R&D and Construction Status of the J-PARC Linac

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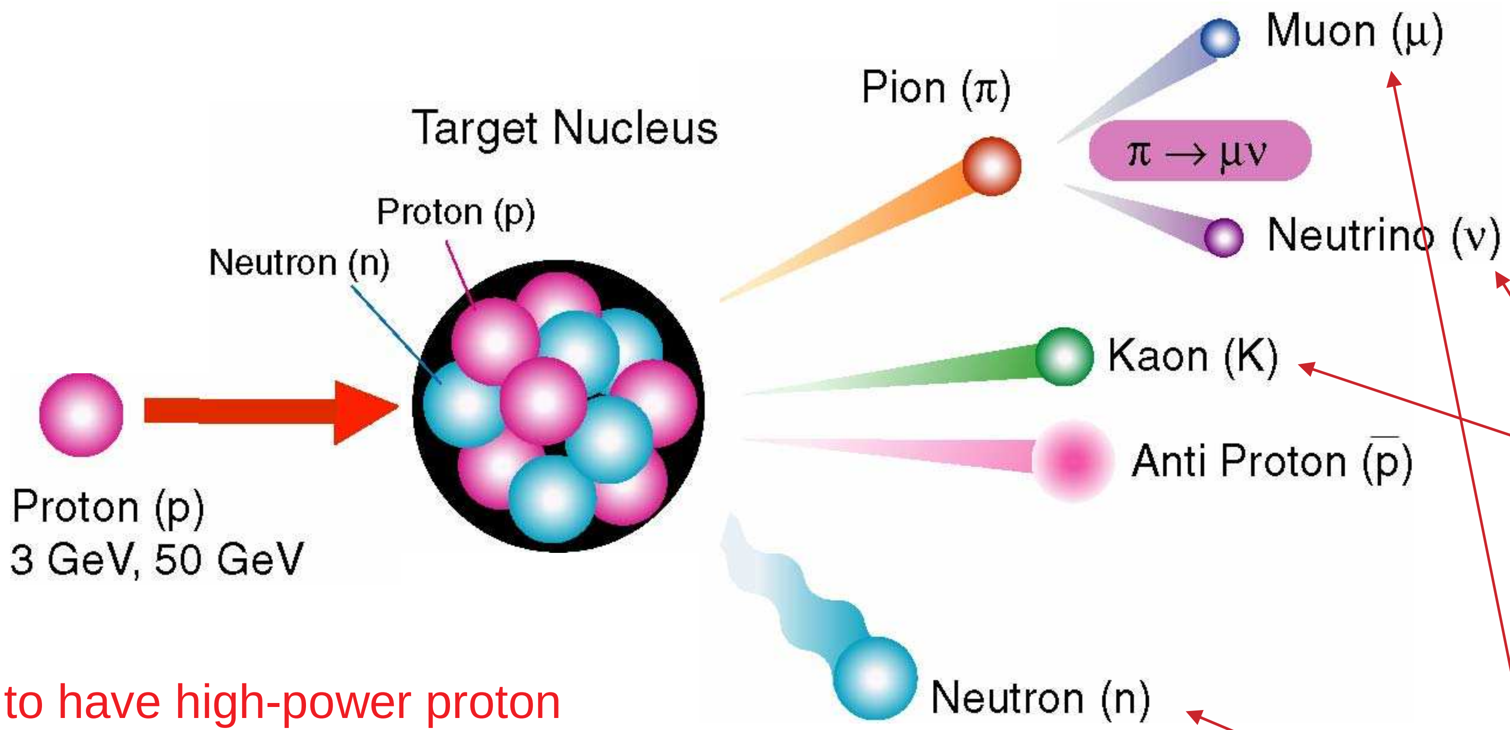
Outline

- J-PARC (Japan Proton Accelerator Research Complex) Project
- Linac Components
  - Parameters, Features and R&D
  - Beam Commissioning of DTL-1
- Linac Building
- Photos of the Linac
- R&D for Upgrade
- Summary

Three Goals at J-PARC

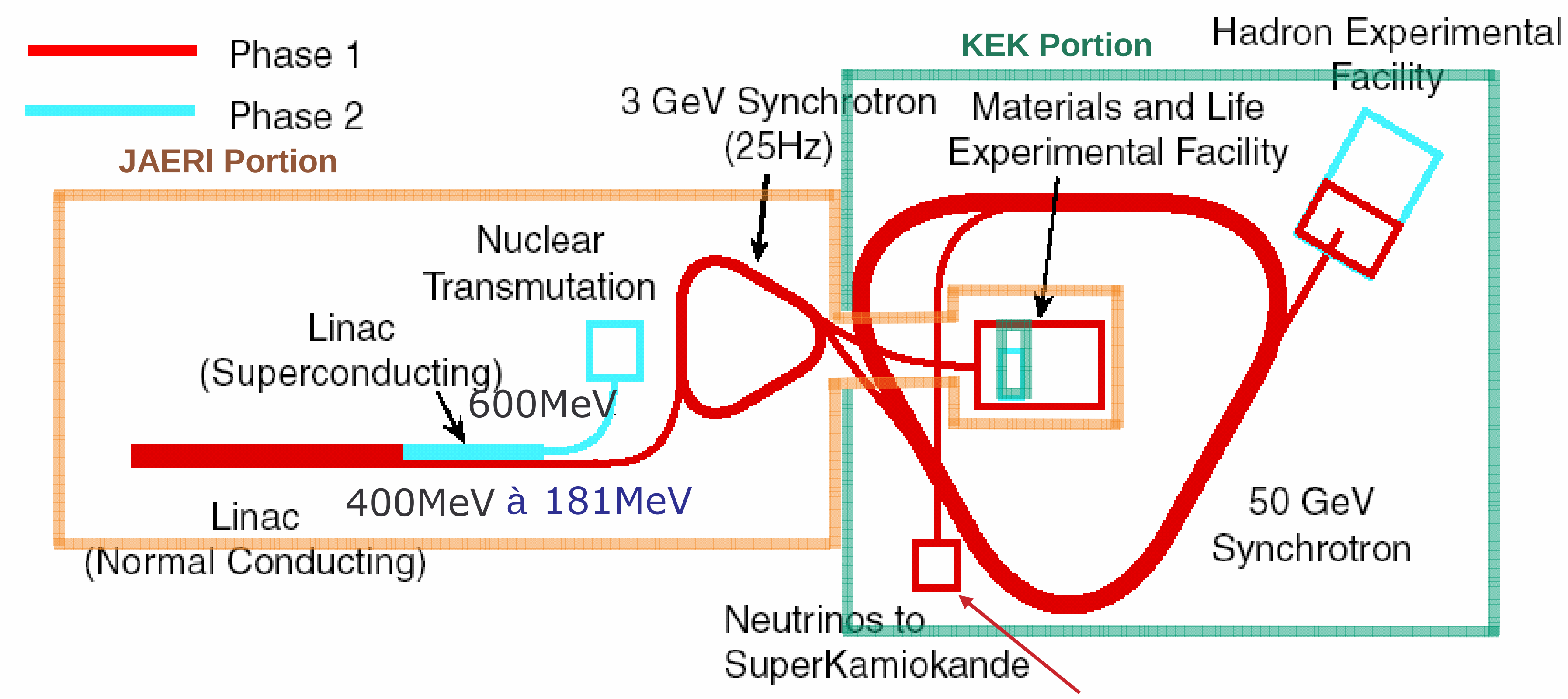


Need to have high-power proton beams
à MW-class proton accelerator
(current frontier is about 0.2 MW)

- Materials & Life Sciences at 3 GeV
- Nuclear & Particle Physics at 50 GeV
- R&D toward Transmutation at 0.6 GeV

J-PARC Facility

Phase-1 and Phase-2



- Budget Overflow: RCS (larger bore, circumference 10/9), Linac (high performance)
- At the initial stage of the Phase 1:

  Linac energy is reduced from 400 MeV to 181 MeV

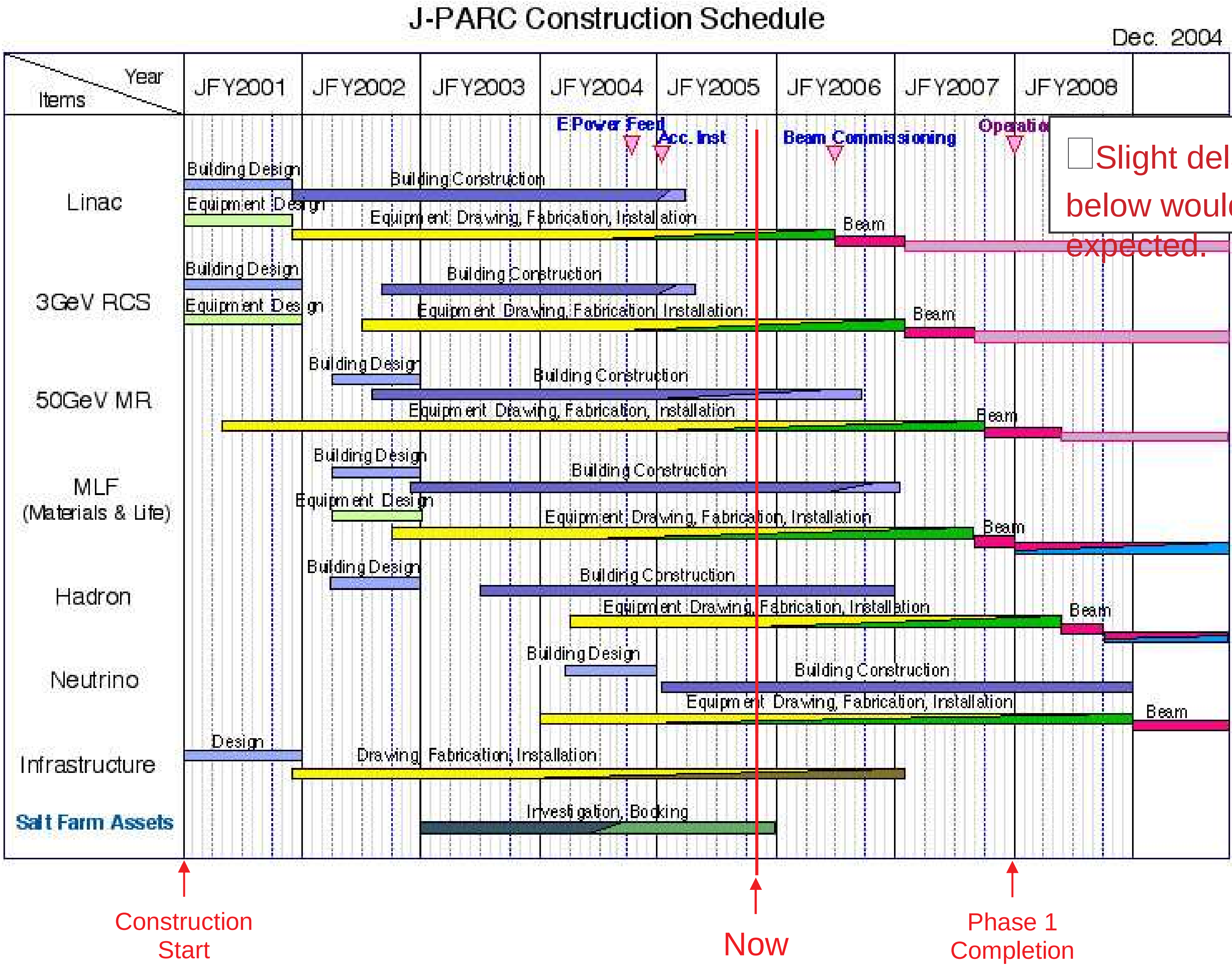
  RCS beam power is also reduced from 1 MW to 0.6 MW


February, 2003


September, 2005

Construction for Buildings

Construction Schedule Phase-



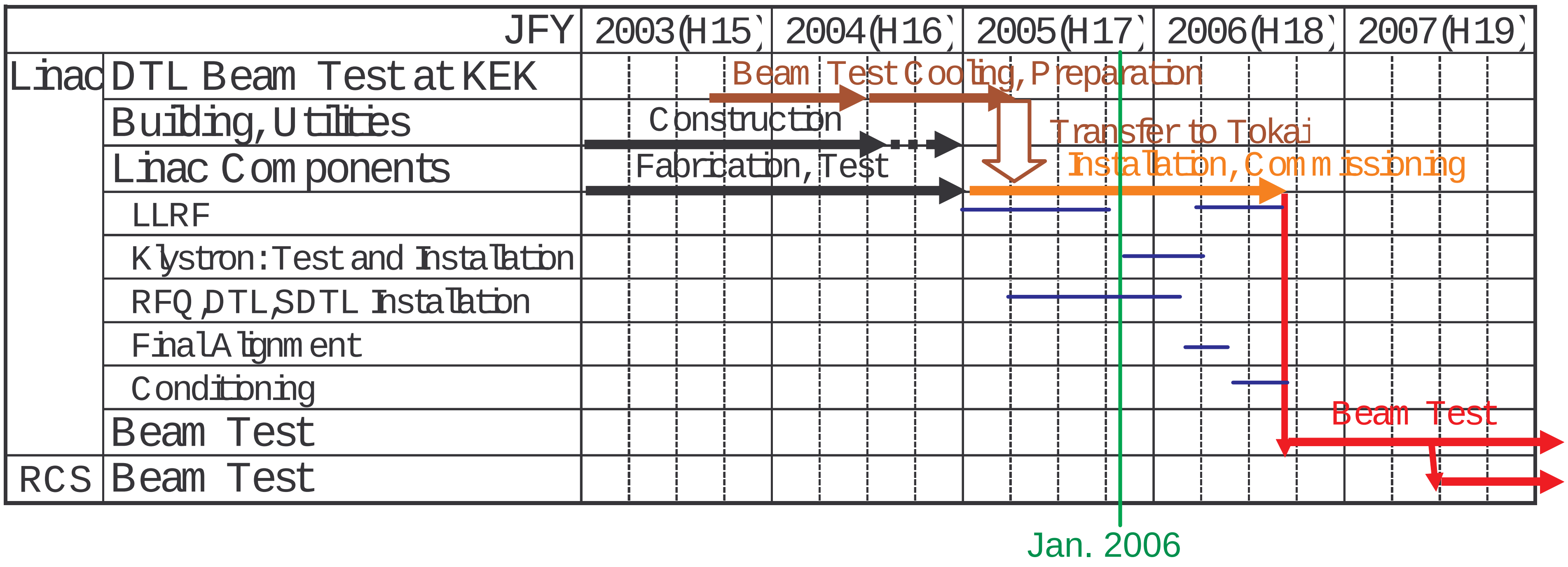
Slight delay than below would be expected.

Japanese Fiscal Year starts from April.

Schedule of the Linac

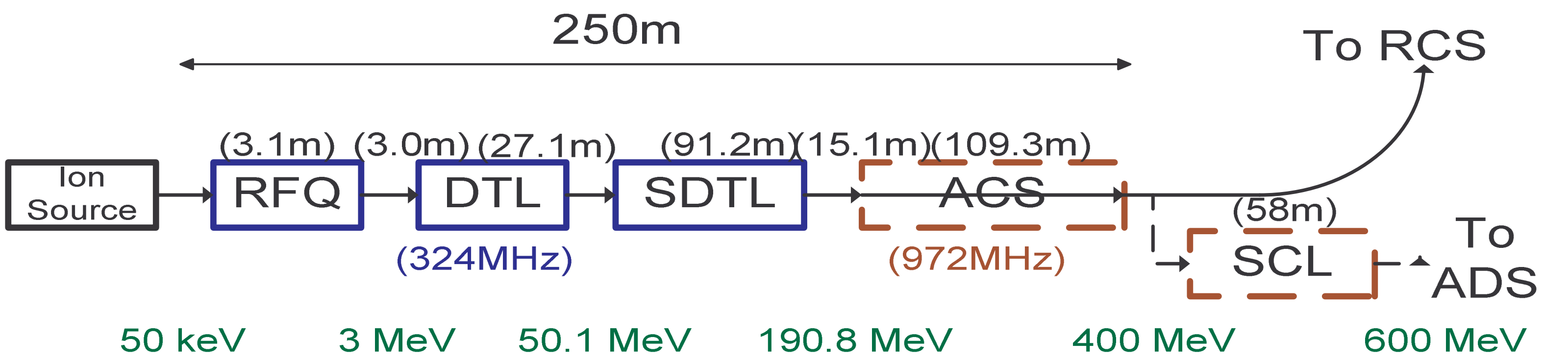
- Status
  - The linac building was accomplished and the machine installation is on the way.
  - Beam test will be started in December, 2006.

Linac commissioning schedule



Parameters of the Linac

- Major Parameters
  - Accelerated particles: H^- (negative hydrogen)
  - Energy: 181 MeV, The last two SDTLs are debunchers (400 MeV for ACS, 600 MeV for SCL)
  - Peak current: 30 mA (50 mA for 1MW at 3GeV)
  - Repetition: 25 Hz (additional 25 Hz for ADS application)
  - Pulse width: 0.5 msec



Block Diagram of the Linac

Features of the Linac

- Features of the J-PARC Linac
  - RFQ: pi-mode stabilizing loops were invented at KEK to eliminate any effects of the deflecting field
  - DTL: Electro-quadrupole magnets in the drift tubes are used to keep flexible knobs for the transverse tuning
  - RF Chopper: A newly devised RF deflecting chopper
  - SDTL: Short tank, no field stabilization necessary

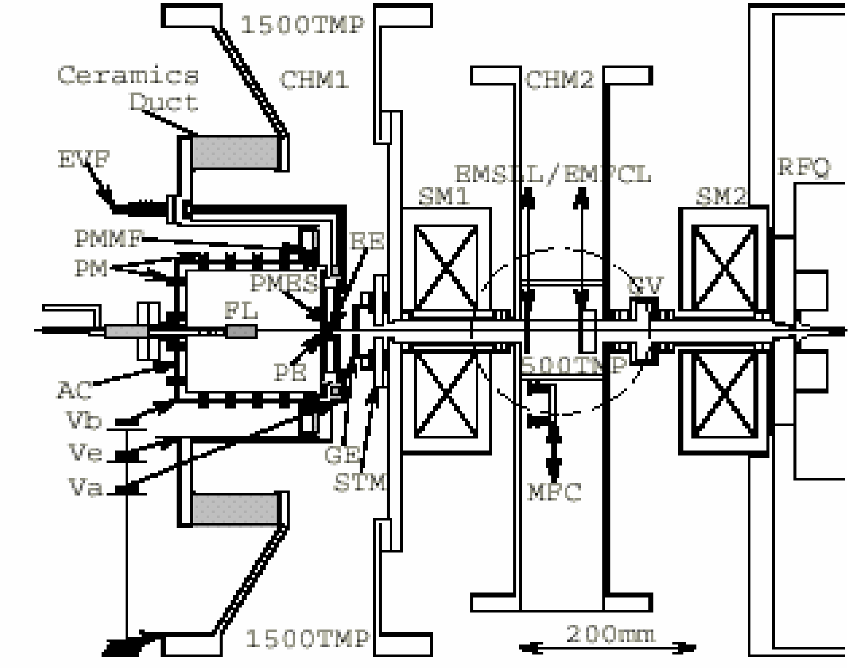
  And so on.

