IBIC2012
International Beam Instrumentation Conference
Tsukuba, Ibaraki, JAPAN, 1st to 4th, Oct. 2011

Progress of Beam Instrumentation in J-PARC Linac

Akihiko MIURA

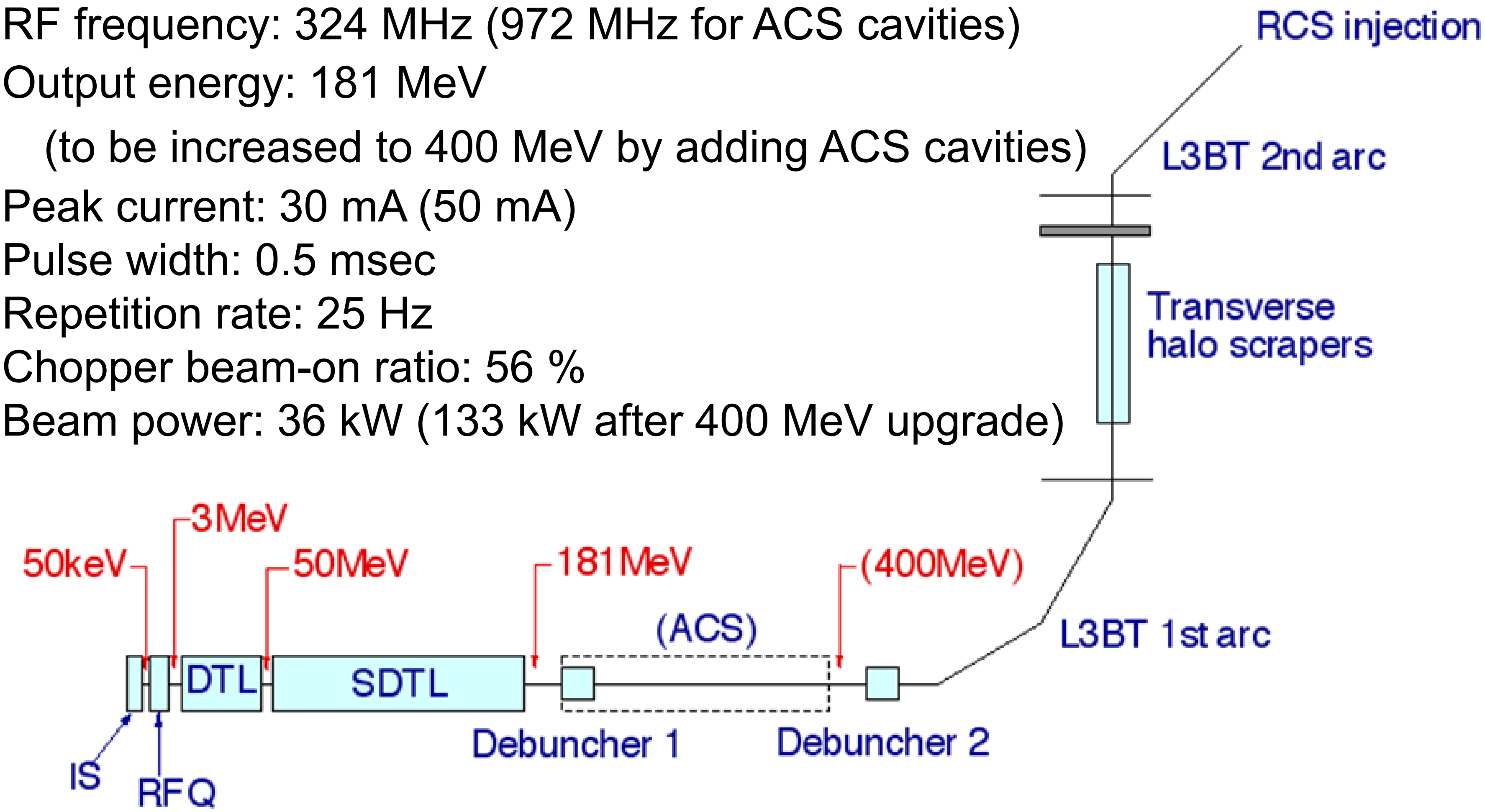
with the Beam Monitor Group in J-PARC

Contents

1. Introduction

Main Parameters of Linac

Ion species: Negative hydrogen ion
RF frequency: 324 MHz (972 MHz for ACS cavities)
Output energy: 181 MeV
(to be increased to 400 MeV by adding ACS cavities)
Peak current: 30 mA (50 mA)
Pulse width: 0.5 msec
Repetition rate: 25 Hz
Chopper beam-on ratio: 56 %
Beam power: 36 kW (133 kW after 400 MeV upgrade)



1. Introduction

Beam Instrumentations

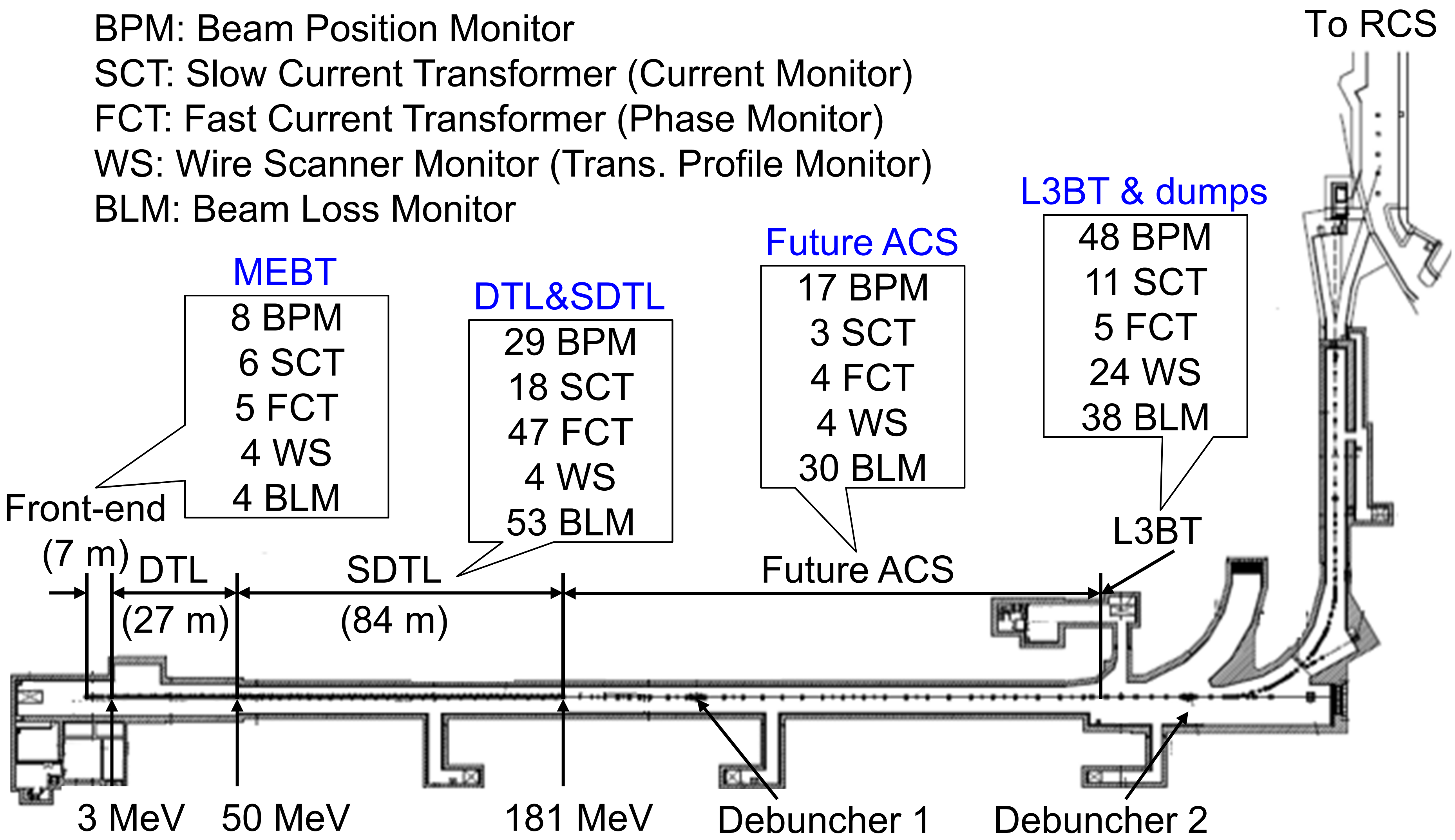
- Commissioning Tools for 181 MeV Operation
  - BPM: Beam Position Monitor
  - BLM: Beam Loss Monitor
  - SCT: Current Monitor (Slow Current Transfer)
  - FCT: Phase Monitor (Fast Current Transfer)
  - WSM: Profile Monitor (Wire Scanner Monitor)
- Development for Energy Upgraded Linac (400 MeV)
  - Scintillation Beam Loss Monitor (X-ray less sensitive)
  - Longitudinal Beam Profile Monitor (Bunch Shape Monitor)
  - Non-destructive Profile Monitor (Laser-based)
- Diagnostic Devices for Beam Physics
  - Beam Loss Track Measurement
  - Measurement of H0 / Intra-beam Stripping (IBSt)

Contents

2. Commissioning Tools

Commissioning Tools

BPM: Beam Position Monitor
SCT: Slow Current Transformer (Current Monitor)
FCT: Fast Current Transformer (Phase Monitor)
WS: Wire Scanner Monitor (Trans. Profile Monitor)
BLM: Beam Loss Monitor

