Fermi National Accelerator Laboratory

FN-282
2600.000

(Report presented at Fermilab
Bubble Chamber Synposium -
September 18-19, 1975)

15-FOOT BUBBLE CHAMBER CHARACTERISTICS

Presented by F. R. Huson

P. Berge, D. Bogert, R. Hanft, R. Harris,
S. Kahn, J. Lannutti, and T. Murphy

September 1975

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

15-FOOT BUBBLE CHAMBER CHARACTERISTICS

Physical Properties

See attached report from "Bubble Chamber Working Group."

Measurement Errors

There have been 3 types of measurements done at Fermilab to study measurement errors in the chamber in hadron film.

Fiducial Measurements to determine reproducibility of fiducials and optical constants. Reproducibility of fiducials is found to be 4μ on film. Variation throughout an exposure is less than or equal to 5μ. Distortion coefficients for mapping the fiducials are determined by a program written at Fermilab.

Track Measurements to determine measurement errors and check distortions

Figure 1. 90 independent measurements by a CRT measuring device of a 3.85 meter wire in the beam plane. Note that views 2 and 3 are curved in the opposite direction, indicating a vertical curve in the wire. This may correspond to the expected sag of the wire.

Figure 2. 40 different 4.3 meter no-field beam tracks.

$$\left\langle \frac{1}{\rho} \right\rangle = 5.4 \pm 13 \times 10^{-5}\ m^{-1}$$

Figure 3. 97 different 4.3 meter 250 GeV/c beam tracks in a magnetic field of 21 kG.

Figure 4. Beam momentum for the 97 tracks in Figure 3.

Mass Measurements for K^o and Λ^o.

Figure 5 shows the mass plots for 387 K^o and 127 Λ^o.

Analysis Rates for Hadron Exposures

The following table gives some scanning and measuring rates achieved at Fermilab in a shop which stresses accuracy, not speed. For comparison (see comments below), data are included from 30" experiments processed by the same workers. The units used are accepted events per hour (not frames per hour), where "hour" means real time at the table, i.e., 6½ hours per shift. In measuring, operators must hand-match the tracks from view to view.

TABLE I

Item	Experiment	Chamber	Events/Hour	Task
1.	234	15'	4.6	thorough scan, prong count, beam count, and Vee search
2.	137	30"	6.0	thorough scan, prong count, beam count, and Vee search
3.	299	30"	4.0	thorough scan, prong count, beam count, and Vee search
4.	311	30"	23.0	rapid scan and prong count
5.	234	15'	1.7	measure beam track, vertex, and two Vees
6.	234	15'	0.6	measure complete event plus two Vees
7.	234	15'	1.4	measure beam track and 4 charged prongs
8.	194	30"	4.6	measure all tracks with P<1.5 GeV (≈5 tracks/event)
9.	311	30"	8.5	measure 2-prongs
10.	37A	30"	0.3	measure 16-prongs.

The table empasizes the fact that 30" Bubble Chamber scanning and measuring rates vary by factors of 6, depending on the experiment and specific rules. Thus, one must be very careful in making comparisons between the two chambers. However, Items 1 and 2 constitute the use of the same scan rules on π^- beam experiments in the two chambers using the same people. The 15' scan rate is 25% slower than the 30" scan rate in this instance.

No such one-to-one correspondence of tasks exists in the measuring realm. One can only say that events which are of physics interest now in the 15' chamber (double Vees) are a factor 3 slower than events typically of interest in the 30" experiments (low multiplicity charged prongs). We can also state that half of the measuring time in the 15' double Vee events is spent check scanning the entire frame for Vees missed in the first scan, so that the rate does go up to 3.4 events/hour when the first scanner digitizes the event.

Florida State reports that it predigitizes 4-prong events on Micrometric tables at the rate of 4 per hour, a task more analogous to 30" chamber work.

In Fermilab's double Vee measuring, 16% of the events (or 8% of the Vees) need to be remeasured because of operator error or geometry program deficiencies.

Short Prongs

Our only quantitative measure of the frequency with which short prongs are unobserved is the rate for 3-prong events. In Experiment 234, the 3-prong to 4-prong ratio was found to be 2.5%, whereas in Experiment 137 (200 GeV π^- in the 30" chamber) the ratio was 0.6%. If all of this loss came from the loss of low-t events, the loss corresponds to a t-bite of $\Delta t = .003\ \text{GeV}^2$, or a lab momentum bite Δp of 15 MeV/c if $P \approx 100$ MeV/c. (We have used $d\sigma/dt \sim e^{-8t}$ in this calculation.)

Event Rates

A comparison of event rates in the 30" and 15' Bubble Chambers can be made between the following 2 experiments:

1.) 200 GeV/c π^- in the 30" 7 tracks/picture 39.3 cm fiducial length .146 events/picture.

2.) 250 GeV/c π^- in the 15' 4 tracks/picture 300 cm fiducial length .64 events/picture.

These two experiments involved the same Fermilab group. The 15' had 4.4 more events per picture. This is just what would be expected:

$$\frac{15'}{30''} = \frac{4}{7} \times \frac{300}{39.3} = 4.4$$

Conclusions

1. On long flat track measurements the rms deviations on film between the points and the fit curve are 4 to 5 μ. Thus, controllable errors such as measuring machine precision, distortion due to lenses or liquid motion, etc., should be held to less than 4μ by experimenters.

2. The "setting error" that is usually put into geometry programs should be 9μ on film. This "setting error" makes the calculated errors of geometry equal the measured distribution of the beam momentum. Note for 3-view reconstruction this would correspond to

$$\frac{9}{\sqrt{3}} \times 60 = 310\mu \text{ in space}$$

which is consistent with

$$\varepsilon = \left(\frac{\Delta p}{p}\right) \frac{\ell^2 H}{2p} \quad \text{('69 NAL Summer Study P. 155).}$$

From Figure 4,

$$\frac{\Delta p}{p} = .04 \text{ for } \ell = 430 \text{ cm, } H = 21 \text{ kG}$$
$$p = 250 \text{ GeV/c}$$

To scale $\frac{\Delta p}{p}$ to 100 GeV/c and H = 30 kG, for 430 cm tracks,

$$\frac{\Delta p}{p} = .04 \times \frac{100}{250} \times \frac{21}{30} = .011$$

For a 200 cm track at 100 GeV/c

$$\frac{\Delta p}{p} = .011 \times \left(\frac{430}{200}\right)^2 = .051$$

This result is consistent with that of Kitigaki (see enclosed paper) who presented a beam momentum distribution for tracks with lengths between 160 and 330 cm.

The momentum equal to the error in curvature of the straight tracks is 7000 GeV/c on a 4.3 meter track in a 30 kG field.

3. The scanning rate for similar scan rules suggests that it takes about 25% more time/event to scan 15-foot film than 30" film. The measuring rate appears to be about a factor of 2 longer/event for the 15'. Part of this factor of 2 is due to taking more points on 15-foot tracks.

4. Although Fermilab uses the high-precision MOMM scan tables, scanning can be done by "normal" scanning machines with minor modifications. For example, FSU has changed the magnification of their machines to 60. Geometry programs can be adopted from Fermilab, Argonne, Brookhaven, or Berkeley.

5. The large demagnification limits the observation of low energy protons. For "4-prong" events the 15-foot chamber has 4 times as many observed "3 prongs" as the 30" chamber.