Ion Source and LEBT

Design parameters

Particle H-
Energy 50 keV
Beam Current > 35 mA
(60 mA for 1MW at 3GeV)
Emittance(rms) ~0.2πmm.mrad

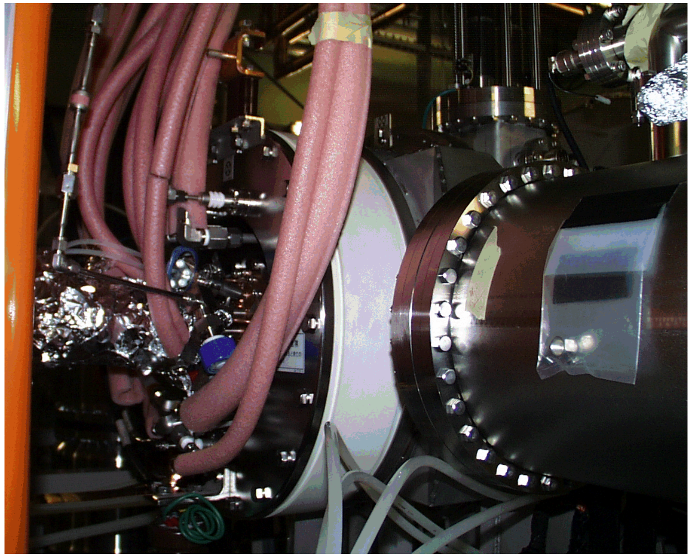
Ion Source at KEK

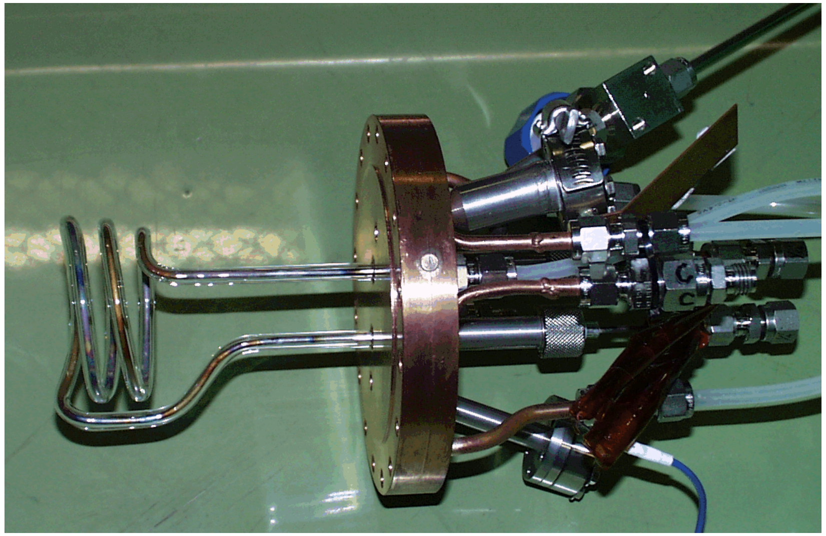


Volume-production type
Plasma chamber: 150X150ϕ
Arc discharge (LaB_6 filament)
Multicusp magnetic field
Aperture: 9mmϕ

Status (without Cs)
Beam current: 38 mA
Emittance: 0.4 πmm.mrad (90%)
Available at the DTL-1 commissioning.

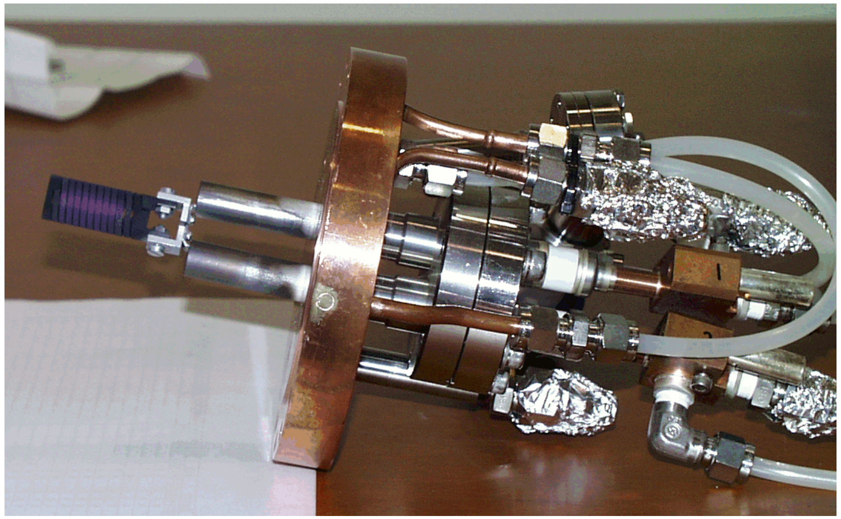
Ion Source at KEK



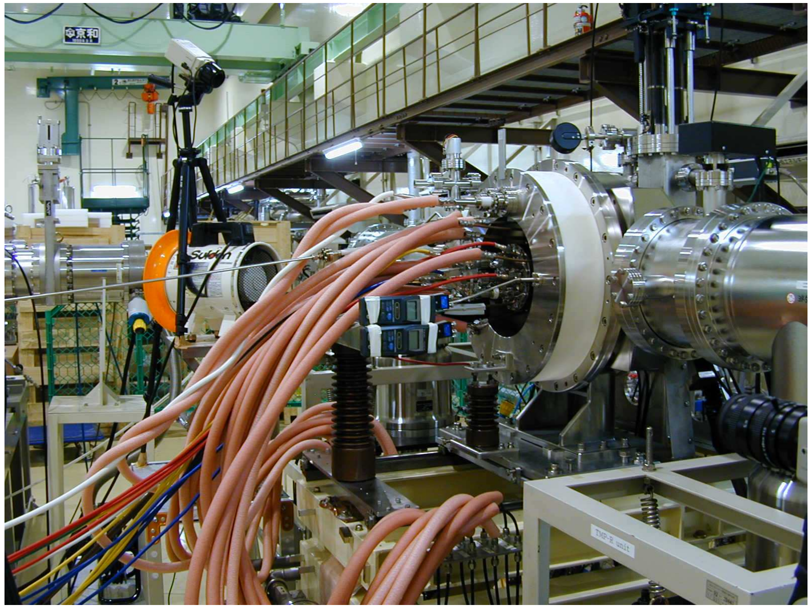


Ion Source at KEK

RF antenna (right top) or LaB_6 filament (right bottom) is available.



Ion Source at JAEA



Photograph of the J-PARC ion source

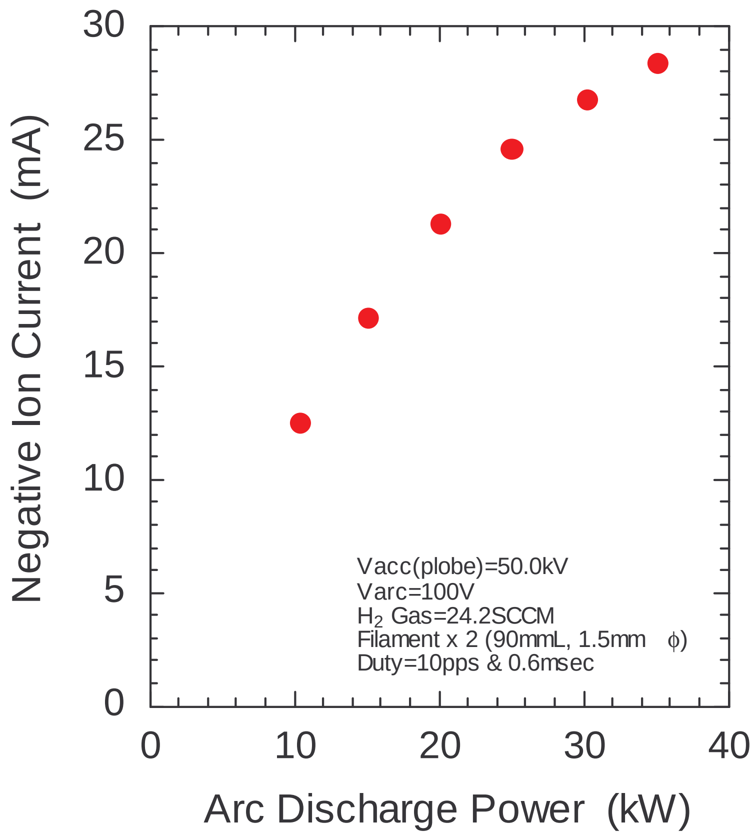
Volume-production type

Plasma chamber: 140X120ϕ

Arc discharge with W filaments (Less fluctuated beam current will be expected)

Multicusp magnetic field

Aperture: 9mmϕ



Negative ion current as a function of the arc discharge power (Without Cs)

This will be used at the linac commissioning.

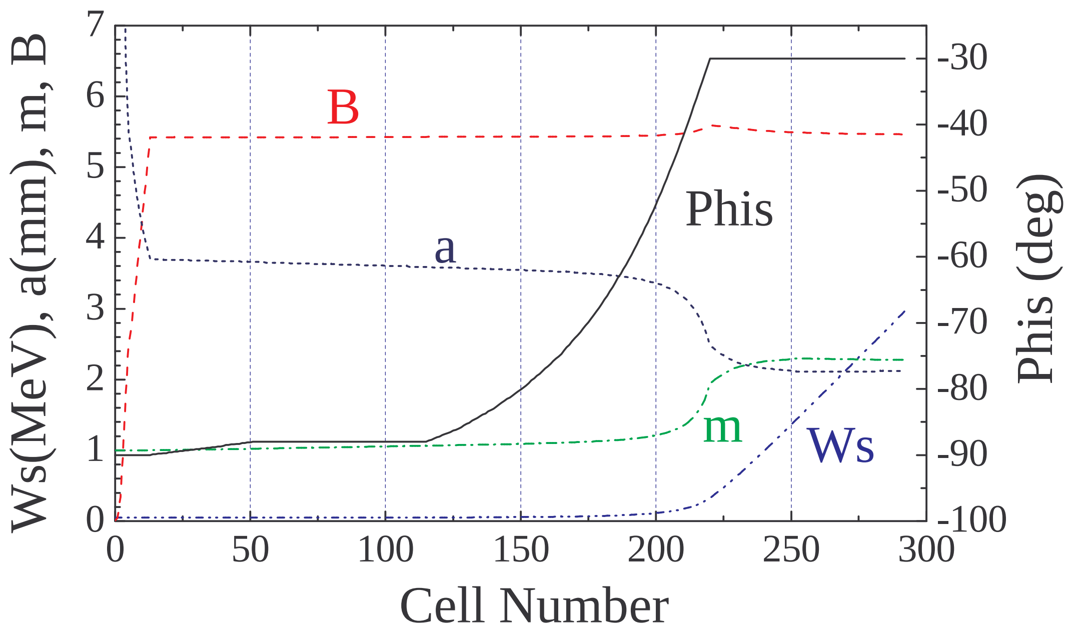
RFQ

Design features

- High ejection energy: 3-MeV
- π-mode stabilizing loop (PISL): to suppress dipole modes for long RFQ
- Cell parameters are designed with KEKRFQ code (by A. Ueno)
    - Gentle Buncher(ϕs=-88~-30deg):Constant Longitudinal Acceptance
      -> Low Longitudinal Emittance

RFQ Parameters (originally for JHF, but will be used at the linac commissioning)

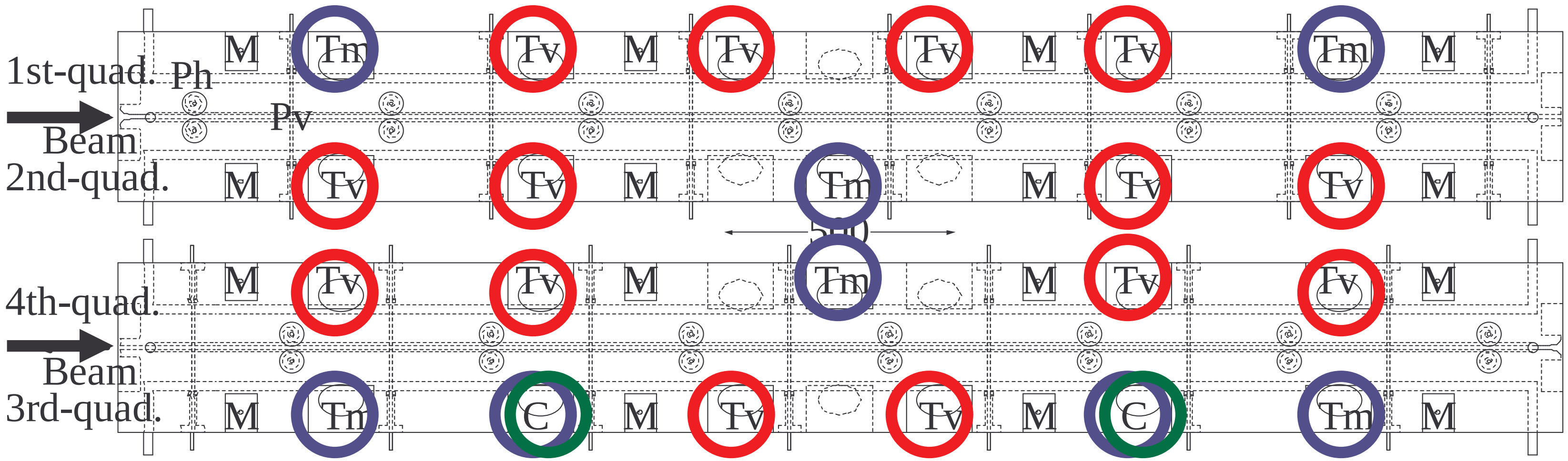
Energy	3 MeV
Current	30 mA
Frequency	324 MHz
Vane Length	3.115 m
Cell Number	294
Vane Voltage	82.9 kV
Maximum Field	1.77 Kilp
Average Bore	3.7 mm
Transmission	94.8% (I_{inj}=36mA)



Cell parameters of JHF-RFQ

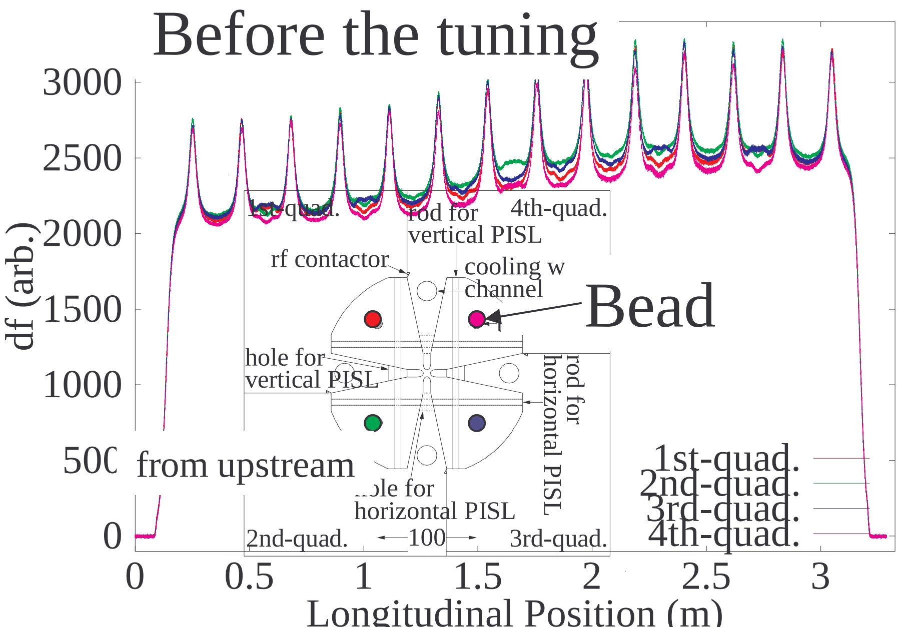
30mA RFQ Low-Power Tuning

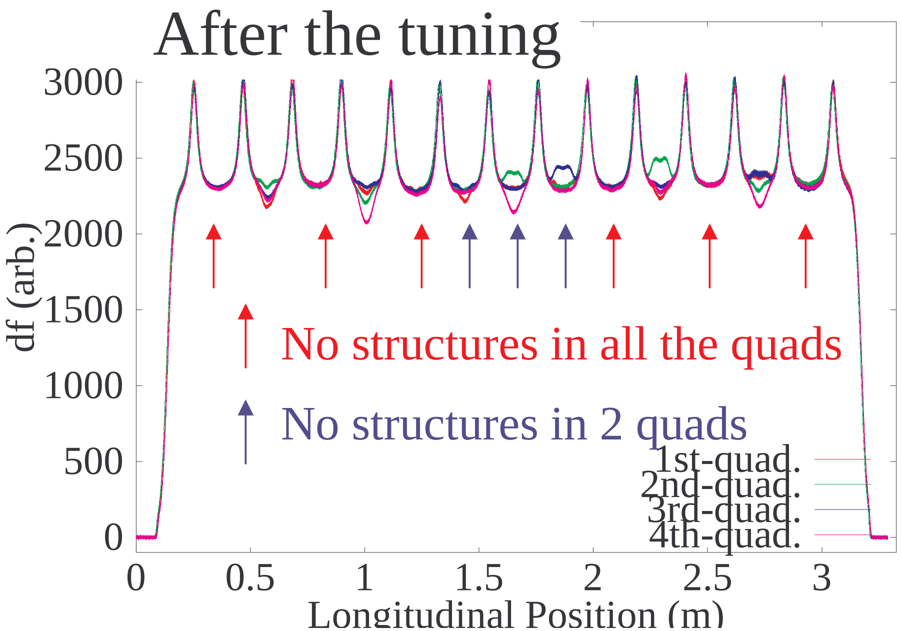
- The 30mA RFQ has 14 Fixed tuners with vacuum ports(Tv), 6 Movable tuners(Tm), and 2 Input Couplers(C).
- The field distributions and resonant frequency are tuned with 14 stub tuners with slits and 8 stub tuners without slits.
- Coupling is tuned to be 1.4 with 2 low power movable couplers installed instead of stub tuners without slits, keeping the field uniformity.

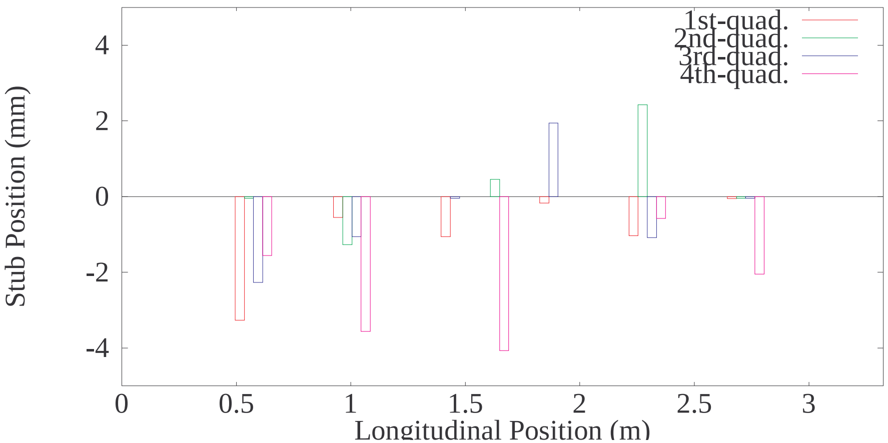


Ph : horizontal PISL, Pv : vertical PISL, M : rf-pick-up monitor, C : coupler
Tm : movable tuner, Tv : stub tuner with slits for vacuum pumping

Low Power Measurements of the 30mA RFQ

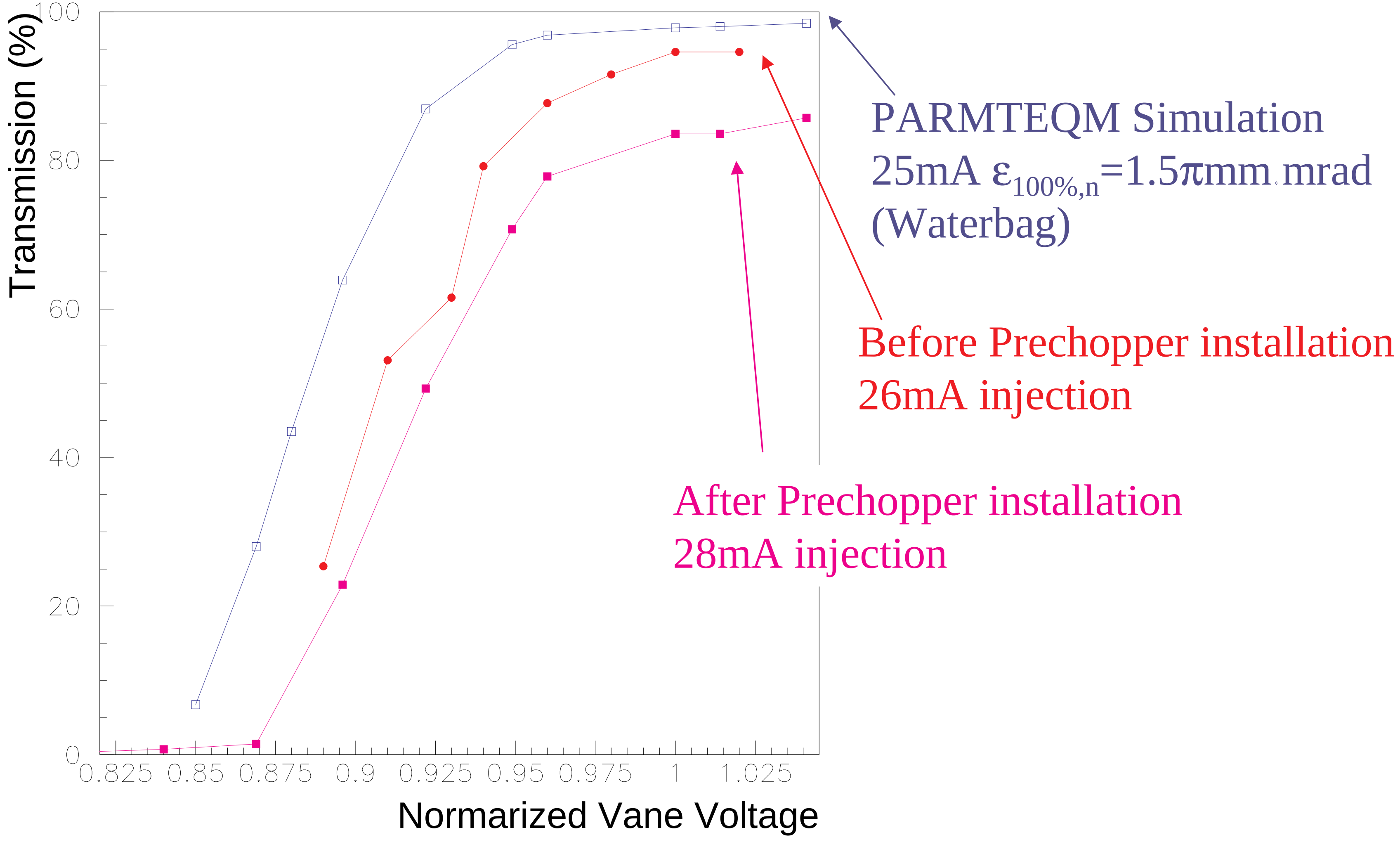






Frequency	323.9 MHz (equivalent to 324MHz in the vacuum)
Q-value	8960 (79% of the SUPERFISH calculation
Field uniformity	<0.6 %
Dipole mode separation	19.1 MHz

