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SDC
SOLENOIDAL DETECTOR NOTES

RADIATION DOSE PROFILES AND ACTIVATION OF THE SDC ENDCAP CALORIMETER

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Abstract: We have used data from the Hanging File Calorimeter to estimate the radiation dose in the SDC endcap Calorimeter as a function of depth and radius. The expected dose at electromagnetic shower maximum is four times the dose at hadronic shower maximum, in good agreement with Monte Carlo Calculations [1]. Assuming a lifetime for the entire experiment of 10 years at 10^{34} cm^{-2} sec^{-1}, the scintillation plastic in the endcap hadron calorimeter above $\eta = 2.2$, 2.4 or 2.6 will require replacement for maximum life time doses of 1, 2 or 3 Mrad, respectively. Activation of the absorber plates at the face of the hadron calorimeter at $\eta = 3$ is estimated to be approximately 200 mrem/hr on contact assuming 30 days of running at $10^{34}cm^{-2}sec^{-1}$ followed by a one day cool down. Longer running periods will increase the activation by factors of 2 to 3 depending on the exact exposure history [2].

Introduction: The radiation dose at electromagnetic and hadronic shower maximum has been estimated in SSC report 1033 (revised)[3] and reference [1]. It has long been realized that the scintillator in the endcap electromagnetic calorimeter will require replacement during the expected 10 to 20 year useful life time of the SDC experiment. It is also anticipated that the plastic in the endcap hadron calorimeter close to the beam line will be radiation damaged. It has been proposed that the annular region of the endcap hadron calorimeter near the beam line be built as a single replaceable hadronic 'plug', as shown in Figure 1. The boundary between the endcap and endplug hadronic calorimeters is intended to be drawn such that the scintillator in the *endcap* will never need to be replaced. We have used data from the Hanging File Calorimeter to compute the longitudinal profile for hadronic showers in order to estimate the radiation dose in the endcap hadron calorimeter as a function of radius and depth. Additionally we have used the results of reference [2] to estimate the activation of the absorber plates to provide guidance in the design, maintenance and eventual disposal of the calorimeter.

Analysis Strategy: At the SSC we expect minimum bias events to consist of approximately equal number of charged pions and photons, with the charged pions having on average twice the energy per particle as the photons from π_0 decay. Assuming an average charged pion transverse momentum of 0.6 GeV/c at the SSC, the momentum of π's in the endcap region approximately 5 GeV(depending on the angle) and 2.5 GeV for photons. The radiation damage to the electromagnetic calorimeter is largely caused by the flux of photons from π_0 decay and is straight forward to estimate. From Reference [1] the radiation dose at electromagnetic shower maximum after 10^7 sec of running at a luminosity of 10^{33} cm^{-2} sec^{-1} is given by:.

$$D = \frac{124. \cosh(\eta)^{2.93}}{r^2} \mu Sv \qquad (1)$$

Using this equation, and a measurement of the *relative* longitudinal dose caused by 2.5 GeV photons as compared to 5 GeV/c pions, we can estimate the dose to the calorimeter as a function of depth.

The relevant data set for this investigation would be 5 GeV/c pions and 2.5 GeV photons. However, the MTEST beam line provides only charged pions and electrons at a minimum momentum of 5 GeV/c, and no photons. Therefore, we will use the following technique to estimate the relative dose rates between the photon and pion components.

Step 1) We assume that the eventual dose per layer is proportional to the light output from the scintillators in the Hanging File Calorimeter.

Step 2) We measure the longitudinal shower profile per electron (or pion) in the Hanging File at 5 GeV/c momentum.

Step 3) We fit the electron profile with a simple functional form suggested in the Particle Data Book [4]:

$$\frac{dE}{dt} = \frac{A\, E_0\, b\, (bt)^{a-1} e^{-bt}}{\Gamma(a)} \qquad (2)$$

where

$$(a-1)/b = \ln (E_0/E_c) + C_i \qquad (3)$$

E_0 is the electron energy, E_c is the critical energy for Pb, t the depth in the calorimeter in radiation lengths, A is a constant relating dE/dt to ADC counts, b is a parameter equal to 0.47 for 5 GeV electrons showers in Pb. C_i is +0.5 for electron showers and -0.5 for photon induced showers.

Step 4) Using the PDG formulation, we estimate the spectrum of 2.5 GeV photon showers by changing E_0 and C_i in the formula above.

Step 5) We normalize the 2.5 GeV shower profile to '1 ' at EM shower maximum and add it to the similarly normalized pion shower profile to obtain a 'normalized' longitudinal shower profile

Step 6) Using equation (1) and the normalized shower profile from step 5) we map the radiation dose over the endcap calorimeters to obtain the dose distribution as a function of radius and depth in the calorimeter.

The Experiment: Figure 2 is a drawing of the layout Hanging file Calorimeter in the MTEST beam line at FNAL. The beam line has 4 sets of single wire drift chambers for momentum analysis and a Cerenkov counter for electron identification. For the analysis presented here, all of the data comes from Run 839, consisting of a roughly equal mixture of electrons and pions of 5 GeV/c nominal momentum. The configuration of the calorimeter absorber plates and 1/8" thick scintillators for this run is presented in Table I.

