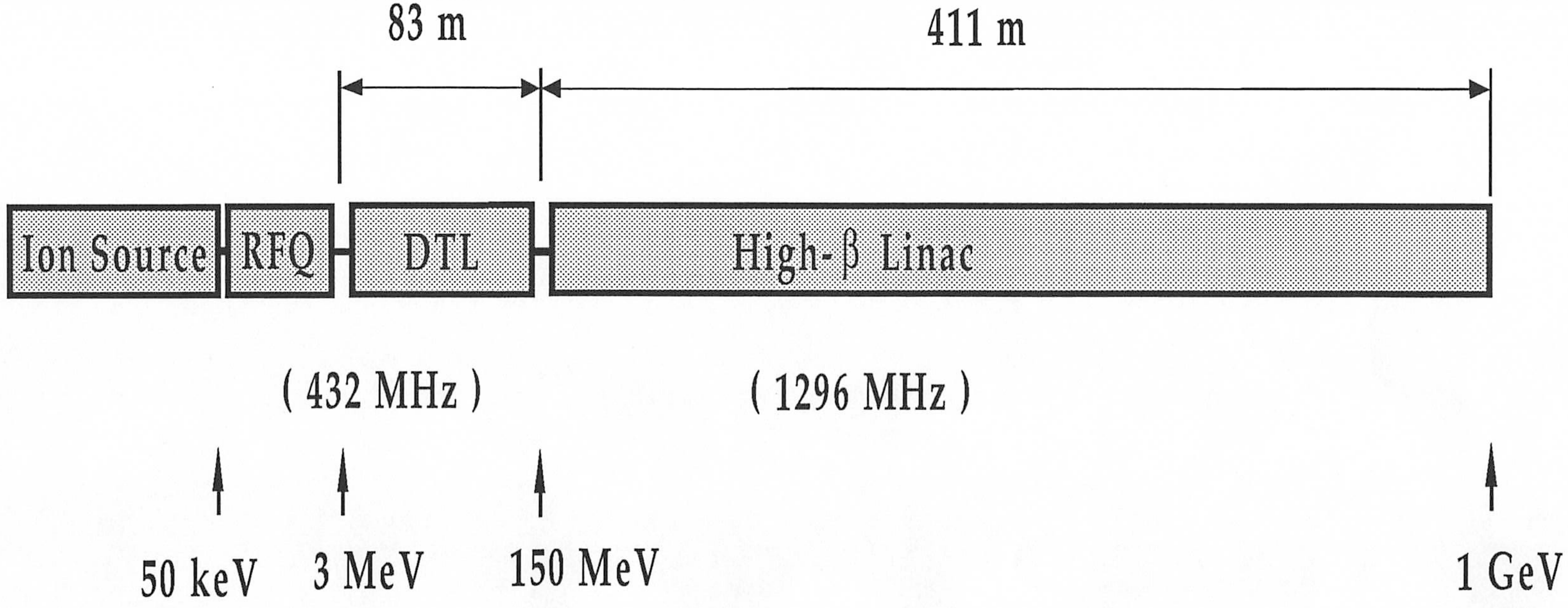
Development of the 1-GeV Proton Linac

* **Design of the 1-GeV Proton Linac**
* 開発の概要
    * RF source
    * Ion source
    * RFQ
    * DTL
    * ACS
* **Beam test in the low-β structure**

Accelerating structure of the 1 GeV proton linac



JHP 1-GeV Proton Linac

- Requirements
  - Proton
  - Average current 400 μA
  - Energy 1 GeV
  - Length 500 m
  - Cost
- Design
  - Peak current 20 mA
  - Pulse length 400 μsec
  - Repetition 50 Hz
  - RF structure
  - RF power source

基本パラメーターの決め方

- **A high-energy, high-intensity proton linac**
  - **a high rf power**
- **Reduce the number of rf sources**
  - **cost performance,**
  - **stable operation with smaller parameters**
  - **easy maintenance**
- **A high power klystrons**
  - **a duty factor of a few percent**
    - **an long rf pulse length of 600 us**
    - **a low repetition rate of 50 Hz**

Parameters of the 1-GeV proton linac

	RFQ	DTL	CCL
Win (MeV)	0.05	3	148
Wout (MeV)	3	148	1010
Frequency (MHz)	432	432	1296
Length (m)	2.7	83	411
Number of cells		342	3568
Number of tanks	1	13	152
RF power (MW)	1	12	99
Number of klystrons	1	12	36

Fundamental parameters

- Accelerating field, Length
  - RF power $\propto$ 1/ Length
  - Cavity cost $\propto$ Length
  - Minimazation of cost by Accelerating field
    - the optimum length of 500 m
- The accelerating frequency
  - shunt impedance
  - cooling of the components
  - acceptance of the structure
  - klystron both for CCL and DTL
    - The nearly highest frequency 1296 MHz

基本パラメーターの決め方

- **Minimizing beam loss**
  - Minimizing the effects of transient and transition
    - Long pulse and low repetition rate
    - transition energy of 3 MeV and 150 MeV
  - Large acceptance and small beam emittance
  - Care of longitudinal emittance
    - RFQ and f(CCL) = 3 x f(DTL)

Key to the design

- **Ability**
- **Efficiency**
  - What is true ability and efficiency?
  - What is the problem?
- **Design, Manufacturing, Tuning and Operation**

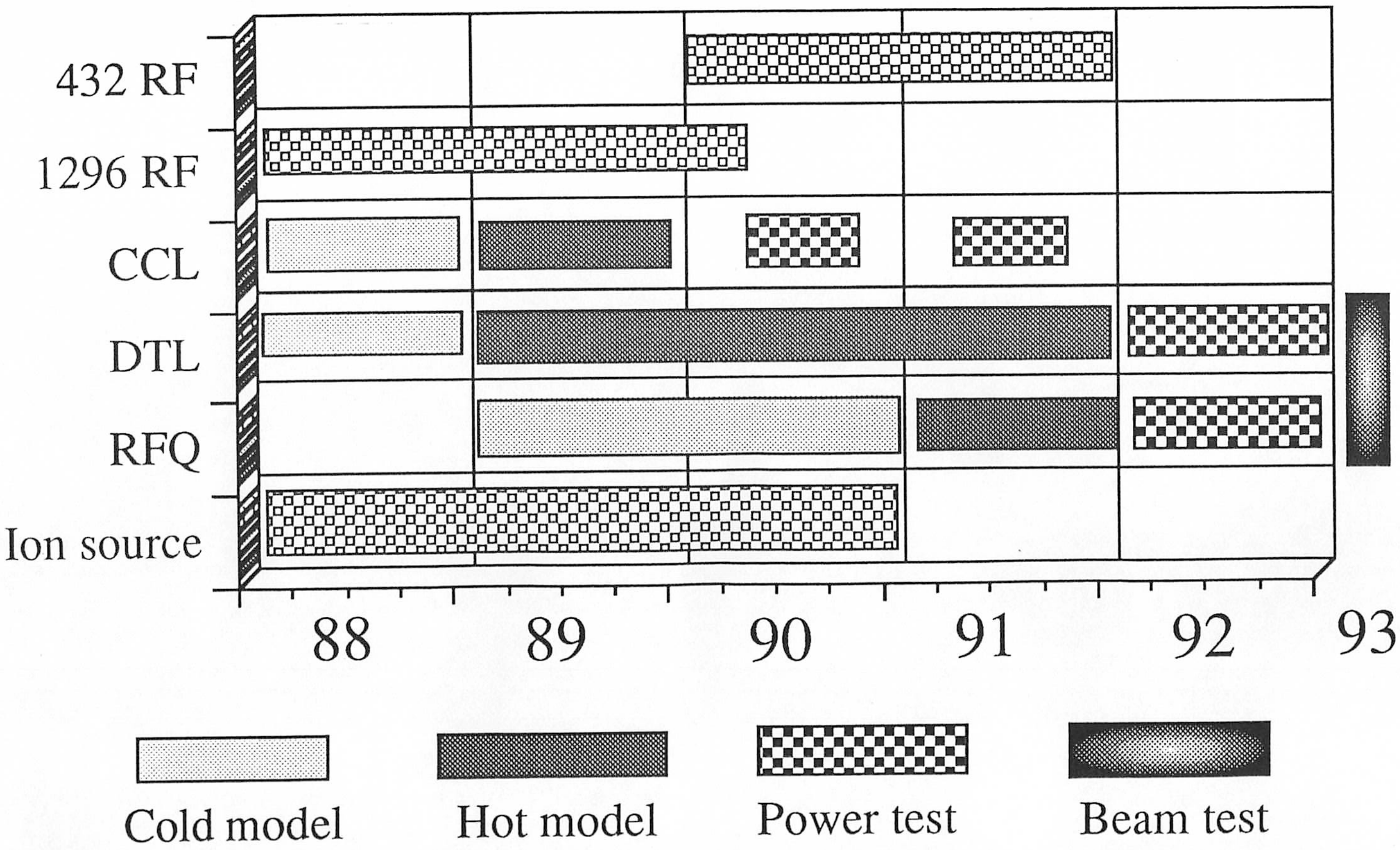
Feasibility test of the linac

- * **Ion source   20 mA, 1 πmmmrad**
- * **RFQ   3 MeV long tank**
- * **DTL   432 MHz structure**
- * **CCL   coupled cavity linac ACS**
- * **1296 MHz power source**
- * **432 MHz power source**

