News from J-PARC: the system, the data and the ~~simulation code~~

Simulation, design and operation experience of Ionization Profile Monitors

21-24/5/2017

J-PARC MR beam monitor G

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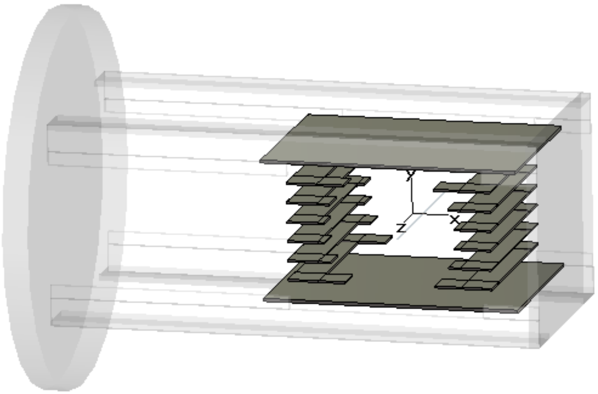
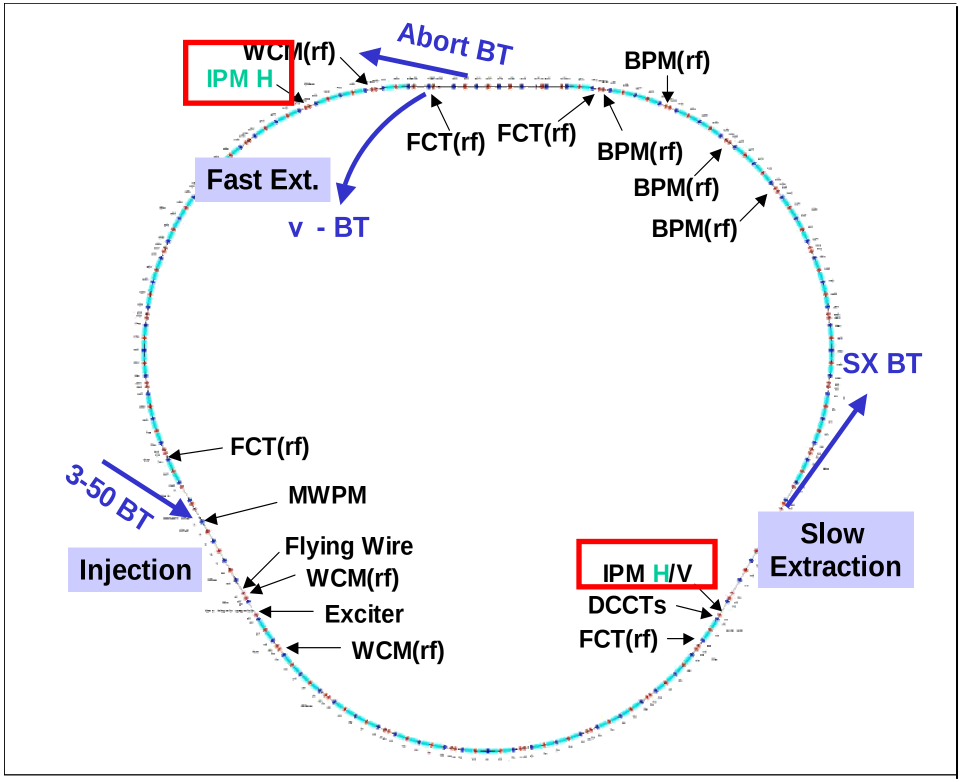
Outline

- J-PARC MR IPM system overview
- Magnet system
- Electron contamination issue
- Beam based MCP gain calibration
- Development of Gated IPM system for J-PARC system
- Data set for IPM simulation from J-PARC
- Summary

