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DESIGN STUDY FOR A HIGH ENERGY MUON BEAM

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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 ($275 \lesssim p \lesssim 750$ 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/π 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/π 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 (π/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 <u>average</u> 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 μ / 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 ~ 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 π/μ contamination at the end of the beam to $<10^{-6}$. The absorber, ~ 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, θ and φ, 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
π^+ { 400 GeV Protons, 0 - 400 GeV/c, 0 - 20 mrad	1.07×10^{12}	3.35×10^{11}
π^+ { 400 GeV Protons, 175 - 400 GeV/c, 0 - 20 mrad	3.36×10^{10}	1.53×10^{10}
x π^+ { 400 GeV Protons, 200 - 400 GeV/c, 0 - 5 mrad	1.87×10^{10}	5.81×10^{9}
x π^+ { 300 GeV Protons, 120 - 300 GeV/c, 0 - 5 mrad	3.79×10^{10}	1.35×10^{9}
π^+ { 1000 GeV Protons, 350 - 1000 GeV/c, 0 - 10 mrad	6.82×10^{10}	3.12×10^{10}
K^+ { 1000 GeV Protons, 350 - 1000 GeV/c, 0 - 10 mrad	6.82×10^{9} +	7.86×10^{9}
* π^+ { 1000 GeV/c Protons, 380 - 1000 GeV/c, 0 - 1.5 mrad	2.18×10^{6}	9.34×10^{5}
* K^+ { 1000 GeV/c Protons, 380 - 1000 GeV/c, 0 -1.5 mrad	2.18×10^{5} +	2.02×10^{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 μ/p		Measured Muon Yield	Predicted Halo*/Beam	Measured Halo/Beam
		π^+	K^+			
150	Beam	$(2.96 \pm 0.52)10^{-7}$		1.7×10^{-7}	4.7 ± 1.9	1.5
	Halo	$(1.4 \pm 0.5)10^{-6}$				
225	Beam	$(5.2 \pm 0.4)10^{-7}$	$(0.86 \pm 0.23)10^{-8}$	2.5×10^{-7}	1.3 ± 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 μ/p

Beam and Tune	Δp*	Wang Muon from π^+	Δp	Adair Muon from K^+
No. 2 750 GeV/c	670 ± 70	$(1.06 \pm 0.08)\ 10^{-5}$	715 ± 99	$(0.13 \pm 0.04)\ 10^{-5}$
No. 2 550 GeV/c	510 ± 63	$(0.88 \pm 0.03)\ 10^{-4}$	546 ± 62	$(0.06 \pm 0.01)\ 10^{-4}$
No. 2 275 GeV/c	264 ± 37	$(2.96 \pm 0.10)\ 10^{-4}$	266 ± 25	$(0.06 \pm 0.01)\ 10^{-4}$
No. 4 750 GeV/c	—	$(4.6 \pm 1.3)\ 10^{-6}$	—	—
No. 4 550 GeV/c	550 ± 60	$(3.0 \pm 0.1)\ 10^{-5}$	—	—
No. 4 275 GeV/c	263 ± 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 μ/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 π^+, and 5,000 K^+)

Parent Particle and Momentum (GeV/c)	Muon Yield μ/p	Halo μ/p	Halo/Beam
800 π^+	$(1.06 \pm 0.08)\ 10^{-5}$	$(0.52 \pm 0.21)\ 10^{-6}$	9%
800 K^+	$(0.13 \pm 0.04)\ 10^{-5}$	$(0.4 \pm 0.2)\ 10^{-6}$	
600 π^+	$(0.88 \pm 0.03)\ 10^{-4}$	$(2.5 \pm 1.1)\ 10^{-6}$	4%
600 K^+	$(0.06 \pm 0.02)\ 10^{-4}$	$(1.0 \pm 1.1)\ 10^{-6}$	
305 π^+	$(2.96 \pm 0.10)\ 10^{-4}$	$(2.0 \pm 0.4)\ 10^{-5}$	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 μ/p	Halo Beam (%)
0.0	$(38 \pm 0.03)\ 10^{-4}$	2.8 ± 1.2
0.25	$(6.0 \pm 0.6)\ 10^{-5}$	4.4 ± 1.7
0.50	$(4.5 \pm 0.05)\ 10^{-5}$	7.7 ± 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.

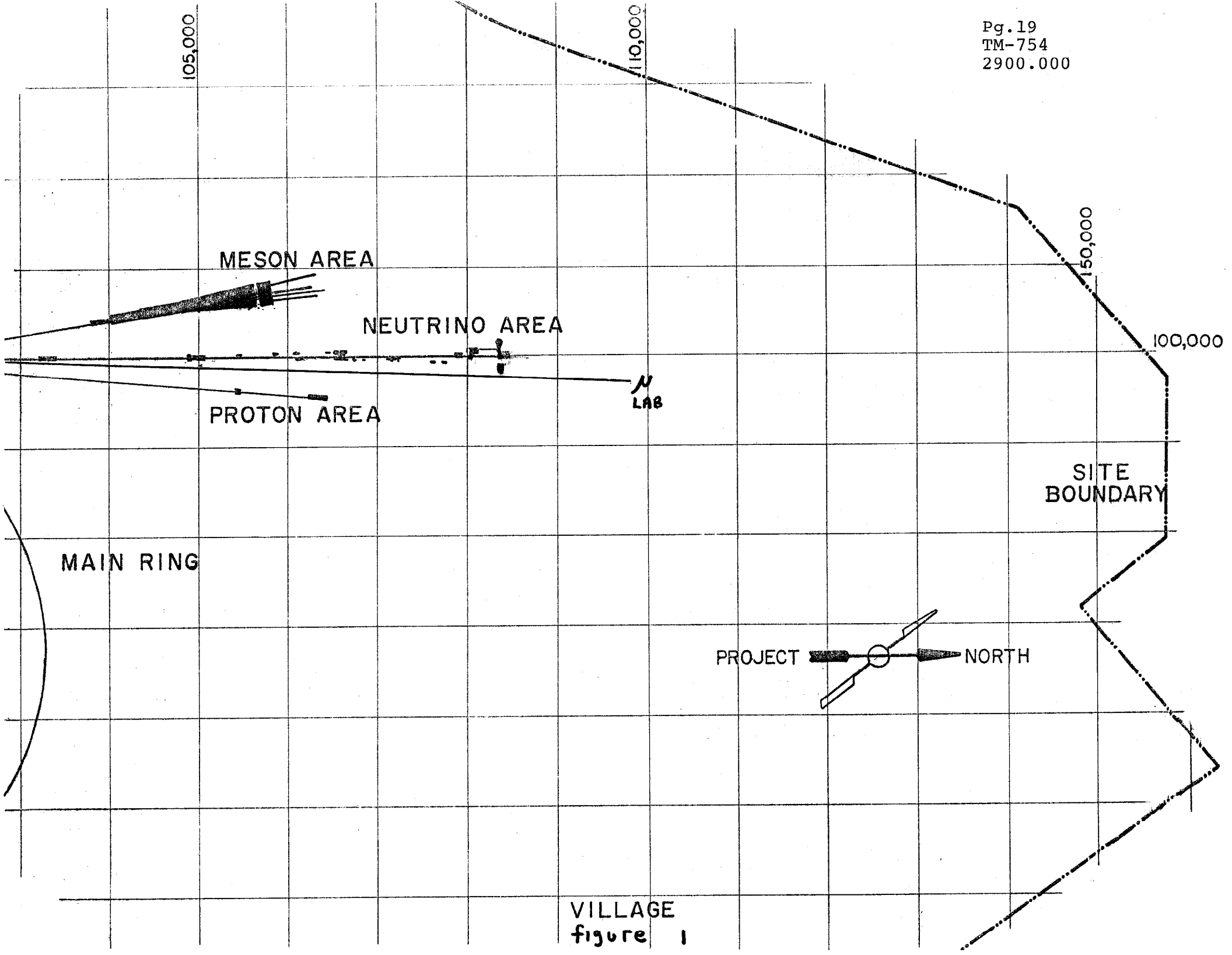
Figure 9 The momentum of the muon beam at the detector versus the decay angle of the parent pions for Beam 2.

