Beam Monitors for the slow-extraction beam line at J-PARC

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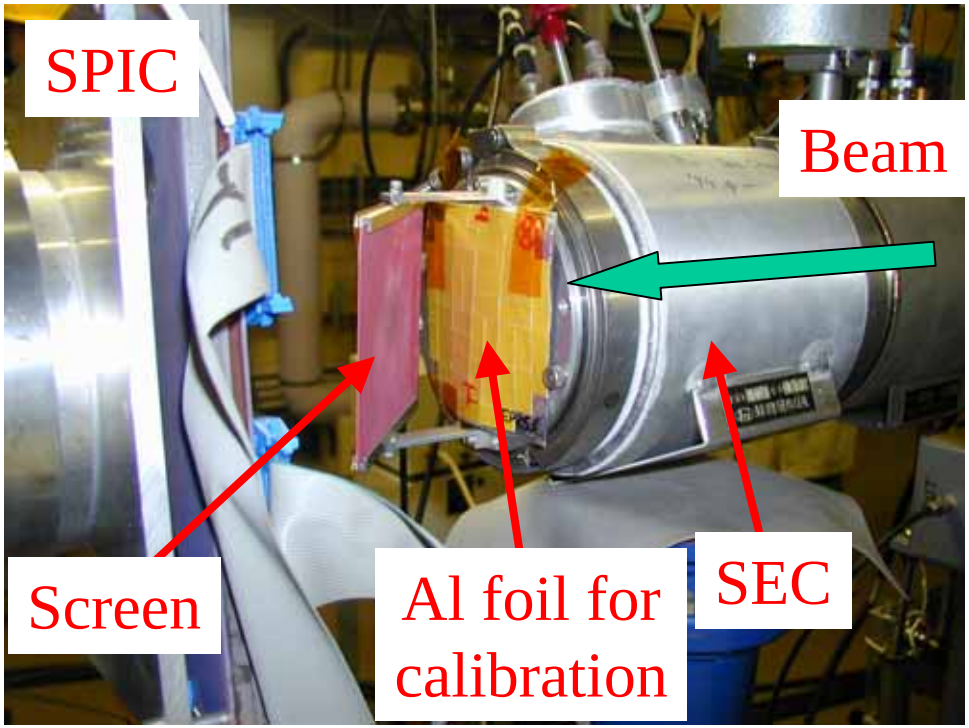
on behalf of
Hadron Beam Line SG
Target and Monitor SG

Beam intensity measurement in KEK-PS extraction beam line

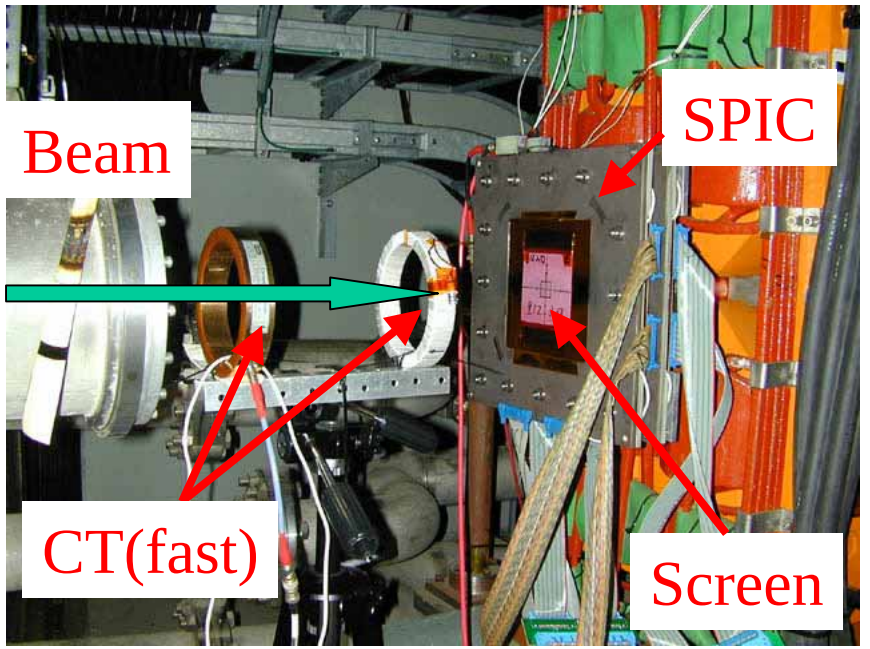
- Secondary emission Electron Chamber (SEC)
  - Good linearity and stability
  - Need vacuum window (Al 100 μm)
  - Deterioration of Al foil
    - after ~ 10^{18} proton / cm^2 irradiation (K. A. Brown et al. in BNL)
  - Need periodic calibration by Al activation method
    - Radiation exposure in handling Al foils