High duty factor 3 %

JHP Linac

Schedule of the development



Design of high-intensity linac
E. A. Knapp

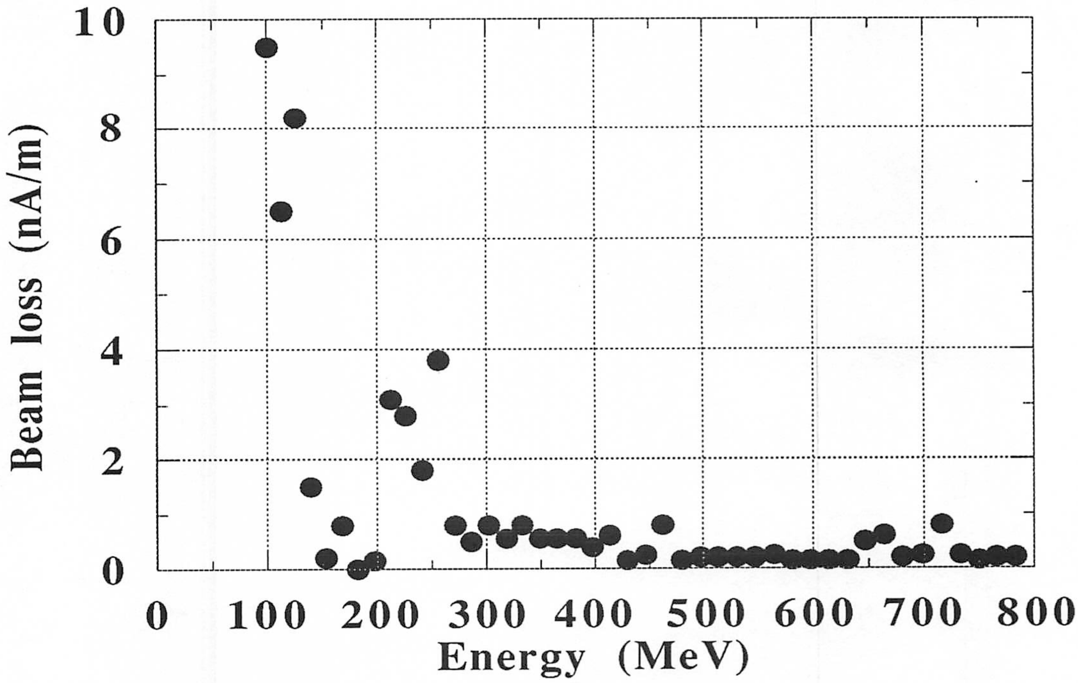
- **The major design problem is associated with control of beam loss when accelerator intensity is increased. 1982**

Beam Loss in LAMPF CCL

estimated fom activation

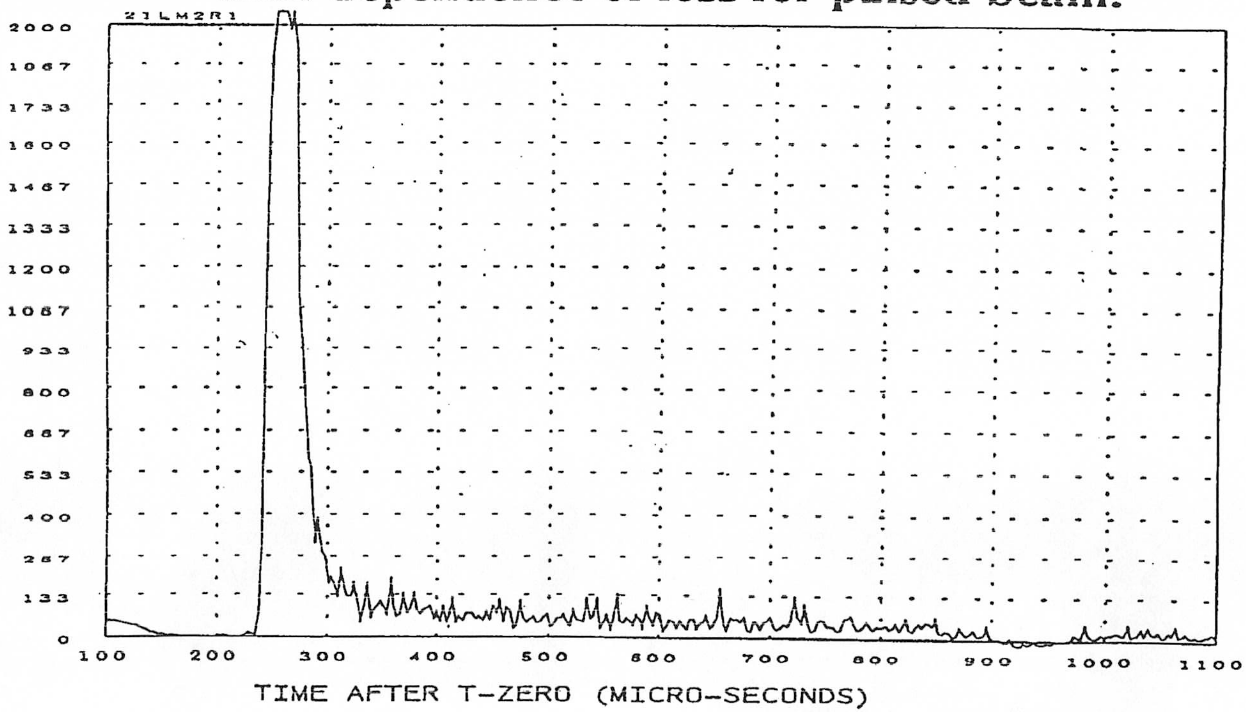
extended operation at 1 mA

from Schriber's data



Transient Beam Loss

LAMPF beam-loss monitor readout, showing time dependence of loss for pulsed beam.



Los Alamos - Brookhaven

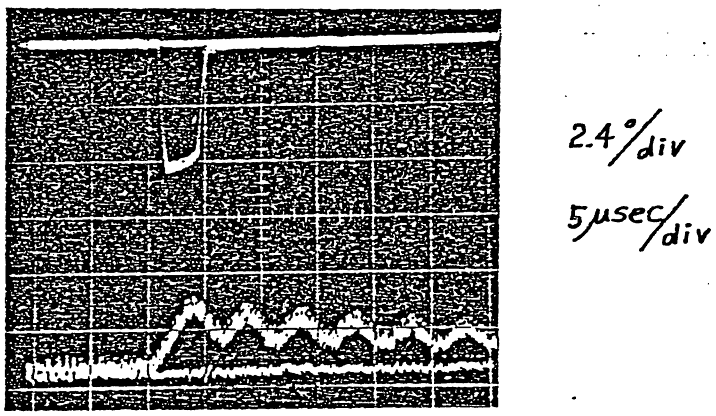


Fig.6 Transient phase shift due to beam loading between z=L and master oscillator. Upper trace is linac beam pulse(~140mA).

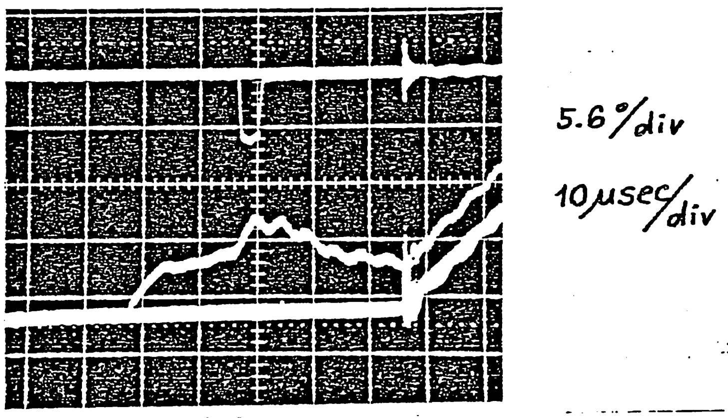
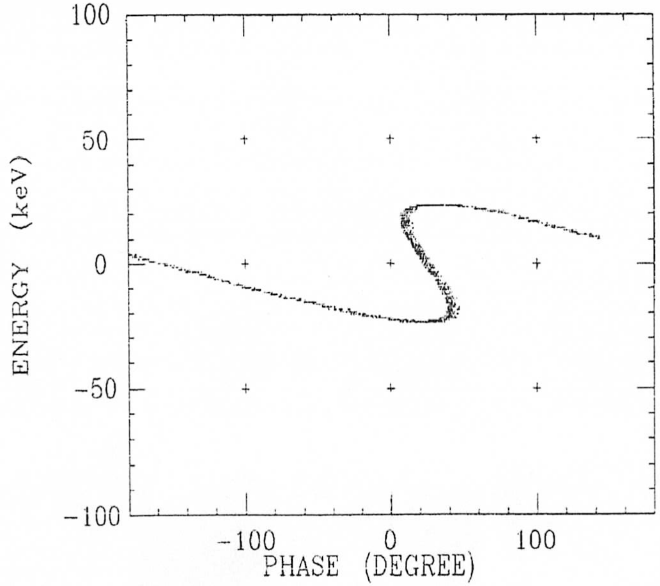


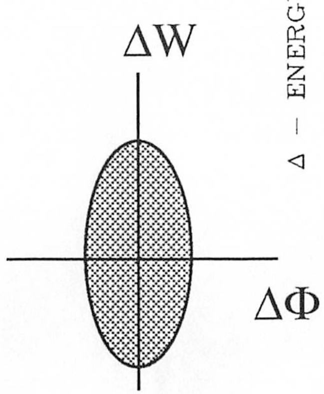
Fig.7 Transient phase shift due to amplitude compensation and beam loading measured at z=0.8L.

