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# MUON BACKGROUND IN COLLIDING-BEAM DETECTOR EXPERIMENTAL HALLS

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## INTRODUCTION:

In the design of an assembly area adjacent to the experimental area which accomodates the colliding-beam detector, it is essential that no major radiation safety problem should occur in the event of castastrophic beam or superconducting doubler magnet failure. Several simple estimates[1,2] have been made during the 1977 Aspen Summer Study to examine the magnitude of muon background in the experimental halls. It was suggested that, for a hall at a perpendicular distance 10 m away from the interaction point, the background may be of the order 1 roentgen equivalent medical (rem) for $5 \times 10^{14}$ 1000 GeV/c protons striking a critical point 140 m upstream of the hall. Although this is reassuring from the safety point of view, it was recommended that a direct measurement of the muon background be made. Further the measurements should be compared with calculations which take properly into account development of cascade showers in transport and direct-lepton production processes.

In this note we report the results of a direct measurement of the muon background underground at 122 m downstream of the main ring D-0 beam abort system. The geometry of beam abort system is similar to that anticipated in the catastrophic failure of the doubler. It is shown that the measured muon background level agrees well early estimates and with a Monte-Carlo calculations[3] which simulates the development of hadron cascades and muon production and transport.

## D-0 BEAM ABORT SYSTEM[4]

Figure 1 shows the schematic plan of the beam abort system in relation to the main ring. The system is centered around one of the six long straight sections, D-0, halfway around the ring from the injection and extraction point. The beam abort operation is to induce a local radial closed-orbit oscillation by a pair of bump magnets. The oscillation brings the MR beam onto the abort target.

The abort target is a 9-ft. long aluminum rod approximately 6 in. by 5 in. cross section. It is mounted inside a shielded block located downstream of the quadrupole doublet at the beginning of the D-0 long drift space. Downstream of the abort target are two absorbers made out of modified main ring magnet cores. The copper coil are replaced by steel. Each absorber is 21 ft. long and has a steel thickness of at least 6 in. in any transverse direction from the beam. The downstream absorbers are positioned to intercept particles coming off the target at angles outward and upward with respect to the center line.

## DETECTOR ASSEMBLY UNDERGROUND

A series of radiation sensitive emulsion plates were placed underground at a distance of 403.6 ft. from the abort target. Twenty emulsion plates were placed at 3 ft. intervals centering about the 0° axis from the abort system. Figure 2 shows the locations of the emulsion plates with respect to the cross section of main ring tunnel at the detector plane. Ten emulsion plates were also inserted on the inside of tunnel. Five additional emulsion plates were placed at 50 ft. further downstream on the 0° axis. The beam center is at an approximate elevation of 725.5 ft., corresponding to ≃ 25 ft. below the ground level.

## DATA

The abort target was irradiated with a total of $5 \times 10^{14}$ protons at 400 GeV. The resultant charged radiation registered with the emulsion plates has been analyzed and measured in mrem. The results of the measurements is also shown in Figure 2. The data exhibit a reduced background within the solid angle subtended by the absorbers, while a 5-10 fold higher background level has been seen beyond it.

The average dosage within the absorber-covered region is 70-80 mrem/$5 \times 10^{14}$ protons, representing a "safe" environment for an experimental area during a catastrophic failure of the main ring bean orbit striking the doubler magnets.

The anticipated muon background at 1000 GeV is 5-10 times that of 400 GeV operation. Thus we anticipate a maximum of approximately 0.5-1.0 rem/$5 \times 10^{14}$ proton at 1000 GeV. This number should be construed as an upper limit since the MR abort system contains substantial air gap (see Figure 1) in the path of cascade shower. However, we do not expect an air gap to be present in colliding beam operations since the doubler magnets are substantially denser in the path of cascade showers than the present geometry.

## COMPARISON OF MEASUREMENT WITH MONTE-CARLO CALCULATIONS

Penetration of prompt and decay muon components of hadron cascades through thick shields have been evaluated extensively by Van Ginnekan.[3] Figures 3 and 4 show the momentum distributions of all (prompt and decay) muons emerging from intermediate depths for soil at either 400 or 1000 GeV.

