Accelerator

Progress of Design
Construction Status
Linac Energy Recovery Scenario

Yoshi Yamazaki

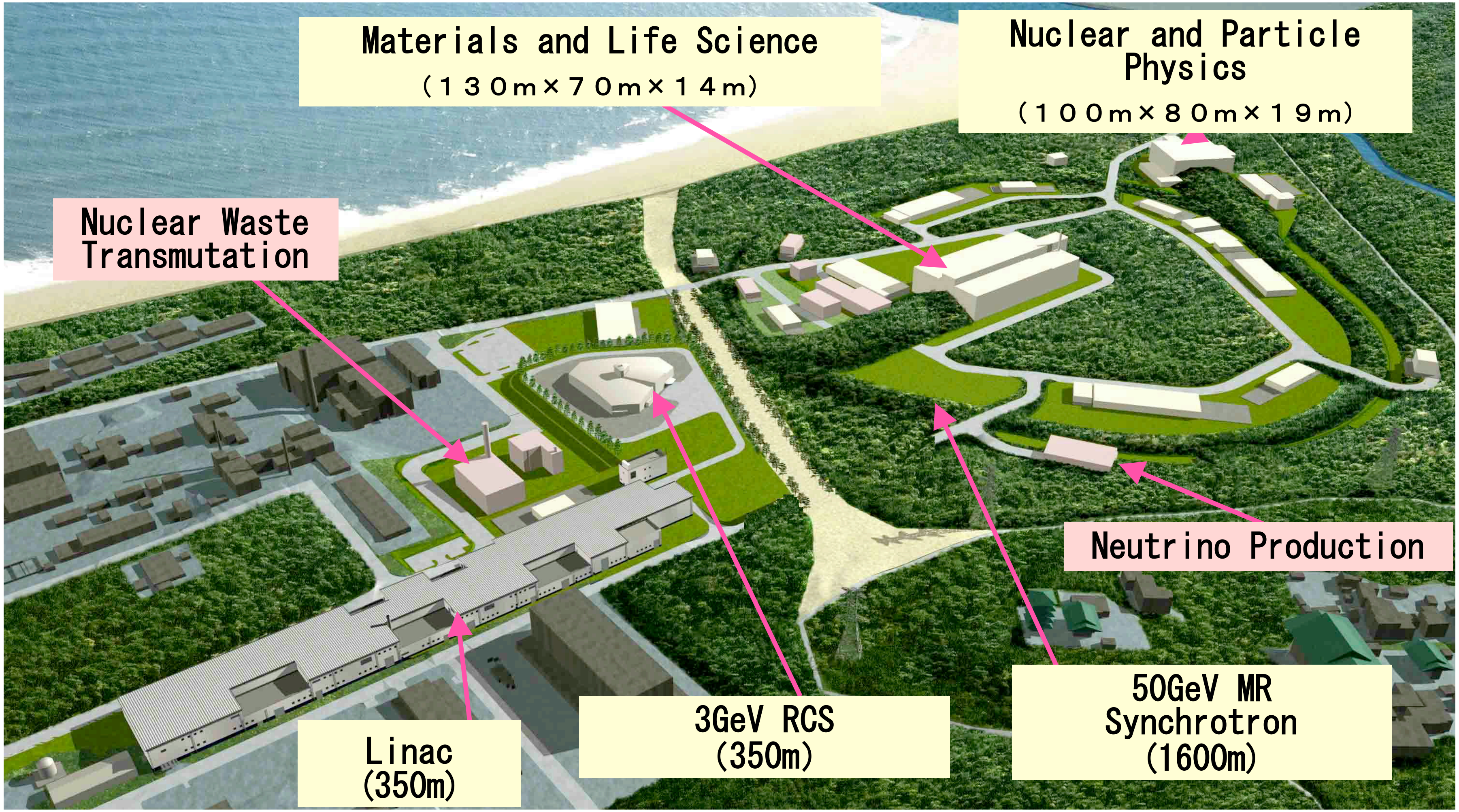
J-PARC Accelerator Group

The 2nd International Advisory Committee Meeting
KEK, Tsukuba, March 10th to 11th, 2003

Content

1. **Reminder**
2. **Progress in Design**
3. **Present Status of Costruction**
4. **Linac Energy Recovery Scenario**
5. **Summary**