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
NEUTRINO AREA
PROTON AREA
ν LAB
SITE BOUNDARY
MAIN RING
PROJECT
NORTH
VILLAGE

figure 1

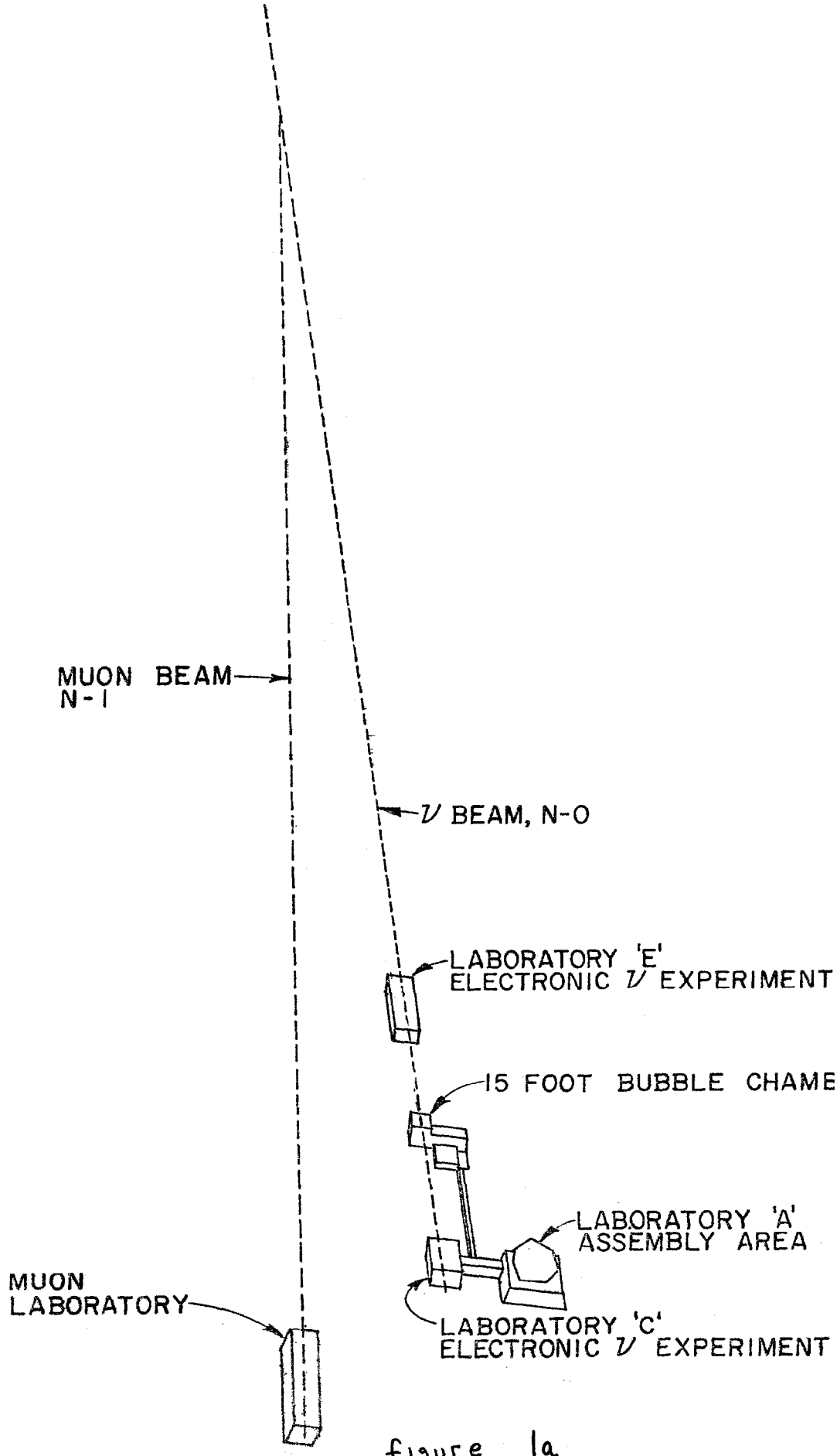

MUON BEAM
N-1
ν BEAM, N-O
LABORATORY 'E'
ELECTRONIC ν EXPERIMENT
15 FOOT BUBBLE CHAME
LABORATORY 'A'
ASSEMBLY AREA
MUON
LABORATORY
LABORATORY 'C'
ELECTRONIC ν EXPERIMENT