Table I: Calorimeter Configuration, Run 839

Compartment	Absorber Material	Absorber Thickness (cm)	Scintillator Thickness (cm)	Nr. of Cells
Electromagnetic	Pb	0.635	2 x 0.32	20
Hadronic	Fe	5.08	2 x 0.32	27
Backstop	Fe	2.54	0.32	1

In addition to satisfying the trigger counter requirements, candidate events are required to have valid signals in scintillation counter

BCD_C4, and no accompanying signals in one of two planes of veto counters (BCD_V and HV_V; See figure 2). Additionally, for this analysis, all events are required to have a reconstructible track in the bend plane of the momentum analyzing magnets. The reconstructed track is required to be within +/- 20 mm of the nominal beam line at the approximate location of the veto counter BCD_V4.

The MTEST beam is a mixture of electrons and pions, and we use a combination of the Cerenkov Counter and the ratio of energy in the electromagnetic compartment to the total calorimeter energy to identify electrons and pions. Figure 3 is a scatter plot of the signal amplitude in the Cerenkov counters versus the ratio of hadronic to total energy in the Hanging File Calorimeter. We identify good electrons by requiring a pulse height of greater than 80 ADC counts in the the Cerenkov counter. Good π's are required to have less than 80 counts in the Cerenkov counter and a ratio of hadronic to total energy in the calorimeter greater than 0.12, as shown in Figure 4.

The Data: After all cuts 190 π's and 569 electrons remain. Figures 5 and 6 shown the longitudinal shower profiles for pions and electrons. The vertical scale in each plot is normalized to ADC counts per particle. Note that in figure 6 the horizontal scale is in radiation lengths, while in Figure 5, the horizontal scale is channel numbers. The first 20 channels of the pion profile correspond to the EM calorimeter, or about 24 radiation lengths. As described in step 3 above, the electron spectrum has been fitted with the functional form of equation 2 (smooth curve). The values used in the fit are listed in Table II. The shape of the distribution is in reasonable agreement with the data.

Given the fitted shape to the 5 GeV electron longitudinal shower profile, we can now estimate the shower profile for a 2.5 GeV photon from equation 2 (step 4, above). This profile is shown in figure 7, properly normalized in ADC counts per photon. We note that the peak of this distribution is about 38 counts, or about 4 times the maximum value of the pion distribution. We now wish to compute the 'normalized' shower profile for 2.5 GeV photons and 5 GeV pions as defined in step 5, above. The normalized distribution is shown in figure 8, where the contents of each bin (B(i)) in this histogram is defined by:

$$B(i) = (G(i) + P(i))/ 38. \qquad (4)$$

where G(i) are the contents of the ith channel of the estimated gamma profile (Figure 6) and P(i) are the contents of the ith channel of the measured pion longitudinal profile (Figure 5). The number 38 comes from the maximum value of the 2.5 GeV gamma profile, figure 7. We note that the radiation dose at EM shower maximum is increased by 10% when the dose from the hadronic showers is included. The dose at EM shower maximum is 4 times the dose at hadron shower maximum.

Table II: 5 GeV/c Electron Shower Profile Parameters

Parameter	Value	Error	Comment
a	3.698		From Ref [4]
b	0.4689		From Ref[4]
A	141.0	6.0	from fit
E/E_c	519.8		E_c from Ref [4]

Relative Dose Profiles: Given the depth per channel (Table I), it is now a simple manner to compute the relative damage in the SDC endcap calorimeter. For each point in the endcap, we:

- Computed the depth into the calorimeter in centimeters, along a line that projects back to the interaction point. We assume the front face of the calorimeter is at z = 4.2 meters from the interaction point

- Interpolate in a table of 'normalized radiation dose' vs depth (cm) to find the relative dose at this location in the calorimeter. We ignore any air gaps.

- Estimate the total radiation dose by multiplying relative dose by the value obtained from equation 1, where the variable '*r*' in equation 1 is interpreted as the distance from the point in the calorimeter and the nominal interaction point.

Figure 9 shows the relative dose contours versus ρ and z , where ρ is the radial coordinate in a cylindrical coordinate system. These dose lines correspond to an integrated luminosity of 10 yr at 10^{34} cm^{-2}

sec^{-1}. Figure 10 shows the same data, but with the edges of the calorimeter and several η boundaries overlaid.

Discussion of Radiation Dose Contours: Clearly, the electromagnetic calorimeter will see a much higher dose than the Hadron calorimeter. The Maximum EM dose appears to be about 50 Mrad at $\eta = 3$. We assume that the boundary between the hadron 'plug' and endcap hadronic modules should be drawn such that the scintillator for the latter never needs replacement. Referring to figure 10, we can construct the following table of expected scintillator dose versus the η boundary between the plug and endcap.

Table III: Maximum Radiation Dose versus η, Endcap Hadronic Calorimeter

Max Allowed Scintillator Dose	Max Endcap η Boundary
1 Mrad	2.2
2 Mrad	2.4
3 Mrad	2.6

For high precision EM calorimetry, currently available scintillator would require replacement after an integrated dose of 1 Mrad. Hence, for current scintillators and fibers the boundary between the endcap and plug hadronic sections should be drawn at $\eta = 2.2$. However, because the the hadron calorimeter is of poorer resolution than the EM calorimeter it presumably could accept more radiation damage before the photon statistics affect the energy resolution. This may drive the boundary and plug towards higher values of η. On the other hand, cost optimization between the plug and endcap regions of the calorimeter may tend to keep the boundary near 2.2 to 2.4. Neither of these two arguments has been incorporated into the present analysis.

