Commissioning of the J-PARC Linac

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For the J-PARC Linac Commissioning Team

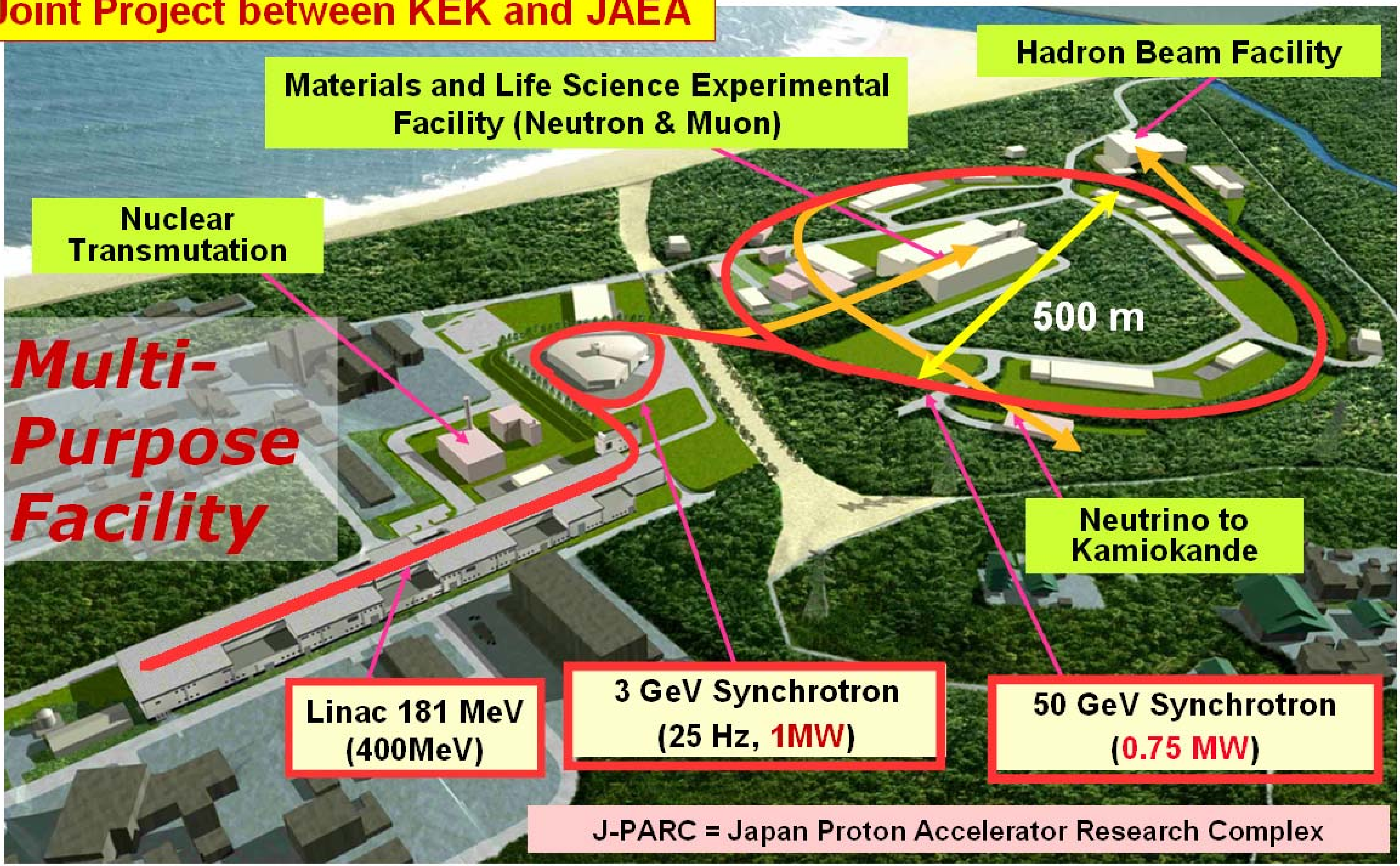
The 2007 Particle Accelerator Conference, June 25-29, 2007, Albuquerque, USA

Outline

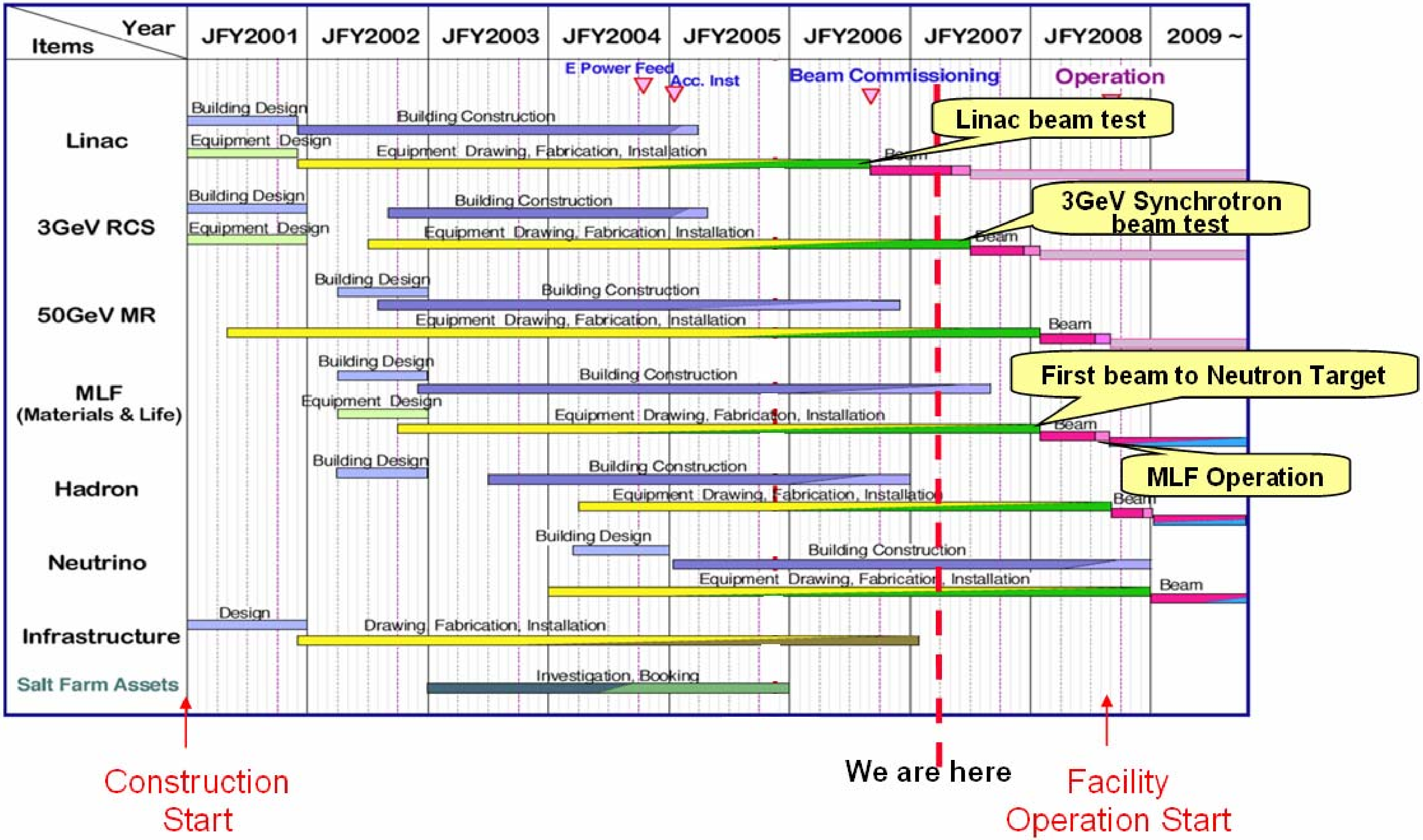
- Construction Status of J-PARC
- Commissioning of the Linac
    - Parameters
    - Timeline
    - Component status
    - Beam commissioning results
- R&D of ACS

J-PARC Facility Layout at Tokai, JAEA Site

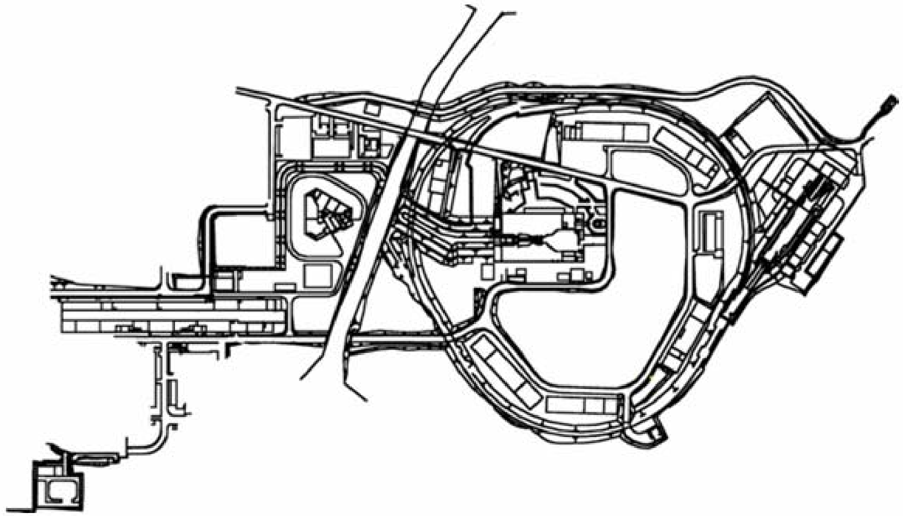
Joint Project between KEK and JAEA



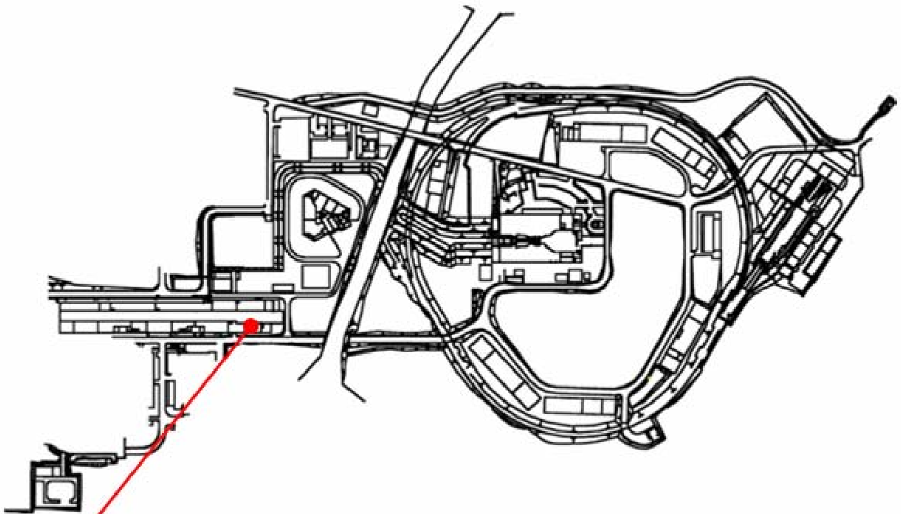
Construction Schedule



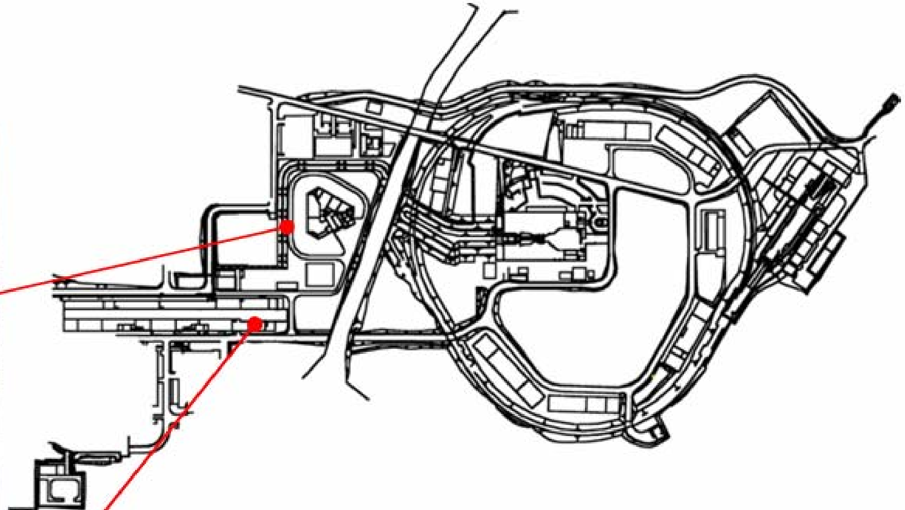
Conventional Facilities



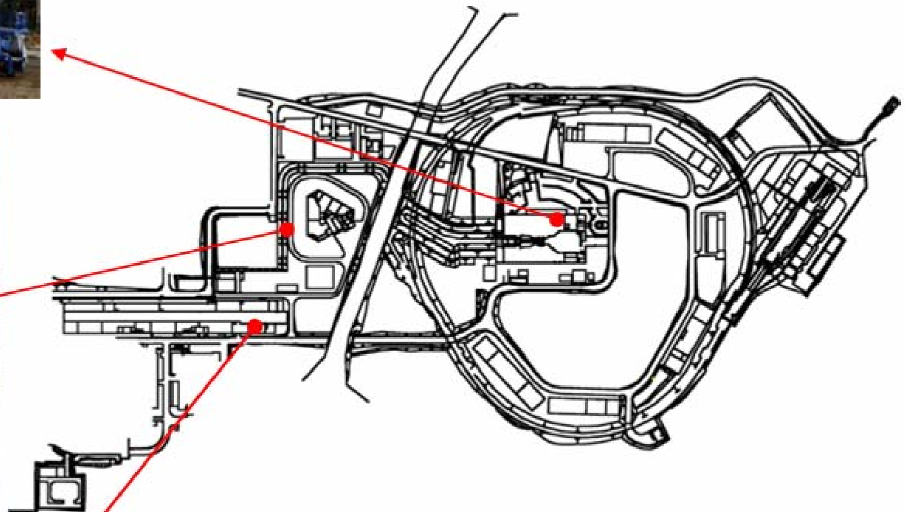
Conventional Facilities



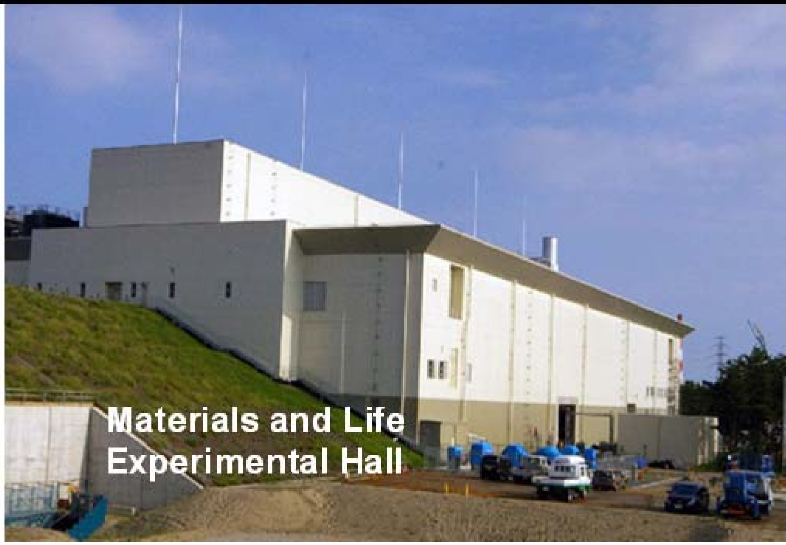
Conventional Facilities



acilities

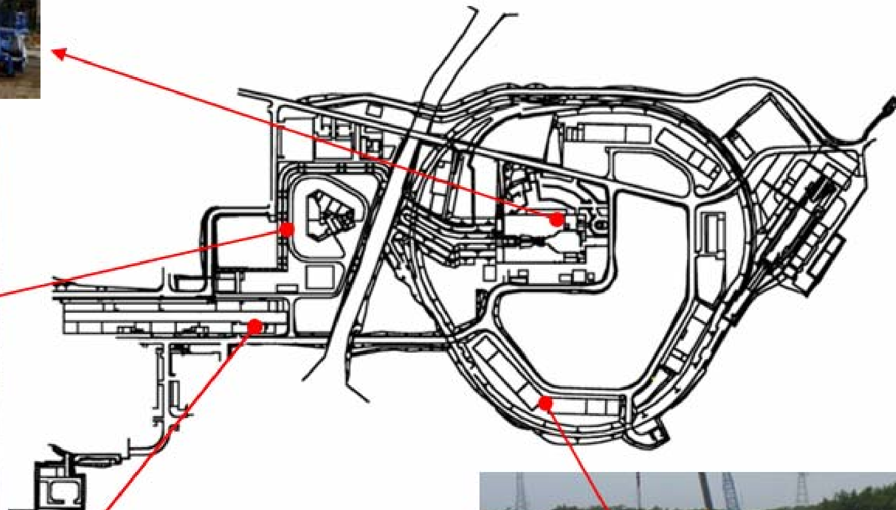


acilities


Materials and Life
Experimental Hall

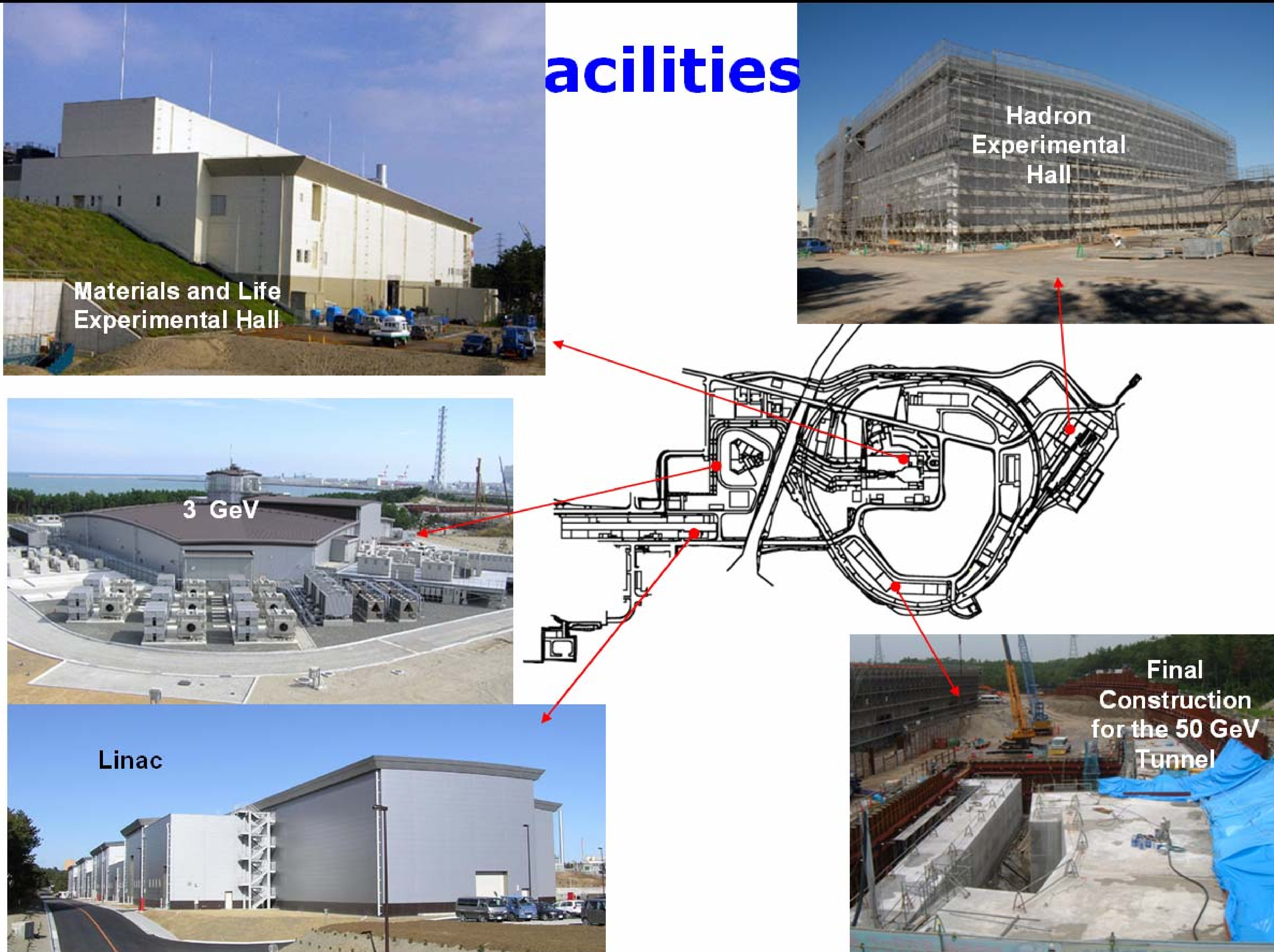

3 GeV

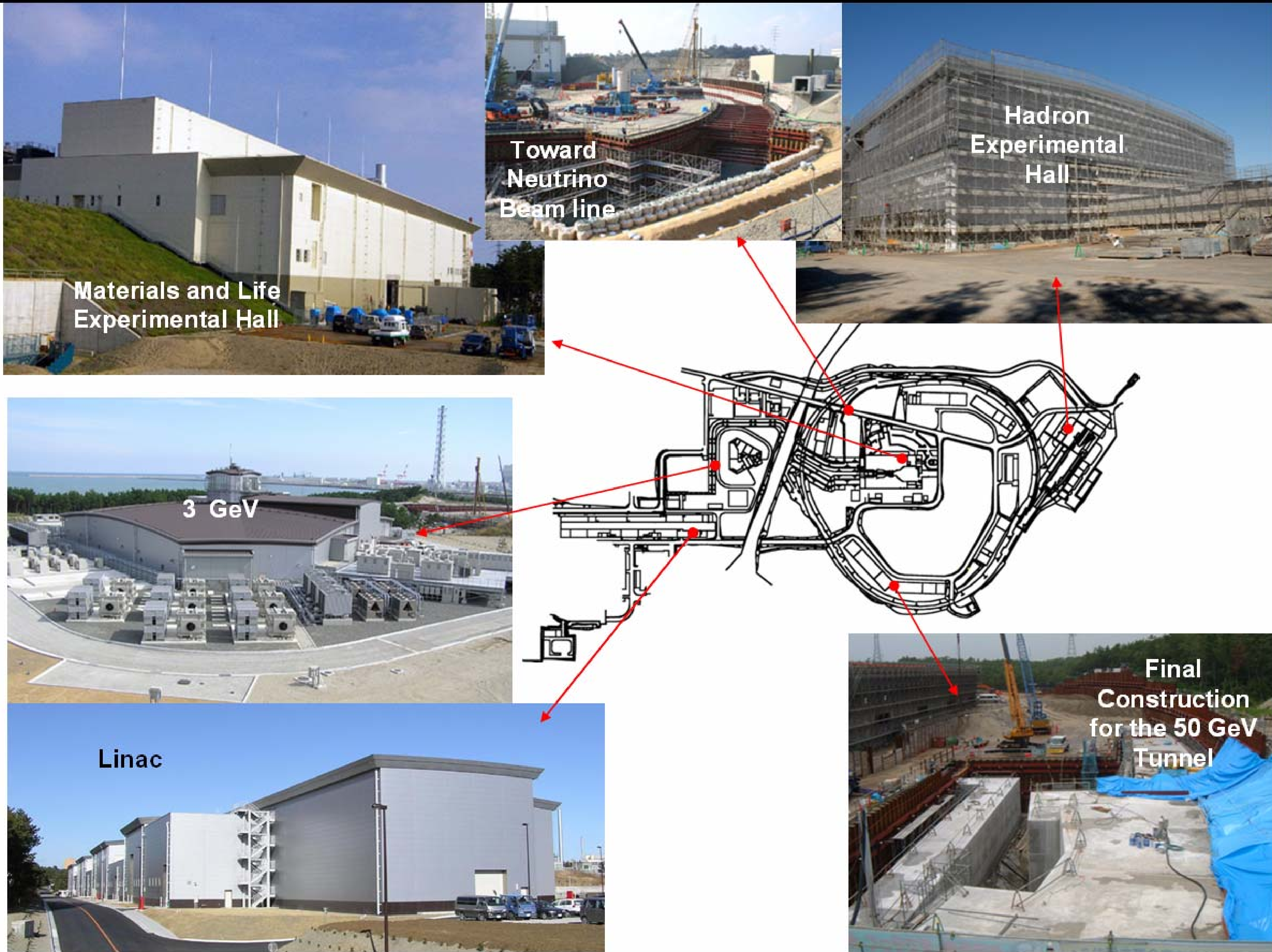

Linac



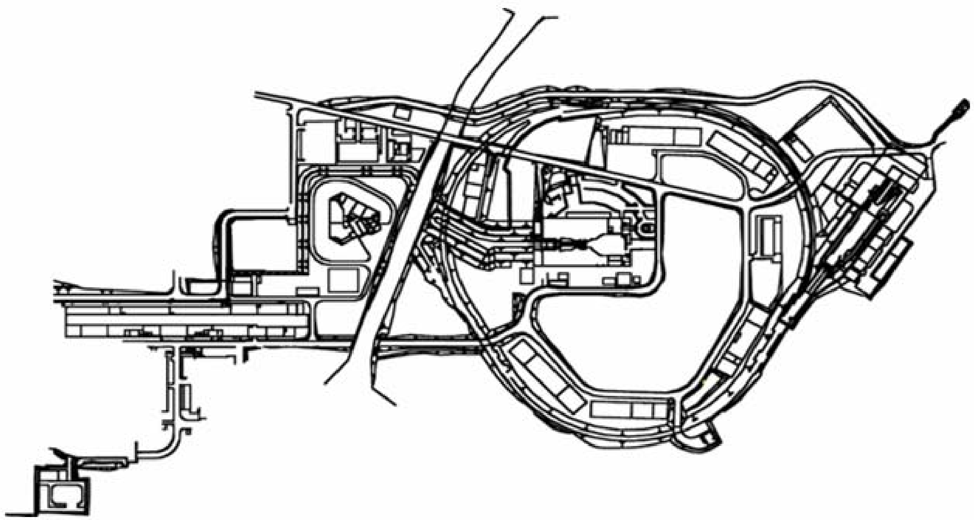

Final
Construction
for the 50 GeV
Tunnel

acilities


Materials and Life
Experimental Hall
Hadron
Experimental
Hall
3 GeV
Linac
Final
Construction
for the 50 GeV
Tunnel


