TM-926
0619.000

SUPERCONDUCTING MESON LEFT BEND BEAM LINE

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Introduction

This report gives the beam line design for converting the major horizontal bend to the Meson Laboratory from conventional magnets to superconducting magnets. Currently this 165 mr bend is accomplished in Switchyard enclosure "C" by five Lambertson magnets and 56 external proton beam dipoles (EPB's). In the new design these magnets are replaced by twelve Lambertson (or H type) magnets and 21 superconducting dipoles. This change conserves electrical energy, as well as allowing the beam to be upgraded to 1 TeV. Present plans are to install the superconducting magnets in the spring and summer of 1980.

Several overall criteria guided the beam design. First, the new beam design in enclosure "C" must match up exactly in angles and position with the present beam line as it enters and leaves enclosure "C". If possible the optics of the new beam line must be the same as at present. The new beam line must work with the present 400 GeV Switchyard as well as the upgraded 1 TeV Switchyard[1]. In particular, the superconducting dipoles were to be installed in their final 1 TeV positions at the start. Changes in position of other magnets was to be minimized in going from 400 GeV to 1 TeV. Space had to be left for the present Neutrino line as well as the upgraded 1 TeV Neutrino/Muon beam lines[2].

Finally, the new beam line had to fit into the present enclosure "C" tunnel. This last requirement was by far the hardest to satisfy and meeting it leaves very little flexibility in the beam design. The rest of this report gives the details of each section of the new beam design. Figure 1 shows the overall layout of the Meson left bends.

Lambertson Magnets

Presently the Meson and Neutrino beam lines are split horizontally by five Lambertson magnets at the upstream end of enclosure "C". One TeV operation will require the addition of more Lambertson magnets as well as several H magnets downstream of the present Lambertsons. The new magnets cannot go upstream of the present Lambertsons as one quickly runs into the upstream wall of enclosure "C". Thus, the bend center for the Meson/Neutrino split will necessarily shift downstream for 1 TeV as compared to the present beam. However, this split bend center must remain fixed for 400 GeV superconducting operation and 1 TeV operation. Rather than change the present position of the Lambertsons, it was decided to add an EPB dipole to the 400 GeV split, thus moving the split bend center downstream. This magnet is shown in figure 2 as MH201. It is in the same z position as the present MH201-2. This magnet will run in series with the five present Lambertsons to produce a total 12 mr split. For 1 TeV opeation this dipole can either be removed or used as a horizontal trim (see figure 3). The new split is required to be greater than the present split of 7.7 mr simply to keep the superconducting dipoles within the confines of the present tunnel. Figure 3 shows the 1 TeV split. Note that a total of 12 magnets are used for the split and that four of them are new (yet to be designed) H type magnets each 10.5 feet long and having the same magnetic field as the Lambertsons. Other magnet arrangements could be used as long as the total bend remained 12 mr and the bend center remained fixed.

Figures 2 and 3 also show the clearance of the split magnets from the west wall of enclosure "C" and from the Neutrino/Muon line to the east. Note no problem is foreseen at 400 GeV, but that the Neutrino/Muon line is very close at 1 TeV. In particular, if the MV100 string is made up of main ring B1 dipoles[2], then the coils of the first B1 magnet probably interferes with the upstream end of the left bend superconductor. However, there is virtually no flexibility in the superconducting left bend beam design at this point. Fortunately, the Neutrino/Muon line should be able to work around this problem, so figure 3 should be viewed as the worst case, not as the final design for Neutrino.

Superconducting Dipoles

The remaining horizontal bend of 153 mr is done using 21 superconducting dipoles. These dipoles are broken up into two strings of ten and eleven magnets as shown on figure 4. Designs using twenty superconductors in two strings of ten were also considered, but they did not satisfy the design criteria as well as using 21 dipoles. Figure 4 also shows the position of two turnaround boxes, two junction boxes and six drift space assemblies. These boxes and assemblies contain cryogenic and vacuum connections, relief valves, and assorted instrumentation. Figures 5 and 6 show the position of the superconductors relative to the tunnel walls at the downstream end of the first string of superconductors and at the upstream end of the second string. These positions are shown as the magnets are closest to the wall there. Note that the closest a magnet comes to a wall is about four to five inches.

Vertical Up Bend

Just before leaving enclosure "C" the Meson beam line is bent up 10 mr by MV204 such that it reaches ground level by Meshall. Currently MV204 is a string of four EPB dipoles as shown in figure 7. At 1 TeV, one needs room for seven EPB dipoles to accomplish this up bend. However, after the superconductors are placed where they must be (to miss the tunnel walls), there isn't enough room for seven dipoles as well as the necessary quadrupoles and horizontal trim. Thus, it was decided to make part of the up bend superconducting by inserting a twelfth superconducting dipole on the downstream end of the second string of superconductors and rotating it ninety degrees (see figure 7). This superconductor is in series with the other 21 superconductors. The remainder of the 10 mr up bend (2.5 mr) is accomplished by two EPB dipoles. By looking at figure 7 one can easily see that the 1 TeV layout shifts the vertical bend center upstream relative to its current position. The bend center cannot remain the same unless one moves the downstream wall of enclosure "C". The beam was designed so that at 400 GeV the 10 mr vertical bend can be done without the use of the rotated superconductor. Four EPB dipoles are used and they are positioned so their vertical bend center is in the same place as the 1 TeV layout. Figure 7 shows the following details of the three different layouts for the downstream end of enclosure "C". First, the drift space assembly inserted between the horizontal superconductors and the vertical superconductor is five feet long, not the usual three feet. The extra length is essential to making the position of the vertical bend center work out for both superconducting solutions. The position of MQ206 and MHT204 is exactly the same in all three layouts. Also the positions of MV204-3 and MV204-4 in the present line are very close to the position of MV204-2 and MV204-3 in the 1 TeV line, so one might consider leaving them in place for all three layouts.

Vertical Dogleg

The beam had to be lowered in order to match up with the changed bend center for the vertical up bends. Also, it was found necessary to lower the beam about two and one half inches in order to provide clearance between the tunnel ceiling and the upstream junction box. Both of these criteria are met by a vertical dogleg made up of MV201 (see figures 2 and 3), and MV203 as shown on figure 8. These two magnets are run in series, and MV201 is in the same position along the beam line as the present MH201-1. MV201 bends the beam down while MV203 bends it up making the beam horizontal again.

Beam Optics

An attempt was made to keep the beam optics in enclosure "C" as close as possible to the present beam optics. Presently, three quadrupoles (MQ201, MQ202, and MQ204) are interspersed among the left bend dipoles and one (MQ203) is in the region between the two main dipole strings (see figures 1 and 8). These four quadrupoles are run rather hard producing horizontal foci or waists near MQ202 and again about one hundred feet downstream of MQ204. The reason for this "strong focus solution" was that it minimized the horizontal excursions of off axis or off momenta beam particles. Thus, the beam was close to achromatic (recombination occurring near the Meshall target) and relatively insensitive to the current regulation in the left bend dipoles. Conventional quadrupoles cannot easily be interspersed among superconducting dipoles and so all four quadrupoles must be placed in the region between the two superconducting strings when superconducting dipoles are used. Since the quadrupoles are moved closer together it was found that the field strength had to be even higher in order to match the present optics. The higher field strength would have required eight quadrupoles instead of four even to run at 400 GeV. At 1 TeV, one required twelve quadrupoles. The placement of these twelve quadrupoles is shown in figure 8, where one includes the quadrupoles shown as optional. Figures 9 to 11 show the beam optics for this strong focus solution with twelve quadrupoles. These optics are quite similar to the present beam optics. Figures 9 and 10 show the horizontal and vertical beam envelopes respectively, while figure 11 shows the horizontal excursions of a particle one tenth of a percent off momentum. These graphs were generated using the page 49 program[3] on the MCR consoles. One should not pay too much attention to the optics downstream of enclosure "C" as the present real beam downstream of enclosure "C", does not look much like page 49 predicts. Since the above solution requires so many quadrupoles an attempt was made to see if an acceptable alternative existed using fewer quadrupoles. Using the page 49 program in the MCR, a solution with only a single horizontal waist in enclosure "C" was found. This weak focus solution uses four quadrupoles and the beam element positions are shown as the "400 GeV Superconducting Line" on figure 8. The field strengths are low enough so that the same four quadrupoles also work at 1 TeV (See the "1 TeV Superconducting Line" on figure 8 without the optional quadrupoles). Figures 12-14 show the beam optics for the weak focus solution. Comparing figures 11 and 14 one sees that an off momentum ray has a much farther excursion at the end of enclosure "C" in the weak focus solution than in the strong focus solution. Experimentally, this means the regulation of the left bend power supply must be much better than it presently is, if the weak focus solution is to work. Possibly it would need to be regulated to .025 percent. At 400 GeV one could test the strong focus solution using only the four quadrupoles by running the quadrupoles as hard as they will go. The strong solution given above requires currents of about 125 amps which are too high, but if one could run at about 100 amps, one could get an approximate strong solution. Figures 15-17 show the beam optics for this case. Note the horizontal envelope is quite wide as it leaves enclosure "C". Clearly if one needed the correct strong focus solution at 400 GeV, one could install eight quadrupoles (install the first and third quadrupole in each group of three). Note that figure 8 shows that the 4 weak focus solution quadrupoles do not move in going to the 8 or 12 quadrupole solutions. In all of the above solutions page 49 was used to vary quadrupole currents and positions in order to obtain the smallest beam envelopes consistent with keeping the excursions of off momentum rays minimized. Other arrangements of quads as to horizontal and vertical focussing properties were tried but none were as good. In the above solutions MQ201 and MQ202 are powered by one power supply and likewise for MQ203 and MQ204. Small improvements in the beam optics were observed by individually powering each of these quadrupoles. However, the improvement didn't seem to justify the extra expense of more power supplies. In all solutions care was taken to see that no quadrupole was placed underneath the overhead hatch (see figure 1).

Power Supplies

Table 1 lists the necessary magnetic fields and the currents in the various magnets for both 400 GeV and 1 TeV operation. The currents are obtained from excitation curves[4] for the particular magnet used. Note that in some cases the magnets are close to saturation and are out of the linear region.

At 400 GeV, the Lambertsons bend 8.79 mr, and MH201 bends 3.21 mr for a total of 12 mr. They are in series and run at 1479 amps. Currently the Lambertsons run about 150 amps lower, so some cabling may need to be upgraded. Since MH201 is in a nonlinear region at 400 GeV, if one wants to change the beam energy, one may want to add a shunt to MH201 so one has some independent control. For example, at 200 GeV one obtains a total 12 mr bend at 723 amps, but the Lambertsons are bending 8.60 mr instead of 8.79 mr. Because of this change, the beam is shifted horizontally about one quarter inch at MH201. A shunt of about 20 amps would correct this. Also, if one wants to be able to run at 450 GeV, then the Lambertson cables and power supply must be good to about 1700 amps.