Activation: Groom has estimated the radioactivation for a hollow iron or lead sphere in reference [2]. We have used Table I from this report to estimate the activation in the SDC endcap calorimeter. Most of the activation occurs in the lead EM section or just at the front of the Hadronic section. The SDC calorimeter consists of a Pb/scintillator EM calorimeter and an Iron/scintillator hadron calorimeter, and this mixture is not considered by Groom. For the purposes of this report, we have used the data from reference [2] for

lead throughout: *i.e.* we have calculated the distance into the (iron) hadron calorimeter as though it were Pb. We have ignored the effects of the scintillator except to reduce the average density of the calorimeter: eg, in the EM calorimeter where there is an equal mixture by volume of scintillator and Pb we have calculated the depth into the calorimeter by assuming 1/2 the density of lead.

Results of the calculation are shown in figure 11, and repeated in figure 12 with the edges of the calorimeter and several η boundaries overlaid. The activation at the face of the EM calorimeter at $\eta = 3$ is about 1600 μSv/hr on contact. Since most of the energy is expected to be radiated in the form of low energy gamma rays, the quality factor for this radiation should be near one and we can translate the dose rate to 160 mrem per hr on contact. Were the EM calorimeter to be removed, dose rate on contact with the hadron calorimeter behind it would be about 200 mrem.

To other points are worth noting. Firstly, the activation calculated here is for 30 days irradiation time at a luminosity of 10^{34} $cm^{-2}sec^{-1}$ followed by 1 day of cool down. Longer exposures will give higher activations. Depending on the exact exposure history, the numbers quoted here could be low by factors of 2 to 3. Secondly, longer cooldown periods do not lead to proportionately lower dose rates. This is because the induced radioactivity cannot be described by a single decay time, but is the sum of many decay products. Increasing the the cooldown period from one day to a full year would reduce the dose rates by a factor of 3 to 4 [5],. because the relevant isotope in an iron calorimeter after a year of cool down is Mn_{54}.

The dose rates from the activation of the absorber plates are within the activation rates seen at accelerators today. One must take care to carefully plan the maintenance and disposal of the calorimeter, since the trend of current regulatory environment is to reduce (rather than increase) the allowed exposures to low level radiation. Given the relatively high activation of the endcap, access to the endcaps at the highest SSC Luminosities will be limited.

Conclusions: We have examined the radiation dose as a function of radius and depth in the SDC endcap calorimeter and found it to agree well with previous estimates The radiation dose at EM shower maximum appears to be about 4 times the dose at hadron shower maximum. Given a scintillation plastic with with a lifetime of 1

Mrad, we would expect the boundary between the endplug and endcap hadron calorimeters to be drawn at $\eta = 2.2$. The aborber plates will be sufficiently radioactive duing high luminosity runnning that special precautions and procedures will be required for access to the tracking volume and disposal of the calorimeter or replacement of scintillator within the calorimeter may be problematical.

References

[1] D. E. Groom, "Radiation Levels at the SSC" , SDC -90-00046, 1990.

[2] D. E. Groom, "Extension of the SSC-SR-1033 Approach to Radioactivation in the LHC and SSC Detectors"; SDC-91-122, 1991., to be published in Proc II Int. Conf on Calorimetry in High Energy Physics, Capri, Italy, 14-18 Oct, 1991.

[3] " Report of the Task Force on Radiation Levels in the SSC Interaction Regions, " ed. by D. E. Groom, SSC Central Design Group Report SSC-SR-1033, 1988 (revised 1990).

[4] " Particle Properties Data Book", Particle Data Group, pp112-115, 1990.

[5] D. E. Groom, Private Communication.

Figure Captions:

[1] Quarter section of the SDC Detector showing the location of the "endplug" hadron calorimeter (hatched region).

[2] Schematic diagram of the MTEST beam at FNAL (not to Scale).

[3] Scatter plot of ADC counts in the Cerenkov counter versus the ratio of Hadronic to total energy in the Hanging File Calorimeter. Electrons are required to have more than 80 counts in the Cerenkov ADC.

[4] Projection of scatter plot of figure 3 on the horizontal scale (hadronic/total energy) Identified pions are required to have hadronic/total energy greater than 0.12, as indicated in the figure.

[5] Longitudinal shower profile for pions of 5 GeV/c nominal momentum. The horizontal scale is in channel number. The first 20

channels are the EM calorimeter, and the remaining channels are the Fe hadron calorimeter, consisting of 2" Fe plates alternating with 1/4" scintillator.

[6] Longitudinal shower profile for electrons of 5 GeV/c nominal momentum. The horizontal scale is in radiation lengths. The actual EM compartment of the calorimeter consists of 20 layers of 1/4" Pb with 20 layers of 1/4" Scintillator. The smooth curve is the functional form of equation 2, fitted to the data with one arbitrary constant for normalization.

[7] 2.5 GeV/c Gamma profile per photon estimated from 5 GeV/c electron data. Horizontal scale is in radiation lengths.

[8] Pion profile as in figure 6, except plotted on the same vertical scale as figure 7 for comparison. Note the horizontal scale is in channel counts, where the first 20 channels correspond to the EM calorimeter.

[9] 'Normalized' longitudinal radiation dose profile for 2.5 GeV photons and 5 GeV pions. The first 20 channels correspond to the EM calorimeter.

[10] Equal dose continous for the SDC endcap after 10 years at luminosity of 10^{34} $cm^{-2}sec^{-1}$. The front of the Calorimeter is at z = 4.2 meters from the interaction point. The distances inside the calorimeter are computed assuming no air gaps or other materials between the scintillator and the absorber plates.

[11] Same data as figure 10, but with the edges of the calorimeter marked as well as a few η boundaries.

[12] Equal activation contours for the SDC endcap after 30 days at luminosity of 10^{34} $cm^{-2}sec^{-1}$ and a one day cooldown. The front of the Calorimeter is at z = 4.2 meters from the interaction point. Any effect of the scintillator on the activation has been ignored. The iron in the hadron calorimeter has been modeled as lead (see text).

