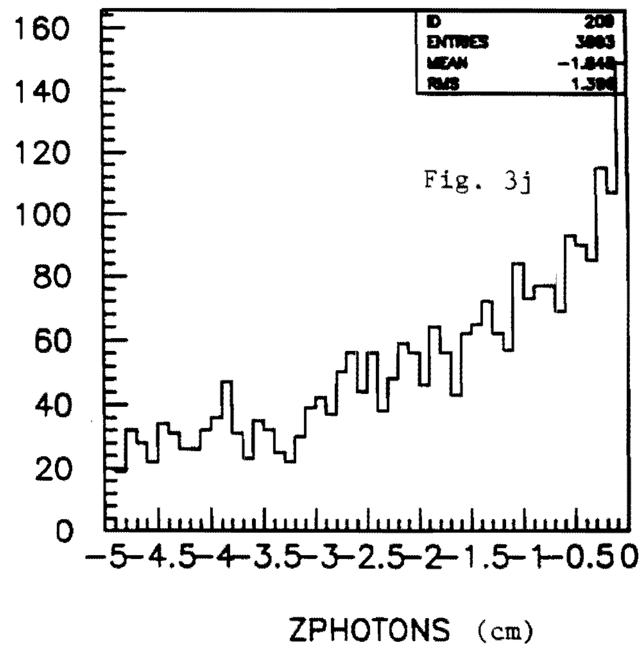


Figure 2


ID 10
ENTRIES 161
MEAN
RMS
Fig. 3a
NUM CHARGED
ID 11
ENTRIES
MEAN
RMS
Fig. 3b
NUM PHOTON
ID 12
ENTRIES 541
MEAN
RMS 0.2117E-01
Fig. 3c
E CHARGED (GeV)
ID 13
ENTRIES
MEAN
RMS
Fig. 3d
E PHOTONS (GeV)


ID 18
ENTRIES 541
MEAN −0.2488E−01
RMS 0.4694
Fig. 3e
THETAx CHARGED (rad)
ID 28
ENTRIES 541
RMS 0.4714
Fig. 3f
THETAy CHARGED (rad)
ID 16
ENTRIES 541
MEAN −0.1519E−01
Fig. 3g
X CHARGED (cm)
ID 17
MEAN 0.1728E−01
Fig. 3h
X PHOTONS (cm)


ID
ENTRIES
373
MEAN
RMS
Fig. 3i
90
80
70
60
50
40
30
20
10
0
−5−4.5−4−3.5−3−2.5−2−1.5−1−0.5 0
ZCHARGED (cm)


ID
ENTRIES
MEAN
RMS
Fig. 3j
160
140
120
100
80
60
40
20
0
−5−4.5−4−3.5−3−2.5−2−1.5−1−0.5 0
ZPHOTONS (cm)

