Fermilab

TM-815
2833.000

A 10^{12}-10^{13} BEAM TARGETING STATION IN THE MESON DETECTOR BUILDING

T. E. Toohig
September 22, 1978

I. Introduction

The experience of running beam during experiment E439 up to intensities of 7×10^{11} in the Meson Detector Building provides an experimental basis for scaling shielding requirements to higher intensities and energies.

Figure 1 shows the shielding layout and measured dose rate alongside the shield.

II. The Hadron Shield

A. Side Shield

1. Scaling to Tevatron Parameters

Under the assumptions of 10^{13}p/min at 1 TeV to Meson with 1/2 to M1 and 1/2 to M2-M6, approximately 10^{11}p/sec will be targeted in the Detector Building. Unlike the problem of ground water contamination, the shielding here can be averaged only over a few pulses at most so the long term operating cycle of the machine is irrelevant. E439 operated routinely at 400 GeV, 2×10^{11}ppp with a 10 sec repetition rate with acceptable levels alongside the shield.

Scaling to Tevatron operation:

	E439	Tevatron	Scale Factor
Intensity	2×10^{10}/sec	10^{11}/sec	x 5
Energy	400 GeV	1000 GeV	x 2
Net			x10

Using $\lambda_t = 100$ gm/cm^2, a factor of 10 reduction requires 230 gm/cm^2 or 38 inches of Fermilab concrete ($\rho = 2.4$ gm/cm^3).

2. High Intensity 400 GeV Operation

For operation at 10^{13}ppp, 10 sec repetition rate, 400 GeV, the shielding must be scaled to accommodate

	E439	High Intensity	
Intensity	2×10^{10} sec	10^{12}p/sec	x50
Energy	400 GeV	400 GeV	x 1
Net			x50

The E439 side shield (cf. Figure 1) consists in 2' of Fe ($\rho = 7.8$ gm/cm^3), 6' of Fermilab concrete ($\rho = 2.4$ gm/cm^3), and 8' of PPA concrete ($\rho = 3.76$ gm/cm^3). The total shield is:

$$S_{439} = 1831 \text{ gm/cm}^2$$

For $\lambda_t = 100$ gm/cm^2, the incremental shield for a factor of 50 is:

$$\Delta S_{10^{13}} = 391 \text{ gm/cm}^2$$

$$S_{10^{13}} = 2222 \text{ gm/cm}^2$$

Substituting steel for the inner H blocks

$$\rho_{eff} = (7.8-2.4) \text{ gm/cm}^3$$

$$\Delta S_{10^{13}} = 29''$$

So, for 10^{13} operation substitute 29" of steel for concrete. In practice, replace the inner two blocks by steel for a conservative 10^{13} side shield. The geometric factor is neglected since the overall dimensions remain the same.

B. The Longitudinal Shield

1. Tevatron Operation

As above, we assume 10^{11}p/sec being targeted at 1000 GeV.

Data from the E439 operation (cf. Appendix 1) indicate that the dose rate at the downstream end of the shield is approximately 1 mrem/hr. Scaling this shield by a factor of 10 as noted above for Tevatron operation, and using $\lambda_L = 155$ gm/cm^2

$$\Delta L_{TeV} = 357 \text{ gm/cm}^2$$

This is equivalent to 5' of Fermilab concrete. Use of the concrete takes care of the familiar leakage of neutrons through steel.

2. High Intensity, 400 GeV Operation

As noted above the proposed high intensity running at 400 GeV is a factor of 50 more intense than the standard operation of E439. From Figure 1, the present shield is 18' long (the spoiler is open across the magnet aperture) so

$$L_{439} = 4279 \text{ gm/cm}^2$$

Assuming $\lambda_L = 155 \text{ gm/cm}^2$ as above

$$\Delta L_{50} = 606 \text{ gm/cm}^2$$

So $$L_{10^{13}} = 4885 \text{ gm/cm}^2$$

The present configuration is modified by adding 30" of iron and the canonical 3' of Fermilab concrete for neutron absorption.

All of this assumes that great care is taken to effectively eliminate cracks, which are notorious for neutron leakage.

III. The Residual Activity due to Hadron Targeting

In Appendix 2, the detailed history of the disassembly of the E439 dump is given. The data indicate, that, with proper modular design of the targeting system, targeting of 10^{13}ppp in the detector Building would not lead to long term contamination or activation of the Detector Building.

IV. The Meson Shield

A Michigan State group carried out exploratory neutrino measurements parasitically to E439. The layout of their apparatus is given in Appendices 3 and 4. In Figure 2 of Appendix 3, the muon flux distribution is given at the downstream face of the neutral hyperon magnet with its channel plugged, effectively 18' of iron beyond the E439 dump discussed above. The readings indicated in Figure 2 should be scaled down by a factor of 5 for the quality factor in the radiation detector that was used.

The data show the expected pattern of a very narrow band of radiation swept vertically by the field of the E439 magnets. Not shown on the figure are the readings on the catwalk above, which were in the several hundred mrem/hr range.

The data indicate that the muon problem is the most serious problem involved in targeting high intensities on the Detector Building floor. For vertical pitching, as in E439, the catwalk at the downstream end of the building would have to be closed or eliminated. However, as far as experiments are concerned, the environment is benign up to several times 10^{12} at least, particularly if the space between the E439 dump and the hyperon magnet used in a setup like the Michigan State experiment, were filled with steel. Since this additional steel would be beyond the hadron shield it would not be activated, and since it is under the 20T crane it is easily moved for use elsewhere.

V. Conclusion

From the data derived from high intensity targeting in the Detector Building for E439, it is reasonable, from a hadron shield viewpoint, to target up to 10^{13}ppp (10^{12} p/sec) in the Detector Building. With not unreasonable vertical pitching and additional passive shielding the associated muon problem is tractable up to several times 10^{12}. Beyond that level, it would be necessary to experimentally configure active and passive muon shields to ensure personnel safety.

