Fermi National Accelerator Laboratory

TM-1564

# The A0 Abort System for the TEVATRON Upgrade

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# THE TEVATRON UPGRADE ABORT SYSTEM

## (i) INTRODUCTION

The installation of electrostatic separator modules at B48 and C17 in the Tevatron necessitates changes to the Tevatron abort system.[1] There will no longer be room for either the proton or antiproton kicker magnets used in the present system. The kickers at C17 will be permanently removed. The kickers at B48 will be temporarily removed for collider operation and will be replaced for fixed target operation.[2] The existing proton abort system will remain unchanged during fixed target operation. This note describes a proposed abort system for operation in the collider mode for 22 on 22 bunches and provides details of specifications for the required components. In certain cases, for example in the case of the pulsers for the magnets and the absorber assembly, system components are designed with the option of upgrading to 44 on 44 bunch operation in mind.

## (ii) SYSTEM REQUIREMENTS

BEAM INTENSITY:
(10 E 10 per bunch)x(22 bunches) @ 150 GEV = 2.2 E 12 PROTONS
(6 E10 per bunch)x(22 bunches) @ 1 TEV = 1.3 E12 PROTONS
(6 E10 per bunch)x(22 bunches) @ 1 TEV = 1.3 E12 ANTIPROTONS

REPETITION RATE:
Proton aborts:
1 @ 150 GEV per 2 minutes for a maximum of 4 hours per day
6 @ 1 TEV per day
Antiproton aborts:
2 @ 1 TEV per day
183 operational days per year

INSTANTANEOUS LOSSES
A beam displacement of 10 mm into the abort absorber and an incident angle of 0.001348 radian ensure that essentially no particles of primary beam energy leave the absorber. Superconducting elements downstream of the abort system can be heated by lower energy secondary particles that escape the

absorber. The quadrupole magnets on either side of the A0 straight section receive the highest flux of this type. The quench limit for elements of this type is approximately 1 mJoule per gram of deposited energy.[3] We assume here that a factor of ten less than this is a safe upper limit.

RESIDUAL RADIOACTIVITY

External surfaces of the absorber assembly are to be less than 0.1 Rad per hour 24 hours after the most recent activation. External hadron and muon fluxes are to be within Fermilab radiation guidelines.

## (iii) THE SYSTEM

The new abort will use all the space in the A0 long straight section. This space will be made available by removing all five extraction Lambertson magnets and the three skew dipole magnets in the extraction channel. The configuration of the new abort system is shown in Figure 1. Both Protons and Antiprotons are kicked downward into a common absorber assembly centered at A0. The closed orbit and aborted beam positions at three different longitudinal locations within the absorber are shown for 150 GEV and 1 TEV in Figures 2 through 4.

It is useful to compare aperture limitations in this case with those of the present abort at C0.[1] The limiting aperture at C0 is the poleface of the Lambertson magnets. For 24 pi mm mr normalized emittance beam (the case for fixed target operation) the aperture is 6.1 sigmas away from the injection orbit at C0. The limiting aperture at A0 is the edge of the beam vacuum tube through the abort absorber. For 15 pi mm mr normalized emittance beam (the case for collider operation) this aperture is 4.7 sigmas away from the injection orbit for protons at A0. A 2mm local vertical bump upward may be needed for this case. This presents no problem since the downward vertical angle of the abort kick can be increased to maintain the same displacement at the face of the absorber . At 1 TEV the proton beam on the separated orbit is 12 sigmas away from the beam tube edge. This is acceptable.

Individual component specifications for the abort system are as follows :

(a) <u>MAGNETS</u>

Five magnets are used to provide the downward kick for each particle beam. The design of this magnet is based on that of the existing Tevatron abort kicker. A detailed description of this type of magnet is given in Reference number four . Specifications for the new magnet are shown in Figure 5. A different poleface gap and width were chosen for this location in order to minimize current needed for the required kick angle. This allowed the use of less expensive and more readily available round ceramic beam tubes instead of the elliptical tubes used previously. Beam positions for separated orbits at the face of the antiproton kicker magnets are shown in Figure 6. Aperture is not a problem for the 44mm beam tube size chosen.

Steel was added to the flux return path in order that the fields inside the steel remain below 18 KG at currents suitable for 2 TEV aborts. This will allow the magnets to be re-used in future energy upgrades.

(b) <u>MAGNET POWER SUPPLIES</u>

Each magnet is powered by its own independent pulsing unit. The specification for this pulser is shown in Figure 7. The design is an improved version of the power supply for the existing Tevatron abort magnets. Thyratron switches must handle higher currents than in the existing system and special attention is paid to preventing spurious tube firing. Operation of the Tevatron in the collider mode does not require response of the abort trigger pulse to the breaking of the abort loop for at least 500 microseconds. This time could be used to charge the pulser capacitors. This provides safety against firing of any of the modules accidentally during stores. Provision for the adoption of pulsed charging techniques will be made in the new pulsers. This option will not be chosen unless data from the

1989 part of the Tevatron collider run with improved trigger circuits indicates that pulse charging is necessary.

The beam loading scheme for 44 bunch operation leaves a 2.6 microsecond gap as shown in Figure 8. The time constant for the rise of the kicker waveform is set by choosing 70% deflection in this amount of time. This is equivalent to 100% deflection in 4.8 microseconds. The required kick angle and the inductance of the magnet / cable system determines the peak current and this in conjunction with the time constant determines the peak voltage on the system. The numbers presented in Figure 7 are based on the assumption that two new service buildings will be constructed at A0 in order to minimize the lengths of cabling between the power supplies and the magnets. If cables are run through the closest existing penetrations at A0, an additional 25 Meters of cable length would be necessary for each magnet. This would have the effect of raising the inductance and therefore the voltage of the system by 25%. When the cost of relocating existing equipment needed for the fixed target program and the cost of installation of the extra lengths of six parallel augmented shield RG-220 cables are considered[5], new service buildings are evidently a cost effective way of providing a high voltage safety margin to ensure reliable operation and minimize related failures.

(c) ABSORBER

The purpose of the absorber assembly is to receive all the primary charged particles in the circulating proton and antiproton beams, to prevent their scattering back into the acceptance of the accelerator, and to contain the shower of secondary and higher order particles that is produced when the beams strike a solid target. The absorber must be constructed in a way that dissipates enough of the energy of the aborted beams to prevent quenching of cryogenic components and that limits radiation flux into the tunnel and other accelerator equipment to within guidelines.

The goal in designing the absorber is to choose a set of materials and arrange them in a way that minimizes the length of the assembly needed to contain the aborted beams and that will not be destroyed by thermal effects from the energy deposition. These destructive effects come about in two ways: long term heating effects that tend to melt metals and make graphite more chemically reactive and thermal shock waves that tend to break any type of material.

The absorber consists of a stack of one inch thick graphite, aluminum, and and steel lamina enclosed in a water cooled aluminum collar assembly. The use of lamina instead of continuous material minimizes the probability of fractures due to thermal shock. The graphite and the steel plates are contained in their own vacuum system that is separated from that of the Tevatron beam vacuum system by a 0.060 inch thick aluminum tube. The vacuum system for the graphite serves two purposes: it provides an inert environment for the heated graphite, thus preventing weight loss due to oxidation and it removes all external atmospheric forces from the beam vacuum tube, lessening the chance of stress induced failure. A cross sectional view of the abort absorber is shown in Figure 9.

INSTANTANEOUS THERMAL EFECTS

The longitudinal arrangement of the graphite, aluminum and steel in the absorber assembly is shown in Figure 10.
The energy deposition per incident 1 TEV proton or antiproton and the instantaneous temperature increment for an abort of 5.3 E 12 particles corresponding to this arrangement are shown in Figures 11 and 12.[6] The maximum energy deposition in the graphite is 678 Joules/gm. The present tevatron abort[7] operates at up to 1000 joules/gm at an intensity of $1.5 \times 10^{13}$. Experience has indicated no problems with operation at this level.

## STEADY STATE THERMAL EFFECTS

The steady state temperature distribution for the specified repetition rate is shown in Figure 13. The water cooling in the aluminum collar assembly has been turned off for these calculations. 500 watts/meter was used as the average energy input. The maximum energy deposition from Figure 11. corresponds to 162 watts / meter for one 1 TEV abort every hour and 30 150 GEV aborts every hour. There are no problems with temperatures even without the water cooling system.

## QUENCH LIMITS OF TEVATRON LATTICE COMPONENTS

Calculations using the MARS10 Monte Carlo program for nuclear shower development show that at 1 TEV the maximum energy deposition in the superconducting coils of the first cryogenic component of the TEVATRON lattice is less than 0.002 mJoule per gram at 1 TEV and 5.3 E 12 particles. This number is derived by scaling the value shown in Figure 14 (for 6.8 mm beam offset) linearly with energy and intensity. This is approximately a factor of 500 below the quench threshold.

Minimizing the energy deposition in the superconducting coils was the criterion that determined the choice of abort layout geometry. The arrangement of a central absorber with magnets on either side was the only pattern found that satisfied the requirements. This is primarily because of the relatively large aborted beam centroid displacement and the fact that the kicker magnets themselves act as absorbers for low energy particles.