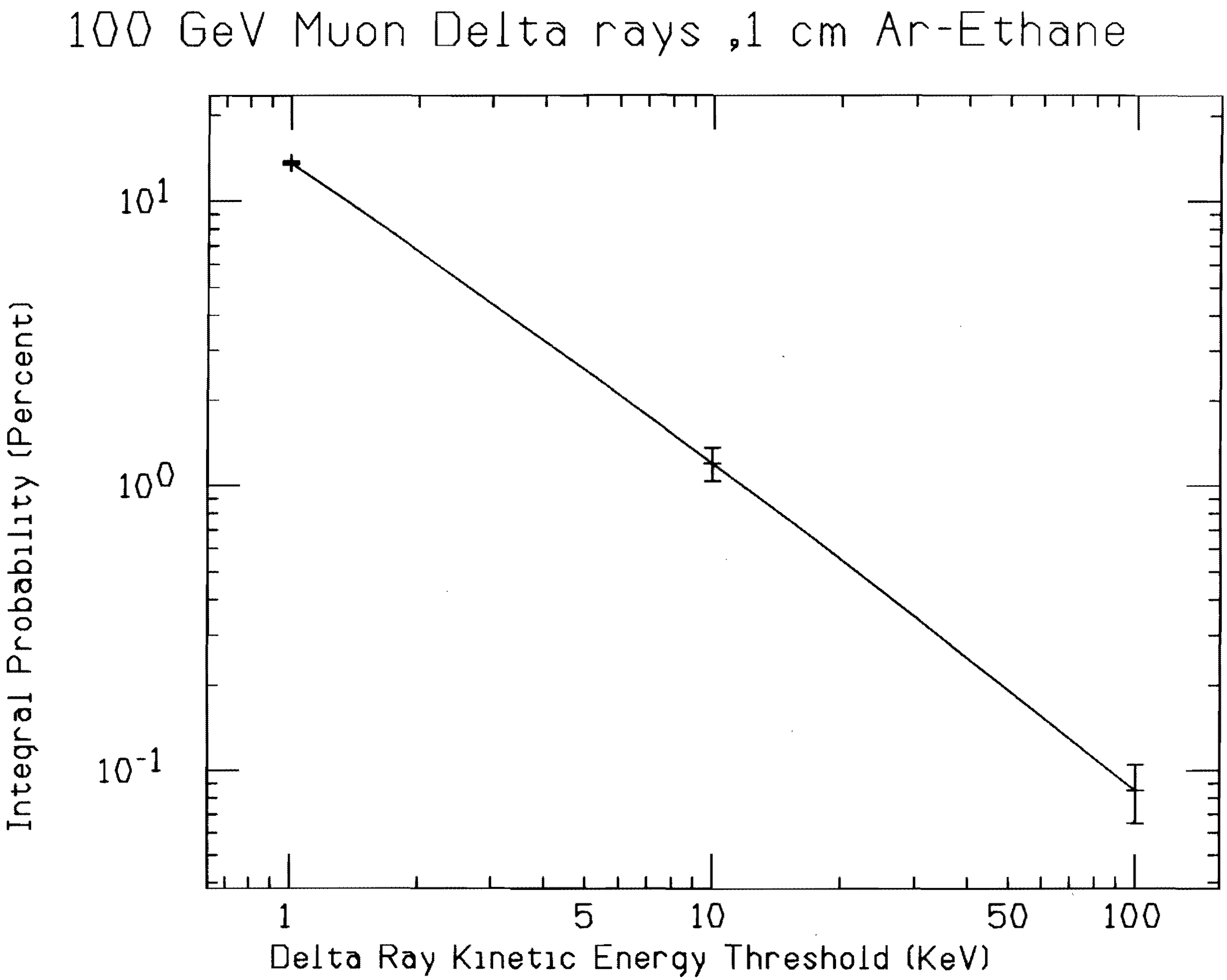

100 GeV Muon Delta rays ,1 cm Ar-Ethane
Integral Probability (Percent)
10^1
10^0
10^-1
1
5
10
50
100
Delta Ray Kinetic Energy Threshold (KeV)

