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TITLE COST PROJECTION FOR A SUPERCONDUCTING LINAC STRUCTURE

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COST PROJECTION FOR A SUPERCONDUCTING LINAC STRUCTURE

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Abstract

The increase of energy of the present 800 MeV proton linac at LAMPF to 1.6 or 2.2 GeV is of primary importance for the proposed future experimental program of this Laboratory. Layout and cost studies have been performed for a) normalconducting and b) superconducting accelerating structures. A more recent cost analysis for a superconducting structure is given in this report.

1 Reconsidering a Superconducting Structure

In March 1987, a special workshop at Los Alamos was organized to investigate the feasibility and cost of a superconducting extension of LAMPF (see Proceedings LA-UR-87-1160). At that time and as a conclusion, it was felt that the fabrication cost of superconducting cavities was prohibitively high.

Today, the rapid progress of the technique and the widening of applications justify a review of this option for LAMPF.

In particular, the limited available length on the mesa (not more than 500 m) calls for a high gradient structure.

A gradient of 5 MV/m is used in most of the known cases, at relatively low operating frequencies. For LAMPF, the cavity frequency to be considered would be 402.5 MHz, a value between the 350 MHz LEP and the 500 MHz DESY/HERA cavities.

Other relevant factors to be considered are

- Cavity losses (RF losses), heat conduction losses.
- The conversion factor for the cryosystem. This determines essentially the cost of energy consumption, which should be estimated for a 25-year operation period.
- Voltage/phase stability.

H. Lengeler's cost estimate of 300 kSF/m for the CERN structure has been taken as one of the main references for calculating the necessary capital investment for the structure. We added 20% installation cost and 35% contingency.

2 Information and Statements

Information and statements on the state of the technique (for high β beams).

Documents from the following Laboratories or authors were taken into account for the study:

- Los Alamos Workshop, March 1987
- CEBAF Design Report
- CERN Reports (Lengeler, Stierlin)
- Wuppertal (H. Piel) Lectures
- DESY/HERA Reports (D. Proch, LAC 88)
- Test Reports on the CERN-LEP Structure
- KEK
- LANL (G. Lawrence, J. McGill)

3 Important Statements

1. CEBAF 5 MeV/m, 1 GeV total
   (Rode, Phillips, Sundelin)
   CORNELL
2. H. Piel. 400 MHz, $Q = 3 \cdot 10^9$ "conservative", calculate with conversion 400-500, rf losses at 5 MV/m = 20 watts/m.
   On heat conduction losses: lowest achieved at Darmstadt (1 watt/m)

On the CERN/LEP cryostat, ask H. Lengler for precise information on rf losses and heat conduction losses.
The rf losses of the 352 MHz 4 cell-unit are 30 watts.
4 pieces built, values measured.

For heat conduction consider rf input coupler size. The rf input power per meter, in our case, would be 35 ma × 12 % duty = 4.2 ma average current, × 5 MV/m = 21 kW/m. For a 1.5 m structure 7.5 MV × 4.2 ma ≈ 30 kW. This would be the same as for the CERN/LEP structure.
Conclusion: = same design as at CERN.
Interatom considers the CERN cryostat the least expensive. Seamless connection tank/tank.

CERN tender opening for 32 structures, 4 cell, by Feb. 24.

3. CERN SPS LEP longterm test.
   D. Boussard et al. (to be presented at the Chicago Conference) 4-cell 350 MHz Nb, installed August 1987 in SPS for test.
   Operation at 7 MV/m.
   Design field 5 MV/m, measured Q=2...3 × 10^9.
   4000 hours operation at 4.5 K.
4. DESY (D. Proch).
   500 MHz, HERA 5 MV/m, Q = 2 × 10^9.
   rf losses 10 watts/cell, 30 cm/cell → 33 W/m.
   Cost 400 kDM/m active, without mounting, without cryotest. Cryoplant at HERA operates with conversion 300.
5. KEK
   16 single resonators 500 MHz.
   5.5 - 8.4 MV/m with tuners.
6. LAMPF (G. Lawrence) rf loss estimate 20 Watts/m, the heat conduction loss should be about 20 Watts/m (for the CERN structure).

