Development of Wide Dynamic Range Beam Loss Monitor System for J-PARC Main Ring

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- Old system
  - Proportional chamber type BLM
  - Merit (High gas gain) and demerit (Gain change)
- New system
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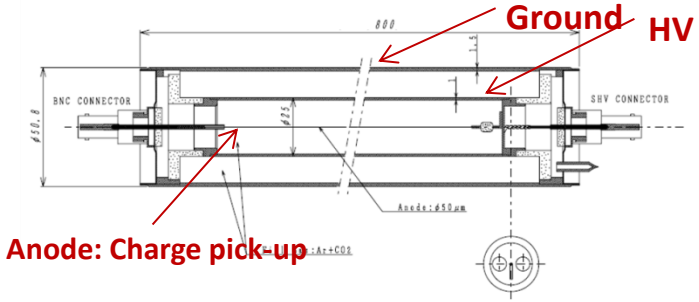
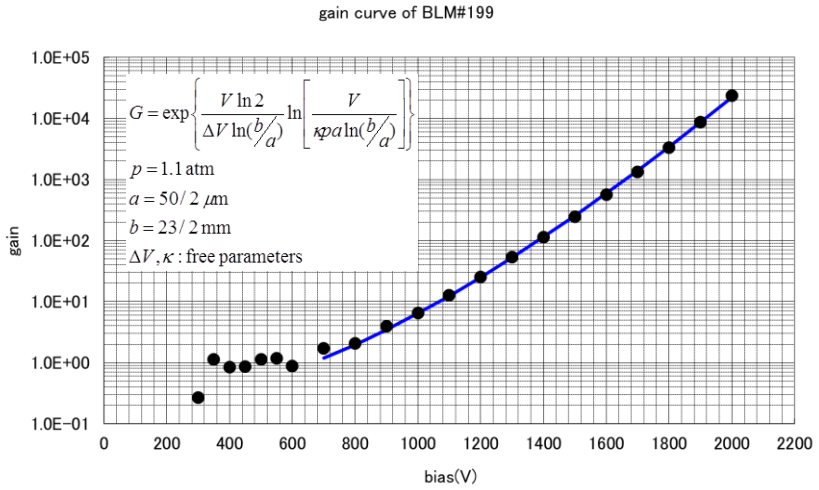
  - New amp and ADC
- Data from the new system
- Summary

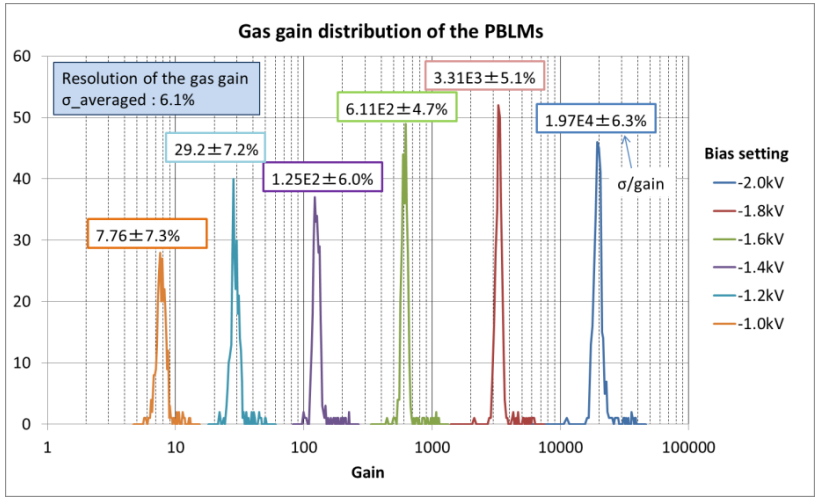
Old BLM system 1

- Old system used mainly proportional chamber type BLM (PBLM)
- High gain: **20000(averaged) @ max. Bias=2kV**
- The high gas gain performance -> **Good performances for early stage of beam commissioning (low intensity, 1% of full)**