figure 1a

fig. 2a FRONT END FOR BEAMS 1-3

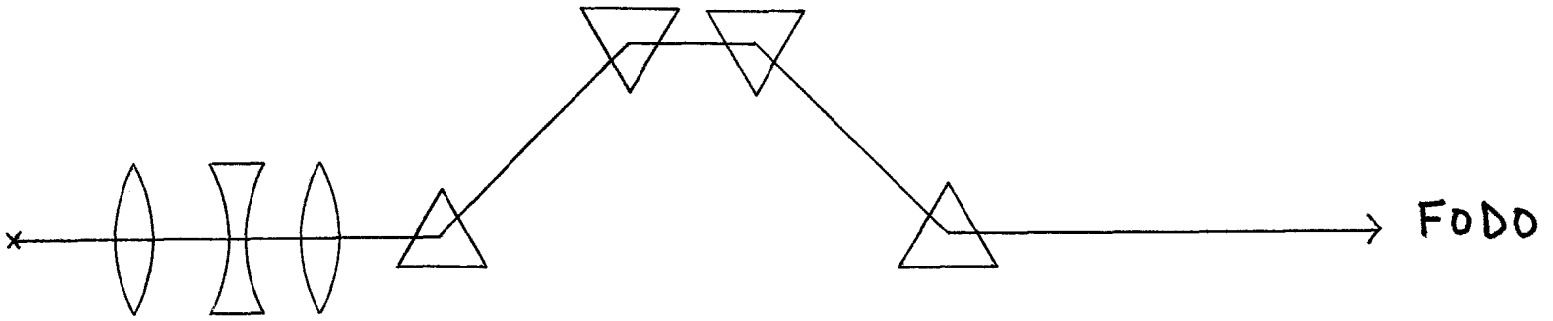
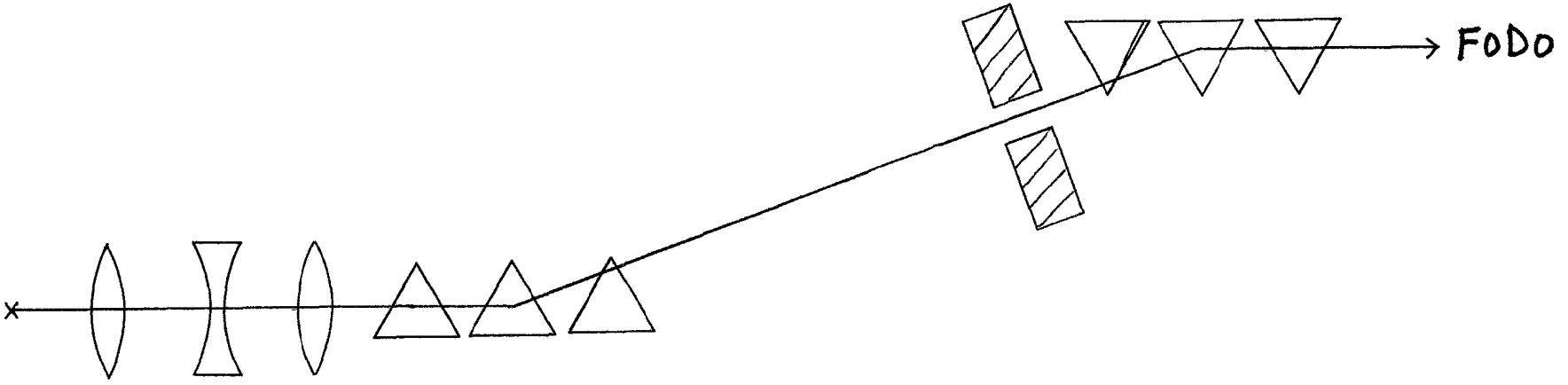


fig. 2b FRONT END FOR BEAM 4



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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 I$                 I   87
  220.000 TO   240.000 I$V                I 1029
  240.000 TO   260.000 I$$$$1             I 1450
  260.000 TO   280.000 I  X$$$$7          I 1185
  280.000 TO   300.000 I   6$$$$$W3       I 1018
  300.000 TO   320.000 I    A$$$$$$RF     I  766
  320.000 TO   340.000 I     5Z$$$$$$Z62I   670
  340.000 TO   360.000 I      BAY$$$$$$DI   474
  360.000 TO   380.000 I      15CO$$$$$$I   371
  380.000 TO   400.000 +       2556I$$$$+   241
  400.000 TO   420.000 I        14CALV$$I   188
  420.000 TO   440.000 I         235CBN$I    97
