Radiation Levels in the MI-60 Enclosure from Tevatron Beam Losses

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This note addresses some of the radiation issues in the MI-60 enclosure due to an accidental total Tevatron beam loss at 1000 GeV. At MI-60, the floor of the Tevatron tunnel is at an elevation of about 2.7 m above the MI tunnel floor. The wall shielding between the Tevatron and the MI tunnel has a minimum thickness of 6 m. This should provide necessary shielding (a reduction factor better than 10^7) for radiation arising from the prompt and secondary neutrons produced due to an accidental loss of the Tevatron beam at any point in the vicinity of MI-60 region (e.g. 36 proton pulses with 1.5E11 ppp at 1 TeV, if lost at a point in Tevatron is expected to give a dose of 4000 Rem at 1ft from the source due to neutrons. Then the 6m soil will attenuate the radiation to about 0.6mrem which is below the minimum occupancy limit). However, it is desirable to study whether the soil thickness tangential to the Tevatron is good enough to shield non-prompt and prompt muons produced from the beam losses in the Tevatron. We report here an estimation of the radiation near MI60 enclosure induced by these muons.

A view of MI60 enclosure is shown in Fig. 1 and the regions of interest are marked by A and B. The first level of the exit stairs near A and B lie along the tangent to the Tevatron bent section from E44- E47. The soil thickness along the tangential path from Tevatron are about 96 m and 136 m for the exit stairs at A and B respectively. A schematic view of the Tevatron tunnel with Tevatron magnet is shown in Fig. 2A. Transverse sectional view of the magnet is shown in the bottom of the Fig. 2A. To estimate the amount of muon induced radiation level, Monte Carlo calculations have been carried out using a suitably modified program, MUSIM (Van Ginneken's program) with an appropriate geometry of the Tevatron dipole magnet and the tunnel. A complete beam loss is assumed to occur due to scraping of the beam by beam pipe or interaction at a point. A maximum magnetic field of up to 4 Tesla is assumed at the time of beam loss. Since the curvature of the Tevatron tunnel is 1 km, the thickness of the steel and the soil through which the beam has to traverse will be different depending upon whether the beam is touching the beam pipe at the far edge or at the near edge of the beam pipe. We have estimated this thickness to be 17.81 m of steel followed by 11.62 m of air for far edge scraping and 9.81 m of steel with

21.7 m of air (out of which beam traverses about 11.26m in the magnetic field at an angle in the beam pipe before it interacts with the magnet) in the case of near edge scraping of the beam. A schematic diagram of this situation is shown in figure 1B. Calculations have been carried out in a cylindrical geometry with respect to the Tevatron beam axis. Distributions of muons will be asymmetric in the horizontal plane because of the magnetic field. Calculations were made for up, down, right and left regions to understand directional dependence of the muon flux. Number of muons coming within $\pm 45^o$ and $\pm 10^o$ transversely have been counted separately. Figure 3 displays the definition of the regions and/or angles (like 90^0 and 20^0) used in the calculations. Figures 4 show the contours of equal radiation doses for the $\pm 10^o$ cases studied here. Table 1 summarizes the results on radiation dose for two locations A and B.

In Fig. 3 we show two different field configurations used here. The field configuration A means $B_x = B_z = 0.0$ and, $B_y = 4$ Tesla for region occupied within coil and $B_y = 1.08$ Tesla in the steel yoke (notice that return field the lines density is reduced by a factor of (3.85 cm/(19.05-4.88) cm)). For the field configuration B we take a realistic B_x especially where the field lines bend. Here, for regions "up" and "down" we have $B_y = B_z = 0.0$ and $B_x = \pm 1.97$ Tesla (= (3.85 cm/7.82 cm)*4 Tesla) and to the left and right we take $B_x = B_z = 0.0$ and, $B_y = 1.08$ Tesla. In the center, the field will be same as in case A. Because of the presence of magnetic field at the time of beam loss a considerable reduction in radiation dose is seen in the forward direction as shown in Fig.4 (compare Fig.4D with Fig. 4A-C). At the same time there will be an increase in the muon deposition at an angle in the horizontal plane. We find a maximum reduction of up to a factor of 50 in the muon dose in the forward direction and approximately an increase by the same amount transversely. This transverse kick does not have much effect on the radiation levels in the MI tunnel. The difference between the radiation levels corresponding to the beam interaction with 17.81 m and 9.81 m magnet is marginal in the forward direction for distances less than 400 m along Z. However, as expected, more transverse spread in radiation level is seen in the case of 17.81 m magnet path as compared with 9.81 m magnet (compare Fig. 3B and 3Ç). The band indicated in Fig. 4 corresponds to a radiation level of 2.5 mrem/ accidental loss of all beam i.e. 36x2E11protons at 1 TeV at a point in the Tevatron ring. This type of beam loss in the Tevatron ring is less likely to happen. Hence we do not include any safety factors in drawing the band.