For 1 TeV, one probably needs to design new Lambertsons and H magnets. Using present Lambertsons requires currents of 2110 amps. The design of these magnets will be done in the context of upgrading the entire switchyard.

The two EPB dipoles for the vertical dogleg are run in series. Independent vertical trim capability is maintained by leaving the present MVT202. MHT202 also remains.

The currents in the superconductors are slightly lower than the currents in the energy doubler dipoles, and thus we have a little extra protection from quenches.

At 1 TeV, some of the quadrupoles will be running between 90 to 100 amps. If this is not feasible, there is room to simply add more quadrupoles in series.

Finally, note that the vertical up bend requires 1400 amps for two EPB dipoles at 1 TeV.

Transport

The exact positions of all the magnets are in transport output. Currently the most up to date is labeled run number 56 for 400 GeV and run number 57 for 1 TeV.

References

1. R. Dixon, "1000 GeV Switchyard Upgrade", October 16, 1978 report.

2. R. Evans, T. Kirk, "Transport of Tevatron Energy Primary Proton Beams to Neutrino Area", TM-796 May 26, 1978.

3. R. Gerig, "Description of Computer Program Beam Line Graphics", April 16, 1975 report.

4. T. Toohig, "Fermilab Magnets, Power Supplies, and Auxiliary Devices: Technical Data", TM-632 December 5, 1975. (Used for EPB dipoles and quadrupoles).

R. Juhala, and D. Krause, "Field Measurements on Lambertson Septum Magnets", TM-435 September 20, 1973. (Used for Lambertsons).

"Design Report, 1979-Superconducting Accelerator", (Used for superconducting dipoles).

TABLE 1
POWER SUPPLY CURRENTS

MAGNET		400 GeV Field kG or kG/in	400 GeV Current Amps	1 TeV Field kG or kG/in	1 TeV Current Amps
Lambertsons					
MLAM1-5		7.33	series 1479		
MH201		14.05			
MLAM1-12				10.42	2110 (Using present Lambertsons)
Vertical Dogleg					
MV201	series	3.38	328	8.44	819
MV203					
Superconductors					
MH202-1,10	series	15.18	1515	37.96	3791
MH203-1,11					
Weak Focus Solution - 4 Quadrupoles Between Superconducting Strings					
MQ201,202		1.56	30	3.89	75
MQ203,204		1.82	35	4.54	90
MQ205		1.56	30	3.89	75
MQ206		0.99	19	2.47	47.5
Approximate Strong Focus Solution 4 Quadrupoles Between Superconductor Strings					
MQ201,202		4.88	100	Will not Work at 1 TeV	
MQ203,204		4.88	100		
MQ205		0.88	17		
MQ206		0.88	17		
Strong Focus 12 Quadrupoles					
MQ201,202		1.87	36	4.67	93
MQ203,204		1.94	37.3	4.84	98
MQ205		0.93	18	2.34	45
MQ206		1.04	20	2.60	50
Vertical Up Bend					
MV204-1,4		10.70	1038		
MV204-1	(Rotated Superconductor)			37.96 (In Series with Other Superconductors)	3791
MV204-2,3				13.64	1400

Figure Captions

Fig. 1. Beam Elements in Meson Left Bend.

Fig. 2. 400 GeV Meson/Neutrino Split with Superconducting Left Bend.

Fig. 3. 1 TeV Meson/Neutrino Split.

Fig. 4. Two Strings of Superconducting Dipoles.

Fig. 5. Beam Elements Position Relative to Wall at Downstream End of First String of Superconductors.

Fig. 6. Beam Elements Position Relative to Wall at Downstream End of First String of Superconductors.

Fig. 7. Beam Elements in Downstream End of Enclosure "C".

Fig. 8. Beam Elements in Region Between Two Superconducting Strings. H and V Refer to Horizontal and Vertical Focussing Quadrupoles Respectively.

Fig. 9. Horizontal Beam Envelope for Strong Focus Solution Using Twelve Quadrupoles.

Fig. 10. Vertical Beam Envelope for Strong Focus Solution Using Twelve Quadrupoles.

Fig. 11. Horizontal Path of off Momentum Particle for Strong Focus Solution Using Twelve Quadrupoles.

Fig. 12. Horizontal Beam Envelope for Weak Focus Solution Using Four Quadrupoles.

Fig. 13. Vertical Beam Envelope for Weak Focus Solution Using Four Quadrupoles.

Fig. 14. Horizontal Path of Off Momentum Particle for Weak Focus Solution Using Four Quadrupoles.

Fig. 15. Horizontal Beam Envelope for Approximate Strong Focus Solution Using Four Quadrupoles.

Fig. 16. Vertical Beam Envelope for Approximate Strong Focus Solution Using Four Quadrupoles.

Fig. 17. Horizontal Path of Off Momentum Particle for Approximate Strong Focus Solution Using Four Quadrupoles.

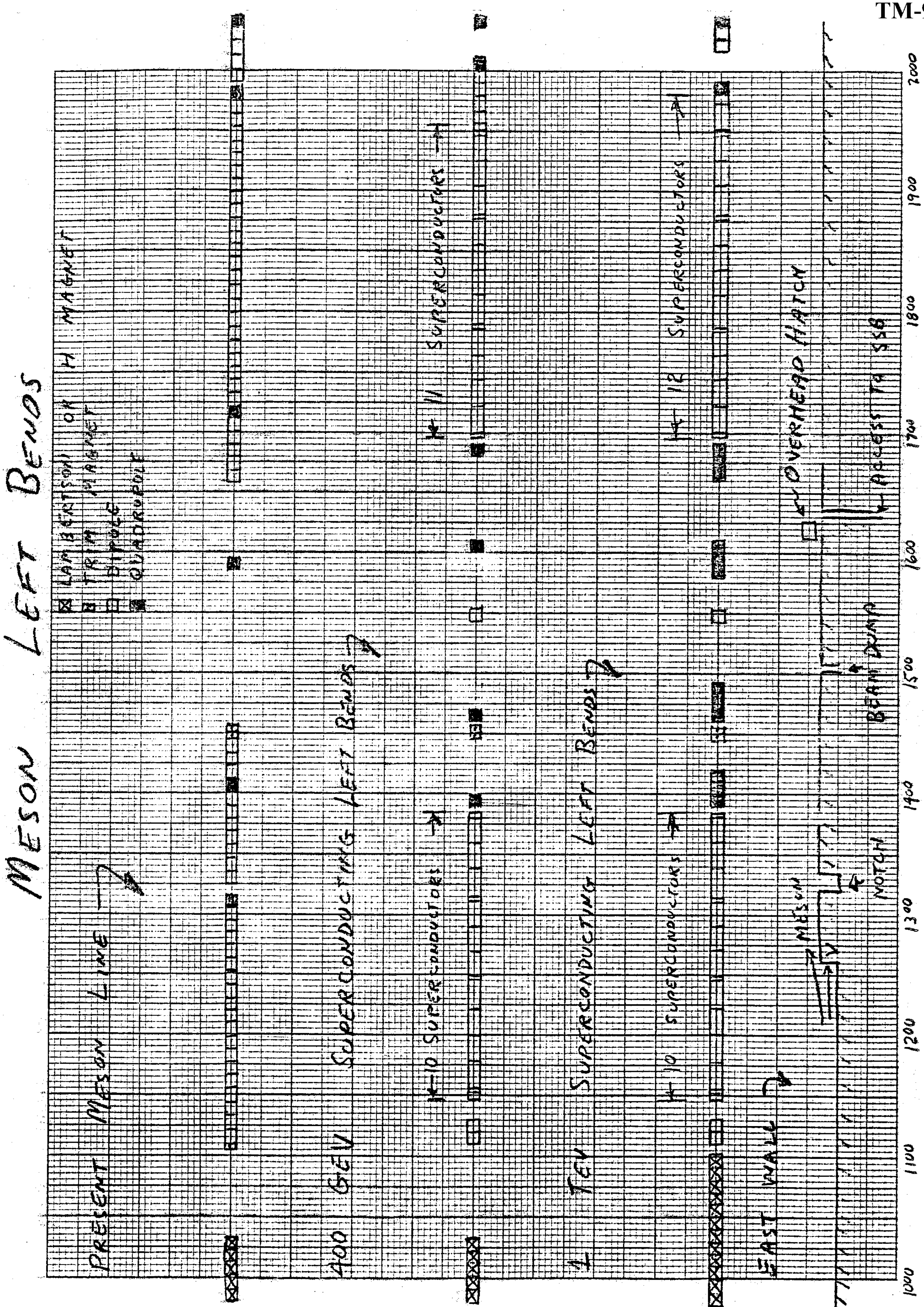

MESON LEFT BENDS
LAMBERTSON OR H MAGNET
TRIM MAGNET
DIPOLE
QUADRUPOLE
PRESENT MESON LINE
400 GEV SUPERCONDUCTING LEFT BENDS
10 SUPERCONDUCTORS
11 SUPERCONDUCTORS
1 TEV SUPERCONDUCTING LEFT BENDS
10 SUPERCONDUCTORS
12 SUPERCONDUCTORS
EAST WALL
MESON
NOTCH
BEAM DUMP
OVERHEAD HATCH
ACCESS TO SSB
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000