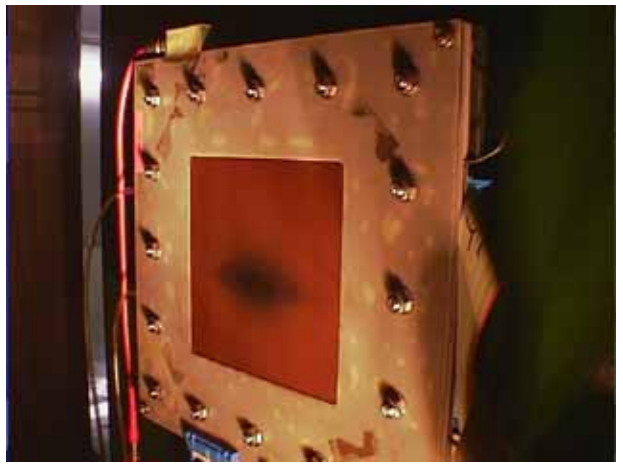
SEC at the extraction point from KEK-PS



Beam profile measurement in KEK-PS extraction beam line

- Phosphor screen + Tube camera
  - Good visibility under high radiation environment
  - Need screen
  - Radiation damage of tube camera (CCD camera doesn't work.)
- Segmented Plate Ionization Chamber (SPIC)
  - Good S/N and stability under high radiation environment
  - Good cost performance
  - Need vacuum window (SUS 50 μm)
  - Deterioration by beam irradiation (1-2 year operation at KEK-PS)





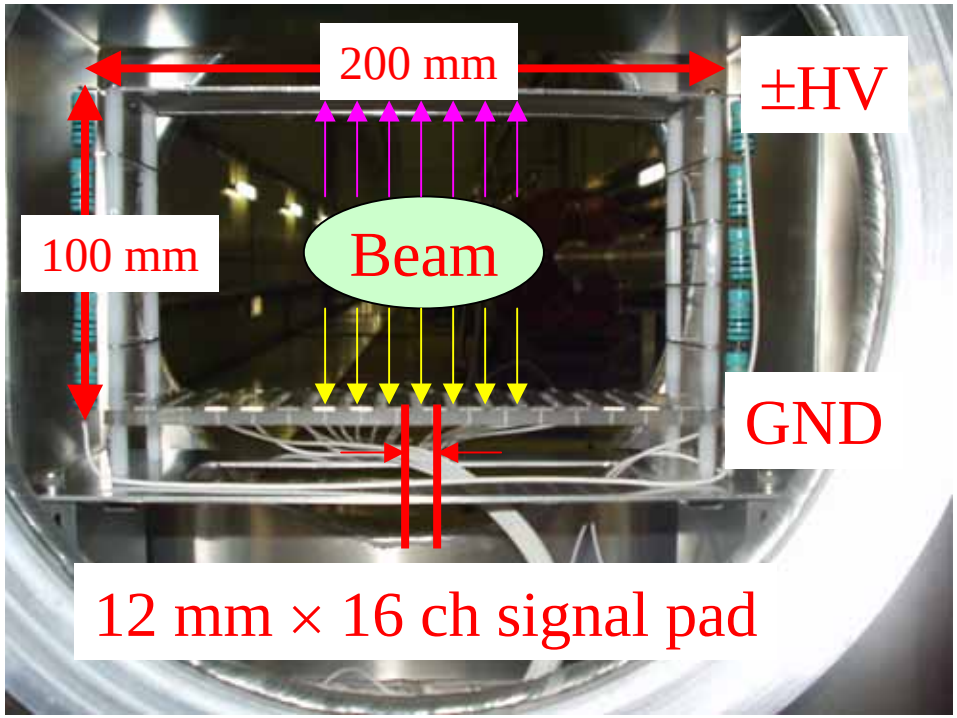
Requirements for the slow-extraction beam monitors in J-PARC

- Limit of on-hand maintenance
  - KEK-PS EP1 beam line: (12 GeV) × (6×10^{12} proton / 2.2 sec) = 5.2 kW
  - Average beam loss: 5.2 kW × 10 % / 400 m = 1.3 W / m
  - Residual dose rate on beam duct ~ 10 mSv/h (Exposure limit: 32 μSv/h)
- Limit of material thickness
  - Materials with 10^{-5} interaction rate (7.5 W for 750 kW)
    - Air: 7.5 mm (STP), 740 m (1Pa), Al: 4 μm, Ti: 2.8 μm, Fe: 1.7 μm
- Radiation hardness
  - Typical requirements for beam line magnets ~10^9 Gy
- Limit of cost
  - Typical number of monitors 20 (Current, Profile), 200 (Loss)