Beam Transmission of the 30mA RFQ

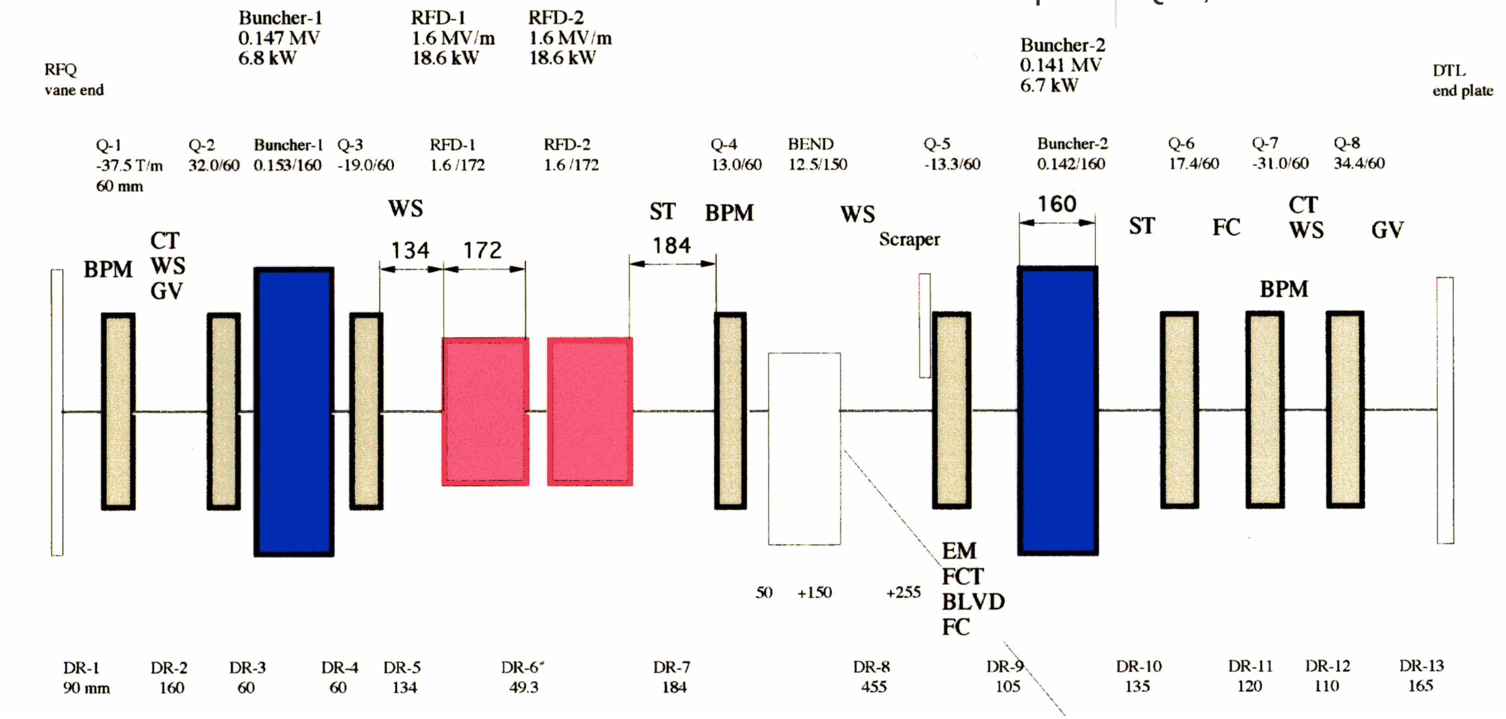


MEBT

Roles of the MEBT (Medium Energy Beam Transport)

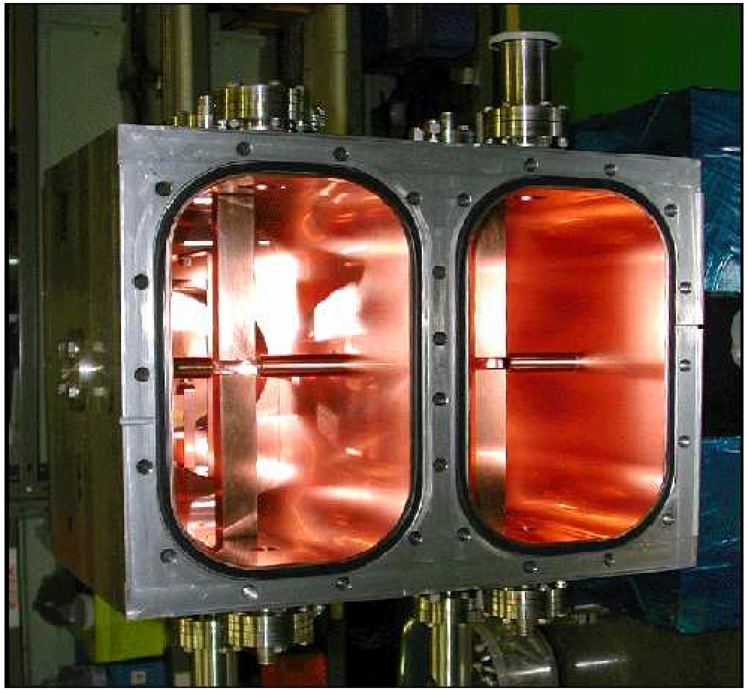
- To match between the RFQ and the DTL
  - Transverse: 8 Quadrupole magnets
  - Longitudinal: 2 bunchers, ~150kV
- To chop intermediate pulses: Newly devised RF deflector

Total Length: 2989.9mm
Normal beam size < 10 mm Deflected < 26 mm
Scraper at Q-5, r=9.5cm

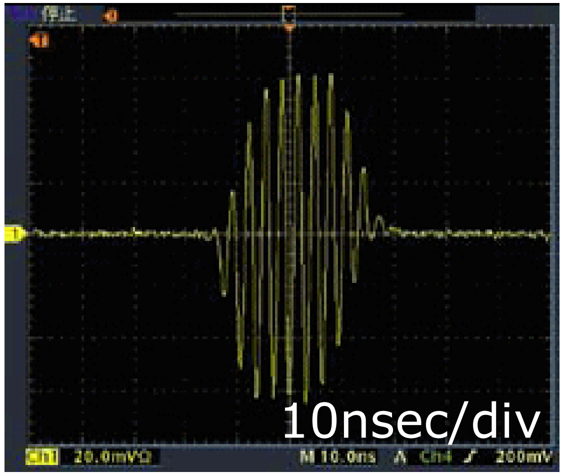


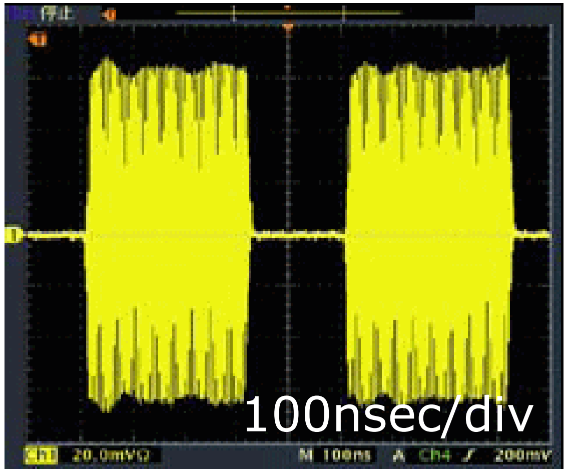
RF Chopper

- RF deflecting fast chopper
  - Frequency 324 MHz
  - Mode TE11, QL~11
  - Rise and Fall times: 15 nsec
  - RF power 36 kW(max)



Inside view of the deflecting chopper cavity





Signal of a chopped beam measured by a BPM

DTL and SDTL

Features

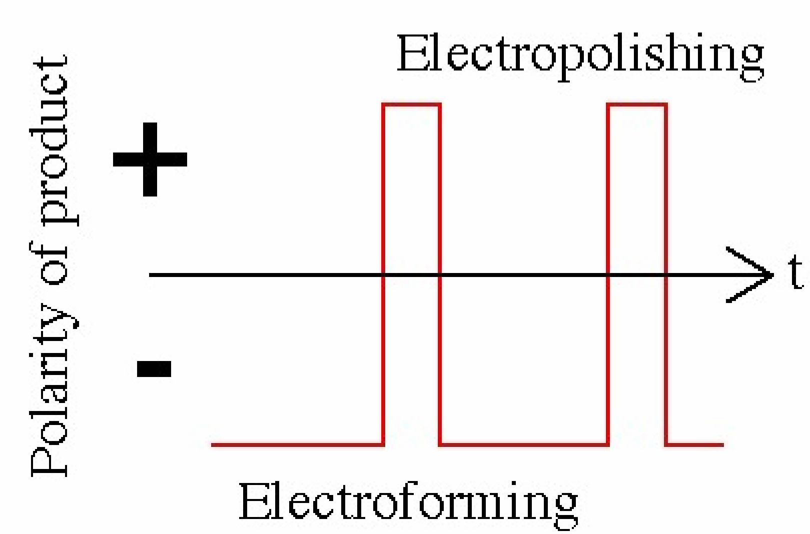
- Separated-type DTL (SDTL)
- New fabrication process: Tank and Q magnets are fabricated with periodic reverse (PR) electroforming

Parameters

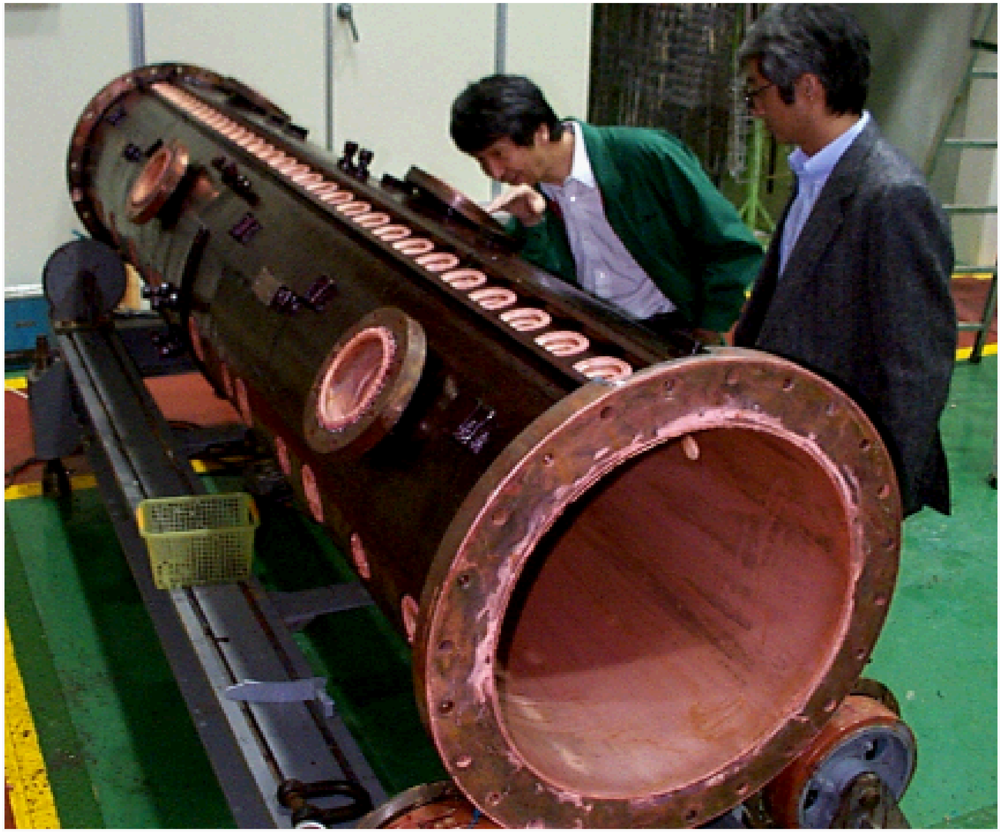
	DTL	SDTL	
Energy	3-50	50-190.8	MeV
Frequency	324	324	MHz
Section Length	27.1	91.2	m
Structure Length	26.7	66.7	m
Accelerating field,E0	2.5-2.9	2.5-3.7	MV/m
Number of Tanks	3	32	
Synchronous phase	-30	-27	deg
Copper RF Power	3.3	16.6	MW
Total RF power @50mA	5.7	23.6	MW
Number of Klystrons	3	16	
Aperture radius	6.5 - 13	18	mm
Number of cells	146	160	

PR Electroforming Tank of DTL and SDTL

We have developed a tank with periodic reverse (PR) electroforming:
Qmeas ~ 0.98 Qideal



(Test cavity : (-) 20 sec (+) 4 sec)



DTL1-1 after the PR Cu electroforming

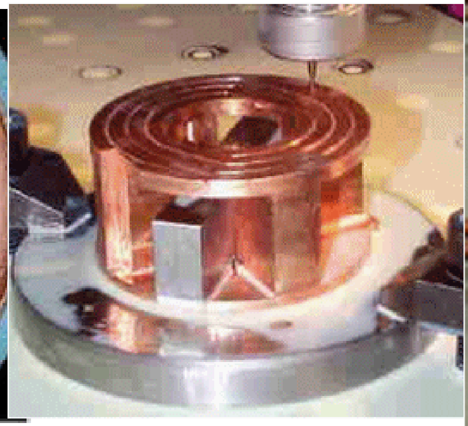
A smooth deposit is obtained by periodically reversed current using a low copper-content acid copper sulfate bath containing no organic additives.

Electro-Quadrupole Magnets in DTL

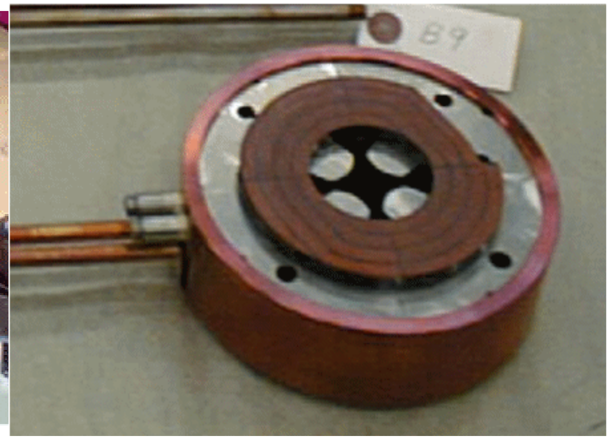
- Compact Electro-Quadrupole Magnets are key points of the J-PARC DTL: 3-MeV injection, 324-MHz DTLs
  - The technology was newly developed for minimizing the size of the coils with water-cooling channels
  - Compact(14cm dia.DT) & High duty factor

Grooves and through holes for water channel

The surface is electroformed.



Forming the coil by cutting.

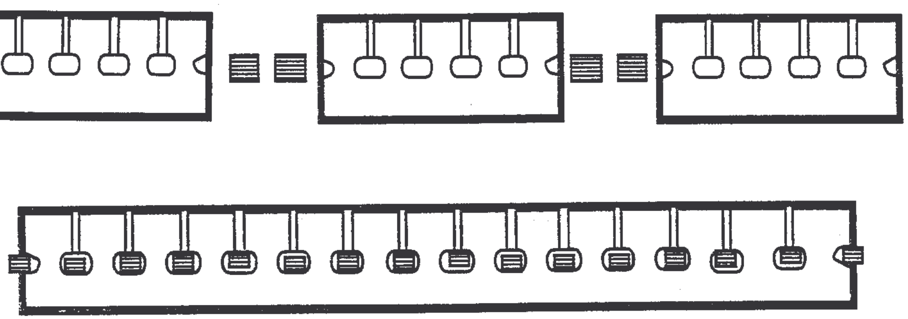


Assembled Q-magnet.

SDTL

Features of the SDTL (Separated-type DTL)

- No Q-magnets in drift tubes
  - Simpler structure
  - Shunt impedance optimization
  - Reduction of the tolerance in alignment of DT and Tank
- Short tank length
  - Stable accelerating field without post couplers
- Separation of the transverse and the longitudinal transition
  - Prevent an abrupt transition and degradation of beam qualities

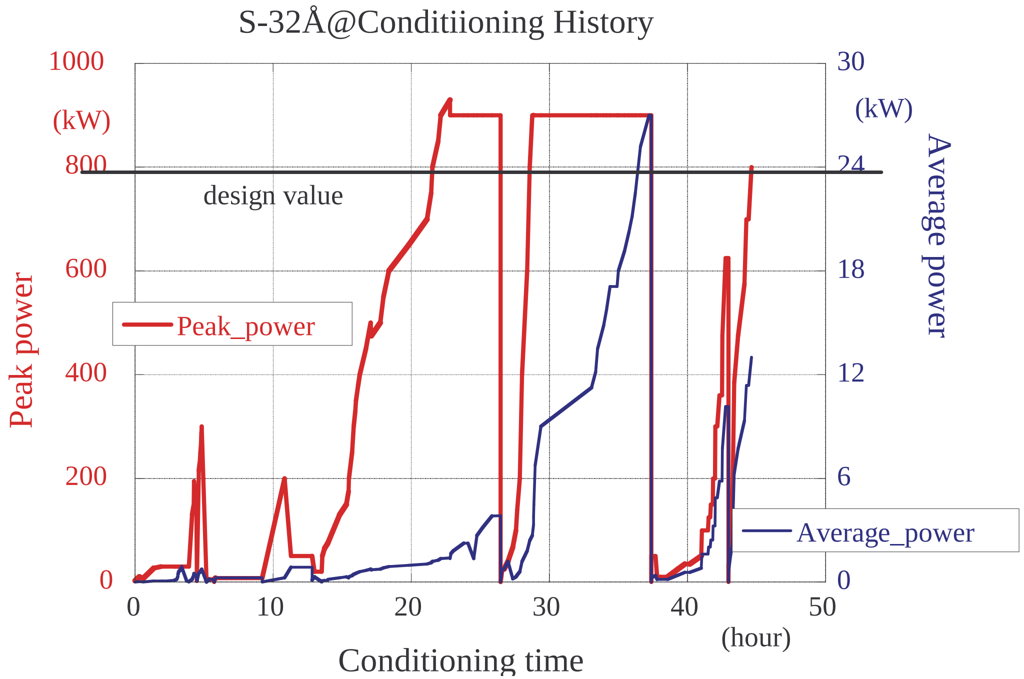


SDTL(upper) and DTL(lower) structures.
The focusing magnets are shown by squares.