6. If measuring errors or short protons are important to an experiment, that experiment should use "hadron lenses" that have a demagnification of 30. These lenses have been discussed in the past at Bubble Chamber Workshops and are feasible to obtain. The cost is about $70K and film costs double.

7. The event rate in the 15' is approximately 4.4 more events/picture for similar experiments. The 30" regains this advantage by multipulsing.

Present Difficulties

During this first year of experience with 15' chamber film, some difficulties have been encountered which make the film analysis less routine than in a small chamber. Many of the problems are similar to the "growing pains" of other chambers and should be overcome within the next year.

1.) The geometry program has difficulty reconstructing tracks which are steeper than 55°.

2.) As is clear from Figures 2 and 3, global distortions have not been entirely mapped away by the optical distortion parameterization.

3.) A large quantity of film exposed thus far is of such poor quality compared to the "best" 15' chamber film, that simi-automatic measurement (SAMM) may not be possible on large parts of the film. Furthermore, manual analysis rates are slower on this film than on the "best" film.

4.) Although SAMM does work in a road-guidance mode on "good" and "best" 15' chamber film, it was necessary first to get the CRT spot size less than 10μ. Users who intend to use CRT devices on 15' film may need to consider running the chamber with larger bubble size.

Figure Captions

1. Deviations of measurements of the wire which spans the chamber from a curve fitted in space by the geometry program, projected back onto the film plane in three views (film plane residuals). Plotted here are the average of 90 independent measurements of about 75 points along the wire by SAMM. The error bars are the rms spread of the 90 measurements. The fitted curve allowed a curvature in the plane perpendicular to the field as a free parameter.

2. Film plane residuals for 40 different beam tracks with no magnetic field, each track measured once. Plotted here are the average of the 40 deviations; the error bar is the rms spread of 40 deviations. The fitted curve allowed a curvature in the xy plane.

3. Film plane residuals for 90 different beam tracks with a magnetic field of 21 kG. See captions 1 and 2.

4. Measured momentum distribution of 97 beam tracks, each measured once by SAMM. The tracks vary in length from 400 to 450 cm. The quoted error, ±9.2 GeV/c, is the rms spread of the distribution. We expect multiple scattering to contribute only 1 GeV/c to the width.

5. Mass distributions for K^o and Λ^o produced by 250 GeV/c π^- in hydrogen.

Publications

1. Florida State University and Fermilab; "Topological Cross Sections and Multiplicity Moments for π^-p Interactions at 250 GeV/c."

2. Fermilab and Florida State University; "Search for Charm in 250 GeV/c π^-p Interactions."

3. Tohoku University; "Characteristics of Track Reconstruction for FNAL 15-foot Bubble Chamber."

4. Tohoku University; Analysis of Two-and Four-Prong Events in π^-p Interactions at 100 GeV/c."

5. Argonne National Laboratory, University of Kansas, State University of New York at Stony Brook, and Tufts University; "Preliminary Study of Inclusive Photon Production from 300 GeV/c pp Collisions in the 15-foot Bubble Chamber."

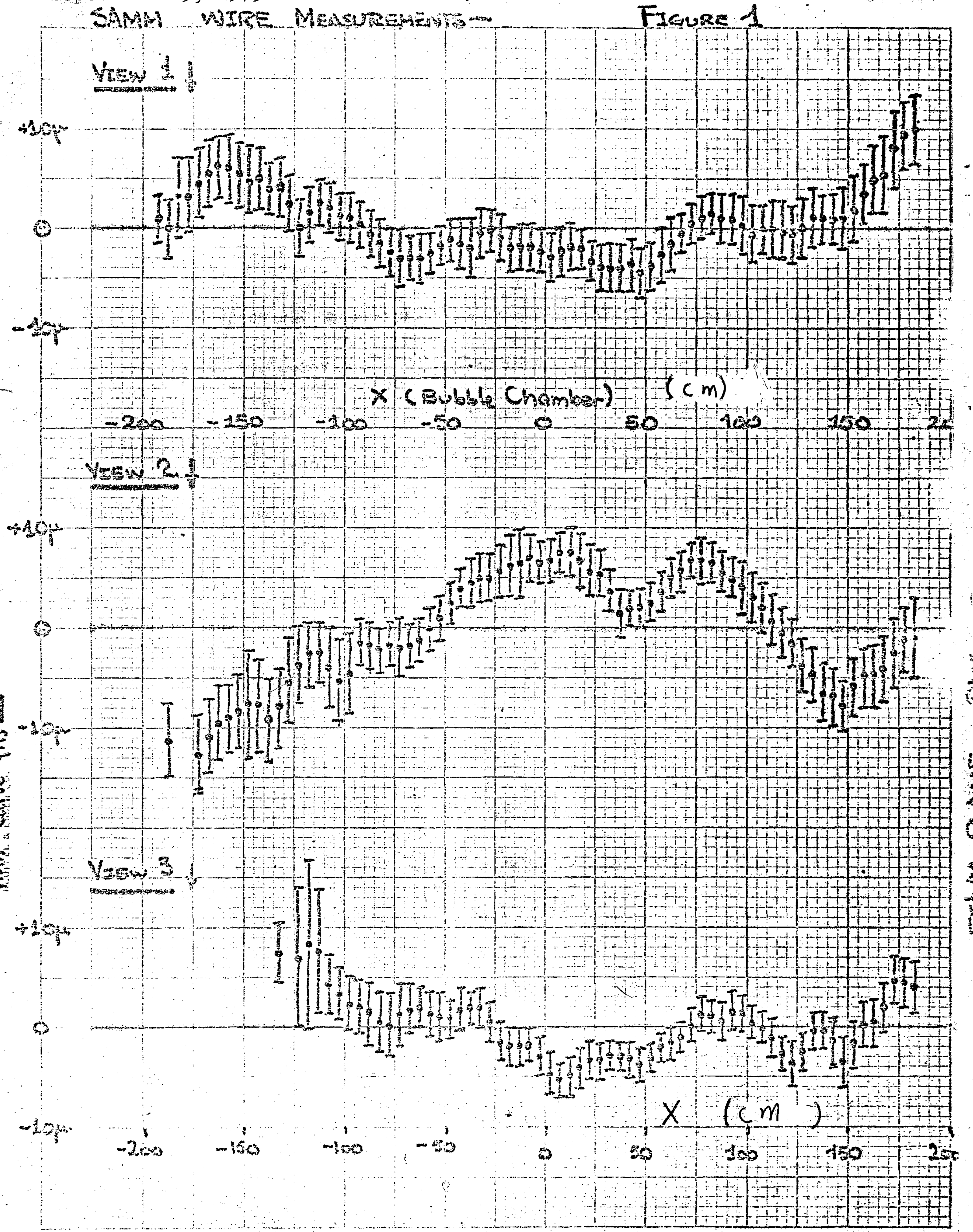

SAMM WIRE MEASUREMENTS —
FIGURE 1
View 1
View 2
View 3
+10μ
0
-10μ
X (Bubble Chamber) (cm)
X (cm)
-200
-150
-100
-50
0
50
100
150
RESIDUALS (microns on film)
from a Curve fit

