GEM TN-92-135
HWB-92-013

# Muon Engineering Status Meeting - Draper

July 23, 1992

Abstract:

Agenda, attendees, and transparencies of the GEM Muon Engineering Status Meeting held at Draper Laboratories on July 23, 1992. Agenda items are: Overview of Activities; Comments; Overview Sector/Wheel; Criteria Doc(Wheel/Sector); Structure/Design/Analysis; Assembly/Installation; Alignment Update; CSC Update; LSDT Update; and Discussion/Action Items.

DRAPER LABORATORY

HWB-92-013

TO: Distribution

FROM: H. Baker

DATE: 24 July, 1992

SUBJECT: Material from 23 July 1992 GEM/Muon Engineering Status Meeting at Draper

The attached material was presented at the subject meeting.

Howard Baker rc

Howard Baker
GEM/Muon
Project Assistant Manager

DISTRIBUTION:

Draper

H. Baker
J. Connelly
M. DePiero
M. Furey
J. Gorman
R. Gustavson
A. Kondoleon
R. Martorana
F. Nimblett
J. Paradiso
G. Quinn
R. Sapienza
M. Socha
E. Womble

M.I.T.

J. Kelsey
L. Osborne
I. Pless
L. Rosenson
F. Taylor

B.U.

S. Whitaker
J. Shank

SSCL

M. Gamble
M. Harris
M. Marx
J. Pier-Amory
G. Sanders
R. Sawicki
E. Walton

HWB/rc

Attachment

The Charles Stark Draper Laboratory, Inc.
555 Technology Square, Cambridge, Massachusetts 02139-3563
Telephone: 617 258-1000

# Agenda

# Agenda

Muon System Engineering Meeting

23 July

At Draper

| *Time* | *Presenter* | *Subject* |
|---|---|---|
| 0830 | Baker | Overview of Activities |
| 0840 | Marx | Comments |
| 0900 | Baker/Gamble/Marx | Overview Sector/Wheel |
| 0915 | Baker/Gamble/Marx | Criteria Doc(Wheel/Sector) |
| 0945 | Gamble/Furey | Structure/Design/Analysis |
| 1045 | Gamble/Gustavson | Assembly/Installation |
| 1115 | Paradiso | Alignment Update |
| 1130 | Polychronakos/Shank | CSC Update |
| 12:00 | All | Lunch Break |
| 1:00 | ~~Kelsey~~ Osborne | LSDT Update |
| 1:30 | All | Discussion, Action Items |
| 2:00 | | Adjourn |

# Attendees List

ATTENDEES LIST-GEM MUON ENGINEERING MEETING

23 July 1992

| NAME | ORG | TEL# | FAX# | E-MAIL |
|---|---|---|---|---|
| HOWARD BAKER | DRAPER | 617-258-3411 | -1335 | hbaker@draper.com |
| DICK GUSTAVSON | DRAPER | 617-258-2914 | -1131 | |
| EDMUND BERK | DRAPER | 617-258-2674 | -1131 | |
| MIKE GAMBLE | SSCL | 214-708-1463 | -6088 | SSCVX1::GAMBLE |
| MARTIN FUREY | DRAPER | 617-258-4662 | -1131 | |
| Rick Sawicki | LLNL | 510/4230963 | 3-4145 | Rick.Sawicki@EDGMAIL.llnl.gov |
| Mike Marx | SSC | 214 708 6188 | 6088 | MARX@SSCVX1 |
| Jim SHANK | Boston U. | 617-3536028 | 353 6047 | shank@BuPHYC.BU.edu |
| Joe Paradiso | Draper | 617-258-2413 | 4444 | paradiso@cernvm |
| Rick Suprenza | CSDL | 617-2[illegible]-2314 | -1131 | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Response to Action Item**

**Marx to Muon Team**

**Mail*Link® SMTP** Returned Mail

---------- Special condition follows ----------
Mail rejected by host: ccfvx3.draper.com
Partial protocol transaction follows:

553 Mailbox syntax is incorrect.

---------- Message follows ----------
Date: 24 Jul 1992 08:45:20 -0500
From: "Howard Baker" <Howard_Baker@qmlink.draper.com>
Subject: Action Item from 7/23
To: "mike marx" <sscvxl::marx>,
"mike marx" <marx@sscvxl.ssc.gov>,
Frank_Nimblett@qmlink.draper.com,
"Frank Taylor" <fet@mitlns.mit.edu>

OFFICE MEMO
Subject: Action Item from 7/23
Time:8:36 AM
Date:7/24/92

Mike-

Re: Muon Support Structure/Barrel Region/Big Wheel Approach

After you left, the projection screen was raised and we all literally went to the chalk board and worked out the facility requirements (overall working/clear area) for assembling the subject structure in an appropriate building. It was literally, 'design' by committee.
Regardless of the orientation of the wheel assembly, horizontal (as it would be positioned in the experimental hall), or vertically (and then rotated to a horizontal position), the required building facility space dimensions would be identical, within a meter or so (the aspect ratio is roughly=1). The approaches (horiz or vert) were worked out independently, but the working space appears to be the same.
The space requirement is highly driven by the loading of chambers.
The loading of chambers is not a trivial effort, but it is workable.
Therefore the GEM Muon System Support Structure Subcommitee for Wheel Assembly Building Space, GMSSSSWABS, requests a building with the following space:

Height= 25 meters
Width= 36 meters

This is something we could 'live' with, to specifically answer your action item. We spent about an hour developing the requirements. Could we live with something less? I'm certain we could (not too much, though), but I think that would require significantly more creativity and much more conceptual design time. Our approach is soft, but conservative.
PS: It was also suggested that a third option (does not effect the building space requirement) be considered, and has to do with the loading of chambers. The idea is to load only (this is for the initially vertical wheel) the middle layer of chambers and then rotate the the wheel to the horizontal position, consistent with the final orientation in the hall, and complete the loading of the other two layers. This perhaps make it easier to rotate the wheel, less sensitive to potentially 'shifting' loads, and less demanding of realignment (tweaking) of chambers.
For the GMSSSSWABS,
howie baker.

Baker/Draper

# OVERVIEW

# OF

# ACTIVITIES

# Short Term Game Plan

Decide which Technologies:

## Schedule

| | |
|---|---|
| Present Time | - Construct full-scale prototype |
| 8/15/92 | - Delivery of chambers to TTR |
| 8/20/92 to 9/15/92 | - Test chambers with cosmics<br>- Determine spacial resolution<br>- operational stability compatibility |
| 8/92 to 10/92 | - Test CSC at RD5 beam at CERN |
| 9/15/92 to 10/7/92 | - Evaluate tests |
| 10/8/92 | - Presents results at SSCL and make recommendations |
| 10/8/92 to 12/15/92 | - Develop choice and write TDR |

## Choices

| | |
|---|---|
| Baseline - 1: | - Choice LSDT or PDT for barrel<br>- Accept RPC for barrel trigger<br>- Accept CSC for endcap |
| Baseline - 2: | - CSC everywhere |
| Baseline - 3 | - Drift option everywhere |

## Engineering Design

| | |
|---|---|
| Support Structure Alignment | - Decision= 9/1/92 |

## Simulations

*Superconducting Super Collider Laboratory*
*2550 Beckleymeade Avenue, Mail Stop 2005*
*Dallas TX 75237-3946*
*(214) 708-6325*
*Fax: (214) 708-6088*

***Physics Research Division***
***GEM Project Office***

## *Memorandum*

**To:** Frank Taylor
**From:** Mike Harris MH
**Subject:** Muon Facilities
**Date:** July 8, 1992

---

I wish to confirm the agreement reached in last Friday's muon meeting where the muon facilities requirements must be fully defined before September, 1992. This may be a difficult task because the chamber technology may not be chosen at that time but, Title 1 of the remaining surface facilities must start the beginning of September.

There are, at the moment, two structure options for supporting the chambers; modular or monolithic. The latter option may be assembled in the magnet assembly building starting April, 1996. The modular option may require additional facilities because of an earlier assembly starting late in 1995. This option also requires a large amount of storage space.

I request that you give these points some consideration and strive to obtain consensus during the next seven weeks which option is preferred by the muon group.

MH/lhb

cc: Howard Baker
Barry Barish
Michael Marx
Frank Nimblett
Joe Pohlen
Tom Prosapio
Gary Sanders

# OVERVIEW

# OF

# SUPPORT STRUCTURE

# SECTOR APPROACH

# GEM MUON SUPPORT STRUCTURE

## OVERVIEW OF *SECTOR (MODULE)* APPROACH

General

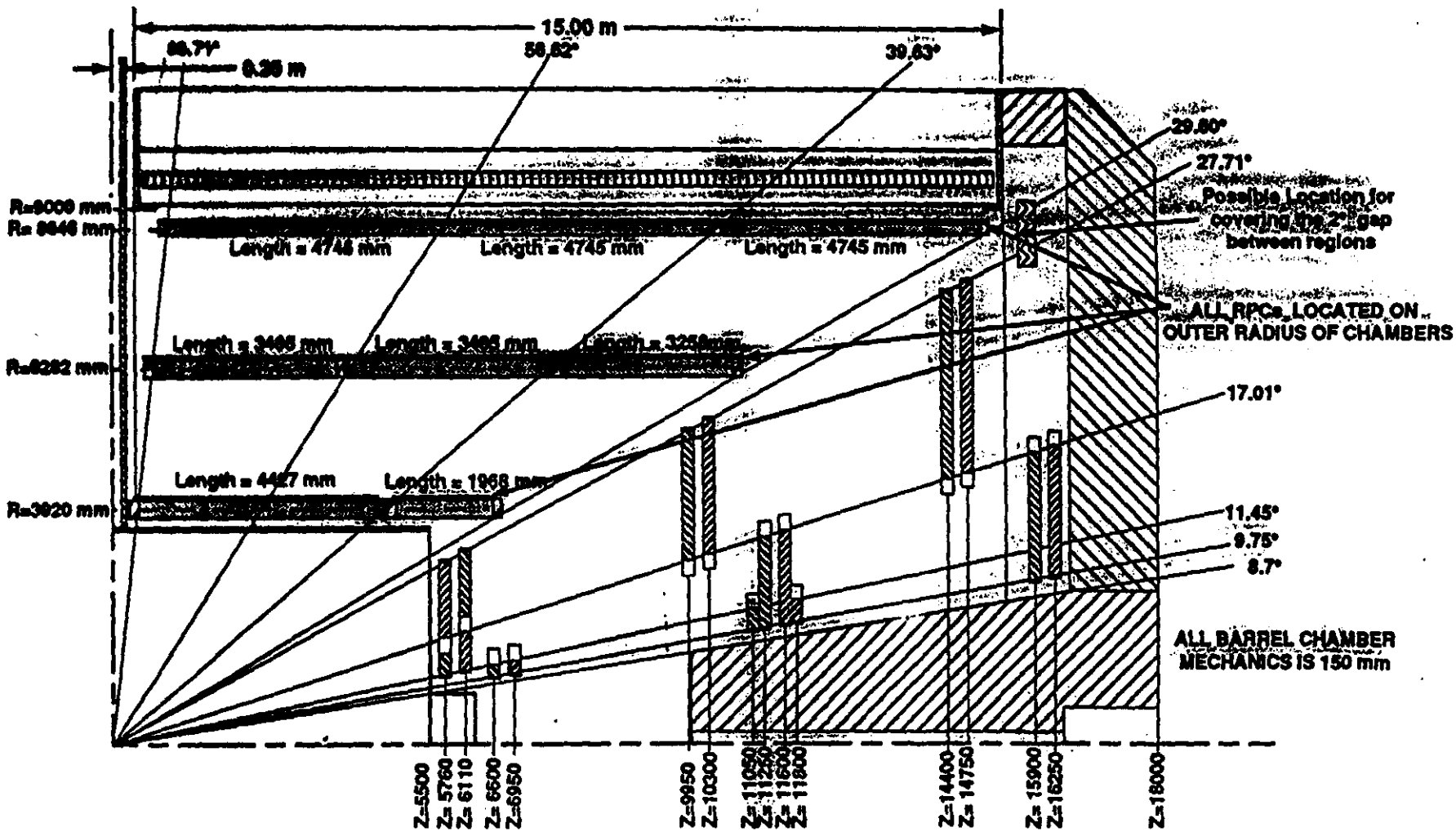
- Muon System--> Largest volume detector element
- Stability requirement of 25u within a muon module
- Barrel region is arranged into 16 nominally identical modules/half barrel
    - Total=32 barrel modules
- Endcap region is arranged into 16 modules of two types (virtually identical)/end
    - Total=32 endcap modules

Barrel Region

- Layered assembly of truss joints; can be disassembled/assembled w/accuracy
- Truss elements-->3" dia Al tubing, 0.025" wall thickness (range from 0.125-0.750")
- Interface to magnet is by means of independent interface plate between magnet endplates and muon support structure module.
- Installation
    - Module-> rails->instal fix->head house->UG->rotary portion/adjust fix ->top staging->pull into magnet on rails-attached to magnet endplate/interface plate

Endcap Region

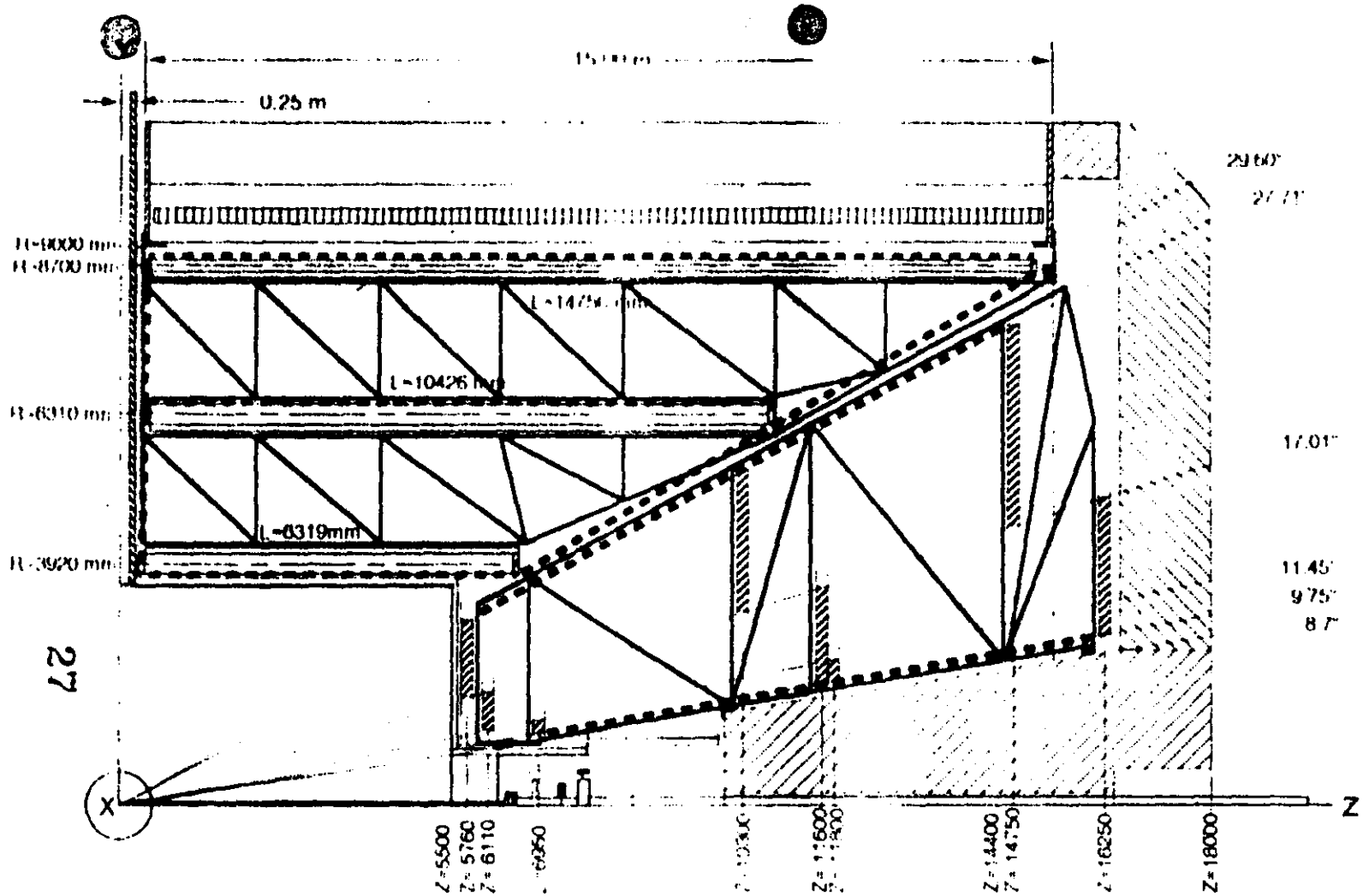
- Basic construction techniques same as barrel region
    - Modules must be joined into assembly
    - Additional attachment points to permit joining of trusses to be provided
- Installation
    - Modules->head house->UG->lifted above FFS->rotary fixture on FFS->16 modules joined together on 2 interface rings




# GEM MUON SYSTEM CHAMBER LAYOUT
# BASELINE II
# (2,3,3 Chambers per Layer-PROJECTIVE GAPS)

Draper Laboratory

GEM Muon System Chamber Layout




# GEM MUON SYSTEM (BASELINE I)
## (Alignment Line Layout)

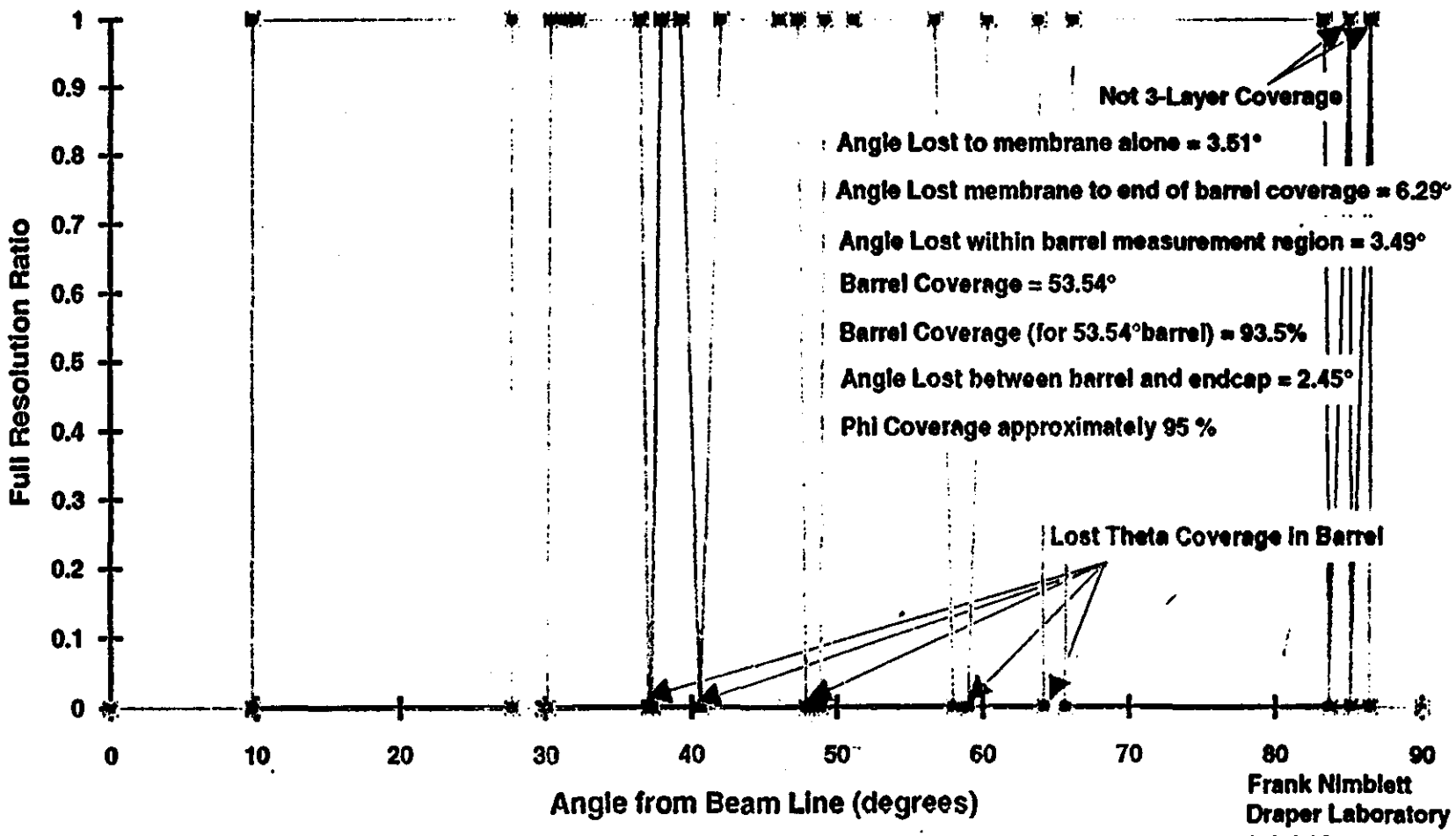
Projective Lines •••••

Barrel Parallel to Beam Line •••••

| | | |
|---|---|---|
| GEM Muon System (BASELINE) (Alignment Line Layout) | | |
| Drawn By | F. Nimblett | Rev (-) |
| Dwg. No: | GMU0013 | 6/30/92 |
| Approved By: | | |

# Theta Coverage for 2,3,4 PDT Chambers per Layer (Non-Projective)

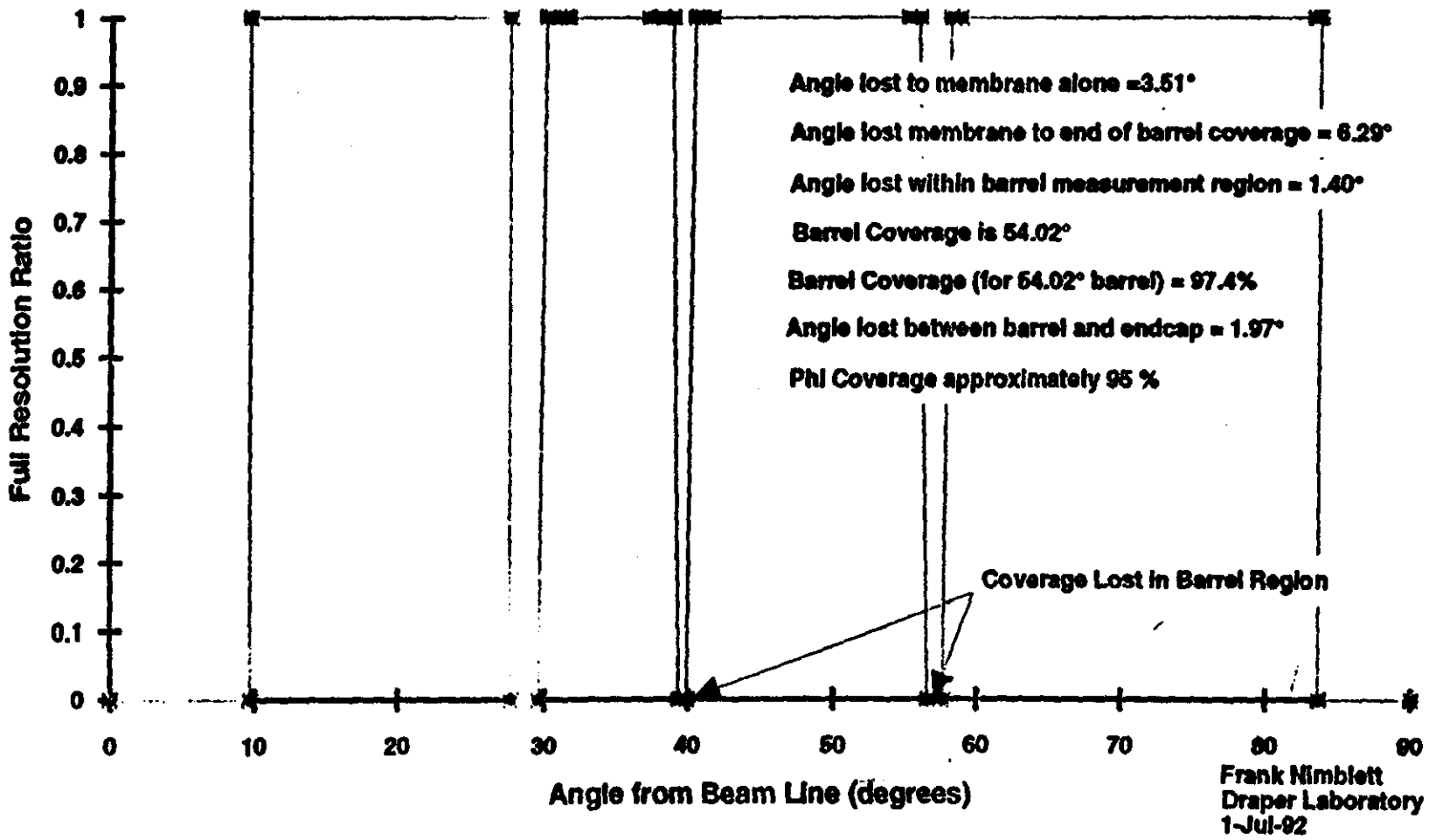
Mechanics on Chamber Ends is 150 mm and space between Chambers is 50 mm

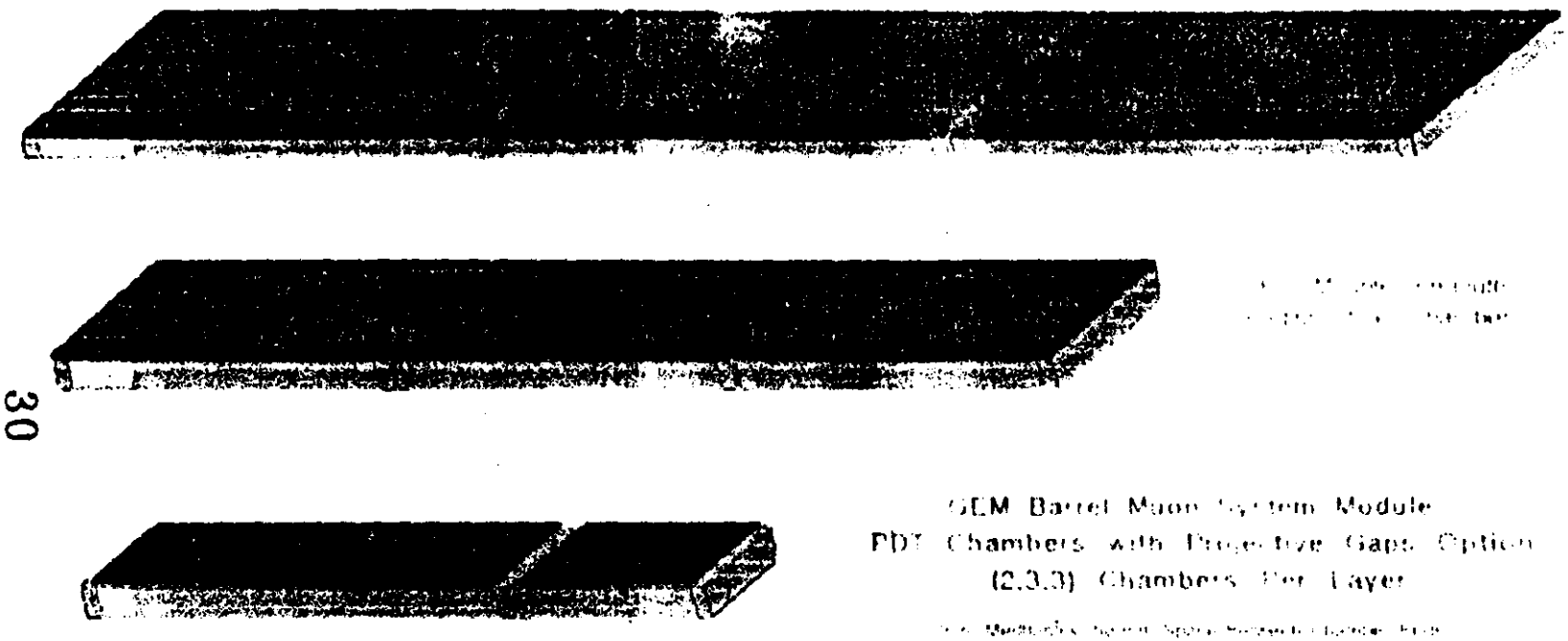



Frank Nimblett
Draper Laboratory
7-Jul-92

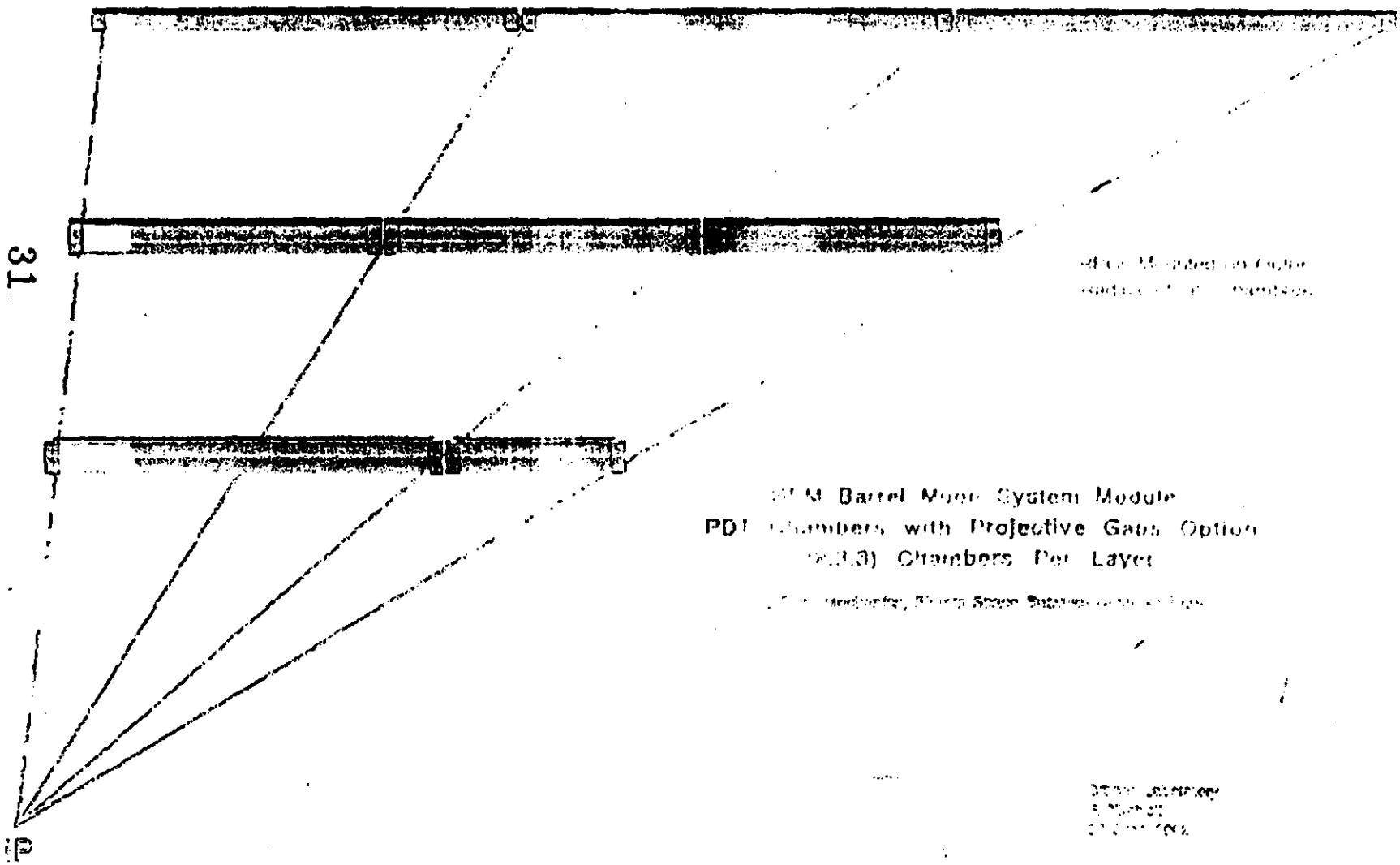
# Theta Coverage for 2,3,3 PDT Chambers per Layer (Projective)

**Mechanics on Chamber Ends is 150 mm and space between Chambers is 50 mm**



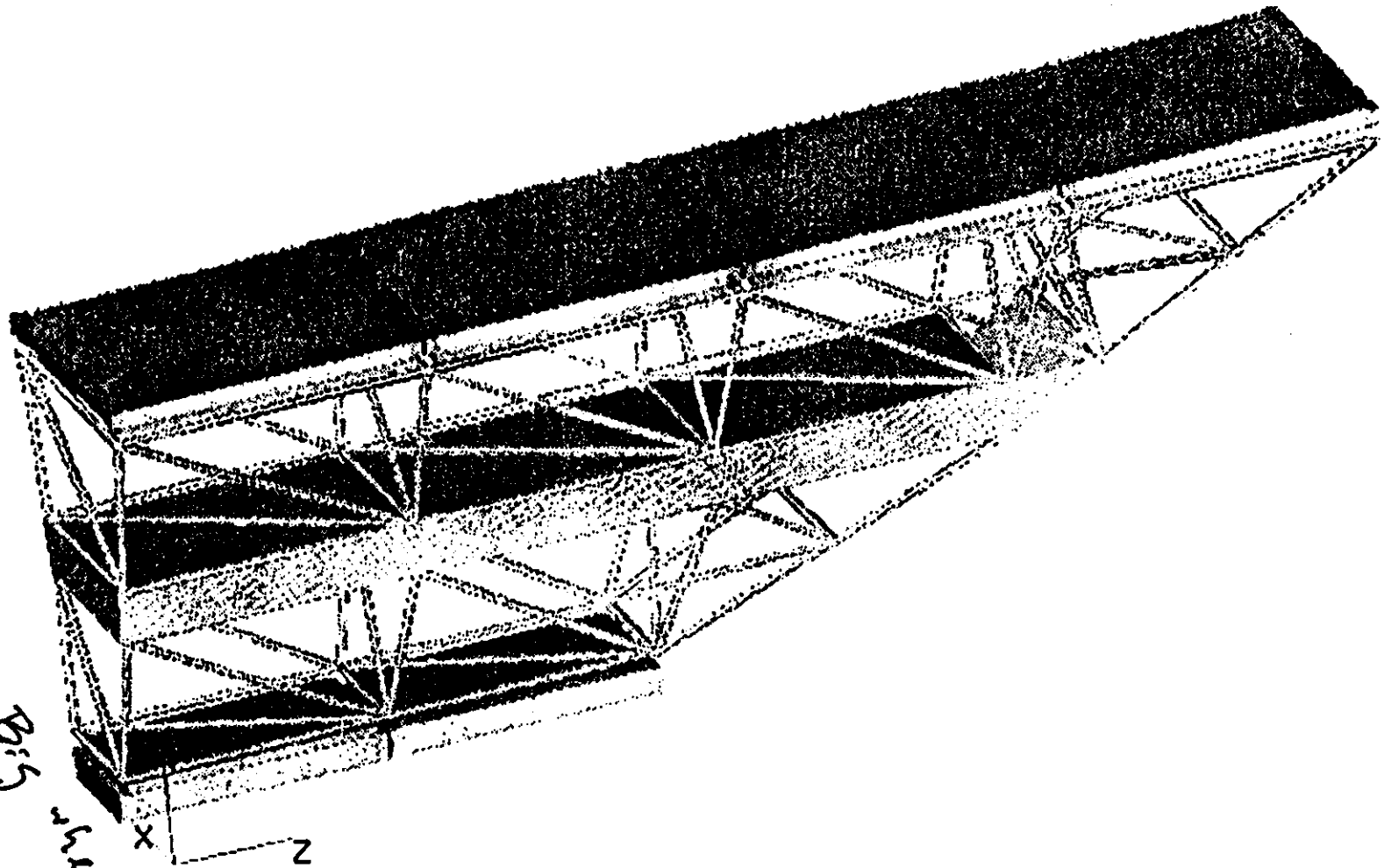


GEM Barrel Muon System Module
PDT Chambers with Projective Gaps Option
(2,3,3) Chambers Per Layer

