Fermi National Accelerator Laboratory

TM-1305

NCenter Wide Band Neutrino Beam

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I. Physical Description

This memo describes the physical properties of the currently operating N-Center wide band neutrino beam - commonly called the triplet train, following a past tradition of a triplet lens configuration. In reality, in order to gain a larger momentum acceptance and to minimize the angular divergence of the beam, a quadruplet beam (4 lenses) employing point-to-parallel optics at a central momentum of 300 GeV was built.

Figure 1 shows a simplified sketch of the beam as it is installed in enclosure NW1, as well as the previous switchyard enclosure, G2. As the primary proton beam enters G2, it is climbing up at an angle of 10mr. The NLAMS in G2 provide a split between beam to the NEast line (when off) and to the NCenter line when on, adding an additional 3mr of upward bend. Trims are located in the downstream end of G2 (NCØH and NCØV) in order to make small steering corrections to the beam as it enters NW1, some 500' further downstream. Because the NEast line does not contain any focussing elements until the downstream end of NW1, the

G2 quads Q120 and Q121 are set to provide a nearly parallel focus into NW1.

In NW1, the nine EPB dipoles comprising NC1DE remove the 13mr of upward bend and direct the beam onto a chord through the earth which uses the target location (Z=3040') and a point near the neutrino detectors (Z=8200') as its two end points. The trim NC1HR provides small horizontal steering corrections. The pretarget quads NC1Q1, NC1Q2A,B and NC1Q3 are set to provide a 2mm spot size on the neutrino production target NC1TGT. After the target, the train quads NC1Q4, NC1Q5, NC1Q6 and NC1Q7 (all 4Q120's) are set to provide point to parallel optics at a central design momentum of 300 GeV. Immediately following the target is a 12' long 6" x 6" water cooled collimator with a 3.5" x 1.5" (HXV) aperture to provide shielding for these downstream magnetic elements.

The primary protons which do not interact in the target are transported along with the secondary beam to a dump at the end of the decay pipe. Following the last magnetic element on the train is 250' of 12" diameter pipe which extends to the downstream end of NW1. Installed in the 6' diameter sewer pipe where past neutrino trains were housed is a 200' long vacuum train of 16" diameter pipe. At this point the beam enters the 30" diameter decay pipe which extends to a Z of 4800' where the hadron beam dumps are located. A detailed drawing of the train elements alone is given in Figure 2.

Beamline instrumentation includes SWICS (segmented wire ionization chambers) and wire SEMS (essentially SWICS which operate without a gas medium) to give information on primary beam steering and size (See Appendix I). In the decay pipe at a Z=4100' (the "expansion port") 2 devices give information about the secondary beam steering, a 7mm copper strip SWIC and a 16" diameter split plate ion chamber providing four signals - east, west, top and bottom. Located in the berm at Z locations of 5020', 5183', 5418' and 6232', respectively, are 6' x 6' copper strip swics (1.5" wide strips) used to measure the muon flux produced during the hadronic decays. Primary proton beam intensities are measured with 3 separate devices located in the upstream end of NW1; a SEM, a toroid and an RF cavity. Further information about the beam monitoring system can be found in Reference 1.

The NCenter beam is also used to provide a primary proton transport system for slow spill beam to the NWest production target located in the decay pipe at Z=4600'. In order to provide a reasonable spot size on target for this slow spill beam, the neutrino production target was made moveable, travelling in and out (a total travel of 3") in ≈ 1/2 second about each fast spill, using a gear linkage system driven by a Slo-syn motor mounted exterior to the radiation shielding. Figures 3A, B show the target construction and Appendix II gives details of the target readout. Different focusing conditions are necessary for fast and slow spill beams, so that quads NC1Q2A,B run at low currents for slow spill and pulse to a high level for each fast spill. In addition, because of the different trajectories followed by the fast and slow spills, steering correction magnets and a small wide aperture bending magnet located at the end of the train (NW1W) also change levels between slow and fast spills. Details on magnet currents are given in Appendix III.

The train is currently shielded to accept a flux of 10^{13} 800 GeV protons/min.[2]

II. Beam Properties

The wide band neutrino beam has no bending magnets after the target, so in principle it transports all momenta from 0 up to the primary proton momentum. Not all momenta have the same angular acceptance, however. We have chosen a central design momentum of 300 GeV, and used two programs to study the physical properties of the beam - DECAY TURTLE[3] and NUADA[4], both employing a particle production model based on data taken at CERN[5]. For DECAY TURTLE, we generated rays over a phase space of 6mr x 6mr, 90% $\Delta p/p$. The acceptance of the beam was a very slow function of proton spot size on target, out to a 6mm x 6mm spot. Figures 4 and 5 show the angular acceptance of the beam as a function of momentum bite for the horizontal and vertical planes, respectively. Figure 6 and 7 show the secondary beam divergence in the horizontal and vertical planes, respectively. Figures 8 and 9 show the spatial distribution of muons from π and k decay, respectively, in the first muon SWIC.

Neutrino fluxes and event rates are predicted using NUADA. Figures 10, 11 and 12 compare wide band beam neutrino fluxes and narrow band beam fluxes at primary proton energies of 800, 900 and 1000 GeV, respectively. Table I gives event rates in a 1m radius detector of mass 100 tons per 10^{13} protons on target for each of these different primary momenta. (It should be pointed out that recent measurements[6] have determined that additional berm shielding will be necessary for primary energies in excess of 800 GeV, probably in the form of a high Z material such as lead located early in the shield). Finally, Figure 13 shows neutrino and anti-neutrino event rates at 800 GeV in the wide band beam, for a 1.35m radius detector.

III. Acknowledgements

Putting this beamline together was an enormous effort and I would like to take this opportunity to name and thank several of the principal people involved - Herm Stredde, mechanical engineer; Leon Beverly, electrical engineer, Anthony Malensek, engineering physicist; Steve Butala, radiation safety; Don Carpenter and the Lab 7 staff, mechanical assembly; Fred Borcherding, neutrino monitoring instrumentation.

Table I

CC Neutrino and AntiNeutrino Event Rates/10^{13} protons in a 100 ton 1m Radius Detector as a Function of Primary Proton Energy.

Proton Energy	Neutrino Event Rate	Anti-Neutrino Event Rate
800 GeV	7.84	1.25
900 GeV	10.24	1.73
1000 GeV	12.75	2.28

References

1. F. Borcherding, "Neutrino Flux Monitoring", unpublished.

2. D. Cossairt, private communication.

3. DECAY TURTLE, D. Carey, 1982.

4. NUADA, D. Carey and V.F. White, 1975.

5. A. Malensek, FN-341, "Empirical Formula for Thick Target Production".

6. A. Malensek and L. Stutte, "A Study of the Neutrino Berm Integrity", in progress.

Figure Captions

1. Overview of enclosure NW1, which contains the neutrino beam, as well as the previous switchyard enclosure G2.

2. Detailed drawing of wide band beam elements.

3A.B. Neutrino production target construction.

4. Horizontal angular acceptance vs. momentum bite.

5. Vertical angular acceptance vs. momentum bite.

6. Horizontal beam divergence.

7. Vertical beam divergence.

8. Spatial distribution of Muons from π decay in the first muon swic.

9. Spatial distribution of muons from K decay in the first muon swic.

10. Wide band and narrow band neutrino beam fluxes at 800 GeV. (1m radius).

11. Wide band and narrow band neutrino beam fluxes at 900 GeV. (1m radius).

12. Wide Band and Narrow band neutrino beam fluxes at 1000 GeV. (1m radius).

13. Neutrino and Anti-Neutrino event rates at 800 GeV in the wide band beam. (1.35m radius).

Revised 3/15/85
January 8, 1985
Linda Stutte

APPENDIX 1

SWICS and Wire SEMS in NW1

The following beam position monitors will be present in enclosure NW1 for the upcoming run. All motions are in/out only, and should be on automatic timers to remove swics from the beam after 30 minutes. The wire sems (NC1WS1 and NC1WS3) are not moveable. SWICS NC1WC3 and NC1WC3A are attached to a single horizontal drive with a swic at each side of a blank space. Motion will be between NC1WC3 in and the blank space. NC1WC3A is to be considered a spare, which can be switched in instead of NC1WC3 remotely using a switch in the G3 blockhouse.

Device	Wire Spacing	Type
NØØWC1 (G2)	2mm	vacuum box style (VBS)
NC1WC1	0.5mm	VBS
NC1WC2	0.5mm	VBS
NC1WS1	0.5mm	Wire Sem
NC1WS3	0.5mm	Wire Sem
NC1WC3	0.5mm	Air swic
NC1WC3A	0.5mm	Air swic
NE1WC1	2mm	VBS
NE1WC2	0.5mm	VBS

LS:mnm
c: R. Sood/T. Murphy
G. Tassotto/A. Malensek
R. Trendler/D. Carpenter
V. Frohne/G. Koizumi
R. Stefanski

Revised March 15, 1985
Revised Feb. 12, 1985
Revised Jan. 21, 1985
January 7, 1985 -
Linda Stutte *Linda*

APPENDIX II

NC1TGT Target Motion

The NC beamline serves two functions in the coming run. One is to provide a high flux neutrino beam during fast spill(s) to the neutrino experiments located at the end of the berm. For this mode of operation the NW1 targt NC1TGT must be in the beam.