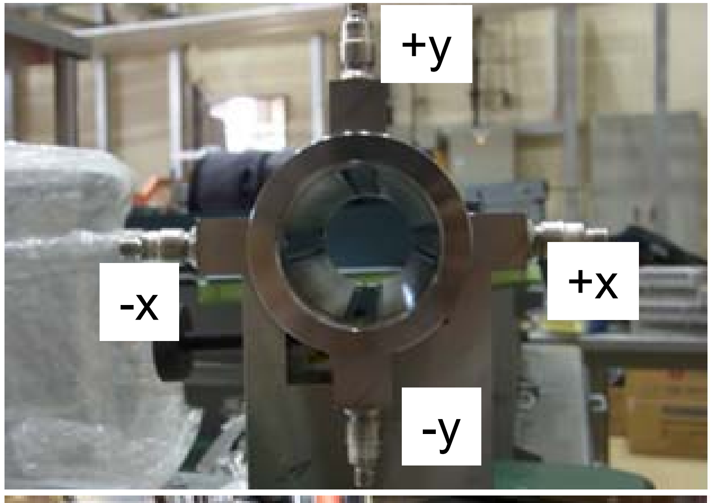


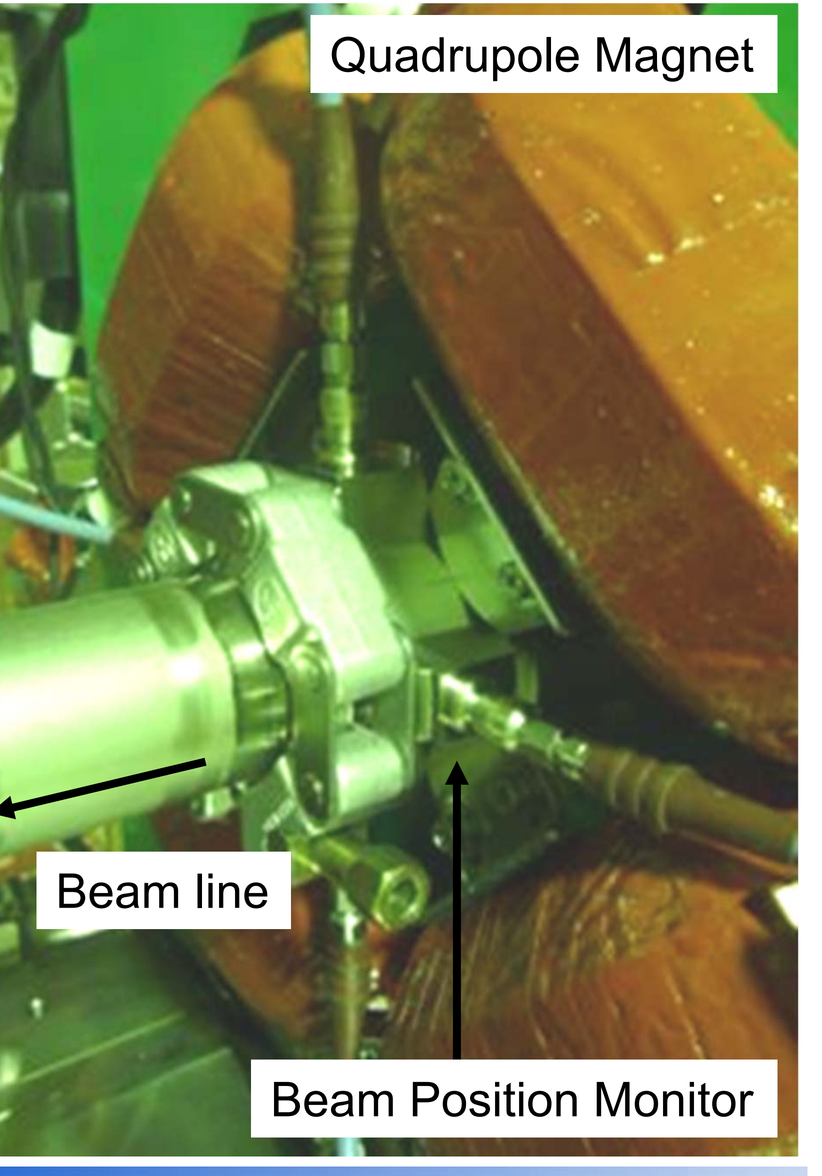
2. Commissioning Tools

Beam Position Monitor (BPM)

Strip-line type is employed.

Resolution
Δx<~0.1 mm
Δy<~0.1 mm





2. Commissioning Tools

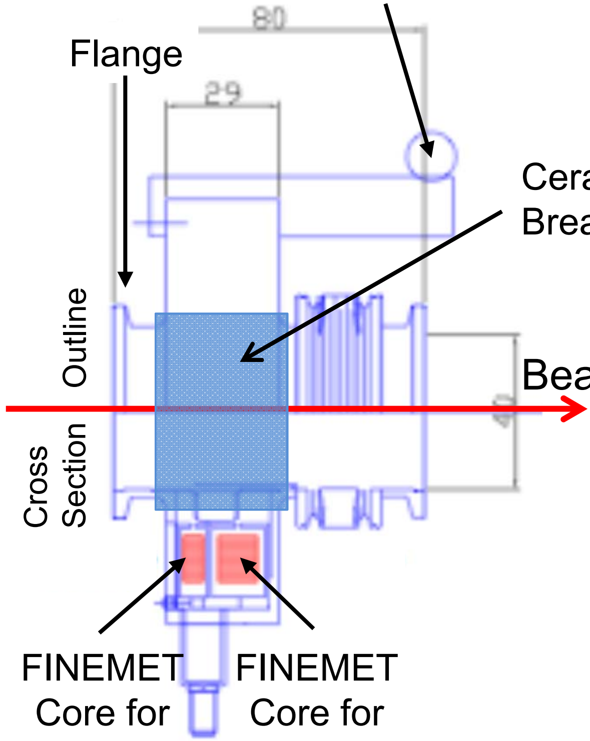
Beam Current (SCT: Slow Current Transformer)
Phase Monitor (FCT: Fast Current Transformer)

Annular magnet core "FINEMET" is employed for the current transformer.

Dynamic Range
- SCT: 0.1 – 80 mA
- FCT: > 30dB

Winding coil,
- SCT: Fifty turns
- FCT: Single turn

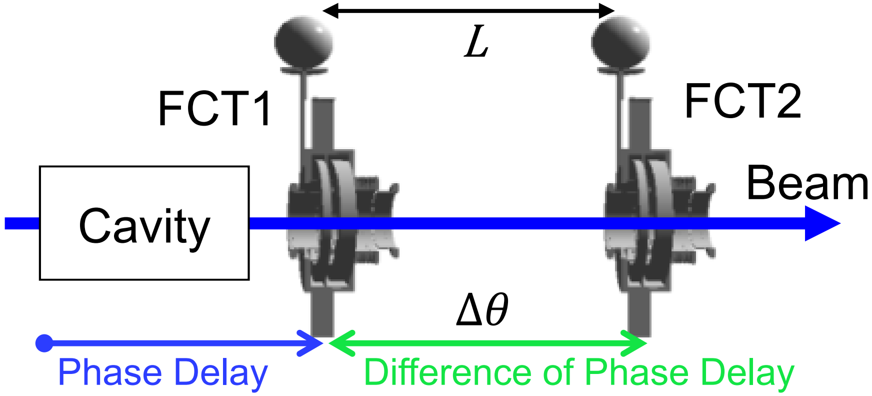
Resolution,
- SCT: ΔIbeam < 1.0 %, Imin ~ 0.1 mA
- FCT: Δφbeam < 1.0 deg. Energy: < 0.1 %



2. Commissioning Tools

Energy Measurement, Phase Scan

Beam energy is measured with the aid of FCT based on the TOF (Time-OF-Flight) method.

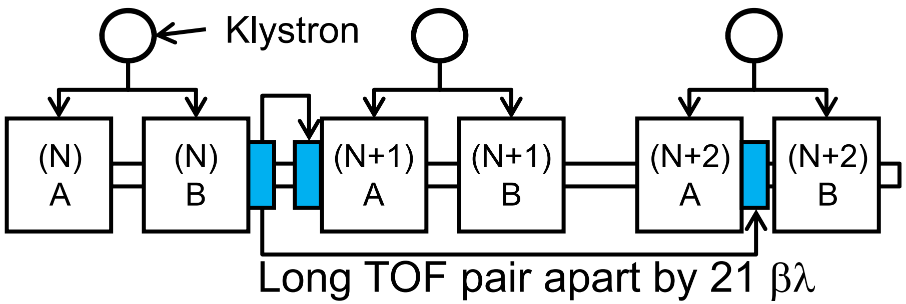


$$K[MeV] = m_0(\gamma - 1)$$

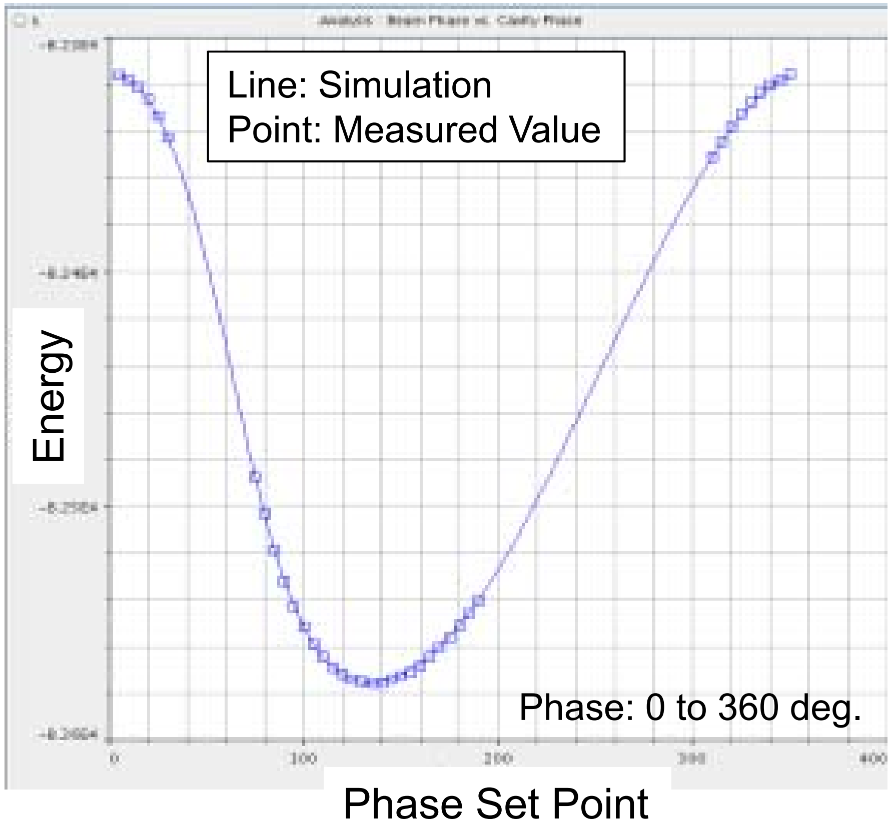
$$\gamma = 1/sqrt(1-\beta),\ \beta = L / (\Delta t \cdot c)$$

$$\Delta t\ [sec] = \Delta\theta / (360 \times 324\ MHz)$$

$$\Delta\theta\ [deg.] = \theta_{FCT1} - \theta_{FCT2} \pm (n \times 360)$$



(e. g. at SDTL03)

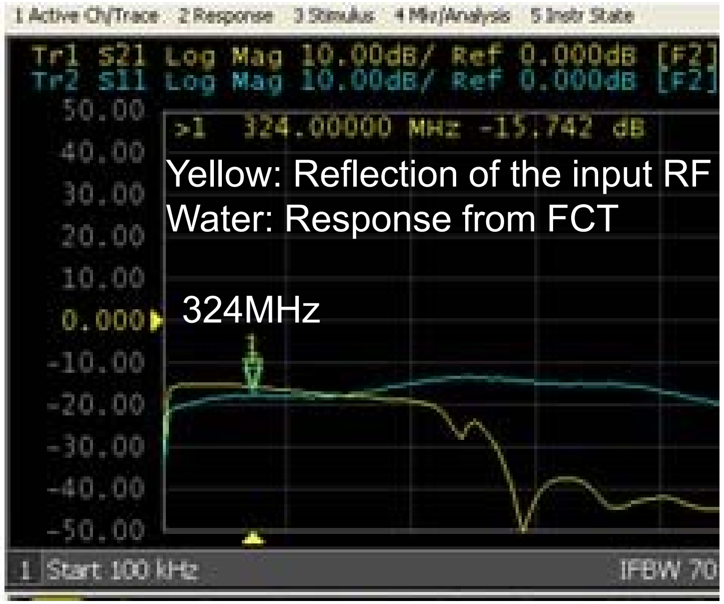


In order to seek an adequate set-point, matching is implemented by the phase scan. The set-point is determined from the best matching point between the measurement and model simulation.