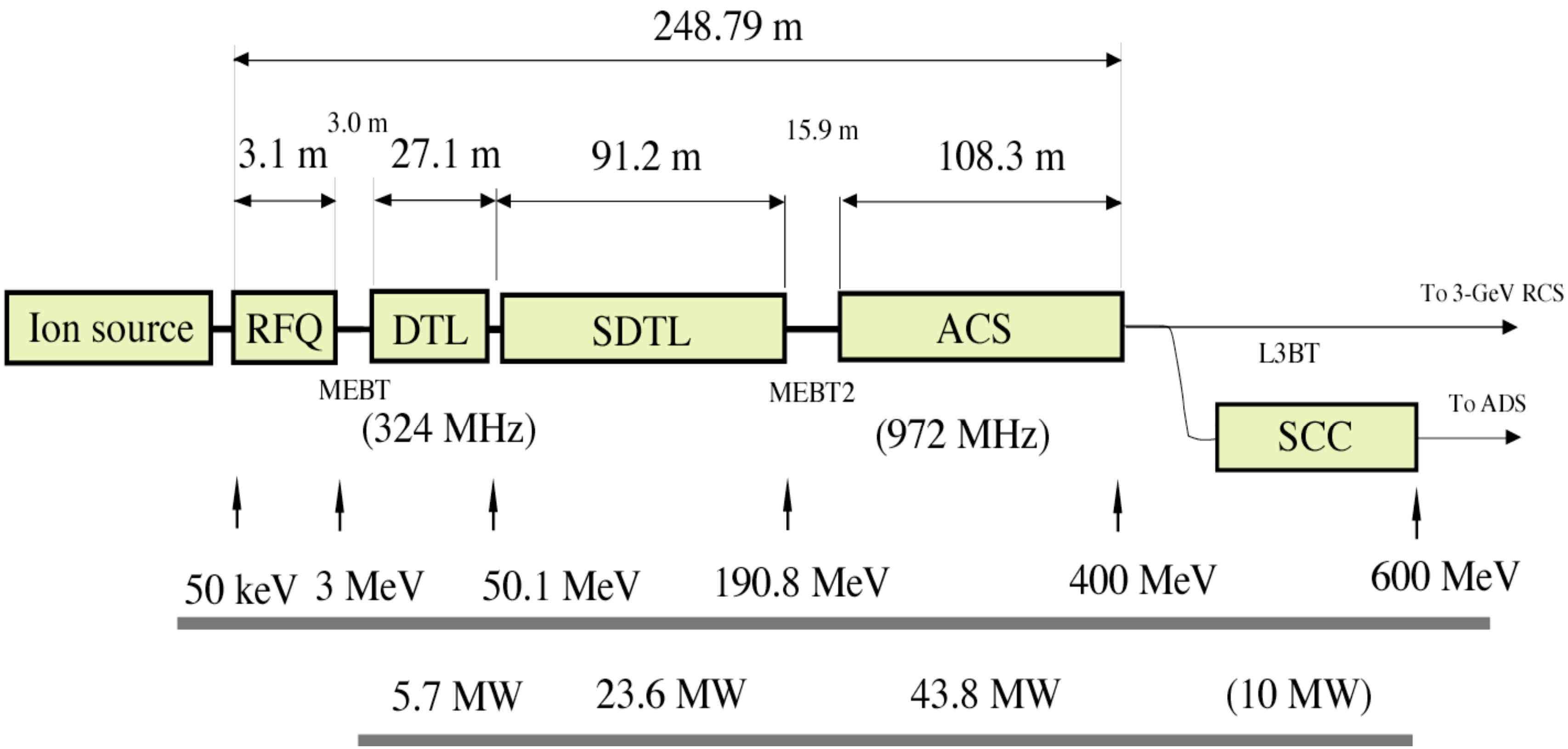
Site View of the Project



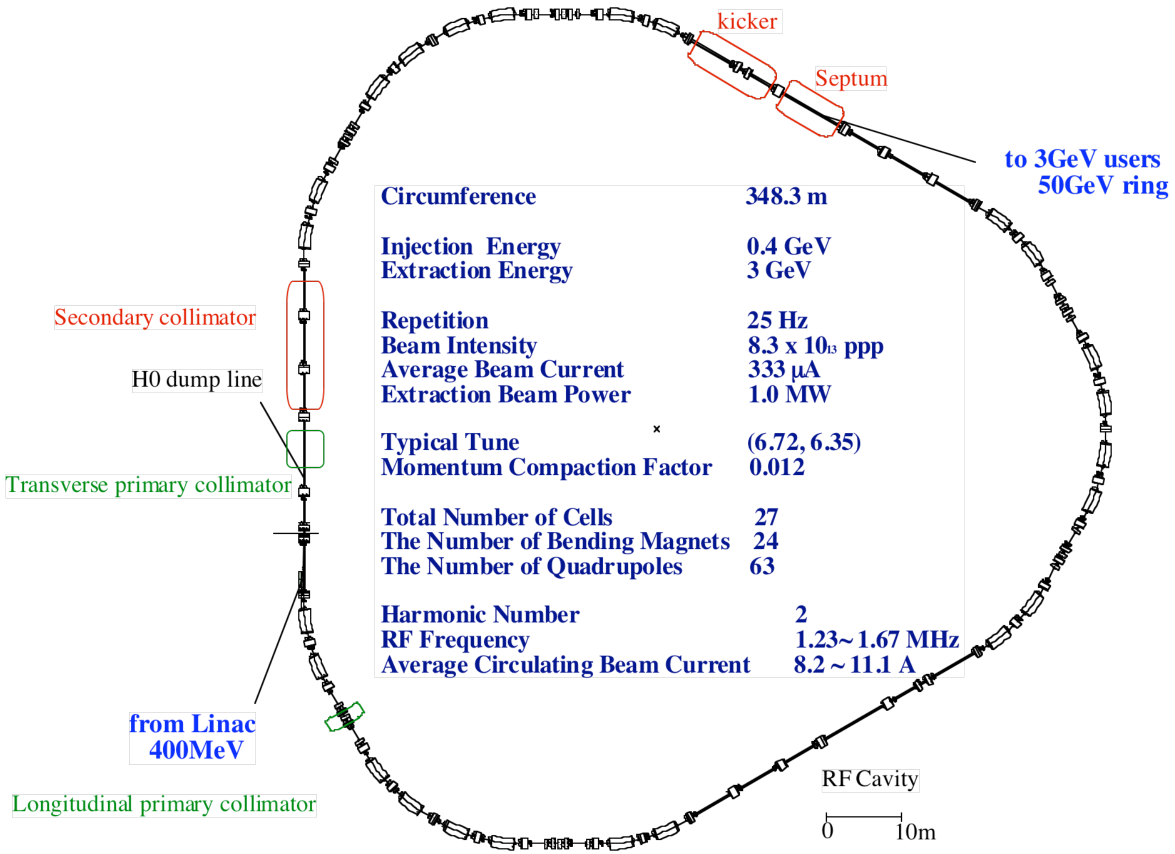
Phase I

Phase II

Proton linac

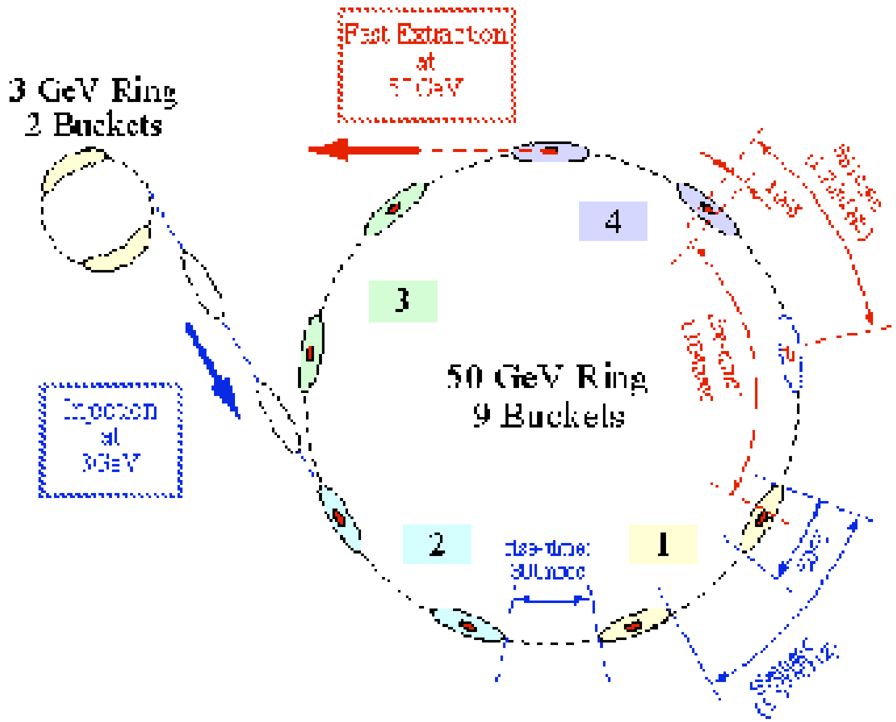


RCS Configuratiion

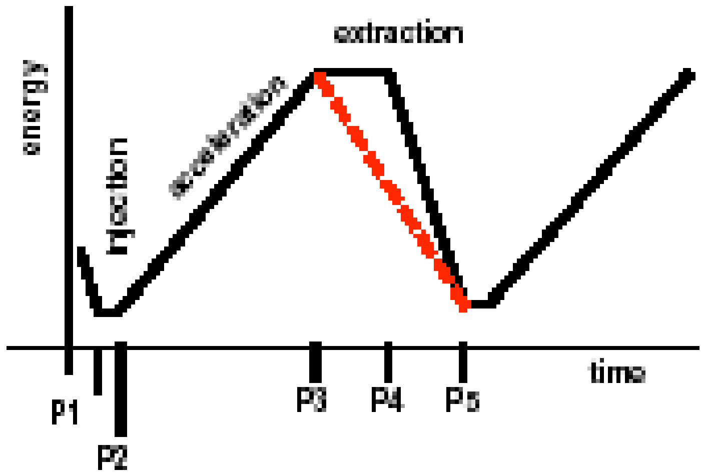


Circumference	348.3 m
Injection Energy	0.4 GeV
Extraction Energy	3 GeV
Repetition	25 Hz
Beam Intensity	8.3×10^{13} ppp
Average Beam Current	333 μA
Extraction Beam Power	1.0 MW
Typical Tune	(6.72, 6.35)
Momentum Compaction Factor	0.012
Total Number of Cells	27
The Number of Bending Magnets	24
The Number of Quadrupoles	63
Harmonic Number	2
RF Frequency	1.23~1.67 MHz
Average Circulating Beam Current	8.2 ~ 11.1 A