A second function of the NC beam is to provide slow spill test beam to users located in NWA. For most of the test beam users, a high quality, well focussed proton beam is needed to produce secondaries off the NW3 target. For this mode of operation, the NC1TGT target must be out of the beam.

In order to provide both modes of operation (out for slow, in for fast spill or in all the time), the following controls have been implemented.

There are 2 named devices which control the target motion. These are NC1TGTPLS ("pulsed") and NC1TGTSTA ("static").

NC1TGTPLS	IN	enables rapid cycling of the target in <u>and</u> out of the beam in a <u>total</u> time of ≈ 0.5 sec. The time(s) at which this motion commences is (are) selected using Ø91T timing module NC1TGTTIM. Each timing pulse should <u>precede</u> the fast spill time by 0.2795 sec.	0 = Out 15 = In
NC1TGTPLS	OUT	disables the rapid cycling mode and enables the static mode.	
NC1TGTSTA	IN	moves the target into the beam and it remains there until a futher command is issued (NC1TGTPLS must be out).	

NC1TGTSTA	OUT	removes the target from the beam and it remains there until a further command is issued (NC1TGTPLS must be out).

Timing module NC1TGTTIM controls the time at which the target is driven into the beam for pulsed operation and also selects times at which a sample and hold records the target position.

NC1TGTTIM.PHA = 5	Selects T5 phase offset
.OFF(0) .OFF(1) .OFF(2) .OFF(3)	should be set 0.2795 sec before each fast spill spike to commence target motion
.OFF(4) .OFF(5) .OFF(6) .OFF(7)	should be set to the time of fast spill for the sample and hold readouts

Readouts available are

NC1TGTL1 L2 L3 L4	LVDT readouts (voltage) for the fast spill	In = 10 Volts OUT = 0 volts
NCITGTIn1 IN2 IN3 IN4	Limit switch readouts for the fast spill	In = 0 volts OUT = 5 volts
NCITGT	LVDT readout (continuous)	

For most times, the target should be operating in a pulsed mode. During shutdowns, target pulsing should be disabled in order to prolong the life of this device.

As this device is complicated to operate and because incorrect operation may result in a substantial loss of beam time, it shall remain under the sole control of the beamline operators until further notice by me.

c: R. Sood/R. Trendler
D. Sorensen/V. Frohne/R. Stefanski
T. Murphy/A. Malensek/G. Koizumi

January 8, 1985
Revised 3/15/85
Linda Stutte

APPENDIX III

Operating Currents for NW1

Supply	Current(Amps)	Polarity
* NCØH	100	+ → east
* NCØV	100	+ → up
NC1Q1	78.6	H Focus
NC1Q2A	26.4 Slow	V Focus
NC1Q2B	71.6 Fast	V Focus
NC1Q3	47.9	V Focus
NCIDE	1206.8	down & east
* NC1HR	100	+ → east
* NC1VR	100	+ → up & west
NC1Q4	988.2	H Focus
NC1Q5	768.7	V Focus
NC1Q6	598.4	H Focus
NC1Q7	532.7	V Focus
NW1W	3320	West
* NEØH	100	+ → east
* NEØV	100	+ → up
NE1ED	1280.5	east & down
* NE1VR	100	+ → up & east
NEIDW	3377.4	down & west
* NE1H	100	+ → east
* NE1V	100	+ → up
* NE1Q1	100	H Focus
* NE1Q2	100	V Focus

1) Note: The stars (*) imply trims or quads whose running currents will vary. These values are for power tests only. When beam begins, start these at zero current.

2) Note: NC1Q2A and NC1Q2B should be power tested to their fast spill values.

3) Note: SWYD supplies not under Research Division control should have the following values:

Supply	Current(Amps)	Polarity
Q103	7.7	V Focus
Q120,120A	50.8	H Focus
Q121,121A	52.1	V Focus
HV120	82.7	Up & west
NLAM	1448.8	Up

LS:mnm

c: R. Sood/T. Murphy
L. Beverly/A. Malensek
R. Trendler/G. Koizumi
V. Frohne/S. Childress
R. Stefanski

G2 FIGURE 1 DEC 18 '84 LINDA

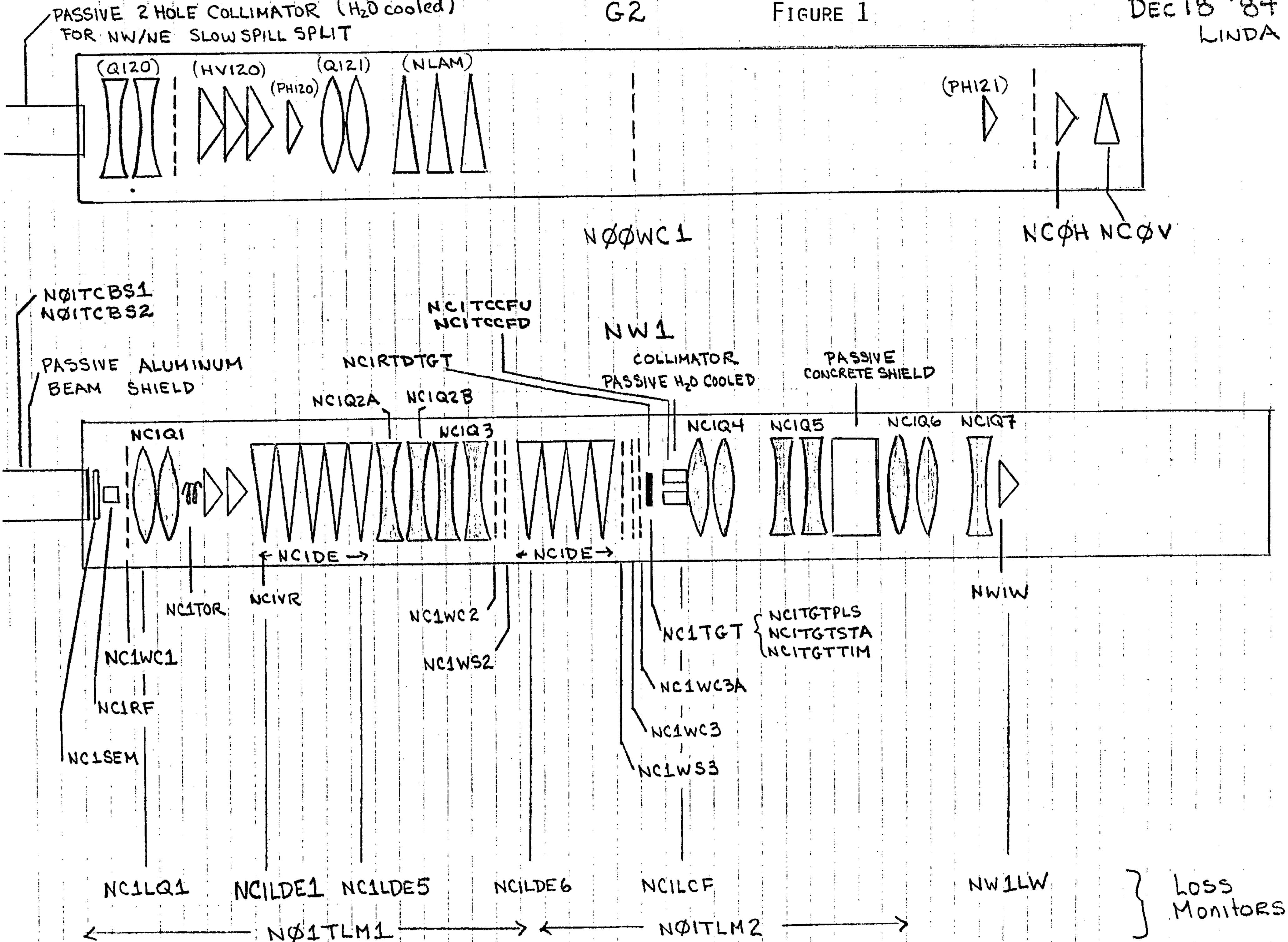
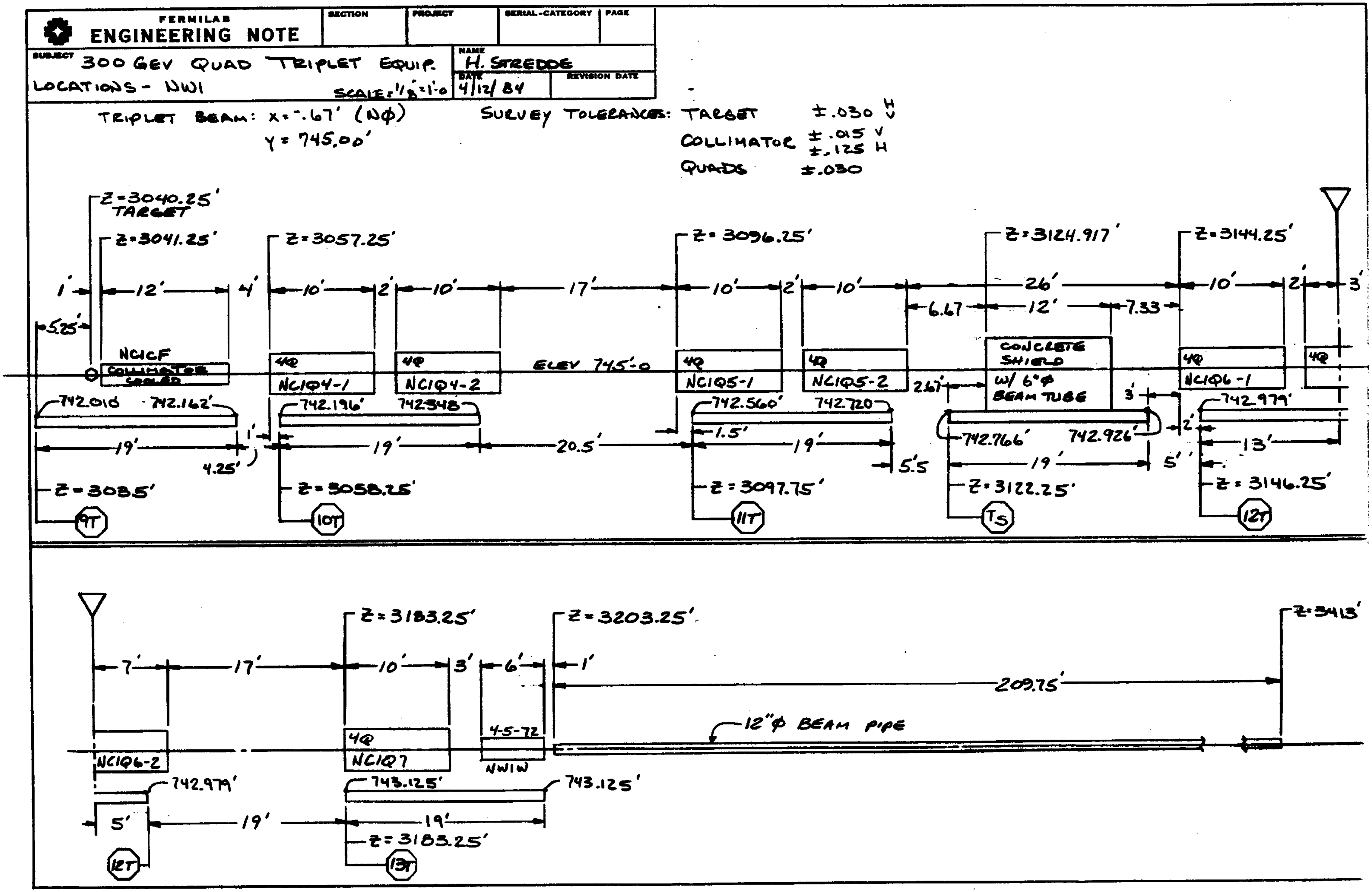