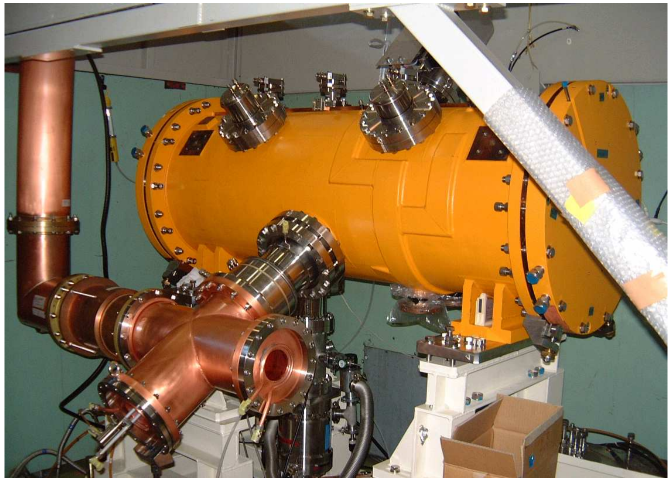
Test Results of SDTL

Separated-type DTL

50-190 MeV acceleration with 32 tanks



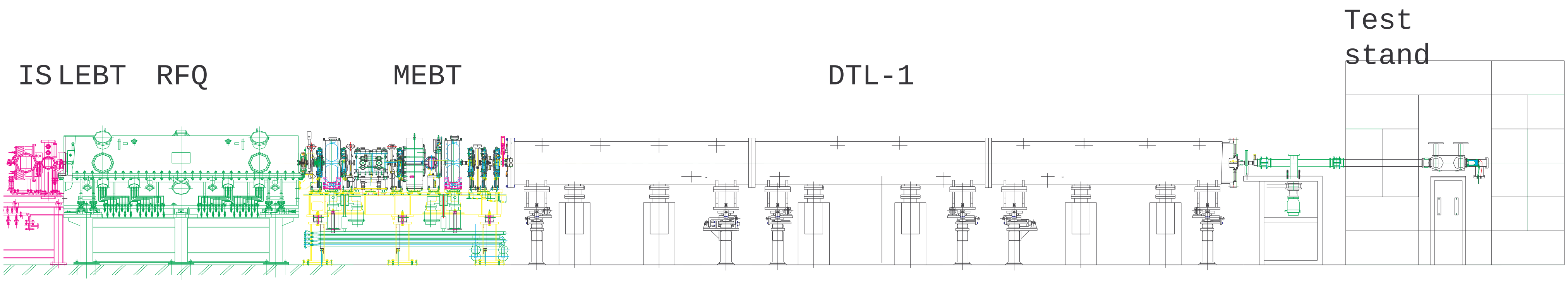
High-power conditioning history of the SDTL#32, the longest cavity.



DT assembling (top) and setting up in the high-power test area (bottom)

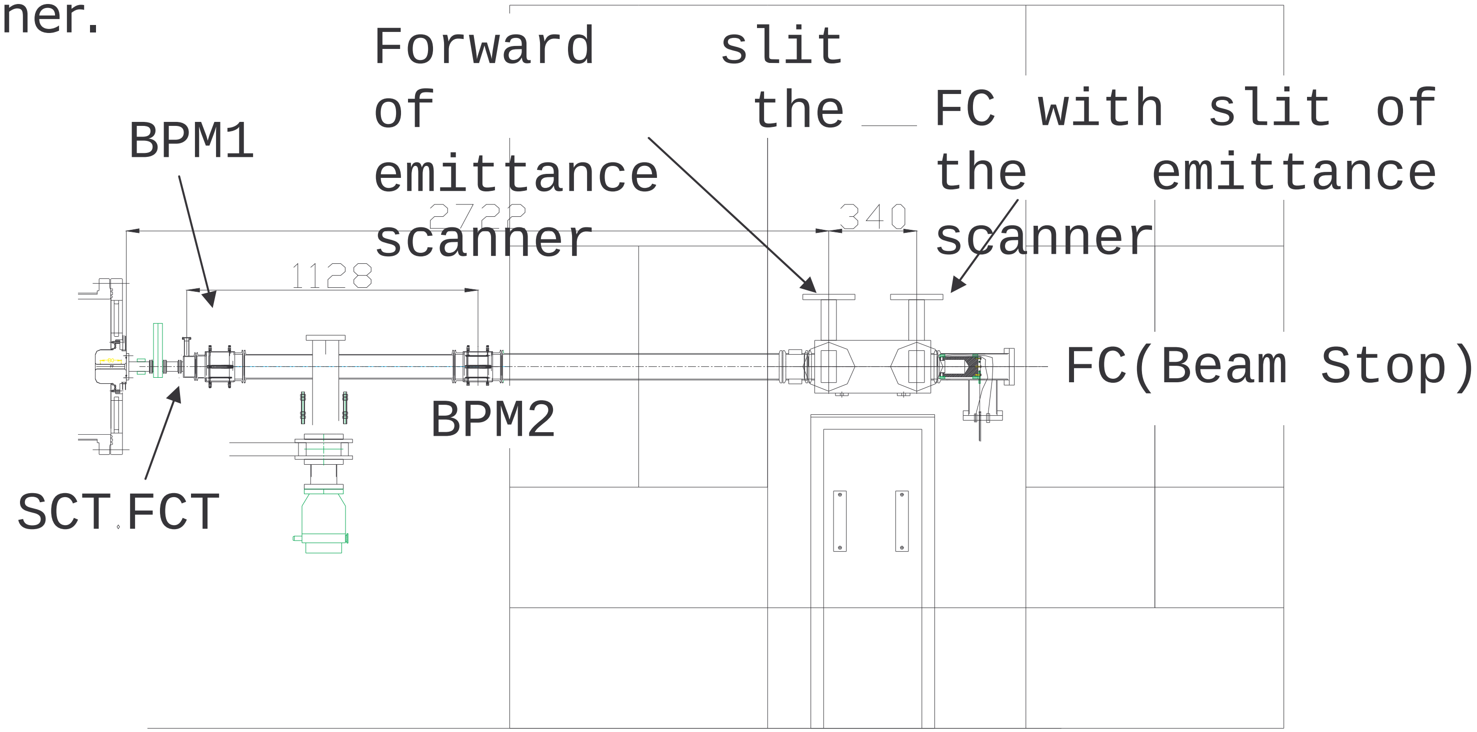
Beam Commissioning of DTL-1

- The DTL consists of 3 tanks (50MeV). The first tank (DTL-1, 19.7MeV) have been commissioned by September, 2004 at KEK.
  - DTL-1: 76 acceleration cells (77 Q-magnets)
  - Typical beam: 5mA, 50μsec, 5, 25Hz (for monitor study)
    30mA, 50μsec, 5Hz (for DTL study)
    30mA, 250μsec, 25Hz (for MEBT study)
  - cf. J-PARC Linac initial phase1 requirement:
    30mA, 500μsec, 25Hz

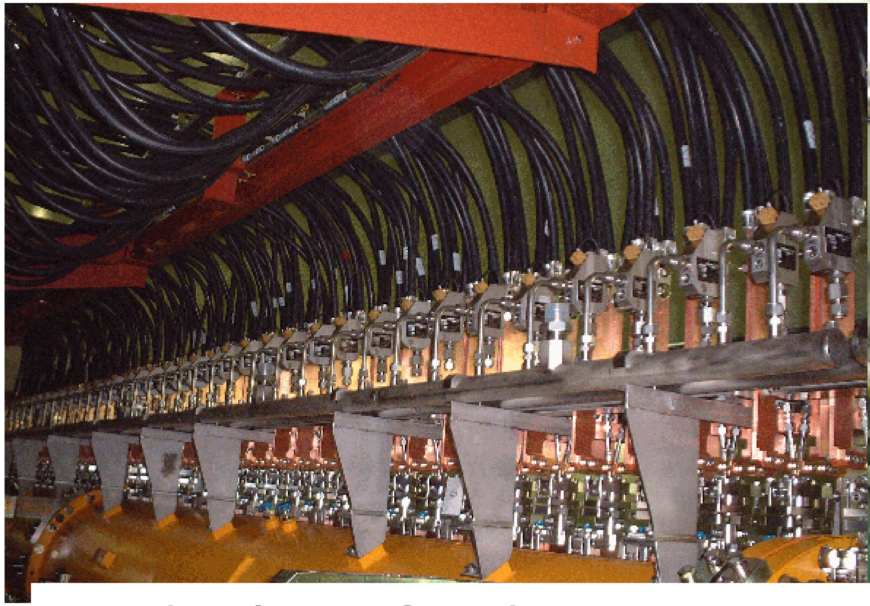


Diagnostics for the DTL-1 Beam Experiment

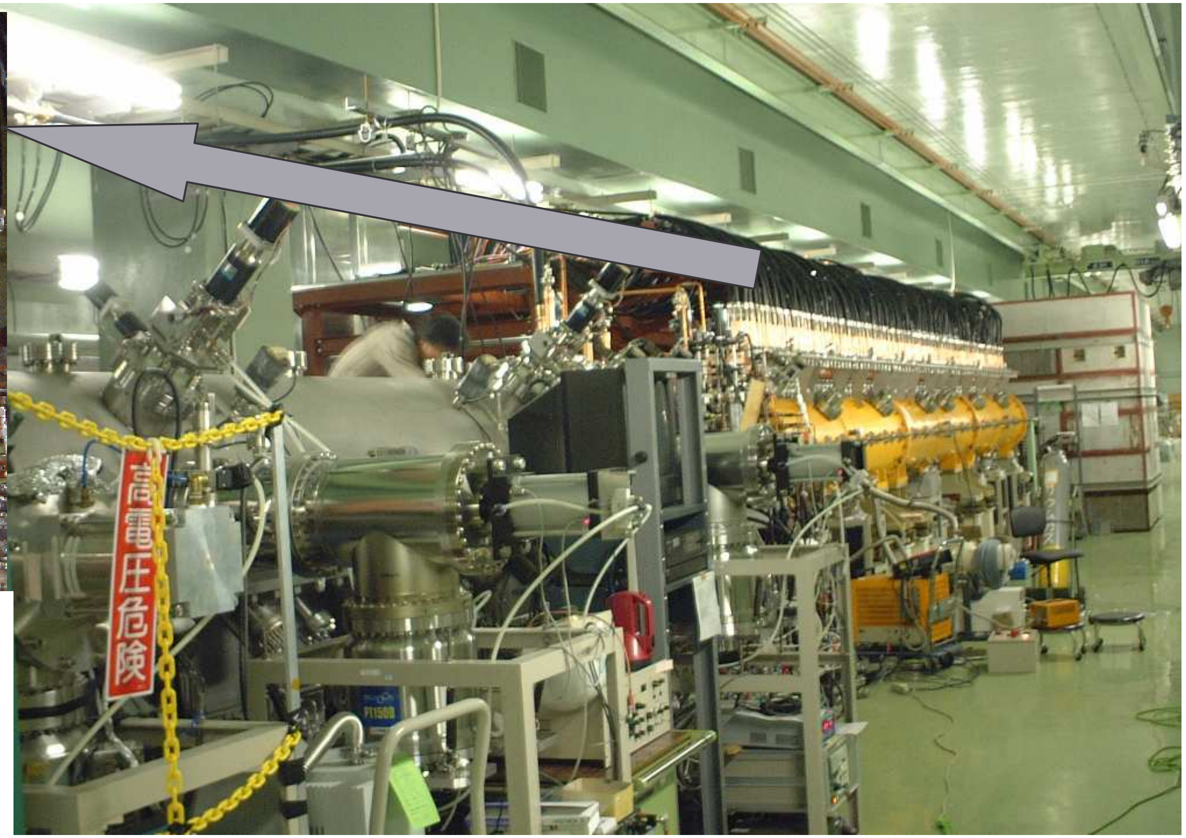
- Beam current is measured with a SCT (Slow Current Transformer) and a FC (Faraday cup).
- Beam phase at the DTL1 exit is measured with a FCT (Fast CT).
- Beam energy is measured by the Time of Flight (TOF) method with the FCT and a BPM (Beam Position Monitor).
- Beam position and angle are measured with two BPM's.
- Beam emittance is measured with a double slit type emittance scanner.



Beam Commissioning of DTL-1



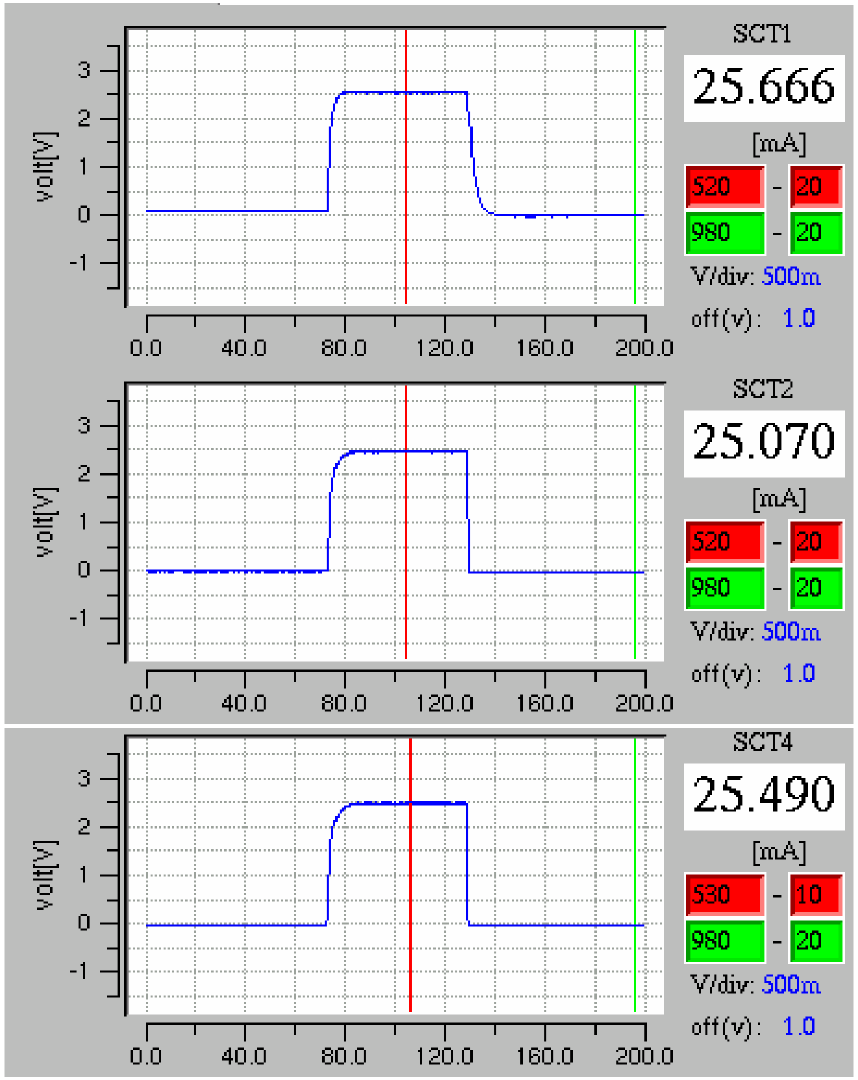
Feeder lines for the Q-magnets



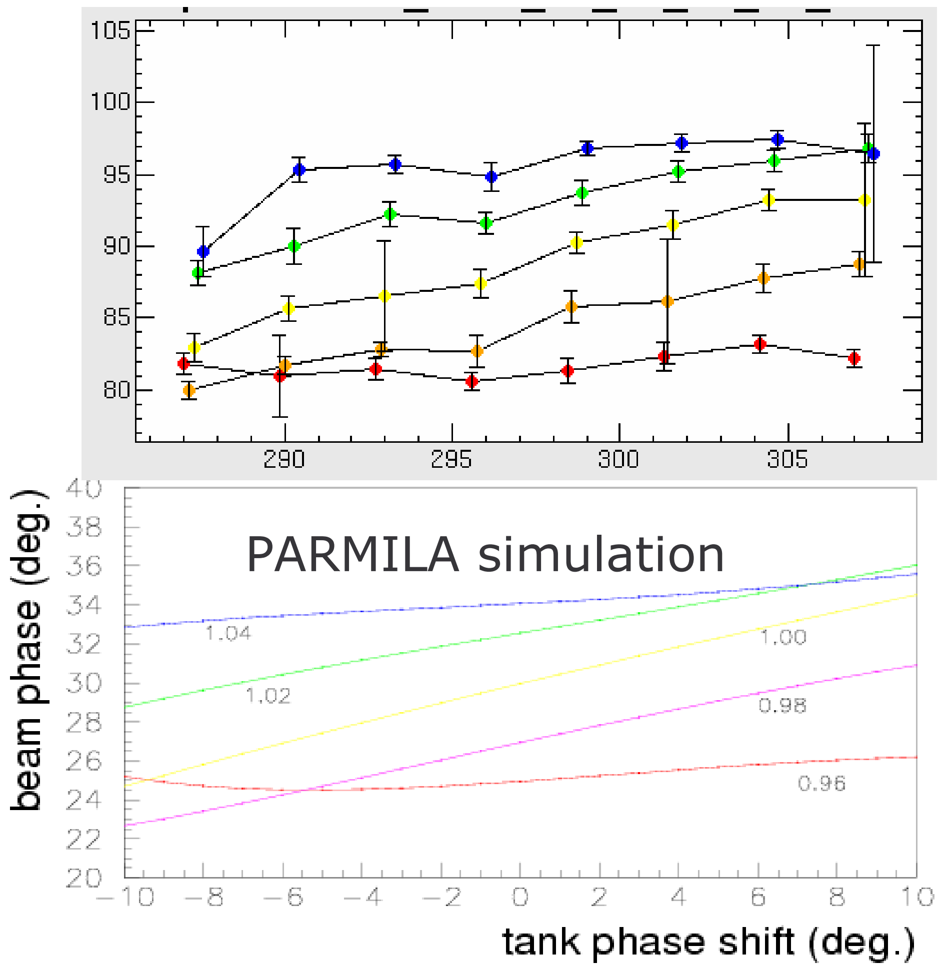
Photograph of the RFQ and DTL-1 (orange cavity) at KEK.

