Beam diagnostic system of the main ring synchrotron of J-PARC

HB2008
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KEK/JAEA

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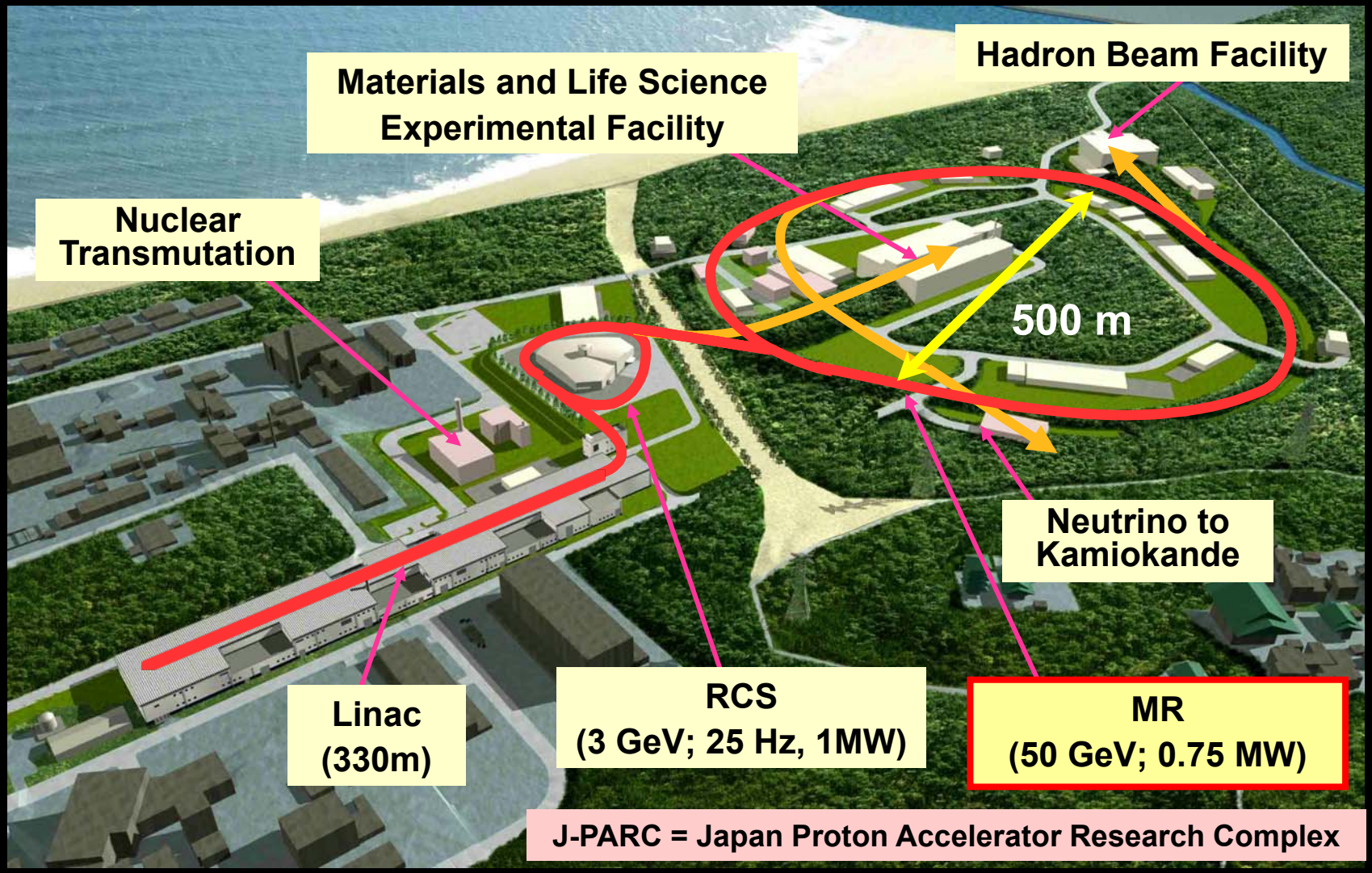
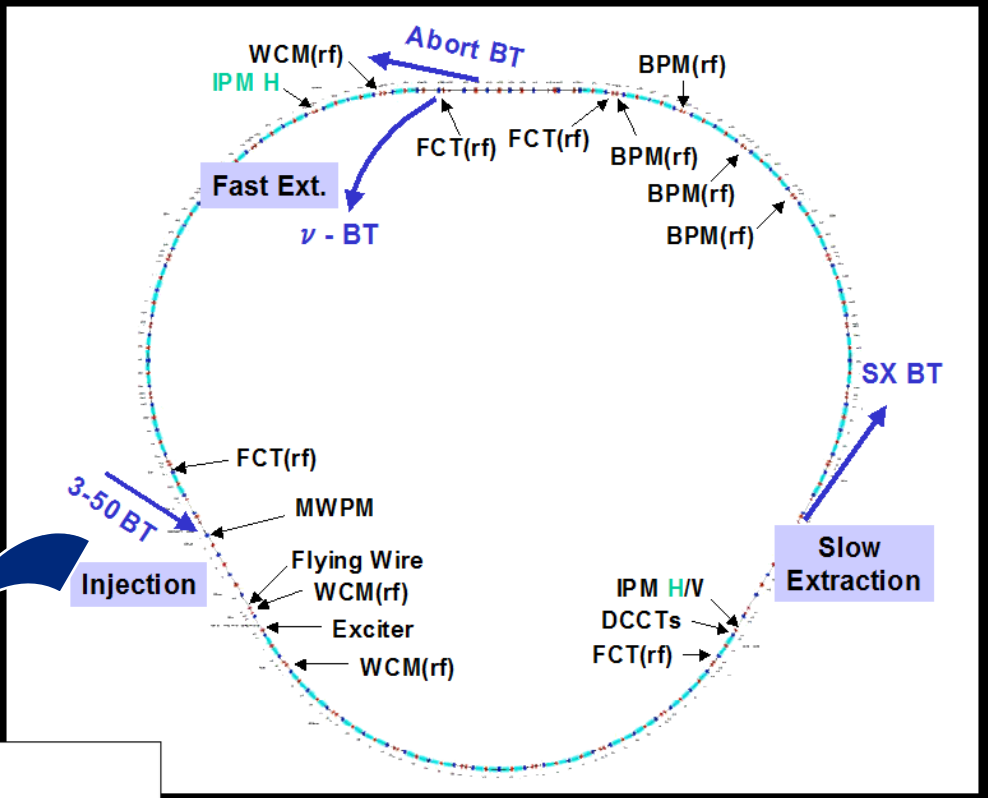
J-PARC

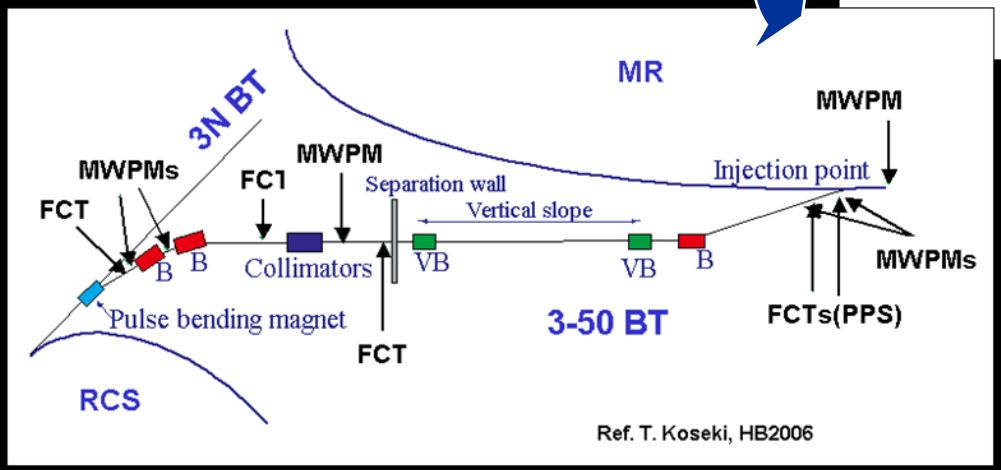

Hadron Beam Facility
Materials and Life Science Experimental Facility
Nuclear Transmutation
500 m
Neutrino to Kamiokande
Linac (330m)
RCS (3 GeV; 25 Hz, 1MW)
MR (50 GeV; 0.75 MW)
J-PARC = Japan Proton Accelerator Research Complex