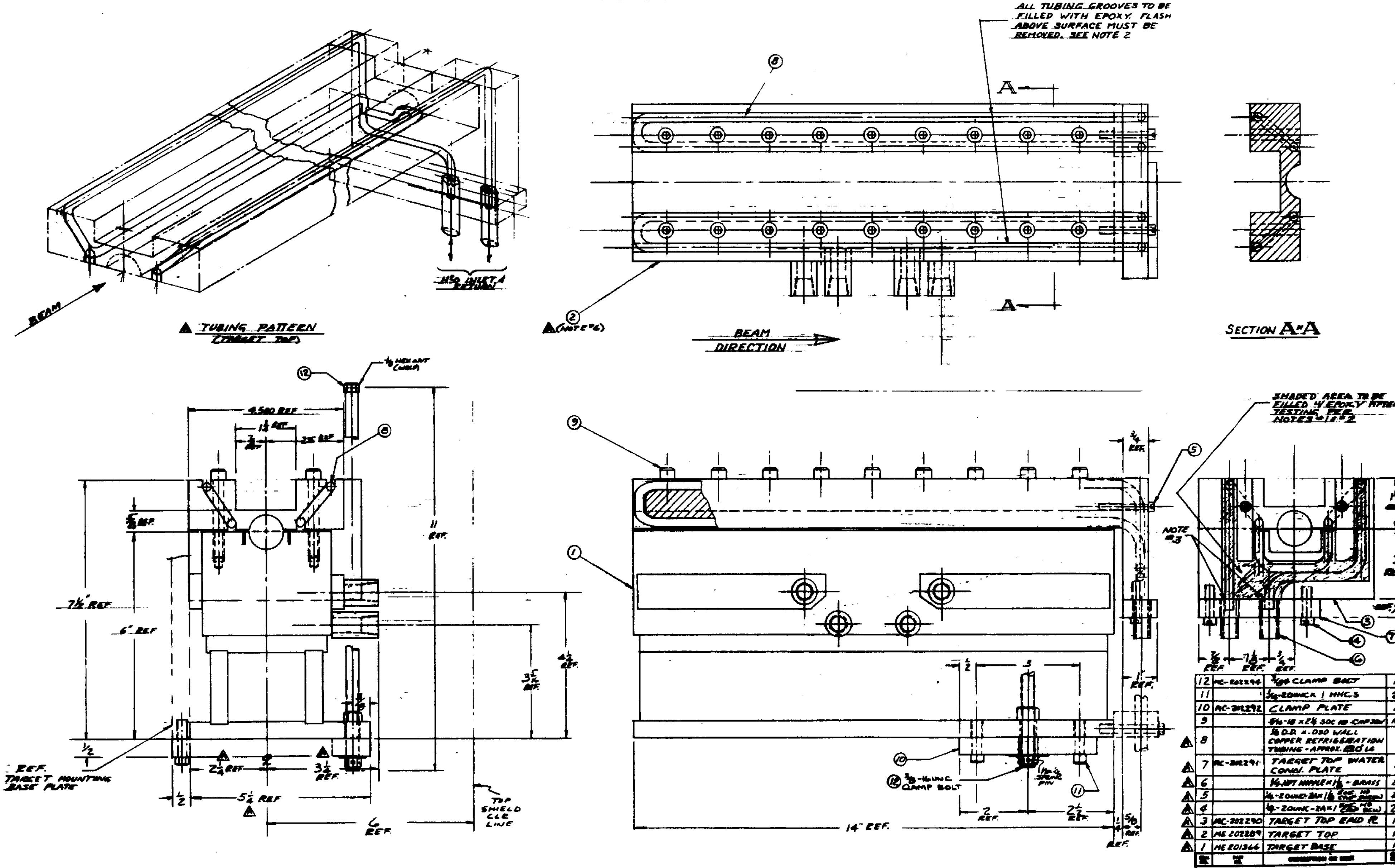
FIGURE 2



FERMILAB ENGINEERING NOTE
SECTION
PROJECT
SERIAL-CATEGORY
PAGE
SUBJECT 300 GEV QUAD TRIPLET EQUIP. LOCATIONS - NW1
SCALE: 1/8"=1'-0
NAME H. STREDDE
DATE 4/12/84
REVISION DATE
TRIPLET BEAM: X = -.67' (NØ) Y = 745.00'
SURVEY TOLERANCES: TARGET ±.030 H V
COLLIMATOR ±.015 V ±.125 H
QUADS ±.030
Z=3040.25' TARGET
Z=3041.25'
Z=3057.25'
Z=3096.25'
Z=3124.917'
Z=3144.25'
NC1CF COLLIMATOR SEALED
4Q NC1Q4-1
4Q NC1Q4-2
ELEV 745'-0
4Q NC1Q5-1
4Q NC1Q5-2
CONCRETE SHIELD W/ 6"Ø BEAM TUBE
4Q NC1Q6-1
742.010
742.162'
742.196'
742.348
742.560'
742.720
742.766'
742.926'
742.979'
Z=3035'
Z=3058.25'
Z=3097.75'
Z=3122.25'
Z=3146.25'
9T
10T
11T
TS
12T
Z=3183.25'
Z=3203.25'
Z=3413'
209.75'
12"Ø BEAM PIPE
NC1Q6-2
4Q NC1Q7
4-5-72 NW1W
742.979'
743.125'
743.125'
Z=3183.25'
12T
13T

REV.	DESCRIPTION
A	TARGET BASE & TOP REVISED FOR AS BUILT SURVEY

FIGURE 3A



NOTES:
1) THERE SHALL BE NO LEAKS, PRIOR TO POTTING THE COPPER LINES, AT A WATER PRESSURE TEST OF 300 PSI.
2) EPOXY CONSISTS OF: 50% HY-SOL + (75% RESIN AND 25% ACTIVATOR), AND 50% BORON NITRIDE.
3) EASY-FLO SILVER SOLDER #35 OR EQUIV.
4) PART MD-201368 DISCONTINUED (NOT USED)
5) FOR PIPING ASSY SEE SHEET 2 OF 2
6) ITEM #2 WAS ME-201367 BEFORE REV. "A"