  440.000 TO   460.000 I         1 39FNQI    77
  460.000 TO   480.000 I           266BEI    39
  480.000 TO   500.000 I            5394I    21
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  520.000 TO   540.000 I             111I     3
  540.000 TO   560.000 I              23I     5
  560.000 TO   580.000 I               1I     1
  580.000 TO   600.000 +               1 +    1
                          +----------+-------+ SUMS
                          S1                S
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        UNDER     IN   OVER
UNDER       0      0      0          HMEAN =      -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
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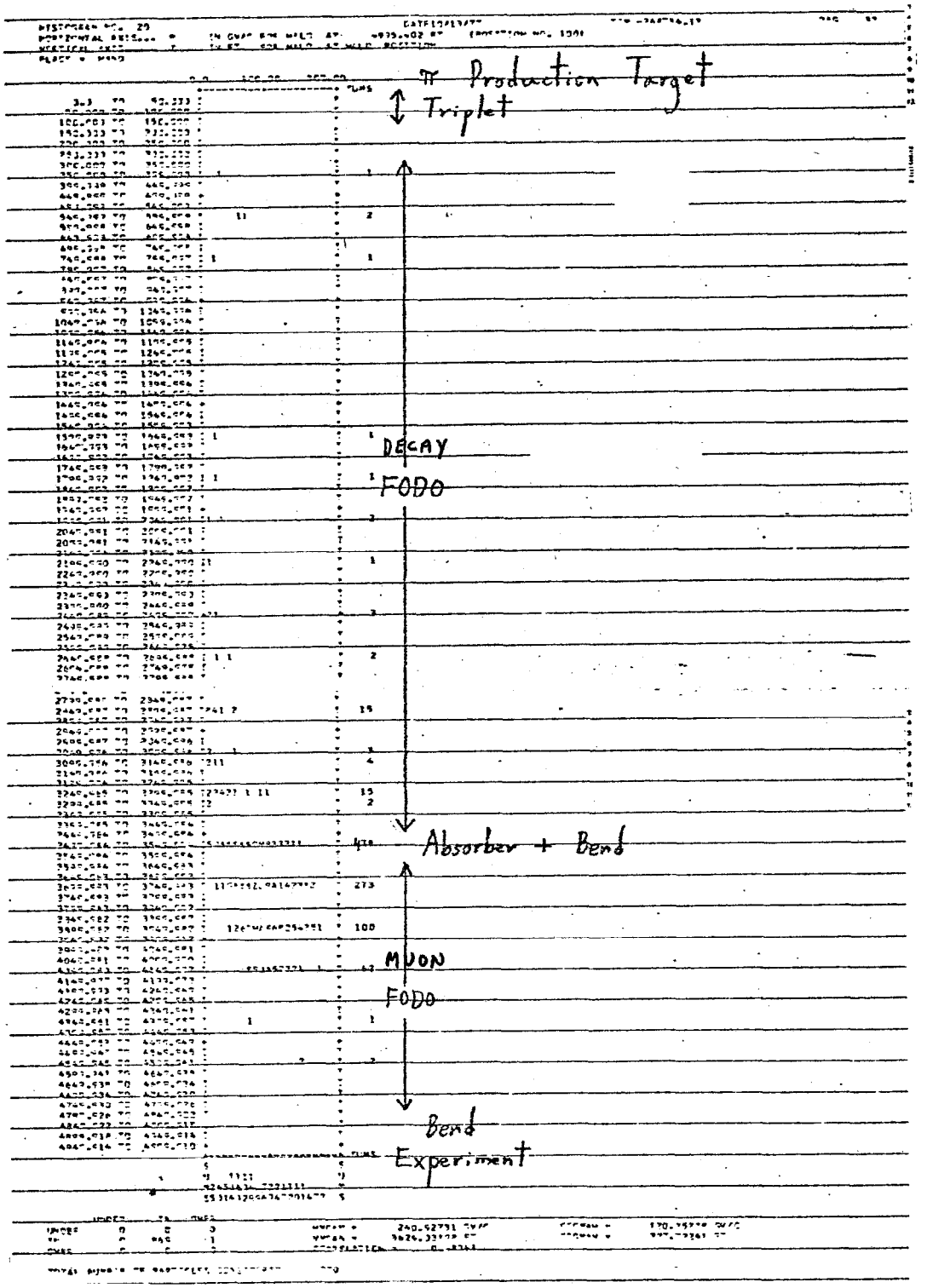
Beam 4 @ 305 GeV/c Tune