Photo of IPM

MR IPM specification



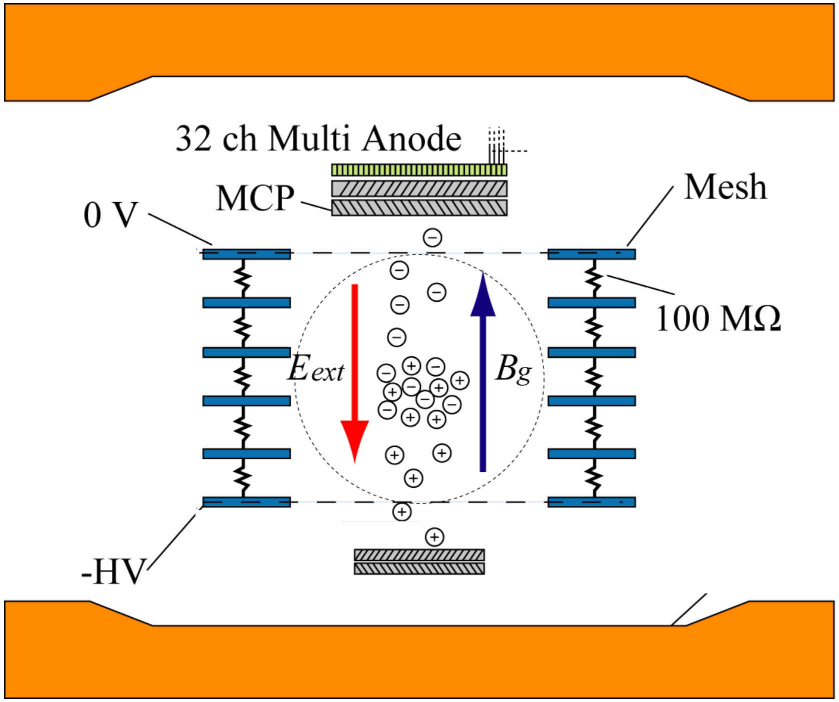


MR IPM specification	
Number	3
Twiss parameter	Vertical βx=12.1m, βy=27.3m,η=0m Horizontal βx=13.1m, βy=21.6m,η=0m Horizontal βx=8.4m, βy=15.5m,η=2.0m
Gap size	130mm
Maximum HV	50kV
Operation voltage	<30kV
w/w.o. Magnet	D2H: w. D2V,D3H:w.o.
Detector	1 chevron MCP
Current pickup	32ch strip anode
Anode width	2.5mm
MCP calibration source	Cold electron source: EGA

IPM components and two mode operations

- A set of electrodes to generate electric field to collect charged particle
- High voltage to overcome the space charge electric field of the high intensity bunched beam
  - Space charge E field
    - **1800kV/m** for MR ext. beam
- 3-pole magnet system to generate guiding field to collect electrons against space charge electric field

Ideally the E and B field doesn't make any force



- MCP to multiply the signal
- Multi strip anode to read out the charge from MCP
- Electron source, EGA (Electron generator arrays), to check gain aging of the MCP -> Will be removed this summer

Two mode operation and related issues

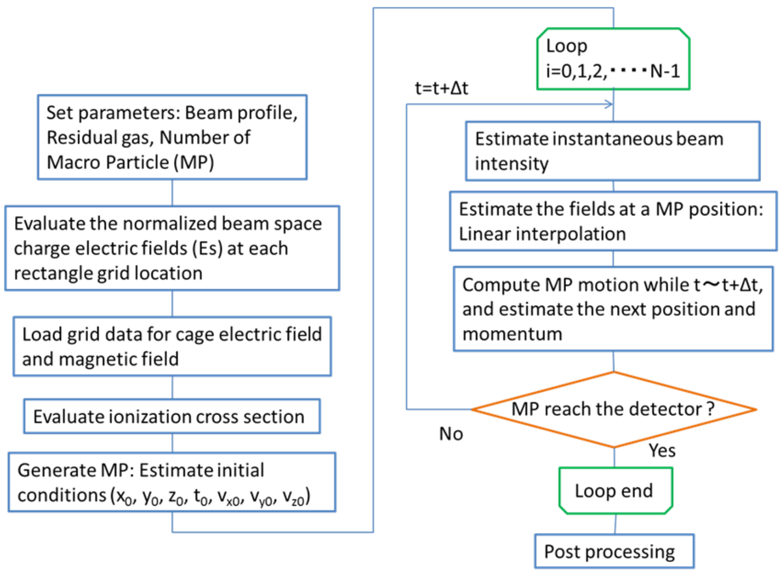
Ion collection without guiding field

The HV is now poor for the extraction beam, thus space charge effect should be taking into account to estimate the emittance