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY
12	MC-202294	1/2" CLAMP BOLT	1
11		1/4-20UNC x 1 HHCS	2
10	MC-202292	CLAMP PLATE	1
9		5/16-18 x 2 1/4 SOC HD CAP SCR	18
8		1/4 O.D. x .030 WALL COPPER REFRIGERATION TUBING - APPROX. 80" LG	
7	MC-202291	TARGET TOP WATER CONN. PLATE	1
6		1/4 NPT NIPPLE [illegible] - BRASS	2
5		1/4-20UNC-2A x 1 [illegible]	2
4		1/4-20UNC-2A x 1 [illegible]	2
3	MC-202290	TARGET TOP END PL	1
2	ME 202289	TARGET TOP	1
1	ME 201366	TARGET BASE	1

DRAWN: B. OUDT
CHECKED: J. BORCH
9205.050-ME 202016
ALUMINUM & NOTED

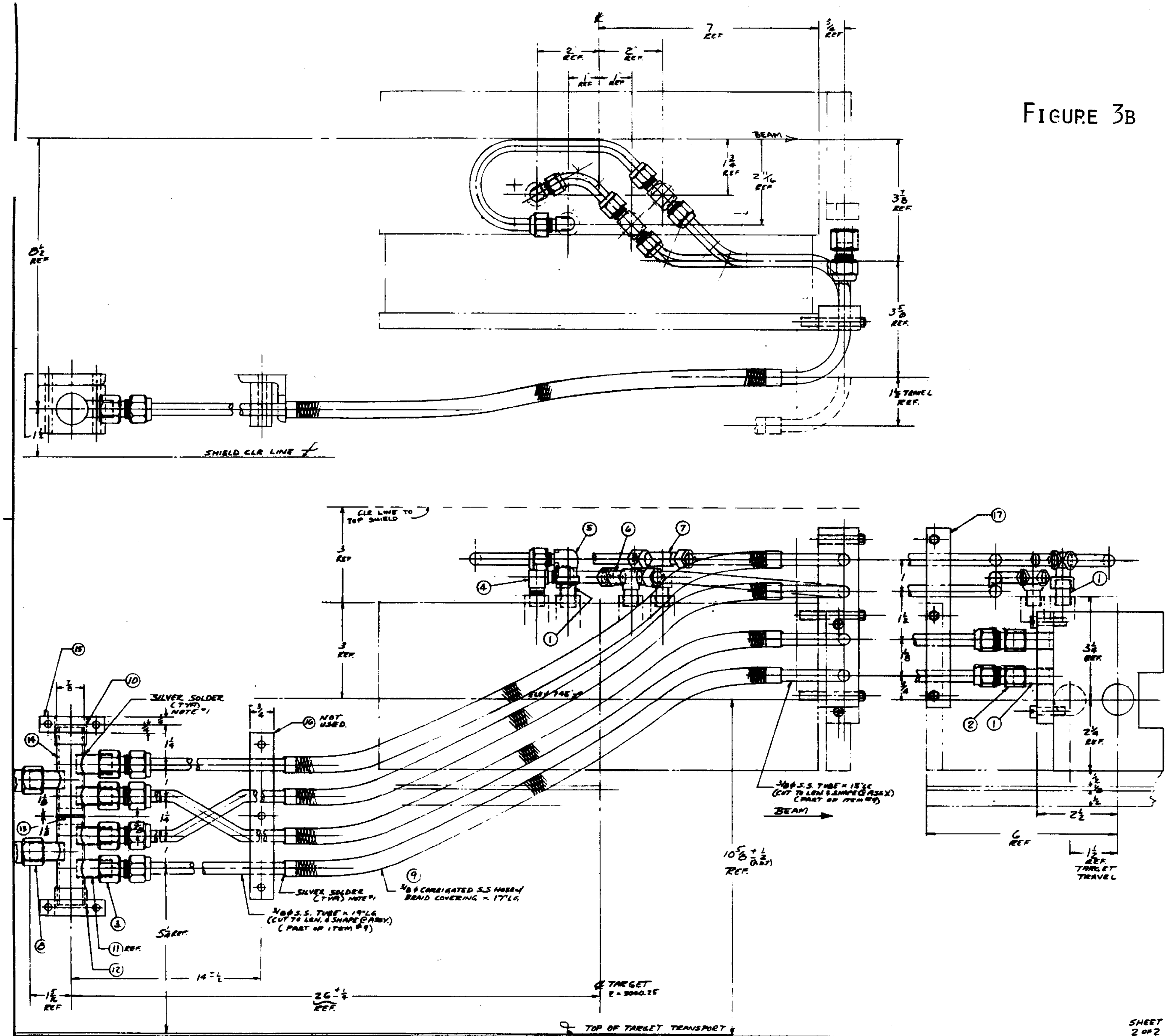
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

TARGET ASSY, 750 GEV ALUMINUM WATER COOLED NEUTRINO SECTION (4T)

SCALE: FULL
9205.050-ME 201236 A

SHEET 1 OF 2

FIGURE 3B



ITEM	PART NO.	DESCRIPTION	QTY
17		CLAMP - ALUM.	1
16		CLAMP - ALUM.	1
15		CLAMP - ALUM.	2
14		7/8 O.D. x [illegible] WALL x 2 3/4 LG TUBE [illegible]	2
13		11/16 Ø BRONZE ROD x 1/2 LG.	1
12		3/8 TUBE CAP - COPPER	[illegible]
11	[illegible]	1/8 NPT PIPE NIPPLE x 1/2	6
10		MANIFOLD (COPPER)	1
9		3/8 Ø S.S. CORRIGATED HOSE ASSEM	4
8	SNAP-TITE TYPE "H"	3/8 BRASS QUICK DISC. COUP. w/ 3/8 FE. NPT - [illegible]	2
7	SWAGELOK B-600-3TTF	3/8 FE. TEE - 1/4 NPT	1
6	SWAGELOK B-600-	3/8 MA. TEE - 1/4 NPT	1
5	SWAGELOK B-600-8-4	3/8 FE ELBOW - 1/4 NPT	1
4	SWAGELOK B-600-2-4	3/8 MA. ELBOW - 1/4 NPT	1
3	SWAGELOK B-600-7-6	3/8 FE. CONN - 3/8 NPT	4
2	SWAGELOK B-600-7-4	3/8 FE. CONN - 1/4 NPT	2
1	[illegible]	1/4 NPT PIPE NIPPLE x 1 1/8	4

H. STREADE
R. PAULUS

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

TARGET WATER PIPING ASSEMBLY
NEUTRINO - QUAD - TRIPLET - ENCL. NW1
R/D MECH. DEPT. (9T)

SHEET 2 OF 2 | FULL | 9205.050-ME-201236

```
HISTOGRAM NO  2
HORIZONTAL AXIS   X' IN MR        FOR RAYS            0.000 FT   FROM THE TARGET
VERTICAL AXIS   OP/P IN PC        FOR RAYS            0.000 FT   FROM THE TARGET, RAYS FLAG AT       160.00

                      -6.000    -3.000     -.000     3.000     6.000 TOTALS
                       I**---**---**---**---**---**---**---**---**I--------
-100.000 TO  -95.000   I                                        I        0
 -95.000 TO  -90.000   I                                        I        0
 -90.000 TO  -85.000   I                                        I        0
 -85.000 TO  -80.000   I                                        I        0
 -80.000 TO  -75.000   I                                        I        C
 -75.000 TO  -70.000   I                  1 3 1                 I        5
 -70.000 TO  -65.000   I               2 1 211141               I       13
 -65.000 TO  -60.000   I           2132523331153 1  31          I       39
 -60.000 TO  -55.000   I    1 123321658345 4134522321 211 1 11  I       78
 -55.000 TO  -50.000   I  2 1121223231727367651634662131222  111I      105
 -50.000 TO  -45.000   I 1 13133 222655166D578656B32524 23132   I      135
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 -40.000 TO  -35.000   I   11 21 1235683F5FH8H8F975654111211 1  I      177
 -35.000 TO  -30.000   I      2 41246564C899GI47A77443 1        I      155
 -30.000 TO  -25.000   I       1 3243BDC7ABHEBFE7663241 1       I      175
 -25.000 TO  -20.000   I        1 1 4369AGACA8B5752312          I      126
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 -15.000 TO  -10.000   I            2353879B57A513341           I       87
 -10.000 TO   -5.000   I            42 87F69C653A51             I       93
  -5.000 TO     .000   I              16548676632322            I       64
    .000 TO    5.000   I              37137A83782113            I       64
   5.000 TO   10.000   I             1 21788CA917 1             I       67
  10.000 TO   15.000   I              1366754944521             I       57
  15.000 TO   20.000   I              133349661421              I       43
  20.000 TO   25.000   I               124555531 1              I       32
  25.000 TO   30.000   I              1 1263346411              I       32
  30.000 TO   35.000   I               1 424592 11              I       29
  35.000 TO   40.000   I                2 45524                 I       22
  40.000 TO   45.000   I                113413122               I       18
  45.000 TO   50.000   I              1 21275 21                I       21
  50.000 TO   55.000   I                  12131                 I        8
  55.000 TO   60.000   I                 4 1 1  1               I        7
  60.000 TO   65.000   I                  1111                  I        4
  65.000 TO   70.000   I                 2122  1                I        8
  70.000 TO   75.000   I               1    21 1                I        5
  75.000 TO   80.000   I                  1 2  1                I        4
  80.000 TO   85.000   I                1 11 1                  I        4
  85.000 TO   90.000   I                   1                    I        1
  90.000 TO   95.000   I                                        I        0
  95.000 TO  100.000   I                                        I        0
                       I**---**---**---**---**---**---**---**---**I--------
                       I                                        I
                       I                                        I
                       I                11111111                I
                       I      1111125588236876329754221   1     I
               TOTALS  I 1206624363553859659975841403905690543311 I     1985

        TOTAL NUMBER OF ENTRIES =        1985 INCLUDING UNDERFLOW AND OVERFLOW AS FOLLOWS

                                 UNDERFLOW        OVERFLOW
                   ACROSS            0               0
                   DOWN              0               0

HISTOGRAM NO  2
HORIZONTAL AXIS   X' IN MR        FOR RAYS            0.000 FT   FROM THE TARGET
VERTICAL AXIS   OP/P IN PC        FOR RAYS            0.000 FT   FROM THE TARGET, RAYS FLAG AT       160.00
```