FIG. 1

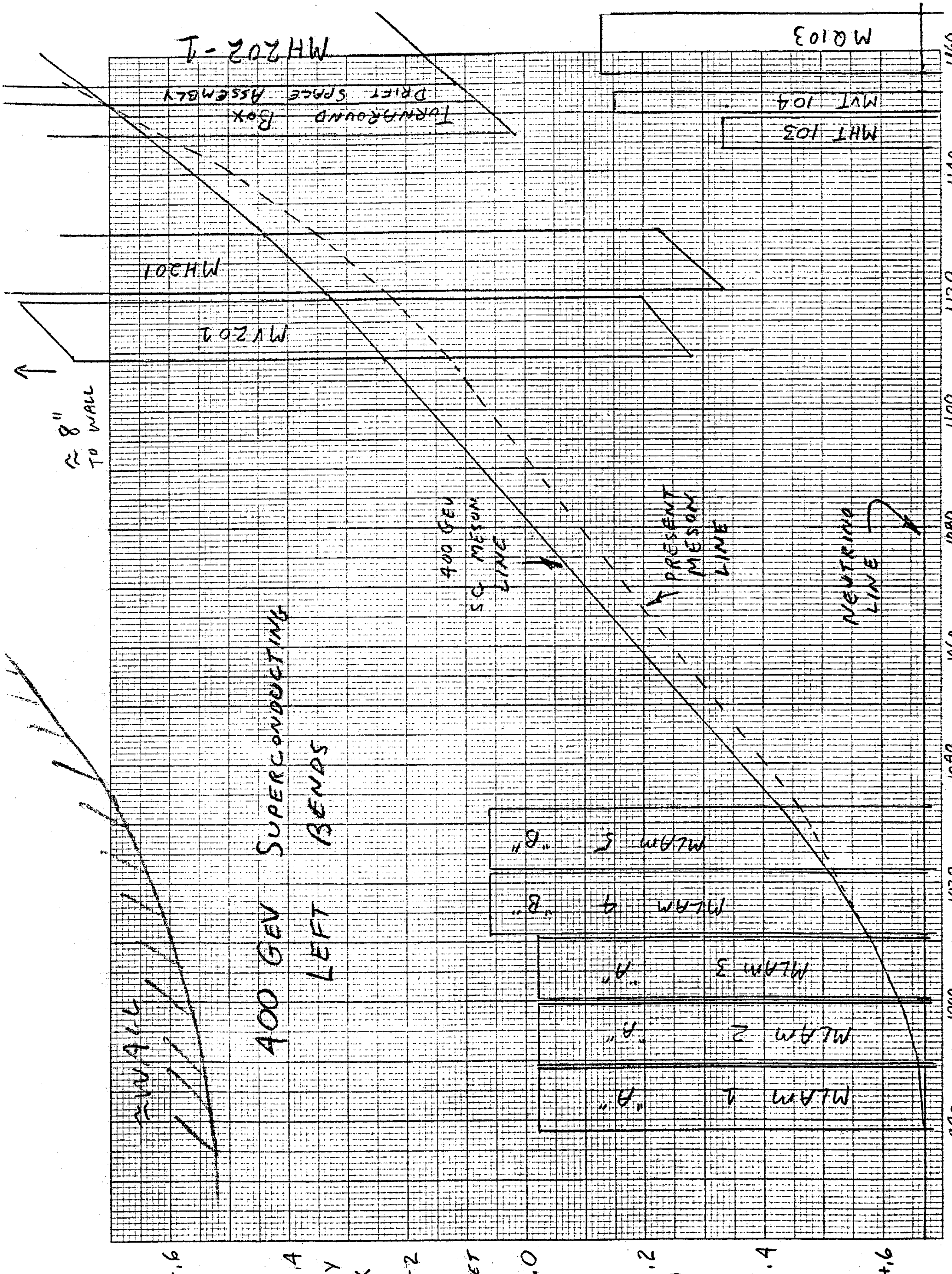
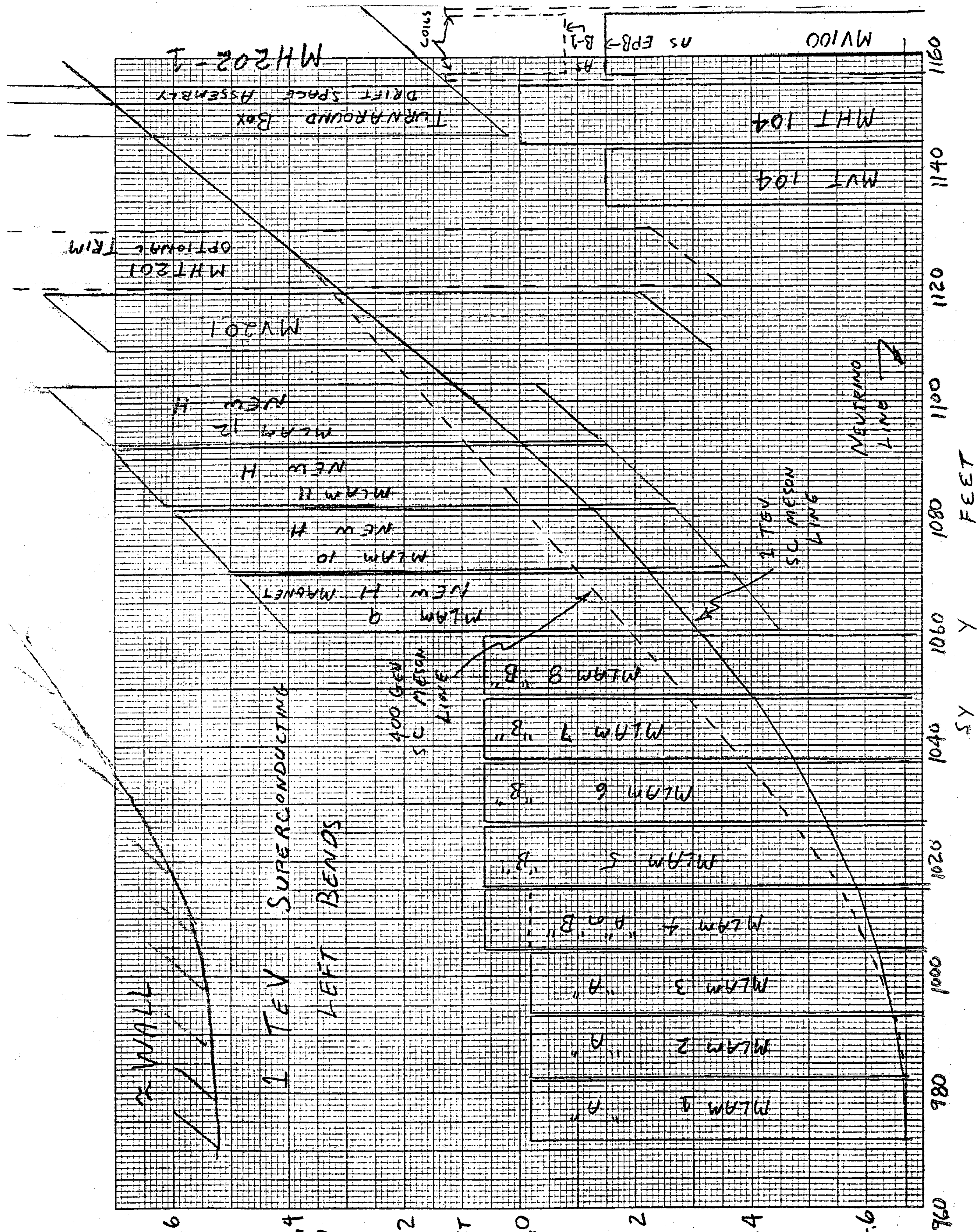
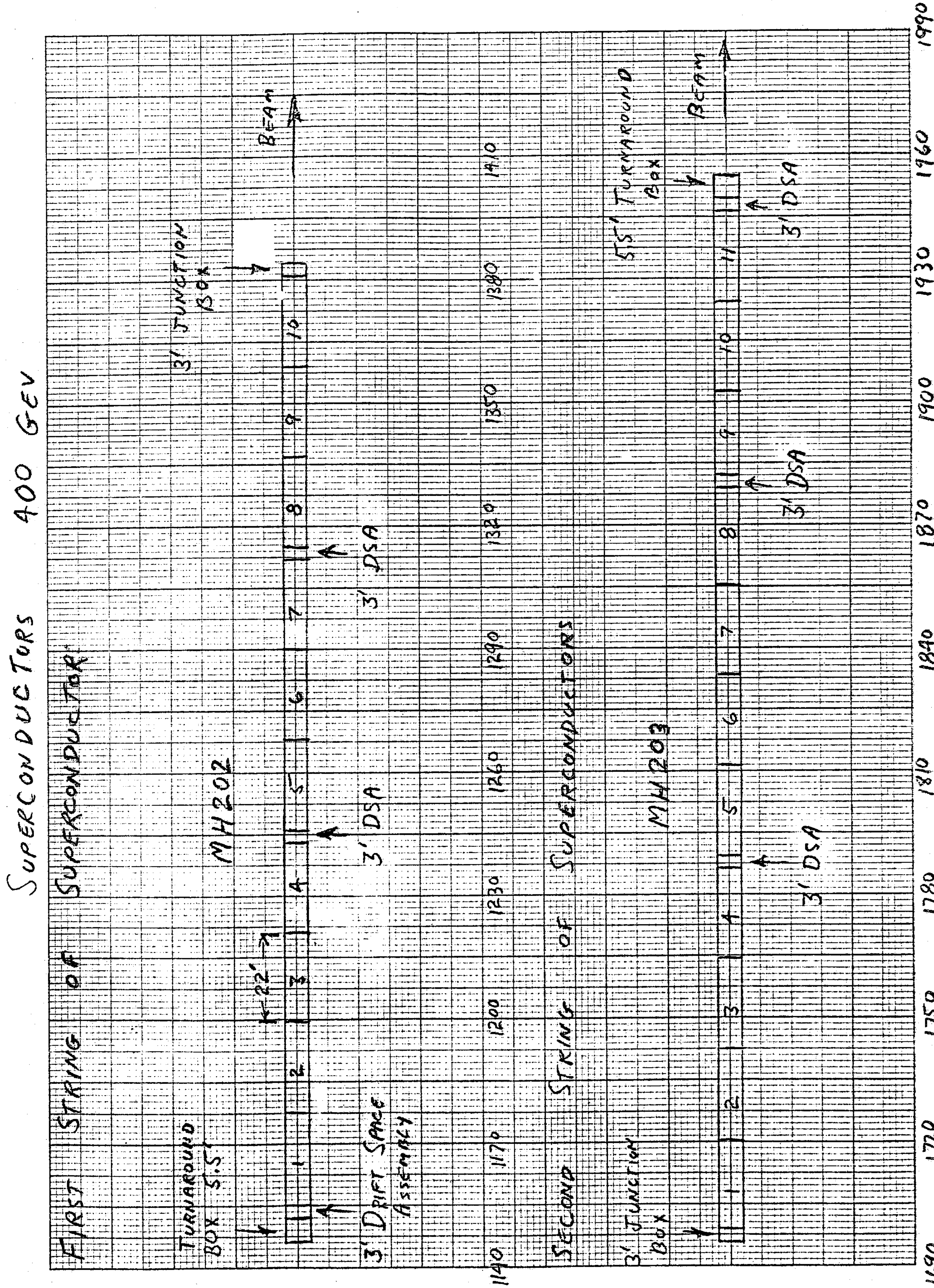

400 GEV SUPERCONDUCTING LEFT BENDS
MH202-1
TURNAROUND BOX
DRIFT SPACE ASSEMBLY
MQ103
MVT 104
MHT 103
MH201
MV201
≈ 8" TO WALL
≈WALL
400 GEV SC MESON LINE
PRESENT MESON LINE
NEUTRINO LINE
MLAM 1 "A"
MLAM 2 "A"
MLAM 3 "A"
MLAM 4 "B"
MLAM 5 "B"
960
980
1000
1020
1040
1060
1080
1100
1120
1140
1160
SY Y FEET
-.6
-.4
-.2
.0
.2
.4
+.6
SY X FEET