Location of instrumentations

List of ring monitor (Blue:future plan)

Monitors	Number
BPM	186
Single-pass BPM	2
Dump/abort BPM	2 + 2
WCM(>100MHz)	3
FCT(～20MHz)	6 + 1 (ν-BT)
DCCT(DC-30kHz)	2
MWPM	1 (inj.), 2 (SX, Abort BT)
Flying Wire (H/V)	1 / 1
IPM (H/V)	2 / 1
BLM	Proportional type 238 Ion chamber type 18



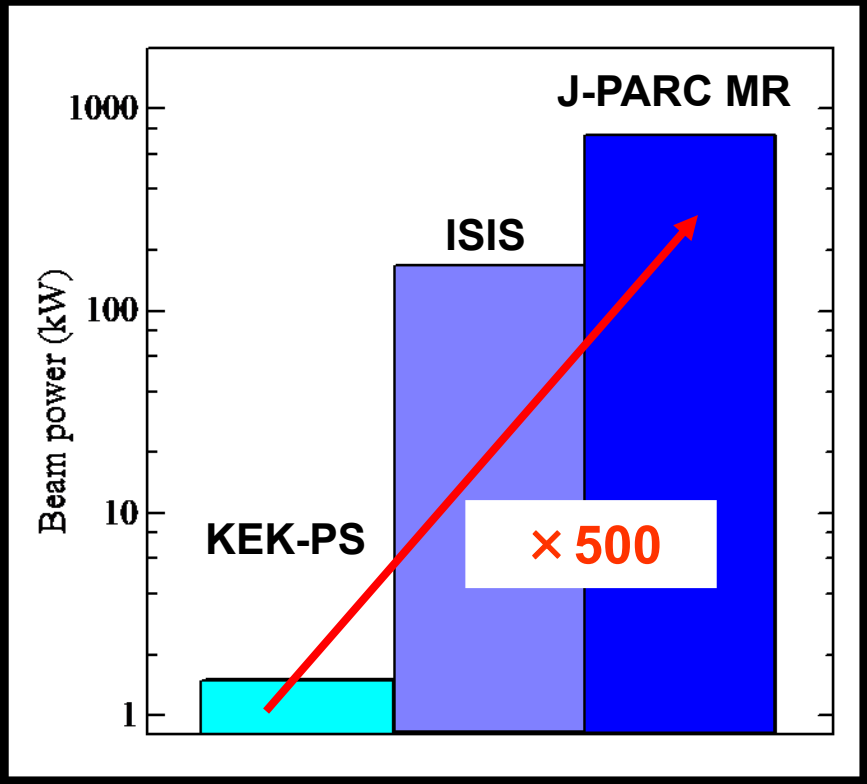


List of 3-50 BT monitor (Blue:future plan)

Monitors	Number
Single-pass BPM	14
FCT(～20MHz)	5
MWPM	5 + 4
BLM	Proportional type 50 Ion chamber type 3

Requirements for beam monitor

J-PARC MR Beam power : ～500×(KEK-PS beam power)
However,
Beam loss criteria: 0.5 W/m same as KEK-PS!!
This criteria corresponds to 1.8% (3GeV)～0.1%(50GeV) beam loss



Beam power up to J-PARC

- Beam loss monitoring covering <0.1% to 100%, dynamic range which is over 10^3 level
- Beam halo monitoring because beam loss originating from halo formation may limit beam current
- Beam current monitoring with wide band and high dynamic range for delicate tuning of RF system

Challenging and essential issue!!

Day-one beam parameters (May, June 2008)

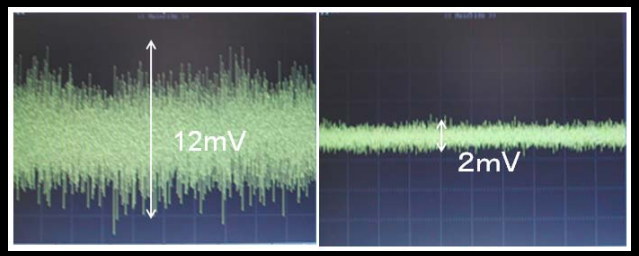
- 100-1000 turn 3 GeV DC mode
- 1/100 particle per bunch
- 1 Bunch inj.

	Design	Day-one	
Particle per pulse	**3.3×10^{14}**	**$4\text{-}5 \times 10^{11}$**	**ppp**
Number of Bunch	**8 (h=9)**	**1 (h=9)**	
Peak current	**41.3-220**	**3**	**A**
Circulating current	**12.4-12.8**	**0.12-0.14**	**A**
velocity	**0.9712-0.9998**	**0.9712**	**1/c**
Bunch half width	**180-33.7**	**40-60**	**ns**
Revolution frequency (1 / f)	**186-191 (5.38-5.24)**	**186 (5.38)**	**kHz (μs)**
RF frequency (1 / f)	**1.67-1.72 (599-581)**	**1.67 (599)**	**MHz (ns)**

Countermeasures against noise problem

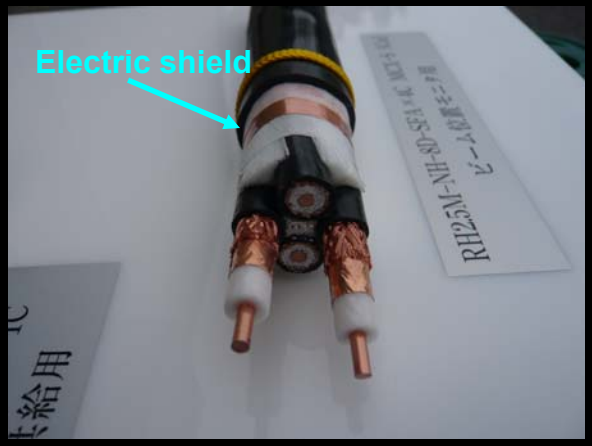
- **High shielded cables tested radiation hardness at Co60 γray facility of Takasaki lab./JAEA**
- **Grounding cupper plates along the ring**
- **Noise cut trans in an AC line**
- **Common mode choke coil in a signal line**

Grounding copper plate

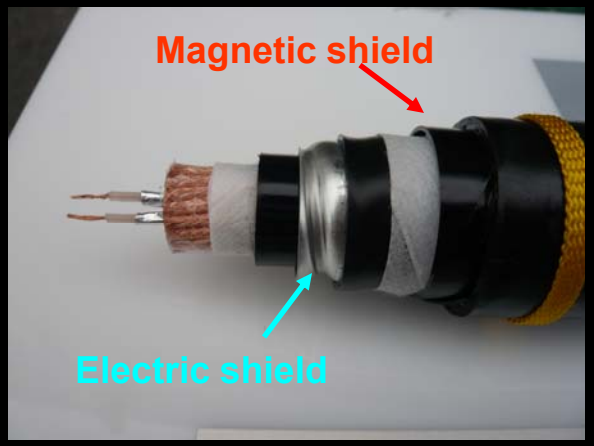


1/6

Connect a electric shield to a grounding copper plate



4 in 1 coaxial cable for BPM



34 in 1 coaxial cable for MWPM and IPM

High shielded cables with radiation hardness (<2.5MGy) for J-PARC Fujikura Ltd.