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
				7

SUBJECT	NAME	DATE	REVISION DATE
E439 Side Shifld Configuration	J. Toohig	9/21/78	

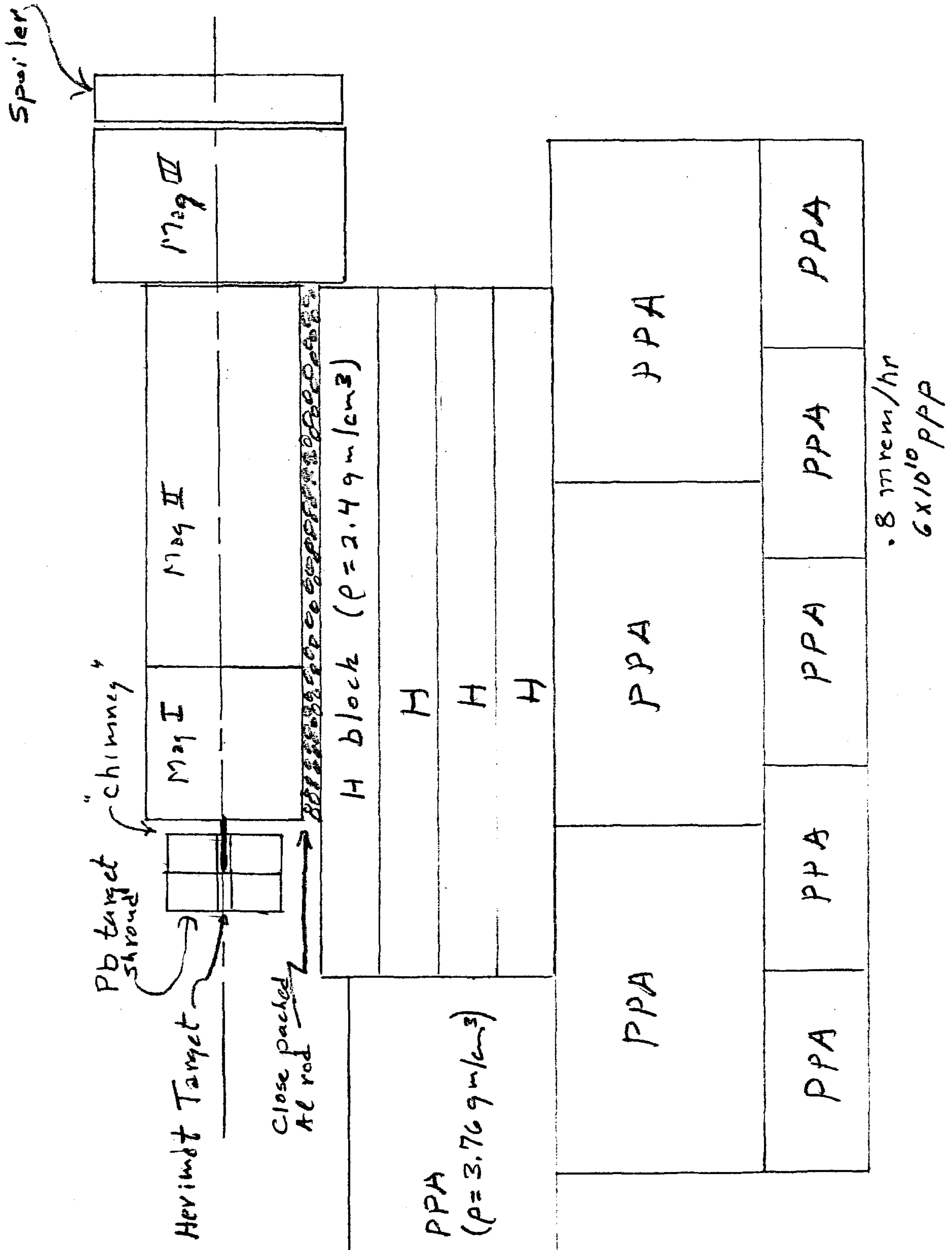


Figure 1

To: Tim Toohig, Head Meson

From: Elizabeth Kaiser, J. Rutherfoord E439

Re: Awschalom, et. al. target dump predictions.

Enclosed is a memo written by Liz Kaiser on the results of a measurement of neutron fluxes behind our magnets compared with the Awschalom, et. al. prediction furnished us by L. Coulson. Steve Velen gave us the TLD's and then calculated the neutron flux from the TLD readings. I hope this is clear.

MINES

TLD'S (THERMOLUCENT DOSIMETERS) WERE PLACED IN THE M2 BEAM LINE DOWNSTREAM OF THE E439 PWC - HODOSCOPE ARRAY BETWEEN MAY 15TH AND 19TH. THE PURPOSE OF THE TLD'S WAS TO MEASURE THE NEUTRON FLUX AND IN SO DOING DETERMINE THE LEVEL AT WHICH NEUTRONS NEEDED TO BE CONSIDERED IN PWC DESIGN.

THE RESULTANT NEUTRON FLUX WAS LOWER (BY ORDERS OF MAGNITUDE) THAN EXPECTED.

TWO SPHERICAL AND ONE CYLINDRICAL TLD (2", 3", 10" IN DIAMETER) WERE PLACED SLIGHTLY OFF THE BEAM LINE, EACH DIAMETER HAVING A DIFFERENT EFFICIENCY IN DETECTING NEUTRONS. RESPECTIVELY, THE 'SPHERES' ARE SENSITIVE TO 1eV, 10eV, AND 8MeV NEUTRONS. (THE 10" 'SPHERE' MAINTAINS SENSITIVITY IN THE .01MeV TO 1MeV RANGE)

THE NEUTRON FLUXES DETERMINED DURING THE MAY 15-19 TIME PERIOD WERE $9.4 \times 10^7 \frac{N}{CM^2}$ (2" SPHERE), $5 \times 10^7 \frac{N}{CM^2}$ (3" SPHERE), AND $1.5 \times 10^6 \frac{N}{CM^2}$ (10" CYLINDER). HOWEVER, ONE'S CONFIDENCE IN THE FLUX IS RESTRICTED TO AN ORDER OF MAGNITUDE, AT BEST, BY THE INTERPRETATION OF THE EFFICIENCIES WITH RESPECT TO ENERGIES OF EACH SPHERE.

DURING THIS TIME PERIOD THE NUMBER OF PROTONS AS MEASURED BY AN ION CHAMBER IN THE M2 BEAM LINE WAS 6.6×10^{13}. THIS YIELDS A NEUTRON : PROTON RATIO OF 1.4×10^{-6} N/P-CM^2 (1eV NEUTRONS), 7.7×10^{-7} N/P-CM^2 (10 eV NEUTRONS), AND 2.3×10^{-8} N/P-CM^2 (8MeV NEUTRONS). THE NUMBER OF PROTONS OBTAINED IS CONSERVATIVE, BECAUSE WE ARE UNABLE TO MEASURE THE NUMBER OF PROTONS ON A CONTINUOUS BASIS WHEN NOT TAKING DATA. HOWEVER, THE 6.6×10^{13} PROTONS FIGURE IS A LOWER LIMIT THAT IS ACCURATE WITHIN A FACTOR OF TWO.

IT WAS INITIALLY PREDICTED BY RADIATION SAFETY THAT FOR EACH PROTON STRIKING OUR TARGET .5 NEUTRONS IN THE 10^{-2} MeV TO 1MeV RANGE WOULD EMERGE FROM THE BACK. UNDER THE ASSUMPTION THAT THESE NEUTRONS ARE DISTRIBUTED WITHIN AN AREA OF ONE-TO-TWO SQUARE METERS, THEN THE PREDICTED FLUX OF NEUTRONS WOULD BE 5×10^{-4} - 2.5×10^{-4} N/P-CM^2. WHEREAS, THE MAGNITUDE OF NEUTRON FLUX THAT WE HAVE MEASURED IS BETWEEN 10^{-8} AND 10^{-6} N/P-CM^2.

EACH TLD CONTAINS A ^{6}Li AND ^{7}Li CHIP. ^{6}Li BEING SENSITIVE TO HIGH ENERGY HADRONS, γ, CHARGED PARTICLES, AND THERMALIZED NEUTRONS. ^{7}Li HAS THE SAME SENSITIVITY WITH THE EXCEPTION OF THE THERMALIZED NEUTRONS. THE Li CHIPS ARE CALIBRATED WITH ^{137}Cesium THUS INCORPORATING A FACTOR OF .25 IN THE MEASUREMENT. IN CALCULATING THE FLUX I HAVE ALSO INCORPORATED A 2.5 REM/RAD CONVERSION AND A FLUX TO DOSE EQUIVALENCY FACTOR. THE LATTER IS ENERGY DEPENDANT. THE TABLE FROM WHICH THE FACTORS WERE OBTAINED IS CONTAINED IN A REPORT ON 'NEUTRON DOSIMETRY ...', # TM-266.