Dispersion at momentum slit

Fig. 3

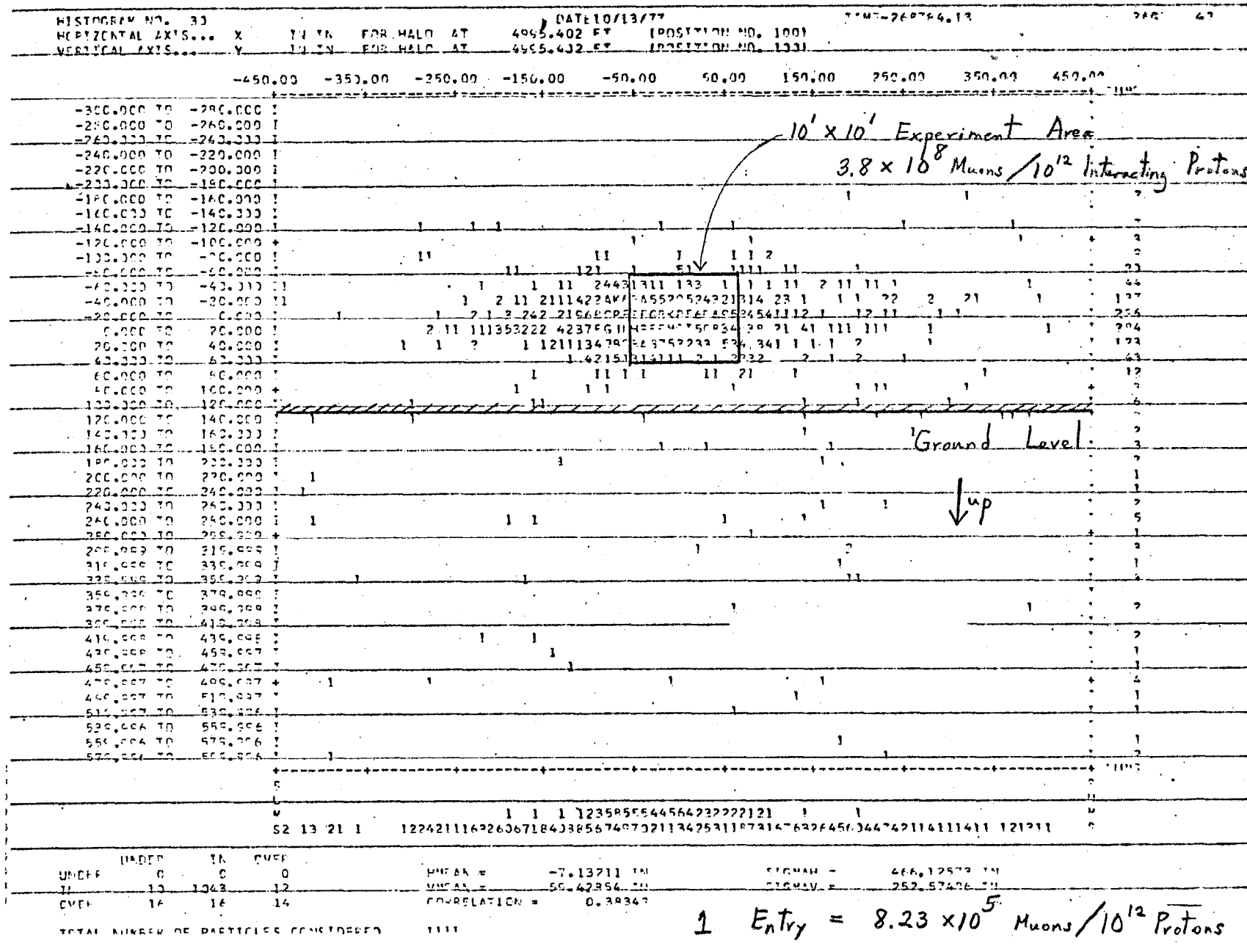
FODO Transmission vs Momentum figure 4



Longitudinal Points of Origin of Halo

Fig. 5

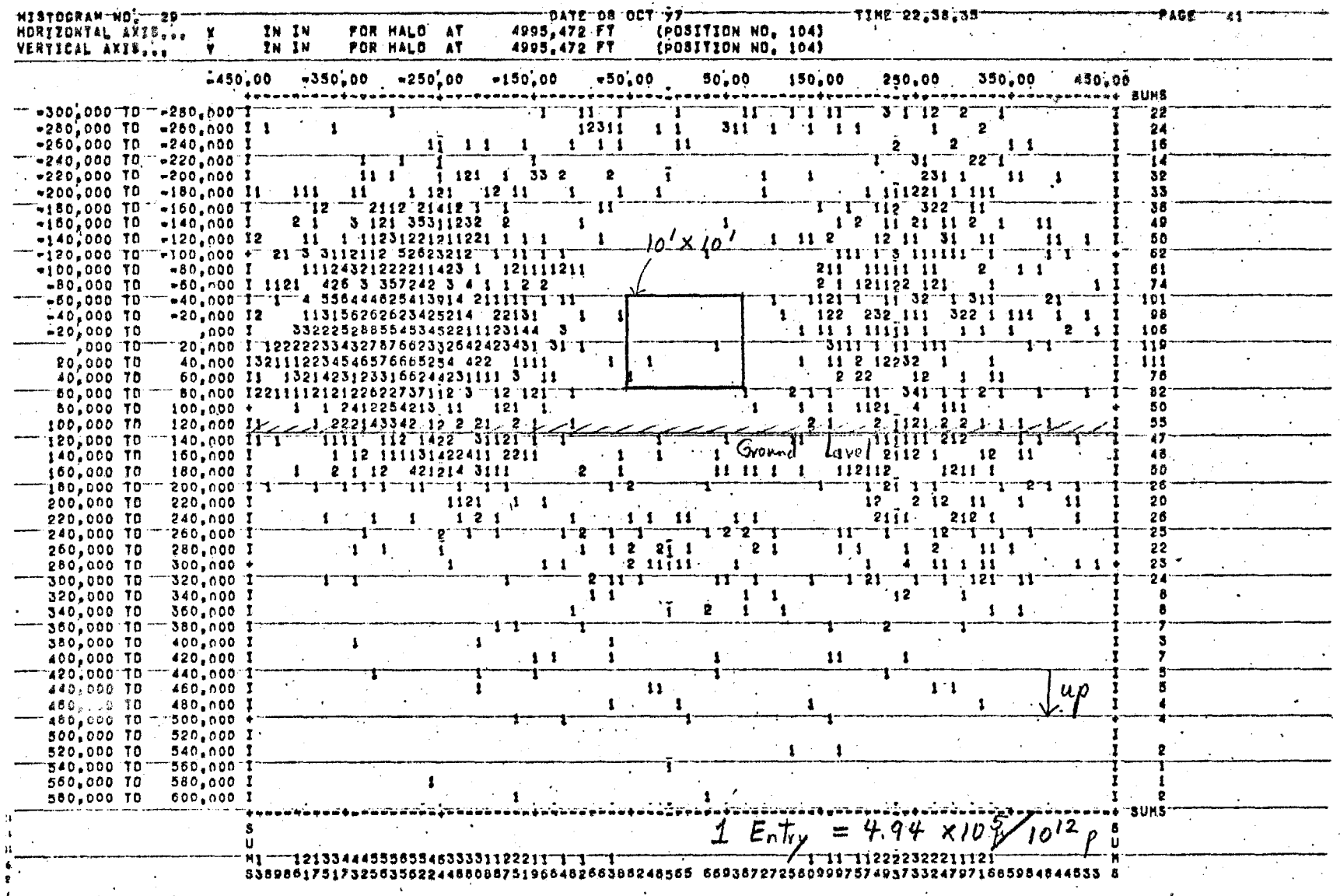
Plt #13



1 Entry = 8.23×10^5 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 SIGMAH = 396.10368 IN
VMEAN = 80.98412 IN SIGMAV = 382.46528 IN
CORRELATION = .13366