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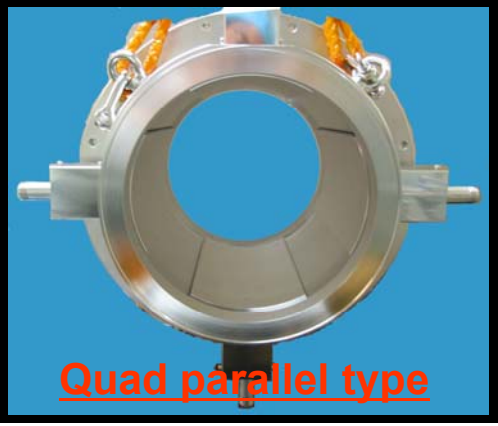
BPM

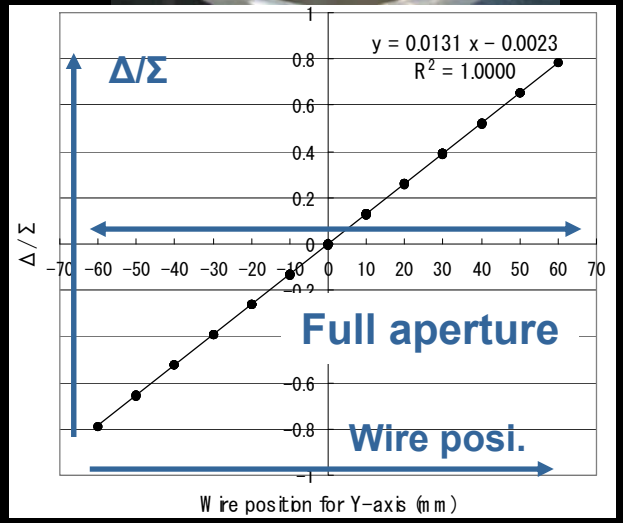
Electrostatic type BPMs are installed near almost all QM

Ring BPM:
- **Mainly used in the ring**
- **Good linear response covering full aperture**
- **Bore: Φ130mm(standard),**
  Φ134, 165, 200, 250, 320mm(special)

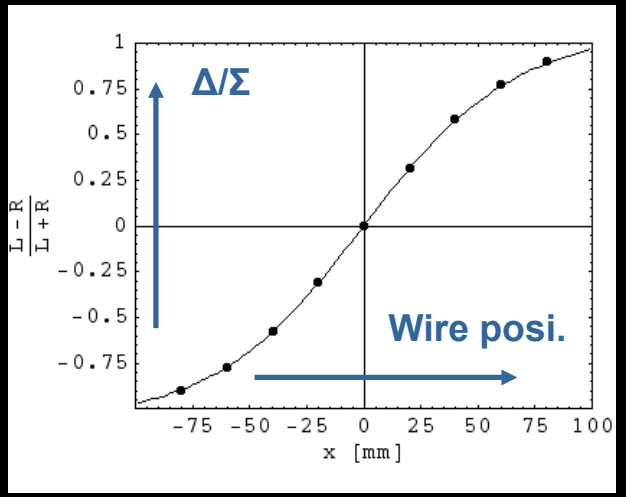
Calibration : wire method

Single pass BPM:
- **Mainly used at 3-50BT**
- **Bore: Φ230, 200mm**





Error (in rms unit)
- **Sensitivity: ±0.00004**
- **Offset: ±0.12 mm**
- **Rotation: ±3.6μrad**



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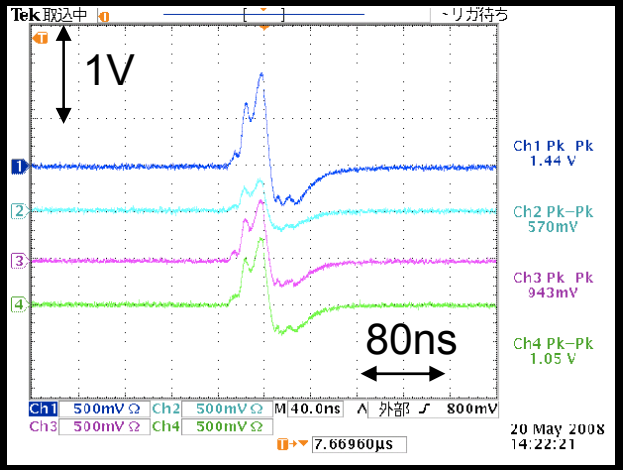
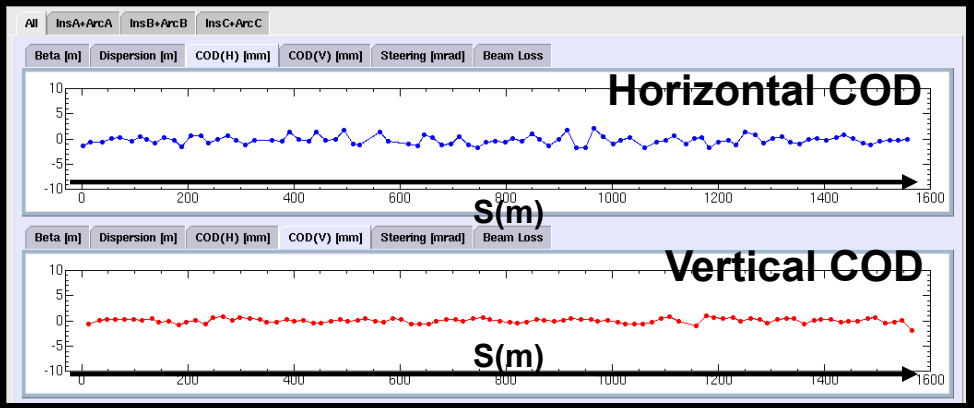
Ring BPM

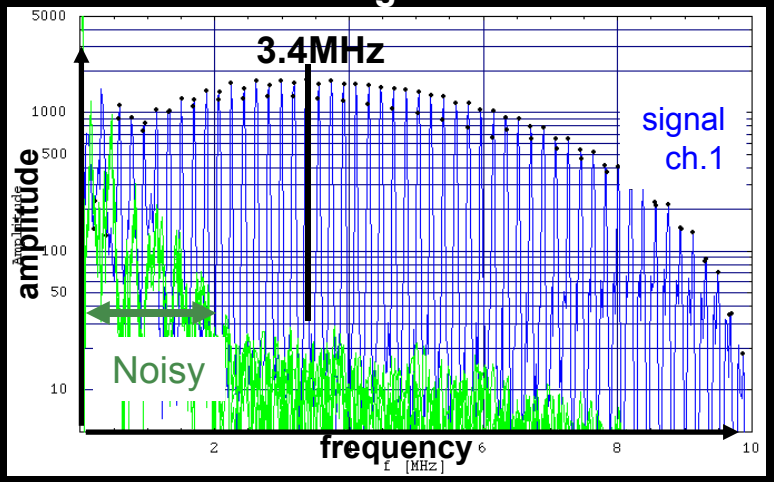
- Lower cut-off frequency is 17MHz⇒differential wave form
- 14 bit, 10MHz, 80 MS/s ADC
- Off-line position calc. (COD mode): Raw signal (4096 point)⇒ average over 4 data (1024 point) ⇒ FFT ⇒ peak search (3.4MHz=2 × f_{rf}) ⇒ Position



Raw signals



Measured COD



FFT of the raw signal

Blue: Signal+noise
Green:noise

BPM installation error (in rms unit)