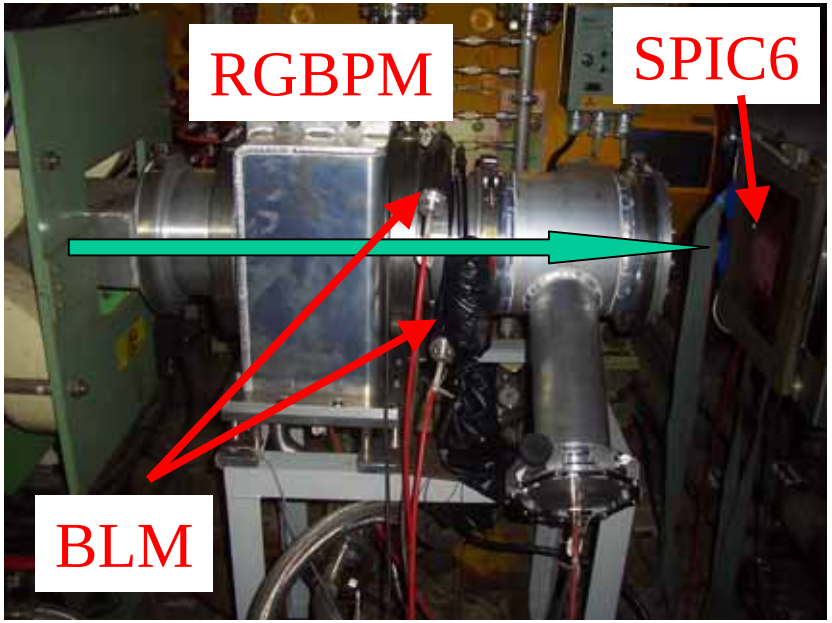
Residual Gas Beam Profile Monitor (RGBPM) in Low-Vacuum

- Collect electrons/ions in residual gas generated by protons
  - # of ion-pair ~ 6.2×10^{8} pair / cm (10^{12} protons, 1Pa vacuum)
- Complete non-destructive monitor
- Wide dynamic range
- Simple structure
- Reasonable cost

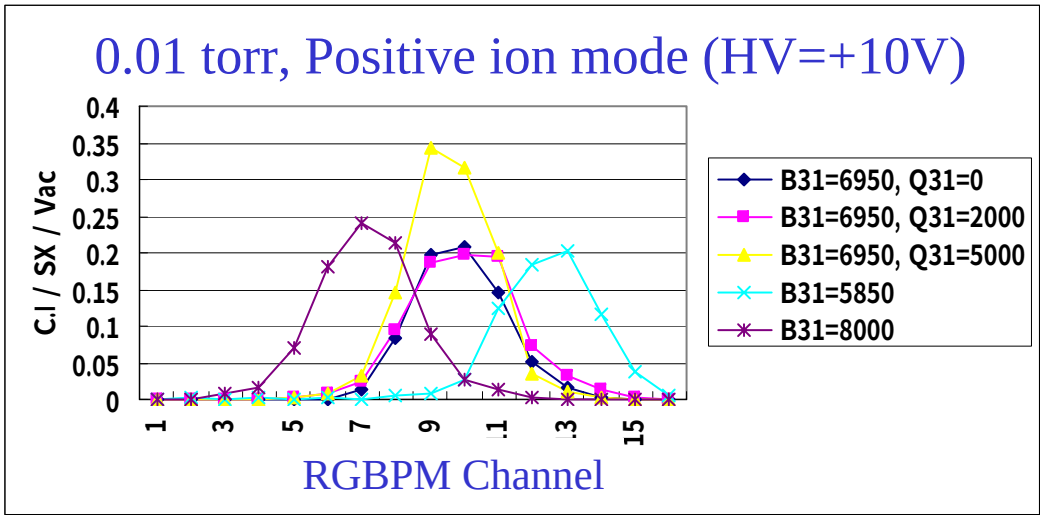
RGBPM prototype installed in vacuum chamber

