Beam instrumentation at the 1-MW proton J-PARC RCS

HB2014
54th ICFA Advanced Beam Dynamics Workshop
on High-Intensity, High-Brightness and High Power Hadron Beams
East Lansing, MI
Nov.12, 2014

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for 3GeV RCS Group

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    redundant MPS by BLM
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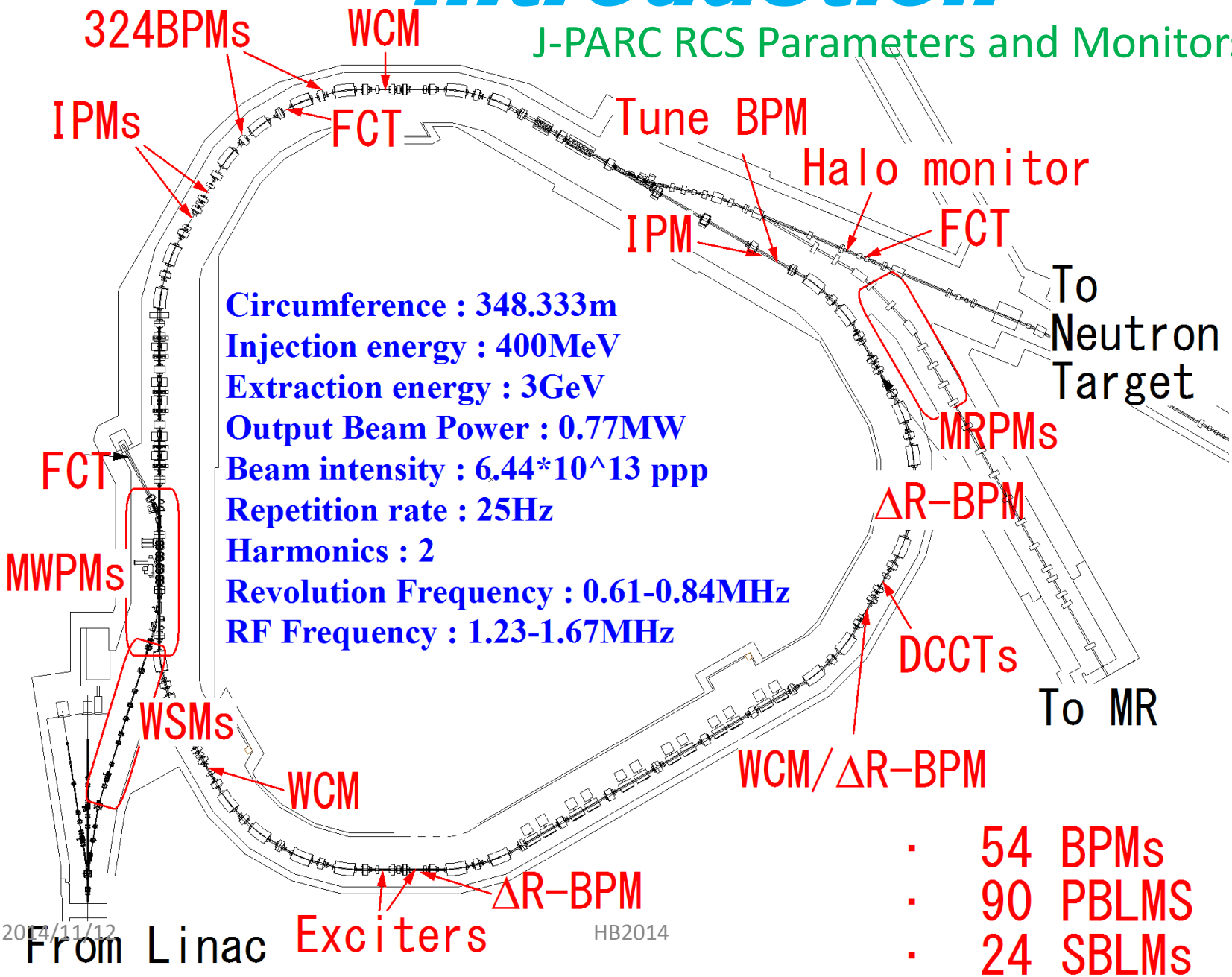
Introduction

J-PARC RCS Parameters and Monitors



Circumference : 348.333m
Injection energy : 400MeV
Extraction energy : 3GeV
Output Beam Power : 0.77MW
Beam intensity : 6.44*10^13 ppp
Repetition rate : 25Hz
Harmonics : 2
Revolution Frequency : 0.61-0.84MHz
RF Frequency : 1.23-1.67MHz

- 54 BPMs
- 90 PBLMS
- 24 SBLMs

Regular monitors for beam commissioning

- **BPM**
- **Exciter & Tune BPM**
- **CT**
- **BLM**
- **IPM**
- **MWPM**

N. Hayashi et. al., "BEAM INSTRUMENTATIONS FOR THE J-PARC RCS COMMISSIONING", Proc. EPAC2008, TUPC034

Beam Position Monitor(BPM)

Inner diameter of the BPM detectors is larger than 250 mm
-> Diagonal cut was chosen to ensure linear response

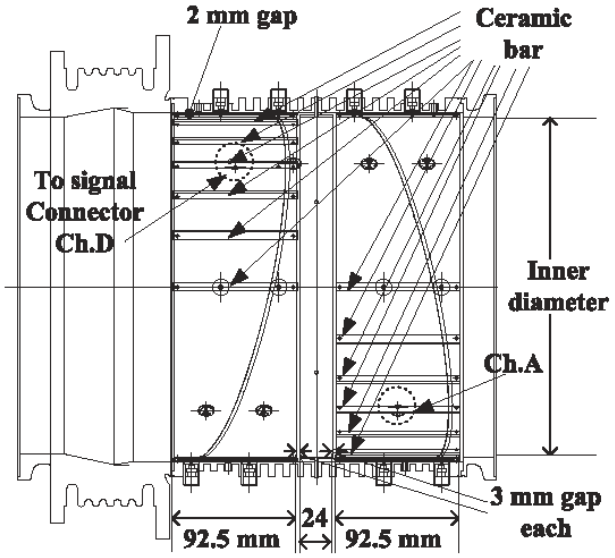
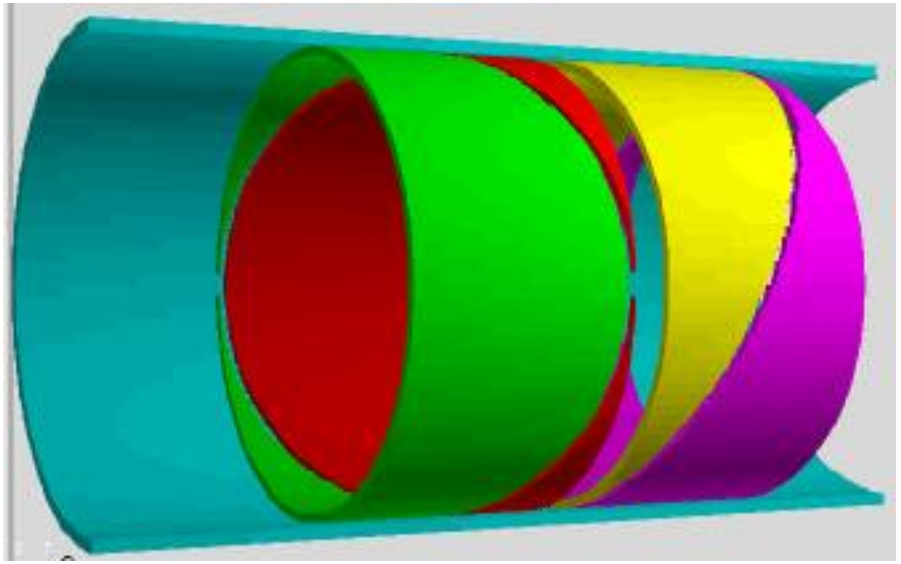


Fig. 7. Inside view of the BPM detector from the top.



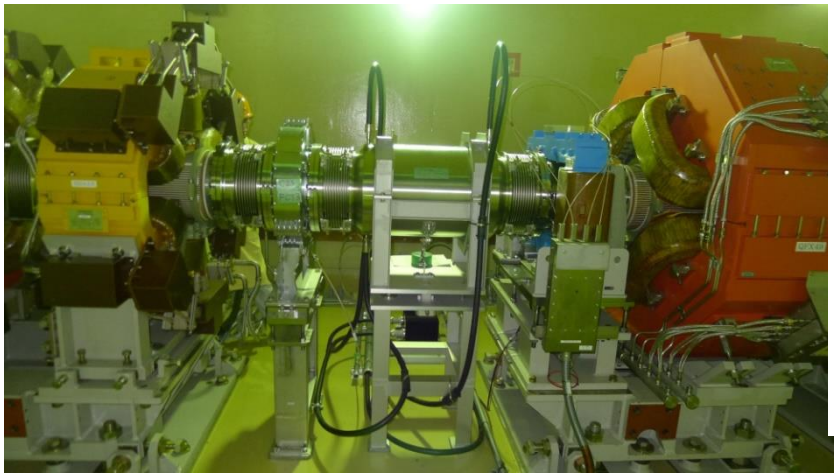
Diagonal cut

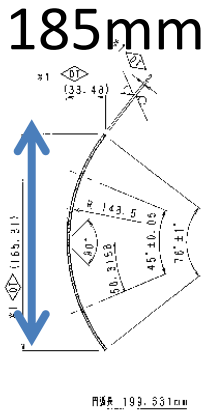
- BPM system can record the full 25 Hz pulse data for the so-called ‘‘COD mode’’ (averaged beam position is stored).
- it can also store the whole waveform data for further analysis, like turn- by-turn position calculation(not 25Hz but 1 shot per several seconds).