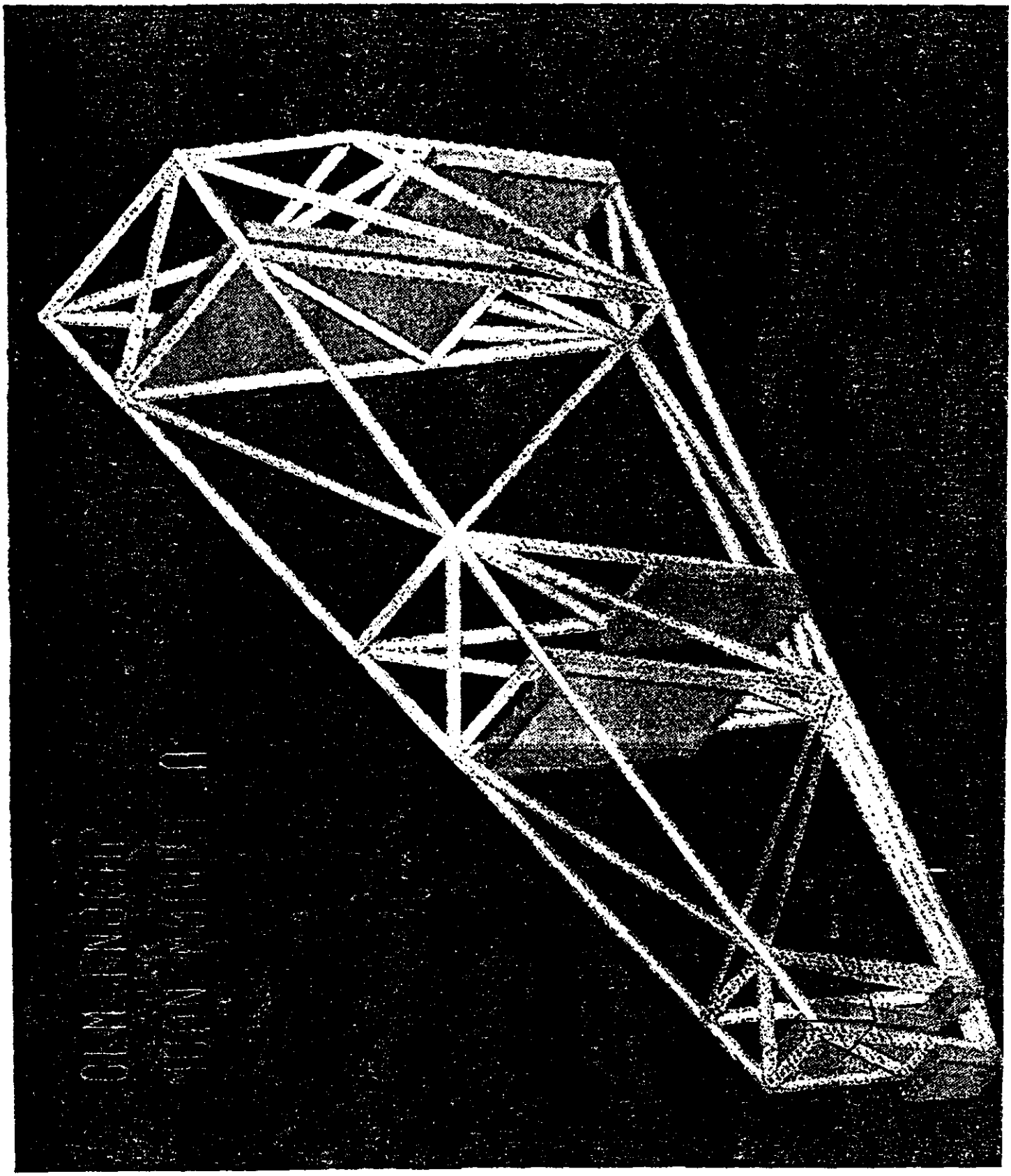

N Barrel Muon System Module
PDT Chambers with Projective Gaps Option
(3,3) Chambers Per Layer

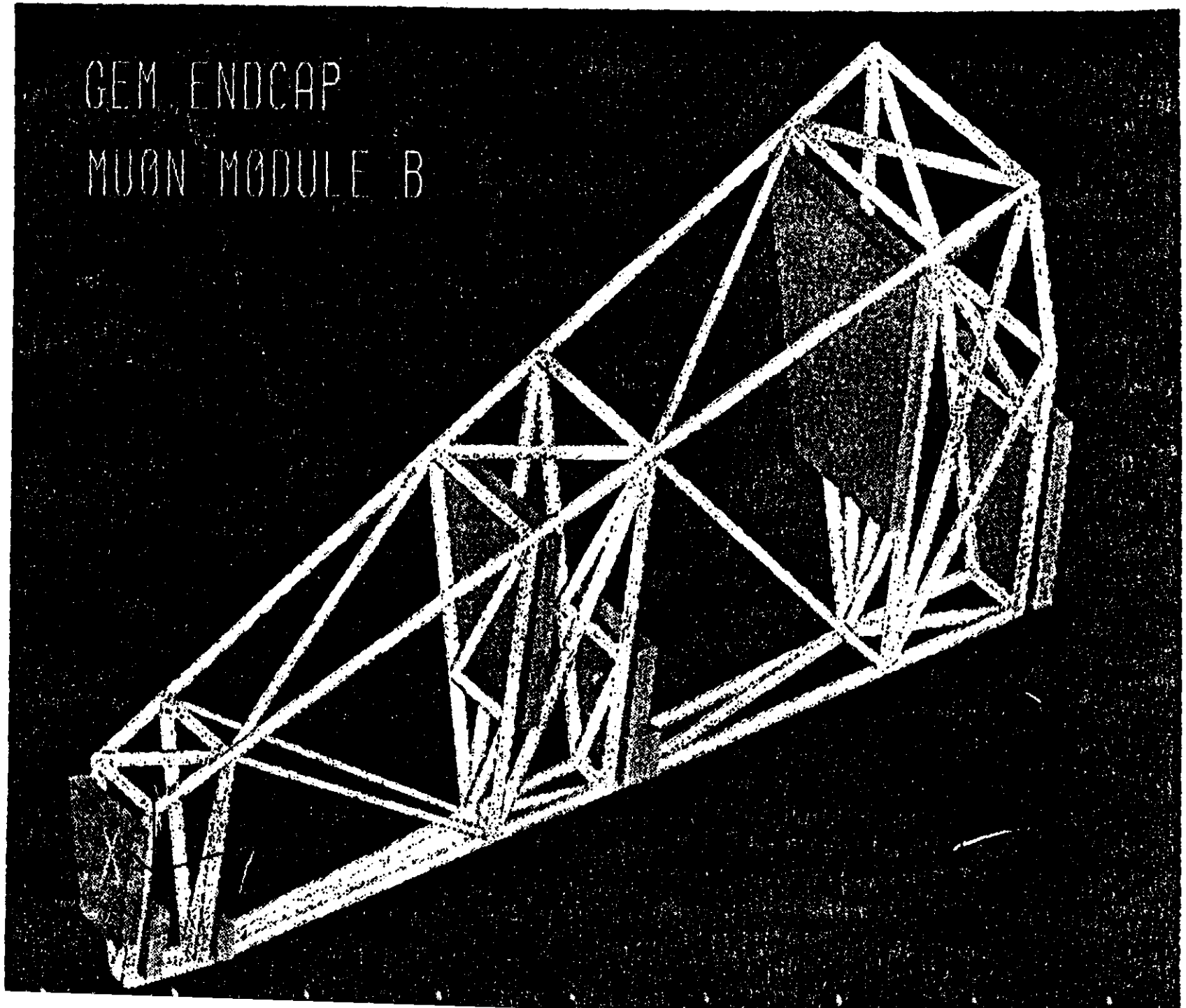
GEM BARREL REGION

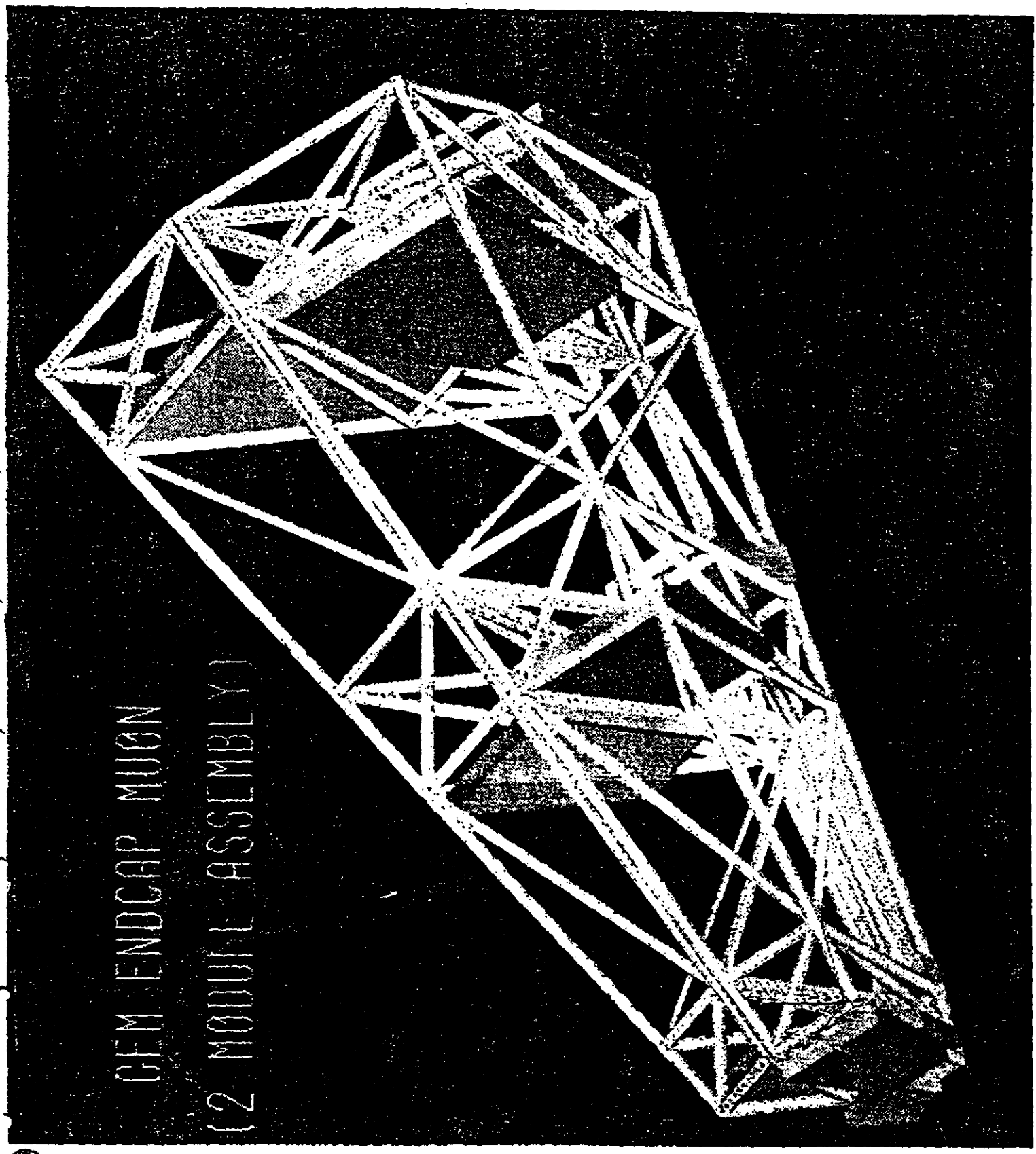
MUON MODULE




Big wheel vs. wedge

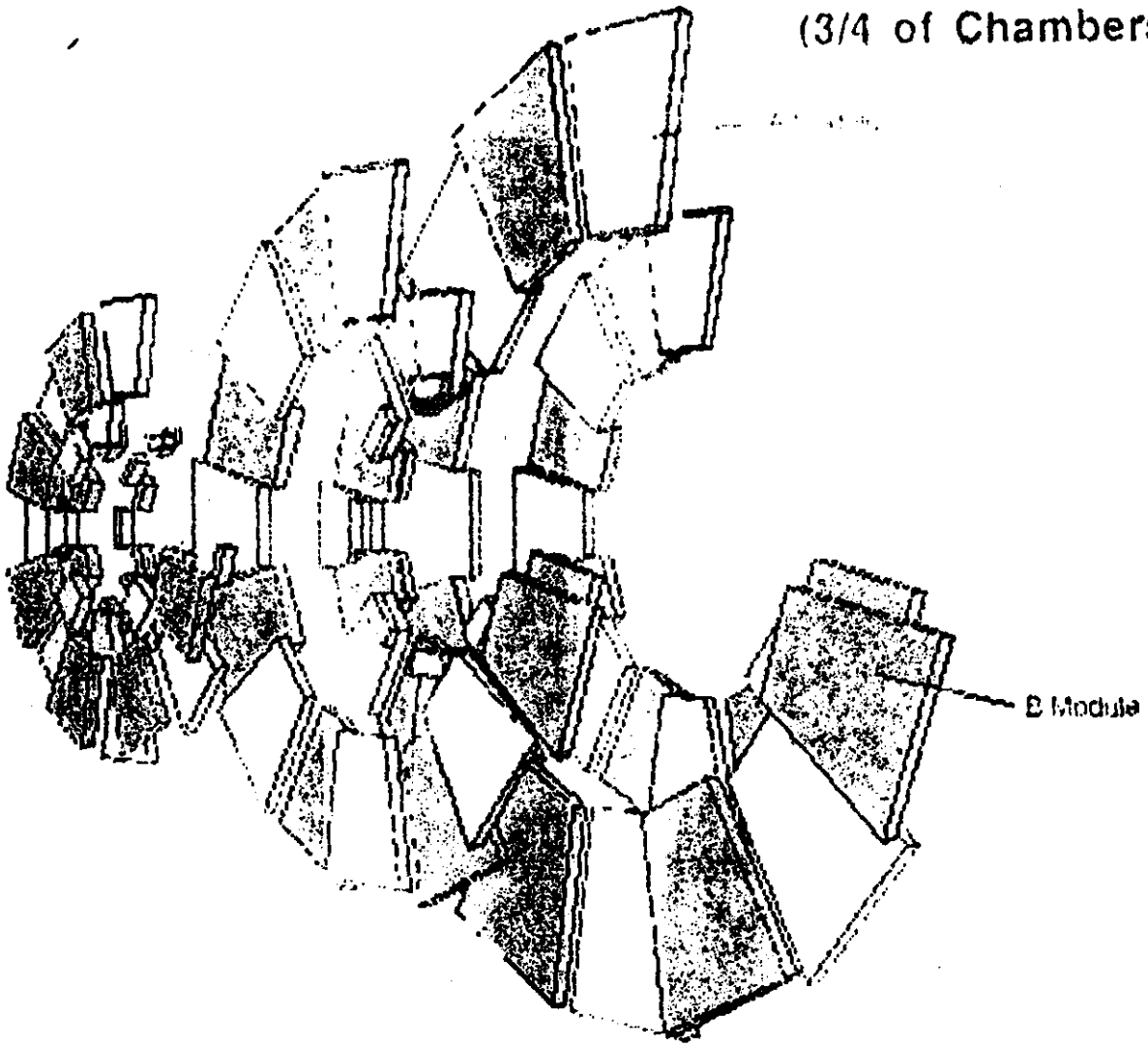



GEM ENDCAP
MUON MODULE B


CFM ENDCAP MUON
(2 MODULE ASSEMBLY)

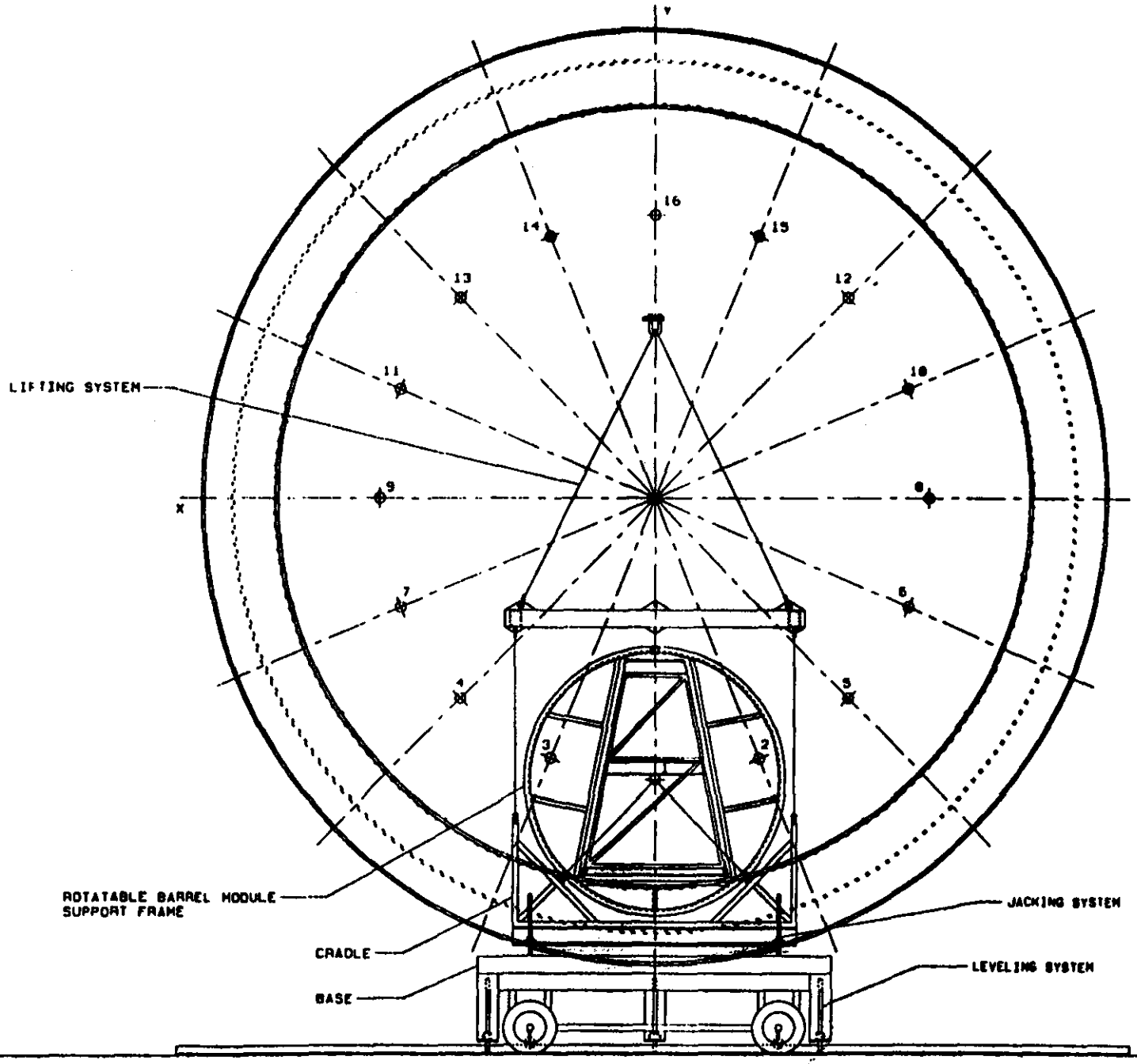
End Caps

## Cathode Strip Chambers
## Baseline Array
## (3/4 of Chambers Shown)

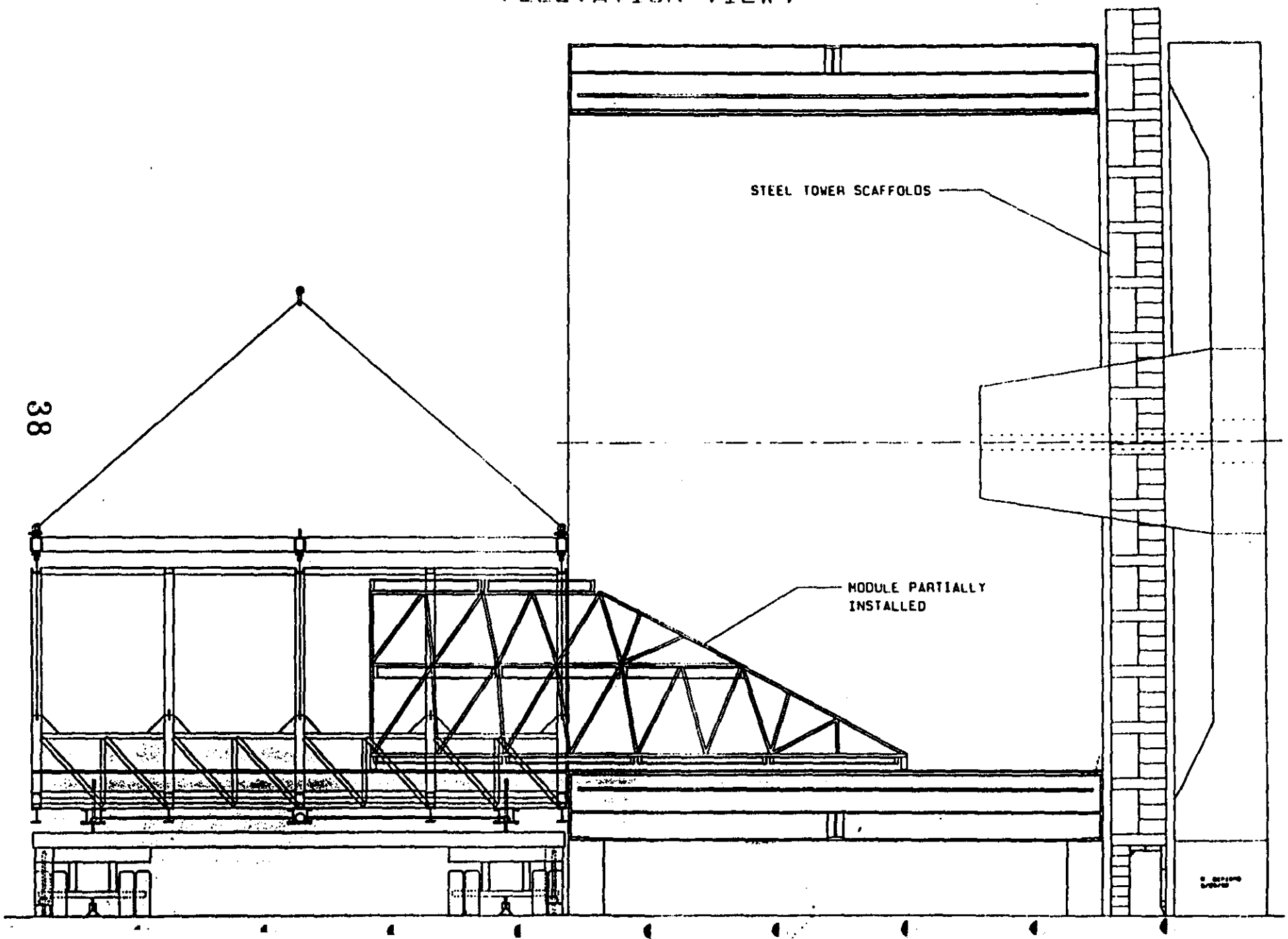



F. Nimblett
Draper Lab
5/2/92

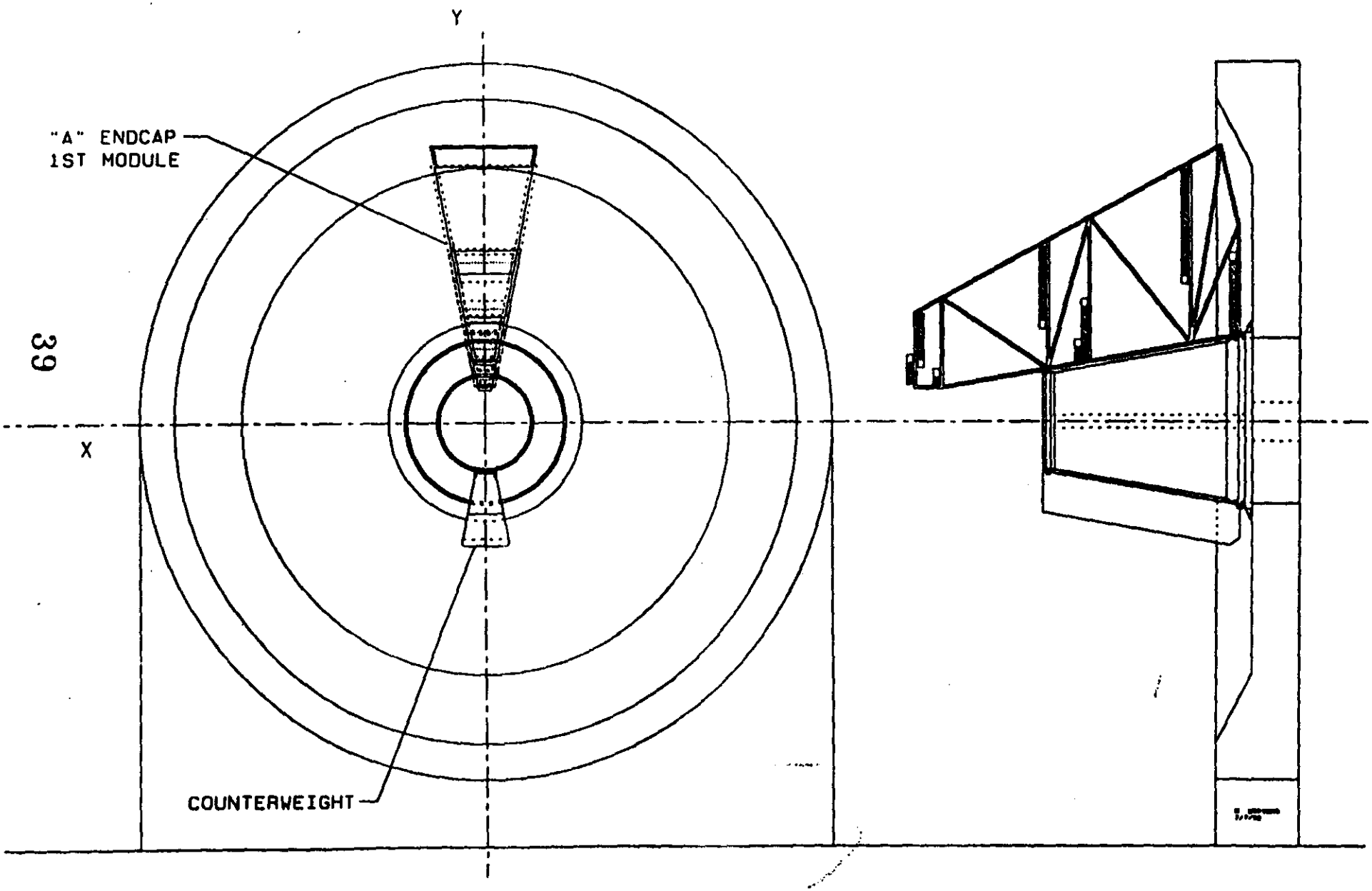
# BARREL REGION INSTALLATION
## (MODULE IN FRAME LOWERED ONTO INSTALLATION FIXTURE)



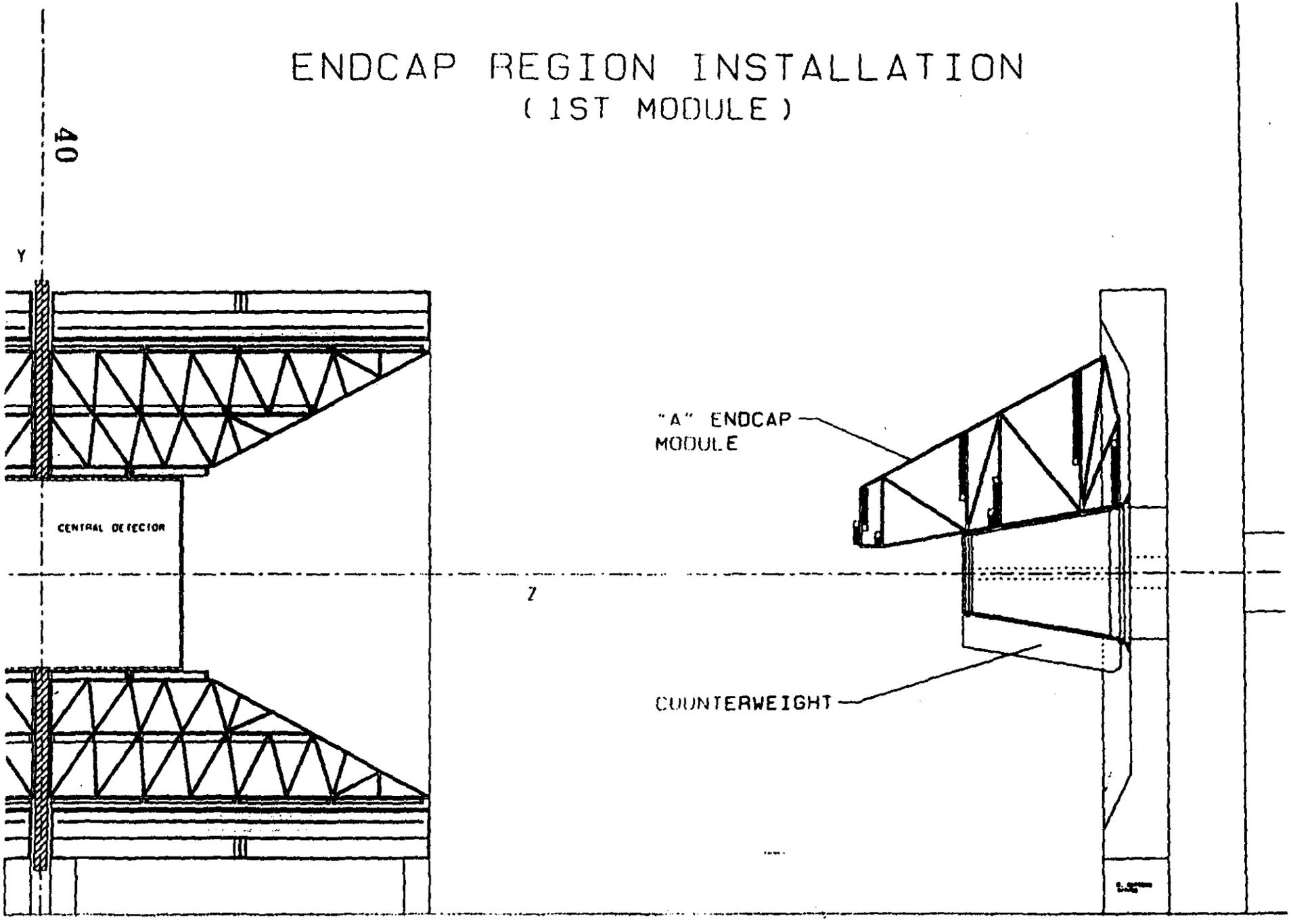
BARREL REGION INSTALLATION
(ELEVATION VIEW)



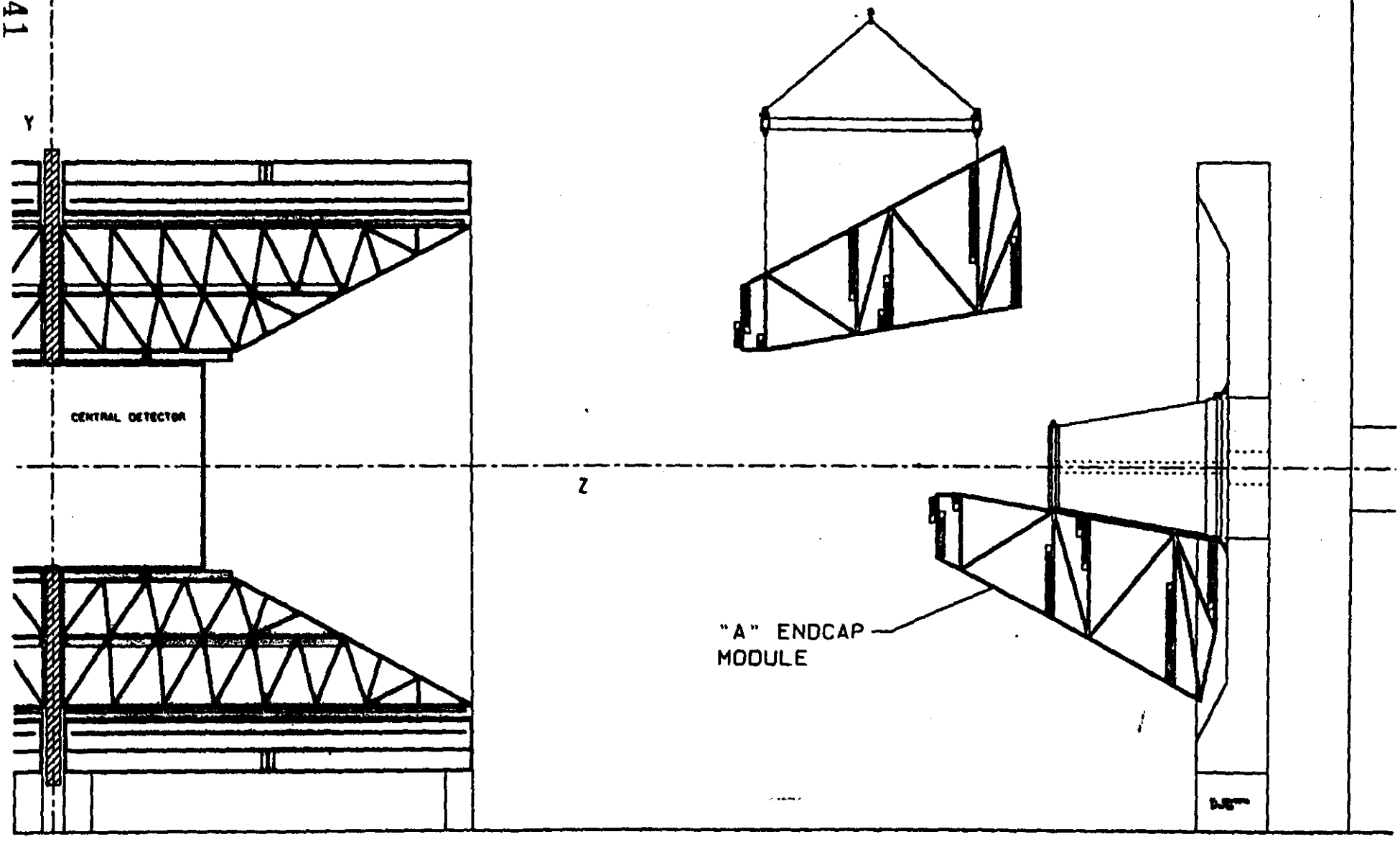
# ENDCAP REGION INSTALLATION
## ( 1ST MODULE )