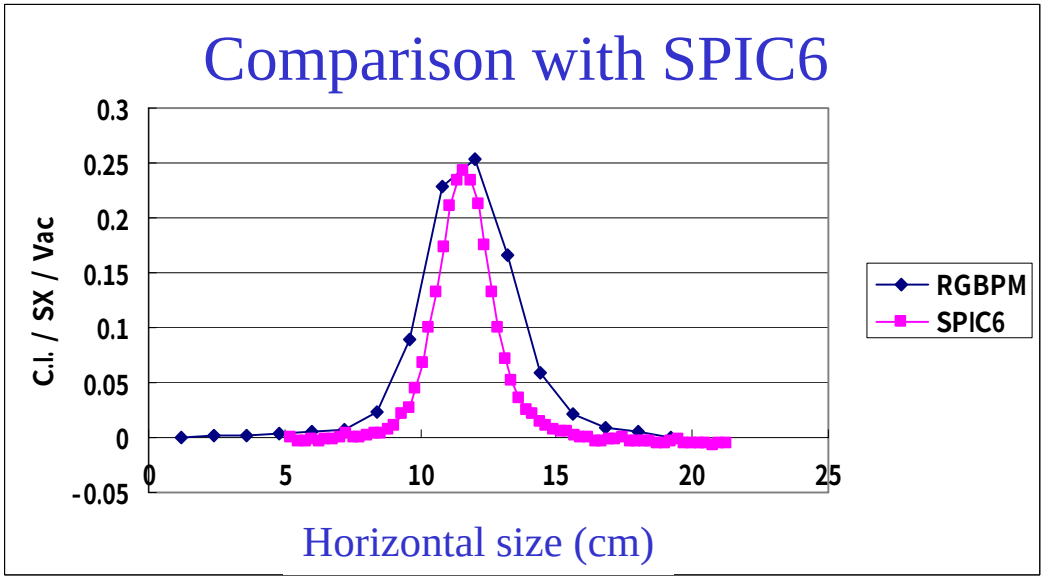


Test results at the EP2 beam line



- Beam position dependence was observed correctly.
- Profile is wider than SPIC
- Need more studies to understand the working principle.





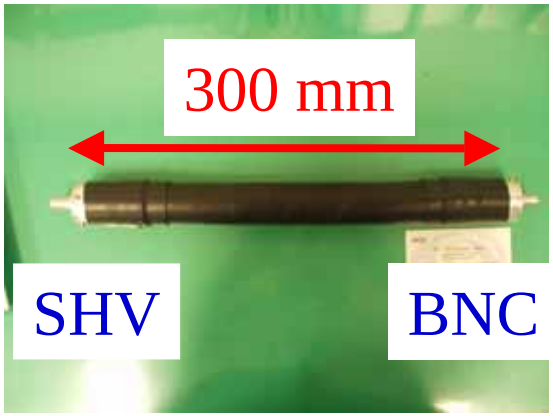
Other candidates for profile monitor

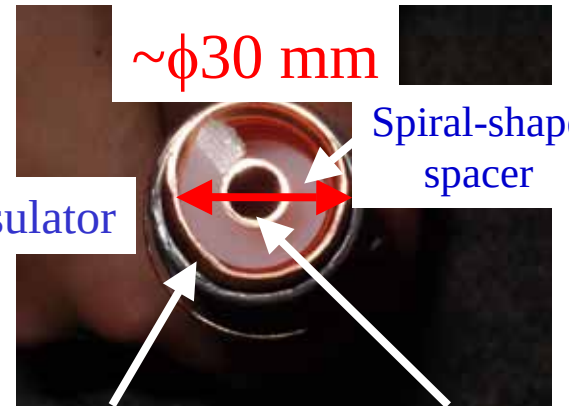
- Segmented Secondary Electron Monitors (SSEM)
  - Minimize material thickness
  - Need moving system
- Measure Optical Transition Radiation with rad-hard camera
  - Minimize material thickness (Ti/Carbon ~10μm)
  - Lifetime of rad-hard camera (CID/CMOS camera)

Beam Loss Monitor (BLM)

- Detect unexpected beam loss
- Make interlock signal to Machine Protection System (MPS)
- Air-ionization chamber used in 12GeV-PS is a good candidate.
  - Simple principle
  - Easy fabrication
  - Good cost performance

BLM prototype using HF-coaxial cable





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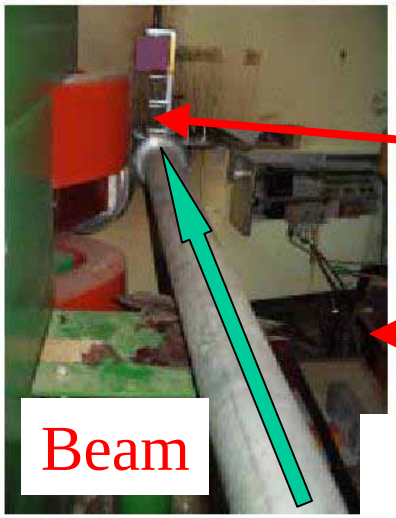
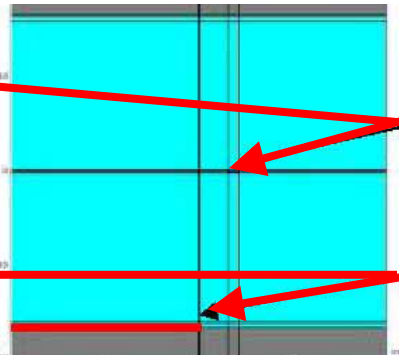