RESIDUAL RADIOACTIVITY OF THE ABSORBER ASSEMBLY

A MARS10 calculation of induced radioactivity at the external surface of the absorber assembly of Figure 9 indicates that contact levels 24 hours after activation will be less that 100 mrem/hr for the 44 bunch operating scenario . This is less than activation levels during fixed target operation for the extraction Lambertson magnets that the absorber will be replacing.

HADRON FLUX INTO THE SOIL

The program CASIM was used to calculate the number of hadrons escaping the absorber assembly. This number was then translated to radiation load on the local aquifer. The results for the geometry of Figure 9 are that a maximum number of 1.5 E 16 particles at 1 TEV can be aborted per year[8] and still remain within Fermilab guidelines.

Some particle counting is necessary to see if this requirement is satisfied by the chosen abort geometry and the operation scenario of section (ii). We first need to translate the 150 GEV proton aborts to their 1 TEV equivalent. (This will be seen to be the predominant radiation load.) For 22 bunches:

(2.2 E 12 $P^+$)x(30/hr)x(4 hr/day)x(183 days/yr) = 4.9 E 16 $P^+$/yr

To calculate equivalent particles at 1 TEV we multiply by the factor $(150/1000)^{0.8}$. This gives 1.1 E 16 particles at 1 TEV.

The contribution of the 1 TEV protons is smaller:

(1.3 E 12 $P^+$)x(10/day)x183 days/yr) = 2.4 E 15 $P^+$/yr

The antiproton contribution is smaller still:

(1.3 E 12 $P^-$)x(2/day)x(183 days/yr) = 0.5 E 15 $P^-$/yr

The total is then: 1.1 E 16 + 2.4 E 15 + 0.5 E 15 = 1.4 E 16/yr.

The geometry of Figure 9 is therefore adequate for 22 bunch operation. CASIM indicates that an additional three inches of steel on the sides and bottom of the absorber increases the allowable number of aborted particles to 2.6 E 16 per year. This would be done in the case of operation at 44 bunches, although it would be necessary to remove approximately one inch of concrete from the surface of the tunnel floor in order to squeeze three inches of steel under the bottom of the assembly.

ABOVE GROUND MUON DOSE RATE

Approximately the same amount of earth shielding exists at A0 as at the site of the present abort at C0. The muon rate will be lower at the A0 abort because of the lower number of beam aborts and the lowered intensity per abort.

(iv) REFERENCES

1) Harrison,M. , The TEVATRON Abort System, UPC-153,11/1981.

2) Malamud,E. , TEVATRON Orbit Separation Design, 9/3/88.

3) Design Report, Fermi National Accelerator Laboratory Superconducting Accelerator, May 1979, p.226.8

4) Krafczyk, G., et. al., A 3 KG Kicker Magnet System for the Tevatron Beam Abort System,IEEE, Vol. NS-28, No. 3, June 1981.

5) Crawford, A., The Effect of Cable Length on th A0 Kickers, Fermilab internal memo, 1/23/89.

6) Crawford, A. and Mokhov, N., Beam Abort Dump for the Tevatron Upgrade, 1-20-89.

7) Kidd,J., et.al., A High Intensity Beam Dump for the TEVATRON Beam Abort System, IEEE, Vol. NS-28, No. 3, June 1981.

8) Yurista, P., Fermilab Engineering note of 2/13/89.

## FIGURE CAPTIONS

FIGURE 1. Tevatron upgrade abort layout.

FIGURE 2. Proton beam position at the absorber face.

FIGURE 3. Separated beam positions at the center of the absorber.

FIGURE 4. Antiproton beam position at the absorber face.

FIGURE 5. Specification of the kicker magnet.

FIGURE 6. Separated beams at the entrance to the antiproton kickers.

FIGURE 7. Magnet pulser specifications.

FIGURE 8. Alternate 44 bunch injection pattern.

FIGURE 9. Cross section of the graphite portion of the absorber.

FIGURE 10. The longitudinal structure of the absorber core.

FIGURE 11. Longitudinal distribution of energy deposition in radial bins of the core.

FIGURE 12. Instantaneous temperature rise distribution corresponding to Figure 11.

FIGURE 13. Graphite temperature in the core.

FIGURE 14. Maximum energy deposition density in the first downstream quadrupole following an abort of 2 E 12 protons at 1.5 TEV.

