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TM-754
2960.000

# DESIGN STUDY FOR A HIGH ENERGY MUON BEAM

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November 1977

## INTRODUCTION

Plans for upgrading the muon physics program at Fermilab have been under discussion for several years and typically focus on an improved muon beam. The Fermilab Summer Study Reports for 1968, 1969, 1970, 1973, 1976 all have papers and discussion on this topic. The last named study stimulated a detailed design project by the authors on which we report in this document. The general guideline we adopted in this work was to create a new muon beam design appropriate to the Tevatron era at Fermilab (1000 GeV protons). The design was further constrained to yield good performance at present lower proton beam energies (400 GeV). Within this context, we applied the following design criteria:

i) high efficiency ($\mu / p \sim 10^{-5}$)

ii) low "halo" (halo/beam $\sim 5\%$)

iii) broad tuning range ($275 \leq p \leq 750$ GeV)

iv) good optical quality ($R_{beam} \lesssim 3$cm)

v) low hadron contamination ($\pi/\mu < 10^{-6}$)

vi) freedom from interference with other beams and equipment

vii) momentum tagging capability ($\Delta p/p \leq 2\%$)

viii) acceptable radiation hazard on-site and at site boundaries.

This preliminary study of several beams along with their associated halos has been done using the Monte Carlo programs DECAY TURTLE[1] and HALO.[2] The CERN-SPS muon beam design expects to realize a halo/beam ratio of $\sim 2\%$ over 4x4 meters[3]; our definition of halo corresponds to a 10 foot x 10 foot area.

## PROTON BEAM

The overall plan for achieving a proton beam and production target for muon experiments separate from the existing N0 beamline is shown in Figures 1 and 1a. The essential features are taken from TM729[4] (alternative 2) with minor modifications. The path of the beam is 30 milliradians to the east and 10 feet below the N0 beamline. The main points of the proposal are:

1) The existing G line is split horizontally with 50 ft. of electrostatic septa at the G1 manhole.
2) A new tunnel section labeled G1.5 will contain 60 feet of Lambertson magnets which bend vertically.
3) G2 will be extended and contain four 22 foot superconducting dipoles run at $\sim$ 40 kilogauss. The dipoles will be rotated so that they complete the 10 milliradian vertical bend started by the Lambertsons, and give a horizontal bend of 30 milliradians.
4) The beam drifts to the Muhall target areas in the vicinity of Enclosure 100 where it is focussed onto the target.
5) The majority of the new beamline can be installed by means of a trenching and pipe burying operation. Since the beam is 10 feet underground, little earth moving will be required for berm construction. There is no interference with Nuhall, the Target Service Building, or modifications to the decay pipe. No penetration of the Neutrino "bathtub" for containing radioactive ground water is necessary nor is any digging of radioactive soil.

## THE MUON BEAM

The muon beam basically consists of two target stations, a front end triplet which efficiently collects the parent particles, a decay section, a hadron absorber, and a part which selects and tags muon momenta and reduces halo. We have mainly employed the WANG[5] parameterization of particle yields with the standard assumption of $K/\pi \approx 0.1$. An alternative

parameterization which makes a definite prediction for the $K/\pi$ ratio at high energies is that due to Adair[6]. The pion yields matching to the acceptance of the proposed beams are compared for these two parameterizations in Table I. The WANG pion yields are about twice those of Adair. Adair predicts a larger $K/\pi$ ratio than the 10% usually assumed.

In order to check these formulae, we have attempted to reproduce the muon yields in the existing muon beam at Fermilab (N1 line). We have used the WANG parameterization, but can scale to the Adair prediction using the pion yields of Table I. The yields are computed using HALO for 150 and 225 GeV/c operation. The targeting angle of the primary proton beam onto the target (with respect to the N1 beamline direction) was 0.3 mr and 0.7 mr, respectively,[7] which required a small modification to be made to the HALO subroutine PIGEN where zero degree targeting and production are assumed. The differences from the zero degree values were <10%. As is seen from Table II, the predictions are in reasonable agreement with the measured yields. The geometry of the N1 beamline assumed in HALO is given in Appendix I.

Four different beam configurations have been considered, although only the two having the best halo to beam characteristics were modeled in detail. For completeness, we give all four beam layouts and note that three of these (called 1-3) have a common front end, Figure 2a, while the fourth is different, Figure 2b. The primary features of each section are described below. The design uses the specifications of an existing quadrupole, the 4Q120[8], and 20 foot long, 15 kilogauss bending magnets with 4"x6" aperture.

A. Target Stations

The proton beam will be directed at either of two targets in Muhall. The two targets will be separated in Z by 24 feet. The upstream target will be used whenever the pion beam is tuned for a momentum greater than 600 GeV/c. Using this scheme the triplet will capture roughly the same $P_\perp$ at high and low energies. These two targets could be placed in two

separate manholes similar to the target manhole that now exists in the decay pipe. It is also possible that a target tube similar to that in Nuhall could be used. One train car containing the target, a collimator and the necessary instrumentation should suffice. The cost of the target tube with its associated tracks and access tunnel is comparable to the cost of the manholes. The manholes offer the advantage of having vacuum all along the beam, however servicing and repairing take longer.

B. Hadron Capture Section

The purpose of this front-end quadrupole triplet section is to collect as many pions and kaons from the target in as large a momentum band as possible. A fifteen foot water-cooled collimator will be placed immediately downstream of the target to absorb low energy/wide angle parent particles. This will be followed by a triplet consisting of ten quadrupoles aligned at zero degrees with respect to the incident proton beam. The configuration is the same at 750 and 550 GeV/c; two quadrupoles and a drift space are interchanged for the 275 GeV/c operation. Beams 1-3 contain bending magnets in a notch arrangement serving to get rid of the low energy/wrong sign parent particles. All particles greater than 0.6p are transported, dispersion-free, to the end of the decay channel where there is a water-cooled beryllium absorber. When the channel is tuned for parent momenta $\geq$600 GeV/c, the 1000 GeV diffracted proton beam is carried along the channel and is dumped at the beryllium absorber. At lower energies the 1000 GeV beam will encounter a conventional dump in the notch. The FODO channel, when tuned for 275 GeV/c muons, cannot transport the diffracted proton beam without significant losses. Beam 4 dumps the protons at the front end and the dipole bending selects $\pm$10% $\Delta P/P$. This eliminates early in the beam some of the particles contributing

to the halo at the end of the beamline. The dispersion at the momentum slit of Beam 4 is shown in Figure 3. Note that there is no horizontal focus at the momentum slit, unlike the CERN beam, but the triplet delivers a parallel beam to the decay FODO. This selection slightly reduces the muon yield as compared to Beams 1-3. These are summarized in Table III.

C. Decay Channel ($\pi$/K Decays)

The criteria for obtaining the highest possible muon flux per proton have been variously described.[9] As illustrated by the CERN design, the FODO array provides the most efficient transport system allowing pions from a wide momentum band to contribute muons to the desired momentum interval.

The decay channel is a FODO array composed of 4Q120 quadrupoles having an average half-aperture of 2.25 inches. The efficiency of the channel as a function of particle momentum is shown in Figure 4. This curve was made with the FODO tuned to maximize the muon flux from parent particles of central momentum P. The transmission of the beamline was studied using the program DECAY TURTLE, modified to input a parent production spectrum. The results of keeping the decay length constant and removing magnets in the Parent FODO are shown in the following table.

| PARENT FODO | | MUON FODO | RELATIVE $\mu$ / p TRANSMISSION | |
|---|---|---|---|---|
| L(feet) | No. of Magnets | L(feet) | 800 | 305 (GeV/c) |
| 200 | 15 | 200 | 1.00 | 1.00 |
| 326 | 10 | 200 | 0.47 | 0.41 |
| 550 | 6 | 200 | 0.41 | 0.30 |
| 3370 | 0 | 200 | 0.08 | 0.06 |
| (parallel beam) | | | | |
| 326 | 10 | 326 | 0.9 | 0.8 |
| 143 | 21 | 143 | 1.03 | 1.12 |

After removing the magnets the channel was tuned for maximum muon flux while being constrained to match into the Muon FODO. The quadrupole strength and hence the phase advance per period is arranged so as to contain with minimum losses the parent beam of central momentum P and a wide momentum band of muons resulting from their decay. One can obtain a better transmission at the expense of a) adding additional matching sections to take the beam from the Parent FODO, make a small beam spot on the beryllium plug, and then match into the Muon FODO, or b) making the distance between quadrupoles, L, the same for both FODO's. The first option is not very attractive because the number of magnets required for the matching sections is comparable to the number removed from the Parent FODO. The second alternative has the drawback of increasing the total length and thus increasing the distance that the utilities have to be extended. In going from L=200 feet to L=326 feet, the length of the Muon FODO increases from 1470 feet to 2350 feet. This distance could be reduced somewhat by increasing the phase advance per period in the Muon FODO, but would save only one magnet and correspondingly only 326 feet. Taking out more magnets would mean that the angular dispersion, $d\theta/dp$, would be non-zero. The maximum field strength of the 4Q120 gives a minimum value for L of 140 feet, and has been included in the table for completeness. We have chosen to study in detail beams with L=200 feet for both FODOs. Use of a phase advance of $\sim 60$ degrees per FODO period for all momenta yields both good transmission and a reasonably small spot size at the beryllium absorber so multiple scattering can be minimized. In this way the absorber can be located within the FODO without additional matching sections. Typically, only a small part of the

halo at the end of the beam originates in the decay channel, as shown by Figure 5.

D. Muon Transport Section

At the end of the decay section and the beginning of the final FODO section is a hadron absorber which reduces the $\pi/\mu$ contamination at the end of the beam to $<10^{-6}$. The absorber, $\sim 35$ feet of beryllium, is located immediately downstream of the last quadrupole of the decay channel and inside the first dipole of the Muon FODO. This will also serve as the primary proton dump when the beam is tuned for high energy positive muons. Following the absorber the first bending magnet selects the desired muon momentum band. Optically this is followed by a continuation of the Parent FODO. The four beams differ in the number of FODO periods used to transport the beam from the absorber to the detector and in the direction of bending, as shown in Figures 8a, 8b, and 8c. In the case of Beam 4, we have simply used the same muon FODO as for Beam 2. Most halo at the experiment originates after the absorber, and Beam 2 is found to have the best halo to beam characteristics. It is envisaged, when desired, that momentum tagging of individual muons entering the detector can be accomplished by following the trajectories through the last dipole, using MWPC's and scintilation counters. The muon yields at the detector for beams 2 and 4 are given in Table III. Three complete periods are used to rotate the phase space by 180 degrees. The final bending magnet, in the same direction as the first, is placed to cancel $d\theta/dp$. Halo removal is accomplished by a series of magnitized iron pipes and toroids.

E. Halo

The halo considerations can be separated into two parts. There is the direct question of how many muons accompany the beam into the detector, and also how many muons irradiate the outside

world. We have been particularly concerned with reducing the former, although we have also estimated the latter. As noted in the 1976 Summer Study[10], the halo muons are best removed by interposing magnetized iron to deflect them away from the beam. The elements introduced are iron toroids (at magnetisations of 15 kg) and sections of magnetized iron beam pipe (this mupipe is described in Appendix III). The mupipe introduces a hard magnetic edge close to the extreme excursion of the beam; we use a pipe with internal and external radii 2 and 3 inches, respectively. The radial dimensions were varied in the study and the criticality of the alignment was estimated. These are followed at strategic places with large magnetic toroids placed so as to intercept the halo deflected out by the mupipe and thus clear out the larger area. There are two toroid sections, one 4 feet and the other 3 feet in radius. Both are 40 feet long with a 3 inch radius hole.

The initial deflection of the unwanted muons is started by the mupipe, and then increased further by the large toroids. This halo distribution at the detector, before any attempt is made to deflect halo from the beam direction, is shown in Figure 6 for Beam 2. We assume the detector would present a cross section not larger than 120" x 120". However, in order to have a clear working space, we also define an area of 300" x 200" about the beam. This consideration was used to fix the lengths of the magnetized Toroids.

Program HALO will indicate where in the beam line the offending muons left the aperture and became halo (see Figure 5 for the beam without magnetic scrapers). This helps in placing the iron. The scrapers we have considered are labelled in Figures 8 (a, b, c). We started off by assuming a 1" wall, 4" ID mupipe with 5 ft. radius, 40 ft. long toroids. The halo/beam ratios resulting for various combinations of these elements are given in Table IV.

From this we have selected beams 2 and 4 for further study with all of the magnetic scrapers shown in Figure 8 included in both cases. Note, we have accepted the program decision that once a muon has hit an aperture it is labelled halo. There remains the possibility of accepting the beam-like halo, i.e. halo close to the real beam, as beam provided it is tagged satisfactorily.

We find that use of a 2" thick beam pipe wall for the first section of mupipe requires a larger toroid, and have settled on 1" thick wall with 4 ft. and 3 ft. radii, respectively, for the upstream and downstream toroids. For Beam 2, we show in Table V the halo/beam ratio with the final scrapers and the triplet and FODO tuned to various muon momenta. The halo is rather constant as the beam momentum decreases.

In order to check the credibility of the HALO results, we have attempted to model the N1 beam/halo situation. With the geometry assumed in Appendix I, Table II compares the halo/beam predictions at both 150 and 225 GeV/c with the observed values. Note that the magnet maps were rough approximations in the case of most of the N1 beam quads; the situation was better for the bending magnets. The 150 GeV/c results are for 300 GeV protons on target. There is reasonable agreement between prediction and measurement.