Figure 4

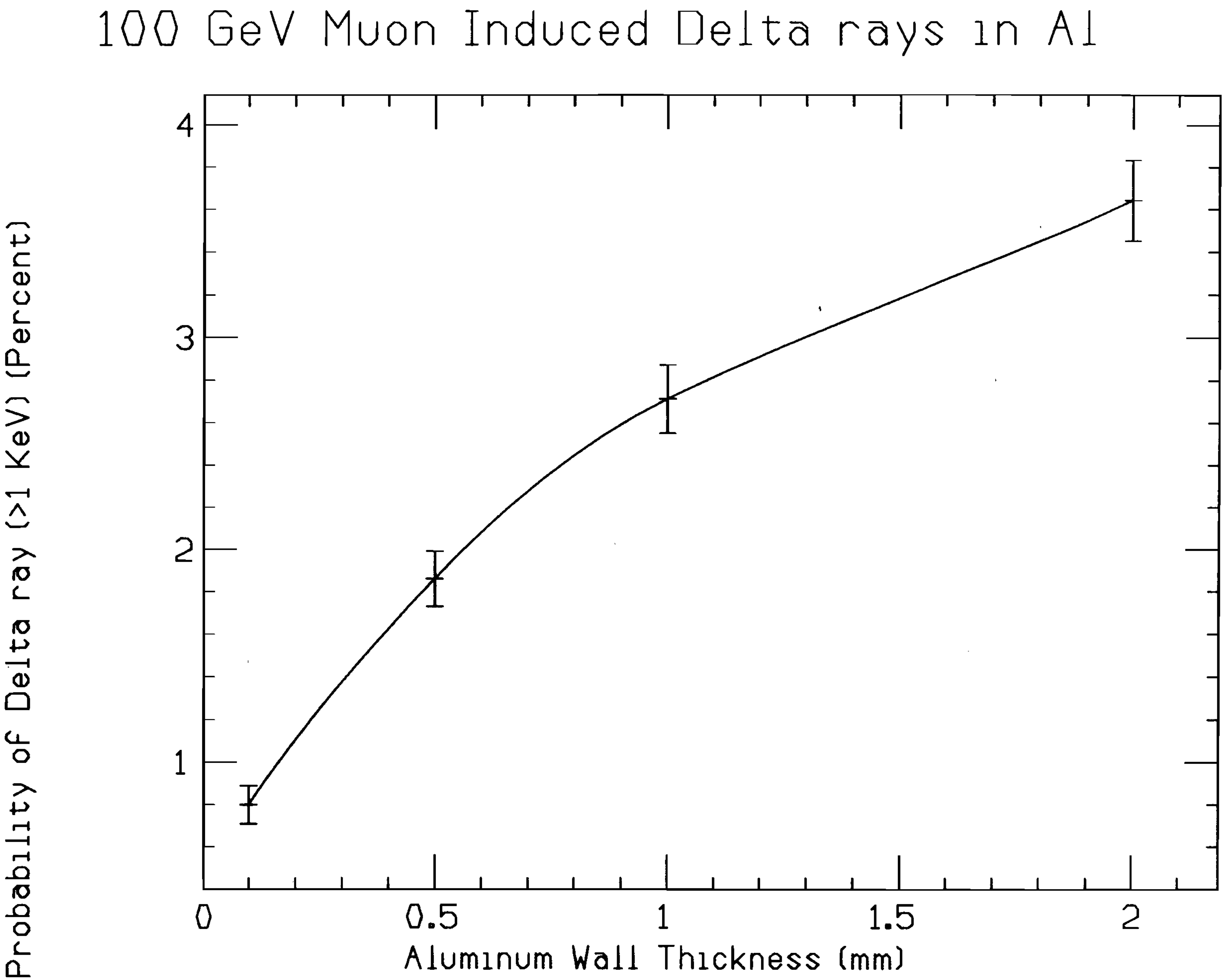

100 GeV Muon Induced Delta rays in Al
Probability of Delta ray (>1 KeV) (Percent)
Aluminum Wall Thickness (mm)
0
0.5
1
1.5
2
1
2
3
4