Fig. 1

FILM RESIDUALS, NO FIELD TRACKS FIGURE 2

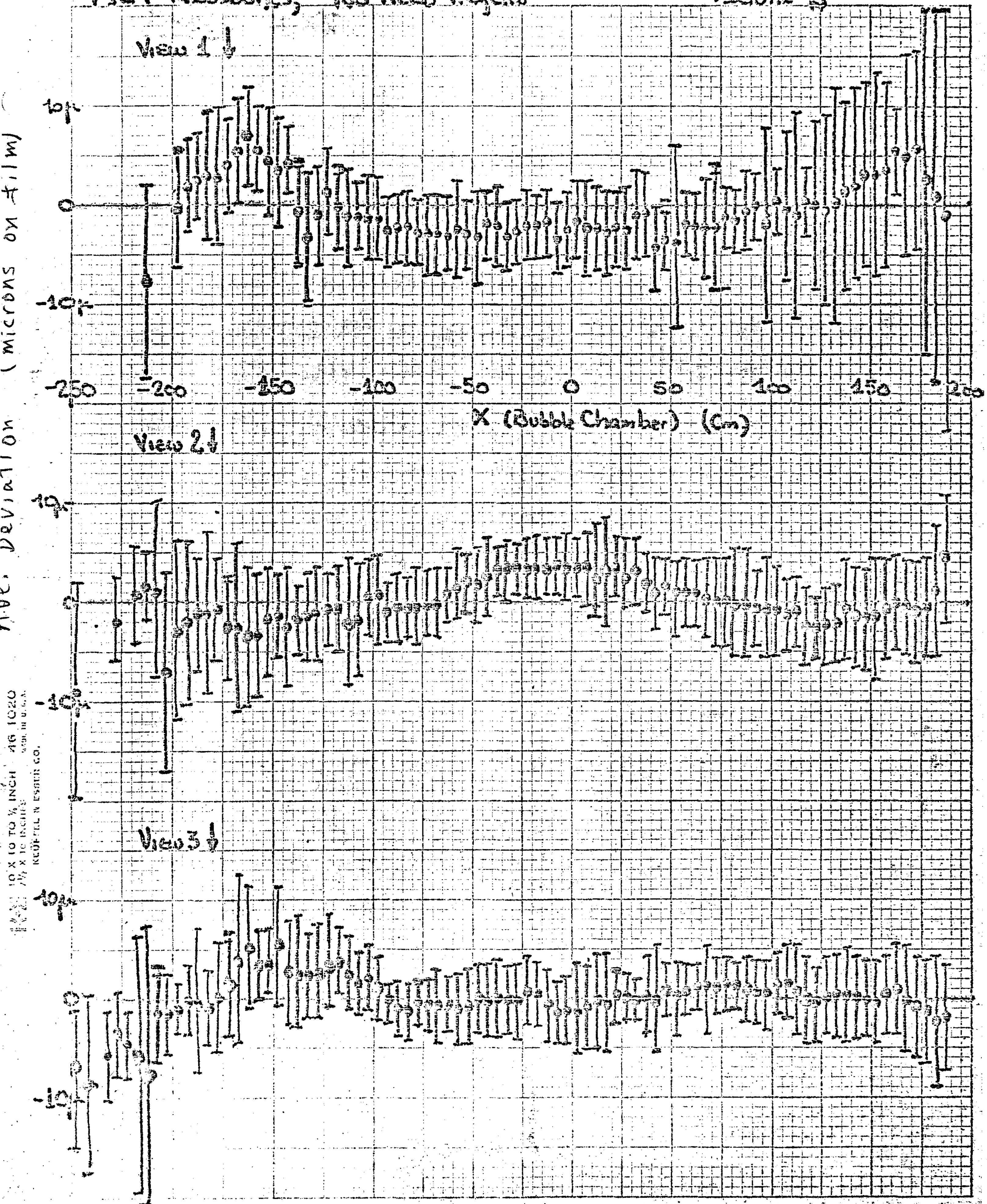


Fig. 2

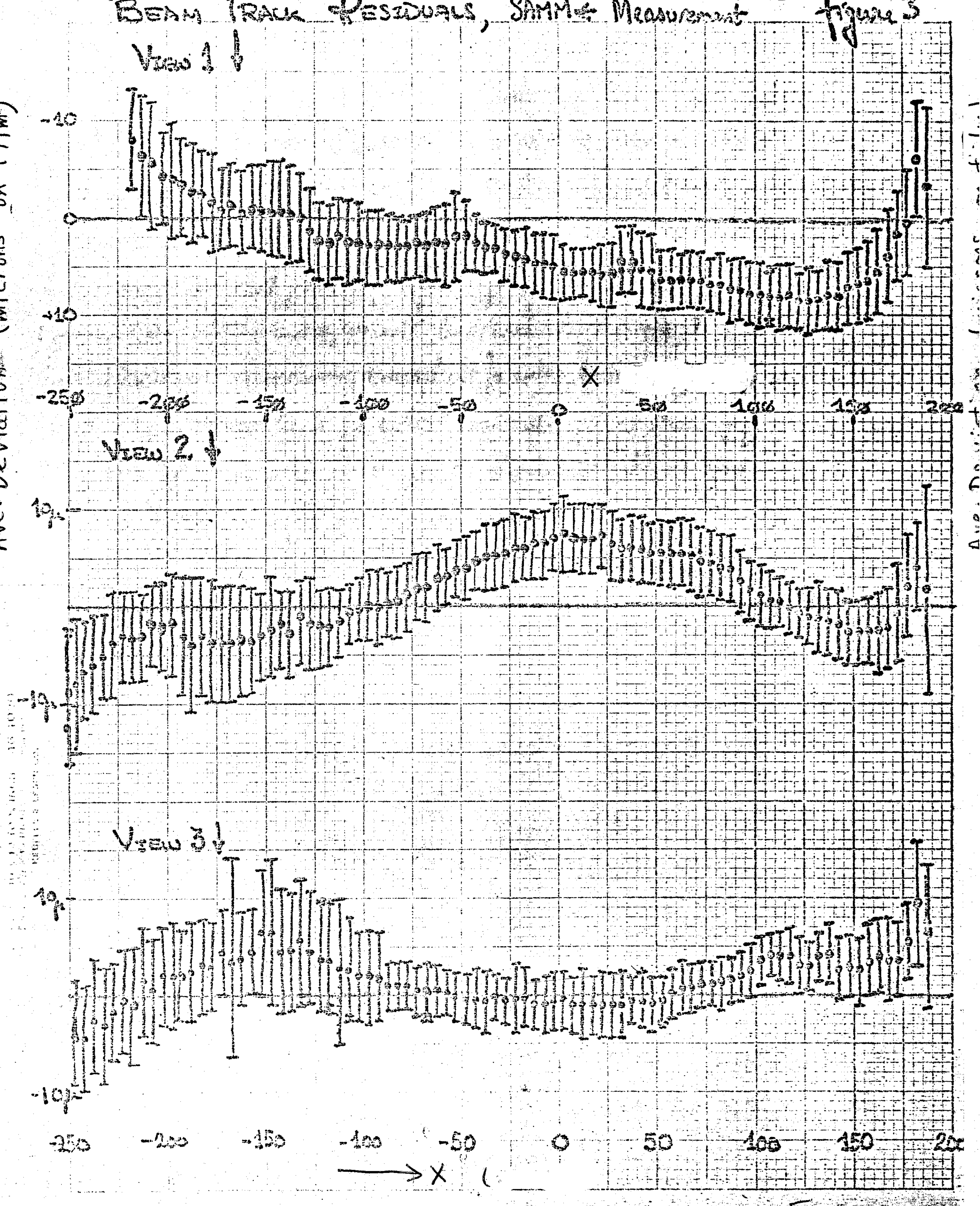

BEAM TRACK RESIDUALS, SAMM Measurement
Figure 3
View 1
-10
+10
-250 -200 -150 -100 -50 0 50 100 150 200
View 2
10μ
-10μ
View 3
10μ
-10μ
-250 -200 -150 -100 -50 0 50 100 150 200
→ X

Fig. 3

Figure 4. Beam SAMM Measurements.