Toward Neutrino Beam line
Hadron Experimental Hall
Materials and Life Experimental Hall
3 GeV
Linac
Final Construction for the 50 GeV Tunnel

Machine Components



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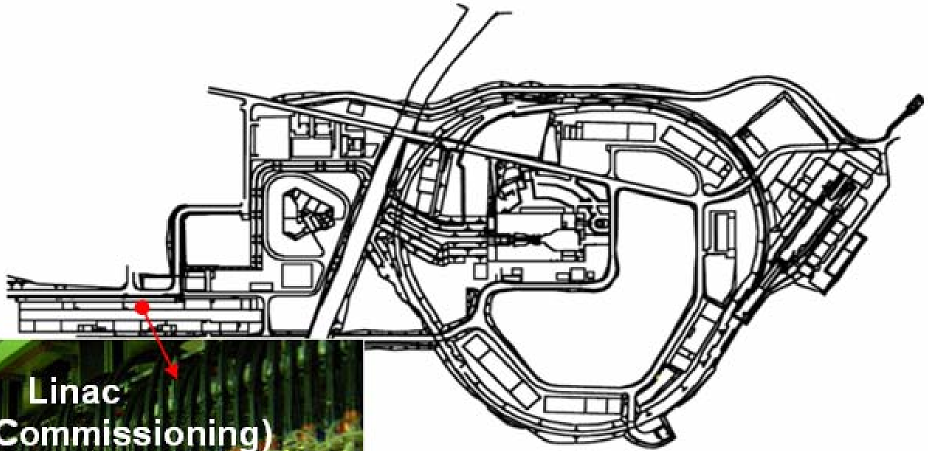
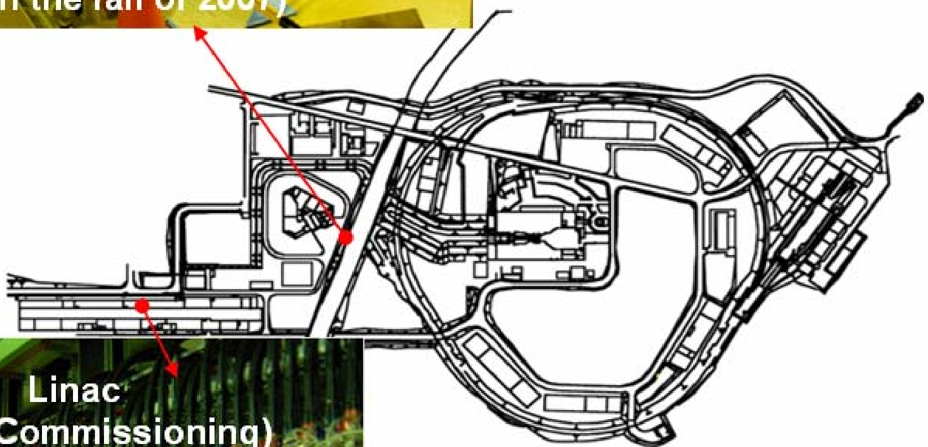
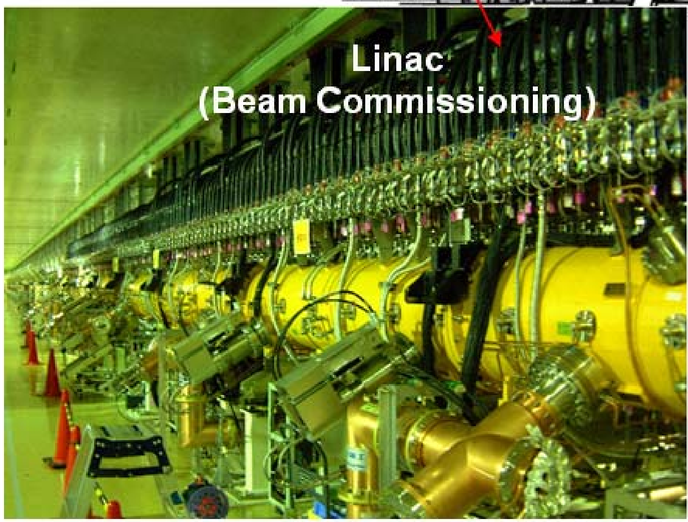


onents

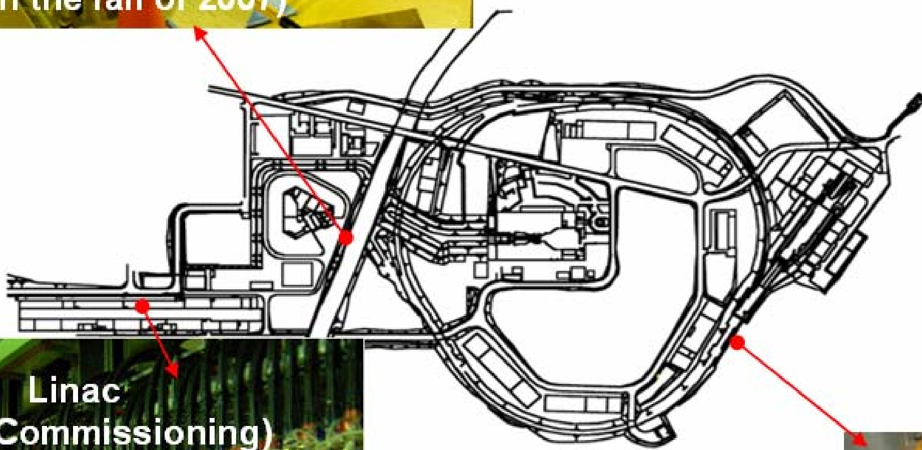

3 GeV Tunnel
(Beam injection in the fall of 2007)

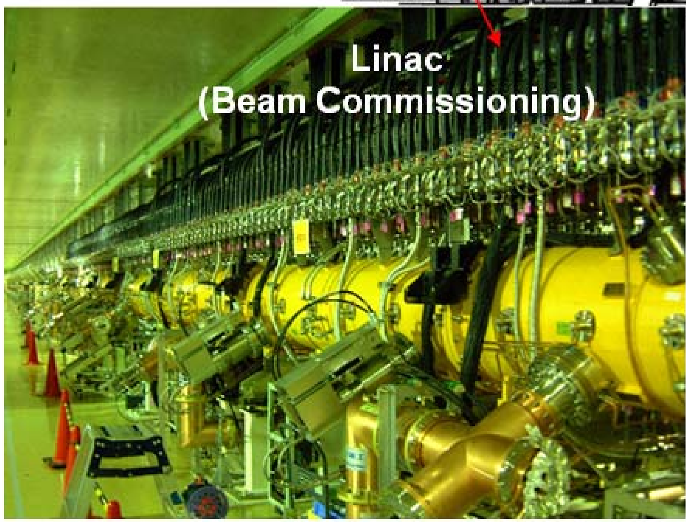



Linac
(Beam Commissioning)

onents


3 GeV Tunnel
(Beam injection in the fall of 2007)




Linac
(Beam Commissioning)


50 GeV Tunnel
(Beam injection in the spring of 2008)

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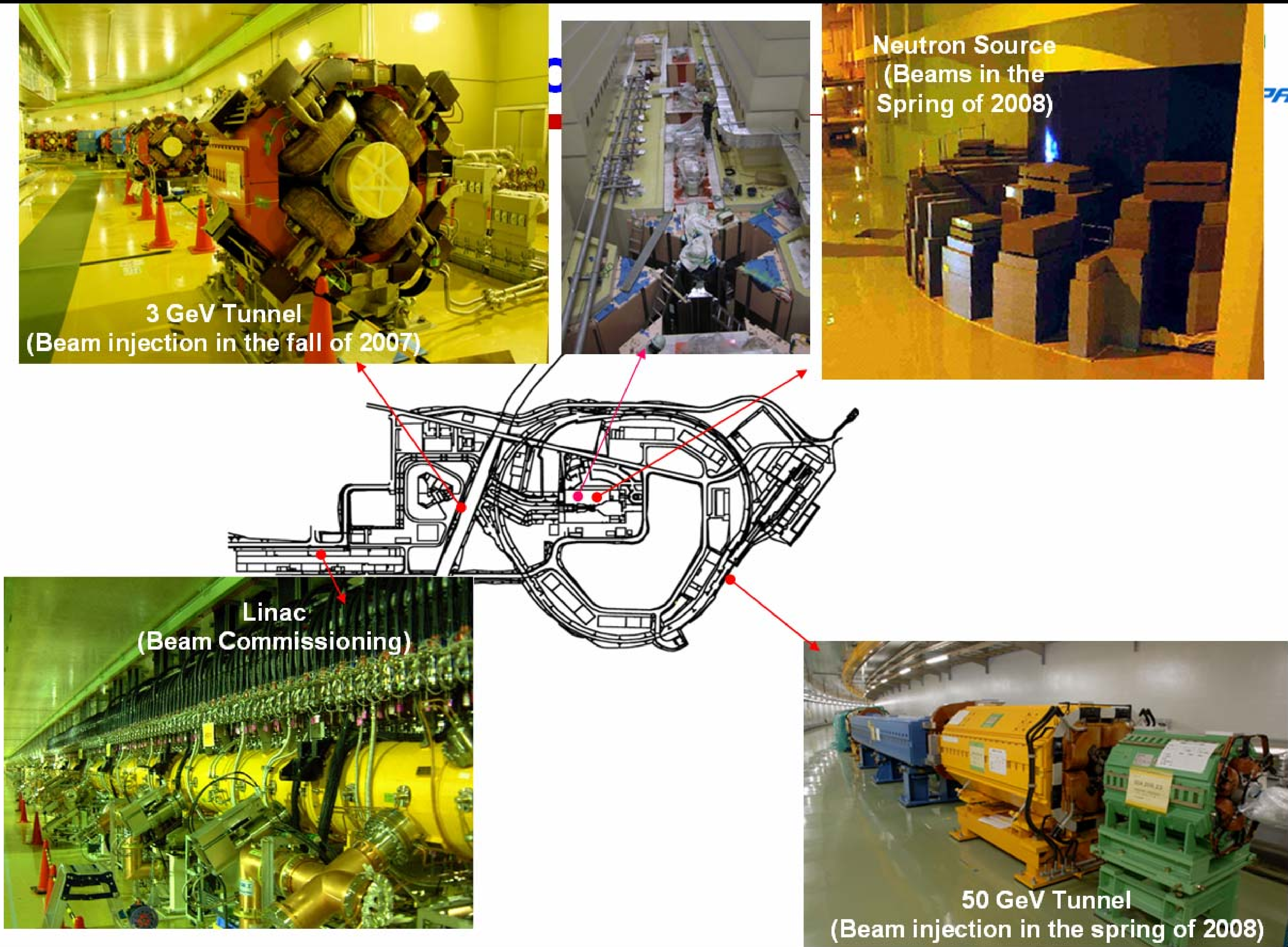
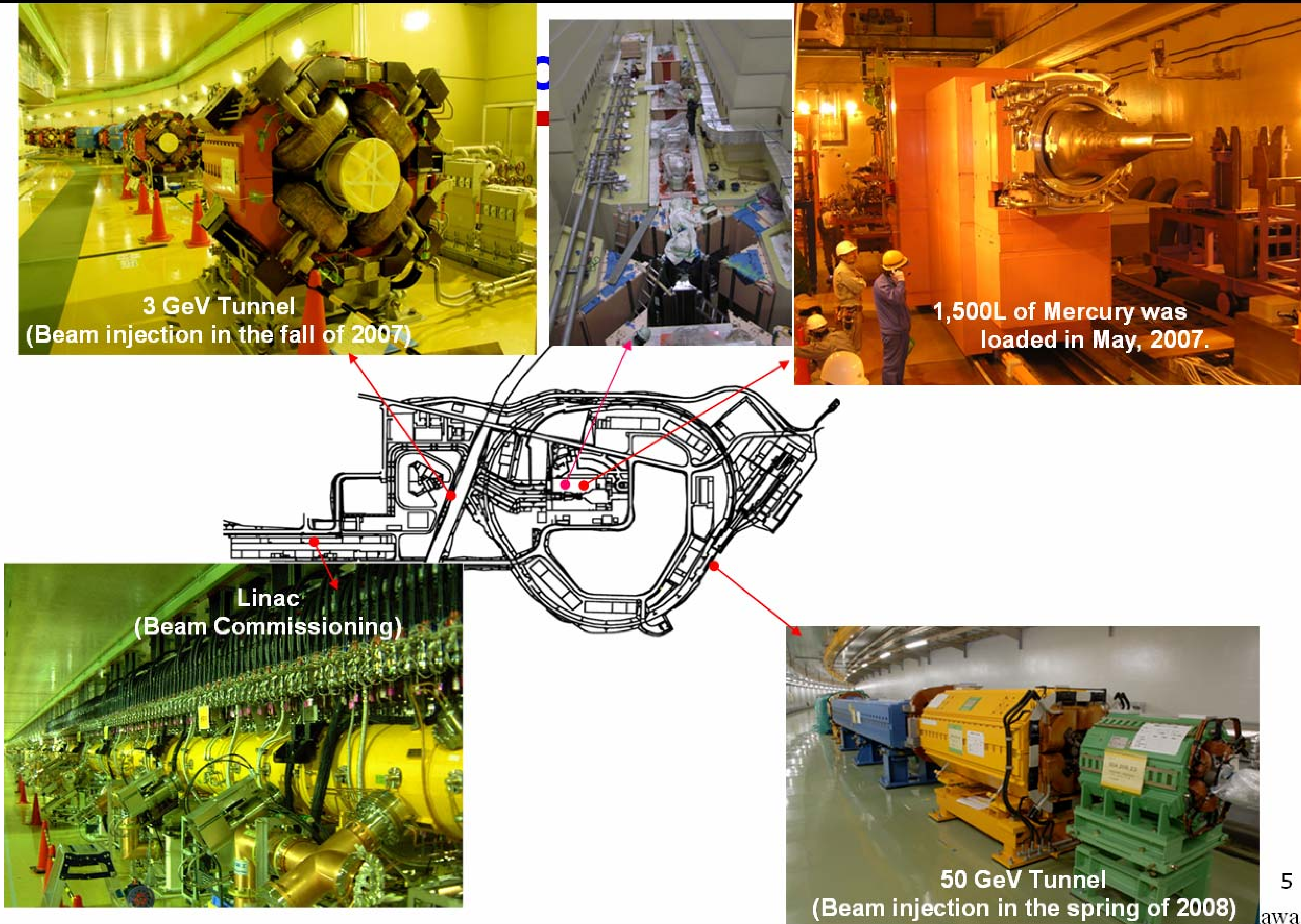
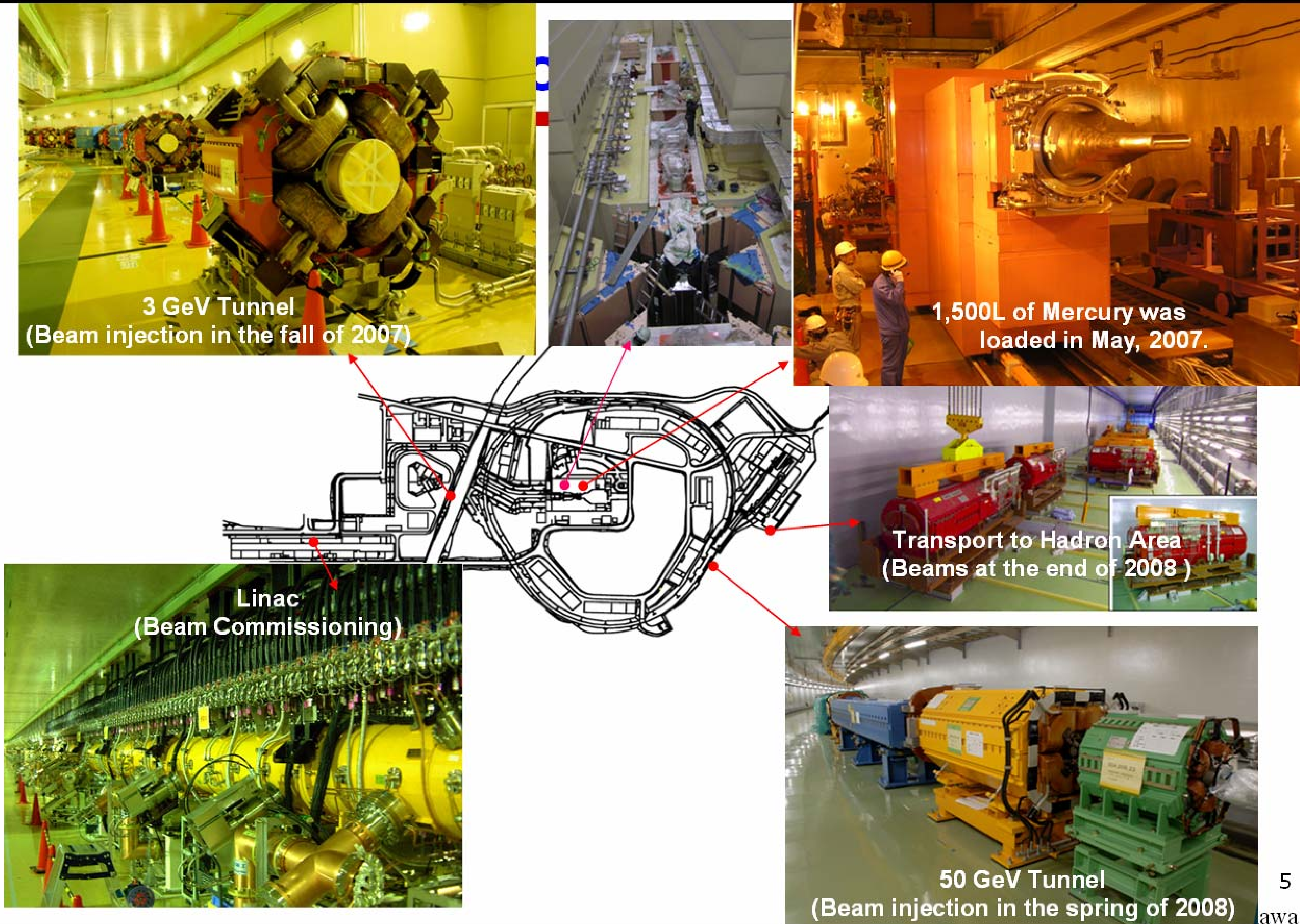
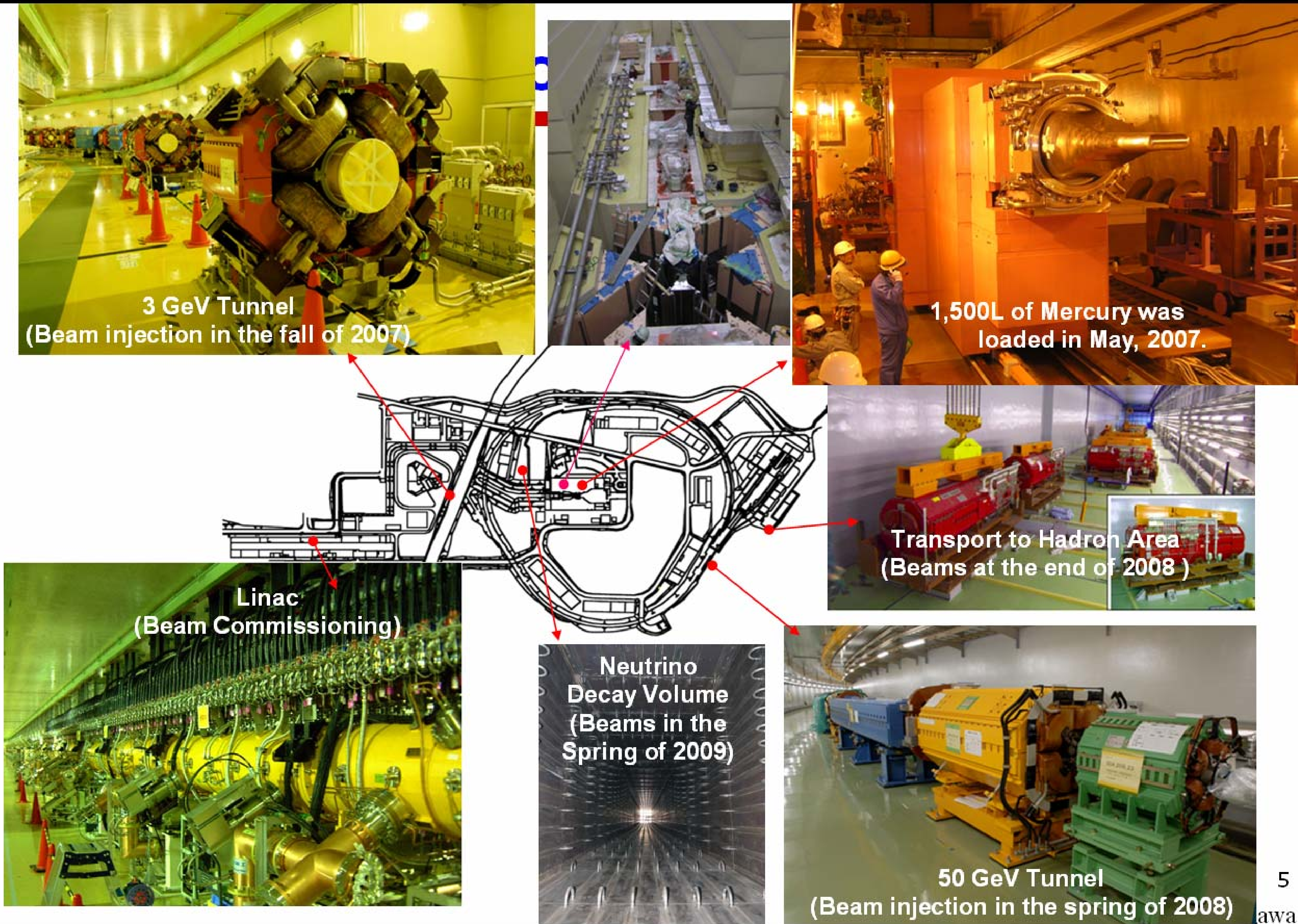

3 GeV Tunnel
(Beam injection in the fall of 2007)
Neutron Source
(Beams in the
Spring of 2008)
Linac
(Beam Commissioning)
50 GeV Tunnel
(Beam injection in the spring of 2008)


3 GeV Tunnel
(Beam injection in the fall of 2007)
1,500L of Mercury was loaded in May, 2007.
Linac
(Beam Commissioning)
50 GeV Tunnel
(Beam injection in the spring of 2008)


3 GeV Tunnel
(Beam injection in the fall of 2007)
1,500L of Mercury was
loaded in May, 2007.
Transport to Hadron Area
(Beams at the end of 2008)
Linac
(Beam Commissioning)
50 GeV Tunnel
(Beam injection in the spring of 2008)


3 GeV Tunnel
(Beam injection in the fall of 2007)
1,500L of Mercury was loaded in May, 2007.
Transport to Hadron Area
(Beams at the end of 2008)
Linac
(Beam Commissioning)
Neutrino Decay Volume (Beams in the Spring of 2009)
50 GeV Tunnel
(Beam injection in the spring of 2008)