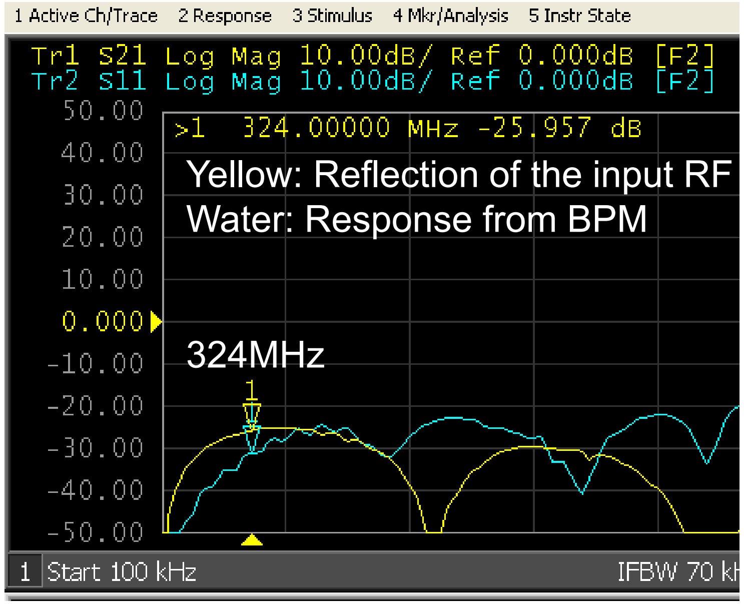
2. Commissioning Tools

Comparison of the Performances Between FCT and BPM

Measured performance data of FCT and BPM using network analyser are shown. Measured signal level is corresponding to 82 mV for FCT and 25 mV for BPM respectively. Signal level from FCT is three times higher than that from BPM.



Performance of FCT



Performance of BPM

2. Commissioning Tools

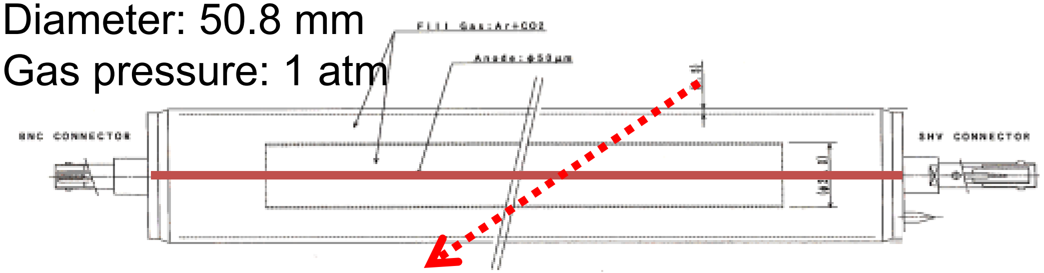
Beam Loss Monitor (BLM)

Gas Proportional BLM, E6876 - 600
Toshiba Electron Tubes & Devices Co. Ltd.,

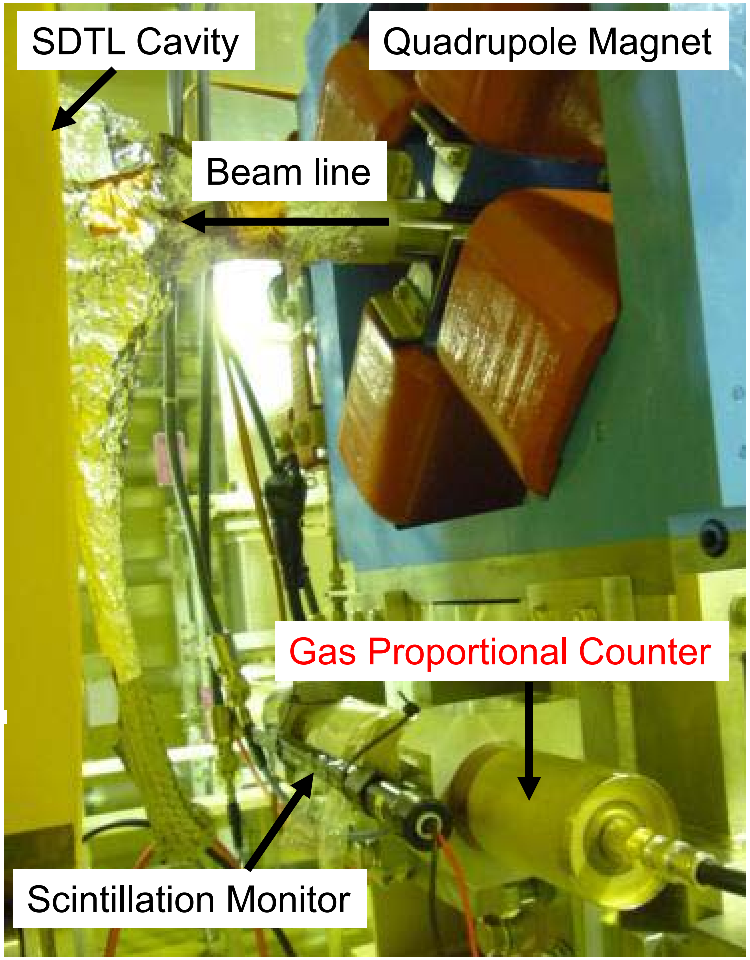
Sensitive for charged particle, X-ray and gamma-ray

Fast time response
It is enough fast to alarm the protection system.
$\tau < 1.0\ \mu s$

Length: 600mm
Diameter: 50.8 mm
Gas pressure: 1 atm



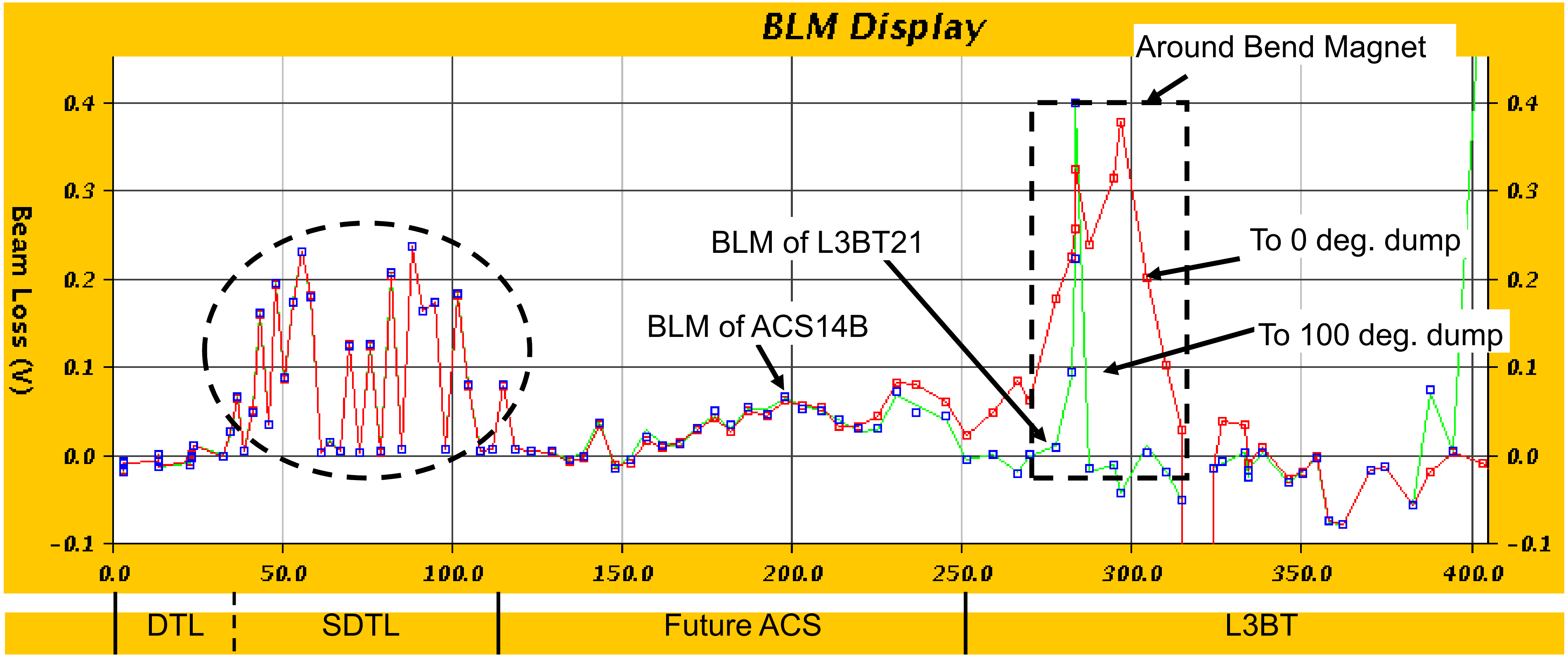
Anode Pt Wire, Φ50um
(Gas: Ar+CO_2)



2. Commissioning Tools

Beam Loss Measurement

125 BPMs are delivered in the beam line.
Beam loss profile at 20 kW operation Jan., 13, 2009, Run 21.

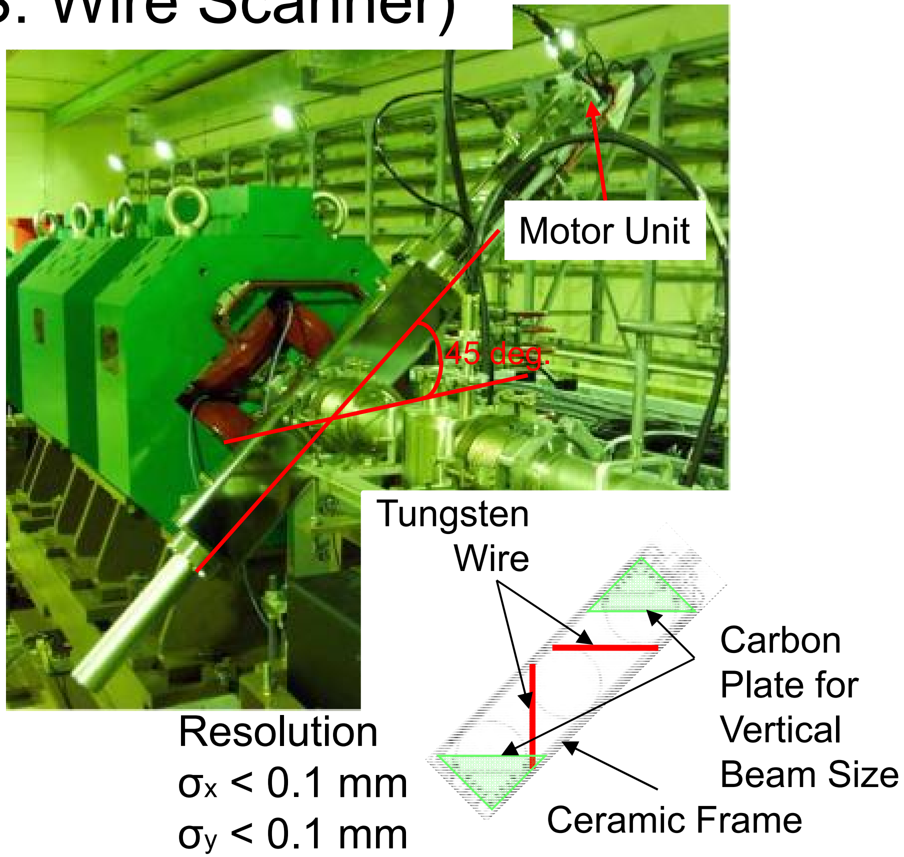


X-ray emitted from the SDTL cavities is detected by the BLM.