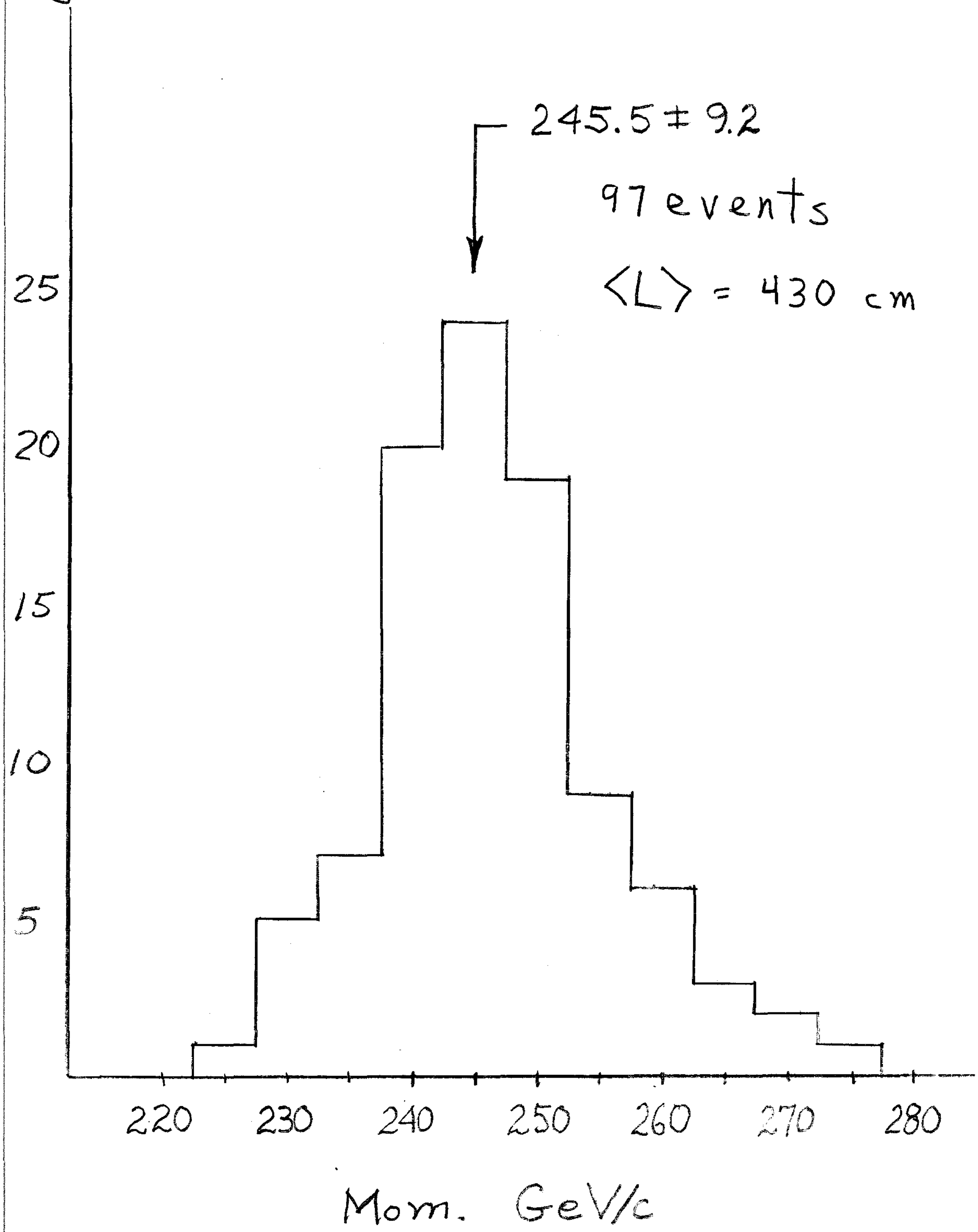
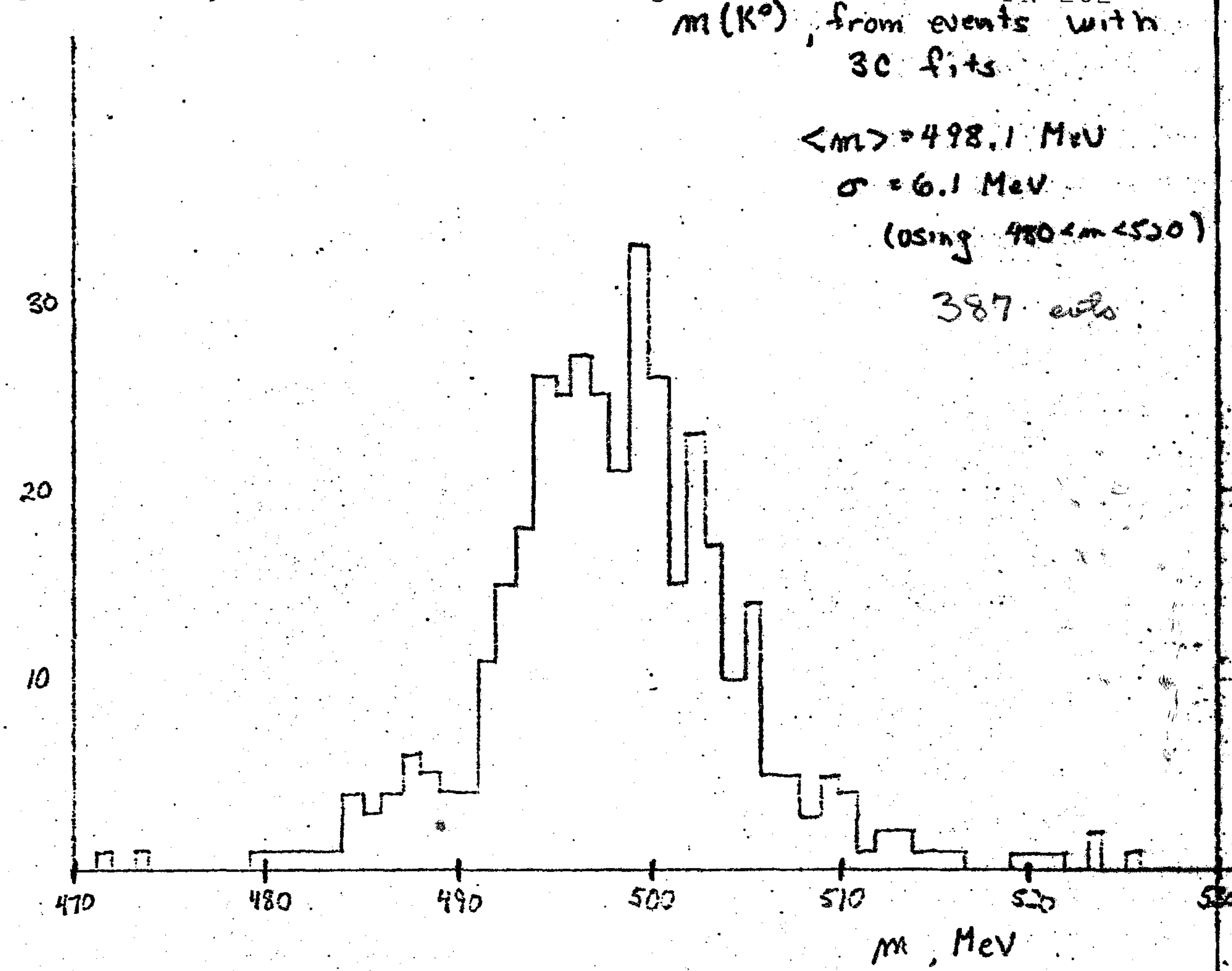
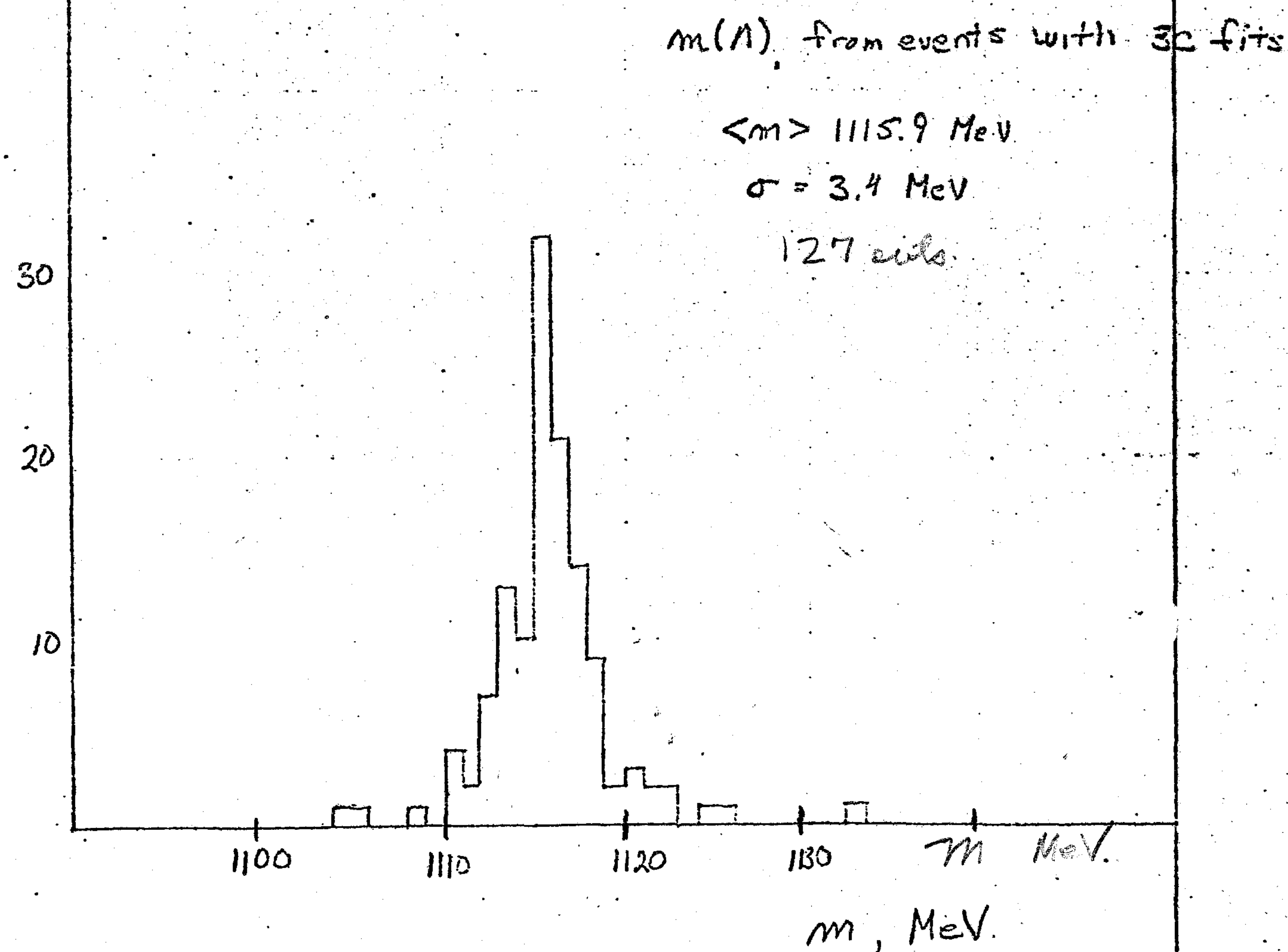