IRRADIATION DESCRIPTION

	TLD AND TYPE	^{137}CS EQUIV. DOSE REC'D	NEUTRON DOSE	~ ENERGY RESPONSE TO NEUTRONS	MAX
2" SPHERE	Z-41-600	260 MRADS	107 MREM	10^{-2} - 10^{3} eV	~ 1 eV
	Z-41-700	89 MRADS			
3" SPHERE	Z-42-600	180 MRADS	61 MREM	10^{-2} - 10^{6} eV	10 eV
	Z-42-700	83 MRADS			
10" CYLINDER	Z-48-600	1.4 RADS	62.5 MREM	10^{6}-5×10^{7} eV	8 MeV
	Z-48-700	1.3 RADS			

ENERGY EFFICIENCY DISTRIBUTION FOR BONNER SPHERE TLD'S

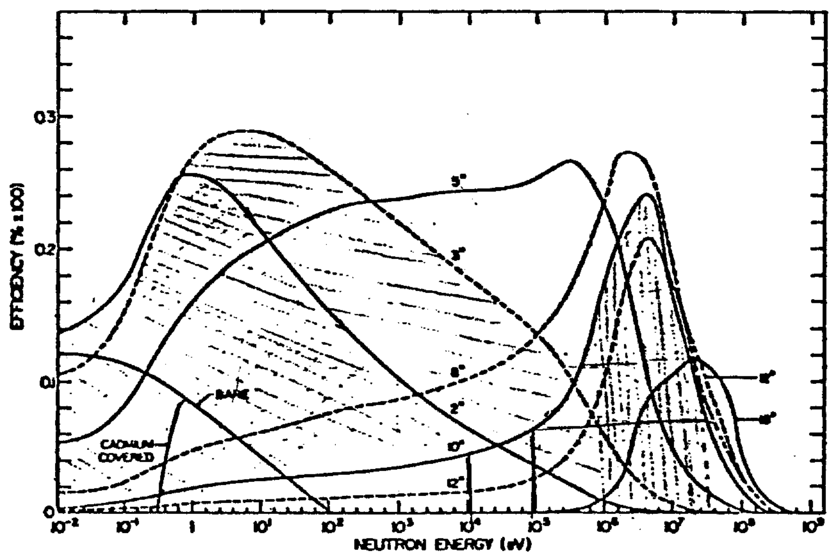


Figure 2 Efficiency of Different-Sized Bonner Spheres for Detecting Neutrons, as a Function of Neutron Energy

TABLE II

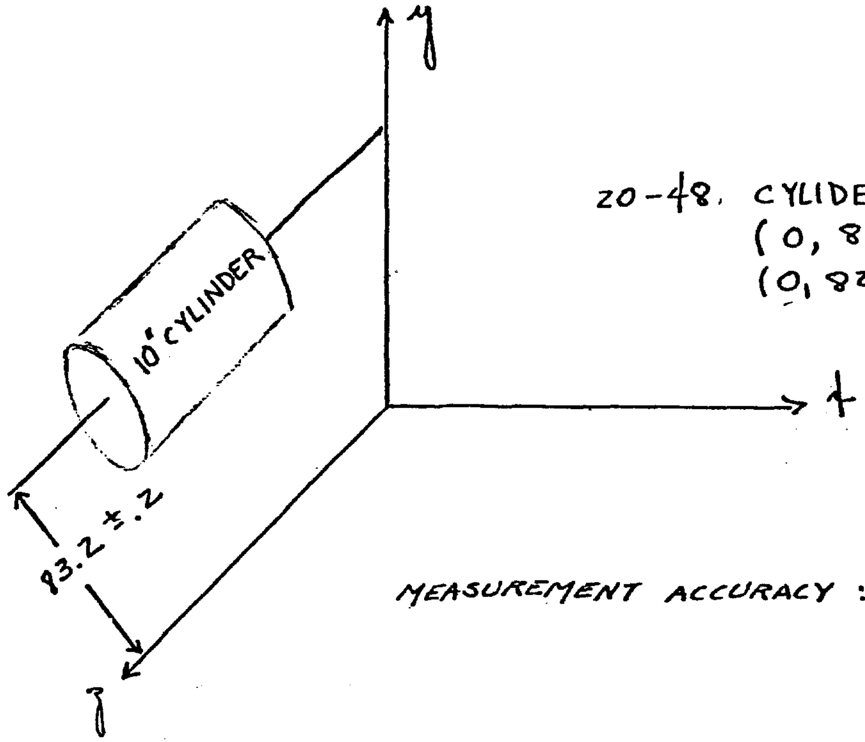
Flux to dose (rad/n/cm^2) and flux to dose equivalent (rem/n lcm^2) us neutron energy for normally incident flux.

ENERGY (MEV)	K(D)	K(DE)
1.00E-07	3.69E-10	1.06E-09
1.58E-07	3.84E-10	1.07E-09
2.51E-07	4.01E-10	1.09E-09
3.98E-07	4.18E-10	1.11E-09
6.31E-07	4.36E-10	1.13E-09
1.00E-06	4.54E-10	1.15E-09
1.59E-06	4.74E-10	1.18E-09
2.51E-06	4.94E-10	1.20E-09
3.98E-06	5.15E-10	1.22E-09
6.31E-06	5.37E-10	1.24E-09
1.00E-05	5.60E-10	1.26E-09
1.59E-05	5.84E-10	1.29E-09
2.51E-05	6.09E-10	1.31E-09
3.98E-05	6.35E-10	1.33E-09
6.32E-05	6.62E-10	1.36E-09
1.00E-04	6.90E-10	1.38E-09
1.59E-04	6.75E-10	1.36E-09
2.51E-04	6.61E-10	1.34E-09
3.99E-04	6.47E-10	1.33E-09
6.32E-04	6.33E-10	1.31E-09
1.00E-03	6.20E-10	1.29E-09
1.59E-03	6.07E-10	1.27E-09
2.52E-03	5.94E-10	1.26E-09
3.99E-03	5.81E-10	1.24E-09
6.32E-03	5.74E-10	1.39E-09
1.00E-02	5.68E-10	1.75E-09
1.59E-02	5.63E-10	2.22E-09
2.52E-02	6.08E-10	2.97E-09
3.99E-02	7.18E-10	4.20E-09
6.32E-02	9.54E-10	5.94E-09
1.00E-01	1.12E-09	8.00E-09
1.59E-01	1.40E-09	1.11E-08
2.52E-01	1.72E-09	1.55E-08
3.99E-01	2.20E-09	2.22E-08
6.32E-01	2.70E-09	3.40E-08
1.00E+00	3.78E-09	3.60E-08
1.59E+00	4.10E-09	3.80E-08
2.52E+00	4.50E-09	3.70E-08
3.99E+00	5.30E-09	3.90E-08
6.33E+00	6.40E-09	4.10E-08

TABLE II (continued)