F. Further Considerations

The low halo-to-beam ratio obtained using the mupipe idea is clearly dependent on introducing the field as close as possible to the beam envelope. We have studied the sensitivity of the result to misalignment by randomly displacing the four sections of mupipe with results shown in Table VI. Clearly the halo and even the muon flux are hurt if misalignments exceeding 1/4" are introduced.

The effect of quadrupole misalignments was studied, and in general the further upstream the misalignment and the lower the momenta, the worse the transmission. Since most of the upstream section of the triplet is running with the quads at full strength, alignment becomes very critical at 275 GeV/c. Misalignments of 0.1" and 0.25" on the two quads running at -5.5 kg/in. reduce the flux at the muon lab by factors of 0.83 and 0.09 respectively at 275 GeV/c. A 0.25" misalignment at 800 GeV/c in these same quads yields a 0.93 reduction factor.

As shown in Figure 9 for Beam 2, there is no strong correlation between the parent decay angle and the muon momenta. However, there is significant polarization information preserved in Beam 4 (see Figure 10) at the expense of intensity.

At the vicinity of the Muon Lab, the angles of the beam, $\theta$ and $\varphi$, are small. This means that either a long hydrogen target or a stacked solid target could effectively be used. The muon fluxes at ground level at the location of the site boundary were estimated using HALO, and indicate a maximum radiation level of about 40 mrem/yr., assuming $10^{13}$ protons on target, and 365 days of operation at a Doubler cycle of 60 seconds. More realistic expectations for annualized total operating times and targetted proton intensities will reduce this level to the order of 10 mr/yr.

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Table I

Yield Per $10^{12}$ Interacting Protons in Hydrogen

| | Wang | Adair |
|---|---|---|
| $\pi^+$ { 400 GeV Protons, 0 - 400 GeV/c, 0 - 20 mrad | $1.07 \times 10^{12}$ | $3.35 \times 10^{11}$ |
| $\pi^+$ { 400 GeV Protons, 175 - 400 GeV/c, 0 - 20 mrad | $3.36 \times 10^{10}$ | $1.53 \times 10^{10}$ |
| x $\pi^+$ { 400 GeV Protons, 200 - 400 GeV/c, 0 - 5 mrad | $1.87 \times 10^{10}$ | $5.81 \times 10^{9}$ |
| x $\pi^+$ { 300 GeV Protons, 120 - 300 GeV/c, 0 - 5 mrad | $3.79 \times 10^{10}$ | $1.35 \times 10^{9}$ |
| $\pi^+$ { 1000 GeV Protons, 350 - 1000 GeV/c, 0 - 10 mrad | $6.82 \times 10^{10}$ | $3.12 \times 10^{10}$ |
| $K^+$ { 1000 GeV Protons, 350 - 1000 GeV/c, 0 - 10 mrad | $6.82 \times 10^{9}$ + | $7.86 \times 10^{9}$ |
| * $\pi^+$ { 1000 GeV/c Protons, 380 - 1000 GeV/c, 0 - 1.5 mrad | $2.18 \times 10^{6}$ | $9.34 \times 10^{5}$ |
| * $K^+$ { 1000 GeV/c Protons, 380 - 1000 GeV/c, 0 -1.5 mrad | $2.18 \times 10^{5}$ + | $2.02 \times 10^{5}$ |

+Assume $K/\pi \sim 0.1$.

xCorresponds approximately to acceptance N1 beam.

*Corresponds to acceptance of Beams 1-4 at 800 GeV/c.

Table II

The Predicted (Wang) and Measured Beam and Halo Rates for the N1 Beam Normalized to $10^{12}$ Incident Protons on One Interaction Length Target [obtained by multiplying thin target yields in hydrogen by 0.37].

| Beam Tune GeV/c | Type | Predicted Muon Yield $\mu/p$ | | Measured Muon Yield | Predicted Halo*/Beam | Measured Halo/Beam |
|---|---|---|---|---|---|---|
| | | $\pi^+$ | $K^+$ | | | |
| 150 | Beam | $(2.96 \pm 0.52)10^{-7}$ | | $1.7 \times 10^{-7}$ | $4.7 \pm 1.9$ | 1.5 |
| | Halo | $(1.4 \pm 0.5)10^{-6}$ | | | | |
| 225 | Beam | $(5.2 \pm 0.4)10^{-7}$ | $(0.86 \pm 0.23)10^{-8}$ | $2.5 \times 10^{-7}$ | $1.3 \pm 0.5$ | 1.9 |
| | Halo | $(7.3 \pm 2.3)10^{-7}$ | $(0.37 \pm 0.37)10^{-7}$ | | | |

*Defined as coincidence between scintillator planes as in the experiment.

Table III

Muon Yields at End of Beam for Given Tune per Interacting Proton in Hydrogen Expressed as $\mu/p$

| Beam and Tune | $\Delta p$* | Wang Muon from $\pi^+$ | $\Delta p$ | Adair Muon from $K^+$ |
|---|---|---|---|---|
| No. 2<br>750 GeV/c | 670<br>±<br>70 | $(1.06 \pm 0.08)\ 10^{-5}$ | 715<br>±<br>99 | $(0.13 \pm 0.04)\ 10^{-5}$ |
| No. 2<br>550 GeV/c | 510<br>±<br>63 | $(0.88 \pm 0.03)\ 10^{-4}$ | 546<br>±<br>62 | $(0.06 \pm 0.01)\ 10^{-4}$ |
| No. 2<br>275 GeV/c | 264<br>±<br>37 | $(2.96 \pm 0.10)\ 10^{-4}$ | 266<br>±<br>25 | $(0.06 \pm 0.01)\ 10^{-4}$ |
| No. 4<br>750 GeV/c | — | $(4.6 \pm 1.3)\ 10^{-6}$ | — | — |
| No. 4<br>550 GeV/c | 550<br>±<br>60 | $(3.0 \pm 0.1)\ 10^{-5}$ | — | — |
| No. 4<br>275 GeV/c | 263<br>±<br>31 | $(1.5 \pm 0.06)\ 10^{-4}$ | — | — |

* Standard Deviation.

Table IV

Halo/Beam Ratio for Various Scraper/Toroid Configurations. All for 800 GeV/c Tune per Interacting Proton in Hydrogen

| Beam | Magnetic Configuration | Beam Muons $\mu/p$ | Halo/Beam |
|---|---|---|---|
| 1 | None | $(1.0 \pm 0.2)\ 10^{-5}$ | 11 |
| 2 | | $(8.37 \pm 1.0)\ 10^{-6}$ | 10 |
| 3 | | $(6.8 \pm 1.4)\ 10^{-6}$ | 9.5 |
| | (S1, S3; T1, T2) | | |
| 2 | | $(8.37 \pm 1.0)\ 10^{-6}$ | ~ 0.5 |
| 3 | | $(6.8 \pm 1.4)\ 10^{-6}$ | ~ 0.5 |
| 1 | (S1, S2, S3, S4; T1, T2) | $(7.6 \pm 1.4)\ 10^{-6}$ | ~ 1.0 |
| 2 | | $(8.37 \pm 1.0)\ 10^{-6}$ | ~ 0.1 |
| 3 | | $(6.3 \pm 1.3)\ 10^{-6}$ | ~ 0.5 |
| 4 | | $(4.6 \pm 1.3)\ 10^{-6}$ | ~ 0.1 |

Table V

Halo/Beam Ratio for Beam 2 per Interacting Proton in Hydrogen

(Statistics for 15,000 $\pi^+$, and 5,000 $K^+$)

| Parent Particle and Momentum (GeV/c) | Muon Yield $\mu/p$ | Halo $\mu/p$ | Halo/Beam |
|---|---|---|---|
| 800 $\pi^+$ | $(1.06 \pm 0.08)\ 10^{-5}$ | $(0.52 \pm 0.21)\ 10^{-6}$ | 9% |
| 800 $K^+$ | $(0.13 \pm 0.04)\ 10^{-5}$ | $(0.4 \pm 0.2)\ 10^{-6}$ | |
| 600 $\pi^+$ | $(0.88 \pm 0.03)\ 10^{-4}$ | $(2.5 \pm 1.1)\ 10^{-6}$ | 4% |
| 600 $K^+$ | $(0.06 \pm 0.02)\ 10^{-4}$ | $(1.0 \pm 1.1)\ 10^{-6}$ | |
| 305 $\pi^+$ | $(2.96 \pm 0.10)\ 10^{-4}$ | $(2.0 \pm 0.4)\ 10^{-5}$ | 7% |
| 305 $K^+$ | $(0.06 \pm 0.02)\ 10^{-4}$ | --- | |

Table VI

The Effects of Mu-Pipe Misalignments for Beam 2.
(Yields are per interacting proton in hydrogen.)
Beam Tuned for 550 GeV/c.

| Magnitude of Random Pipe Translation (Inches) | Muon Yield $\mu/p$ | Halo Beam (%) |
|---|---|---|
| 0.0 | $(8 \pm 0.03)\ 10^{-4}$ | $2.8 \pm 1.2$ |
| 0.25 | $(6.0 \pm 0.6)\ 10^{-5}$ | $4.4 \pm 1.7$ |
| 0.50 | $(4.5 \pm 0.05)\ 10^{-5}$ | $7.7 \pm 3.0$ |

# FIGURE CAPTIONS

Figure 1 Layout of the new muon beam.

Figure 1a Layout of the new muon beam.

Figure 2a The front end and decay channel for Beams 1-4.

Figure 3 The momentum dispersion at the momentum slit of Beam 4 at 275 GeV/c.

Figure 4 FODO transmission as a function of tune momentum. p = the central momentum of the parent particles.

Figure 5 The longitudinal points of origin for halo muons inside a 120" radius area at the end of Beam 2.

Figure 6 The halo, defined as muons which have left the beam aperture, with no magnetic scrapers.

Figure 7 The halo with all scrapers on.

Figure 8 The back end (Muon FODO) for Beams 1-4.

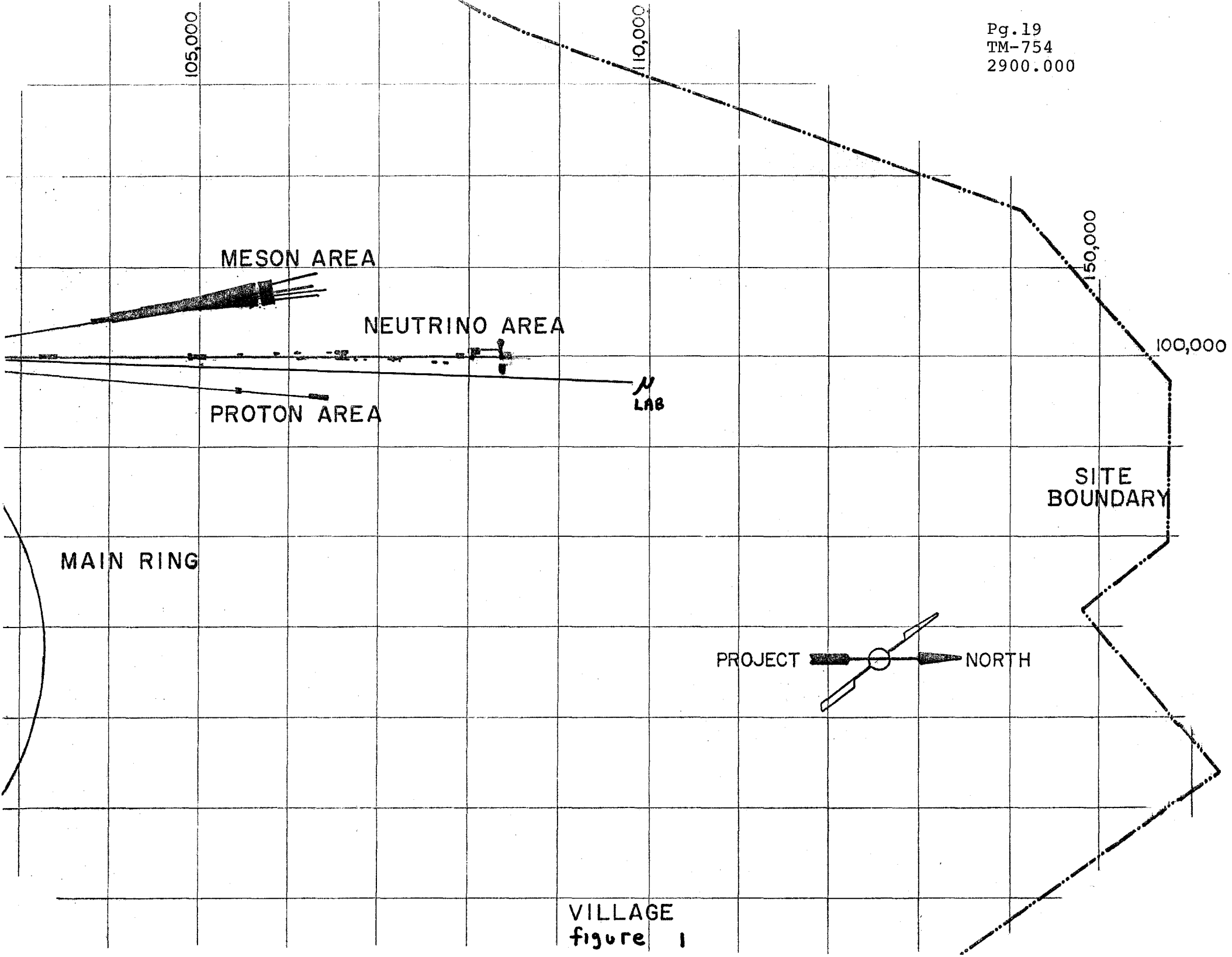
Figure 9 The momentum of the muon beam at the detector versus the decay angle of the parent pions for Beam 2.