For ease of comparison, we converted our beam abort and detector system into a homogeneous soil medium. The effects of air gaps in the system on the momentum distribution of muons have been neglected in this comparison as the air gap begins at 16 collision lengths from the target, well after the peak of the showers. Additionally, since the presence of air gap will only increase the expected muon backgrounds, the calculation should then be a conservative estimate. In table I we show the following absorber material in abort system.

TABLE I MATERIAL SEEN BY THE BEAM IN MR ABORT SYSTEM

| MATERIAL | LENGTH (ft.) | $\rho t$. (g/cm$^2$) |
|---|---|---|
| Aluminum target | 9 | 740 |
| Air gap | 85 | Negligible |
| Fe Absorbers | 42 | 10,241. |
| Air gap | 40 | Negligible |
| Soil | 253 | 15,422. |
| Total thickness | | 26,403 |

The abort system has been approximated by a geometry in which the protons are absorbed by a 132 m soil shield. From Figure 3 we find that, for 400 GeV protons on a 132 m soil shield, the expected muon flux is $5 \times 10^{-9}$ muon/cm$^2$/inc. proton.

Converting this calculated flux into mrem/pulse, we have the total radiation level in mrem/pulse

$= 5 \times 10^{-9}$ ($\mu$/cm$^2$/p) $\times 10^4$ (cm$^2$/m$^2$) $\times 0.3 \times 10^{-8}$ (mrem/$\mu$/m$^2$) $\times 5 \times 10^{14}$ (p/pulse)

$= (75 \pm 75)$ mrem/pulse

This is in excellent agreement with the measurement shown in Figure 2.

## ANTICIPATED RADIATION LEVEL AT 1000 GeV

Since the experimental area is to be designed for use with a 1000 GeV beam, it is necessary to extrapolate the measured radiation level to a higher energy. Figure 4 shows the muon flux calculated for 1000 GeV protons incident on an earth shield. At 140 m (estimated distance of the experimental area from the failure point) away, the calculated muon flux is $\sim 5 \times 10^{-8}$ muons/cm$^2$/proton. This is approximately ten times higher than the case for 400 GeV protons.

Thus we expect a realistic radiation level of 500 mrem/$5 \times 10^{14}$ protons at 1000 GeV. Noting that without stacking the proton beam in the energy doubler, the beam intensity would not be as high as $5 \times 10^{14}$ proton/pulse. Therefore, our estimate is an upper limit.

Given the uncertainty of the calculation presented here, we assign a factor of two in our uncertainty. For the worst geometry, the radiation level in the experimental area should be less then 1 rem/pulse in event of a catastrophic failure.

## CONCLUSIONS

Based on actual measurements of muon background underground 120 m downstream of the main ring D-0 beam abort system, the muon background radiation level will be tolerable ($\lesssim$ 1 rem/$5 \times 10^{14}$ protons) at 1000 GeV in the proposed colliding beam experimental areas. This estimate assumes the worst geometry and the maximum doubler beam flux during a catastrophic failure of the beam.

## REFERENCES

[1] K. W. Chen, "Muon Backgrounds in Experimental Hall", Fermilab Summer Study (1977) p. 289.

[2] B. Sadoulet, "Radiation Problems with Assembly Halls Adjacent to Experimental Halls", Fermilab Summer Study, (1977) p. 307.

[3] A. Van Ginnekan, "Penetration of Prompt and Decay Muon Components of Hadronic Cascades Through Thick Shields", Fermilab Report TM-630 (1975).

[4] R. Carrigan et. al., "Main Accelerator Abort System", Fermilab Internal Report (1972).

## FIGURE CAPTIONS

Fig. 1 Geometry for beam abort system in this experiment.

Fig. 2 Results of muon background for $5 \times 10^{14}$ protons at 400 GeV incident on the beam abort system at D-0. The radiation level was measured at a plance 133 m (403') from the beam abort target. Note that the region enclosed by the dashed square is shadowed by the two 20' absorber magnets immediately downstream the target.