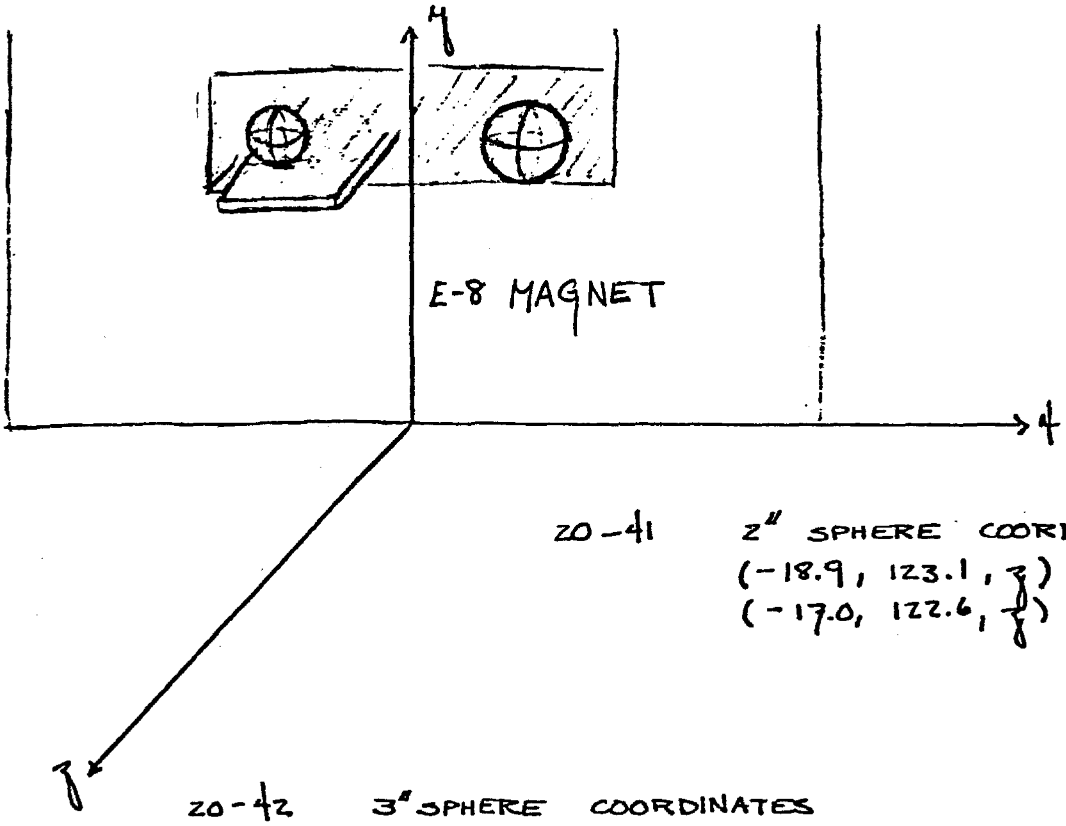
ENERGY (MeV)	K(D)	K(DE)
1.00E+01	7.00E-09	4.20E-08
1.59E+01	8.84E-09	5.48E-08
2.52E+01	9.52E-09	7.20E-08
3.99E+01	9.87E-09	7.80E-08
6.33E+01	1.00E-08	5.50E-08
1.00E+02	1.10E-08	5.00E-08
1.59E+02	1.25E-08	5.24E-08
2.52E+02	1.65E-08	5.80E-08
3.99E+02	2.25E-08	6.80E-08
6.33E+02	3.30E-08	8.50E-08
1.00E+03	4.20E-08	1.15E-07
1.59E+03	5.70E-08	1.42E-07
2.52E+03	8.00E-08	1.80E-07
4.00E+03	1.12E-07	2.25E-07
6.33E+03	1.50E-07	2.83E-07
1.00E+04	2.15E-07	3.53E-07
1.59E+04	2.93E-07	4.50E-07
2.52E+04	4.00E-07	5.60E-07
4.00E+04	5.50E-07	7.10E-07
6.33E+04	7.50E-07	8.80E-07
1.00E+05	1.05E-06	1.11E-06
1.59E+05	1.45E-06	1.41E-06
2.52E+05	2.00E-06	1.80E-06

TLD COORDINATES



20-48. CYLIDER COORDINATES
(0, 83.2 ± .2, z) ← END
(0, 82.9, z) ← START

MEASUREMENT ACCURACY : CYLINDER : ± .4
SPHERES : ± .6



20-41 2" SPHERE COORDINATES
(−18.9, 123.1, z) ← END
(−17.0, 122.6, z) ← START

20-42 3" SPHERE COORDINATES
(6.2, 121.3, z) ← END
(5.7, 120.8, z) ← START

RADIATION REPORT ON E-439 DUMP REMOVAL

On May 22, 1978 the tear-down and removal of the E-439 M2 dump was begun.

Radiation levels, measured with an elron, were not found to be as severe as expected.

ITEM	RADIATION LEVEL (mrem/hr) Coils	Bases
target block	6,000	---
magnet 1	2,000	800
magnet 2	500	50
magnet 3	< 1	< 1

All readings were made at contact at the hottest point except the target block which was estimated assuming a $1/r^2$ fall-off

Contamination levels were determined by taking a wipe on about 10 cm^2 of surface and reading it using a Nucleus pancake probe. Background readings were about 20 counts-per-minute (cpm).

As expected the hottest wipe, 5,280 cpm, came from the re-entrant cavity. The next hottest wipes were taken on the target block with readings between 300 to 100 cpm. The two faces of magnet 1 and the upstream face of magnet 2 all yielded readings between 350 and background. In fact for both magnets the contamination levels dropped to background within a 2 foot radius of the beam centre-line. No contamination was seen on magnet 3.

Contamination on walls, rod and other items was all found to be less than 100 cpm.

No tungsten or tungsten products were seen on a wipe made just prior to the tear-down.

Airborne contamination did not exceed 1.6×10^{-8} $\mu C/cm^3$ and in fact this was the maximum observed and occurred while rod was being removed from around the target blocks.

On the recommendation of the radiation safety group, items that were over 100 mrem/hr or that had contamination readings above 100 cpm were painted to affix the contamination.

A total of .371 man-rem was accumulated by 13 people during this job.

GROUP (# of people)		EXPOSURE TOTAL (mrem)
Meson operators	(2)	6
Riggers		
in-house	(3)	119
on site	(4)	25
E-439		
experimenters	(2)	56
RSO and		
assistant	(2)	165

Over 1/3 of the total exposure was accumulated during radiation surveys, contamination checks, painting and contamination cleanup. Possibly as much as 100 mrem could have been avoided had the aluminium rods been pre-bundled for immediate crane handling.

The packing of items should be arranged to allow the hottest and largest parts of the dump to be removed first in order to reduce man-rem in handling small, one-at-a-time items.

If the target block and re-entrant cavity block had been welded together some time could have been saved in handling.

The suggested target drawer concept would probably keep exposures within tolerable levels even at far higher beam intensities and would do away with the piecemeal disassembly of the dump.

In future, all items going into dumps of this sort should be thoroughly cleaned to prevent contamination levels similar to those found in the re-entrant cavity.

Lastly a word of thanks to Sam Childress and John Rutherfoord of E-439 for their assistance with the dump tear-down.

RT:bb

cc: D. Jovanovic
J. Peoples
R. Pollock
J. Rutherfoord
T. Toohig
File

QF = 5 in instrument
9/8/78 Conversation with R. Gustafson: He inquired of L. Jones who said quoted numbers are raw numbers from the beam-on matter.