Figure 10 The momentum of the muon beam at the detector versus the decay angle of the parent pions for Beam 4.

Figure 11 The x distribution of the muon beam at the detector.

Figure 12 The y distribution of the muon beam at the detector.

Figure 13 The p distribution of the muon beam at the detector.


105,000
110,000
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MESON AREA
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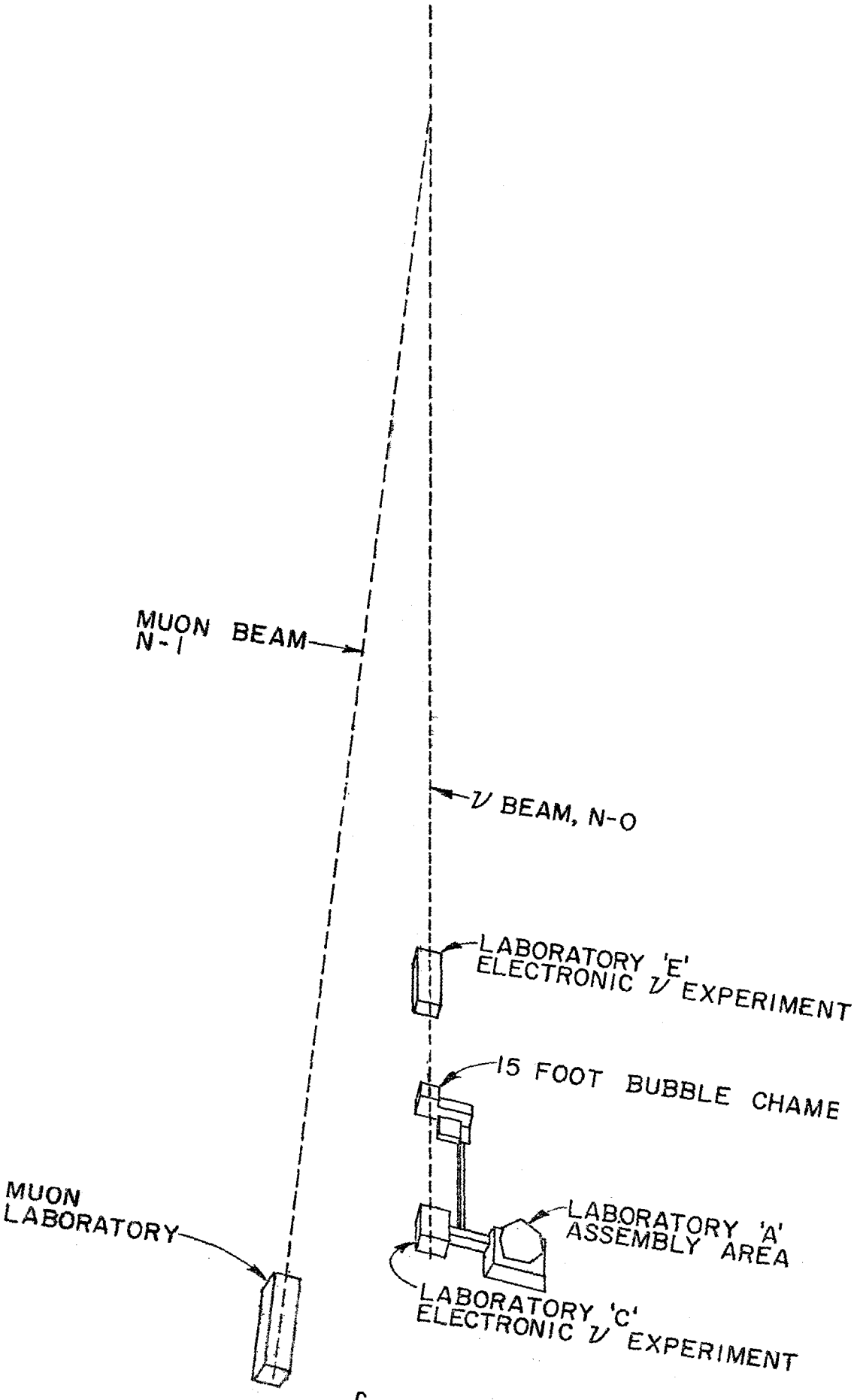
PROTON AREA
ν LAB
SITE BOUNDARY
MAIN RING
PROJECT
NORTH
VILLAGE

figure 1


MUON BEAM
N-1
ν BEAM, N-O
LABORATORY 'E'
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15 FOOT BUBBLE CHAME
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LABORATORY
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ASSEMBLY AREA
LABORATORY 'C'
ELECTRONIC ν EXPERIMENT

figure 1a

fig. 2a FRONT END FOR BEAMS 1-3

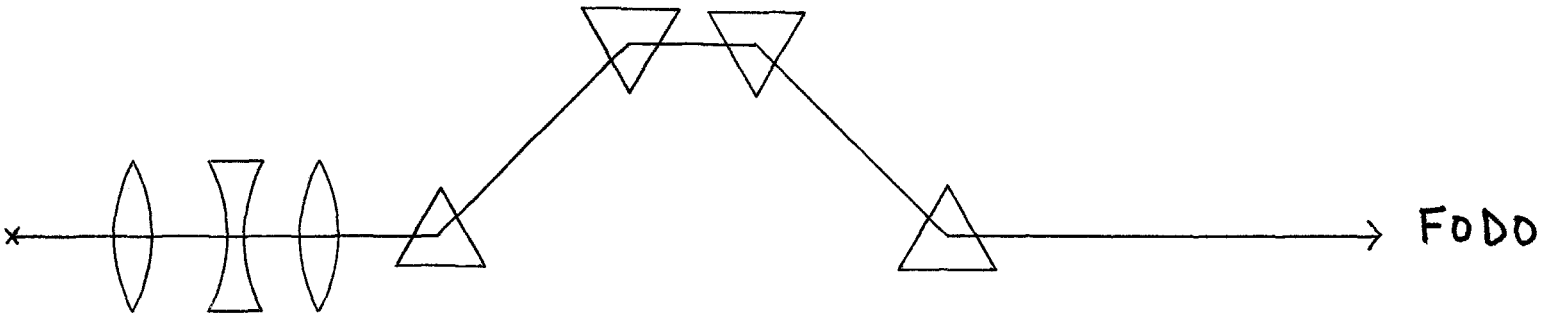
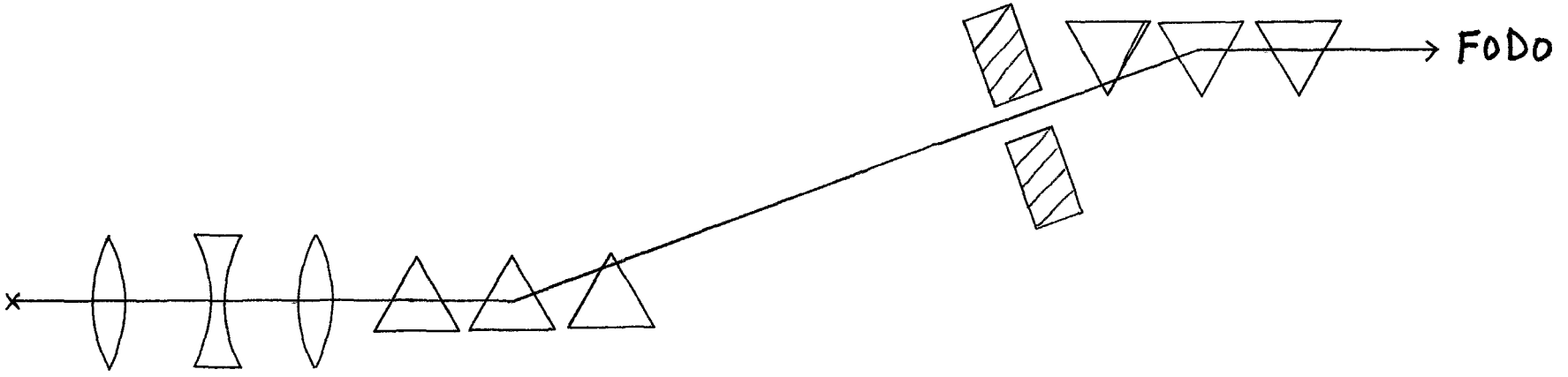



fig. 2b FRONT END FOR BEAM 4



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VERTICAL AXIS...    P     IN GEV/C FOR PI    AT     285.972 FT    (POSITION NO.  28)

                        *4.00      1.00
                        +---------+-------+ SUMS
   200.000 TO   220.000 I8                I   87
   220.000 TO   240.000 I8V               I 1029
   240.000 TO   260.000 I$$$$1            I 1450
   260.000 TO   280.000 I  X$$$$7         I 1185
   280.000 TO   300.000 I   6$$$$$W3      I 1018
   300.000 TO   320.000 I    A$$$$$$RF    I  766
   320.000 TO   340.000 I     5Z$$$$$$$Z62I  670
   340.000 TO   360.000 I      BAY$$$$$$DI  474
   360.000 TO   380.000 I      15CD$$$$$$I  371
   380.000 TO   400.000 *       2556I$$$$+  241
   400.000 TO   420.000 I        14CALV$$I  188
   420.000 TO   440.000 I         235CBN$I   97
   440.000 TO   460.000 I         1 39FNQI   77
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   540.000 TO   560.000 I              23I    5
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   580.000 TO   600.000 *               1 *   1
                        +---------+-------+ SUMS
                        S1                S
                        U2855555443333222U
                        M906436065972286 4M
                        S8102309384292385 8

        UNDER     IN   OVER
UNDER       0      0      0          MMEAN =      *1.62268 IN          SIGMAM =      3.66881 IN
IN       2868   7737    830          VMEAN =    294.06753 GEV/C        SIGMAV =     93.27319 GEV/C
OVER        0      3    172          CORRELATION =      .91257