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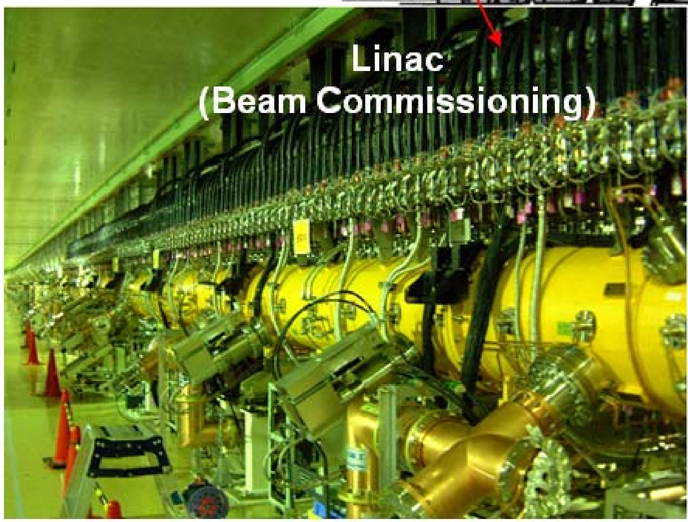
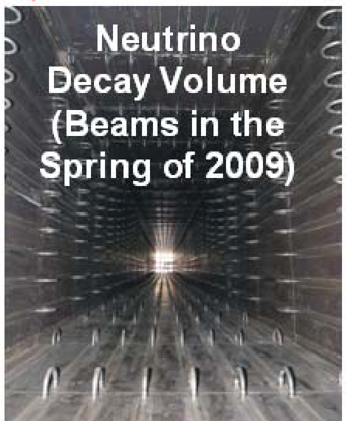
Over 75% of the construction was completed

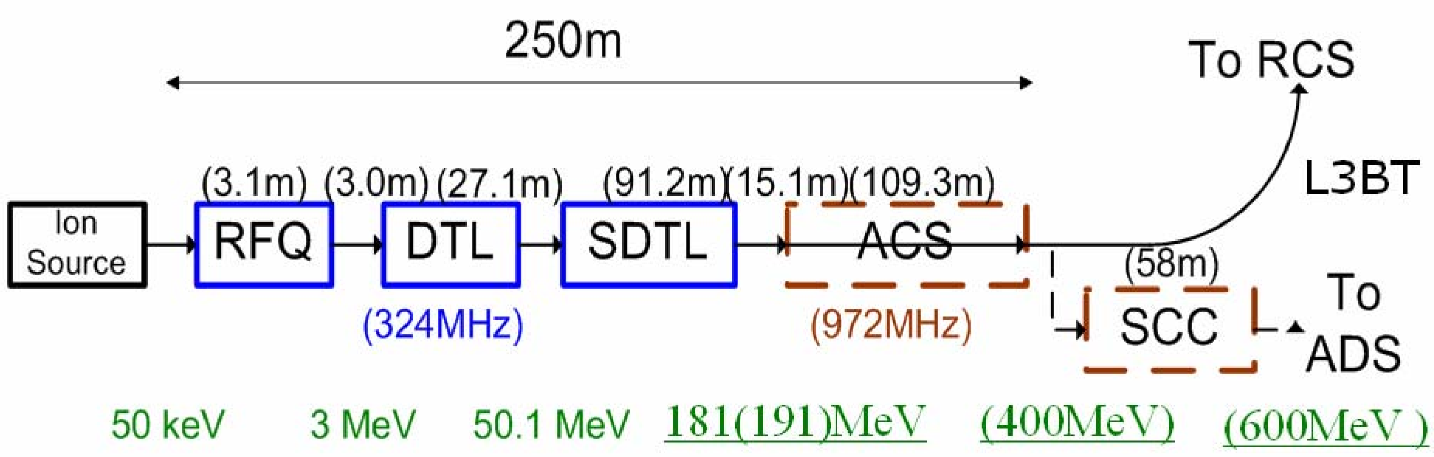




Linac Commissioning

Parameters

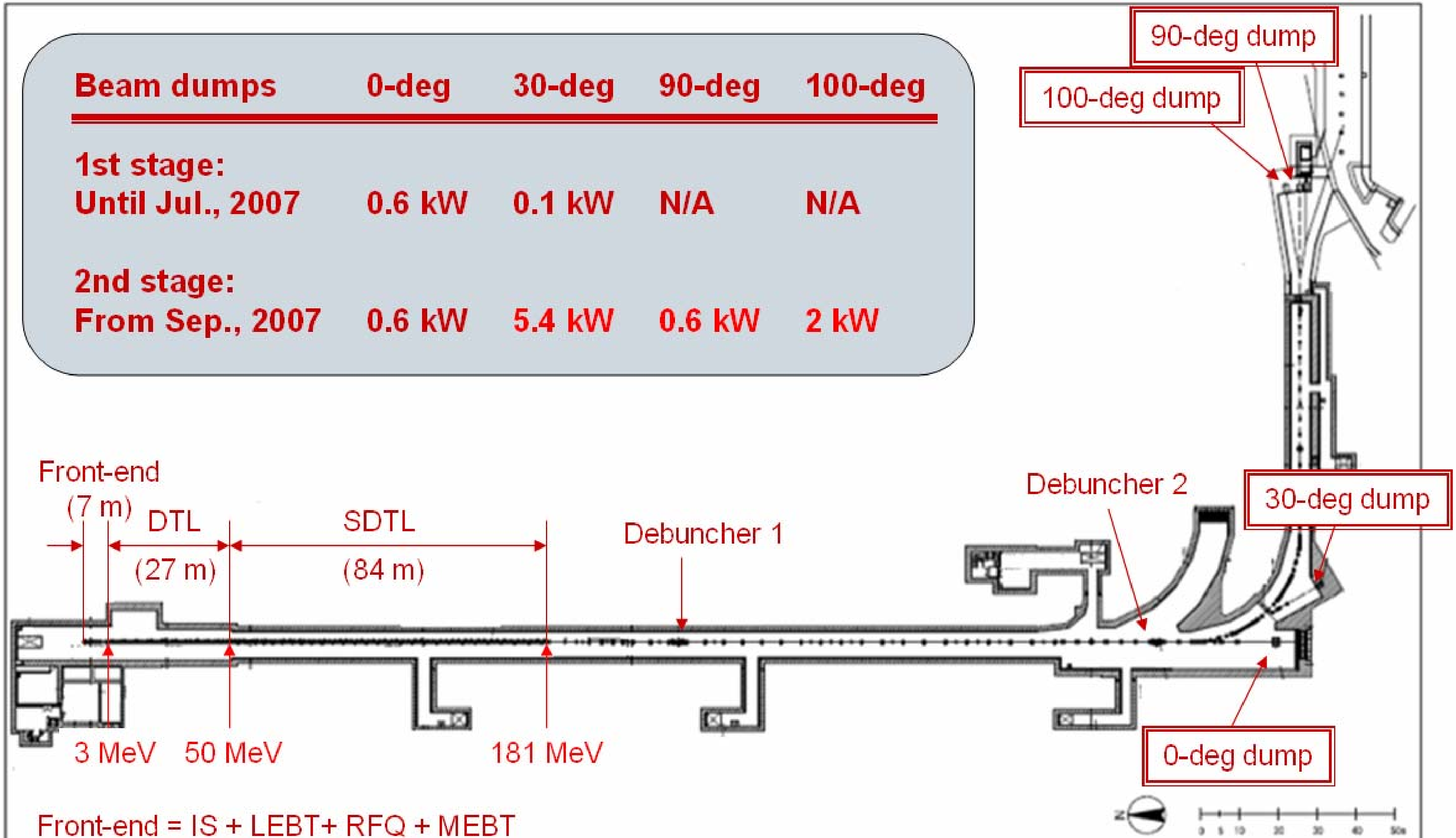
- Major Parameters
  - Accelerated particles: H^- (negative hydrogen)
  - Energy: 181 MeV, The last two SDTLs are debunchers (400 MeV for ACS, 600 MeV for SCC)
  - Peak current: 30 mA (50 mA for 1MW at 3GeV)
  - Repetition: 25 Hz (additional 25 Hz for ADS application)
  - Pulse width: 0.5 msec



Block Diagram of the Linac

Commissioning Stages

Beam dumps	0-deg	30-deg	90-deg	100-deg
1st stage: Until Jul., 2007	0.6 kW	0.1 kW	N/A	N/A
2nd stage: From Sep., 2007	0.6 kW	5.4 kW	0.6 kW	2 kW



Front-end = IS + LEBT+ RFQ + MEBT

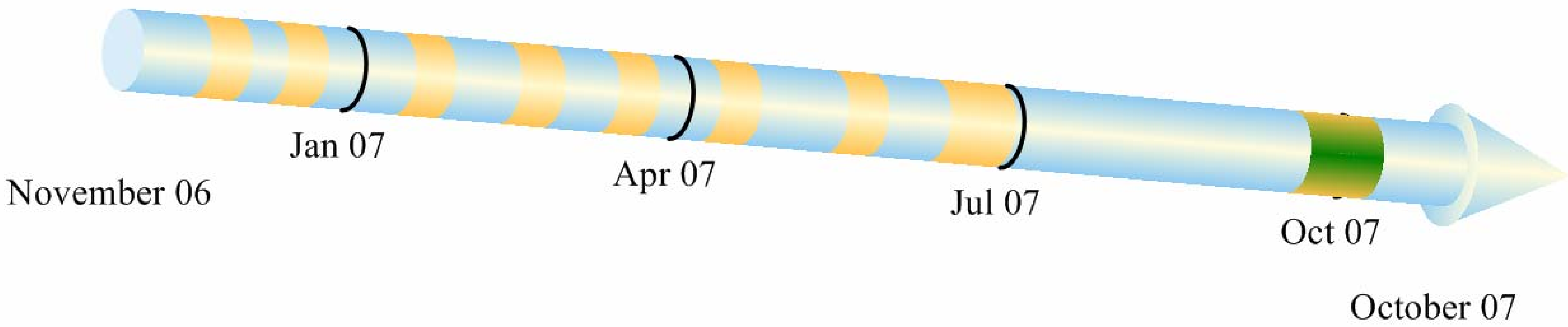
Priorities in the 1st Stage

- **To pass the government inspection for licensing**
  - Beam energy of 181 MeV
  - 20 % or more of the licensed beam power: 120 W beam power for 0-deg dump, 20 W for 30-deg dump
  - Radiation leakage should be less than the allowed limit

- **To realize the beam conditions to start RCS commissioning**
  - Energy: 181 MeV, peak current: 5mA, pulse width: 50μs, repetition: 5 Hz
  - Debuncher operation: control the momentum spread
  - Chopper operation: make gaps in the circulating beam
  - Single-bunch operation: reduce beam loss
  - Stable operation

Timeline of the Beam Commissioning

- Three or four weeks commissioning cycle.
- A two week beam commissioning run and a one or two week interval.



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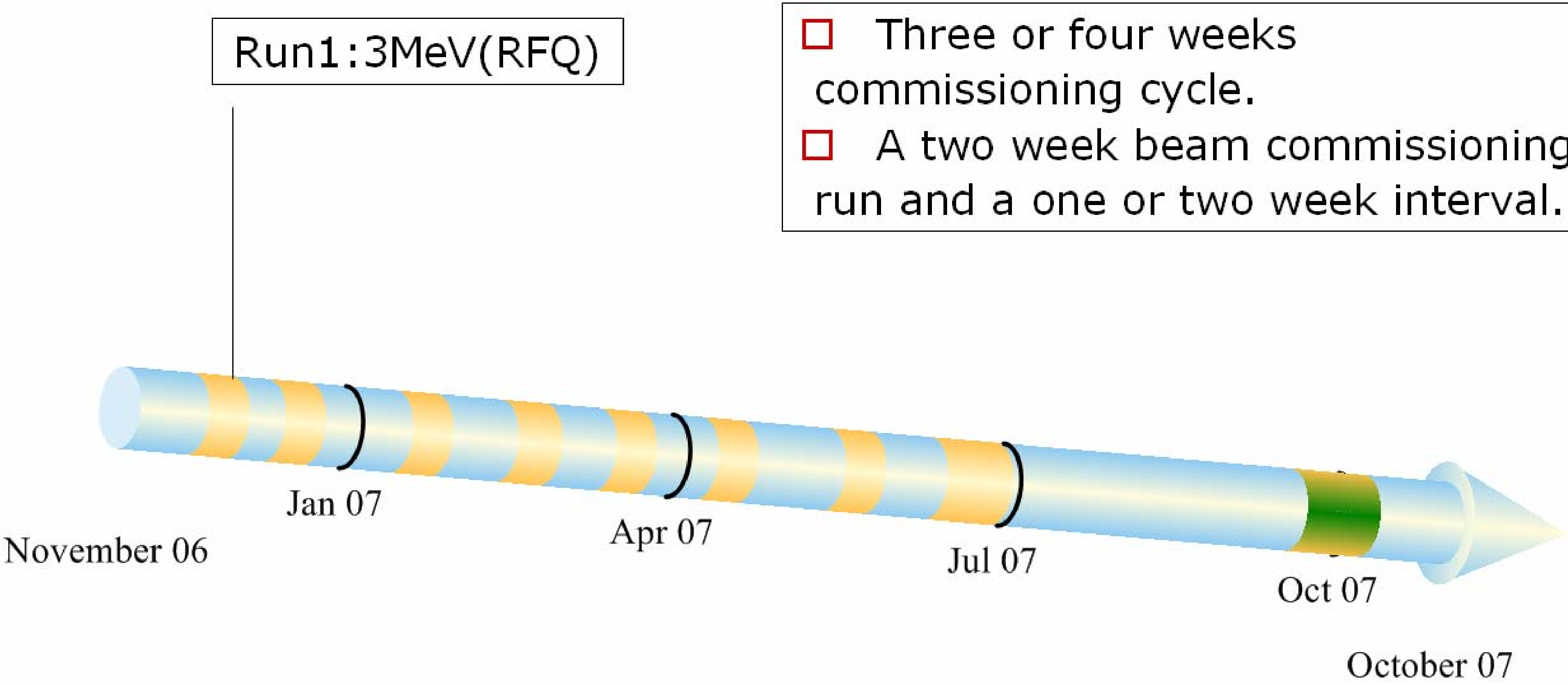

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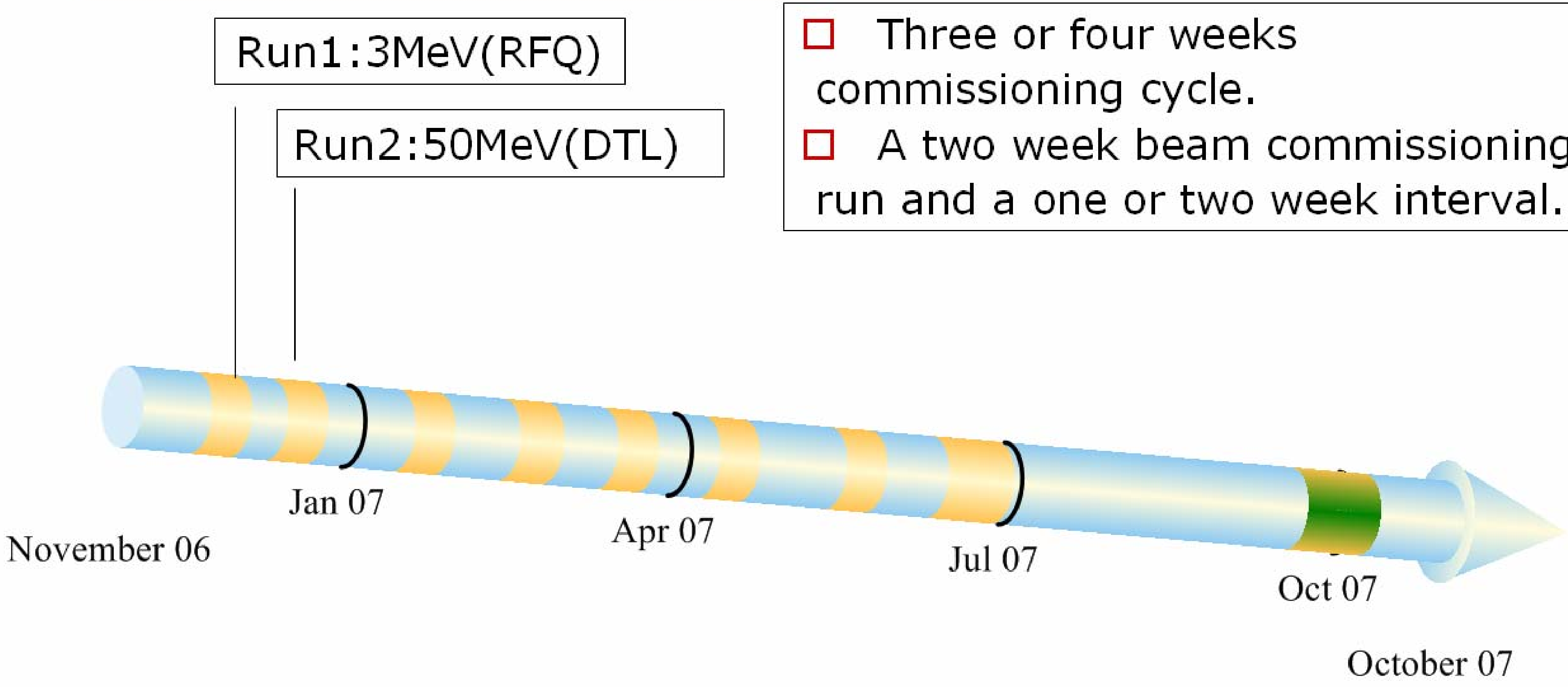


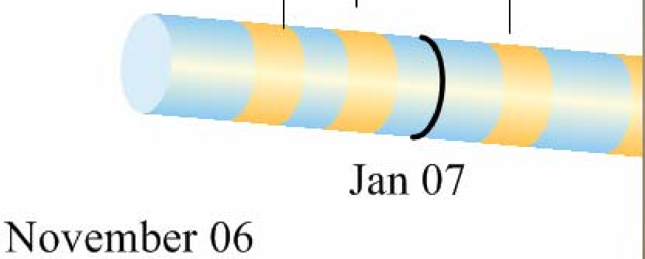
Timeline of the Beam Commissioning

Run1:3MeV(RFQ)

Run2:50MeV(DTL)

Run3:181MeV(SDTL)

- Three or four weeks commissioning cycle.
- A two week beam commissioning run and a one or two week interval.



Timeline of the Beam Commissioning

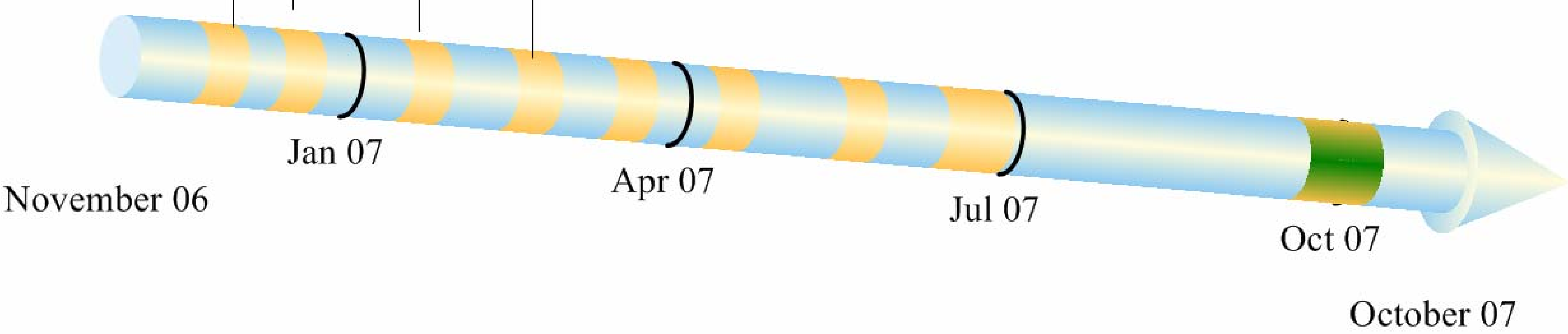
- Three or four weeks commissioning cycle.
- A two week beam commissioning run and a one or two week interval.

Run1:3MeV(RFQ)

Run2:50MeV(DTL)

Run3:181MeV(SDTL)

Run4:Government Inspection



Timeline of the Beam Commissioning

- Three or four weeks commissioning cycle.
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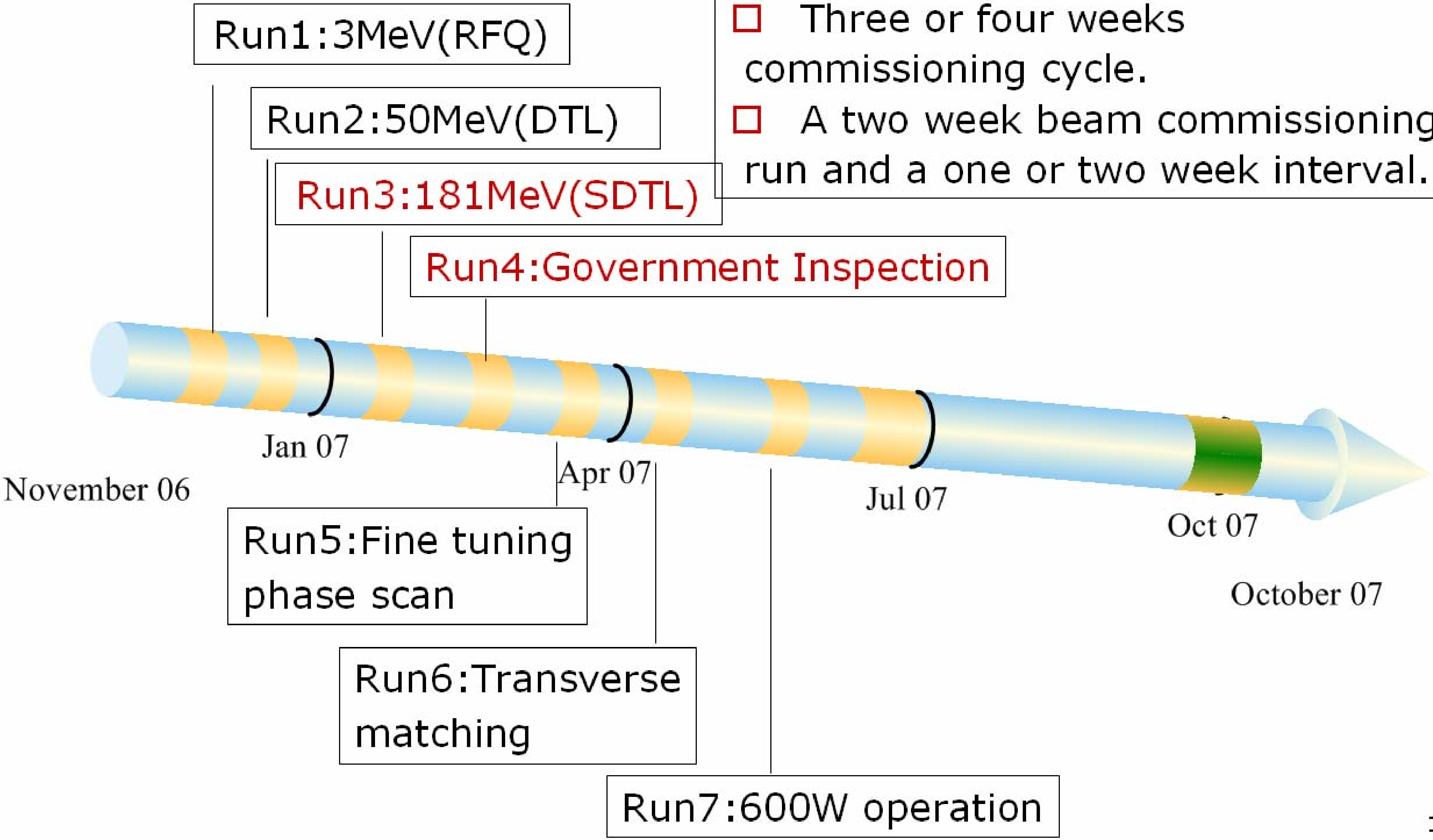