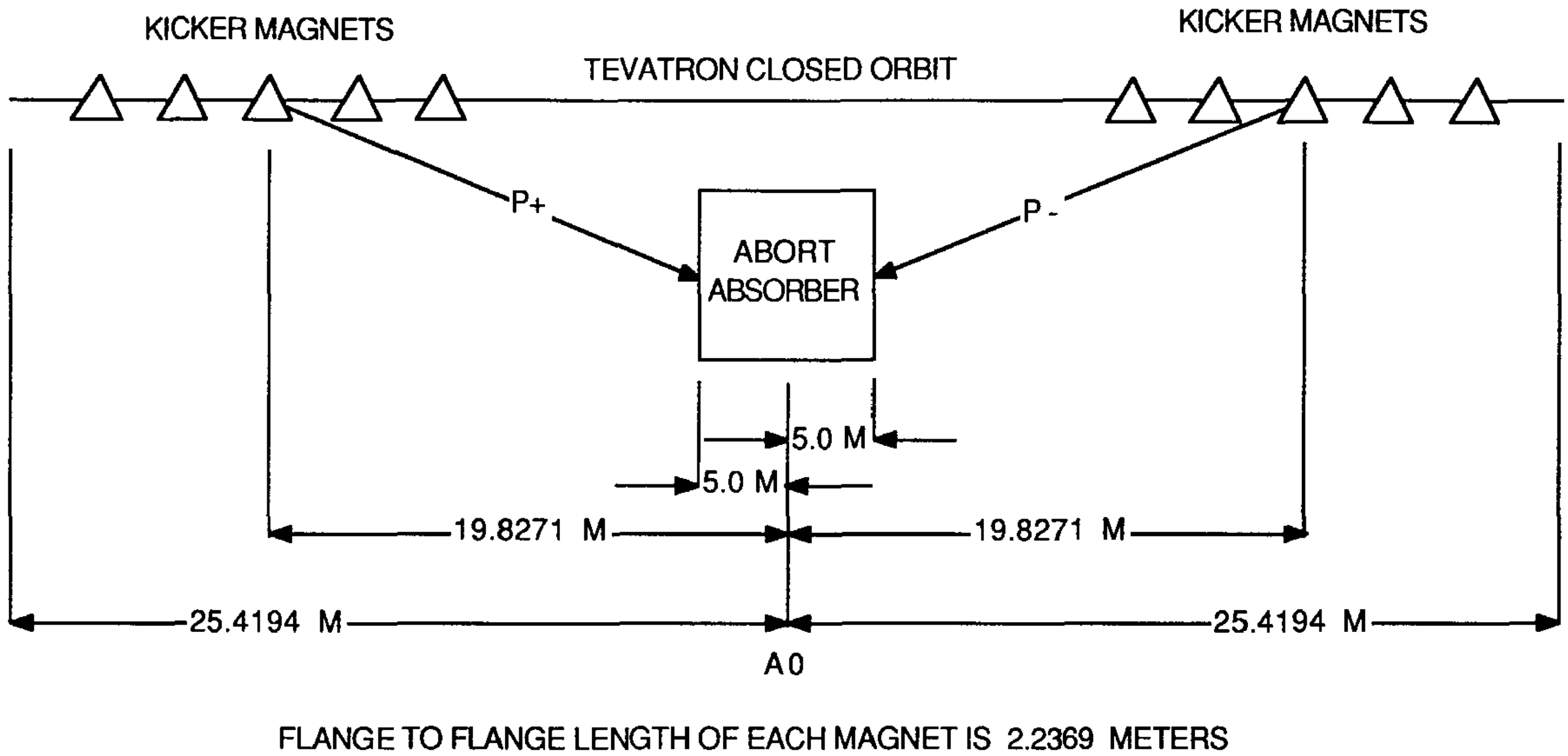



FIGURE 1. TEVATRON UPGRADE ABORT LAYOUT

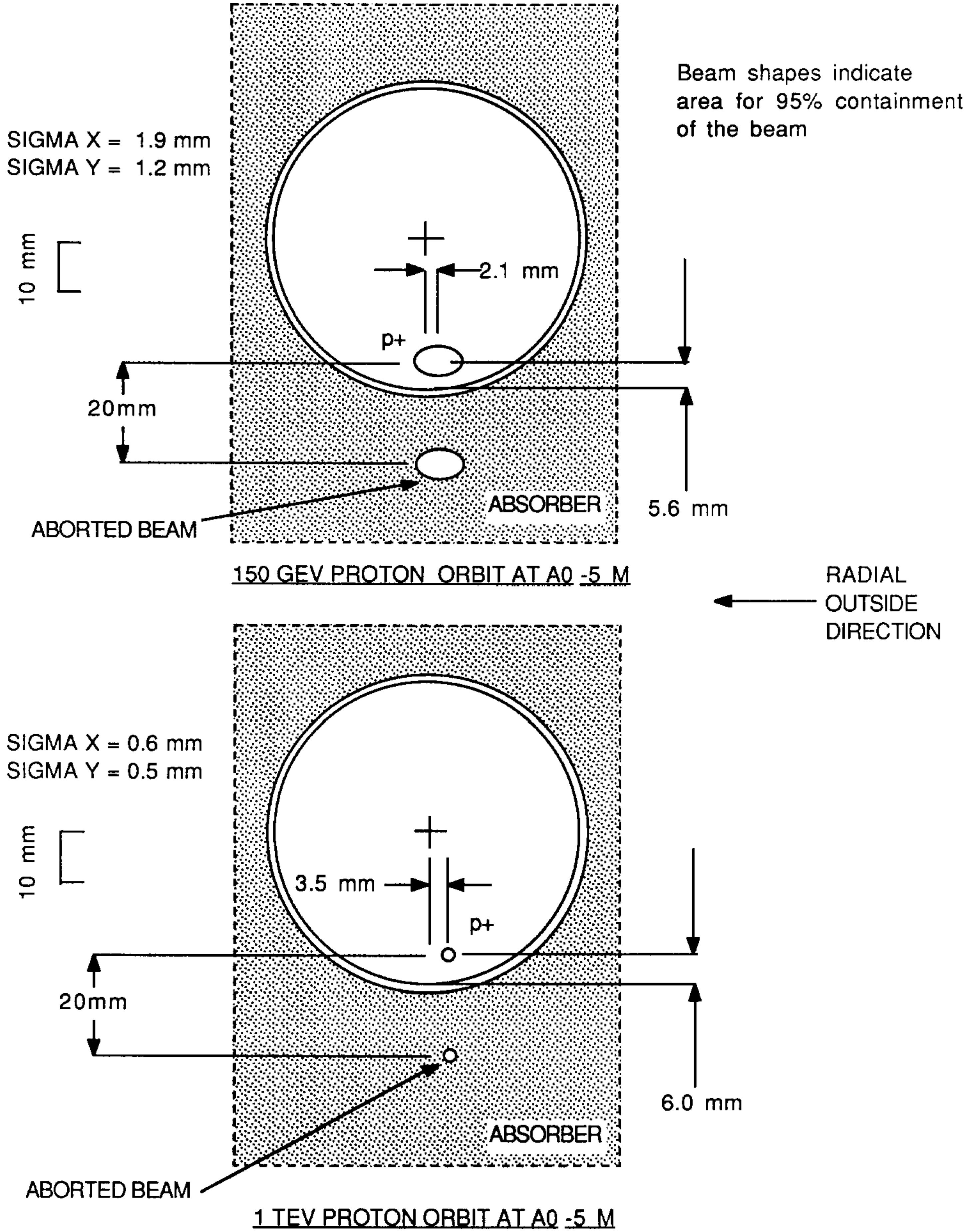



FIGURE 2. PROTON BEAM POSITION AT THE ABSORBER FACE

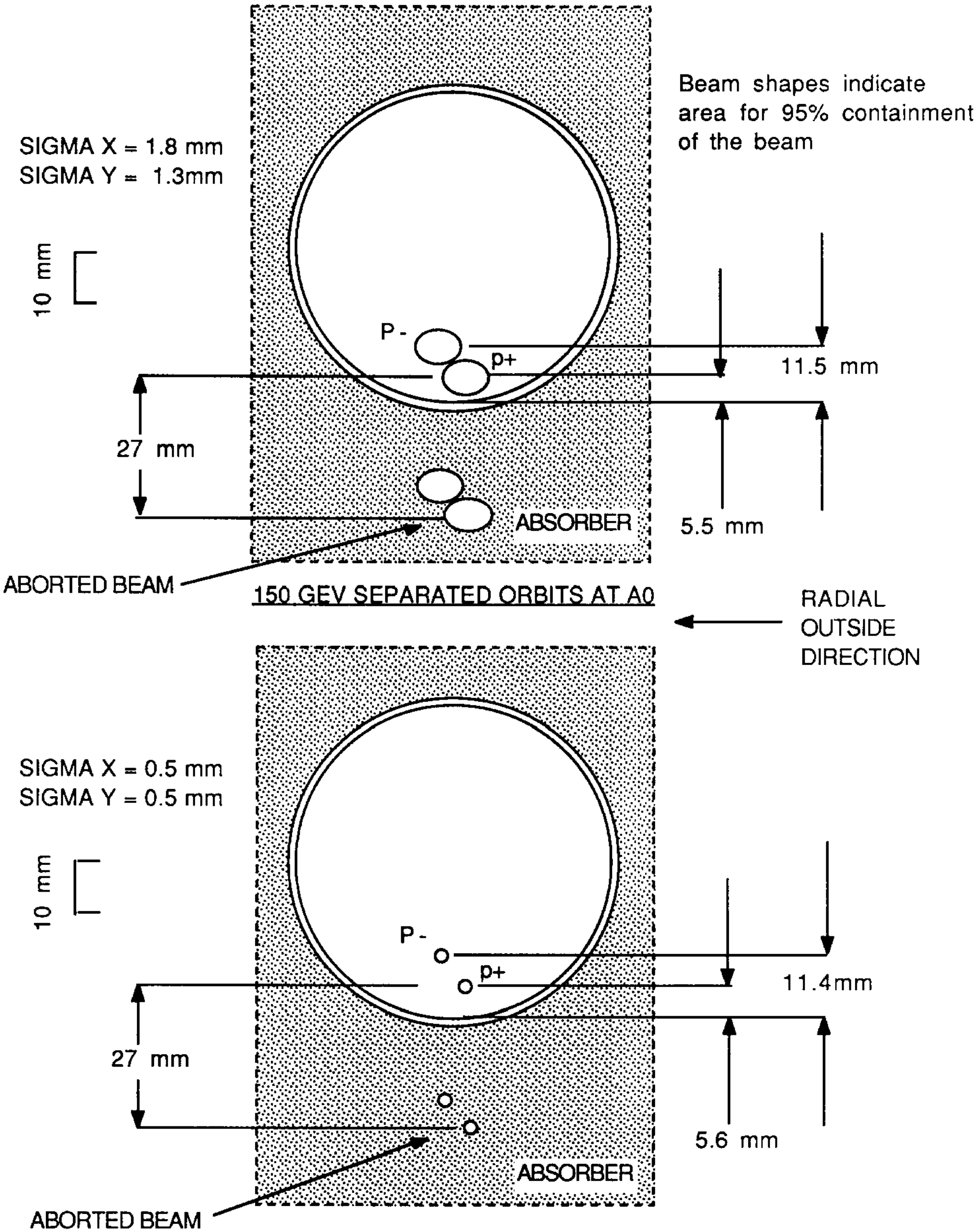
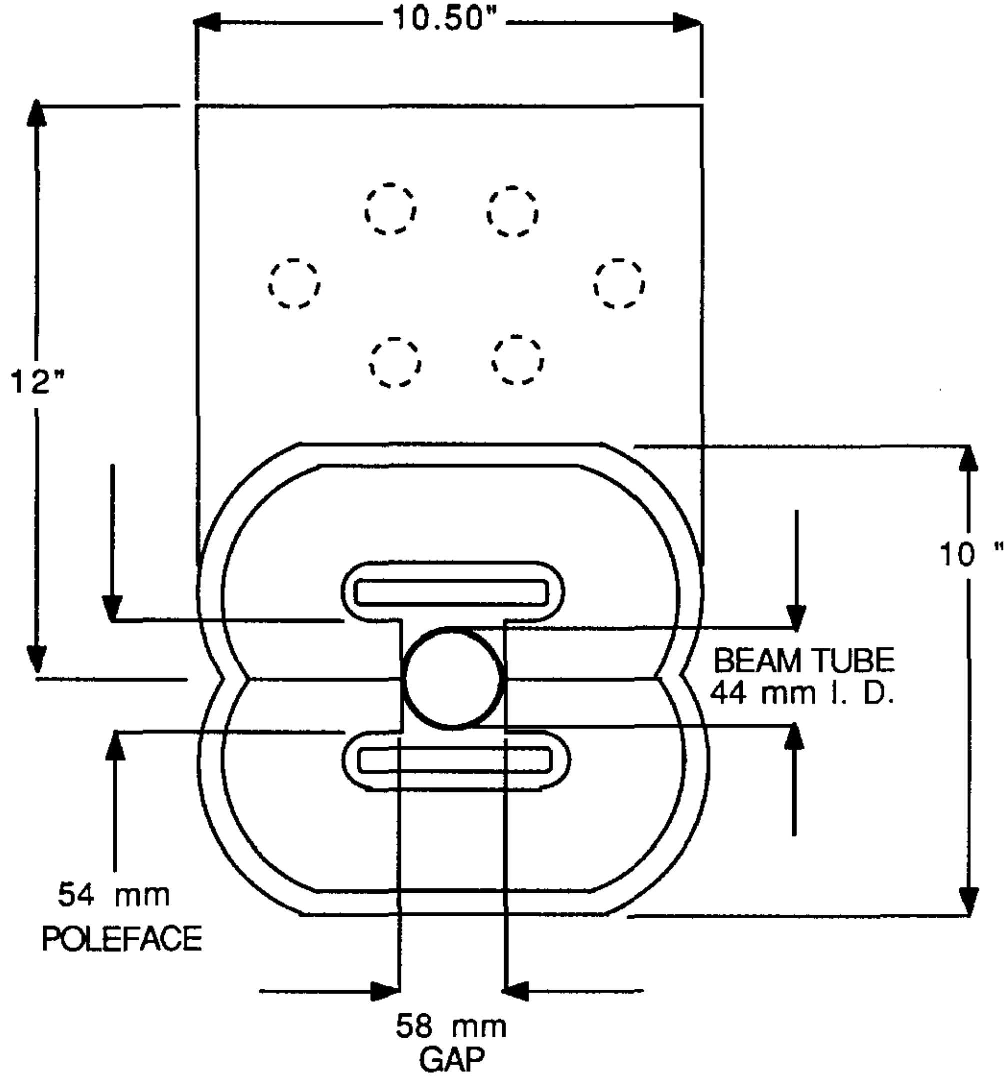