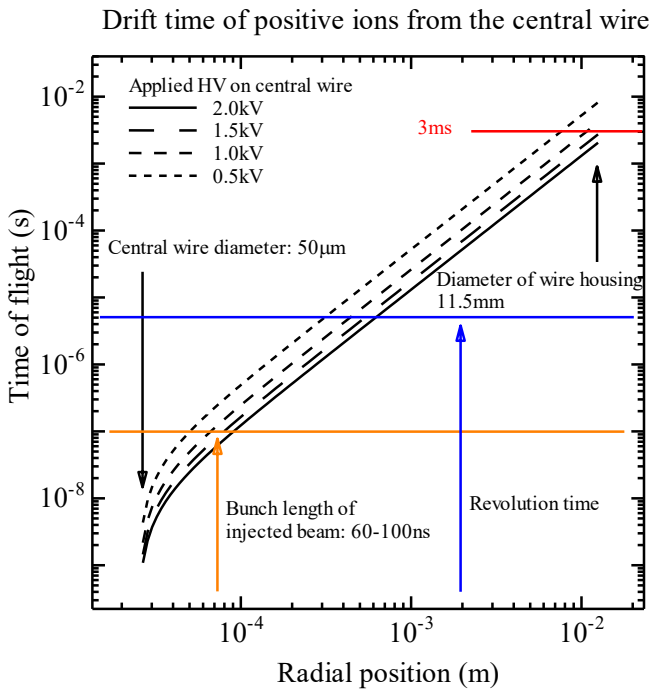


- Manufacturer : Toshiba Electron Tubes & Devices
- anode wire : ϕ50 μm, Pt
- Inner tube : ϕ23 mm (inside), SUS304
- Outer tube : ϕ47.8 mm (inside), SUS304
- Gas : Ar+CO_2 1%
- Gas pressure: 1.1 atm



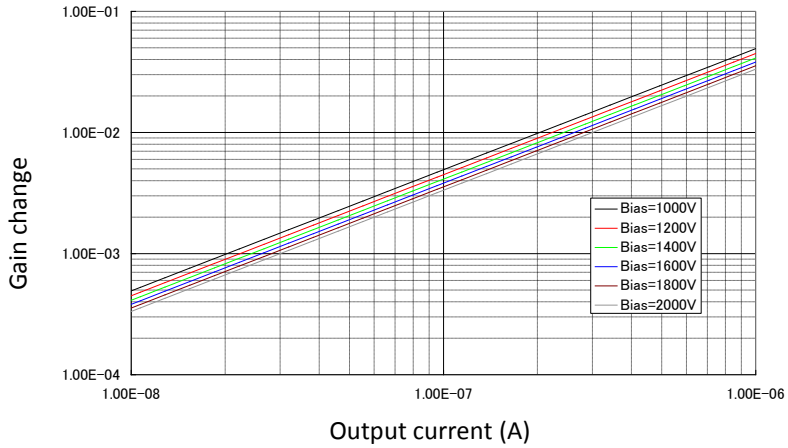


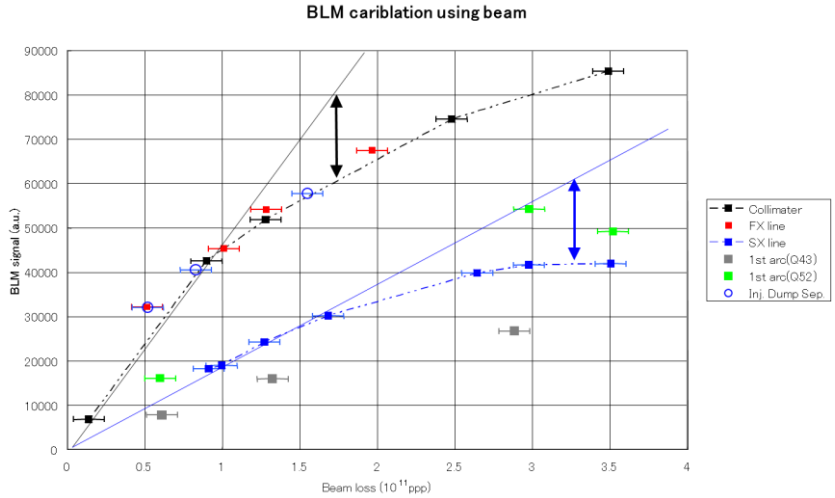
Old system 2



- Due to the **slow drift velocity of the ion**, it takes about **3ms from anode to HV tube**.
- The positive ion in the gas **decreases E field near anode** and thus **gas gain decreases.**
- Depending on the intensity of output current, the gain will be changed
  - **1 μA and 10 μA output DC current** results in **4 % and 40 % decrease** in case of -1.6kV bias
  - The output **DC current should be kept under 1μA** .
- The dynamic range is limited to by this saturation current -> **Cannot cover whole range of beam loss event.**
- Shows non-linearity, Under estimation in case of high level beam loss which occurred for example in the collimator section.
- Conversion impedance of the front end amp was 100kΩ. The output voltage is only 0.1 V for 1μA input -> **New Amp**

Gain reduction due to large output current





Requirements for the new system

- ***Intensity : 4E11 ～4E13 ppb***

Detect losses from the low intensity beams during the beam commissioning phase, where the beam intensity is only **1 % of the designed maximum intensity of 4E13 protons** per bunch (eight bunches for full).

- ***MPS : Beam dump within 100us***

Detect an unusual loss of power in the beam and send an alarm to the Machine Protection System (MPS) **to dump the beam within 100 μs.**

- ***Loss power : 0.5W/m @Arc section, 2kW@Collimators, 7.5kW@SX, 1.125kW@FX***

Beam power loss limits in the main ring (MR) are **0.5 W/m** @arc sections, **2 kW@**collimators, 7.5 kW@slow extraction (SX) section, and 1.125 kW@fast extraction (FX) section.