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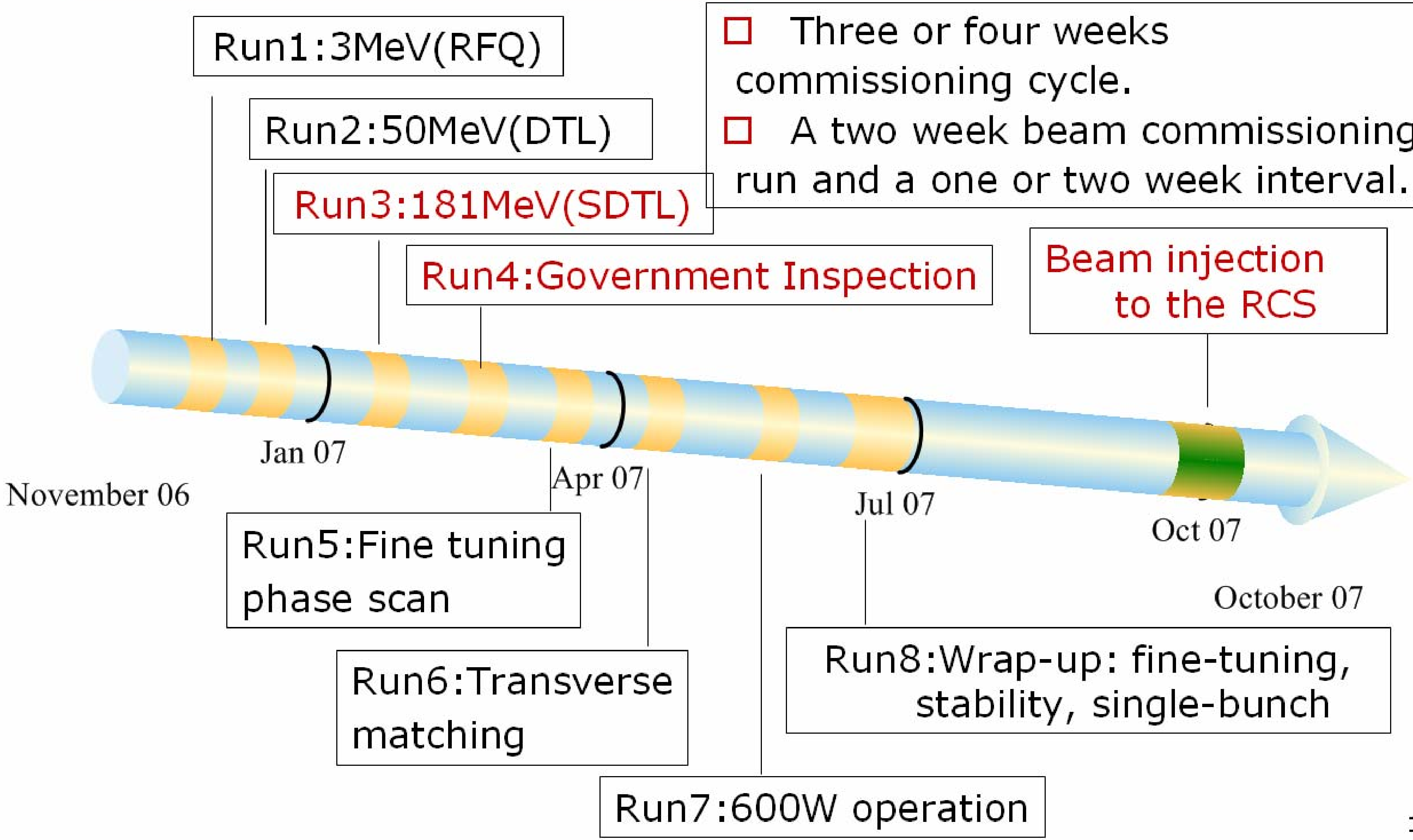
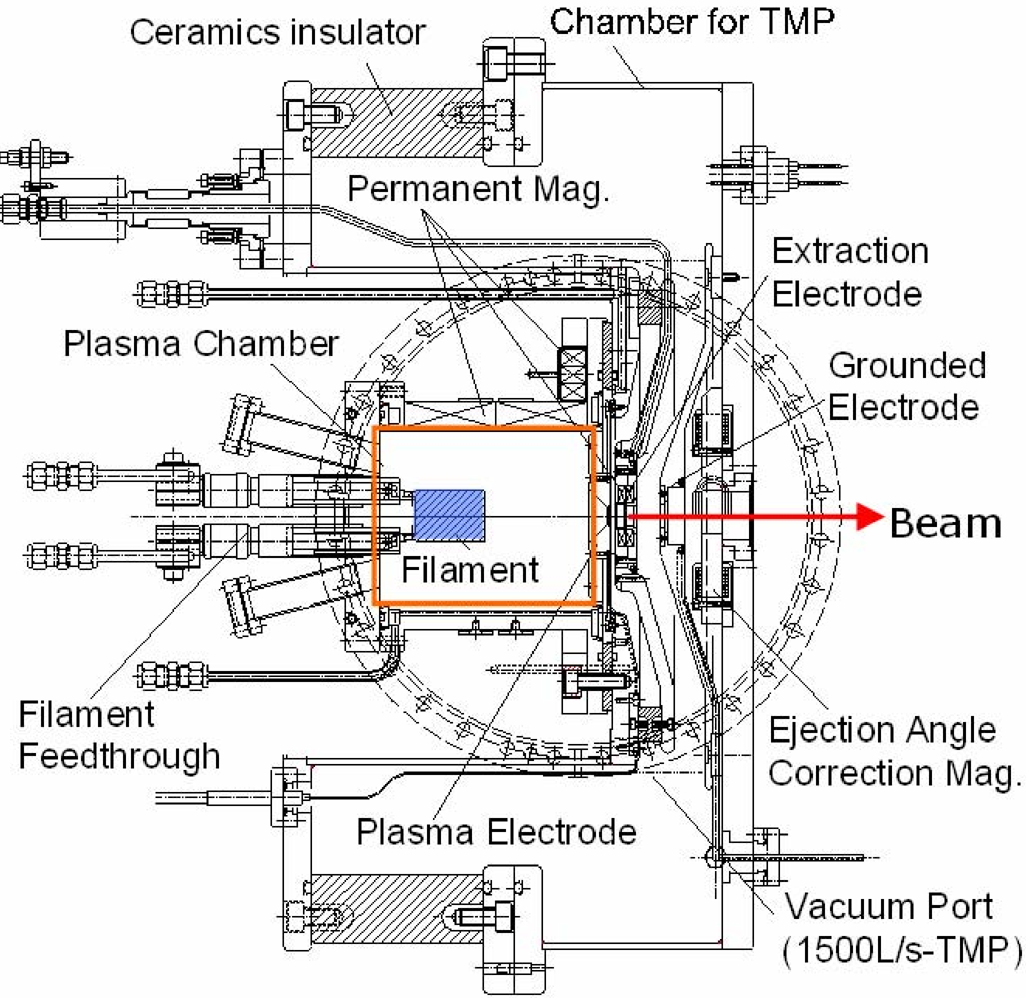


Ion Source



J-PARC Ion source

*Plasma production :
Cesium free
Arc discharge (LaB6 filament)

*Plasma chamber :
100mm diam. 120mm length

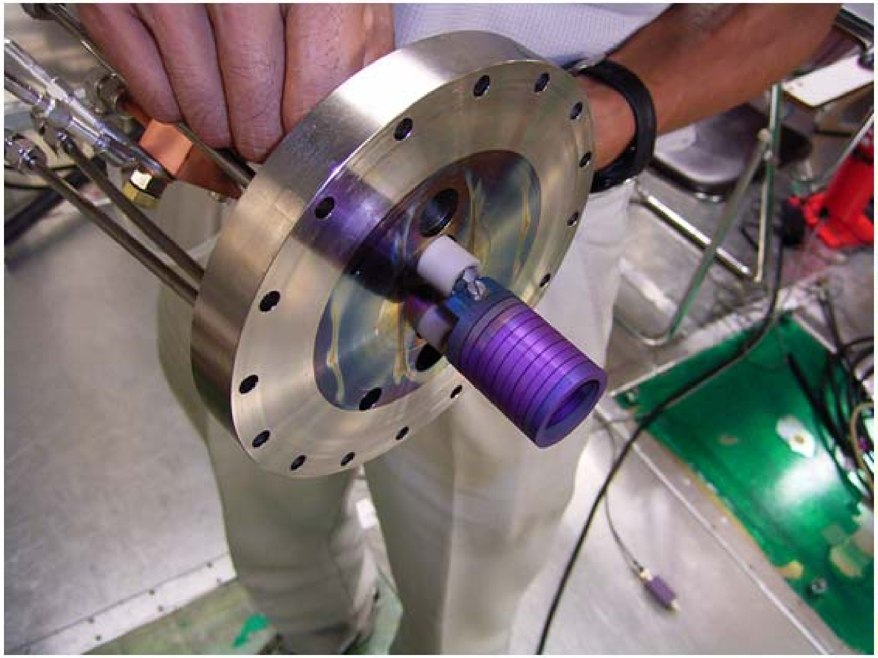
*Number of filament : 1

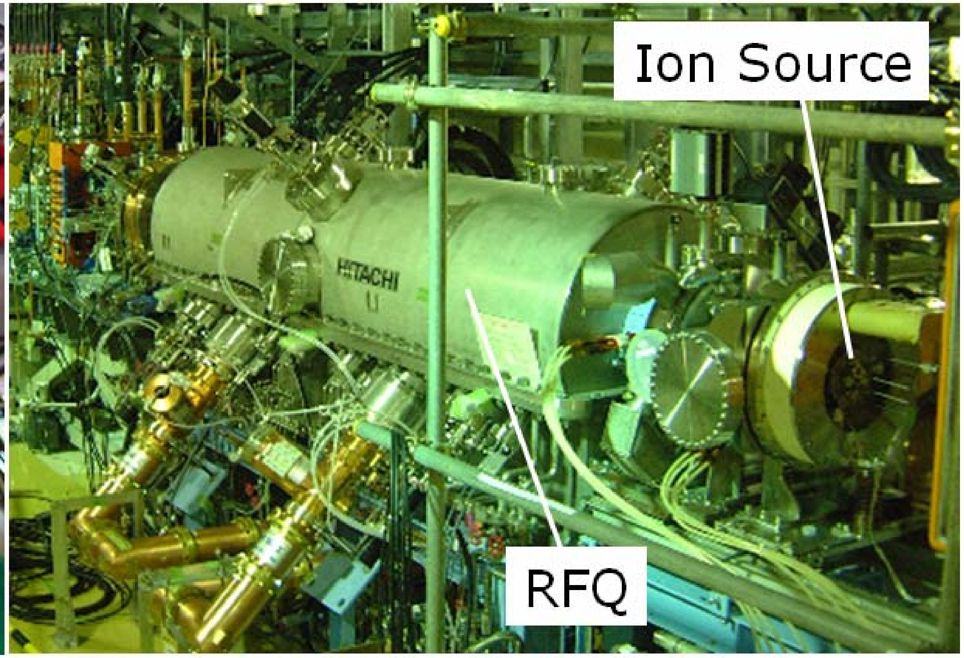
*Beam aperture : 9mm diam.

*Number of electrode : 3

*electron suppression :
magnets in extraction electrode

Ion Source





LaB6 filament

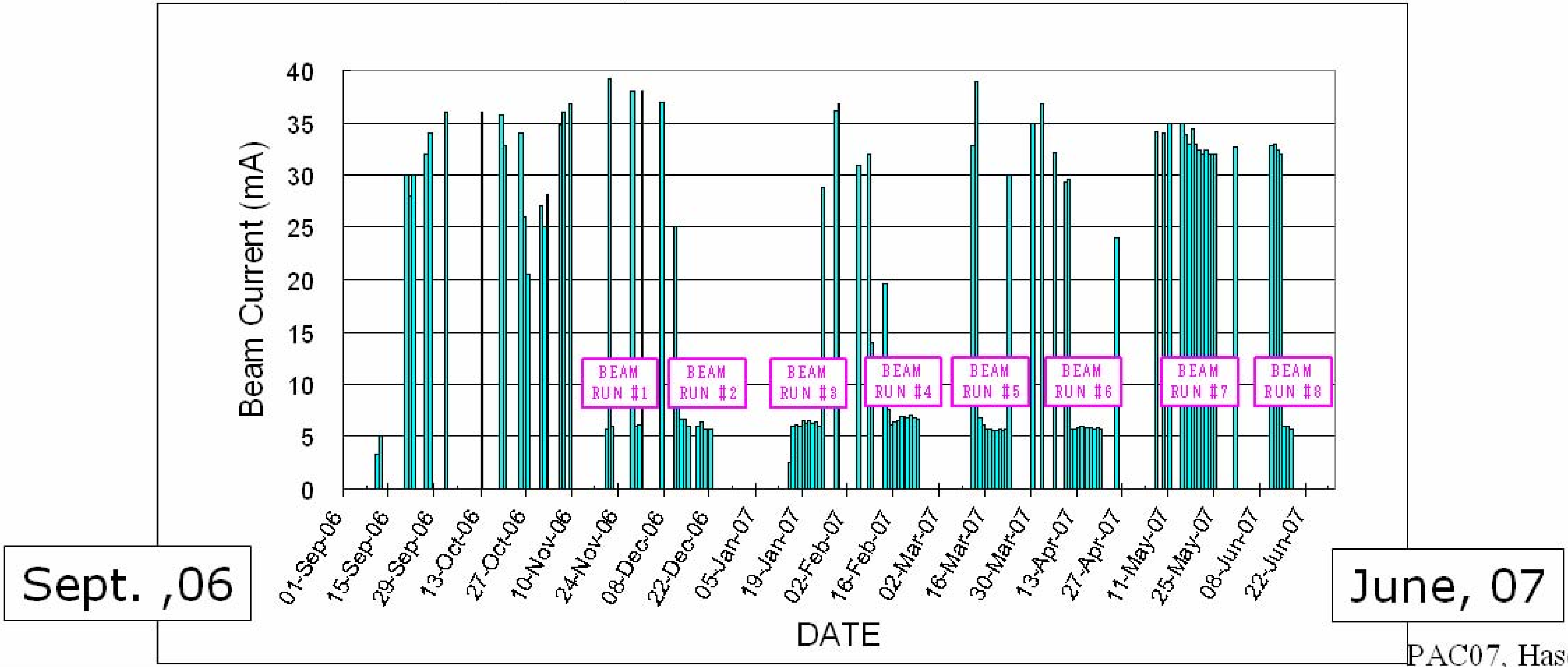
The ion source is driven with a helix type LaB6 filament. (29.5mmD, 49mmH).

Ion source and RFQ

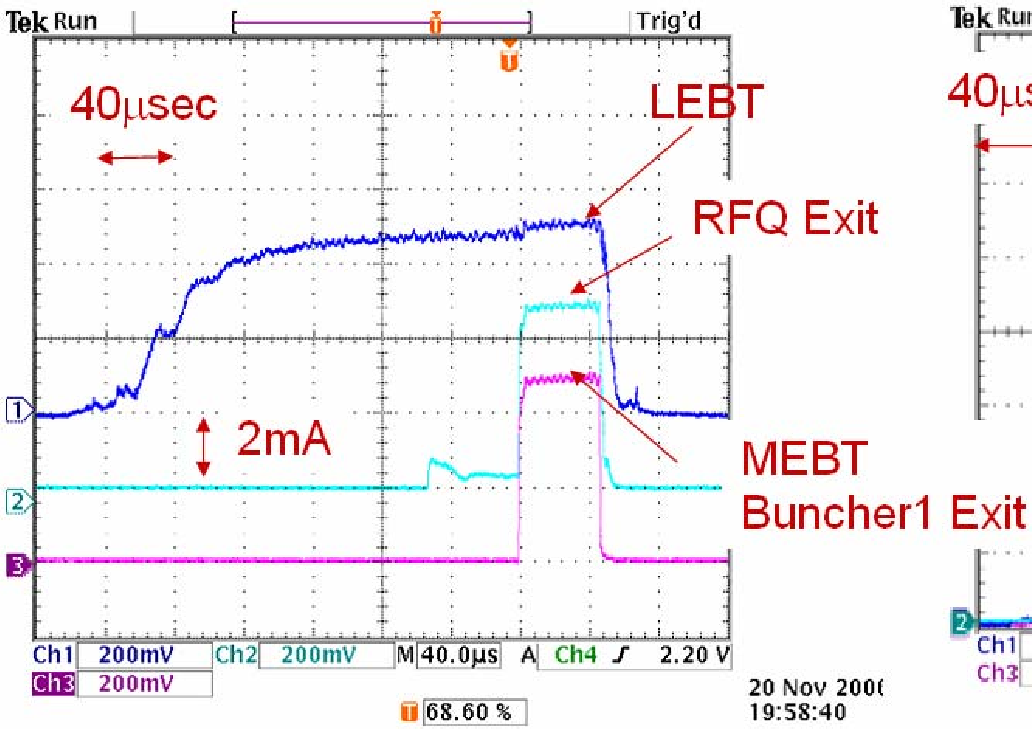
The ion source is in the insulator to take minimum length to the RFQ.

Operation History of the Ion Source

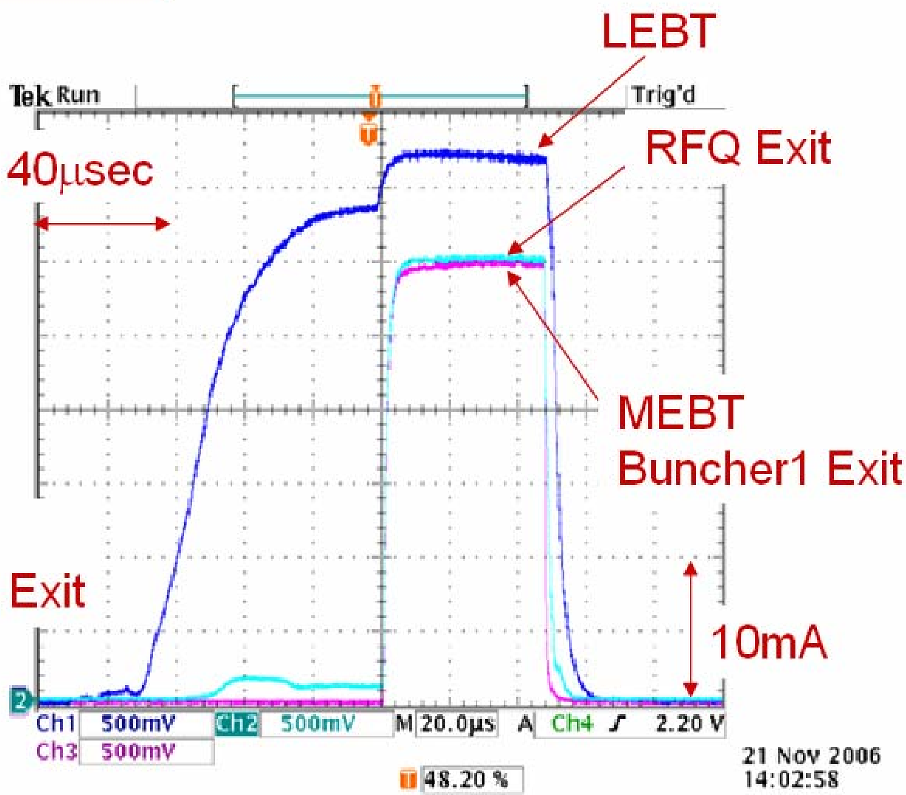
- The same LaB6 filament has been used since the operation was started on 11-Sep-2006.
  Ion source R&D operation : 274 hours: typical intensity 33 mA (~55kW, ~0.8%)
  Linac beam commissioning operation : 370 hours: typical intensity 5.5 mA (~25kW, ~0.8%)
  -> Total operating time (= filament lifetime) : 644 hours (as of 17-Jun-2007)
- The lifetime will be extended furthermore because we have not observed remarkable filament consumption yet.



Waveforms at the Front End



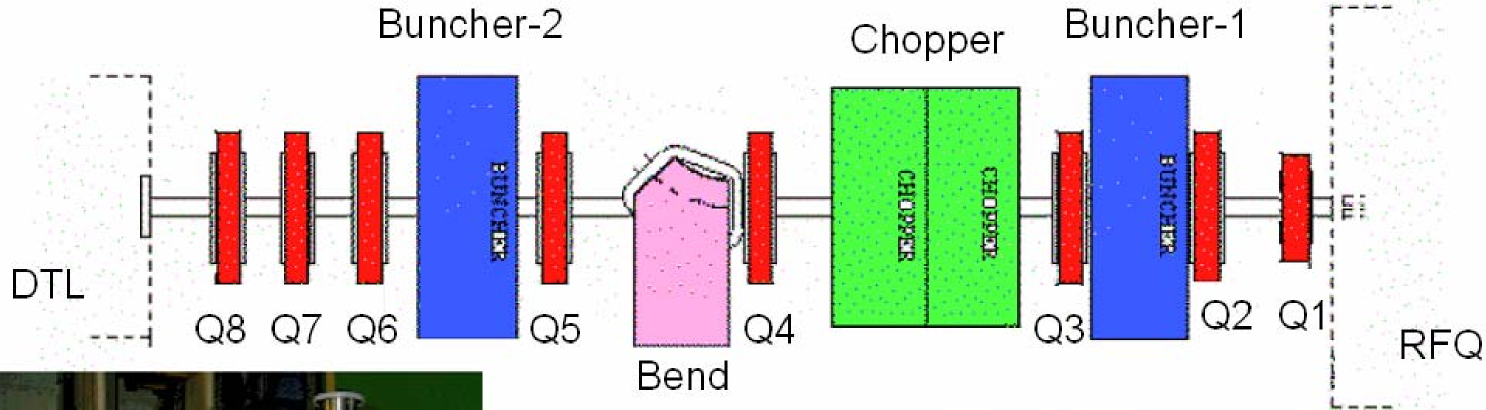
Waveforms at 5mA（3MeV, 50μs, 5Hz)

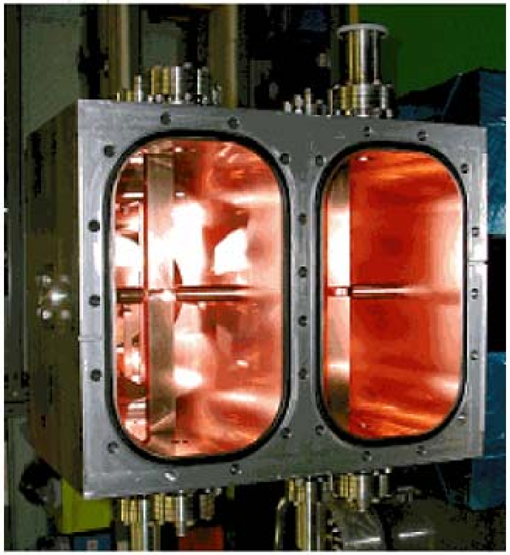


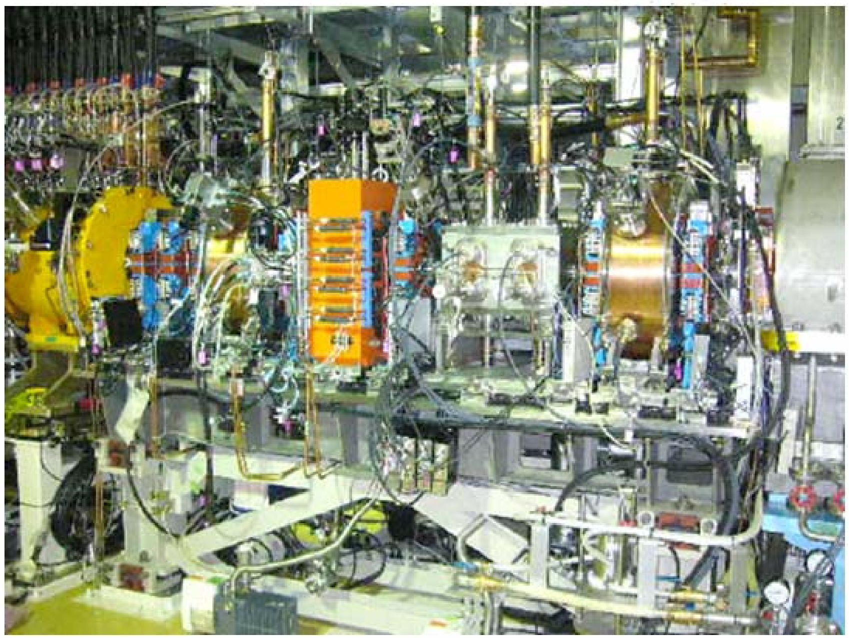
Waveforms at 30mA（3MeV, 50μs, 5Hz)

Ion source acceleration voltage is modulated by 12.5kV during the RFQ acceleration.

Medium Energy Beam Transport

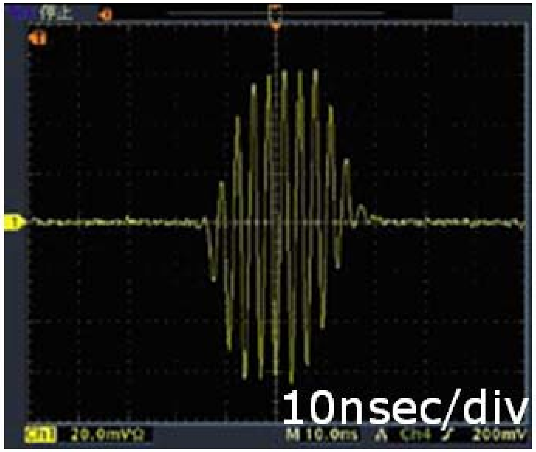


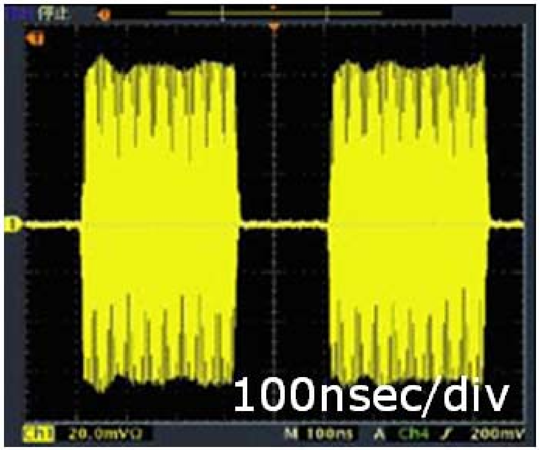




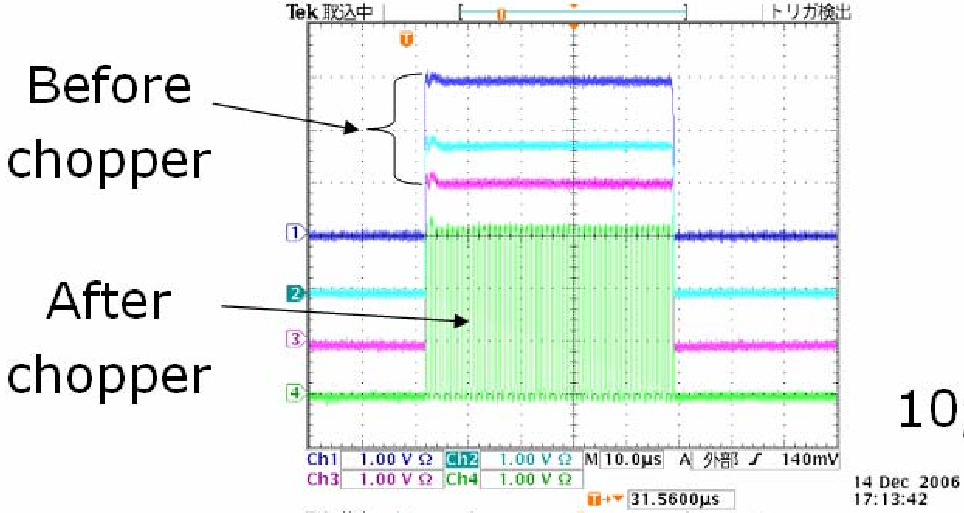
Inside of the chopper cavity
324 MHz, Mode TE11, QL~11
Rise and Fall times: 15 nsec

Beam Chopping

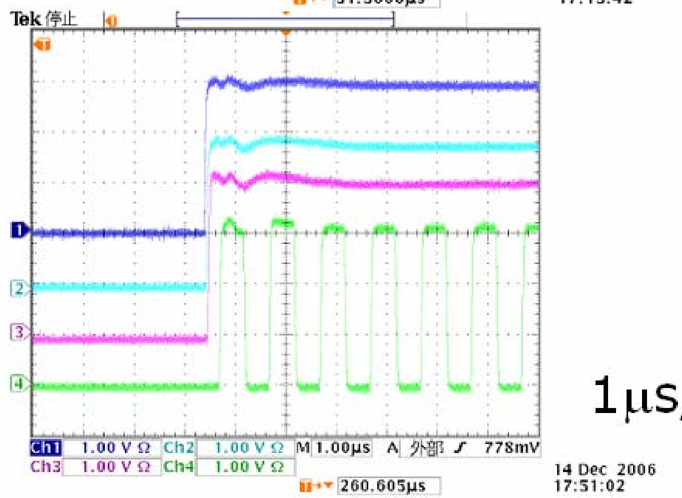




Signal of a chopped beam measured by a BPM at KEK in 2003.