Fig. 3 Calculated muon fluxes at shallow and intermediate depths in a soil shield or radius for (a) decay muons only and (b) all (prompt + decay) muons for 400 GeV/c protons incident on the shield. See Reference (3) for details.

Fig. 4 Same as Figure 3 for 1000 GeV/c incident protons on a soil shield.

MAIN RING BACKGROUND MEASUREMENTS

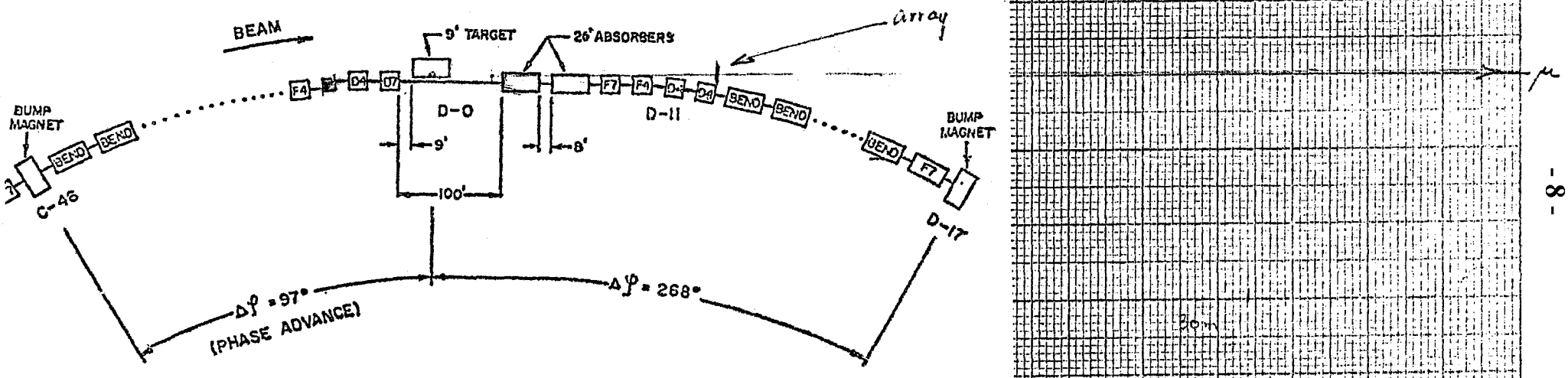


Figure 1. A schematic plan of the abort system.