TOTAL NUMBER OF PARTICLES CONSIDERED 1847

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

fig. 8a BEAM 1

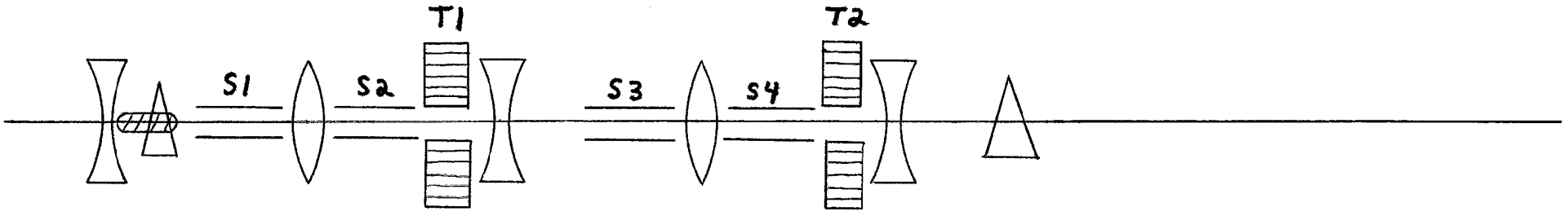


fig. 8b BEAM 2 & 4

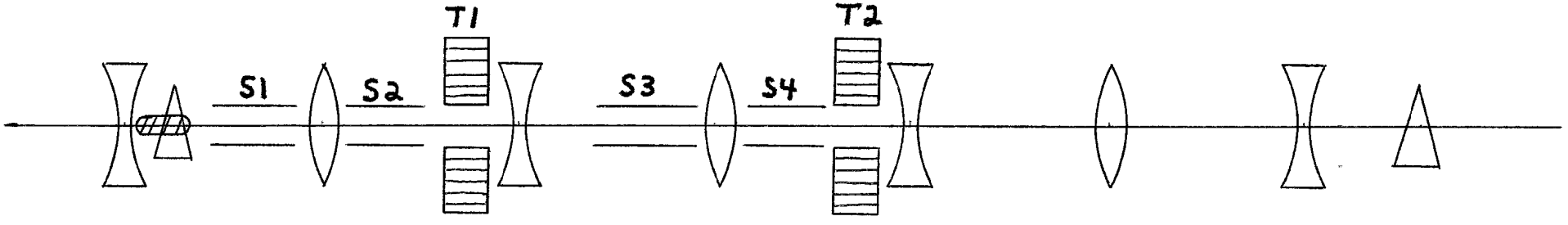
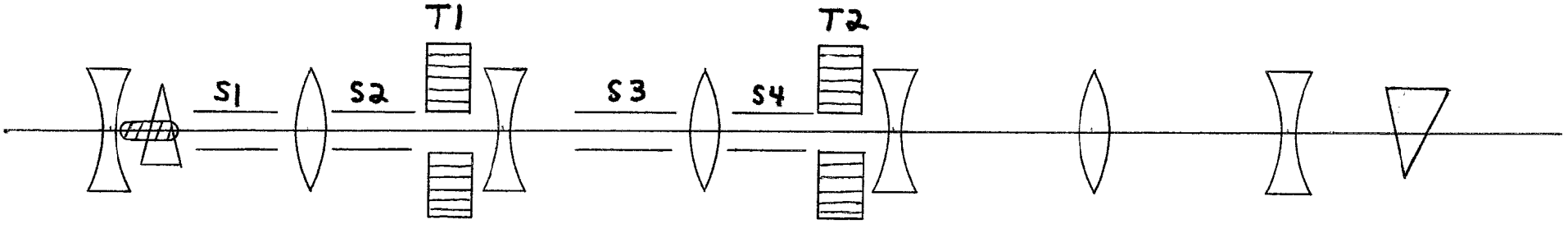


fig. 8c BEAM 3



```
HISTOGRAM NO.   9                                                    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    1112     I   16
  460.000 TO   480.000 I 111  111131125 2 31     I   25
  480.000 TO   500.000 I      2 1 113133423 3     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 I1 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          1111111219 M
                            S1442244438442789908 4S

        UNDER     IN   OVER
UNDER       0      0      0          HMEAN =        .38782          SIGMAH =        .45962
IN          0    211      0          VMEAN =     507.80819 GEV/C    SIGMAV =     61.38586 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          48A8AGHE61I    94
   540,000 TO   560,000 I           248ECGGEHI   103
   560,000 TO   580,000 I             49AGKJII    96
   580,000 TO   600,000 +             137FPS9+    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                   1 U
                          M      1 11333455780RM
                          S 134858674553827363 2S

        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
```

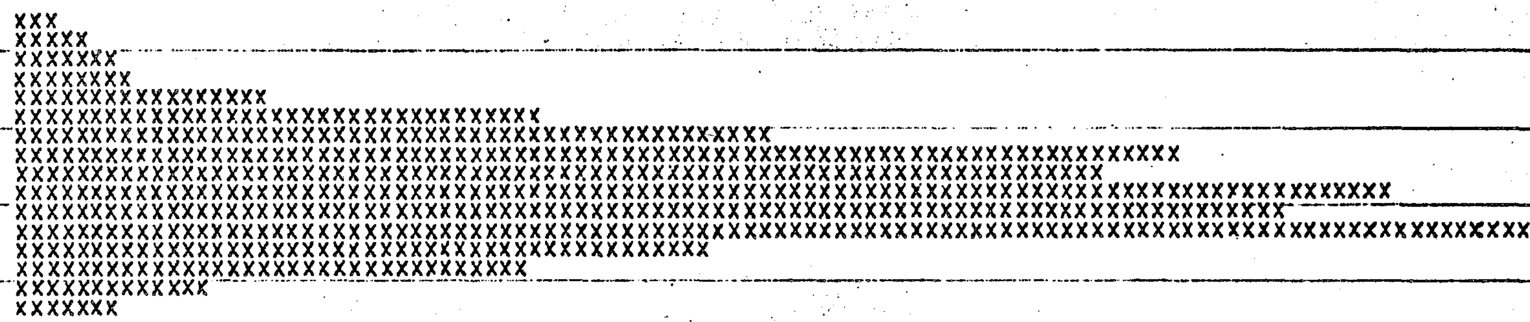
Fig. 10 Beam 4 550 GeV/c

```
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
```

INTERVAL		
-2.500 TO	-2.250	0
-2.250 TO	-2.000	0
-2.000 TO	-1.750	3
-1.750 TO	-1.500	5
-1.500 TO	-1.250	6
-1.250 TO	-1.000	7
-1.000 TO	-.750	15
-.750 TO	-.500	30
-.500 TO	-.250	42
-.250 TO	.000	65
.000 TO	.250	61
.250 TO	.500	77
.500 TO	.750	71
.750 TO	1.000	84
1.000 TO	1.250	39
1.250 TO	1.500	29
1.500 TO	1.750	11
1.750 TO	2.000	6
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

INTERVAL		SCALE FACTOR.. 100 X*S EQUAL 100 ENTRIES
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	X
400.000 TO 420.000	2	XX
420.000 TO 440.000	10	XXXXXXXXXX
440.000 TO 460.000	18	XXXXXXXXXXXXXXXXXX
460.000 TO 480.000	53	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
480.000 TO 500.000	95	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
500.000 TO 520.000	100	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
520.000 TO 540.000	85	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
540.000 TO 560.000	67	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
560.000 TO 580.000	54	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
580.000 TO 600.000	36	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
600.000 TO 620.000	25	XXXXXXXXXXXXXXXXXXXXXXXXX
620.000 TO 640.000	5	XXXXX
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	CODES 2	CODES 3	PARAMETERS 1	PARAMETERS 2	PARAMETERS 3	PARAMETERS 4	PARAMETERS 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	2	3	PARAMETERS 1	2	3	4	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	167.090 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									
		DRF			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									

... SYS DESCRIPTION. DATE 9/20/77 TIME=268774.98 PAGE 4

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

SYS DESCRIPTION DATE 9/23/77 TIME-268274.58 PAGE 7

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

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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    -790.000 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     94.972 FT
                           DRF                  1    1.500 FT
 12     96.472 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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SYS DESCRIPTION. DATE 9/22/77 TIME-268780.94 PAGE 3

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	563.970 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										