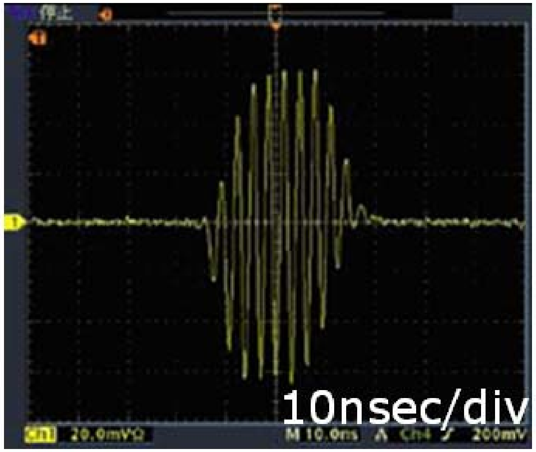
10μs/div

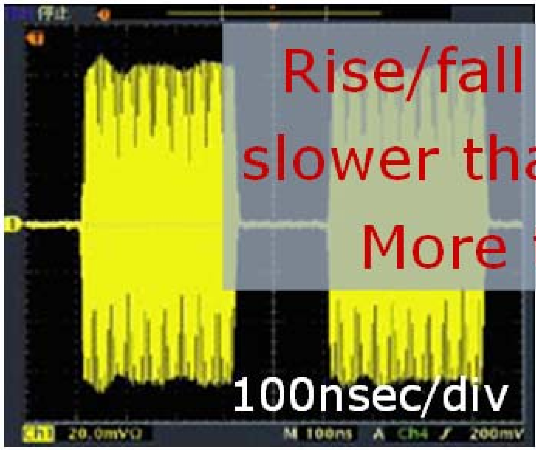


1μs/div

Signal of a chopped beam in the commissioning run.

Beam Chopping

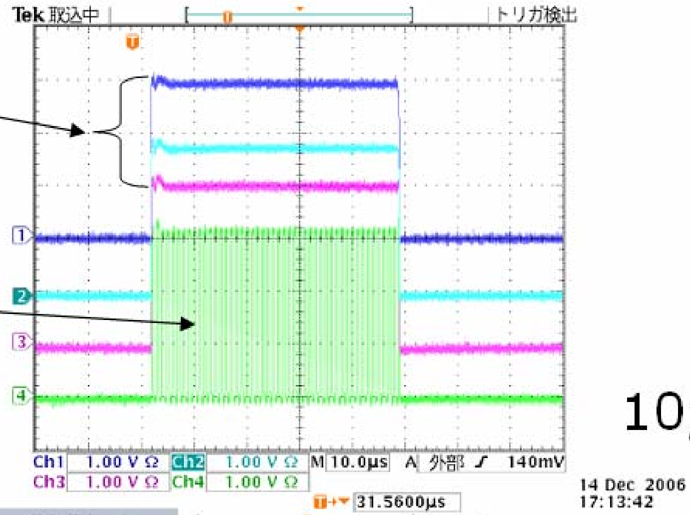




Signal of a chopped beam measured by a BPM at KEK in 2003.

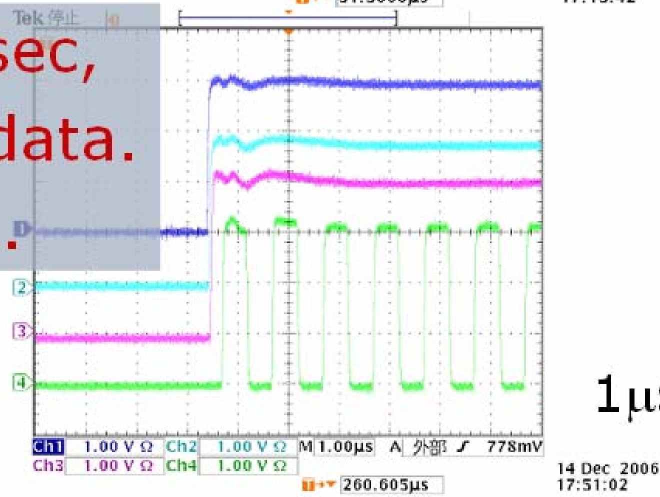
Before chopper

After chopper



10μs/div

Rise/fall time is 20-30 nsec, slower than the previous data. More tuning is needed.



1μs/div

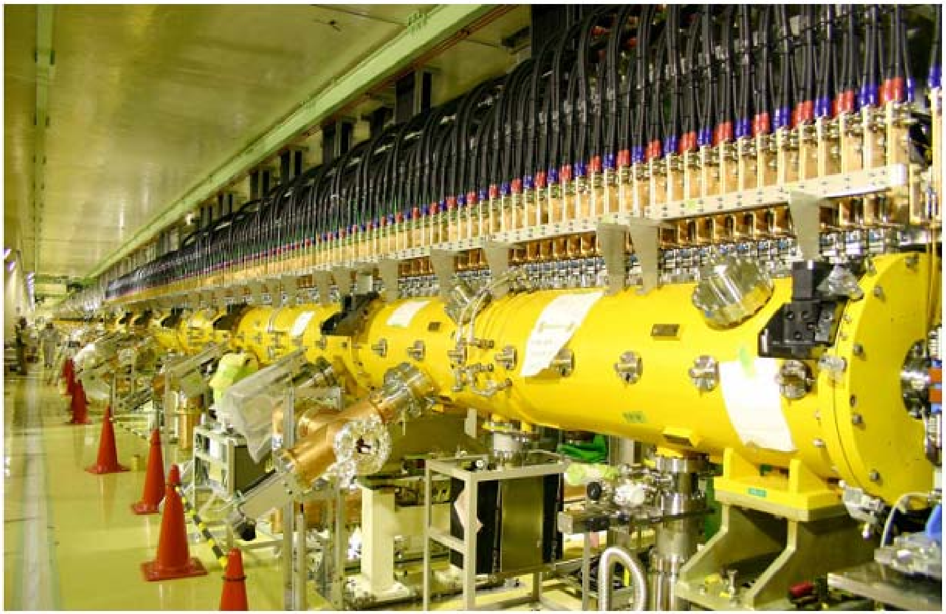
Signal of a chopped beam in the commissioning run.

DTL/SDTL

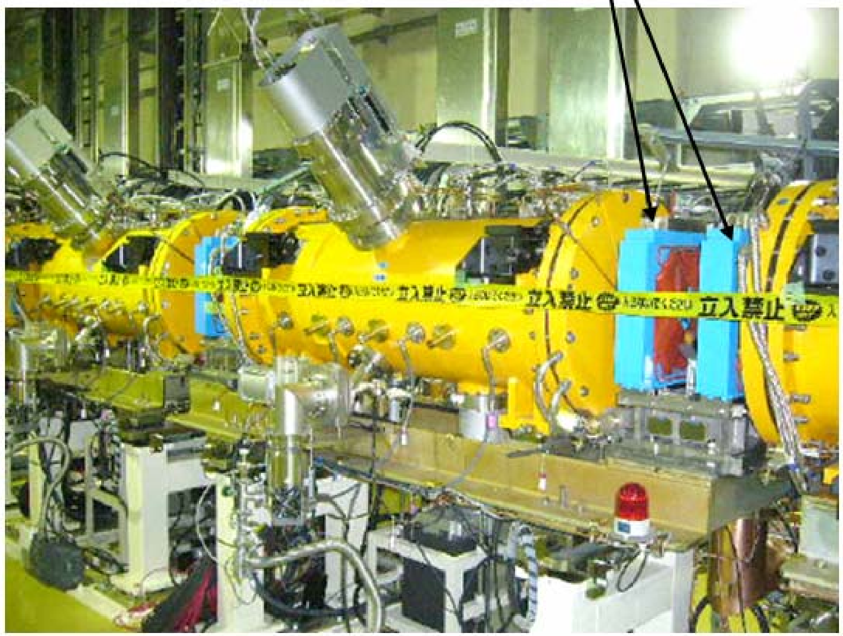
Main Parameters

	DTL	SDTL	
Energy	3-50	50-190.8	MeV
Frequncy	324	324	MHz
Section Length	27.1	91.2	m
Accelerating Field, E0	2.5-2.9	2.5-3.7	MV/m
Number of Cavities	3	32	

Q-magnets



DTL



SDTL

DTL/SDTL

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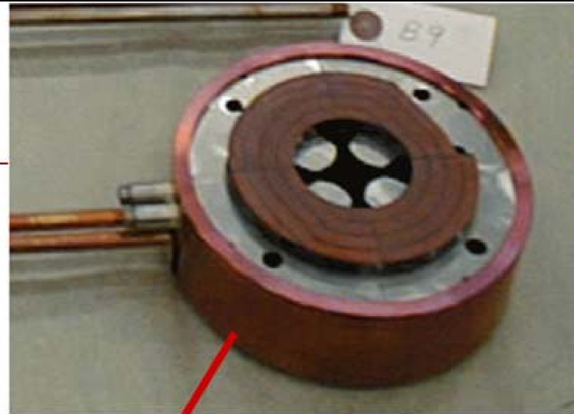
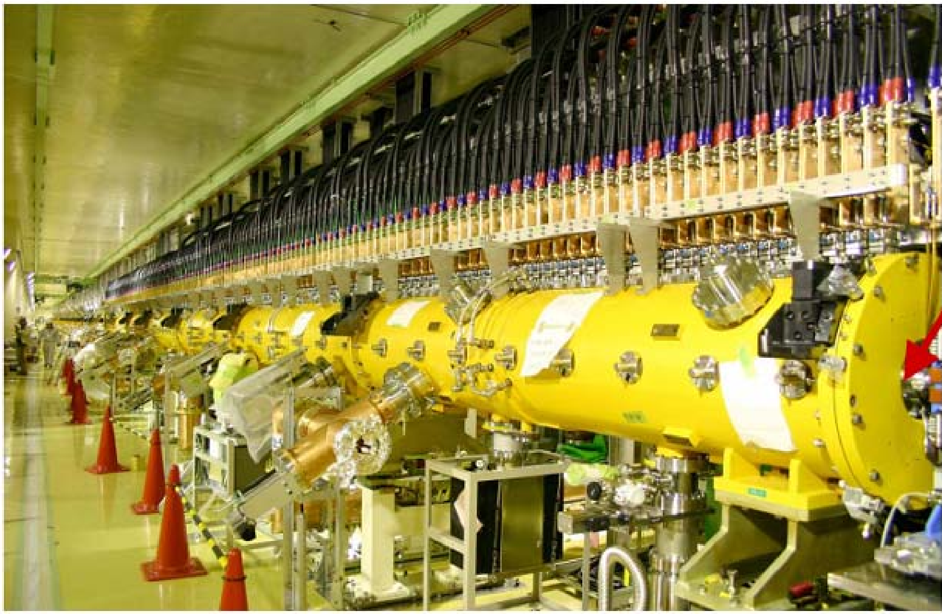
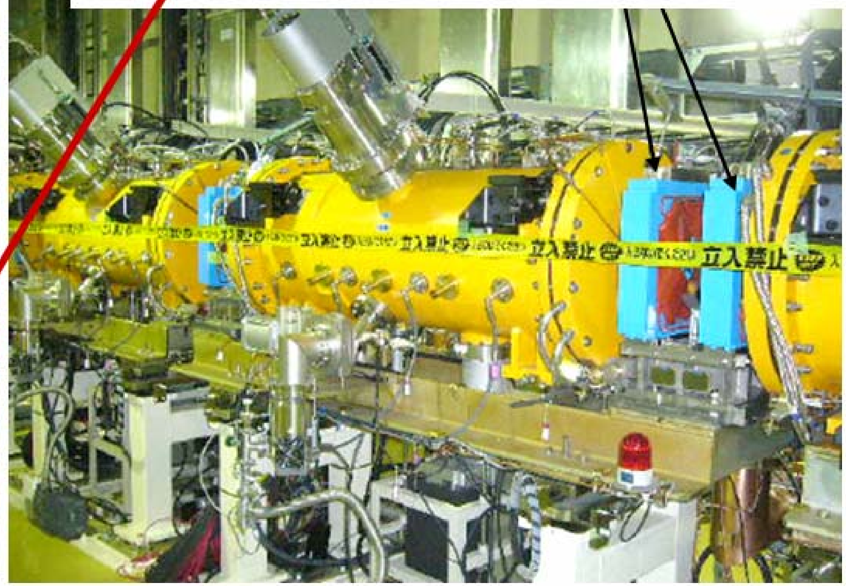


Compact electro-quadrupole magnets are accommodated as tuning knobs.



DTL



SDTL

DTL/SDTL

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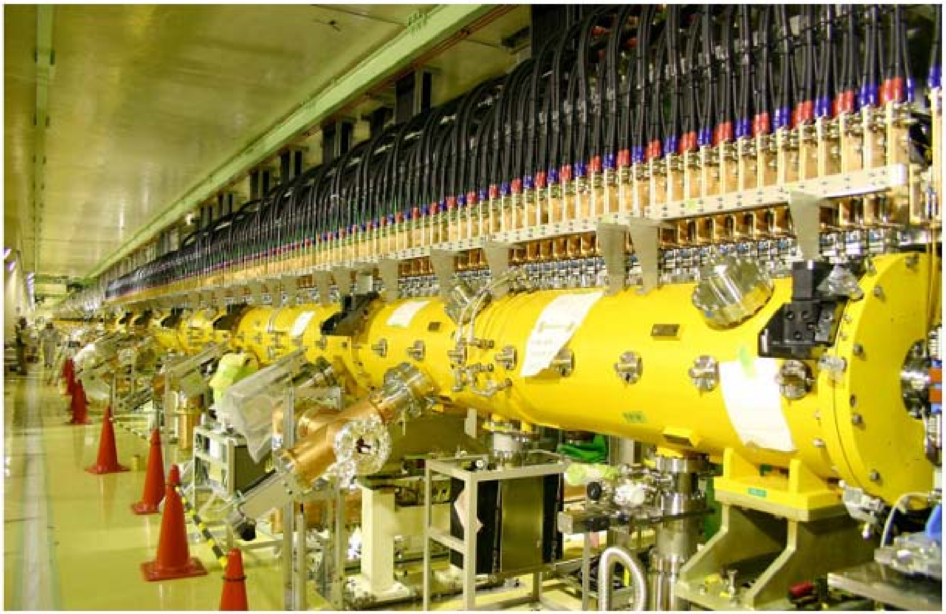
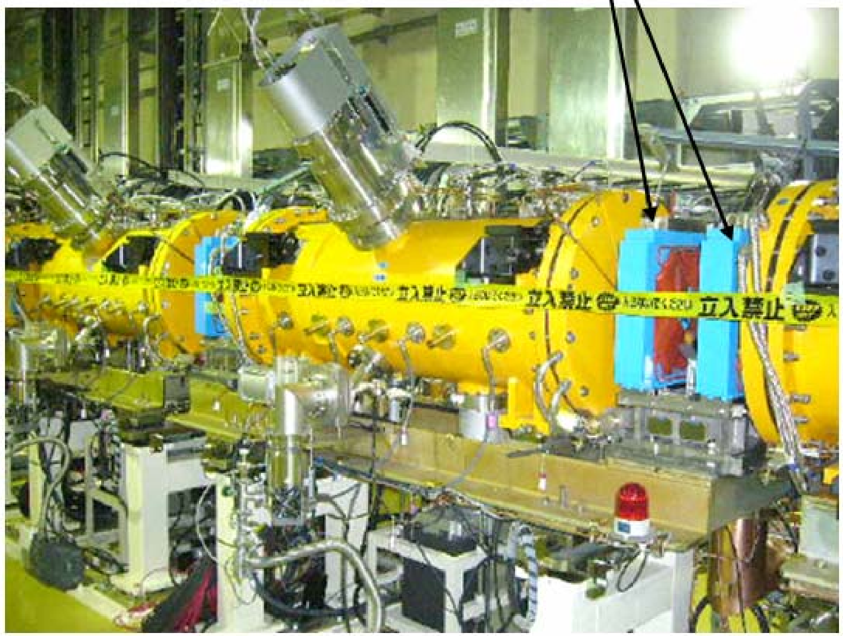


DTL

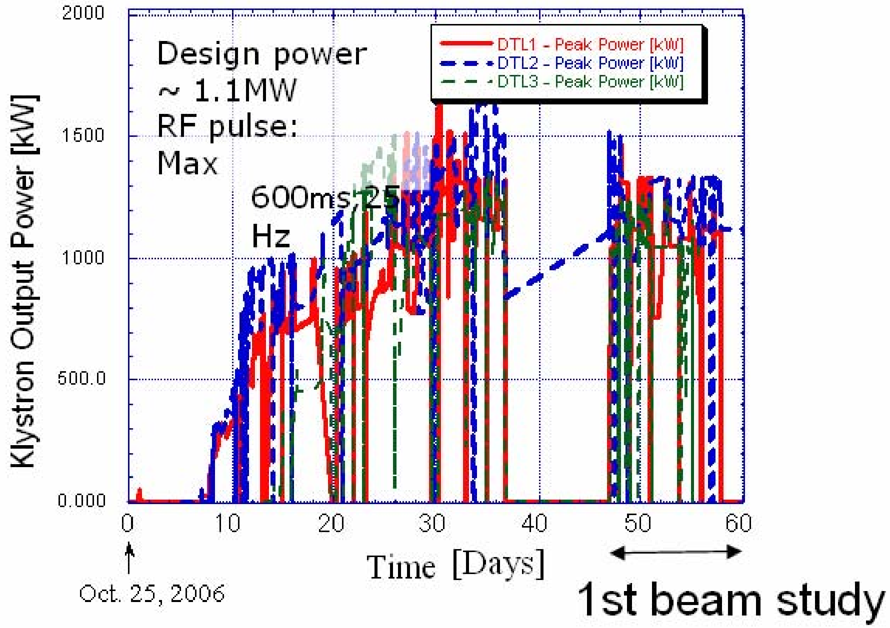


SDTL

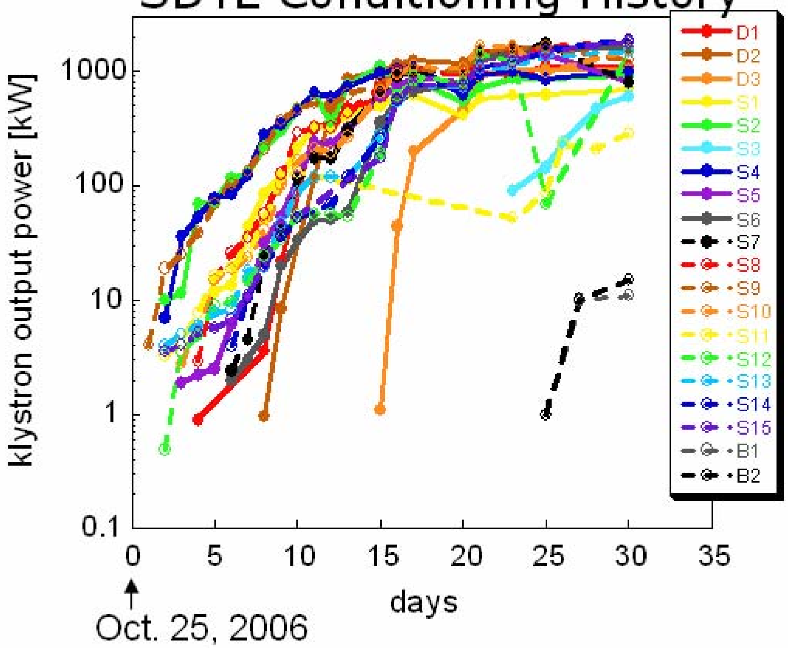
Cavity Conditioning

TUPAN058

DTL Conditioning History



SDTL Conditioning History



We achieved the design power about in a month.

Fault rate: about 6~8 trips / hour/ linac (20 klystrons) , higher than the expectation of 2.

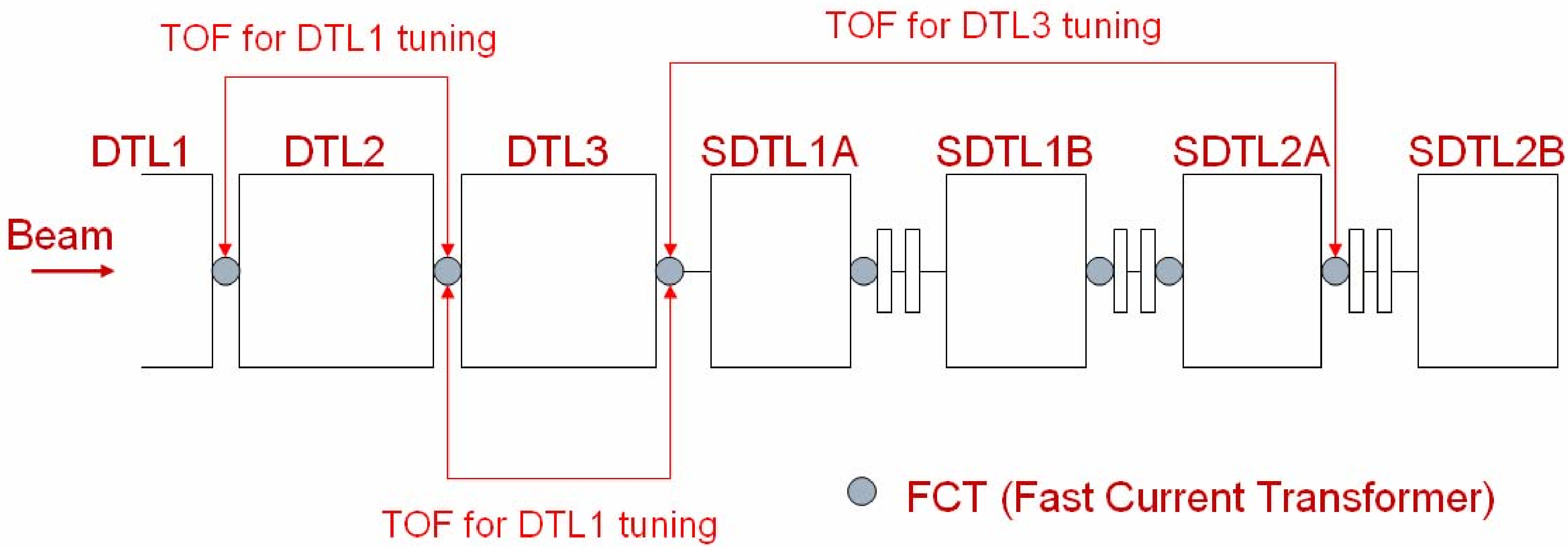
Cause of fault :

Some cavities need more conditioning time.