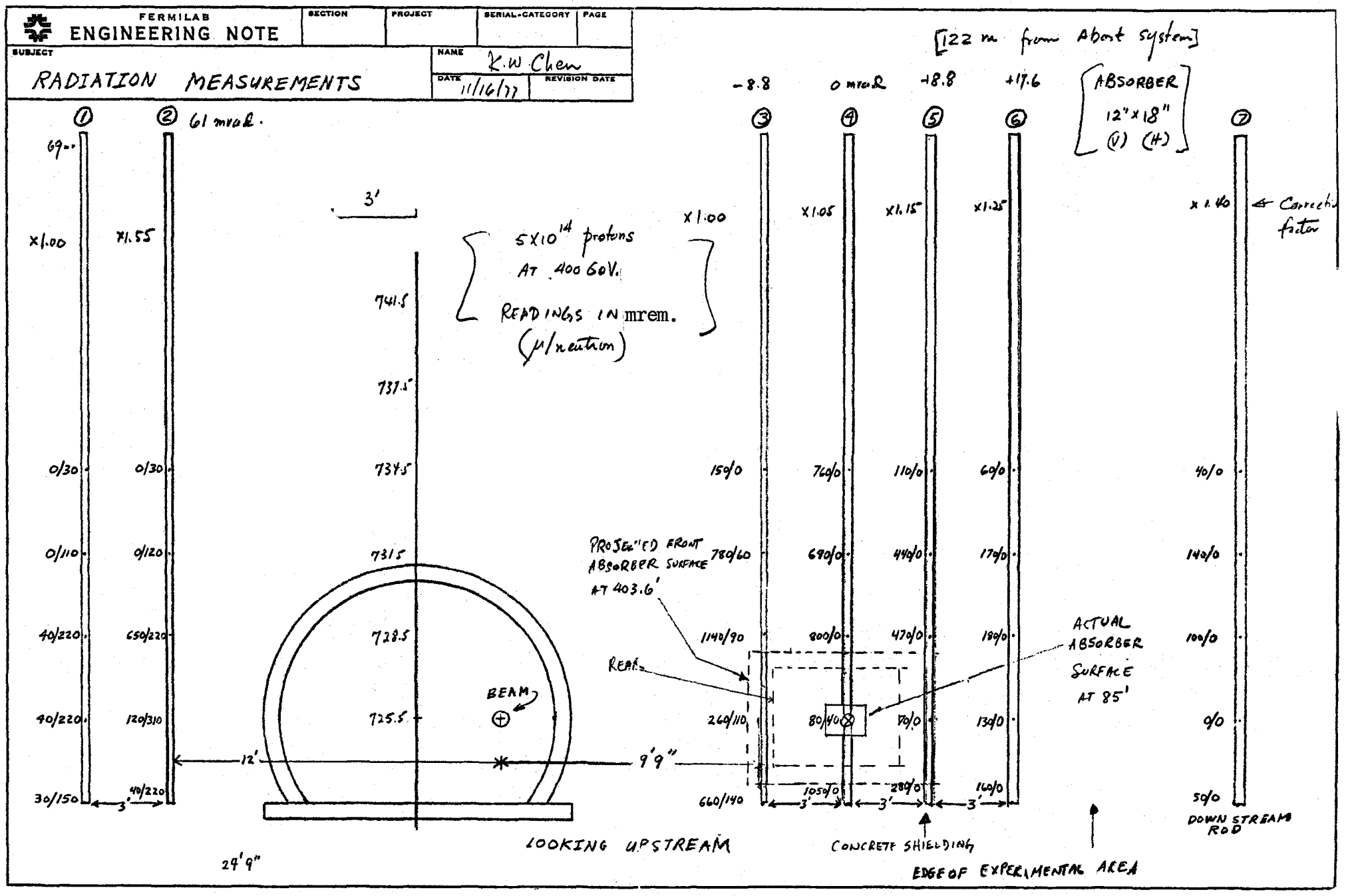
FERMILAB
ENGINEERING NOTE
SECTION
PROJECT
SERIAL-CATEGORY
PAGE
SUBJECT
RADIATION MEASUREMENTS
NAME
K.W. Chen
DATE
11/16/77
REVISION DATE
[122 m from Abort system]
ABSORBER
12"x18"
(V) (H)
-8.8
0 mrad
+8.8
+17.6
61 mrad.
3'
5X10^14 protons
AT 400 GeV.
READINGS IN mrem.
(μ/neutron)
x1.00
x1.55
x1.05
x1.15
x1.25
x1.40
Correction factor
741.5
737.5
734.5
731.5
728.5
725.5
69
0/30
0/110
40/220
30/150
0/30
0/120
650/220
120/310
40/220
159/0
780/60
1140/90
260/110
660/140
760/0
690/0
800/0
80/40
1050/0
110/0
440/0
470/0
70/0
280/0
60/0
170/0
180/0
130/0
160/0
40/0
140/0
100/0
0/0
50/0
PROJECTED FRONT ABSORBER SURFACE AT 403.6'
REAR
ACTUAL ABSORBER SURFACE AT 85'
BEAM
12'
9'9"
29'9"
LOOKING UPSTREAM
CONCRETE SHIELDING
EDGE OF EXPERIMENTAL AREA
DOWN STREAM ROD