- Offset: Δx=0.41±0.96mm, Δy=-0.35±0.50mm
- Rotation: 0.96±3.3 mrad

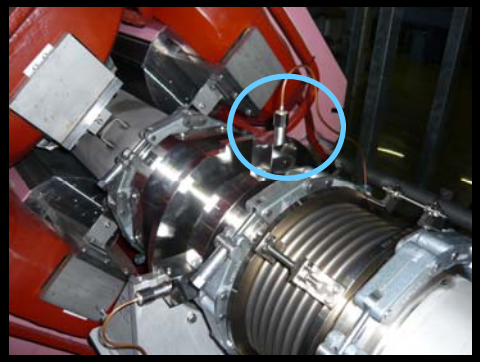
K. Hanamura *el al*

Not yet calibrated

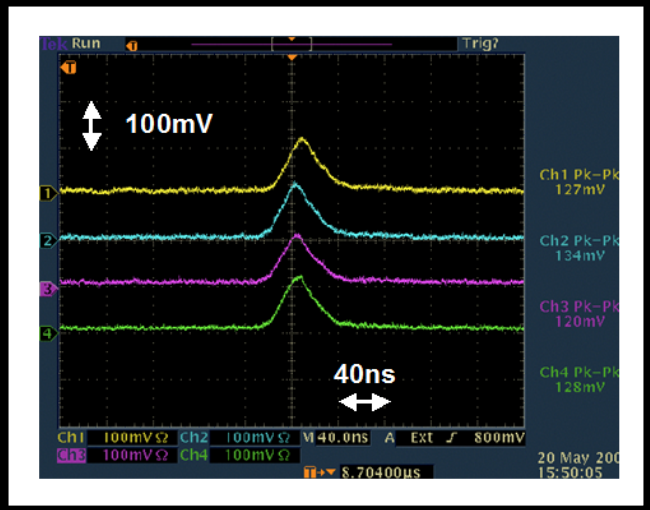
Present position resolution: ~0.5 mm

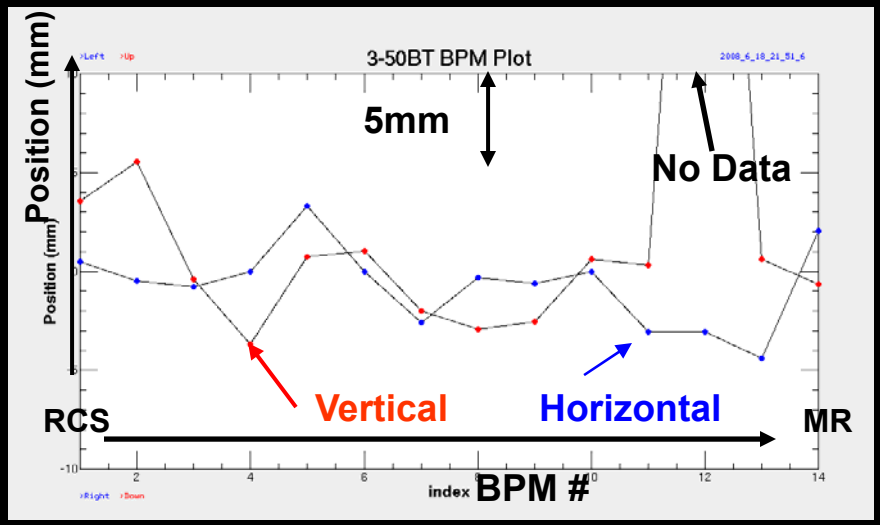
Single-pass BPM (3-50BT)

- To expand lower cut-off frequency, a transformer has installed at an output connector ⇒ 230kHz
- 8 bit, 100MHz, 2GS/s ADC
- Q-mode measurement (future plan)



2:15 transformer at output connector



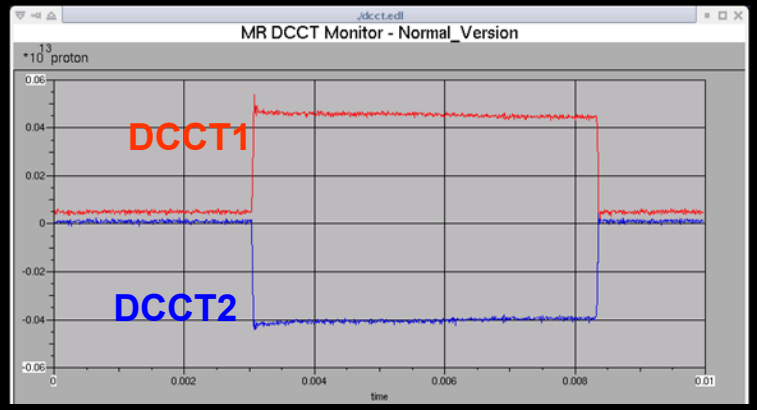


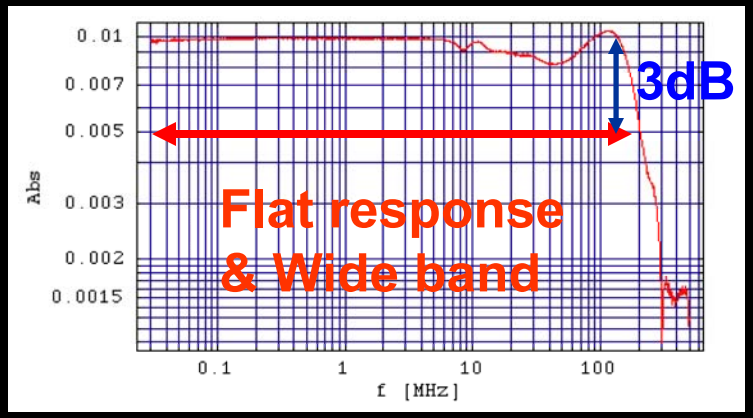
Beam current monitors

DCCT

S. Hiramatsu *et. al*

- FINEMET (HITACHI metal Ldt.) core
- Frequency band: DC~20kHz
- Gain selection: 0.2A, 2A, 20A
- $\Delta I < 100\mu A \Rightarrow \Delta N_B \sim 6.5 \times 10^9$ ppp(rms)

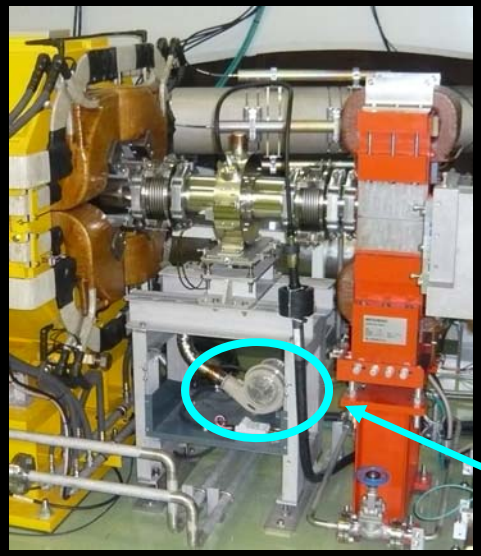




FCT

D. Arakawa *et. al*

- FINEMET (HITACHI metal Ldt.) core
- Frequency band: 16Hz~180MHz
- RF phase feedback



WCM

D. Arakawa *et. al*

- FINEMET (HITACHI metal Ldt.) core
- Lower cut-off frequency: 150, 380, 400
- Shunt impedance: 92mΩ
- Heat load on resister is 40-50W
  ⇒Air blow system is needed
- RF feedforward for beam loading

Tune meter

- Horizontal and Vertical exciters have been installed
- The maximum exciter power is 2kW input by using white noise with band width of 1-2MHz
- Beam oscillation is analyzed by “Real-time spectrum analyzer”