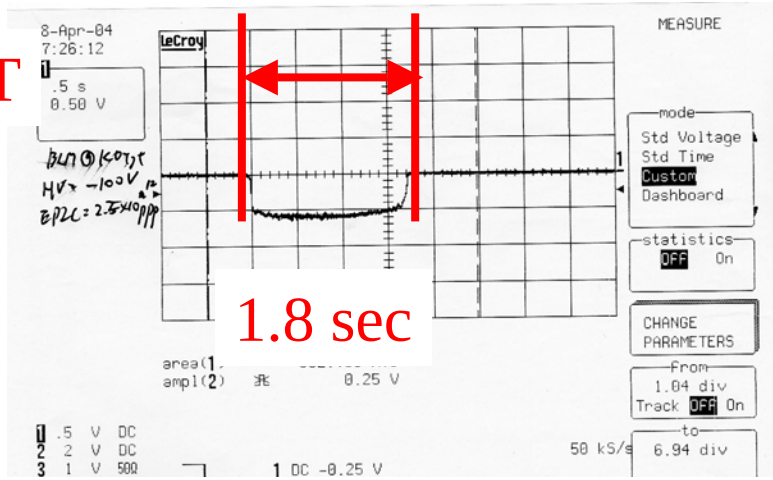
MARS modeling



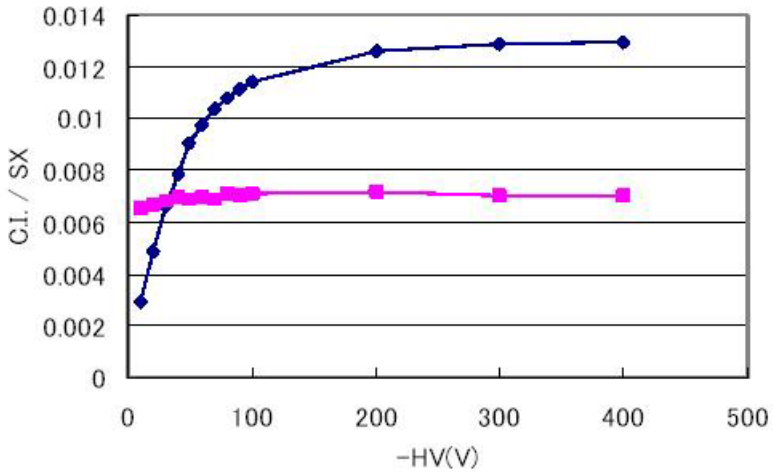
Calculation：12.6nC/pulse

Measured： 6.5nC/pulse

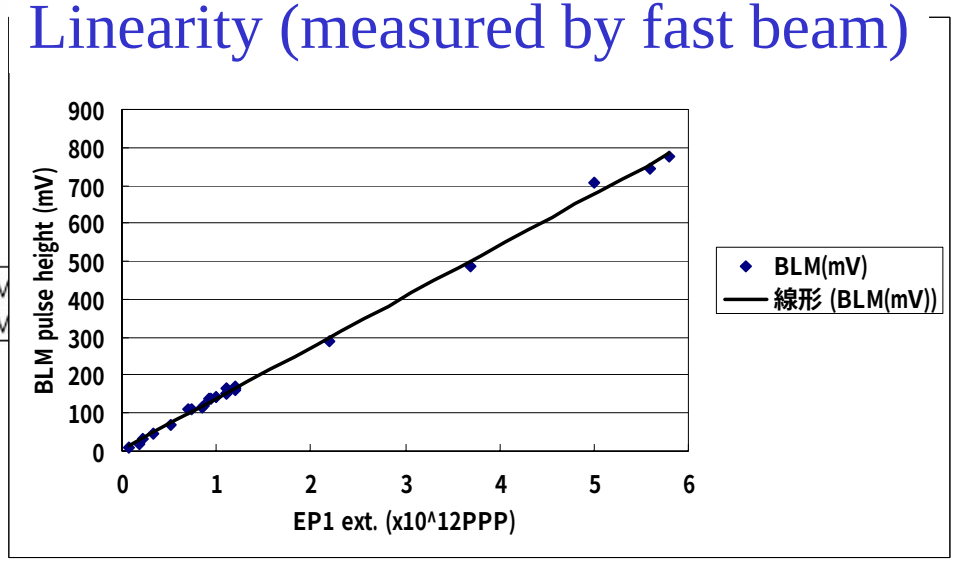
Raw signal by slow beam



Plateau curve