FIG. 2



MH202-1
TURNAROUND BOX
DRIFT SPACE ASSEMBLY
COILS
MV100
MHT 104
MVT 104
MHT201
OPTIONAL TRIM
MV201
MLAM 12
NEW H
MLAM 11
NEW H
MLAM 10
NEW H
MLAM 9
NEW H MAGNET
MLAM 8 "B"
MLAM 7 "B"
MLAM 6 "B"
MLAM 5 "B"
MLAM 4 "A" "B"
MLAM 3 "A"
MLAM 2 "A"
MLAM 1 "A"
1 TEV SUPERCONDUCTING LEFT BENDS
WALL
400 GEV SC MESON LINE
1 TEV SC MESON LINE
NEUTRINO LINE
FEET
SY
SY X
FEET

FIG. 3



SUPERCONDUCTORS 400 GEV
FIRST STRING OF SUPERCONDUCTOR
MH202
TURNAROUND BOX 5.5'
3' DRIFT SPACE ASSEMBLY
22'
3' DSA
3' JUNCTION BOX
BEAM
1140
1170
1200
1230
1260
1290
1320
1350
1380
1410
SECOND STRING OF SUPERCONDUCTORS
MH203
3' JUNCTION BOX
5.5' TURNAROUND BOX
3' DSA
BEAM
1690
1720
1750
1780
1810
1840
1870
1900
1930
1960
1990
Z FEET

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FIG. 4

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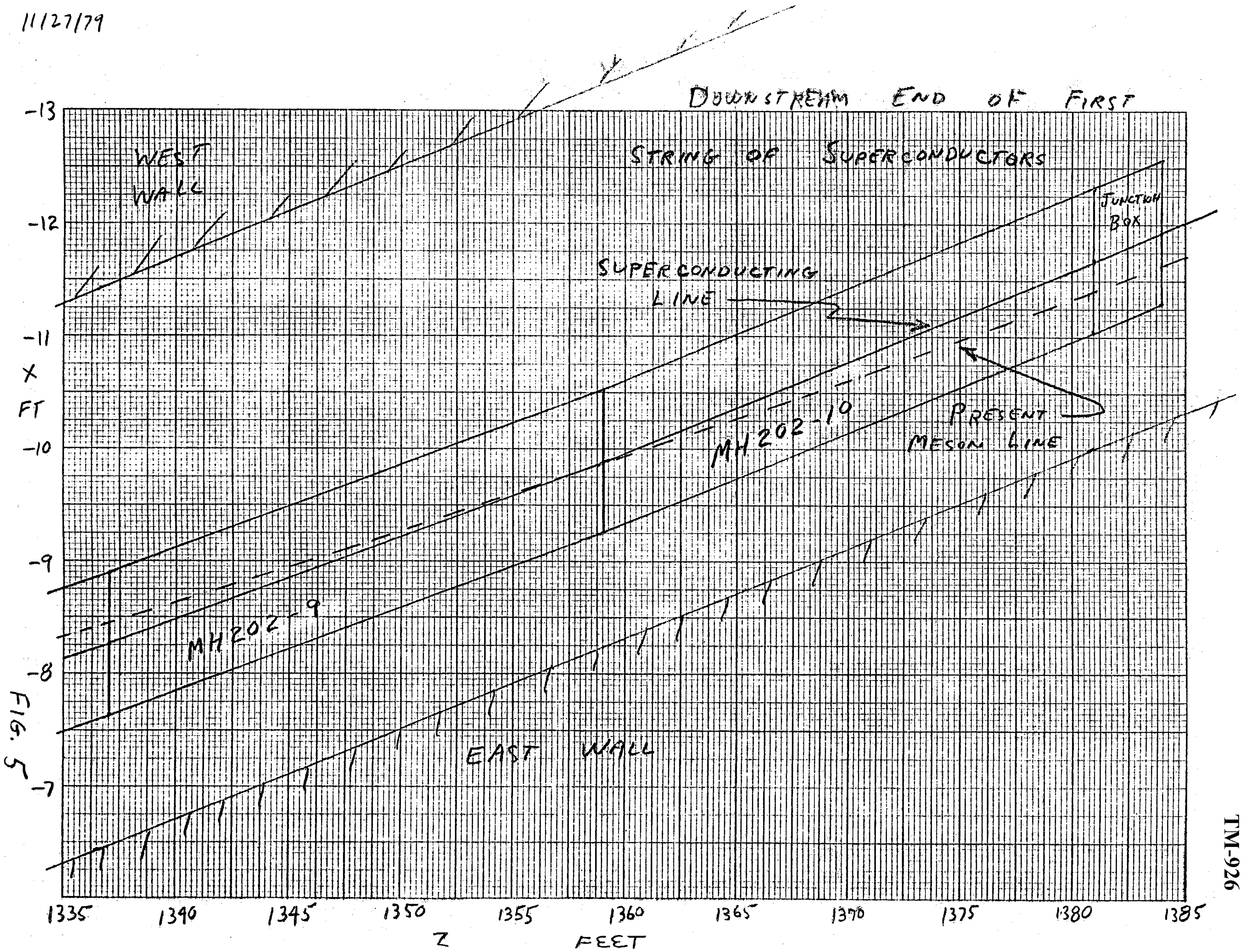

Downstream End of First String of Superconductors
West Wall
Junction Box
Superconducting Line
Present Meson Line
MH202-10
MH202-9
East Wall
-13
-12
-11
X FT
-10
-9
-8
-7
1335
1340
1345
1350
1355
1360
1365
1370
1375
1380
1385
Z FEET

FIG. 5

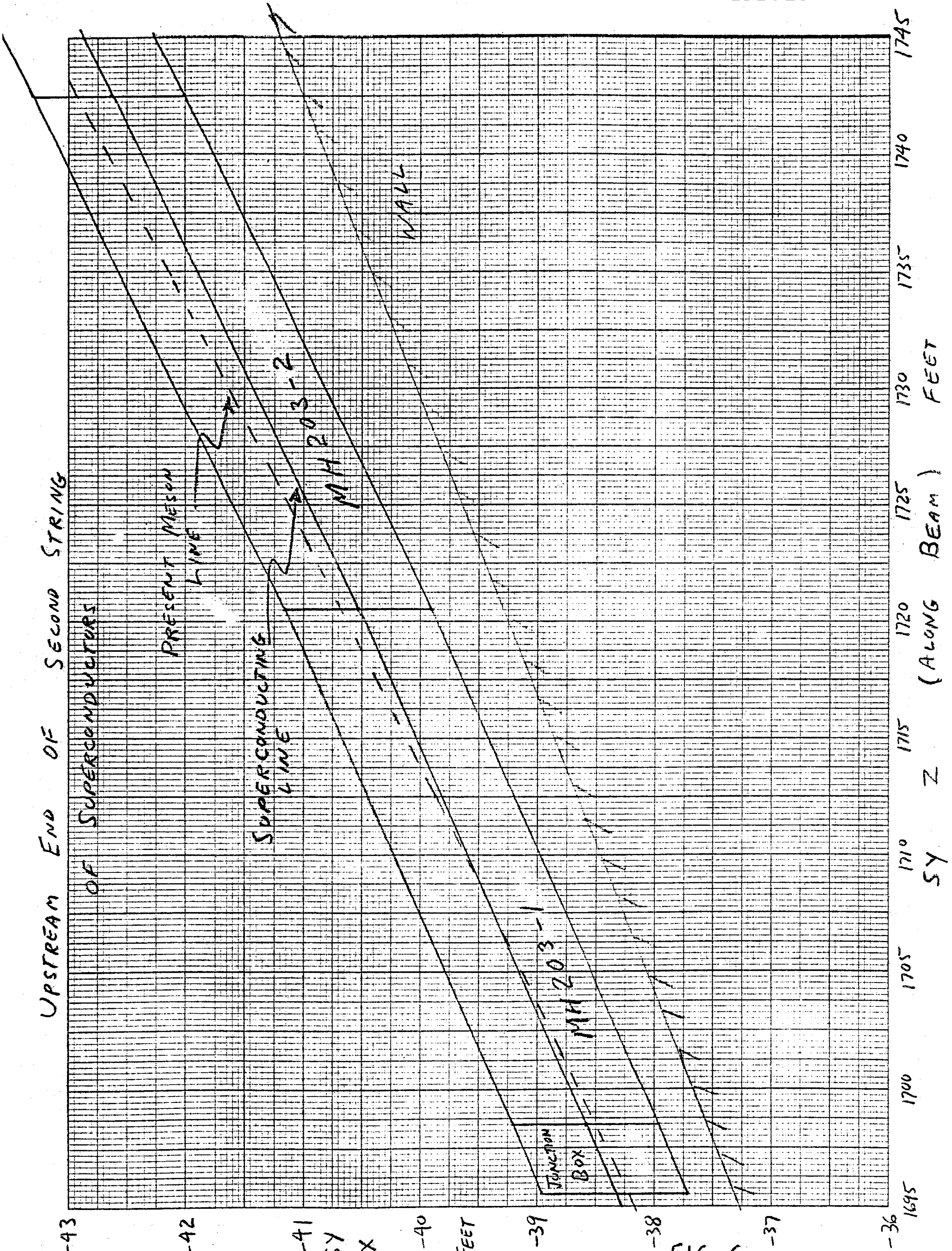
UPSTREAM END OF SECOND STRING
OF SUPERCONDUCTORS
PRESENT MESON LINE
SUPERCONDUCTING LINE
WALL
MH 203-2
MH 203-1
JUNCTION BOX
SY X FEET
SY Z (ALONG BEAM) FEET
-43
-42
-41
-40
-39
-38
-37
-36
1695
1700
1705
1710
1715
1720
1725
1730
1735
1740
1745