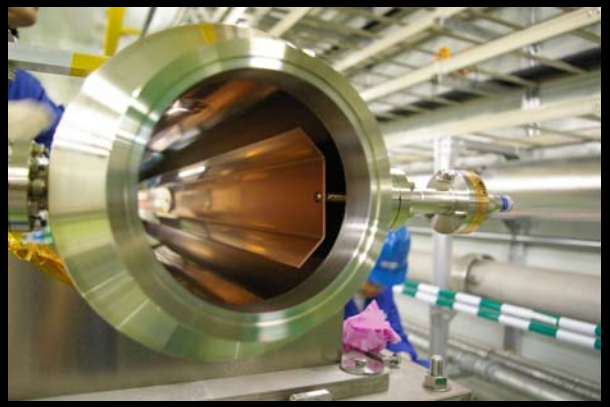
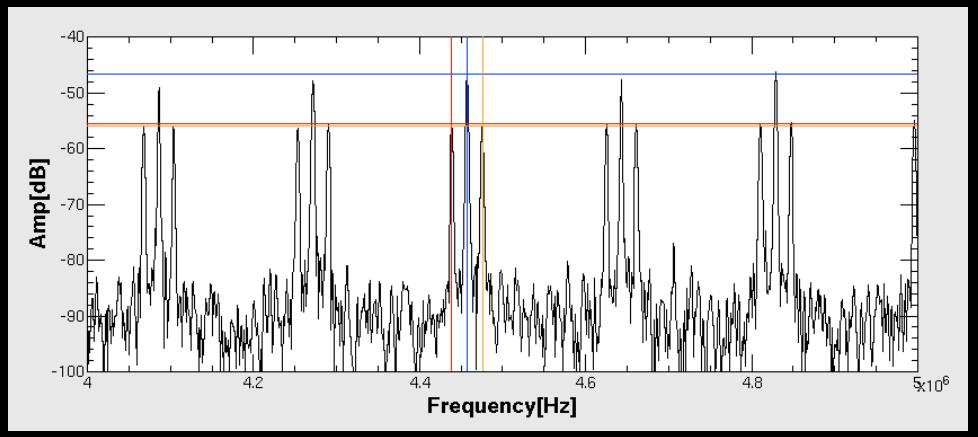
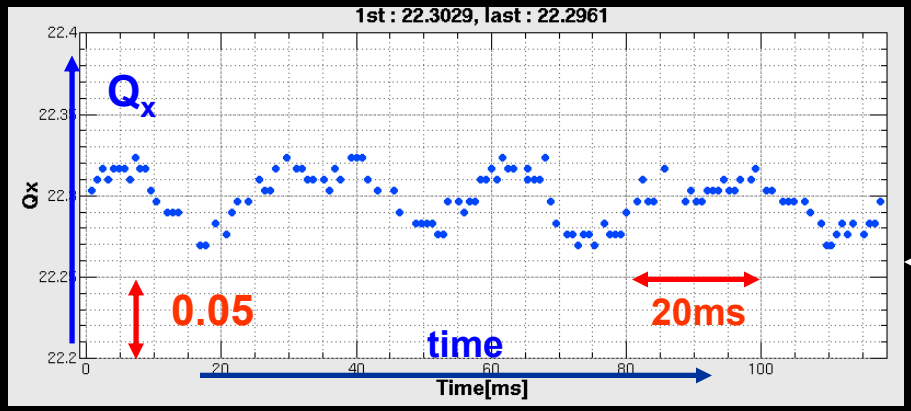


Photo. of an exciter



Measured betatron oscillation frequency

Resolution of tune: Δν~0.007



Beam fluctuation due to ripple of power supply was measured

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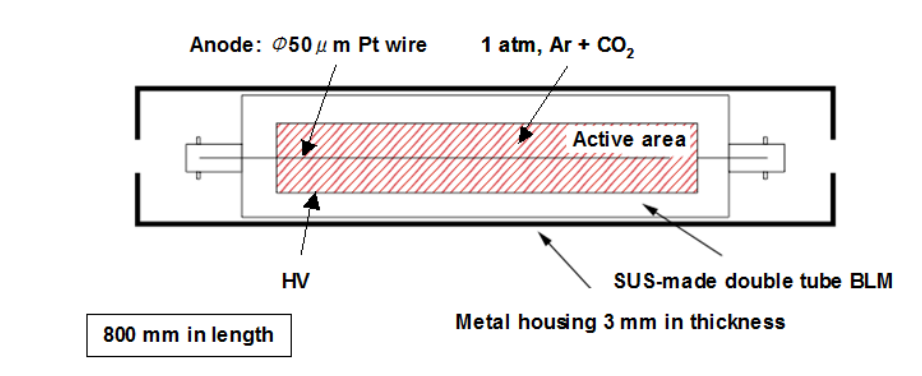
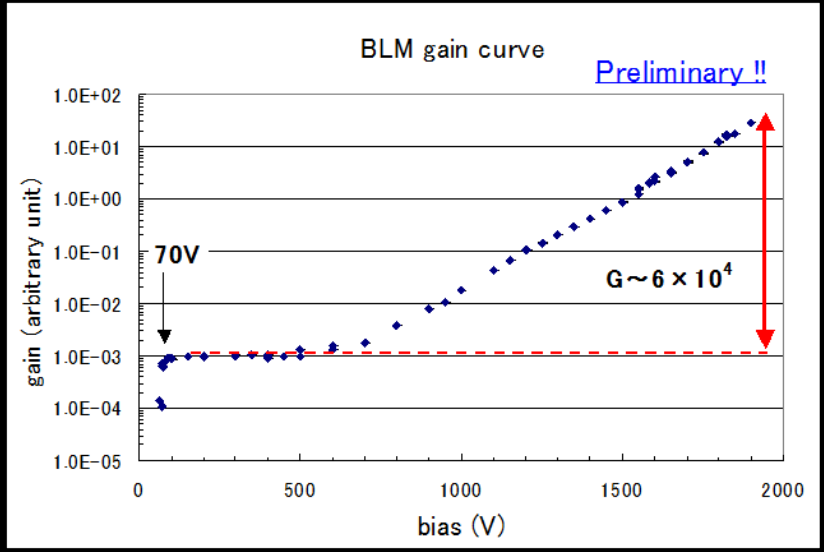
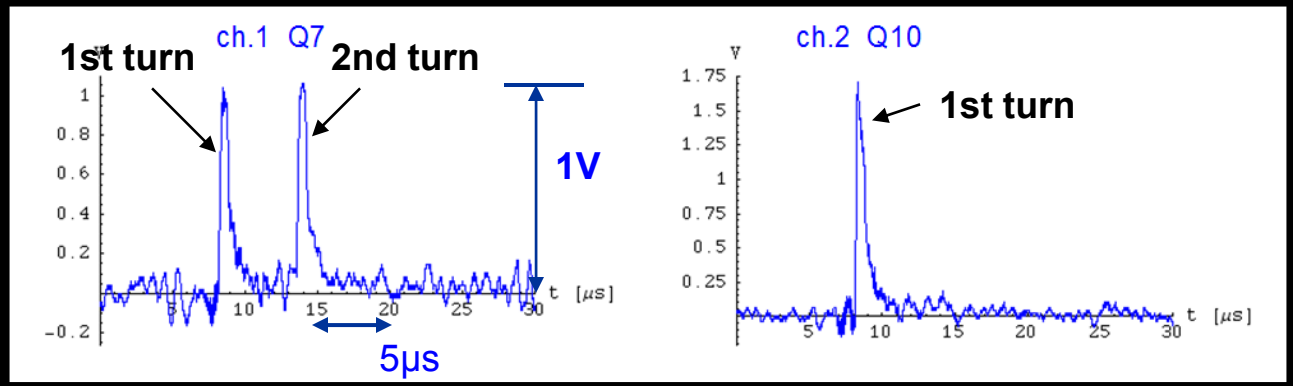
BLM1