- ***Activation control: Residual dose measurement***

The level of activation of the components should be kept within the limits set for workers to perform hands-on maintenance. Should set the limits for each device **for the unscheduled and urgent repair-works for a malfunction of the device,** and it depends also on the number of workers and specialists, how many processes and how difficult to do it ,,,,,etc, in addition to **the daily exposure limit, 0.5 mSv for men and 0.3 mSv for women in J-PARC. Residual dose measurement is required.**

- ***Total dynamic range : >120dB***

From residual doses: as low as **10 μSv/h** to control activation level.

To intense beam loss : **0.053 Gy/Cycle for 2kW beam power lost** uniformly in the **collimators**

The dynamic range wider than **120 dB.**

- ***Bandwidth : Another fast type BLM detector under development***

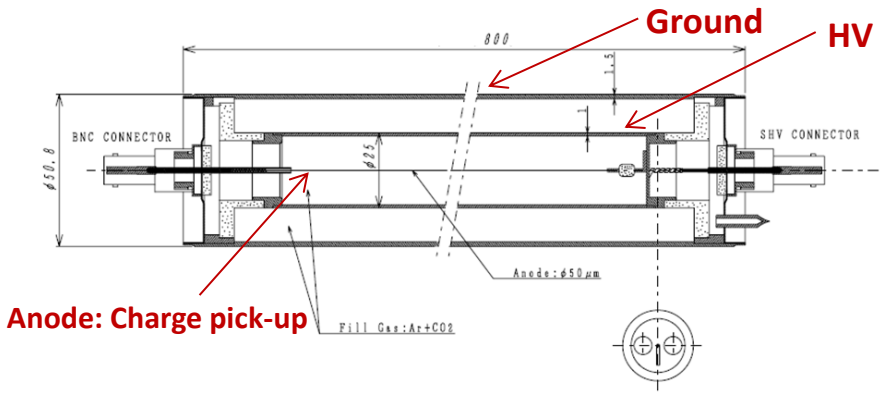
Turn-by-turn beam losses : 200 kHz.

To study the **head-tail instability: 100 MHz** would be needed.

Another type of detector is now testing.

How to improve dynamic range : dual detector system

Proportional Gas Chamber BLM : PBLM

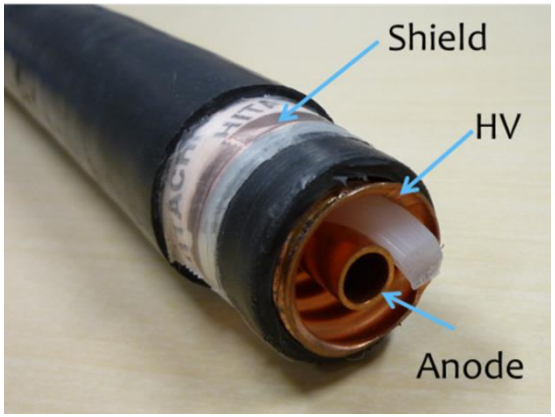


- Manufacturer : Toshiba Electron Tubes & Devices
- anode wire : ϕ50 μm, Pt
- Inner tube : ϕ23 mm (inside), SUS304
- Outer tube : ϕ47.8 mm (inside), SUS304
- Length : 800 mm
- Gas : Ar+CO_2 1%
- Gas pressure : 1.1 atm
- Gas gain : 2E4 @ max. Bias=-2kV

$$I_{output} = G_{gas} I_{initial}$$

1～20000 depending on bias voltage

Air Ionization chamber : AIC

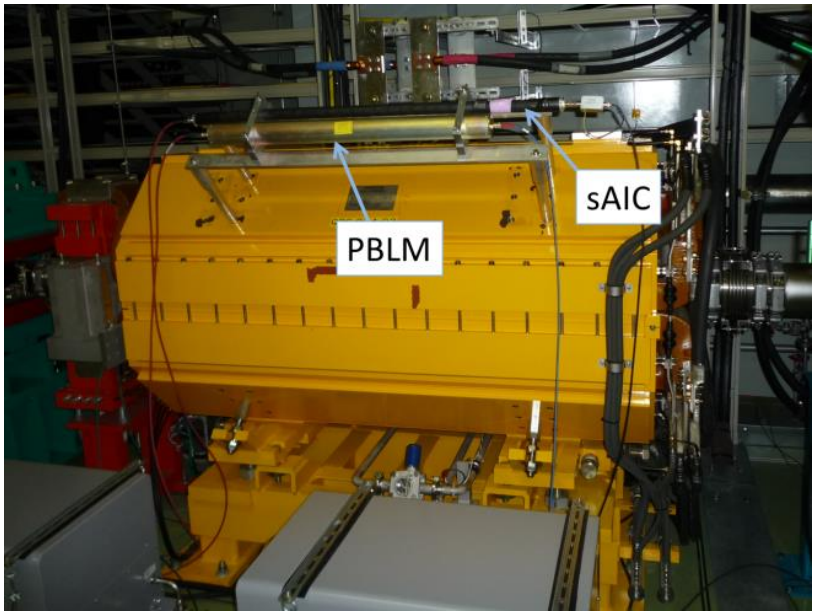


- Cable type : 20D (Cu tube and corrugate tube, polyethylene ribbon insulator, Cu tape shield)
- Gas : Air (not sealed)
- Gas pressure : Same as pressure in the tunnel
- Gas gain : 1.0
- Max. Bias : 500 V
- length: 1m type (sAIC), ave. 84m type (longAIC)