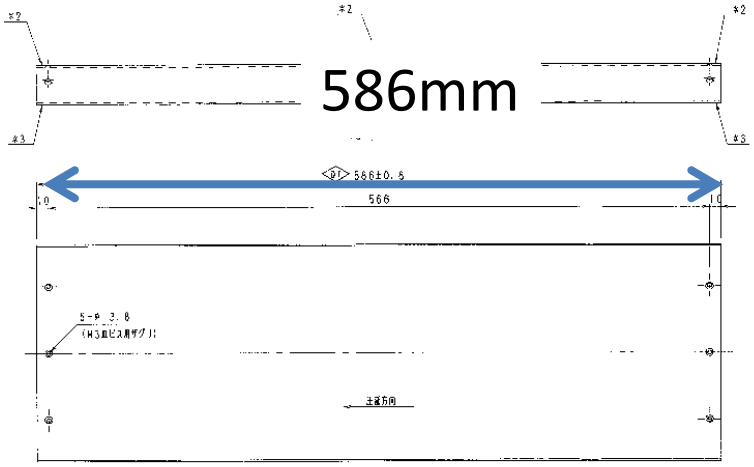
The position accuracy is estimated to be about 0.5 mm using a newly developed Beam Based Alignment method.

N. Hayashi et. al., “Beam position monitor system of J-PARC RCS”, NIM A, Volume 677, p. 94-106

Tune measurement





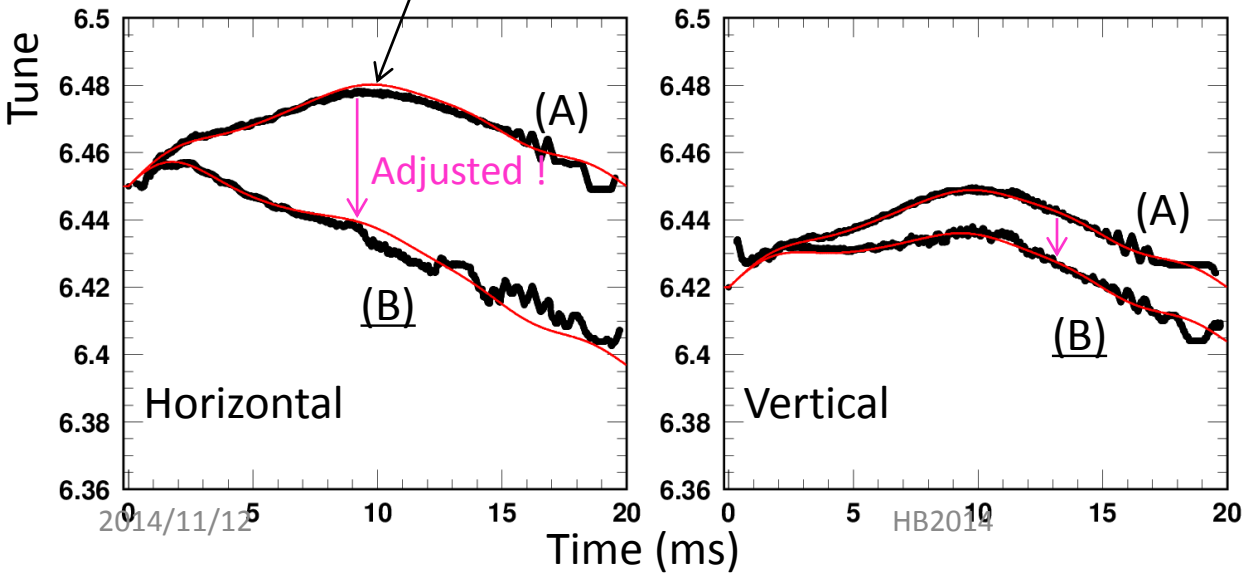


Exciter AMP

Freq:100 kHz-7 MHz

Power:1 kW

Small loss appeared here due to the stopband of ν=6.5.



— Measurement

— Calculation

Current Transformer(CT)

Dump line FCT
:limit beam current to dump

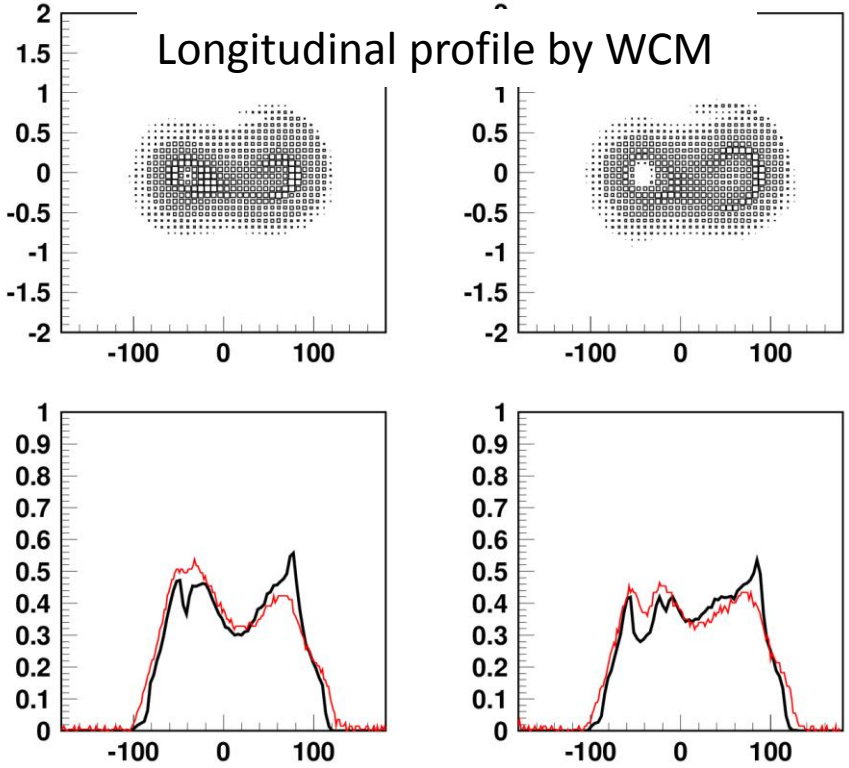
V_2/V_1=80%
ϕ_2=-100 to 0 deg
$\Delta p/p$=-0.1%(left), -0.2%(right)

1st DCCT:purchased from Bergoz (BDCCT-S-380-H)
2nd DCCT:made by the FINMET(FT3M)
- Range:150mA-15A
- Bandwidth:DC-20kHz
- Inner Diameter:380mm
- 2nd DCCT Coil:1000turn

Fast CT:made by the FINMET(FT3M)
- Coil:20turn
- Bandwidth:2kHz-10MHz

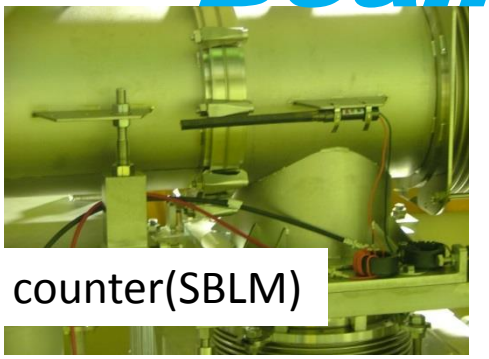
WCM:Shunt impedance: 0.1 ohm(10 ohm*100 para)

Longitudinal profile by WCM



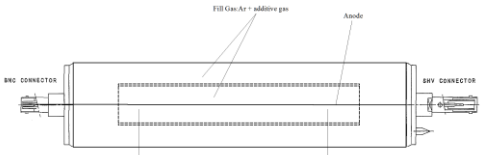
Measurements (WCM)
Numerical simulations

Beam Loss Monitor



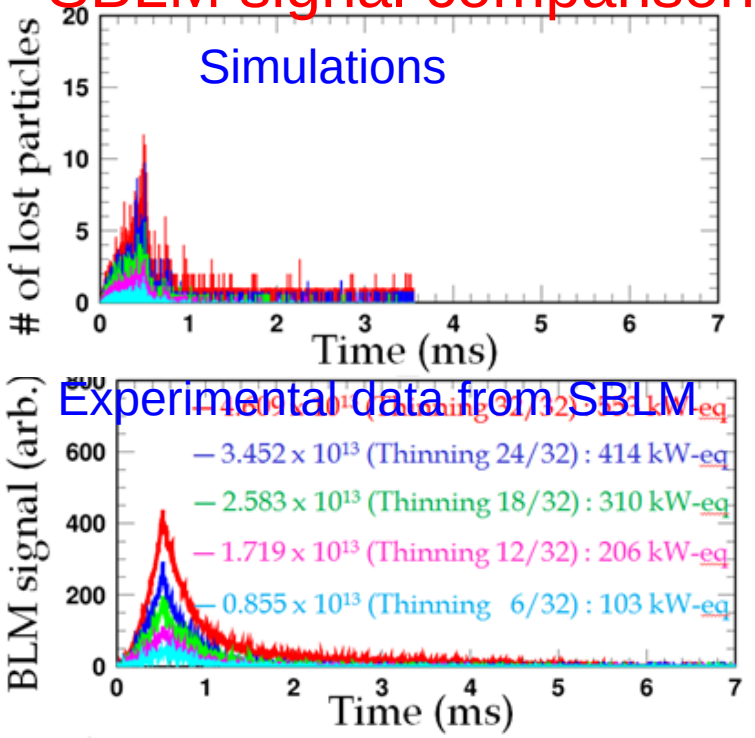
Scintillation counter(SBLM)