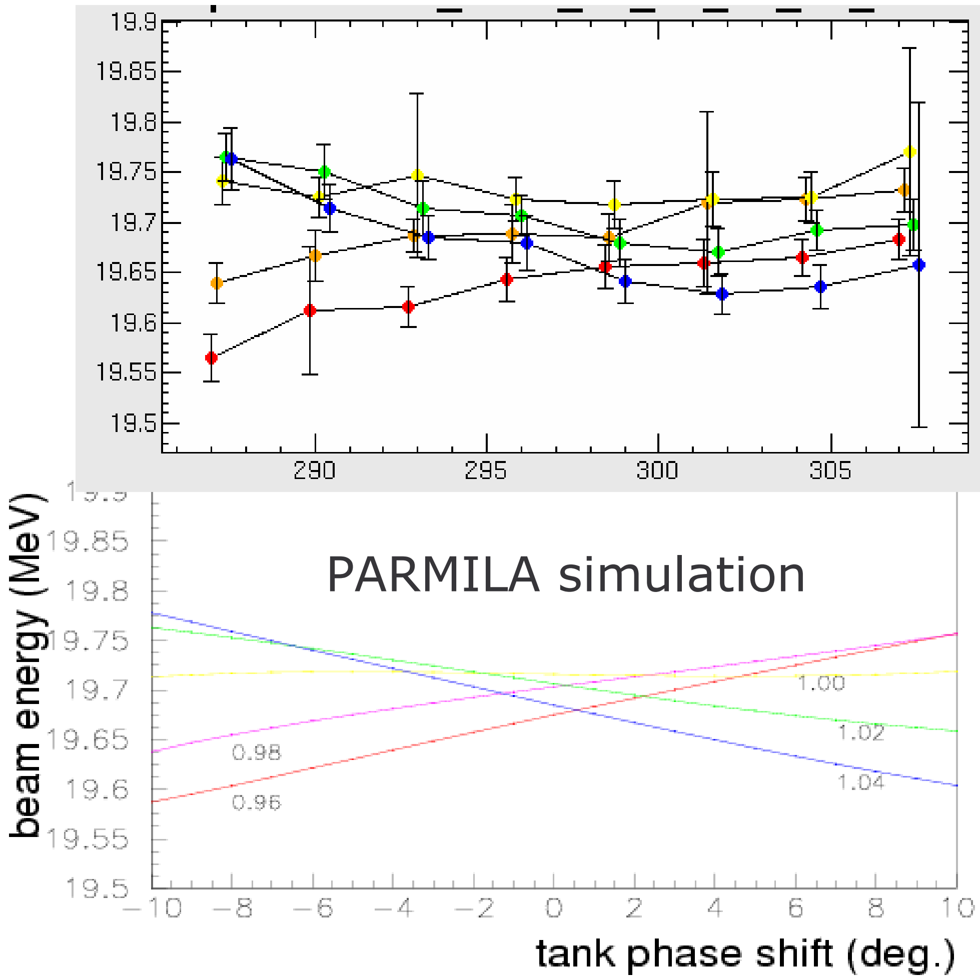
DTL-1 Transmission

- Beam current waveforms at the exits of the RFQ (top), the MEBT (middle), the DTL-1 (bottom)
- 50μsec,5Hz
  (duty 0.025%)
- Transmission through DTL-1:100%



Phase-Amplitude Scan



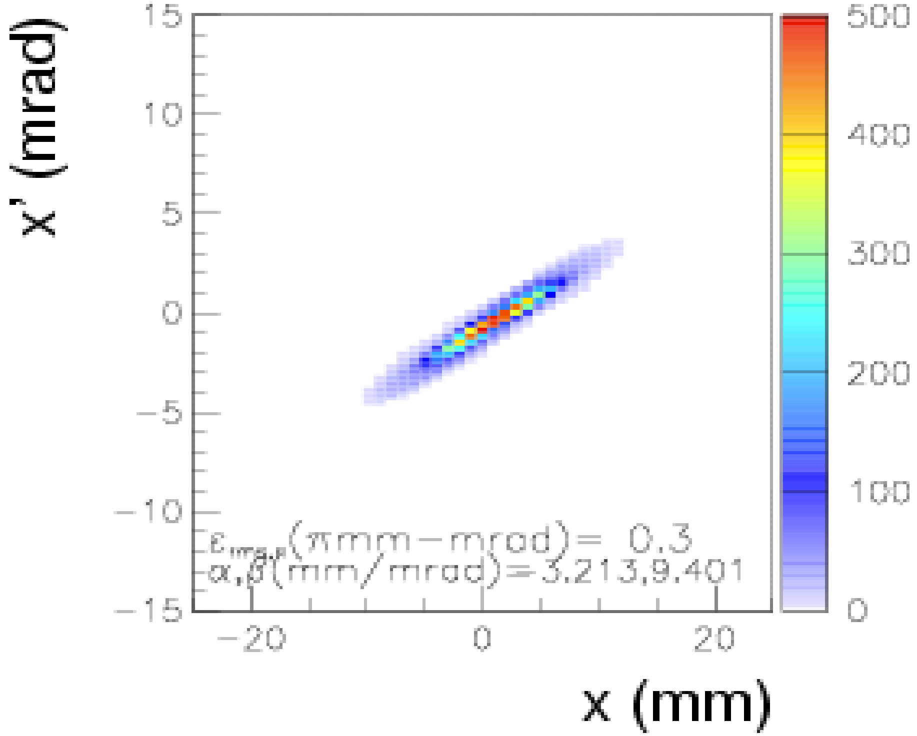


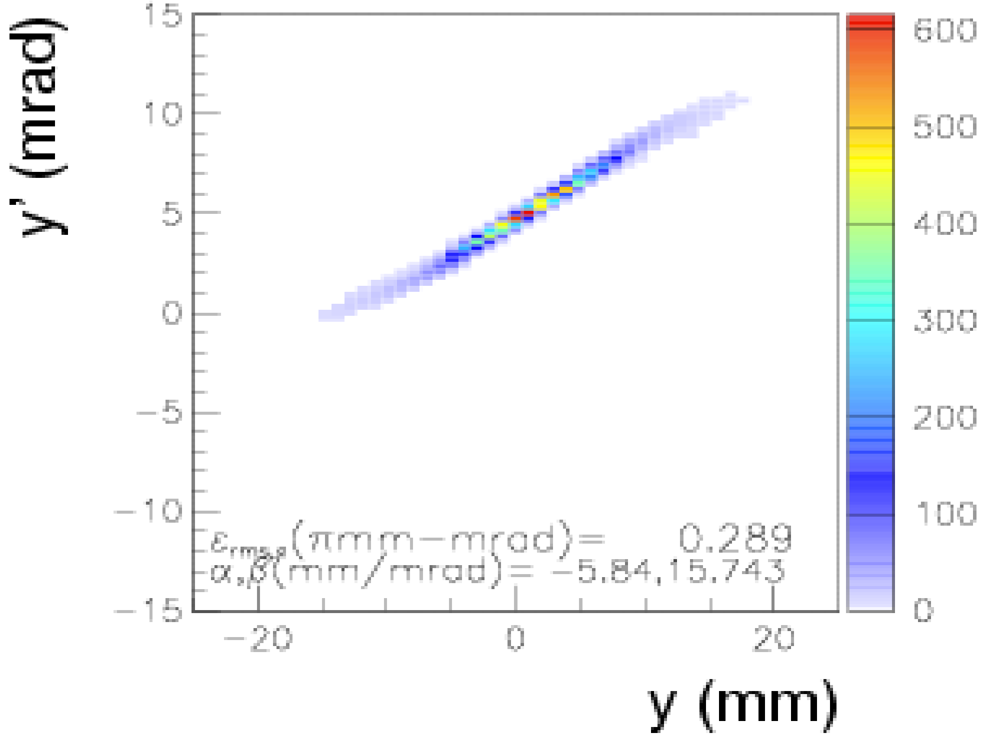
Phase-amplitude scan curves: beam phase measured with FCT (left) and energy measured by TOF (right).

1%, 1-deg set point accuracy is achievable

Transverse Emittance after the DTL-1

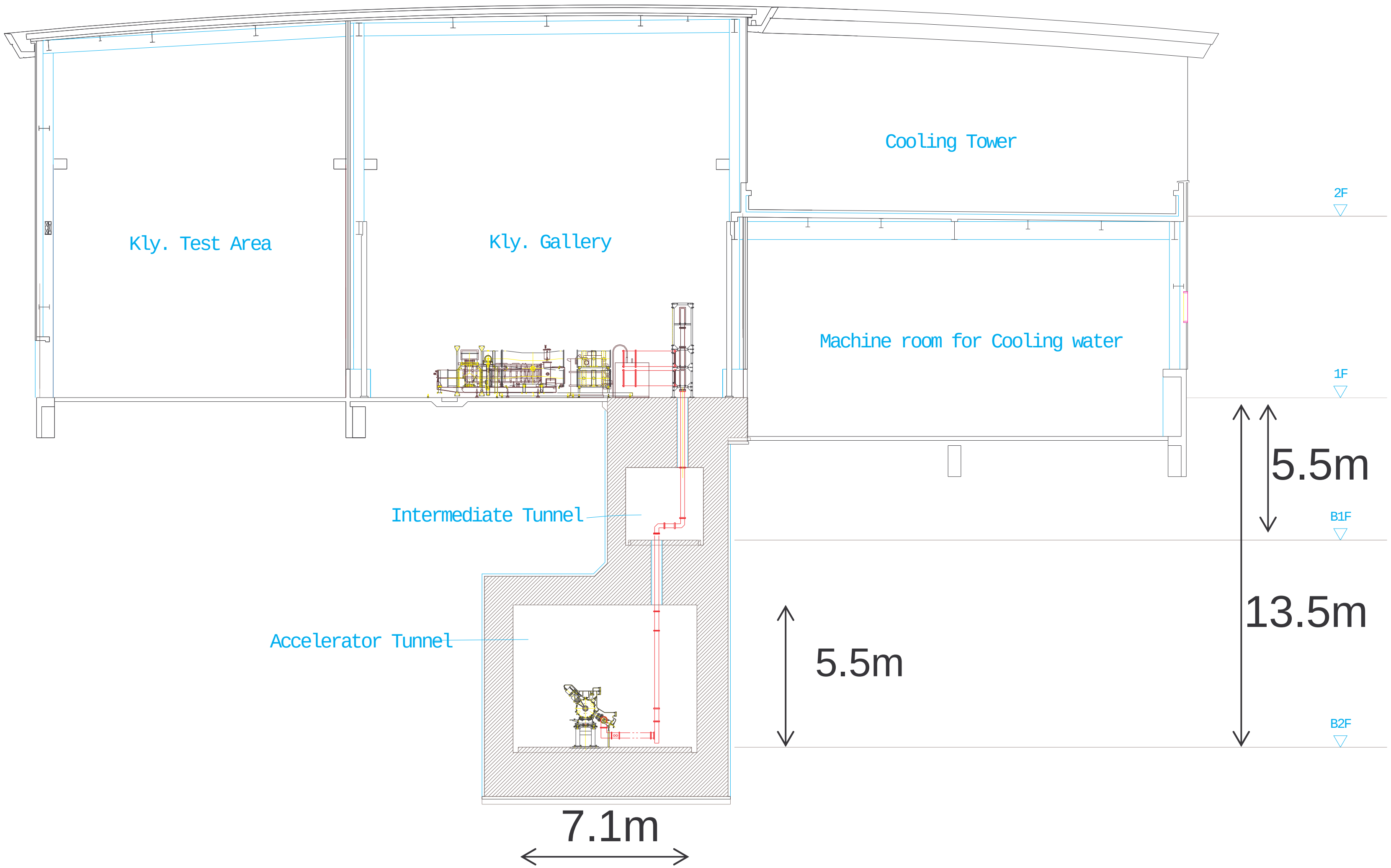
- Transverse emittances measured with double slit emittance scanners
  - Measured 0.3π (X) and 0.29π-mm-mrad (Y) (rms,norm.)
  - Reference 0.25π (X) and 0.26π-mm-mrad (Y) (rms,norm.)



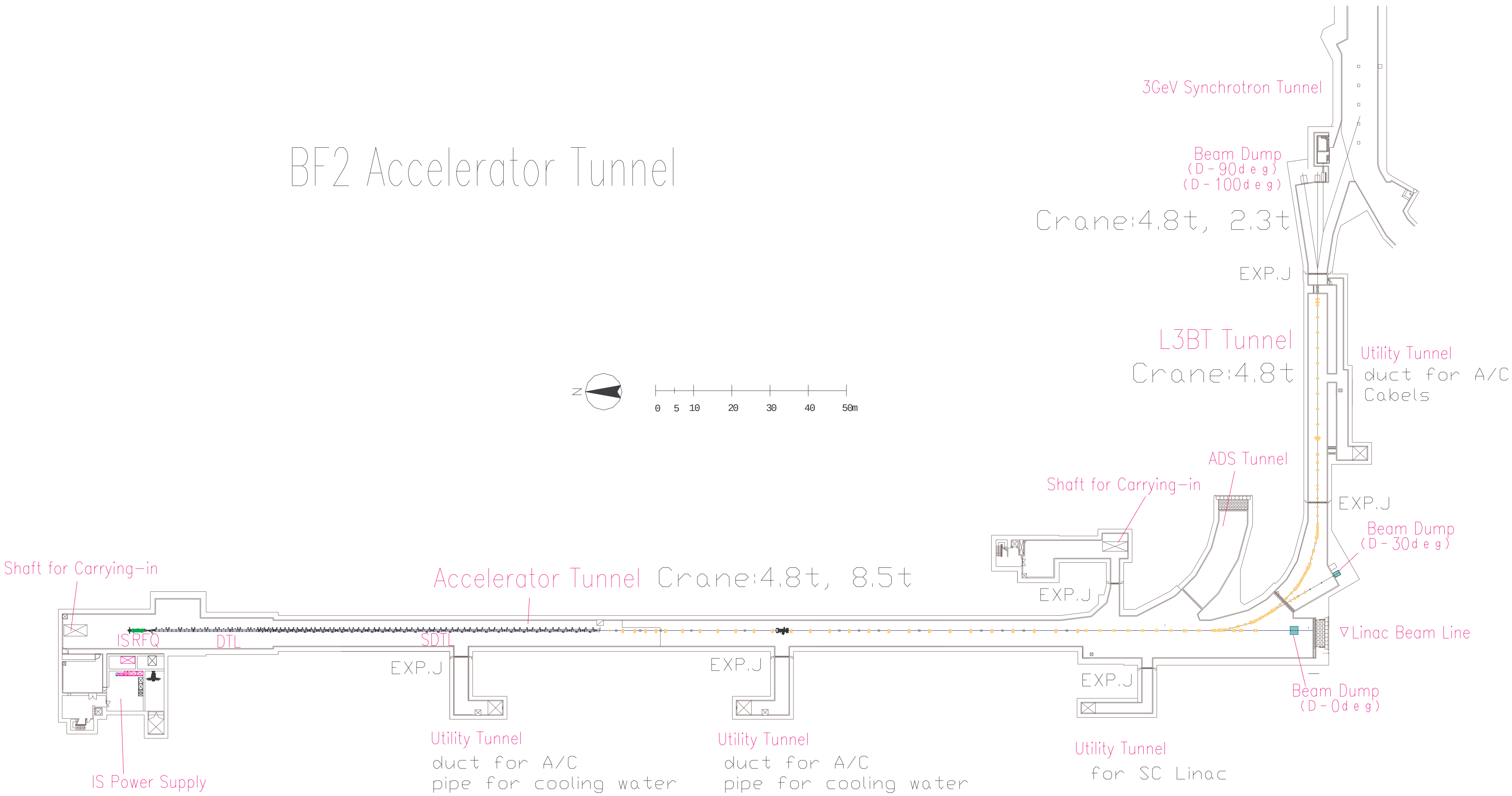


Linac Building Design

Typical Cross Sectional View



Layout in the Linac Tunnel



Layout on the 1st Floor Level

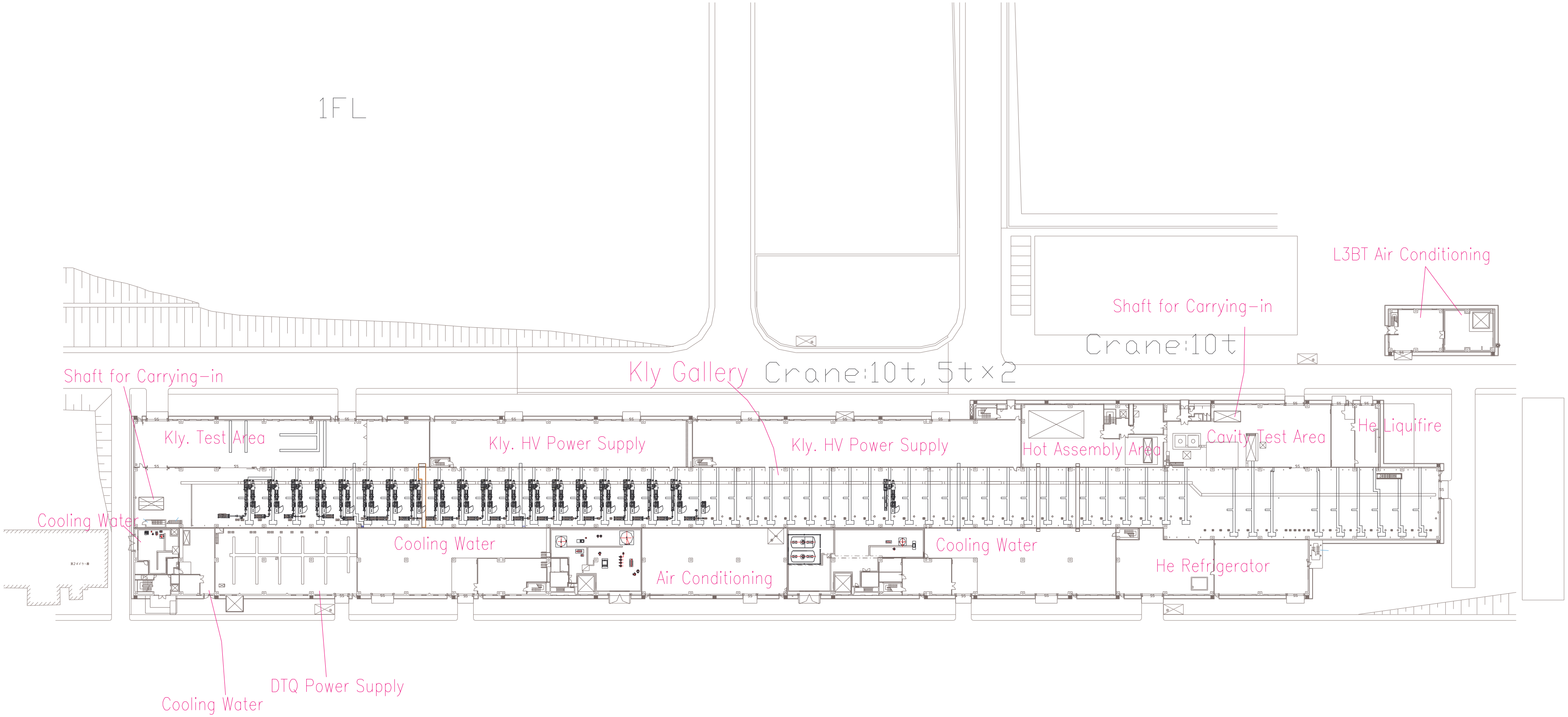
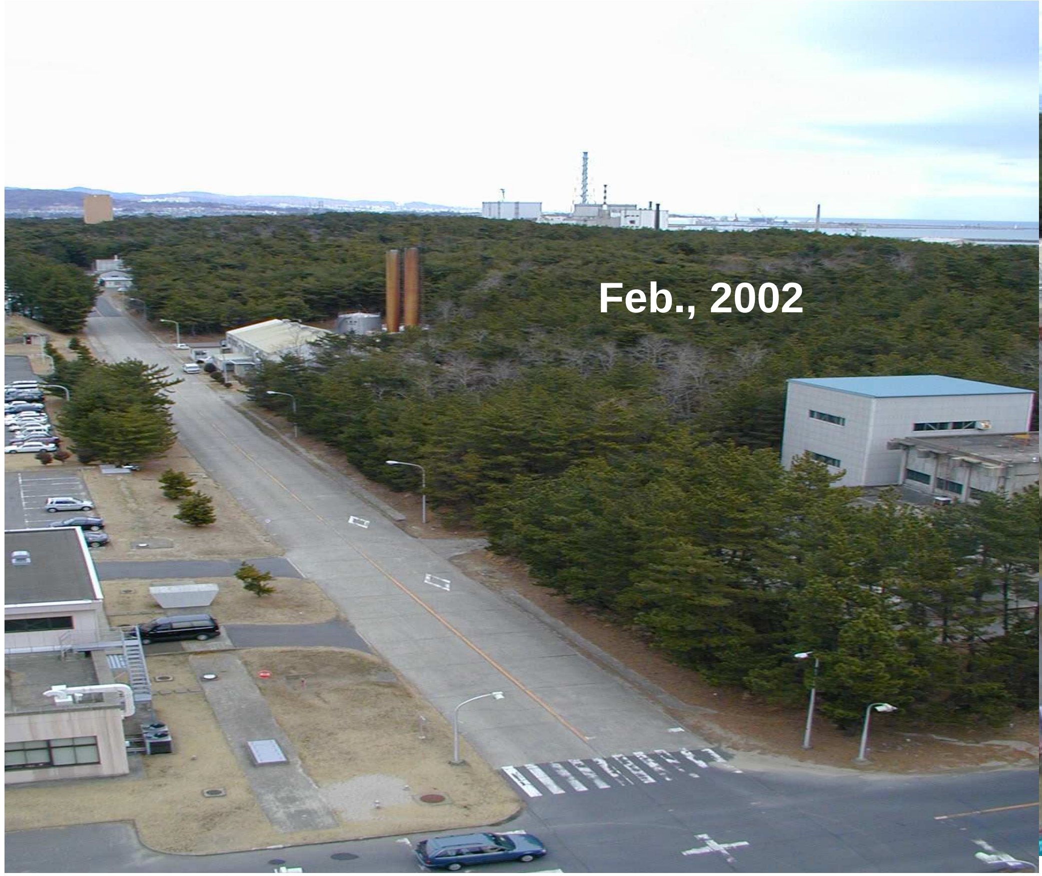


Photo Gallery of the J-PARC Linac

Linac Building



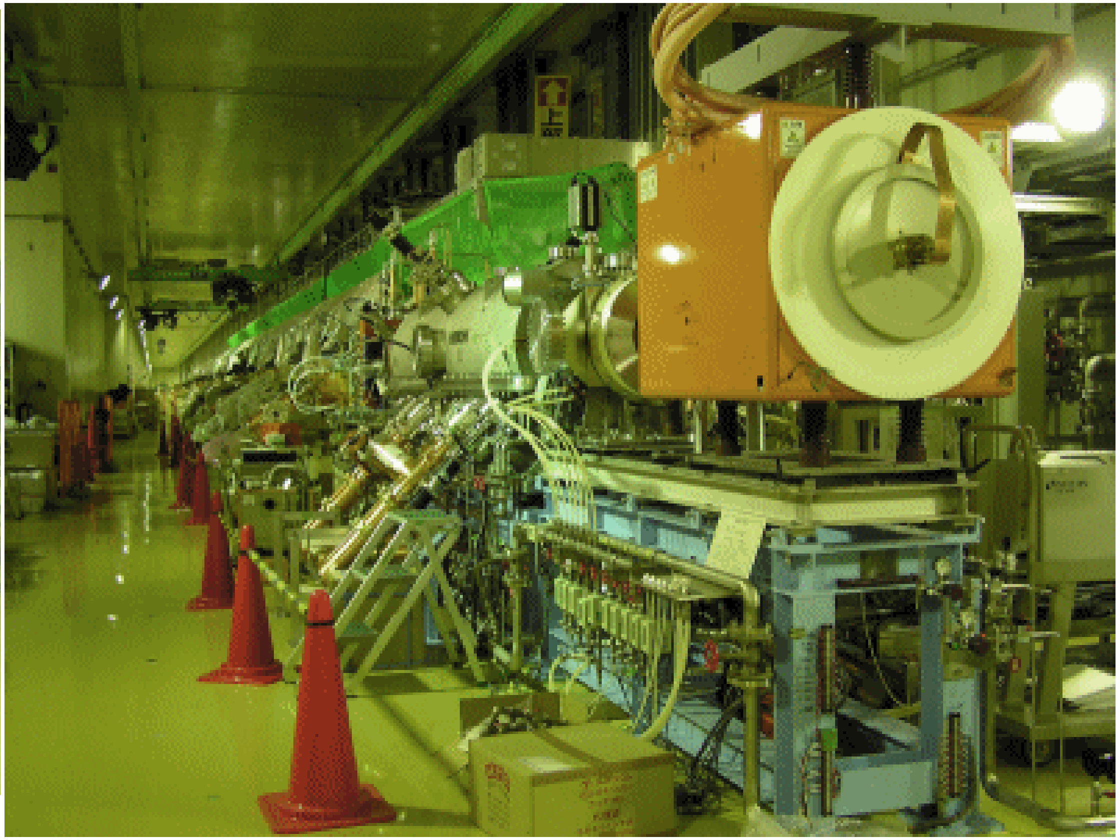
The change of a scenery around the linac area.