$$I_{output} = 1 \times I_{initial}$$

Different type of detectors can cover wide range of signal

New Detector setup



PBLM and sAIC installed at QM
848 mm from the beam line

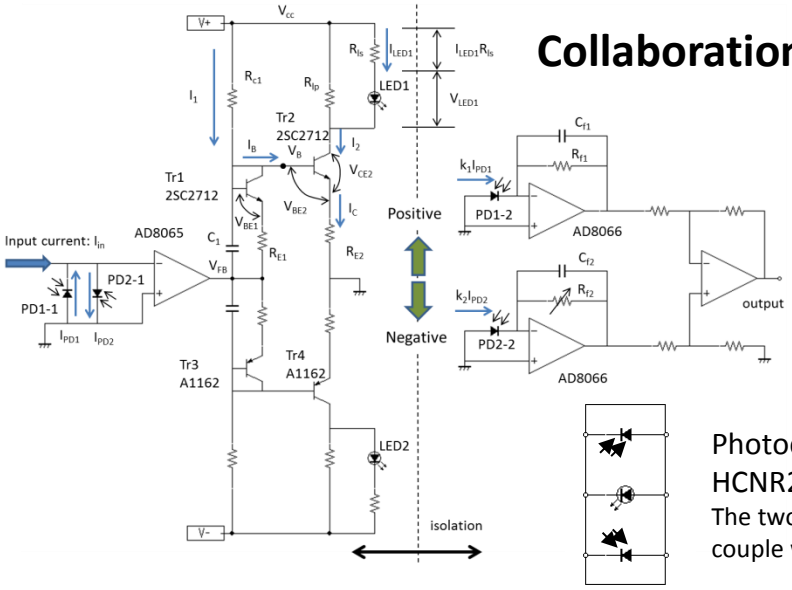
longAIC installed on the cable rack
3 m from the beam line

Number of detectors

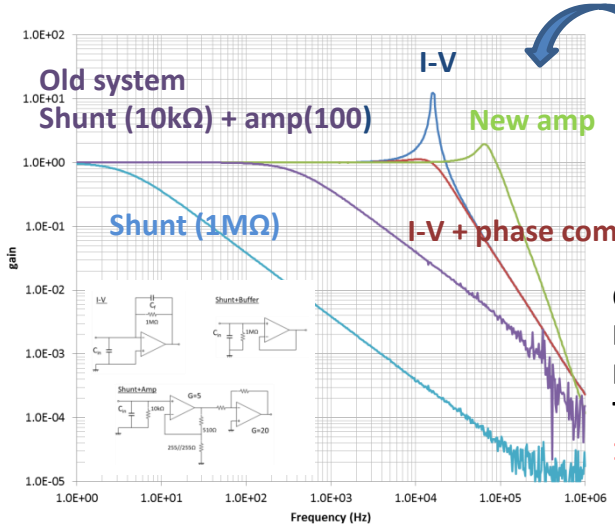
- PBLM : 216 (at each QM) + special (on request)
- sAIC : 53 (only in straight section)
- longAIC : 19 (Cover whole MR tunnel)

New “isolation” amp and new ADC system

Collaboration with GIGA



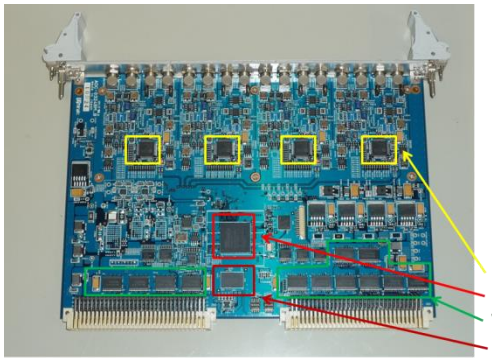
Photocoupler:
HCNR201(Avago)
The two PDs are couple with LED