Comparison between old and new method

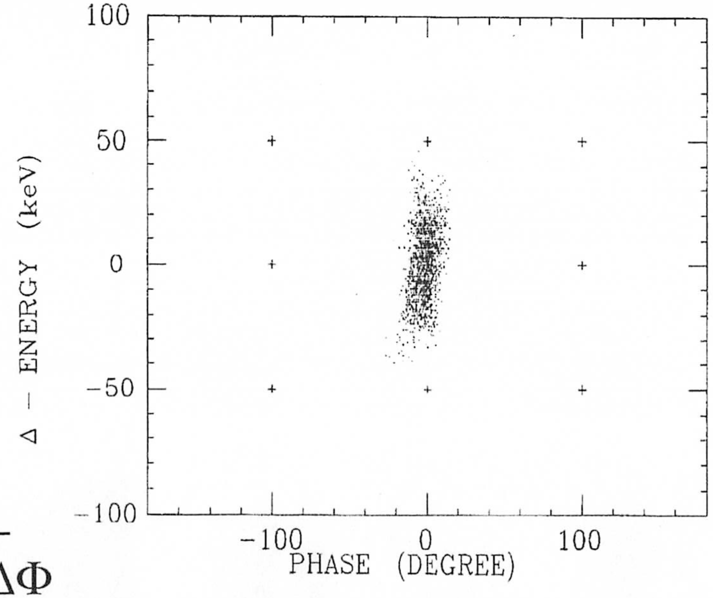
Injection into DTL



Cockcroft + buncher

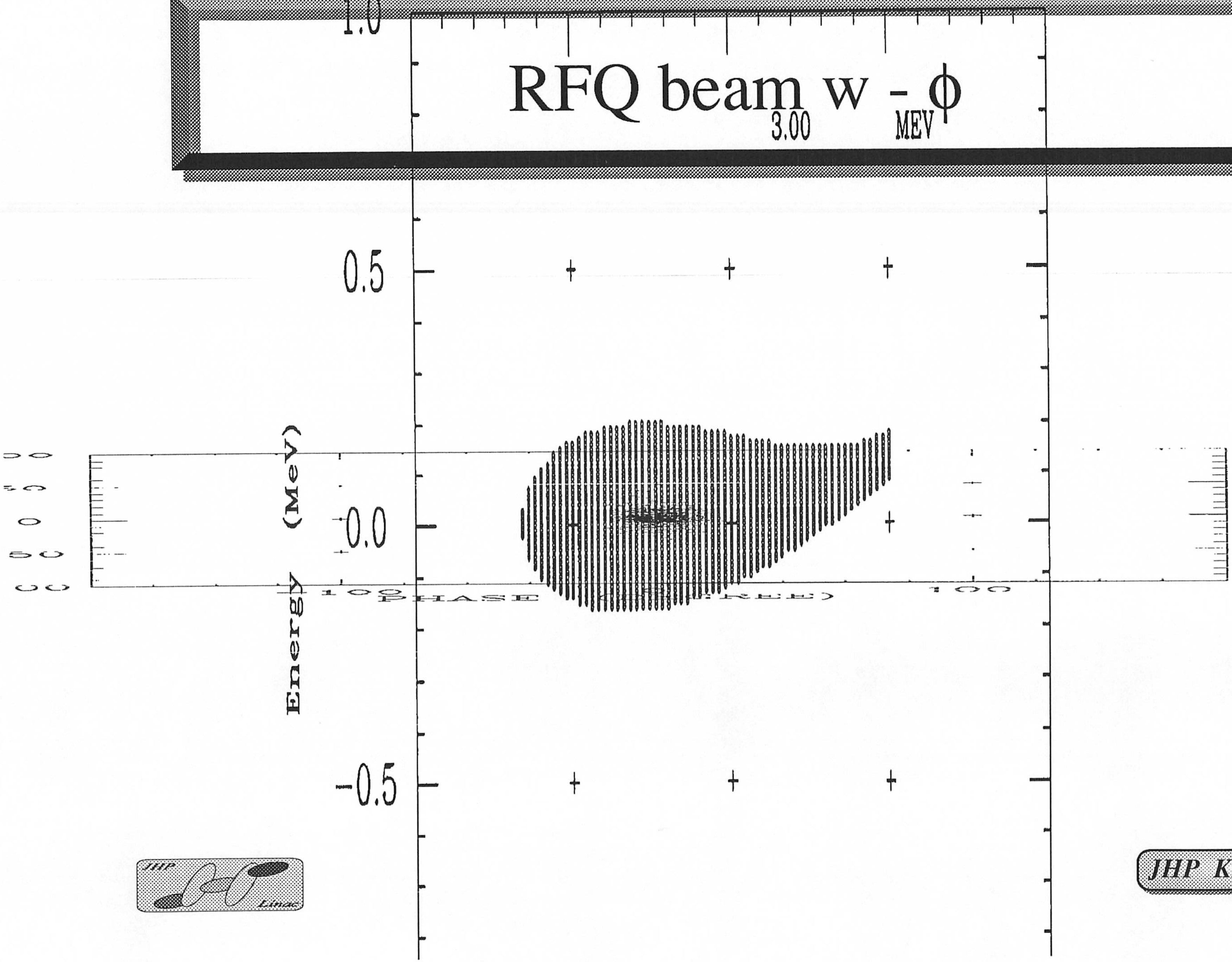


emittance



RFQ

RFQ beam w - ϕ



考課表

March 1992

	Klystron	400 μsec PS	600 μsec PS
1296 MHz RF	○	○	91
432 MHz RF	△	/	91

	Cold model	Hot model	RF test	Beam test	Beam line
RFQ	○	△	92	93	93
DTL	○ △	△	92	93	93
ACS	○ △	○	○	/	△

JHP Linac

Members of the 1-GeV linac Project

KIHARA,
YAMAZAKI

RF Structure

Mori,
Takagi

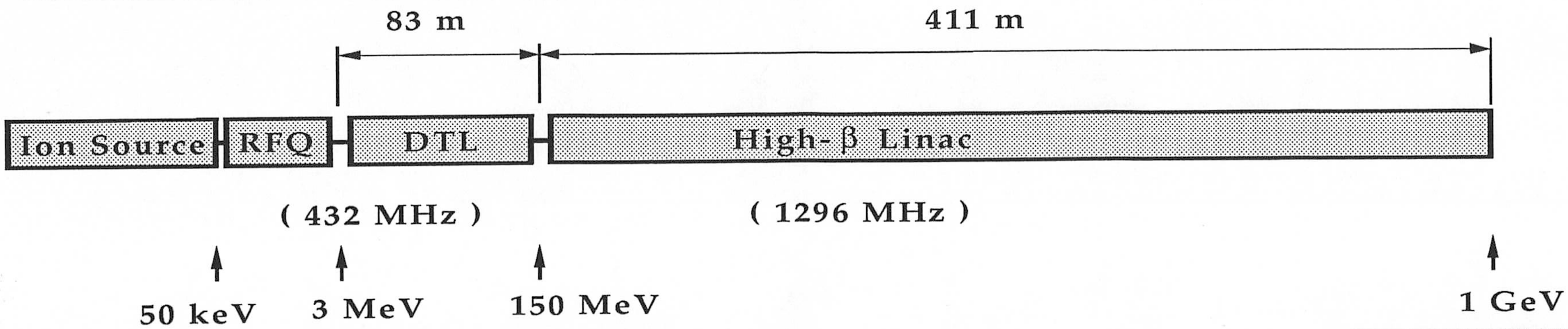
Ueno

Naito,
Kato,
Takasaki

Kageyama,
Morozumi,
Yoshino

RF Source

Anami, Takasaki, Kubo,
Ono, Fukuda, Takeuchi,
Takenaka, Kudo, Kubota,
Kawamura, Hanaki, Abe,
Igarashi, Takashima



Latest Development Items

* **High intensity reliable long-life ion source**
* **A long RFQ with a new stablizing idea and design method**
* **DTL with new mechanical design**
* **CCL with a newly developed structure**
* **L-band RF power source with the most powerful modulator**

RFQ Linac

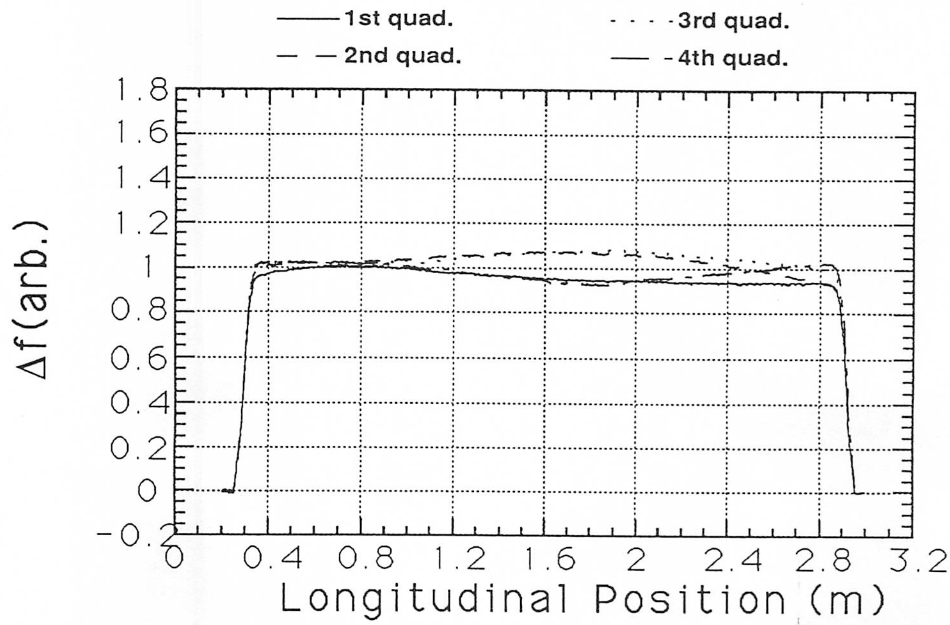
Ueno

- Input energy 50 keV Output energy 3 MeV
- Frequency 432 MHz Vane length 2.7 m
- Minimum bore radius 0.24 cm
- RF power 0.8 MW
  - Transverse emittance (90%) 1.1 πmmmrad
  - Energy spread (90%, full) 0.03 MeV
  - Phase spread (90%, full) 15 deg

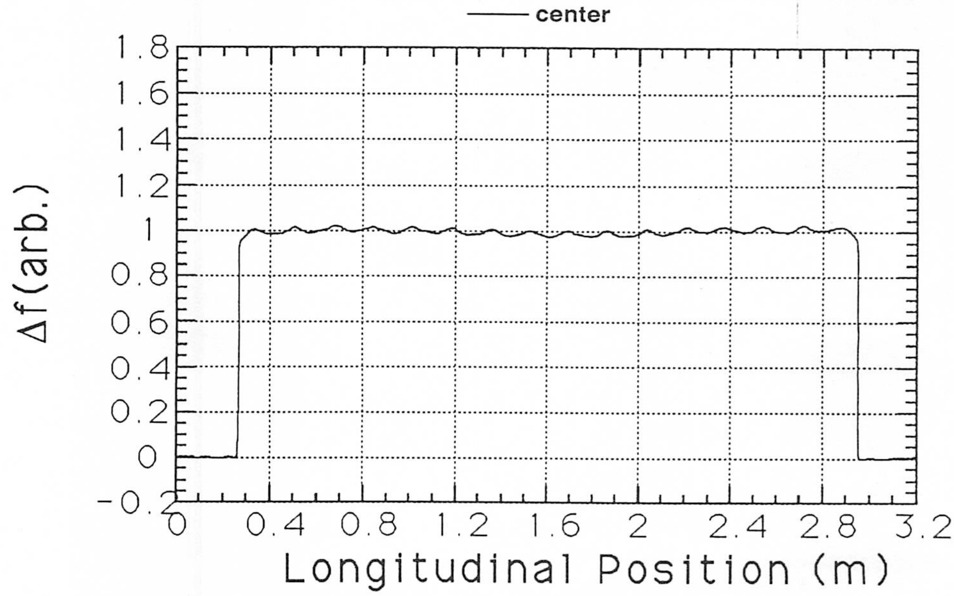
RFQ Development

- A new beam-dynamics design procedure (KEKRFQ)
- A full-scale cold model
- PISL(π-mode stabilization loop)
- High-power model
- RF test and beam test