[13] Same data as figure 12, but with the edges of the calorimeter marked as well as a few η boundaries.

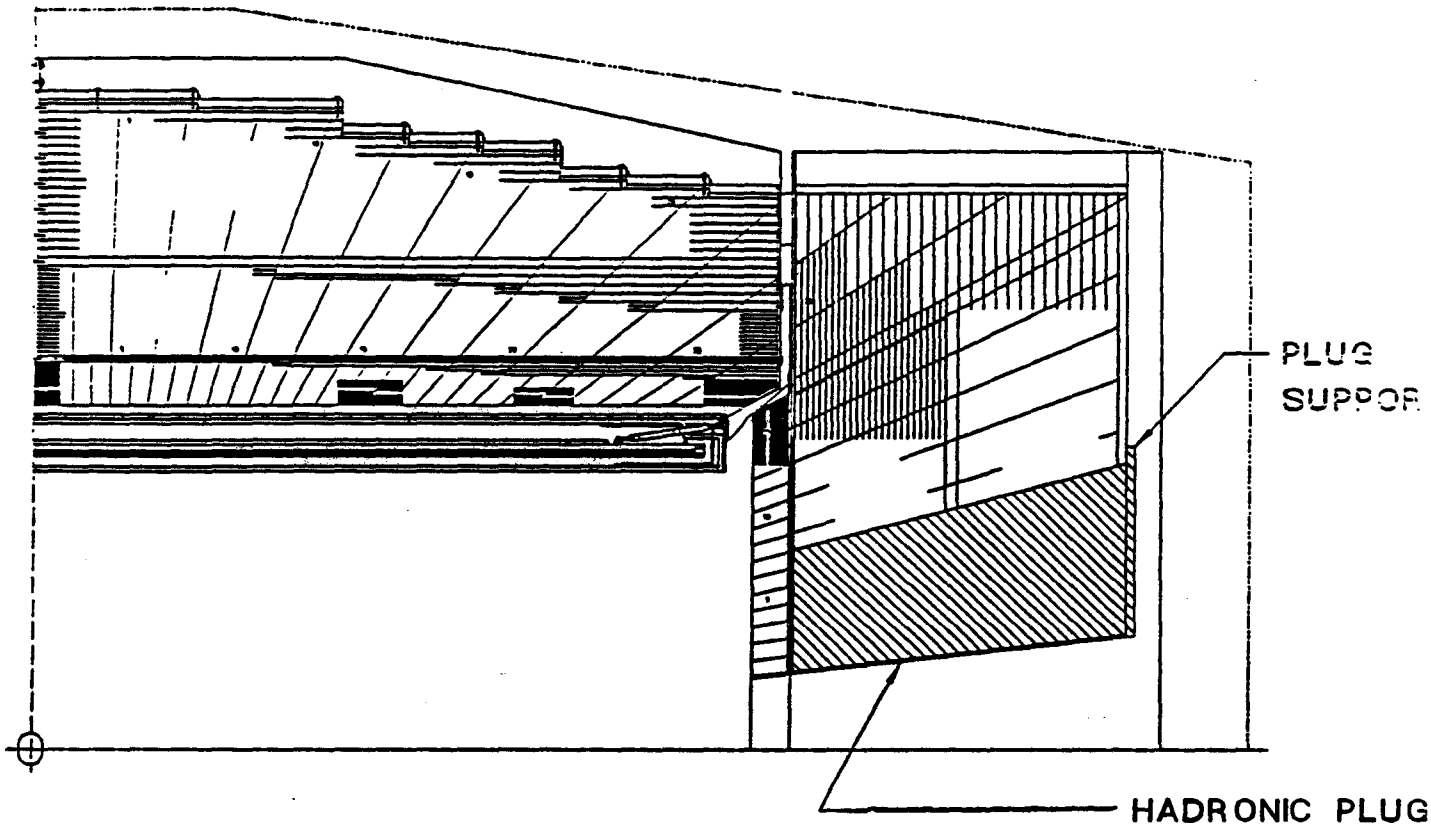


Figure 1

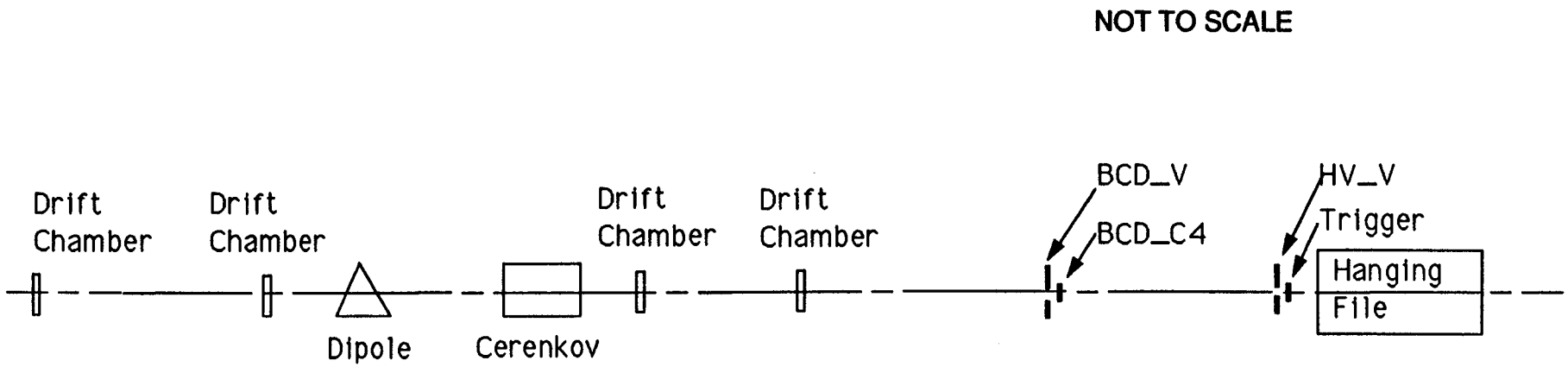
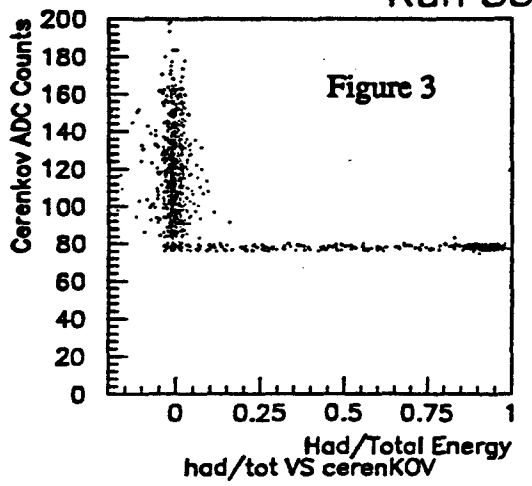
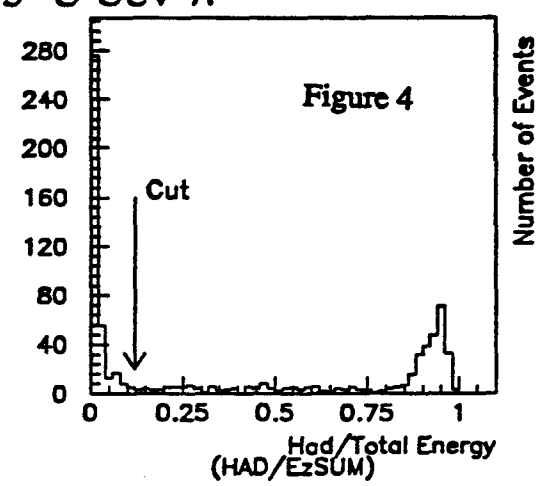

NOT TO SCALE
Drift Chamber
Drift Chamber
Dipole
Cerenkov
Drift Chamber
Drift Chamber
BCD_V
BCD_C4
HV_V
Trigger
Hanging File