Fig. 2

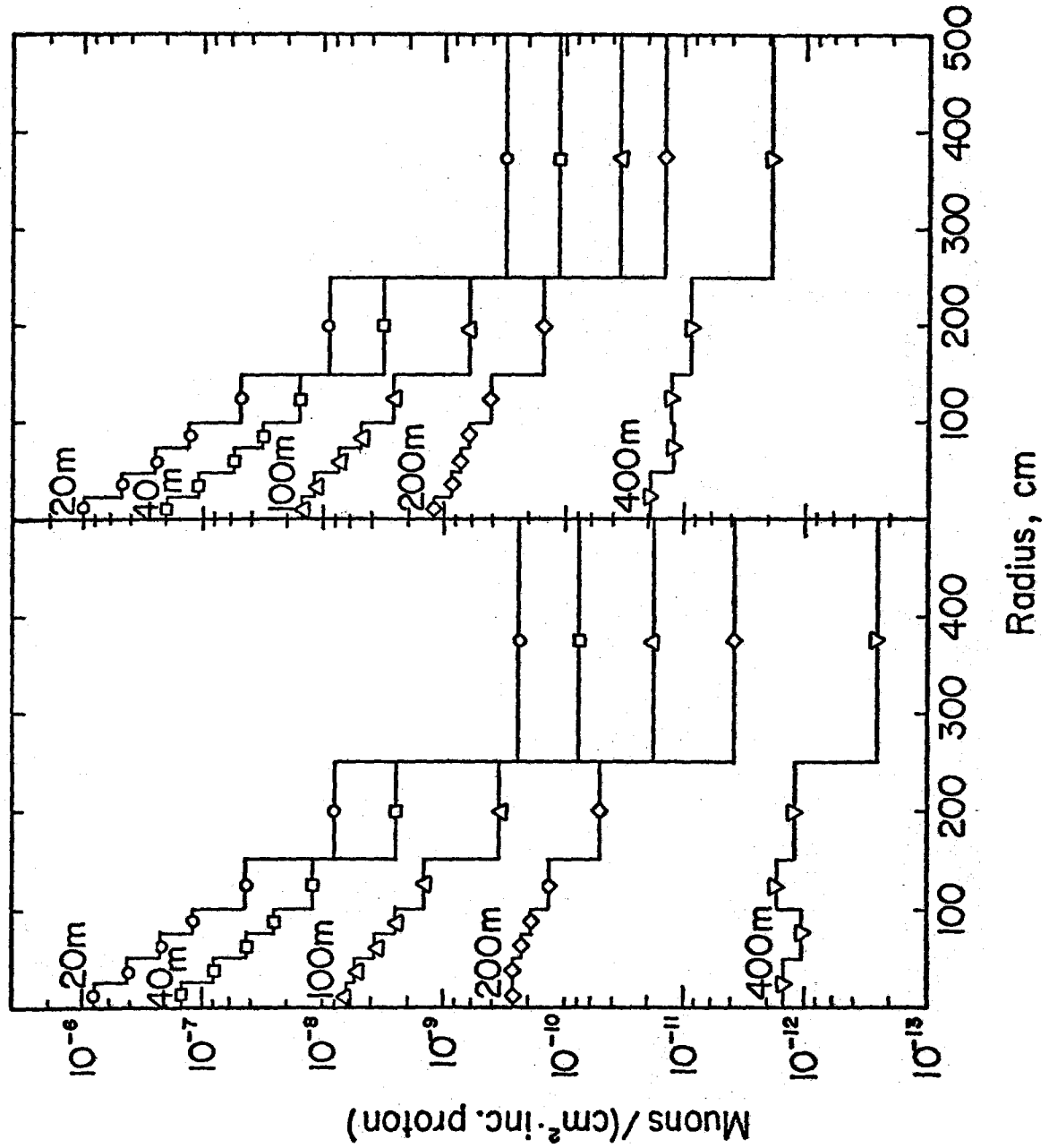
Muons /(cm²·inc. proton)
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
20m
40m
100m
200m
400m
100
200
300
400
500
Radius, cm
(a)
(b)