Field measurements ---- RFQ



Without PISL

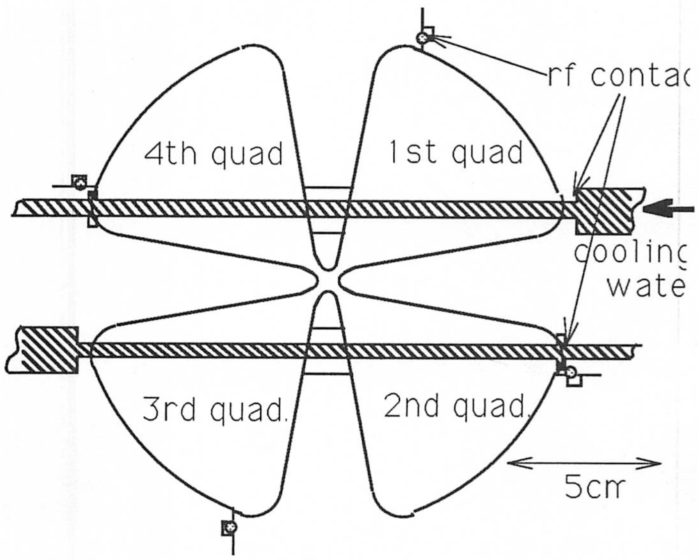


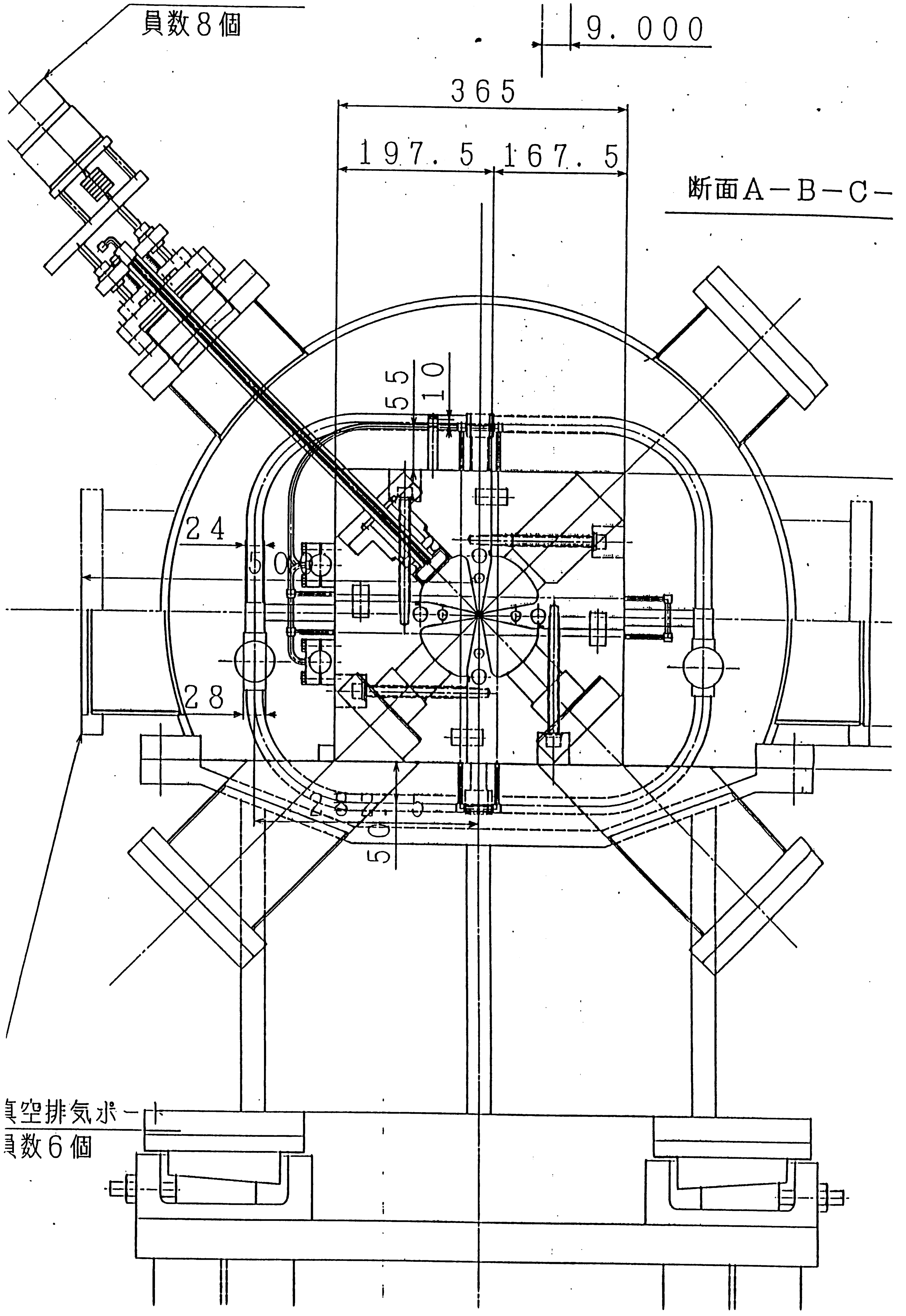
With PISL

JHP Linac

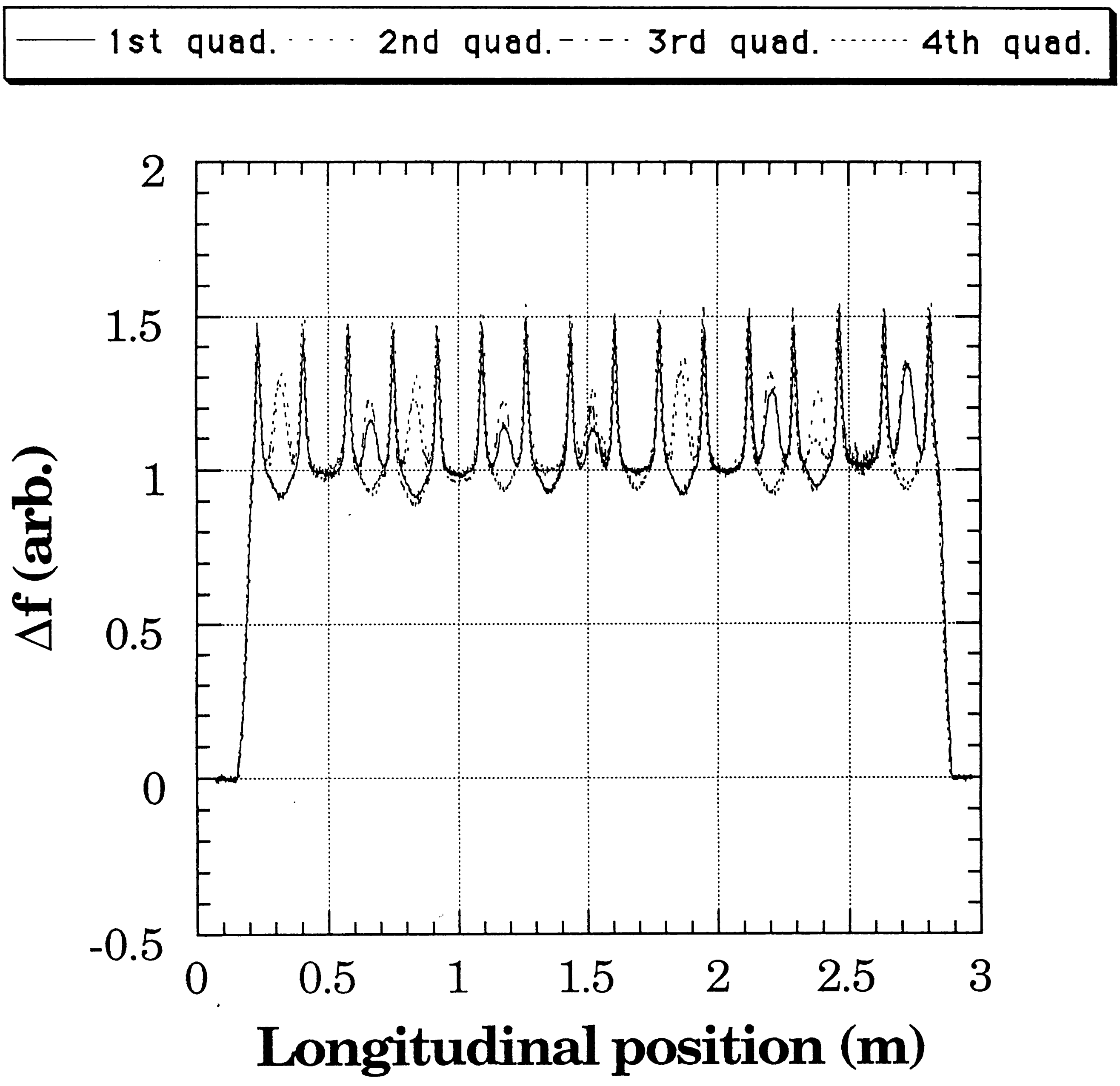
Geometry of PISL

Ueno

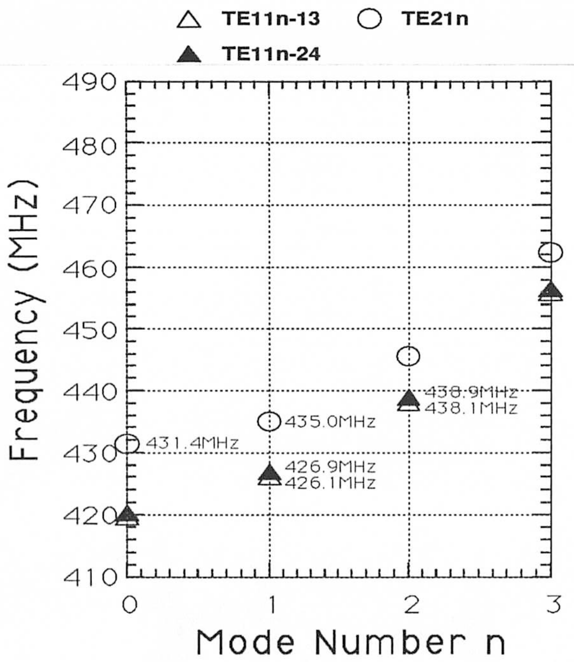




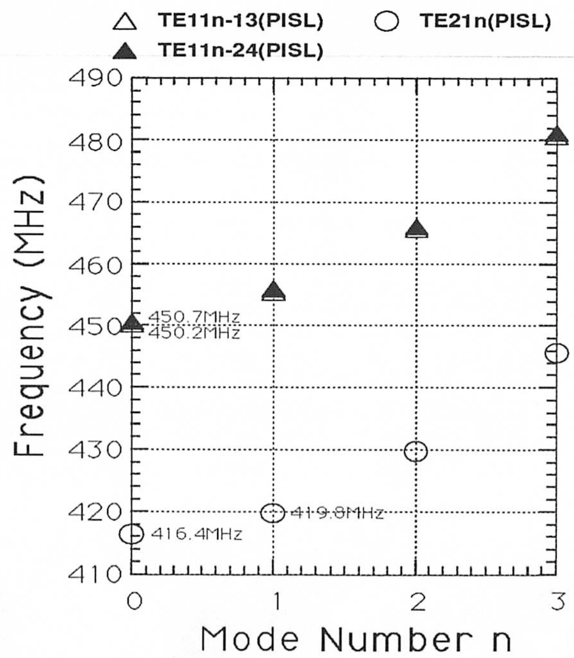
員数8個
9.000
365
197.5
167.5
断面A−B−C−
55
10
24
50
28
282.5
50
真空排気ポート
員数6個