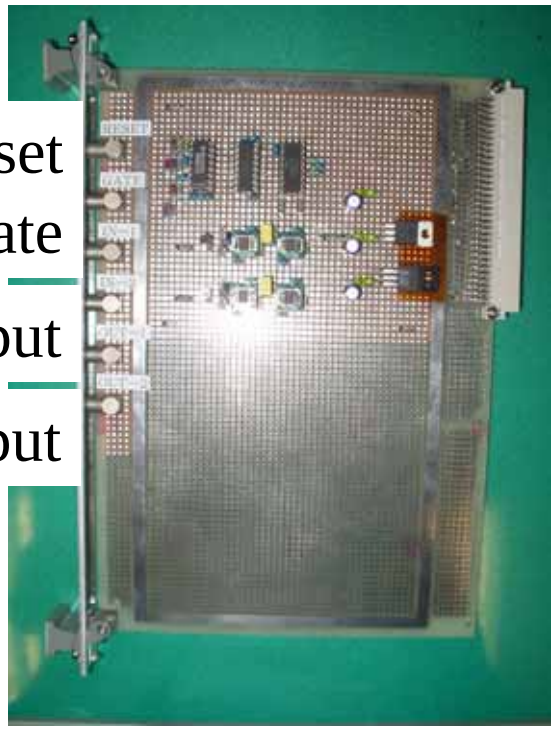
Linearity (measured by fast beam)

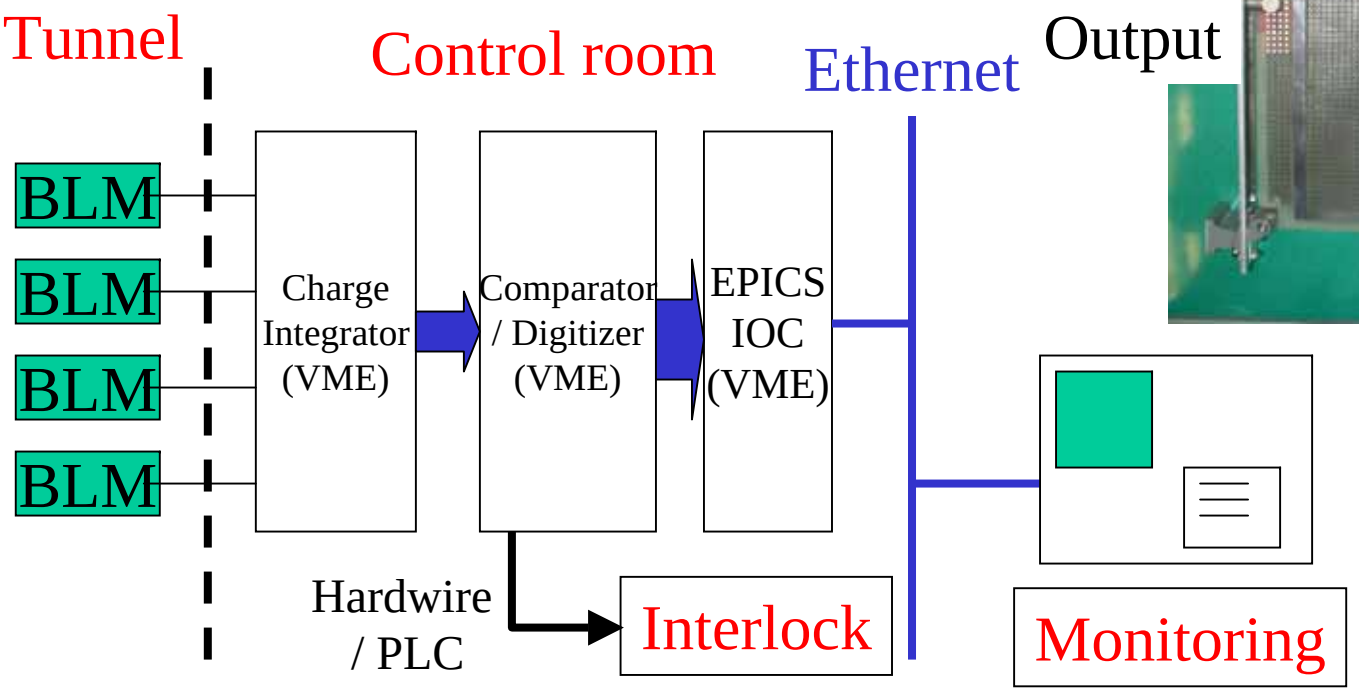


Electronics for beam monitors

- Charge integration in ~ 1 sec extraction time
- Make Interlock signal to MPS (BLM)
- Control by EPICS