FIGURE 3. SEPARATED BEAM POSITIONS AT THE CENTER OF THE ABSORBER

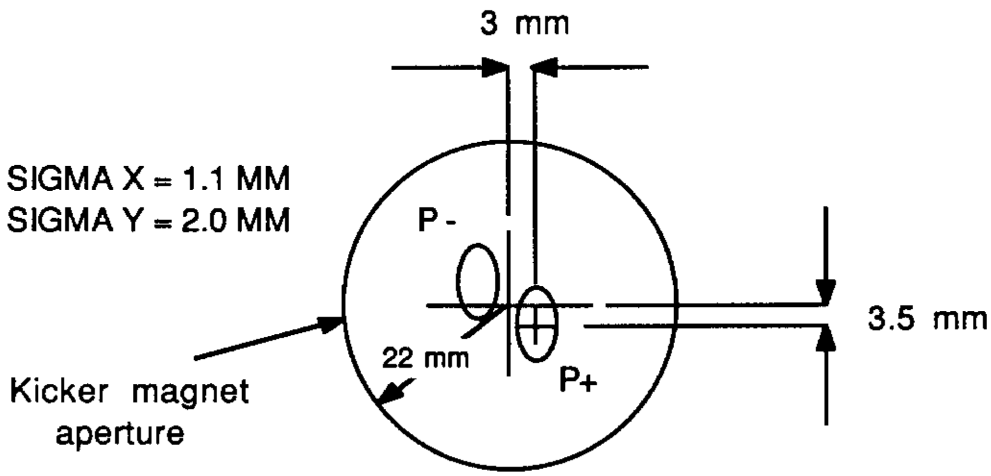



Magnet cross section showing cable connection box

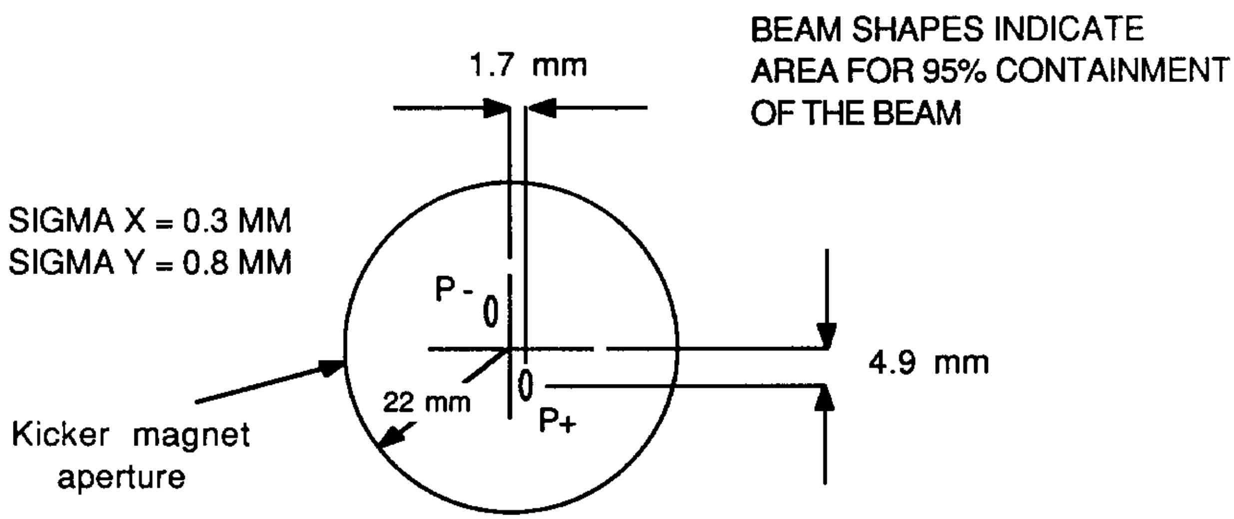
SPECIFICATIONS:

| | |
|---|---|
| Physical length: | 2.2369 M |
| Active length: | 1.9179 M |
| Magnetic field: | 4.689 KG |
| Current: | 22.817 KA |
| Inductance: | 3.15 Micro Henry |
| Field Uniformity: | Better than 5% within a radius of 15 mm |

FIGURE 5. SPECIFICATION OF THE KICKER MAGNET

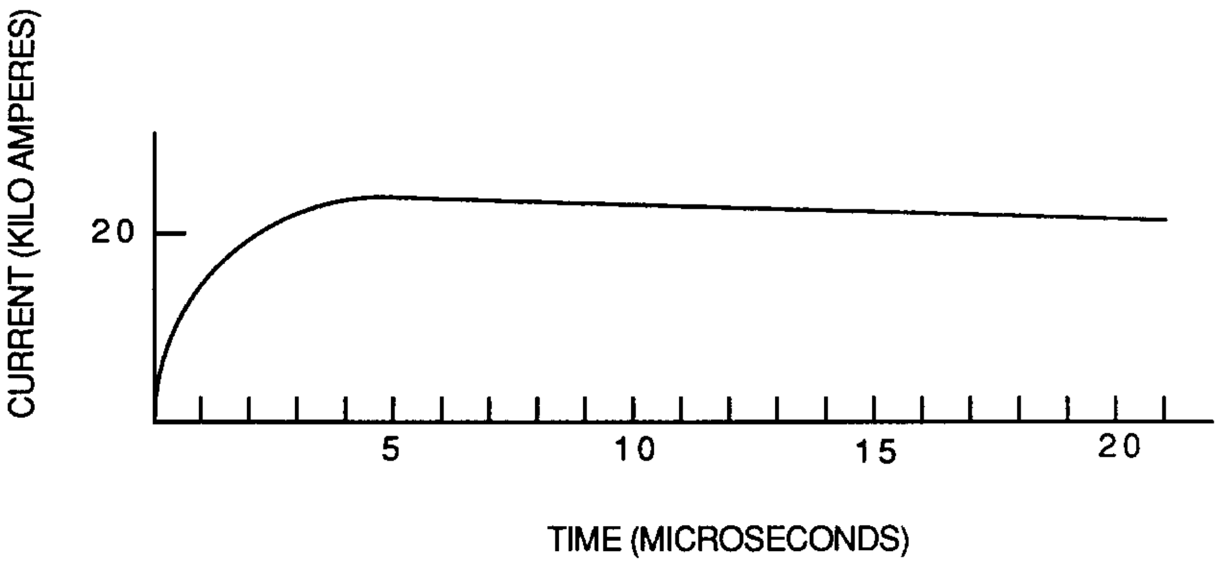



150 GEV SEPARATED ORBITS AT A0 + 25 METERS




1 TEV SEPARATED ORBITS AT A0 + 25 METERS

FIGURE 6. SEPARATED BEAMS AT THE ENTRANCE TO THE ANTIPROTON KICKERS




| | |
|---|---|
| PULSE WAVEFORM: | ONE QUARTER SINE WAVE RISE FOLLOWED BY FLAT TOP. |
| TIME CONSTANT: | 4.8 E -6 SEC FOR SINE WAVE (0 - 90 DEGREES) |
| MAXIMUM DROOP FOR FLAT TOP: | 10% IN 16.2 MICROSECONDS |
| CURRENT: | 22.817 KILO AMPERES |
| CABLE: | 6 X RG 220 |
| CABLE LENGTH: | 15 METERS |
| CABLE INDUCTANCE: | 0.6 E -6 HENRY |
| SYSTEM INDUCTANCE: | 3.8 E -6 HENRY |
| VOLTAGE: | 28.4 KILO VOLTS |
| CAPACITANCE: | 2.5 E -6 FARAD |