1st quad.
2nd quad.
3rd quad.
4th quad.
2
1.5
1
0.5
0
-0.5
Δf (arb.)
0
0.5
1
1.5
2
2.5
3
Longitudinal position (m)

Dispersion



(a)PISL設置前



(b)PISL設置後

JHP Linac

Length of RFQ

	Frequency	Length	L/λ
JHP	432	2.63	3.8
Kyoto	433.3	2.19	3.2
INS TALL	100	7.25	2.4
INS Split Coaxial	25.5	2.1	0.18

JHP Linac

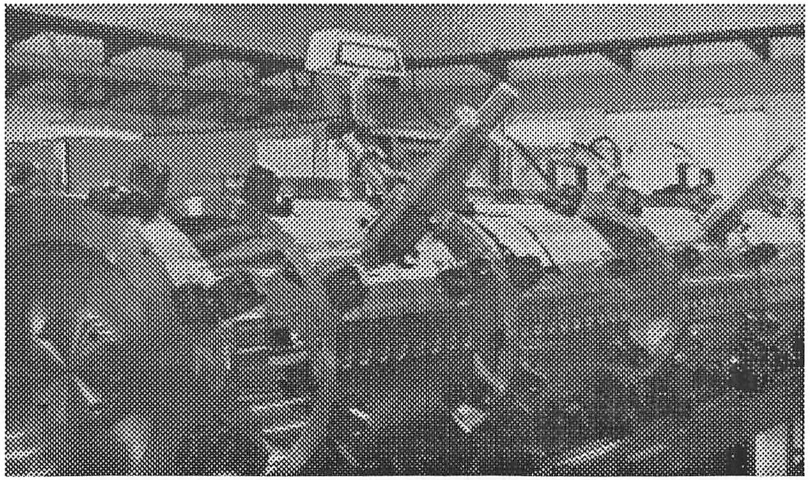
Features of the JHP DTL

* **High frequency 432 MHz**
* **Focusing with permanent quadrupole magnet**
* **High energy injection at 3 MeV using RFQ**
* **Stability for high-duty factor operation**

New techniques for DTL

Naito et al.

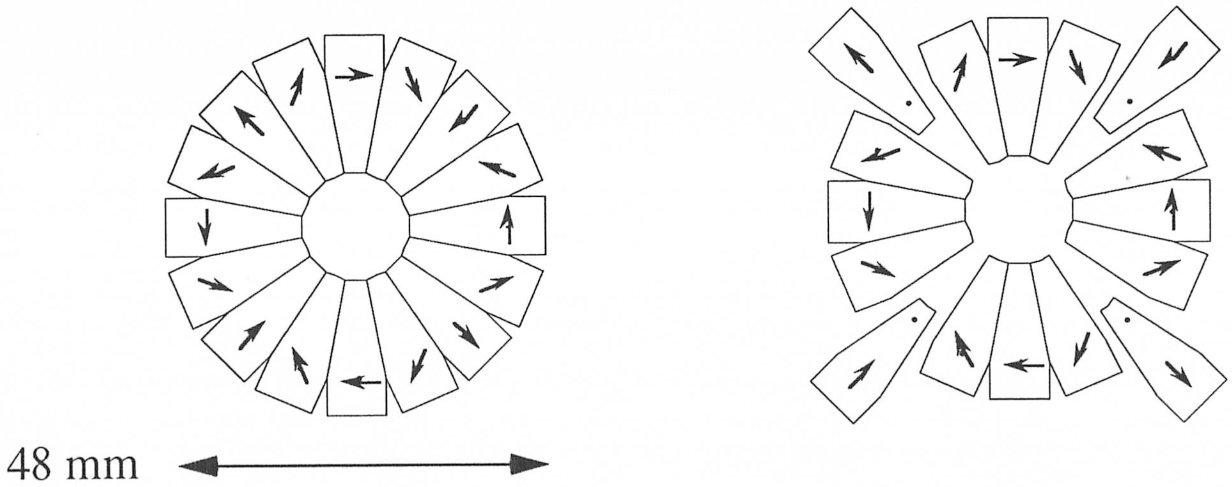
- ステム固定法
- 焼きばめ法
- Q-magnet 組立法
- ユニットタンク方式



DTL development

- Cold model cavity
  - Field stabilization
  - Fabrication technique
- New fabrication technique
- High-power model cavity
  - Fabrication
  - Tuning
  - RF test
  - Beam test

Permanent Q-magnet (16 segment)