---> Suppression of X-ray noise should be considered using another detector.

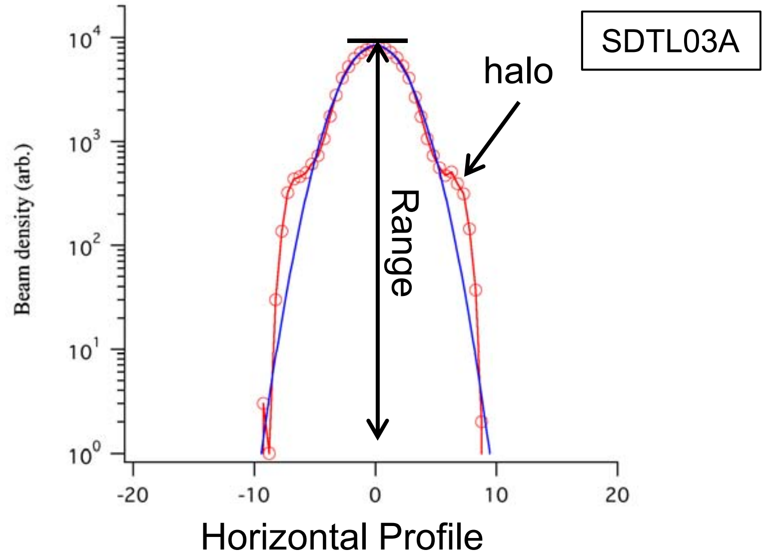
2. Commissioning Tools

Beam Profile Monitor (WS: Wire Scanner)

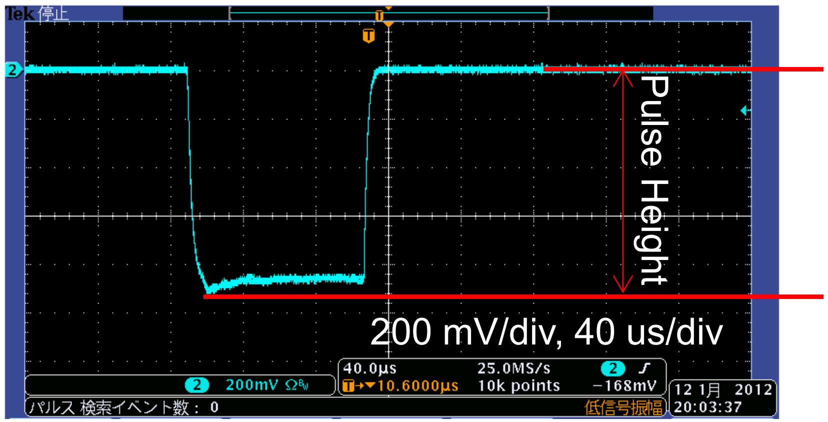


Resolution
$\sigma_x < 0.1$ mm
$\sigma_y < 0.1$ mm

Four WSs are located in each matching section periodically.
Dynamic range reaches four orders.



Example of Transverse Profile



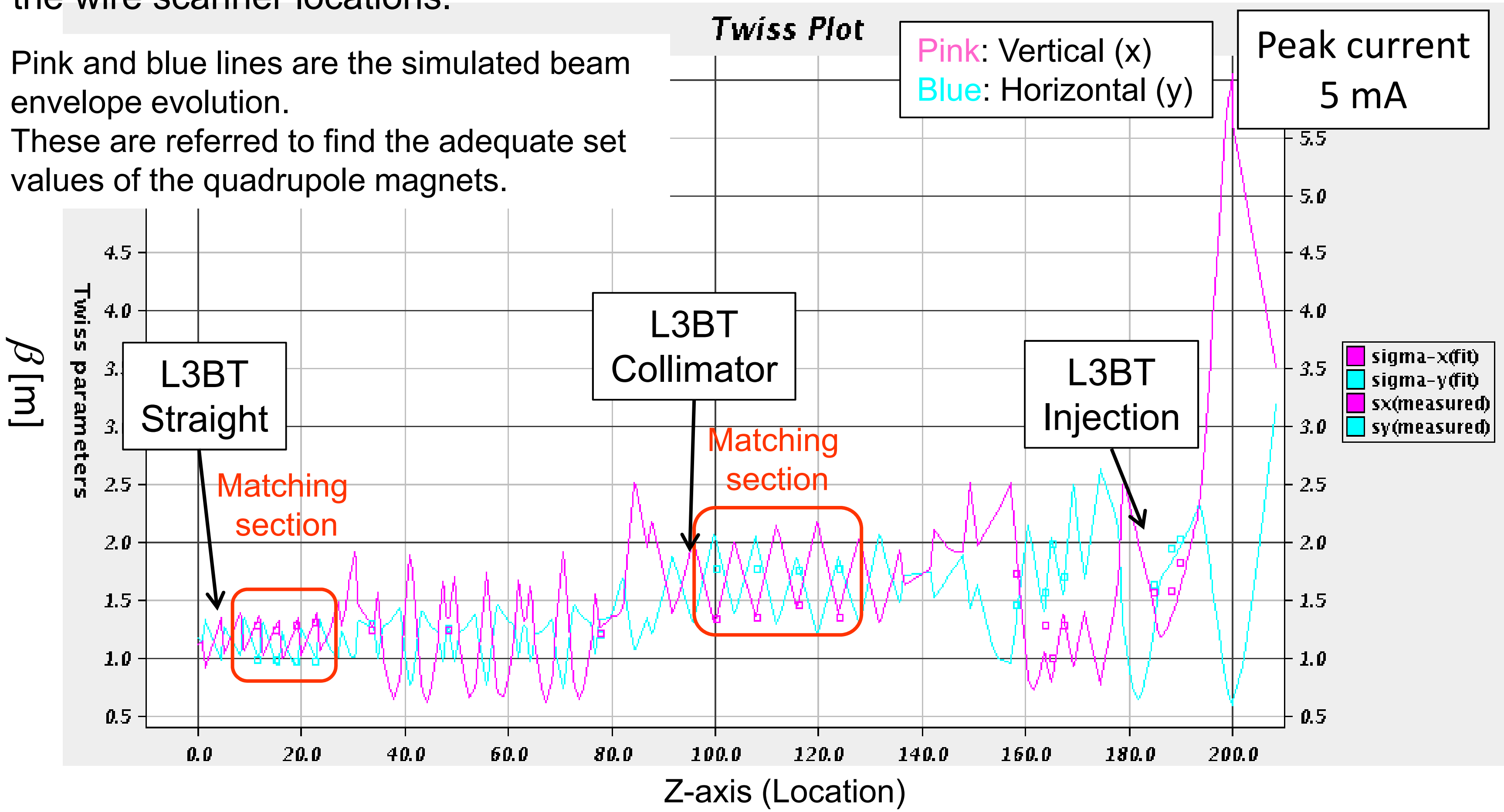
Signal Obtained at the Peak of Beam Pulse

2. Commissioning Tools

Transverse Matching

After matching of collimator section,
June, 6, 2008 (Run 16)

WSs are located periodically.
Quadrupole magnets located before the WSs are tuned to have the same beam width at the wire scanner locations.



2. Commissioning Tools - unique application

SDTL Longitudinal Acceptance

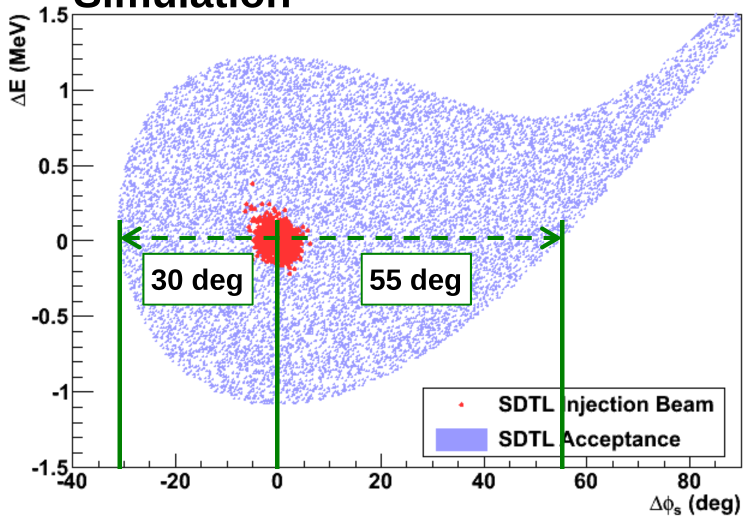
Simulation indicates the acceptance has enough margin to beam profile, however we have to check

- actual acceptance is as large as simulation or not.
- the actual acceptance margin is enough for beam profile or not.

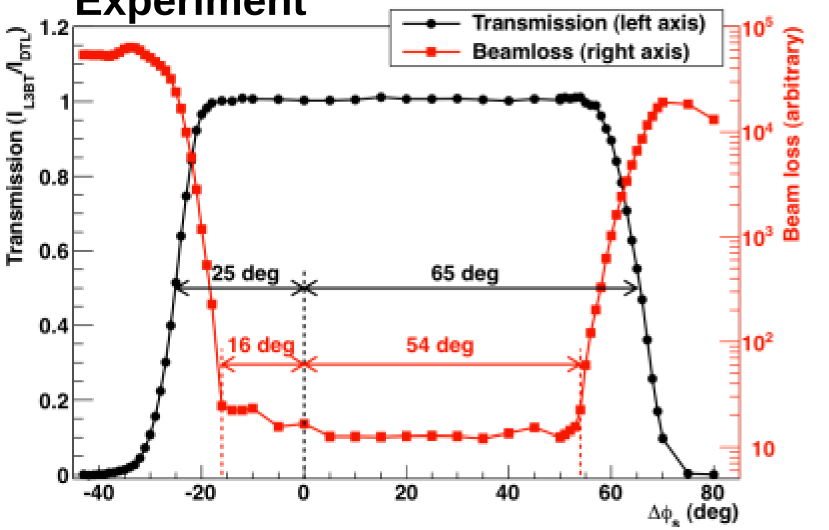
Measure the acceptance on $\Delta\phi_s$ direction by phase scan, in which we change the driven phase of all SDTL cavities, we take beam transmission through SDTLs.

As the results, acceptance has enough margin for the beam.