In spite of the reduction in radiation at low angles there could be some spots in the MI-60 enclosure with high radiation due to straight muons coming from Tevatron beam loss at E44-E47 sections. Calculations made using correct soil thickness from the point of beam loss to the point of interest, show that the location B(hall way in the exit stairs near MI quad 532) the radiation would exceed the minimum occupancy limit (10 mrem/accident) for loss of Tevatron beams more than 5E12 protons. (During the present Tevatron collider run, the total proton intensity should not exceed 1E12). Region A (exit stairs leading to the MI-60 circular labyrinth and straight section) may be considered as minimal occupancy with proper signs.

Table I. An evaluation of muon doses in the MI-60 enclosure from Tevatron losses at 1000 GeV at 4 Tesla.

The Beam Loss at a point = No. of Bunch x Proton Bunch Intensity (or Beam loss/Accident)

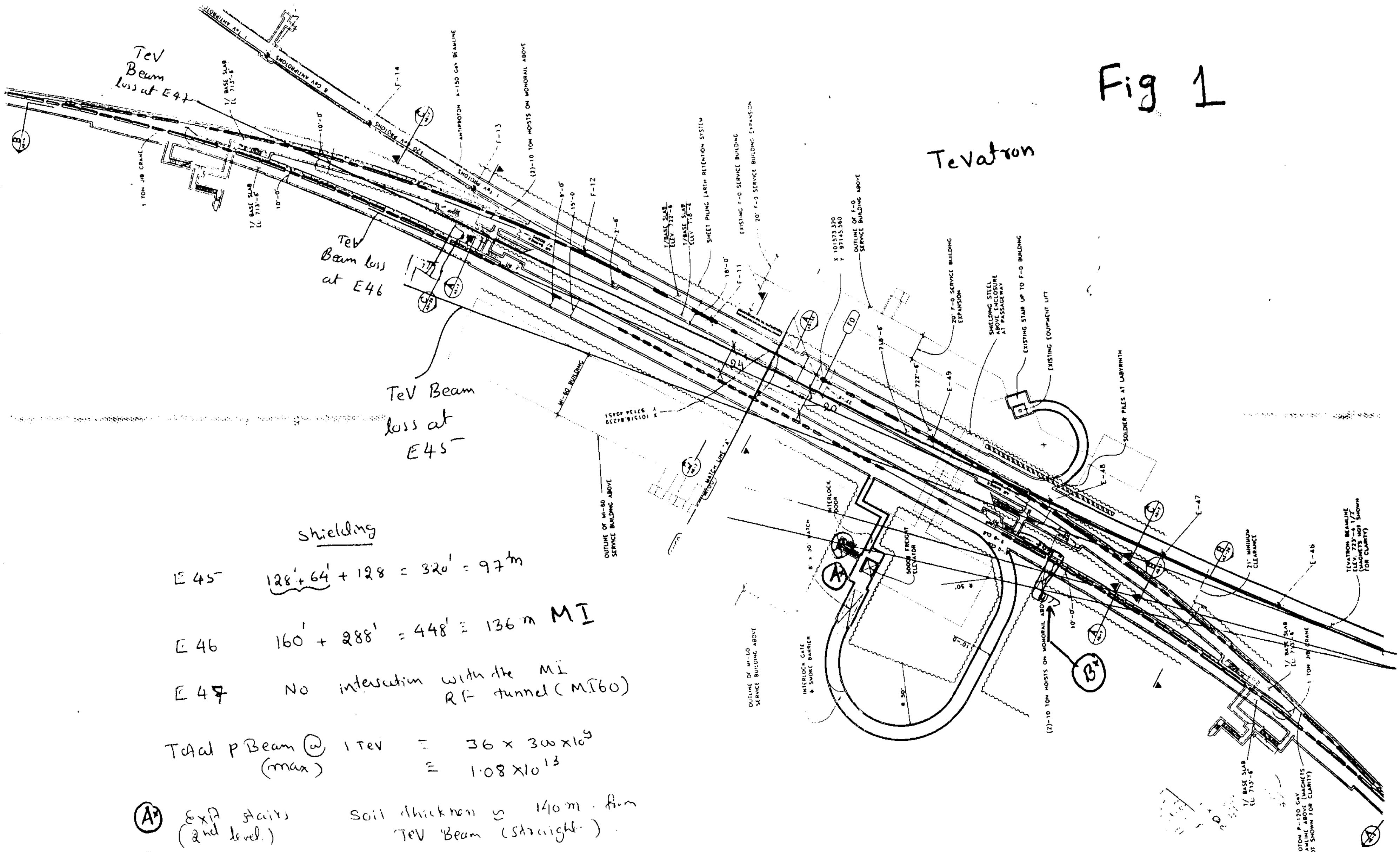
$$= 6 \text{ X } 150 \text{ X } 10^9 \text{ protons (for Collider Run IB)}$$