Fig. 4


m(K°), from events with 3C fits
<m> = 498.1 MeV
σ = 6.1 MeV
(using 480 < m < 530)
387 evts
30
20
10
470
480
490
500
510
520
530
m, MeV


m(Λ), from events with 3C fits
<m> 1115.9 MeV
σ = 3.4 MeV
127 evts
30
20
10
1100
1110
1120
1130
m MeV
m, MeV

C. Nation l Accelerator Laboratory

1. Physical Description of Facilities and Operating Mode

a. NAL - 30-in. Bubble Chamber

The 30-in. bubble chamber was brought to NAL from ANL to serve as an initial unique detector to look for new high energy phenomena. This program has produced 195,000 pictures in FY 1973. It has also become evident that good experiments can be done with the 30-in. bubble chamber in combination with upstream and downstream counter and spark chamber arrays. There are 18 university groups involved in these hybrid experiments. The present plan is for the chamber to be in operation almost continuously.

This bubble chamber, originally built at MURA and previously operated at Argonne, is located at the end of Hadron Beam N3 in the Neutrino Area. The facility includes tagging capabilities for incoming beam particles using proportional wire chambers for determining particle direction and Cerenkov counters for mass identification. Systems for downstream tagging of secondary particles are also being developed.

The chamber sensitive volume consists of a 30-in. diameter cylinder, 15-in. deep. Expansion is provided by three 6-in. diameter pistons at the top, which have shown good multiple pulsing capabilities. The magnetic field at the center of the chamber is 30 kilogauss with the magnet operating at 18,000 amperes. The chamber has dark field illumination, with a separate flash tube for each of four views. Normally, these views are photographed directly with separate cameras using 35 mm sprocketed film. For special exposures an alternative formet is available in which the four views are mirrored to give adjacent images on one reel of 70mm sprocketed film.

Fig. III-10 is a cross section of the chamber assembly, and Fig. III-12 illustrates the NAL beam layout and location of the 30-in. and 15-ft. bubble chambers.

Table III-4 summarizes the design features of the chamber.