Simulation



Experiment



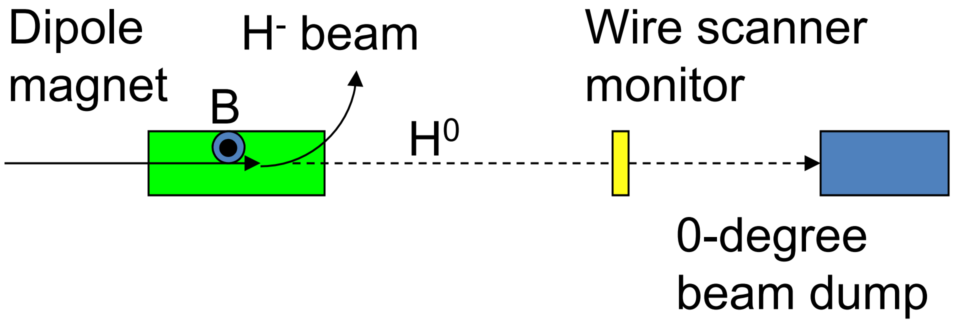
Beam transmission by SCT : Beam core information

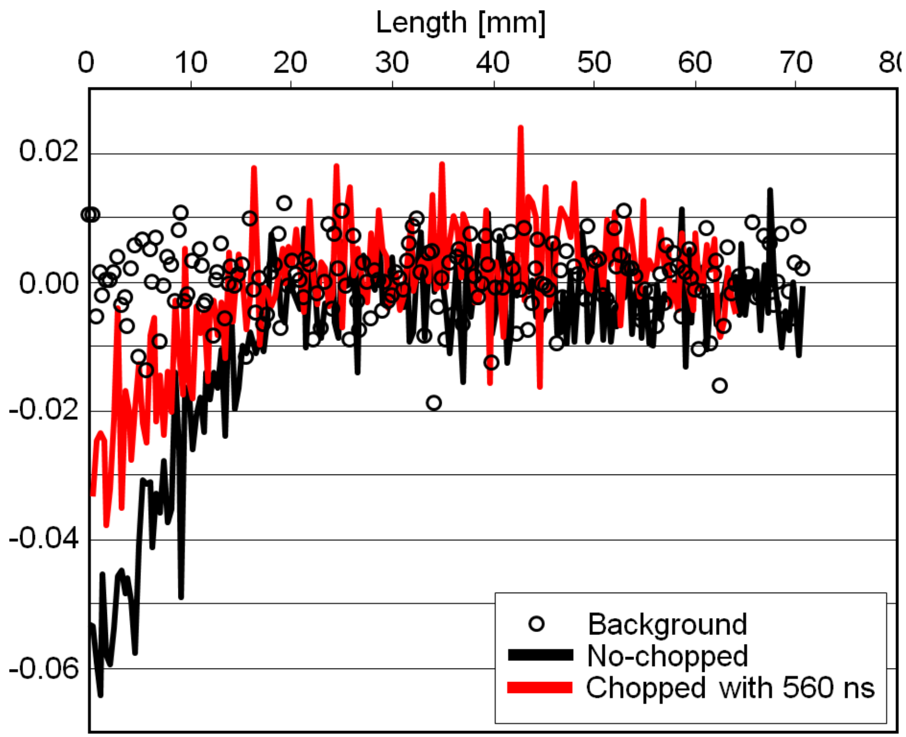
Beam loss by BLM : Beam halo information

2. Commissioning Tools - unique application

H0 Particle Measurement

H^0 was observed with a wire scanner monitor at the straight beam dump with bending magnet on.



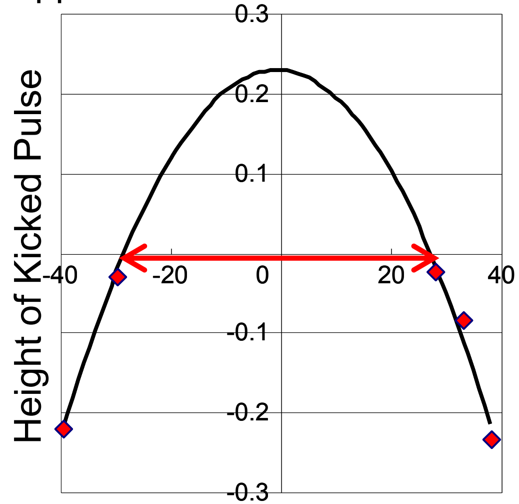


2. Commissioning Tools - unique application

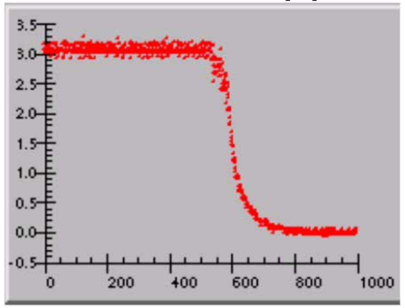
Chopper Tuning

All beam pulse is kicked by the tuned phase of RF chopper.
Wave form disappeared in the CT signal.

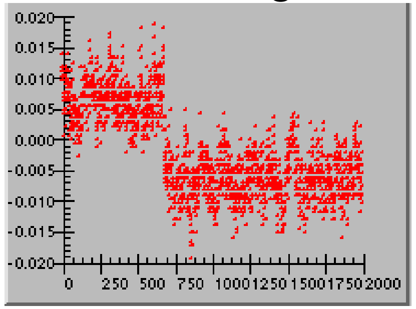
Optimized phase can be taken by the hyperbolic approximation.



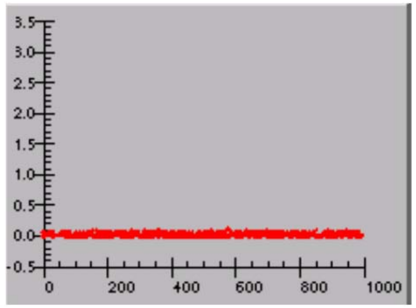
CT Wave Form



(a) Before Kicked

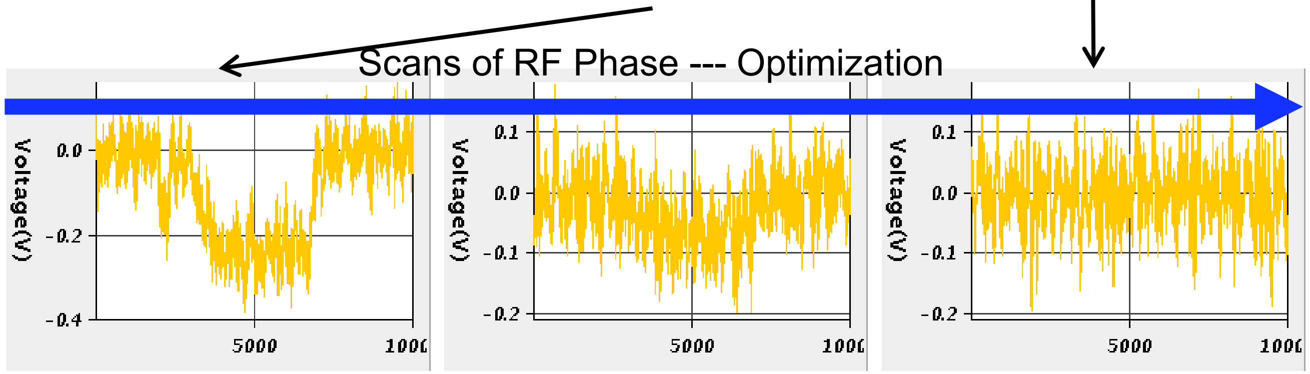


(b) Kicked by Detuned Chopper



(c) Kicked Beam

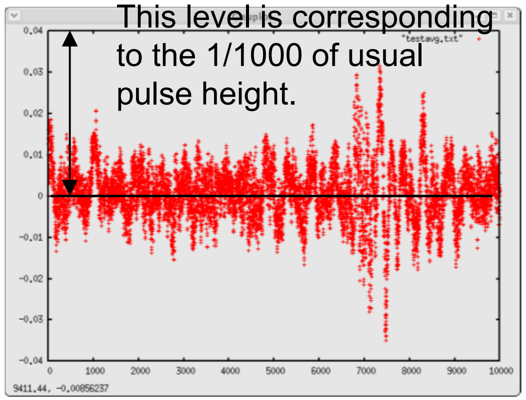
Beam Pulse by WS



(a) Kicked by Detuned Chopper. Beam pulse still remains.

(b) During Phase Scanning. Small beam pulse still remains.

(c) Kicked by Tuned Chopper. No beam pulse remains.



Wave form taken by WS.
Over 100 shots are averaged.

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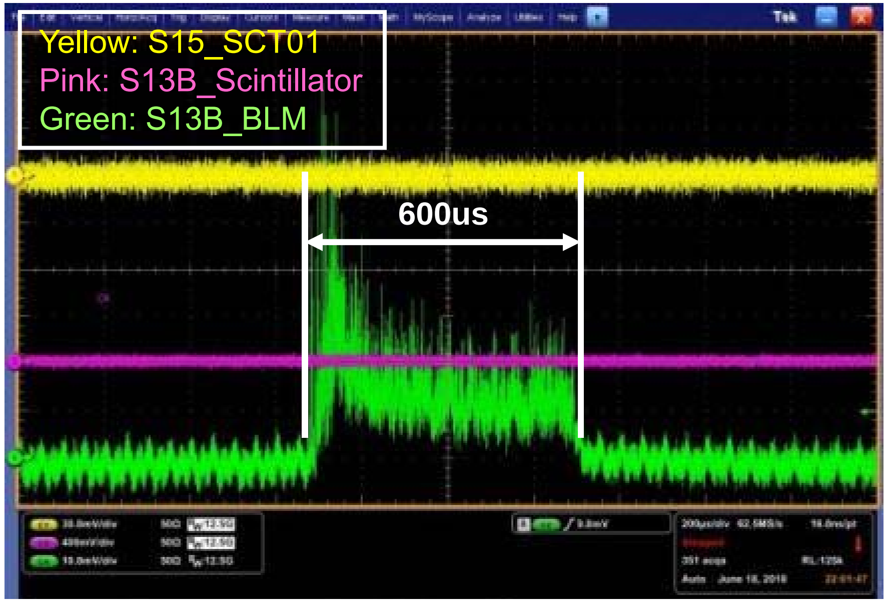
3. Development for Energy Upgraded Linac

Scintillation Beam Loss Monitor (under study)

Gas proportional BLM is sensitive to X-ray from the cavity.



The plastic scintillation monitor with less X-ray sensitivity is employed to measure the beam loss.

Clear beam loss signals with low noise is successfully measured and the high time resolution of the beam loss is confirmed.