Injection Scheme to 50-GeV MR

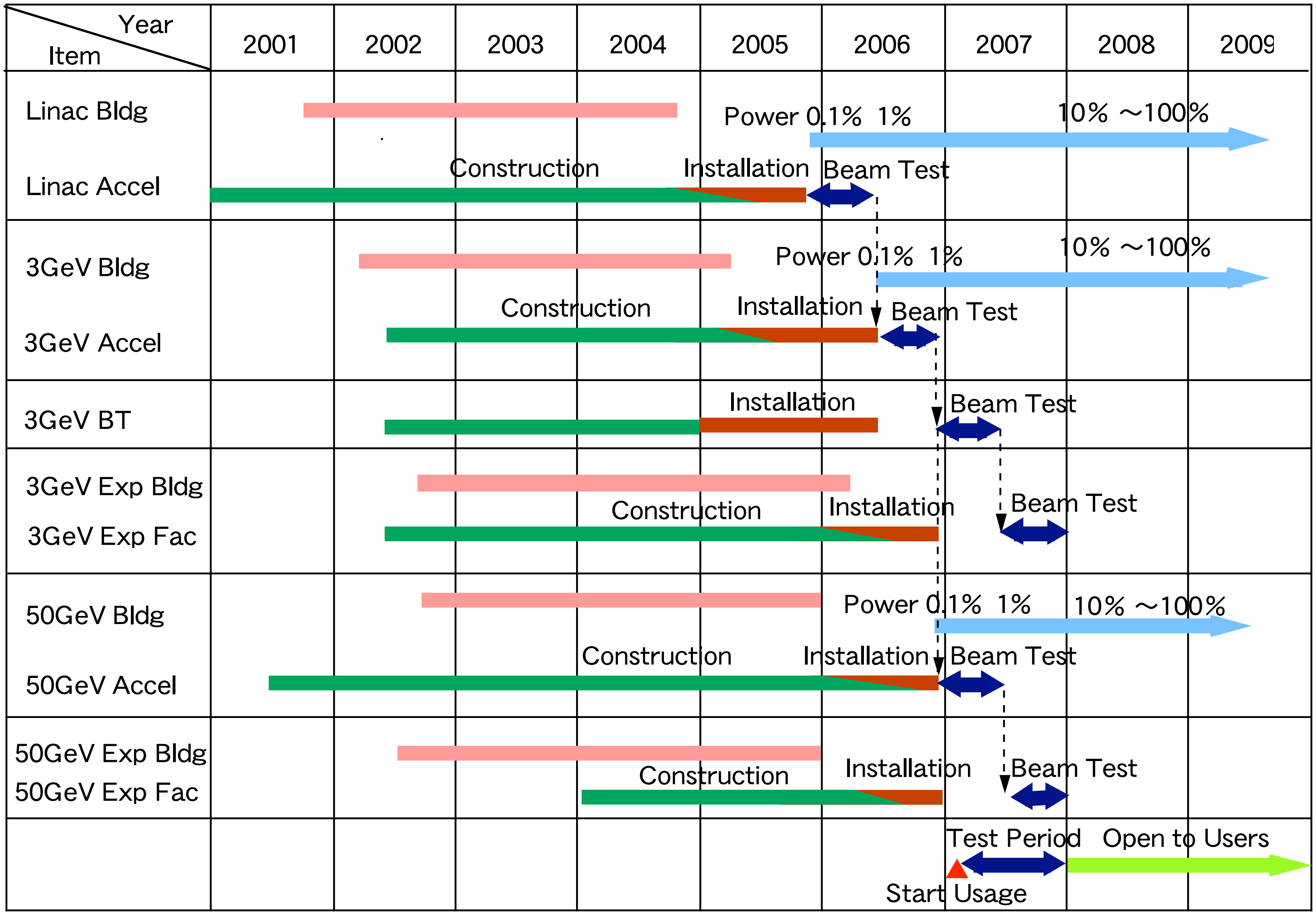


Acceleration Cycle

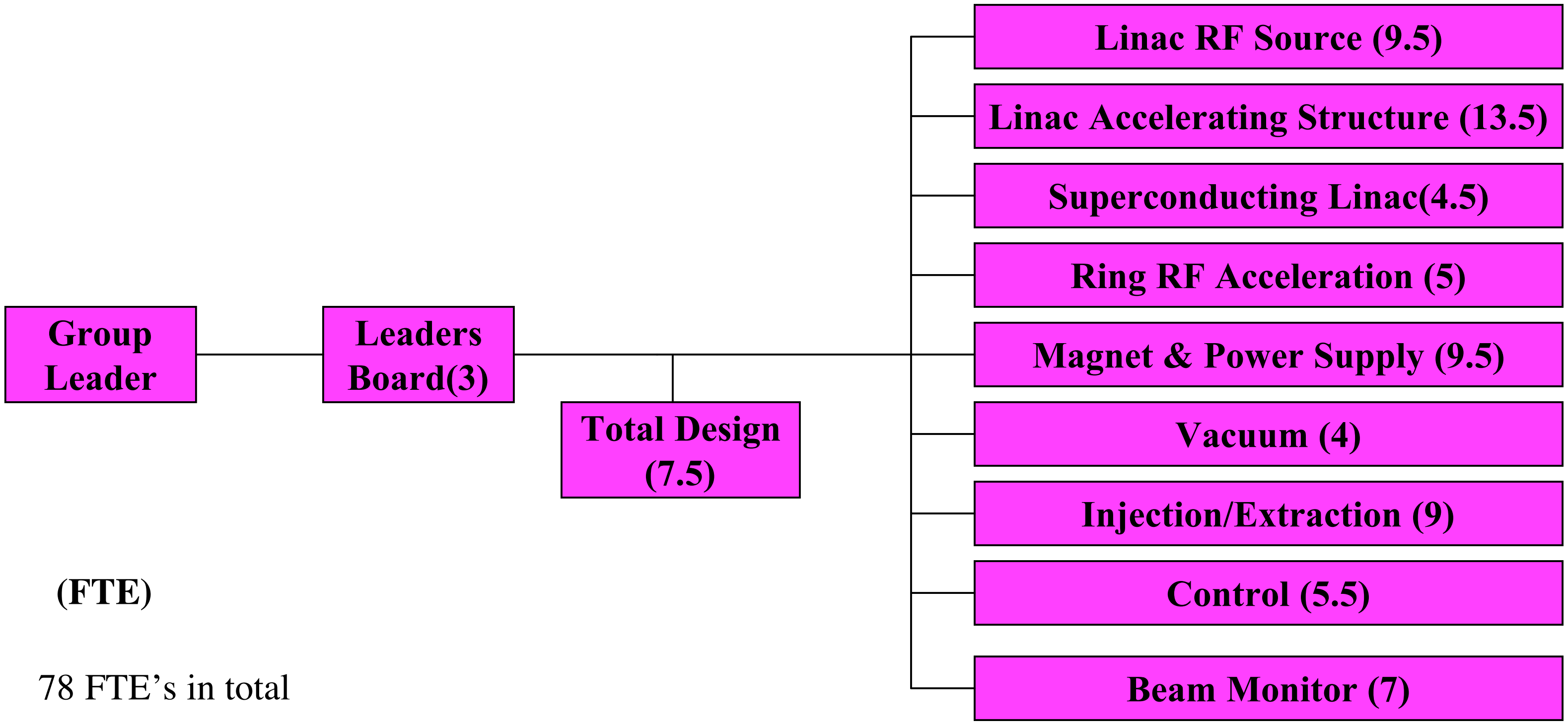


P1 - P2(injection)	0.14 s
P2 - P3(acceleration)	1.9 s
P3 - P4(extraction)	0.7 s
P4 - P5	0.9 s
total	3.64 s
slow extraction of 50GeV	
duty factor	0.20
average current	15μA

Construction, Commissioning Schedule



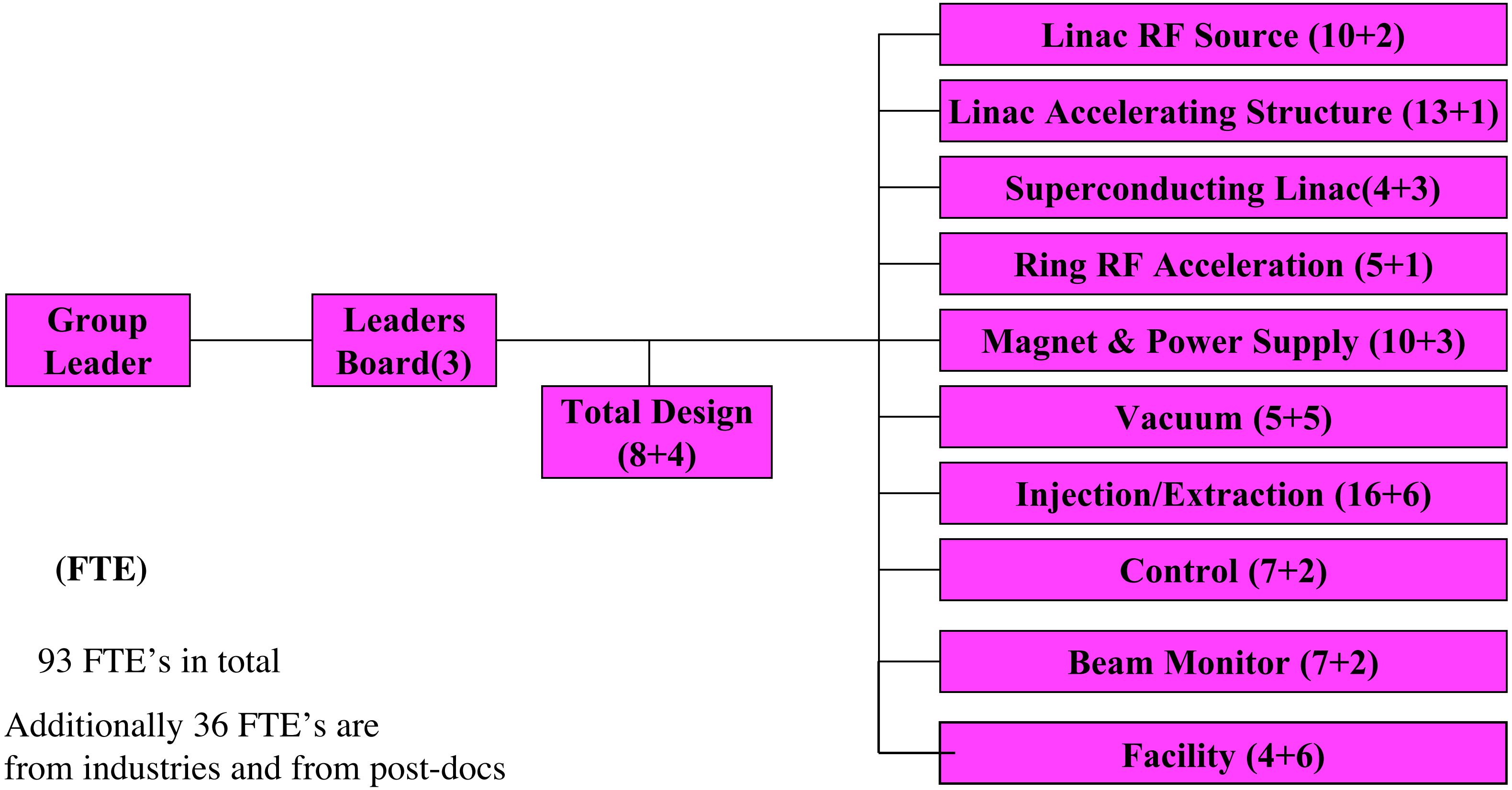
Accelerator Group Organization (Instrument Construction) as May, 2002



78 FTE's in total

Additionally 32 FTE's are from industries and from post-docs

Accelerator Group Organization (Instrument Construction) as March, 2003



(FTE)

93 FTE's in total

Additionally 36 FTE's are
from industries and from post-docs

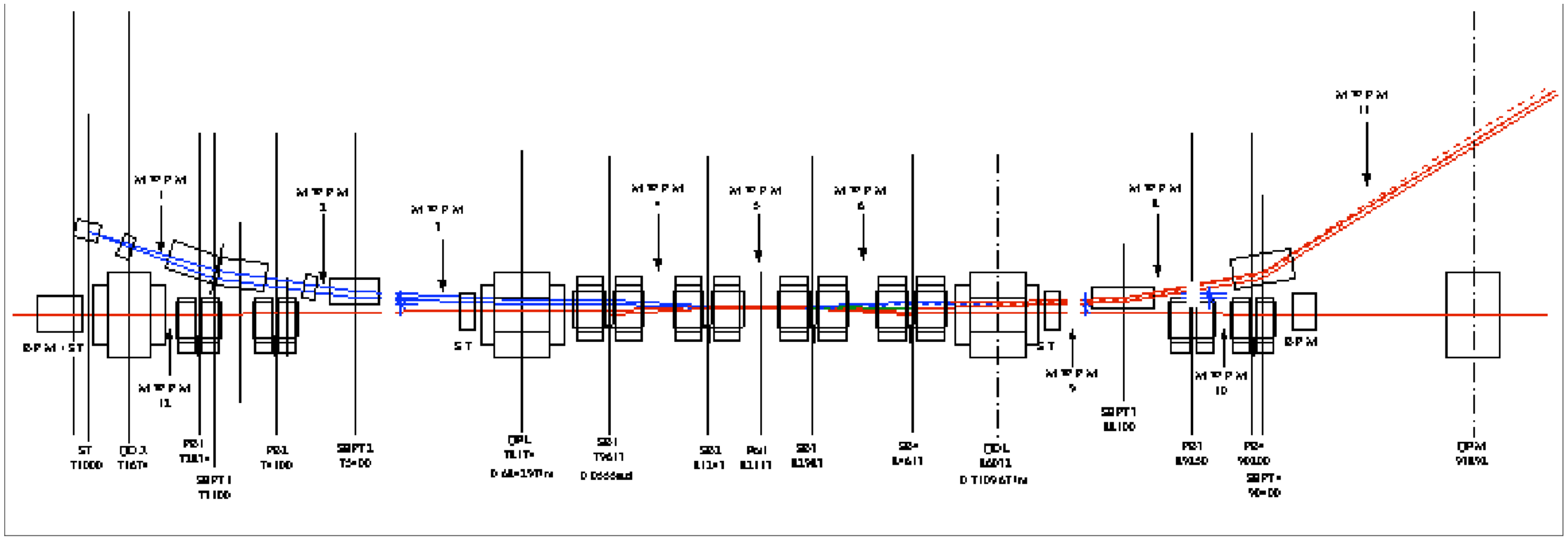
2. Progress in Design

- **Linac to RCS Beam Transport (L3BT). More stable against the space charge effect ---- *Takao Kato***
- **Injection Scheme to RCS ----------- *Izumi Sakai***
- **The number of Q families reduced from 11 to 7**