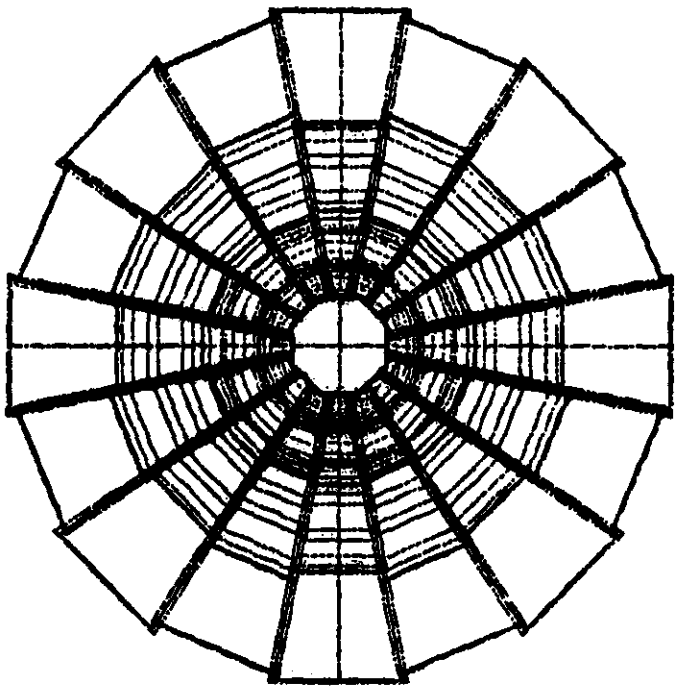


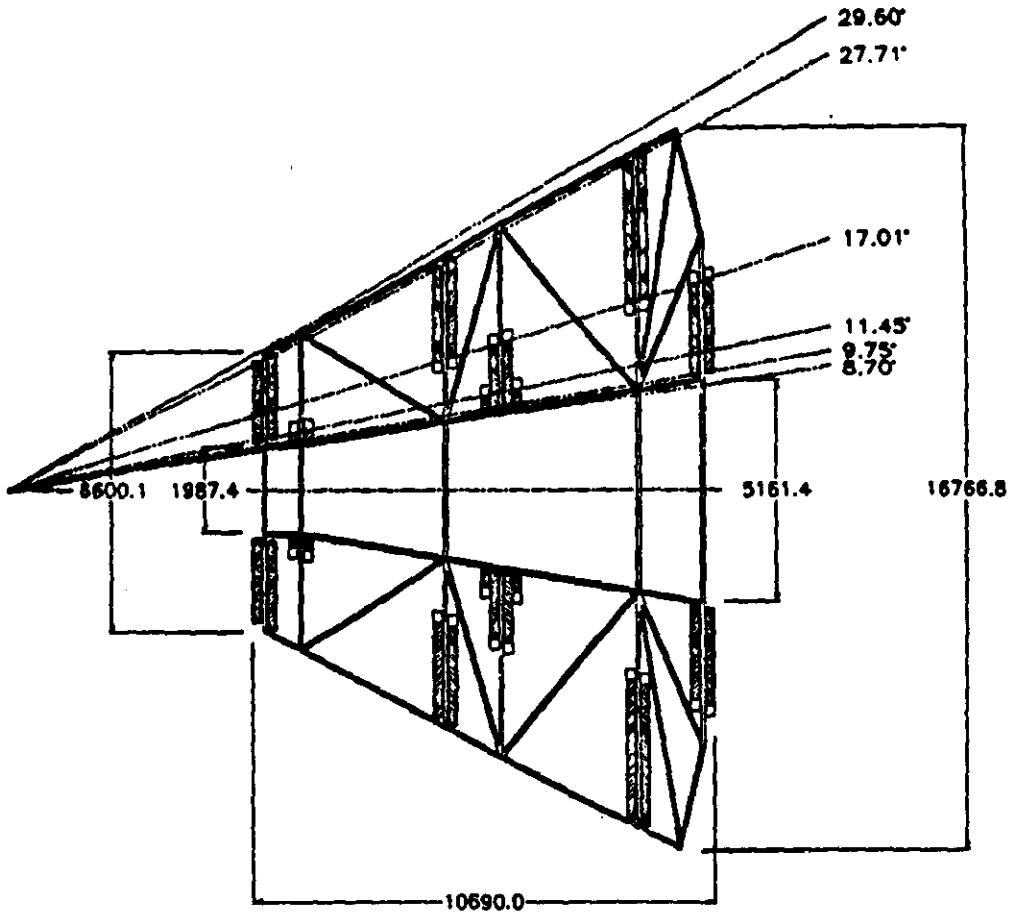
# ENDCAP REGION INSTALLATION
## ( 1ST MODULE )



# ENDCAP REGION INSTALLATION
## (2ND MODULE)



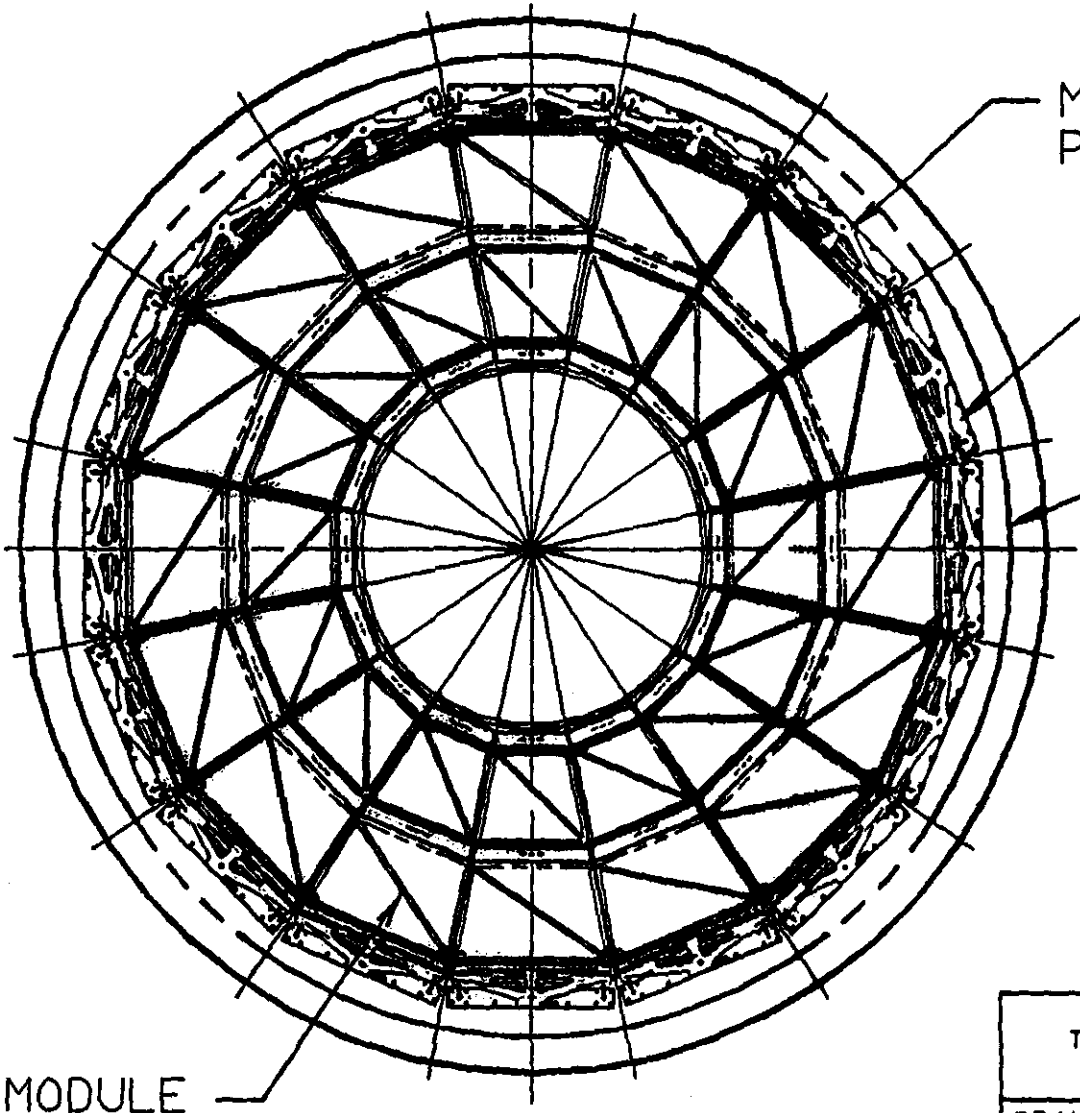





PART NO.
SEE PL

GEM ENDCAP MUON SYSTEM ASSEMBLY

E31993 292933




| | | |
|---|---|---|
| THE CHARLES STARK DRAPER LABORATORY INC. CAMBRIDGE, MASSACHUSETTS, 02139 | | |
| DRAWN BY B.D.BIGGIO | APPD BY | DATE 30JUN92 |
| GEM BARREL REGION MUON SYSTEM (END VIEW) | | |
| SIZE A / FSCM NO. 51993 | DRAWING NO. 292932-01 | REV - |
| SCALE NONE | | SHEET 1 OF |

# Notes

# CRITERIA FOR EVALUATION

# OF

# THE MUON SUPPORT STRUCTURE

# OPTIONS

Frank Nimblett
7/16/92

DRAFT

# Criteria For Evaluation Of The Muon Support Structure Options

**Options Under Consideration for the Barrel Region:**
- Independently supported muon modules (16 per end, 32 total)
- Monolithic Structure

**Options Under Consideration for the Endcap Region:**
- Independently installed muon modules (16 per end, 32 total) but tied together to form a monolith.
- Monolithic Structure

**Categories where evaluation criteria should be applied:**
- Structure Design (Barrel Region)
  - Long term Stability (Creep Characteristics to be less than (1??) micro inches per inch per year. For 6061-T6 aluminum, this implies a maximum stress of (14 ksi) which 50% of the micro yield stress (28ksi). This specification would be for all elements to permit the possibility of long term operation without physical adjustments exclusive of other disturbances.
  - Design structures to handle a minimum of (2.0 ??)g's in any planned orientation without exceeding the micro yield limits for the selected structure materials in order. This to maximize the possibility of maintaining alignment during handling operations.
  - Structure to be designed to accommodate the proposed Baseline 1.1 option which utilizes 2,3,3 PDT chambers per layer in the barrel in a manner that the lost space at the chamber ends is projective with respect to the IP.
  - Structure design should maximize both Phi and Theta angular coverage
  - Accessibility of chamber position adjustments with an emphasis on the middle chamber access.
- Assembly of structure (procedures (off-site vs on-site), fixtures, schedule (total time), and manpower)
- Fabrication and storage of chambers.
- Assembly of chambers into structure(procedures, fixtures, risk to chambers, schedule, manpower and effects on chamber design if applicable).
- Attachment of mechanical services (DC Power, HV, cables, gas lines and any other controls )
- Alignment of the three layers of chambers within the structure
- Testing of three layer modules on the surface (cosmic ray testing)
- Handling and storage of Modules or the Monolith
- Installation of muon system into the barrel (procedures, fixtures, risks, schedule (total time and coordination with other subsystems), manpower)
- Alignment following installation ??.
- Attachment and verification of cables and gas services.
- Options for replacement of chambers; do they exist and what are they ?

Frank Nimblett
Draper Laboratory
09 July 1992

# Muon MODULE vs The BIG WHEEL Concept

- Module Good Points
  - Concept of build, align, store and install proven at CERN (L3)
  - General concepts of compensation and easily applicable to Module
  - Physical Size is ONLY the size of a mobile home!
  - Access of personnel to portions of the module via simple staging, or suitable lifting devices appears best with a module concept .
  - Opportunity for consistent assembly process with compenstion for structural deformations exists.
  - Verification of alignment is accomlished by rotating module to the final orientation relative to gravity.
  - Potential for learning curve improvements for production seems high.
  - Actual mounting hardware can be used to maximize confidence in the validity of the alignment process. Fixturing appears relatively simple.
  - Use of cosmic rays for verification of operation and alignment also exists if straight-line monitors have adequate range or if adjustments can be easily made to bring them temporarily into range.(horizontal or near horizontal placement of the chambers is a benfit for this operation).
  - Cabling and Plumbing operations seem relatively easy for the module.
  - Option of removing an individual module exists for either barrel or endcap.

- Module Bad Points
  - This concept needs a special building "Muon Assy Building" plus storage space equivalent to the Magnet Assy Bldg. and the Magnet Coil Assy. Bldg.
  - Assembly schedule is currently setup to be finish as the last module is needed for installation to limit the storage capacity needs. Additional off-site storage could solve that problem.
  - Installation time appears very tight for both the barrel and endcap assemblies!
  - Endcap Installation still requires the joining of 16 modules per end into a "space-frame" structure. Unkown procedure to assure endcap alignment, but accessibility to endcap is quite good in comparison to the barrel region.
  - Chamber storage prior to installation is a problem for this system and the BIG WHEEL.

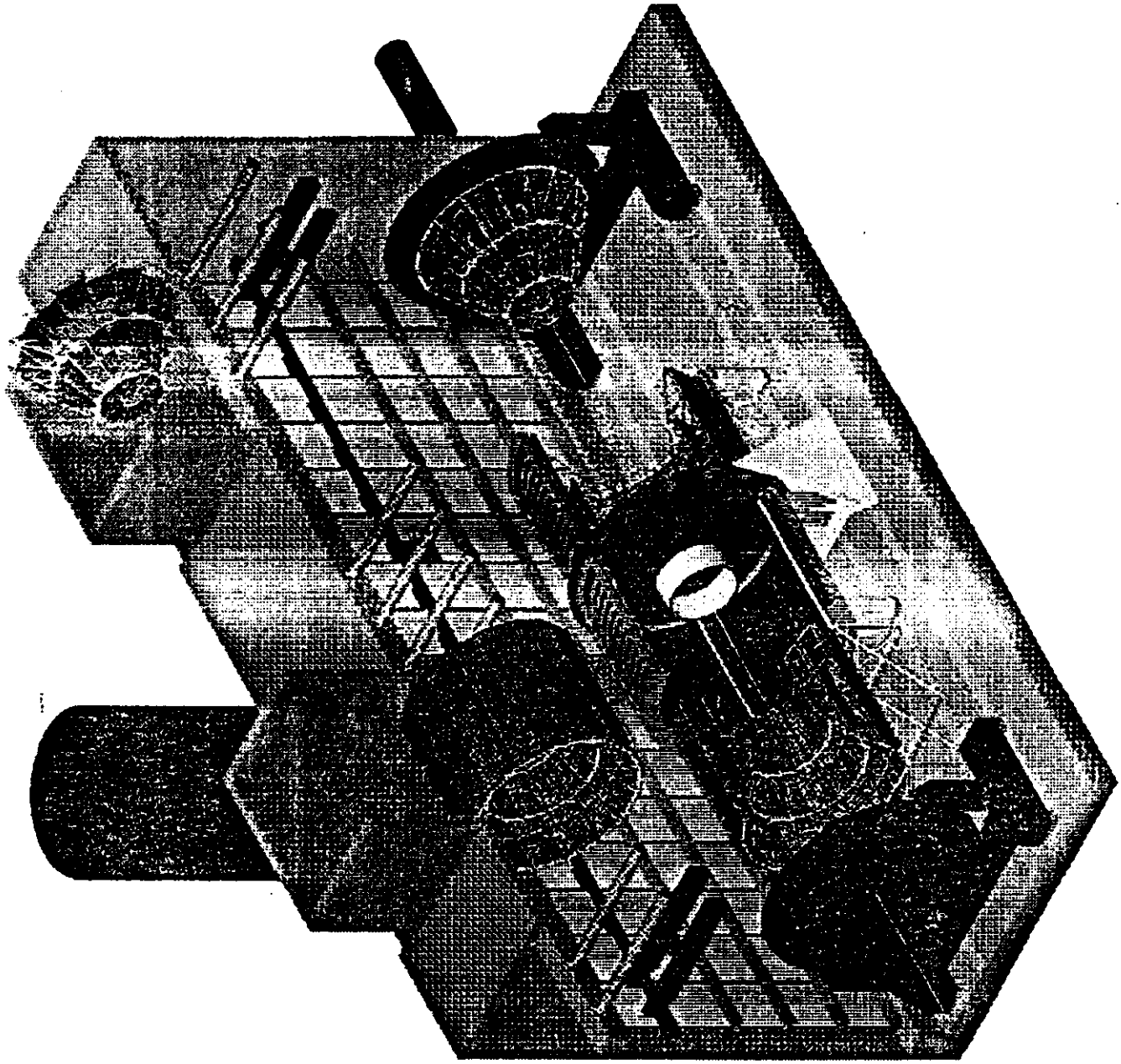
- BIG WHEEL Good Points

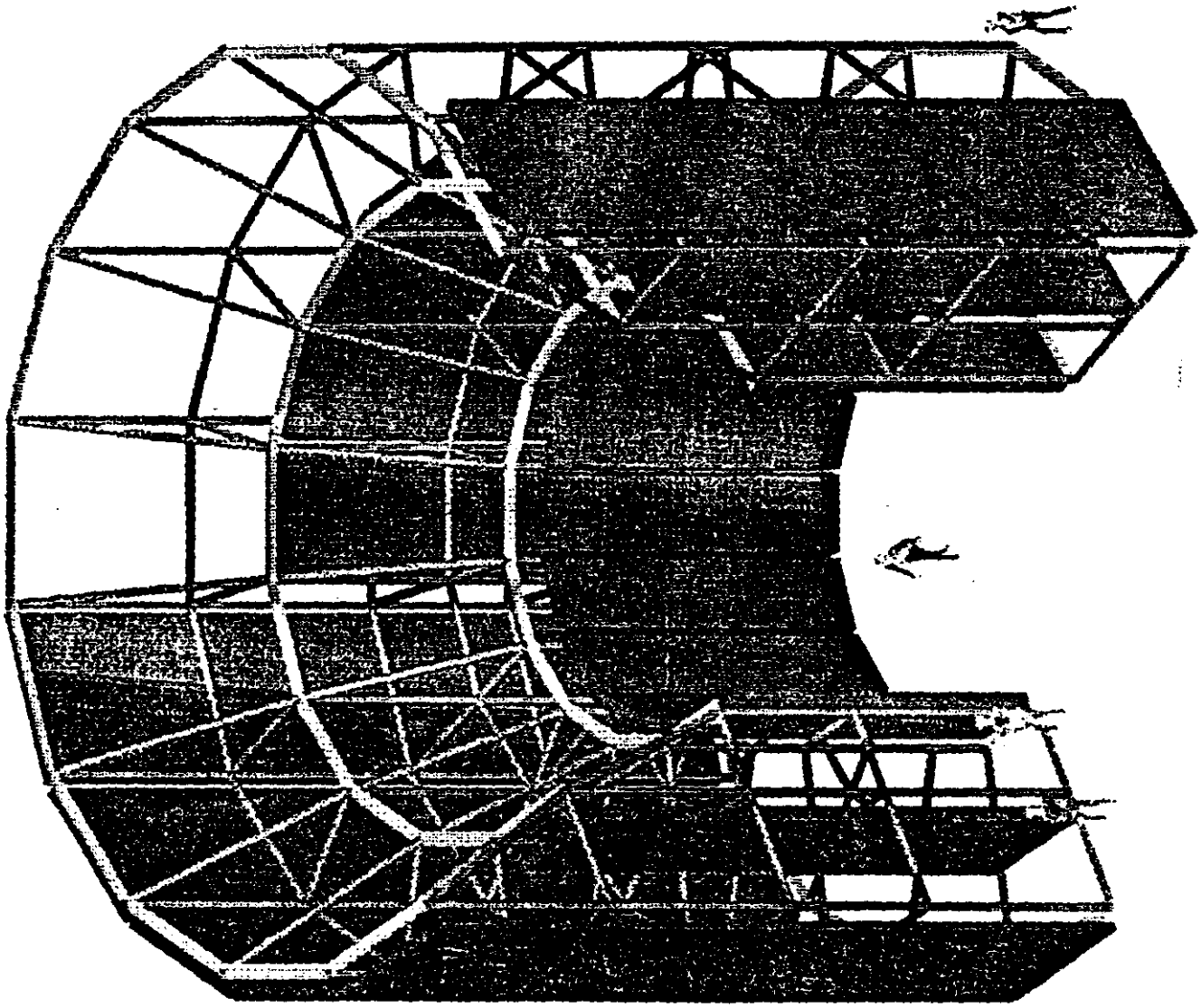
  - The ability to build one monolythic support structure for either the barrel or the endcap should maximize coverage of the selected region by minimizing material (no double dipping!)
  - The BIG WHEEL does only need the "Modified Magnet Assy. Building for assembly.
  - Installation time should be shorter than for the module.
  - Coordnation of installation with other subsystems should be easier due to the shorter time required.
  - Simple support system, duplicated prior to installation is a good feature, but doesn't appear better than than that offered by the individual module concept.

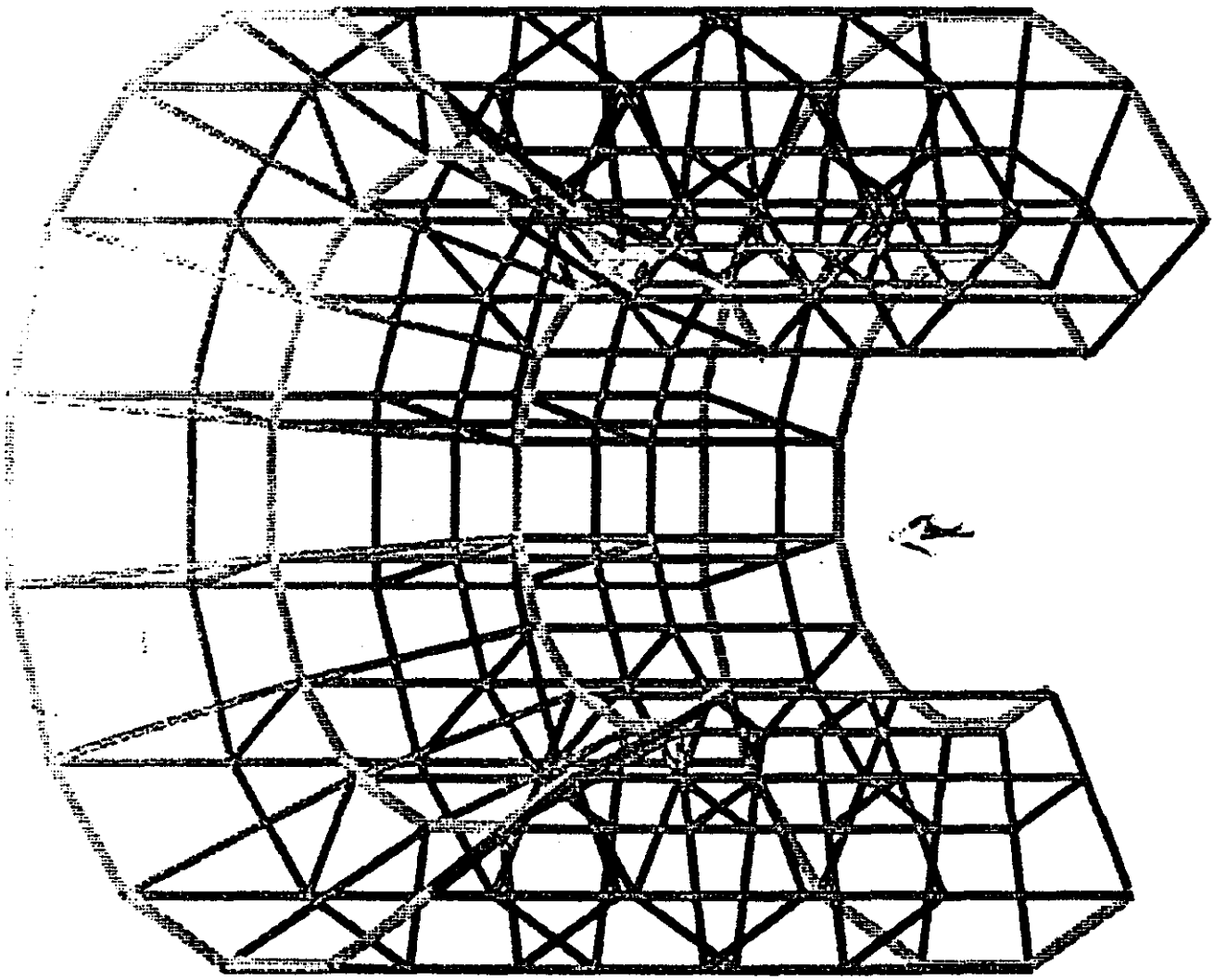
- BIG WHEEL Bad Points

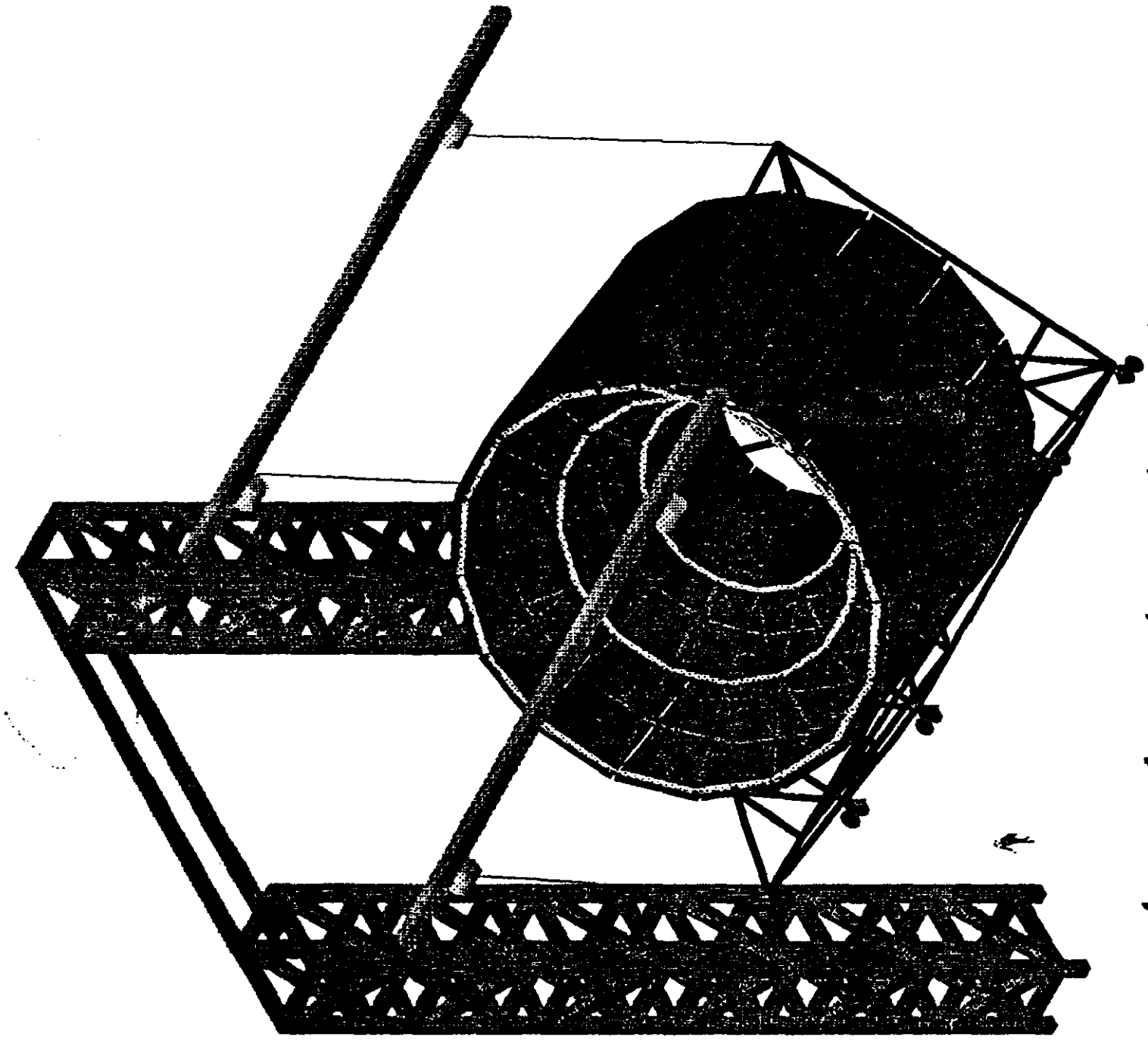
  - The size of this rather delicate asssembly is that of the magnet half for the barrel region.
  - Assembly sequence of vertical installation of chambers following by the rotation of the entire assembly to axis horizontal places additional demands on chamber interface axial restraints.
  - This rotation from vertical to horizontal appears risky and will certainly require some substantial fixturing and places additional demands ont the support structure.
  - The physical act of aligning these chambers in this structure appears very difficult at best. We are talking about something the size of a five story office building.
  - Accessibility to the chambers will be difficult! Remote actuation may be required (actually not a bad idea for
  - Compensation for structural deformations will have no benefit of an assembly learning curve.
  - Verification of alignment using cosmic rays does not appear to be good option for the side mounted chambers.
  - Point Loading characteristics for the BIG WHEEL could be nearly an order of magnitude higher than for an individual module.
  - The risk to alignment or damage while moving and then lowering this large and delicate structure into the underground hall and placing onto the temporary support tube appears higher than for the module.It is done only once however!
  - Option of removing an individual module does not exist.
  - What are the real cost savings for not having Muon Assy Bldg. but having to make substantial alterations of the Magnet Assy Bldg?