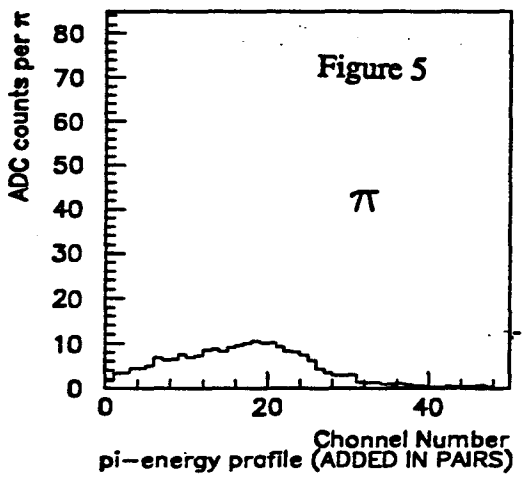
Figure 2

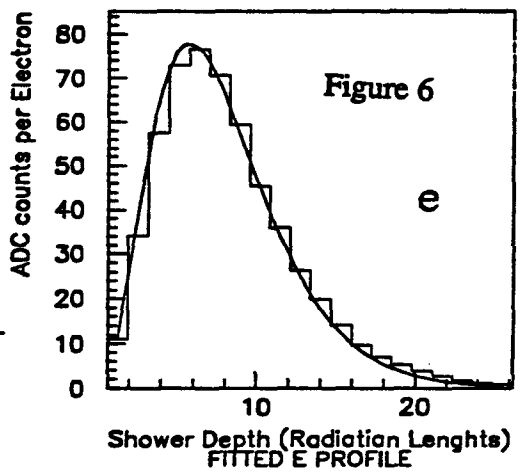
10/01/92 17.32

Run 839 5 GeV π



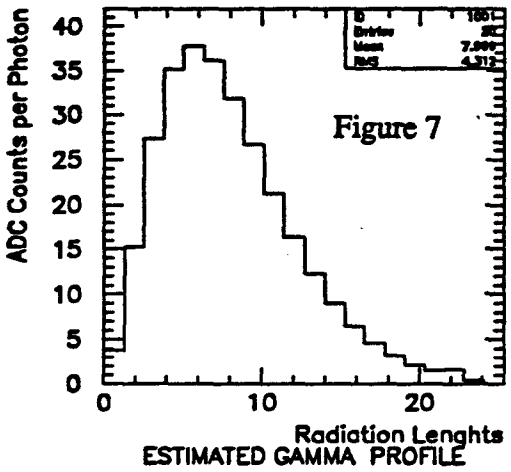


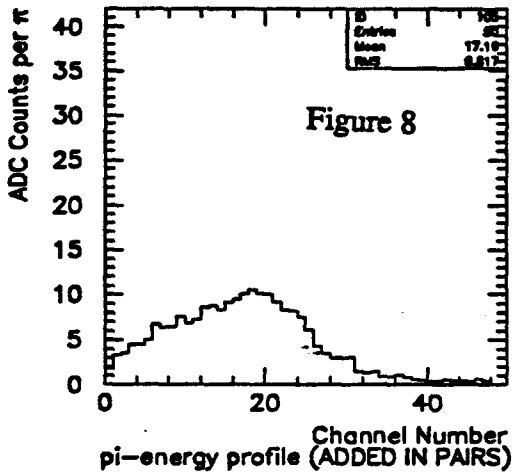


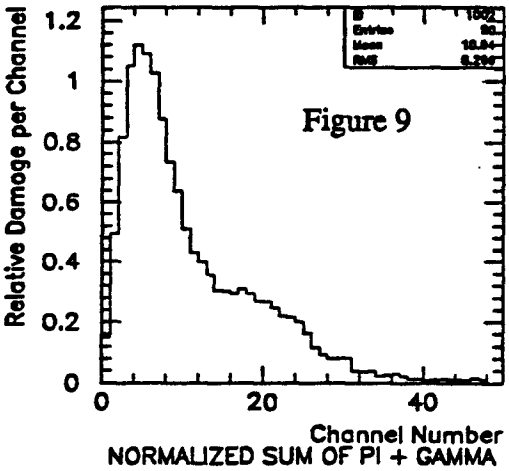


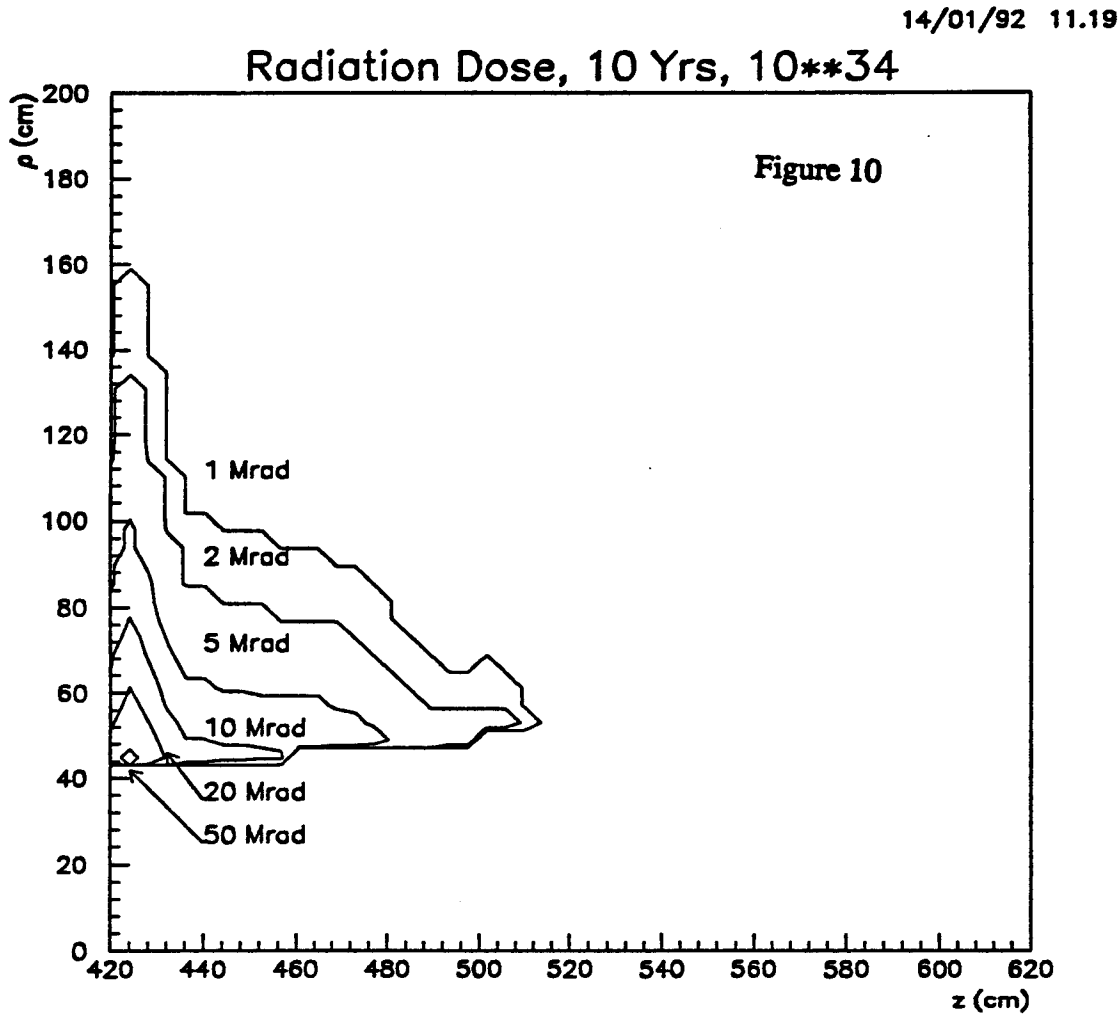
13/01/92 12.38

Run 839 5 GeV π