  ------------*Kazami Yamamoto*
- **Longitudinal Bucket Manipulation**

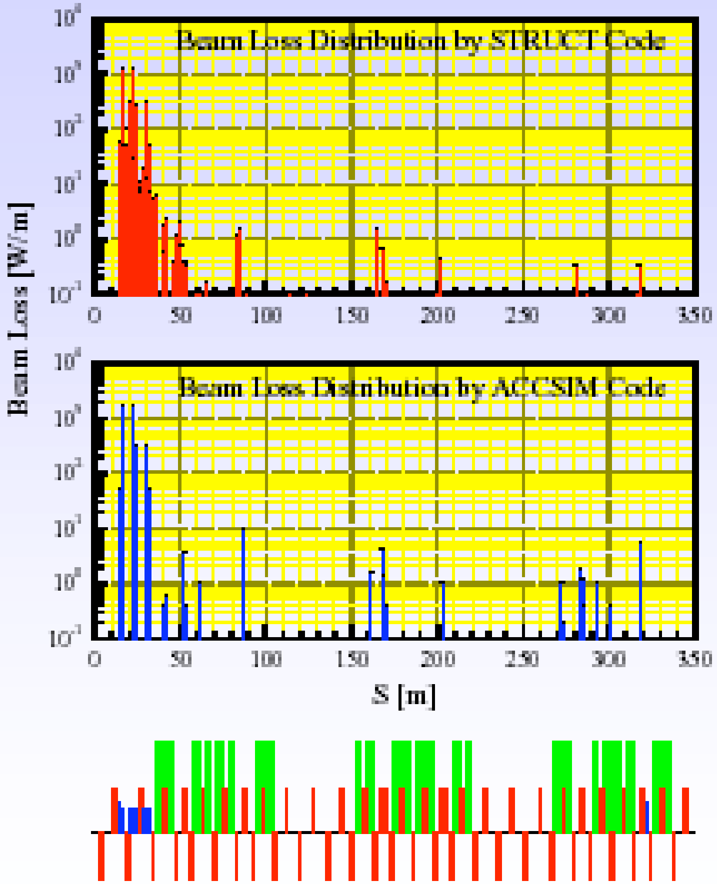
  ----------- *Masanobu Yamamoto*

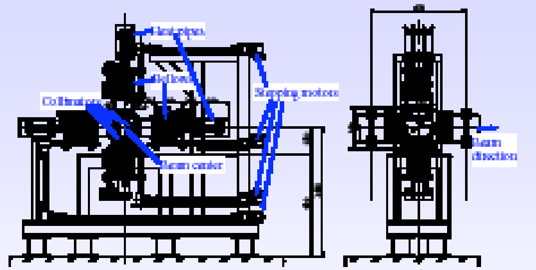
New Injection System to RCS

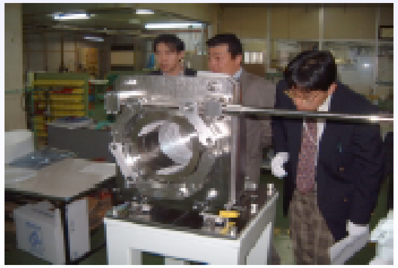


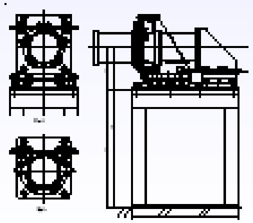
Collimation System for RCS

Comparioson of the two beam-loss simulations









●位置制御試験
●冷却試験
●インピーダンス測定
●遠隔着脱真空試験

Impedance Measurement with wire method

ワイヤー法による測定

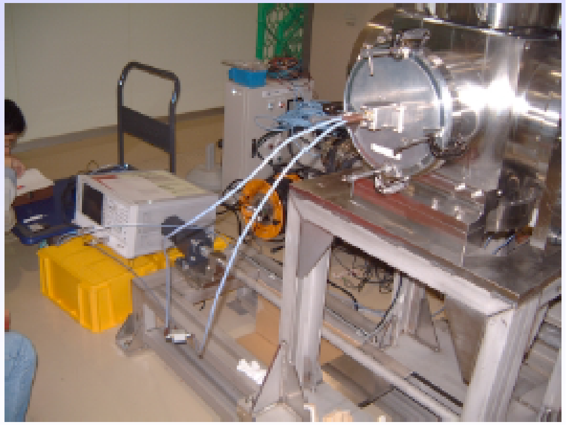
Longitudinal Impedance

$$\frac{Z_L}{n} \simeq 0.20 \quad \Omega @ Injection$$

$$\simeq 0.28 \quad \Omega @ Extraction$$

⇓

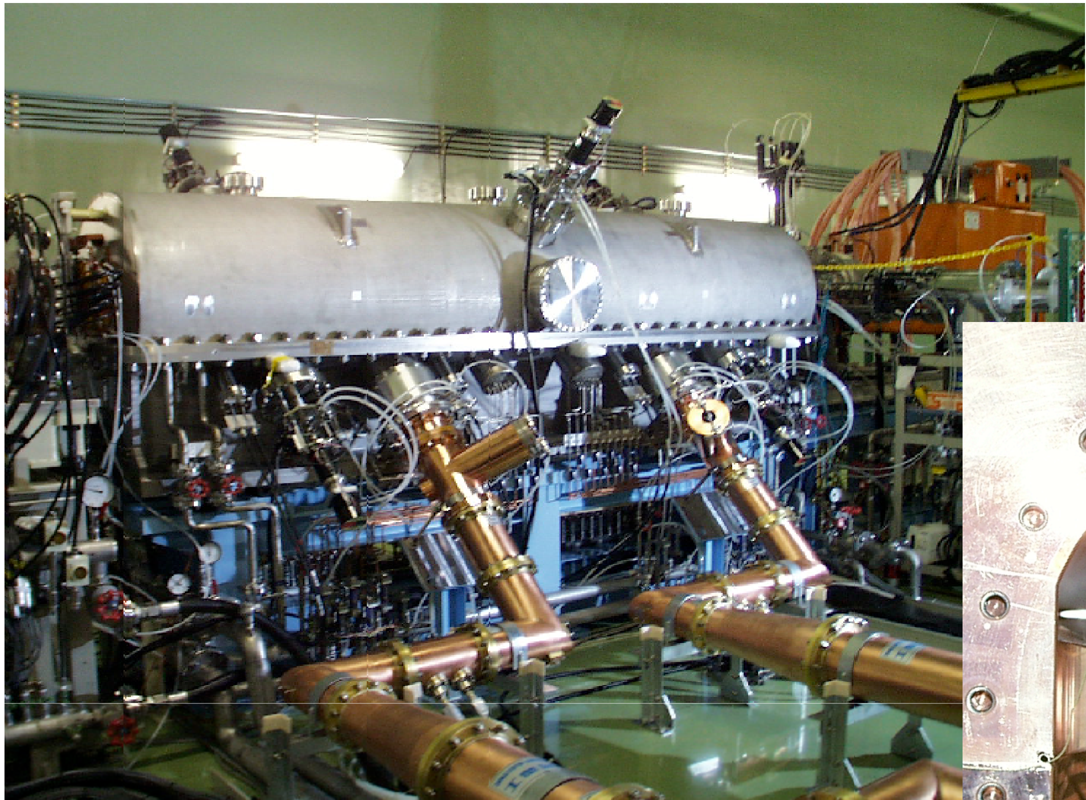
Criteria 420Ω@Injection
6.6Ω@Extraction
には収まりそう



3. Present Status of Costruction (Linac)

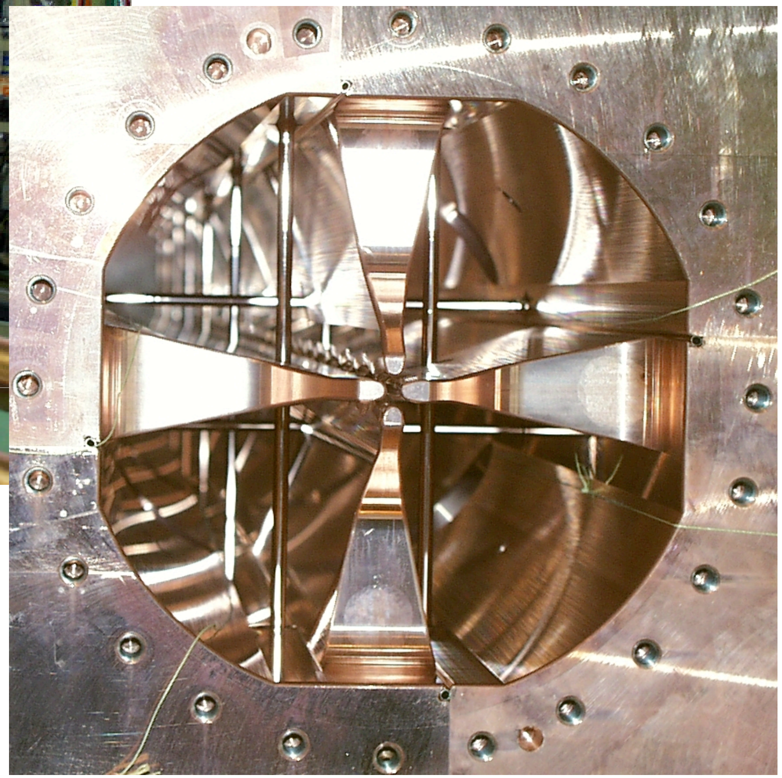
- **Beam commissioning of MEBT ----- *Masanori Ikegami***
- **Ion Source, present and future ------ *Akira Ueno***
- **Most of the major components for 200-MeV linac were ordered (77 %). The remaining components include**
- **Computer Control**
- **Bus Duct for DTL magnets**
- **Installation/Alignment/Wiring/Piping**