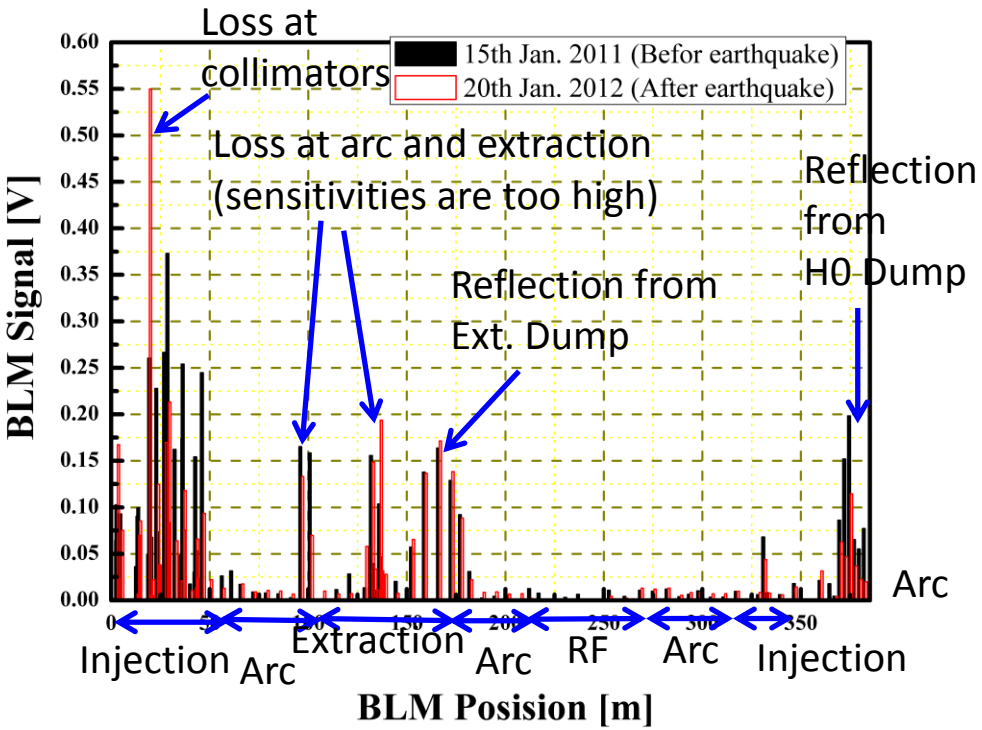
Proportional counter(PBLM)



PBLM put around the RCS:MPS

SBLM signal comparison

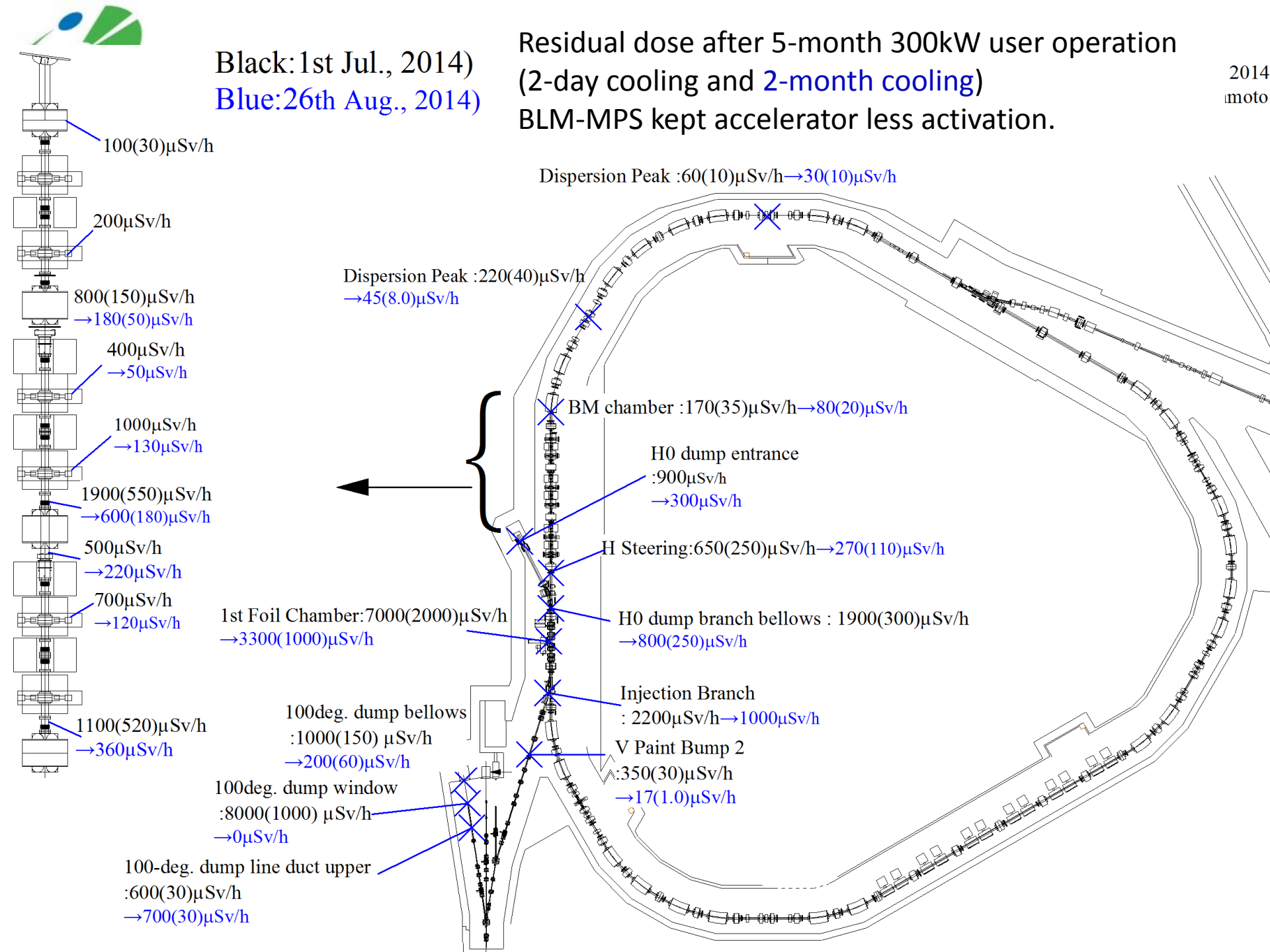




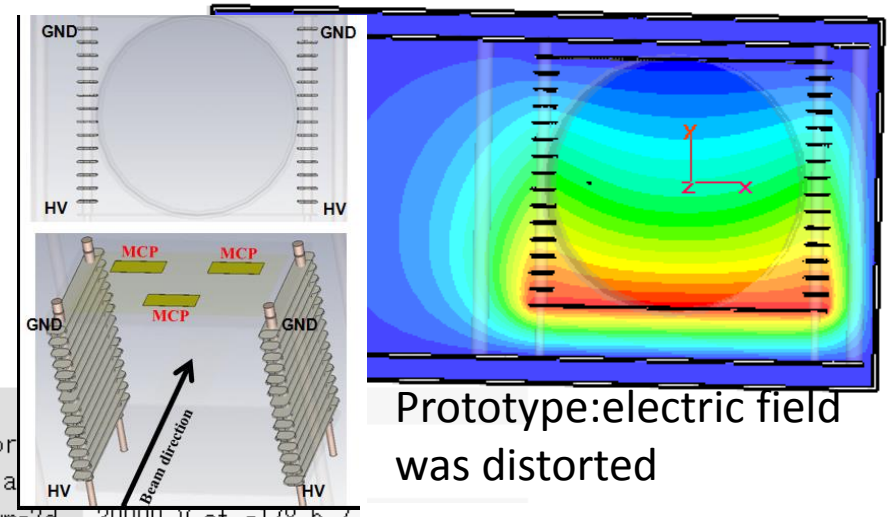
The time structure and the amount of the beam loss are well in agreement with the simulation.

Integrations of PBLM signal are archived at all times.

PBLM signals are also compared with the limit value at every shot.

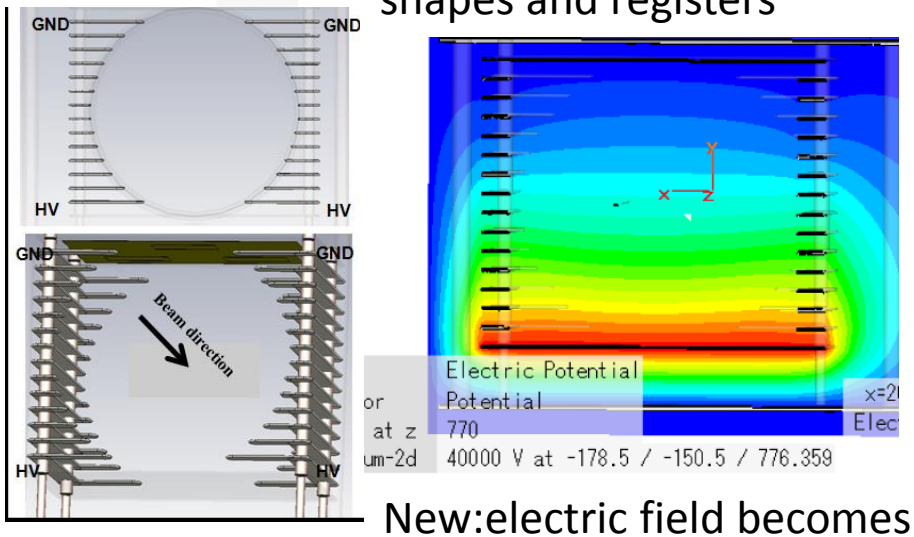

Black:1st Jul., 2014)
Blue:26th Aug., 2014)
Residual dose after 5-month 300kW user operation
(2-day cooling and 2-month cooling)
BLM-MPS kept accelerator less activation.
2014
moto
100(30)μSv/h
200μSv/h
800(150)μSv/h
→180(50)μSv/h
400μSv/h
→50μSv/h
1000μSv/h
→130μSv/h
1900(550)μSv/h
→600(180)μSv/h
500μSv/h
→220μSv/h
700μSv/h
→120μSv/h
1100(520)μSv/h
→360μSv/h
Dispersion Peak :60(10)μSv/h→30(10)μSv/h
Dispersion Peak :220(40)μSv/h
→45(8.0)μSv/h
BM chamber :170(35)μSv/h→80(20)μSv/h
H0 dump entrance
:900μSv/h
→300μSv/h
H Steering:650(250)μSv/h→270(110)μSv/h
1st Foil Chamber:7000(2000)μSv/h
→3300(1000)μSv/h
H0 dump branch bellows : 1900(300)μSv/h
→800(250)μSv/h
Injection Branch
: 2200μSv/h→1000μSv/h
100deg. dump bellows
:1000(150) μSv/h
→200(60)μSv/h
V Paint Bump 2
:350(30)μSv/h
→17(1.0)μSv/h
100deg. dump window
:8000(1000) μSv/h
→0μSv/h
100-deg. dump line duct upper
:600(30)μSv/h
→700(30)μSv/h