200 T/m　　Bore radius 7 mm

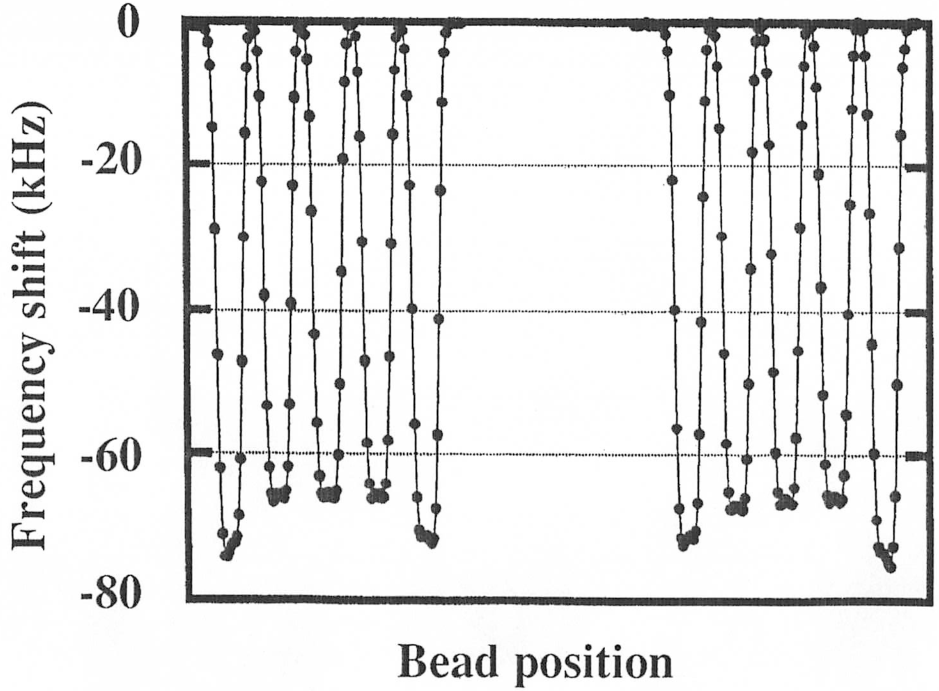
segment size 17 x 6.4 x 30 mm

希土類鉄磁石$Nd_2Fe_{14}B$

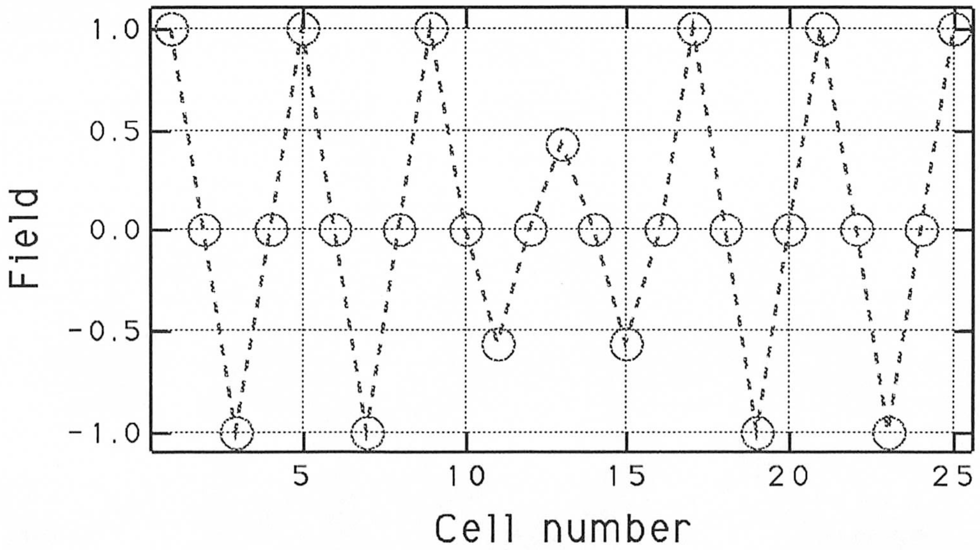
希土類コバルト磁石 SmCo

ACS field distribution

Kageyama



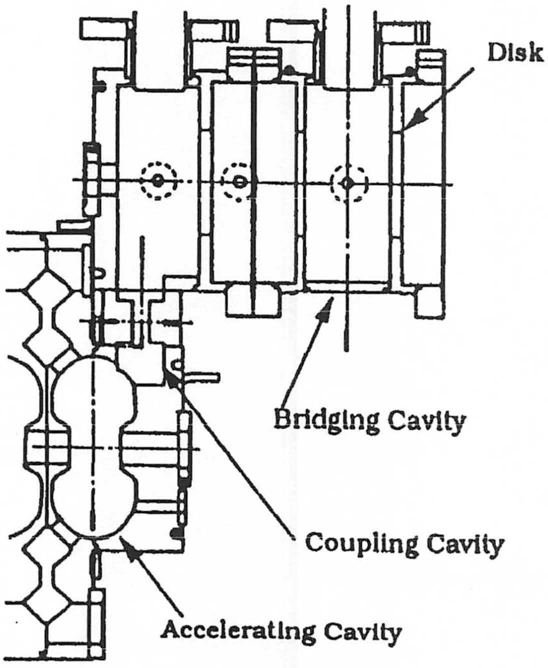
CCL 10 cell accelerating mode

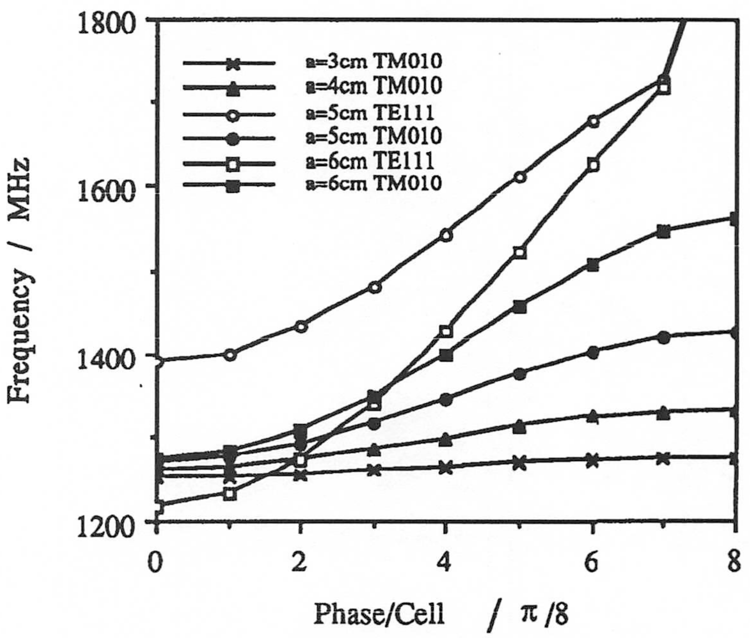


Multi-cavity design

by Morozumi

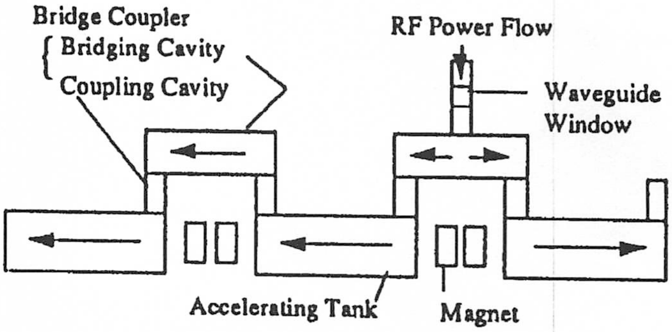
- **avoid mode mixing**
- **strong inter-cell coupling**
- **small power loss**
- **easy tuning**





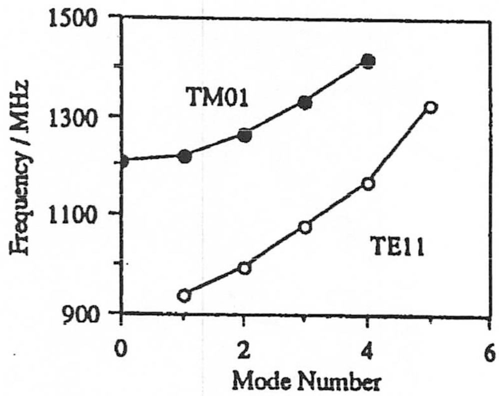
Multi-cavity bridge coupler

- **Connect two unit tanks**
- **Feed RF power**

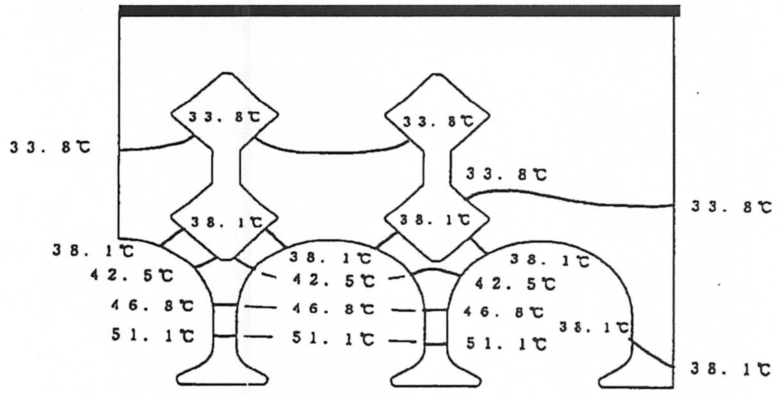


* Single cylindrical cavity

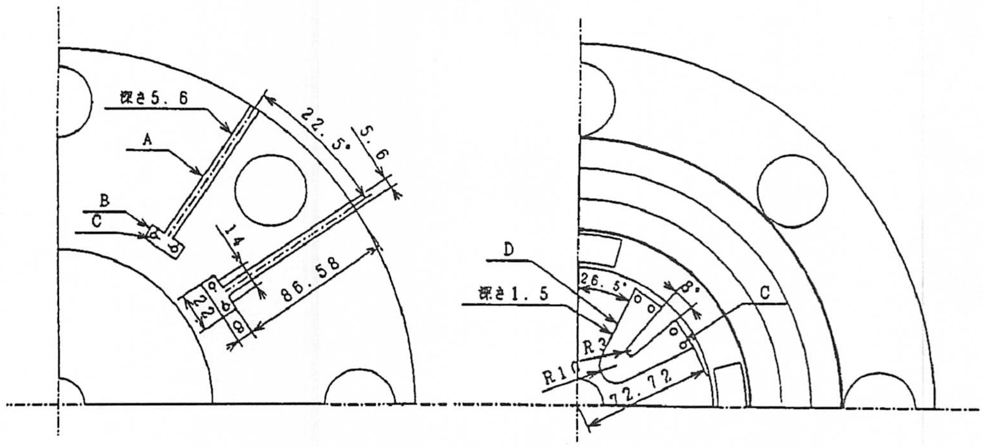
D = 19 cm
L = 80 cm
mode mixing



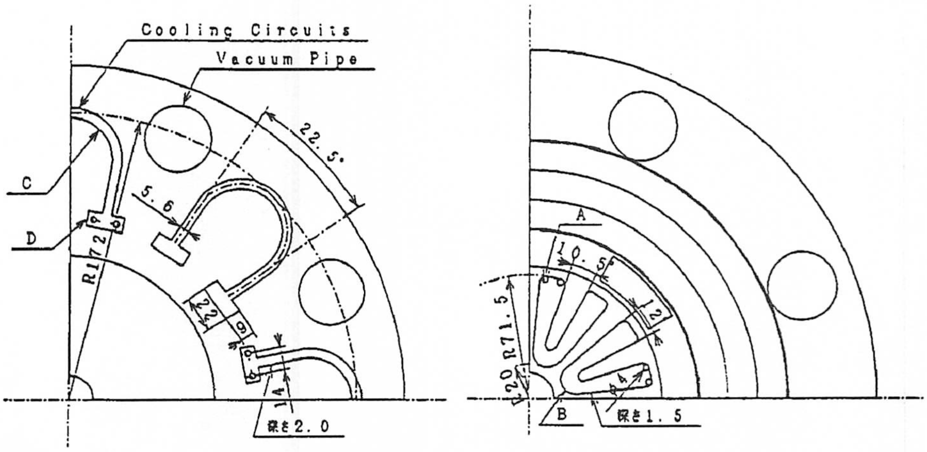
ACS cooling geometry



Type A

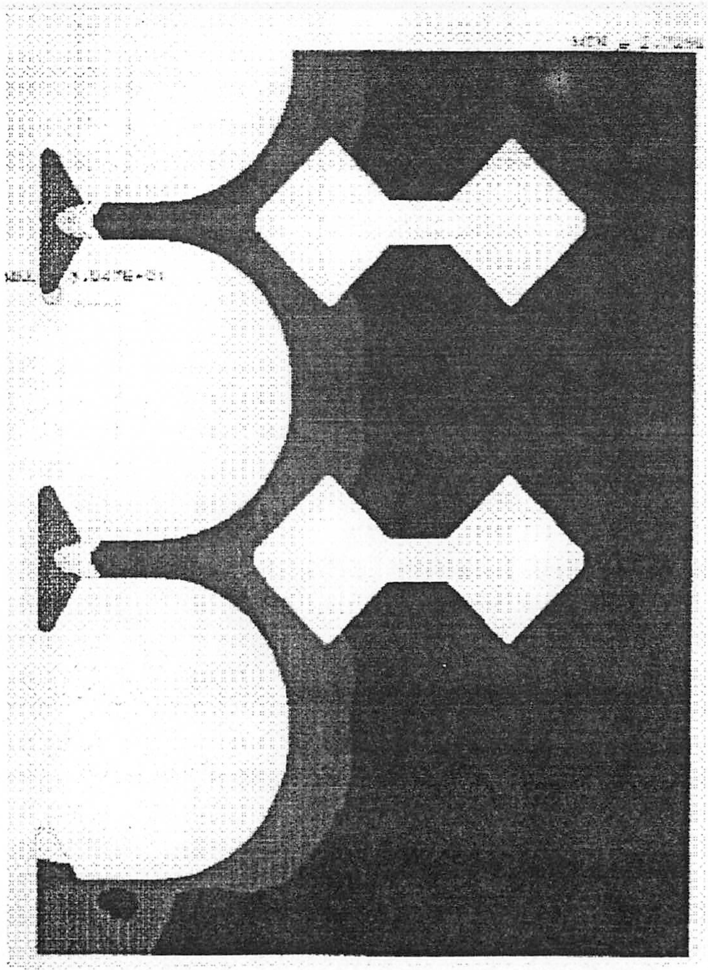


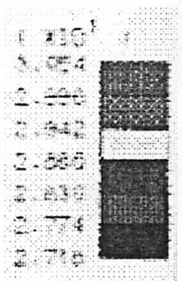
Type B



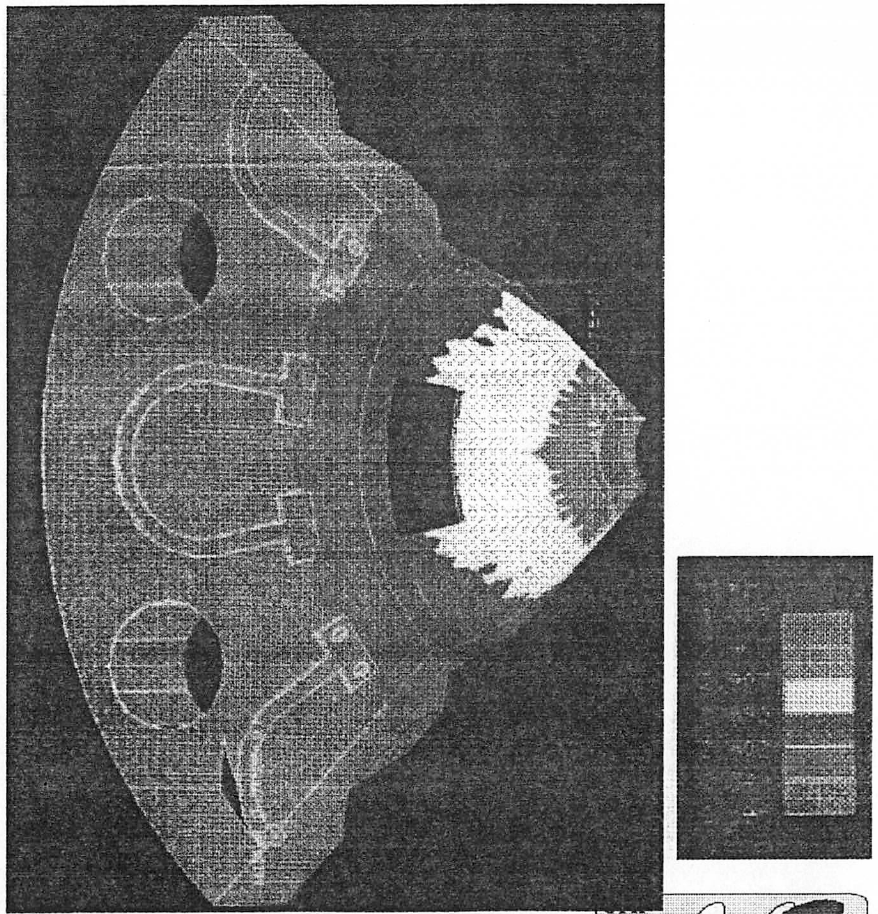
Type C

Results of 2-D and 3-D thermal calculation





2-D calculation



3-D calculation

ACS cooling by CAD

Yoshino et al.