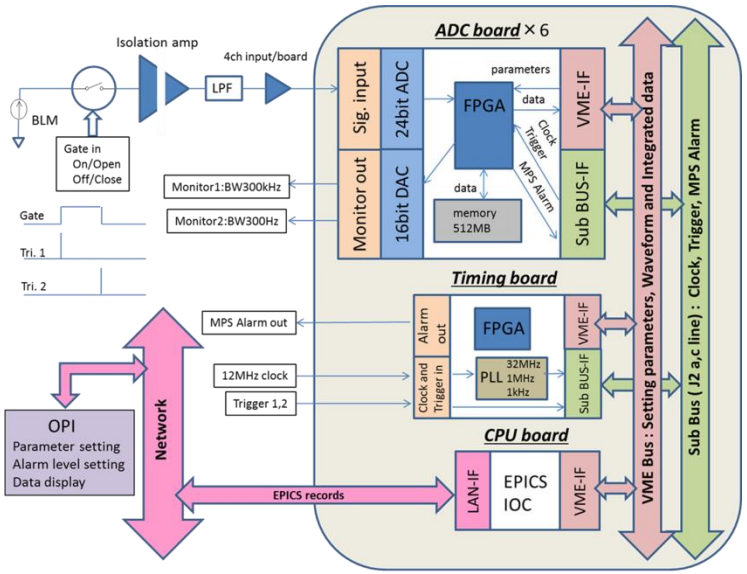
Same op-amp : AD8065
Same input C : 30nF
Same conv. Imp. : 1MΩ

Offset drift : 5μV/K => 5pA/K
IMRR : 94dB @ 50Hz
Noise density : 1/25
THD : 90dB @ 1kHz
10kHz LPF is used to improve SN

Collaboration with HIRAKU



Photos of the new ADC board for BLM system



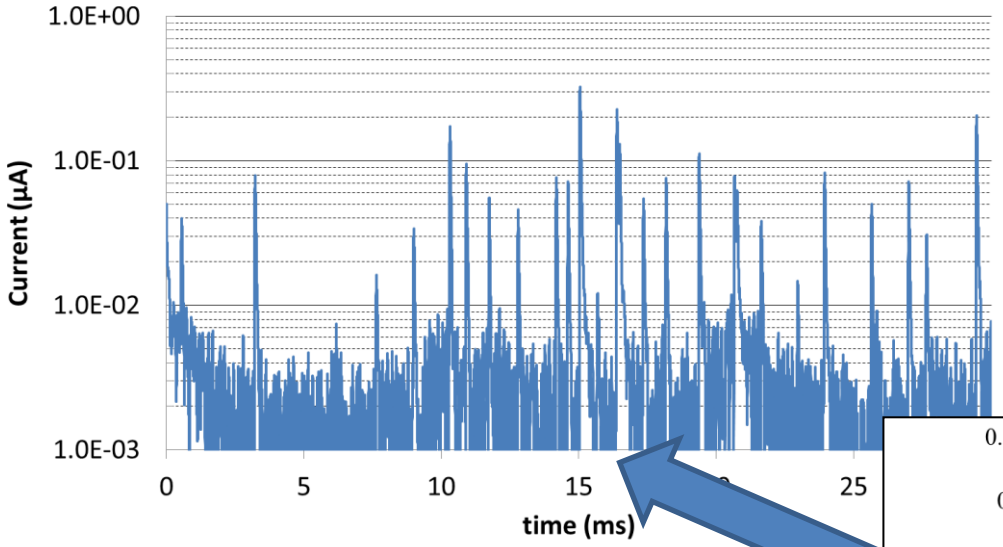
Block diagram of the new data taking system

Comparisons between old and new system

- 216 PBLM (every QM) + 19 longAIC
- Front end analog-amp
  - Capacitance at input nodes : **10～30 nF**
  - I/V Conv imp. : **100kΩ（Shunt R=10kΩ, Gain=10)**
  - Bandwidth: **DC – 500~1.5kHz depending on cable length**
  - Max. input current: **100 uA**
  - **WF signal** and **Integ. Charge signal (WF)**
  - **Analog comparators** to make alarm signal for MPS system
- ADC: **Insufficient performances!!**
  - **Use for integ. charge WF signal, no ADCs for fast WF signals**
  - Only **100 times AD** per cycle (2.48s cycle @FX, 6s cycle @SX)
  - **±20000** AD point
- Data handling
  - **EPICS**