Fig. 3

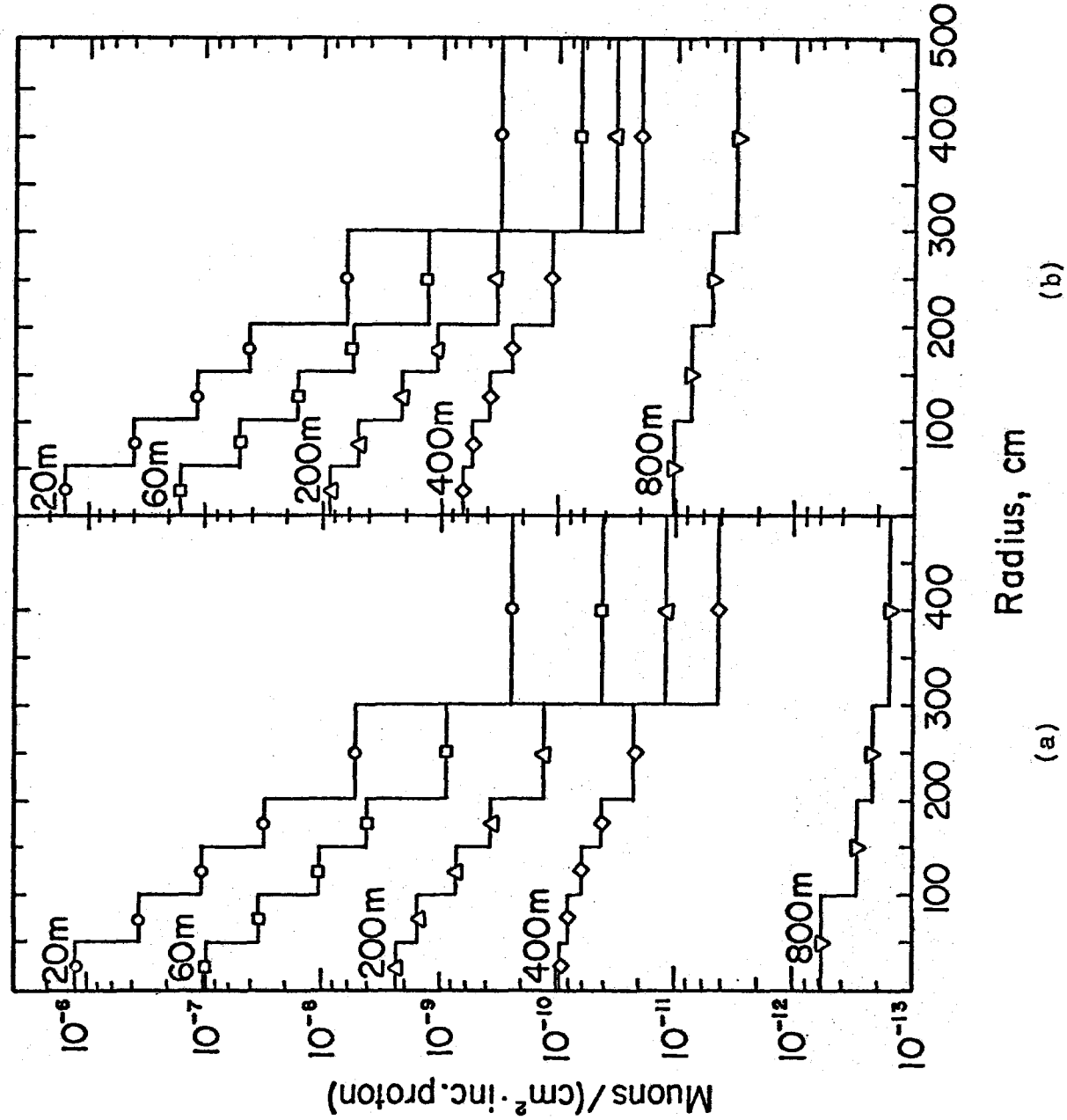
Muons/(cm$^2$·inc.proton)
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
20m
60m
200m
400m
800m
100
200
300
400
500
Radius, cm
(a)
(b)

Fig. 4