Cavity and Cryostat Design

A few examples (Figs. 1 to 4) should illustrate the various solutions applied at CERN, CEBAF and DESY

4 Conclusion for Cost Projection

In order to establish cost spreadsheets and charts for a superconducting extension of LAMPF, most of the comments mentioned above were taken into account.

It was decided to:

- take RF losses of 20 Watt/m at 5 MV/m
- take the heat conduction loss as 20 Watt/m
- take a conversion factor 500
- take the structure cost of CERN and DESY
- follow CERN tender results (for confirmation or updating of the structure cost).

5 Results for 800 MeV and 600 MeV Extensions

Charts 1 and 2 show the dependence of

- Linac Equipment Cost
- 25 year lifetime cryo-cost and
- the total cost including 25 year rf power consumption cost.

For reasons of simplicity, these values were shown for only four different gradients, namely 1 MeV/m, 2 MeV/m, 5 MeV/m, and 10 MeV/m.

A few other values are contained in the corresponding Tables 1 and 2.

Not included in the estimates are internal personnel costs.

800 MeV High-Duty-Factor Extension:

The necessary capital investment for the structure – including associated equipment – is 48 M$, and about 13 M$ for the rf power sources. These values apply for a gradient of 5 MeV/m.

We have based the capital investment for rf power amplifiers on the best known value of 0.5 M$ per 1.2 MW module, which is valid for the current 805 MHz modules and should not change much for a 402.5 MHz frequency.

In fact, a promising candidate for rf power amplification at 400 MHz should be the klystrode (see separate progress report by M. B. Shrader).

600 MeV Low-Duty-Factor Extension:

We also show the cost of a subsequent linac section of 600 MeV, which would be of interest for injection into the AHF synchrotron. This section would operate with a relatively low duty factor. We have assumed a 1% duty cycle, and tentatively, a low rf efficiency.

The capital investment for the structure would be 35 M$ plus about 10 M$ for rf power amplifiers.

Lifetime Operating Cost:

In a normalconducting structure with modest beam current the lifetime operating cost is mainly determined by the copper loss in the structure. In comparison to this, the lifetime-cryo-cost for a superconducting structure can be expected to be much lower, typically by a factor 3 to 5. An even better result may be possible with improved cryo-systems (with conversion factors below 500). As to the ratio of rf lifetime power cost to cryo-cost, this ratio would be approximately 3:2 or 1:3, respectively, in our two examples.

Required Length of Buildings:

The structure length in the worksheets is active length. To include space required for focusing quadrupoles and other elements, the total length of the sections will increase by about 85%, based on a packing factor of 54%.

This would lead to about 300 m for the 800 MeV extension, and about 225 m for the 600 MeV extension.

6 Remarks on Implementation

Superconducting rf structures have so far been applied to CW electron and positron beams.

Application results for pulsed proton beams are not known (at least not to the author).

The excitation of rf cavities of extremely high Q values with high-current beam pulses needs particular attention.

In order to make a "low risk investment" with a "high risk technique" (if this qualification is justified), the following steps are recommended:

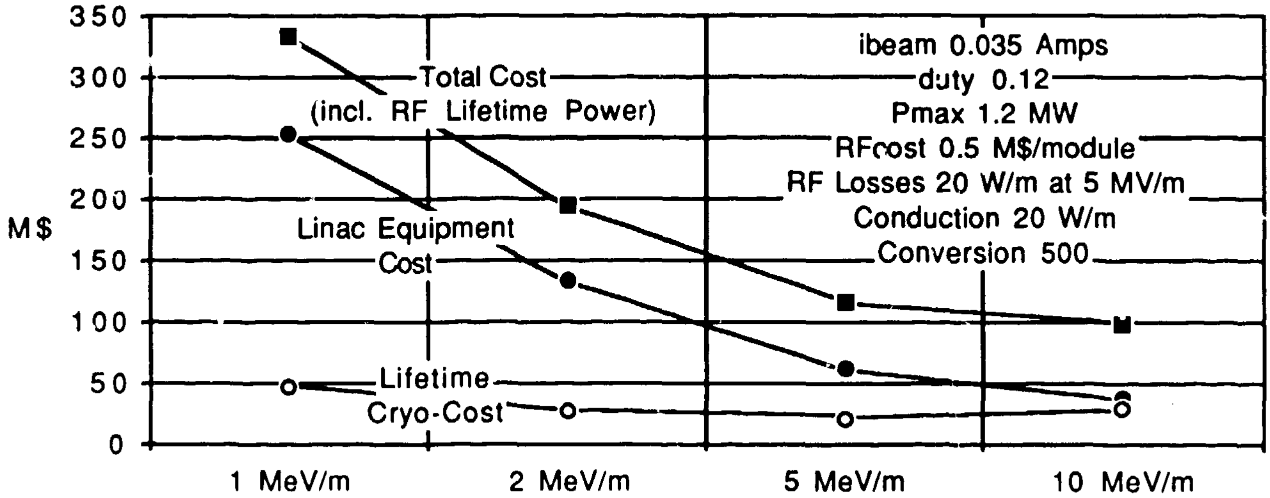
- tentative replacement of one or two 805 MHz linac sections by 402.5 MHz superconducting sections in the existing LAMPF linac;
- further steps only after beam tests and acceleration tests have been convincing;
- operation of several superconducting sections with proper amplitude and phase tolerances. For this, it will be necessary to carefully
  1. study transients
  2. study higher-order modes
  3. study feedback and feedforward.

The proper solution of these problems is mandatory and represents a big challenge for good rf engineers. A success would be an important step forward in accelerator technique.

7 Acknowledgment

The author has been stimulated by Arch Thiessen to undertake this study, and has profited very much from his suggestions and critics. Special thanks are also due to H. Piel, D. Proch, and G. Lawrence for valuable information.