FIGURE 7. MAGNET PULSER SPECIFICATIONS

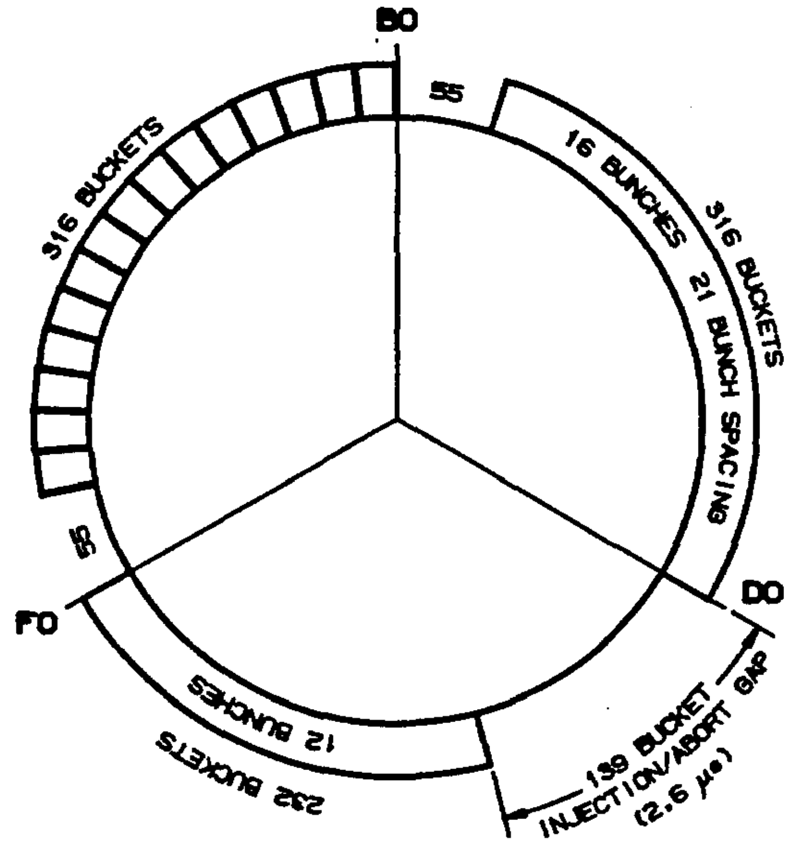
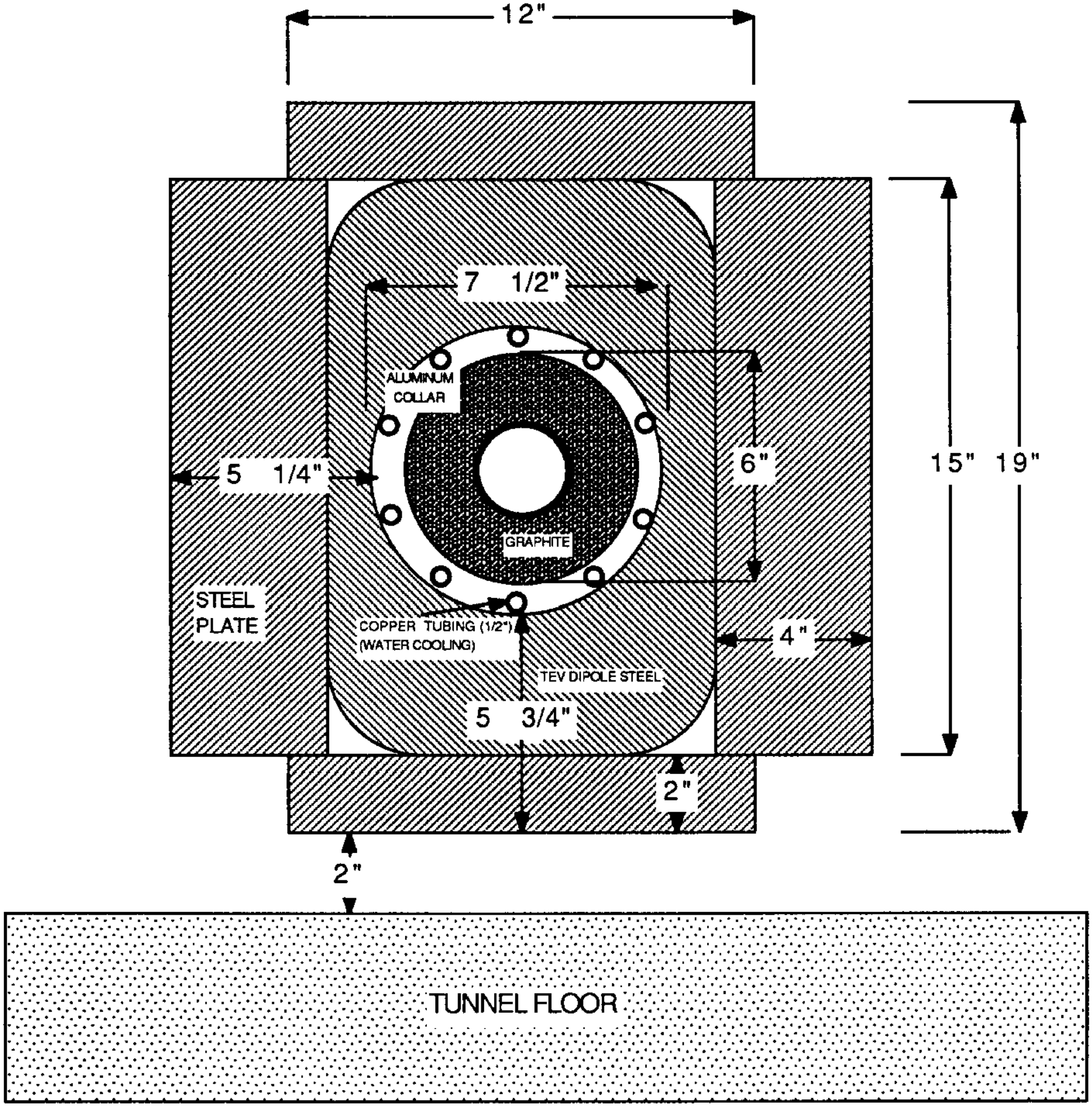