FIG. 6

11/27/79

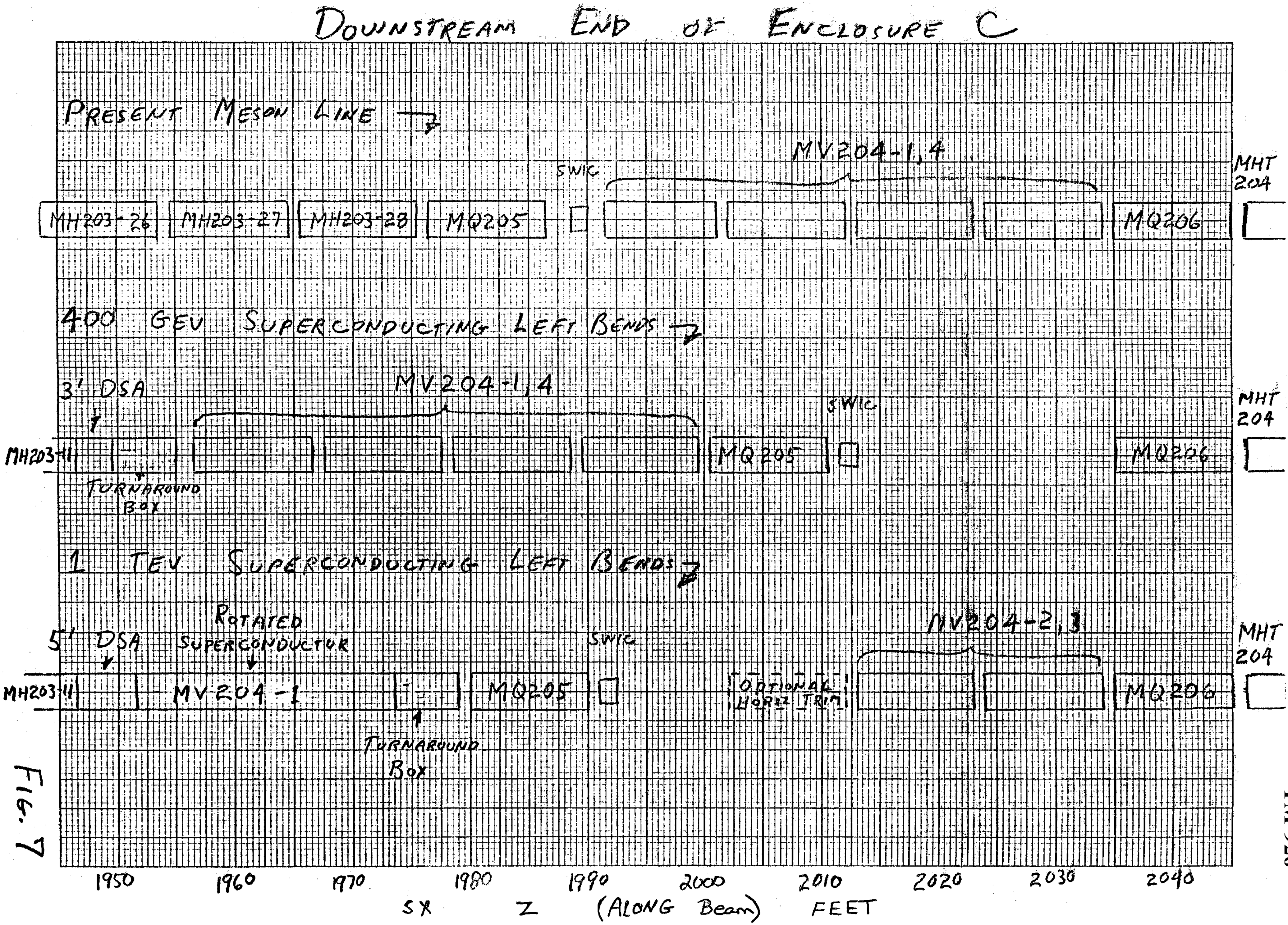
DOWNSTREAM END OF ENCLOSURE C
PRESENT MESON LINE
MV204-1,4
SWIC
MHT 204
MH203-26
MH203-27
MH203-28
MQ205
MQ206
400 GEV SUPERCONDUCTING LEFT BENDS
3' DSA
MV204-1,4
SWIC
MHT 204
MH203-11
TURNAROUND BOX
MQ205
MQ206
1 TEV SUPERCONDUCTING LEFT BENDS
5' DSA
ROTATED SUPERCONDUCTOR
SWIC
MV204-2,3
MHT 204
MH203-11
MV204-1
MQ205
OPTIONAL HOR'Z TRIM
MQ206
TURNAROUND BOX
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
SX Z (ALONG Beam) FEET

FIG. 7

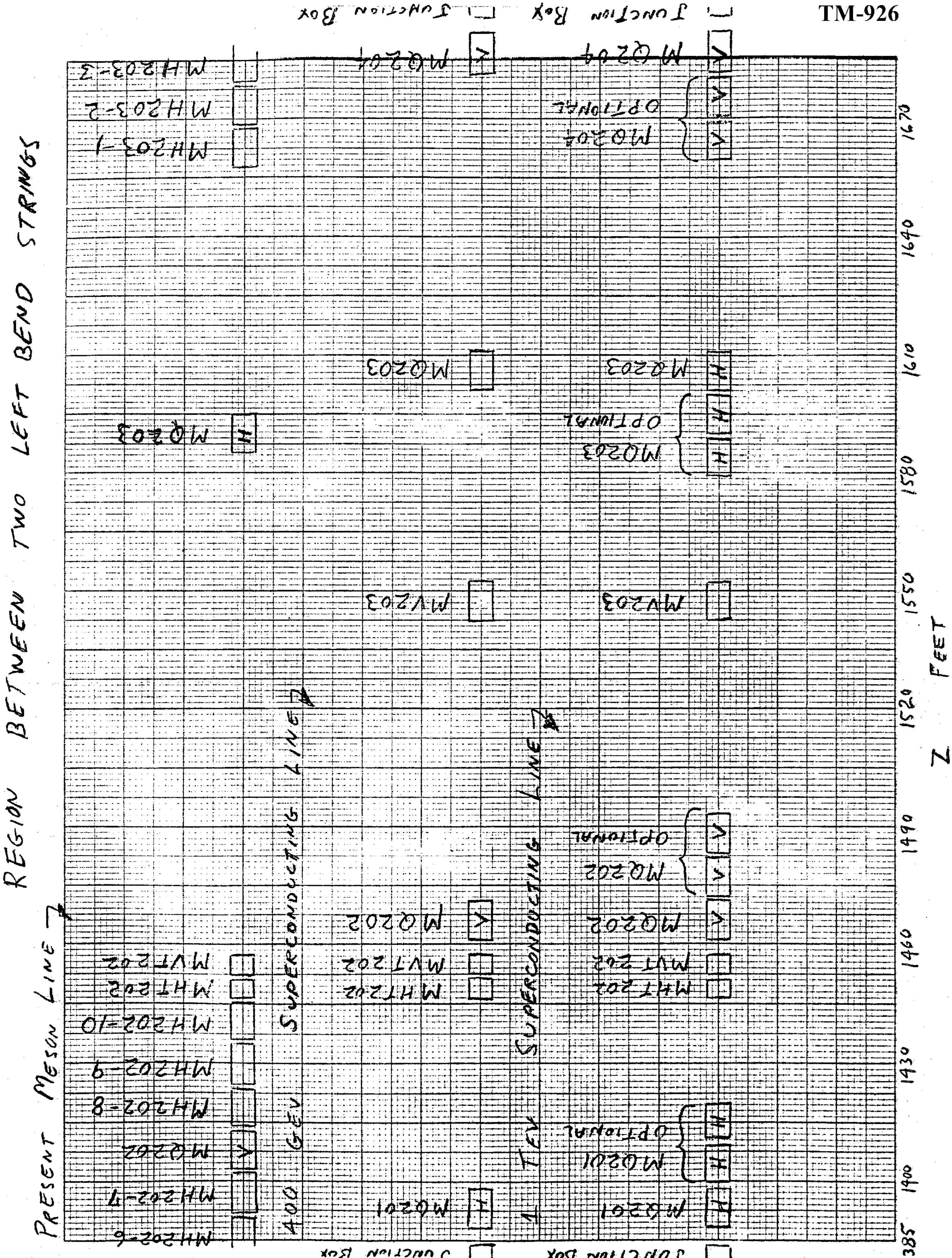
REGION BETWEEN TWO LEFT BEND STRINGS
PRESENT MESON LINE
400 GEV SUPERCONDUCTING LINE
1 TEV SUPERCONDUCTING LINE
Z FEET
1385
1400
1430
1460
1490
1520
1550
1580
1610
1640
1670
JUNCTION BOX
MH202-6
MH202-7
MQ202
MH202-8
MH202-9
MH202-10
MHT202
MVT202
MQ203
MH203-1
MH203-2
MH203-3
MQ201
MQ202
MV203
MQ204
OPTIONAL

FIG. 8

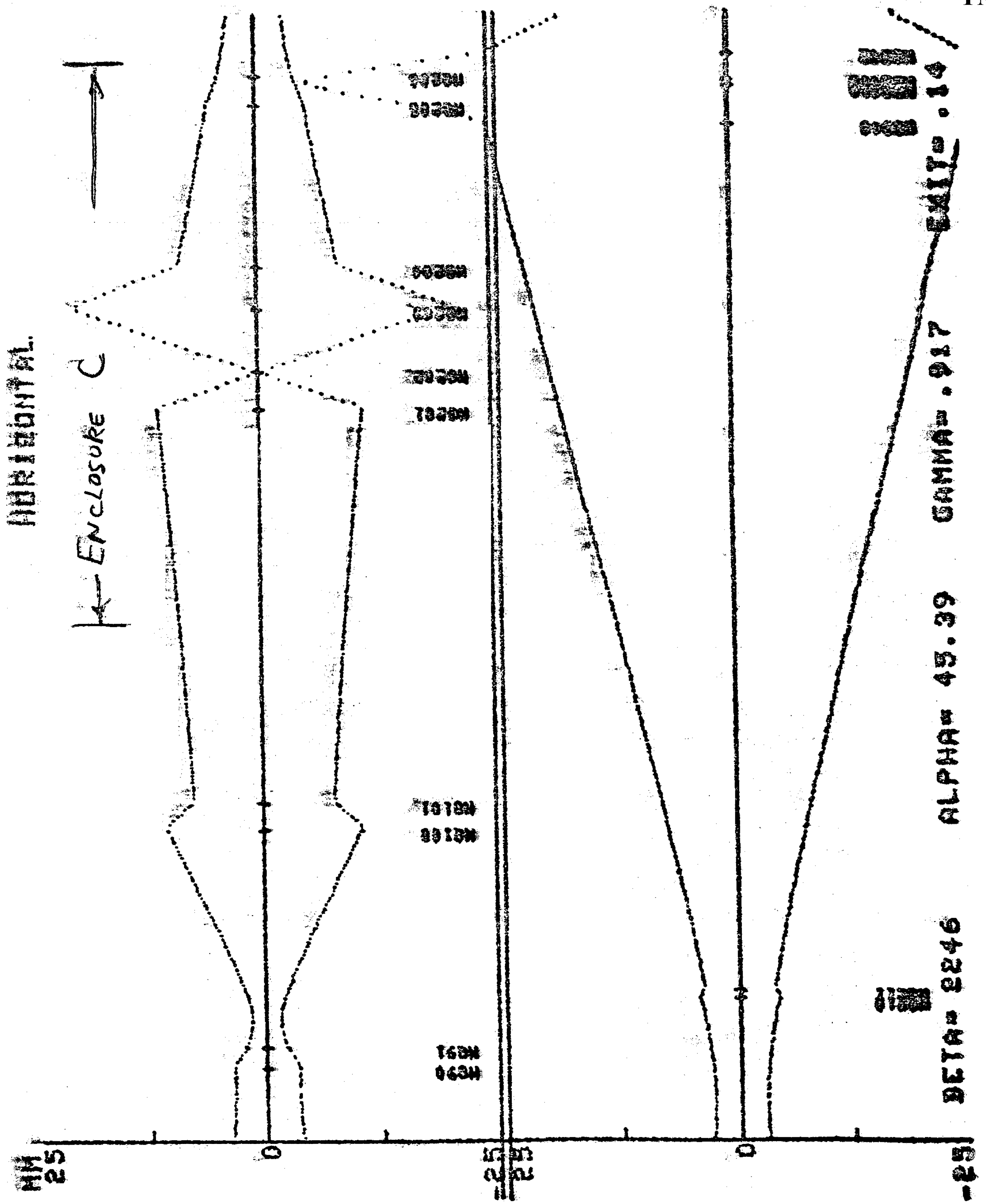
HORIZONTAL
Enclosure C
BETA= 2246 ALPHA= 45.39 GAMMA= .917 EXIT= .14
MM
25
0
-25