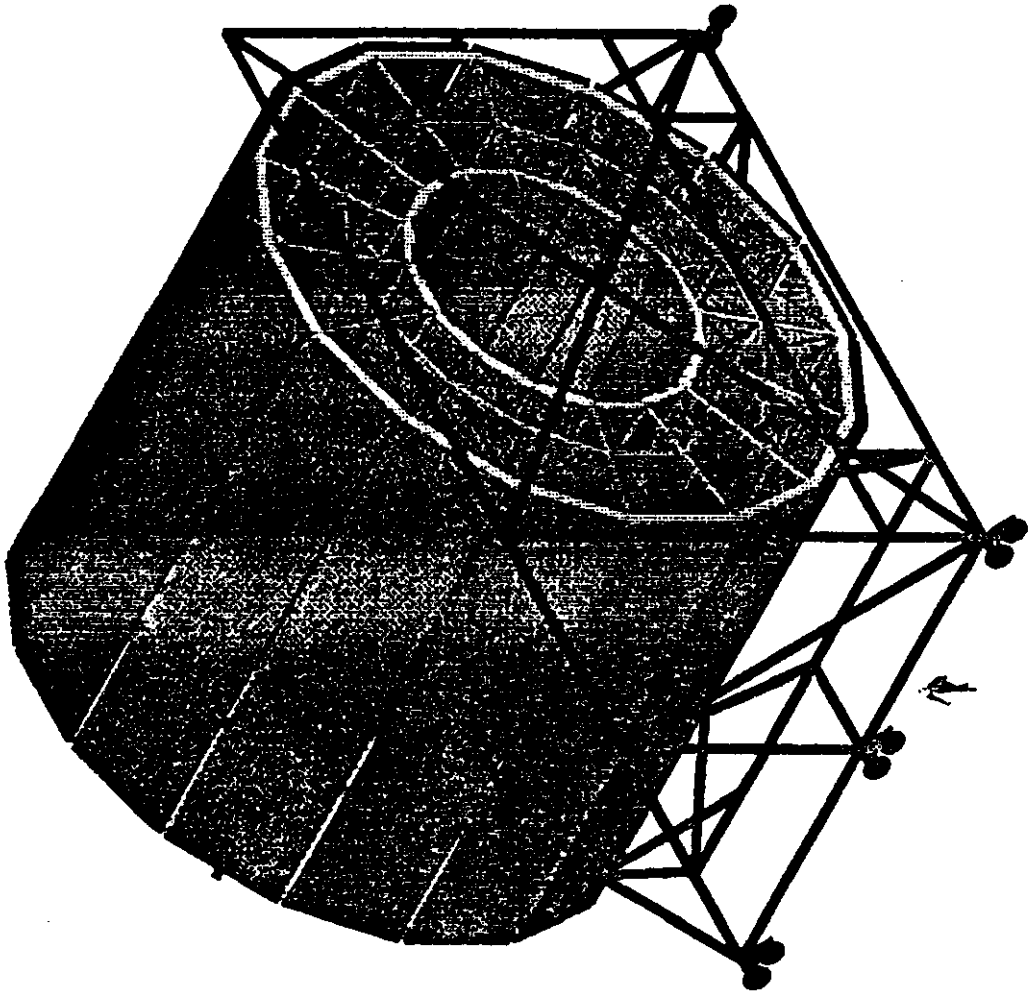
# Marx/SSCL

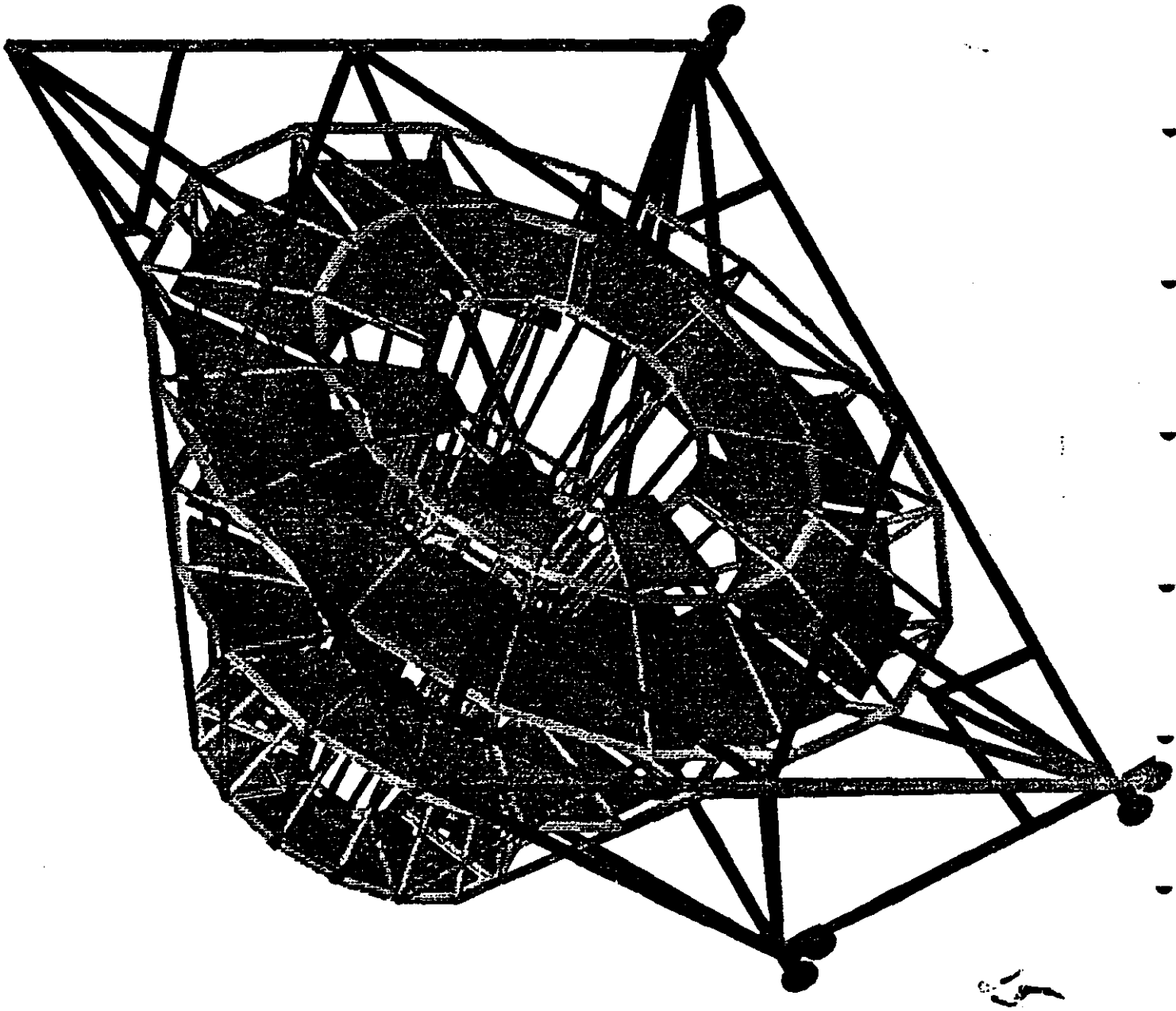


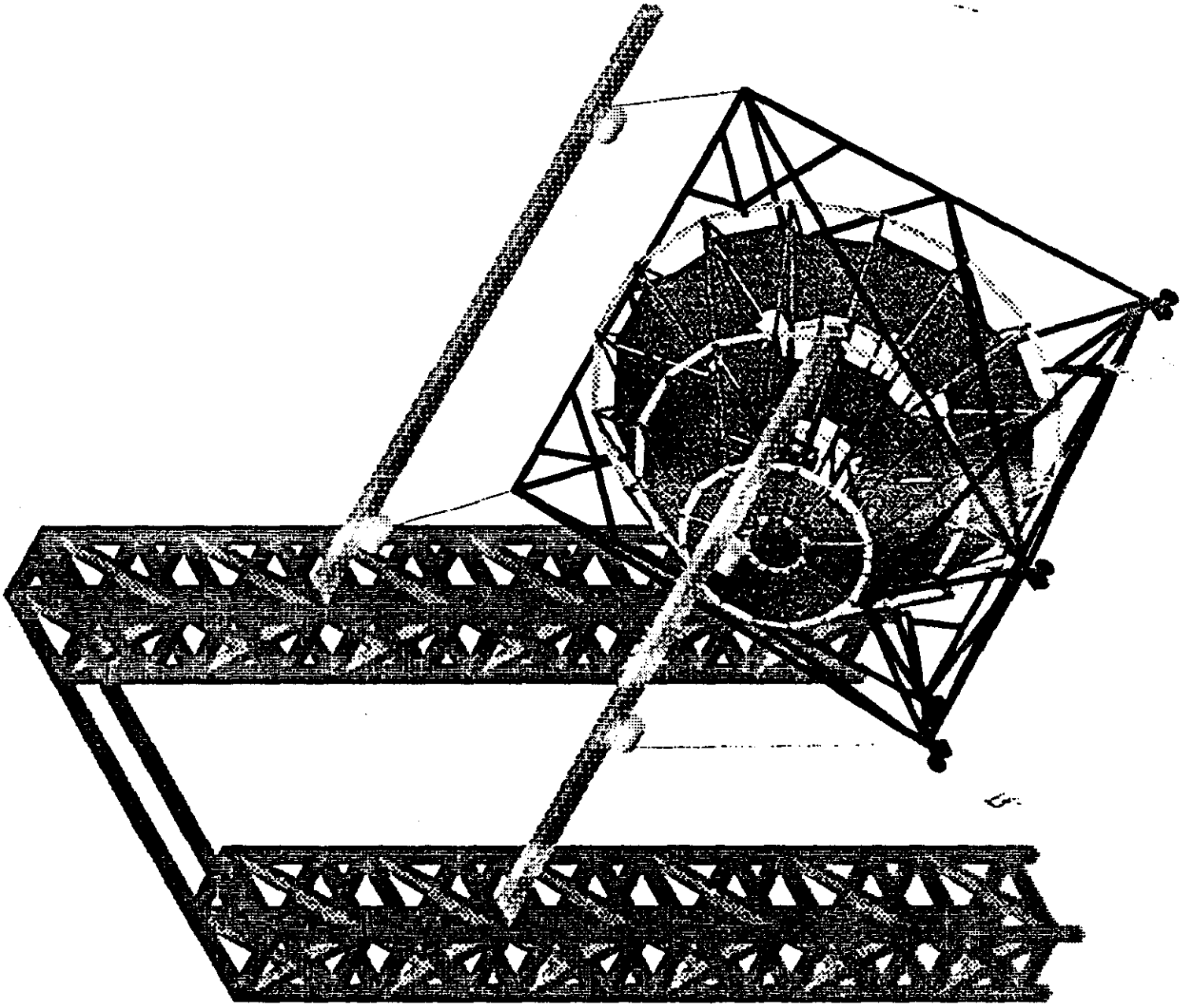


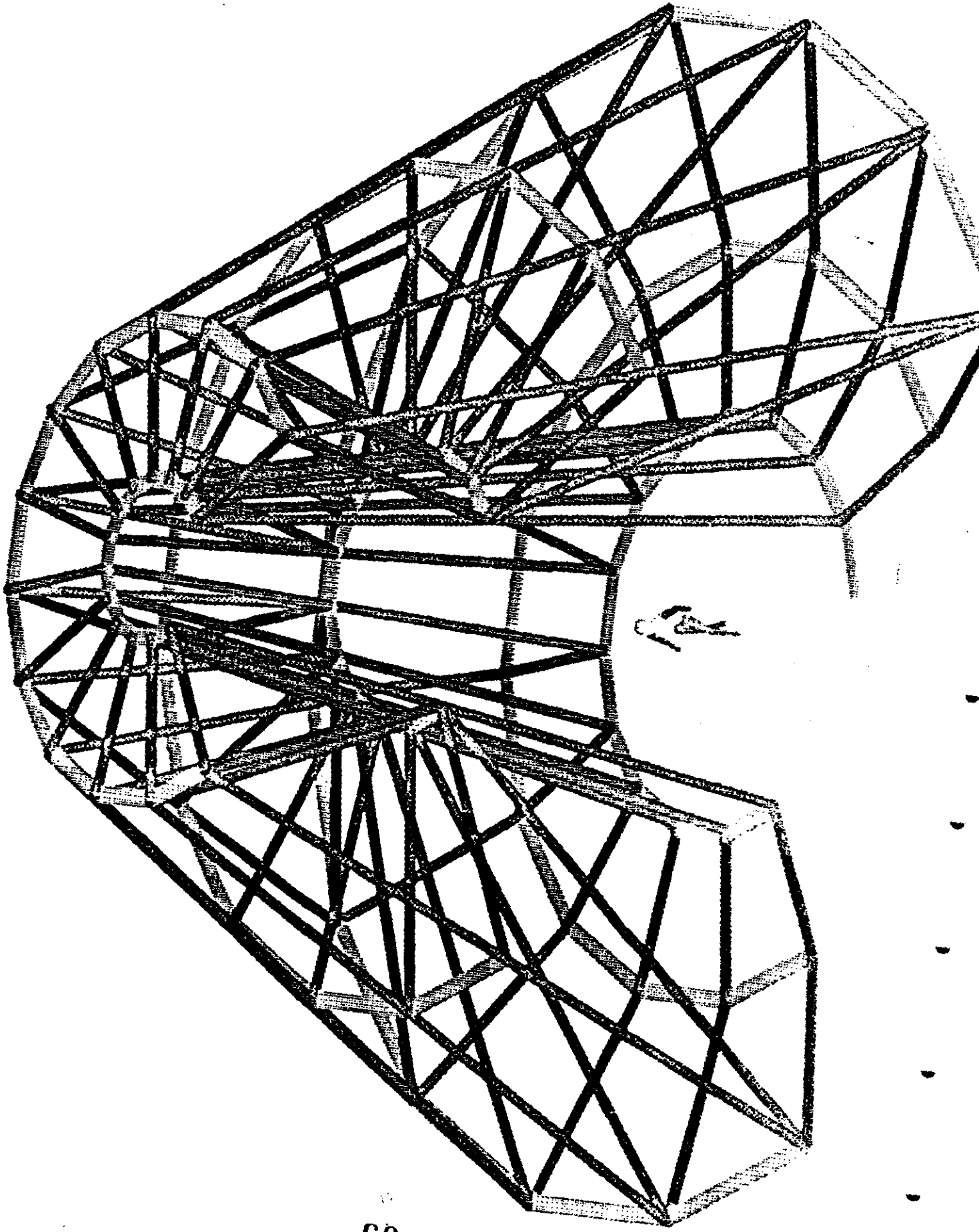




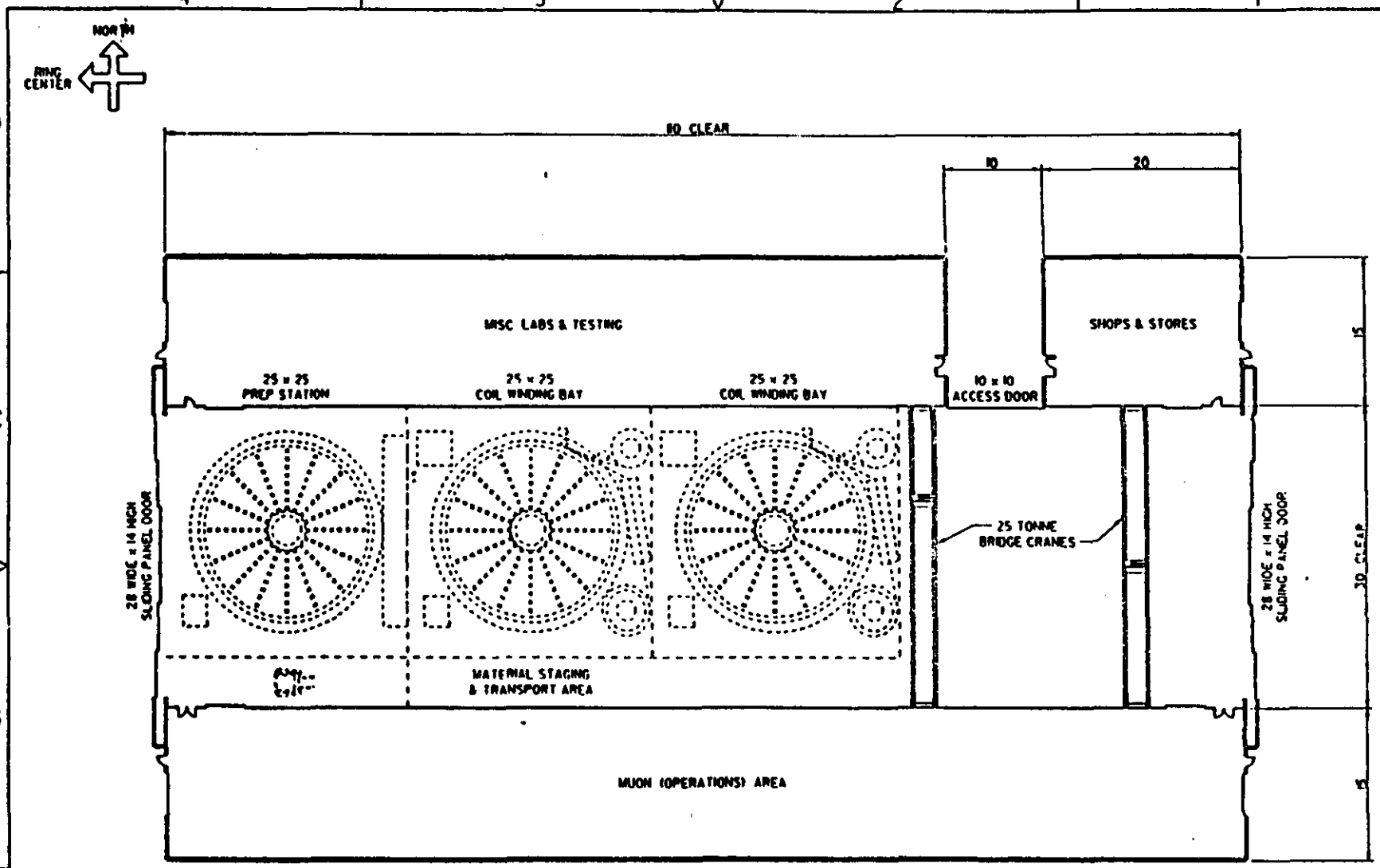








30.0
55.0
20.0
60.0
30.0
45.0
60.0
408.1
240.0




FLOOR PLAN

DIMENSIONS ARE SHOWN IN METERS UNLESS NOTED OTHERWISE.

THIS IS A CAD GENERATED DRAWING. DO NOT MAKE MANUAL REVISIONS OR ALTERATIONS.

PHYSICS RESEARCH DIVISION

SSC

GEM EXPERIMENTAL FACILITIES

COIL WINDING BUILDING

FLOOR PLAN

CCD-000201 | 003

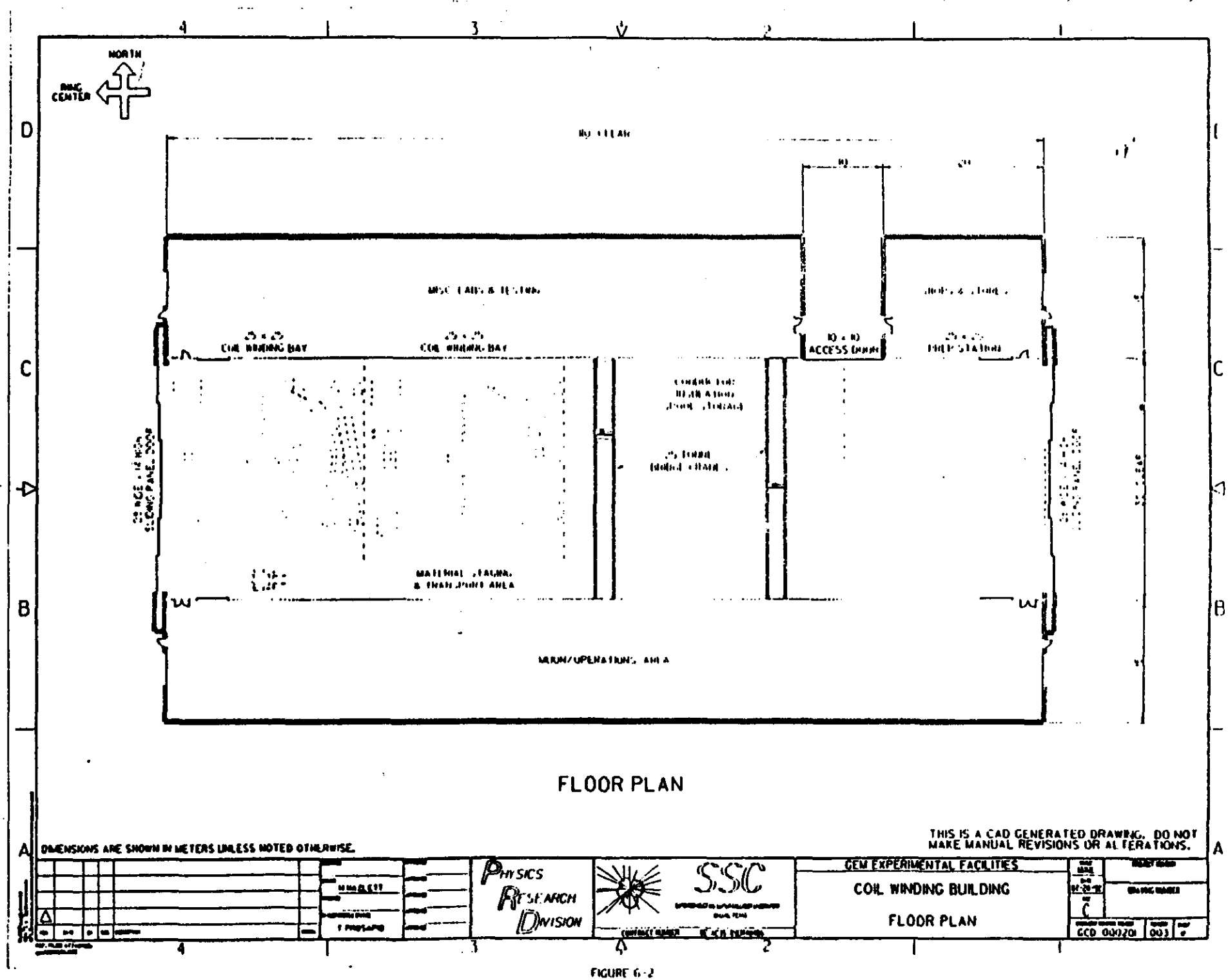
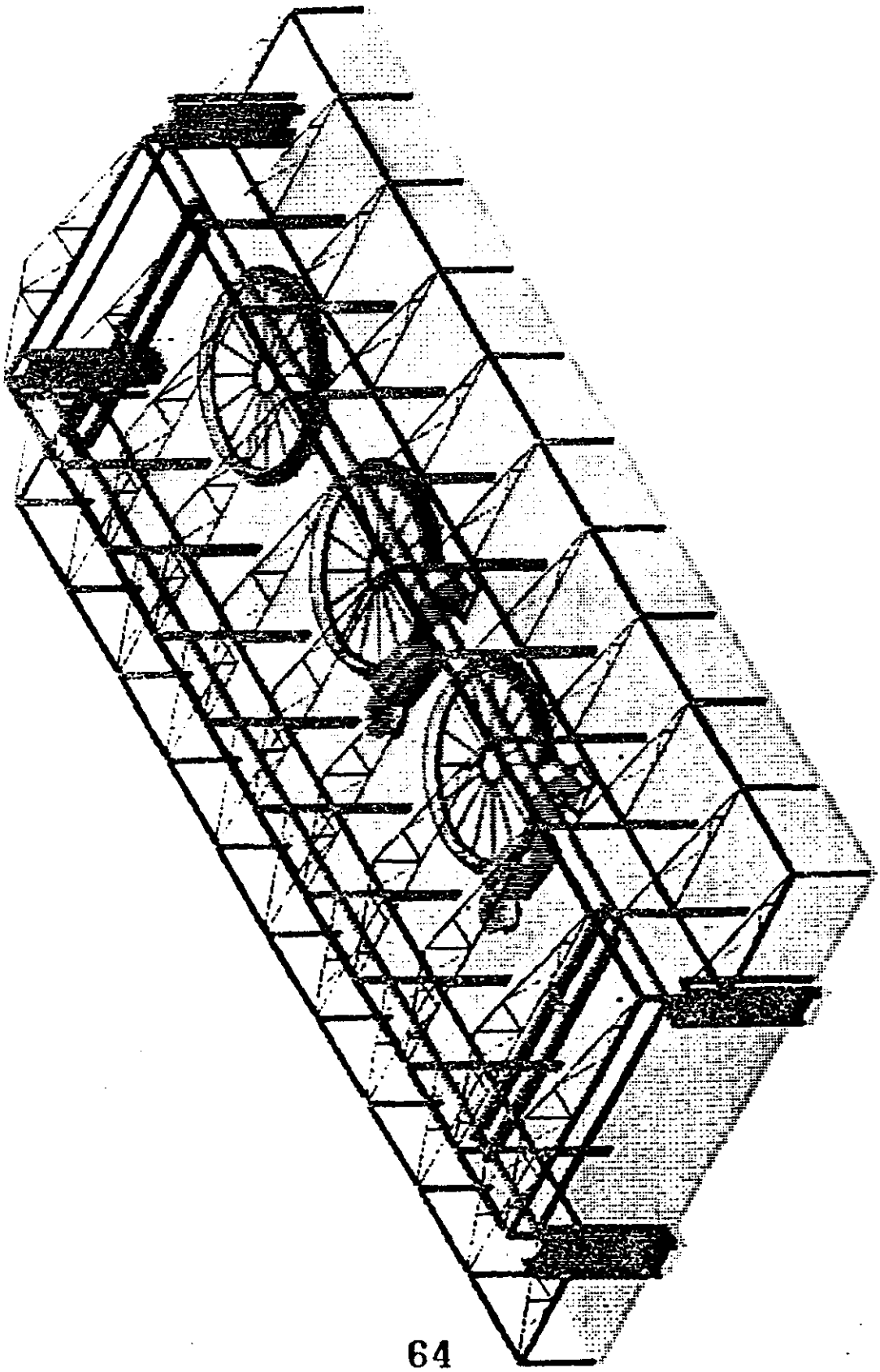
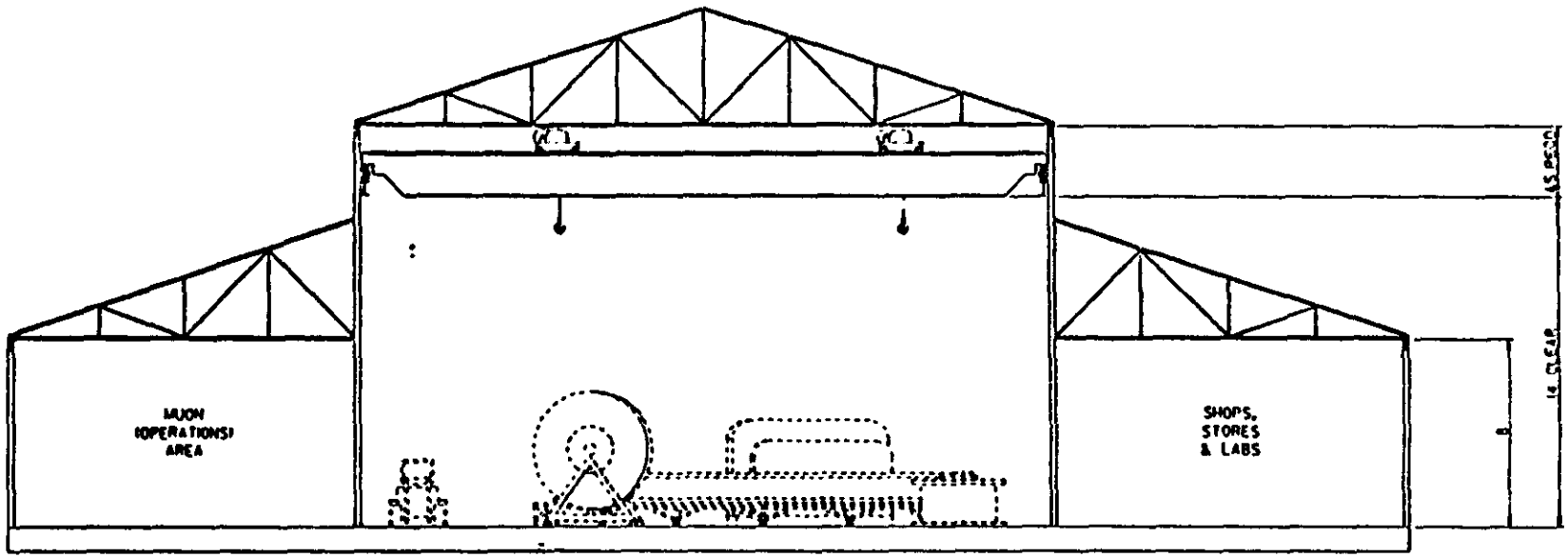

NORTH
RING CENTER
COIL WINDING BAY
COIL WINDING BAY
ACCESS DOOR
MATERIAL STAGING & TRANSPORT AREA
MAIN/OPERATIONS AREA
FLOOR PLAN
DIMENSIONS ARE SHOWN IN METERS UNLESS NOTED OTHERWISE.
THIS IS A CAD GENERATED DRAWING. DO NOT MAKE MANUAL REVISIONS OR ALTERATIONS.
PHYSICS RESEARCH DIVISION
SSC
GEM EXPERIMENTAL FACILITIES
COIL WINDING BUILDING
FLOOR PLAN
GCD 000201
003

FIGURE 6-2






DIMENSIONS ARE SHOWN IN METERS UNLESS NOTED OTHERWISE.

THIS IS A CAD GENERATED DRAWING. DO NOT MAKE MANUAL REVISIONS OR ALTERATIONS.

PHYSICS RESEARCH DIVISION

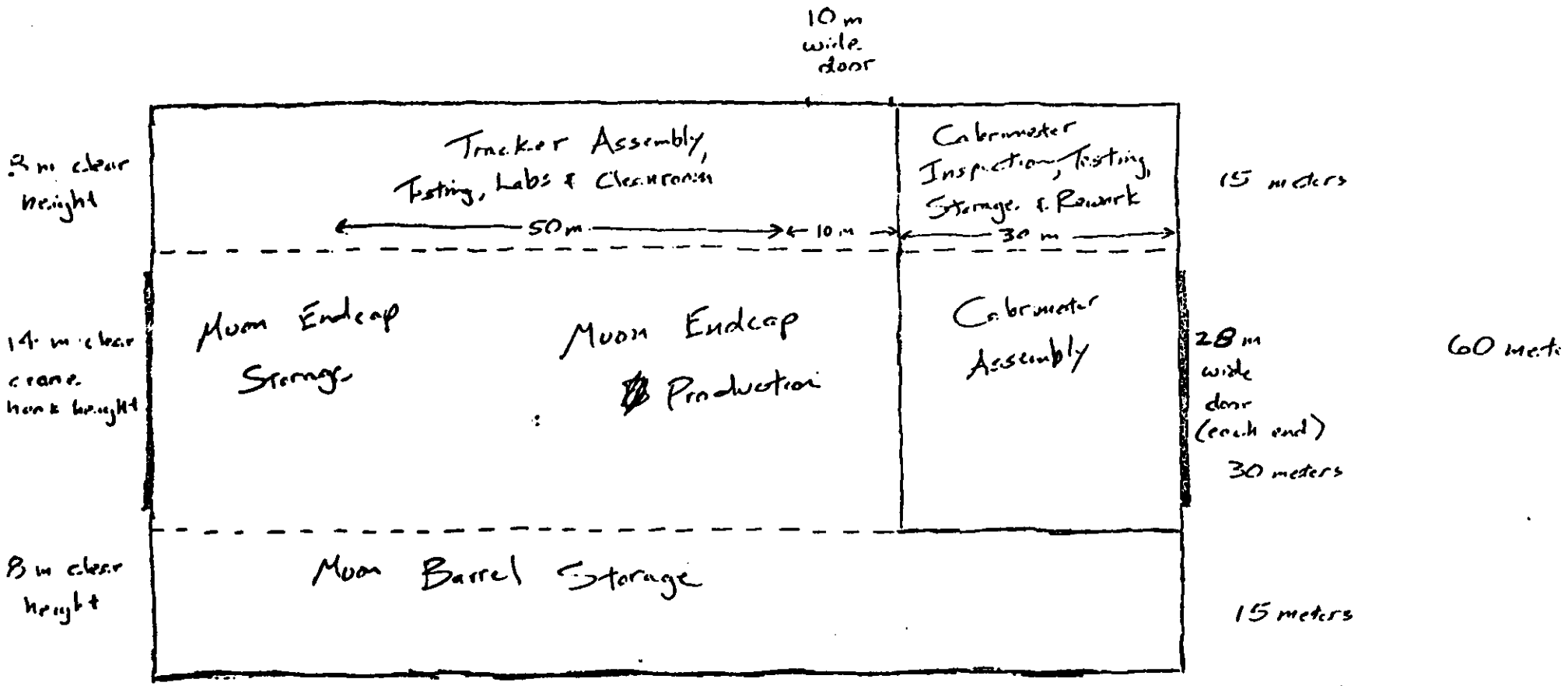
SSC

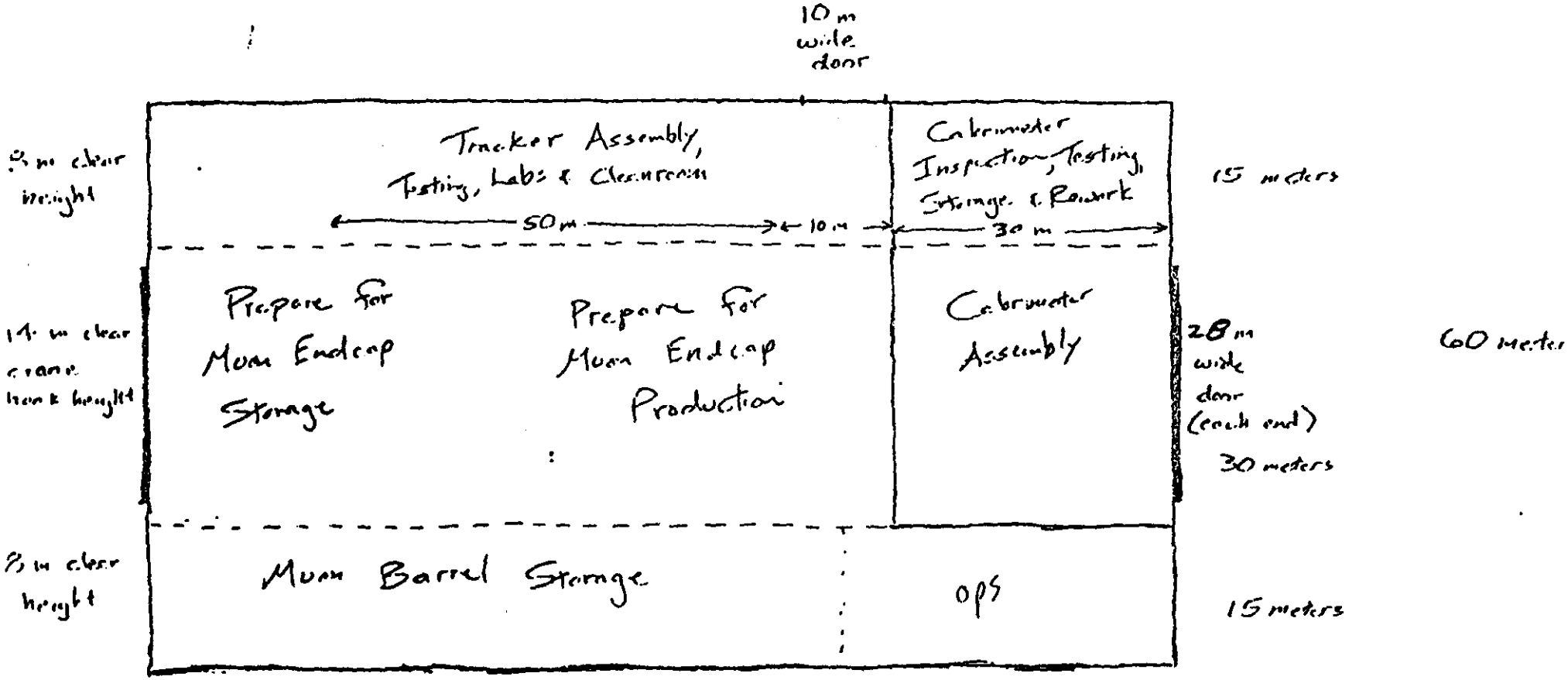
GEM EXPERIMENTAL FACILITIES

COIL WINDING BUILDING

SECTION

GCD-000202 003

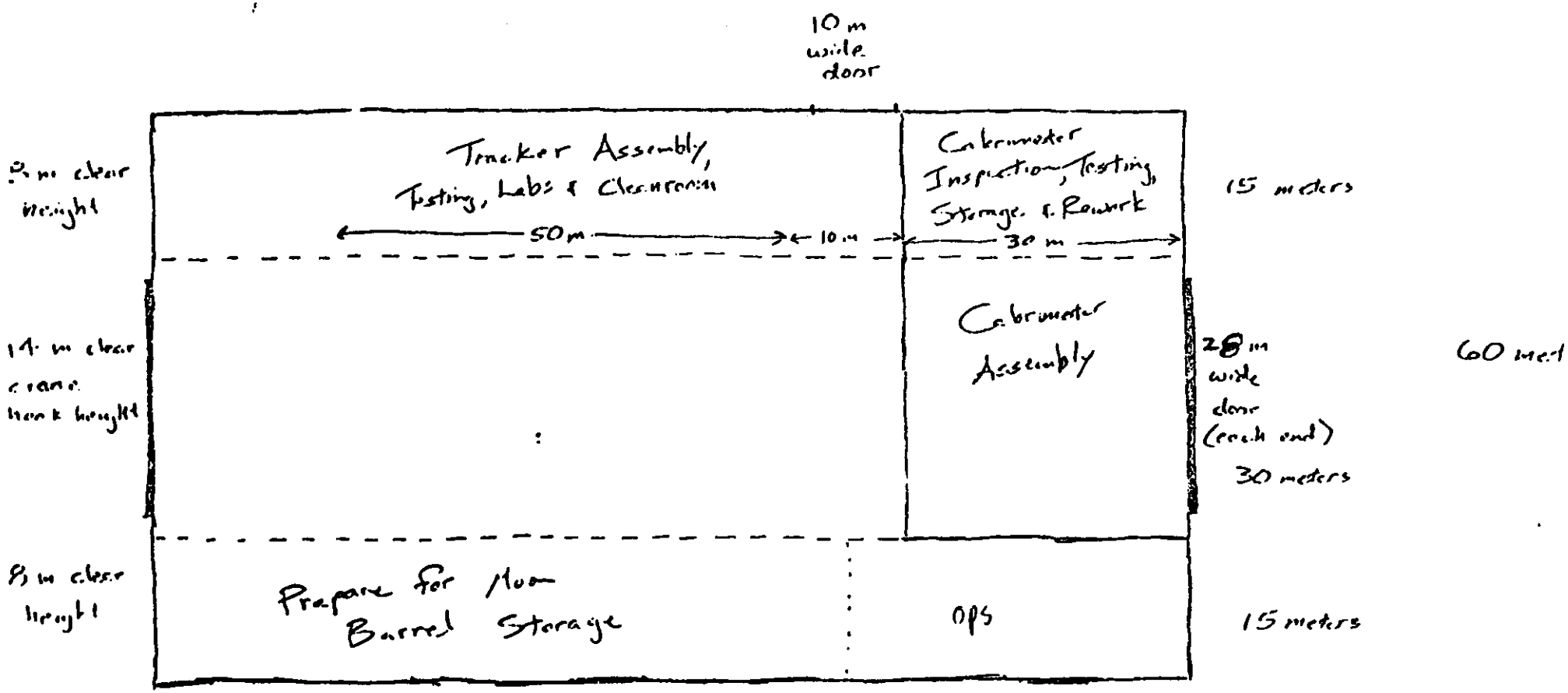

10 m wide door
8 m clear height
Tracker Assembly, Testing, Labs & Cleanroom
50 m
10 m
Calorimeter Inspection, Testing, Storage & Rework
30 m
15 meters
14 m clear crane hook height
Muon Endcap Storage
Muon Endcap Production
Calorimeter Assembly
28 m wide door (each end)
30 meters
60 meter
8 m clear height
Muon Barrel Storage
15 meters
110 meters
Dec. '96 .. Dec. '97

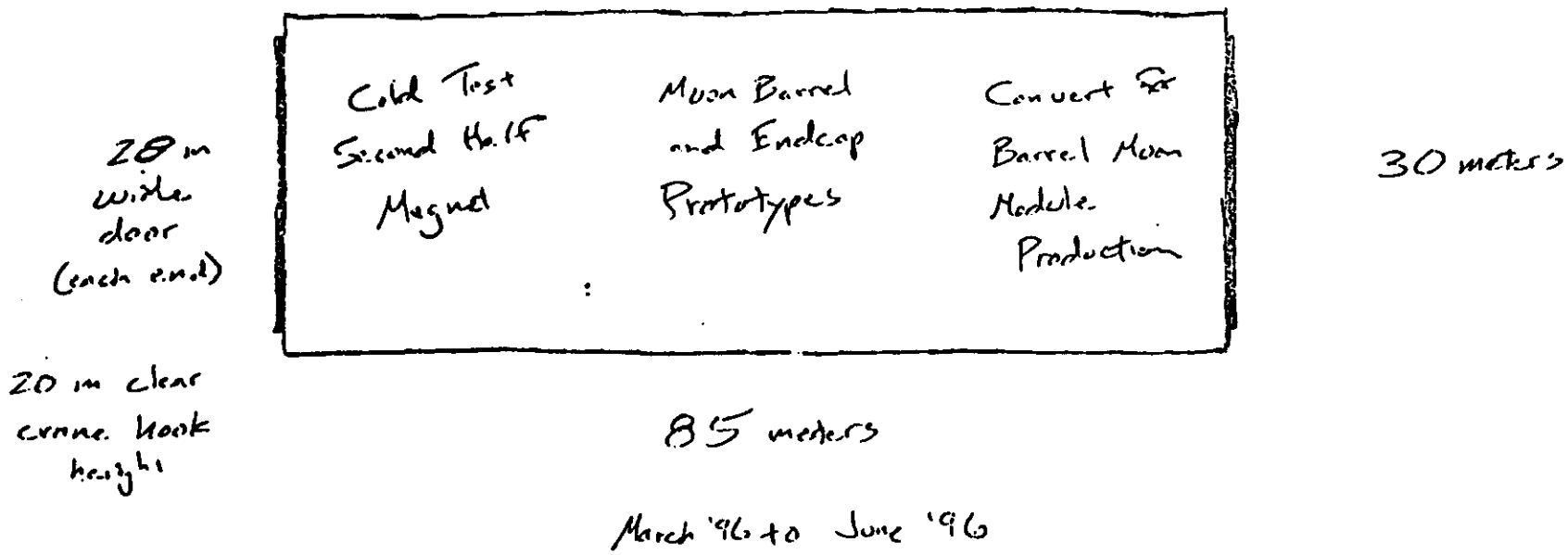


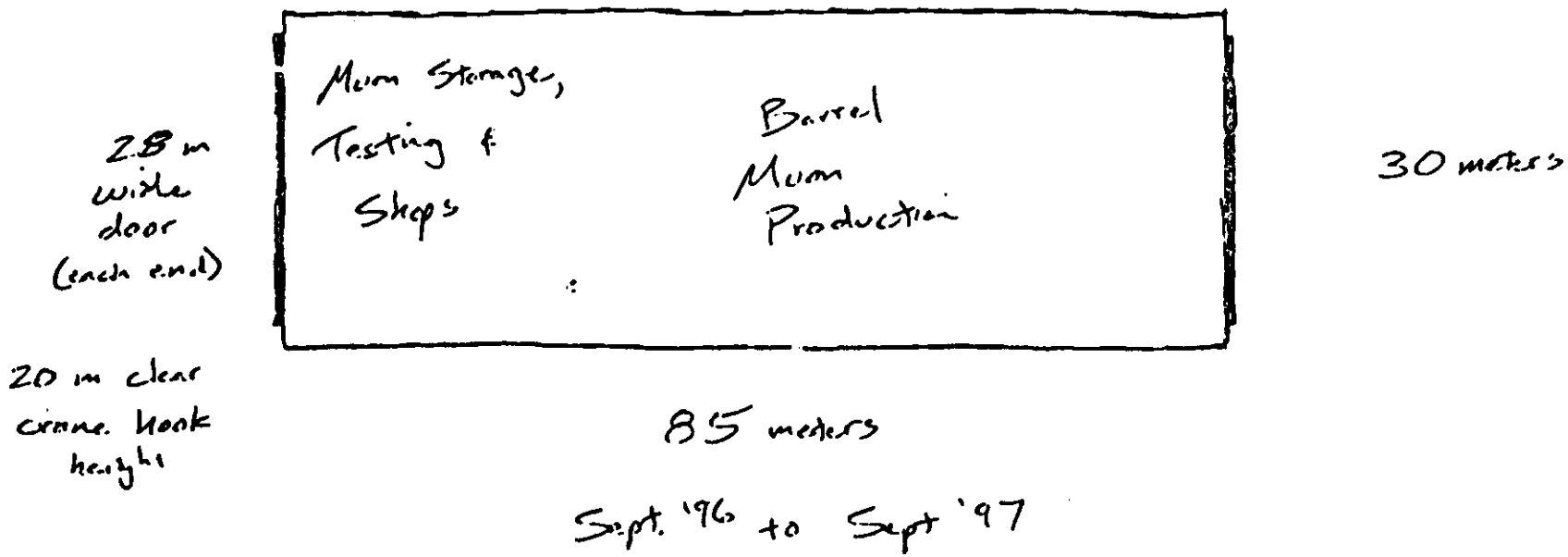

110 meters

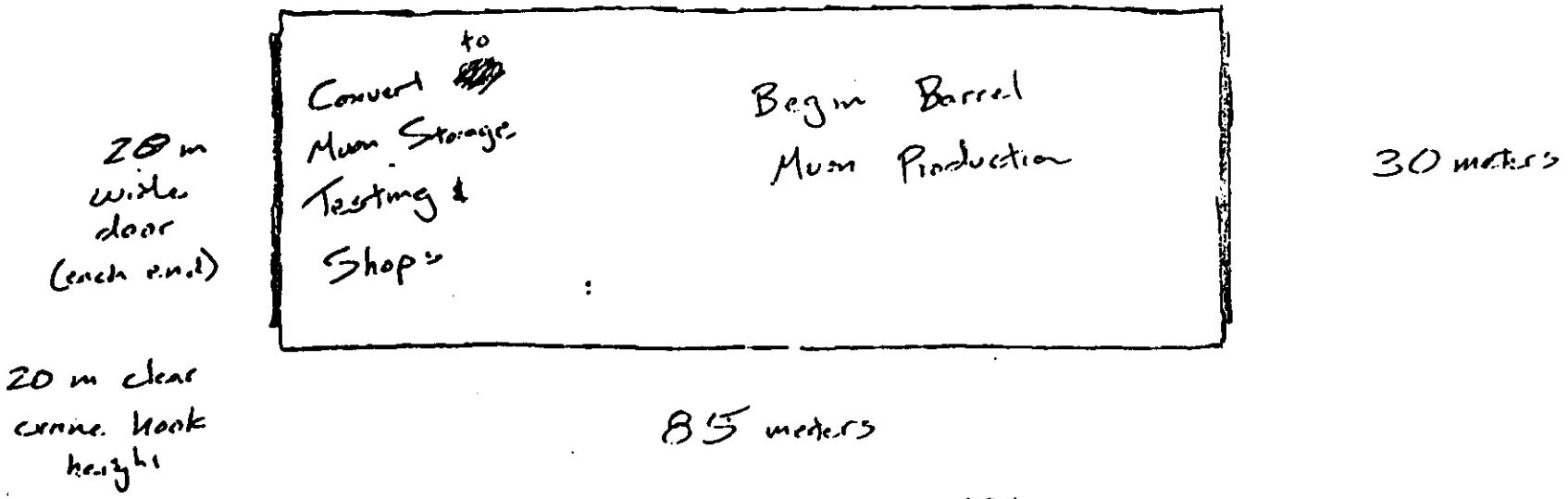
Sept. '96 to

Dec. '96


10 m wide door
Tracker Assembly, Testing, Labs & Cleanroom
50 m
10 m
Calorimeter Inspection, Testing, Storage & Rework
30 m
15 meters
Calorimeter Assembly
28 m wide door (each end)
30 meters
60 met
Prepare for Non Barrel Storage
OPS
15 meters
110 meters
Oct '95
Sept. '96