FIGURE 4

FIGURE 4

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HISTOGRAM NO  3
HORIZONTAL AXIS    Y' IN MR         FOR RAYS              0.000 FT    FROM THE TARGET
VERTICAL AXIS    DP/P IN PC         FOR RAYS              0.000 FT    FROM THE TARGET, RAYS FLAG AT        16C

                          -6.000    -3.000     -.000     3.000     6.000 TOTALS
                           I**---**---**---**---**---**---**---**---**I--------
-100.000 TO -95.000 I                                              I     0
 -95.000 TO -90.000 I                                              I     0
 -90.000 TO -85.000 I                                              I     0
 -85.000 TO -80.000 I                                              I     0
 -80.000 TO -75.000 I                                              I     0
 -75.000 TO -70.000 I                   23                         I     5
 -70.000 TO -65.000 I                   85                         I    13
 -65.000 TO -60.000 I                  1LE3                        I    39
 -60.000 TO -55.000 I                  GNRC                        I    78
 -55.000 TO -50.000 I                 5LOMLC                       I   105
 -50.000 TO -45.000 I               59IMPIKB52                     I   135
 -45.000 TO -40.000 I              8JFIJHVUICG1                    I   198
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 -35.000 TO -30.000 I              3CDIEJHIG7981                   I   155
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 -25.000 TO -20.000 I             1398BFIJAAD342                   I   126
 -20.000 TO -15.000 I             1397DKAABA5532                   I   109
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 -10.000 TO  -5.000 I              367AADBA86333                   I    93
  -5.000 TO    .000 I             1 2286D7832741                   I    64
    .000 TO   5.000 I              172577BC5421                    I    64
   5.000 TO  10.000 I              22667B8A5631                    I    67
  10.000 TO  15.000 I              12455AG552 2                    I    57
  15.000 TO  20.000 I              1131854A343                     I    43
  20.000 TO  25.000 I              1118374421                      I    32
  25.000 TO  30.000 I                42255464                      I    32
  30.000 TO  35.000 I                245627 21                     I    29
  35.000 TO  40.000 I               1433442 1                      I    22
  40.000 TO  45.000 I                3221352                       I    18
  45.000 TO  50.000 I                 265431                       I    21
  50.000 TO  55.000 I               11   111111                    I     8
  55.000 TO  60.000 I                3    22                       I     7
  60.000 TO  65.000 I                1  2    1                     I     4
  65.000 TO  70.000 I                1111 31                       I     8
  70.000 TO  75.000 I                  11 12                       I     5
  75.000 TO  80.000 I                   2 2                        I     4
  80.000 TO  85.000 I                   1111                       I     4
  85.000 TO  90.000 I                      1                       I     1
  90.000 TO  95.000 I                                              I     0
  95.000 TO 100.000 I                                              I     0
                    I**---**---**---**---**---**---**---**---**I--------
                    I                                              I
                    I                                              I
                    I               111233211                      I
                    I              413740055284                    I
            TOTALS  I 00000000000004033727277103900000000000000 I   1985
      TOTAL NUMBER OF ENTRIES =        1985 INCLUDING UNDERFLOW AND OVERFLOW AS FOLLOWS

                              UNDERFLOW        OVERFLOW
               ACROSS             0                0
               DOWN               0                0
```

FIGURE 5


```
HISTOGRAM NO  3
HORIZONTAL AXIS    Y' IN MR         FOR RAYS              0.000 FT    FROM THE TARGET
VERTICAL AXIS    DP/P IN PC         FOR RAYS              0.000 FT    FROM THE TARGET, RAYS FLAG AT        16
```


FIGURE 5

```
HISTOGRAM NO 13
DISTRIBUTION OF    X' IN MR        FOR RAYS          160.000 FT    FROM THE TARGET

          INTERVAL                                    SCALE FACTOR.. 100 X'S EQUAL    479 ENTRIES

LESS THAN        -5.000        8   X

   -5.000 TO     -4.750        0
   -4.750 TO     -4.500        1
   -4.500 TO     -4.250        4
   -4.250 TO     -4.000        2
   -4.000 TO     -3.750        2
   -3.750 TO     -3.500        0
   -3.500 TO     -3.250        4
   -3.250 TO     -3.000        2
   -3.000 TO     -2.750        2
   -2.750 TO     -2.500        3
   -2.500 TO     -2.250        4
   -2.250 TO     -2.000       12   XX
   -2.000 TO     -1.750       10   XX
   -1.750 TO     -1.500       21   XXXX
   -1.500 TO     -1.250       31   XXXXXX
   -1.250 TO     -1.000       43   XXXXXXXX
   -1.000 TO      -.750       74   XXXXXXXXXXXXXXX
    -.750 TO      -.500      104   XXXXXXXXXXXXXXXXXXXXX
    -.500 TO      -.250      175   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    -.250 TO      0.000      477   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
    0.000 TO       .250      479   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .250 TO       .500      188   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .500 TO       .750      133   XXXXXXXXXXXXXXXXXXXXXXXXXXX
     .750 TO      1.000       61   XXXXXXXXXXXX
    1.000 TO      1.250       47   XXXXXXXXX
    1.250 TO      1.500       30   XXXXXX
    1.500 TO      1.750       17   XXX
    1.750 TO      2.000       12   XX
    2.000 TO      2.250        7   X
    2.250 TO      2.500        7   X
    2.500 TO      2.750        4
    2.750 TO      3.000        1
    3.000 TO      3.250        3
    3.250 TO      3.500        2
    3.500 TO      3.750        2
    3.750 TO      4.000        4
    4.000 TO      4.250        0
    4.250 TO      4.500        0
    4.500 TO      4.750        1
    4.750 TO      5.000        0

GREATER THAN      5.000        8   X

        TOTAL NUMBER OF ENTRIES =       1985      INCLUDING UNDERFLOW AND OVERFLOW
        CENTER =    -.007   RMS HALF WIDTH =    1.006