FIG. 9

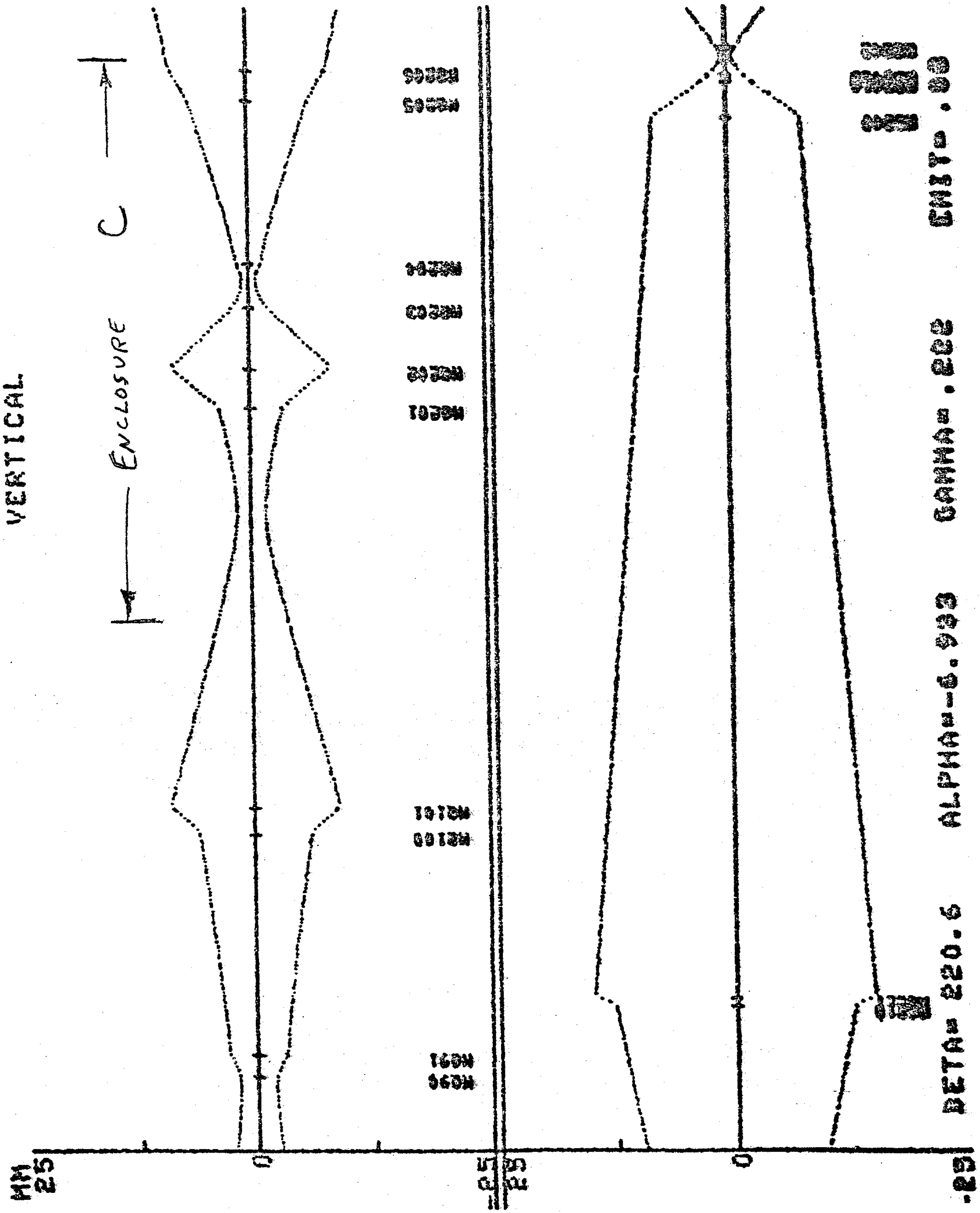
VERTICAL
ENCLOSURE C
BETA= 220.6
ALPHA=-6.933
GAMMA= .222
MM
25
0
.25