Gain curve of the BLM measured by using secondary cosmic rays, mainly muon

BLMs have been installed at each QM



Raw signal
bias: 1.6kV, Z_{in} of amp: 50Ω, amp gain: ×10

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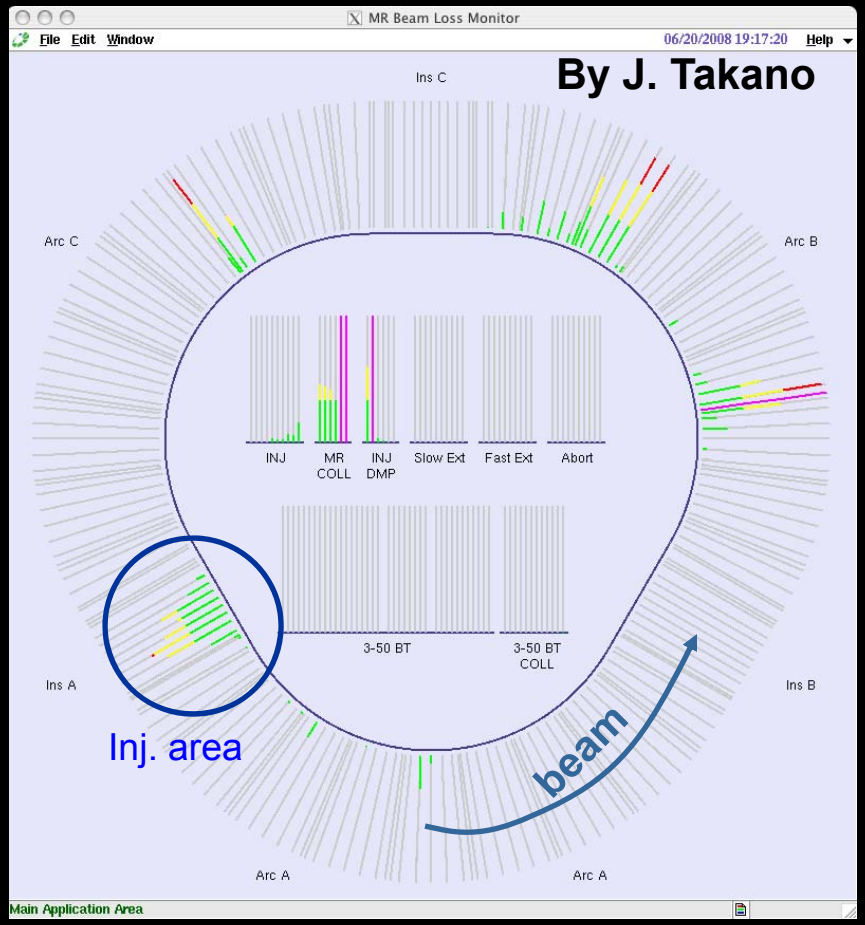
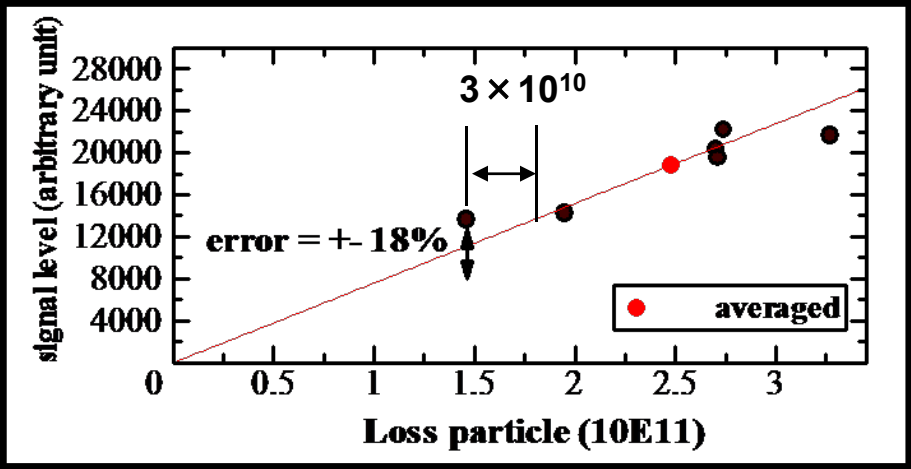
BLM2

- Sum of beam loss signals from inj. to ext.
- Loss signals are just shown in arbitrary unit
- HV=1.6kV, Zin=1kΩ, amp gain=10



Beam loss distribution



Correlation between sum of all BLM signals and a number of loss particle

Error: ±18% ⇒ 3×10^{10} ppp

◎ Beam loss criteria

0.5W/m for 0.75MW, 3.3×10^14 ppp

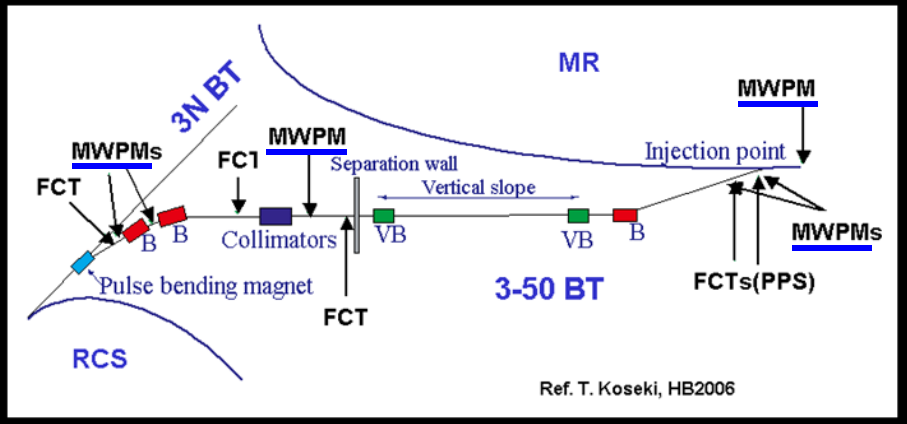
0.1% for 50 GeV ⇒ 1.6×10^9 ppp at each BLM
1.8% for 3 GeV ⇒ 29×10^9 ppp at each BLM

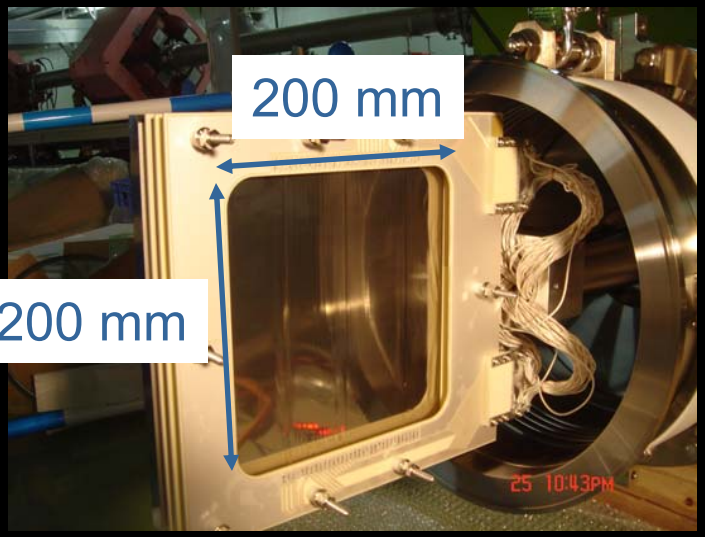
We should study more about …..

- Error source
- Reliability on AC mode operation
  - Signal dependence on beam energy
- How to determine the HV
  - Space charge problem should be considered on high gain operation

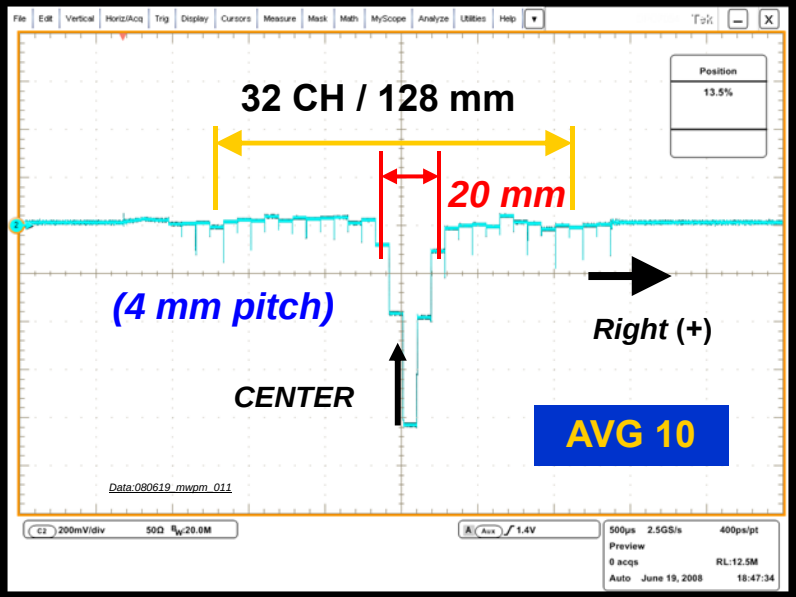
Multi-wire profile monitor: MWPM

- Wire target using tungsten wire of
  30 μm for day-one
  Number of channel: 32 / 64
  Pitch: 2.5, 3.5, 4.0, 4.5 mm
- Carbon ribbon type target is
  under development