Figure 5

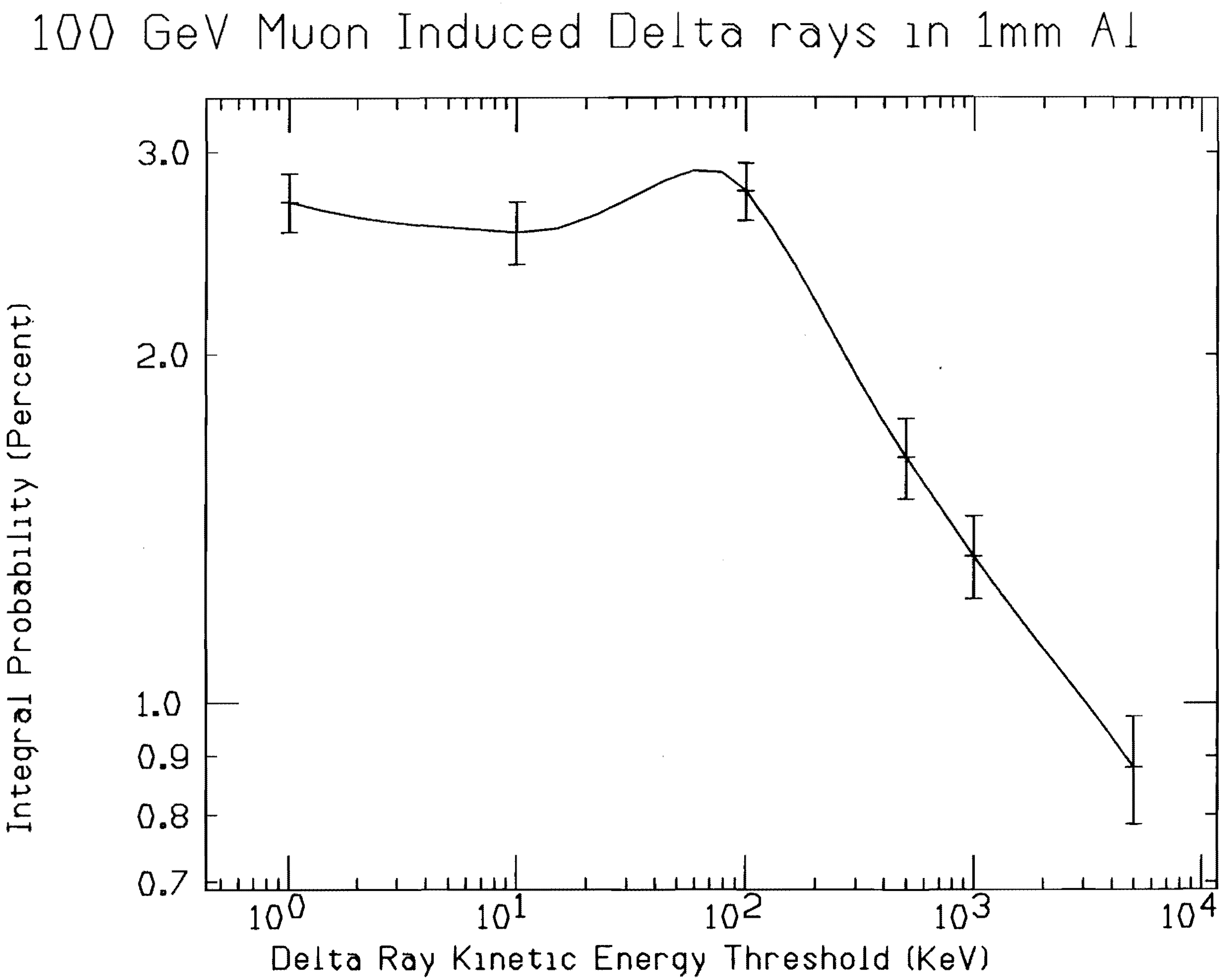