	Method	ΔT	Δx	Δf	Fabrication
Type A	Outer	35	26 μm	-300 kHz, -200 kHz	○
Type B	Outer	11			△
Type C	Outer	3	4 μm	-80 kHz, -40 kHz	△

1 kW/cell, 5 liter/min/cell

Tin = 25, Tout = 28 degrees

RF Power Source

Anami et al.

	TH2104A	TH2134
Frequency MHz	1296	432
Cathode voltage kV	140	110
Beam current A	105	45
Peak rf power MW	6	2
Efficiency %	40	40
Rf pulse length μsec	600	600
Repetition rate Hz	50	50
Number	14	38

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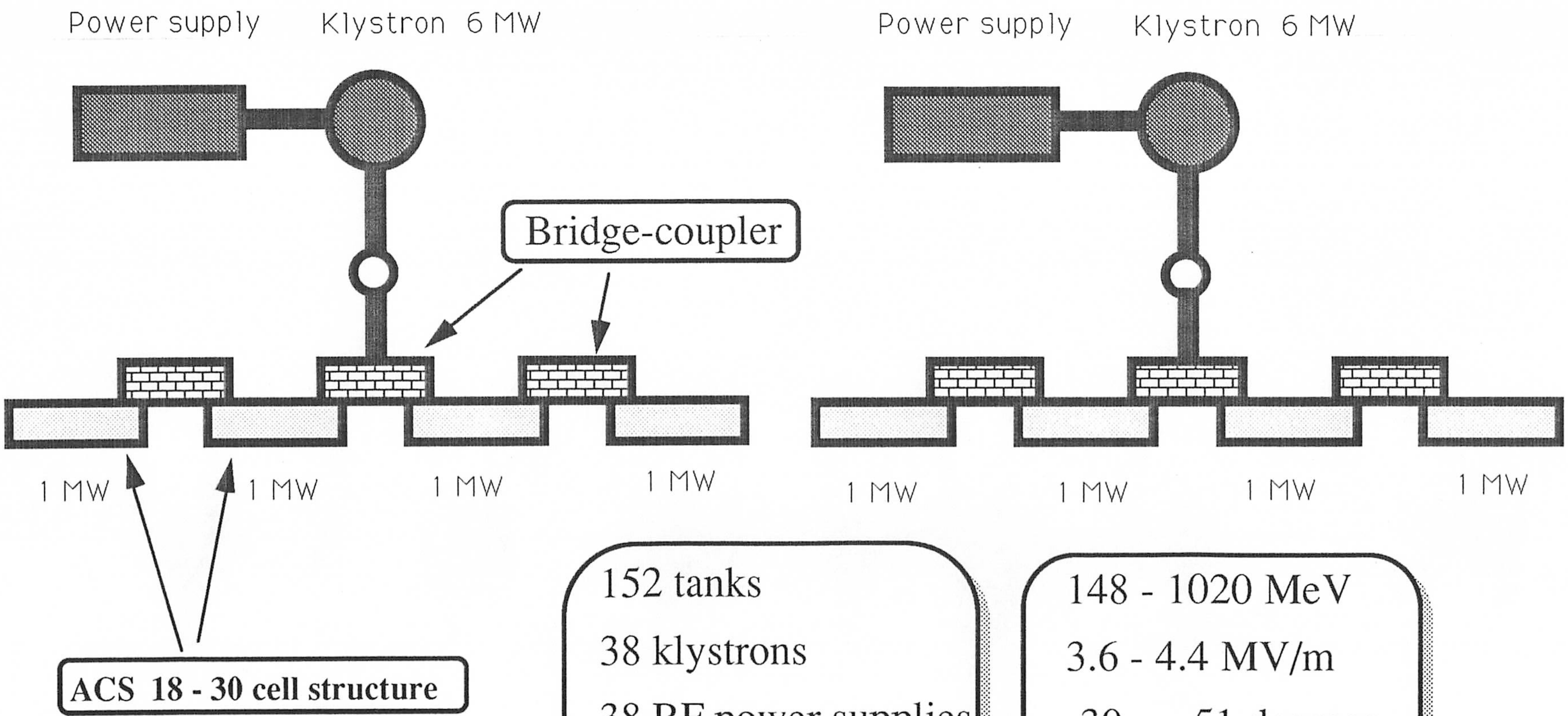
(RF + CCL) structure



152 tanks

38 klystrons

38 RF power supplies

3576 cells

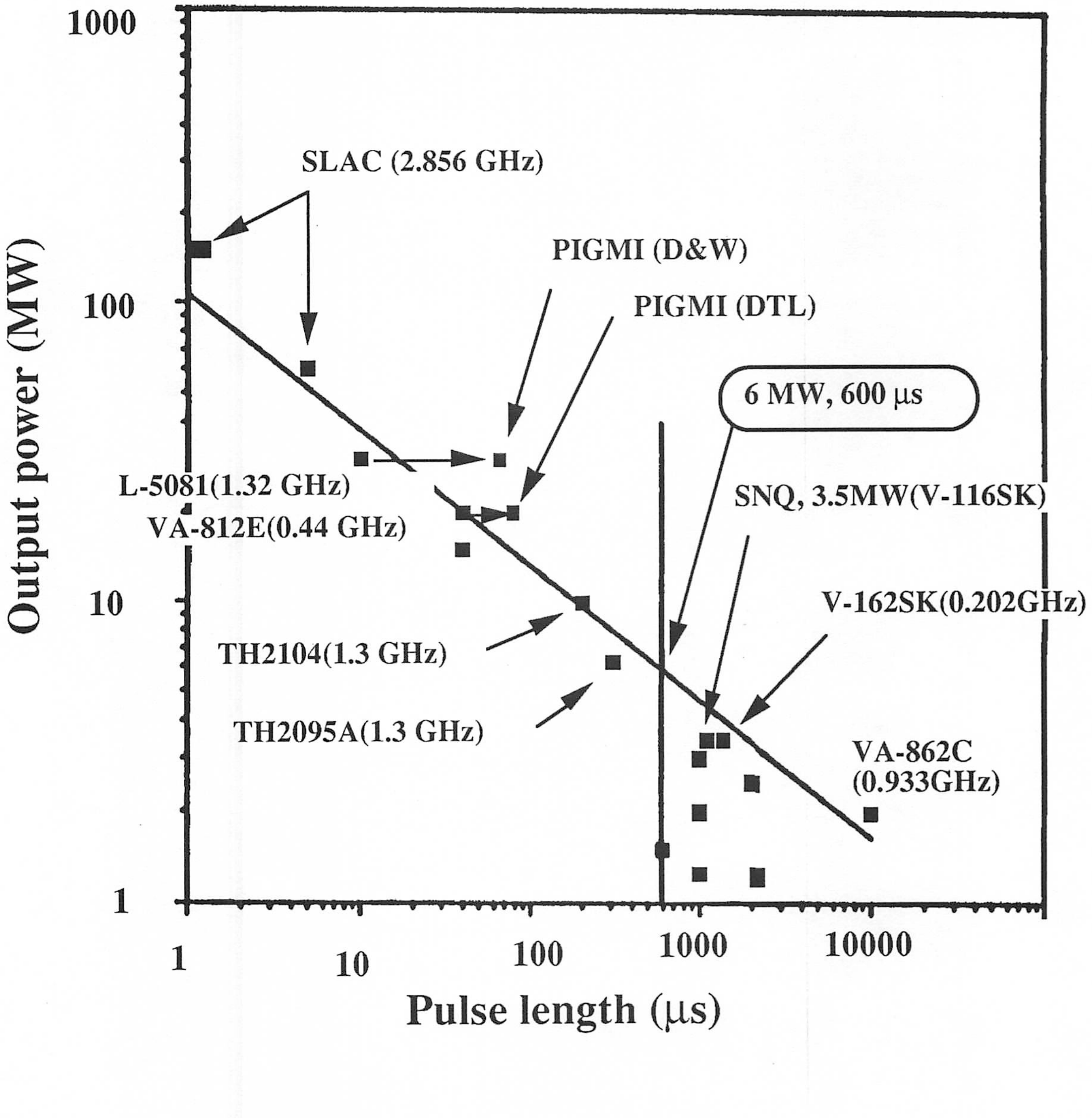
148 - 1020 MeV

3.6 - 4.4 MV/m

-30 ~ - 51 degrees

RF power vs pulse length

by Anami



L-Band Modulator

PFN

Peak Power MW	**15**
Rise Time μs	**25**
Repetition	**50**
Ave. Power MW	**0.45**
Cell Number	**50**
Impedance Ω	**26.7**
Charging Voltage kV	**40**
Inductance μH	**160**
Capacitance μF	**0.22**

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UHF power supply

Peak power MW	5.5
Max. DC voltage kV	110
Peak current A	46
Ave. current A	1.5
Modulation anode	
Modu. anode vol. kV	90
Peak current A	1
pulse width μs	650