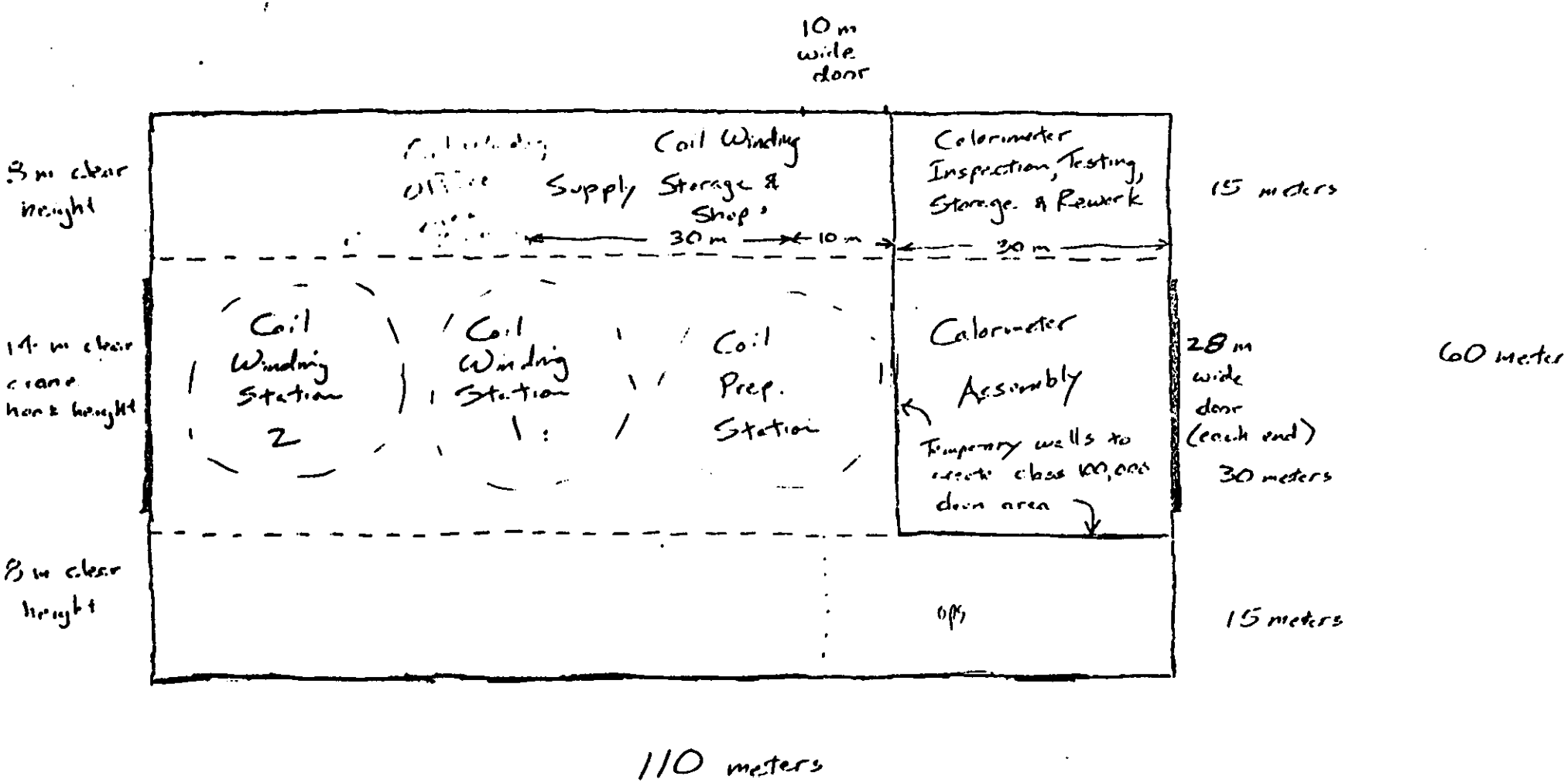

28 in wider door (each end)
Cold Test Second Half Magnet
Muon Barrel and Endcap Prototypes
Convert for Barrel Muon Module Production
30 meters
20 in clear crane hook height
85 meters
March '96 to June '96

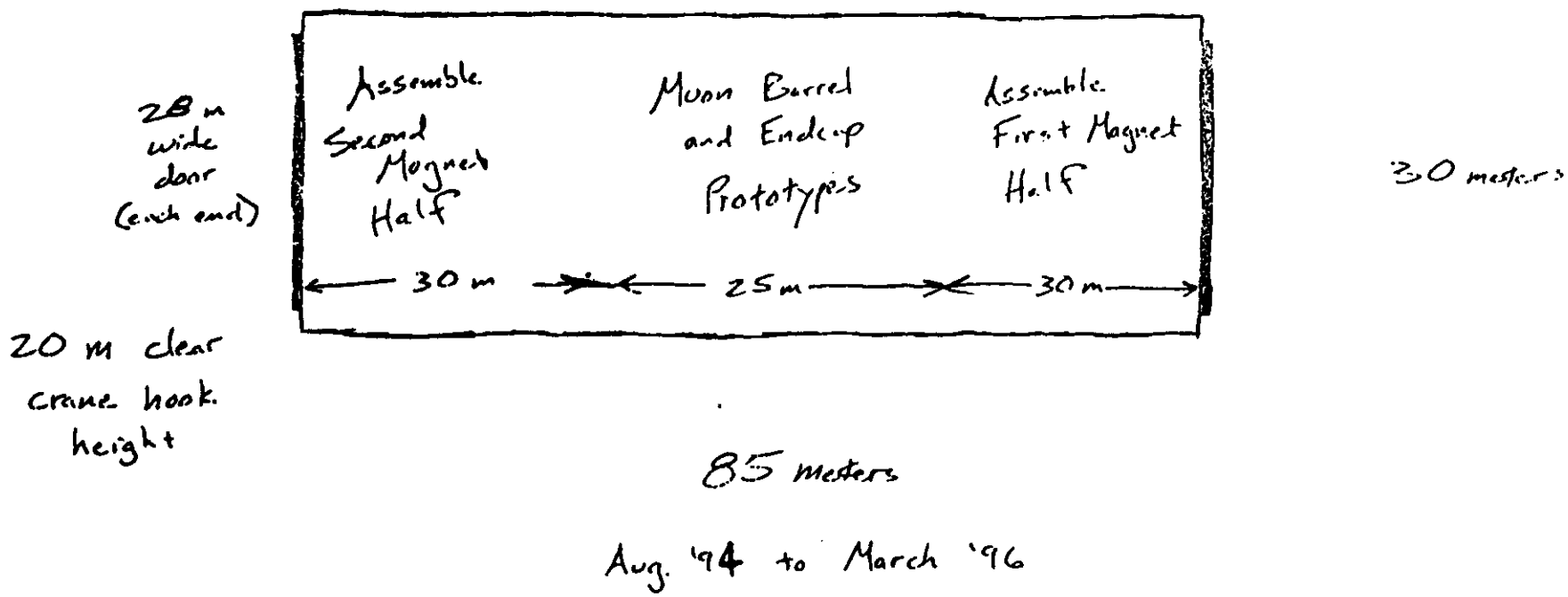

Mum Storage,
Testing &
Shops
Barrel
Mum
Production
2.8 m
wide
door
(each end)
30 meters
20 m clear
crane. hook
height
85 meters
Sept. '96 to Sept '97





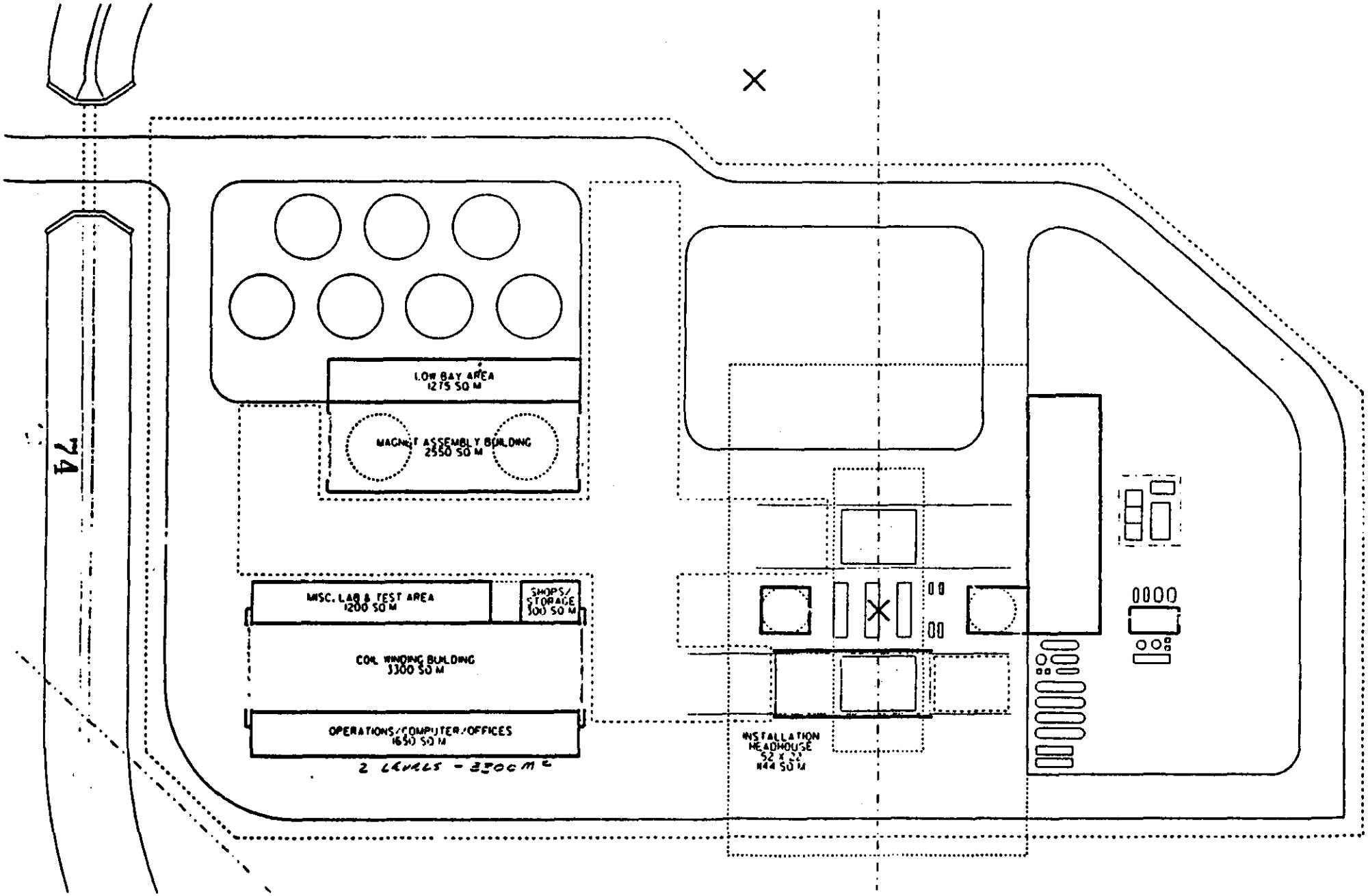

Mount Assembly Building


10 m wide door
8 m clear height
Coil Winding Supply Storage & Shop
30 m
10 m
Calorimeter Inspection, Testing, Storage & Rework
30 m
15 meters
14 m clear crane hook height
Coil Winding Station 2
Coil Winding Station
Coil Prep. Station
Calorimeter Assembly
Temporary walls to create class 100,000 clean area
28 m wide door (each end)
30 meters
60 meters
8 m clear height
15 meters
110 meters




Aug. '94 to March '96

Magnet Assembly Building


LOW BAY AREA
1275 SQ M
MAGNET ASSEMBLY BUILDING
2550 SQ M
MISC. LAB & TEST AREA
1200 SQ M
SHOPS/
STORAGE
300 SQ M
COIL WINDING BUILDING
3300 SQ M
OPERATIONS/COMPUTER/OFFICES
1650 SQ M
2 LEVELS - 3300 M²
INSTALLATION
HEADHOUSE
52 X 22
1144 SQ M

Furey/Sapienza/Draper

# SSC END CAP AND BARREL REGION STRUCTURAL ANALYSIS RESULTS

M. Furey and R. Sapienza



DRAPER LABORATORY

# ANALYSIS ASSUMPTIONS

G.E.M. 23 JULY 1992

- Linear material properties
- Small displacement theory (consistent with linear assumption)
- Material: 6061-T6 Al
  - Properties taken from MIL-HDBK-5C
- Element cross-section properties taken from Structural Aluminum Design, Reynolds Co., 1966
- Support structures modeled as space frames
  - Joints capable of resisting bending moments
- Truss tubes checked for buckling:
  - Design safety factor chosen as 5
  - Member end conditions assumed to be pinned-pinned (conservative)
- Assembly first mode natural frequencies estimated as greater than:
  - $fn = (1/2\pi)(G/\delta max)^{0.5}$
- Member natural frequencies calculated assuming pinned-pinned end conditions

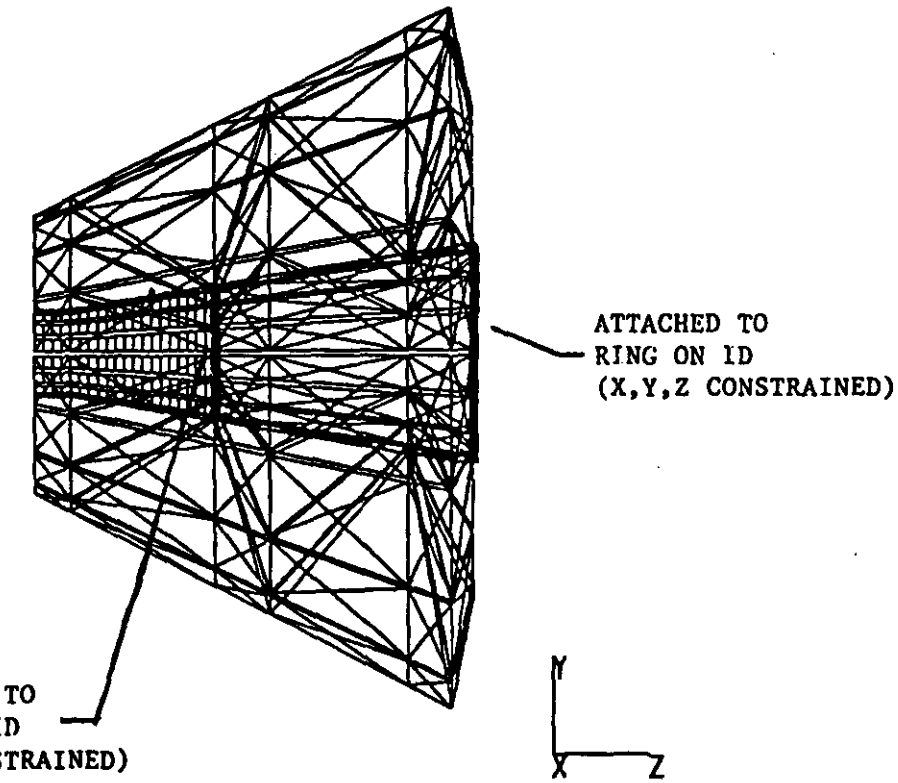
DRAPER LABORATORY

# END CAP FFS MOUNT

G.E.M.

23 July 1992

- Results Summary
  - maximum deflection 1.5 mm
  - minimum stress safety factor of 12.5 relative to yield
  - maximum force ≈ 1.17E4 N
  - buckling safety factor design criterion minimum of 5
    - members not meeting criterion to be reinforced
  - global fn > 13 Hz
  - lowest member fn ≈ 8 Hz



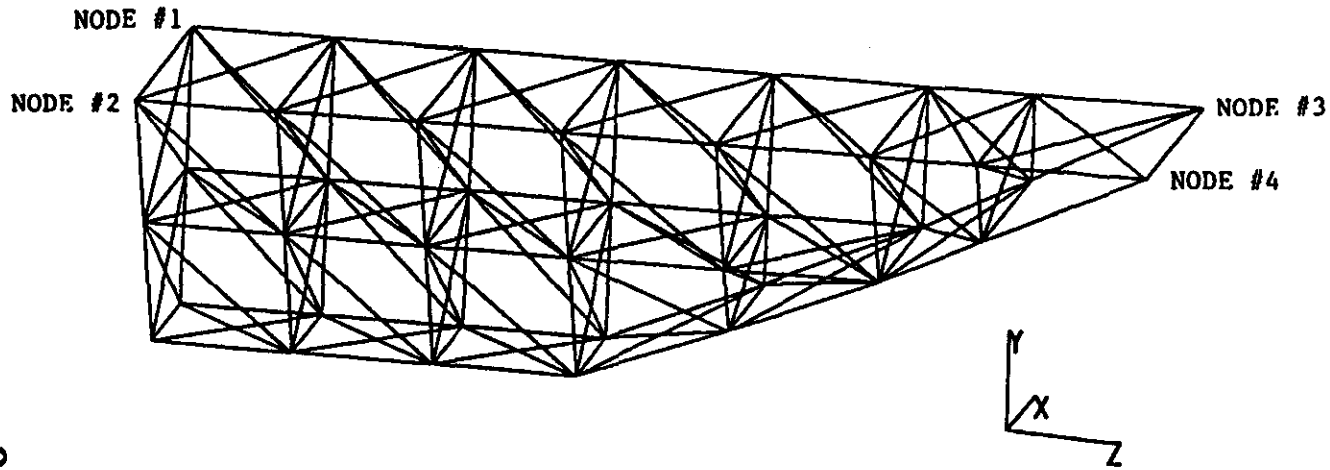



DRAPER LABORATORY

# BARREL REGION

G.E.M.

23 July 1992




NODE #1 X,Y,Z CONSTRAINED
NODE #2 Y,Z CONSTRAINED
NODE #3 X,Y CONSTRAINED
NODE #4 Y CONSTRAINED

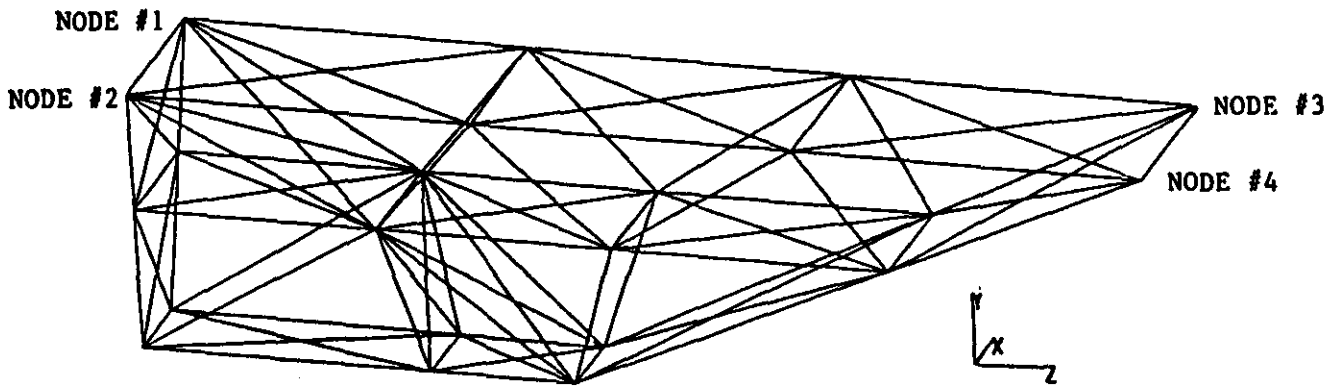
- Results Summary
  - maximum deflection 5.0 mm
  - minimum stress safety factor of 13.5 relative to yield
  - maximum force ≈ 2.48E4 N
  - buckling safety factor design criterion minimum of 5
  - global fn > 7 Hz
  - lowest member fn ≈ 12 Hz

DRAPER LABORATORY

# BARREL REGION
# PROJECTIVE GAP OPTION

G.E.M.

23 July 1992




NODE #1 X,Y,Z CONSTRAINED
NODE #2 Y,Z CONSTRAINED
NODE #3 X,Y CONSTRAINED
NODE #4 Y CONSTRAINED

- Results Summary
  - 2,3,3 chambers/layer
  - structure has 22 joints vs. 40 for present baseline design and is 55% lighter
  - maximum deflection 4.2 mm
  - minimum stress safety factor of 15.5 relative to yield
  - maximum force ≈ 1.99E4 N
  - buckling safety factor design criterion minimum of 5
  - global fn > 7.6 Hz
  - lowest member fn ≈ 7 Hz

DRAPER LABORATORY

# BARREL REGION: BIG WHEEL CONCEPT QUICK LOOK

G.E.M.

23 July 1992

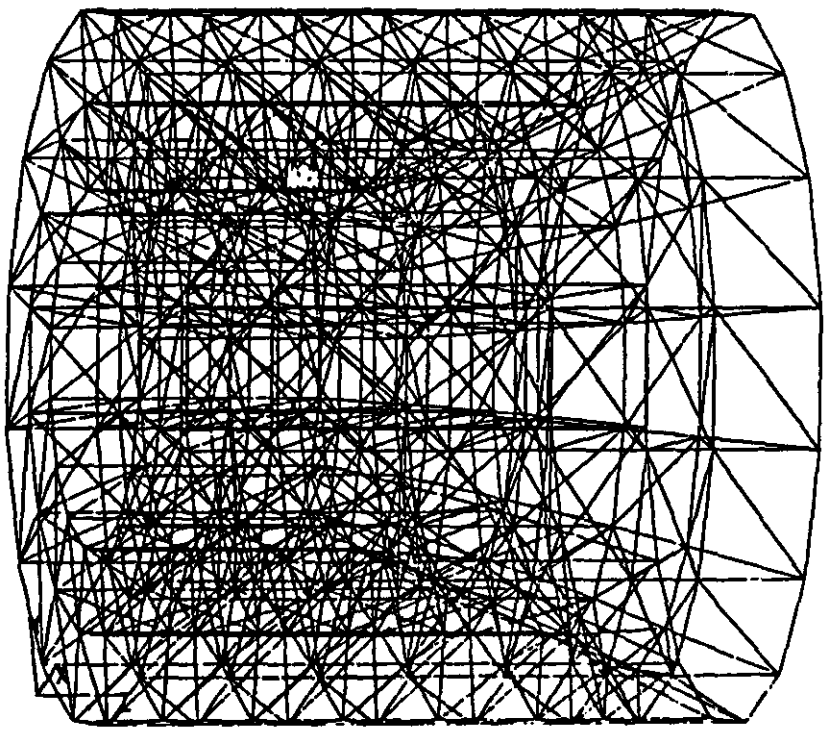
- Assembled as complete unit then positioned and attached to magnet ring
- Four attachement points
  - Two at each end on horizontal through center line
- Maximum deflection in operational orientation 12.6 mm
- Axial forces in members high in operational orientation, compared with other barrel region approaches considered
  - Forces nearly an order of magnitude greater than in the projective gap option
  - Big wheel maximum force ≈ 1.54E5 N
  - Buckling safety factor design criterion of 5 not met in 227 members
- <u>Note:</u> This was a quick look assessment. Concept is doable with further refinement.

DRAPER LABORATORY

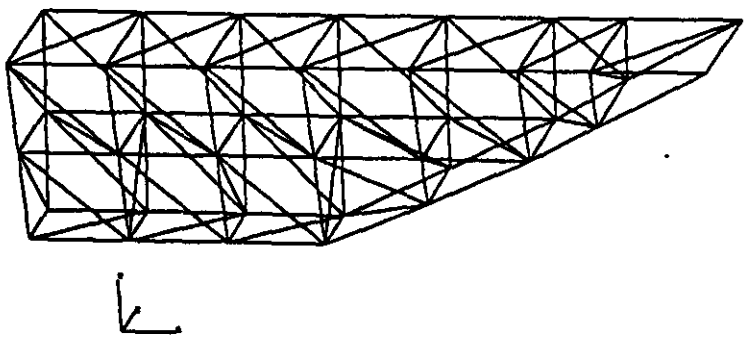
# BIG WHEEL QUICK LOOK STRUCTURE

G.E.M.

23 July 1992



16 SECTION BIG WHEEL BARREL REGION



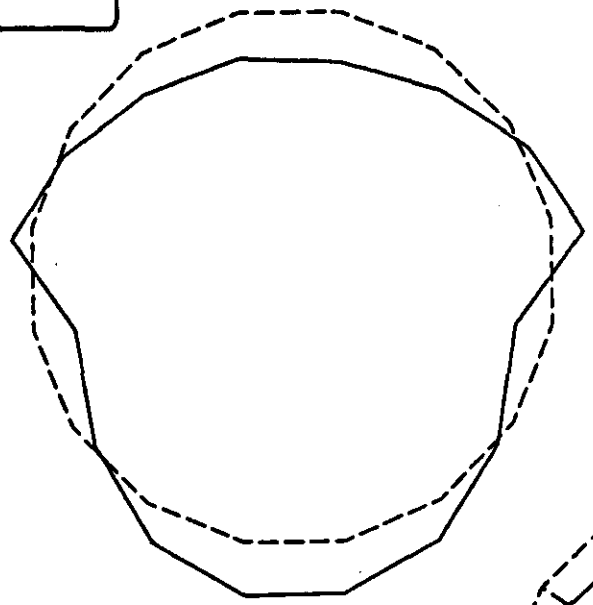
SINGLE BIG WHEEL BARREL SECTION

DRAPER LABORATORY

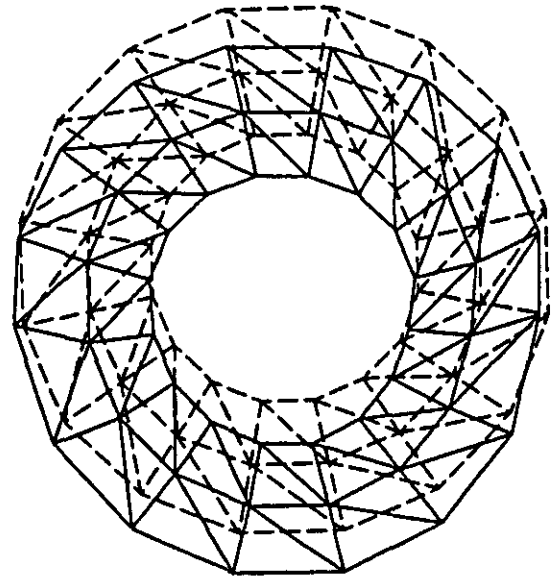
# BIG WHEEL QUICK LOOK
# DEFORMATION SECTION CUTS

G.E.M.

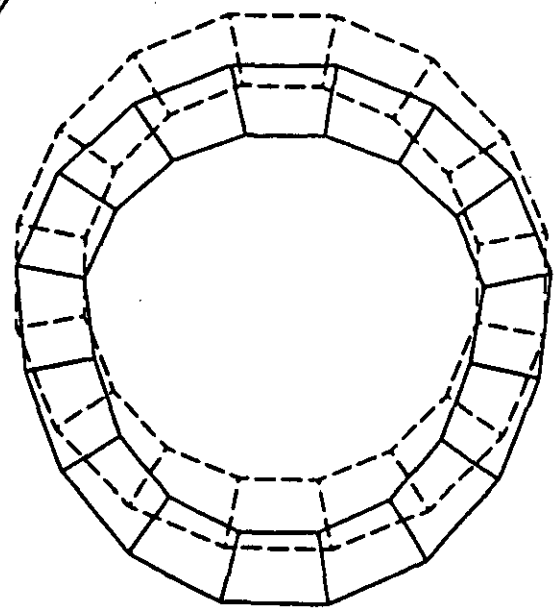
23 July 1992



OUTER END RING CUT



INNER END RING CUT

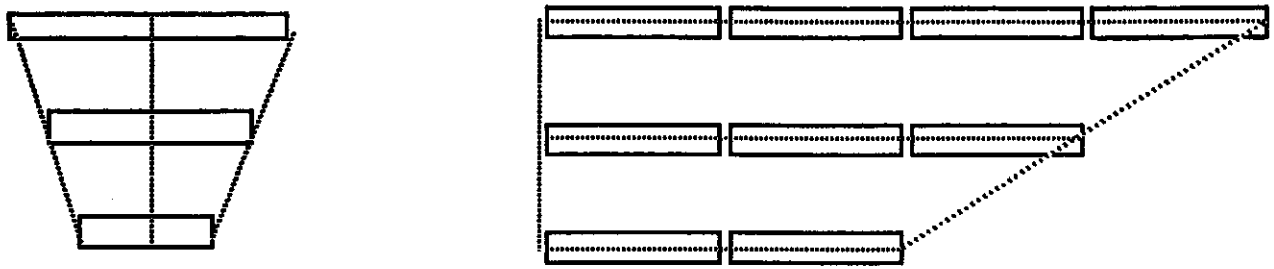


MAXIMUM DEFORMATION CUT

DRAPER LABORATORY

Paradiso/Draper

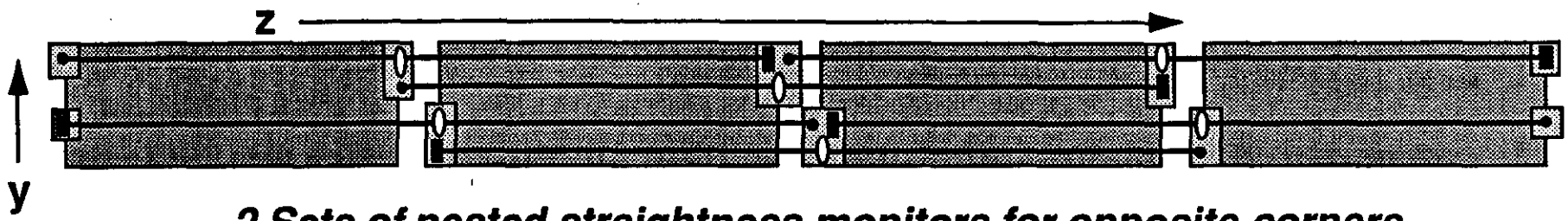
# Baseline Analysis



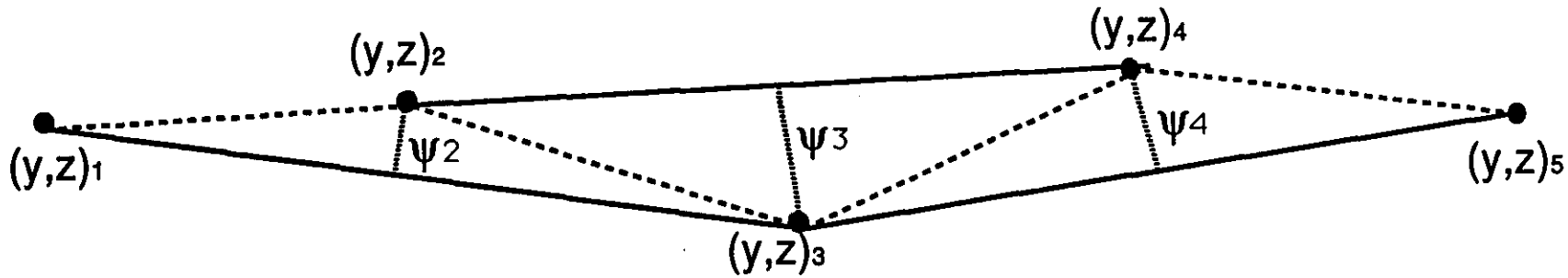
- MATLAB program nearly complete to verify alignment scheme.
- Assume four projective 3-point lines ($\phi = \pm 11.25°$, $\theta = 90°, 30°$), multipoint line along z (pick up each chamber edge relative to endpoints, where projective lines run).
- Three hierarchies of transformations implemented:
  - Rotate each chamber about its center in 3 axes, and translate.
  - Rotate each layer in 3 axes, and translate.
  - Rotate entire hexant relative to IP and translate.
- Straight lines from IP (infinite momentum muons) detected in displaced chambers.
- Alignment measurements taken (multipoint SWAT and nested SM assumed for z-axis).
- Sagitta corrected through linear interpolation of alignment data.

→ Check concept validity, "torque" mysteries, etc.
Extend to higher-order bending modes?