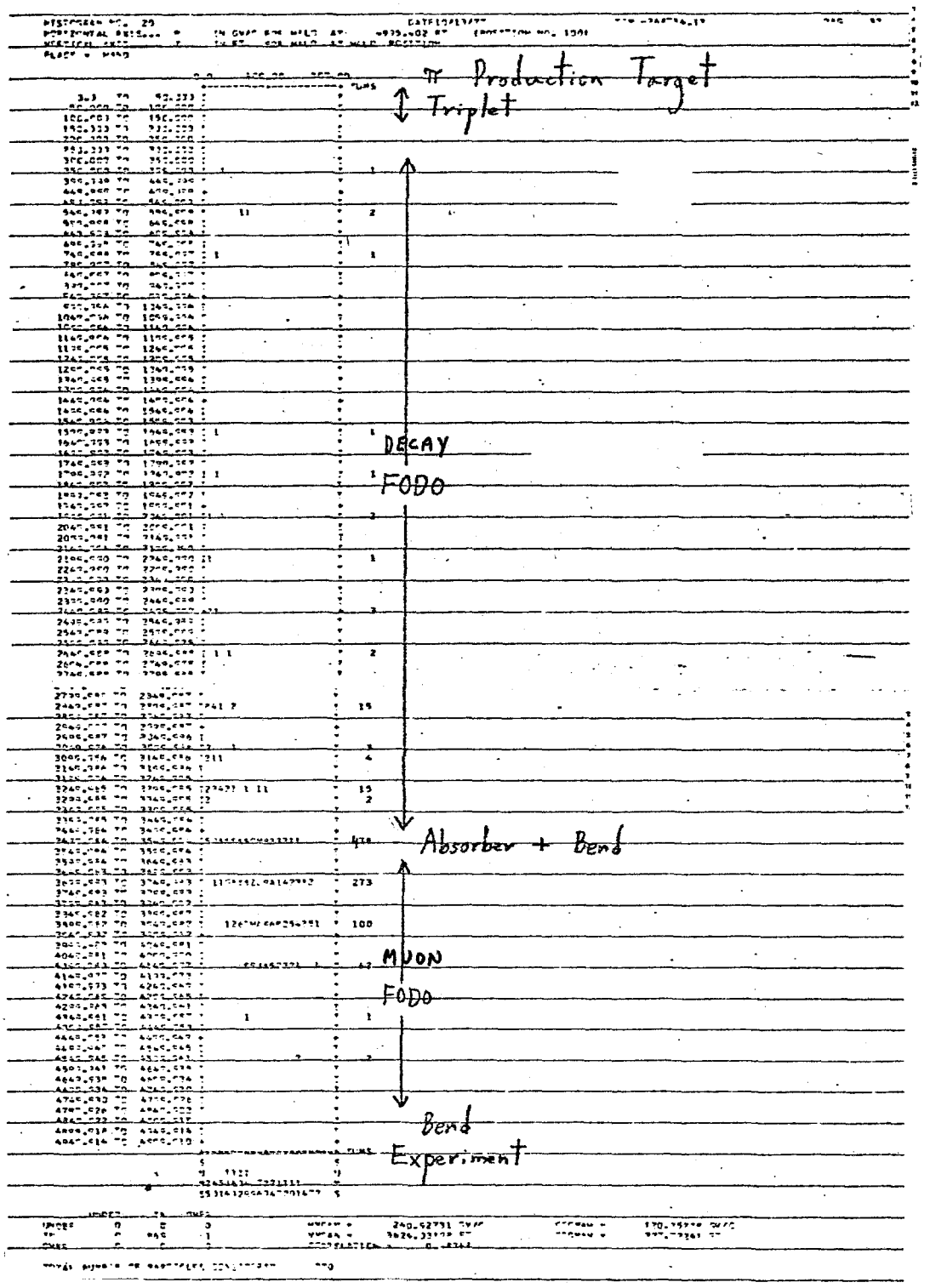
TOTAL NUMBER OF PARTICLES CONSIDERED    11610
```

Beam 4 @ 305 GeV/c Tune

Dispersion at momentum slit

Fig. 3

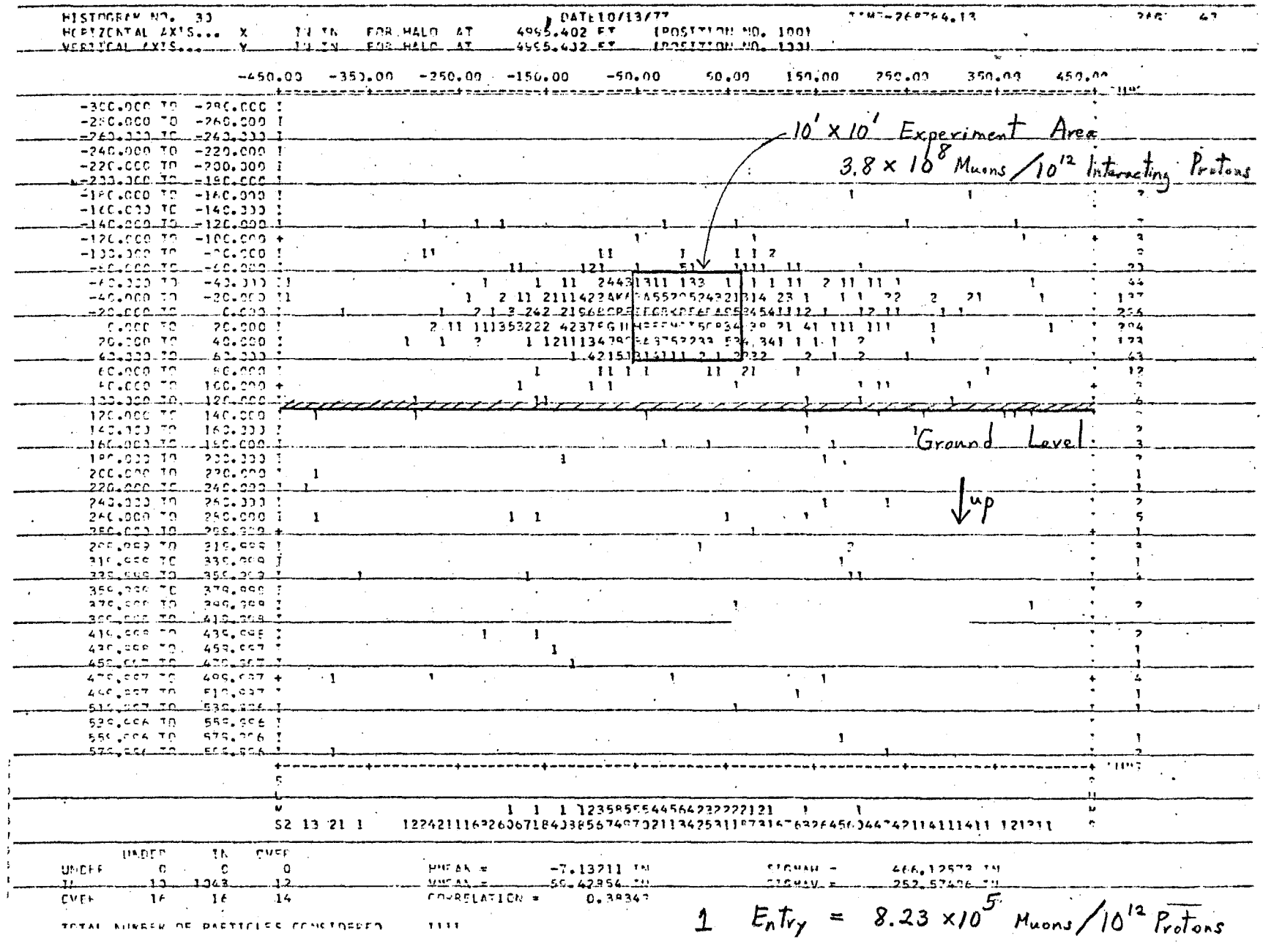
FODO Transmission vs Momentum figure 4




Longitudinal Points of Origin of Halo

Fig. 5

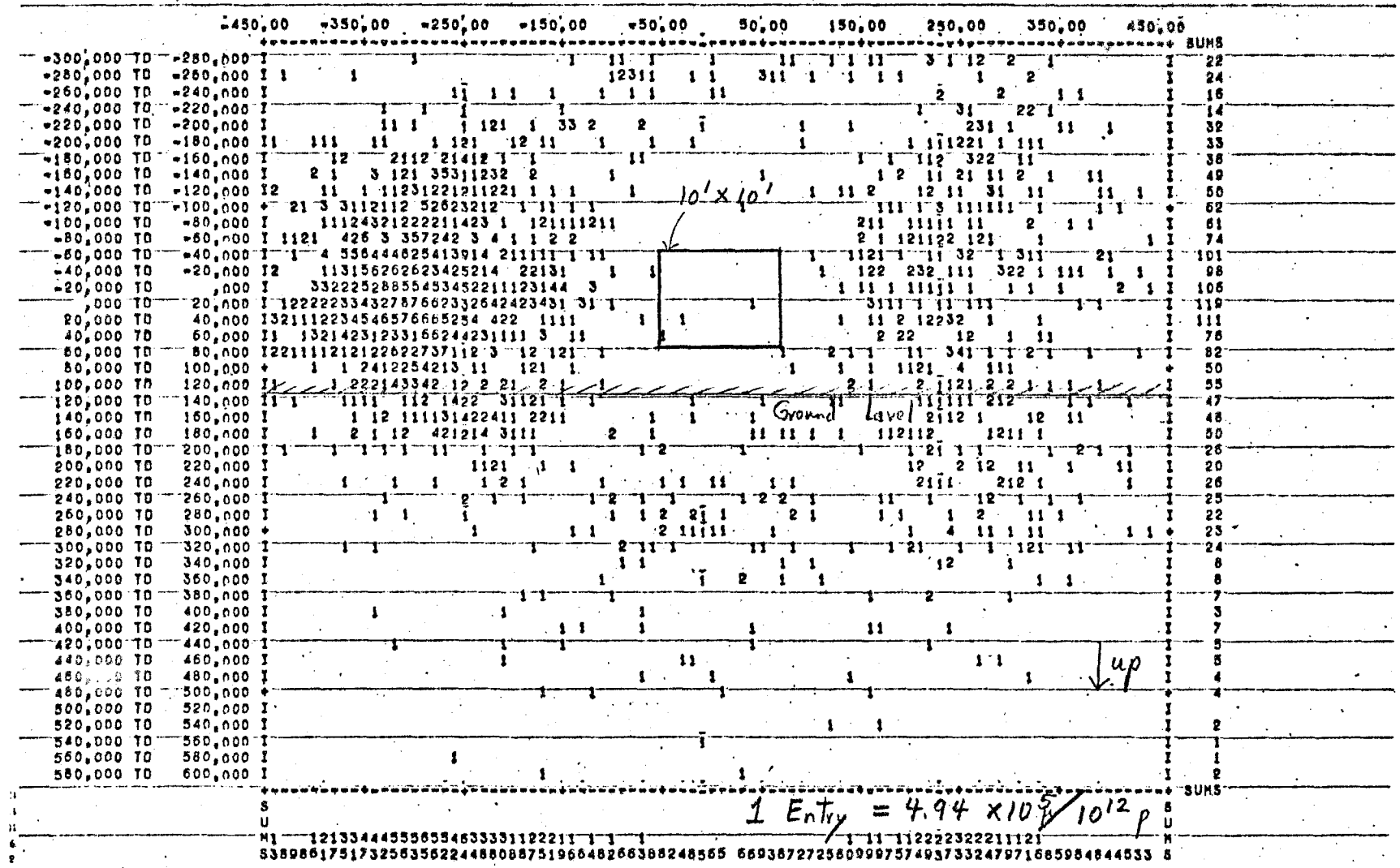
Plot #13




1 Entry = $8.23 \times 10^5$ Muons / $10^{12}$ Protons

Fig. 6

HISTOGRAM NO. 29 DATE 08 OCT 77 TIME 22.38.35 PAGE 41
HORIZONTAL AXIS... X IN IN FOR HALO AT 4995.472 FT (POSITION NO. 104)
VERTICAL AXIS... Y IN IN FOR HALO AT 4995.472 FT (POSITION NO. 104)




| | UNDER | IN | OVER |
|---|---|---|---|
| UNDER | 0 | 45 | 0 |
| IN | 24 | 1641 | 44 |
| OVER | 24 | 30 | 31 |

HMEAN = -83.07578 IN
VMEAN = 80.98412 IN
CORRELATION = .13366
SIGMAH = 396.10368 IN
SIGMAV = 382.46528 IN

TOTAL NUMBER OF PARTICLES CONSIDERED 1847

Fig. 7 Beam 2 550 Gev/c 40' long Toroids

fig. 8a BEAM 1

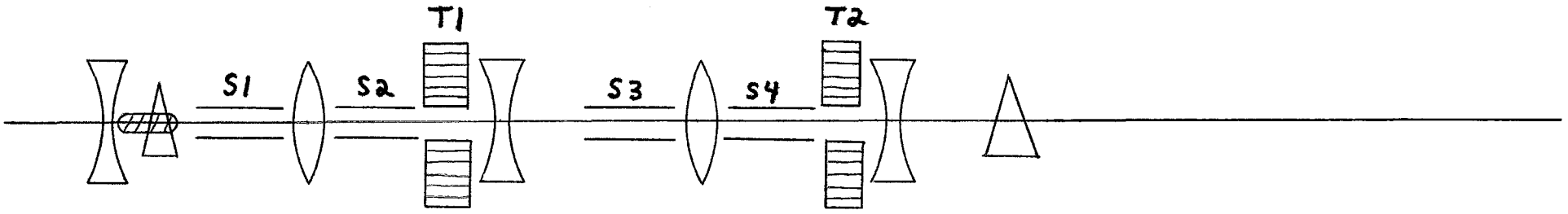



fig. 8b BEAM 2 & 4

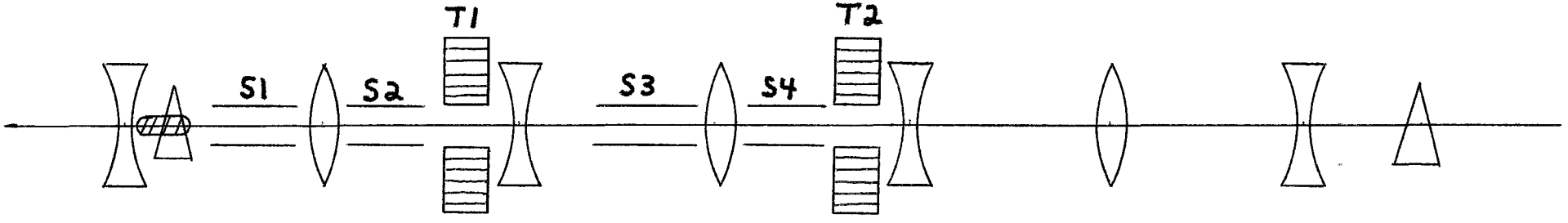
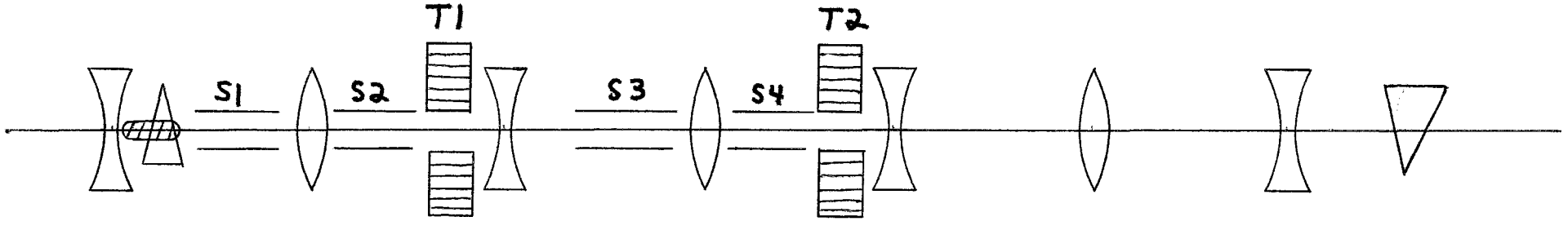



fig. 8c BEAM 3



```
HISTOGRAM NO.   8                                          DATE 08 OCT 77                    TIME 22.38.35                    PAGE   20
HORIZONTAL AXIS...  COSTH IN        FOR MU    AT DECAY POSITION
VERTICAL AXIS...    P     IN GEV/C FOR MU     AT      4995.472 FT     (POSITION NO. 104)