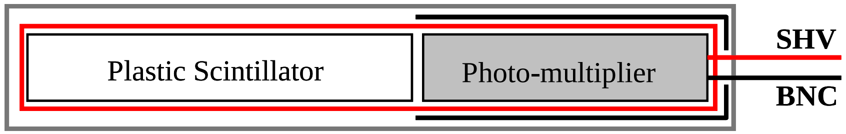
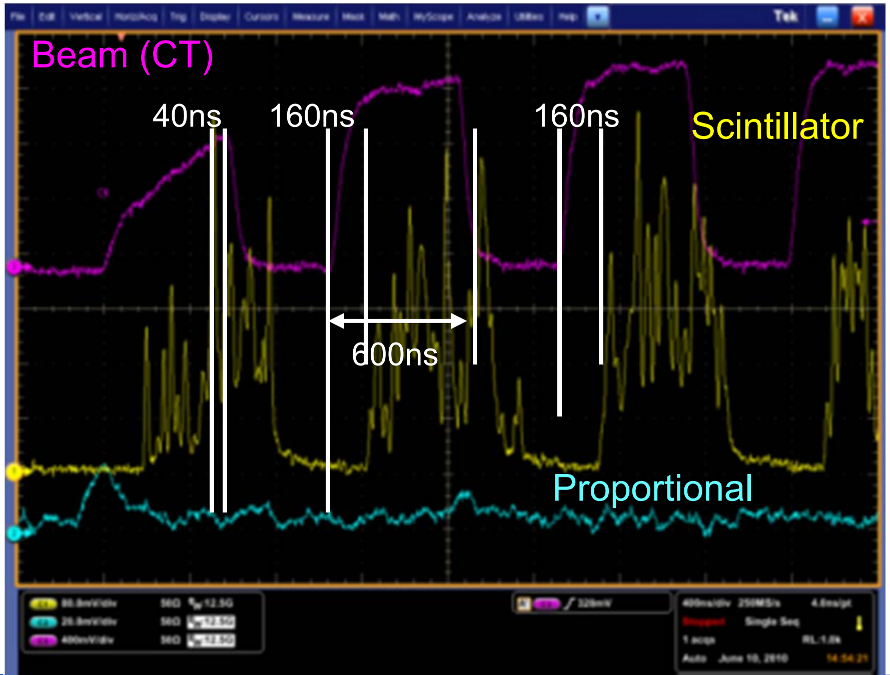


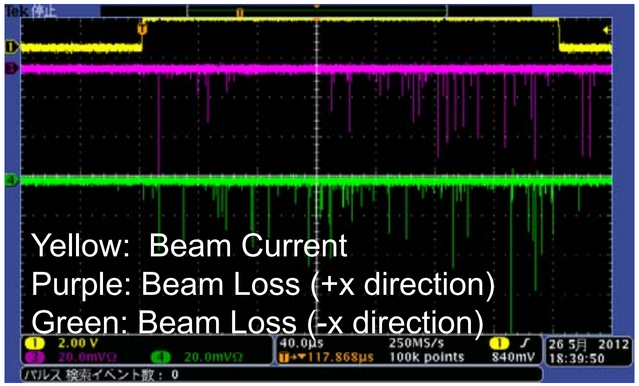
Photo-multiplier: Hamamatsu H3164-10
(gain : 1.1 x 10^6, peak wavelength : 420 nm)
Plastic scintillator: Saint-Gobain BC-408
(peak emission wavelength: 425 nm)



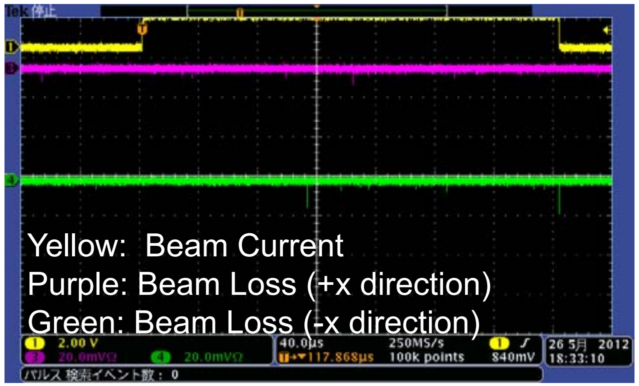
3. Development for Energy Upgraded Linac

Beam Loss Measurement at DTL Section

- Higher residual radiation was recognized at the surface of drift tube linac (DTL) cavity.
- Scintillation beam loss monitors are installed at some points with particularly high radiation to investigate the cause of the radiation.
- Although the DTL section is low energy part of the linac, fine structure of the beam loss was observed by the scintillation BLM.
- We measured the beam loss occurred at the DTL varying the beam orbit.



Beam orbit is corrected.



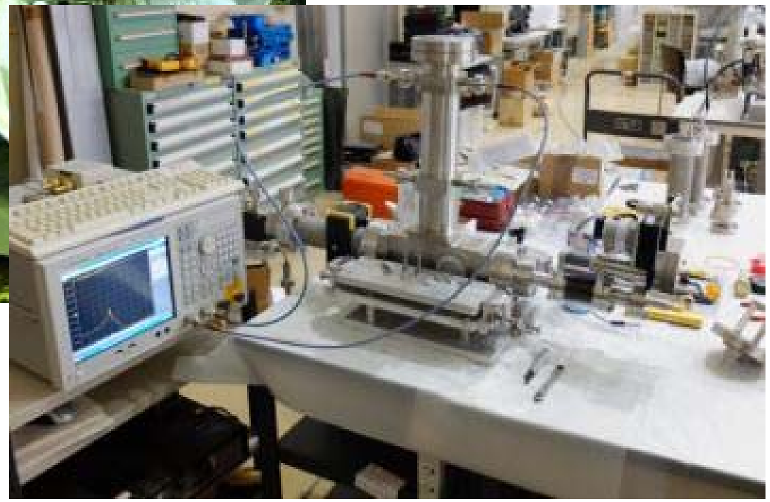
Beam orbit is slightly shifted.

3. Development for Energy Upgraded Linac

Bunch Shape Measurement for Energy Upgraded Linac

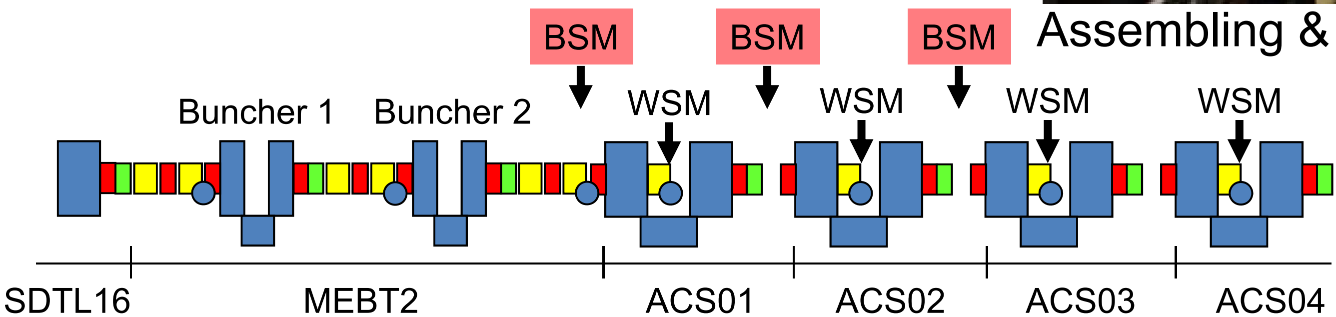
Three bunch shape monitors are installed in order to tune the longitudinal matching, because the different acceleration frequency is employed between SDTL (324MHz) and ACS (972MHz).

Installation



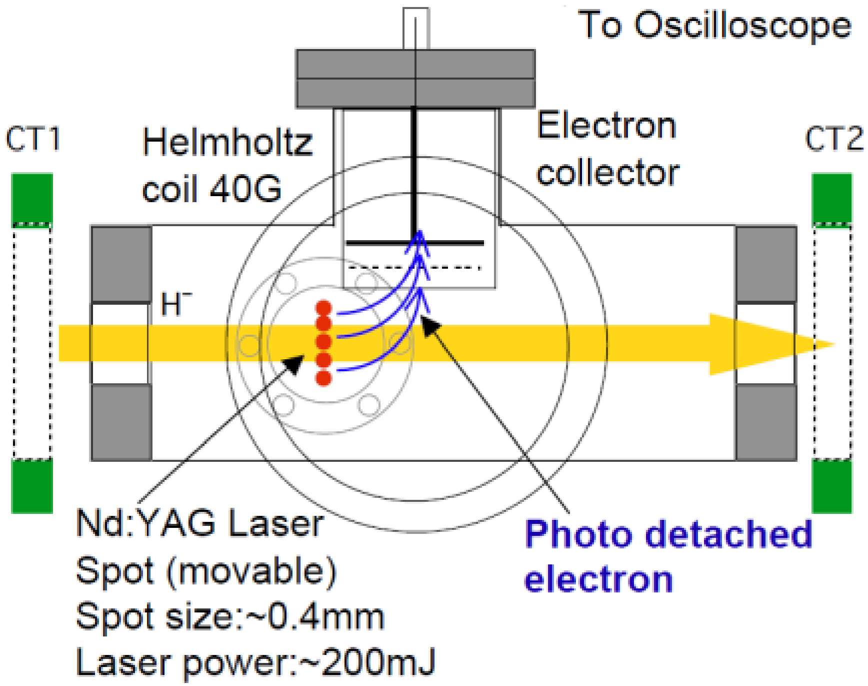
Assembling & Tuning in Test Bench

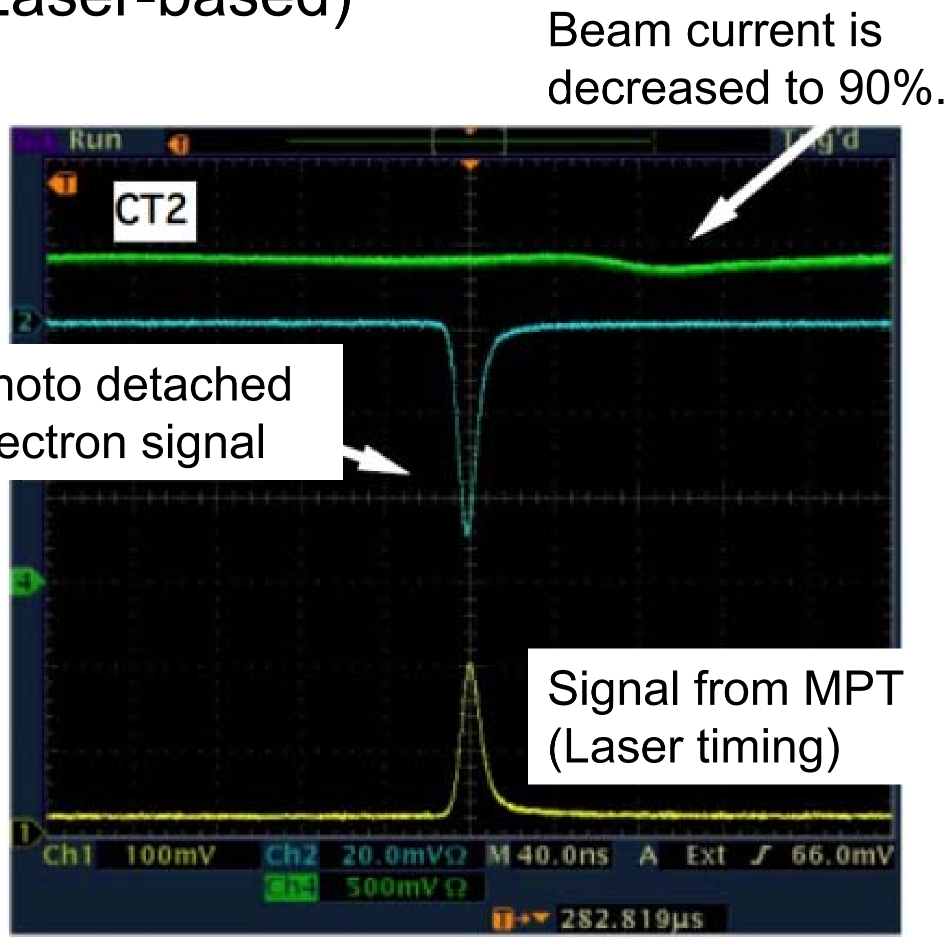
Position of BSMs in ACS Section



3. Development for Energy Upgraded Linac

Non-destructive Profile Monitor (Laser-based)





Laser beam is injected into MEBT1 horizontally.
Good S/N ratio, stable signal was observed.
The feasibility of Laser profile monitor was clearly demonstrated.

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4. Diagnostic Devices for Beam Physics

Recent Topics: Measurement of Intra-Beam-Stripping

- For the continual beam operation, a major operation goal is the decrease of beam loss.
- It has been recently suggested that intra- (H-) beam-stripping contributes significantly to beam losses in an H- linac.