# Nested SM's




***2 Sets of nested straightness monitors for opposite corners***

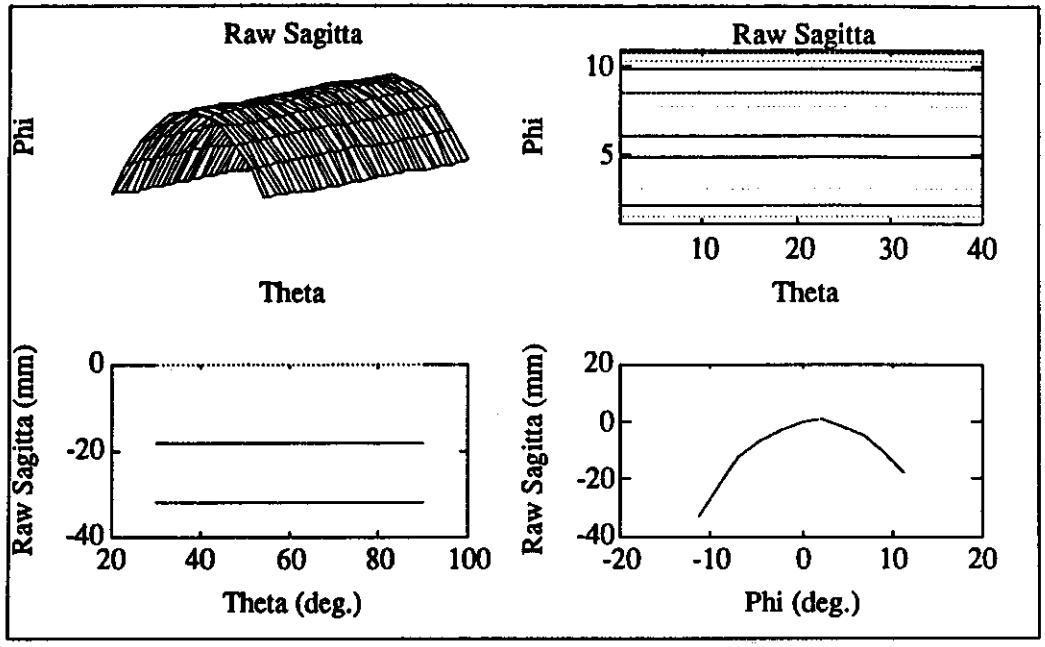



***Measurements for one SM string***

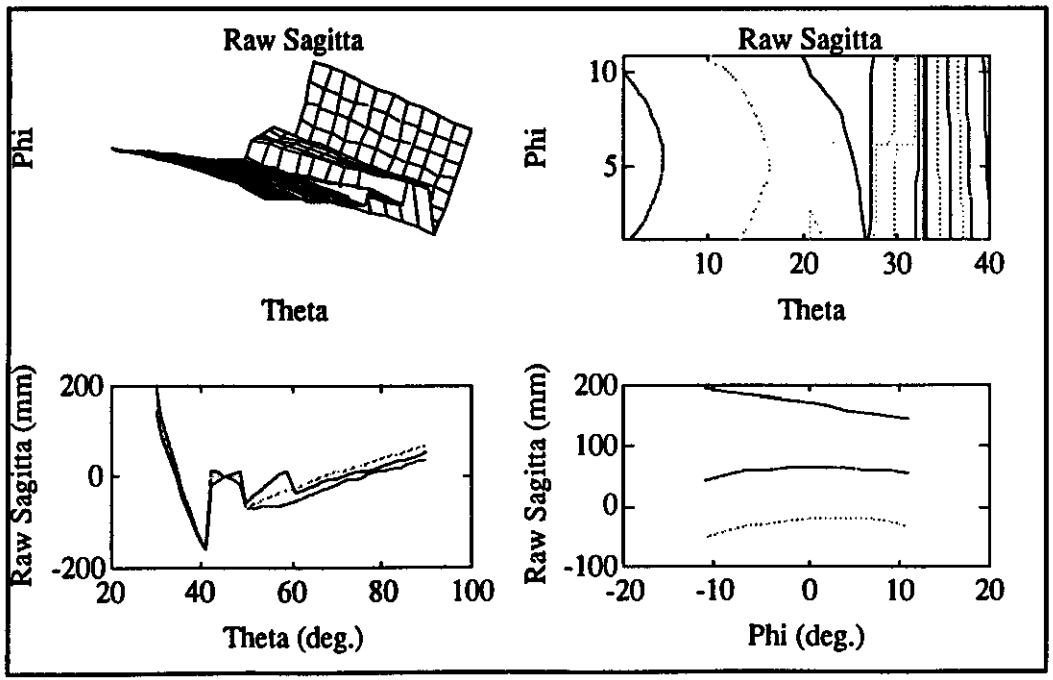
$$y = b\,([I] - [A])^{-1} \qquad b = \begin{bmatrix} 0 \\ \psi_2 \\ \psi_3 \\ \psi_4 \\ 0 \end{bmatrix} \qquad [A] = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ \frac{z_2}{\Delta z_{13}} & 0 & -\frac{z_2}{\Delta z_{13}} & 0 & 0 \\ 0 & \frac{z_3}{\Delta z_{24}} & 0 & -\frac{z_3}{\Delta z_{24}} & 0 \\ 0 & 0 & \frac{z_4}{\Delta z_{35}} & 0 & -\frac{z_4}{\Delta z_{35}} \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

**(Positioning errors add in quadrature; worst case = √3 ??)**

# Induced Sagitta Errors




**Beam-axis rotation of middlelayer (0.1 radian)**




**Each Chamber randomly rotated and/or translated**

# Centroiding Receivers w. Wider Range

IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 26, NO. 12, DECEMBER 1991 1863

## An Object Position and Orientation IC with Embedded Imager

David L. Standley, *Member, IEEE*

*Abstract*—A CMOS VLSI chip that determines the position and orientation of an object against a dark background is described. The chip operates in a continuous-time analog fashion, with a response time as short as 200 μs and power consumption under 50 mW. A self-contained photoresistor array acquires the image directly, and the output is a set of eight currents from which the position and orientation can be found. Orientation is determined to within ±2° or better for moderately sized and sufficiently elongated objects. Chip dimensions are 7900 μm × 9200 μm.

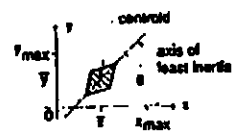
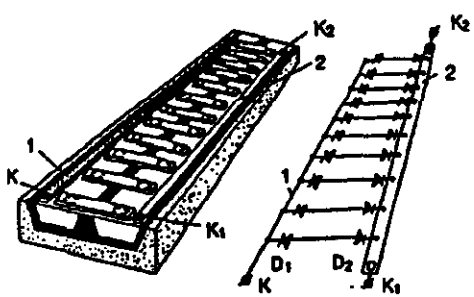



Fig. 1. Example of object centroid and axis of least inertia.

- MIT Vision project; fabricated imaging array that extracts moments & feature data (29x29 pixels, 190 μm; active area = 7.9 x 9.2 mm).
- Others; Cal Tech, Sel-Spot, etc.

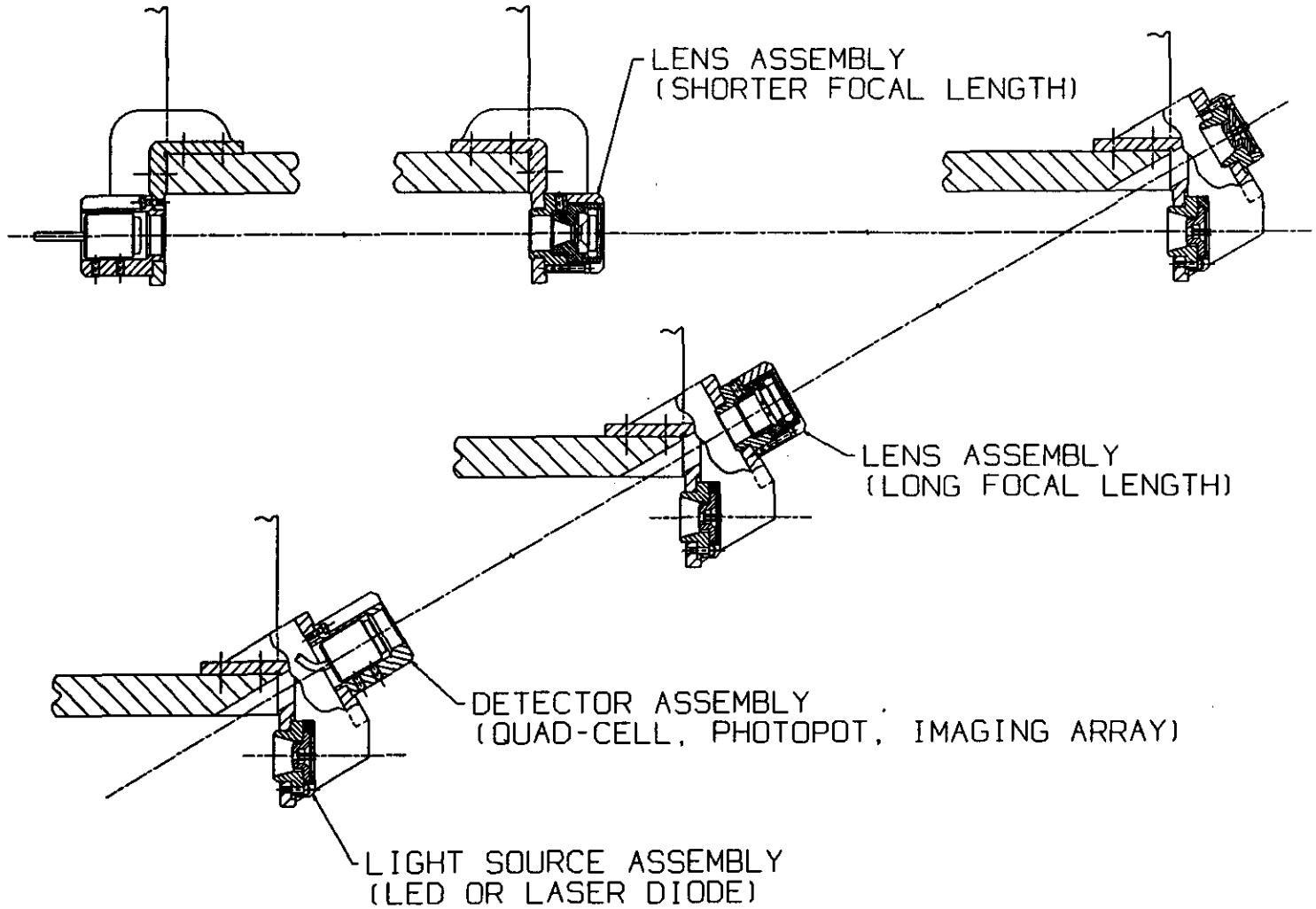
92

TECHNOEXAN




K, $K_1$, $K_2$ — electrodes
1 — common bus
2 — potentiometric resistor

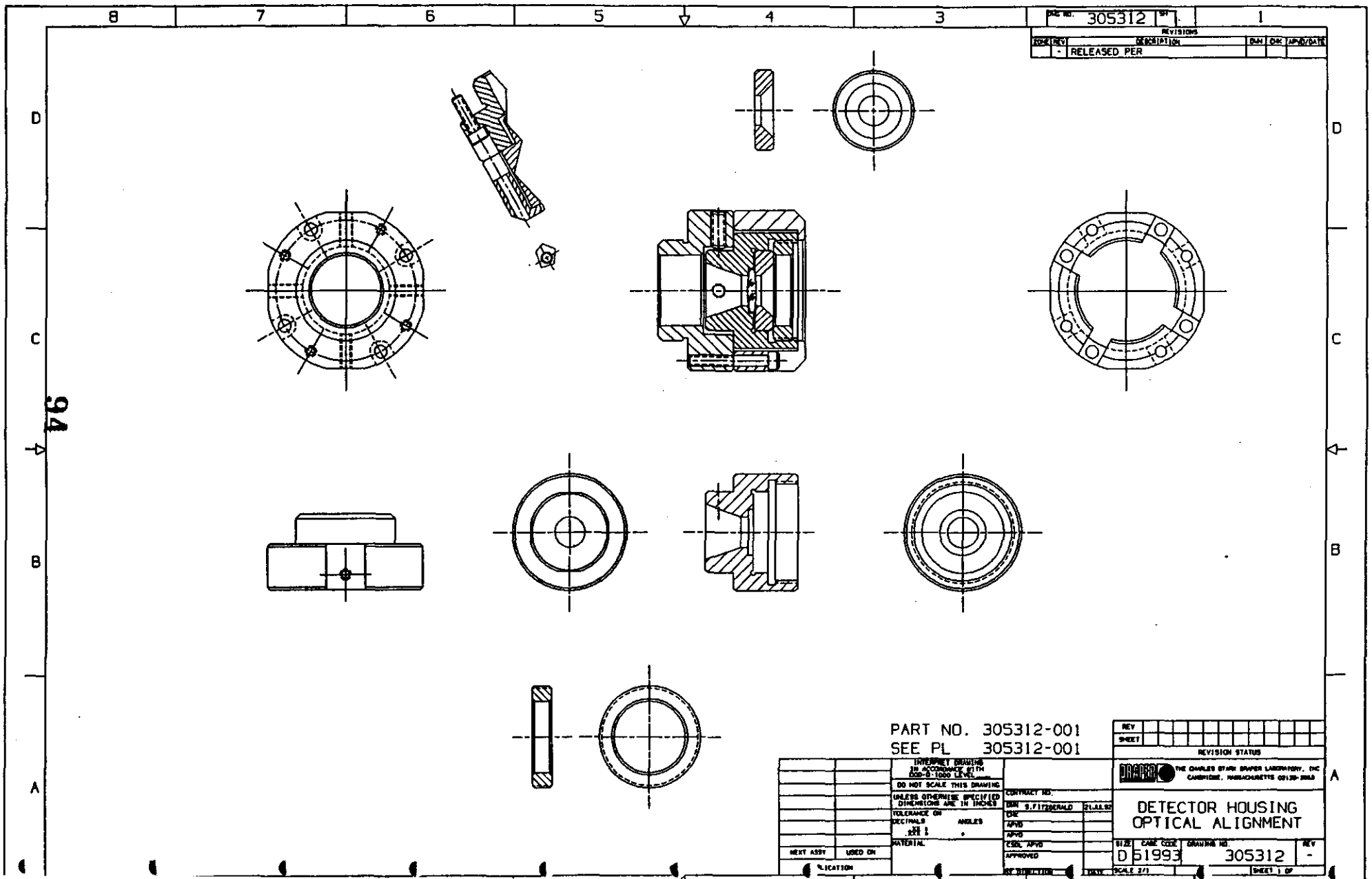
- Line array that autocentriods (Soviet venture located by BNL group)




PART NO. 292934-001
SEE PL

ALIGNMENT HARDWARE
(GEM BARREL
MUON SYSTEM)

E 61993 | 292934 | -

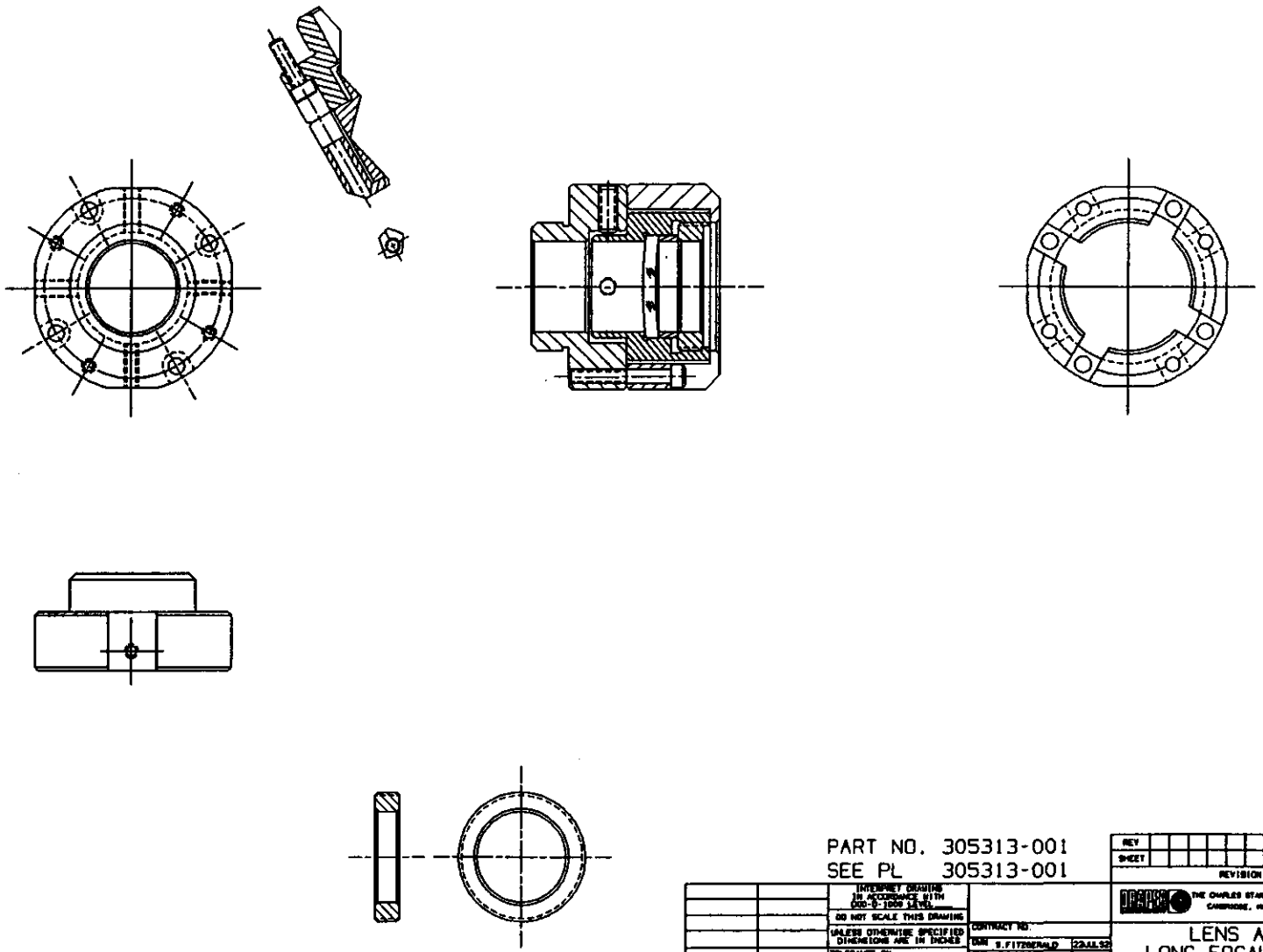


305312
REVISIONS
ZONE REV DESCRIPTION DWN CHK APVD/DATE
- RELEASED PER
PART NO. 305312-001
SEE PL 305312-001
INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000 LEVEL
DO NOT SCALE THIS DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCE ON DECIMALS ANGLES
MATERIAL
NEXT ASSY USED ON
CONTRACT NO.
DWN S.FITZGERALD 21JUL92
CHK
APVD
APVD
CSDL APVD
APPROVED
BY DIRECTION DATE
REV
SHEET
REVISION STATUS
THE CHARLES STARK DRAPER LABORATORY, INC
CAMBRIDGE, MASSACHUSETTS 02139-3563
DETECTOR HOUSING
OPTICAL ALIGNMENT
SIZE D CAGE CODE 51993 DRAWING NO. 305312 REV -
SCALE 2/1 SHEET 1 OF

DWG NO. 305313 SH 1

REVISIONS

| ZONE | REV | DESCRIPTION | DWN | CHK | APVD/DATE |
|---|---|---|---|---|---|
| | - | RELEASED PER | | | |



PART NO. 305313-001
SEE PL 305313-001

| | |
|---|---|
| NEXT ASSY | USED ON |
| APPLICATION | |

INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000 LEVEL

DO NOT SCALE THIS DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCE ON DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

CONTRACT NO.

DWN S.FITZGERALD 22JUL92

CHK

APVD

APVD

ENGL APVD

APPROVED

MFG DIRECTOR DATE

REV

SHEET

REVISION STATUS

THE CHARLES STARK DRAPER LABORATORY, INC
CAMBRIDGE, MASSACHUSETTS 02139-3563

LENS ASSY
LONG FOCAL POINT
OPTICAL ALIGNMENT

| SIZE | CAGE CODE | DRAWING NO. | REV |
|---|---|---|---|
| D | 61993 | 305313 | - |

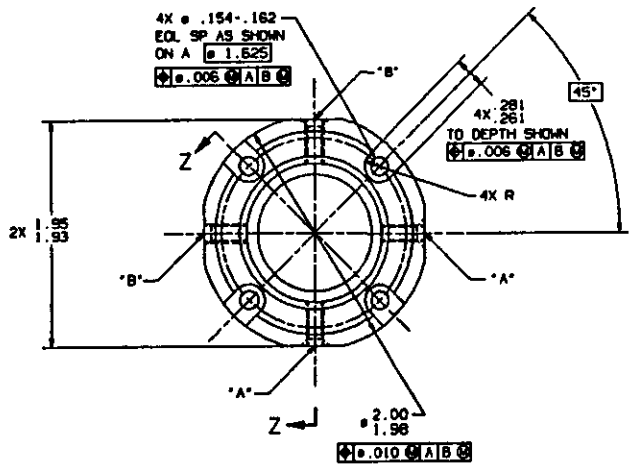
SCALE 2/1 SHEET 1 OF

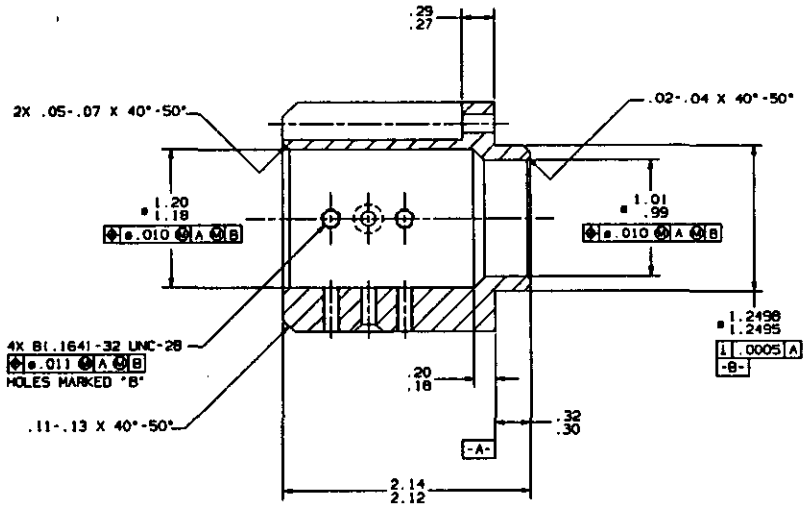
95

DWG NO. 305311 SH

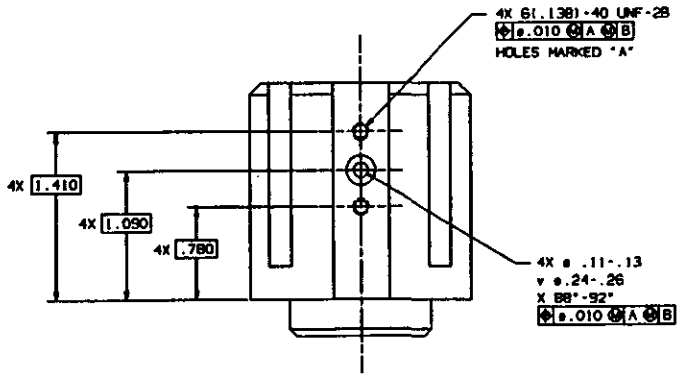
REVISIONS

| ZONE | REV | DESCRIPTION | DWN | CHK | APVD/DATE |
|---|---|---|---|---|---|
| | - | RELEASED PER | | | |




SECTION Z-Z




PART NO. 305311-001
SEE PL

| REV | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SHEET | | | | | | | | | | | |

REVISION STATUS

INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000 LEVEL
DO NOT SCALE THIS DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCE ON DECIMALS .XX ± .XXX ± ANGLES ±
MATERIAL

CONTRACT NO.
DWN S.FITZGERALD 15JUL92
CHK
APVD
APVD
CSOL APVD
APPROVED

NEXT ASSY | USED ON
LOCATION

THE CHARLES STARK DRAPER LABORATORY, INC
CAMBRIDGE, MASSACHUSETTS

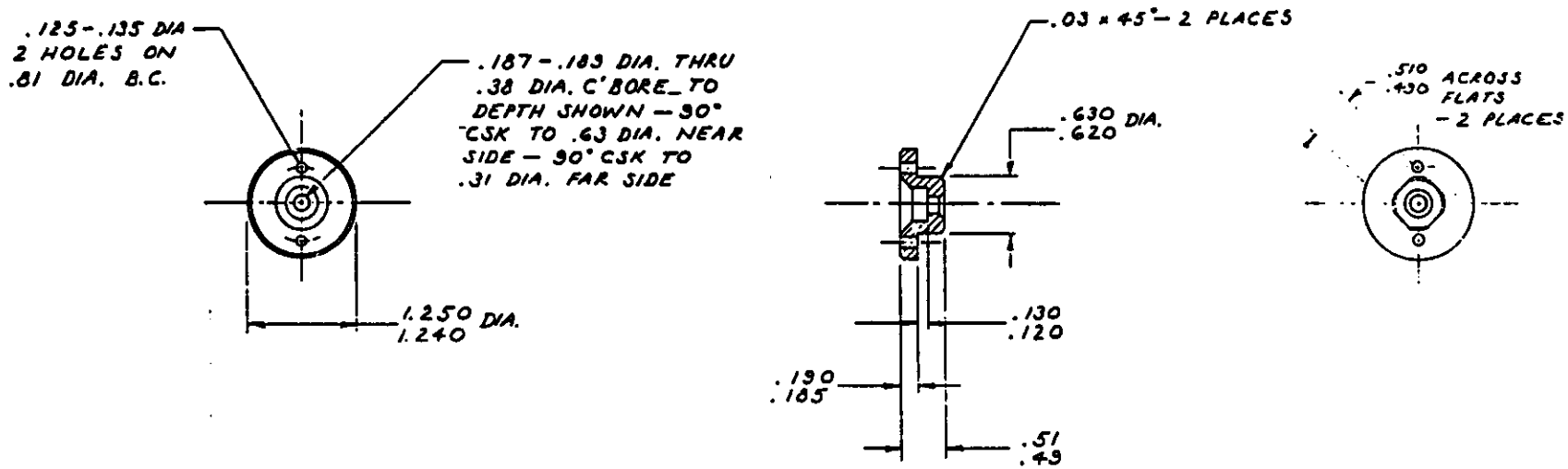
# DETECTOR HOUSING OPTICAL ALIGNMENT

| SIZE | CAGE CODE | DRAWING NO. | REV |
|---|---|---|---|
| D | 61993 | 305311 | - |

SCALE 2/1 SHEET 1 OF

96

| REVISIONS | | | | | |
|---|---|---|---|---|---|
| ZONE | REV | DESCRIPTION | DWN | DATE | APPROVED |
| | | | | | |




**PART NO.**
**SEE PL**

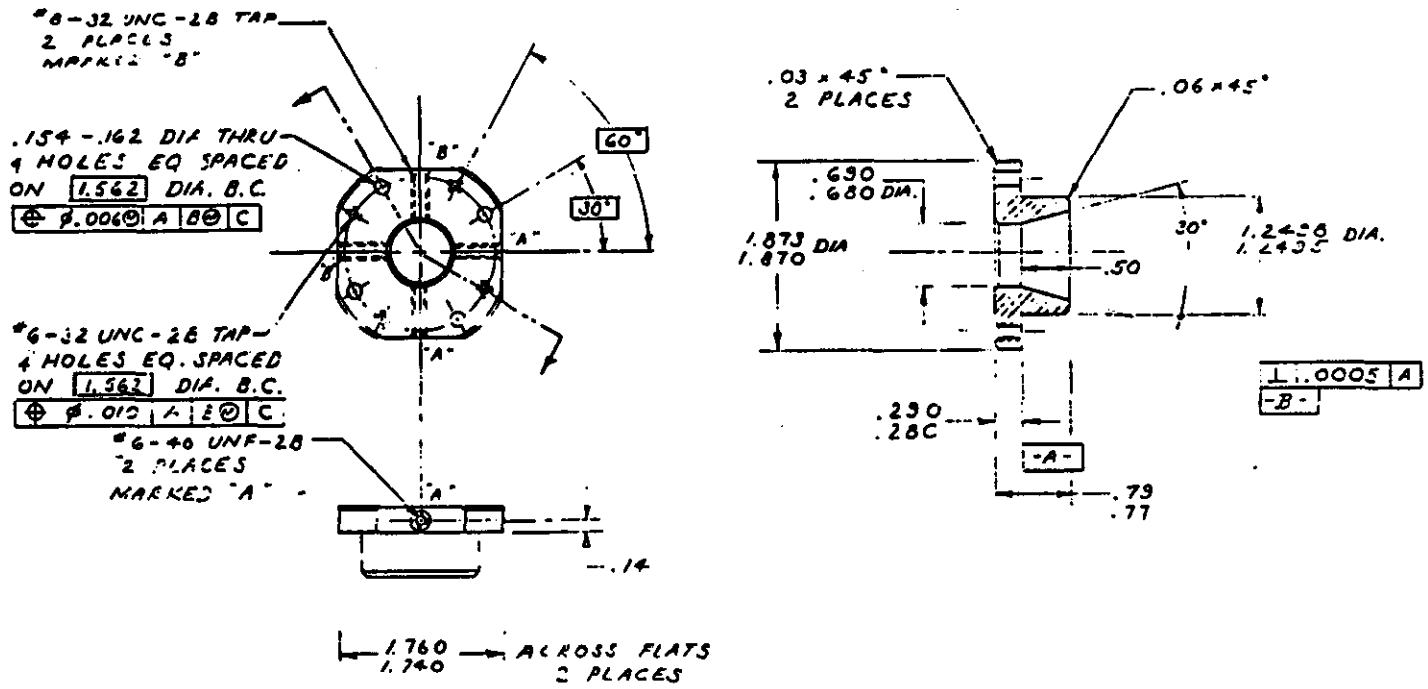
| | | | |
|---|---|---|---|
| | | INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000 LEVEL ___ | CONTRACT NO. |
| | | DO NOT SCALE THIS DRAWING | ISSUE DATE |
| | | UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES | DRAWN BY E.C. BERK — DATE 17 MAY 72 |
| | | TOLERANCE ON DECIMALS .XX ± .01 .XXX ± — ANGLES ± 5° | CHECKED BY |
| | | | APPROVED BY |
| | | | APPROVED BY |
| | | | CSDL APPROVED |
| NEXT ASSEMBLY | USED ON | MATERIAL STAINLESS STEEL TYPE 303 | APPROVED |
| APPLICATION | | | BY DIRECTION |

THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASSACHUSETTS 02139

L.E.D. HOLDER — OPTICAL ALIGNMENT —

| SIZE | FSCM NO. | DWG NO. | REV |
|---|---|---|---|
| C | 51993 | | — |
| SCALE | | | SHEET 1 |

| REVISIONS | | | | | |
|---|---|---|---|---|---|
| ZONE | REV | DESCRIPTION | DWN | DATE | APPROVED |
| | | | | | |

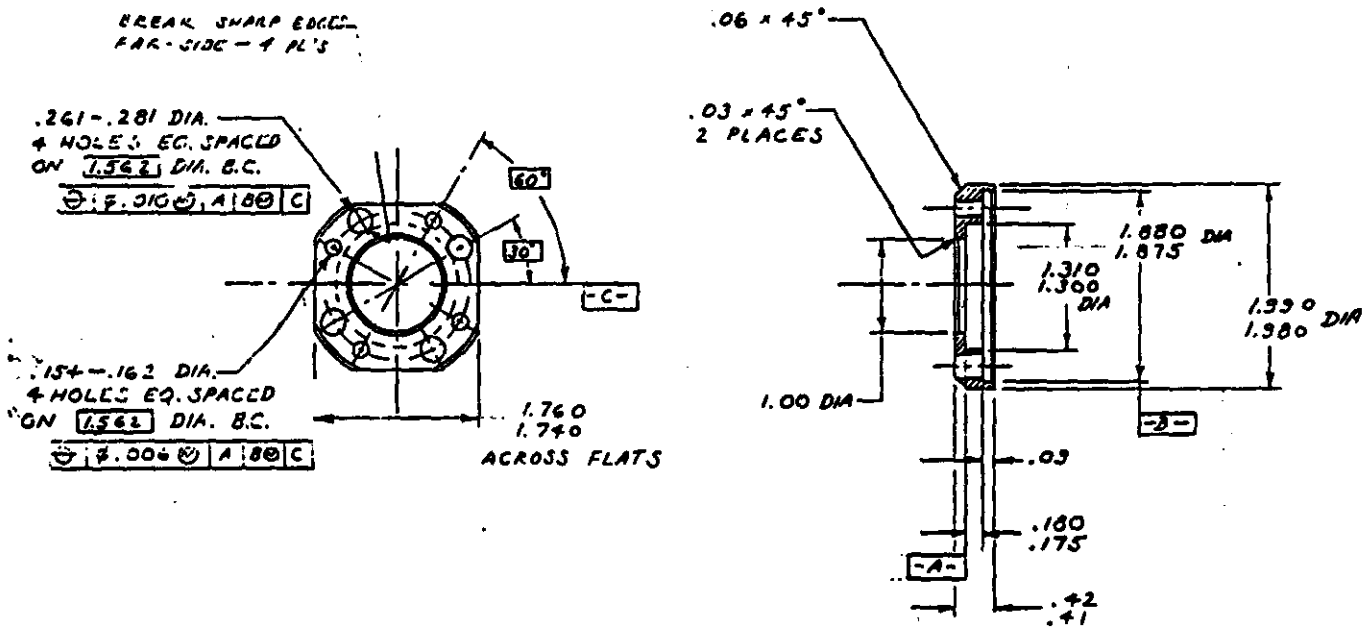



**PART NO.**
**SEE PL**

| | | | | |
|---|---|---|---|---|
| | | INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000 LEVEL ___ | CONTRACT NO. | THE CHARLES STARK DRAPER LABORATORY, INC. CAMBRIDGE, MASSACHUSETTS 02139 |
| | | DO NOT SCALE THIS DRAWING | ISSUE DATE | |
| | | UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES | DRAWN BY E.C. BERK / DATE 16 JAN 81 | HOUSING – L.E.D. — OPTICAL ALIGNMENT |
| | | TOLERANCE ON DECIMALS .XX ±.01 .XXX ± / ANGLES ±5° | CHECKED BY | |
| | | | APPROVED BY | |
| | | | APPROVED BY | |
| | | | CSDL APPROVED | |
| NEXT ASSEMBLY | USED ON | MATERIAL STAINLESS STEEL TYPE 303 | APPROVED | SIZE C / FSCM NO. 51993 / DWG NO. / REV — |
| | LOCATION | | | SCALE / SHEET |

98

| REVISIONS | | | | | |
|---|---|---|---|---|---|
| ZONE | REV | DESCRIPTION | DWN | DATE | APPROVED |




**PART NO.**
**SEE PL**

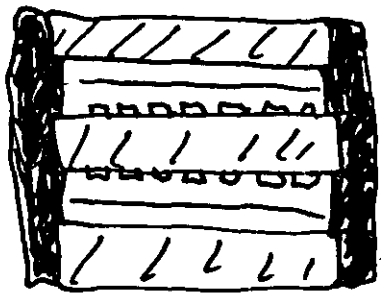
| | | | | |
|---|---|---|---|---|
| | | INTERPRET DRAWING IN ACCORDANCE WITH DOD-D-1000 LEVEL ___ | CONTRACT NO. | THE CHARLES STARK DRAPER LABORATORY, INC. CAMBRIDGE, MASSACHUSETTS 02139 |
| | | DO NOT SCALE THIS DRAWING | ISSUE DATE | |
| | | UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES | DRAWN BY E.C. BERK — DATE 16 JUL 78 | CLAMP RING, L.E.D. — OPTICAL ALIGNMENT |
| | | TOLERANCE ON DECIMALS .XX ±.01 .XXX ± — ANGLES ±5° | CHECKED BY | |
| | | | APPROVED BY | |
| | | | APPROVED BY | |
| | | MATERIAL STAINLESS STEEL TYPE 303 | CSDL APPROVED | SIZE C — FSCM NO. 51993 — DWG NO. — REV — |
| NEXT ASSEMBLY | USED ON | | APPROVED | |
| APPLICATION | | | BY DIRECTION | SCALE — SHEET 1 |

Shank/BU

# CATHODE STRIP Chamber Prototype Testing
BU, BNL, ORNL, SUNY-SB

Boston U. : 3 doublets 50cm × 50cm
2 finished Aug 1

BNL : 2 doublets 250cm × 50cm done early Aug.



RD5 runs: July 27 - Aug 14
Sep 24 - Oct 10
Oct 29 - Nov 12

Large Prototype under construction 1m × 2m
Completion late Sept.

TTR :

Gustavson/Draper

# G E M

## Muon Subsystem

## *Manufacturing Issues*

# GEM Muon Subsystem

## *Design Issues*

- Theoretical % coverage
- Technology understanding
- Fabrication techniques
- Assembly techniques
- Installation techniques
- Mechanical interfaces
- Stiffness / stability

## *Manufacturing Issues*

- Number to be built
- Alignment criteria
- Fabrication procedures
- Assembly procedures
- Installation procedures
- Schedule
- Storage requirements
- Production Improvement

# Muon Subsystem Support Structure

## *Manufacturing issues*

Need design time estimate for all systems.