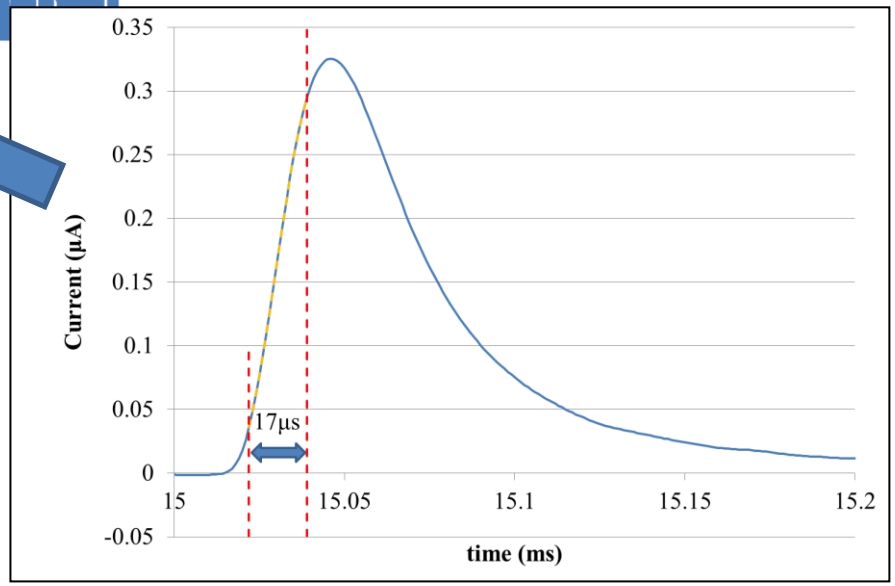
- 216 PBLM+**sAIC(only in straight section)**+19longAIC
- **Photo-coupler isolated** Front end analog-amp: **High I/V conv., and Fast!!**
  - Capacitance at input nodes : **10～30 nF**
  - I/V Conv imp. : **1MΩ (×10)**
  - Bandwidth: **DC – 10kHz (× 20 ～ 7)**
  - Max. input current: **10 uA (1/10)**
  - **WF signal**
- ADC: **Low noise and low offset drift!!**
  - 2 types of waveforms and 1 scaler output: **1MS/s, 1kS/s, integrated charge**
  - **24 bit** with sign, **16.5 ENOB for 1MS/s**
  - **Shot-by-shot offset subtraction**
  - **Digital comparators** for MPS, output analog ports to MPS unit
- Data handling
  - **EPICS**

Signal rise time: Impulse response



Setting

- Bias voltage : **-2.0kV (max.)**
- Source: γ from activated QM magnet
- The 10-90% rise time : **17 μs**

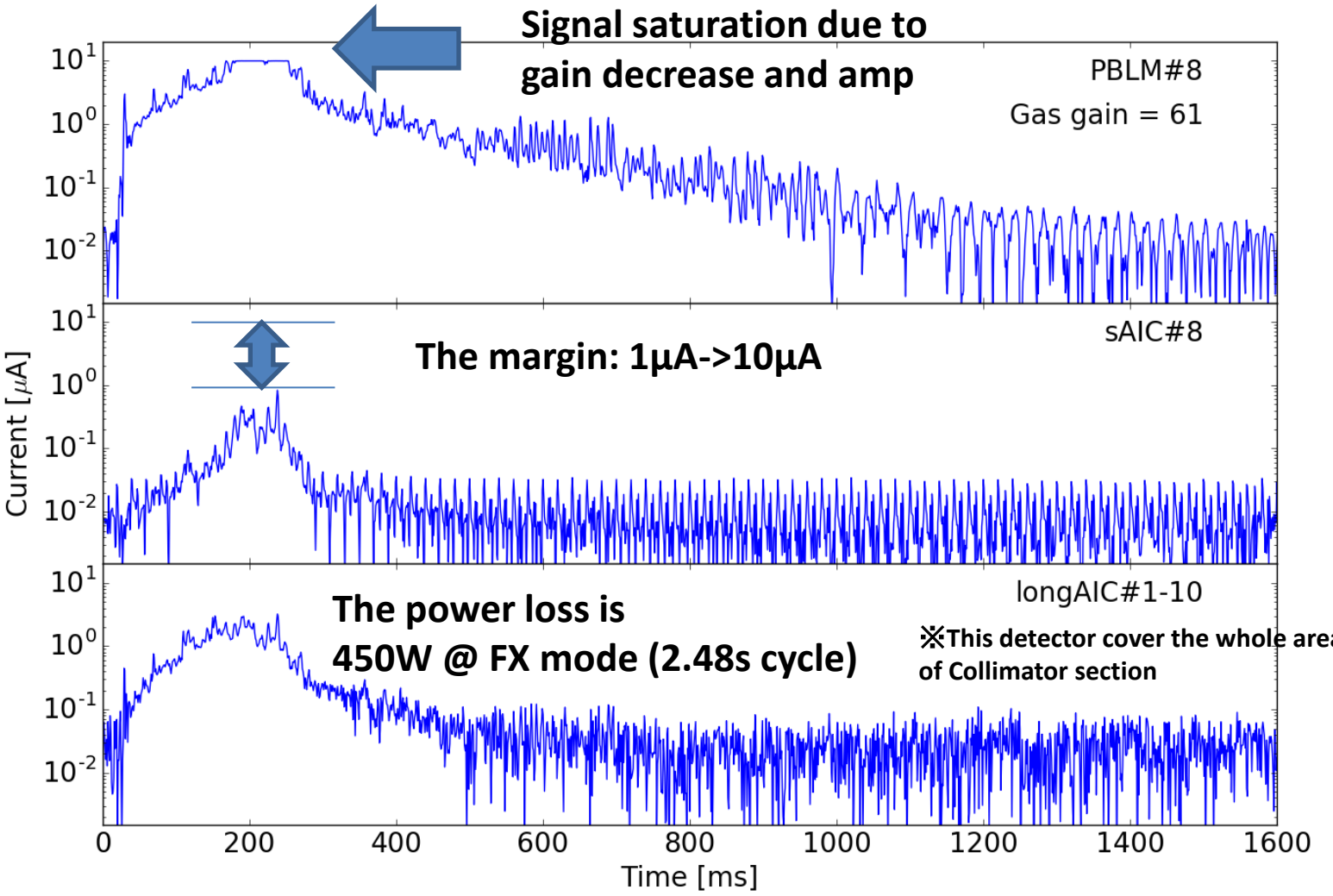


The requirement for MPS: dump the beam within 100 μs

- Rise time: 17 μs
- ADC processing time to generate MPS alarm: 2 μs
- MPS unit processing time : 1 μs
- cable delay : a few μs

Sum : 20+(a few) μs - > OK!!