Reflection, Arcing (recover automatically in 1 s)

DCPS #3 HV down (1 fault / day) by noises to the trigger circuit

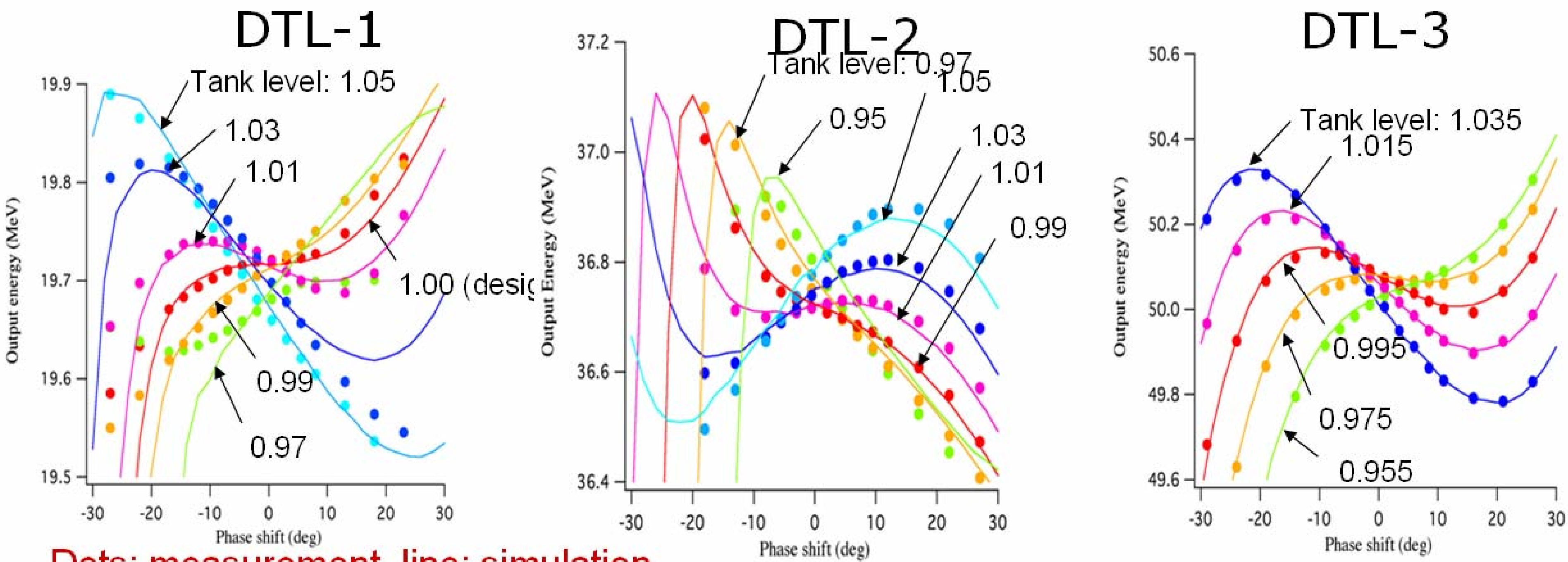
DTL Tuning: TOF and Phase Scan



A phase-scan tuning has been performed measuring the output energy with Time-of-Flight (TOF) method using two downstream FCT's.

The tank between the FCT pair is to be turned off and detuned while tuning to avoid influences on the TOF measurement.

DTL Phase Scan

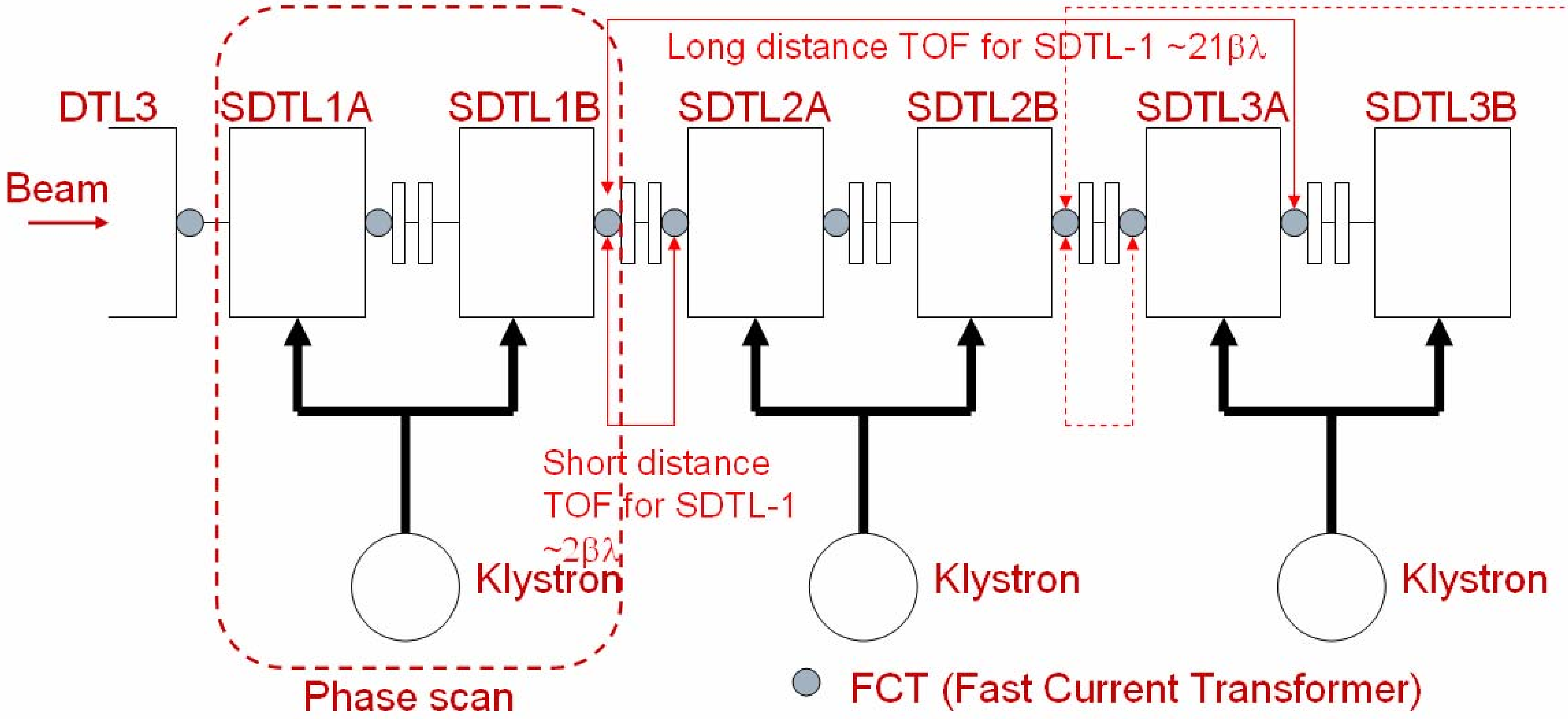


Dots: measurement, line: simulation

- The experimental results in dots and the simulation results show a reasonable agreement in the vicinity of the design set point, while they tend to deviate with lower tank level.
- The current FCT-TOF performance meets the tuning goal of 1degree and 1%.

TUPAN053

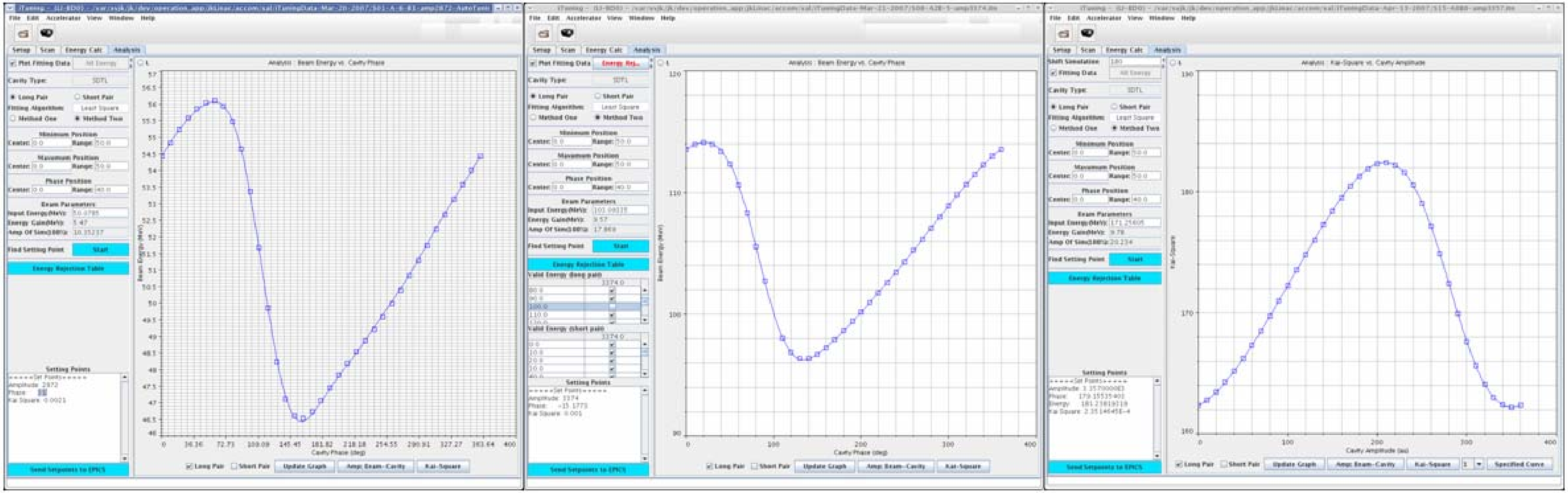
SDTL Tuning: Phase Scan



- Setting of the RF phase and amplitude is also used by phase scan method.
- The two neighboring tanks are driven by one klystron. The RF phase and amplitude tuning is performed klystron by klystron.
- Short base-line pair and long base-line pair are used: to avoid miscounting of the wave number of the long pair.

SDTL Phase Scan

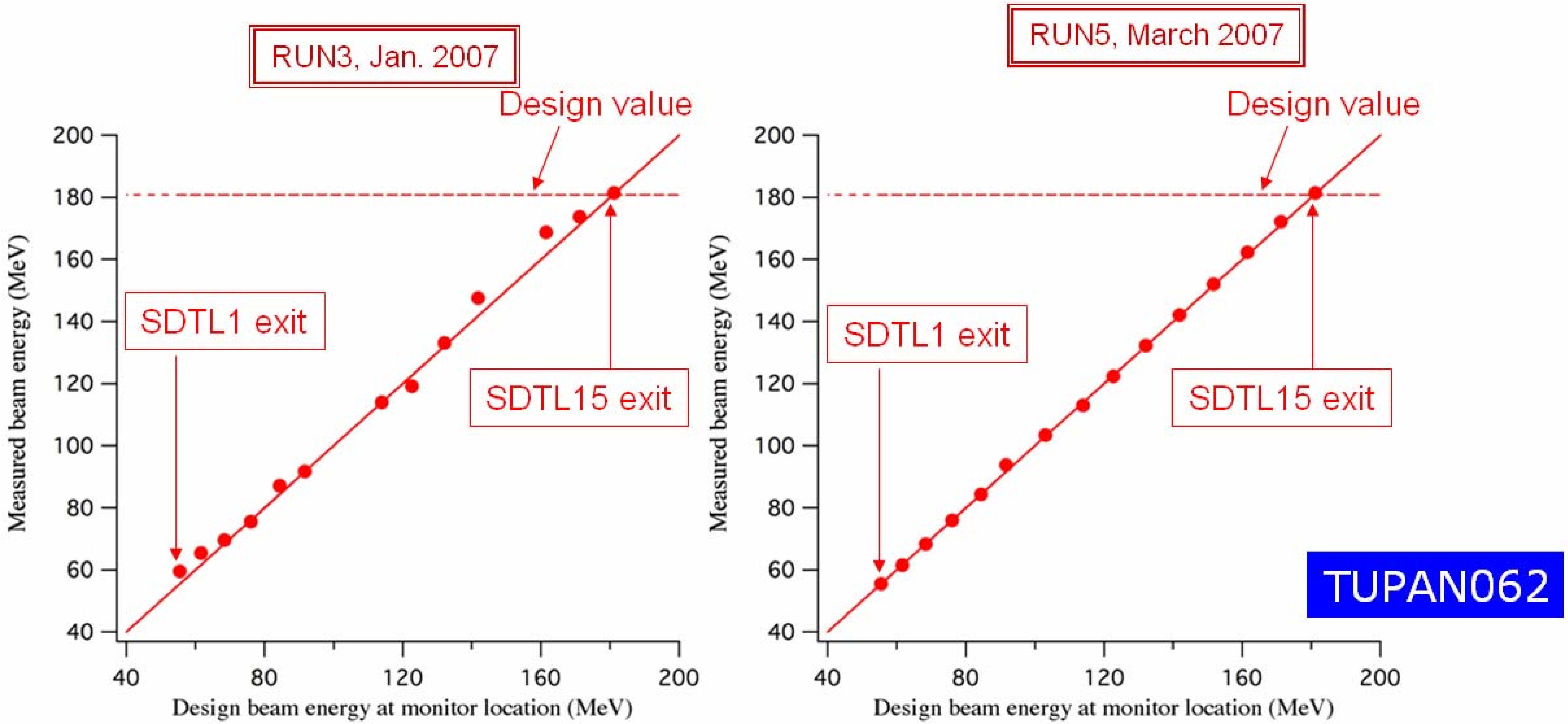
SDTL1 SDTL8 SDTL15



Dots: measurement, line: simulation

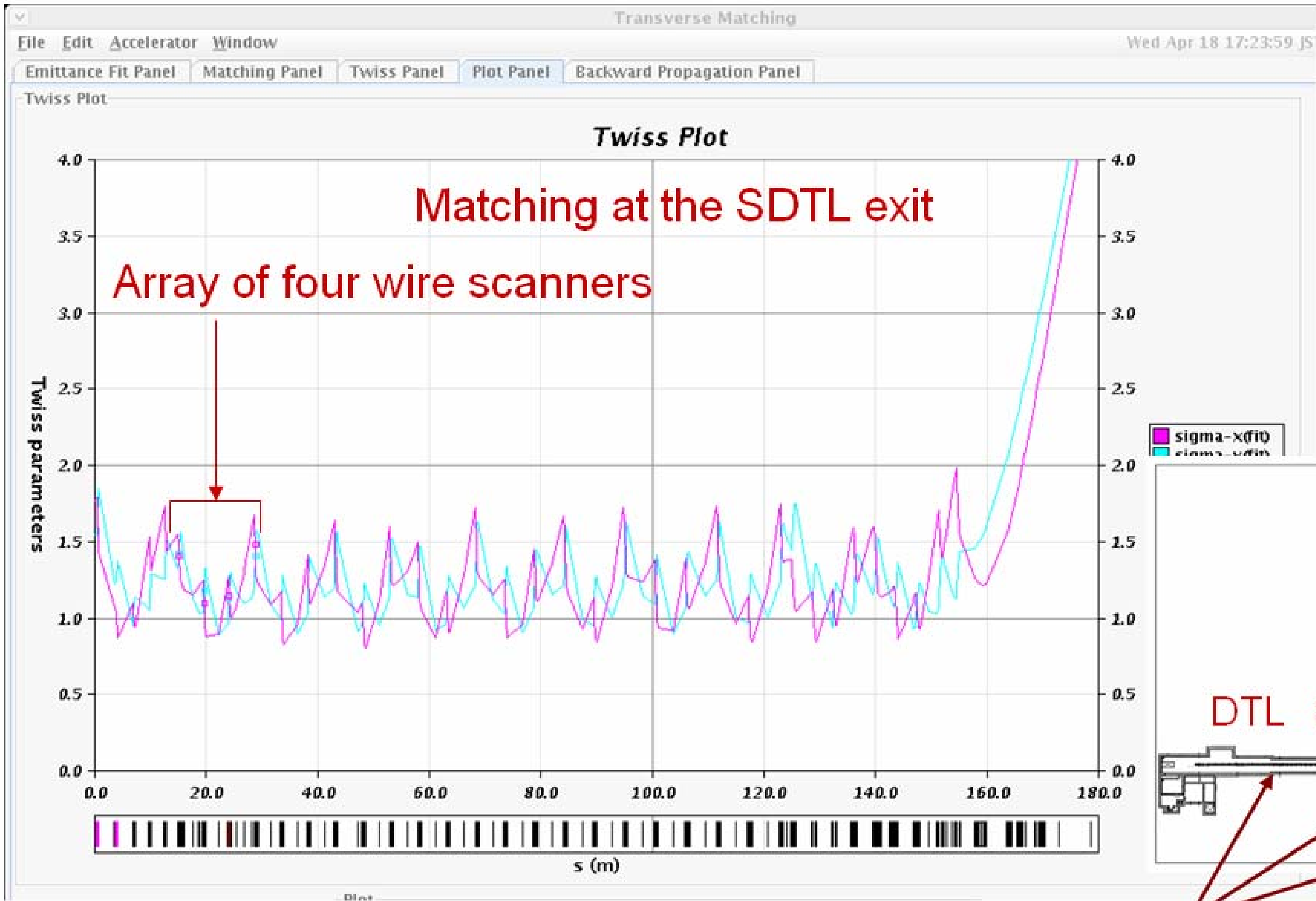
- Excellent match for the phase signature with simulations.
- The current FCT-TOF performance meets the tuning goal of 1degree and 1%.

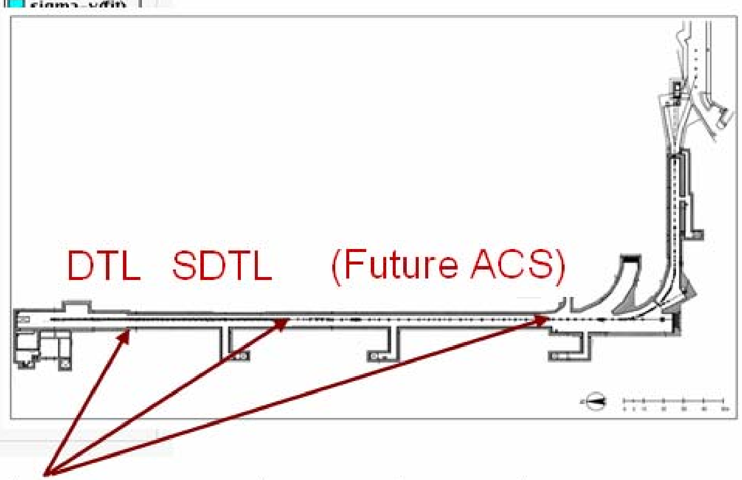
SDTL Phase Scan Results: Energy



- The RF tuning was rough in January, the 1st acceleration of 181 MeV. The energies of each unit is somewhat deviated from the design energy.
- After the fine tuning in March, the energy of each unit matches well to the design energy.

Transverse Matching



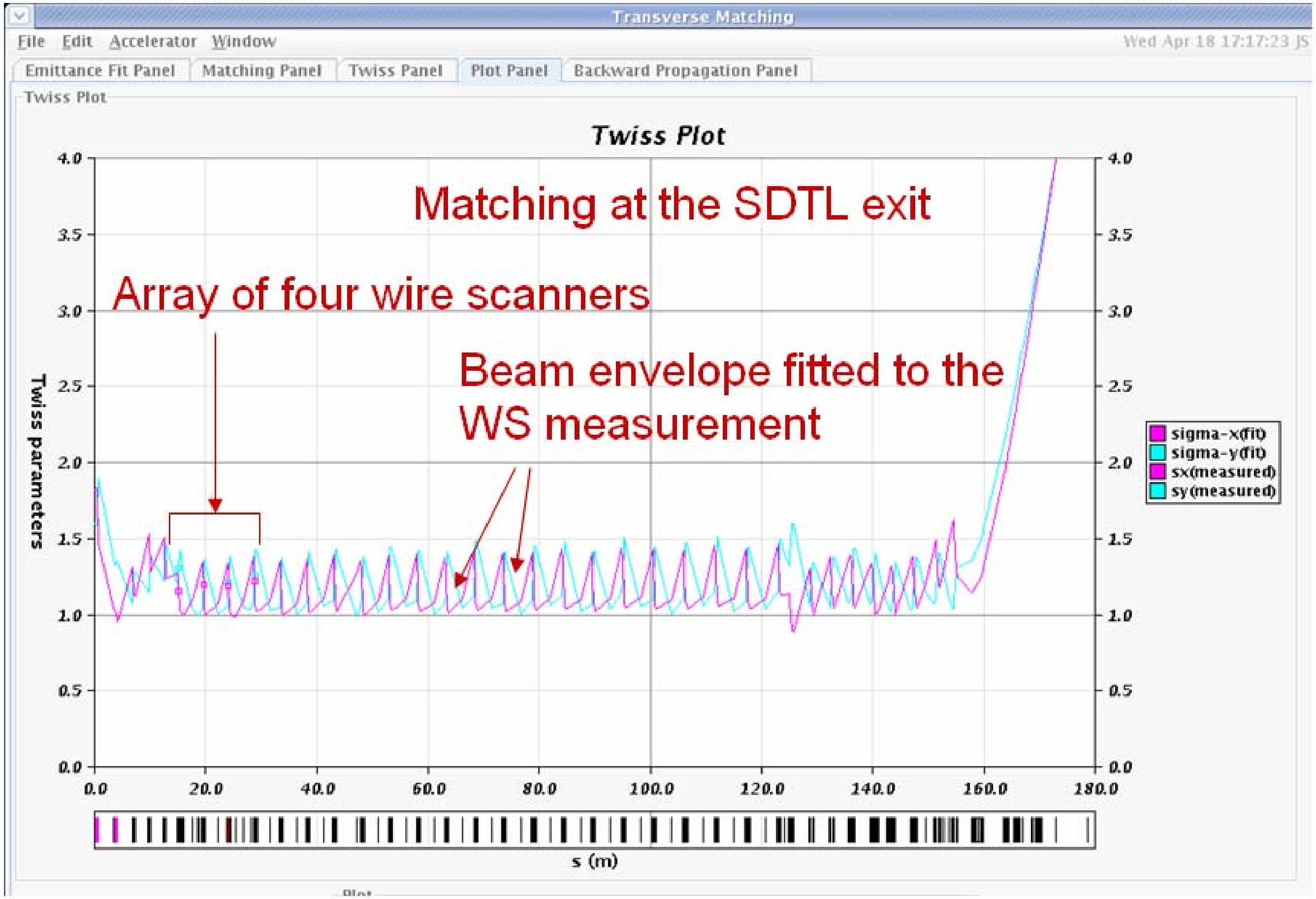


Before matching

MOPAN044
TUPAN039
THPAN043

- A model-based transverse matching has been conducted at three matching sections in the linac and the succeeding beam transport.
- This figure shows the envelopes after the SDTL before matching.

Transverse Matching (cont.)

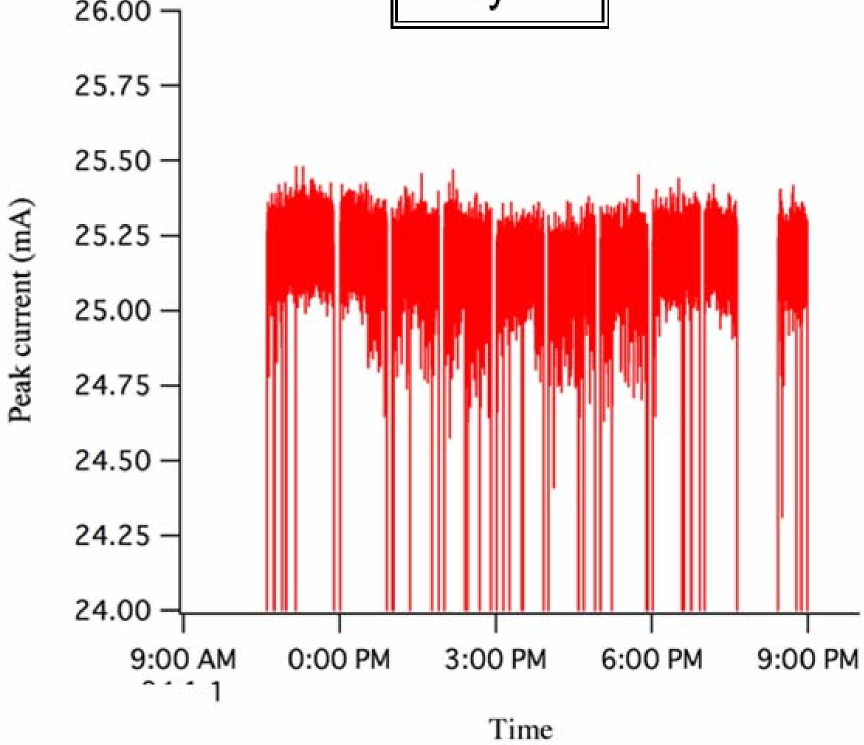


After matching

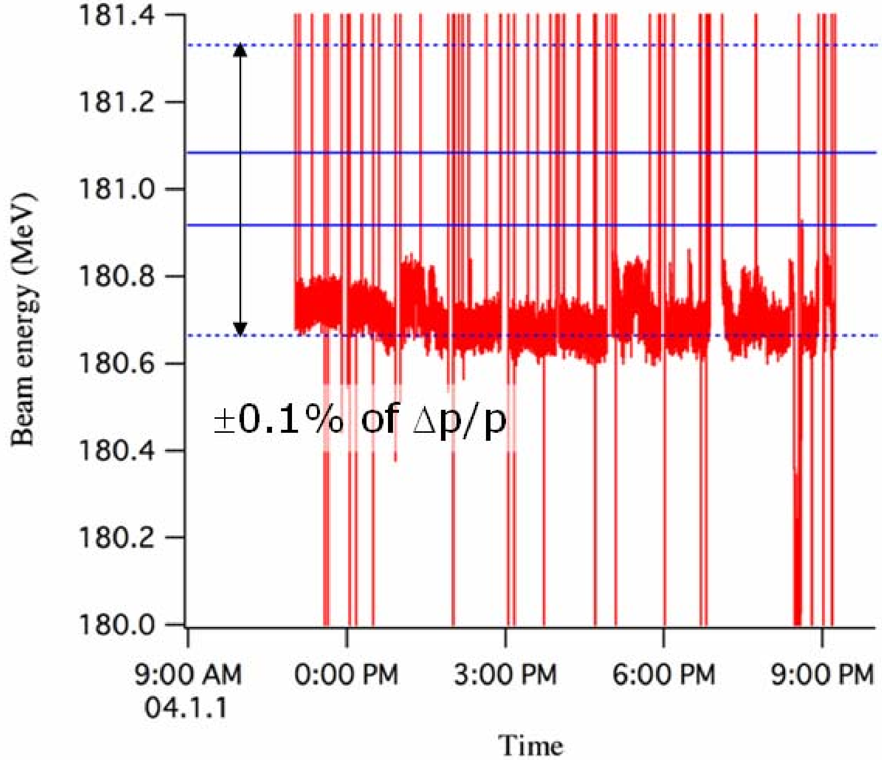
- The matching was performed to have uniform beam widths with the four wire scanners. Transverse mismatching of a few percent has been achieved without iteration.