Typical wire target

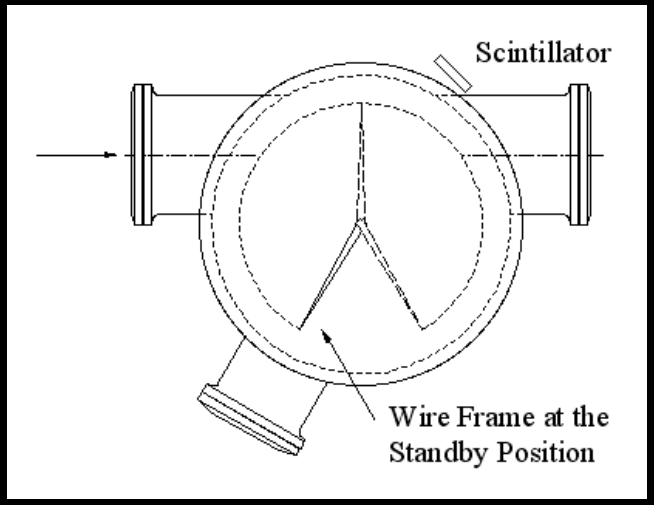


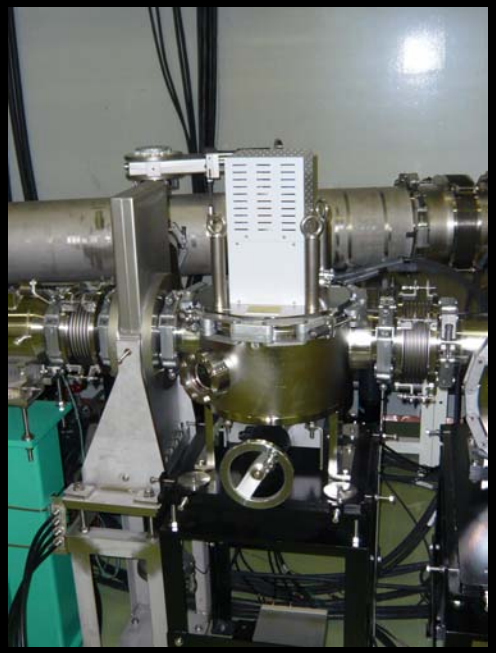
Measured horizontal beam profile

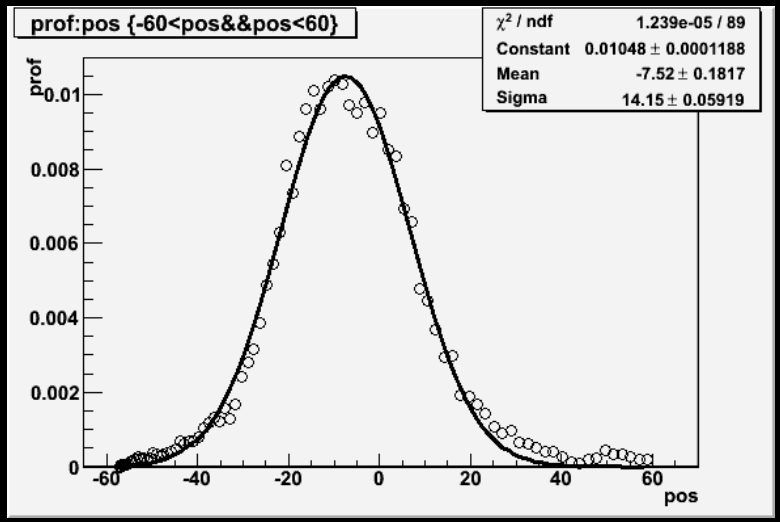
S. Igarashi *et. al*

Flying wire profile monitor

- One horizontal type for day-one
- Vertical one is now under development
- Wire:Carbon fiber of 7μm in diameter
- Wire speed: 10m/s
- 1 profile / 0.1s







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Residual gas ionization profile monitor: IPM

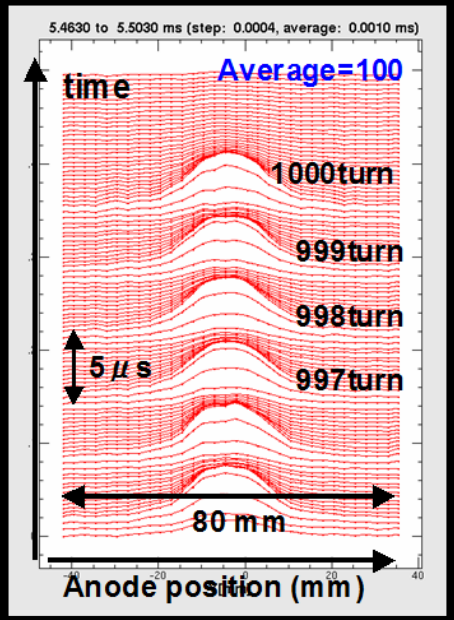
Ion collection with HV
- 35kV for day-one ⇒ will be upgraded to 50kV

Electron collection with magnetic field
- Require for 0.75MW beam profile measurement
- ⇒future plan

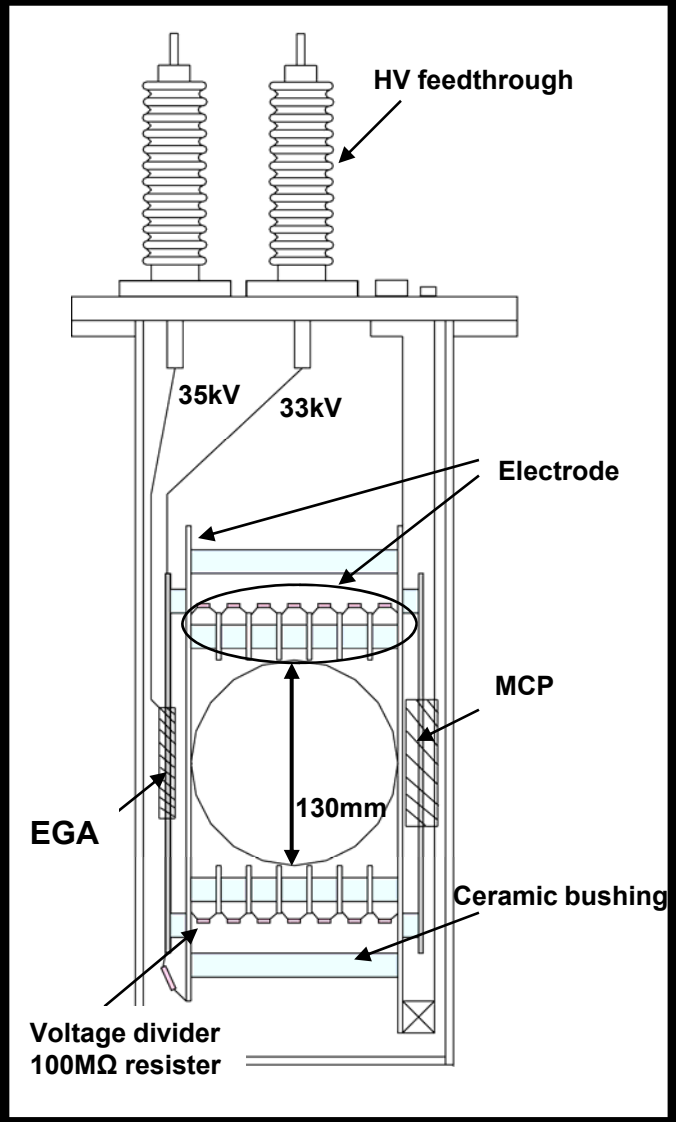
Micro Channel Plate (MCP) for signal read out device
- 2 stage MCP assembly with 32 ch strip anode
- Active area: 31 × 81 mm^2
- Width of each anode: 2.5 mm
- Gain: ~10 ^{6}

Calibration devise to check MCP gain balance
- Electron generator arrays ⇒ Photonis Ltd.