30mA RFQ

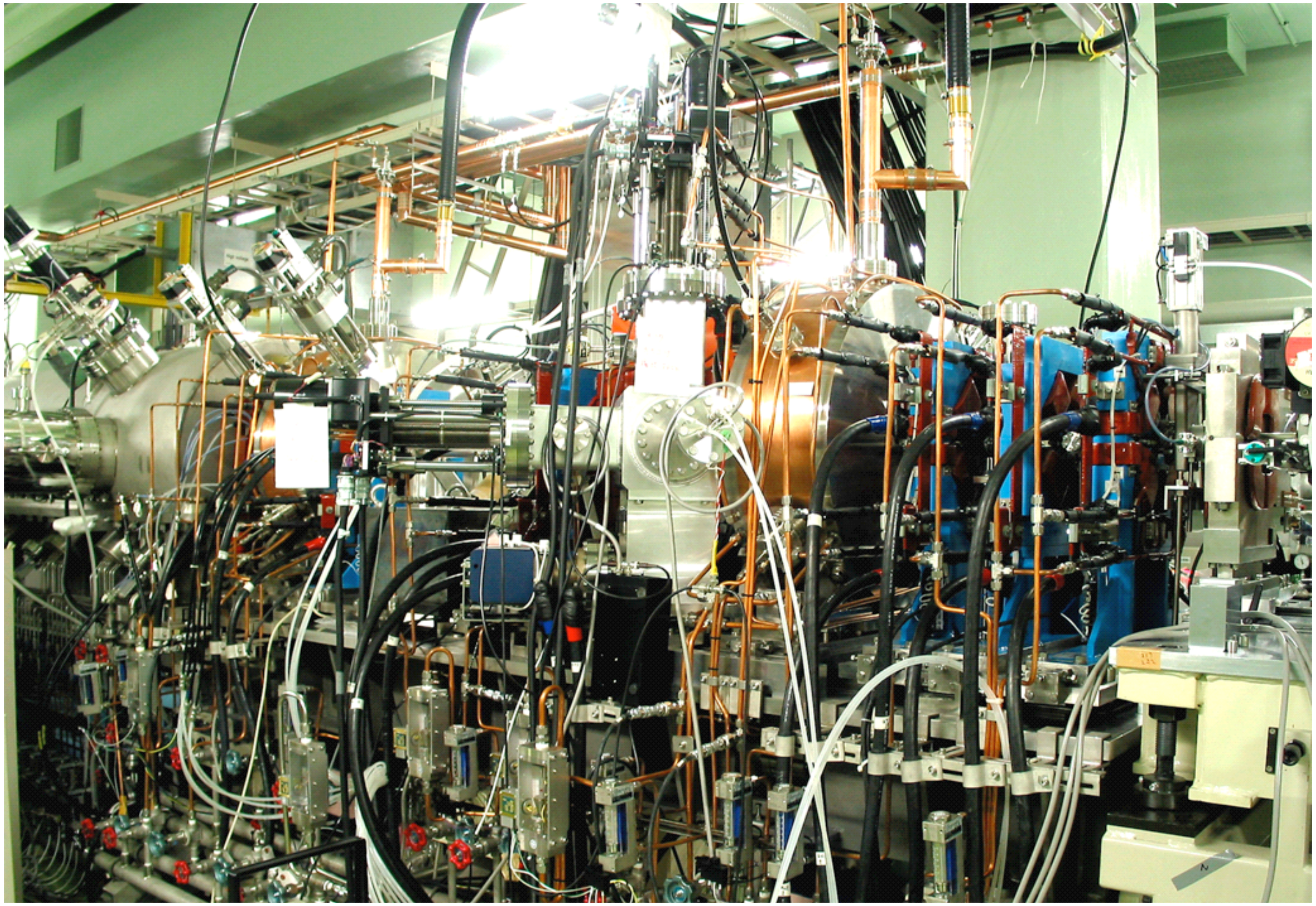


The 30mA RFQ
installed in the test area

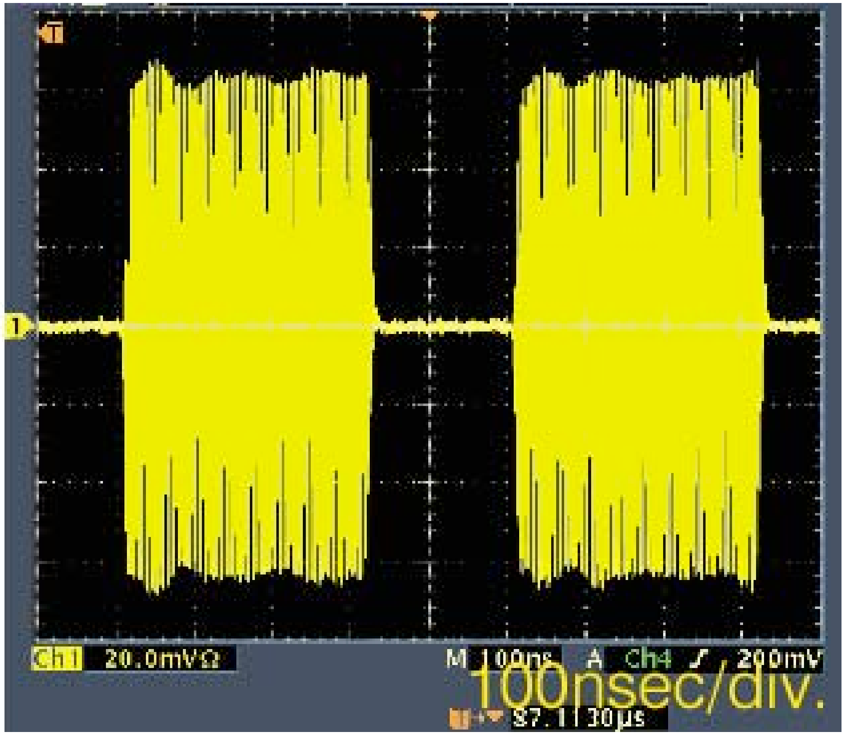
Inside view of the RFQ
stabilized with PISLs