Ionization Profile Monitor(IPM)

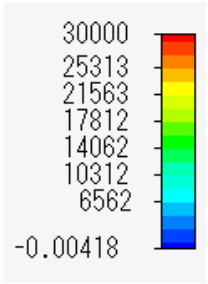


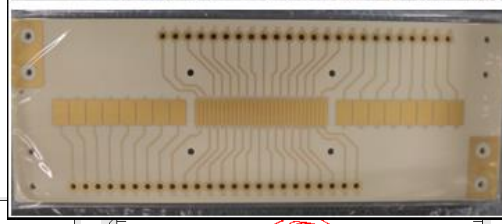
Prototype:electric field was distorted

Improves the electorode shapes and registers

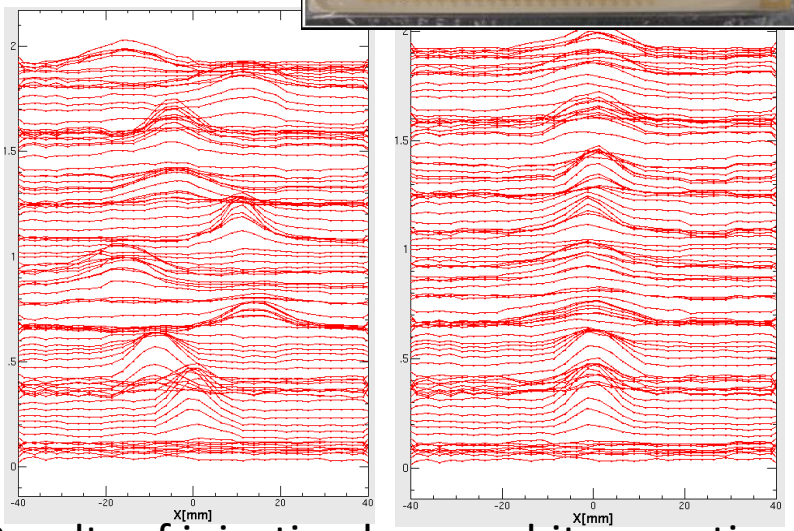


New:electric field becomes uniform





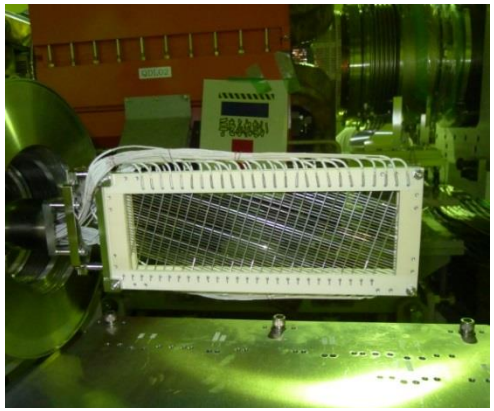
3 IPM installed
2:Dispersive Arc
1:Ext-straight
(Dispersion free)



Results of injection beam orbit correction

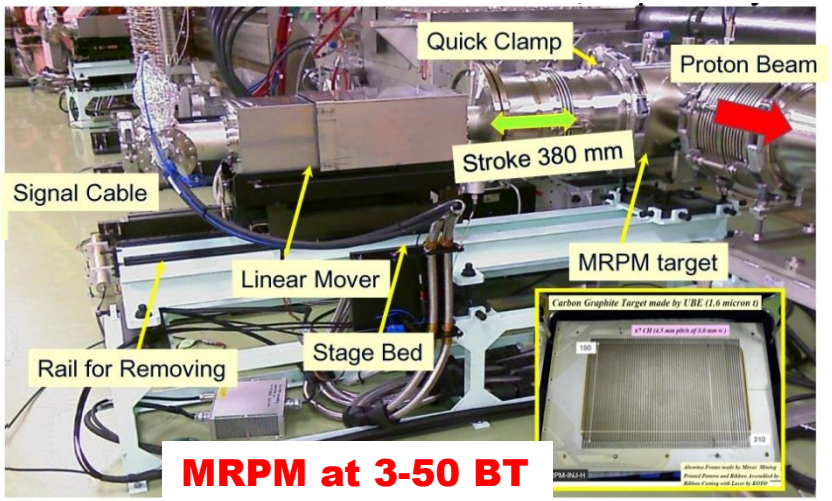
H. Harada et. al., "UPGRADE OF IONIZATION PROFILE MONITOR (IPM) IN THE J-PARC 3-GeV RCS", Proc. IPAC2012, MOPPR029

Wire Scan Monitor(WSM) /Multi Wire Profile Monitor(MWPM) /Multi Ribbon Profile Monitor(MRPM)

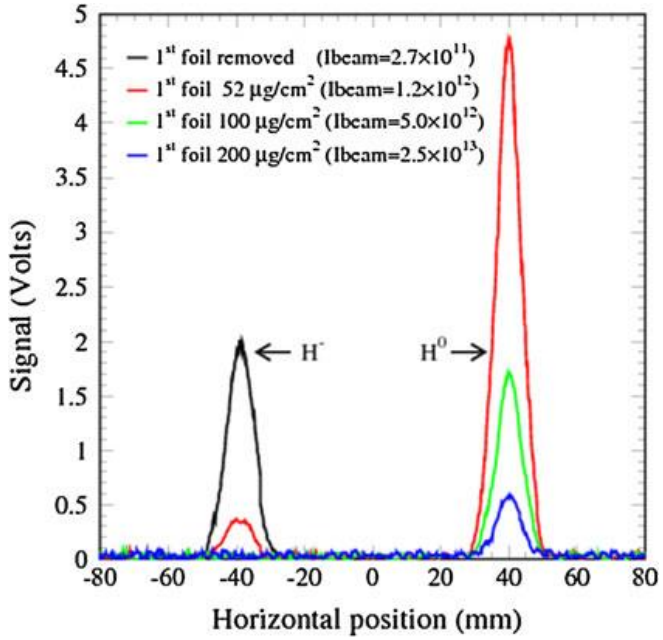


MWPM at RCS injection point

- Used at beam transport lines or one-pass operation (L3BT, 3-50BT or injection line correction)
- MWPM7 (installed in the injection dump line) is used not only to measure the profile, but to measure the amount of H^0 and H^- unstripped particles



MRPM at 3-50 BT



Y. Hashimoto et. al., "MULTI-RIBBON PROFILE MONITOR USING CARBON GRAPHITE FOIL FOR J-PARC", Proc. HB2010, WEO2A01

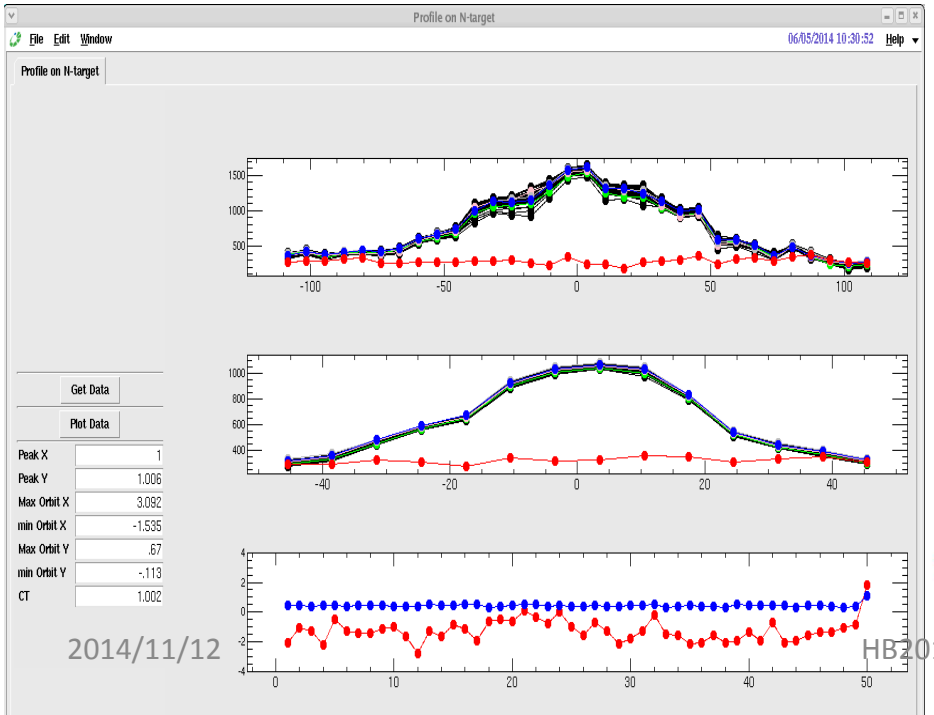
P. K. Saha et. al., "Quantitative monitoring of the stripper foil degradation in the 3-GeV rapid cycling synchrotron of the Japan proton accelerator research complex", J. Radioanal. Nucl. Chem. 299, **2**, 1041-1046 (2014)