Need fabrication procedure (or quote) for all components (chamber parts, structural members, joints, etc.)

Need assembly procedure (with time and tooling costs) for each chamber type.

Need assembly procedure (with time and tooling costs) for each structure type.

# Muon Subsystem Support Structure

## *Manufacturing issues*

Need installation (in hall) procedure for each structural alternative.

Global and local alignment to be included in the assembly / installation procedures.

What are the storage requirements for chambers ?

How easily can chambers be replaced ?

EXAMPLE

# APPLICABLE TECHNOLOGY CHART

Title GEM Muon Barrel Assy. Date 23 April 1992

240 Working Days per Year

1 Shifts Available

0 s Station-to-Station Move Time

10 % Min. Attractive Rate of Return

2 yr Capital Recovery Period

25 Average Loaded Labor Rate ($/h)

| | Units | Days required |
|---|---|---|
| Production Batch Data | 17 | 240 |

RESOURCE Data Set Name: MUBRLRES TASK Data Set Name: MUBRLTSK

For each resource:

- C Hardware cost ($)
- P Installed cost / Hardware cost - rho Factor
- ε Up-time expected (%)
- v Operating / Maintenance rate ($/hr)
- $t_c$ Tool change time (sec)
- $m_s$ Maximum stations per worker

when a resource can be used on a task:

Operation time (sec) | Tool number

Hardware cost ($)

| TASK Number \ RESOURCE | MN1 (C: 500, P: 1.2, ε: 90, v: 3, $t_c$: 0, $m_s$: .83) | KRT (C: 20000, P: 1.2, ε: 90, v: 3, $t_c$: 0, $m_s$: 2) | MN2 (C: 500, P: 1.2, ε: 90, v: 3, $t_c$: 0, $m_s$: .83) | C: P: ε: v: $t_c$: $m_s$: | C: P: ε: v: $t_c$: $m_s$: | C: P: ε: v: $t_c$: $m_s$: |
|---|---|---|---|---|---|---|
| 1. Check Assy. stand | 14400 101<br>60000 | | | | | |
| 2. Assemble Barrel Structure | 345600 102<br>2000 | | | | | |
| 3. Adjust Structure | 144000 103<br>20000 | | | | | |
| 4. Install Hardware | 28800 102<br>2000 | | | | | |
| 5. Install (8) dummy chambers | 72000 104<br>90000 | | | | | |
| 6. Install measuring hardware | 57600 105<br>40000 | | | | | |
| 7. Calibrate structure | 345600 106<br>5000 | | | | | |
| 8. Remove dummies & measuring eqpt. | 129600 102<br>2000 | | | | | |
| 9. Move structure to module station | | 14400 201<br>0 | | | | |
| 10. Install Muon chambers | 129600 108<br>10000 | | | | | |
| 11 Install RPC chambers & support | 129600 109<br>10000 | | | | | |

Prepared by: REG/ASK Sheet 1 of 2

EXAMPLE

# APPLICABLE TECHNOLOGY CHART

Title GEM Muon Barrel Assy. Date 23 April 1992

_____ Working Days per Year

_____ Shifts Available

_____ s Station-to-Station Move Time

_____ % Min. Attractive Rate of Return

_____ yr Capital Recovery Period

_____ Average Loaded Labor Rate ($/h)

| | Units | Days required |
|---|---|---|
| Production Batch Data | | |

RESOURCE Data Set Name: MUBRLRES TASK Data Set Name: MUBRLTSK

For each resource:

- C Hardware cost ($)
- P Installed cost / Hardware cost - rho Factor
- ε Up-time expected (%)
- v Operating / Maintenance rate ($/hr)
- $t_c$ Tool change time (sec)
- $m_s$ Maximum stations per worker

when a resource can be used on a task:

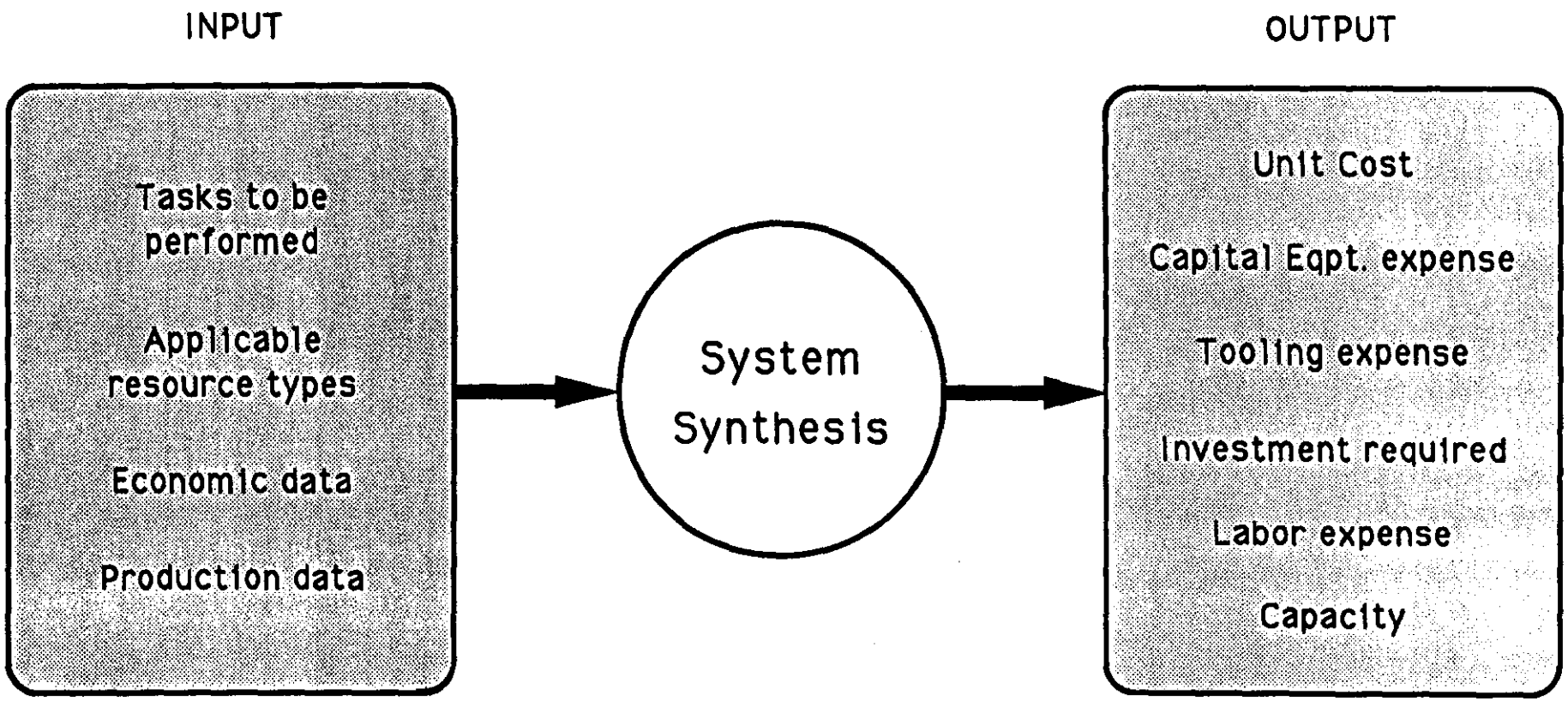
Operation time (sec) | Tool number

Hardware cost ($)

| Number | TASK \ RESOURCE | MN1 (C: P: ε: v: $t_c$: $m_s$:) | KRT (C: P: ε: v: $t_c$: $m_s$:) | MN2 (C: P: ε: v: $t_c$: $m_s$:) | (C: P: ε: v: $t_c$: $m_s$:) | (C: P: ε: v: $t_c$: $m_s$:) | (C: P: ε: v: $t_c$: $m_s$:) |
|---|---|---|---|---|---|---|---|
| 12. | Install piping & cabling | 259200 110 10000 | | | | | |
| 13. | Gas & Elect. test | | | 129000 301 50000 | | | |
| 14. | Install alignment & compensators | 129600 112 10000 | | | | | |
| 15. | Alignment test | | | 172800 302 50000 | | | |
| 16. | Move to rotation station | | 14400 201 0 | | | | |
| 17. | Adjust module in assigned position | 115200 114 80000 | | | | | |
| 18. | Remove from station | 28800 115 5000 | | | | | |
| 19. | Move to transport fixture | 14400 116 30000 | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Prepared by: REG/ASK

Sheet 2 of 2






DRAPER LABORATORY

REFERENCE

# DRAPER LABORATORY Pro-active Method for Concurrent Design

The techniques outlined below have been applied to the *assembly* of a wide variety of *electro-mechanical products* (both commercial and military). Starting with easily derived data about a "product", this PC-based method helps the user create a sequence, develop a process plan, establish a task/resource matrix, and design an assembly system.

## A. Product data requirements

For each module/sub-assembly (concept / development / final design):

1. Components: bounding box dimensions (X, Y and Z), weight, code and description.

2. Physical mates: components involved, generic characteristic (type of mate), number of such mates involved (e.g. multiple bolts), general direction of mate (X, Y or Z)

## B. Assembly Sequence (S)

1. Component bounding boxes for the major assembly directions can be shown in an exploded view. User can rearrange the order and may realize assembly difficulties which were not apparent earlier.

2. Program determines the nominal assembly sequence. User can readily alter the order to compensate for unusual or unexpected (by the program) conditions.

## C. Assembly Process Plan (P)

1. User specifies sequence location of in-process test(s).

2. Program establishes details of the assembly process plan.

3. User has the option of deleting non-component steps in the plan.

4. An assembly "score" is determined based upon the ratio of total tasks to the number of components plus one and upon the overall assembly difficulty. This "score" provides an indication of the "goodness" of the particular assembly sequence.

D. Task/Resource Matrix (M)

1. Program establishes applicability of the three generic resource types (manual, fixed automation, or programmable automation).

2. Time and cost requirements are estimated heuristically (calculations are based on data from a wide variety of products).

3. Program suggests appropriate programmable devices. User can alter the fundamental cost data and any specific performance data for each resource type.

4. Matrix exhibits the cost and performance characteristics of all applicable resources for each task.

E Assembly System Design (ASDP)

Utilizes company economic criteria/data as well as the task/resource matrix.

1. General Solution: a. Table showing system devices and costs as well as a weighted combination of these parameters called a "rating". The minimum number of pallets is also determined; b. Graph of unit costs expected; c. Graph of stations required; d. Graph of required investment; e. Graph of "Rating"

2. Specific Solution: a. Complete print-out of cost and time allocations; b. System schematic (used by engineers); c. Cost vs. batch size vs. utilization graph (used by accountants).

3. Word description of system. (optional): For each workstation: a. Station number and type; b. Description of task(s) to be performed; c. Effective capacity (jobs per hour); d. Capital equipment and tooling costs.

# Production

# Improvement

# Behavior

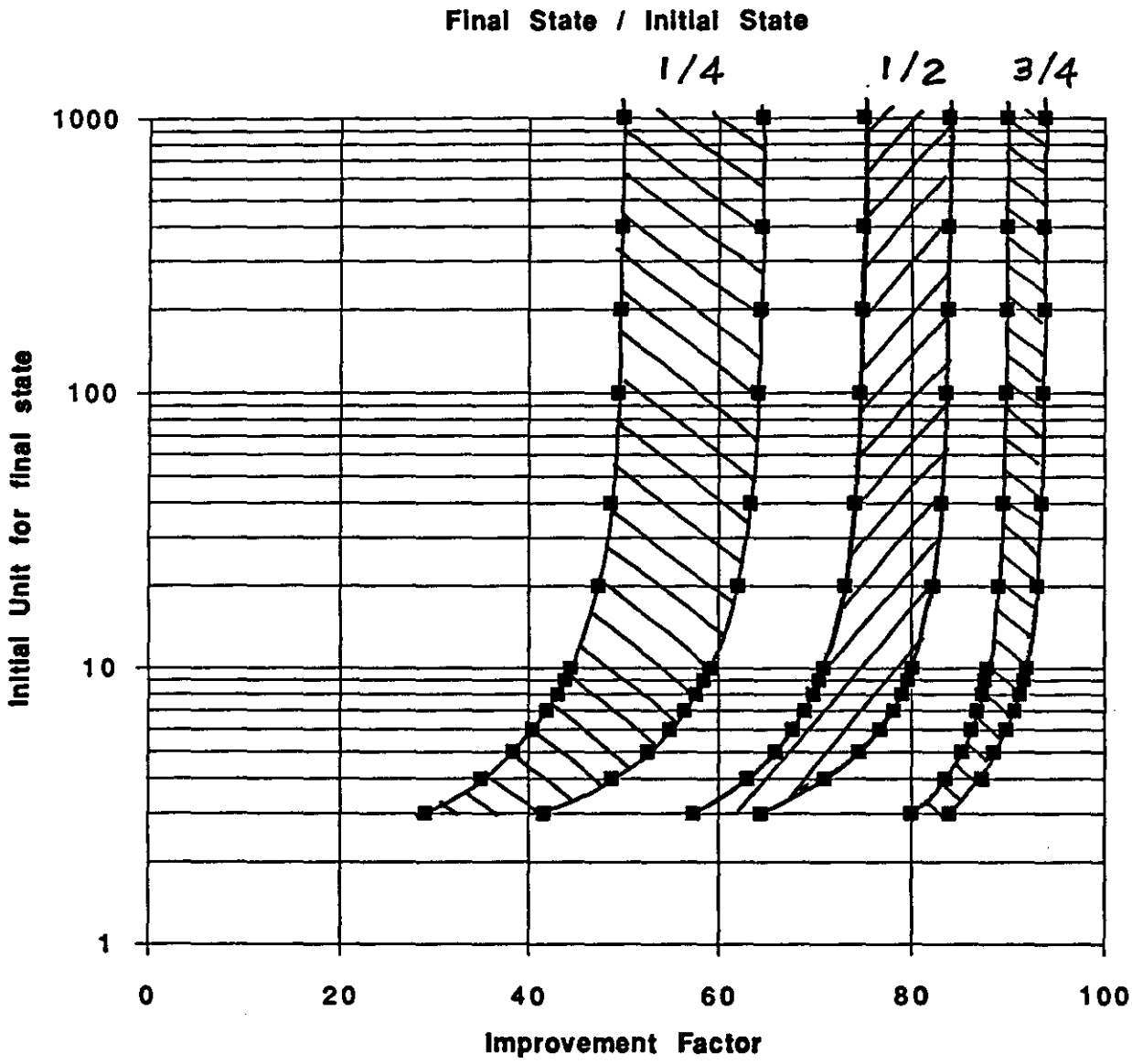
# Production Improvement Behavior

Applies to yield improvement (expressed as 1 / yield).

Applies to cycle time improvement (directly).

Based upon change from initial state (at unit 1) to a final state (beginning at a prescribed unit).

An IMPROVEMENT FACTOR is specified (similar to learning curve %, it has prescribed bounds).


Final State / Initial State
1/4
1/2
3/4
1000
100
10
1
Initial Unit for final state
0
20
40
60
80
100
Improvement Factor

# Production Improvement Behavior

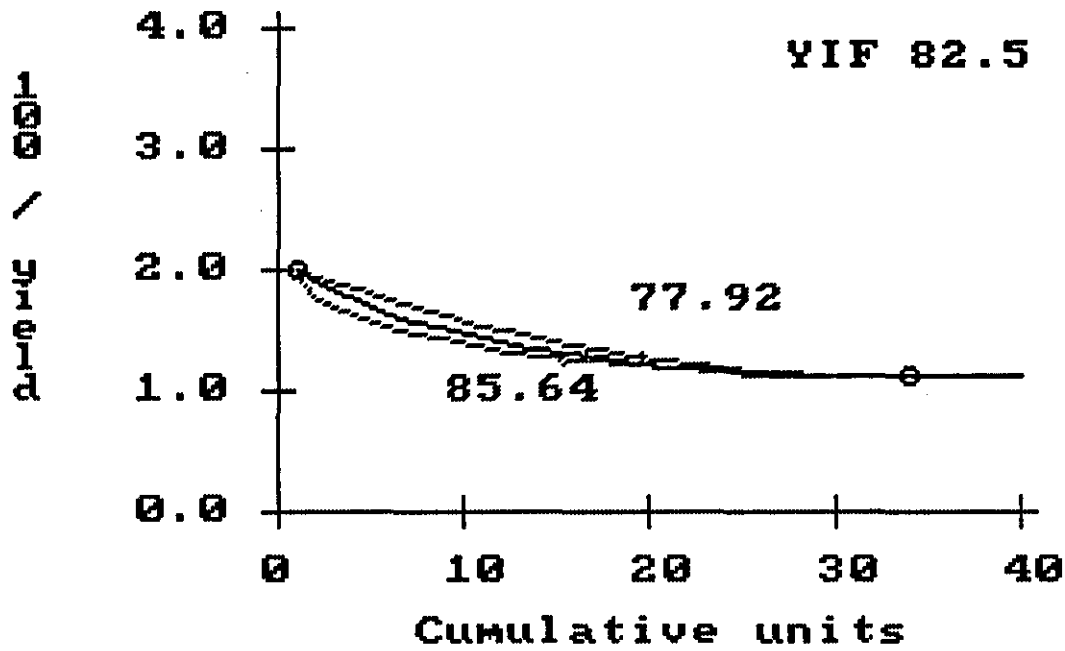
Yield improves from an initial condition to a "steady-state" value which commences when a prescribed number of "good" units (Q) has been produced.

The behavior expected is prescribed using a "Yield Improvement Factor" (YIF).

Production Improvement Estimation Program 07-21-1992 13:38:29

50.00% yield for first unit

90.00% final value @ 34.00 cumulative units




100/
/yield = 2.427 -1.316 * sqr[ 1 - [(units - 34.000)/ 34.887]^2 ]

46.14 total units required

# Production Improvement Behavior

Cycle time improves from an initial condition to a "steady-state" value that begins when the cumulative units necessary to produce (Q) usable units has been reached.

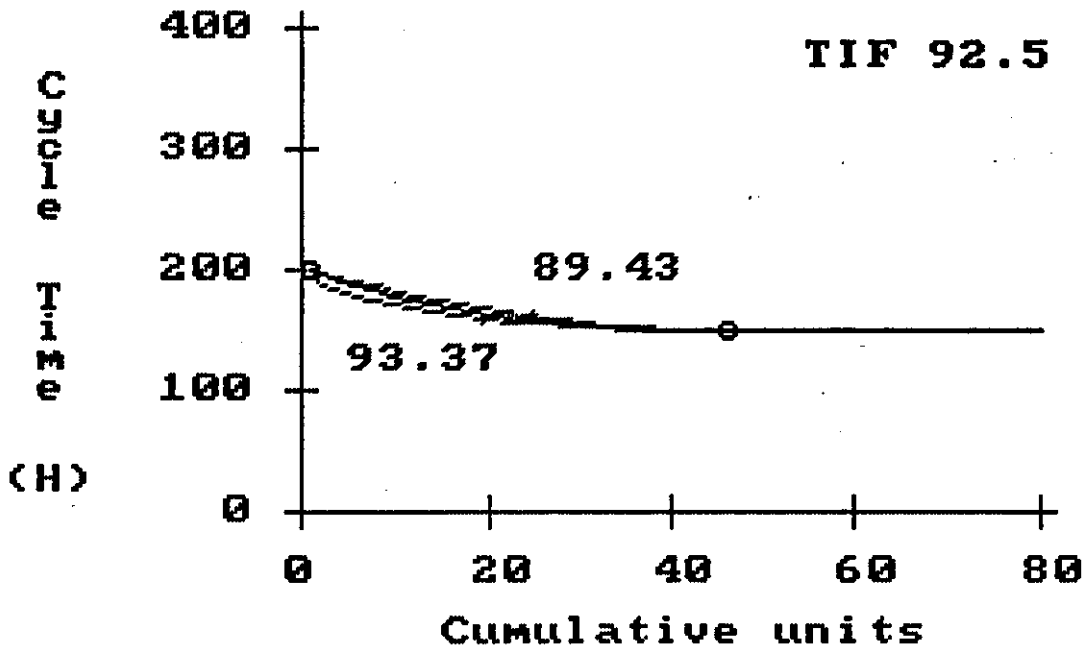
The expected behavior is prescribed using a "Time Improvement Factor" (TIF).

Production Improvement Estimation Program 07-21-1992 13:39:54

224 Working days per year, 1 shifts per day

200.00 H cycle time for first unit

150.00 H final value @ 46.14 cumulative units




cycle
time = 258.164 -108.164 * sqr[ 1 - [(units - 46.139)/ 53.539]^2 ]

# Production Improvement Behavior

The YIF and TIF factors are combined into a "Capability Improvement Factor" (CIF).

$$CIF = \sqrt{YIF * TIF}$$

*Yield Improvement*

*Cycle Time Improvement*

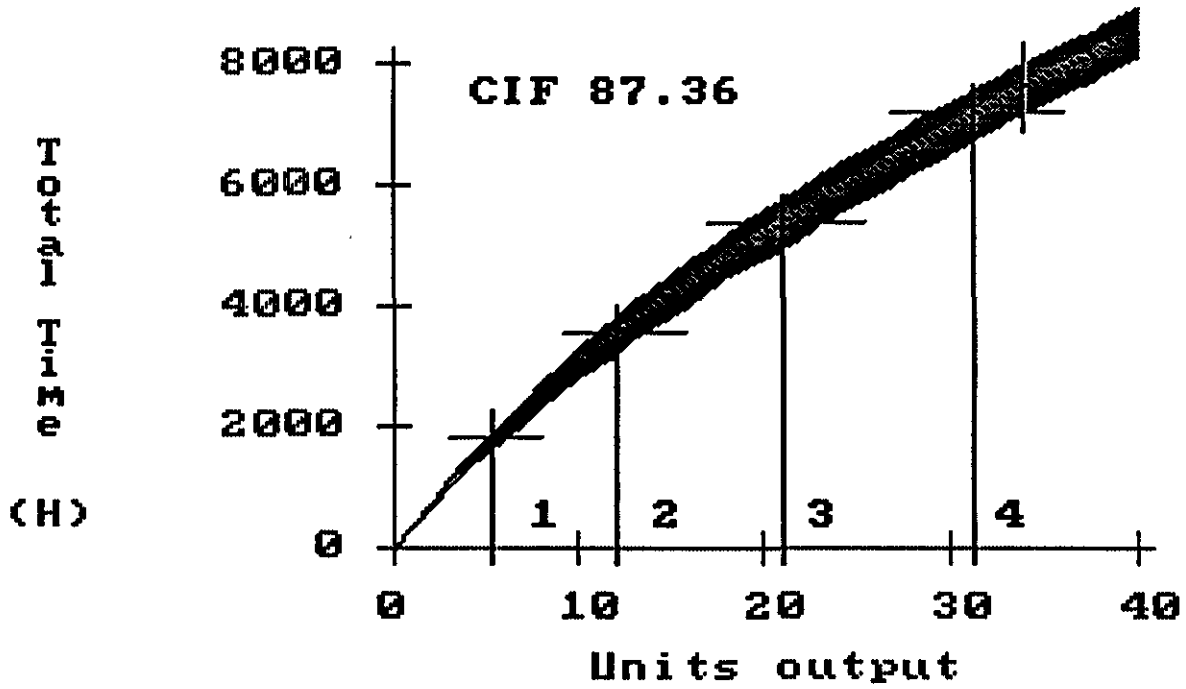
*1 shift Example*

Production Improvement Estimation Program 07-21-1992 13:41:24

224 Working days per year, 1 shifts per day

200.00 H cycle time for first unit

150.00 H final value @ 46.14 cumulative units




| year | units processed | nominal time (H) | final unit | cycle time (H) | yearly output | total output |
|---|---|---|---|---|---|---|
| 1 | 9.49 | 188.89 | 9.49 | 180.26 | 5.19 | 5.19 |
| 2 | 10.53 | 170.13 | 20.02 | 163.77 | 6.98 | 12.17 |
| 3 | 11.34 | 158.04 | 31.36 | 154.41 | 8.85 | 21.02 |
| 4 | 11.82 | 151.56 | 43.18 | 150.19 | 10.32 | 31.34 |
| 5 | 11.94 | 150.03 | 55.13 | 150.00 | 10.75 | 42.09 |

Production Improvement Estimation Program 07-21-1992 13:42:23

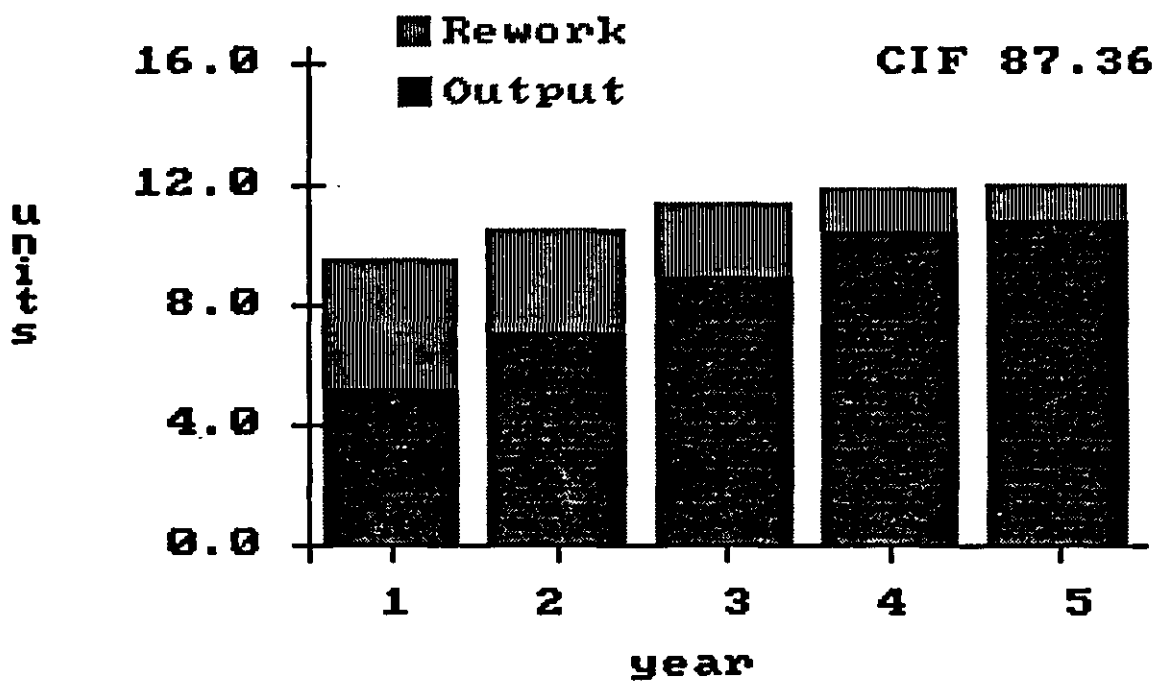
50.00% yield for first unit

90.00% final value @ 34.00 total good units

224 Working days per year, 1 shifts per day

200.00 H cycle time for first unit

150.00 H final value @ 46.14 cumulative units



*Yield Improvement*

*Cycle Time Improvement*

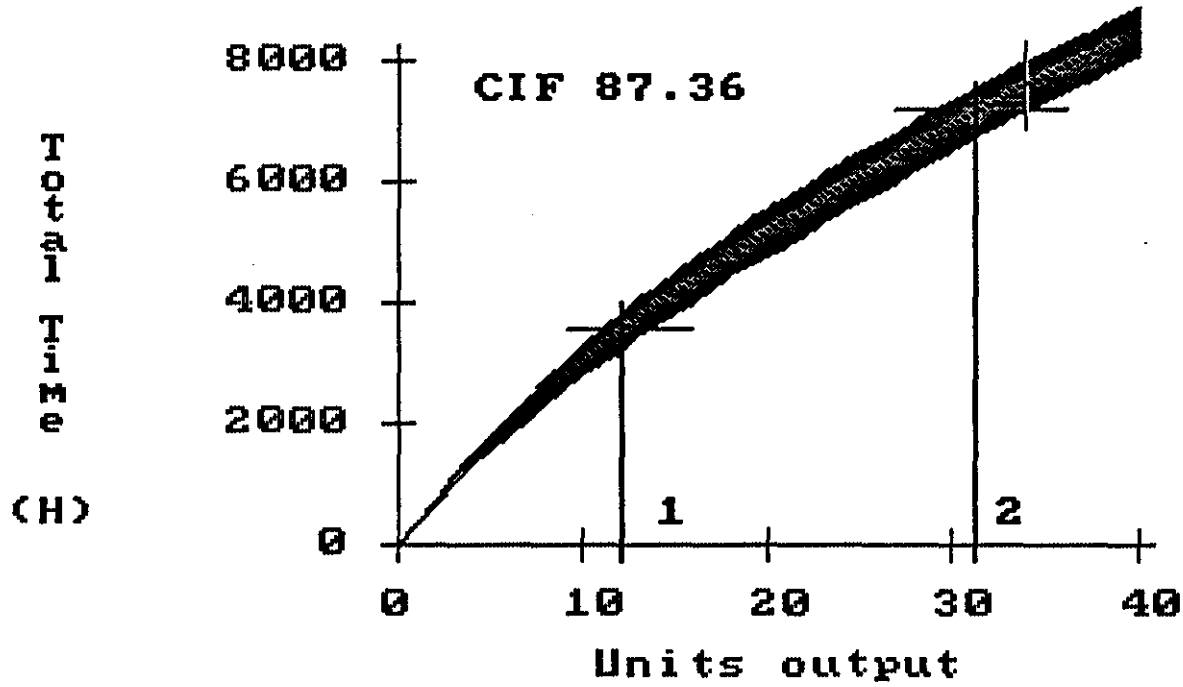
*2 shift Example*

Production Improvement Estimation Program 07-21-1992 13:46:19

224 Working days per year, 2 shifts per day

200.00 H cycle time for first unit

150.00 H final value @ 46.14 cumulative units




| year | units processed | nominal time (H) | final unit | cycle time (H) | yearly output | total output |
|---|---|---|---|---|---|---|
| 1 | 20.02 | 179.02 | 20.02 | 163.77 | 12.17 | 12.17 |
| 2 | 23.16 | 154.73 | 43.18 | 150.19 | 19.17 | 31.34 |
| 3 | 23.89 | 150.01 | 67.07 | 150.00 | 21.50 | 52.84 |

Production Improvement Estimation Program 07-21-1992 13:47:51

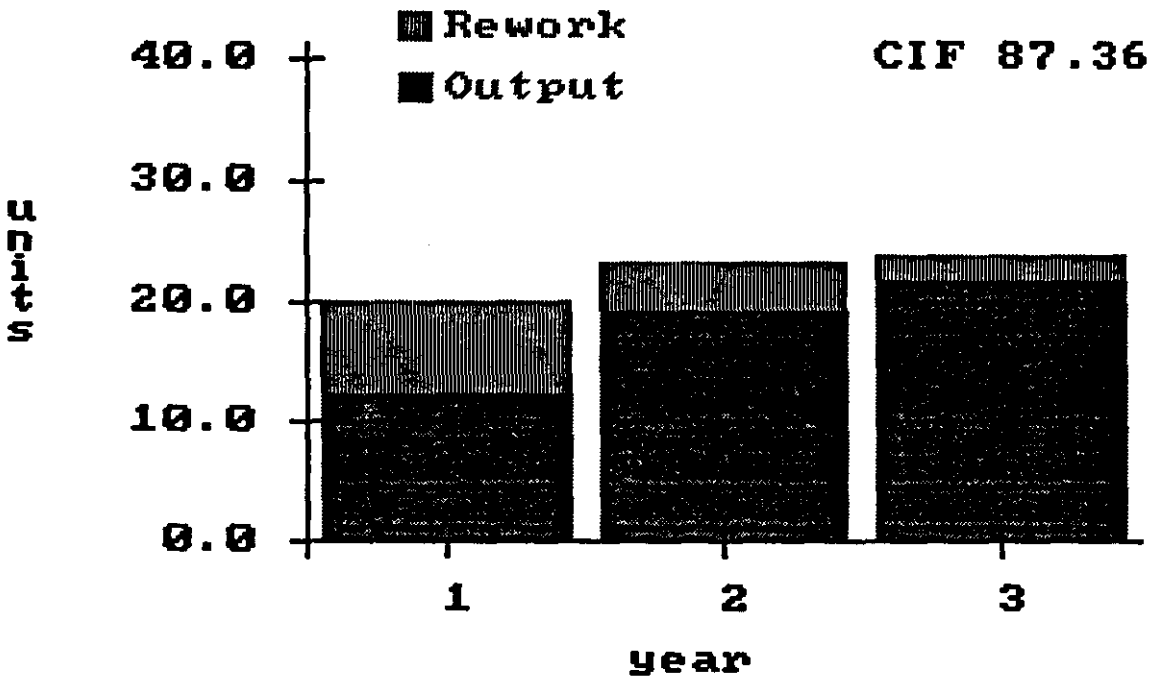
50.00% yield for first unit

90.00% final value @ 34.00 total good units

224 Working days per year, 2 shifts per day

200.00 H cycle time for first unit

150.00 H final value @ 46.14 cumulative units



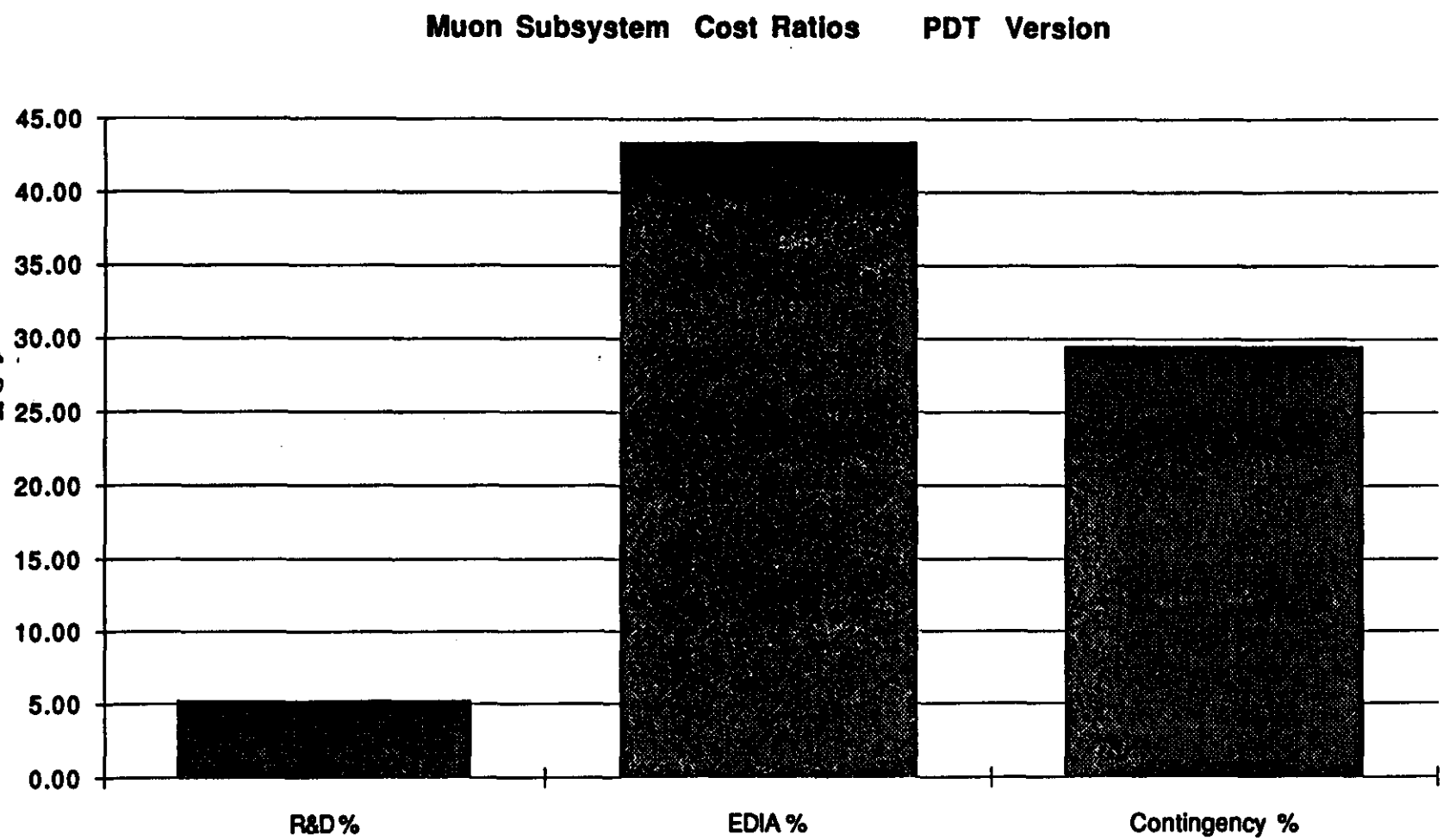
# GEM

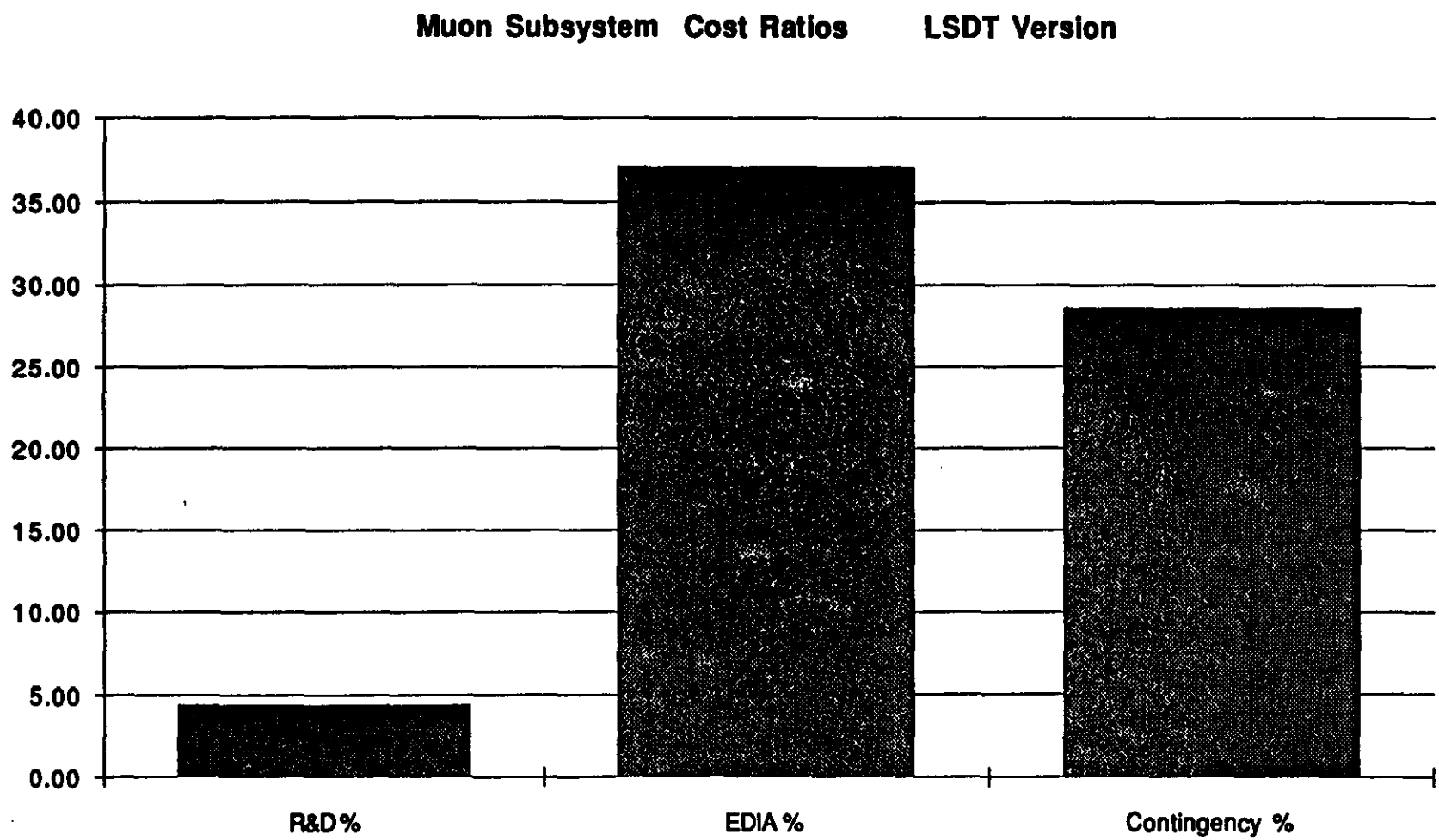
## Muon Subsystem Cost Matrix

## Revision 12

7 July 1992

DRAPER LABORATORY


Muon Subsystem Cost Ratios PDT Version
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
R&D %
EDIA %
Contingency %