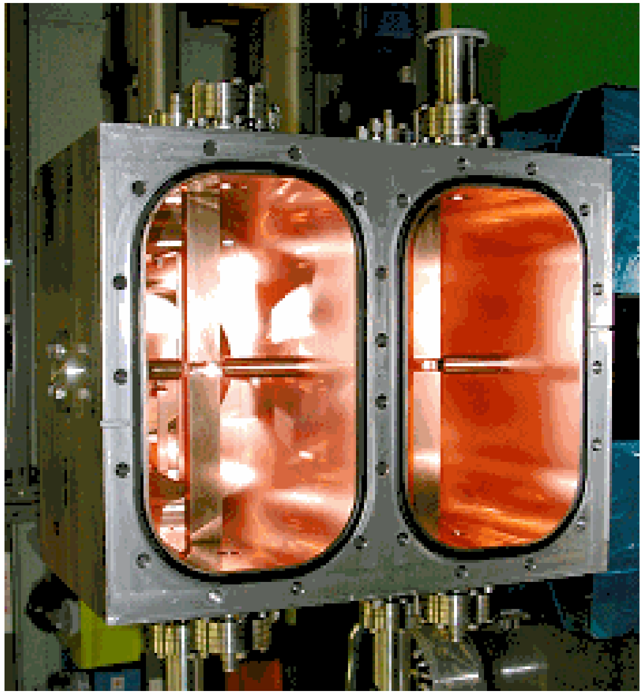
MEBT Photograph

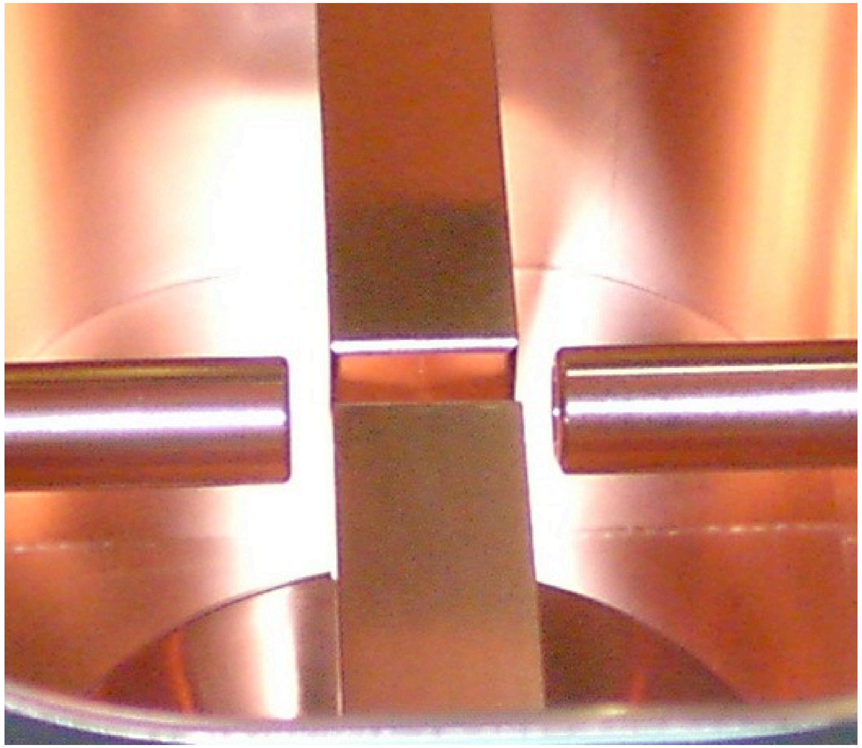


Wave Forms of Chopped Beam



Chopper Cavity installed at the MEBT



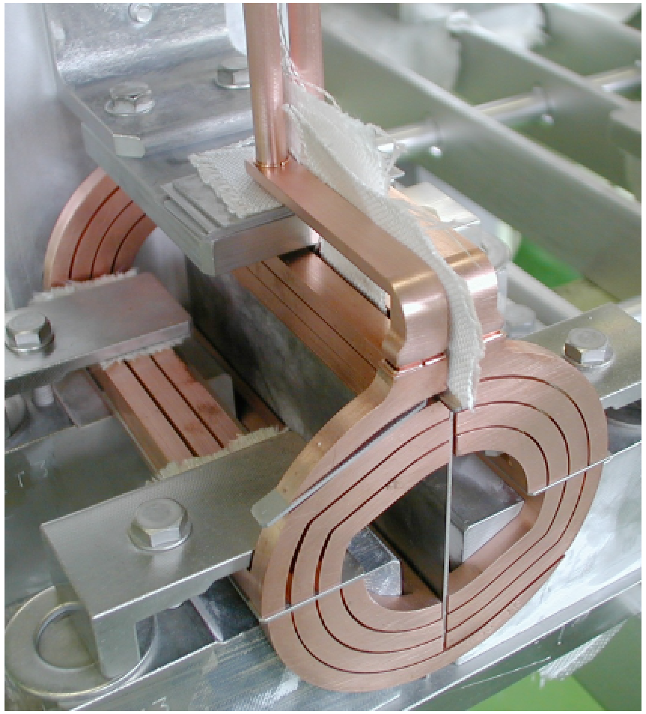


Measured Emittance

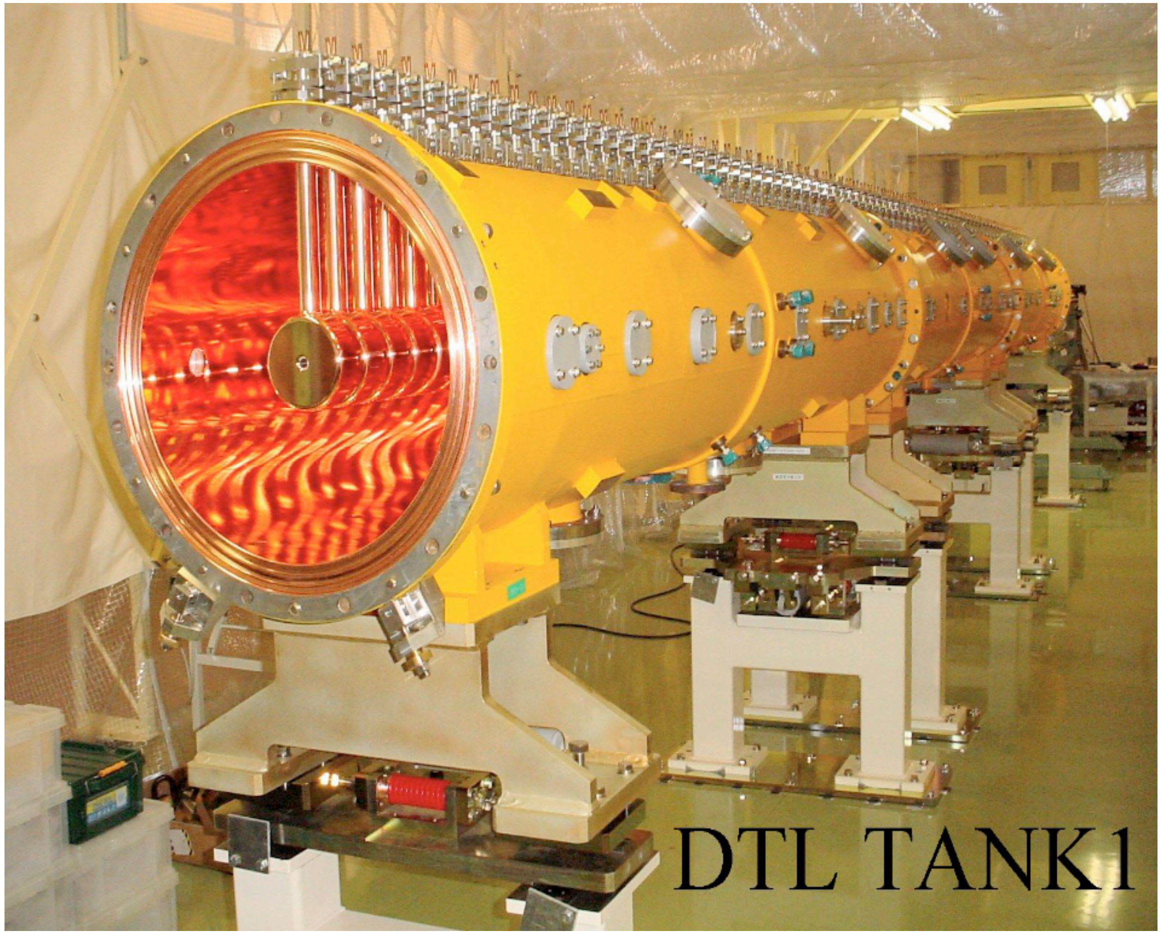
	Normalized rms emittance (π•mm•mrad)		
	MEBT exit		RFQ exit
Peak current	28.5 mA	24 mA	10 mA
Horizontal	0.252	0.227	0.173
Vertical	0.214	0.220	0.194
Measured	Jan., 2003	Jul., 2002	

Coil of Electromagnet in Drift Tube

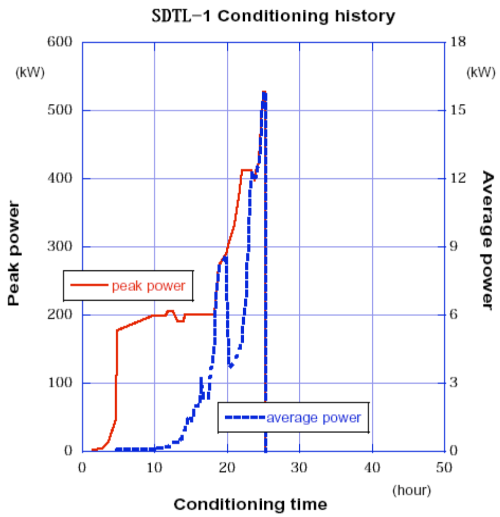
The coil is electroformed and Wire-cutted.

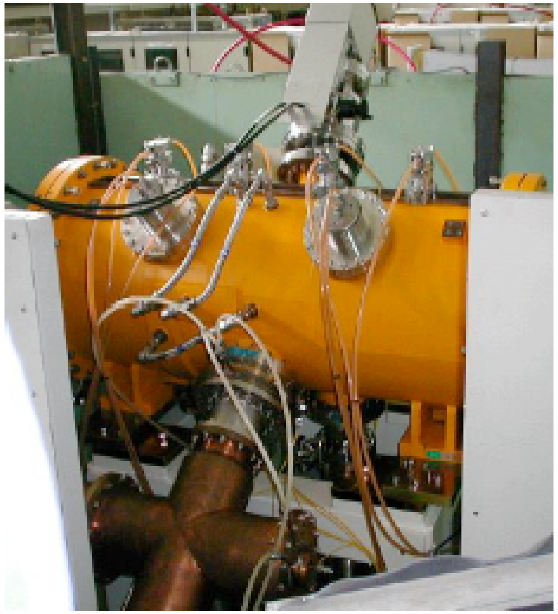


DTL Tank 1 with DT's Installed



Conditioning of SDTL1





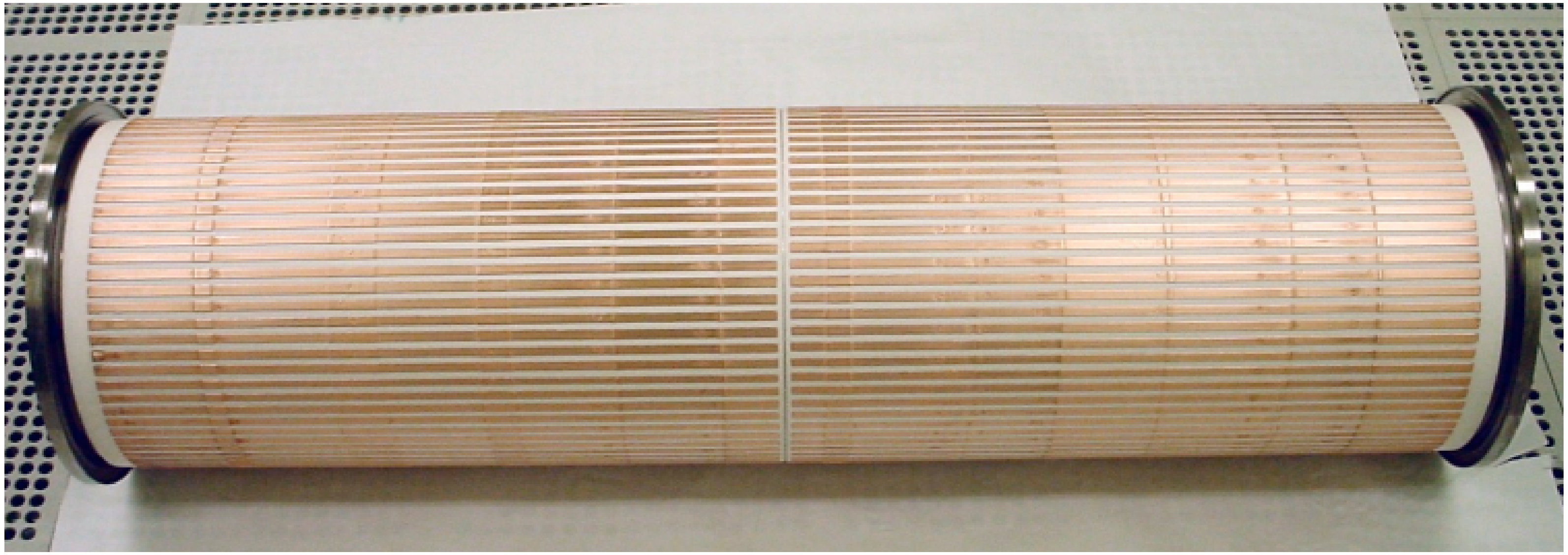
3. Present Status of Costruction (3-GeV RCS) (1)

- **Rapid-Cycling Magnet System (including experimental results on the stranded cables) ------- *Norio Tani***
- **Half of the major components ordered (53 %) including**
  - **Magnets**
  - **Half of the magnet resonant power supplies**
  - **Vacuum chambers in B and Q magnets**
  - **Half of RF system**
  - **Half of Beam Extraction System**
  - **Cooling System**

3. Present Status of Costruction (3-GeV RCS) (2)

- **The remaining components (47 %) include**
  - **Half of the magnet resonant power supplies**
  - **Vacuum system including pumps and monitors**
  - **Half of RF system including cavities**
  - **Beam Monitors**
  - **Beam Injection Systems**
  - **Half of Beam Extraction System**
  - **Computer Control**

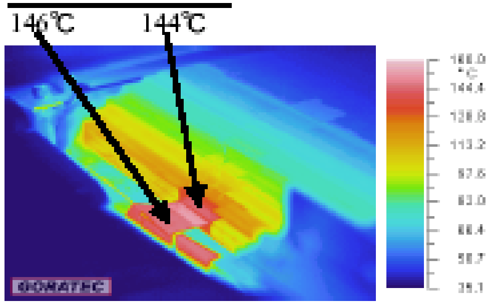
Ceramics Vacuum Chamber with RF Shield



R&D Bending Magnets for the RCS (1)