In LINAC2012 conference (held at Tel-Aviv at sept. 9 – 14.)

- Contribution of intra-beam-stripping was tested experimentally at SNS by accelerating a proton beam with an inverse optics.
- SNS presented that the experimental analysis results are in good agreement with the theoretical estimates with emphasis on understanding beam loss in terms of intra-beam-stripping.

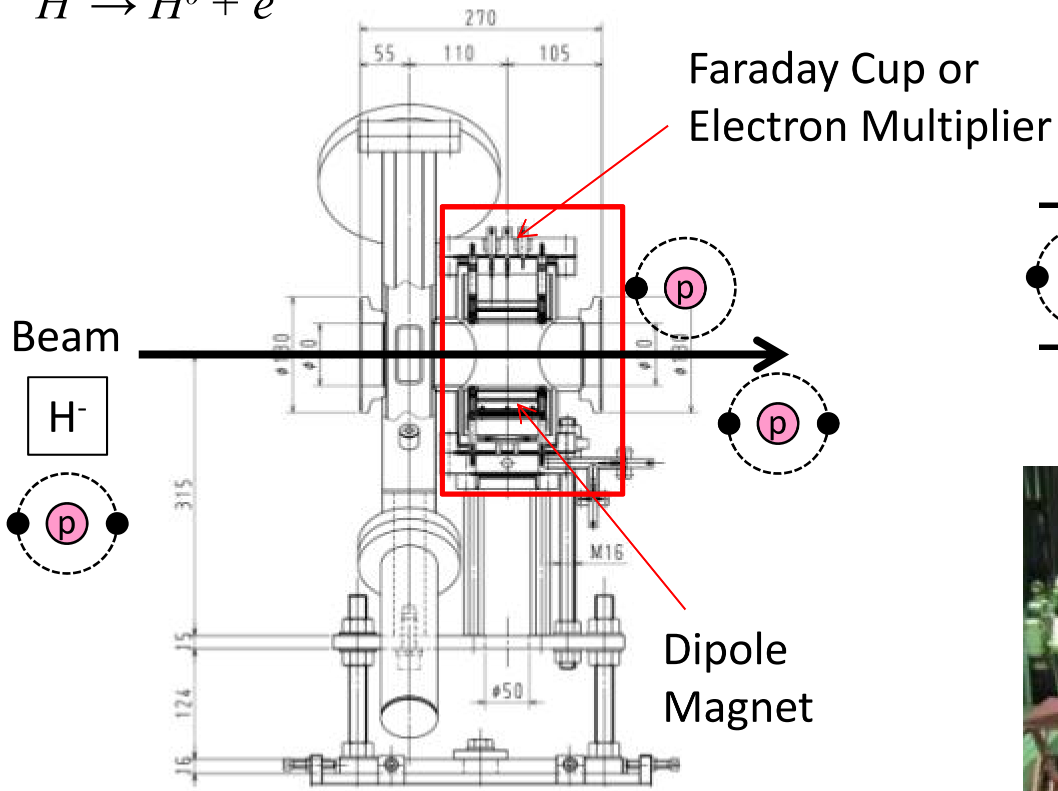
V. Lebedev, LINAC10, THP080
J. Galambos, LINAC12, MO2A02

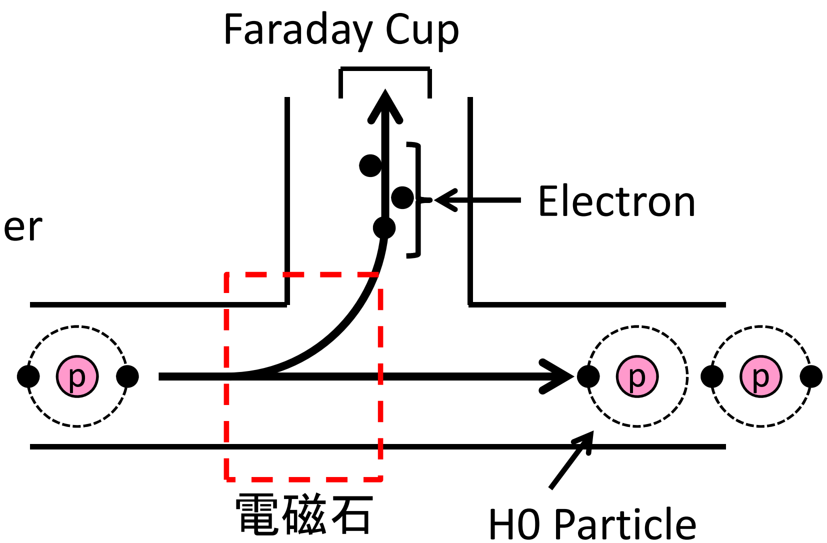
4. Diagnostic Devices for Beam Physics

Recent Topics: Measurement of Intra-Beam-Stripping

Electron Detector

$H^{-} \rightarrow H^{0} + e^{-}$





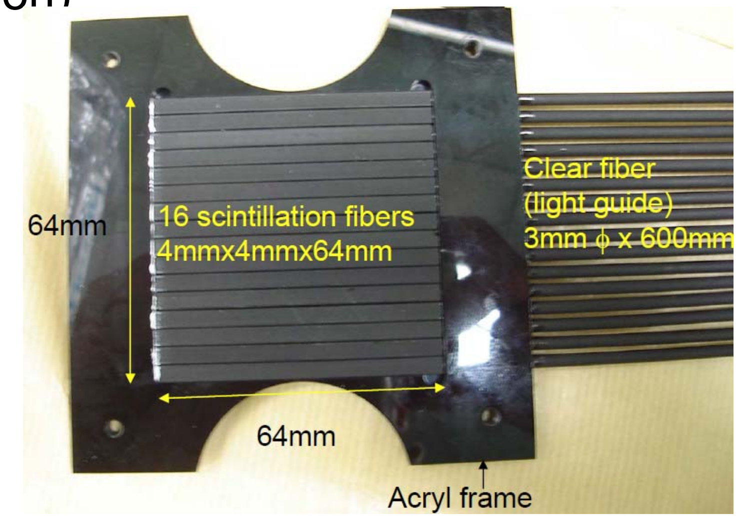
4. Diagnostic Devices for Beam Physics

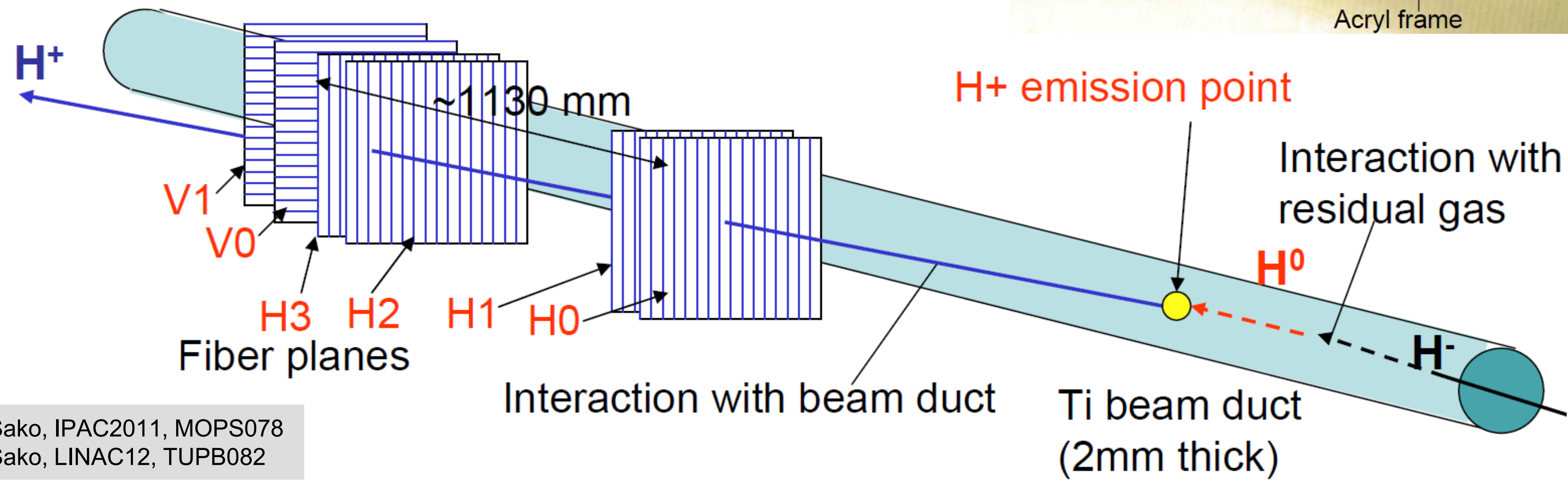
Proton Track Measurements with Scintillating Fibers

Count the number of H+ from H0 (residual gas interaction)

- One H+ corresponds to one lost H-
- Reconstruct a track passing through all fiber planes
- Energy measurement with time of flight
- By fiber positions, emission point can be measured!

Beam loss distribution along beam duct: “Proton telescope”





H. Sako, IPAC2011, MOPS078
H. Sako, LINAC12, TUPB082

4. Diagnostic Devices for Beam Physics

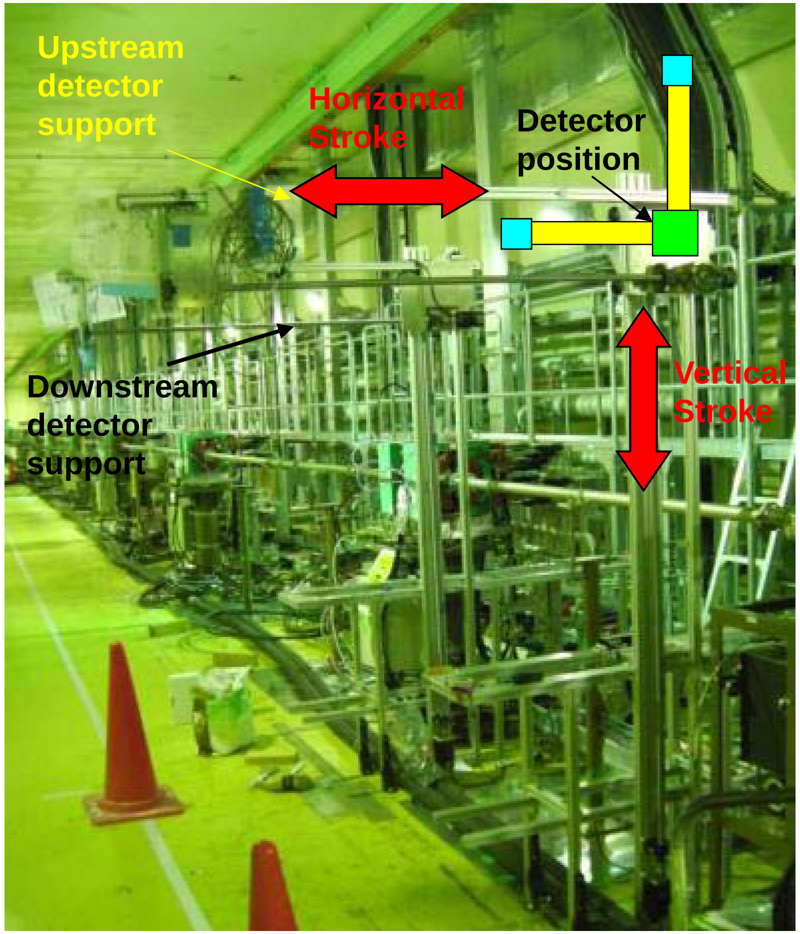
Proton Track Measurements with Scintillating Fibers

We measured charged particle tracks using scintillating fiber detectors with a fast trigger scheme.