Beam Current and Energy Stability

May 24

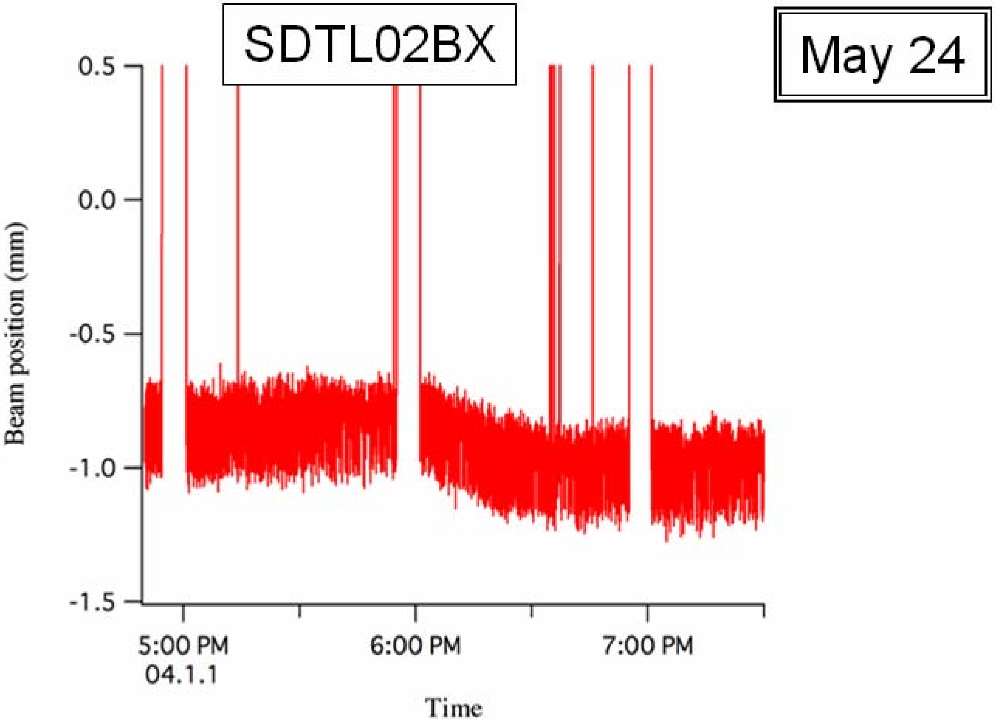


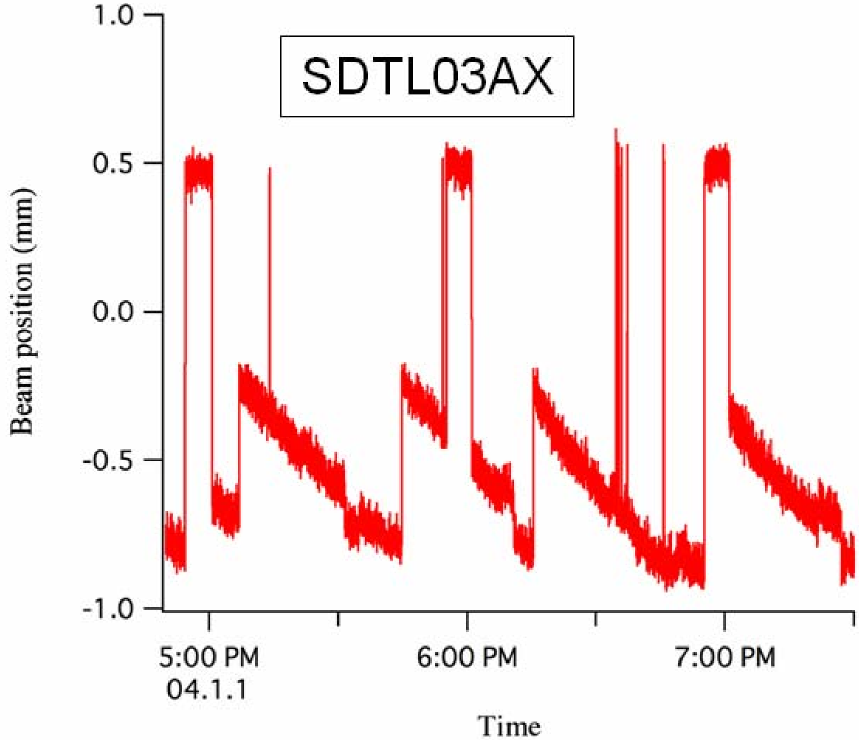
May 23



- Beam Current variation is approximately ±1% measured by Slow CT at the exit of debuncher-2.
- Energy variation is ±0.1MeV measured with TOF by FCT pairs after the debuncher-2. This corresponds to Δp/p of ±0.02%, that would meet the RCS requirement of ±0.1%.

Beam Position Stability





Good position stability up to the SDTL-2 was performed, but positions were moving after the SDTL-3 in 0.5-1 hour cycle.

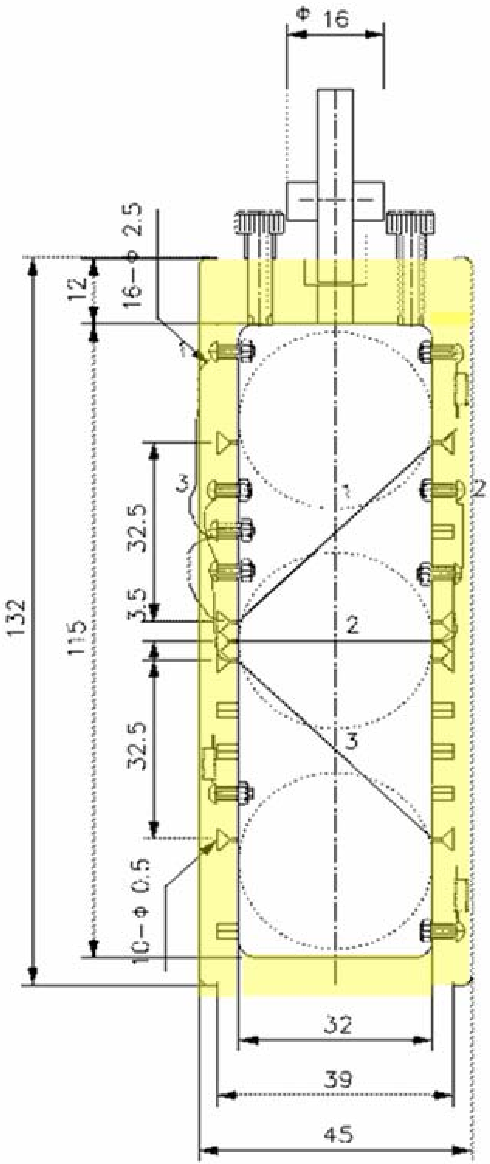
We suspected a Q-magnet rare short, higher order mode in the cavity, etc., for this instability.

Beam Position Stability

We found out the reason last week.

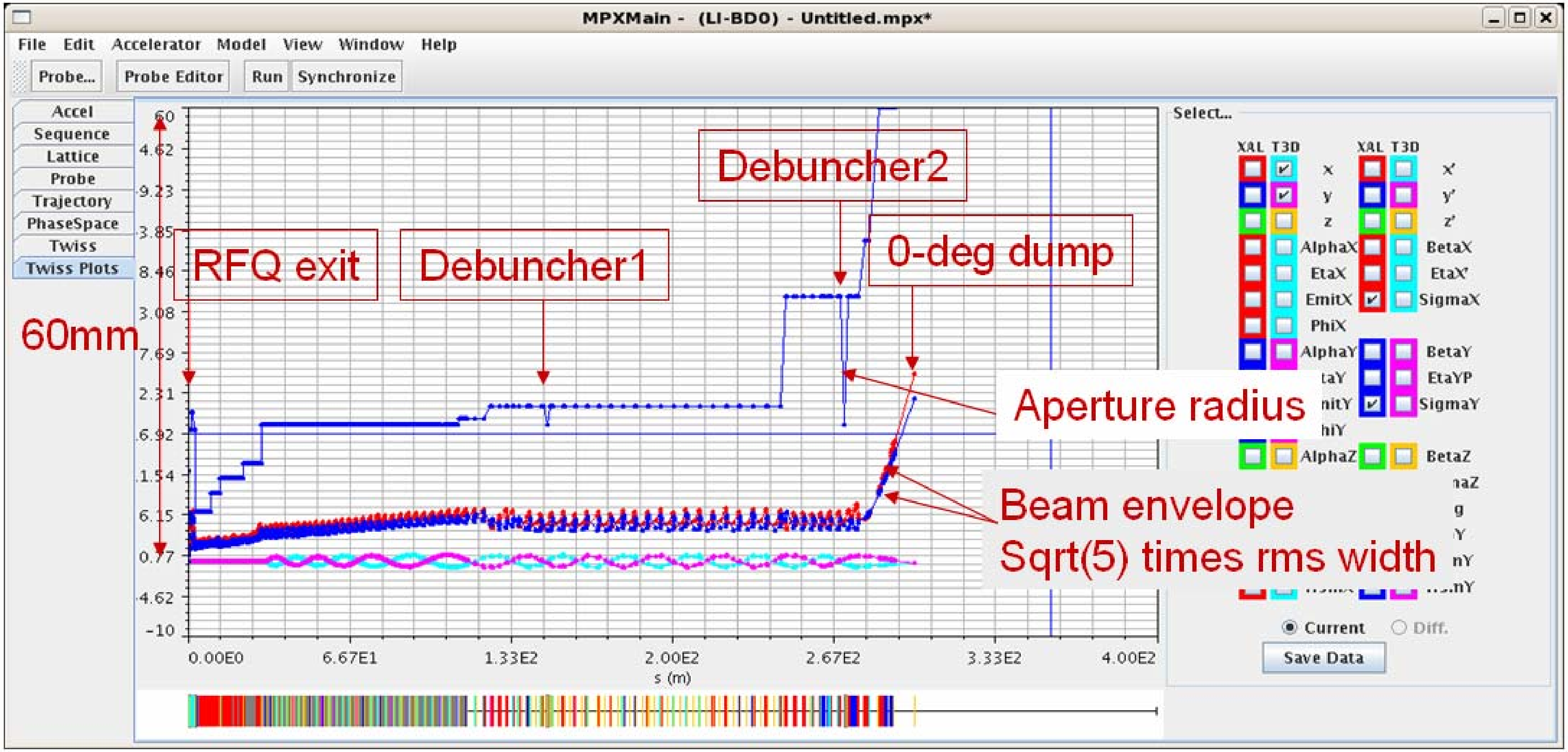
The frame of the wire scanner is made of ceramics. Electrons from the cavity charge up the frame, and induced voltage steers the beam.

-> We will improve or change them before the RCS commissioning.



PAC07, Hasegawa

Aperture along the linac



In 181 MeV operation, the last two SDTL tanks are utilized as debunchers, which makes narrow sections in the beam transport. Excess beam losses have been anticipated in these sections.

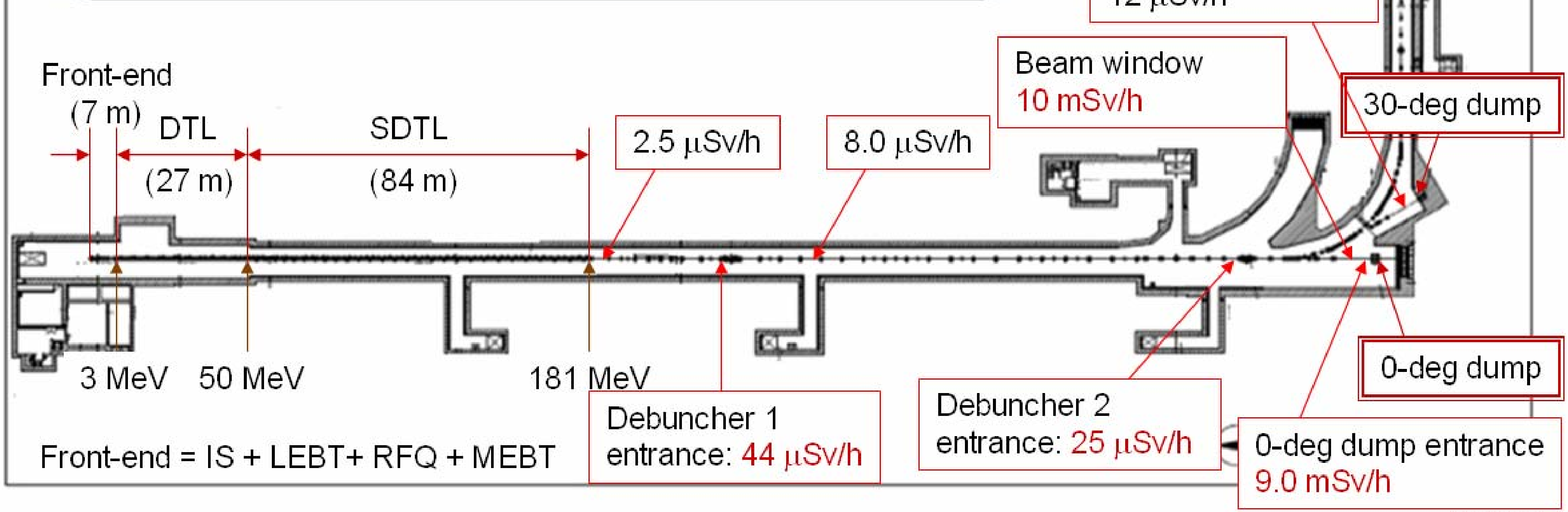
Residual Radiation Level in April

6 hours after beam shut down (Apr. 20, 2007)

With contact on the vacuum chamber

Apr. 20: 3 MeV operation for 0-deg dump

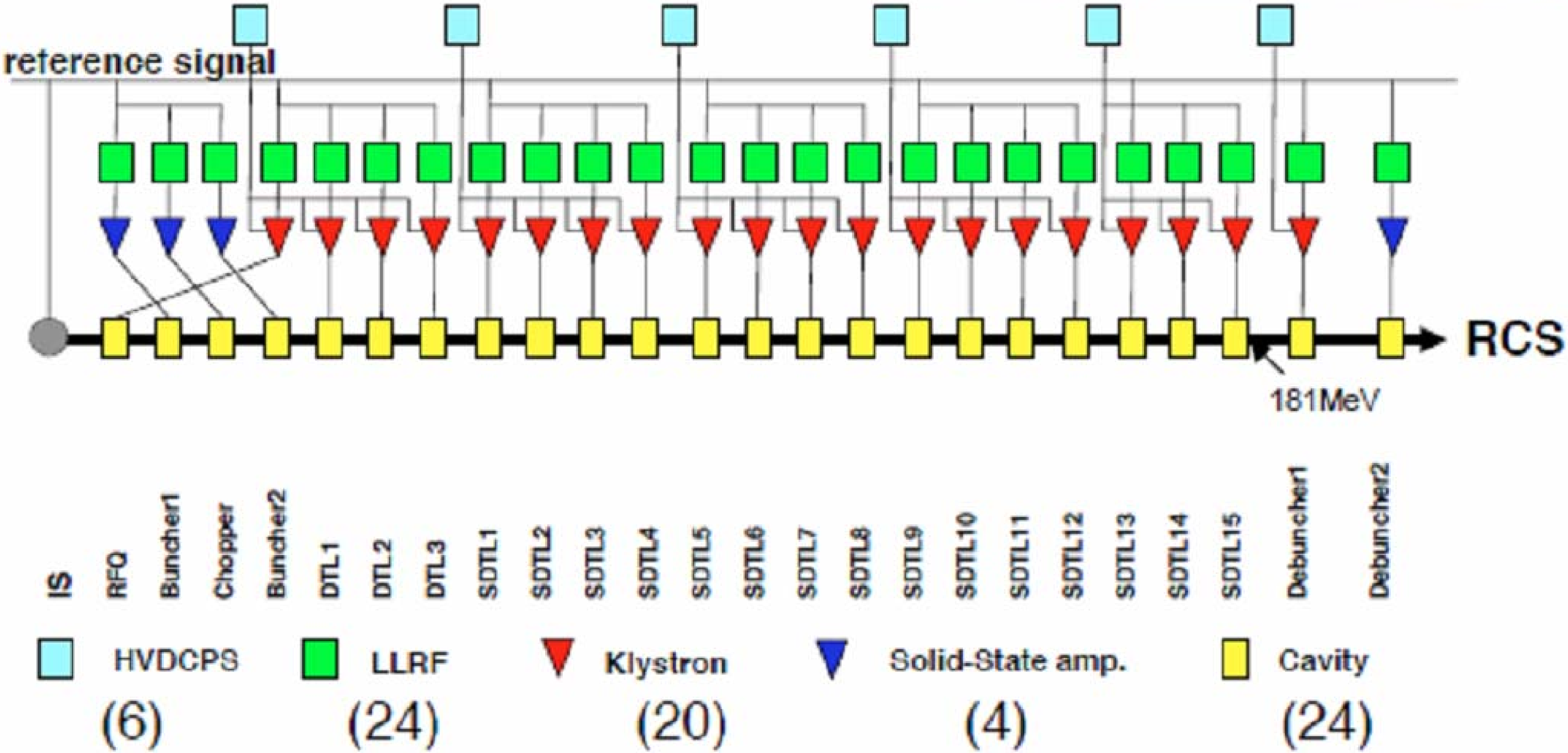
Apr. 19: 181 MeV operation with 120 W beam power
BPM beam based calibration and orbit correction



Linac RF System

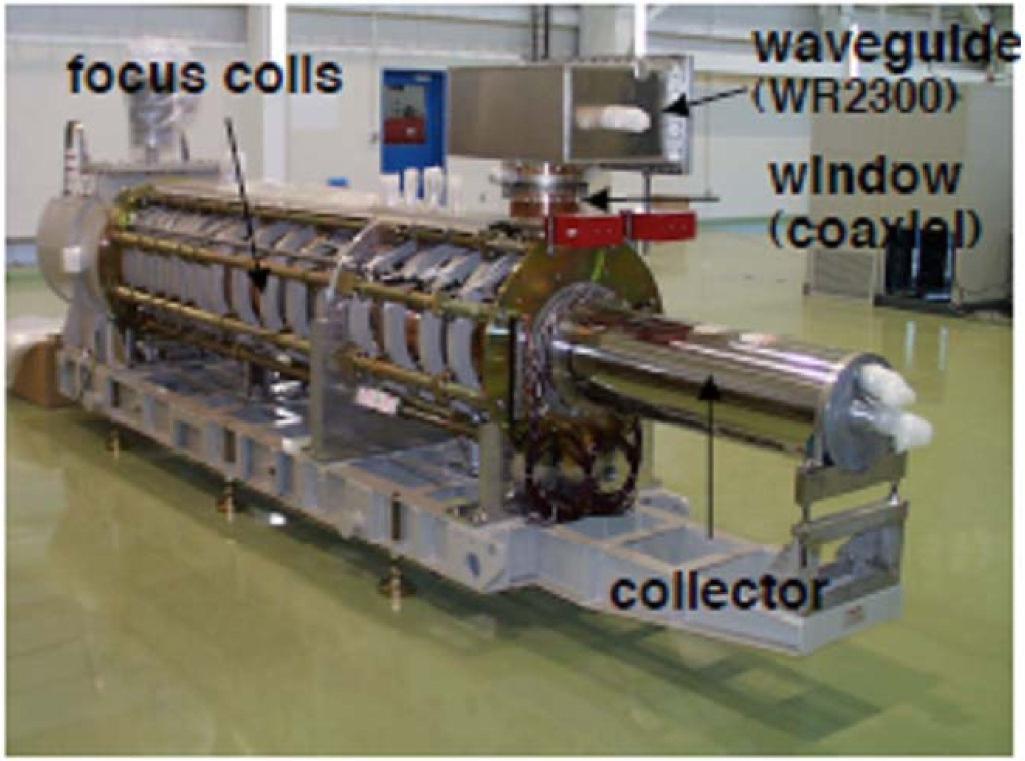
- Operation frequency: 324 MHz
- Total 20 klystrons (max.3 MW),
  6 DCPS (#1~6)
- RF flat top: 600 μs (25Hz)
- Requirements of cavity field stability

  <±1% (amplitude), < ±1deg (phase)



egawa

324MHz Klystron



324MHz Klystron (E3740A)

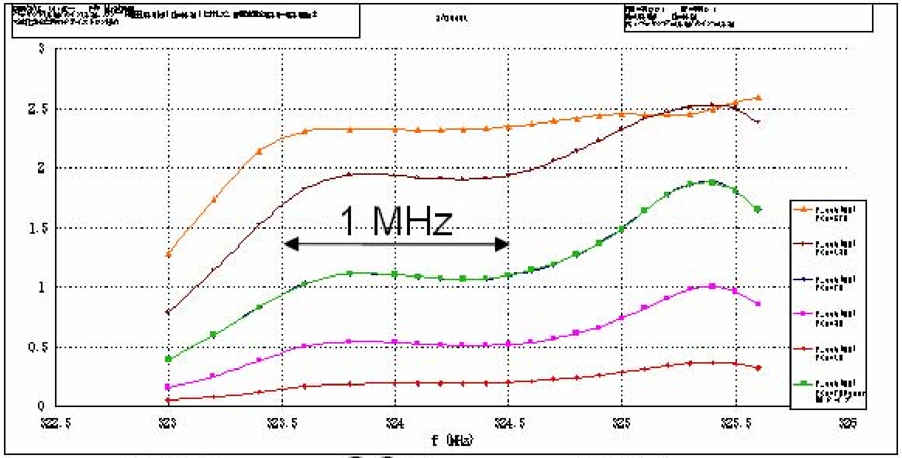
Length 5m, Weight 3t

Main Parameters

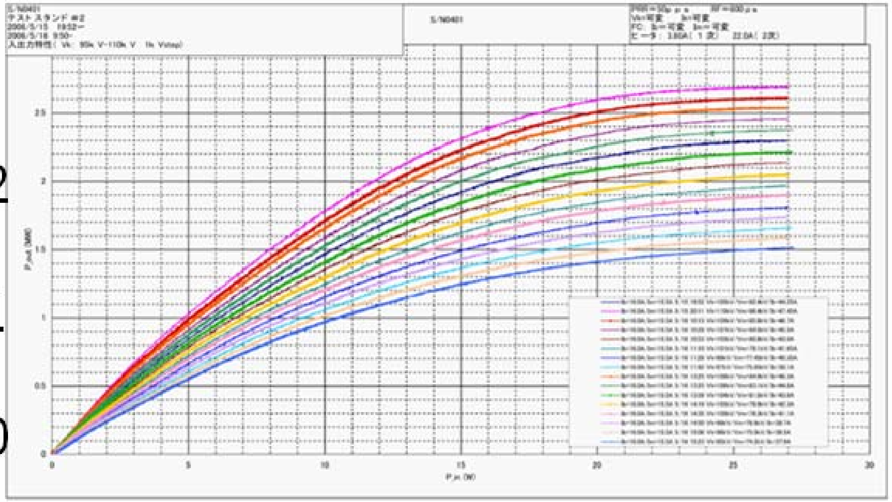
Peak Power	2.5 (max. 3.0) MW
Pulse Width	650 μs
Repetition	50 Hz (25 Hz)
μ-Perveance	1.37 A/V $^{3/2}$
Gain	50 dB
Efficiency	55 %
Beam Voltage	105 (max. 110) kV
Beam Current	45 (max. 50) A
Mounting Position	Horizontal
# of Klystrons	23=20+3(spares)

- 20-unit klystrons are operating for 2,300-2,500 hours. (As of June 2007)
- We have no troubles, such as a discharge in e-gun, vacuum degradation, arcing in output window.