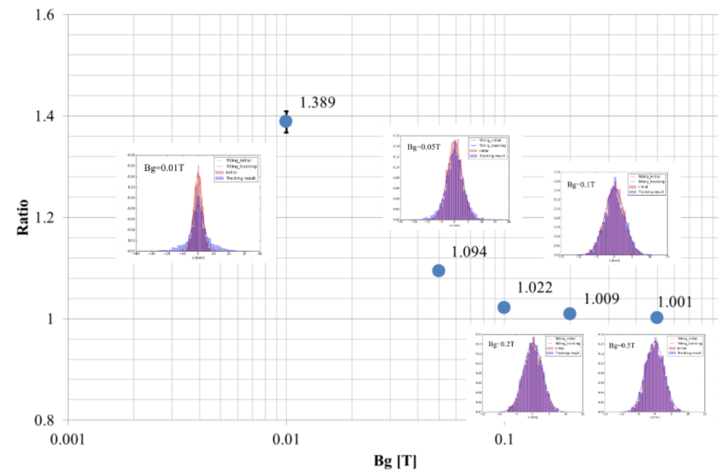
Guiding field assisted electron collection

Is it possible to collect electrons only from the ionization process?

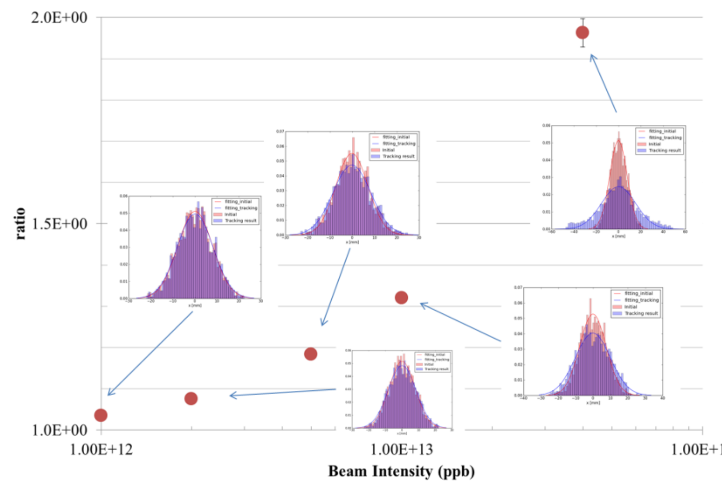
Magnet : Required B



Flow chart of the code IPMsim3D



Electron collection w. Bg at the flat top energy of 30GeV

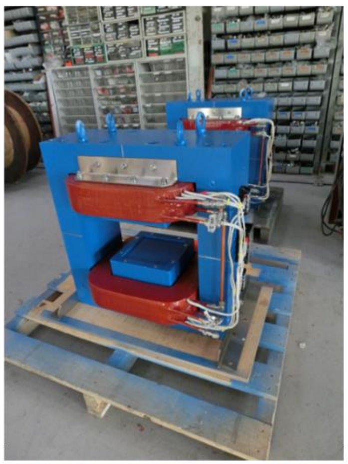


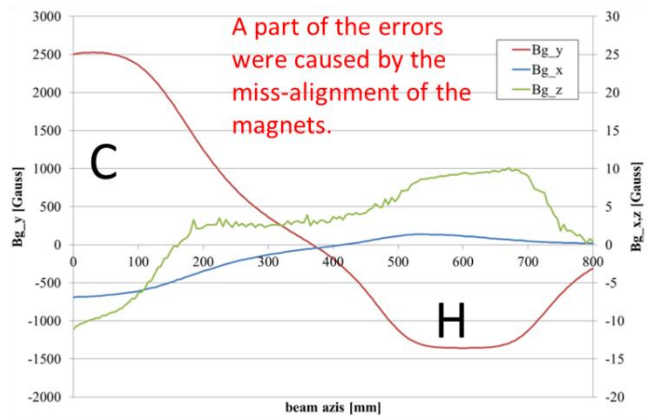
Ion (m/q=1) collection w. Bg=0.2T for the bunched beam at the injection energy of 3GeV