Linac Building

The building was accomplished in April, 2005.

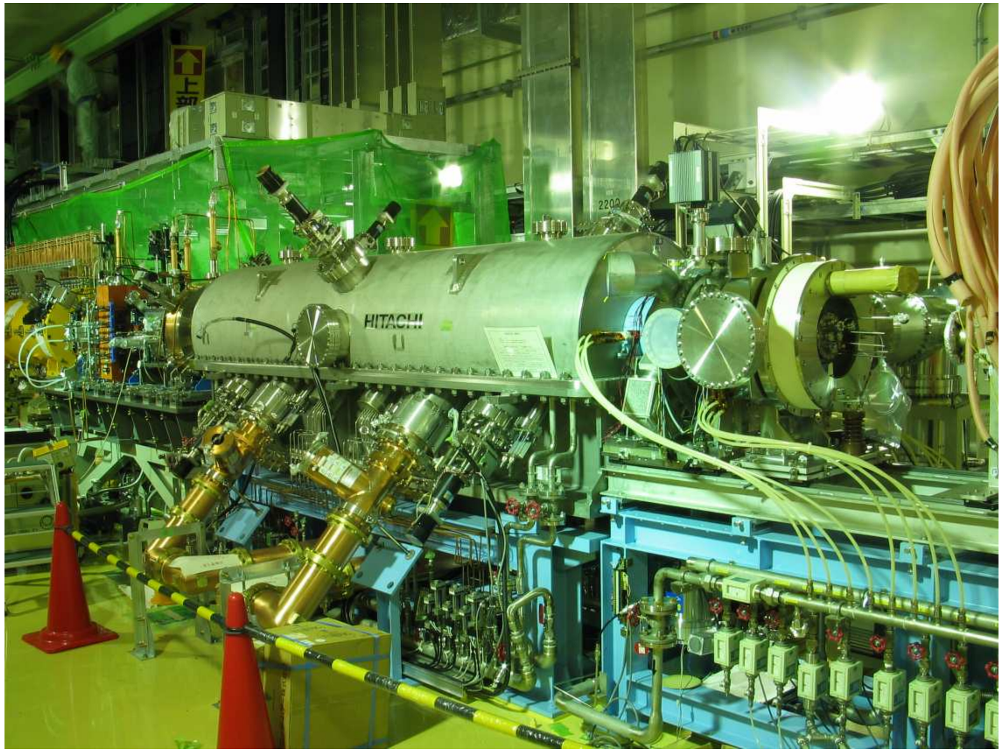
Linac Tunnel (Front End)

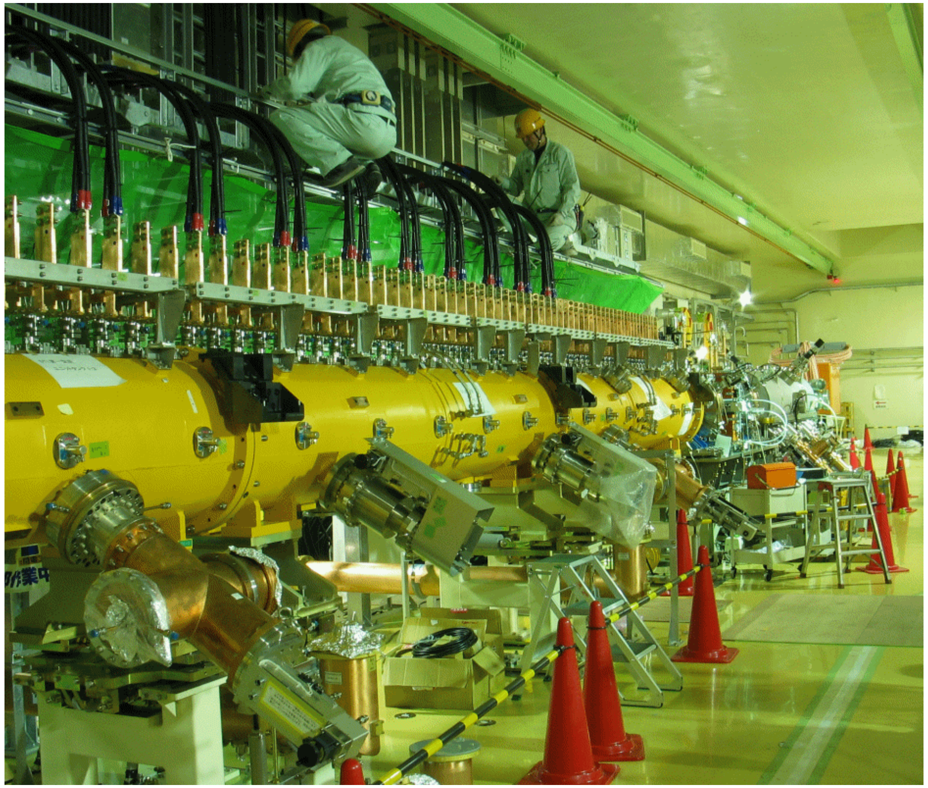
May, 2005



January, 2006

Linac Tunnel (RFQ and DTL)

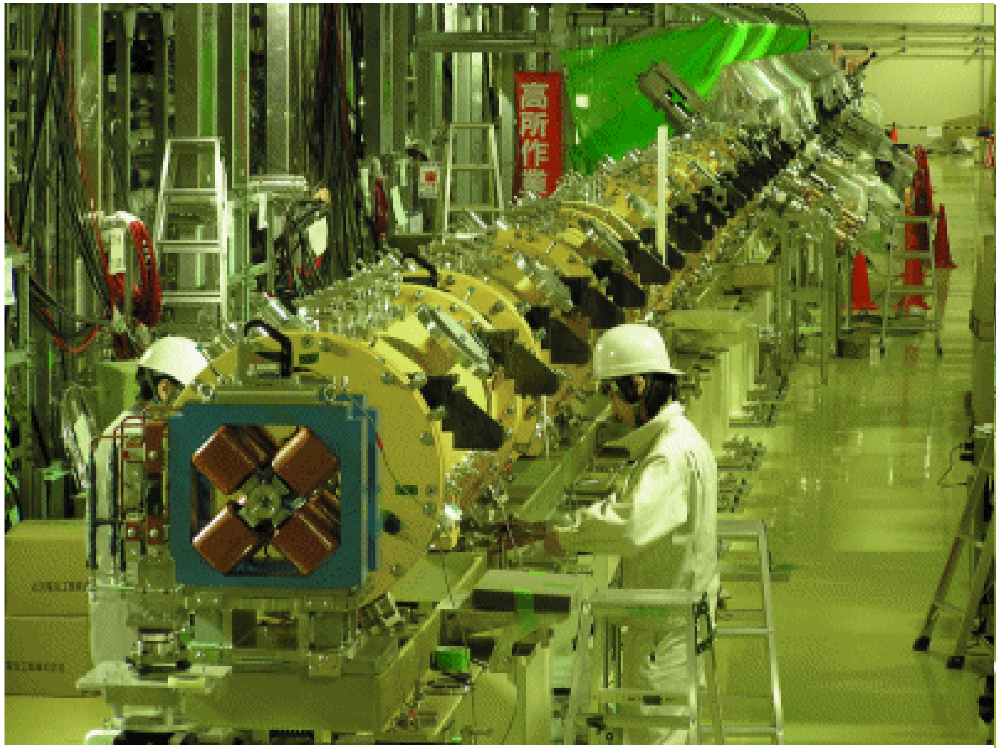




Ion Source, RFQ and MEBT

DTQ feeder connection

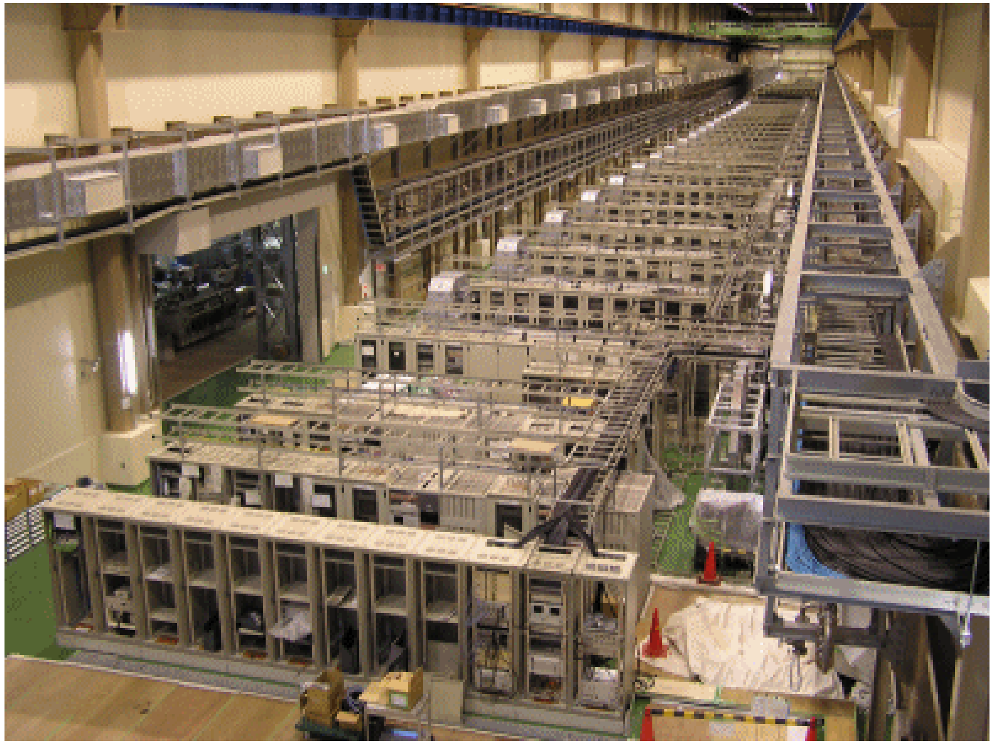
Linac Tunnel (SDTL and BT)

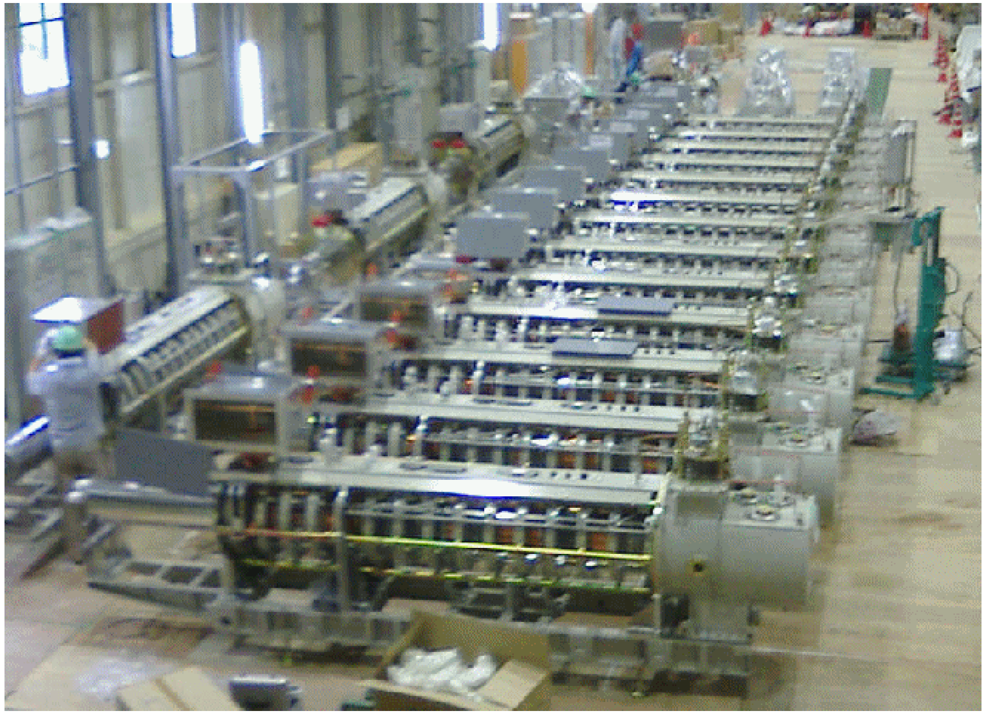


Installation of the SDTL

Arc section from the Linac to the RCS

Klystron Gallery





Klystron Gallery
Many 19-inch rack cabinets have been installed.

324-MHz Klystrons
After the conditioning, they will be installed at each station.

RF Source

324-MHz waveguide (left) and Klystron test stand for two units (right)

1(RFQ)+3(DTL)
+15(SDTL)
+1(Debuncher)=20

Component	# of Need	# of Stock	Evaluating (Long Run)	Vendor
Klystron	20 unit	24 (incl. prototype)	5 unit	TOSHIBA
Tr AMP	4 units	4	3 unit	NEC
KLY DCPS	6 set	6	2 set	HITACHI
Modulator	20 unit	20	5 unit	HITACHI
Circulator	20 unit	20	5 unit	NIHON KOSHUHA
Wave guide	24 set	24	2 set	FURUKAWA
LLRF	24 set	24	0 set	THAMWAY

Status of the RF source

R&D for upgrade

We have some upgrade plans and R&D is under way.

- RFQ: 30mA -> 50 mA
  (for 0.6 to 1.0 MW at 3GeV)
  high-current and high-duty design

- ACS (Annular Coupled Structure): 200 -> 400 MeV
  (for higher injection energy at the RCS)

- SCL (Superconducting Linac): 400 -> 600 MeV
  (for tests of Accelerator Driven Nuclear Transmutation application)

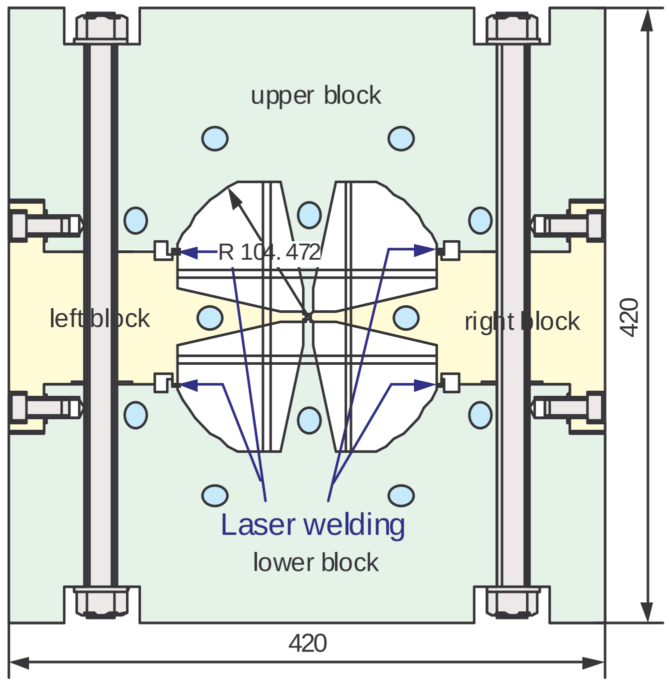
50 mA-RFQ: Design

Features of the 50 mA-RFQ

- Optimized for 50 mA and high duty operations
- Integrated type by using a laser beam welding: the weld seals the RF contact and the vacuum

50 mA-RFQ parameters

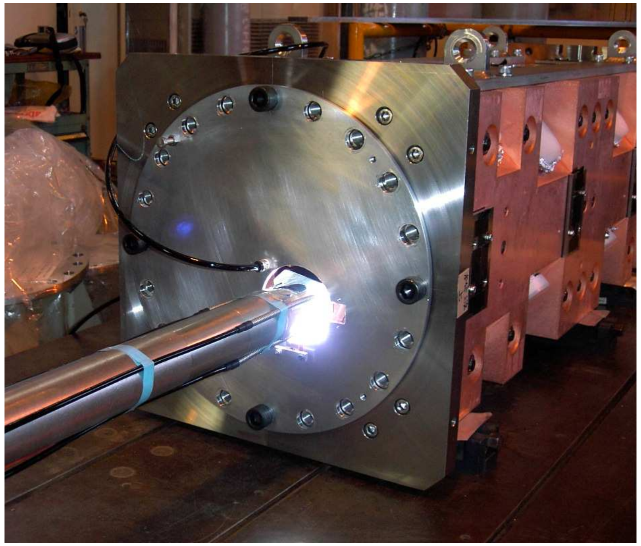
Energy In/Out(MeV)	0.05 / 3
Peak output beam current (mA)	50
Transmission (%)	94
Operation frequency (MHz)	324
Structure type	4-vane
Vane length (m)	3.874
Mode stabilization	PISL
Stable phase (deg.)	-35
Max. surface field (Kilpatric)	1.77
Peak RF power (MW)	0.53
Peak wall power loss (MW)	0.38



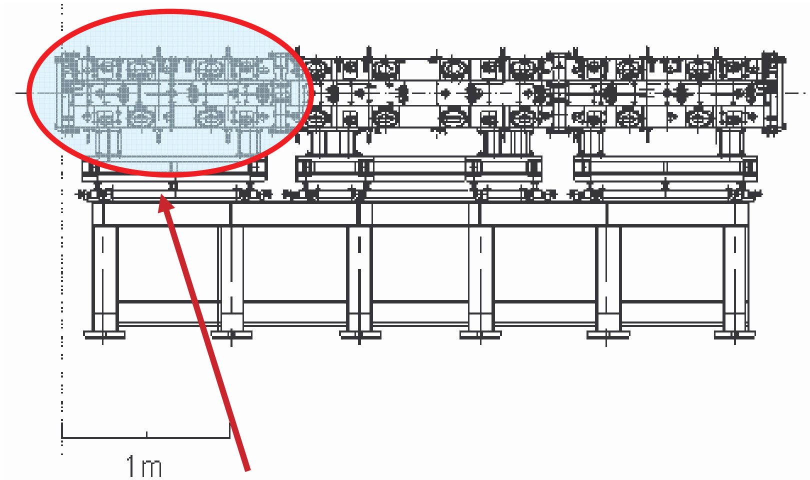
Cross section of 50 mA-RFQ

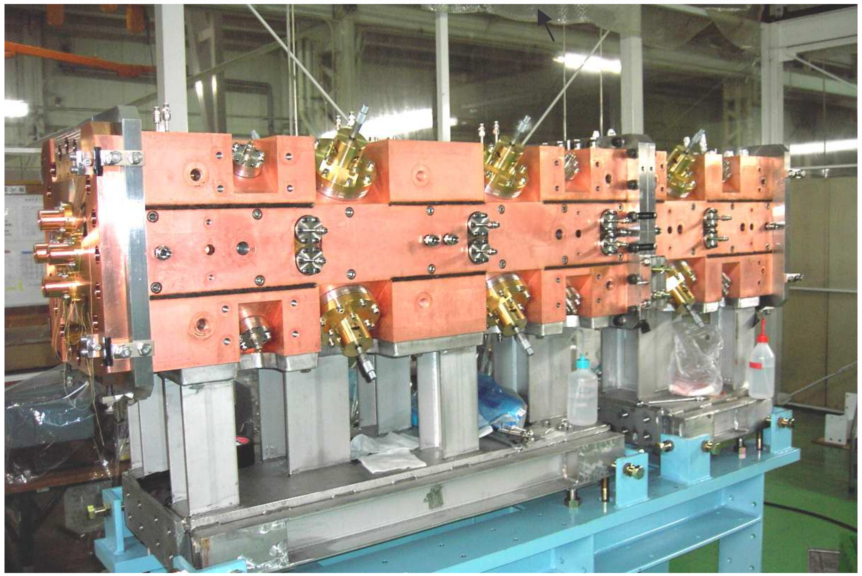
50 mA-RFQ: R&D

50mA RFQ welding test



- Assemble of the cavity with Laser Beam Welding(LBW) has been successfully finished.
- Laser : CO_2 laser 5kW CW





View of the 50 mA- RFQ and the R&D machine

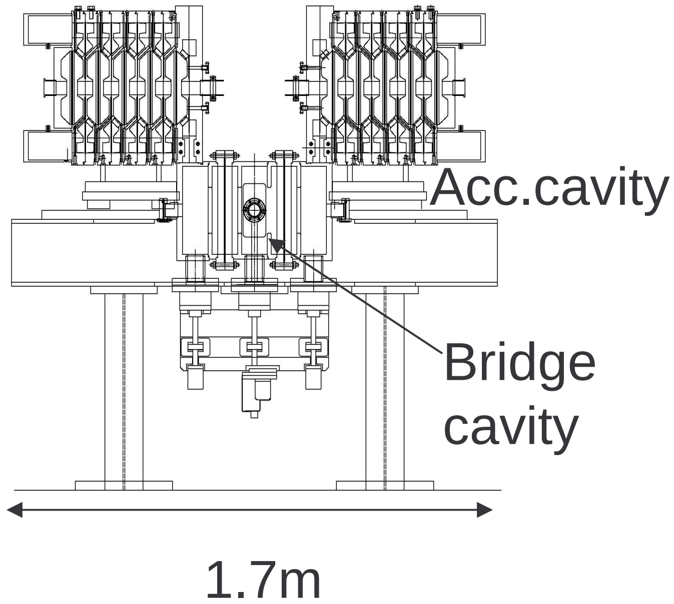
R&D of ACS (buncher)

The linac starts with 180 MeV temporary, but will be upgraded to 400 MeV with 21 ACS modules, two bunchers and two debunchers.