APPENDIX III

UM HE 78-34
July, 1978

The Muon Flux from E439 Beam Dump Targeting

L.W. Jones, H.R. Gustafson, K. Heller, M.J. Longo, B.P. Roe

University of Michigan
Department of Physics
Ann Arbor, MI 48109

The E4 calorimeter was set up 22 m from the face of the E439 heavimet target. The E439 detector consisted of 5.5 m of iron magnetized to 21 k Gauss and of the 5.4 m E8 sweeping magnet, with its aperture plugged and with no field. Thus there was a total of 10.9 m of iron in the beam line with the front portion magnetized in a horizontal plane so as to produce a vertical $\Delta p = 3.5$ GeV/c (Figure 1).

A three counter telescope straddling the calorimeter (900 g/cm^2 Fe) defined an axial (0.3 m)^2 area ($\Delta\Omega \cong 2 \times 10^{-4}$ sr). Muons were detected in this telescope at a rate of ~5000 per 10^{11} protons, or ~ $2.5 \times 10^{-4} \mu$ per (proton.sterad.) on axis.

The radiation, running at a flux of ~ 10^{11} protons per pulse on the E439 target, was mapped in the plane between the E8 magnet and the calorimeter, with readings noted on Figure 2. The proton flux on target was only known approximately and fluctuated during this period, so that these readings may have a relative uncertainty of a factor of 2. Some single unshielded counters had very high singles rates; whereas the 60 x 60 cm^2 counters on the beam axis had a counting rate of about 10,000 per 10^{11} protons on target the large counters off of the median plane contributed a summed anticoincidence rate of over 25 million per 10^{11} protons. From the scintillation counter data, it appears that most of the radiation is due to muons.

The gross pattern seen here is a dramatic flux increase in the vertical midplane and a gradual falloff in flux in the horizontal midplane.

Some of the muon flux came not from the E439 target but from the meson target 450 m upstream. With the M2 beam stop in and the beam-line magnets turned off the muon flux was about 300-400 per pulse of 5×10^{12} protons on the meson target.

The muons detected from the E439 target must either be quite energetic or have a pathological history in the apparatus. To be detected in this muon telescope a muon from the target would have a minimum momentum correlated with its production transverse momentum; if $p_{\perp} \leqslant 1$ GeV, $p \geqslant 270$ GeV; if $p_{\perp} \leqslant 2$ GeV, $p \geqslant 130$ GeV.