Clear time-of-flight peaks of protons, which are consistent with proton energies in the simulation.

Detector is upgraded!

- Addition: both horizontal and vertical tracks reconstruction
- Remotely-controlled detector: moving system (horizontal and vertical)



Detector System Upgrade

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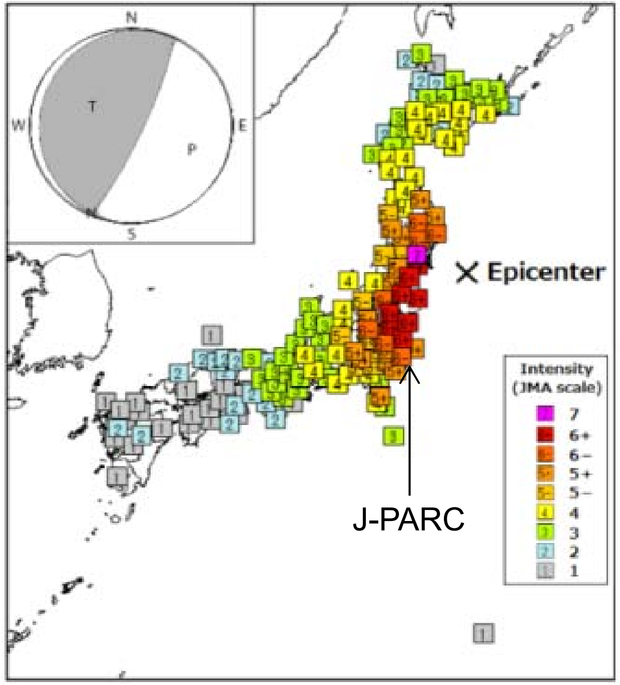
5. Recovery from the Earthquake

The East Japan Great Earthquake

K. Hasegawa, IPAC2011, WEPS095
K. Hasegawa, LINAC12, FR2A01

The great earthquake occurred on March 11, 2011.
The seismic intensity: 6-minus (JMA scale) at J-PARC.
Although Tsunami hit the Tokai-site coast, the height was fortunately below the floor level of J-PARC.



Seismic Intensity (Data from National Research Institute).

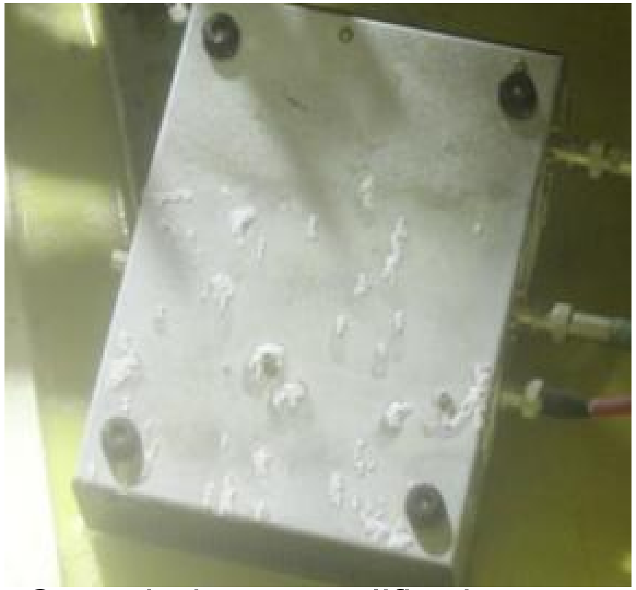
Entrance of the Linac

About 1.5 m drop over a wide area.
All electric wires and water pipes were damaged.

5. Recovery from the Earthquake

Flooding at the Linac Tunnel

Groundwater leaked into the tunnel: depth of 10 cm (150 tons) within two weeks



Corroded pre-amplifier boxes on the floor by strong alkaline.

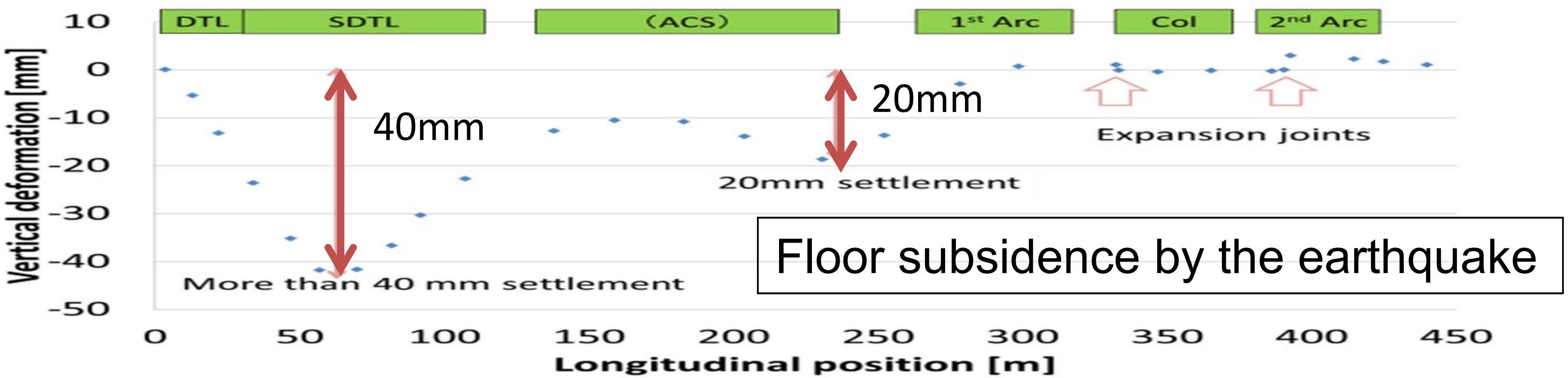
Some flooded pumps were broken.

5. Recovery from the Earthquake

Subsidence of the Tunnel

T. Morishita, IPAC2011, WEPS049
K. Hasegawa, LINAC12, FR2A01

Subsidence: 40 mm (DTL and SDTL section) and 20 mm (now BT, future ACS section)
Continued floor elevation change by June: precise alignment carried out after that.

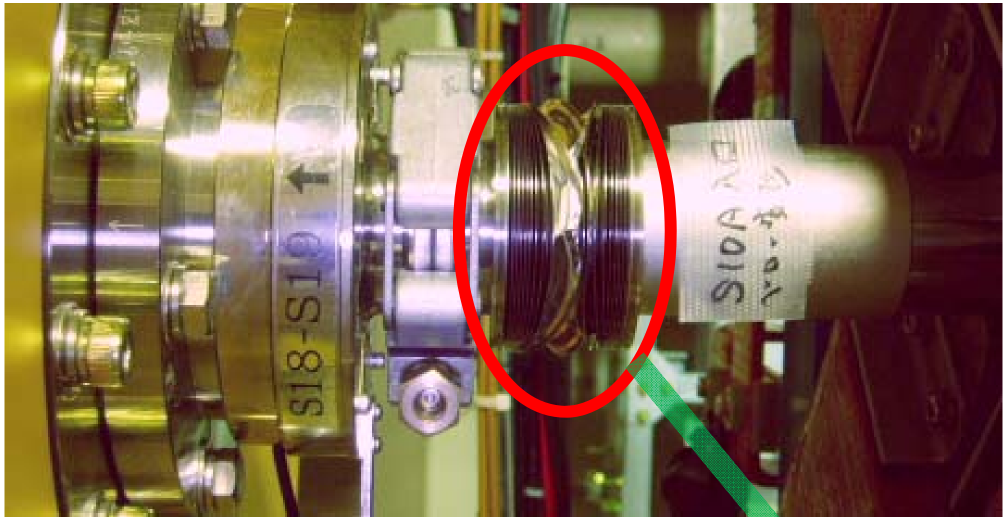


5. Recovery from the Earthquake

Damage of Beam Monitors and Bellows

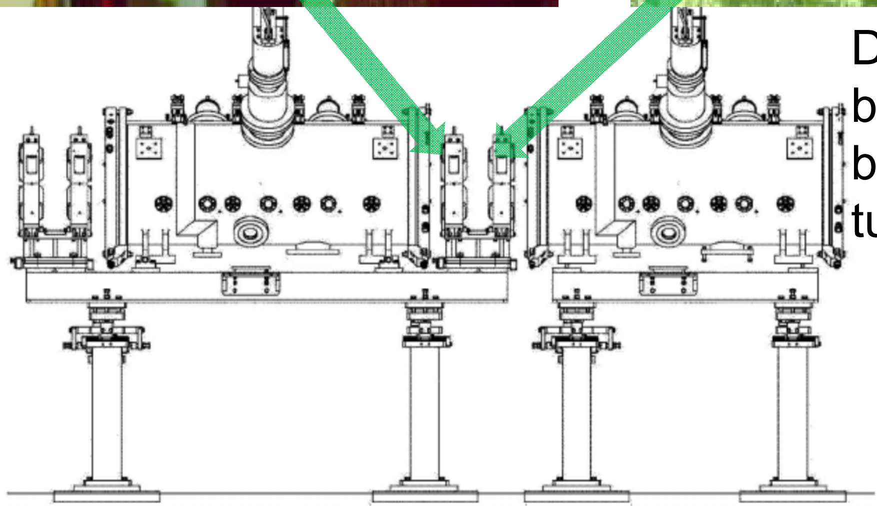
A. Miura, IPAC2011, WEPC144
K. Hasegawa, LINAC12, FR2A01

Distorted bellows between SDTL tanks



Broken current transformer

Bellows and monitors could not stand for these flexibilities and broken.



Detouchment of the brazing section between the ceramic tube and stainless duct

5. Recovery from the Earthquake

Summary

Numbers of Installed and Damaged Monitors

Section	Number	BPM with Bellows	SCT	FCT
MEBT1	Installed	8	6	5
	Damaged	1	0	0
DTL	Installed	0	3	3
	Damaged	0	2	2
SDTL	Installed	32	15	44
	Damaged	6	0	17

- About one-thirds of FCT monitors had damaged in SDTL section.
- All damaged monitors had been exchanged until the end of November, 2011.
- Beam commissioning started from December, 2011.

Summary

- We employed following monitors as commissioning tools:
  Strip-line type beam position monitor,
  Gas proportional beam loss monitor,
  Slow / fast current transfer as the current / phase monitor, and
  Wire scanner for beam profile measurement.
- For energy upgraded project, we developed
  Scintillation beam loss monitor (X-ray less sensitive),
  Bunch shape monitor for longitudinal profile measurement and
  Laser-based non-destructive profile monitor.
- For the increasing of output energy, key word is a “intra-beam stripping (IBSt)” as the cause of beam loss.

Acknowledgements

J-PARC Monitor Group

We thank to following researchers and engineers for their efforts and kind advice.

Linac

A. Miura, T. Miyao

RCS: Rapid-cycling synchrotron

K. Yamamoto, N. Hayashi, M. Yoshimoto, H. Harada, S. Hatakeyama, R. Saeki

MR: Main Ring

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Thank you!

We welcome you to visit J-PARC.