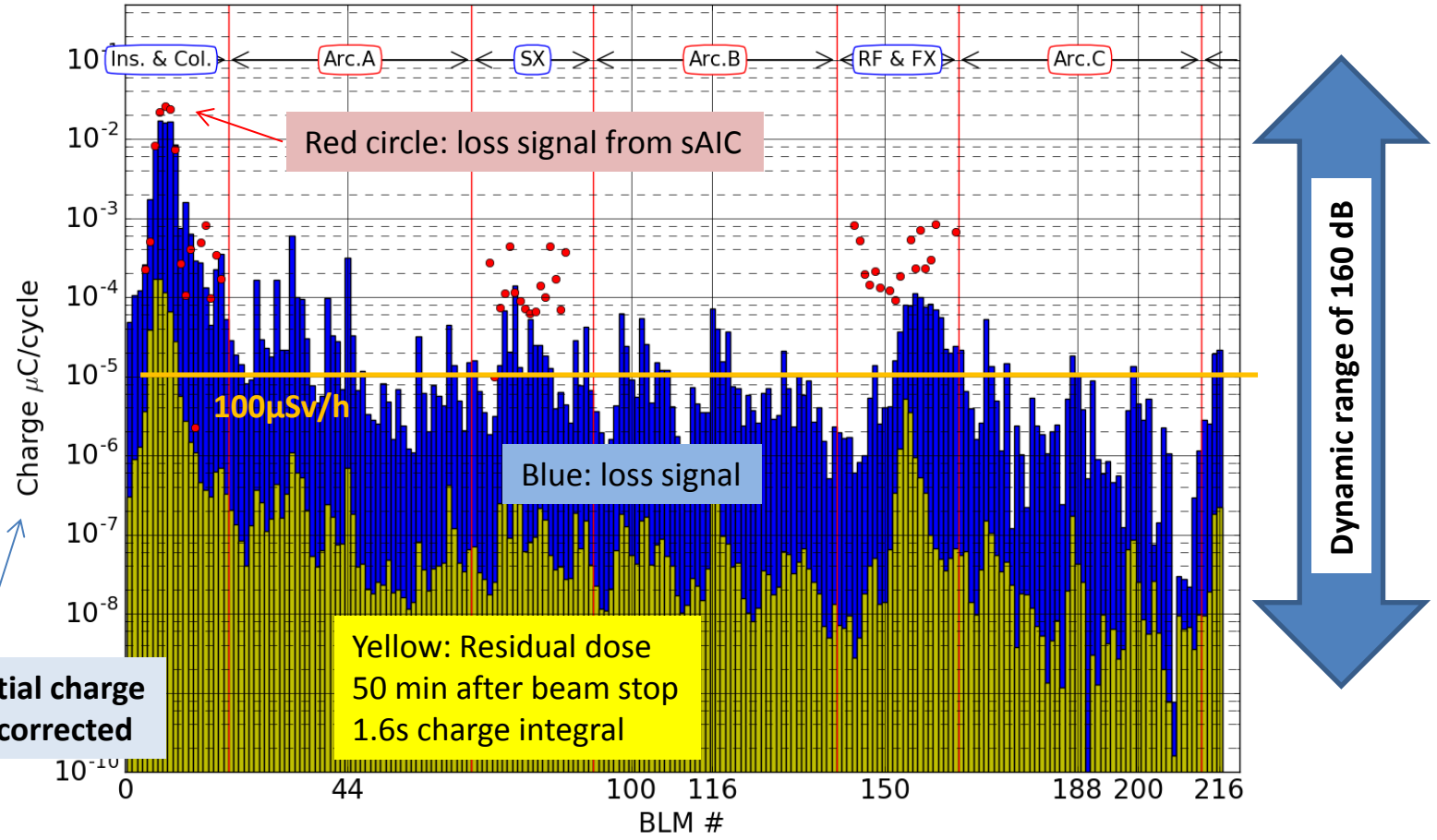
Signals from 3 detectors : PBLM, sAIC, long AIC
Collimator section : 460kW FX operation