Temperature Measurments of the End Plates

Without the slit



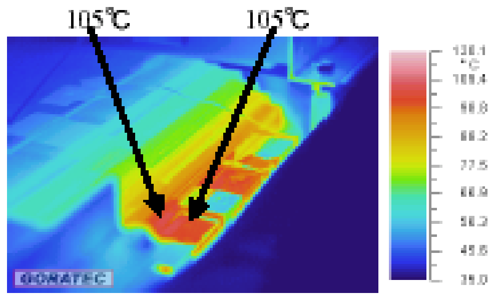
Two-dimensional model

Eddy loss : 0.971kW

Mean temp. : 144℃

Measurement of the end plate temp. : 146℃

With the slit



Two-dimensional model

Eddy loss : 0.572kW

Mean temp. : 91℃

Measurement of the end plate temp. : 105℃

3. Present Status of Costruction (50-GeV MR) (1)

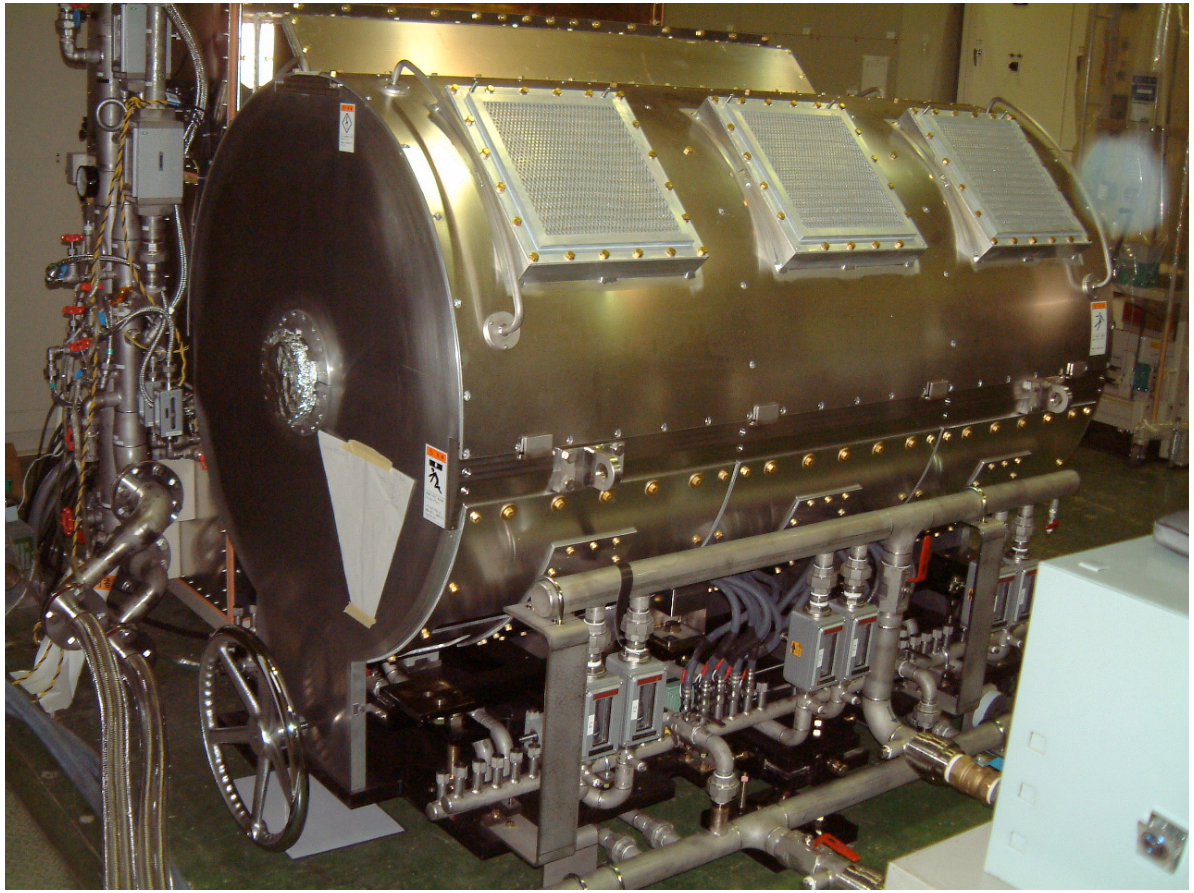
- **MA-loaded cavity system ---------------- *Chihiro Ohmori***
- **Fabrication and Field Measurement of the Magnet**

  ------ *Masafumi Muto*
- **Half of the major components ordered including**
- **Magnets and power supplies**
- **Vacuum system**
- **Beam monitor system**
- **Part of RF system**

3. Present Status of Costruction (50-GeV MR) (2)

- The remaining components include
  - Most of RF system
  - Beam Injection/Extraction Systems
  - Cooling system
  - Computer Control
  - Installation/Alignment/Wiring/Piping

RF Accelerating Cavity



500 kW peak power
50 % duty
50 hours

4. Linac Energy Recovery Scenario (1)

Budget Overflow

- **Present estimate of the budget overflow is approximately 85-oku yen (6.4 % of total cost).**
- **The exact value is dependent upon the result of the biddings of the remaining main components.**
  - **Increase in the RCS circumference by 10/9**
  - **Increase in RCS aperture by a factor of 1.5 both horizontal and vertical**
  - **Much more sophisticated injection system with many bump magnets.**
  - **(More precise field control in both phase and amplitude is necessary for the linac in order to overcome the space charge problem by controlling $\Delta p/p$ within 0.1 %(control system, cooling water system, tighter specification for the accelerating structures).)**

Comparison of the Lattice Parameters of the 3-GeV RCS (1)

----- The Circumference is increased by a factor of 10/9 ---

	New Lattice	Previous
Circumference	348.3 m	313.5 m
Typical Tune	(6.68, 6.27)	(7.35, 5.8)
Transition Gamma	9.17	9.05
Maximum RF Voltage	467 kV	420 kV
Maximum RF Voltage per Cavity	42 kV	42 kV
The Number of RF Cavities	11 (+1)	10 (+1)

Comparison of the Lattice Parameters of the 3-GeV Synchrotron (2)

----- The Emittance is increased by a factor of 3/2 ---

	New Lattice	Previous
Painting Emittance at Injection(□ mm.mrad)		
	216	144
Collimator Acceptance	324	216
Physical Aperture	486	324
Bunching Factor with 2nd harmonic		
	0.41	0.41
Incoherent Tune Shift with	0.16	0.23
Bunching Factor without	0.27	0.27
Incoherent Tune Shift	0.24	0.35

Comparison of the Lattice Parameters of the 3-GeV Synchrotron (3)

The Emittance is increased by a factor of 3/2,while the gap of the BM is as it is.
The number of families is increased.

	New Lattice	Previous
Bending		
The Number of Magnets	24	24
Gap Height	210 mm	210 mm
Good Field Region	240 mm	190 mm
Quadrupole		
The Number of Magnets	60	66
The Number of Families	7	7

4. Linac Energy Recovery Scenario (2)

What to do ?

- We have to close the ring.
- We can inject the beam with a lower energy. Experiments with a lower beam power are possible.

  - Set the minimum injection energy to 200 MeV.
  - Order and complete the building, the tunnel, the infrastructure, the 200-MeV linac, the 3-GeV RCS and 50-GeV MR. The building and the tunnel can accommodate the 400-MeV linac.
  - Waiting for the results of the bidding of the major components, we will try to increase the linac energy as high as possible.

4. Linac Energy Recovery Scenario (3)

- The project director and the JAERI/KEK managements have been making and will make every effort to obtain the budget to complete the 200-400 MeV linac.
- Actually, the Ministry of Education, Science, Technology, Culture, and Sport (Monbu-Kagaku-Sho, Mon-Ka-Sho) tried to fund this by a supplementary budget, last year, although the result was not successful.

Problem

◆ Even if the proposal is approved the earliest possible, the recovery can start in 2004, two years later than originally planned.

◆Nearly one year beam shut-down is necessary for the installation at the midst of the high time of the experiment with a few-100 kW beam power.

This will be never approved by the users.

4. Linac Energy Recovery Scenario (4)

- *Recovery Scenario*

- The components to be installed outside the tunnel can be installed and tested without any disturbance on the beam operation.
- On the other hand, the components to be installed inside the tunnel needs the beam shut down.

- **Usually, the machine operation is shut down for three months in every summer, since the electricity cost is very high in the summer season. These three months will be used to install the cavities.**
- **If the cavities are not used for the acceleration, the recovery of the beam intensity will not take much more time than the start-up after the usual summer shut down.**
- **For this, all the lattice quadrupole magnets without the CCL should be set in the same way as the case with the CCL. (There will be no problem for the beam transport through the detuned CCL, although some worry exists, regarding the beam blow up by the resonance hitting.)**

Linac Energy Recovery Schedule Proposed

LINAC 400 MeV Recovery Schedule 2003.2.18

	The First Year	The 2-nd Year	The 3-rd Year	The 4-th Year	The 5-th Year
Shut Down	July,Aug.	July-Sept.	July-Sept.	July-Sept.	July-Dec.
Operation	Scheduled Operation				400MeV Commissioning
Electricity		Distribution Step up			Sep.-Dec.
		Wiring			
Cooling Water	Step up Work	Test Run			
Control		Device Control Program			
			Wirig		
		Commissioning Program			
ACS Assembly	Test Area Set up				
	RF System Set up				
	ACS Cavity Production				
		ACS Cavity Assembly ,High Power Test			
		ACS+Q-Mag Assembly, Alignment			
	Q-Mag,Beam Monitor Production and Test				
Kly.PS		Set up			
		Wiring			
RF System	Production				
			Set up ,Test		
		ACS System Test, Tuning (Occasional)			
		Beam Acceleration Test (If Possible)			
Tunnel	WG Set up	Wiring,Piping	Wiring,Piping	Wiring,Piping	
		ACS Installation	ACS Installation	ACS Installation	RFQ,Debuncher Replace
		Buncher(MEBT2) Installation			RF System Tuning
					LINAC Commissioning
					3GeVCommissioning

4. Linac Energy Recovery Scenario (5)

- It will take three summer shut-downs for the installation.
- During the beam operation, one can finish the power test and other component test without any disturbance on the beam operation.
- During the fourth shut down, the beam will be accelerated up to 400 MeV, will be injected to the RCS and so forth.
- It is very hard to estimate how long it takes to recover the same beam intensity as that of the lower injection energy. We hope we need, at most, additional two or three months to the three-month shut down.
- If the funding is not too late, the 400-MeV injection can start just after the maximum beam power of around 0.6 MW with the 200-MeV injection is achieved. Then, little delay in the gradual beam power up.

This scenario was reviewed by Director's Ad Hoc Committee,
on March 5, 2003.

We would like the ATAC and IAC to support the above specification change and the injection-energy recovery scenario from the viewpoints of the beam power margin.

Comparison of the space-charge tune shifts

Tune shift has the meaning as a scaling tool.

Table: Comparison of the Tune Shifts for Various Beam Currents and Energies.