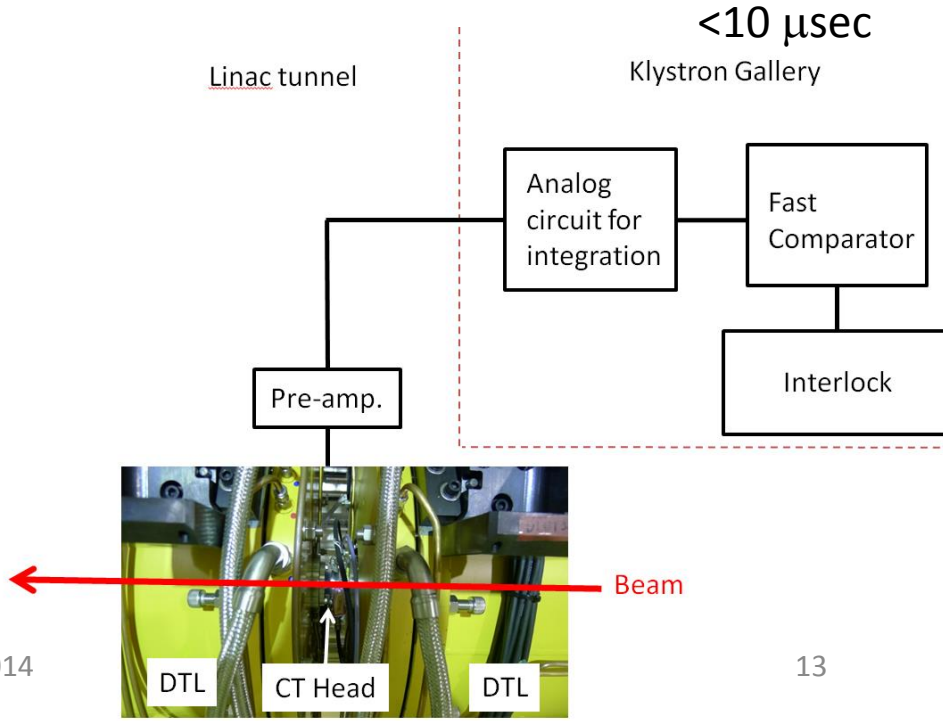
New monitors for further safety/quality of beam

- **Monitors for safety/stable operation**
  - **Fast interlock by CT and profile check on target**
- **Injection halo monitors**
  - **VWM**
  - **L3BT Scrapers & BLM, CT**
- **Extraction Halo monitors**
  - **WSM&BLM**
  - **OTR monitor**
- **Delayed proton monitor for μ-e conversion measurement**

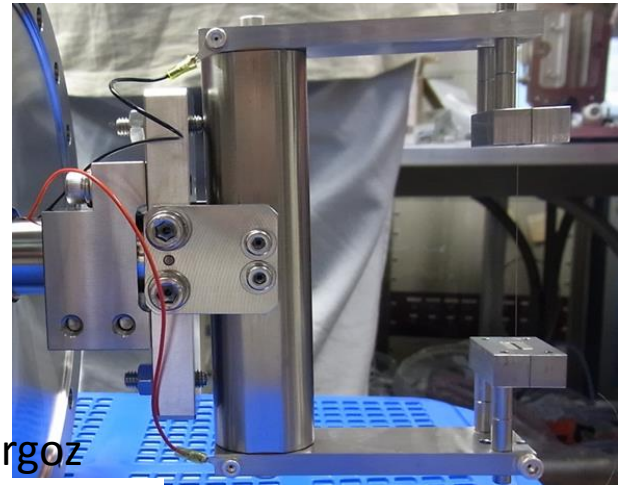
Monitors for safety/stable operation

- The radiation leak accident was happened in the hadron experimental hall at J-PARC on May 23, 2013. The accident was caused by a target sublimation due to an abnormal beam extraction from the main ring.
- To detect and prevent the radiation leakage, we improved the monitoring systems and interlocks.
  - ✓ Monitoring of the beam profile on the mercury target
  - ✓ New interlock system that can stop the beam immediately when the beam current exceed the limit.



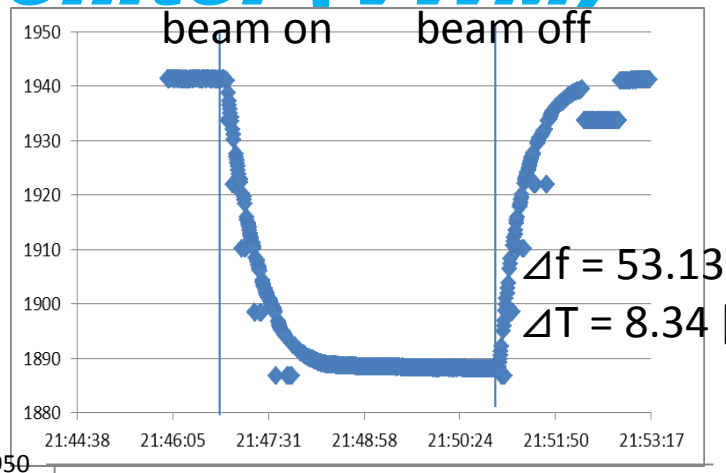


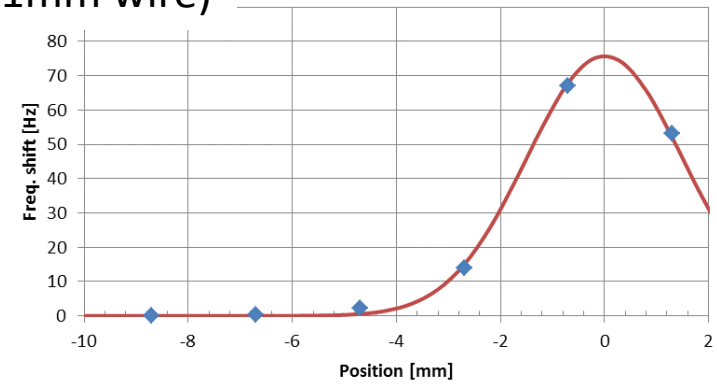
Injection beam halo monitor(1) Vibration Wire Monitor (VWM)

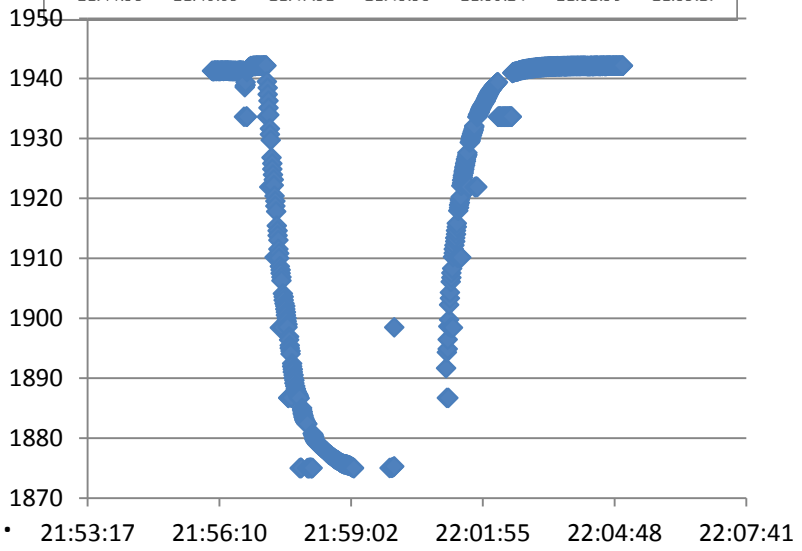


purchased from Bergoz

(sus316L, ϕ0.1mm wire)