Chart 1

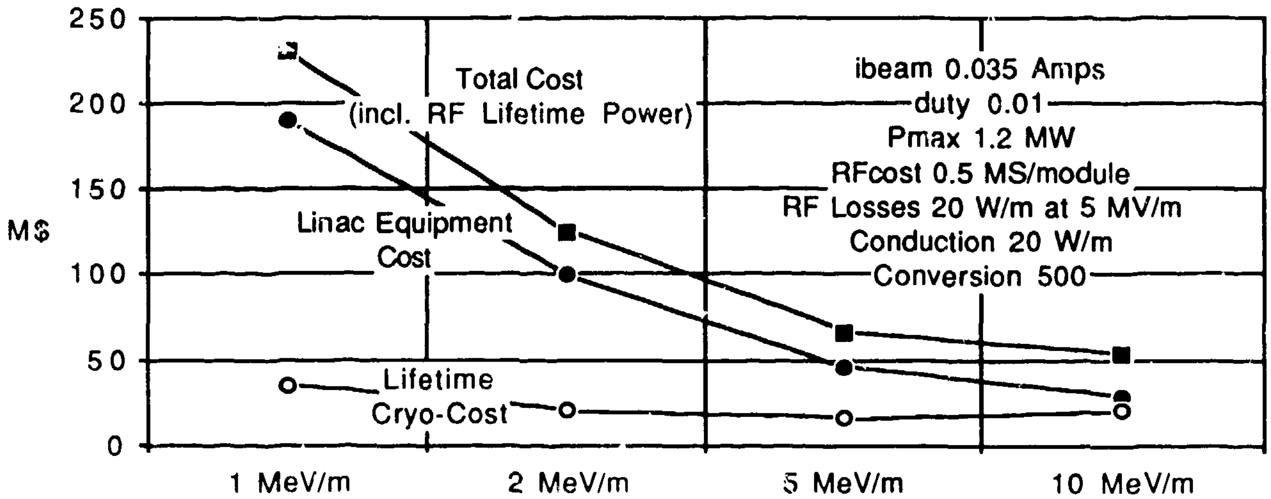


800 MeV High-Duty-Factor Superconducting Linac,
Required Capital Investment for Different Gradients

Table 1

Hi Duty Factor Superc. Linac Cost Spreadsheet 2/15/89 (Sc)									
Headroom	1.1								
Pmax	1.2	MW							
Pavg	0.144	MW							
eff	0.5								
RFcost	0.5	M$/module		hrspyear	4000	hrs/yr			
Life	25	Years		kwh	0.05	$/kW-hr			
Str	0.3	M$/meter		Power	0.2	M$/MWyear			
Zshunt	1000	GOhm/meter							
dE	800	MeV		Loss	0.02	kW/m at 5 MV/m+20 W/m			
ibeam	0.035	Amps		Conversio	500				
duty	0.12						Linac	Lifetime	
		Peak RF	RF	Struct.	Lifetime		Equipm.	Cryo	
Grad	Length	Power	Cost	Cost	Power	Total1	Cost	Cost	Total2
(MeV/m	(meters)	(MW)	(M$)	(M$)	(M$)	(M$)	(M$)	(M$)	(M$)
1	800	28	12.8	240	33.6	286	252.8	46.82	333
2	400	28	12.8	120	33.6	166	132.8	26.97	193
5	160	28	12.8	48	33.6	94.4	60.83	20.75	115
10	80	28	12.8	24	33.6	70.4	36.83	28.16	98.6
1.6	500	28	12.8	150	33.6	196	162.8	31.57	228
3.2	250	28	12.8	75	33.6	121	87.83	21.48	143
8	100	28	12.8	30	33.6	76.4	42.83	24.53	101