Need averaging to reduce the statistical error due to number of ions
- Number of ions is about a several 10000 per bunch for designed beam, that is only a several hundreds for day one beam



Turn by turn beam profile

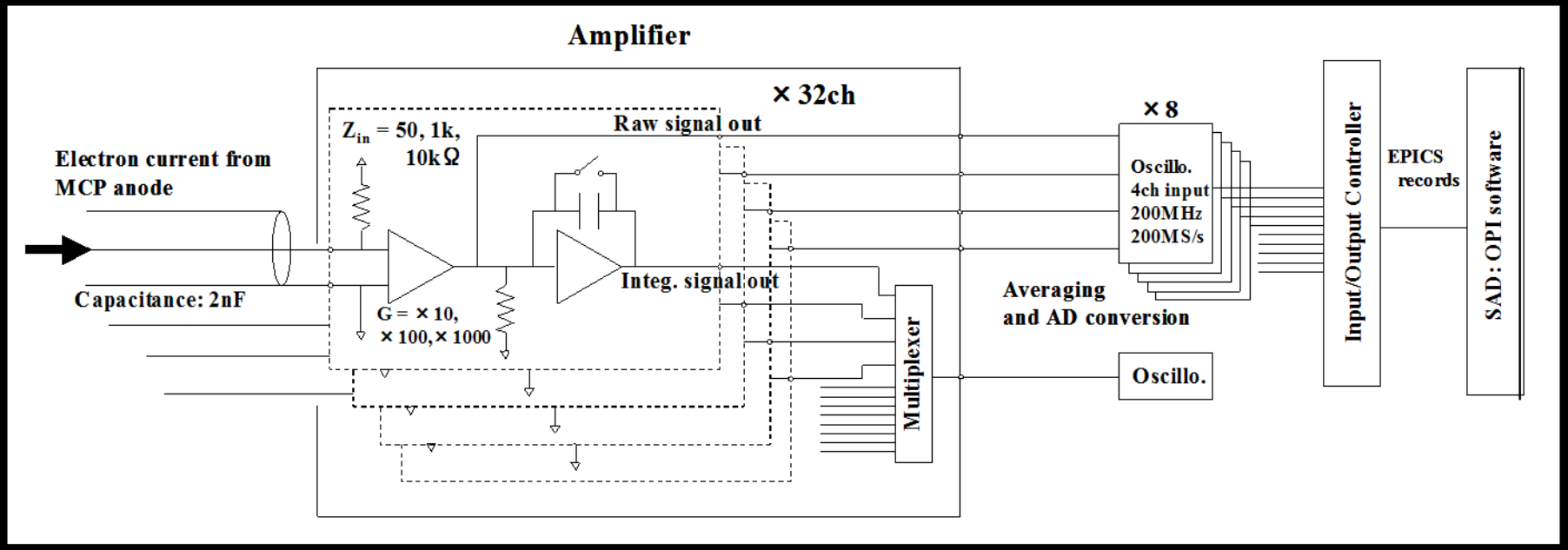


Cross section of V-IPM

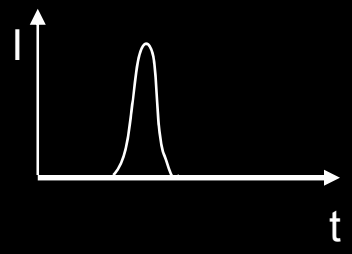
Summary

- Various instrumentations are installed and used on Day-one beam commissioning
- The beam current was 1/100 of designed value, however, the system shows good performances
- Some monitors will be installed until this December
  - Two horizontal IPMs ⇒ straight (η=0) and arc. (η=2.0m) sections
  - One MWPM and 2 BPMs for abort dump line
  - Six Screen monitors for slow extraction line
  - One FCT for ν BT line
- The performance tests on AC mode (up to 30 GeV) operations will start from this December

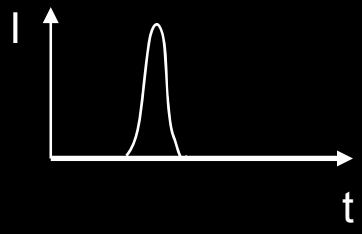
Signal flow diagram of IPM



Beam current

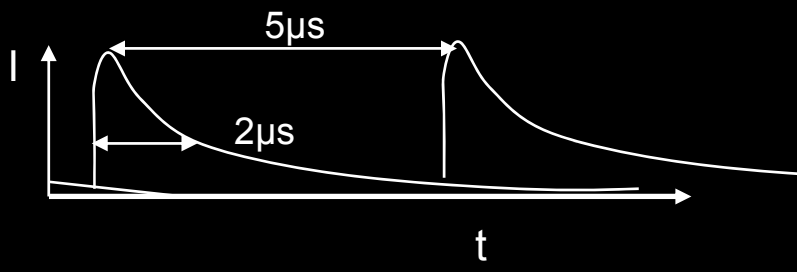


Out put current from MCP anode



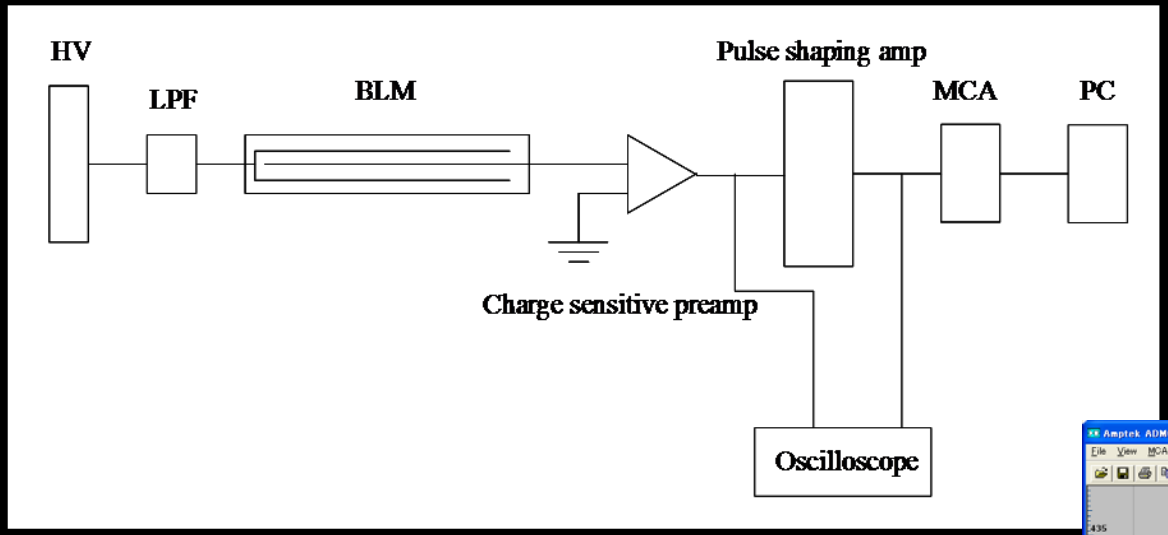
MCP has a fast response time of about 200ps !

Out put voltage from amp.

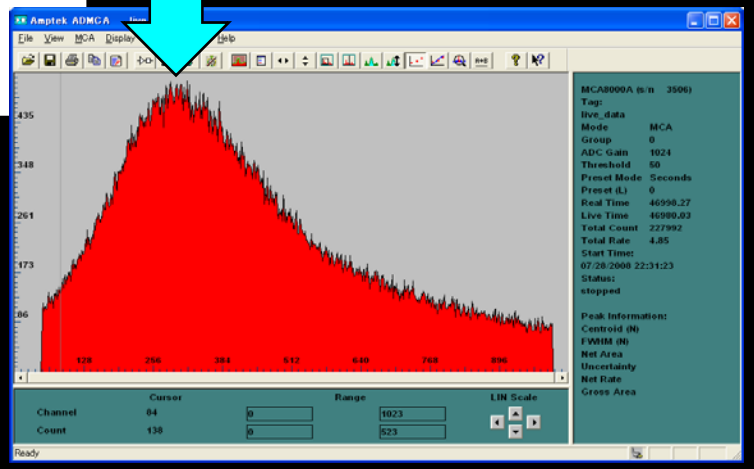


Wave form with decay constant Determined by cable capacitance and input impedance

BLM calibration setup



Peak pos. vs. HV was measured



Energy spectrum of secondary cosmic rays (muons)

FCT: frequency response