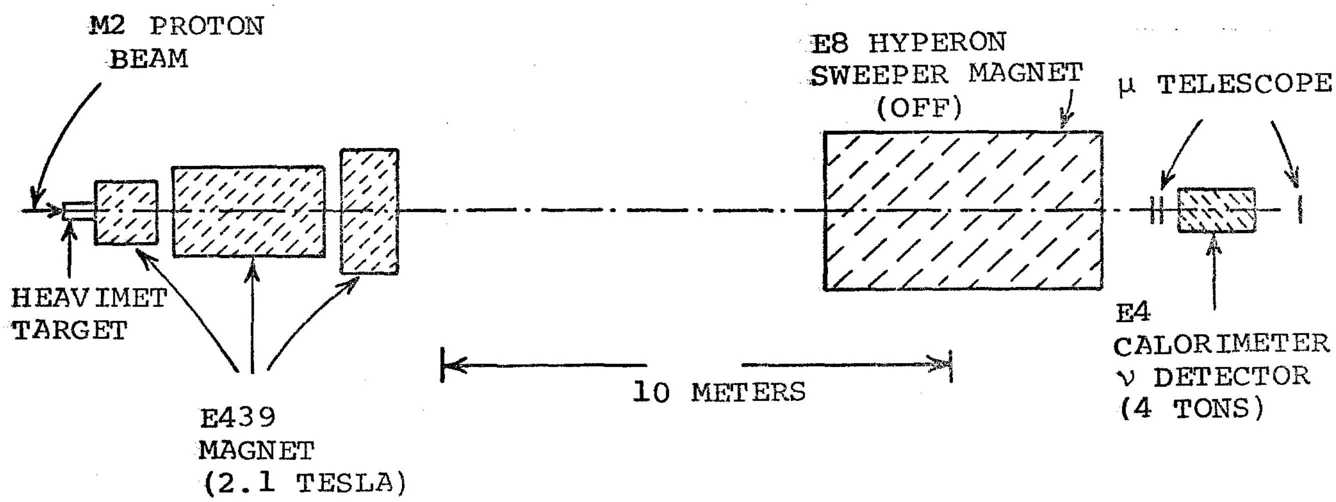


FIGURE 1

EXPERIMENT
CONFIGURATION

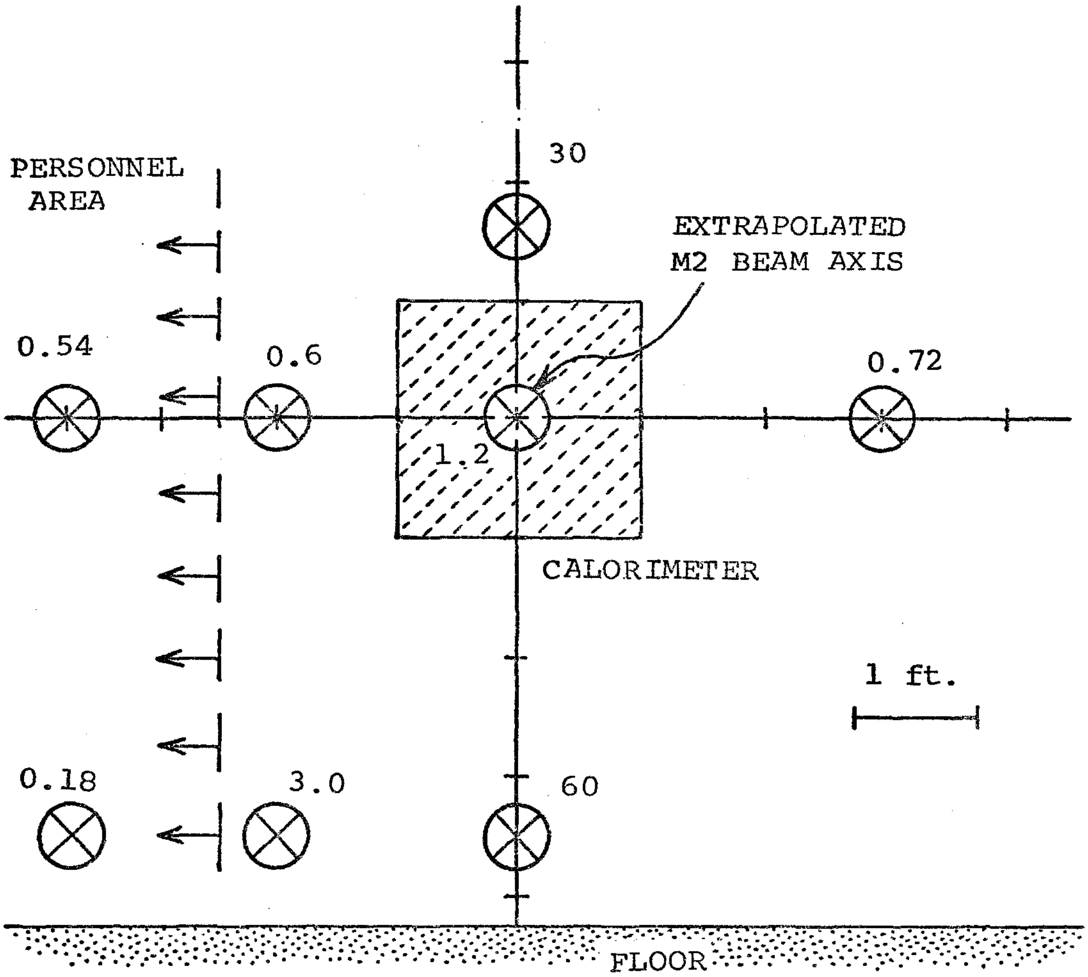
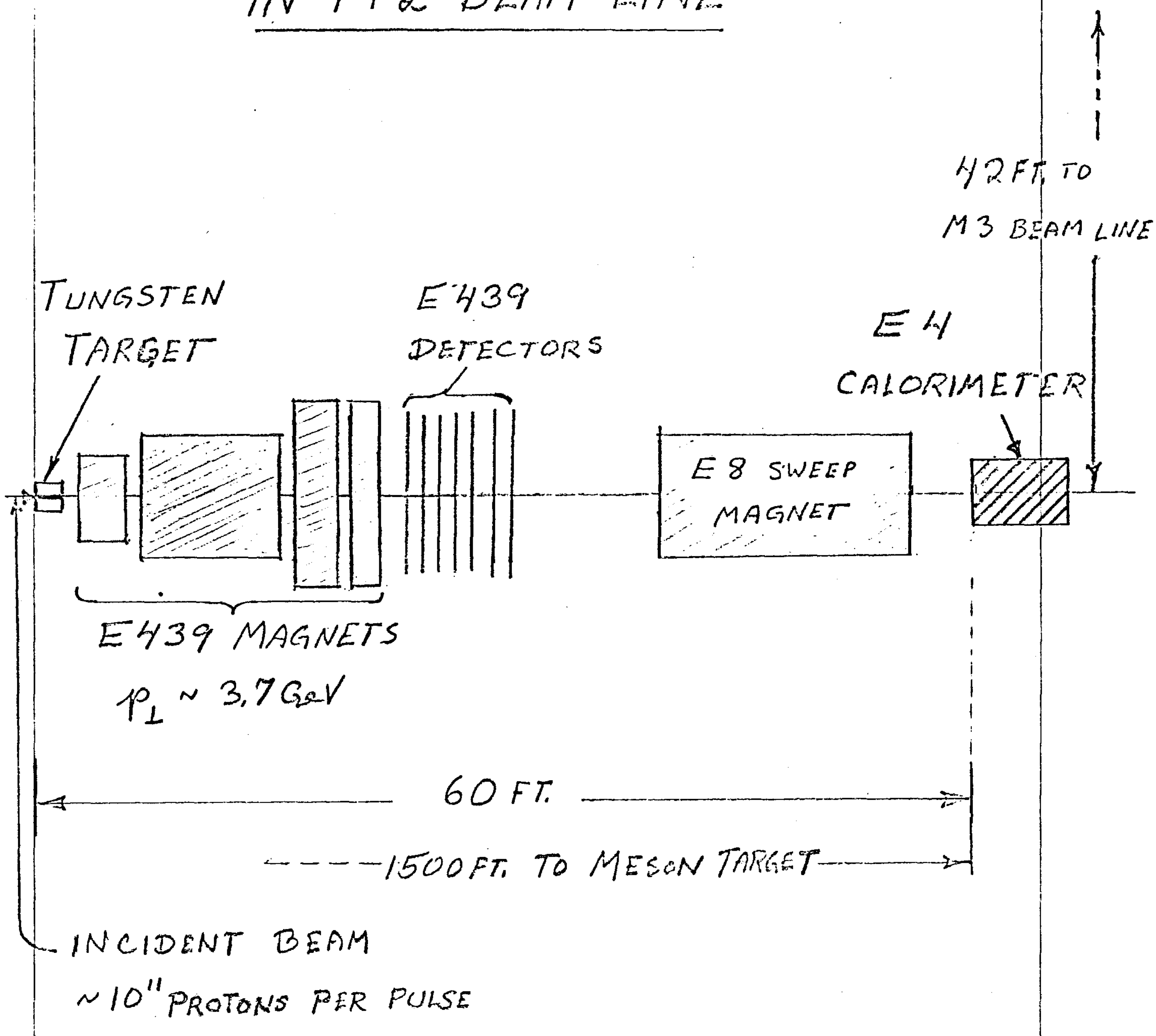


FIGURE 2

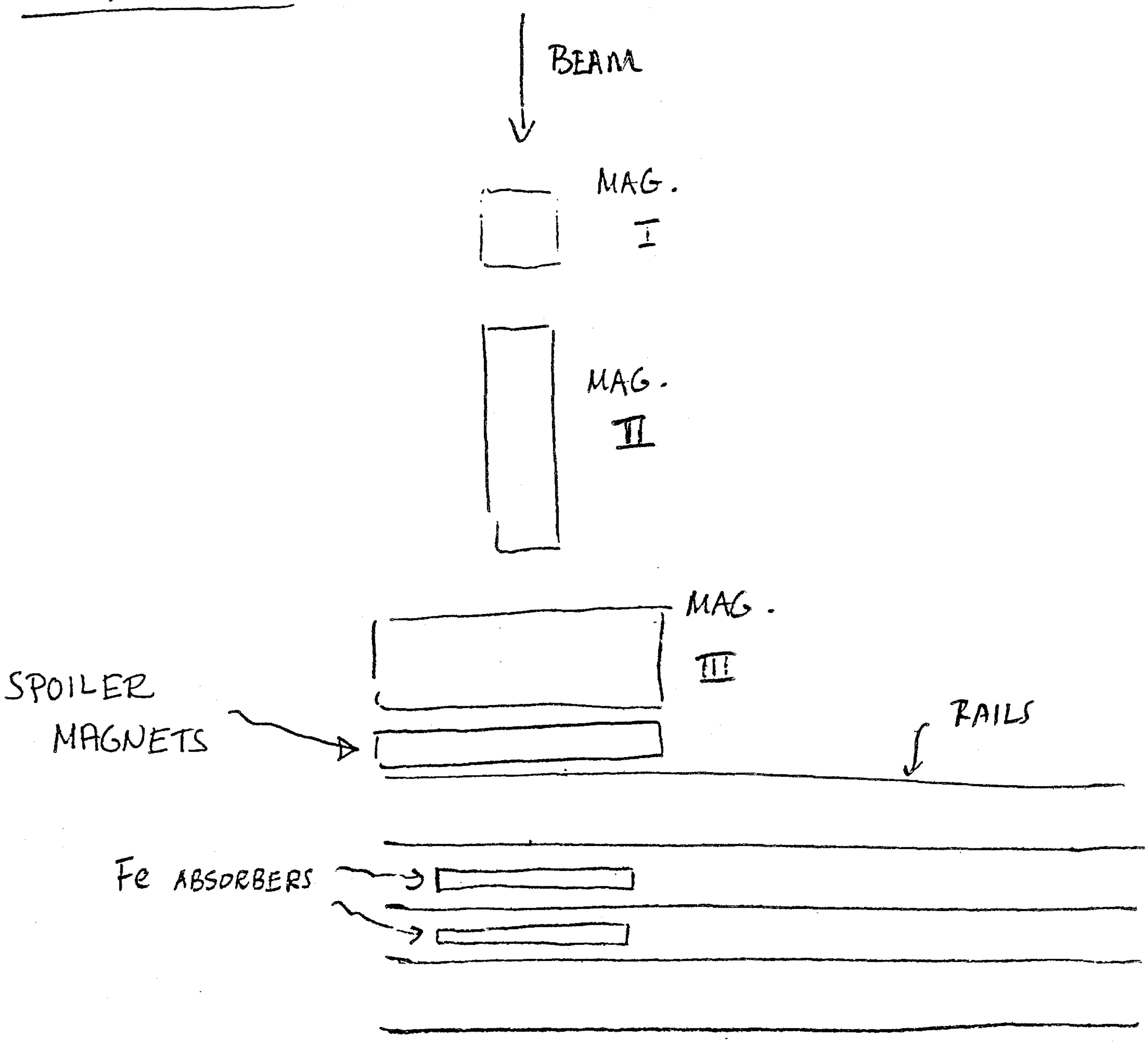
RADIATION LEVEL (MUONS) AT NEUTRINO TEST AREA BEHIND E439.
LEVELS ARE IN mR PER HOUR WITH $\sim 10^{11}$ PROTONS PER PULSE ON E439 TARGET.