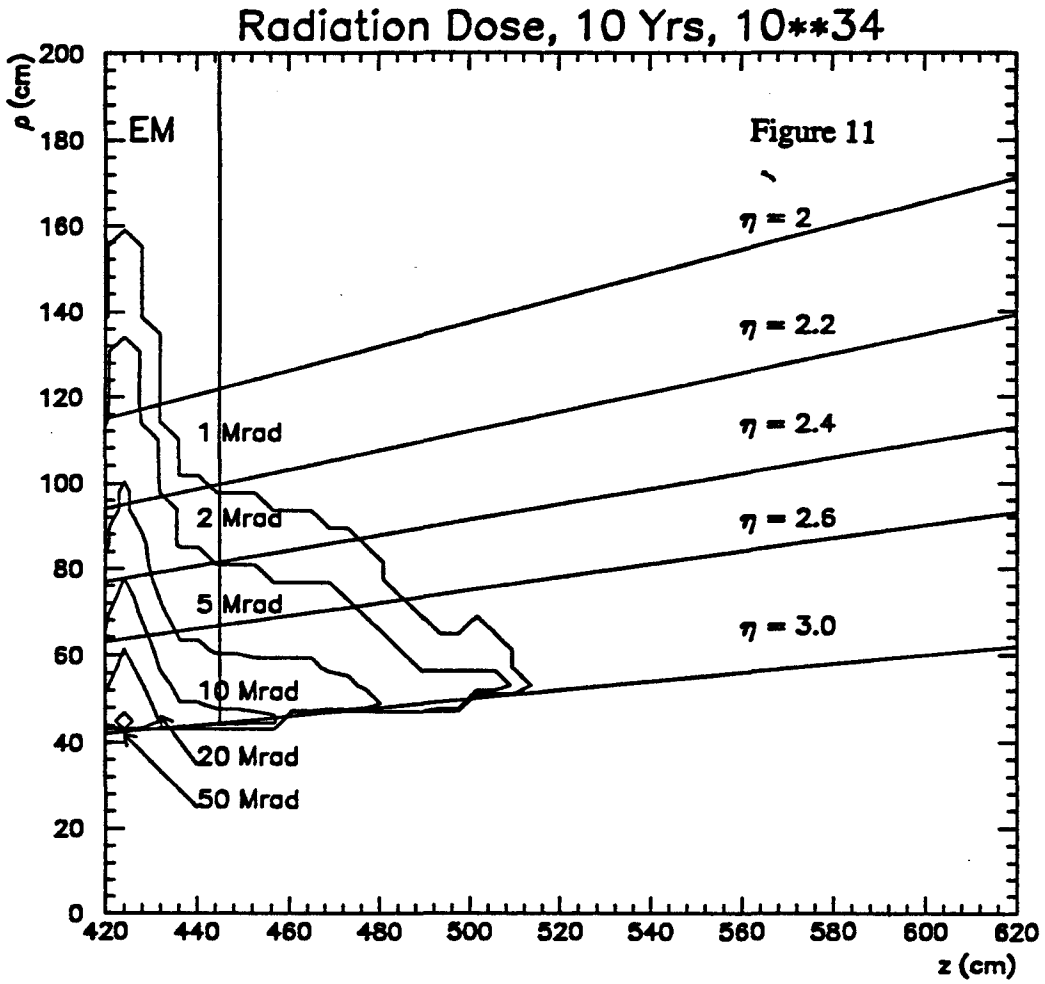




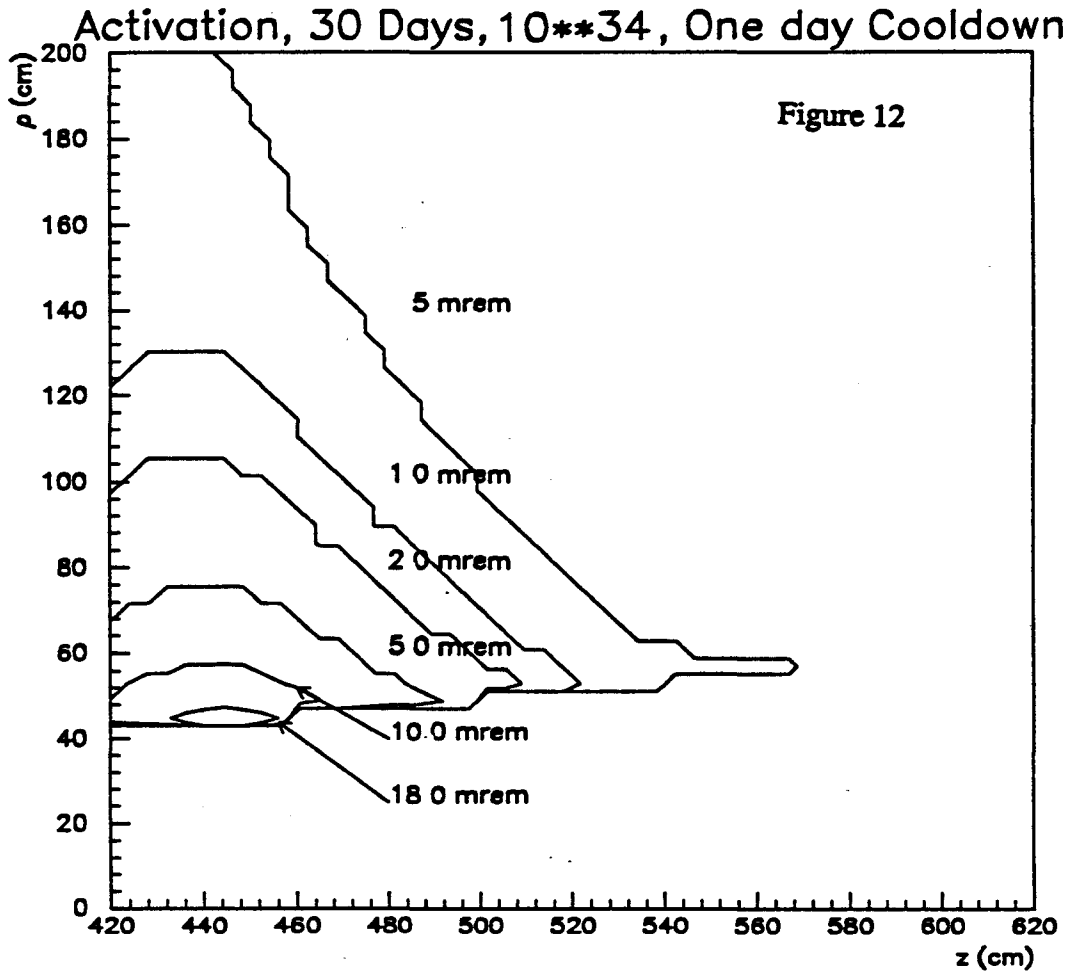



14/01/92 11.19
Radiation Dose, 10 Yrs, 10**34
Figure 10
ρ (cm)
z (cm)
1 Mrad
2 Mrad
5 Mrad
10 Mrad
20 Mrad
50 Mrad
0
20
40
60
80
100
120
140
160
180
200
420
440
460
480
500
520
540
560
580
600
620

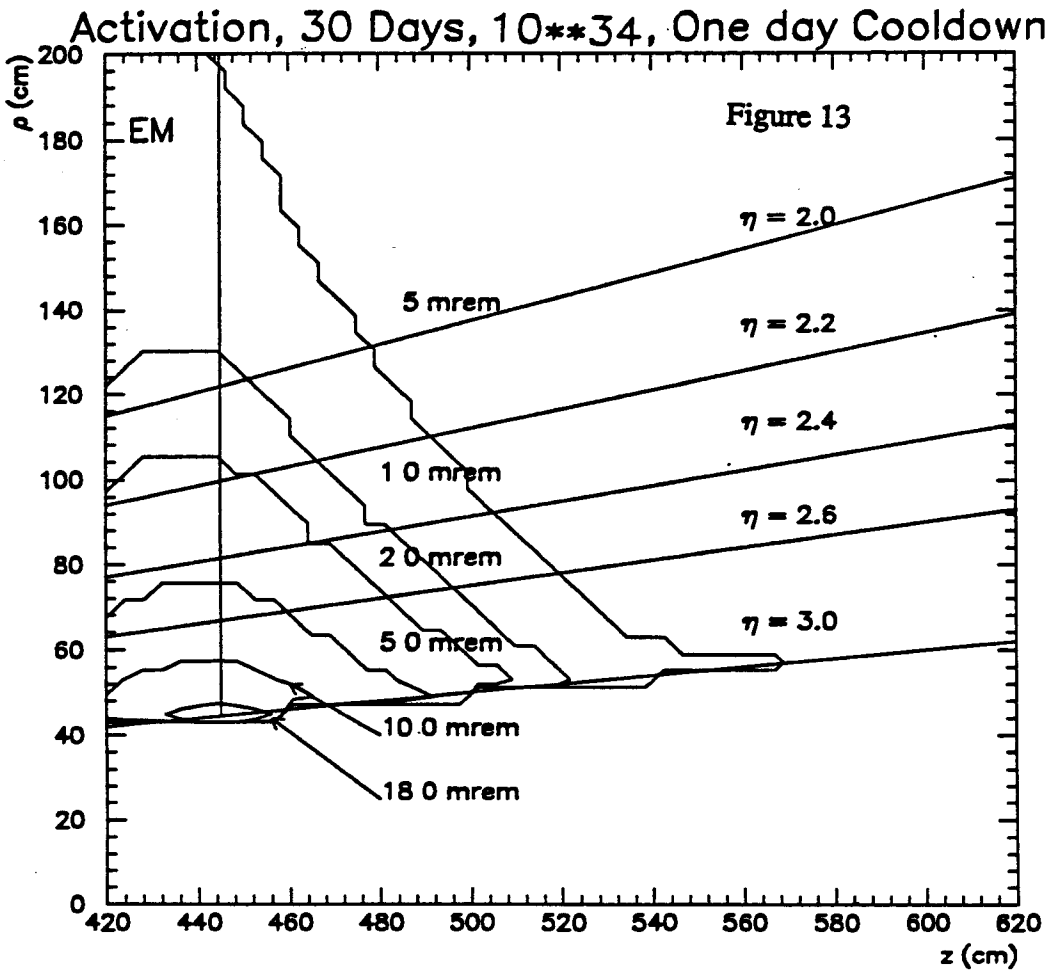
21/01/92 13.49


Radiation Dose, 10 Yrs, 10**34
ρ (cm)
z (cm)
EM
Figure 11
η = 2
η = 2.2
η = 2.4
η = 2.6
η = 3.0
1 Mrad
2 Mrad
5 Mrad
10 Mrad
20 Mrad
50 Mrad
0
20
40
60
80
100
120
140
160
180
200
420
440
460
480
500
520
540
560
580
600
620

21/01/92 13.06


Activation, 30 Days, 10**34, One day Cooldown
Figure 12
ρ (cm)
z (cm)
5 mrem
1 0 mrem
2 0 mrem
5 0 mrem
10.0 mrem
18 0 mrem
0
20
40
60
80
100
120
140
160
180
200
420
440
460
480
500
520
540
560
580
600
620

21/01/92 13.50


Activation, 30 Days, 10**34, One day Cooldown
Figure 13
EM
ρ (cm)
z (cm)
η = 2.0
η = 2.2
η = 2.4
η = 2.6
η = 3.0
5 mrem
1 0 mrem
2 0 mrem
5 0 mrem
10 0 mrem
18 0 mrem
0
20
40
60
80
100
120
140
160
180
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