SYS DESCRIPTION. DATE 9/22/77 TIME-268780.94 PAGE 4

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									

SYS DESCRIPTION. DATE 9/22/77 TIME-268780.94 PAGE 5

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	3303.960 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	3503.960 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	ORF		4.000 IN		0.0 IN	0.0 IN	0.0 DEG
		ORF			2	10.000 FT				
88	3943.957 FT	APE	CIRC	ORF		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
		ORF			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	ORF		4.000 IN		0.0 IN	0.0 IN	0.0 DEG
		ORF			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	4363.933 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	M86		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 θ, $L(\theta)$ can be found from:

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

ρ = 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 ~0.008 mr for p=800 GeV/c, and at ~0.03 mr for p=100 GeV/c.

figure A1

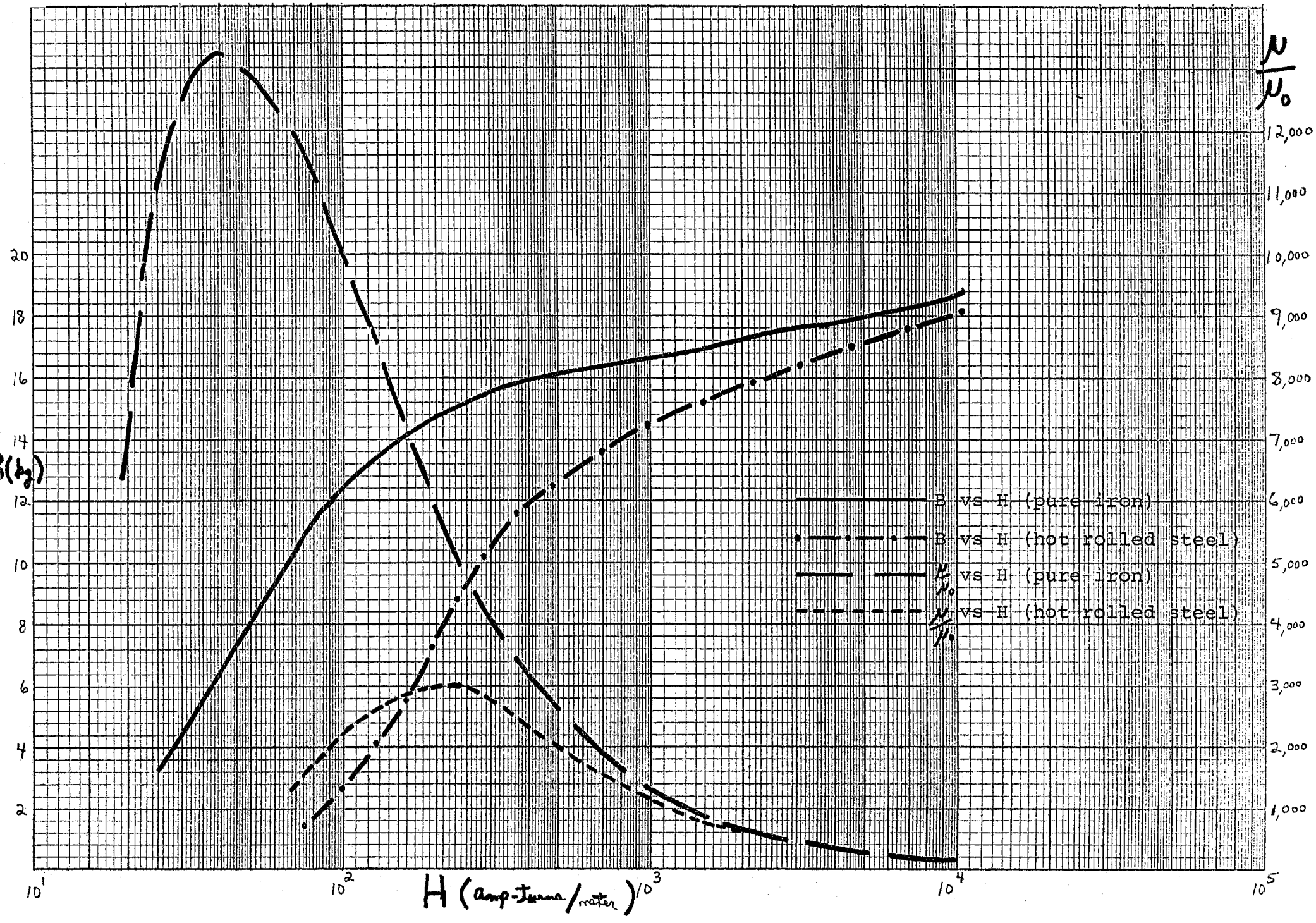

B (kg)
20
18
16
14
12
10
8
6
4
2
μ/μ_0
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
10^1
10^2
10^3
10^4
10^5
H (amp-turns/meter)
B vs H (pure iron)
B vs H (hot rolled steel)
μ/μ_0 vs H (pure iron)
μ/μ_0 vs H (hot rolled steel)