NATIONAL ACCELERATOR LABORATORY
30 INCH BUBBLE CHAMBER

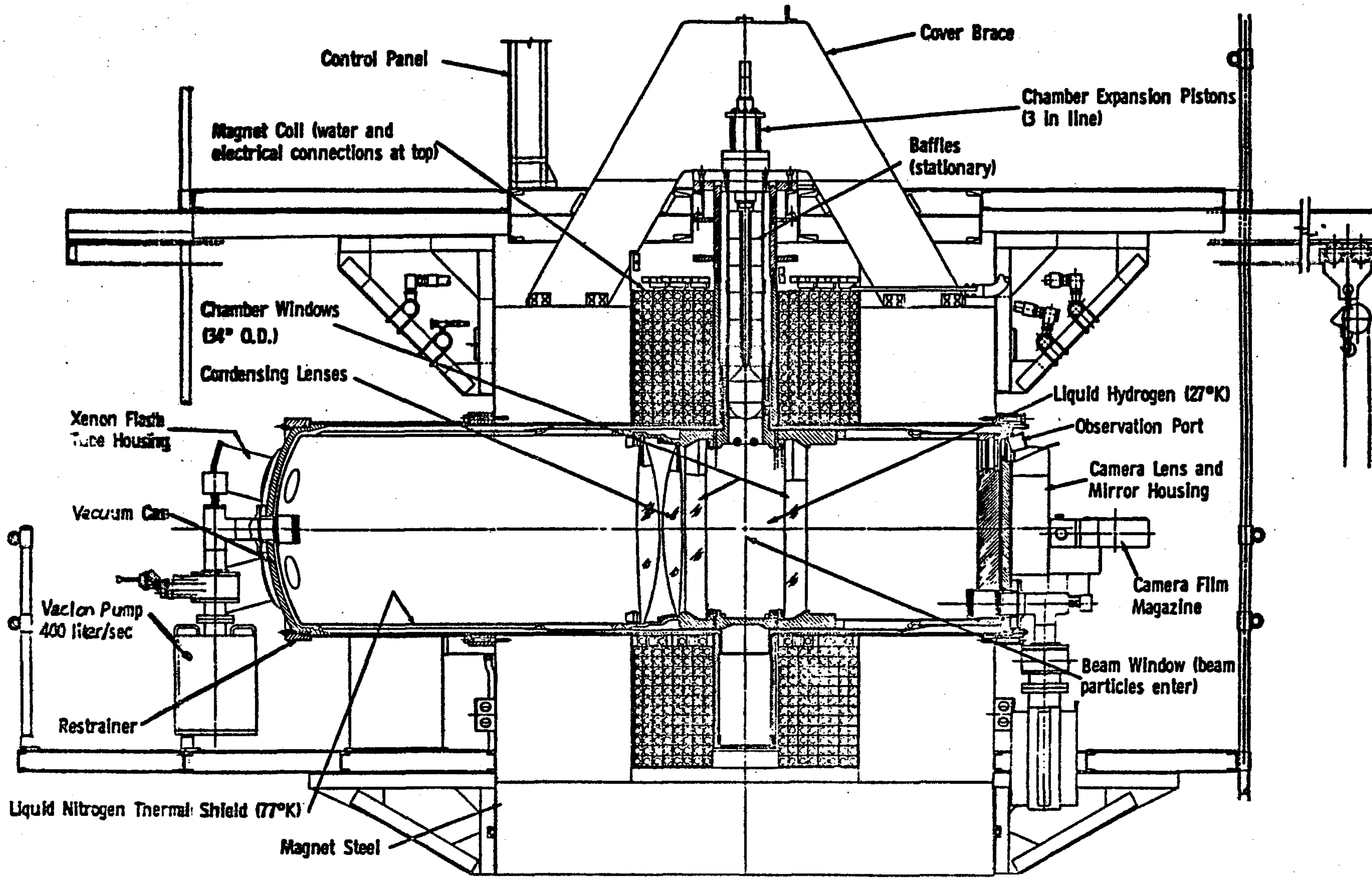


FIG. III-10

TABLE III-4

National Accelerator Laboratory - 30-Inch Bubble Chamber

Summary of Design Features

HYDROGEN CHAMBER

Inner Dimensions:	30" dia. x 15" deep
Material:	Chromarc 55 Stainless Steel
Total Liquid Volume:	212 liters
Volume Expanded:	212 liters
Visible Volume:	190 liters

Nominal Operating Pressure/Temperature:

Hydrogen	-	75 psia/25°K
Deuterium	-	95 psia/31°K
Neon-Hydrogen	-	130 psia/30°K

EXPANSION SYSTEM

Cold Pistons - Diameter: 3 pistons, each 6.5 inches
- Material: Stainless Steel
- Stroke for 0.8% Expansion Ratio: 1.12 inches

Actuator - Pneumatic

Repetition Rate
- Synchronized with NAL synchrotron
- Multipulsing: minimum interval between expansions 200 milliseconds

Reciprocating Mass - 45 lbs.

MAGNET - CONVENTIONAL COPPER COILS WITH IRON RETURN FRAME

Central Magnetic Field: 30 kilogauss
Magnet Current: 18,000 amperes

OPTICS

Camera Positions: 4
Chamber Window: BK-7 glass
Camera Lens: 125 mm (80 mm)
Film Size: 70 mm (35 mm) Formats
Film: Eastman Kodak Dacomatic Mylar Base
Illumination: Dark-field
Flash: Elliptical Xenon Discharge Tubes
Average Demagnification on Film: 11/1 for 70 mm film; 12/1 for 35 mm film formats
Setting Error: 35 microns in space

TABLE III-4 (Cont'd)

REFRIGERATION SYSTEM

Hydrogen Refrigeration @ 25°K
Nominal Refrigeration Capacity: 500 watts

BEAMS

Hadron Beam N3, 25-500 GeV, Beam tracks tagged by MWPC and Cerenkov

HYBRID

Four wide-gap optical spark chambers immediately downstream

TST

None. Preliminary design estimates are encouraging.

PLATES

Previous runs with two tantalum plates, 1 rad. length each.

b. NAL - 15-ft. Bubble Chamber

NAL has under construction a 15-ft. bubble chamber. It is the intent to operate this chamber for two user groups at a time by having six cameras arranged in two sets of three each--one set for hadron physics and one for neutrino physics. The chamber is designed to pulse five times per accelerator pulse. Two beams are directed to the chamber; one will give hadrons up to full accelerator energy, and one will give neutrinos.

The chamber is constructed of spherical shapes to minimize chamber and vacuum tank wall thickness. The optics system is bright-field illumination with Scotchlite, fisheye optics, 108° lens and 70mm film. It has a six-ft. diameter fiberglass piston with pressure assisted lip seal rings. The super-conducting magnet has 400 megajoules of stored energy and gives a central field of 30 kg.

The magnet, expansion system, hydrogen refrigerator and chamber have been tested independently. First tracks in the chamber with the magnetic field on were photographed in September 1973. It is expected that physics runs will begin in early 1974.

Fig. III-11 is a cross section and top (cutaway) view of the chamber assembly, and Fig. III-12 illustrates the beam layout and location of the 30-in. and 15-ft. bubble chambers.

Table III-5 summarizes the design features of the chamber.

2. Cost and Manpower Data

a. Operating Costs and Capital Improvements

i. NAL - 30-in. Bubble Chamber

	FY 1972	FY 1973	FY 1974
Operating Costs	$ 170K	$ 500K	$ 650K
Capital Improvements		20	20

Breakdown of FY 1973 and FY 1974 Operating Costs:

	FY 1973	FY 1974
Salary and Wages	300	300
Gases (not including D_2)	50	50
Film	50	100
Power	50	150
Material and Services	50	50

(Budget based on 600K pictures in FY 1974).