- A buncher cavity (β=0.556) is under fabrication.
  972MHz,5+5 accelerating cell cavities and 5-cell bridge cavity

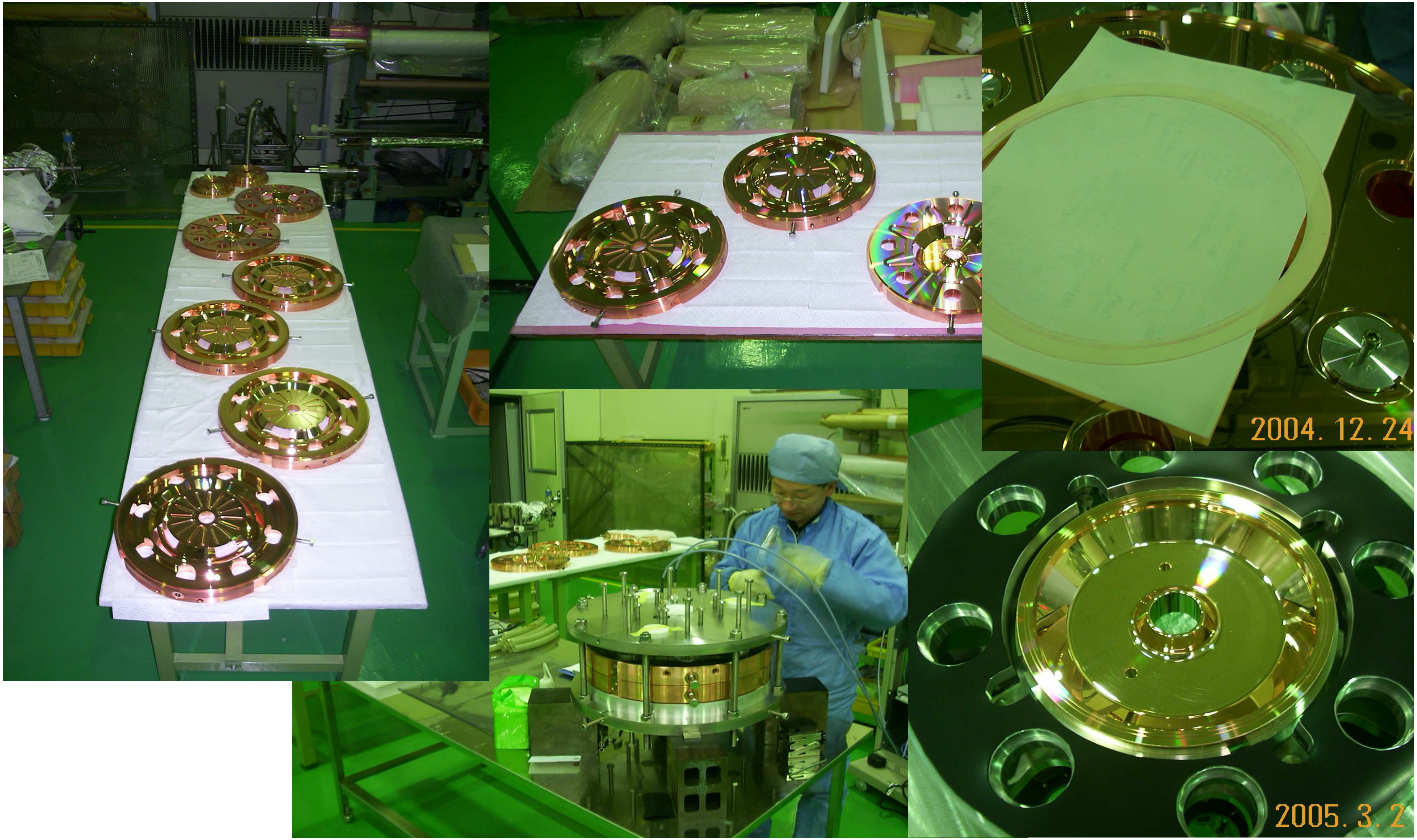
Major Parameters of the ACS section

Energy	190.8-400	MeV
Frequency	972	MHz
Section Length	107.2	m
E0	4.12	MV/m
Number of module	21	



ACS-type buncher cavity

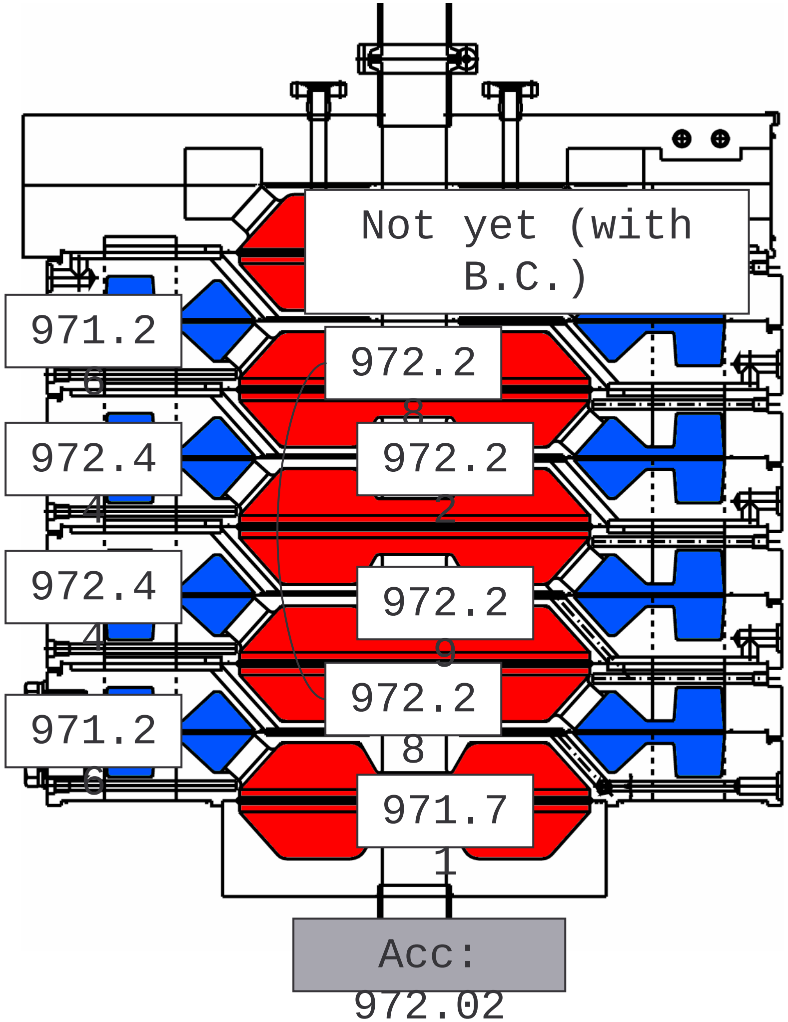
Half-cell Pieces for ACS buncher



5-cell Measurements of ACS Buncher

Measured Results and Status

Frequency in the Tank1



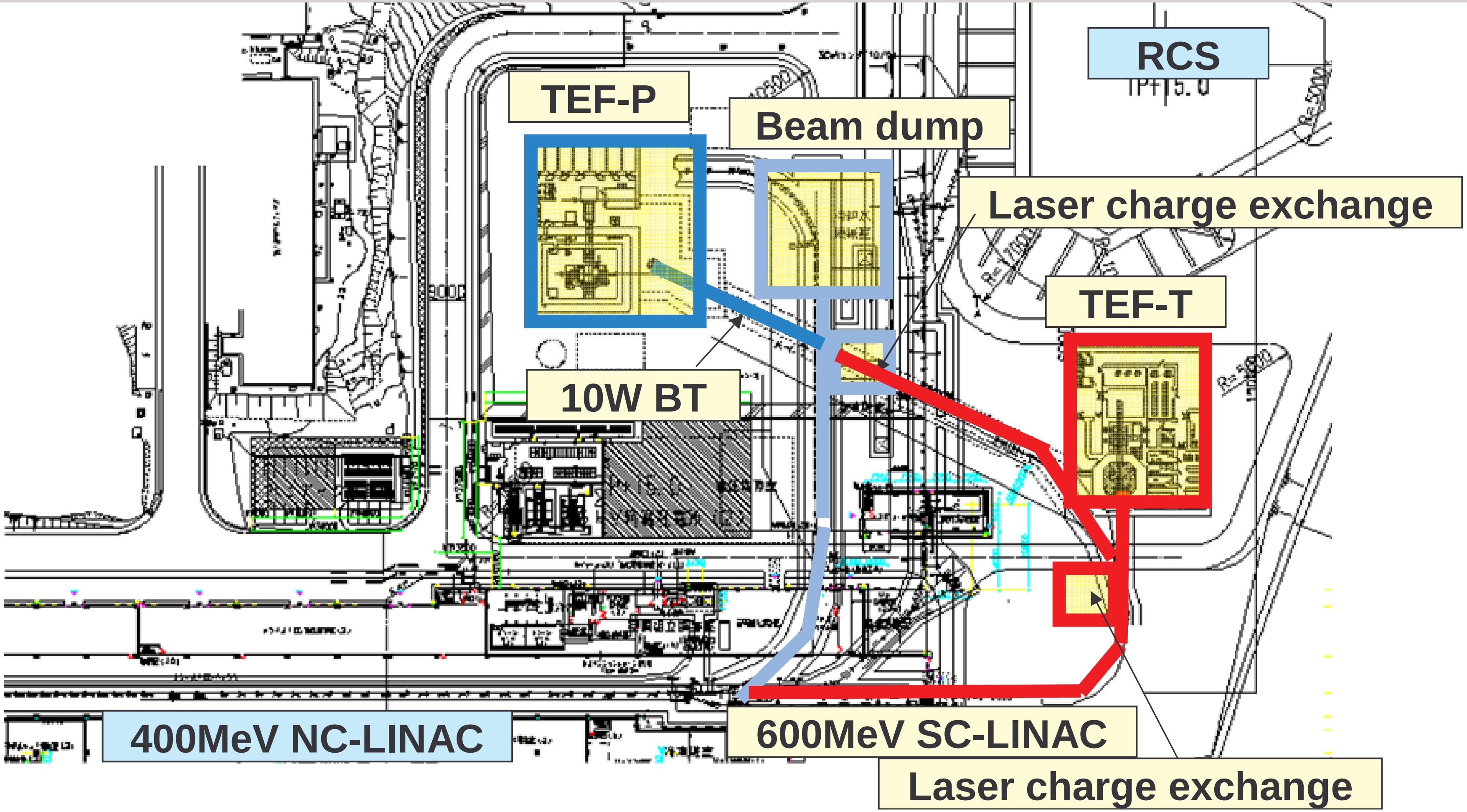
Status of the buncher

- All parts have been fabricated.
- Tank-2: Brazing was finished. Vacuum test is underway.
- Tank-1: Fixed a slight leakage in a part. Brazing is going on.
- Bridge: Brazing will be carried out in February.

- High-power test at JEAE will be expected in this April.

Layout Plan of the Superconducting Linac

- 600MeV, 200kW (Maximum) proton beam accelerated by SC-Linac will be injected into Transmutation Target Experimental Facility (TEF-T).
- 10 W beam is extracted by the laser charge exchange and transported to Transmutation Physics Experimental Facility (TEF-P).



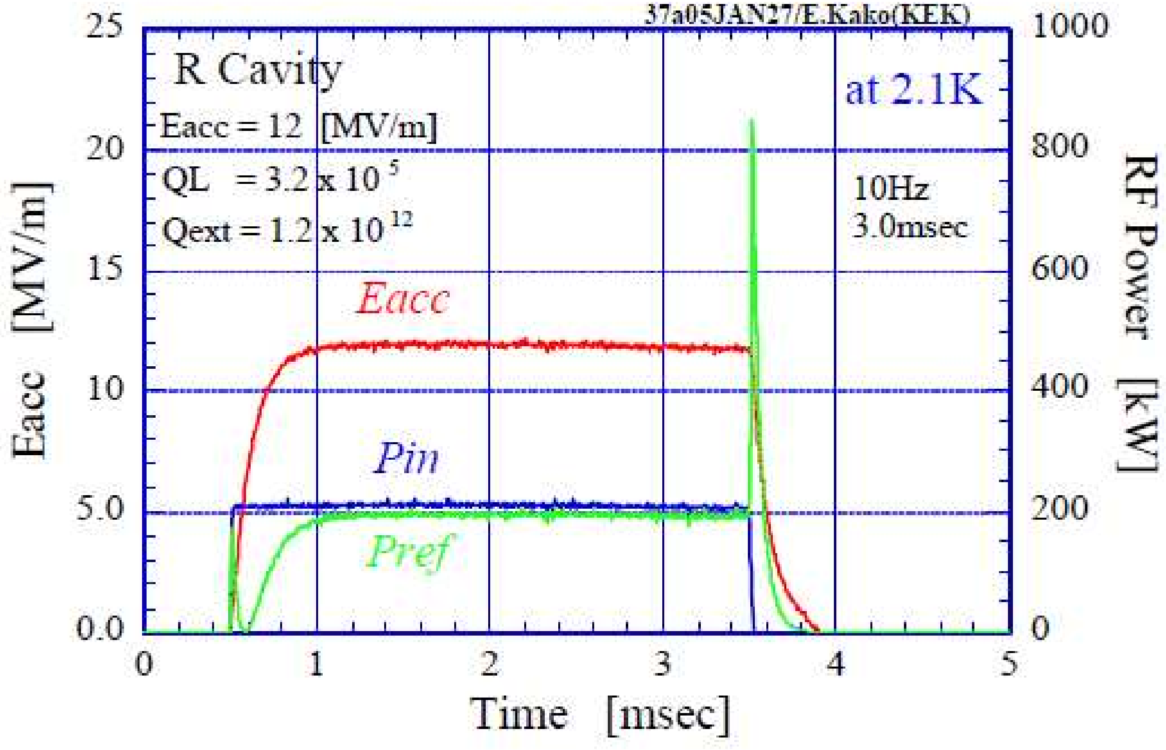
R&D for Superconducting Linac

- Energy: 400- 600 MeV
- Construction of 972 MHz Prototype Cryomodule
  - β=0.725 (424 MeV)
  - Tests of Pulsed Operation at 2K He
  - 25Hz, 3.0msec, Eacc=10MV/m (Epeak=30MV/m)

Superconducting Cavity

Cryomodule

R&D Results and Status of the SCL



RF pulse signals at 12MV/m

Status

- Test of prototype cryomodule in the pulse mode operation is underway.
- Accelerating field of 12 MV/m is achieved.
- Effect of Lorentz-force detuning and compensation are studied.

Summary

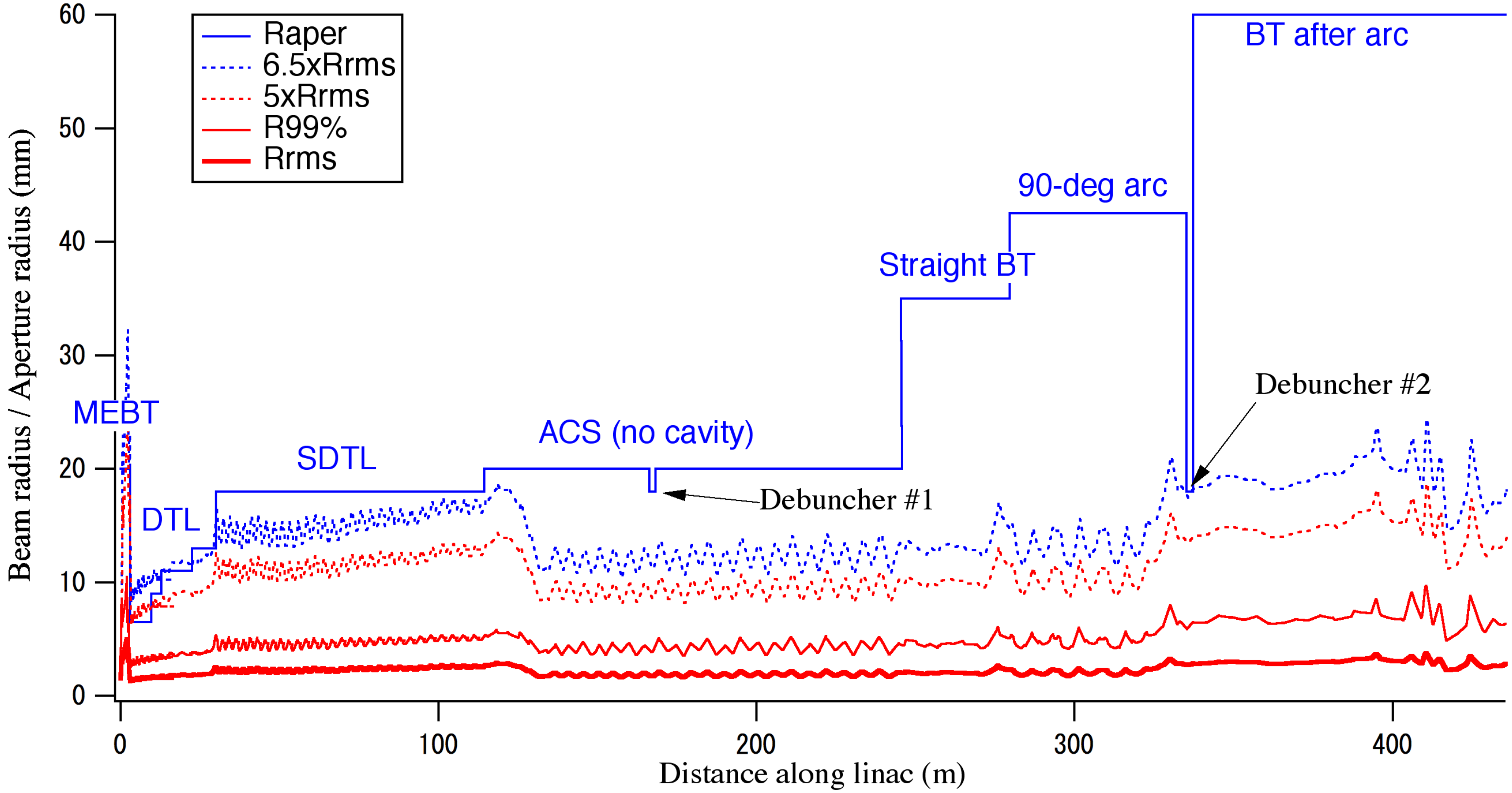
- J-PARC linac is based on many newly developed technologies
  - The development has been successful.