figure A2

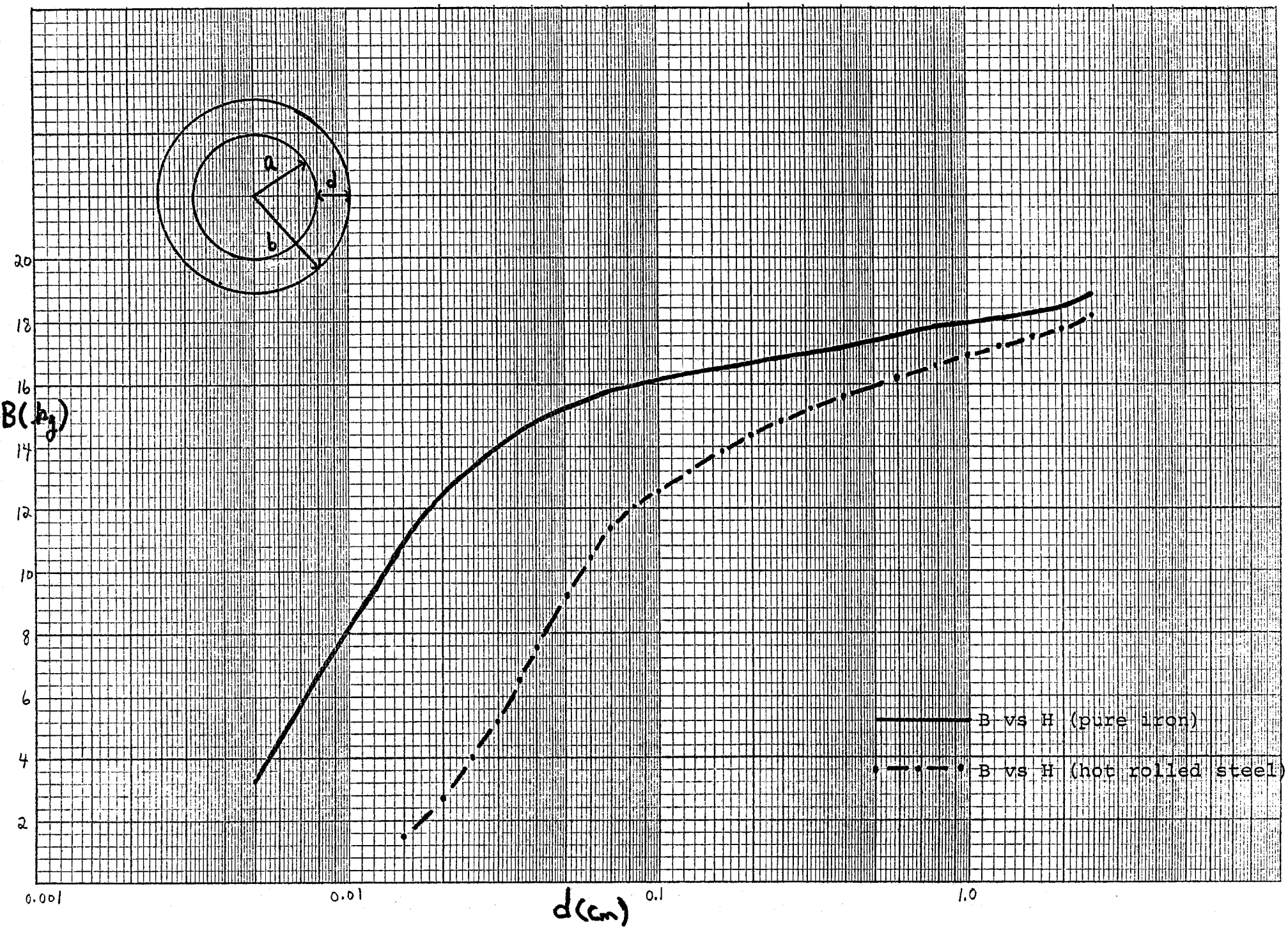
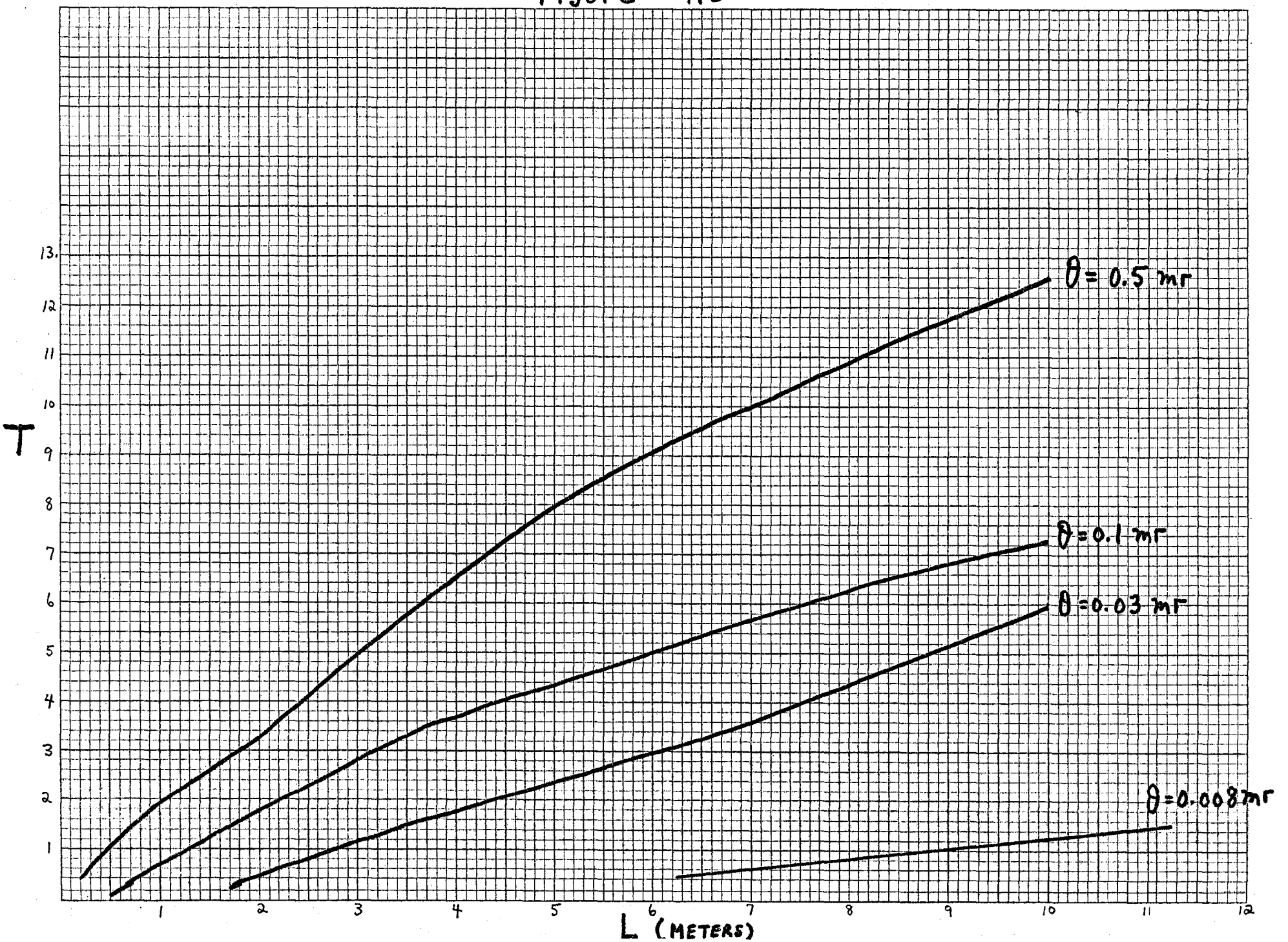

a
d
b
20
18
16
B(kg)
14
12
10
8
6
4
2
0.001
0.01
0.1
1.0
d(cm)
B vs H (pure iron)
B vs H (hot rolled steel)

figure A3


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