FIG. 8 ALTERNATE 44 BUNCH INJECTION PATTERN




LENGTH OF RECTANGULAR STEEL SHELL IS 3 METERS

LENGTH OF DIPOLE STEEL IS 4.5 M

VACUUM TUBE IS 2.5" OD X 0.060"WT

FIGURE 9. CROSS SECTION OF THE GRAPHITE PORTION OF THE ABSORBER

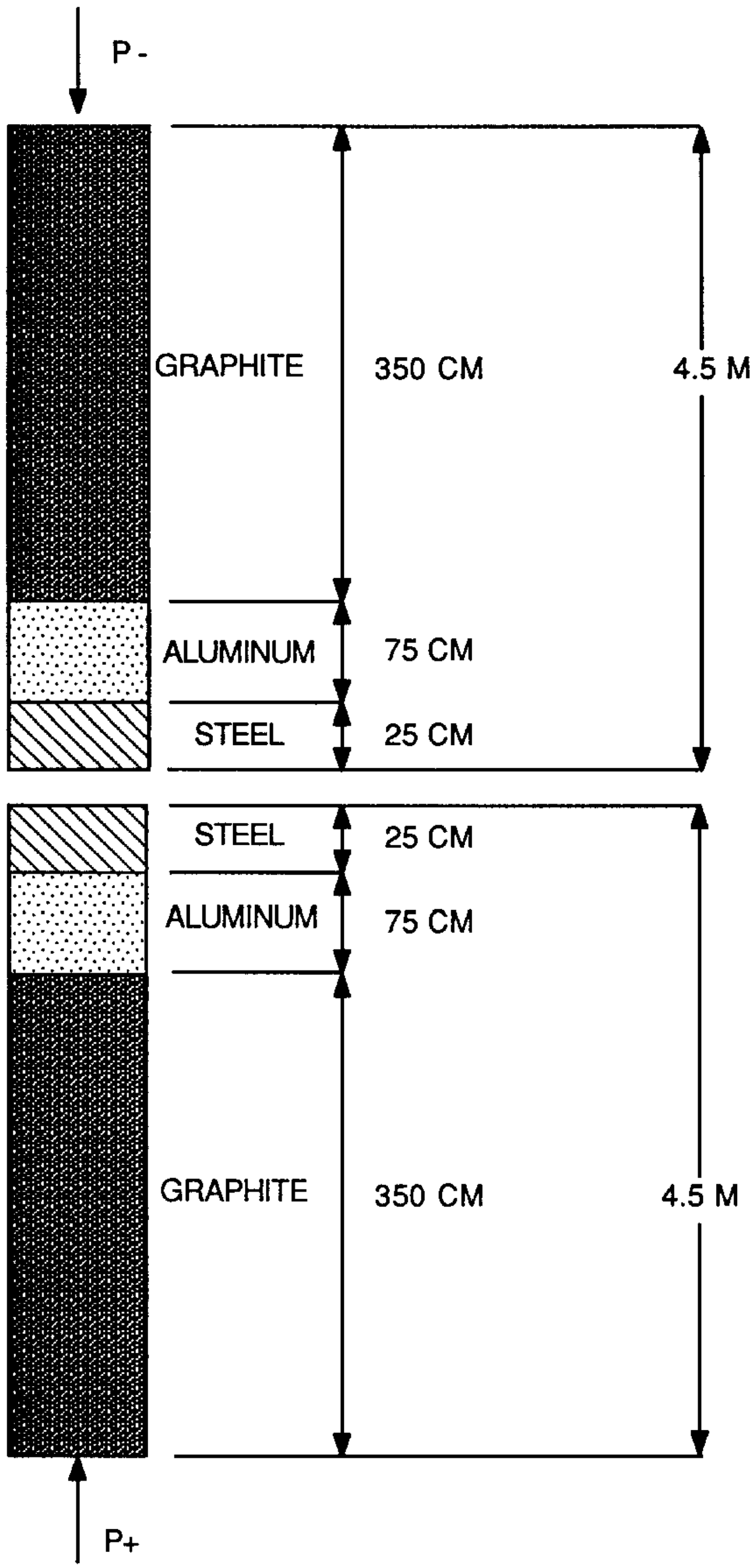



FIGURE 10. THE LONGITUDINAL STRUCTURE OF THE ABSORBER CORE

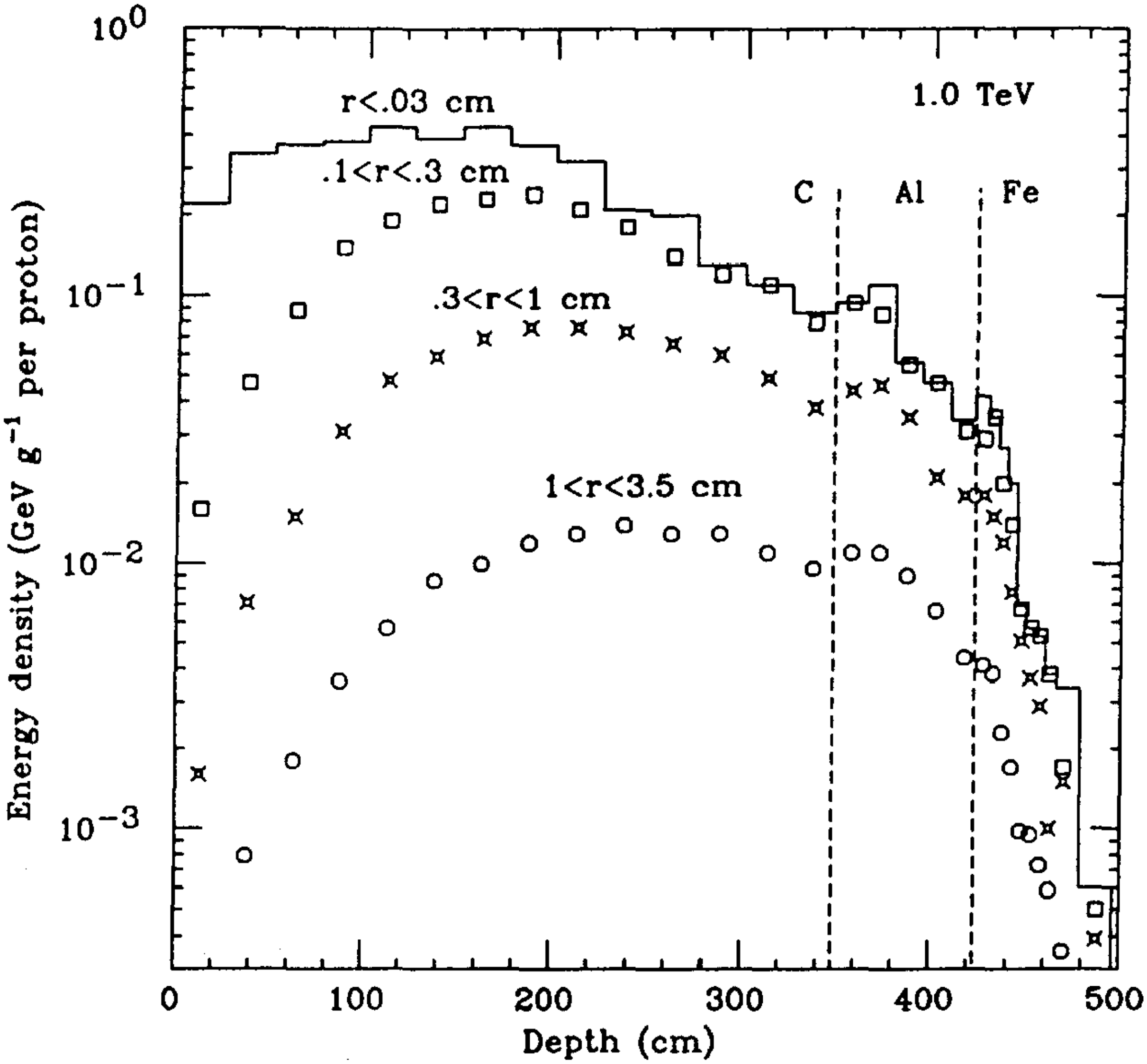



Fig. 11. Longitudinal distributions of energy deposition density in the various radial bins of the core of the internal beam dump at the 1.0 TeV abort

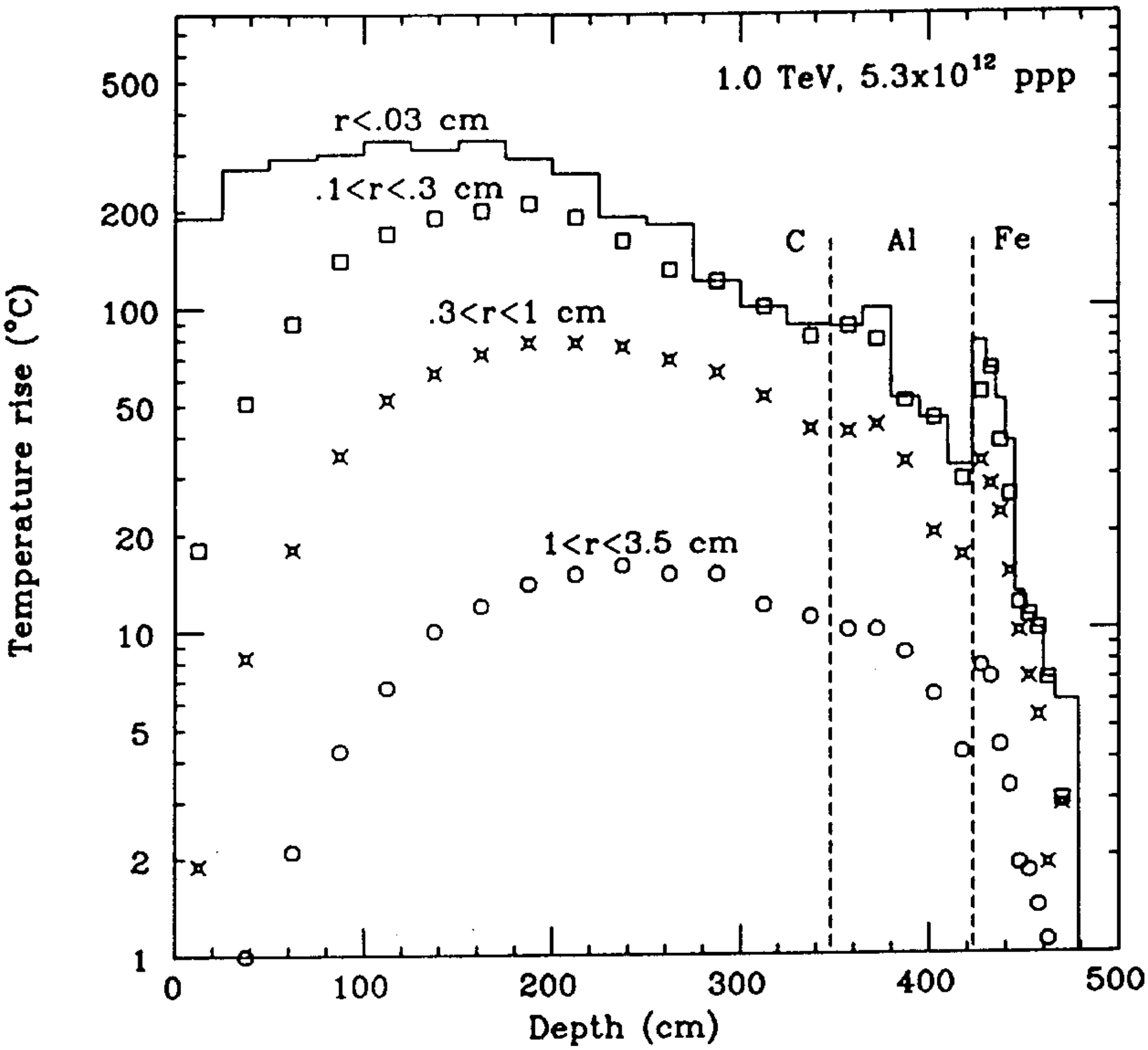



Fig. 12. Instantaneous temperature rise distribution correspondingly to Fig.11 for the beam abort of $5.3 \times 10^{12}$ protons, To = 27 °C