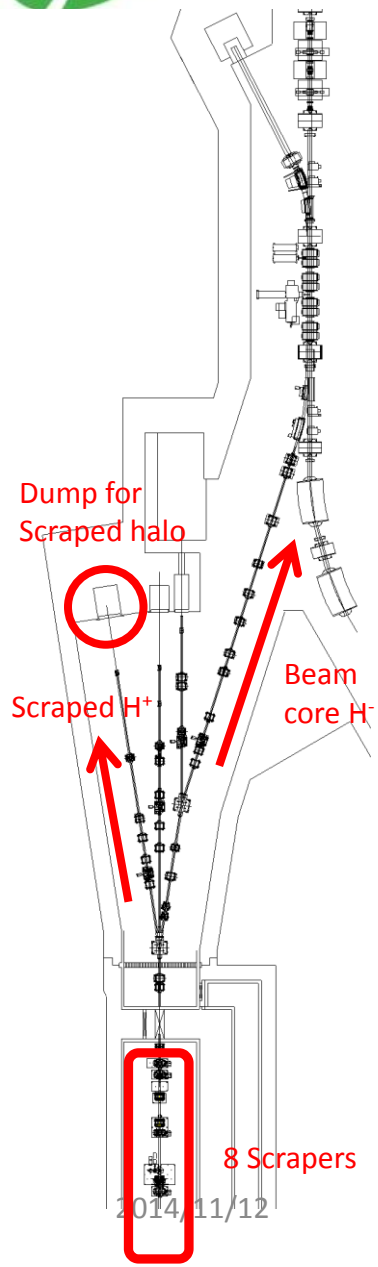


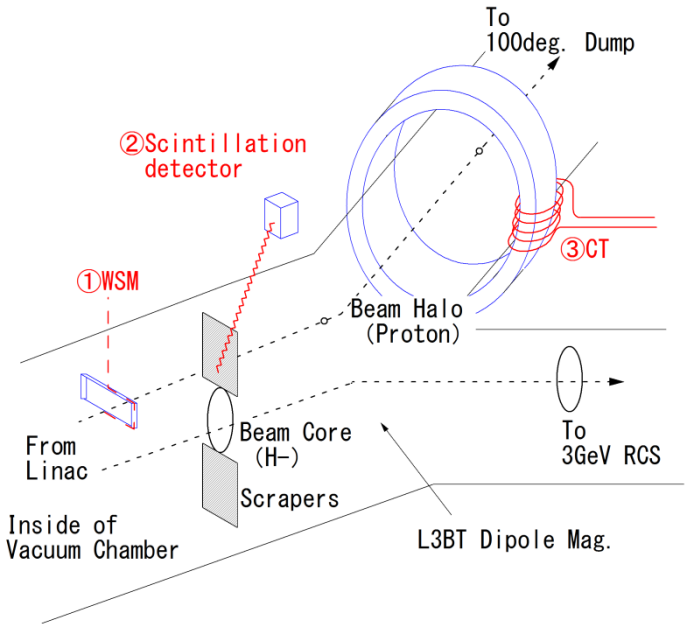


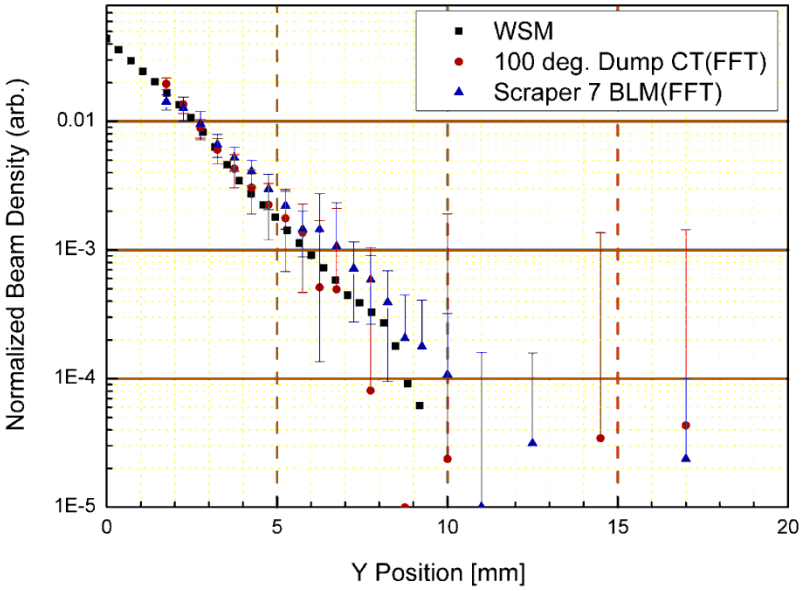
- We tested VWM to measure injection beam profile.
- But, we cannot take data at some frequencies.
- Perhaps electric circuit has some problem.

K. Okabe et. al., "Feasibility Studies of a Vibration Wire Monitor and a Halo Scraper in the J-PARC L3BT", Journal of the Korean Physical Society, Vol. 63, No. 7, October 2013, pp. 1379~1384

Injection beam halo monitor(2)
L3BT Scrapers & BLM, CT





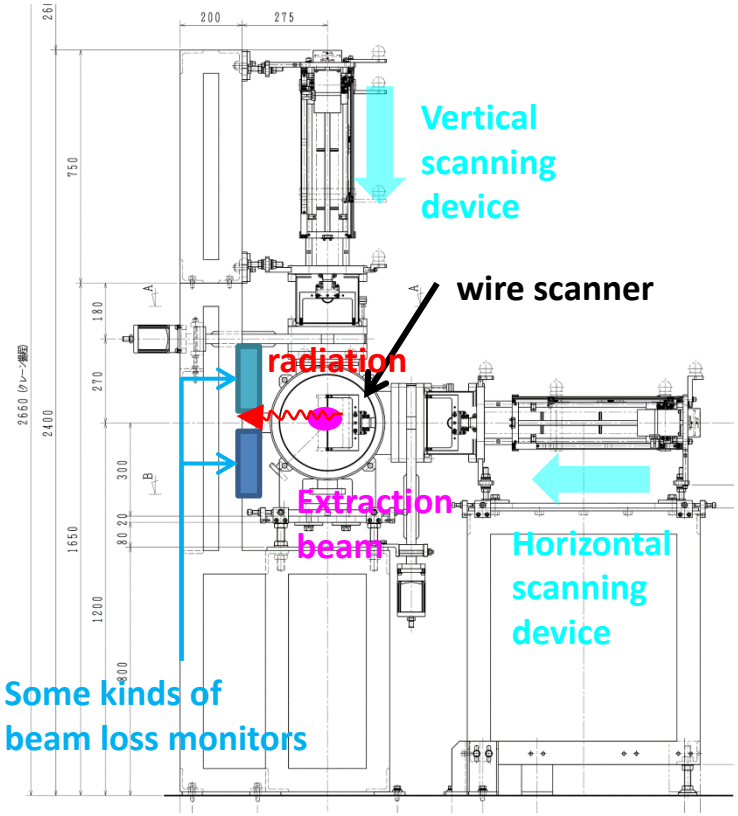


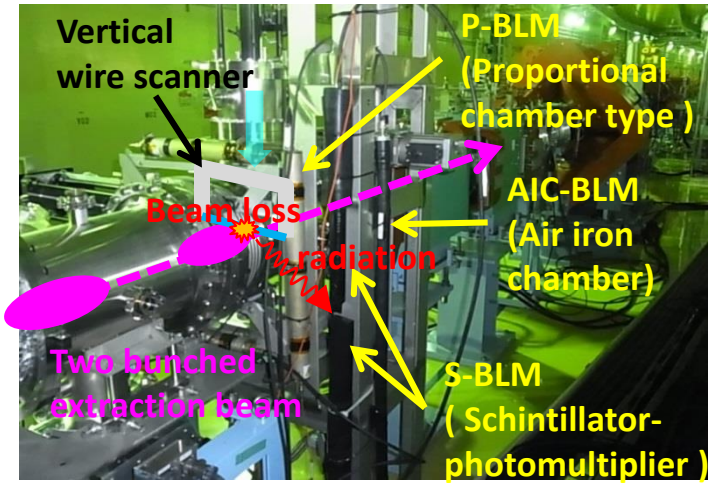
- The amount of the scraped halo (H-) was measured by the scintillation detector and the CT at dump line.
- This system has two advantages of
  1) redundant monitors by another principles
  2) absolute value measurement by CT
- Measured results are consistent, and the scintillation detector and the CT are able to detect less than 1E-4 halo.

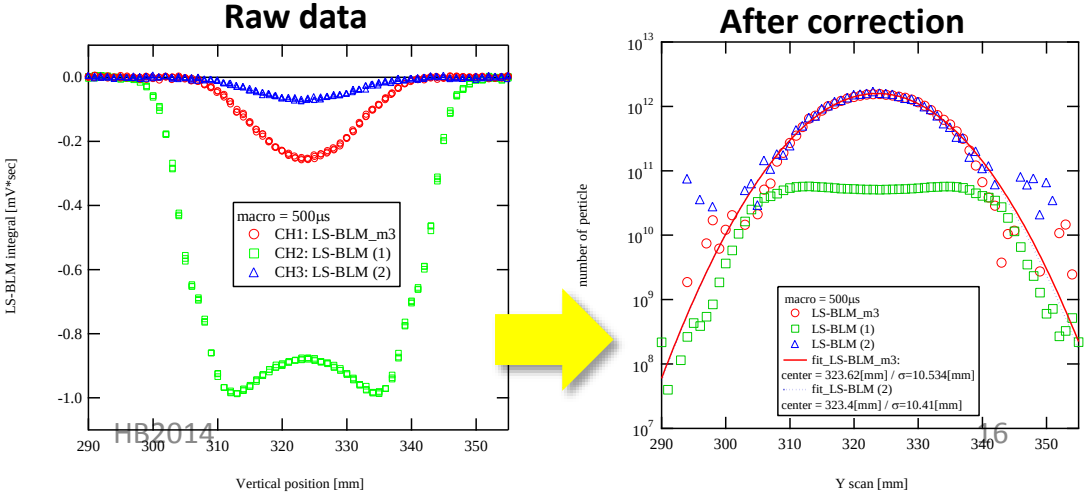
K. Okabe et. al., "Feasibility Studies of a Vibration Wire Monitor and a Halo Scraper in the J-PARC L3BT", Journal of the Korean Physical Society, Vol. 63, No. 7, October 2013, pp. 1379~1384

Extraction beam halo monitor(1) WSM & BLM

- New beam halo monitor is combined a wire type beam scraper and some beam loss monitors.
- To use the beam loss monitors with different sensitivities, it has wide dynamic range. Beam profile including both of the beam core and halo can be measured.