HISTOGRAM NO 13
DISTRIBUTION OF    X' IN MR        FOR RAYS          160.000 FT    FROM THE TARGET
```

FIGURE 6

FIGURE 6

ISTOGRAM NO 14
ISTRIBUTION OF Y' IN MR FOR RAYS 160.000 FT FROM THE TARGET

SCALE FACTOR.. 100 X'S EQUAL 458 ENTRIES

INTERVAL			
ESS THAN		-5.000	0
-5.000	TO	-4.750	0
-4.750	TO	-4.500	0
-4.500	TO	-4.250	0
-4.250	TO	-4.000	0
-4.000	TO	-3.750	0
-3.750	TO	-3.500	0
-3.500	TO	-3.250	0
-3.250	TO	-3.000	0
-3.000	TO	-2.750	0
-2.750	TO	-2.500	0
-2.500	TO	-2.250	0
-2.250	TO	-2.000	4
-2.000	TO	-1.750	15
-1.750	TO	-1.500	35
-1.500	TO	-1.250	37
-1.250	TO	-1.000	38
-1.000	TO	-.750	92
-.750	TO	-.500	118
-.500	TO	-.250	198
-.250	TO	0.000	458
0.000	TO	.250	439
.250	TO	.500	185
.500	TO	.750	132
.750	TO	1.000	69
1.000	TO	1.250	62
1.250	TO	1.500	45
1.500	TO	1.750	28
1.750	TO	2.000	22
2.000	TO	2.250	6
2.250	TO	2.500	0
2.500	TO	2.750	0
2.750	TO	3.000	0
3.000	TO	3.250	0
3.250	TO	3.500	0
3.500	TO	3.750	0
3.750	TO	4.000	0
4.000	TO	4.250	0
4.250	TO	4.500	0
4.500	TO	4.750	0
4.750	TO	5.000	0
REATER THAN		5.000	0

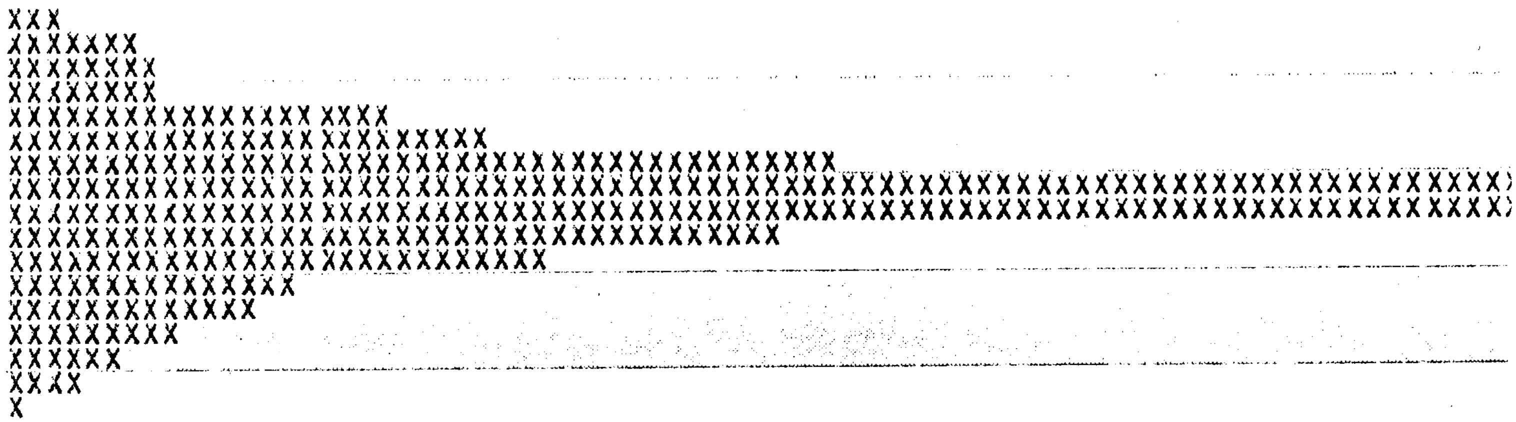


FIGURE 7

TOTAL NUMBER OF ENTRIES = 1985 INCLUDING UNDERFLOW AND OVERFLOW
CENTER = .016 RMS HALF WIDTH = .673

ISTOGRAM NO 14
ISTRIBUTION OF Y' IN MR FOR RAYS 160.000 FT FROM THE TARGET

FIGURE 7

```
HISTOGRAM NO 38
HORIZONTAL AXIS      X IN IN        FOR RAYS          1820.000 FT    FROM THE TARGET
VERTICAL AXIS        Y IN IN        FOR RAYS          1820.000 FT    FROM THE TARGET

                   -100.000   -50.000     -.000    50.000   100.000 TOTALS
                      I**---**---**---**---**---**---**---**---**---**I--------
-100.000 TO  -95.000 I          1                                     I     1
 -95.000 TO  -90.000 I                                                I     0
 -90.000 TO  -85.000 I                                                I     0
 -85.000 TO  -80.000 I                                                I     0
 -80.000 TO  -75.000 I                                                I     0
 -75.000 TO  -70.000 I                                                I     0
 -70.000 TO  -65.000 I                                                I     0
 -65.000 TO  -60.000 I                                                I     0
 -60.000 TO  -55.000 I                                                I     0
 -55.000 TO  -50.000 I                 1                              I     1
 -50.000 TO  -45.000 I   1                                            I     1
 -45.000 TO  -40.000 I                                                I     0
 -40.000 TO  -35.000 I              1      1                          I     2
 -35.000 TO  -30.000 I            1          1                        I     2
 -30.000 TO  -25.000 I             1 1 11111                          I     7
 -25.000 TO  -20.000 I              1 2 242111     11                 I    16
 -20.000 TO  -15.000 I             11114774213                        I    32
 -15.000 TO  -10.000 I     1 1    1124376D9424                        I    58
 -10.000 TO   -5.000 I 1           232 28IJ795            1           I    80
  -5.000 TO     .000 I        1 1 11123E$$E8212    11                 I   141
    .000 TO    5.000 I        1    2134K$$G3462 2 1                   I   154
   5.000 TO   10.000 I  1         214255IH394123                      I    77
  10.000 TO   15.000 I 11       211 2119AF82121     1                 I    59
  15.000 TO   20.000 I              1 283624  1                       I    30
  20.000 TO   25.000 I          1  1 123243121        1               I    22
  25.000 TO   30.000 I 1                13231 1                       I    12
  30.000 TO   35.000 I          1 1          21                       I     5
  35.000 TO   40.000 I                                                I     0
  40.000 TO   45.000 I     1       1        1                         I     3
  45.000 TO   50.000 I                                                I     0
  50.000 TO   55.000 I                  1                             I     1
  55.000 TO   60.000 I                                                I     0
  60.000 TO   65.000 I              1     1                           I     2
  65.000 TO   70.000 I                                                I     0
  70.000 TO   75.000 I          1                                     I     1
  75.000 TO   80.000 I                                                I     0
  80.000 TO   85.000 I                                                I     0
  85.000 TO   90.000 I                                                I     0
  90.000 TO   95.000 I                              1                 I     1
  95.000 TO  100.000 I                                                I     0
                      I**---**---**---**---**---**---**---**---**---**I--------
                      I                                                I
                      I                                                I
                      I                  11                            I
                      I             11128677422                        I
            TOTALS    I 03201020120719275693315609 3203302000100 0 I      708

      TOTAL NUMBER OF ENTRIES =        995 INCLUDING UNDERFLOW AND OVERFLOW AS FOLLOWS

                            UNDERFLOW       OVERFLOW
                  ACROSS       133             143
                  DOWN           4               7
```

FIGURE 8


```
HISTOGRAM NO 38
HORIZONTAL AXIS      X IN IN        FOR RAYS          1820.000 FT    FROM THE TARGET
VERTICAL AXIS        Y IN IN        FOR RAYS          1820.000 FT    FROM THE TARGET
```

FIGURE 8

```
HISTOGRAM NO 38
HORIZONTAL AXIS      X IN IN        FOR RAYS        1820.000 FT    FROM THE TARGET
VERTICAL AXIS        Y IN IN        FOR RAYS        1820.000 FT    FROM THE TARGET

                          -100.000   -50.000    -.000    50.000   100.000 TOTALS
                          I**---**---**---**---**---**---**---**-**I--------
-100.000 TO  -95.000 I                      1                 I       1
 -95.000 TO  -90.000 I                                        I       0
 -90.000 TO  -85.000 I             1                          I       1
 -85.000 TO  -80.000 I                 1       1     1        I       3
 -80.000 TO  -75.000 I                    1         1         I       2
 -75.000 TO  -70.000 I                        1           1   I       2
 -70.000 TO  -65.000 I                                        I       0
 -65.000 TO  -60.000 I      1             1 1    1            I       4
 -60.000 TO  -55.000 I                 1      1   1           I       3
 -55.000 TO  -50.000 I            2         1 2          1    I       6
 -50.000 TO  -45.000 I       1     1   1 1111                 I       7
 -45.000 TO  -40.000 I          1   1    1                    I       3
 -40.000 TO  -35.000 I      1             1       1       1   I       4
 -35.000 TO  -30.000 I       1   1 111 1   12  1 11  11       I      14
 -30.000 TO  -25.000 I      1    1  1  11 11121   1     2     I      14
 -25.000 TO  -20.000 I       1 1 1 14221 122212 21            I      26
 -20.000 TO  -15.000 I        1    1 1  1532112  2 1         1I      22
 -15.000 TO  -10.000 I         1   2 425233522  1             I      32
 -10.000 TO   -5.000 I  1     1     51 335A46121111     2 1   I      49
  -5.000 TO     .000 I 2           221125CA 33 22    2        I      49
    .000 TO    5.000 I          1  11 286E84422111    1       I      57
   5.000 TO   10.000 I      1    11  132344734   11 1         I      37
  10.000 TO   15.000 I     11   1    21 3751 21 1 111   1     I      30
  15.000 TO   20.000 I         1    1  221  3  2              I      12
  20.000 TO   25.000 I   1      1211 12  1311        1        I      16
  25.000 TO   30.000 I   1  1    1 1   121  1   1 1           I      11
  30.000 TO   35.000 I      111    1 1 11 1 1  1 1  1         I      12
  35.000 TO   40.000 I  1                 1  1 11  11   1     I       8
  40.000 TO   45.000 I                  1   3 1               I       5
  45.000 TO   50.000 I  11                                    I       2
  50.000 TO   55.000 I 1     1   1       1 1 1  2             I       8
  55.000 TO   60.000 I              11  1 1                   I       4
  60.000 TO   65.000 I           2      1                     I       3
  65.000 TO   70.000 I                   1  1  1              I       3
  70.000 TO   75.000 I1                           1           I       2
  75.000 TO   80.000 I                            1           I       1
  80.000 TO   85.000 I        1  1              1             I       3
  85.000 TO   90.000 I                 1      1               I       2
  90.000 TO   95.000 I          1                             I       1
  95.000 TO  100.000 I        1                    1          I       2
                     I**---**---**---**---**---**---**---**-**I--------
                     I                                        I
                     I                                        I
                     I                                        I
                     I           1 11113355332111 1           I
              TOTALS I 1333017553514376312860806139045520613001 I     461