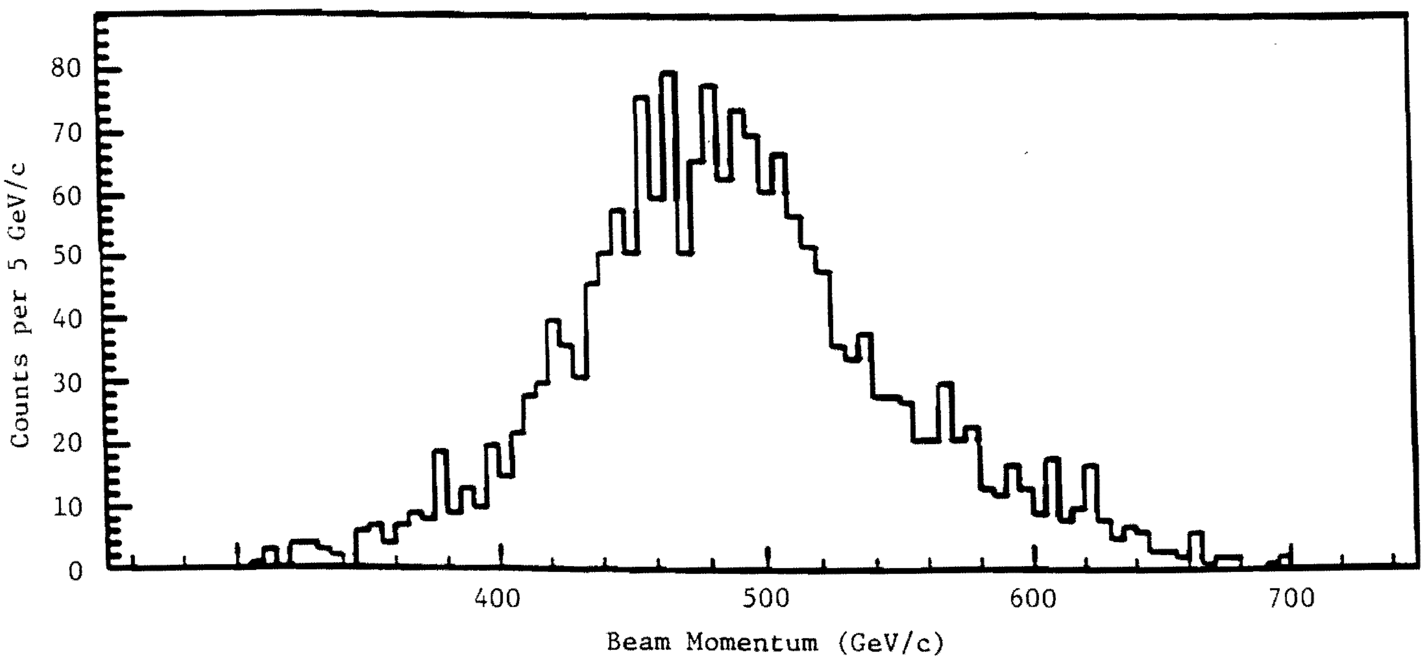
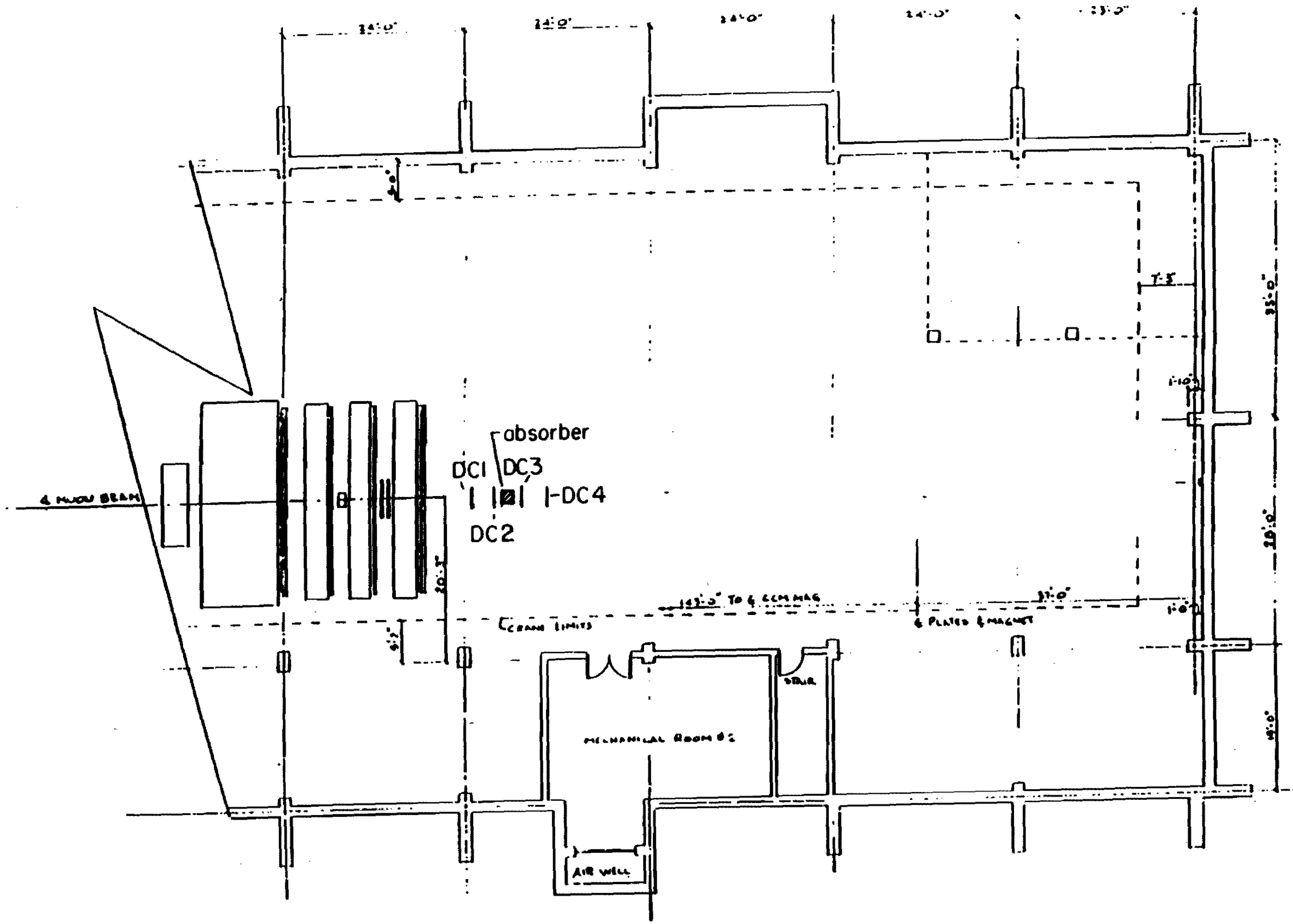