LOCATION OF E 4 CALORIMETER RELATIVE TO E439 SYSTEM IN M2 BEAM LINE



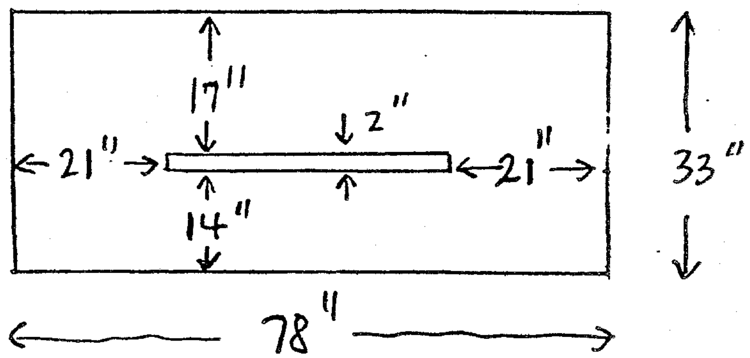
(D)

E439 LAYOUT



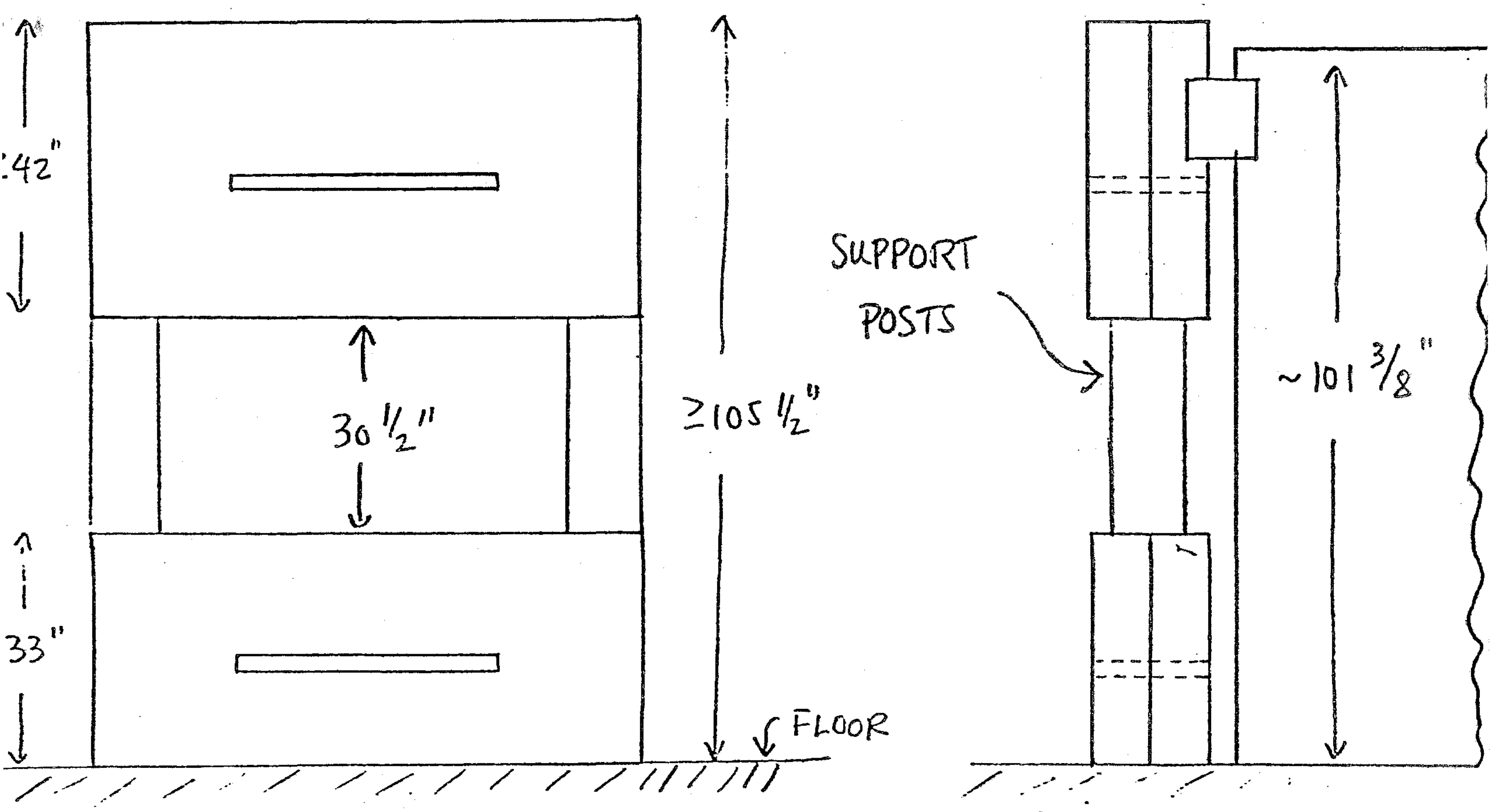
(C)

⑤ BOTTOM SPOILER (~16" THICK)