                          -1.00      0.00      1.00
                            +----------+----------+ SUMS
  200.000 TO   220.000 I                          I
  220.000 TO   240.000 I                          I
  240.000 TO   260.000 I                          I
  260.000 TO   280.000 I                          I
  280.000 TO   300.000 I                          I
  300.000 TO   320.000 I                          I
  320.000 TO   340.000 I                          I
  340.000 TO   360.000 I  11                      I    2
  360.000 TO   380.000 I                          I
  380.000 TO   400.000 + 1          11 11         +    5
  400.000 TO   420.000 I      11     11  1111     I    8
  420.000 TO   440.000 I       1   2212 1 314     I   17
  440.000 TO   460.000 I  1 11112 21   11121     I   16
  460.000 TO   480.000 I 111  111131125 2 31     I   25
  480.000 TO   500.000 I      2 1 113133423 31     I   28
  500.000 TO   520.000 I       1  132134231 3     I   24
  520.000 TO   540.000 I 1        11 12 2224     I   17
  540.000 TO   560.000 I 1  1     412112141 12     I   22
  560.000 TO   580.000 II 1        1 221 1123     I   15
  580.000 TO   600.000 +          1111 2423 6     +   21
  600.000 TO   620.000 I           1  12 1  2     I    7
  620.000 TO   640.000 I              2   1      I    3
  640.000 TO   660.000 I                          I
  660.000 TO   680.000 I                          I
  680.000 TO   700.000 I                          I
  700.000 TO   720.000 I                 1        I    1
  720.000 TO   740.000 I                          I
  740.000 TO   760.000 I                          I
  760.000 TO   780.000 I                          I
  780.000 TO   800.000 +                          +
                            +----------+----------+ SUMS
                            S                     S
                            U                     U
                            M          1111111212 M
                            S1442244438442789908 43

      UNDER     IN   OVER
UNDER     0     0      0          HMEAN =        .38782          SIGMAH =        .45962
IN        0   211      0          VMEAN =     507.80819 GEV/C    SIGMAV =     61.38566 GEV/C
OVER      0     0      0          CORRELATION =     .22298

TOTAL NUMBER OF PARTICLES CONSIDERED      211
```

Fig. 9 Beam 2 550 GeV/c

```
HISTOGRAM NO.   8                                   DATE 09 OCT 77                TIME 13.15.35                PAGE   21
HORIZONTAL AXIS...  COSTH IN        FOR MU    AT DECAY POSITION
VERTICAL AXIS...    P     IN GEV/C FOR MU     AT     5025.972 FT    (POSITION NO. 108)

                        *1.00      0.00      1.00
                        +----------+----------+ SUMS
  200.000 TO   220.000 I                      I
  220.000 TO   240.000 I                      I
  240.000 TO   260.000 I                      I
  260.000 TO   280.000 I                      I
  280.000 TO   300.000 I                      I
  300.000 TO   320.000 I                      I
  320.000 TO   340.000 I                      I
  340.000 TO   360.000 I                      I
  360.000 TO   380.000 I 1 1                  I    2
  380.000 TO   400.000 +  111                 +    3
  400.000 TO   420.000 I  115 5 2             I   14
  420.000 TO   440.000 I  11223  1            I   10
  440.000 TO   460.000 I     251428           I   22
  460.000 TO   480.000 I    145869851         I   47
  480.000 TO   500.000 I      1 33797H4       I   51
  500.000 TO   520.000 I         27879CC62    I   65
  520.000 TO   540.000 I           48A8AGHE61 I   94
  540.000 TO   560.000 I             248ECGGEHI  103
  560.000 TO   580.000 I               49AGKJII   96
  580.000 TO   600.000 +               137FP59+   88
  600.000 TO   620.000 I                  28DLI   55
  620.000 TO   640.000 I                  1189I   19
  640.000 TO   660.000 I                    46I   10
  660.000 TO   680.000 I                     1I    1
  680.000 TO   700.000 I                      I
  700.000 TO   720.000 I                      I
  720.000 TO   740.000 I                      I
  740.000 TO   760.000 I                      I
  760.000 TO   780.000 I                      I
  780.000 TO   800.000 +                      +
                        +----------+----------+ SUMS
                        S                     S
                        U                     U
                        M       I 11333455780RM
                        S 1348586745538273632 8

        UNDER     IN   OVER
UNDER       0      0      0          HMEAN =        .50204              SIGMAH =        .39023
IN          0    680      0          VMEAN =     540.78180 GEV/C        SIGMAV =      53.44699 GEV/C
OVER        0      0      0          CORRELATION =      .86090

TOTAL NUMBER OF PARTICLES CONSIDERED      680
```

Fig. 10 Beam 4 550 GeV/c

```
HISTOGRAM NO  7
DISTRIBUTION OF    X IN IN        FOR MU            4973.972 FT    FROM THE TARGET

          INTERVAL                                  SCALE FACTOR.. 100 X'S EQUAL    84 ENTRIES

LESS THAN      -2.500           0

  -2.500 TO    -2.250           0
  -2.250 TO    -2.000           0
  -2.000 TO    -1.750           3   XXX
  -1.750 TO    -1.500           5   XXXXX
  -1.500 TO    -1.250           6   XXXXXXX
  -1.250 TO    -1.000           7   XXXXXXXX
  -1.000 TO     -.750          15   XXXXXXXXXXXXXXXXX
   -.750 TO     -.500          30   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -.500 TO     -.250          42   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -.250 TO      .000          65   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    .000 TO      .250          61   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    .250 TO      .500          77   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    .500 TO      .750          71   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    .750 TO     1.000          84   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   1.000 TO     1.250          39   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   1.250 TO     1.500          29   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   1.500 TO     1.750          11   XXXXXXXXXXXXX
   1.750 TO     2.000           6   XXXXXXX
   2.000 TO     2.250           0
   2.250 TO     2.500           0

GREATER THAN    2.500           0

          TOTAL NUMBER OF ENTRIES =       551      INCLUDING UNDERFLOW AND OVERFLOW
          CENTER =     .329   RMS HALF WIDTH =     .698