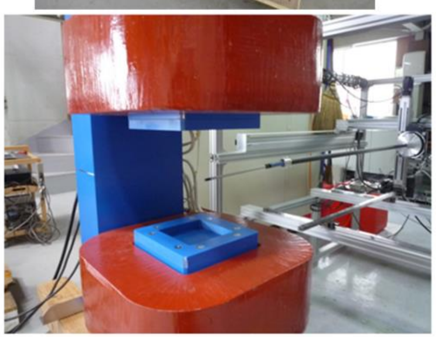
Magnet : performance

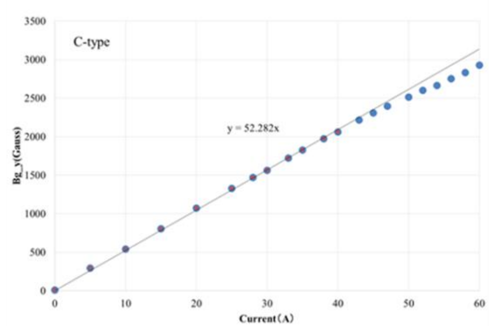
Requirements of magnets

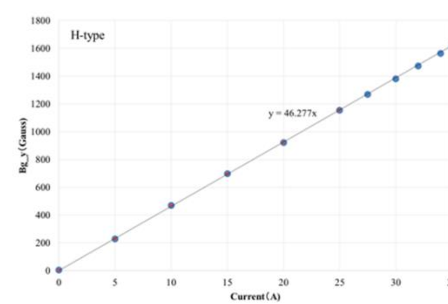
Type	Pole gap[mm]	B at center [T]	Effective area [mm]	Error fields, Bx/By, Bz/By	Flatness	Cooling
C	220	0.25	(x,y,z)=-45~45, 40~40, 20~20	<1%	<5%	Water
H	130	0.13	(x,y,z)=-45~45, 40~40, 20~20	<1%	<5%	Air







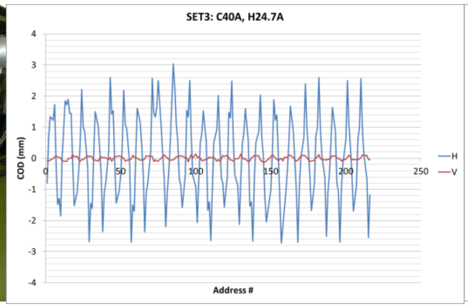


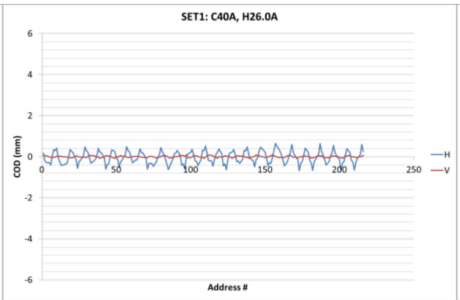


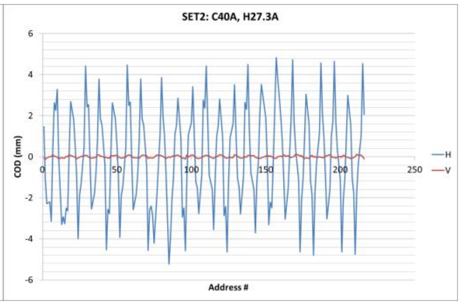
Magnet : Current balance tuning

Residual BL product ->
Horizontal kick -> COD_x

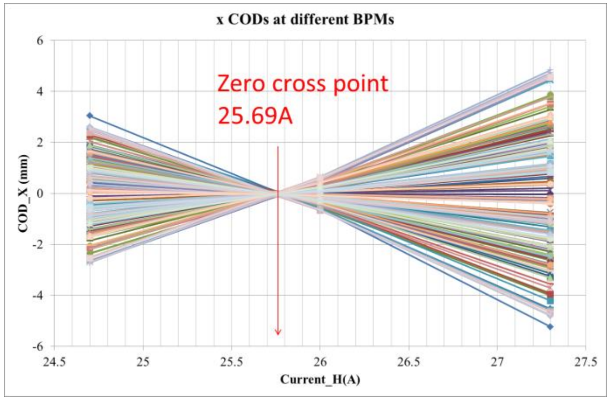
The CODs along MR ring at different current settings
(40, 24.7), (40, 26.0), (40, 27.3)