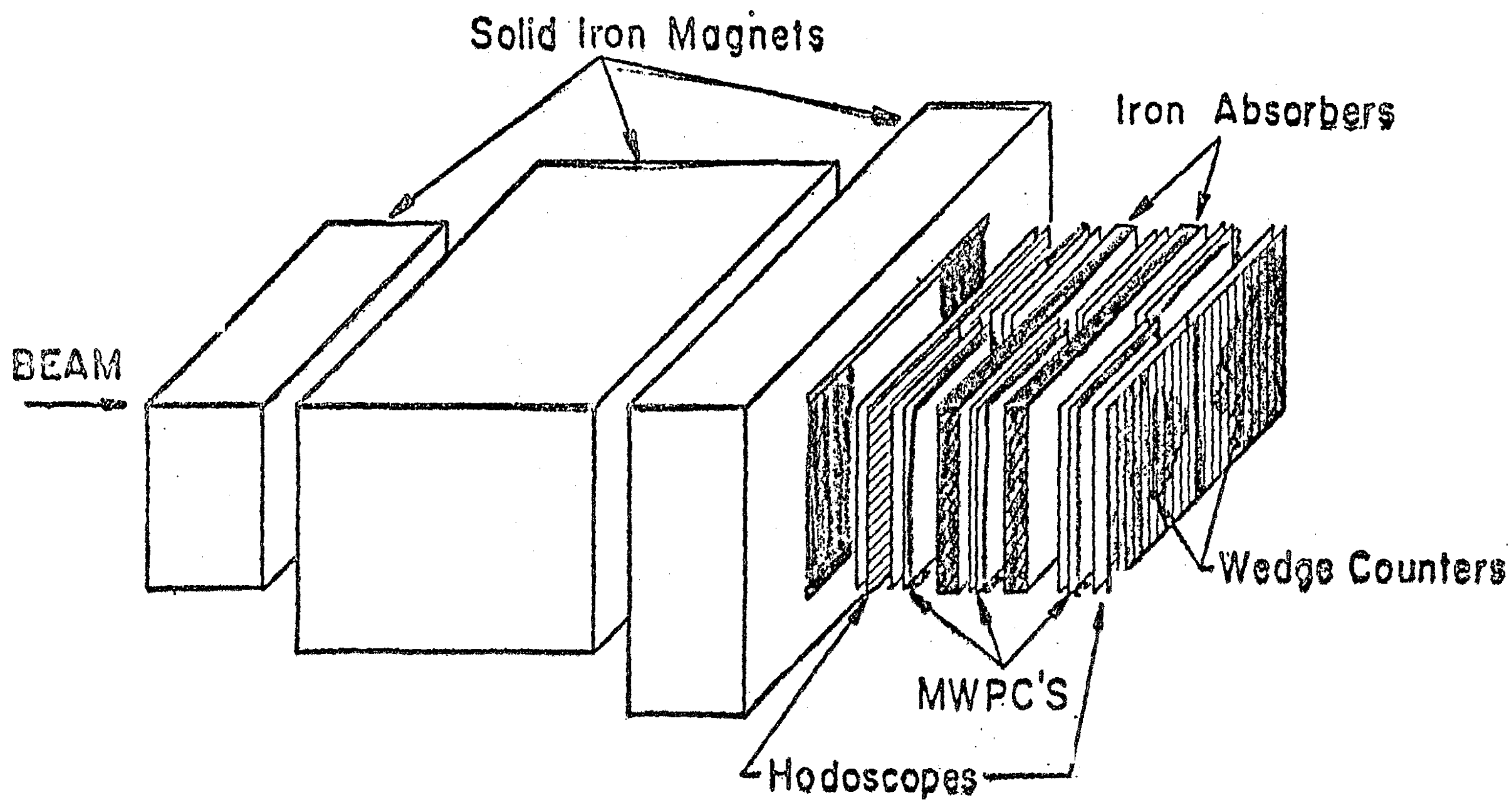


⑥ SPOILER ASSEMBLY

MAG III



Multi Muon Detector Schematic



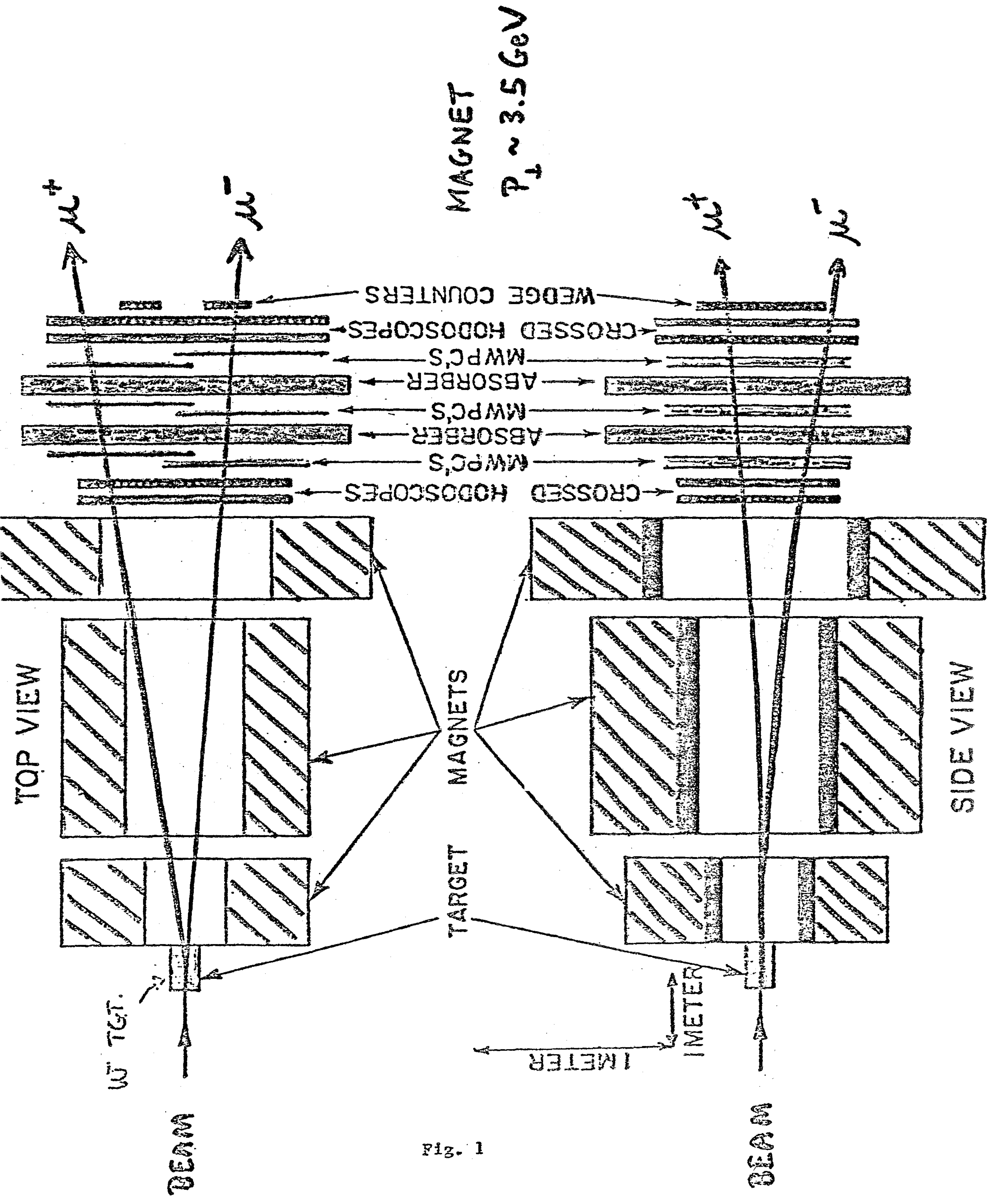

MAGNET
$P_\perp \sim 3.5$ GeV
μ+
μ-
μ+
μ-
WEDGE COUNTERS
CROSSED HODOSCOPES
MWPC'S
ABSORBER
MWPC'S
ABSORBER
MWPC'S
CROSSED HODOSCOPES
TOP VIEW
MAGNETS
SIDE VIEW
TARGET
W TGT.
1 METER
1 METER
BEAM
BEAM

Fig. 1