- Construction status
  - Most of the components have already delivered and installation is progressing well.
  - Beam test of the linac will be scheduled from December, 2006

- R&D for upgrade
  - R&D of the RFQ, ACS and SCL is under way for the energy and beam current upgrade.

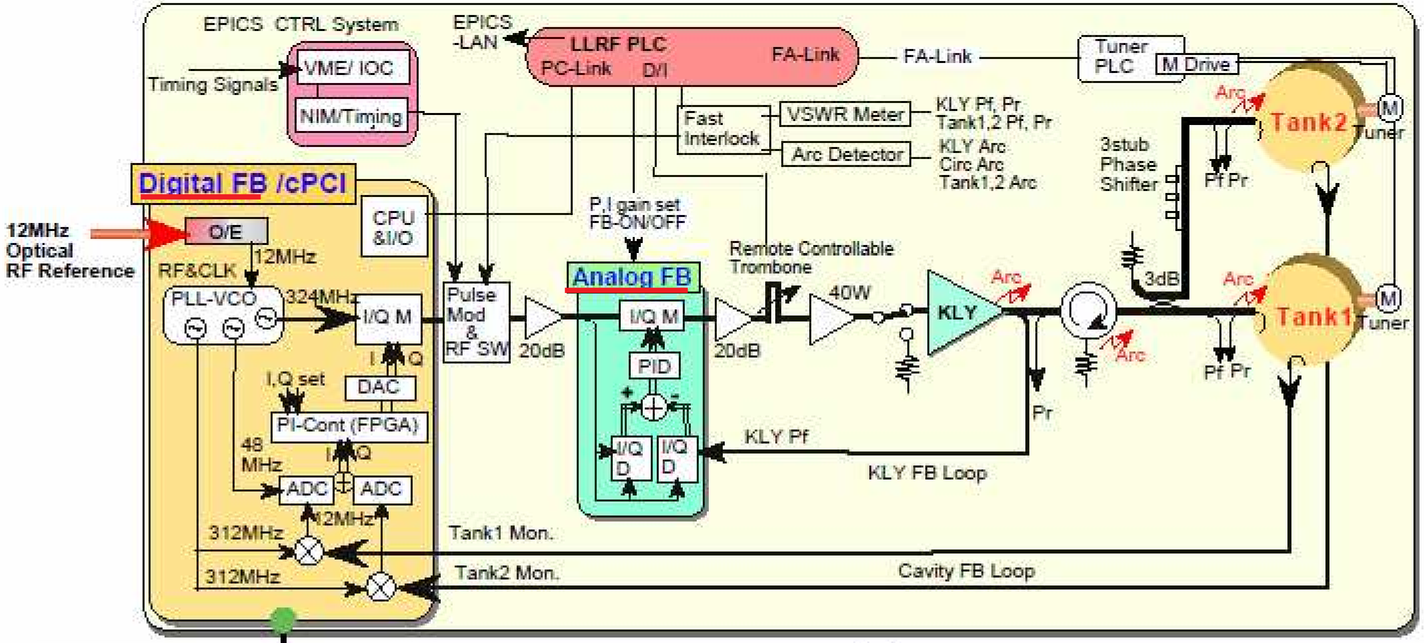
End of the talk

Stronger quadrupole case ($T_T/T_l = 2$)

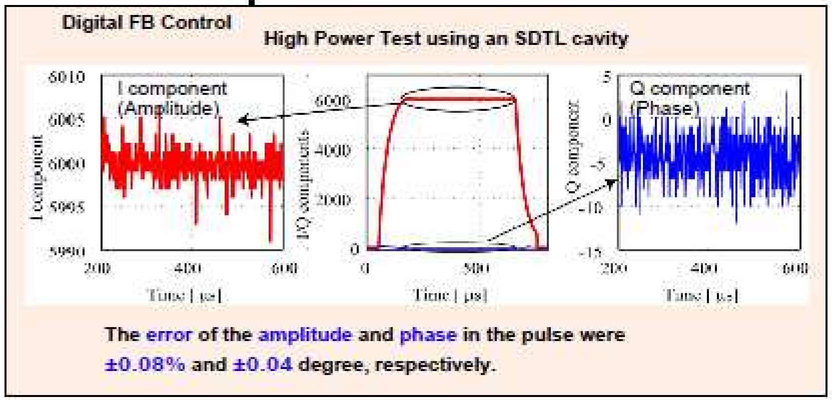


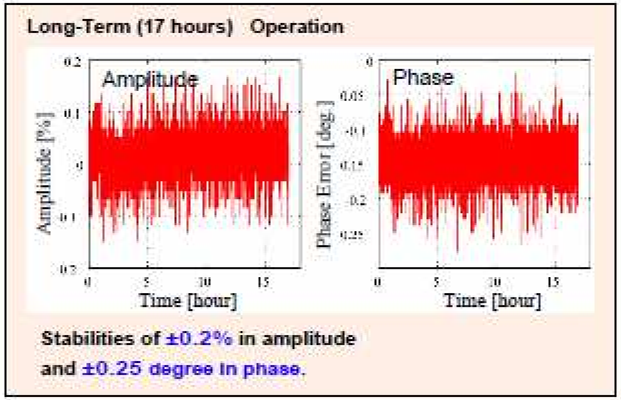
$R_{aper}/R_{rms} > 6.5$ is satisfied in the stronger quadrupole case, which can be achieved with DC excitation of DTQ's.

Low level RF system



Errors within a pulse:
<±0.08%
<±0.04deg.
*One SDTL

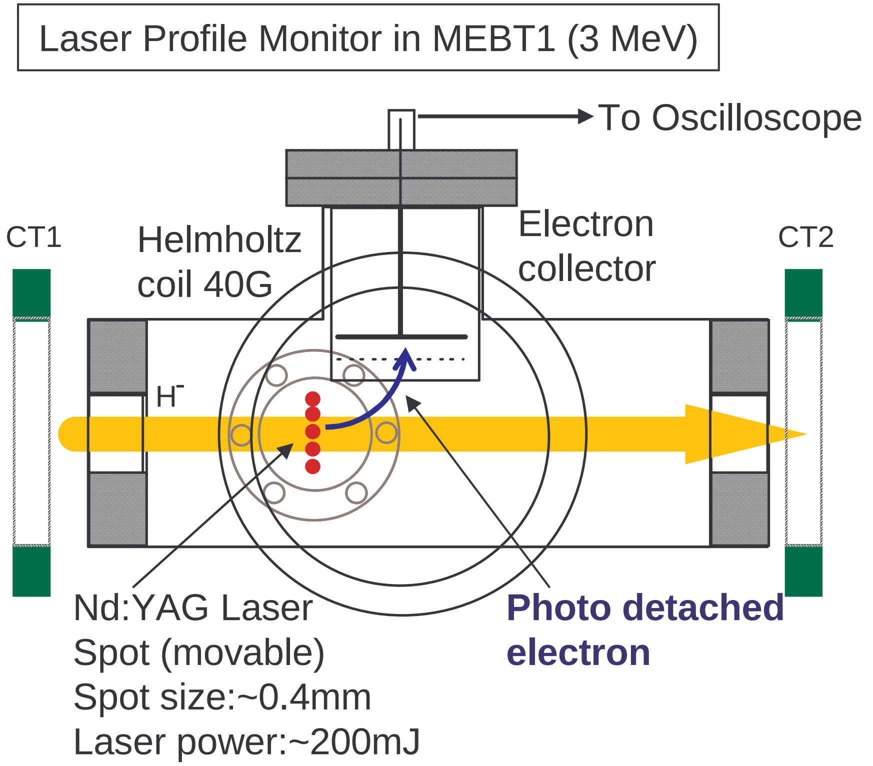


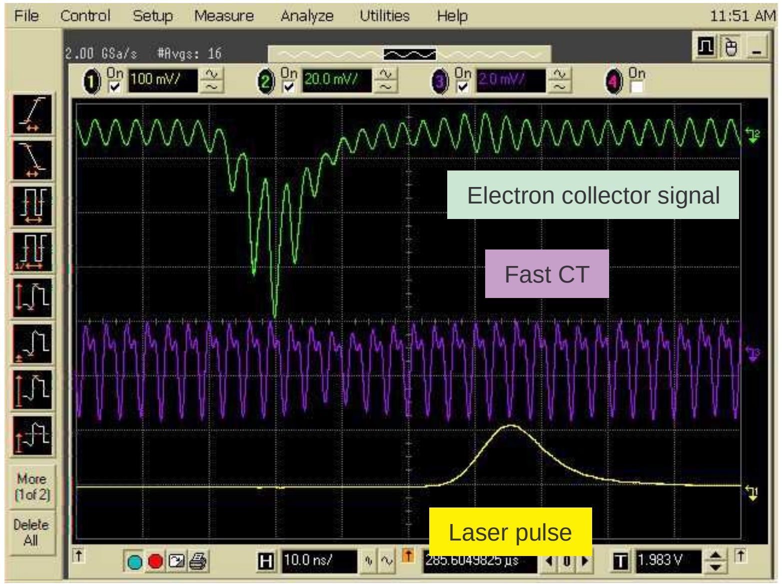


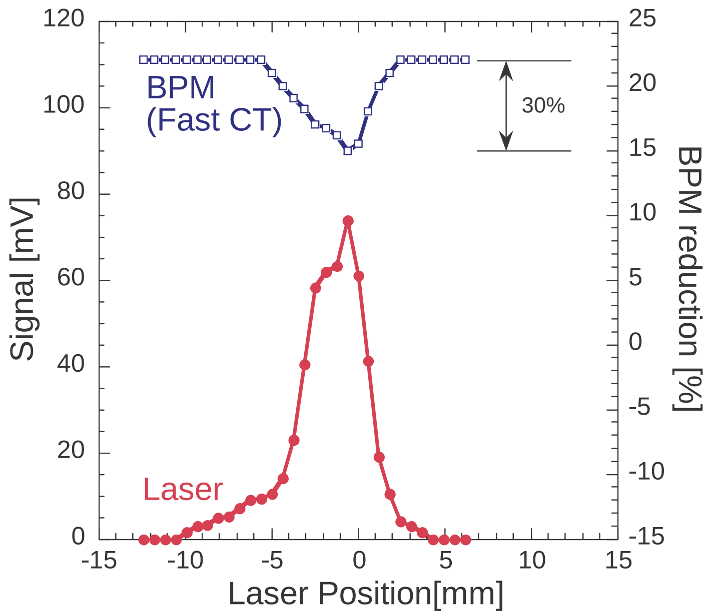
Long-Term Errors:
<±0.2%
<±0.25deg.
*One SDTL

High power test of 2 SDTL cavities with a Klystron is scheduled in April, 2005.
*Vector sum of fields in 2 cavities is feed-backed (feed-backing each frequency by an auto-tuner).

Laser Profile Monitor





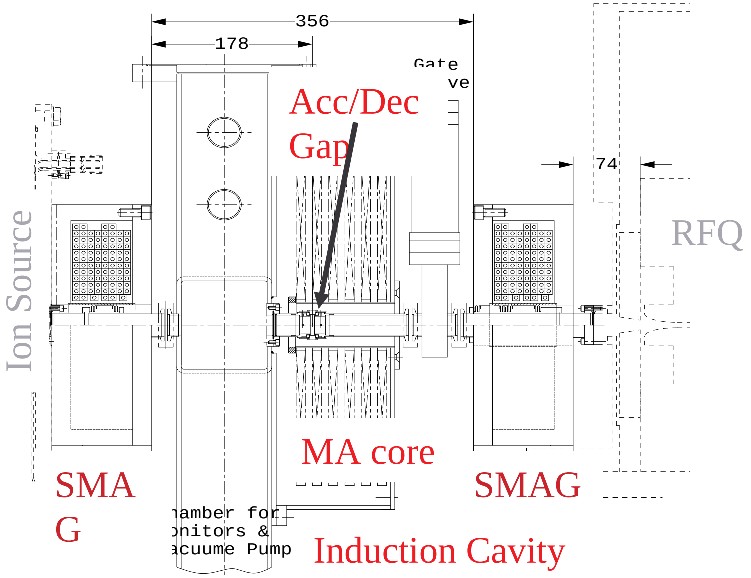


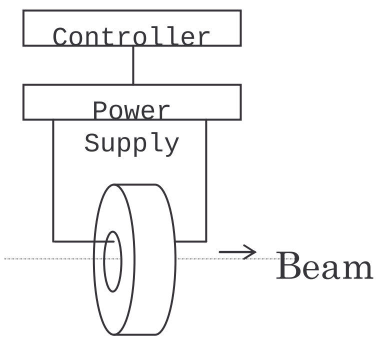
- Micro bunch waves of <3nsec can be observed.
- Beam current reduction was clearly detected with fast current transformer and BPM.
- Laser based beam profile is consistent with results of wire scanners.

LEBT with Pre-chopper

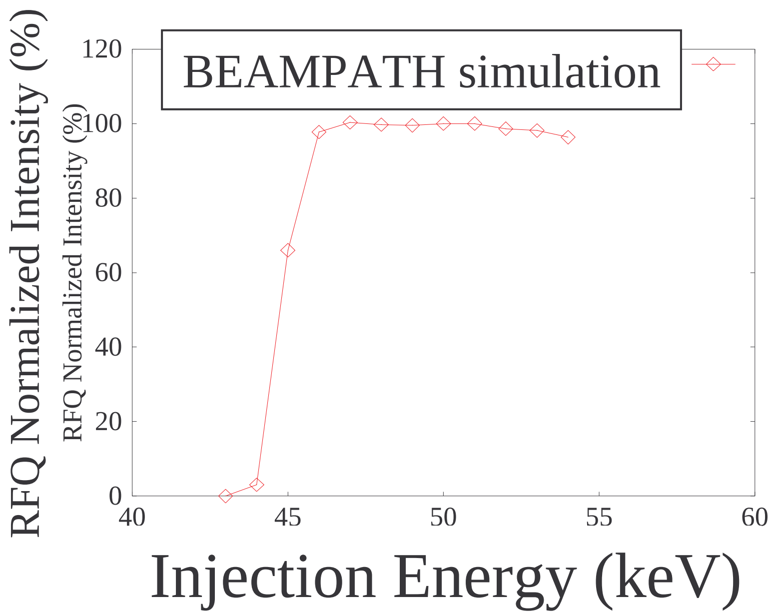
Features

- Focusing : 2 solenoid magnets (SMAG) for matching
- Pre-chopping : Energy modulation with an Induction Cavity (filtering with the RFQ)





Schematic drawing of the Pre-chopper



Transmission of the RFQ as a function of injection energy

4. Cooling Water System

RI#2	IS	27ºC±2ºC	Purifier, O_2 rejection
RI#3	DTL,SDTL tank (steel)	27ºC±0.2ºC	Purifier, O_2 rejection
RI#4	RFQ,DTL,SDTL (Cu)	27ºC±0.2ºC	Purifier, O_2 rejection
RI#6	L3BT Magnet	27ºC±2ºC	Purifier, O_2 rejection
Cold#1	Kly, IS PS	27ºC±1ºC	Purifier
Cold#3	Kly	27ºC±7ºC	Purifier
Cold#4	Kly HV PS	27ºC±7ºC	Purifier
Cold#5	DTQ PS	27ºC±7ºC	Purifier
Constant	RF signal distribution	27ºC±0.1ºC	Purifier

Status of RF source

Manufacturing of all the high-power components are finished.

Component	# of Need	# of Stock	Evaluating (Long Run)	Vendor
Klystron	20 unit	24 (incl. prototype)	5 unit	TOSHIBA
Tr AMP	4 units	4	3 unit	NEC
KLY DCPS	6 set	6	2 set	HITACHI
Modulator	20 unit	20	5 unit	HITACHI
Circulator	20 unit	20	5 unit	NIHON KOSHUHA
Wave guide	24 set	24	2 set	FURUKAWA
LLRF	24 set	24	0 set	THAMWAY

1(RFQ)+3(DTL)
+15(SDTL2n-1&2n:n=1~15)
+1(Debuncher-1)=20

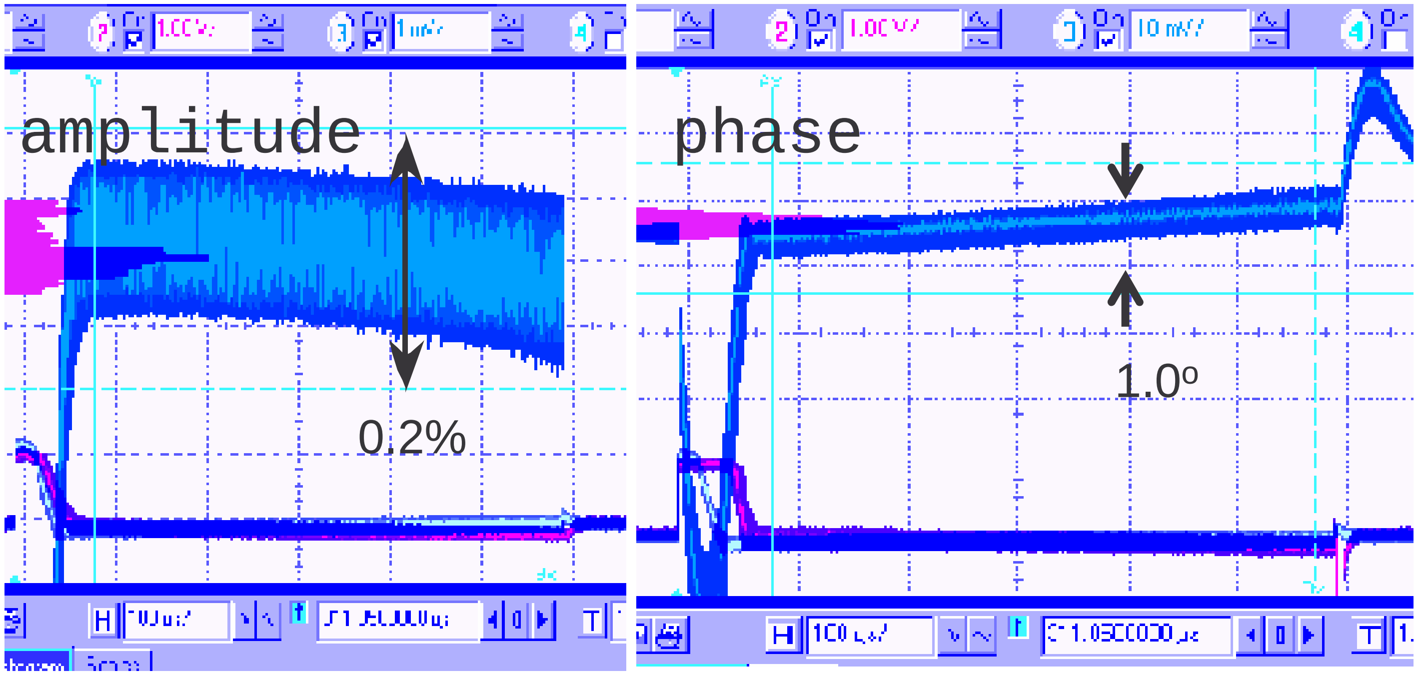


Klystrons, a circulator and wave guides


Hadron Experimental Hall
50 GeV
Materials & Life
Experimental Hall
Neutrino
3 GeV
Linac
Sept. 15, 2005

RF Stability in the DTL-1

- Pulse-to-pulse stabilities of the amplitude and phase in the DTL-1 were measured.
- At this stage, an analog feedback was applied. For the J-PARC linac, a digital feedback will be used.
- The sag in the pulse will be improved to add a feedback loop to stabilize the Klystron output.



Linac Building Design

General Layout

2F: Air conditioning
AC electric services

1F:Klystron, Mag. PS,
Cooling water

GL

BF1: Intermediate Tunnel

BF2: Accelerator Tunnel