FIG. 10

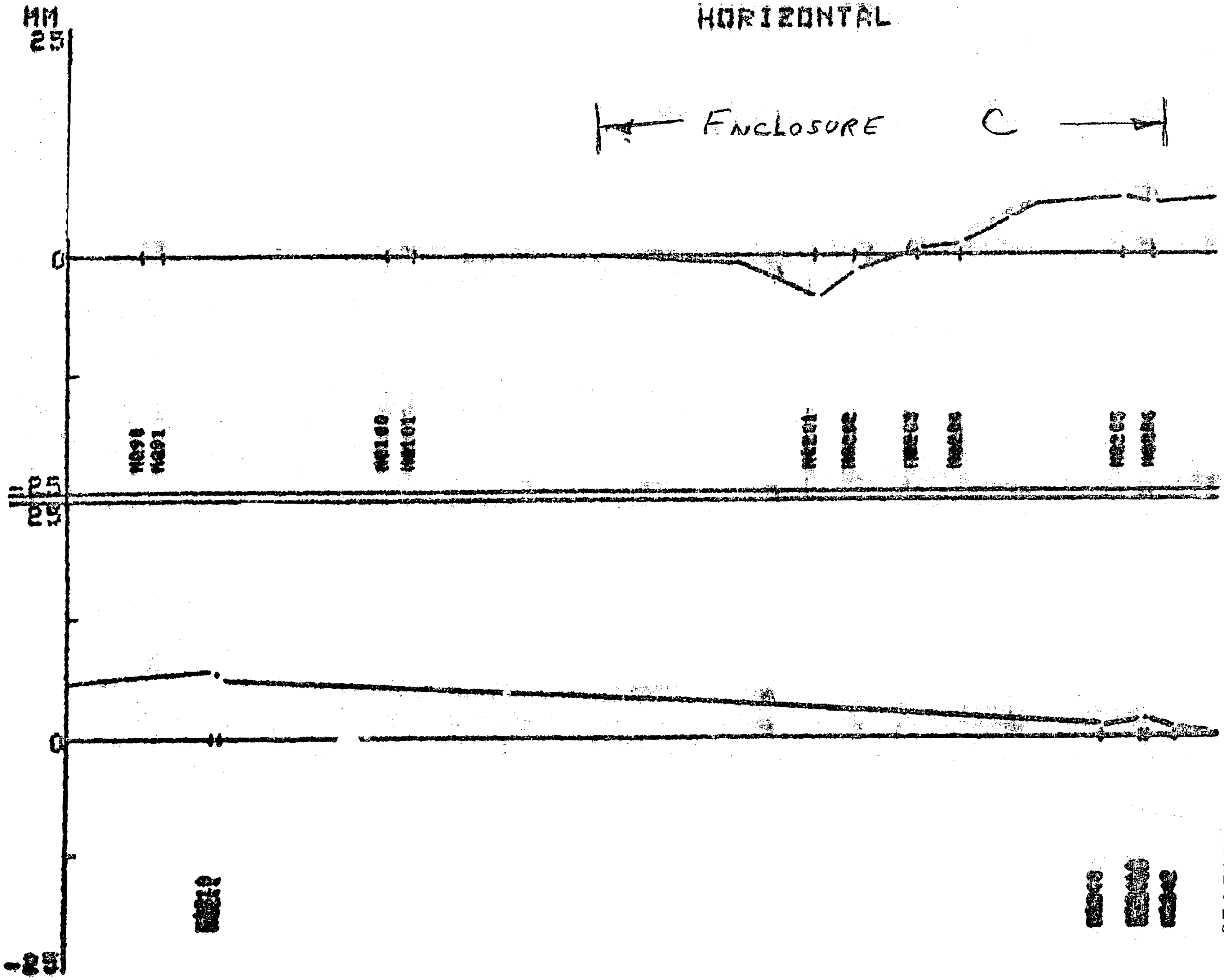

Fig. 11

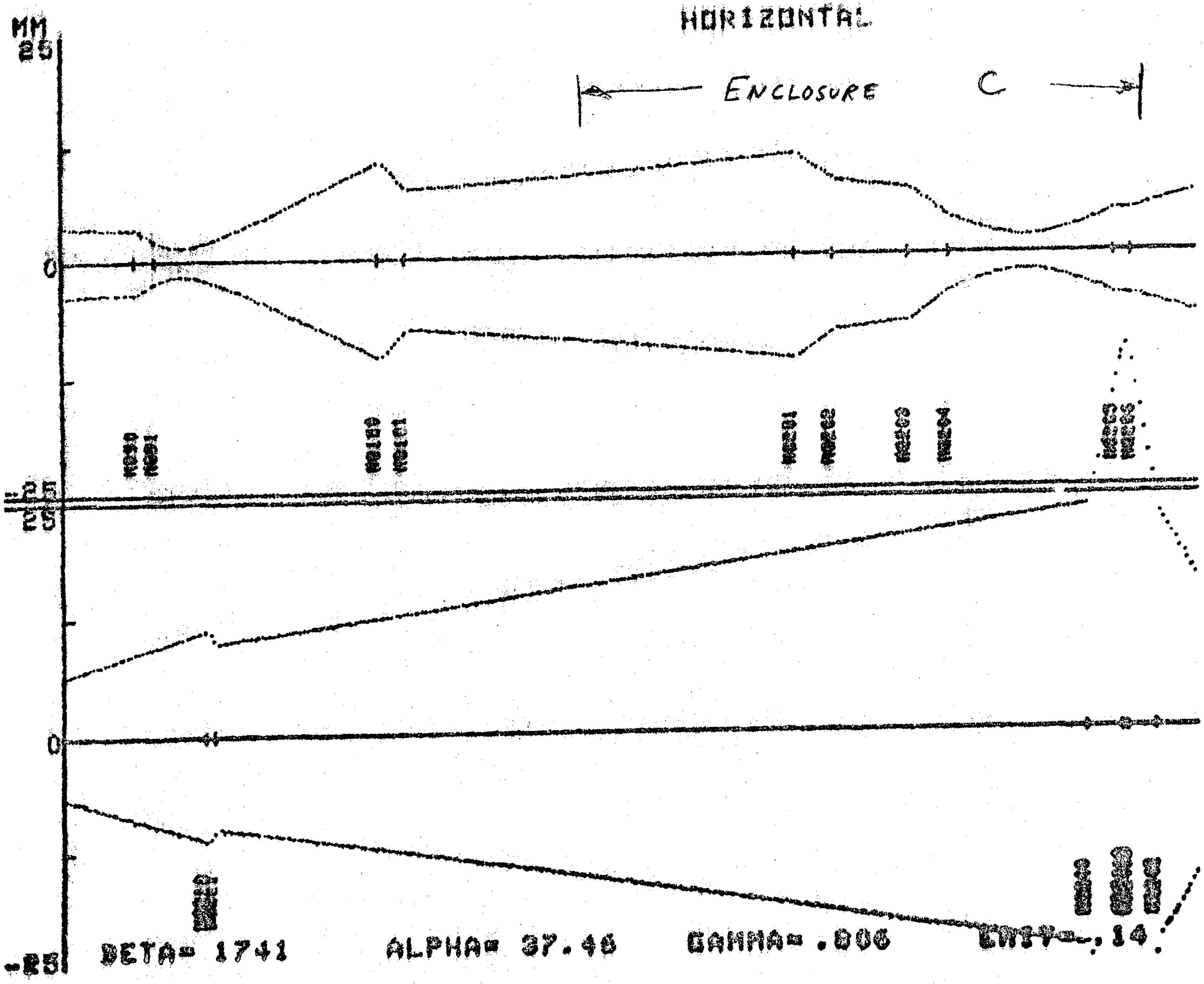
HORIZONTAL
ENCLOSURE C
MM
25
0
-25
25
0
-25
BETA= 1741
ALPHA= 37.46
GAMMA= .006