$$= 36 \text{ X } 150 \text{ X } 10^9 \text{ protons (for Collider Run II)}$$

Locations and Distances	Angle=90^o @	Angle= 20^o	Expected Muon Dose Run IB	Expected Muon Dose Run II
2nd level Exit Stairs to circular labyrinth(A) 140 m	1E-15 Rad/p	7E-16 Rad/p	1 mr/acc.	4 mr/acc.
2nd level Exit Stairs Near Quad 532 (B) 100 m	3E-15 Rad/p	2E-15 Rad/p	2 mr/acc.	11 mr/acc.

@ Notice that the average muon dose from 90^o is considerably larger than those from 20^o. Since the muon deposition increases radially in the horizontal plane due to magnetic field, the inclusion of large transverse angle (90^o) in the averaging processes will give high dose as compared to that for small transverse angle (20^o). Hence using 90^o averages will over estimate the dose and they are not used here.

Fig 1



<u>Shielding</u>

E45   128' + 64' + 128 = 320' = 97 m

E46   160' + 288' = 448' = 136 m MI

E47   No intersection with the MI RF tunnel (MI60)

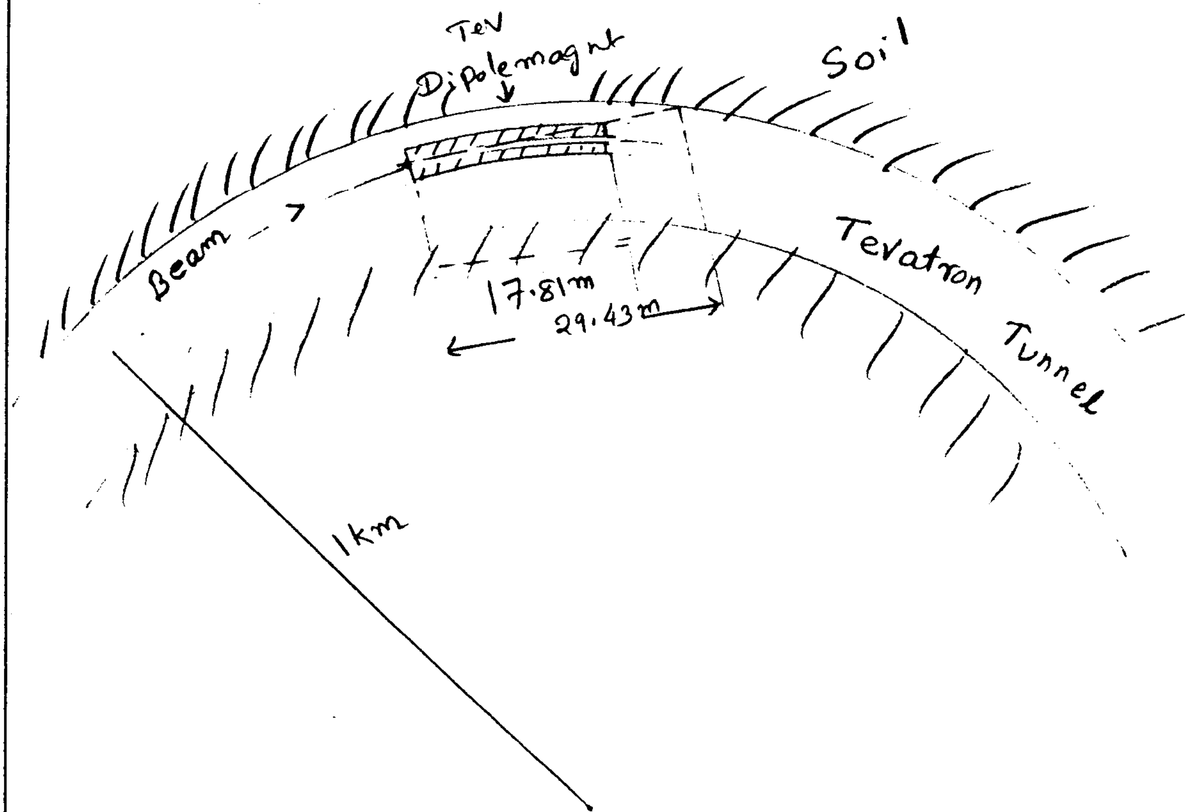
Total p Beam @ 1 TeV (max) = 36 × 300 × 10^9 = 1.08 × 10^13