Muon Subsystem Cost Ratios LSDT Version
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
R&D %
EDIA %
Contingency %

Muon Subsystem Cost Summary - Rev. 12 (w/o chamber electronics) 7/8/92

| WBS No. | Item | Engrg/Design | M&S | Insp/Admin | Materials | Assembly | Installation | Equipment | Sub-total | Contingency | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (-3.1) | Totals - PDT | 10.117 | 3.035 | 10.485 | 19.123 | 19.828 | 2.416 | 7.172 | 72.176 | 20.355 | 92.531 |
| (-3.2) | Totals - LSDT | 10.265 | 3.042 | 10.474 | 28.425 | 18.518 | 2.416 | 7.851 | 80.991 | 22.962 | 103.953 |
| 03.1.1 | Central Region - PDT | 4.433 | 0.962 | 3.9 | 11.957 | 14.468 | 1.439 | 4.397 | 41.556 | 12.133 | 53.689 |
| 03.1.1.1 | Installation | 0.891 | 0.075 | 0.221 | 0.56 | 0 | 1.439 | 2.31 | 5.496 | 1.322 | 6.818 |
| 03.1.1.2 | Sector Assembly | 1.668 | 0.408 | 2.799 | 8.717 | 12.98 | 0 | 1.927 | 28.499 | 8.315 | 36.814 |
| 03.1.1.2.3 | PDT chambers | 0.332 | 0.086 | 0.882 | 5.99 | 8.414 | 0 | 0.15 | 15.854 | 4.714 | 20.568 |
| 03.1.1.2.4 | RPC chambers | 0.332 | 0.089 | 0.934 | 1.491 | 2.7 | 0 | 0.346 | 5.892 | 1.734 | 7.626 |
| 03.1.1.2.5 | Structure | 0.555 | 0.072 | 0.422 | 0.292 | 0.906 | 0 | 0.856 | 3.103 | 1.043 | 4.146 |
| 03.1.1.2.6 | Alignment | 0.153 | 0.112 | 0.407 | 0.684 | 0.264 | 0 | 0 | 1.62 | 0.345 | 1.965 |
| 03.1.1.3 | Electronics | 0.153 | 0.075 | 0.154 | 0.2 | 0.19 | 0 | 0 | 0.772 | 0.178 | 0.95 |
| 03.1.1.4 | Gas Systems | 1.257 | 0.334 | 0.57 | 2.08 | 0.638 | 0 | 0.16 | 5.039 | 1.618 | 6.657 |
| 03.1.1.5 | Cooling Systems | 0.464 | 0.07 | 0.156 | 0.4 | 0.66 | 0 | 0 | 1.75 | 0.7 | 2.45 |
| 03.2.1 | Central Region - LSDT | 4.581 | 0.969 | 3.889 | 21.259 | 13.158 | 1.439 | 5.076 | 50.371 | 14.74 | 65.111 |
| 03.2.1.1 | Installation | 0.891 | 0.075 | 0.221 | 0.56 | 0 | 1.439 | 2.31 | 5.496 | 1.322 | 6.818 |
| 03.2.1.2 | Sector Assembly | 1.816 | 0.415 | 2.788 | 18.019 | 11.67 | 0 | 2.606 | 37.314 | 10.922 | 48.236 |
| 03.2.1.2.3 | LSDT chambers | 0.48 | 0.095 | 0.882 | 15.085 | 7.17 | 0 | 0.829 | 24.541 | 7.304 | 31.845 |
| 03.2.1.2.4 | RPC chambers | 0.332 | 0.089 | 0.934 | 1.491 | 2.7 | 0 | 0.346 | 5.892 | 1.734 | 7.626 |
| 03.2.1.2.5 | Structure | 0.555 | 0.089 | 0.422 | 0.292 | 0.906 | 0 | 0.856 | 3.12 | 1.043 | 4.163 |
| 03.2.1.2.6 | Alignment | 0.153 | 0.112 | 0.407 | 0.684 | 0.264 | 0 | 0 | 1.62 | 0.345 | 1.965 |
| 03.2.1.3 | Electronics | 0.153 | 0.075 | 0.154 | 0.2 | 0.19 | 0 | 0 | 0.772 | 0.178 | 0.95 |
| 03.2.1.4 | Gas Systems | 1.257 | 0.334 | 0.57 | 2.08 | 0.638 | 0 | 0.16 | 5.039 | 1.618 | 6.657 |
| 03.2.1.5 | Cooling Systems | 0.464 | 0.07 | 0.156 | 0.4 | 0.66 | 0 | 0 | 1.75 | 0.7 | 2.45 |
| 03.1.2 | End Cap Region | 2.501 | 0.584 | 3.289 | 7.166 | 5.36 | 0.977 | 2.775 | 22.652 | 7.002 | 29.654 |
| 03.1.2.1 | Installation | 0.297 | 0.036 | 0.182 | 0.311 | 0 | 0.977 | 1.5 | 3.303 | 0.795 | 4.098 |
| 03.1.2.2 | Sector Assembly | 1.341 | 0.332 | 2.26 | 4.734 | 4.477 | 0 | 1.145 | 14.289 | 4.577 | 18.866 |
| 03.1.2.2.3 | CSC chambers | 0.332 | 0.086 | 0.864 | 3.353 | 3.397 | 0 | 0.042 | 8.074 | 2.906 | 10.98 |
| 03.1.2.2.4 | Structure | 0.555 | 0.14 | 0.768 | 0.084 | 0.487 | 0 | 0.453 | 2.487 | 0.772 | 3.259 |
| 03.1.2.2.5 | Alignment | 0.157 | 0.074 | 0.473 | 1.112 | 0.22 | 0 | 0 | 2.036 | 0.489 | 2.525 |
| 03.1.2.3 | Electronics | 0.155 | 0.017 | 0.142 | 0.631 | 0.119 | 0 | 0 | 1.064 | 0.245 | 1.309 |
| 03.1.2.4 | Gas Systems | 0.629 | 0.167 | 0.285 | 1.04 | 0.319 | 0 | 0.08 | 2.52 | 0.809 | 3.329 |
| 03.1.2.5 | Cooling Systems | 0.079 | 0.032 | 0.42 | 0.45 | 0.445 | 0 | 0.05 | 1.476 | 0.576 | 2.052 |
| 03.1.3 | Project Mgmt. | 0 | 0.435 | 3.296 | 0 | 0 | 0 | | 3.731 | 0.373 | 4.104 |
| 13 | R&D | 1.791 | 0.754 | 0 | 0 | 0 | 0 | | 2.545 | 0.509 | 3.054 |
| 23 | Concept Design | 1.392 | 0.3 | 0 | 0 | 0 | 0 | | 1.692 | 0.338 | 2.03 |

# GEM Muon Subsystem Cost Matrix

changes made for Revision 12-1

| | PDT | | LSDT | |
|---|---|---|---|---|
| | Rev. 11 | Rev. 12 | Rev. 11 | Rev. 12 |
| EDIA | 1.32 M$ | 1.30 M$ | 1.30 M$ | 1.46 M$ |
| Materials | 8.08 M$ | 5.99 M$ | 3.66 M$ | 15.09 M$ |
| Assembly Labor | 6.88 M$ | 8.41 M$ | 6.25 M$ | 7.17 M$ |
| Equipment | 0.36 M$ | 0.15 M$ | 0.36 M$ | 0.83 M$ |
| Chmbr. Sub-Total | 16.64 M$ | 15.85 M$ | 11.57 M$ | 24.54 M$ |
| Contingency | 4.95 M$ | 4.71 M$ | 3.43 M$ | 7.30 M$ |
| Chamber Total | 21.59 M$ | 20.57 M$ | 14.99 M$ | 31.85 M$ |
| Net change | - 1.02 M$ | | + 16.85 M$ | |

8 July 1992

DRAPER LABORATORY

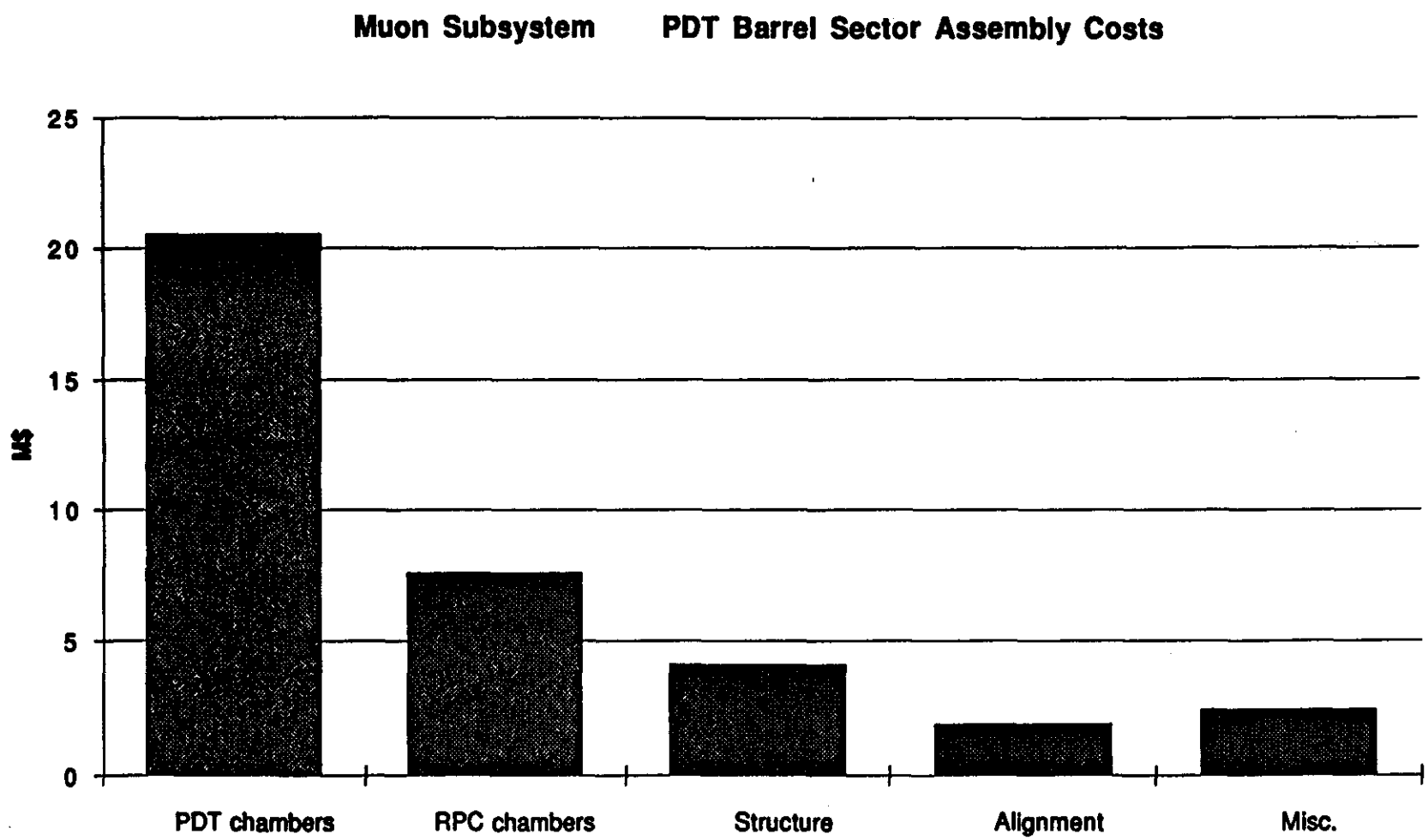
# GEM Muon Subsystem Cost Matrix

**LSDT Chamber materials** changes made for Revision 12

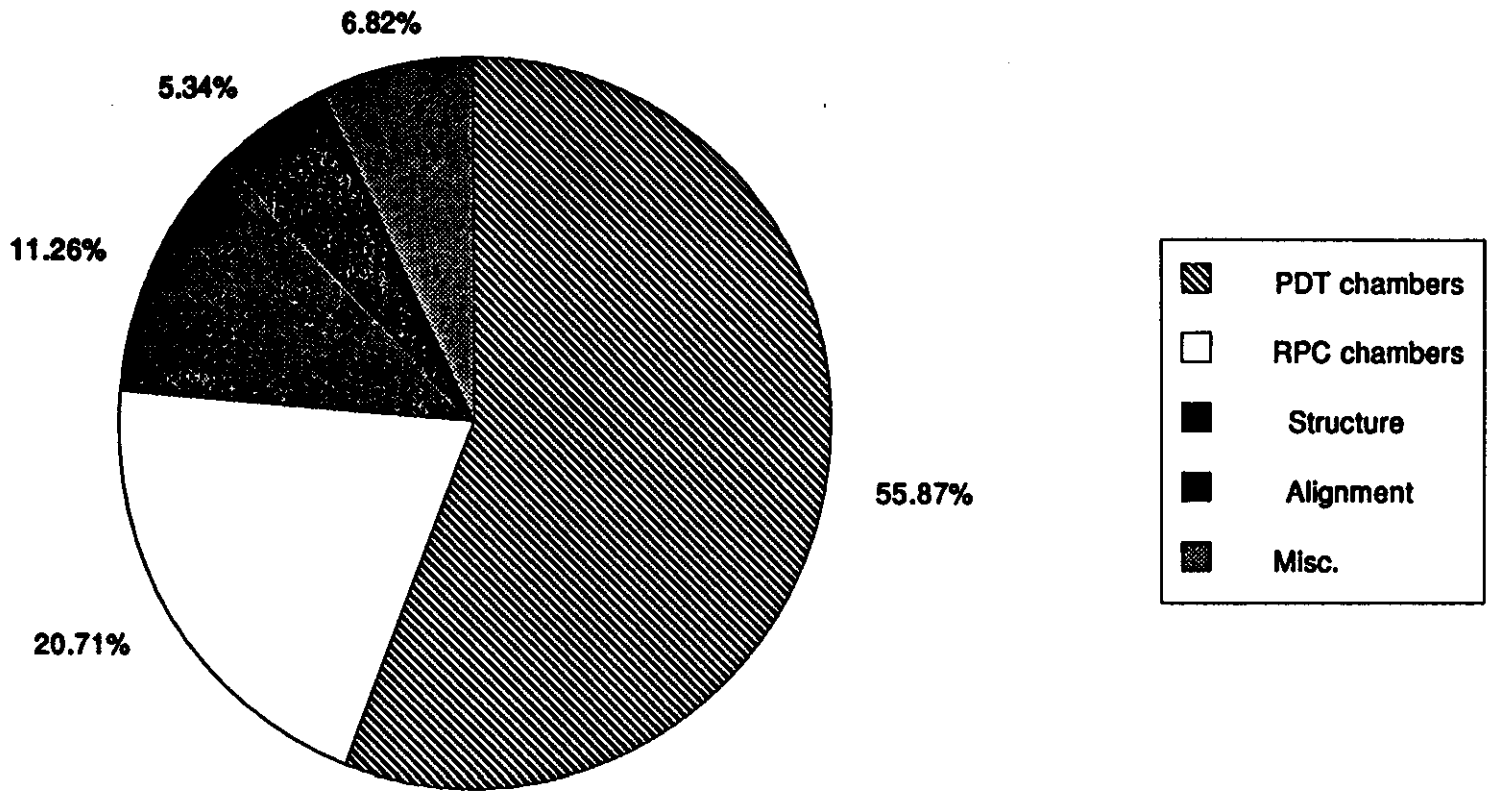
| | Rev. 11 | Rev. 12 |
|---|---|---|
| aluminum for enclosures | 0.55 M$ | 7.28 M$ |
| bridges | 1.50 M$ | 1.45 M$ |
| cathode planes | 0.09 M$ | 4.30 M$ |
| Hexcell | 0.55 M$ | 1.52 M$ |
| Chamber Sub-Total | 3.66 M$ | 15.09 M$ |
| Net change | + 11.43 M$ | |

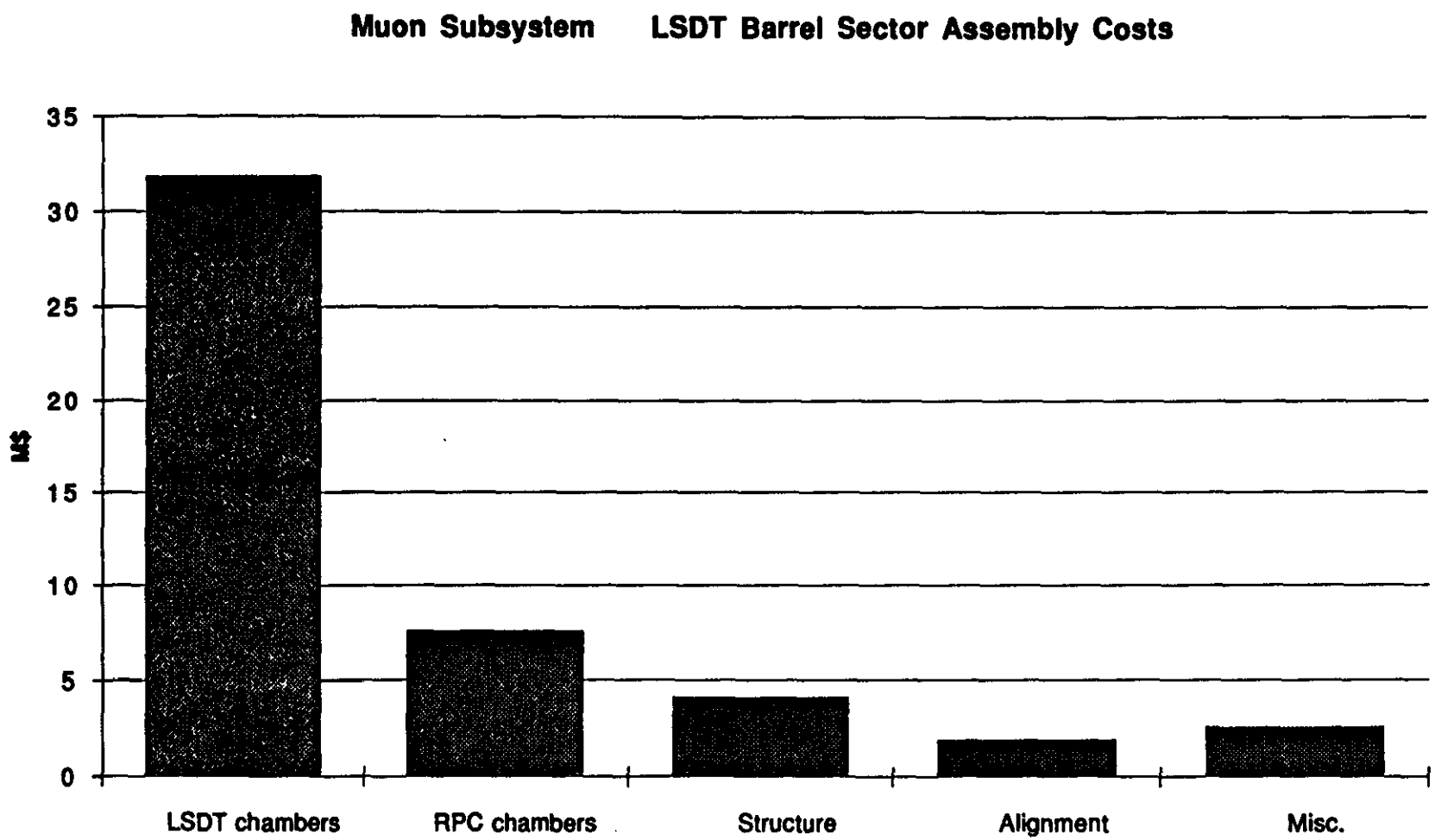
8 July 1992

DRAPER LABORATORY

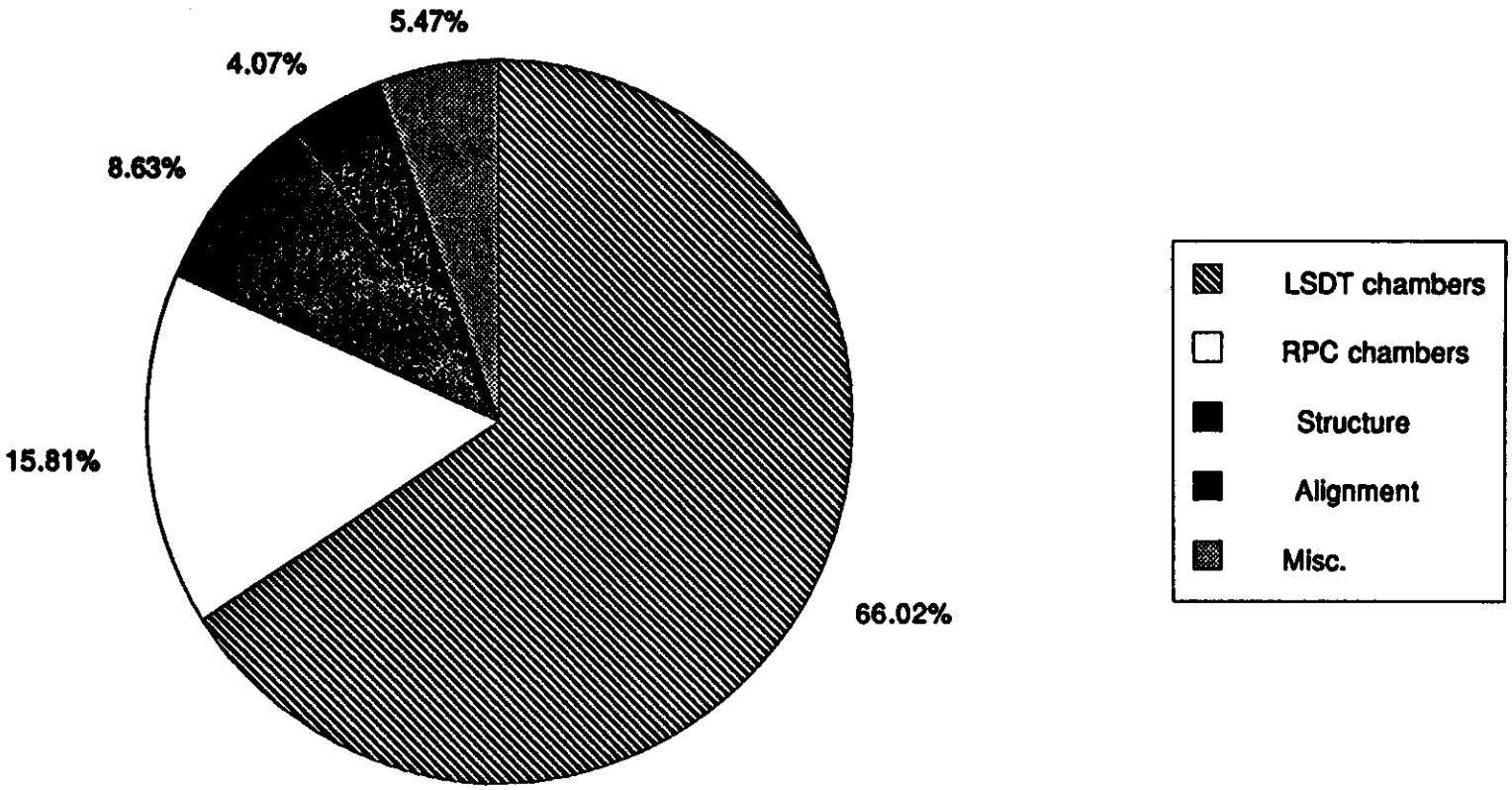

Muon Subsystem PDT Barrel Sector Assembly Costs
25
20
15
10
5
0
M$
PDT chambers
RPC chambers
Structure
Alignment
Misc.

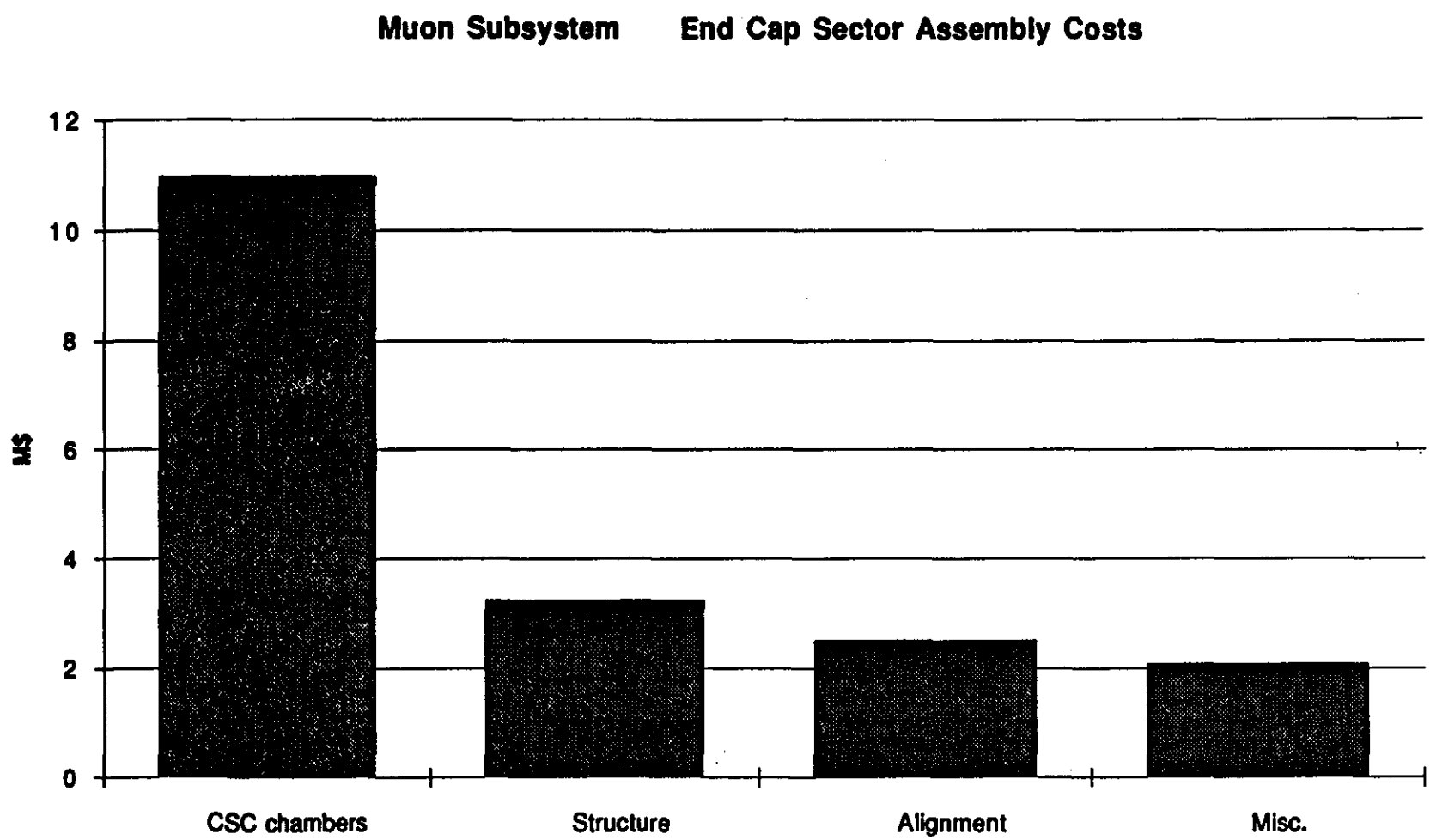
**Muon Subsystem PDT Barrel Sector Assembly Costs**



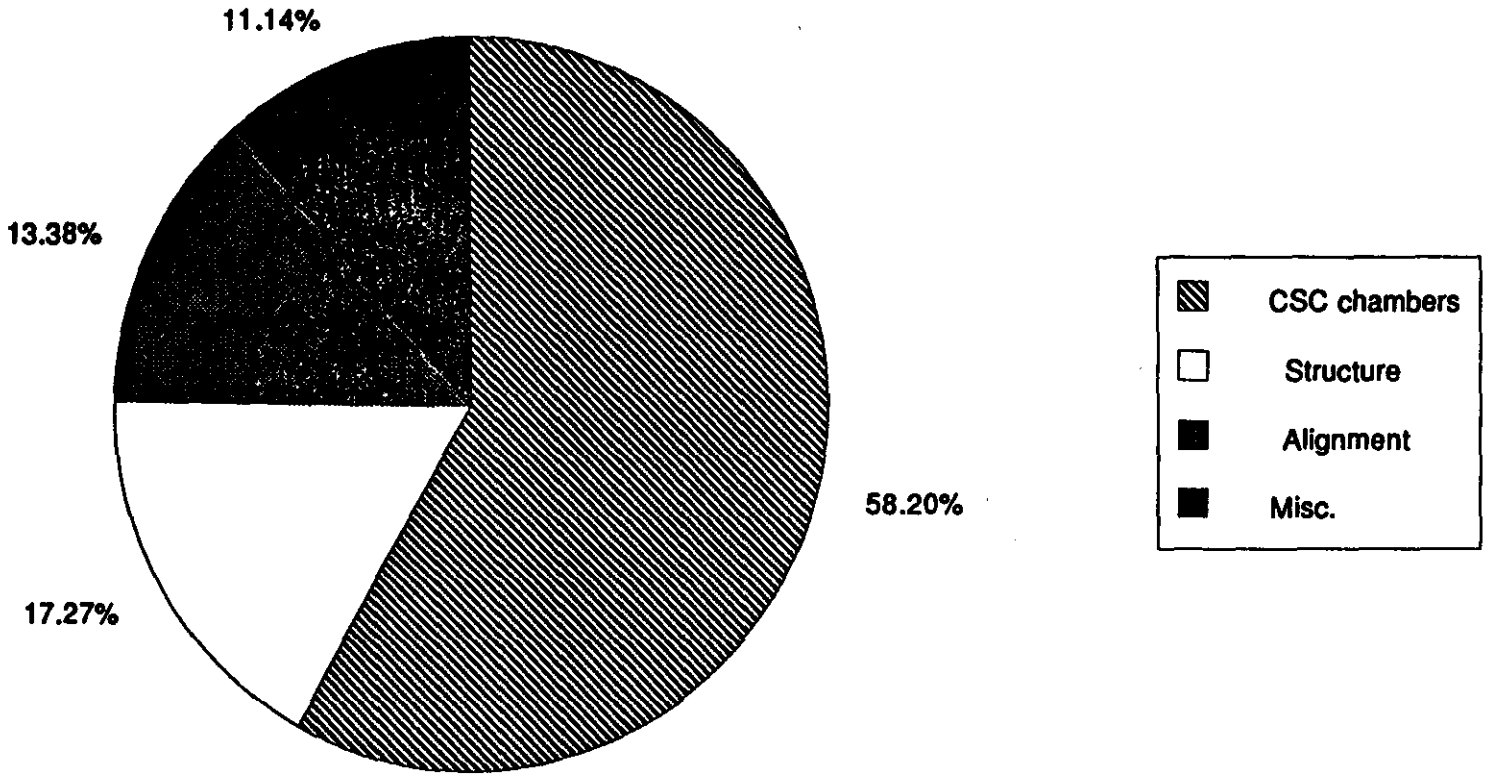

Muon Subsystem LSDT Barrel Sector Assembly Costs
35
30
25
20
15
10
5
0
$M
LSDT chambers
RPC chambers
Structure
Alignment
Misc.

**Muon Subsystem LSDT Barrel Sector Assembly Costs**




Muon Subsystem End Cap Sector Assembly Costs
$M
12
10
8
6
4
2
0
CSC chambers
Structure
Alignment
Misc.

**Muon Subsystem End Cap Sector Assembly Costs**



# GEM Muon Subsystem Cost Matrix

## Revision Status

| Sub-system | Date of Latest Change |
|---|---|
| PDT Chambers | 8 July 1992 |
| LSDT Chambers | 29 June 1992 |
| RPCs | 16 June 1992 |
| CSCs | 16 June 1992 |
| Structures | 16 June 1992 |
| Alignment | 3 May 1992 |
| Gas Systems | 3 June 1992 |
| Cooling Systems | 31 January 1992 |

15 July 1992

DRAPER LABORATORY