FIG. 12

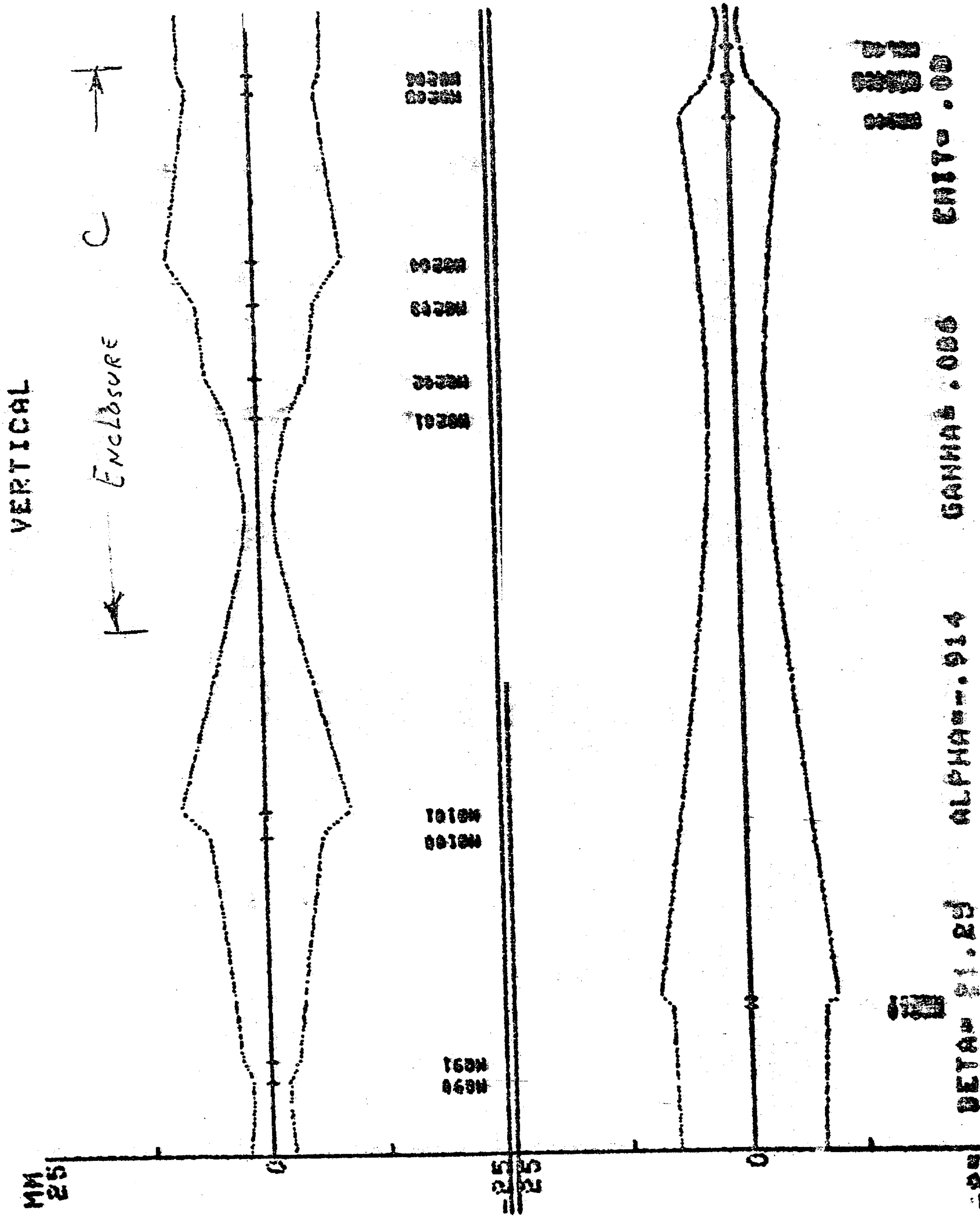

FIG. 13

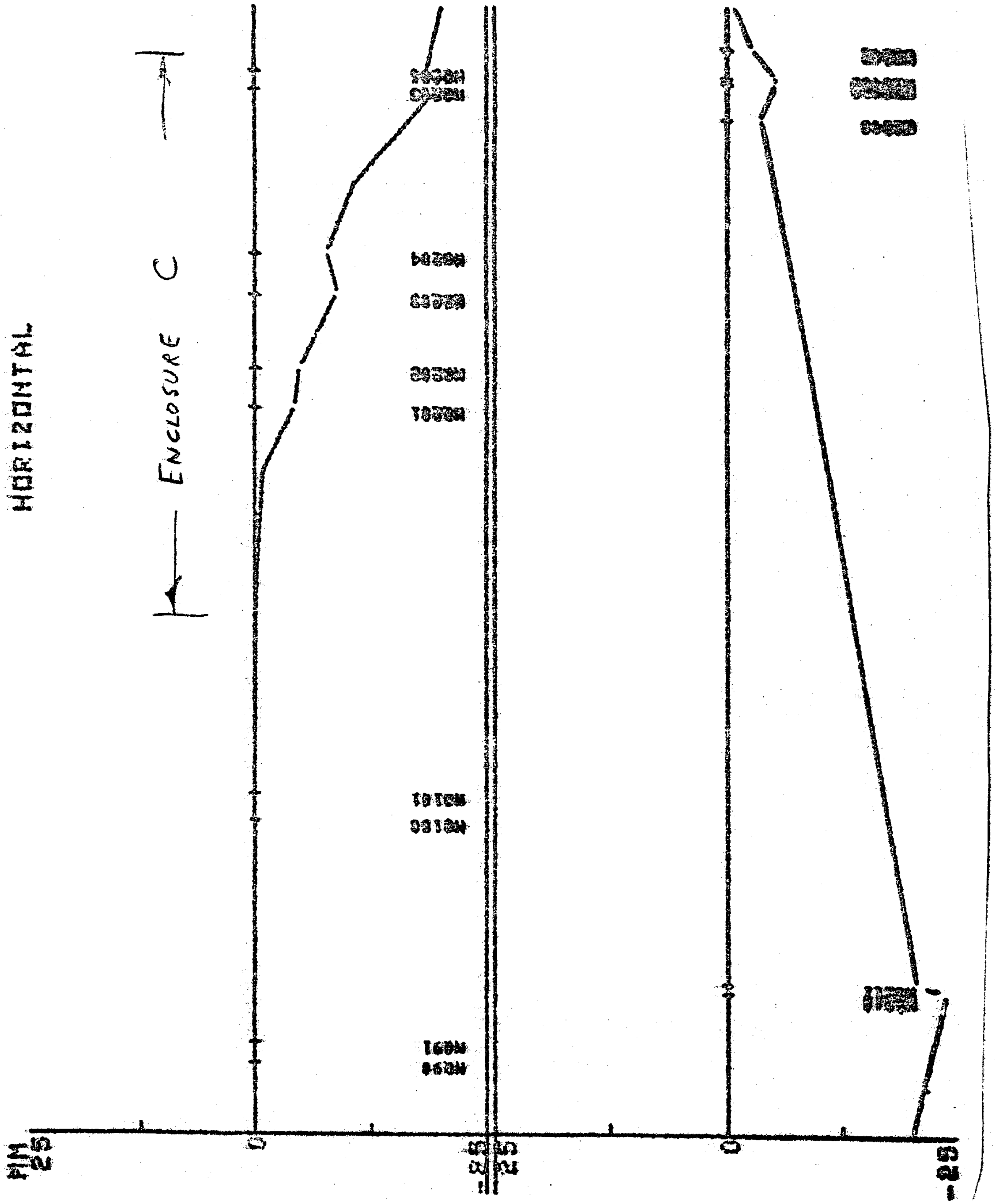

FIG. 14

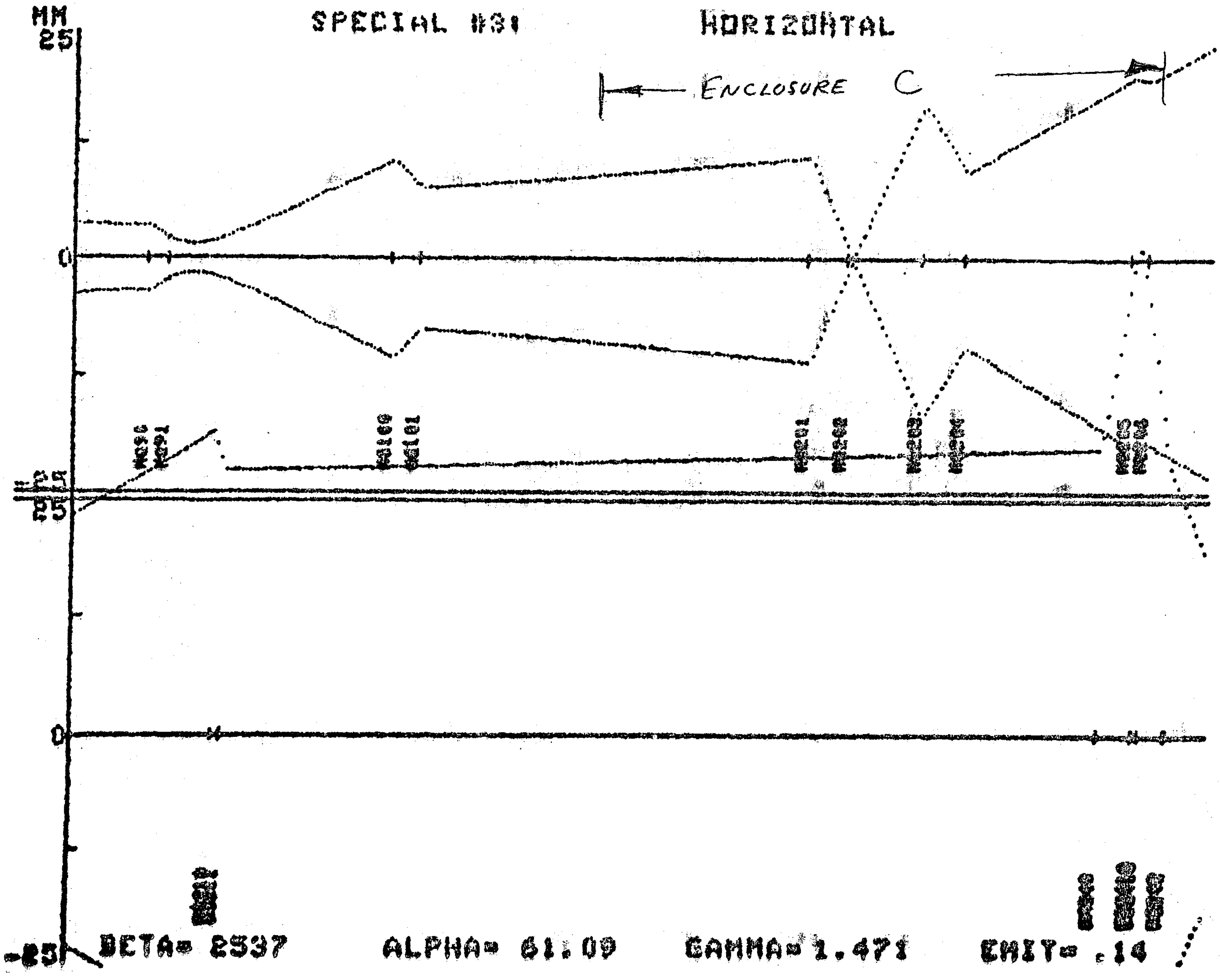
SPECIAL #31
HORIZONTAL
MM
25
0
-25
ENCLOSURE C
BETA= 2537
ALPHA= 61.09
GAMMA= 1.471
EMIT= .14

FIG. 15

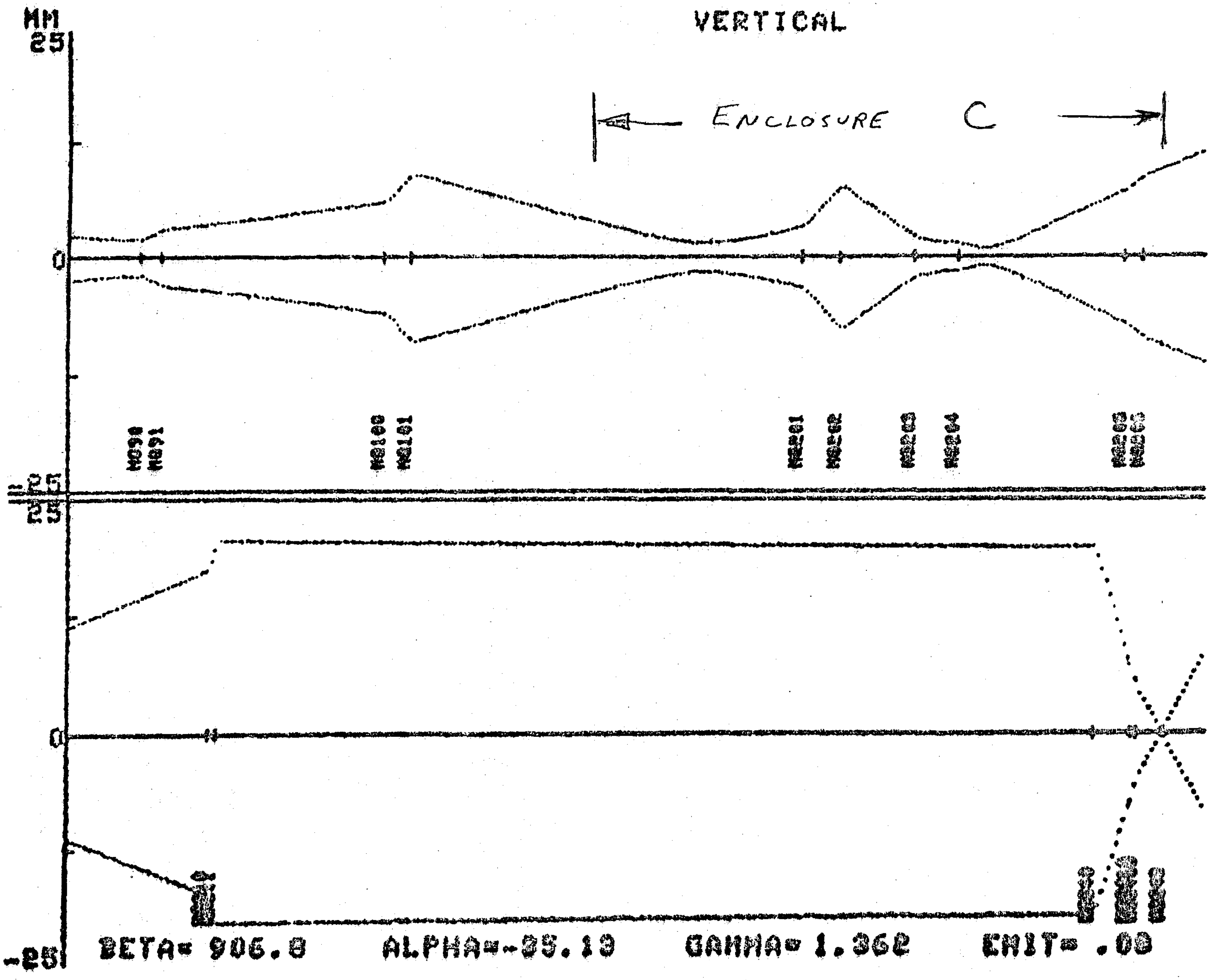
MM
25
VERTICAL
ENCLOSURE C
0
-25
25
0
-25
BETA= 906.8
ALPHA=-25.13
GAMMA= 1.362
EMIT= .08

FIG. 16

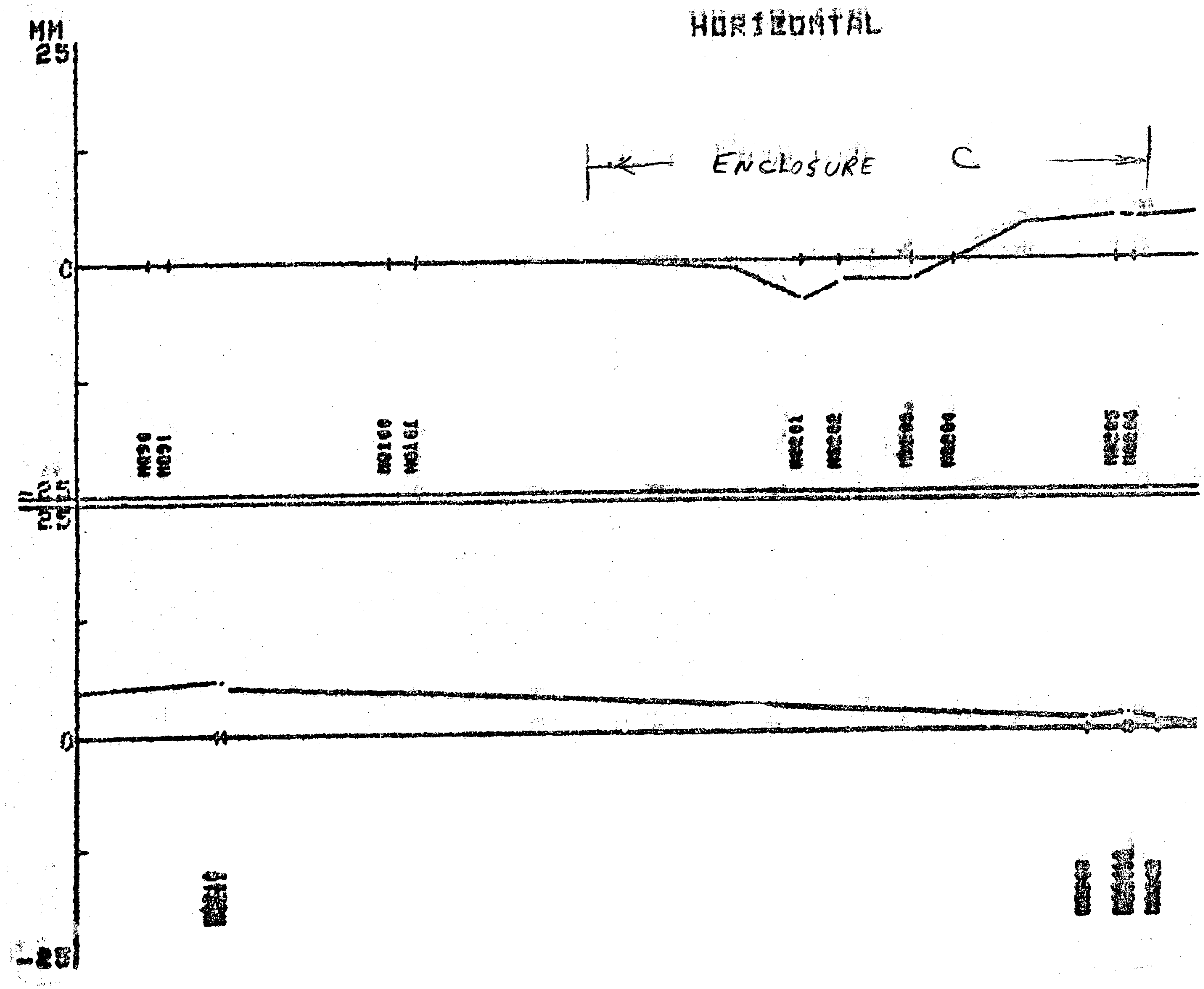

FIG 17