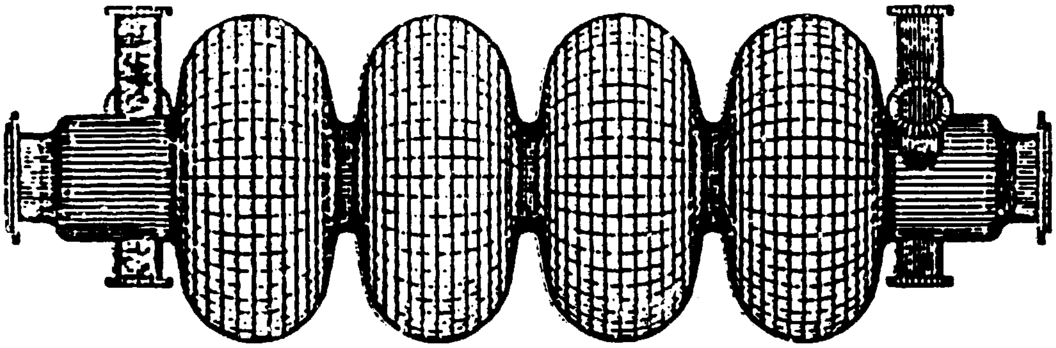
Chart 2



600 MeV Low-Duty-Factor Superconducting Linac,
Required Capital Investment for Different Gradients

Table 2

Lo Duty Factor Superc. Linac Cost Spreadsheet 2/17/89 (Sc)									
Headroom	1.1								
Pmax	1.2	MW							
Pavg	0.144	MW							
eff	0.2								
RFcost	0.5	M$/module		hrspyear	4000	hrs/yr			
Life	25	Years		kwh	0.05	$/kW-hr			
Str	0.3	M$/meter		Power	0.2	M$/MWyear			
Zshunt	1000	GOhm/meter							
dE	600	MeV		Loss	0.02	kW/m at 5 MV/m+20 W/m			
ibeam	0.035	Amps		Conversion	500				
duty	0.01						Linac	Lifetime	
		Peak	RF	Struct.	Lifetime		Equipm.	Cryo	
Grad	Length	Power	Cost	Cost	Power Cost	Total1	Cost	Cost	Total2
(MeV/m)	(meters	(MW)	(M$)	(M$)	(M$)	(M$)	(M$)	(M$)	(M$)
1	600	21	9.63	180	5.25	195	189.6	35.11	230
2	300	21	9.63	90	5.25	105	99.63	20.22	125
5	120	21	9.63	36	5.25	50.9	45.63	15.56	66.4
10	60	21	9.63	18	5.25	32.9	27.63	21.12	54
1.6	375	21	9.63	112.5	5.25	127	122.1	23.68	151
3.2	187.5	21	9.63	56.25	5.25	71.1	65.88	16.11	87.2
8	75	21	9.63	22.5	5.25	37.4	32.13	18.4	55.8



350 MHz niobium cavity foreseen for the energy upgrade of LEP
The whole unit has a length of 2.4 m.

(Piel 88)

Fig. 1

Superconducting rf-module for HERA

$f = 500$ MHz $\quad Q = 2 \times 10^9 \quad P_{beam} \leq 100$ kW

$E_{acc} = 5$ MV/m $\quad T = 4.2$ K $\quad P_{4.2K} \leq 100$ W

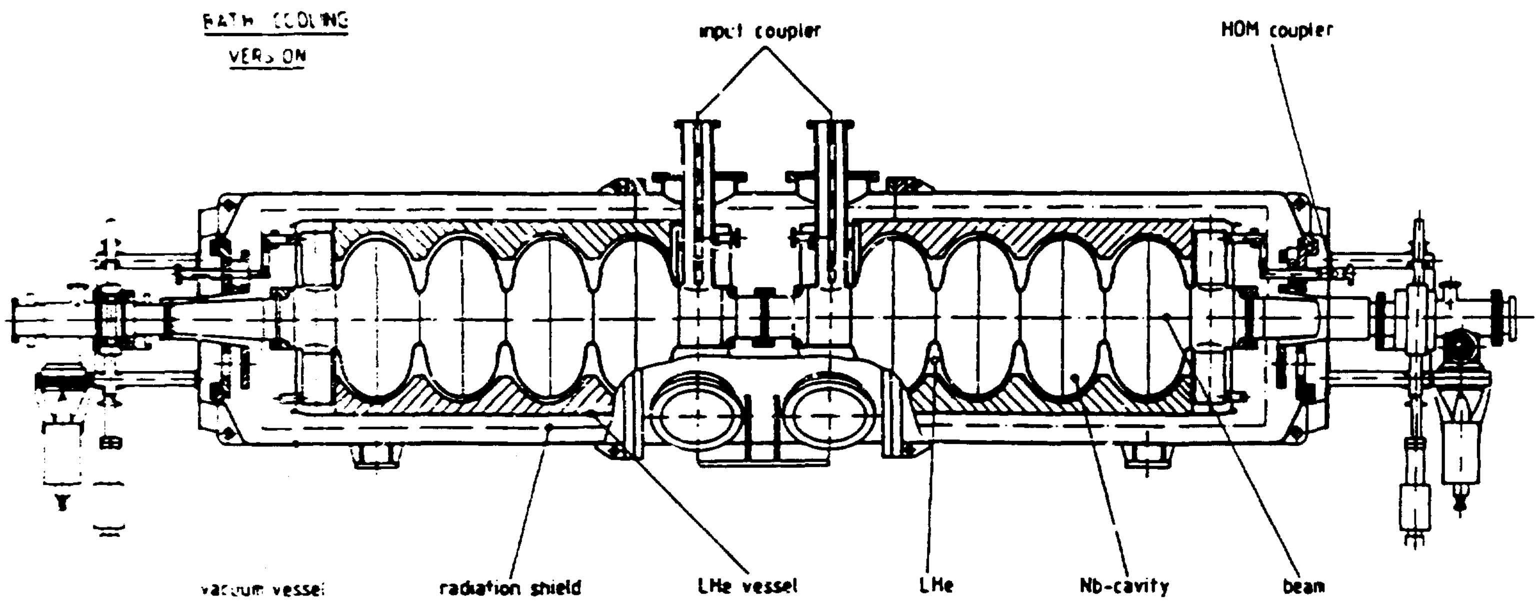


Fig. 2

(D. Proch 88)