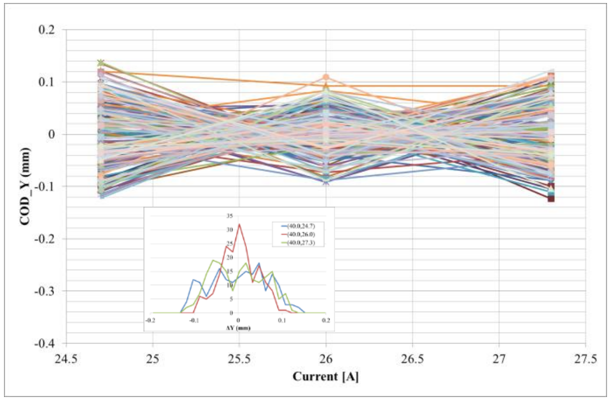







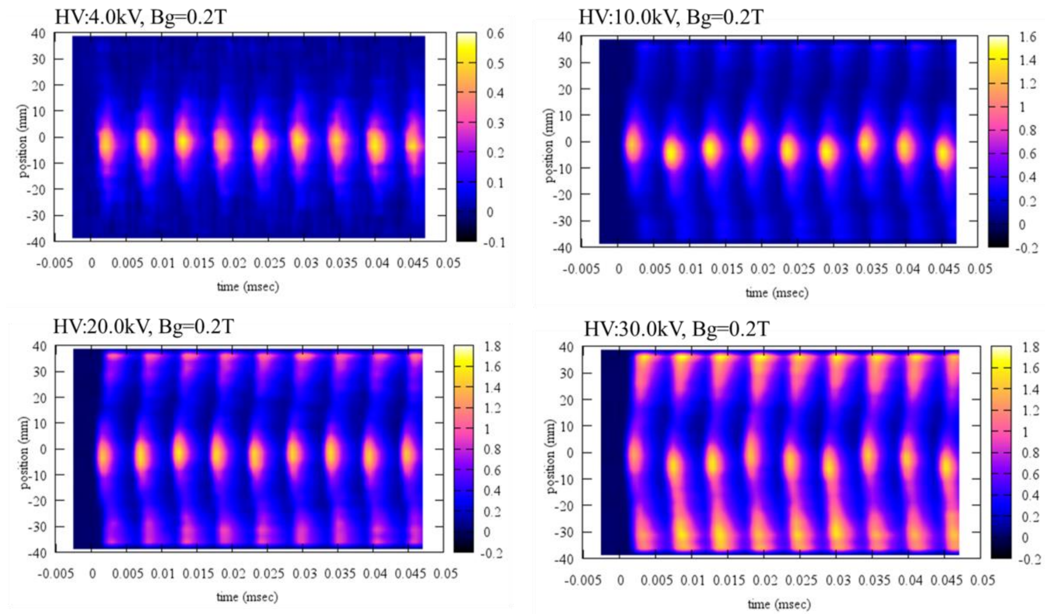
The cross points showing COD_x = 0 mm suggest that the current setting of (40.0, 25.7) is appeared to be the balanced setting. We have also checked the vertical CODs and these does not shows clear position deviations, however the histograms of the (40.0, 26.0) is somehow narrower than that of the others. Since the magnet alignment criterion was less than 1mrad, so we expect that the alignment error of the H-type magnet induces small vertical kick and thus CODs, which are less than 100µm.