HISTOGRAM NO  7
DISTRIBUTION OF    X IN IN        FOR MU            4973.972 FT    FROM THE TARGET
```

figure 11

HISTOGRAM NO 8
DISTRIBUTION OF Y IN IN FOR MU 4973.972 FT FROM THE TARGET

| INTERVAL | | | SCALE FACTOR.. 100 X'S EQUAL 145 ENTRIES |
|---|---|---|---|
| LESS THAN | -2.500 | 0 | |
| -2.500 TO | -2.250 | 0 | |
| -2.250 TO | -2.000 | 0 | |
| -2.000 TO | -1.750 | 0 | |
| -1.750 TO | -1.500 | 0 | |
| -1.500 TO | -1.250 | 0 | |
| -1.250 TO | -1.000 | 5 | XXX |
| -1.000 TO | -.750 | 18 | XXXXXXXXXXXX |
| -.750 TO | -.500 | 31 | XXXXXXXXXXXXXXXXXXXXX |
| -.500 TO | -.250 | 86 | XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX |
| -.250 TO | .000 | 145 | XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX |
| .000 TO | .250 | 139 | XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX |
| .250 TO | .500 | 73 | XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX |
| .500 TO | .750 | 38 | XXXXXXXXXXXXXXXXXXXXXXXXXX |
| .750 TO | 1.000 | 12 | XXXXXXXX |
| 1.000 TO | 1.250 | 4 | XX |
| 1.250 TO | 1.500 | 0 | |
| 1.500 TO | 1.750 | 0 | |
| 1.750 TO | 2.000 | 0 | |
| 2.000 TO | 2.250 | 0 | |
| 2.250 TO | 2.500 | 0 | |
| GREATER THAN | 2.500 | 0 | |

TOTAL NUMBER OF ENTRIES = 551 INCLUDING UNDERFLOW AND OVERFLOW
CENTER = -.010 RMS HALF WIDTH = .393

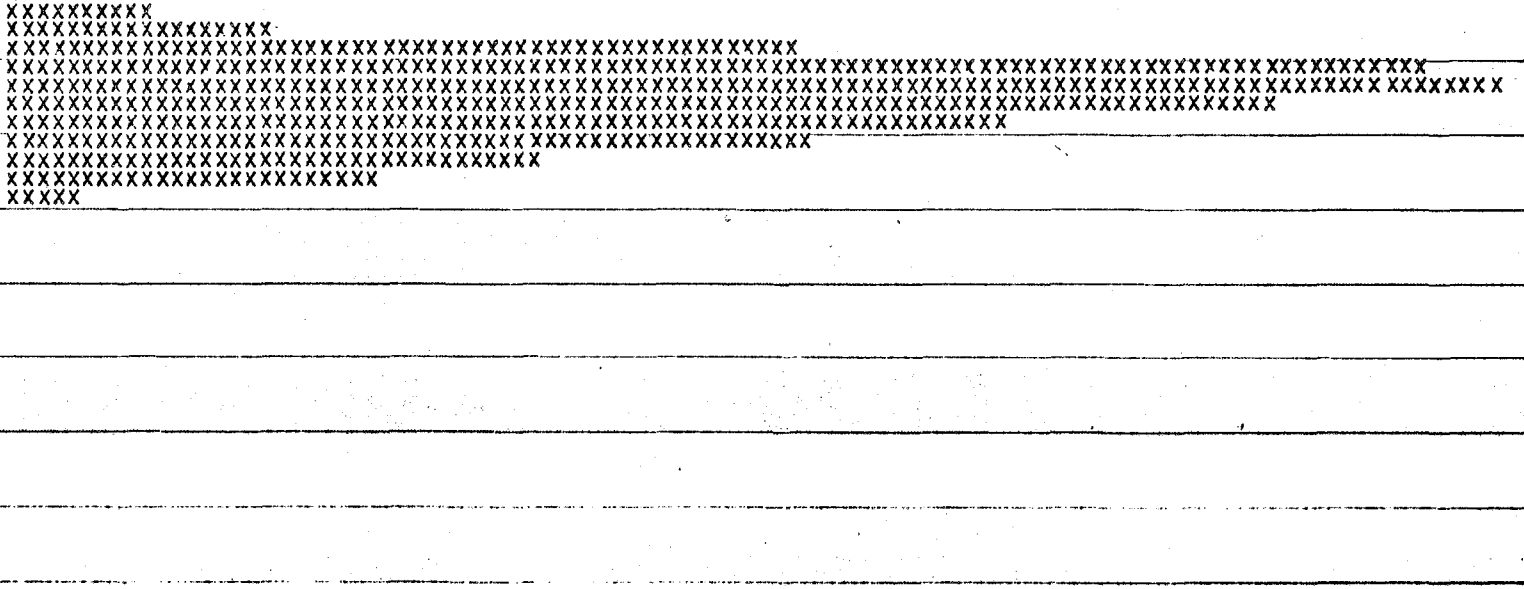
HISTOGRAM NO 8
DISTRIBUTION OF Y IN IN FOR MU 4973.972 FT FROM THE TARGET

figure 12

HISTOGRAM NO 10
DISTRIBUTION OF P IN GEVC FOR MU 4973.972 FT FROM THE TARGET

SCALE FACTOR.. 100 X'S EQUAL 100 ENTRIES

| INTERVAL | | |
|---|---|---|
| LESS THAN | 0.000 | 0 |
| 0.000 TO | 20.000 | 0 |
| 20.000 TO | 40.000 | 0 |
| 40.000 TO | 60.000 | 0 |
| 60.000 TO | 80.000 | 0 |
| 80.000 TO | 100.000 | 0 |
| 100.000 TO | 120.000 | 0 |
| 120.000 TO | 140.000 | 0 |
| 140.000 TO | 160.000 | 0 |
| 160.000 TO | 180.000 | 0 |
| 180.000 TO | 200.000 | 0 |
| 200.000 TO | 220.000 | 0 |
| 220.000 TO | 240.000 | 0 |
| 240.000 TO | 260.000 | 0 |
| 260.000 TO | 280.000 | 0 |
| 280.000 TO | 300.000 | 0 |
| 300.000 TO | 320.000 | 0 |
| 320.000 TO | 340.000 | 0 |
| 340.000 TO | 360.000 | 0 |
| 360.000 TO | 380.000 | 0 |
| 380.000 TO | 400.000 | 1 |
| 400.000 TO | 420.000 | 2 |
| 420.000 TO | 440.000 | 10 |
| 440.000 TO | 460.000 | 18 |
| 460.000 TO | 480.000 | 53 |
| 480.000 TO | 500.000 | 95 |
| 500.000 TO | 520.000 | 100 |
| 520.000 TO | 540.000 | 85 |
| 540.000 TO | 560.000 | 67 |
| 560.000 TO | 580.000 | 54 |
| 580.000 TO | 600.000 | 36 |
| 600.000 TO | 620.000 | 25 |
| 620.000 TO | 640.000 | 5 |
| 640.000 TO | 660.000 | 0 |
| 660.000 TO | 680.000 | 0 |
| 680.000 TO | 700.000 | 0 |
| 700.000 TO | 720.000 | 0 |
| 720.000 TO | 740.000 | 0 |
| 740.000 TO | 760.000 | 0 |
| 760.000 TO | 780.000 | 0 |
| 780.000 TO | 800.000 | 0 |
| 800.000 TO | 820.000 | 0 |
| 820.000 TO | 840.000 | 0 |
| 840.000 TO | 860.000 | 0 |
| 860.000 TO | 880.000 | 0 |
| 880.000 TO | 900.000 | 0 |
| 900.000 TO | 920.000 | 0 |
| 920.000 TO | 940.000 | 0 |
| 940.000 TO | 960.000 | 0 |
| 960.000 TO | 980.000 | 0 |
| 980.000 TO | 1000.000 | 0 |
| GREATER THAN | 1000.000 | 0 |



TOTAL NUMBER OF ENTRIES = 551 INCLUDING UNDERFLOW AND OVERFLOW
CENTER = 522.654 RMS HALF WIDTH = 43.623

figure 13

# APPENDIX I

## The Parameters Used In HALO For The N1 Beam

SYS DESCRIPTION.  DATE 9/20/77  TIME-268774.88  PAGE 2

| POSITION NO. | LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 36.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | | 540.000 IN | 360.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| 1 | 0.0 FT | | | | | | | | | |
| | | DRF | | | 8 | 17.500 FT | | | | |
| 2 | 17.500 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 1.500 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 10 | 10.000 FT | 3.271 KG | 1.500 IN | | |
| 3 | 27.500 FT | | | | | | | | | |
| | | DRF | | | 1 | 1.000 FT | | | | |
| 4 | 28.500 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 1.500 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 10 | 10.000 FT | 3.271 KG | 1.500 IN | | |
| 5 | 38.500 FT | | | | | | | | | |
| | | DRF | | | 2 | 4.000 FT | | | | |
| 6 | 42.500 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | 0.0 KG | 1.000 IN | | |
| 7 | 49.500 FT | | | | | | | | | |
| | | DRF | | | 1 | 1.000 FT | | | | |
| 8 | 50.500 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | 0.0 KG | 1.000 IN | | |
| 9 | 57.500 FT | | | | | | | | | |
| | | DRF | | | 4 | 4.000 FT | | | | |
| 10 | 61.500 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | 0.0 KG | 1.000 IN | | |
| 11 | 68.500 FT | | | | | | | | | |
| | | DRF | | | 1 | 1.000 FT | | | | |
| 12 | 69.500 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | 0.0 KG | 1.000 IN | | |
| 13 | 76.500 FT | | | | | | | | | |
| | | DRF | | | 4 | 4.890 FT | | | | |
| 14 | 81.390 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | -2.190 KG | 1.000 IN | | |
| 15 | 88.390 FT | | | | | | | | | |
| | | DRF | | | 1 | 1.110 FT | | | | |
| 16 | 89.500 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | -2.190 KG | 1.000 IN | | |
| 17 | 96.500 FT | | | | | | | | | |
| | | DRF | | | 1 | 3.000 FT | | | | |
| 18 | 99.500 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | 0.0 KG | 1.000 IN | | |
| 19 | 106.500 FT | | | | | | | | | |
| | | DRF | | | 10 | 33.000 FT | | | | |
| 20 | 139.500 FT | | | | | | | | | |
| | | APE | ELL | QUAD | | 1.000 IN | 2.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q310 | | 7 | 7.000 FT | 2.397 KG | 1.000 IN | | |
| 21 | 146.500 FT | | | | | | | | | |

SYS DESCRIPTION DATE 9/20/77 TIME-268774.88 PAGE 3

| POSITION NO. | LENGTH | TYPE | CODES 1 | CODES 2 | CODES 3 | PARAMETERS 1 | PARAMETERS 2 | PARAMETERS 3 | PARAMETERS 4 | PARAMETERS 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 146.500 FT | | | | | | | | | |
| | | DRF | | | 5 | 13.080 FT | | | | |
| 22 | 159.580 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | M84 | | 7 | 7.500 FT | -1.760 KG | 150.000 GV/C | | |
| 23 | 167.080 FT | | | | | | | | | |
| | | CRF | | | 1 | 2.500 FT | | | | |
| 24 | 169.580 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 18.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | | 360.000 IN | 264.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| 24 | 169.580 FT | | | | | | | | | |
| | | DPF | | | 50 | 1146.809 FT | | | | |
| 25 | 1316.388 FT | | | | | | | | | |
| | | TUN | RECT | DIRT | | 19.000 IN | 20.000 IN | -12.500 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | | 600.000 IN | 372.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| 25 | 1316.388 FT | | | | | | | | | |
| | | APE | RECT | DRF | | 2.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | AL | 19.000 IN | 20.000 IN | -12.500 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 3 | 10.750 FT | | | | |
| 26 | 1327.138 FT | | | | | | | | | |
| | | APE | RECT | DRF | | 2.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | FE | 19.000 IN | 20.000 IN | -12.500 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 3 | 10.750 FT | | | | |
| 27 | 1337.888 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 5 | 21.500 FT | | | | |
| 28 | 1359.388 FT | | | | | | | | | |
| | | TUN | RECT | DIRT | | 60.000 IN | 60.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | | 600.000 IN | 372.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| 28 | 1359.388 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | M84 | | 10 | 20.000 FT | -7.845 KG | 150.000 GV/C | | |
| 29 | 1379.387 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 5 | 18.000 FT | | | | |
| 30 | 1397.387 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | M84 | | 10 | 20.000 FT | -7.845 KG | 150.000 GV/C | | |
| 31 | 1417.387 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 5 | 30.000 FT | | | | |
| 32 | 1447.387 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | M84 | | 10 | 20.000 FT | -7.845 KG | 150.000 GV/C | | |
| 33 | 1467.386 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 6 | 54.000 FT | | | | |
| 34 | 1521.386 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 10 | 10.000 FT | -2.565 KG | 2.500 IN | | |
| 35 | 1531.386 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 5 | 30.000 FT | | | | |
| 36 | 1561.386 FT | | | | | | | | | |

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| POSITION NO. | LENGTH | TYPE 1. | CODES 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|
| 36 | 1561.396 FT | | | | | | | | |
| | | APE | CIRC | QUAD | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q413 | 10 | 10.000 FT | 2.595 KG | 2.500 IN | | |
| 37 | 1571.385 FT | | | | | | | | |
| | | TUN | CIRC | DIRT | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | 360.000 IN | 252.000 IN | -156.000 IN | 0.0 IN | 0.0 DEG |
| 37 | 1571.385 FT | | | | | | | | |
| | | APE | CIRC | DRF | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | 10 | 283.100 FT | | | | |
| 38 | 1854.485 FT | | | | | | | | |
| | | TUN | RECT | DIRT | 60.000 IN | 60.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | 360.000 IN | 252.000 IN | -180.000 IN | 0.0 IN | 0.0 DEG |
| 38 | 1854.485 FT | | | | | | | | |
| | | APE | ELL | QUAD | 2.500 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | QDPB | 7 | 7.000 FT | 3.975 KG | 1.500 IN | | |
| 39 | 1861.485 FT | | | | | | | | |
| | | APE | CIRC | DRF | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | 1 | 1.900 FT | | | | |
| 40 | 1863.385 FT | | | | | | | | |
| | | APE | ELL | QUAD | 2.500 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | QDPB | 7 | 7.000 FT | -3.975 KG | 1.500 IN | | |
| 41 | 1870.385 FT | | | | | | | | |
| | | APE | CIRC | DRF | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | 3 | 6.000 FT | | | | |
| 42 | 1876.384 FT | | | | | | | | |
| | | APE | RECT | BEND | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB2 | 10 | 20.000 FT | 7.845 KG | 150.000 GV/C | | |
| 43 | 1896.384 FT | | | | | | | | |
| | | APE | CIRC | DRF | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | 1 | 1.400 FT | | | | |
| 44 | 1897.784 FT | | | | | | | | |
| | | APE | RECT | BEND | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB2 | 10 | 20.000 FT | 7.845 KG | 150.000 GV/C | | |
| 45 | 1917.784 FT | | | | | | | | |
| | | APE | CIRC | DRF | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | 1 | 1.400 FT | | | | |
| 46 | 1919.184 FT | | | | | | | | |
| | | APE | RECT | BEND | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB2 | 10 | 20.000 FT | 7.845 KG | 150.000 GV/C | | |
| 47 | 1939.183 FT | | | | | | | | |
| | | TUN | CIRC | DIRT | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | 360.000 IN | 252.000 IN | -180.000 IN | 0.0 IN | 0.0 DEG |
| 47 | 1939.183 FT | | | | | | | | |
| | | APE | CIRC | DRF | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | 10 | 371.666 FT | | | | |
| 48 | 2310.850 FT | | | | | | | | |
| | | TUN | RECT | DIRT | 60.000 IN | 60.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | 360.000 IN | 252.000 IN | -180.000 IN | 0.0 IN | 0.0 DEG |
| 48 | 2310.850 FT | | | | | | | | |
| | | APE | CIRC | DRF | 3.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | ABS | CIRC | POLY AIR | 3.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | 5 | 20.000 FT | | | | |
| 49 | 2330.849 FT | | | | | | | | |

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| NO. | POSITION LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 2330.849 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | ABS | RECT | POLY | FE | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB2 | | 10 | 20.000 FT | -7.751 KG | 148.200 GV/C | | |
| 50 | 2350.849 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 1.400 FT | | | | |
| 51 | 2352.249 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | ABS | RECT | POLY | FE | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB2 | | 10 | 20.000 FT | -7.688 KG | 147.000 GV/C | | |
| 52 | 2372.249 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 1.400 FT | | | | |
| 53 | 2373.649 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | ABS | RECT | POLY | FE | 2.000 IN | 1.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB2 | | 10 | 20.000 FT | -7.625 KG | 145.800 GV/C | | |
| 54 | 2393.648 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 6.000 IN | | 0.0 IN | 2.000 IN | 0.0 DEG |
| | | TUNO | ELL | | | 480.000 IN | 252.000 IN | -240.000 IN | 0.0 IN | 0.0 DEG |
| 54 | 2393.648 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 10 | 169.400 FT | | | | |
| 55 | 2563.048 FT | | | | | | | | | |
| | | TUN | RECT | DIRT | | 60.000 IN | 60.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | | 480.000 IN | 252.000 IN | -240.000 IN | 0.0 IN | 0.0 DEG |
| 55 | 2563.048 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q610 | | 4 | 4.000 FT | 8.494 KG | 6.000 IN | | |
| 56 | 2567.048 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 2.000 FT | | | | |
| 57 | 2569.048 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q610 | | 4 | 4.000 FT | 8.494 KG | 6.000 IN | | |
| 58 | 2573.049 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 2.200 FT | | | | |
| 59 | 2575.248 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q610 | | 4 | 4.000 FT | 8.494 KG | 6.000 IN | | |
| 60 | 2579.248 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 16.700 FT | | | | |
| 61 | 2595.948 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q610 | | 4 | 4.000 FT | -8.494 KG | 6.000 IN | | |
| 62 | 2599.947 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 1.900 FT | | | | |
| 63 | 2601.847 FT | | | | | | | | | |

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| NO. | POSITION LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 63 | 2601.847 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q610 | | 4 | 4.000 FT | -8.494 KG | 6.000 IN | | |
| 64 | 2605.847 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 2.200 FT | | | | |
| 65 | 2608.047 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q613 | | 4 | 4.000 FT | -8.494 KG | 6.000 IN | | |
| 66 | 2612.047 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 6.000 IN | | 0.0 IN | 2.000 IN | 0.0 DEG |
| | | TUNO | ELL | | | 540.000 IN | 252.000 IN | -300.000 IN | 0.0 IN | 0.0 DEG |
| 66 | 2612.047 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 10 | 233.600 FT | | | | |
| 67 | 2845.646 FT | | | | | | | | | |
| | | TUN | RECT | DIRT | | 60.000 IN | 60.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | ELL | | | 610.000 IN | 252.000 IN | -480.000 IN | 0.0 IN | 0.0 DEG |
| 67 | 2845.646 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 1.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB3 | | 10 | 20.000 FT | 7.594 KG | 145.200 GV/C | | |
| 68 | 2865.646 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 1.500 FT | | | | |
| 69 | 2867.146 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 1.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB3 | | 10 | 20.000 FT | 7.594 KG | 145.200 GV/C | | |
| 70 | 2887.146 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 1.200 FT | | | | |
| 71 | 2888.346 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 2.000 IN | 1.500 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB3 | | 10 | 20.000 FT | 7.594 KG | 145.200 GV/C | | |
| 72 | 2908.345 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 6.000 IN | | 0.0 IN | 2.000 IN | 0.0 DEG |
| | | TUNO | ELL | | | 610.000 IN | 252.000 IN | -480.000 IN | 0.0 IN | 0.0 DEG |
| 72 | 2908.345 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 5 | 85.500 FT | | | | |
| 73 | 2993.845 FT | | | | | | | | | |
| | | TUN | RECT | AIR | | 360.000 IN | 120.000 IN | 120.000 IN | 60.000 IN | 0.0 DEG |
| | | TUNO | RECT | | | 361.000 IN | 121.000 IN | 120.000 IN | 60.000 IN | 0.0 DEG |
| 73 | 2993.845 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 6.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 20.000 FT | | | | |
| 74 | 3013.845 FT | | | | | | | | | |
| | | APE | RECT | DRF | | 4.000 IN | 4.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | AIR | DIRT | 100.000 IN | 50.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 3.000 FT | | | | |
| 75 | 3016.845 FT | | | | | | | | | |
| | | APE | RECT | DRF | | 4.000 IN | 4.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 1 | 3.000 FT | | | | |
| 76 | 3019.845 FT | | | | | | | | | |

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| NO. | POSITION LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 76 | 3019.845 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 72.000 IN | 18.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB36' | | 2 | 13.300 FT | 14.520 KG | 145.200 GV/C | | |
| 77 | 3033.145 FT | | | | | | | | | |
| | | APE | RECT | DRF | | 4.000 IN | 4.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 26.600 FT | | | | |
| 78 | 3059.745 FT | | | | | | | | | |

# APPENDIX II

## The Parameters Used in HALO For The Four Doubler Muon Beams

```
MUON OR NEUTRINO BEAM.
MUON MOMENTUM          0.0   TC     1000.000 GV/C
IN THE HISTOGRAMS BELOW, 1 ENTRY REPRESENTS  0.14814E 07 MUONS OR NEUTRINOS