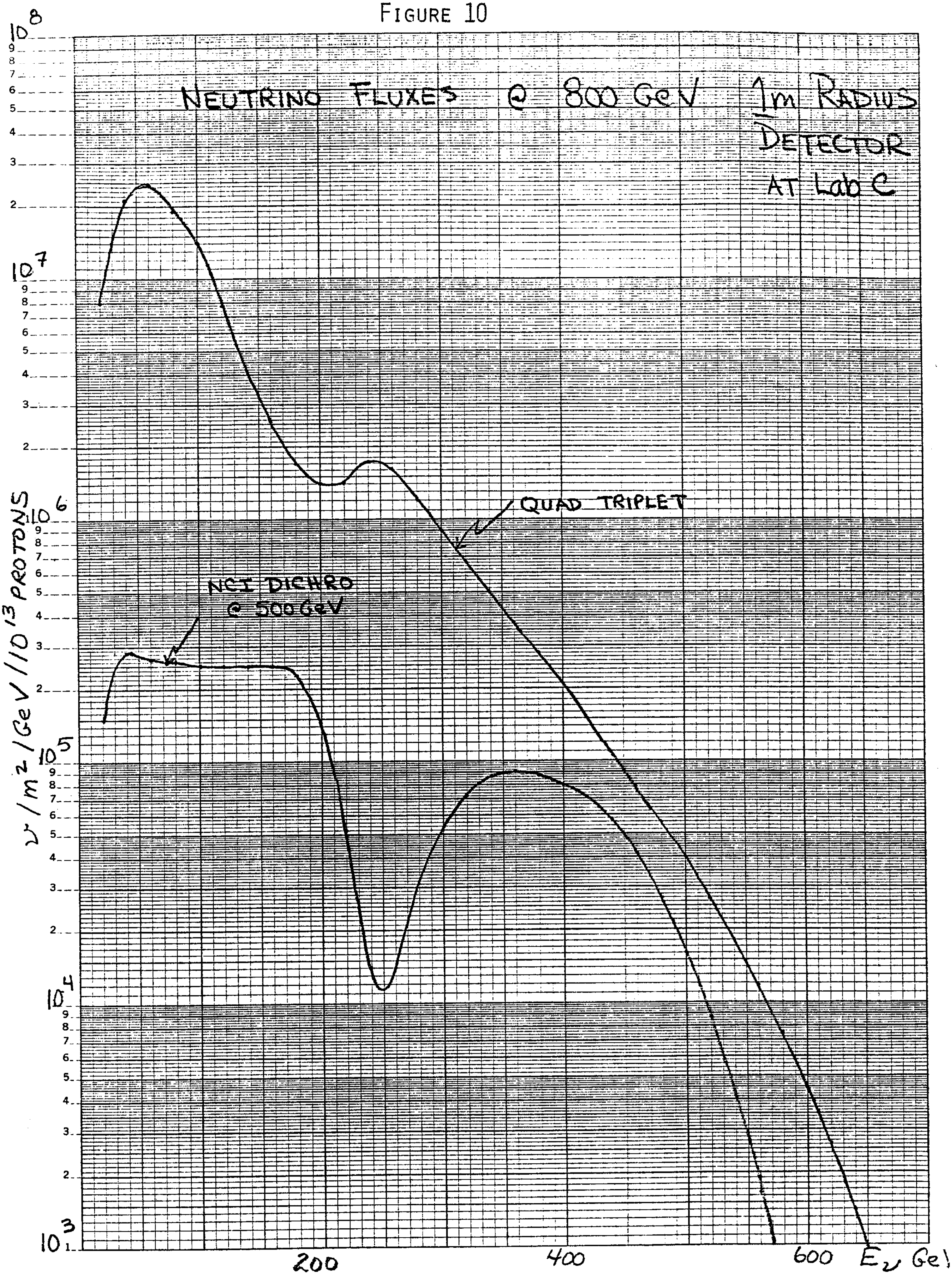
        TOTAL NUMBER OF ENTRIES =        710 INCLUDING UNDERFLOW AND OVERFLOW AS FOLLOWS

                                 UNDERFLOW        OVERFLOW
                       ACROSS       116             113
                       DOWN           9              11