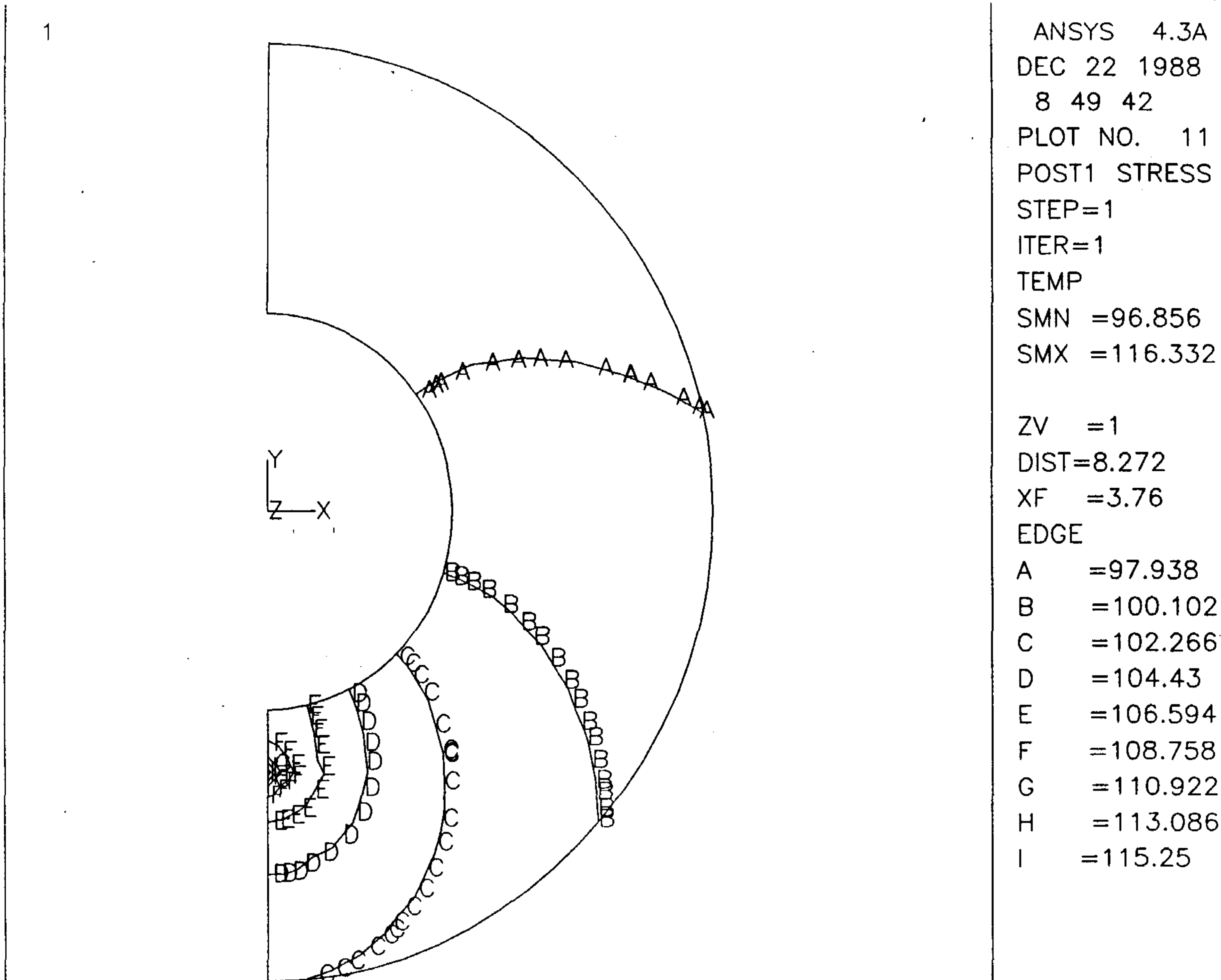



FIGURE 13.
GRAPHITE TEMPERATURE DISTRIBUTATION (CELSIUS)

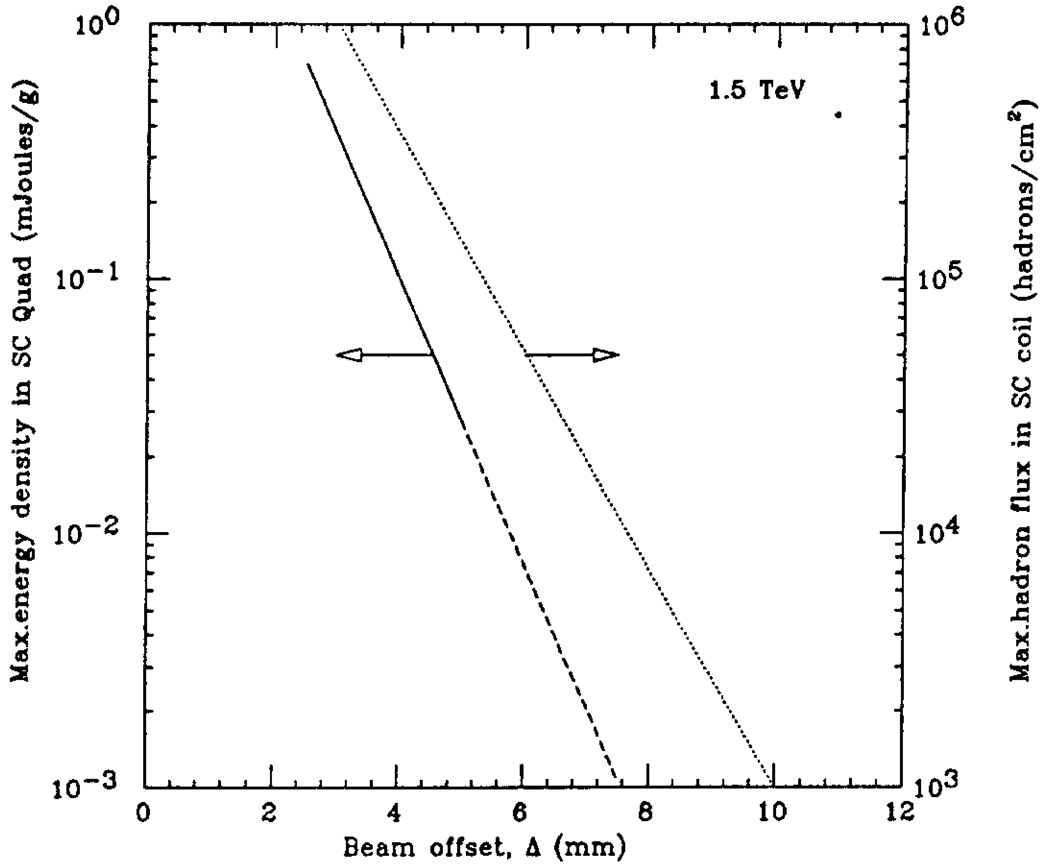



Fig. 14 Maximum energy deposition density in the first downstream quadrupole superconducting coils and corresponding hadron flux at $2x10^{12}$ proton abort versus beam displacement in the dump

# APPENDIX

## BEAM TRAJECTORIES AND PROPERTIES ACROSS THE A0 STRAIGHT SECTION

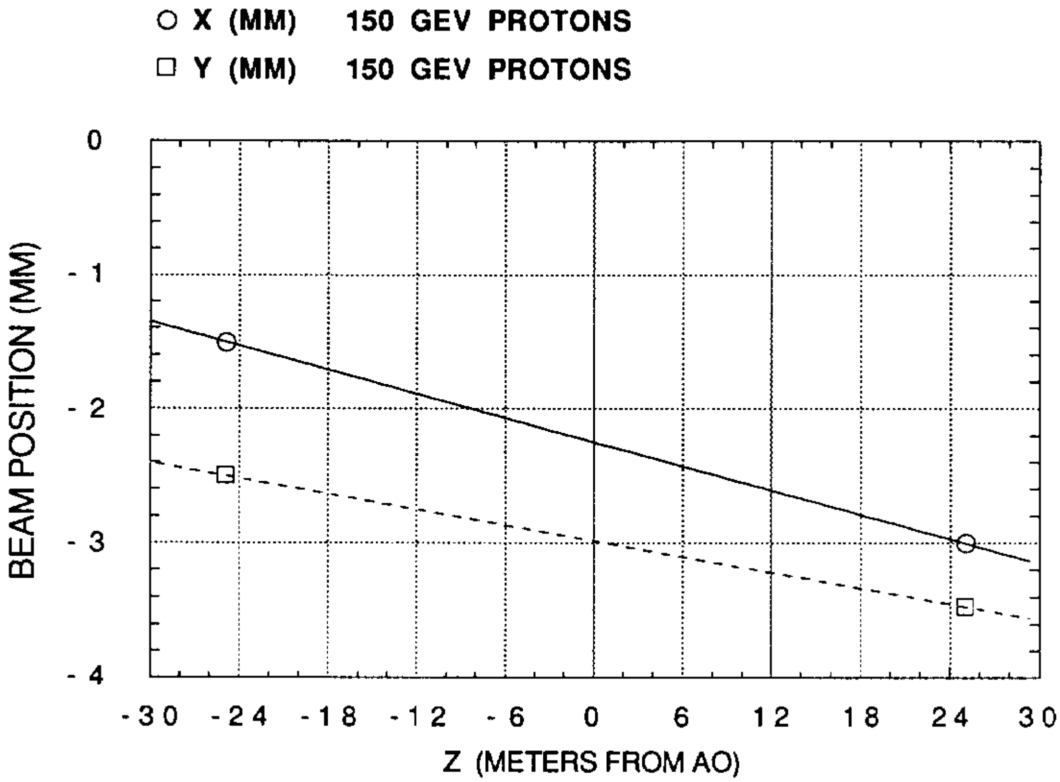
The graphs on the following pages were made from data from the following sources:

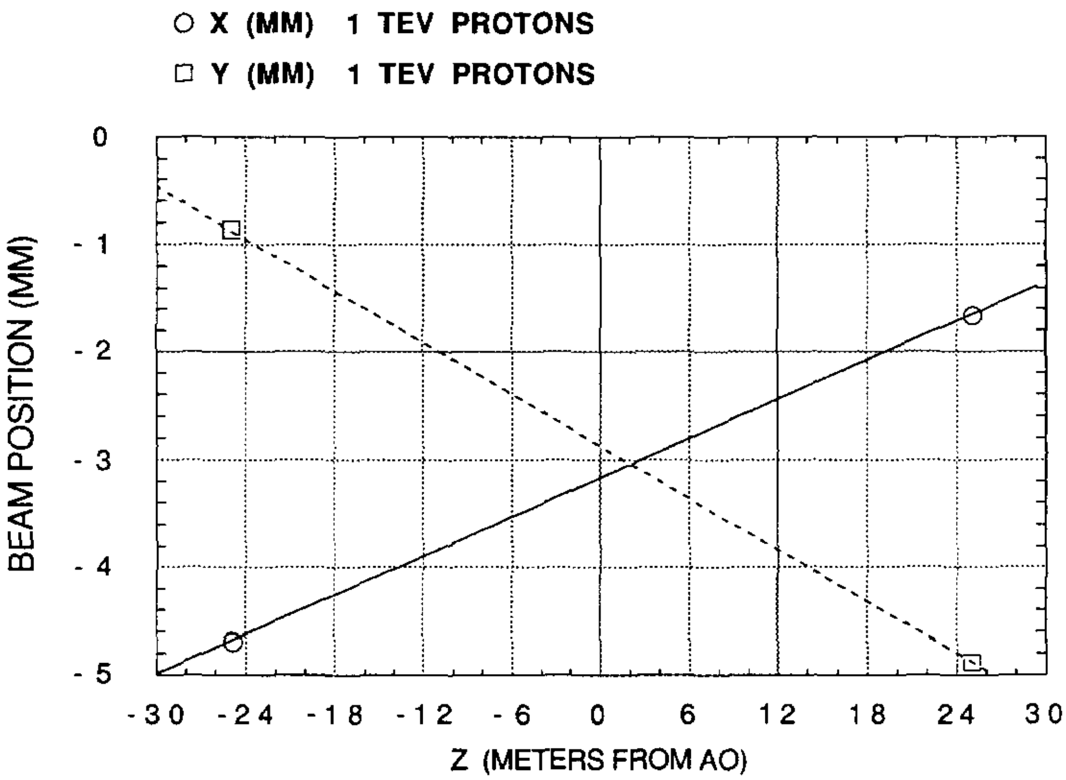
Beam Position: Ernie Malamud's separated helical orbit scheme for Beta star = 50 cm and injection. The quadrupoles on either side of the A0 straight section have the usual polarity of the fixed target lattice.

Beam Sigma: Glenn Goderre's version of the scheme above. Known as the K-50 lattice for low beta and K-INJ for injection.

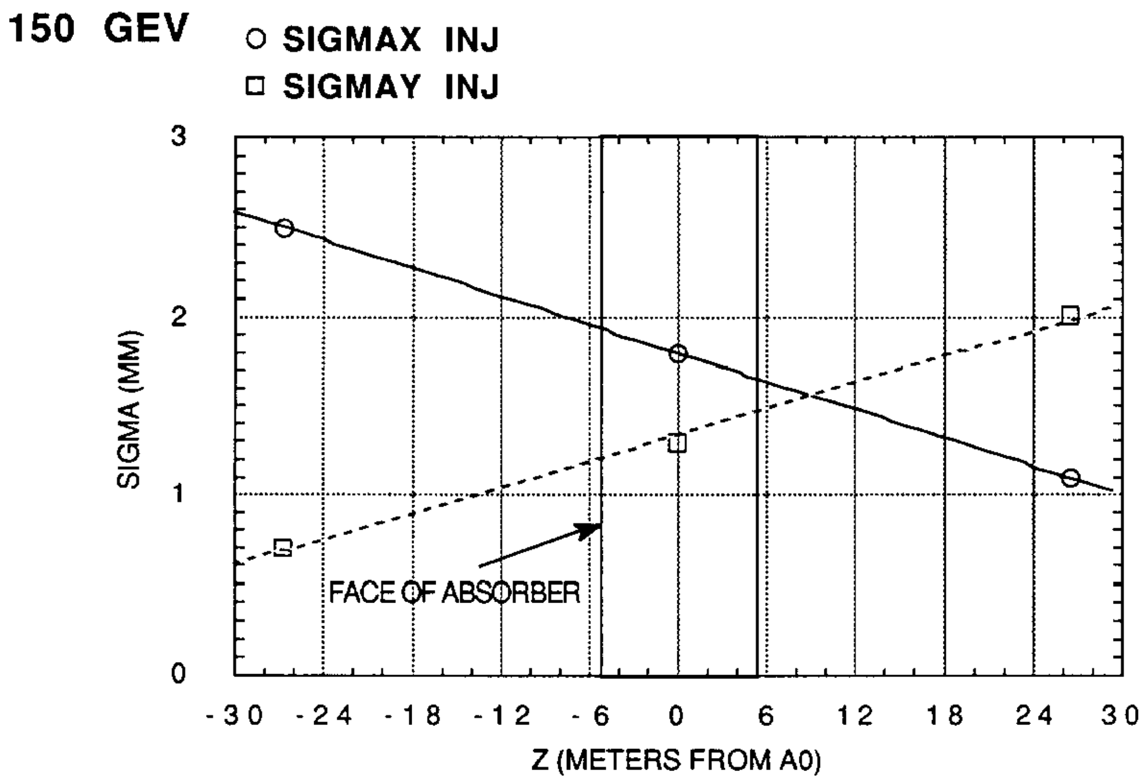
These use: sigma(p) = 75 MEV
emittance(H) = (V) = 15 pi mm mr

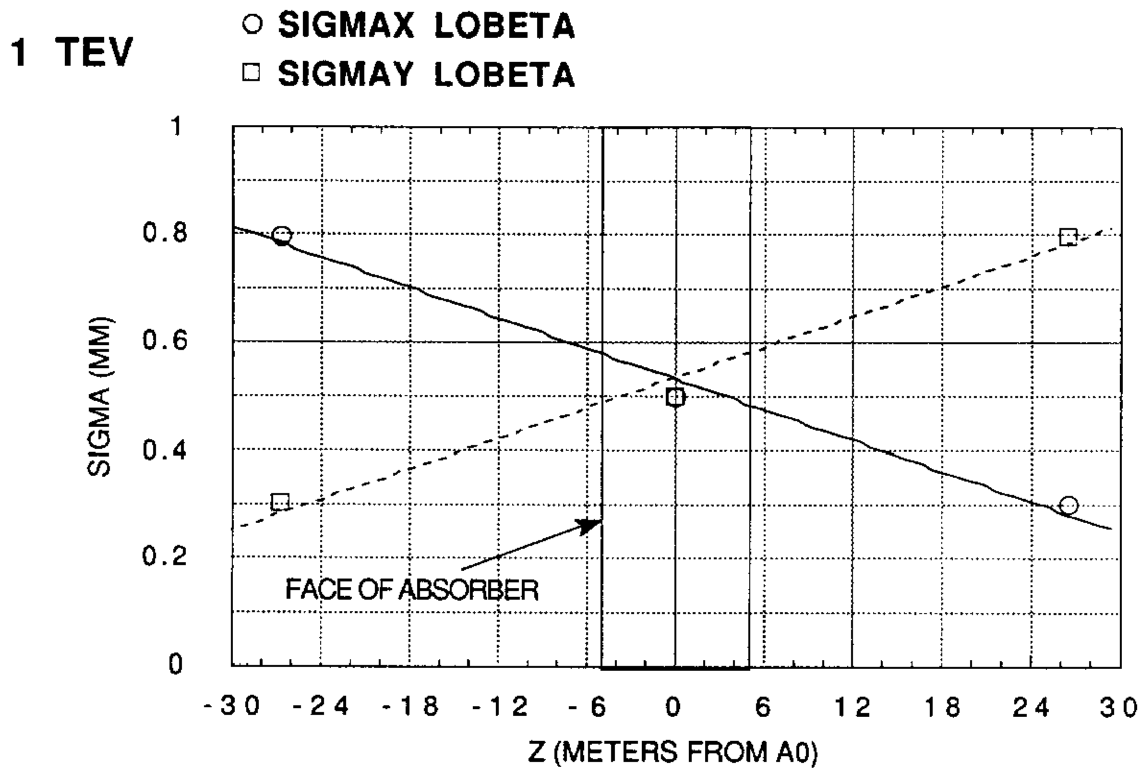
The graphs were then used to determine beam position and sizes for the figures shown in the text, for example, Figures 2 through 4 and 6.


○ X (MM) 150 GEV PROTONS
□ Y (MM) 150 GEV PROTONS
BEAM POSITION (MM)
0
-1
-2
-3
-4
-30
-24
-18
-12
-6
0
6
12
18
24
30
Z (METERS FROM AO)



○ X (MM) 1 TEV PROTONS
□ Y (MM) 1 TEV PROTONS
0
- 1
- 2
- 3
- 4
- 5
BEAM POSITION (MM)
-30 -24 -18 -12 -6 0 6 12 18 24 30
Z (METERS FROM AO)


150 GEV
SIGMAX INJ
SIGMAY INJ
3
2
1
0
SIGMA (MM)
FACE OF ABSORBER
-30
-24
-18
-12
-6
0
6
12
18
24
30
Z (METERS FROM A0)



1 TEV
SIGMAX LOBETA
SIGMAY LOBETA
SIGMA (MM)
1
0.8
0.6
0.4
0.2
0
FACE OF ABSORBER
-30
-24
-18
-12
-6
0
6
12
18
24
30
Z (METERS FROM A0)