SYS DESCRIPTION.                          DATE 9/22/77                TIME-268780.94                PAGE   2

   POSITION                TYPE        CODES                          PARAMETERS
 NO.      LENGTH              1     2     3        1                2                3              4              5

  1      0.0   FT
                           TUN    RECT  DIRT        60.000 IN        48.000 IN       0.0   IN       0.0   IN       0.0   DEG
                           TUND   RECT            900.000 IN       900.000 IN       0.0   IN    -750.000 IN       0.0   DEG
  1      0.0   FT
                           DRF                 2    24.000 FT
  2     24.000 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT       -5.400 KG       1.000 IN
  3     34.000 FT
                           DRF                 1     1.500 FT
  4     35.500 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT       -5.400 KG       1.000 IN
  5     45.500 FT
                           DRF                 1     1.500 FT
  6     47.000 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT       -5.400 KG       1.000 IN
  7     57.000 FT
                           DRF                 2     6.472 FT
  8     63.472 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT        4.774 KG       1.000 IN
  9     73.472 FT
                           DRF                 1     1.500 FT
 10     74.972 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT        4.774 KG       1.000 IN
 11     84.972 FT
                           DRF                 1     1.500 FT
 12     86.472 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT        4.774 KG       1.000 IN
 13     96.472 FT
                           DRF                 1     1.500 FT
 14     97.972 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT        4.774 KG       1.000 IN
 15    107.972 FT
                           DRF                 1     1.500 FT
 16    109.472 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT       -3.297 KG       1.000 IN
 17    119.472 FT
                           DRF                 1     1.500 FT
 18    120.972 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT       -3.297 KG       1.000 IN
 19    130.972 FT
                           DRF                 1     1.500 FT
 20    132.472 FT
                           APE    CIRC  QUAD         2.250 IN                       0.0   IN       0.0   IN       0.0   DEG
                           QUAD   Q410        5    10.000 FT       -3.297 KG       1.000 IN
 21    142.472 FT
```

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| POSITION NO. | LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 142.472 FT | | | | | | | | | |
| | | DRF | | | 1 | 1.500 FT | | | | |
| 22 | 143.972 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -1.341 KG | 1.000 IN | | |
| 23 | 153.972 FT | | | | | | | | | |
| | | DRF | | | 3 | 14.500 FT | | | | |
| 24 | 168.472 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 3.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB6 | | 5 | 20.000 FT | -11.250 KG | 600.000 GV/C | | |
| 25 | 188.472 FT | | | | | | | | | |
| | | DRF | | | 8 | 45.000 FT | | | | |
| 26 | 233.472 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 3.000 IN | 2.000 IN | -1.000 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB6 | | 5 | 20.000 FT | 11.250 KG | 600.000 GV/C | | |
| 27 | 253.472 FT | | | | | | | | | |
| | | DRF | | | 1 | 1.000 FT | | | | |
| 28 | 254.472 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 3.000 IN | 2.000 IN | -1.000 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB6 | | 5 | 20.000 FT | 11.250 KG | 600.000 GV/C | | |
| 29 | 274.471 FT | | | | | | | | | |
| | | DRF | | | 8 | 45.000 FT | | | | |
| 30 | 319.471 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 3.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | MB6 | | 5 | 20.000 FT | -11.250 KG | 600.000 GV/C | | |
| 31 | 339.471 FT | | | | | | | | | |
| | | DRF | | | 3 | 14.500 FT | | | | |
| 32 | 353.971 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.682 KG | 1.000 IN | | |
| 33 | 363.970 FT | | | | | | | | | |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 34 | 373.970 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 35 | 543.970 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.682 KG | 1.000 IN | | |
| 36 | 573.970 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 37 | 583.969 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 38 | 773.969 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.682 KG | 1.000 IN | | |
| 39 | 783.969 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 40 | 793.969 FT | | | | | | | | | |

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| POSITION NO. | LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 793.969 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 41 | 983.969 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.682 KG | 1.000 IN | | |
| 42 | 993.968 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 43 | 1003.968 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 44 | 1193.968 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.682 KG | 1.000 IN | | |
| 45 | 1203.968 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 46 | 1213.967 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 47 | 1403.967 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.682 KG | 1.000 IN | | |
| 48 | 1413.967 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 49 | 1423.967 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 50 | 1613.966 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.682 KG | 1.000 IN | | |
| 51 | 1623.966 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 52 | 1633.966 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 53 | 1823.966 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.682 KG | 1.000 IN | | |
| 54 | 1833.965 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 55 | 1843.965 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 56 | 2033.965 FT | | | | | | | | | |

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| NO. | POSITION LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 56 | 2033.965 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.682 KG | 1.000 IN | | |
| 57 | 2043.965 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 58 | 2053.964 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 59 | 2243.964 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.682 KG | 1.000 IN | | |
| 60 | 2253.964 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 61 | 2263.964 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 62 | 2453.963 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.682 KG | 1.000 IN | | |
| 63 | 2463.963 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 64 | 2473.963 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 65 | 2663.963 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.682 KG | 1.000 IN | | |
| 66 | 2673.962 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 67 | 2683.962 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 68 | 2873.962 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.682 KG | 1.000 IN | | |
| 69 | 2883.962 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 70 | 2893.961 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 71 | 3083.961 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.682 KG | 1.000 IN | | |
| 72 | 3093.961 FT | | | | | | | | | |

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| POSITION NO. | LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | 3093.961 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | DRF | | | 2 | 10.000 | FT | | | | | | | | |
| 73 | 3103.961 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 | IN | 900.000 | IN | 0.0 | IN | -780.000 | IN | 0.0 | DEG |
| | | DRF | | | 10 | 190.000 | FT | | | | | | | | |
| 74 | 3293.960 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | QUAD | Q410 | | 5 | 10.000 | FT | 2.682 | KG | 1.000 | IN | | | | |
| 75 | 3303.963 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | DRF | | | 2 | 10.000 | FT | | | | | | | | |
| 76 | 3313.960 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 | IN | 900.000 | IN | 0.0 | IN | -780.000 | IN | 0.0 | DEG |
| | | DRF | | | 10 | 190.000 | FT | | | | | | | | |
| 77 | 3503.963 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | ABS | CIRC | BE | BE | 2.250 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | QUAD | Q410 | | 5 | 10.000 | FT | -2.458 | KG | 1.000 | IN | | | | |
| 78 | 3513.959 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | DRF | | 3.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | ABS | RECT | BE | BE | 60.000 | IN | 48.000 | IN | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | DRF | | | 5 | 1.500 | FT | | | | | | | | |
| 79 | 3515.459 FT | | | | | | | | | | | | | | |