Integrated charge plot :
Initial charge, gas gain corrected: 460kW FX

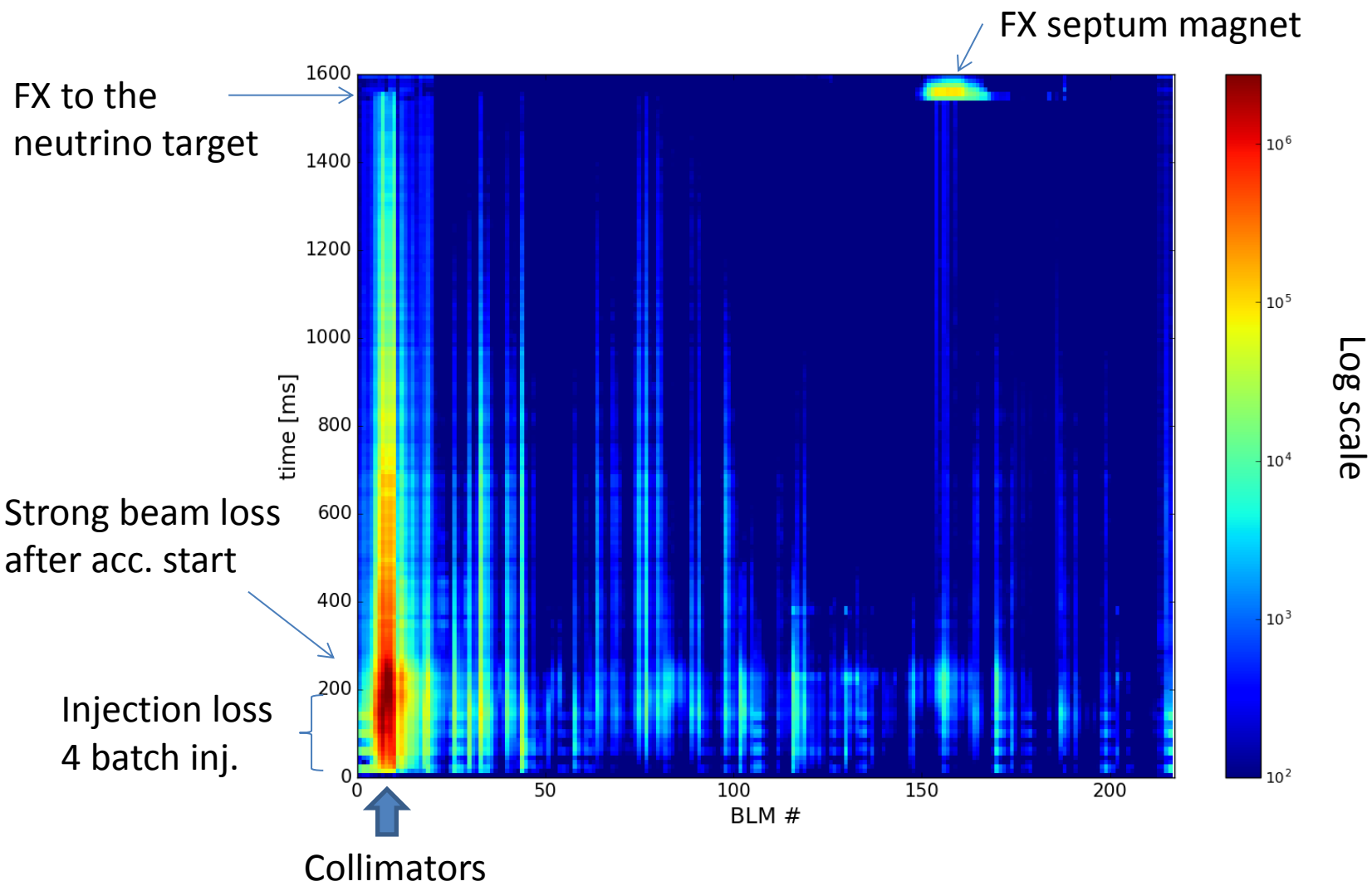
Bias set for PBLM :

- Beam loss mode -> Inj. and Colli. section : **-1.3kV (G=61)**, the others : **-1.6kV (G=628)**
- Residual dose mode -> all set as **-2.0 kV (G=2E4)**



2D loss map from PBLMs : 460kW FX

The key details of the beam losses: positions, timings, and intensities



Summary

- The new BLM system for the J-PARC MR has been operating successfully since last summer.
- Thanks to the high gas gain performance of the PBLM and the combined use of the sAIC, the system dynamic range is now wider than 160 dB.
- The present signal rise time of 17 μs is likely to be fast enough to ensure that the MPS system will dump the beam within 100 μs.
- The output signal of the longAIC was calibrated using the controlled beam losses at the Collimators and Arc A and Arc B.
- The beam power loss in the Injector and Collimator section was 450 W in the FX mode operation which outputs 460 kW beam power.
- To improve signal-to-noise ratio of the waveform data obtained, further studies are needed.
- A new OPI will start operation from this Oct. after this summer shut down
- We are now designing another fast BLM system that shows bandwidth of more than 200 kHz.