100 GeV Muon Induced Delta rays in 1mm Al
Integral Probability (Percent)
3.0
2.0
1.0
0.9
0.8
0.7
10^0
10^1
10^2
10^3
10^4
Delta Ray Kinetic Energy Threshold (KeV)

Figure 6



80
70
60
50
40
30
20
10
0
Counts per 5 GeV/c
400
500
600
700
Beam Momentum (GeV/c)

Figure 7



MUON LABORATORY
PLAN VIEW

Figure 8a

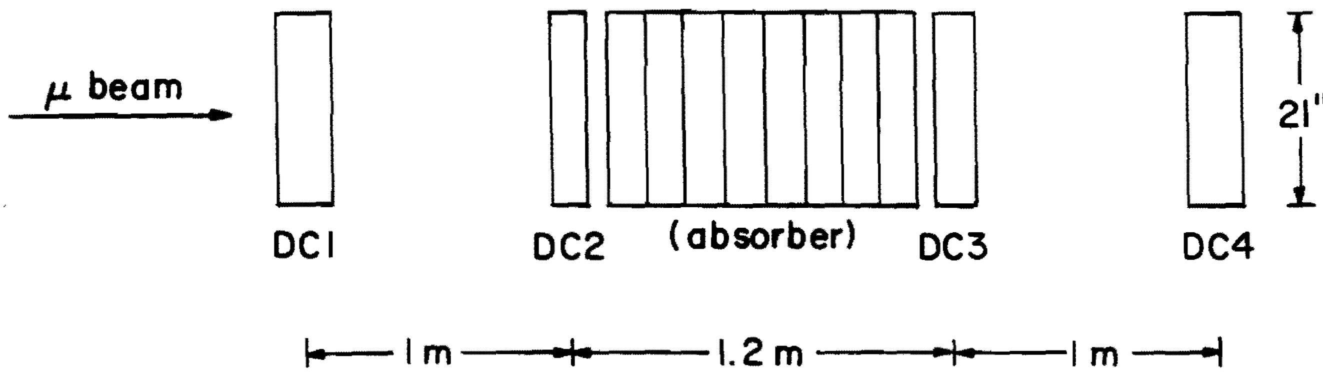


Figure 8b