Characteristics of the Klystron



Frequency Characteristics

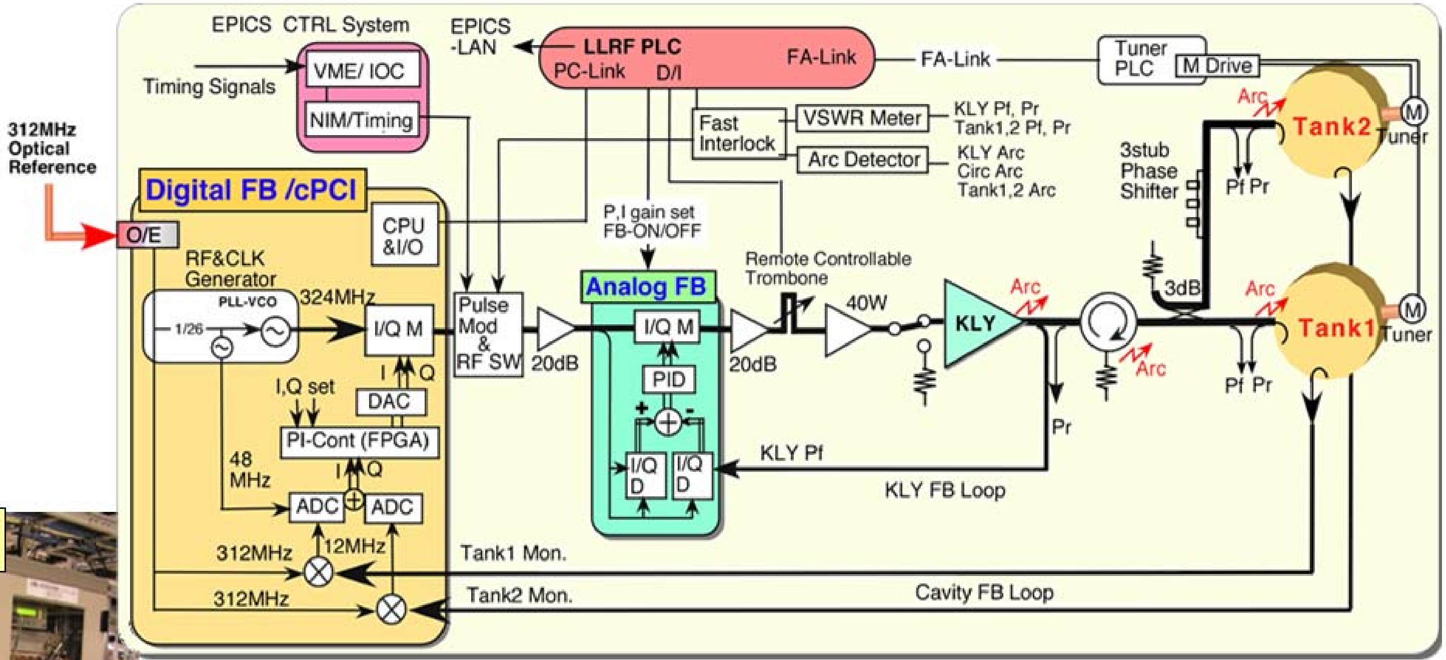


Input/Output Characteristics

Enough bandwidth and smooth input/output curves for various Cathode voltages were obtained.

These are important properties for the stable feedback.

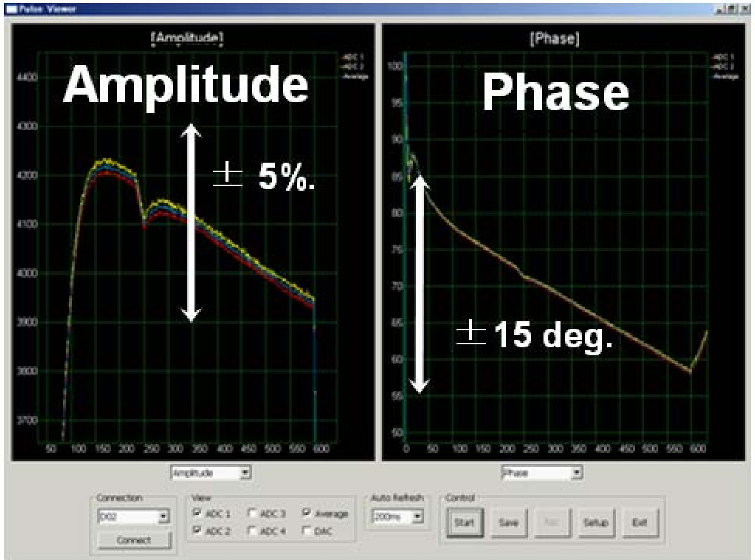
Low Level RF System



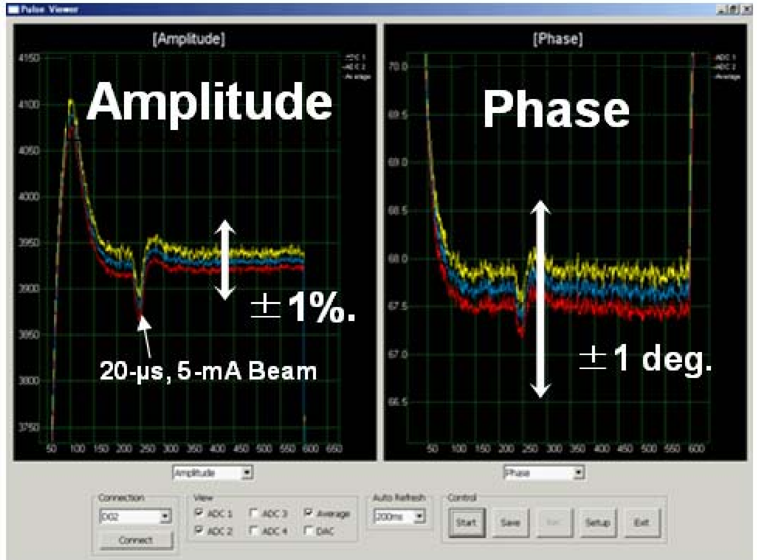
- FB&FF Control for Stabilization of Cavity Field
- One klystron feeds 2 cavities (SDTL section)
- The FB system controls the vector sum of the 2 cavity fields.

Performance of the FB Control

Cavity field stabilization (600-μs RF pulse)



No Feedback Control

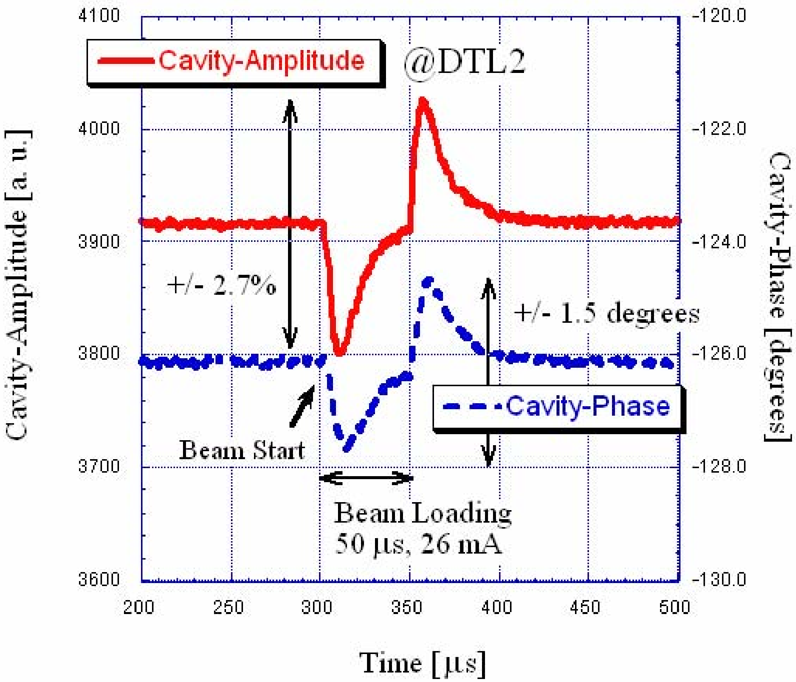


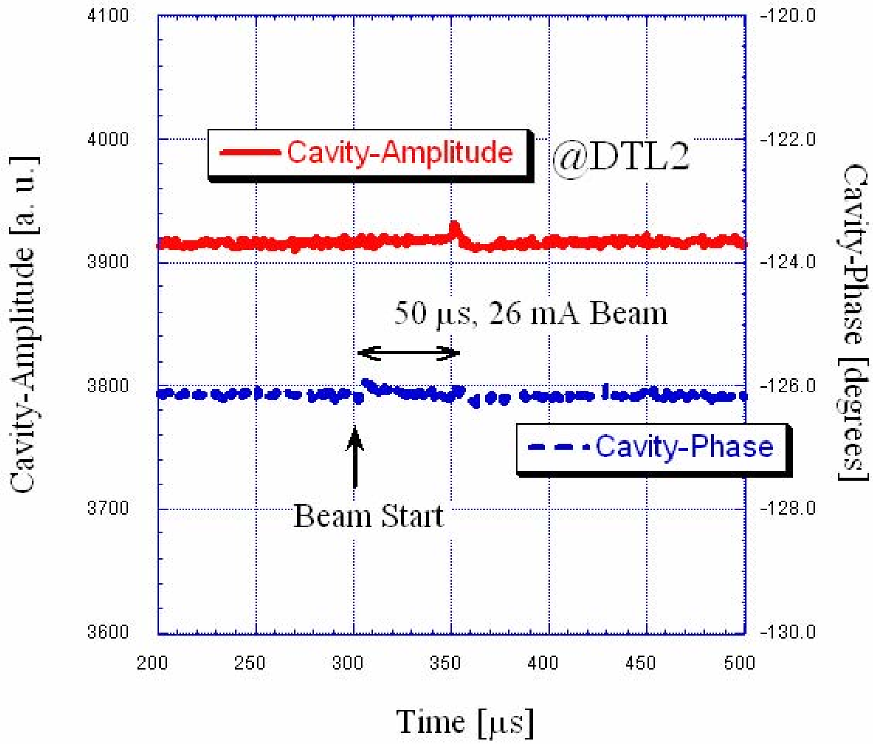
With Feedback Control
(Gain: P=5, I=5/1000)

10% in amplitude and 25 degrees in phase sages are due to the Klystron DC voltage sag of about 3.4%

Amplitude and phase are stabilized to be ±0.15% and ±0.15 degrees, respectively. But we still have a ripple at the transient.

Feed-forward Control





The beam loading ripple caused by a beam of 26 mA peak current and 50 μs duration in the DTL is almost completely compensated.

WEPMN039,WEPMN024

Energy Upgrade: ACS

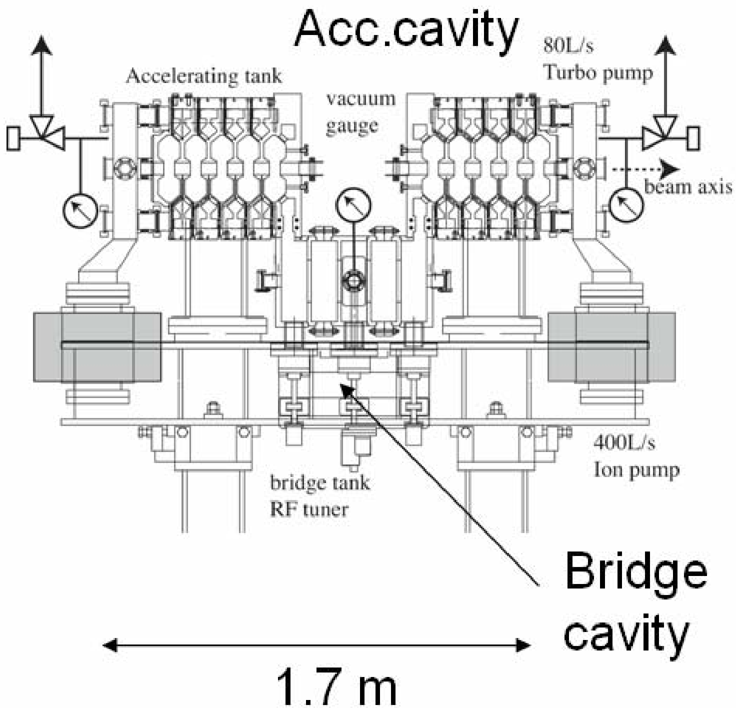
The linac starts with 181 MeV for the time being, but will be upgraded to 400 MeV with 21 ACS modules, two bunchers and two debunchers.

- A buncher cavity (β=0.556) has been fabricated and high-power tested.

  972MHz,5+5 accelerating cell cavities and 5-cell bridge cavity

Major Parameters of the ACS section

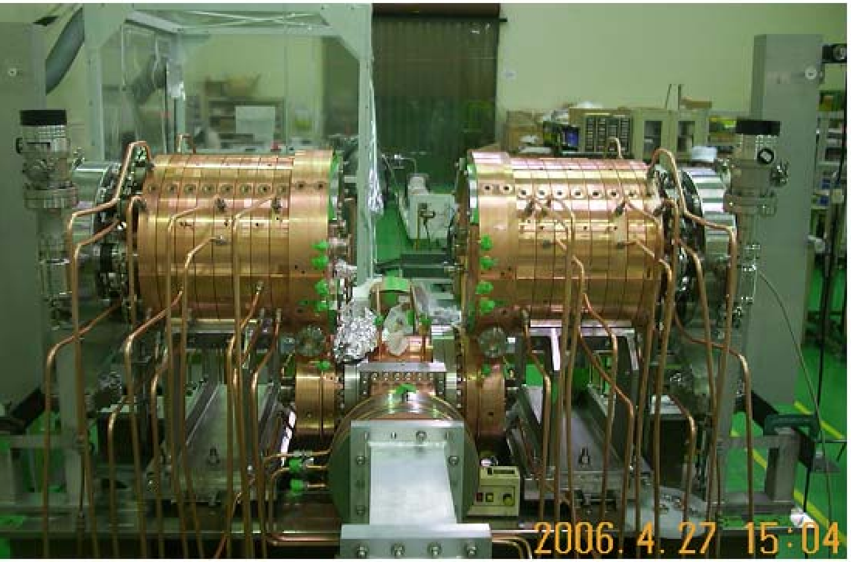
Energy	190.8-400	MeV
Frequency	972	MHz
Section Length	107.2	m
E0	4.12	MV/m
Number of module	21	



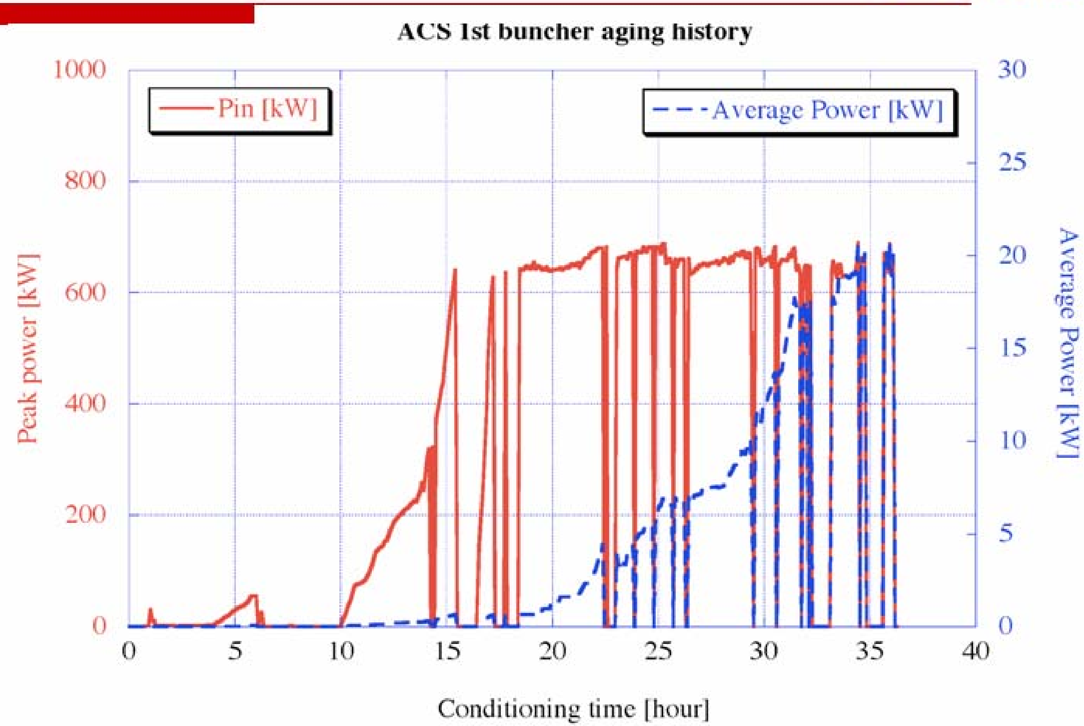
ACS-type buncher cavity

TUPAN056

High Power Test of ACS-type Cavity



ACS-type buncher cavity



Aging history
(Peak power: red, average power: blue)

We have confirmed the high power input and stable operation.

-> We are going to the next step, actual ACS module development.

Summary

- Construction of J-PARC is progressing well.
- Linac beam was successfully accelerated to 181 MeV in January, 2007.

 -Performance of linac

 -Ion Source with LaB6 filament

 -The 20 Klystron RF systems with LLRF control

 We will provide a lot of information to the accelerator community of 324 (or 325) MHz operations.

- Further work and R&Ds

 -RCS injection from September

 -The annular coupled structure (ACS) linac development (and construction, hopefully)

Linac Status on Web

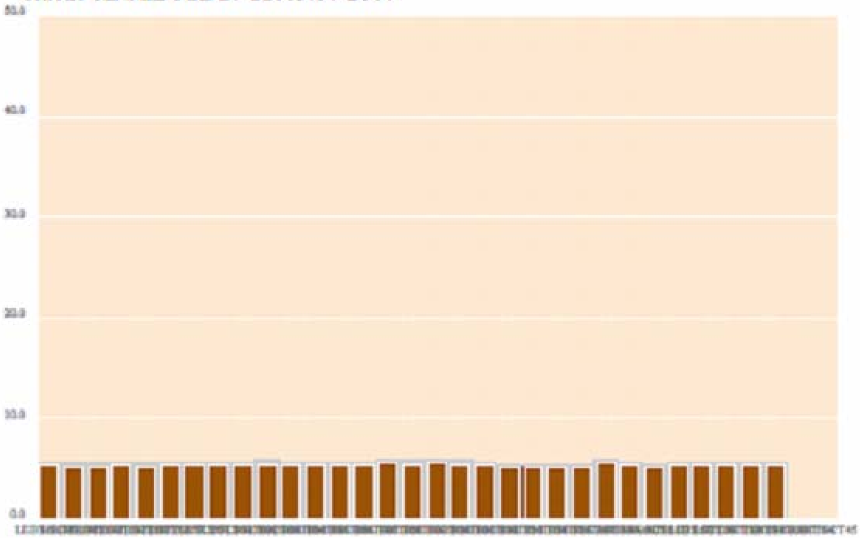
http://www.j-parc.jp/Acc/en/operationE.html

J-PARC LINAC Status

status on Sun Jun 17 11:43:57 2007

status:

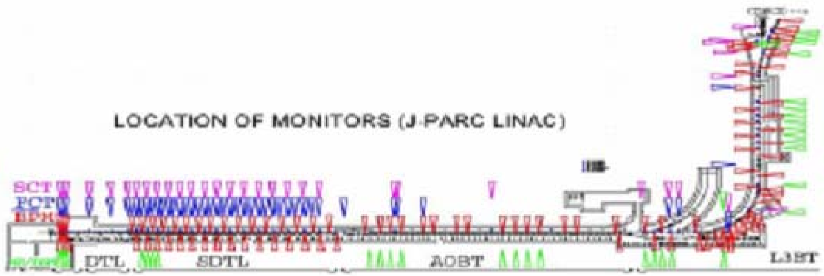
LEBT:SCT01	5.38mA
MEBT1:SCT01	5.25mA
MEBT1:SCT03A	5.23mA
MEBT1:SCT03B	5.30mA
MEBT1:SCT05	5.23mA
MEBT1:SCT08	5.42mA
DTL1:SCT01	5.35mA
DTL2:SCT01	5.30mA
DTL3:SCT01	5.27mA
S01B:SCT00	5.46mA
S02B:SCT00	5.36mA
S03B:SCT00	5.41mA
S04B:SCT00	5.40mA
S05B:SCT00	5.38mA
S06B:SCT00	5.53mA
S07B:SCT00	5.43mA
S08B:SCT00	5.50mA
S09B:SCT00	5.49mA



S10B:SCT00	5.42mA
S11B:SCT00	5.19mA
S12B:SCT00	5.12mA
S13B:SCT00	5.18mA
S14B:SCT00	5.12mA
S15B:SCT00	5.49mA
ACS03A:SCT00	5.32mA
ACS03B:SCT00	5.17mA
ACS11B:SCT01	5.34mA
L3BT:SCT06	5.27mA
L3BT:SCT12	5.40mA
L3BT:SCT14	5.32mA
BD0:SCT06	5.30mA
BD03:SCT04	0.00mA
L3BT:SCT45	0.00mA

IS/RFQ section:
LEBT:SCT01, MEBT1:SCT01~SCT05
DTL section:DTL1:01~DTL3:SCT01
SDTL section:S01B:SCT00 - S15B:SCT00
A0BT section:ACS03A:SCT00 ~ ACS11B:SCT01

L3BT section:L3BT:SCT06 ~L3BT:SCT14



Update Graph

'07, Hasegawa

End of the talk

J-PARC Construction View

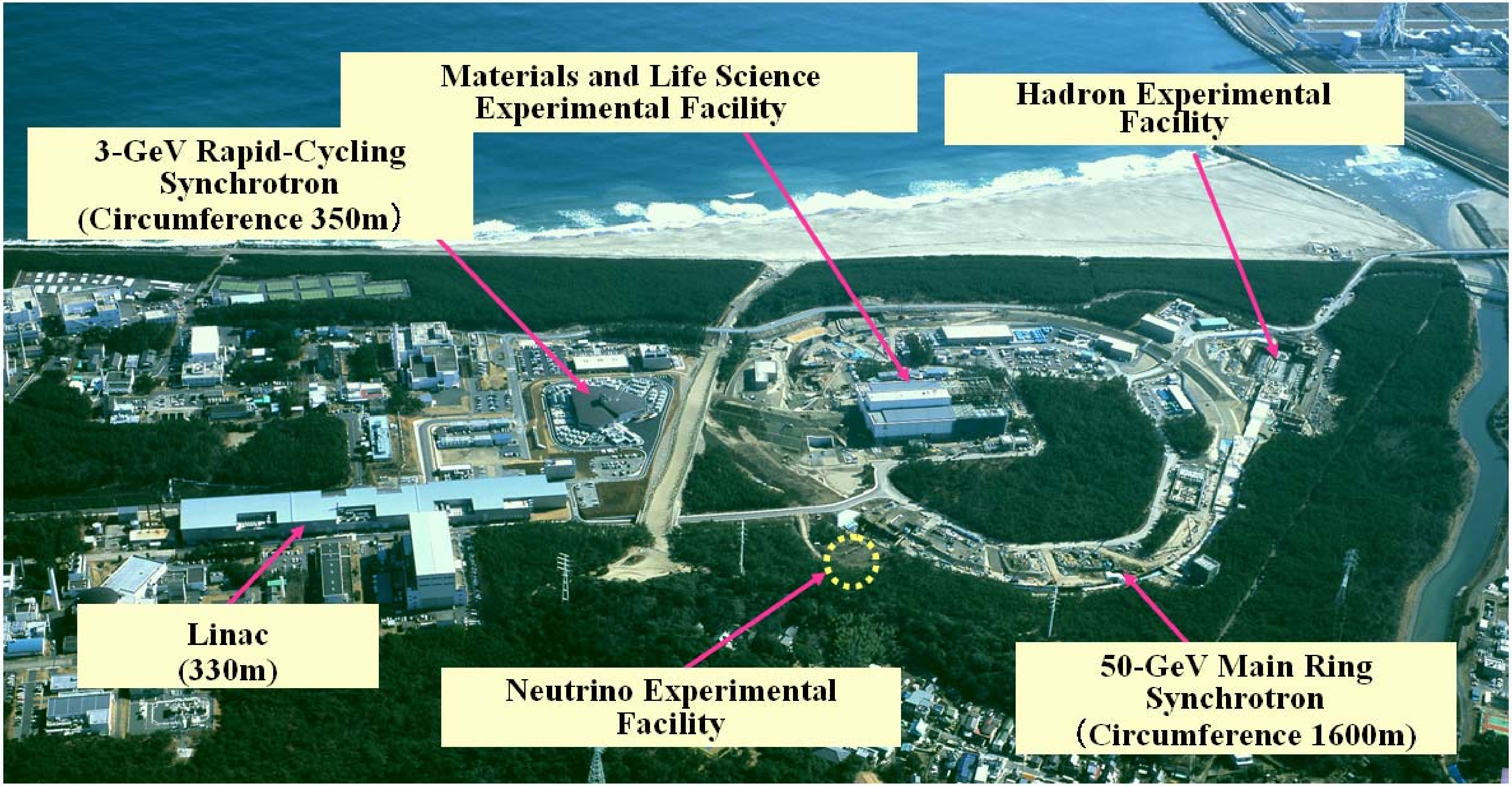


Photo in Feb. 2006