A prototype of VME-integrator board
by Prof. Inaba and Saito



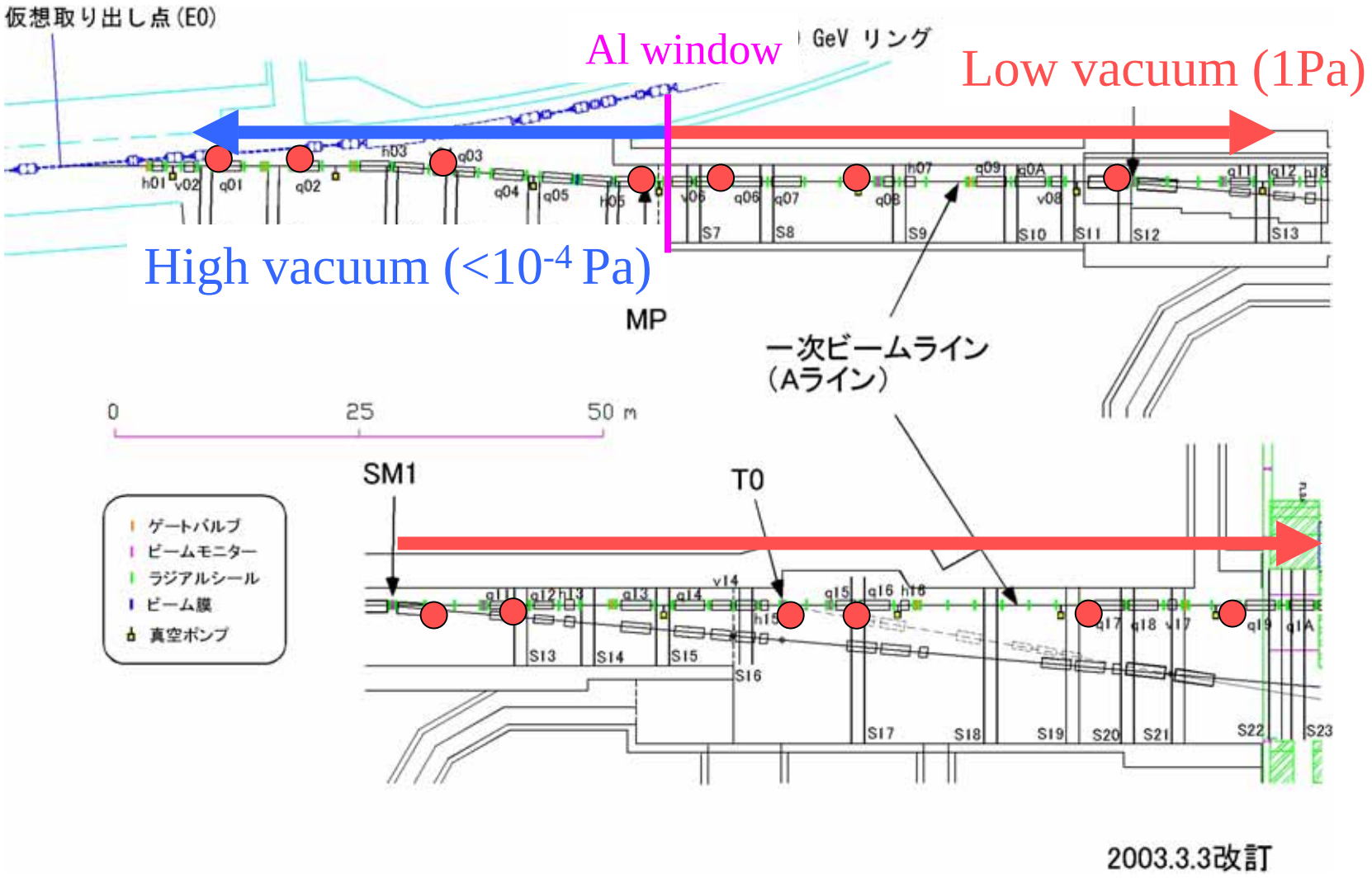


Thanks to KEK electronics and online group

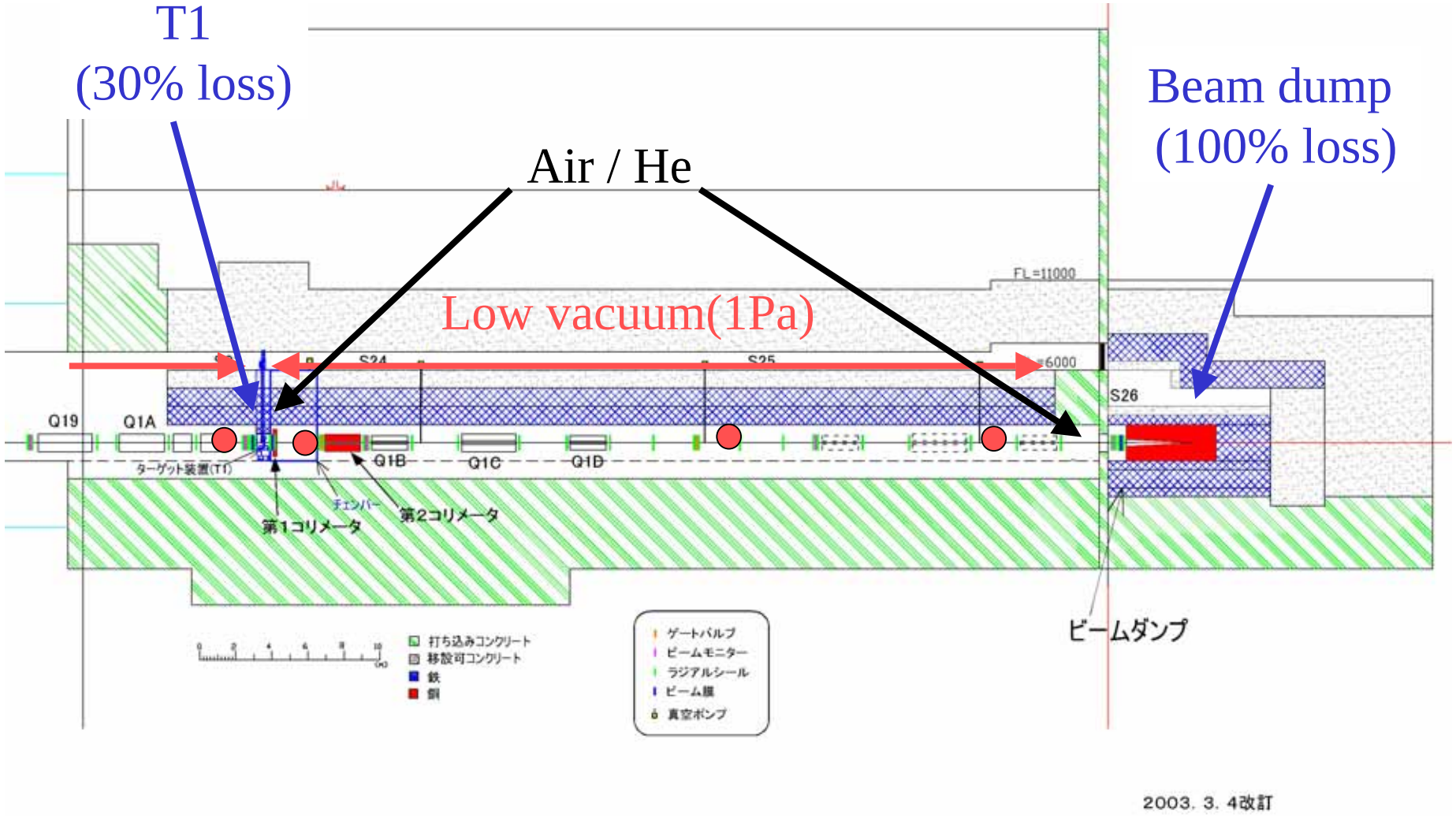
Difficulties to measure intensity of slow-extraction beam

- DCCT (DC Current Transformer)
  - Sensitivity limit: ~ 10 μA (J-PARC full beam: ~50μA)
  - Unavailable for low current beam (~10^{12} ppp)
- Direct measurement of beam magnetic field by SQUID + High Temperature Superconducting magnetic shield (T. Watanabe et al. ,RIKEN)
  - Radiation damage of SQUID device ??
  - Need cooling device working in beam line
  - Expensive !
- Possible solution: Summing up RGBPM signals

Configuration of beam monitors in beam switching yard (SY)



Configuration of beam monitors in HD-hall



Summary and future prospects

- RGBPM is feasible for J-PARC slow beam, but need more studies about profile width.
- BLM using coaxial cable working well.
- Electronics and control system is being designed with help of KEK electronics and online group.
- Beam test must be completed by KEK-PS shutdown.
- Need more idea about beam intensity monitors
- We need more help from outside.