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Modulator Circuit

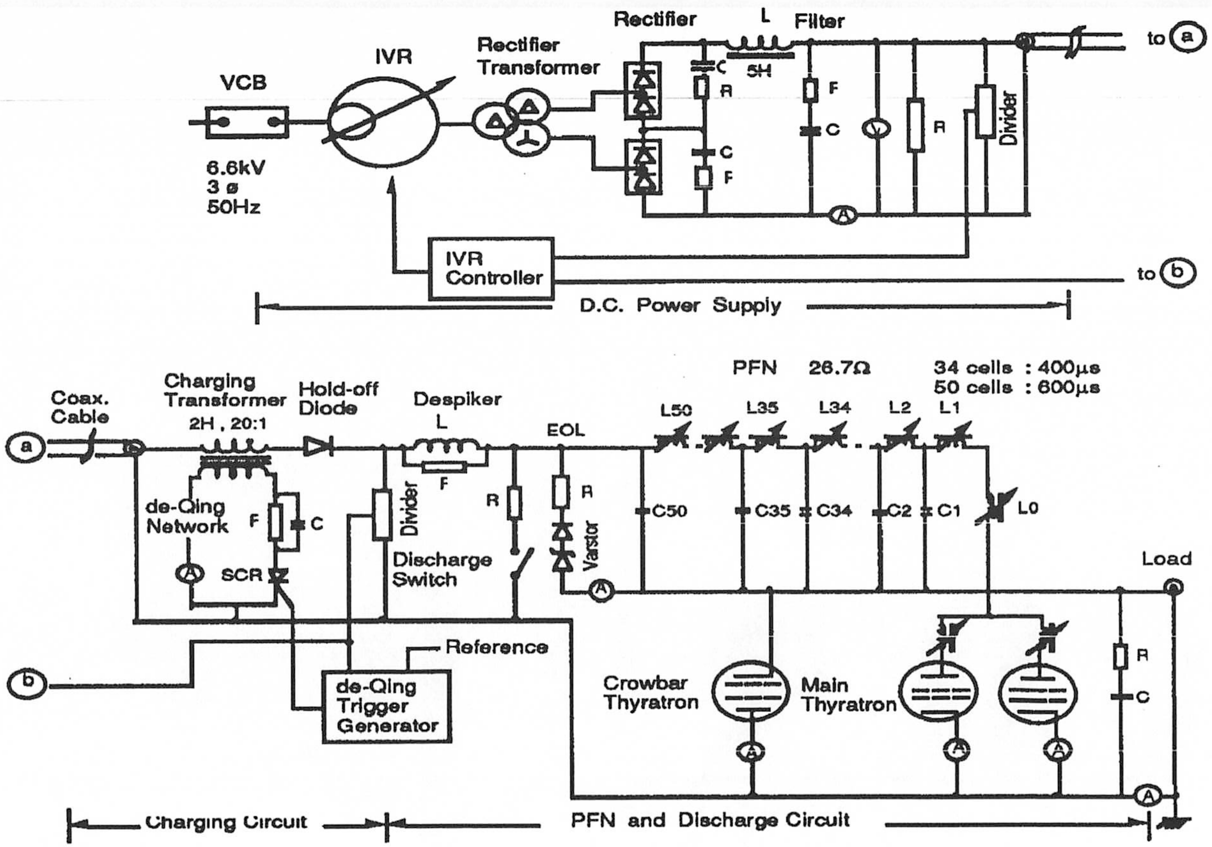


Figure 1 Schematic circuit of the prototype modulator.

F259 parallel

↓

SCR

Typical pulse shape

Ono et al.

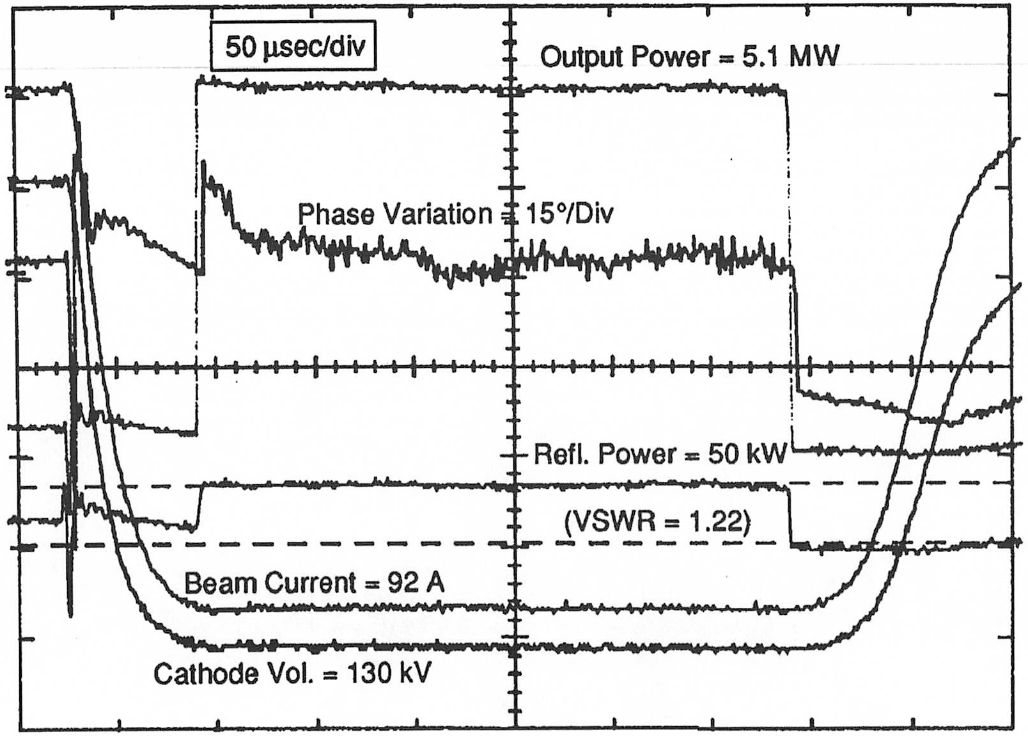


FIGURE 2 Typical pulse shape data at 5MW output.

Other developed items

* Pulse transformer — Kubo et al.
* Rf control system — Hanaki et al.
* More powerful klystron — Fukuda et al.
* Rf windows — Takeuchi et al.

Future Problem

* Beam test
* High-β DTL
* Low-β ACS
* Beam transport line
* UHF RF source
* Update of L-band RF

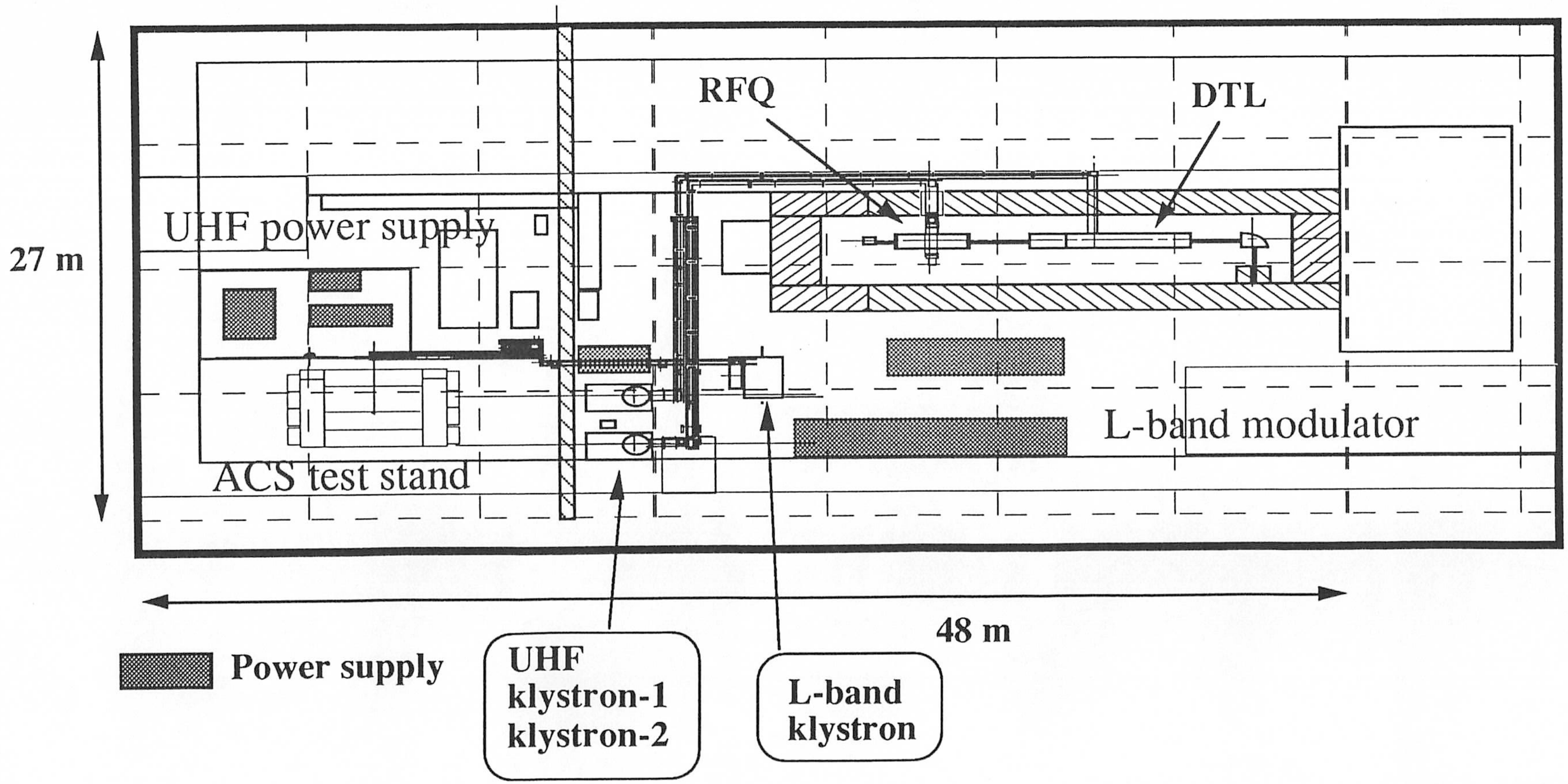
JHP Linac

Beam test in Jan. 1993

* Ability of each component
  * I.S, RFQ, DTL, Beam line, Monitor
* High power RF test
* Beam quality in low-β part
  * I.S+LEBT+RFQ+MEBT+DTL (6 - 10 MeV)

JHP Linac

1-GeV linac beam test stand



New Approach to Recent Study

- **Accumulation of knowledge and experience**

- **CAD** **New Application using Computer Aided Design**
  - **rf coupling in ACS design**
  - **PISL in RFQ design**
  - **Rf coupler in DTL design**
  - **Rf windows**
  - **Thermal and cooling estimation in RF structure**
  - **Circuit simulation in pulsed power amp.**

但し misread されぬよう

JHP Linac

CAD　Computer Aided Design

- **rf coupling in ACS design**
- **PISL in RFQ design**
- **end-part of the vane in RFQ**
- **post-coupler in DTL**
- **rf coupler in rf structure**
- **rf windows**
- **thermal and cooling estimation in RF structure**
- **rf circuit simulation**
- **space-charge effects**

3 次元電磁場計算 **MAFIA**

supercomputer

JHP Linac