| | | APE | RECT | BEND | | 3.000 | IN | 2.000 | IN | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | ABS | RECT | BE | BE | 3.000 | IN | 2.000 | IN | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | BEND | M86 | | 5 | 20.000 | FT | 11.000 | KG | 550.000 | GV/C | | | | |
| 80 | 3535.459 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 | IN | 900.000 | IN | 0.0 | IN | -780.000 | IN | 0.0 | DEG |
| | | DRF | | | 3 | 28.500 | FT | | | | | | | | |
| 81 | 3563.959 FT | | | | | | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 3.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | TUNO | RECT | | | 930.000 | IN | 930.000 | IN | 0.0 | IN | -780.000 | IN | 0.0 | DEG |
| 81 | 3563.959 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | SCR | | 2.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | SCR | | | 10 | 150.000 | FT | 15.000 | KG | 0.0 | IN | 2.000 | IN | 3.000 | IN |
| 82 | 3713.958 FT | | | | | | | | | | | | | | |
| | | TUN | RECT | DIRT | | 60.000 | IN | 48.000 | IN | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | TUNO | RECT | | | 900.000 | IN | 900.000 | IN | 0.0 | IN | -780.000 | IN | 0.0 | DEG |
| 82 | 3713.959 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | QUAD | Q410 | | 5 | 10.000 | FT | 2.458 | KG | 1.000 | IN | | | | |
| 83 | 3723.958 FT | | | | | | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | DRF | | | 2 | 10.000 | FT | | | | | | | | |
| 84 | 3733.958 FT | | | | | | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 3.000 | IN | | | 0.0 | IN | 0.0 | IN | 0.0 | DEG |
| | | TUNO | RECT | | | 900.000 | IN | 900.000 | IN | 0.0 | IN | -780.000 | IN | 0.0 | DEG |
| 84 | 3733.958 FT | | | | | | | | | | | | | | |

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| NO. | POSITION LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 84 | 3733.958 FT | | | | | | | | | |
| | | APE | CIRC | SCR | | 2.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | SCR | | | 10 | 150.000 FT | 15.000 KG | 0.0 IN | 2.000 IN | 3.000 IN |
| 85 | 3883.958 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 60.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | RECT | | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| 85 | 3883.958 FT | | | | | | | | | |
| | | APE | CIRC | SCR | | 3.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | SCR | | | 10 | 40.000 FT | 15.000 KG | 0.0 IN | 3.000 IN | 60.000 IN |
| 86 | 3923.958 FT | | | | | | | | | |
| | | TUN | RECT | DIRT | | 60.000 IN | 48.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | RECT | | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| 86 | 3923.958 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.458 KG | 1.000 IN | | |
| 87 | 3933.957 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 88 | 3943.957 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC DIRT | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 40.000 FT | | | | |
| 89 | 3953.957 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 3.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | RECT | | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| 89 | 3983.957 FT | | | | | | | | | |
| | | APE | CIRC | SCR | | 2.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | SCR | | | 10 | 150.000 FT | 15.000 KG | 0.0 IN | 2.000 IN | 3.000 IN |
| 90 | 4133.953 FT | | | | | | | | | |
| | | TUN | RECT | DIRT | | 60.000 IN | 48.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | RECT | | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| 90 | 4133.953 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.458 KG | 1.000 IN | | |
| 91 | 4143.949 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 92 | 4153.945 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 3.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | RECT | | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| 92 | 4153.945 FT | | | | | | | | | |
| | | APE | CIRC | SCR | | 2.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | SCR | | | 10 | 150.000 FT | 15.000 KG | 0.0 IN | 2.000 IN | 3.000 IN |
| 93 | 4303.941 FT | | | | | | | | | |
| | | TUN | CIRC | DIRT | | 60.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | RECT | | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| 93 | 4303.941 FT | | | | | | | | | |
| | | APE | CIRC | SCR | | 3.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | SCR | | | 10 | 40.000 FT | 15.000 KG | 0.0 IN | 3.000 IN | 60.000 IN |
| 94 | 4343.938 FT | | | | | | | | | |
| | | TUN | RECT | DIRT | | 60.000 IN | 48.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | TUNO | RECT | | | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| 94 | 4343.938 FT | | | | | | | | | |

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| POSITION NO. | LENGTH | TYPE | CODES 1 | 2 | 3 | PARAMETERS 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 94 | 4343.938 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.458 KG | 1.000 IN | | |
| 95 | 4353.934 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 96 | 4363.930 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 97 | 4553.926 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | 2.458 KG | 1.000 IN | | |
| 98 | 4563.922 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | DRF | | | 2 | 10.000 FT | | | | |
| 99 | 4573.918 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 190.000 FT | | | | |
| 100 | 4763.914 FT | | | | | | | | | |
| | | APE | CIRC | QUAD | | 2.250 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | QUAD | Q410 | | 5 | 10.000 FT | -2.458 KG | 1.000 IN | | |
| 101 | 4773.910 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 5 | 90.000 FT | | | | |
| 102 | 4863.906 FT | | | | | | | | | |
| | | APE | RECT | BEND | | 3.000 IN | 2.000 IN | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | BEND | V86 | | 5 | 20.000 FT | 11.000 KG | 550.000 GV/C | | |
| 103 | 4883.902 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 4.000 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 900.000 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 111.500 FT | | | | |
| 104 | 4995.398 FT | | | | | | | | | |
| | | APE | CIRC | DRF | | 0.0 IN | | 0.0 IN | 0.0 IN | 0.0 DEG |
| | | COLL | RECT | VAC | DIRT | 8999.996 IN | 900.000 IN | 0.0 IN | -780.000 IN | 0.0 DEG |
| | | DRF | | | 10 | 6599.996 FT | | | | |
| 105 | 11595.395 FT | | | | | | | | | |

APPENDIX III

## PROPERTIES OF THE MUPIPE

A) Magnetic Field

Using $\oint \vec{H} \cdot d\vec{s} = I$ we obtain

$$\vec{H}(r) = 0 \qquad r < a$$

$$\vec{H}(r) = \frac{I}{2\pi r}\hat{\theta} \qquad r > b$$

$$\vec{H}(r) = \frac{I\left(r^2 - a^2\right)}{2\pi r\left(b^2 - a^2\right)}\hat{\theta} \qquad a < r < b$$

$$\vec{B}(r) = \mu(H)\,\vec{H}$$

Of primary interest is the region $a<r<b$. Figures A1 and A2 show the relevant quantities for pure iron and for hot rolled low-carbon steel. ( See reference 11). The parameters were I=5000 amps, a=2 inches, and b=3 inches. $d \equiv r-a$. In both pure iron and hot rolled steel, the magnetic field attains very high values after only penetrating a small distance into the mupipe wall.

B. Power (D. C.)

$$p = I^2 R = \frac{I^2 \quad L}{\pi\left(b^2 - a^2\right)}$$

Using $\rho = 1.6 \times 10^{-5}$ cm, we obtain

$$\frac{p}{L} = 4 \text{ watts/cm} = 122 \text{ watts/foot}$$

C) Deflection in pure iron

$$p_{\perp MS} = 0.15\sqrt{\frac{L}{0.0176\ \text{m}}} = 0.113\sqrt{L}\ \ \text{GeV/c}\ \ (\text{meters})^{-1/2}$$

$$p_{\perp B} = 0.03BL$$

$$T = \frac{p_{\perp B}}{p_{\perp MS}} = \frac{0.03BL}{0.113\sqrt{L}} = 0.265B\sqrt{L}\ \ \text{kg}^{-1}\ \text{meters}^{-1/2}$$

At what angle does a particle have to enter the wall of the mupipe so that L is large enough for $p_{\perp B} > p_{\perp MS}$? For a particle that enters the wall at an angle $\theta$, $L(\theta)$ can be found from:

$$L^2 = 2\rho^2\theta^2 + 2\rho d - \rho d\theta^2 - 2\rho\theta\sqrt{\rho^2\theta^2 + 2\rho d - d^2 - \rho d\theta^2}$$

$\rho$ = the radius of curvature

d = depth into the wall

For a particle that overcomes multiple scattering, the average B field is 16.7 kg and calculating L, gives L=9 meters for p = 800 GeV/c, and L=3 meters for p=100 GeV/c. Figure A3 shows T vs L for several angles and indicates that the field wins over the multiple scattering at $\sim$0.008 mr for p=800 GeV/c, and at $\sim$0.03 mr for p=100 GeV/c.

figure A1

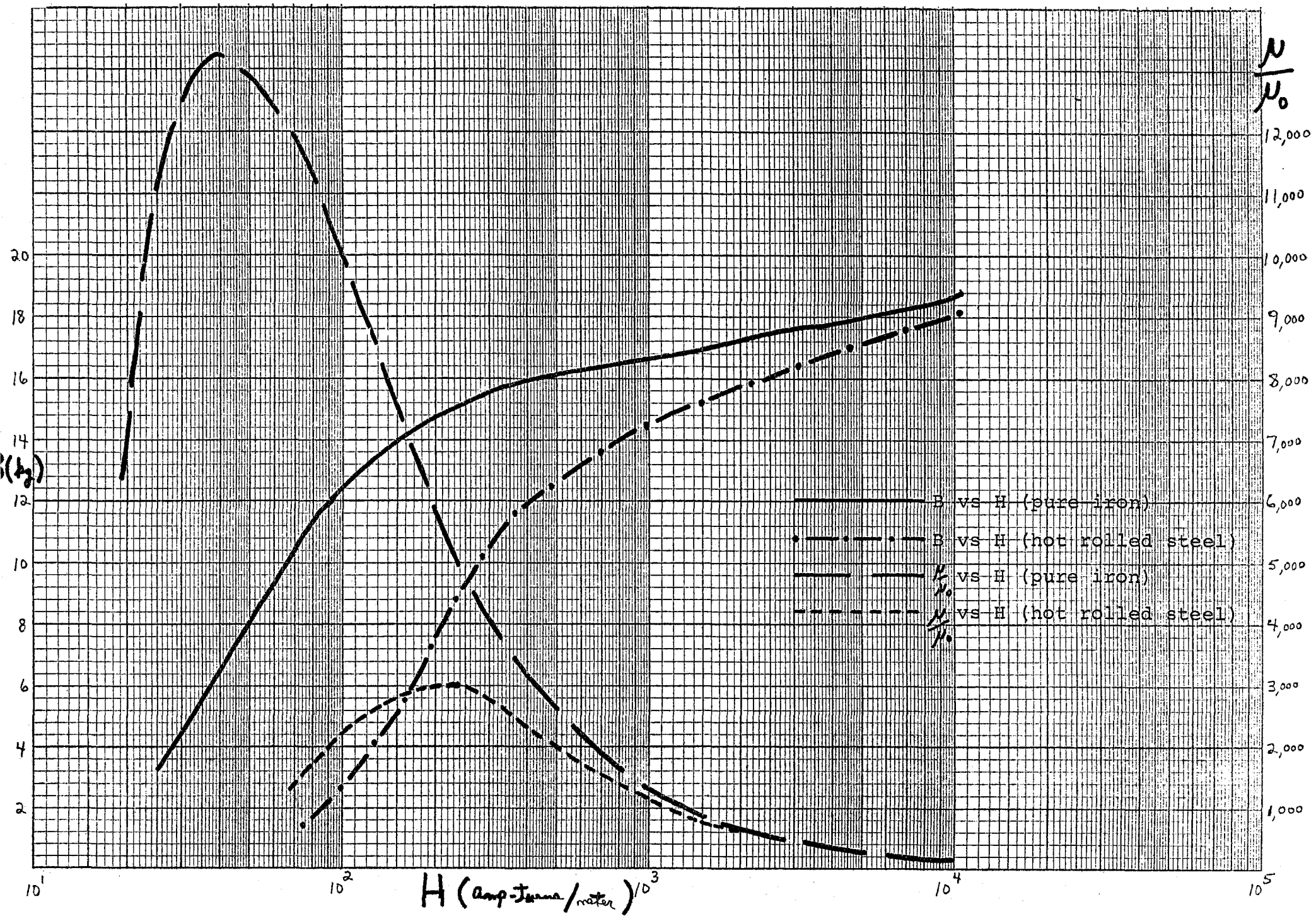

μ/μ₀
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
20
18
16
14
12
10
8
6
4
2
B(kg)
B vs H (pure iron)
B vs H (hot rolled steel)
μ/μ₀ vs H (pure iron)
μ/μ₀ vs H (hot rolled steel)
10¹
10²
10³
10⁴
10⁵
H (amp-turns/meter)

figure A2

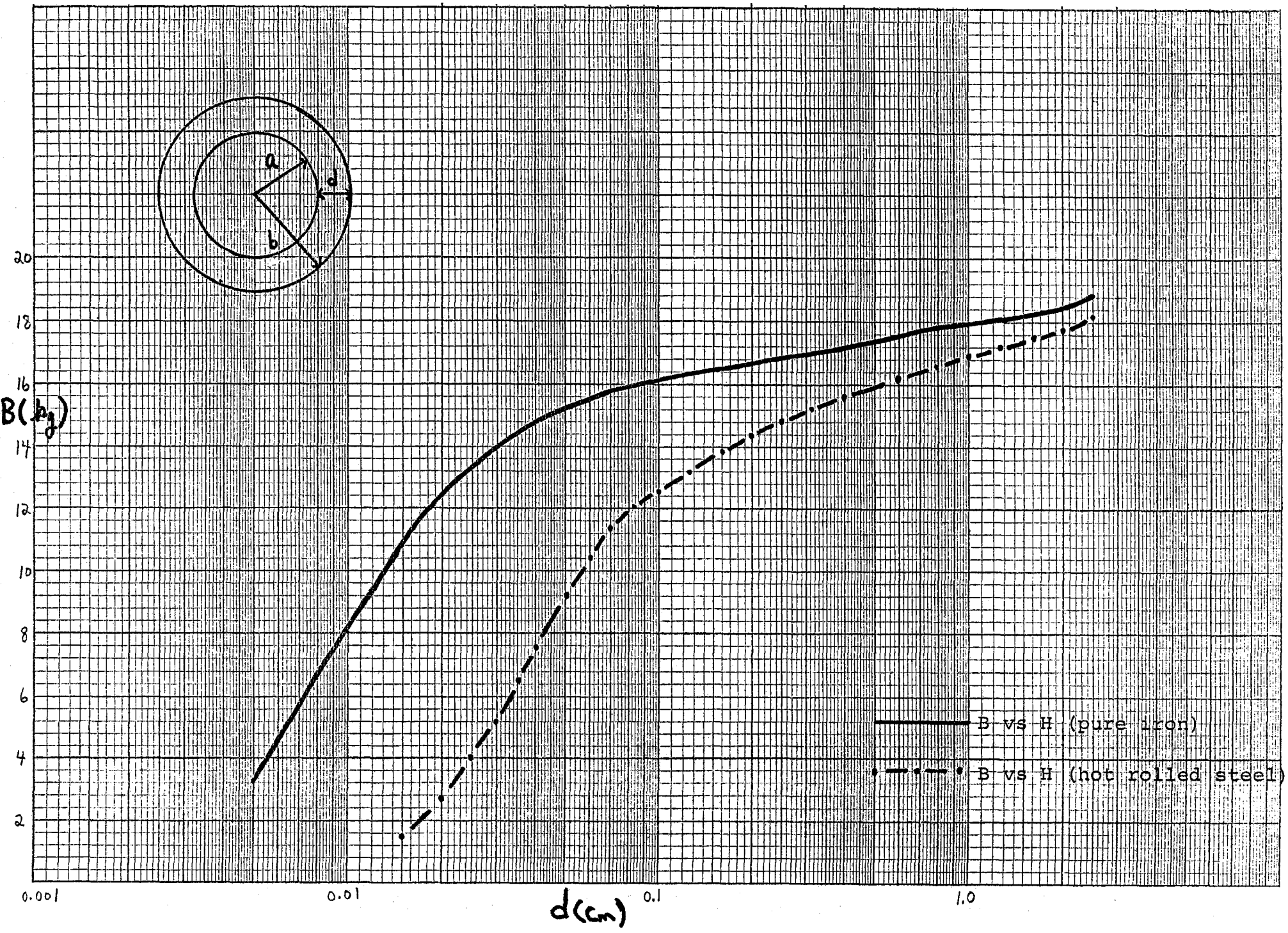
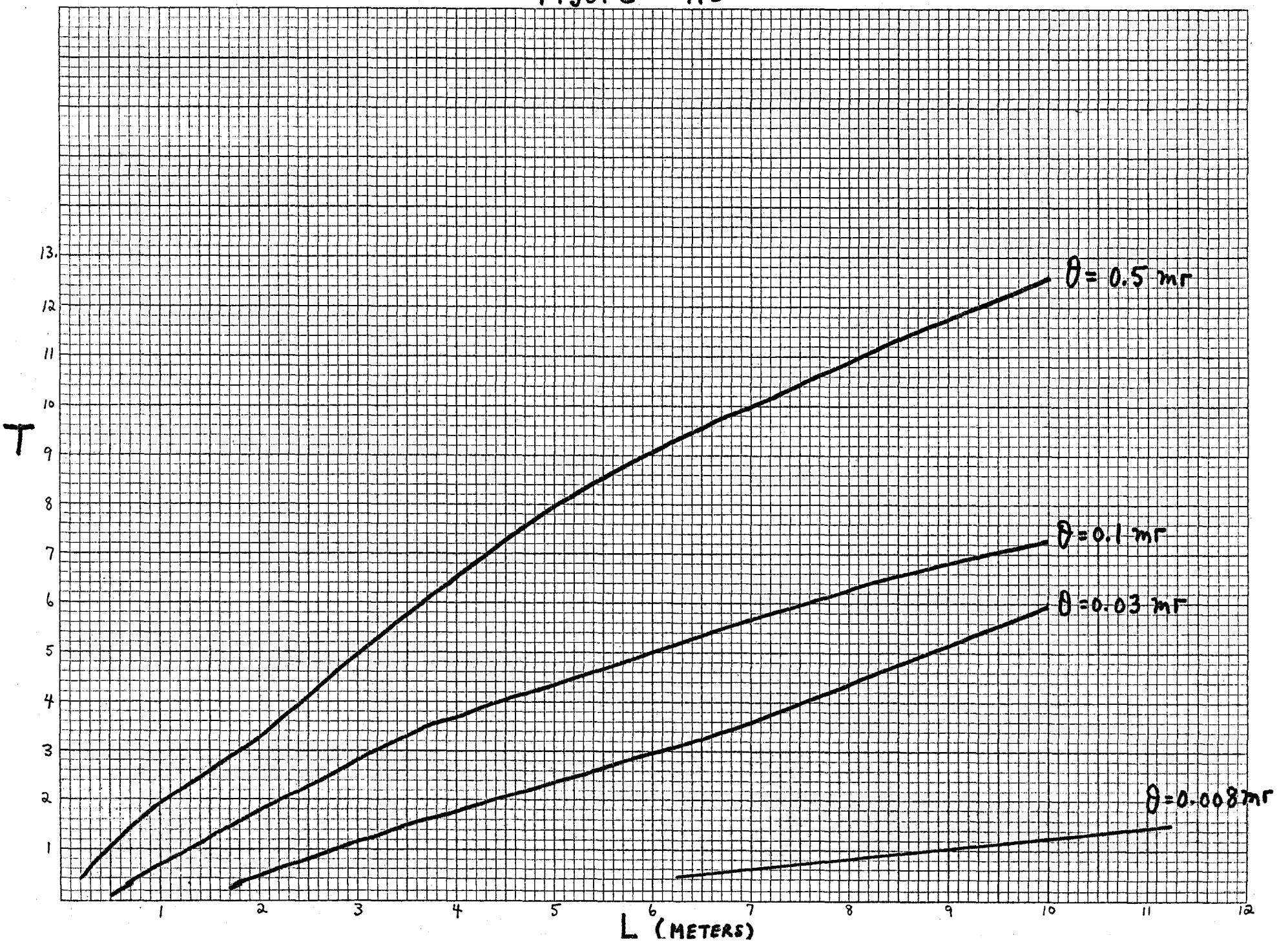

a
d
b
20
18
16
14
12
10
8
6
4
2
B(kg)
0.001
0.01
0.1
1.0
d(cm)
B vs H (pure iron)
B vs H (hot rolled steel)

figure A3


T
13.
12
11
10
9
8
7
6
5
4
3
2
1
θ = 0.5 mr
θ = 0.1 mr
θ = 0.03 mr
θ = 0.008 mr
1
2
3
4
5
6
7
8
9
10
11
12
L (METERS)