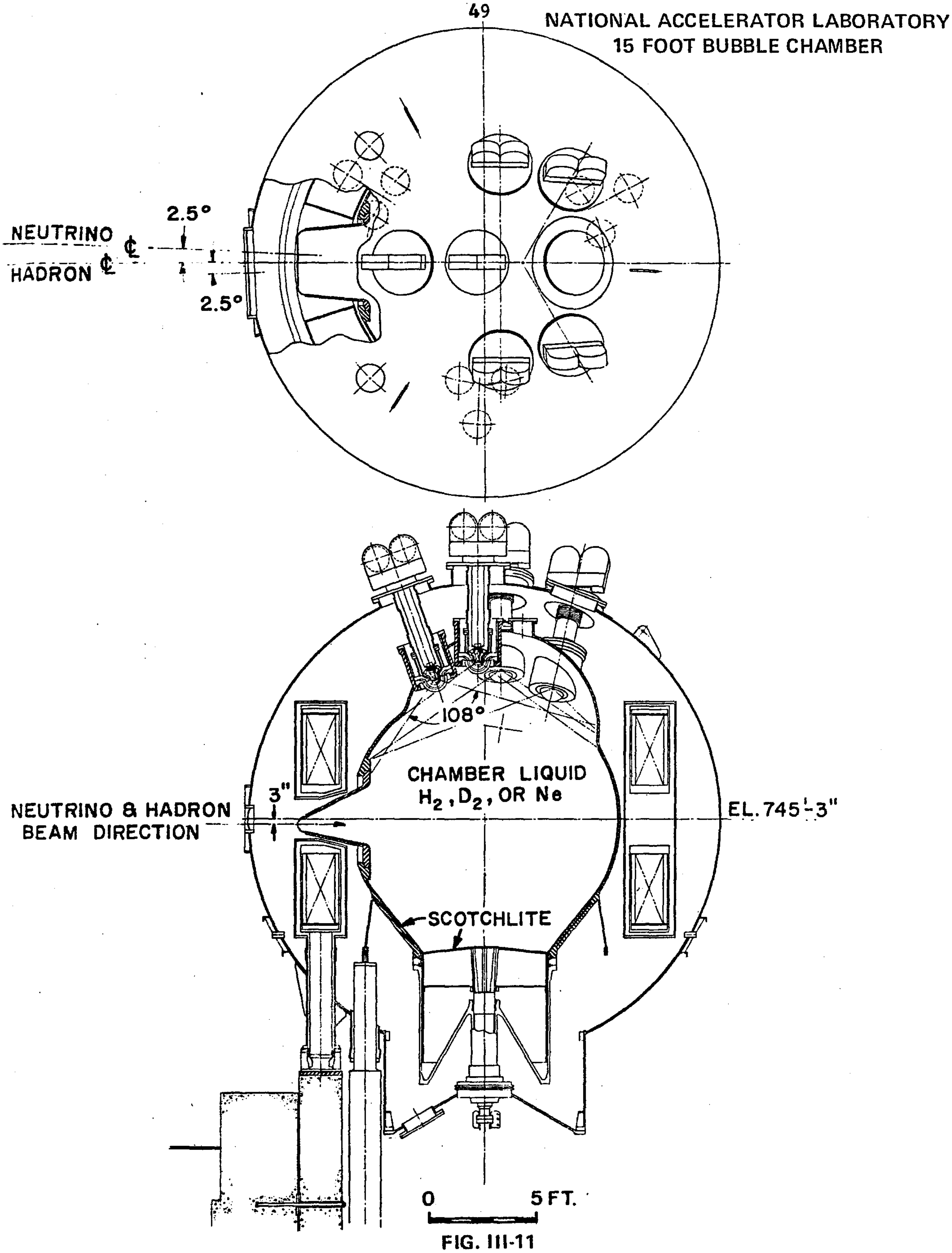

NATIONAL ACCELERATOR LABORATORY
15 FOOT BUBBLE CHAMBER
2.5°
NEUTRINO ₵
HADRON ₵
2.5°
108°
CHAMBER LIQUID
H_2, D_2, OR Ne
3"
NEUTRINO & HADRON
BEAM DIRECTION
EL. 745'-3"
SCOTCHLITE
0
5 FT.

FIG. III-11

TABLE III-5

National Accelerator Laboratory - 15-Foot Bubble Chamber

Summary of Design Features

HYDROGEN CHAMBER

Outside Diameter:	12.5 feet sphere plus 15 feet along beam		
Material:	Type 316L Stainless Steel		
Total Liquid Volume:	35,400 liters		
Volume Expanded:	33,400 liters		
Visible Volume:	28,000 liters		
Nominal Operating Pressure/Temperature:			
	Hydrogen	-	75 psia/25°K
	Deuterium	-	95 psia/31°K
	Neon-Hydrogen	-	130 psia/30°K
Vent Size:	Gas - 1-inch line		
	Liquid - 3-inch line		

EXPANSION SYSTEM

Cold Piston - Diameter: 70.849 inches
- Material: Fiberglass reinforced plastic with A-286 Stainless Steel shaft

Hydraulic Actuator - Piston Diameter: 20" gas side-16" oil side
- Maximum travel: 10 inches
- Stroke for 1% Expansion Ratio: 5.0 inches
- Force Available: 500,000 lbs.

Repetition Rate - 5 Expansions every 5 seconds

Reciprocating Mass - 4500 pounds

MAGNET - SUPERCONDUCTING

Coil I.D.: 168 inches

Coil O.D.: 200 inches

Operating Temperature: 4.2°K

Central Magnetic Field: 30 kilogauss

Magnet Current: 5000 amperes

Magnet Dewar Operating Pressure: 20 psia

Magnet Dewar Liquid Capacity: 10,000 liters

Magnet Dewar Material: Type 304L Stainless Steel

Vent Size: Gas - 3-inch
Emergency - one 12-inch rupture disc

TABLE III-5 (Cont'd)

OPTICS

Camera Positions: 2 sets of 3
Window Material: BSC-7 for large window - Quartz for 2 small windows
Camera Lens: 37 mm, 108°
Film Size: 70 mm
Film: Eastman Kodak Microfile AHU ~~mylar~~ ESTAR base (Panchromatic)
Illumination: Bright-Field Retrodirective
Flash: Circular Xenon Discharge Tubes
Retrodirector: Scotchlite
Average Demagnification on Film: 60
Setting Error: Unmeasured. We hope $\leq$ 300 microns in space.

VACUUM TANK

Outside Diameter: 22 feet
Material: Type 304 Stainless Steel
Operating Pressure: 10^{-4} to 10^{-6} torr
Vent Size: One 12-inch rupture disc

REFRIGERATION SYSTEM

Hydrogen Refrigeration @ 25°K
Nominal Refrigeration Capacity: 9.5 kilowatts
System supplied from the Dewar.
Nominal Compressor Capacity: 800 SCFM

Helium Liquefier @ 4.5°K
Nominal Capacity: 100 liters/hour
System supplied from Dewar.
Nominal Compressor Capacity: 500 SCFM

CRYOGENIC LIQUID STORAGE CAPACITIES

Helium Storage Dewar:	10,000 liters
Hydrogen Storage Dewar:	15,000 gallons
Deuterium Storage Dewar:	13,000 gallons
Neon Storage Dewar:	13,000 gallons
Nitrogen Storage Dewar:	15,000 gallons

PLATES

Can be installed.

TRACK-SENSITIVE TARGET (TST)

Under development.

BEAMS

Neutrino beam (ν, $\bar{\nu}$ - peaked at 20 GeV).
Unseparated hadron beam (25-500 GeV/c).

HYBRID

External muon identifier consisting of ~30 1x1 m^2 wire chambers.