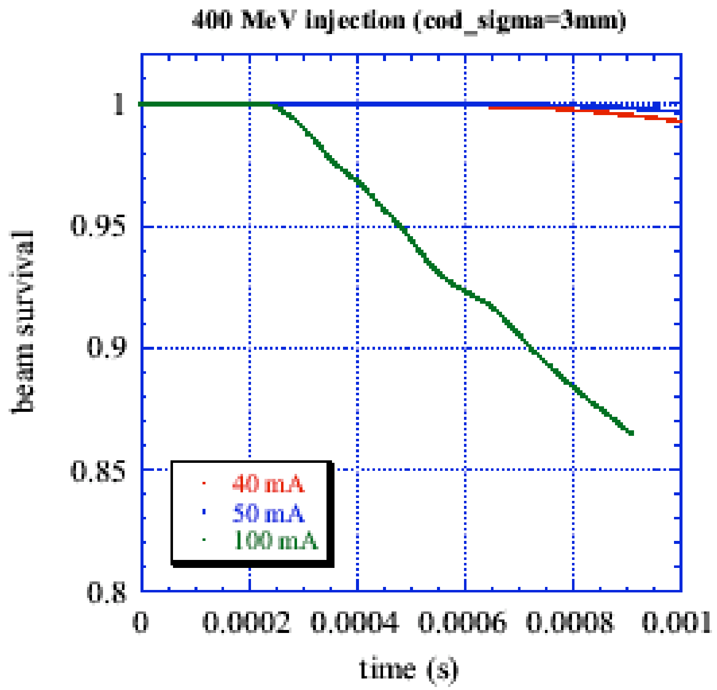
	JHF	J-PARC	J-PARC
Beam Power	0.6 MW	1 MW	0.6 MW
Beam Current	200 μA	333 μA	200 μA
Number of Particles N	5×10^{13}	8.3×10^{13}	5×10^{13}
Injection Energy	200 MeV	400 MeV	180 MeV
$\beta^2\gamma^3$ at injection	0.572	1.475	0.501
Painting Emittance ε (unnormalized, π mm mrad)	214	216	216
Bunching Factor B_f	0.27	0.41	0.41
Tune Shift $\Delta\nu$	– 0.37	– 0.16	– 0.27

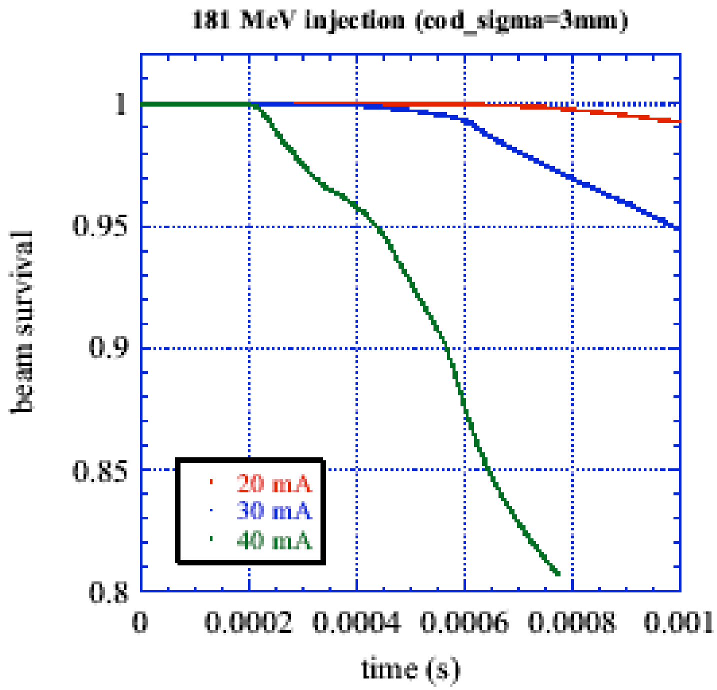
Classical Proton Radius: $r_p = 1.53 \times 10^{-18}$

Lasslett Tune Shift: $\Delta\nu = - r_p N / 2\pi\beta^2\gamma^3 (\varepsilon/\pi) B_f$

1) The collimator aperture is 1.5 times as large as the painting emittance, while the physical aperture is 1.5 times as large as the collimator one.
2) The tune shift of the SNS is – 0.20 at the injection energy of 1 GeV.
3) The collimator can stand 3% beam loss at the injection of 400 MeV. It can stand the 10% beam loss or more at 200 MeV, 200 μA.

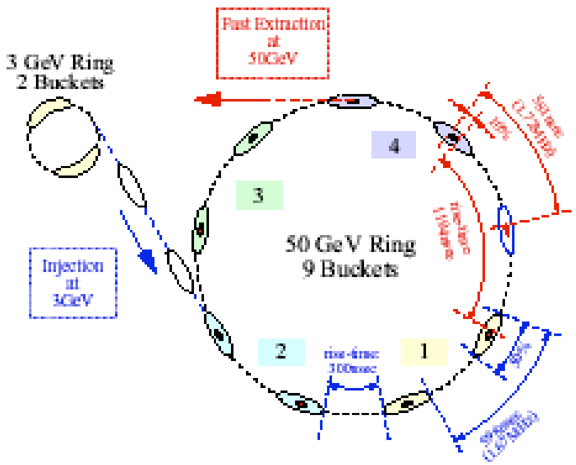
Beam Loss in RCS with 400-MeV and 181-MeV Injections

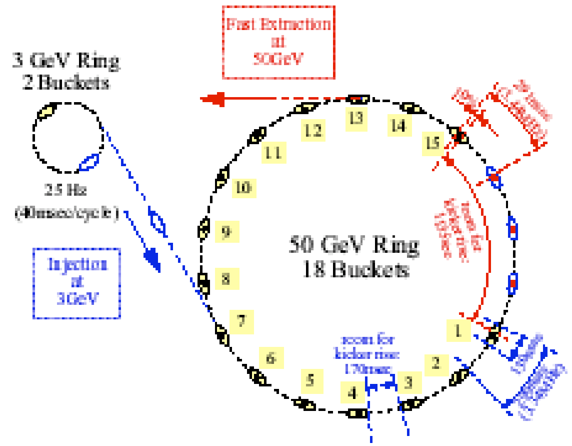




20 mA: 0.4 MW
30 mA: 0.6 MW
40 mA: 0.8 MW
50 mA: 1.0 MW

Two Injection Schemes from 3-GeV RCS to 50-GeV MR





Fast Extraction : 15 μA (3.52 s)
18.6 μA (2.84 s)
Slow Extraction: 15 μA (3.52 s)

18 μA (3.28 s)
15 μA (3.96 s)
if 0.6-MW RCS, and

if 0.6-s injection is possible with this beam current (tune shift is - 0.14).

Summary

- Progress in the accelerator design has been achieved on the beam injection system, the BT from linac to RCS, and so forth.
- The construction of the accelerator components is on schedule, except for the CCL.
- The recovery scenario of the CCL is formed with little disturbance on the beam operation.
- Archaeological excavation of the salt pans remains may delay the civil engineering construction for the 50-GeV MR longer than half a year, having a big impact on the beam commissioning of the MR.

Emittance Growth in RCS (400-MeV injection, 1.5 MW)

By Takayama et al.

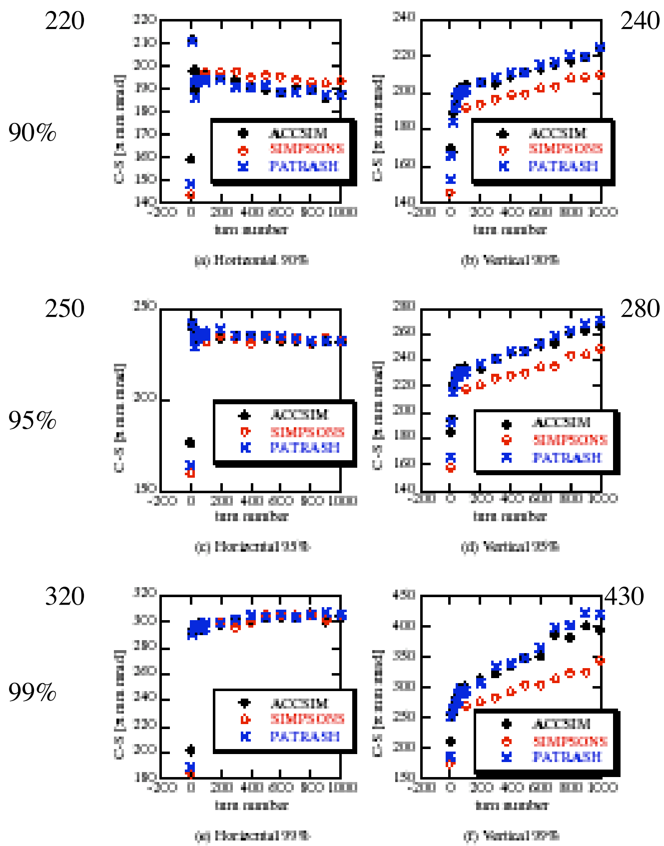
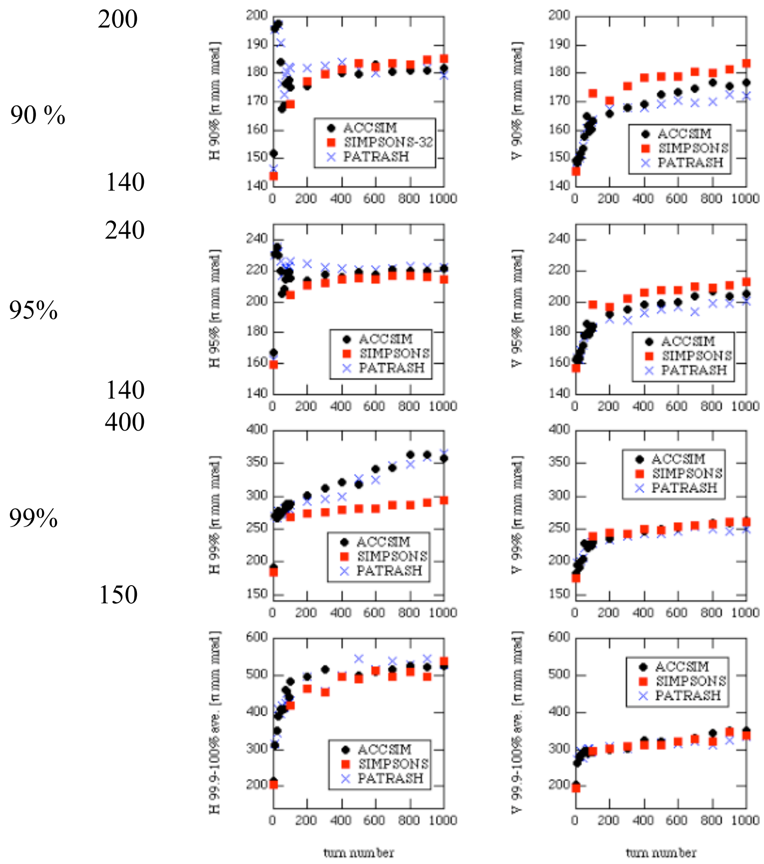


Fig.7 Time evolution of the emittance in the case of 30A.

30A

The tuneshift of the 400-MeV injection, 1.5-MW extraction is the same as that of the 180-MeV injection, 0.5-MW extraction.

Emittance Growth in RCS (400-MeV injection, 1 MW)



Courant-Snyder Invariant
20A, Sext on, 100%Q

Horizontal Vertical

By Takayama et al.

The 97 % emittance should be confined in 324 π mm mrad.

Emittance Growth in RCS with 181-MeV Injection