(A*) Exit stairs (2nd level)   Soil thickness ≃ 140 m from TeV Beam (straight)

(B*) Exit stairs (2nd level)   Soil thickness ≃ 110 m from (TeV Beam straight)

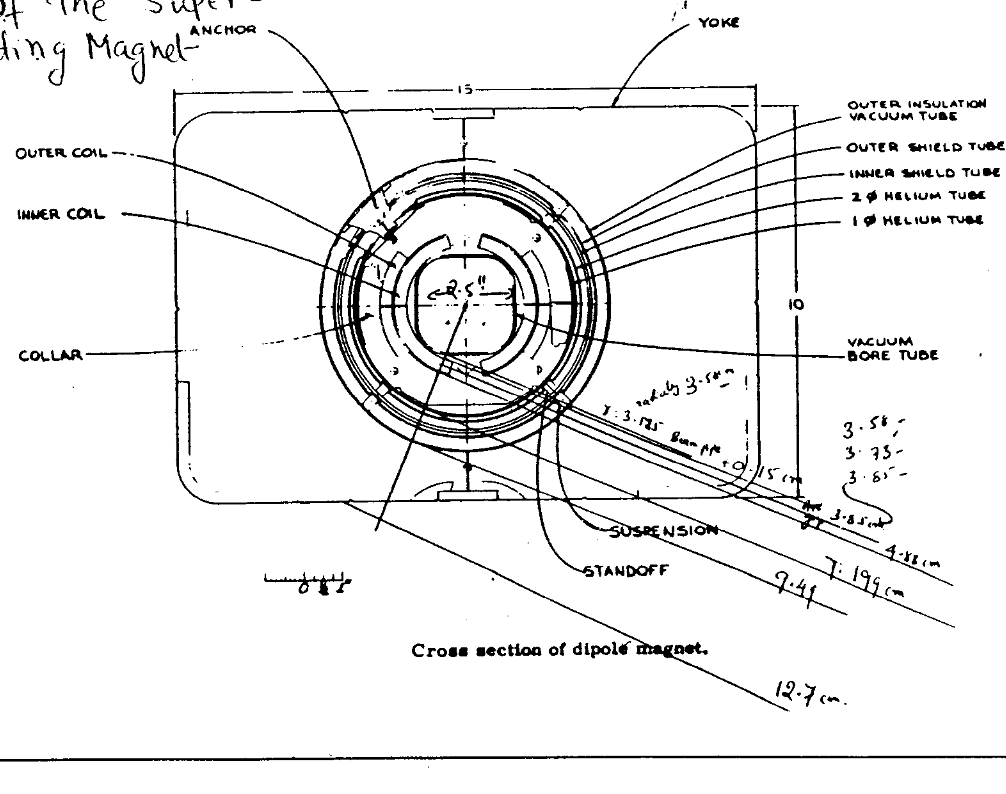
FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT	NAME
Fig. 2A	DATE / REVISION DATE



A transverse View of the Super-conducting Magnet

A report on the Design of the Fermi N A L Superconducting Acc (May 1979)



Cross section of dipole magnet.