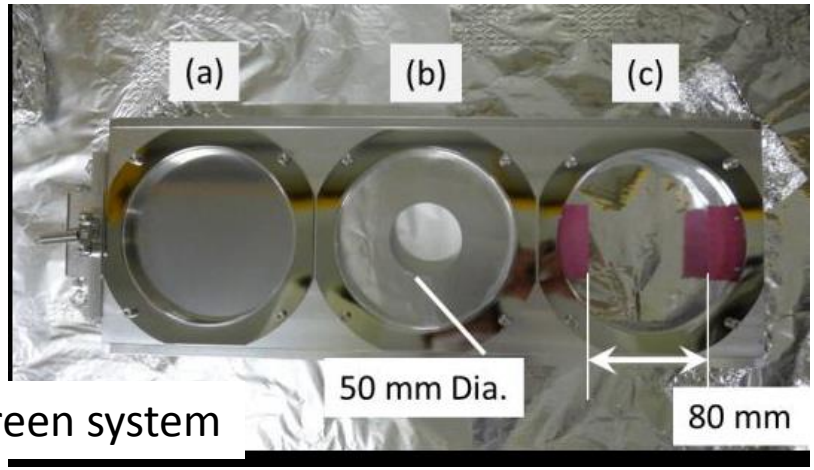




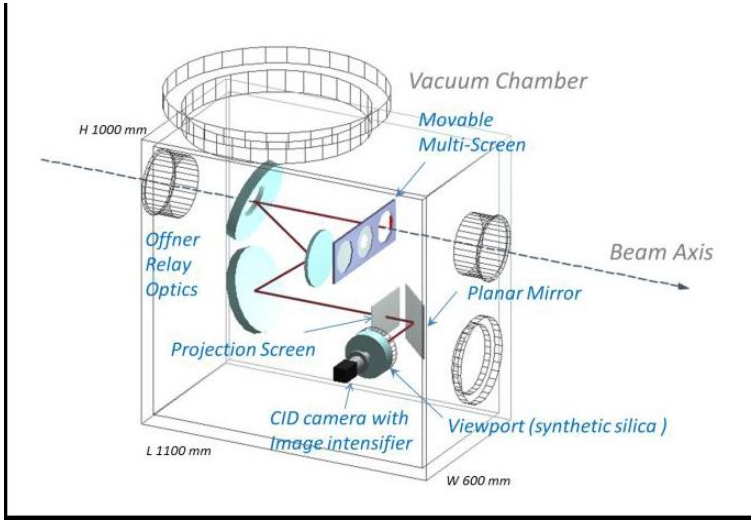


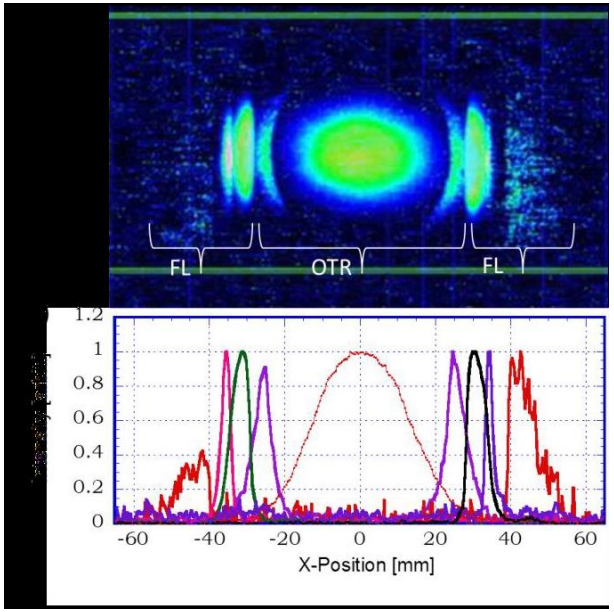
M. Yoshimto, et. al., "Beam halo measurement using a combination of a wire scanner type beam scraper and some beam loss monitors in J-PARC 3-GeV RCS.", HB2014, MOPAB44

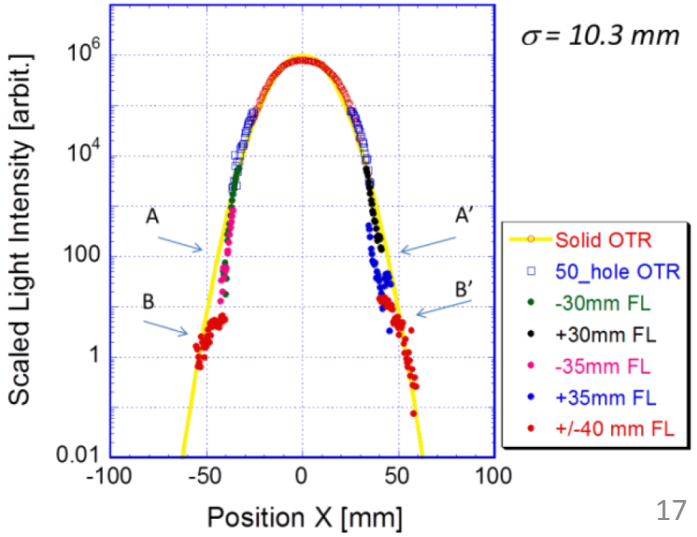
Extraction beam halo monitor(2)
Optical Transition Radiation monitor (OTR)



multi-screen system



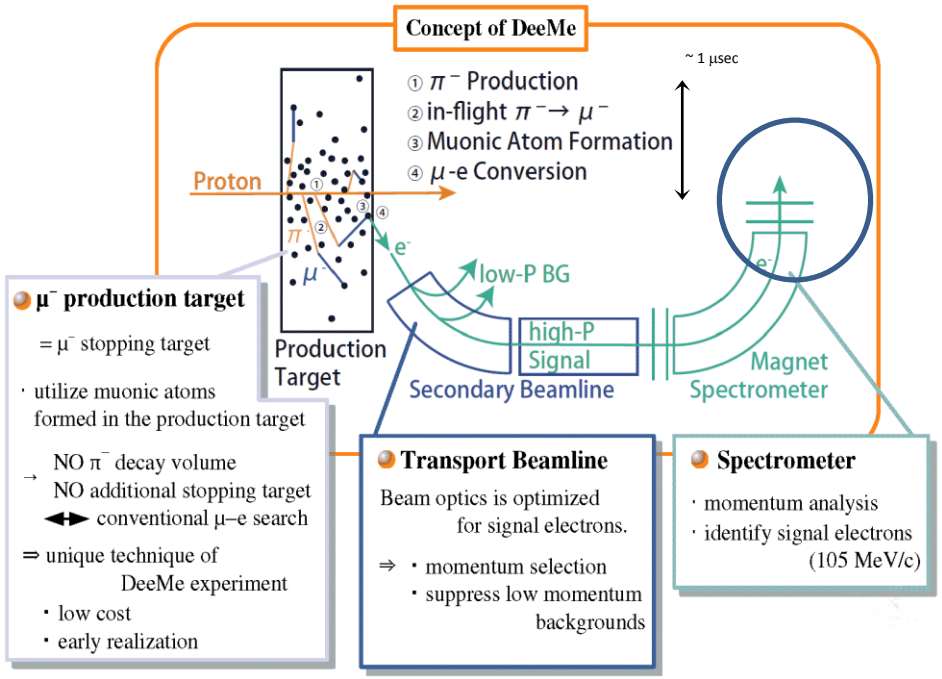


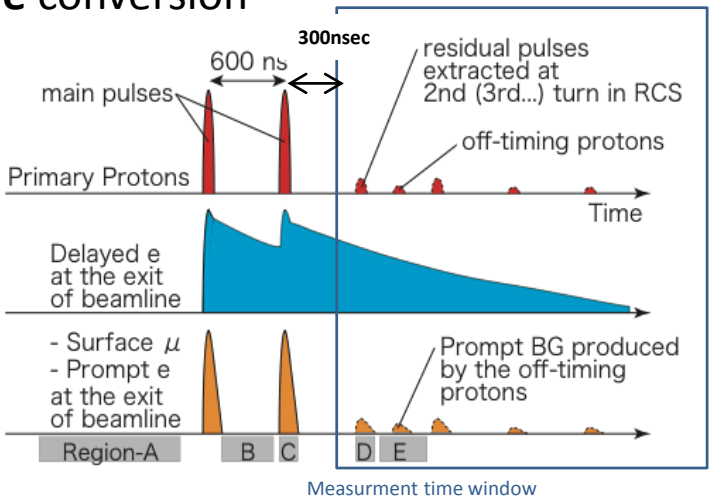


Y. Hashimoto et. al., "Two-dimensional and Wide Dynamic Range Profile Monitor Using OTR/Fluorescence Screens for Diagnosing Beam Halo of Intense Proton Beams", HB2014, TU02AB

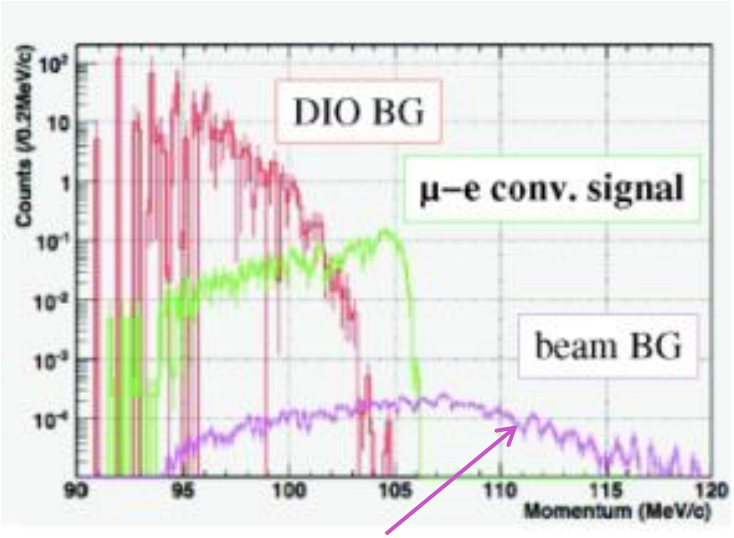
Delayed proton monitor for μ-e conversion measurement

DeeMe=**D**irect **e**lectron **e**mission measurement for **M**u- **e** conversion