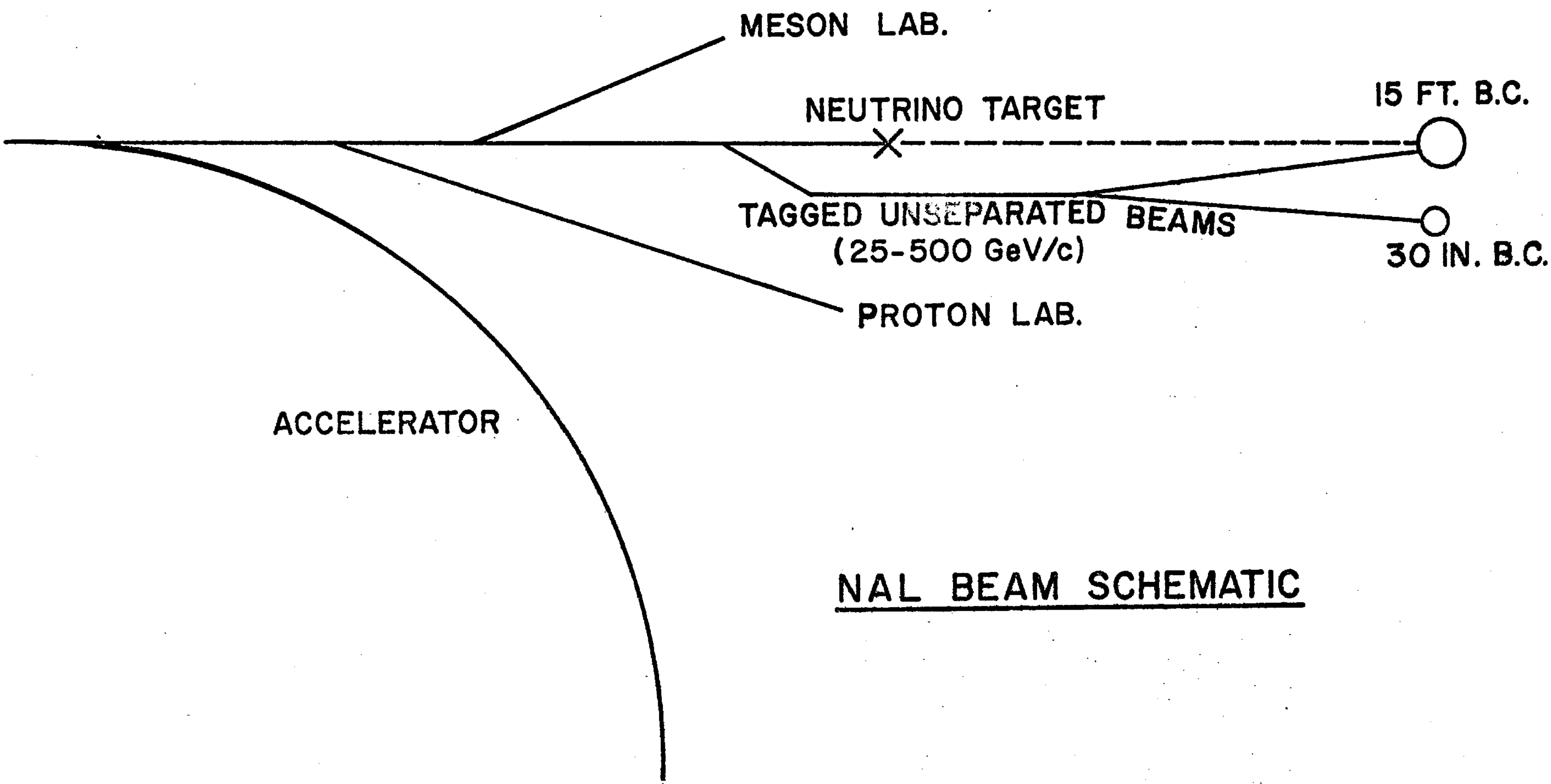

MESON LAB.
NEUTRINO TARGET
15 FT. B.C.
TAGGED UNSEPARATED BEAMS
(25-500 GeV/c)
30 IN. B.C.
PROTON LAB.
ACCELERATOR
NAL BEAM SCHEMATIC

Fig. III-12

ii. NAL - 15-Ft. Bubble Chamber

	FY 1972	FY 1973	FY 1974
Operating Costs	$	$	$1230
Capital Improvements			300

Breakdown of FY 1974 Operating Costs:

Salary and Wages	600
Gases (not including D_2)	100
Film	170
Power	10
Material Services	350

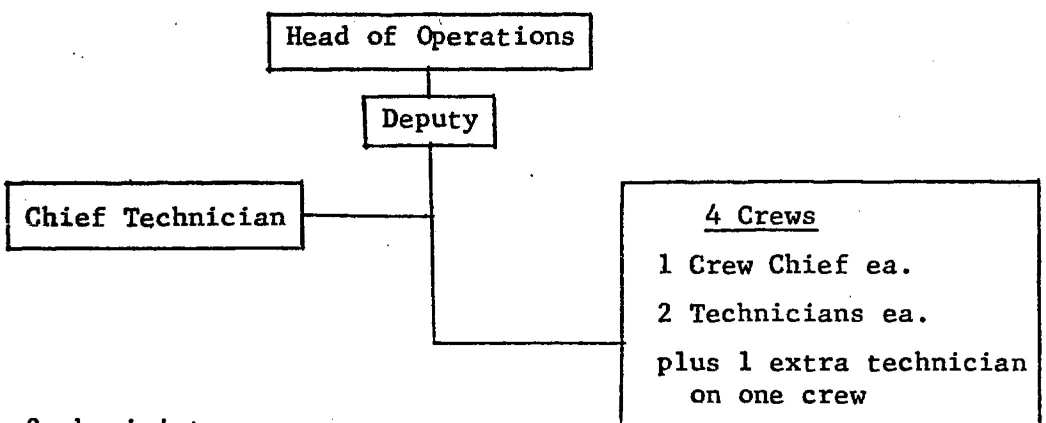
(Budget based on 500K pictures in FY 1974).

b. Personnel

i. NAL - 30-In. Bubble Chamber

Professional	2
4 Crews	12
Maintenance	2
Shop	
Secretaries	1/2

Crew Organization



2 physicists
14 technicians

ii. NAL - 15-Ft. Bubble Chamber

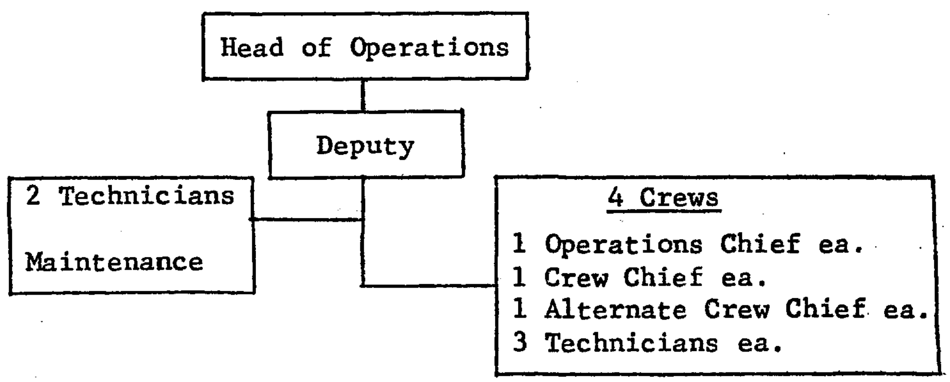
Operation

Professional	7
4 Crews	20
Maintenance	2
Shop	1
Secretaries	1-1/2

Research and Development

Professional	5
Drafting	3
Technicians	3
Shop	1
Secretary	1/2

Crew Organization



1 Physicist
5 Engineers
22 Technicians