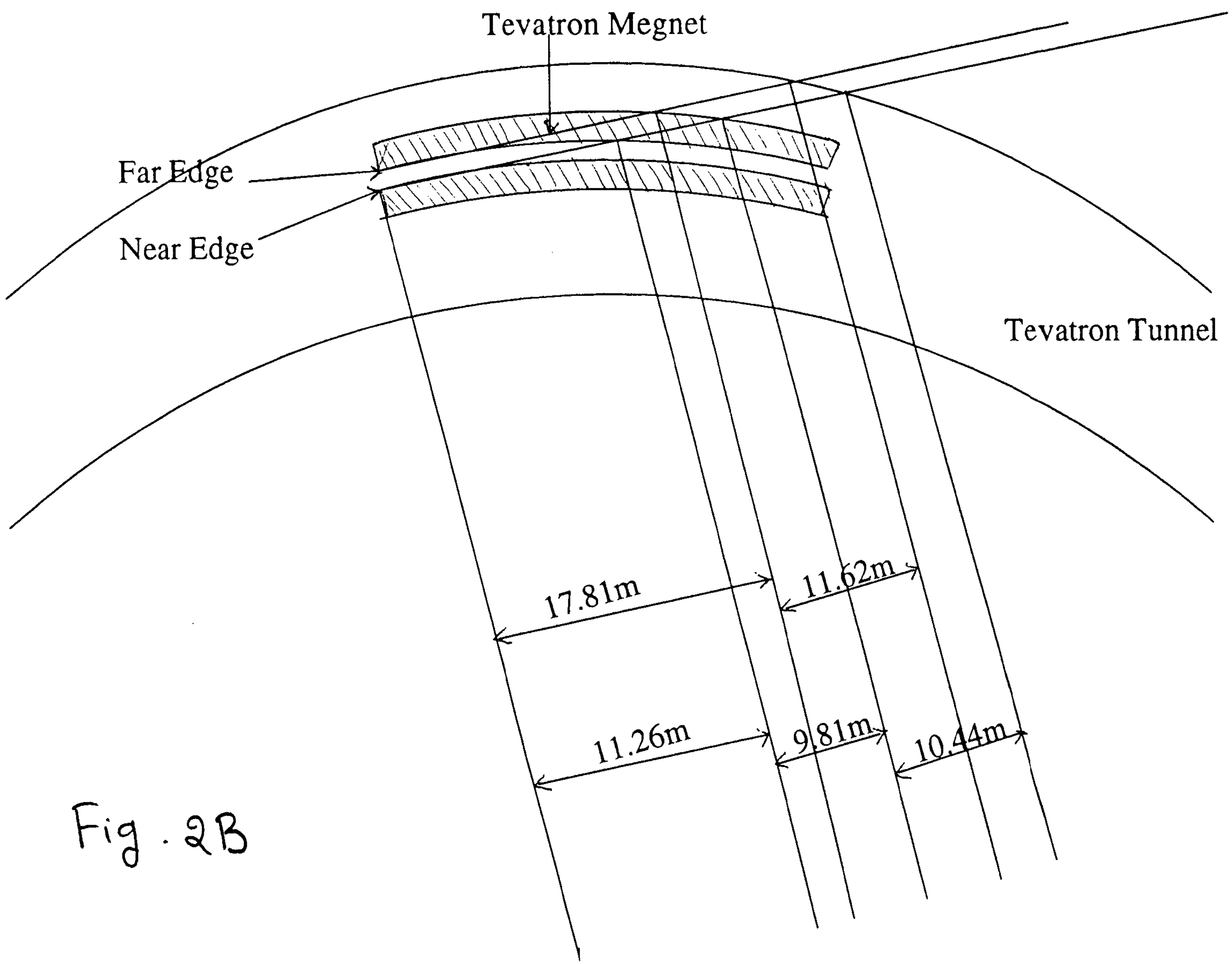
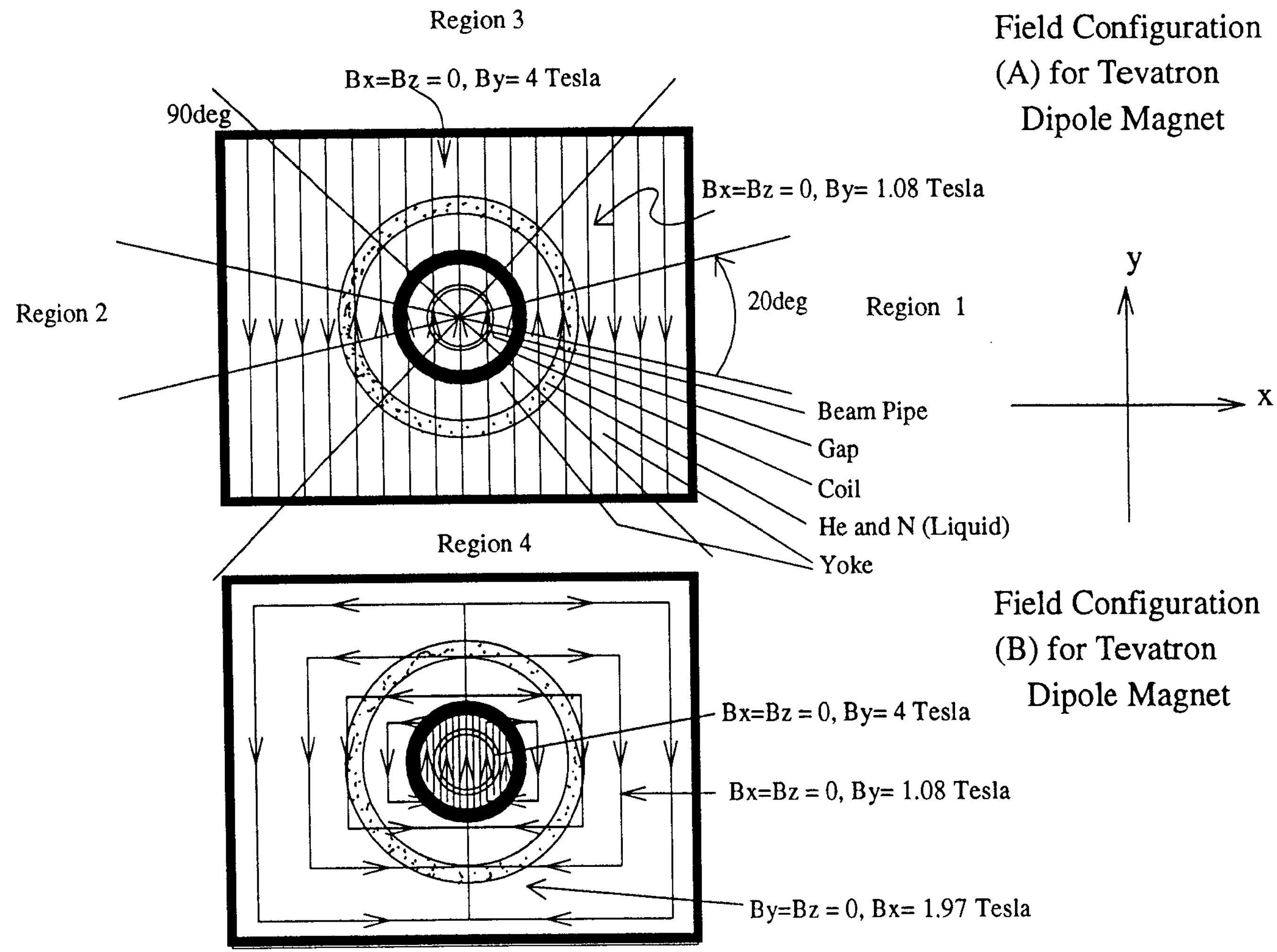

Tevatron Megnet
Far Edge
Near Edge
Tevatron Tunnel
17.81m
11.62m
11.26m
9.81m
10.44m

Fig. 2B



Region 3
Bx=Bz = 0, By= 4 Tesla
90deg
Bx=Bz = 0, By= 1.08 Tesla
Region 2
20deg
Region 1
Beam Pipe
Gap
Coil
He and N (Liquid)
Yoke
Region 4
Bx=Bz = 0, By= 4 Tesla
Bx=Bz = 0, By= 1.08 Tesla
By=Bz = 0, Bx= 1.97 Tesla
Field Configuration
(A) for Tevatron
Dipole Magnet
y
x
Field Configuration
(B) for Tevatron
Dipole Magnet

Fig. 3