Measurment time window



Beam background when BG proton exists 10^{-18}

->Required rate of delayed proton : < 10^{-18}

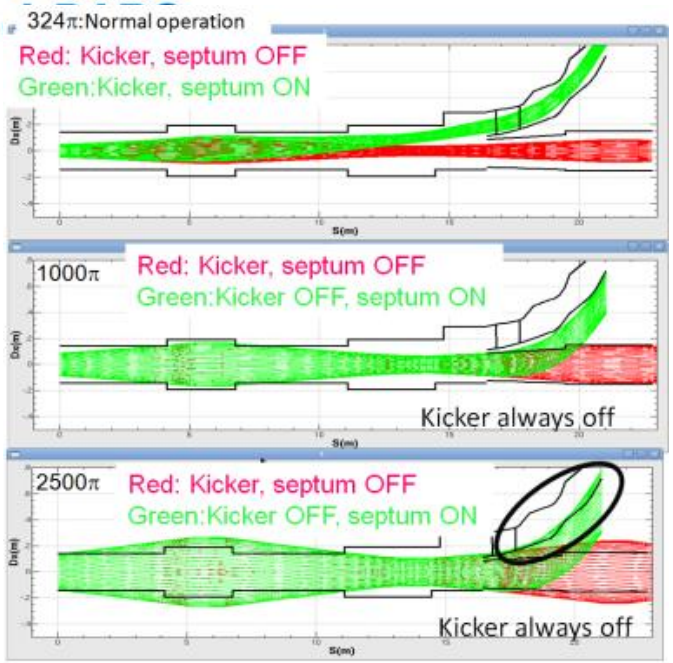
->Correspond to less than few protons within 1 hour

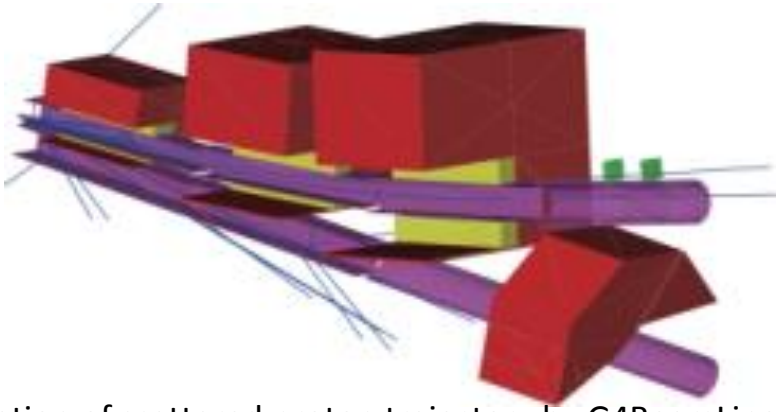
= $9*10^4$ shot(Rep. = 25Hz) (1 pulse ～ $1*10^{14}$ protons)

->It is impossible to measure such slight protons by ordinary monitors

K. Yamamoto et. al., "Measurement system of the background proton in DeeMe experiment at J-PARC", Proc. 2nd International Symposium on Science at J-PARC (2014)

Delayed proton monitor for μ-e conversion measurement



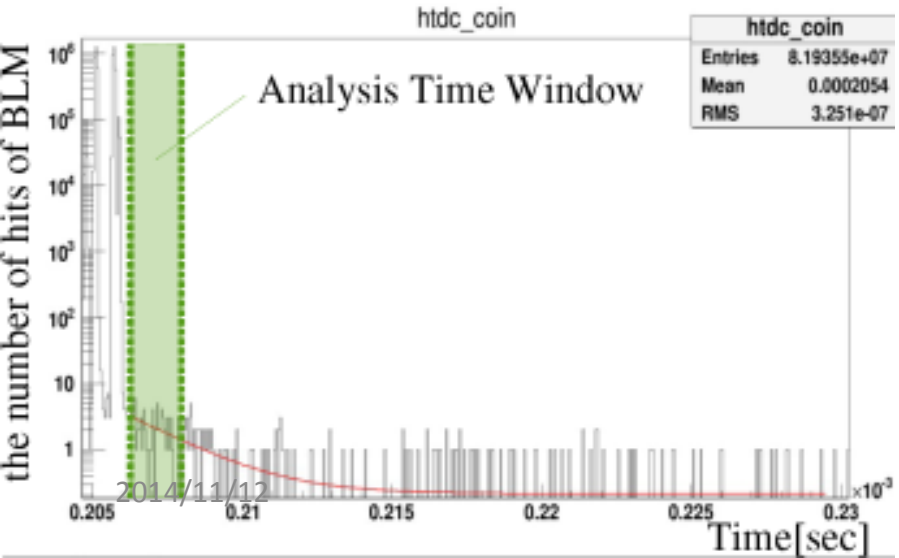


Estimation of scattered proton trajectory by G4BeamLine

-> Assume 324～5000π mm-mrad. emittance uniform beam

Ratio of the number of the proton that hit the outside scintillators to the number of the proton that pass through the 3NBT line

N[scintillator hit]/N[Pass through 3NBT]=ε=0.025



Measurement:

Mar. 7, 2013 –May 25, 2013

Total coincident count in the time window:87

Total extracted protons:

$3.13*10^{21}$

$R_{delayed\ p}=1.1*10^{-18}$

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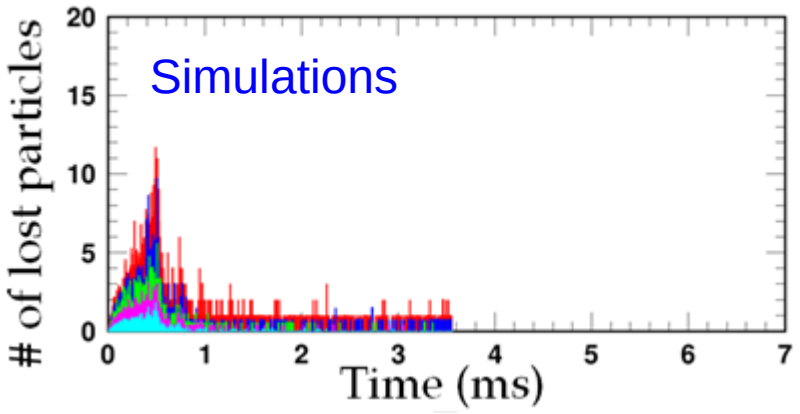
Summary

- We achieved 770kW output power.
- Since regular monitors worked well, so far we understand the characteristics of the beam.
- To establish further stable and safety operation, some monitors and interlocks are improved
- To reduce the beam loss, high sensitive halo monitors are developed.

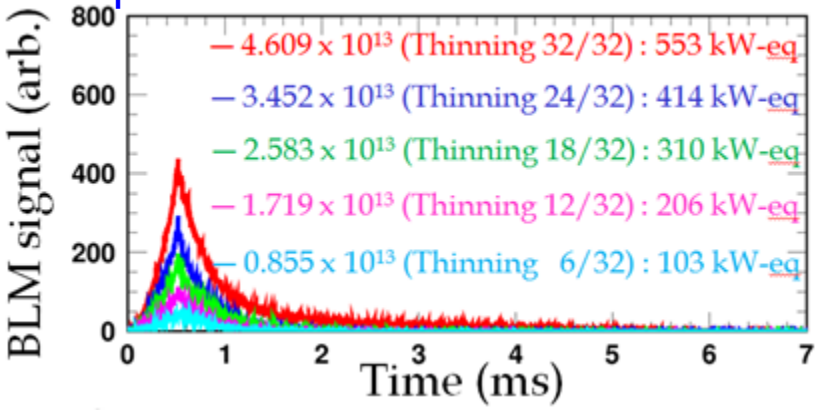

J-PARC

Beam Loss Monitor

SBLM signal comparison

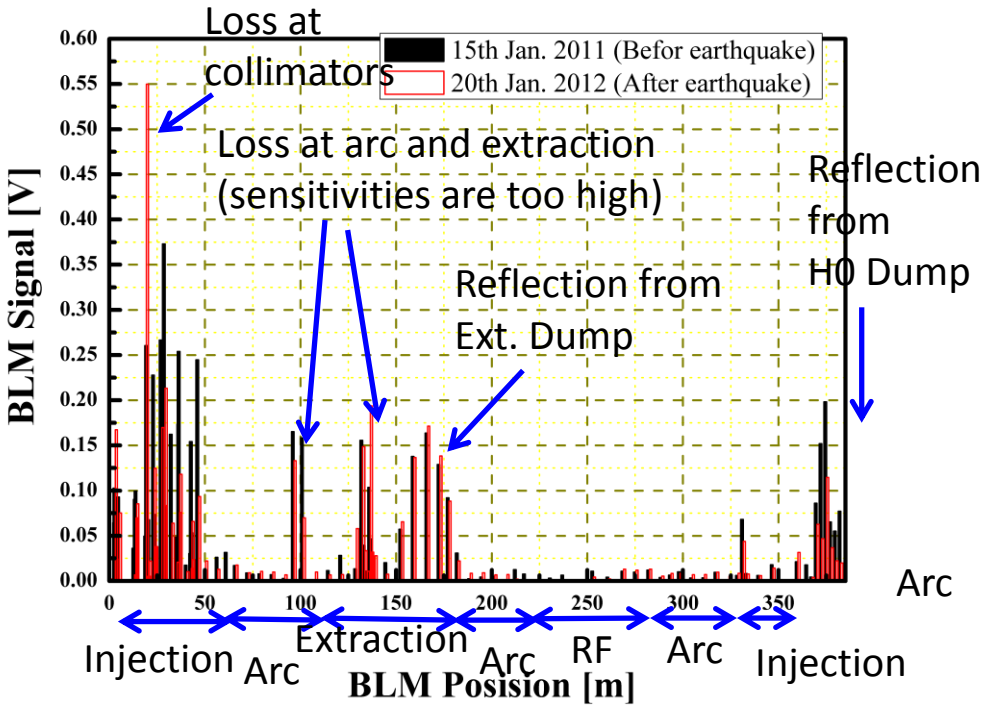


Experiments data from SBLM



The time structure and the amount of the beam loss are well in agreement with the simulation.

PBLM signals around the RCS



Integrations of PBLM signal are archived at all times.
PBLM signals are also compared with the limit value at every shot.

Monitors for safety/stable operation (2) redundant MPS by BLM

CH1: CHOP2 RF
CH2: CHOP1 RF
CH3: RCS BLM MPS