CRYOSTAT AND CAVITY PAIR CEBAF

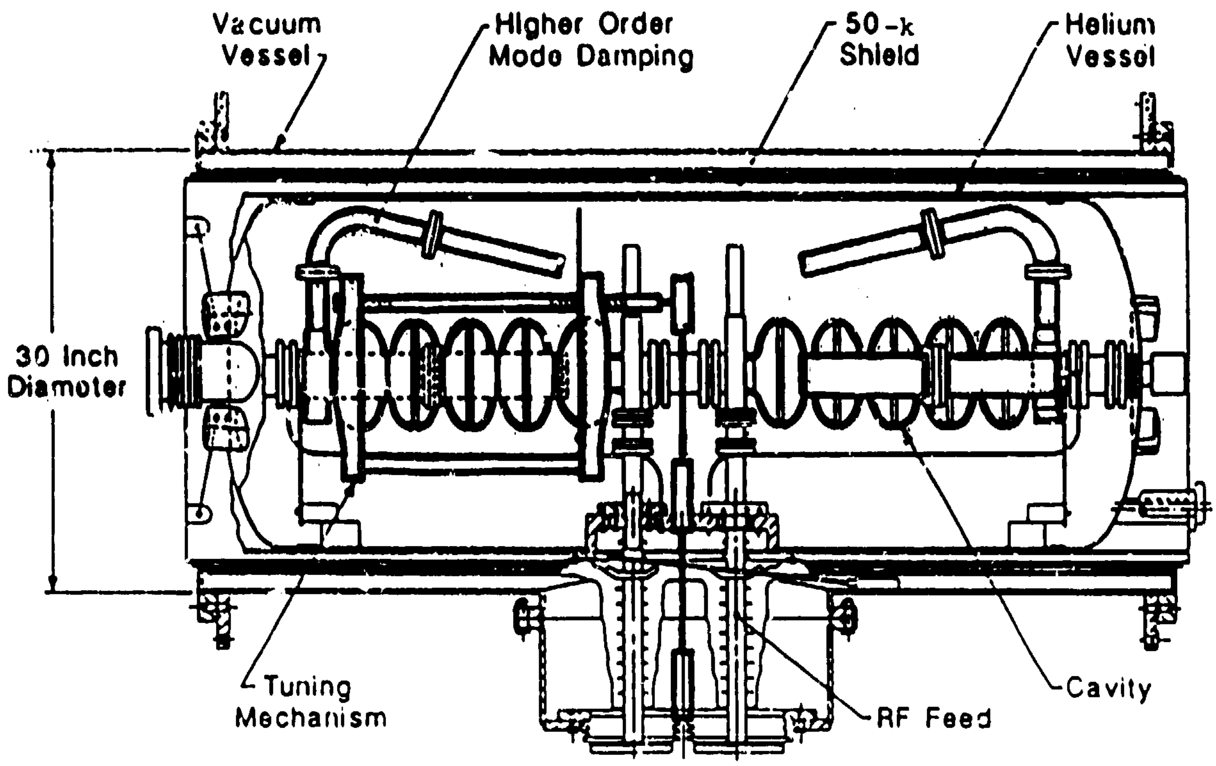
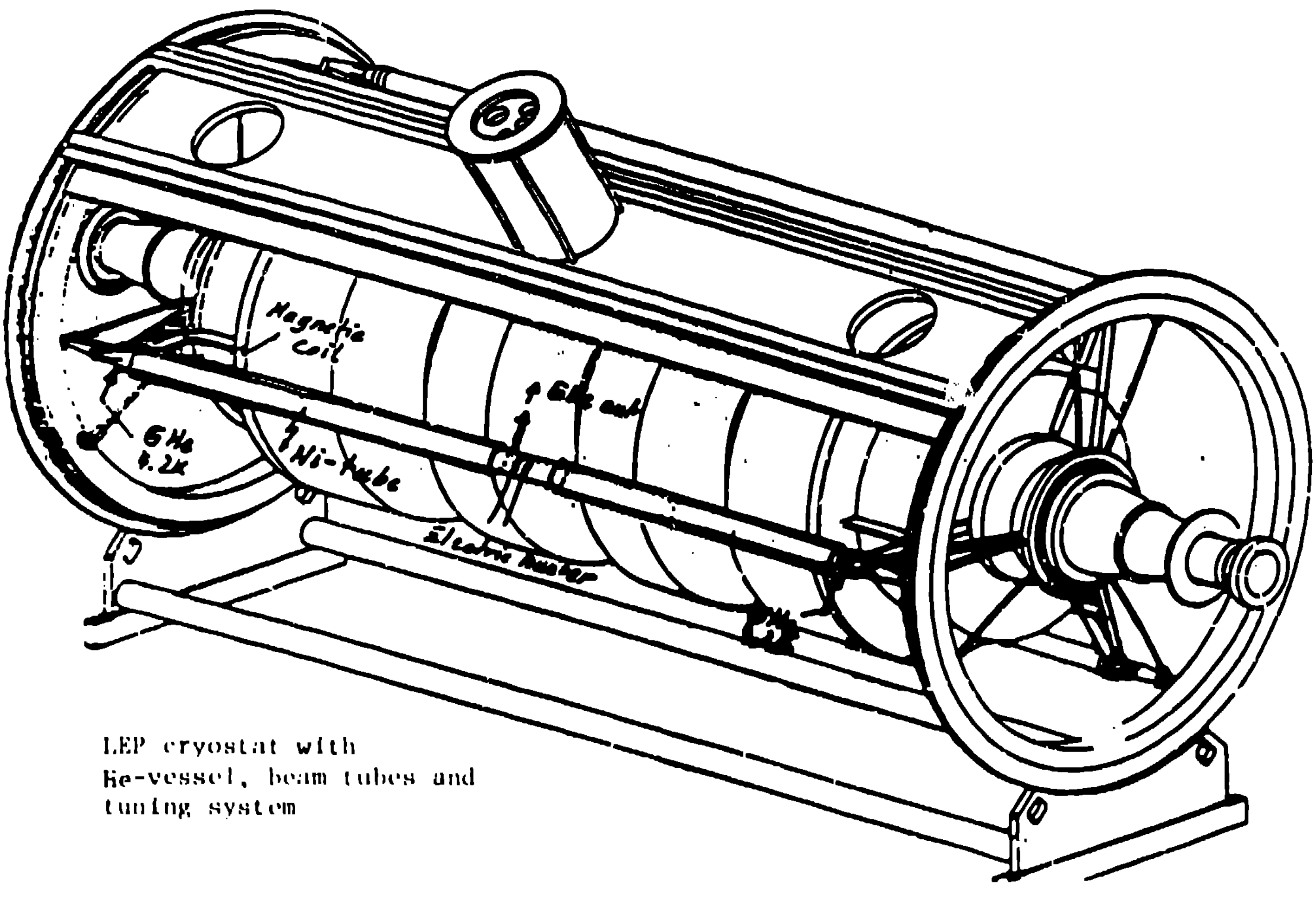


Fig. 3 (R. Sundelin, L. Phillips, CORNELL/CEBAF 87)



LEP cryostat with
He-vessel, beam tubes and
tuning system

Fig. 4

(H. Lengeler, CERN 87)