HISTOGRAM NO 38
HORIZONTAL AXIS      X IN IN        FOR RAYS        1820.000 FT    FROM THE TARGET
VERTICAL AXIS        Y IN IN        FOR RAYS        1820.000 FT    FROM THE TARGET
```

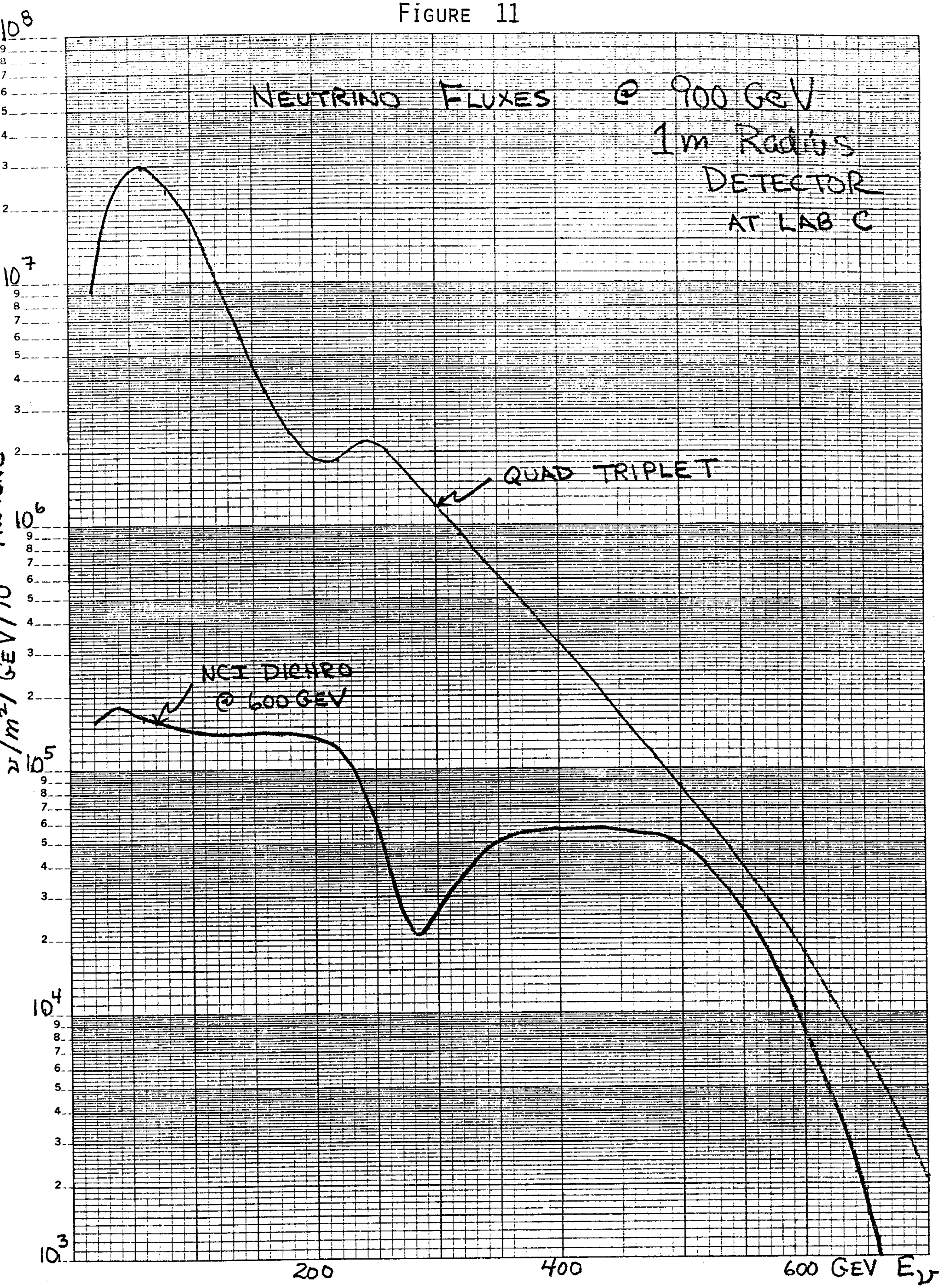
FIGURE 9

FIGURE 10



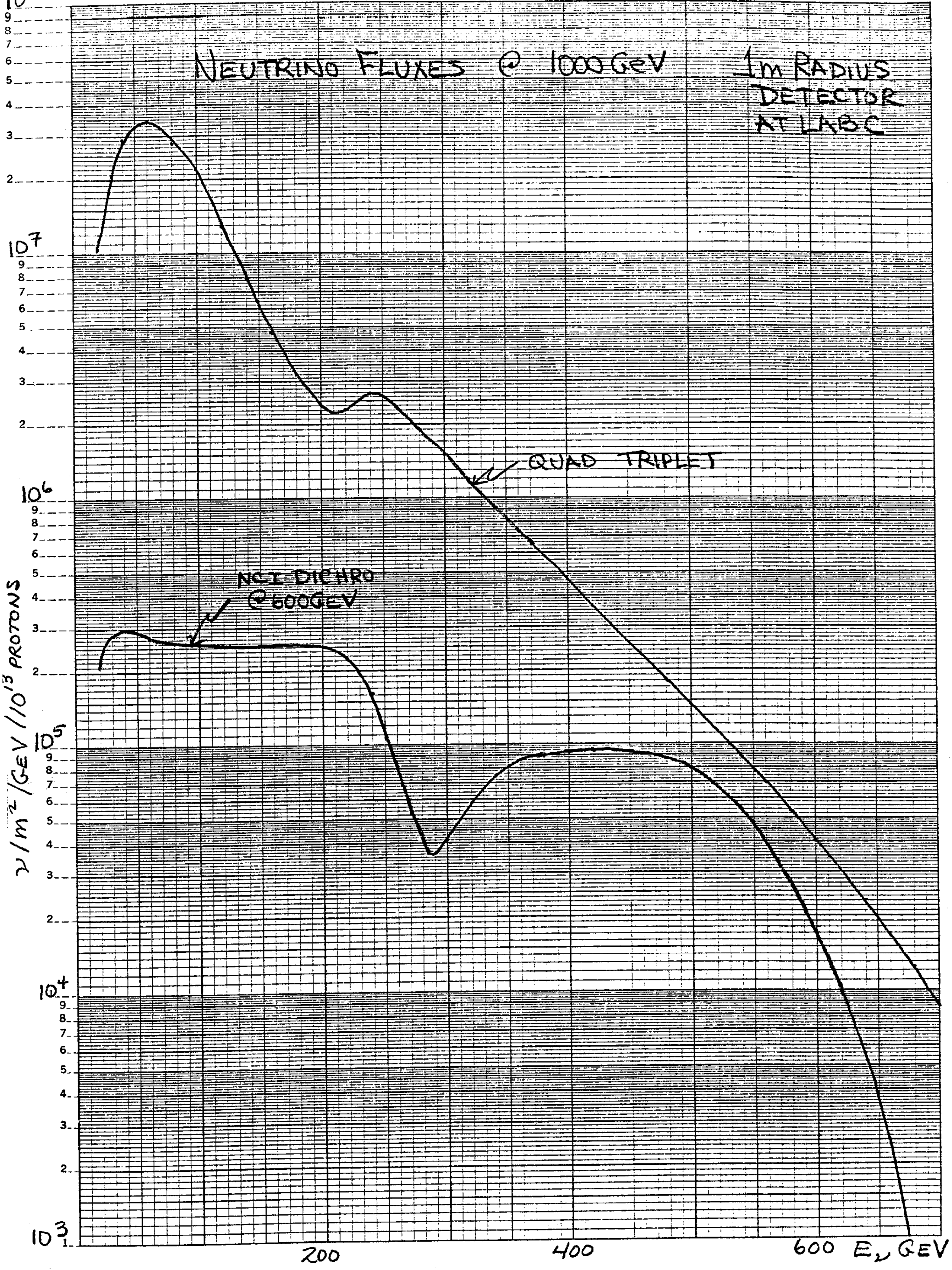
NEUTRINO FLUXES @ 800 GeV 1m RADIUS DETECTOR AT Lab C
QUAD TRIPLET
NCI DICHRO @ 500 GeV
ν / m² / GeV / 10¹³ PROTONS
E_ν GeV
200
400
600
10⁸
10⁷
10⁶
10⁵
10⁴
10³

FIGURE 11



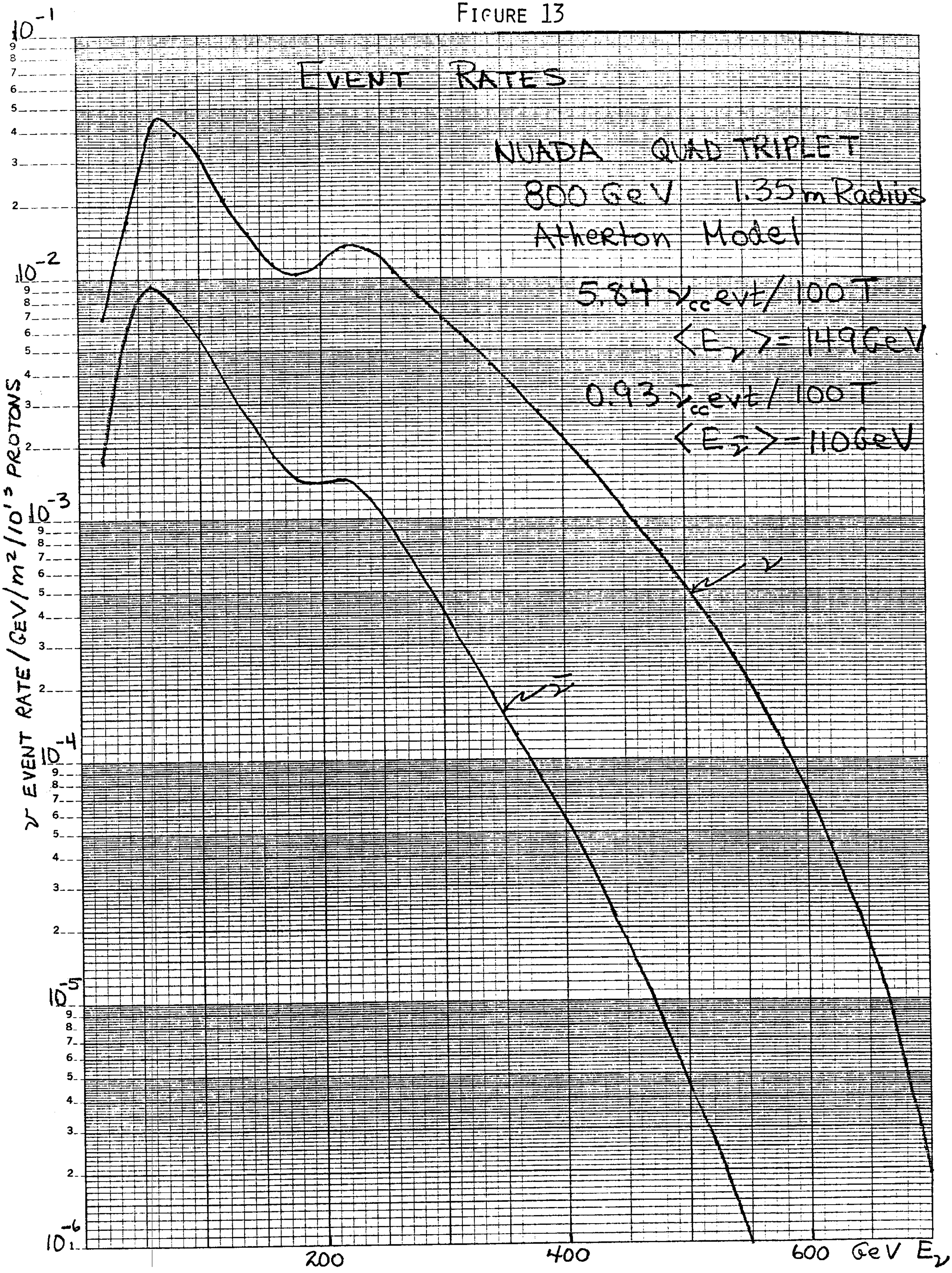
NEUTRINO FLUXES @ 900 GeV
1m Radius
DETECTOR
AT LAB C
QUAD TRIPLET
NCI DICHRO
@ 600 GEV
ν/m²/ GEV/10¹³ PROTONS
10⁸
10⁷
10⁶
10⁵
10⁴
10³
200
400
600 GEV
E_ν

FIGURE 12



NEUTRINO FLUXES @ 1000 GeV
1m RADIUS DETECTOR AT LABC
QUAD TRIPLET
NCI DICHRO @600GEV
ν/m²/GEV/10¹³ PROTONS
E_ν GEV
10⁸
10⁷
10⁶
10⁵
10⁴
10³
200
400
600

FIGURE 13


EVENT RATES
NUADA QUAD TRIPLET
800 GeV 1.35 m Radius
Atherton Model
5.84 ν_{cc} evt/100T
$\langle E_\nu \rangle$ = 149 GeV
0.93 $\bar{\nu}_{cc}$ evt/100T
$\langle E_{\bar{\nu}} \rangle$ = 110 GeV
ν
$\bar{\nu}$
ν EVENT RATE / GEV/m²/10¹³ PROTONS
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
200
400
600 GeV E_ν