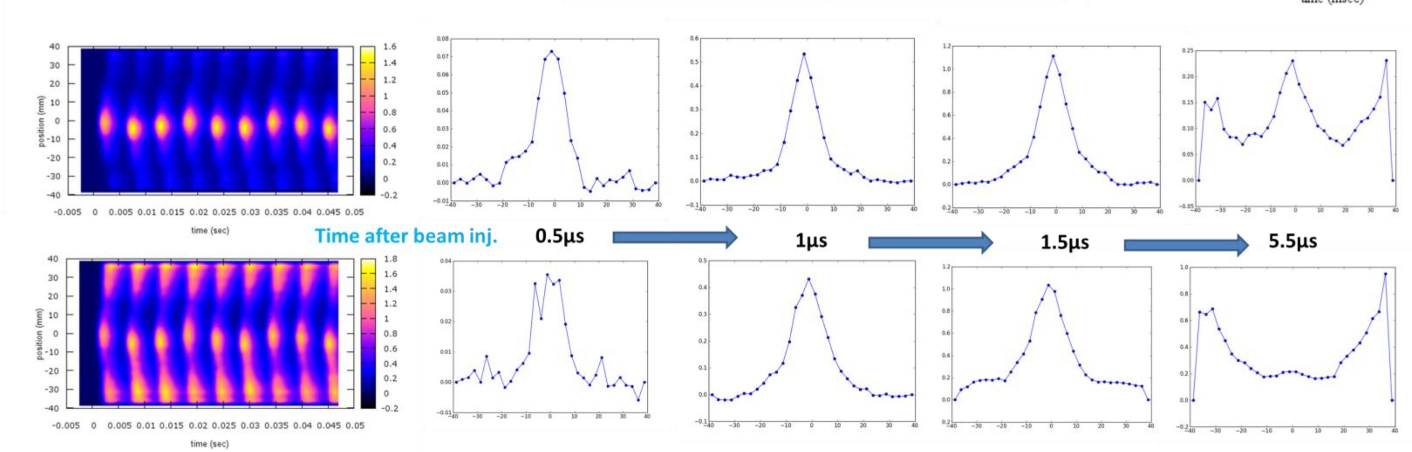




Contamination issue : Electron collection with the magnetic field

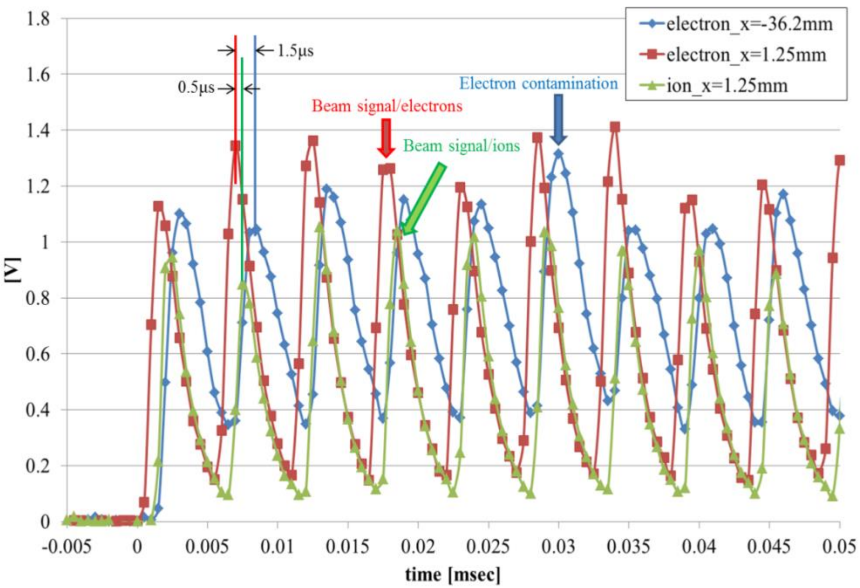
- The turn by turn profile showed beam induced contamination, and it depends on HV
- The contaminant electrons appeared ~1.5 μs after the beam passage
- Mechanism of this contamination issue is under investigation

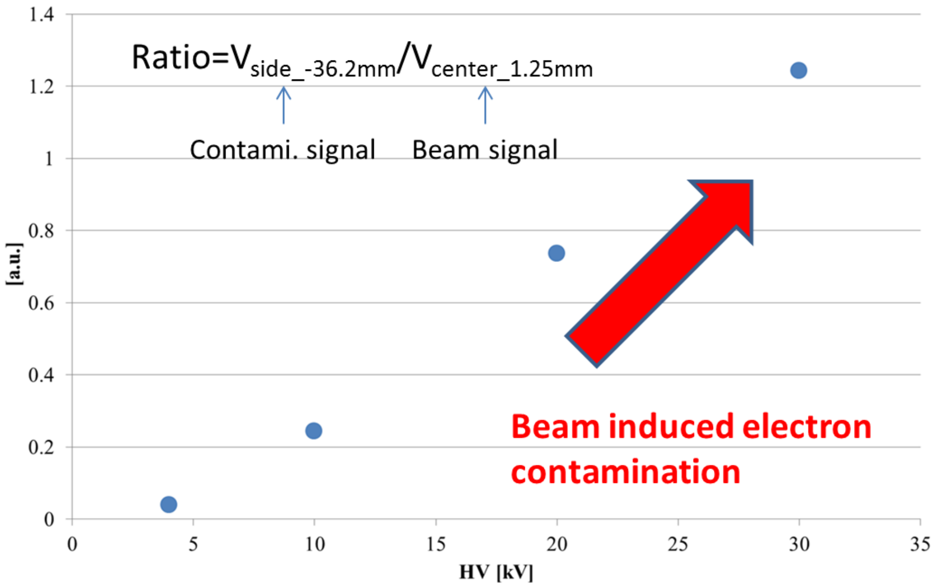




Sliced profile at selected time, 0.5, 1, 1.5, and 5.5 μs after the beam injection

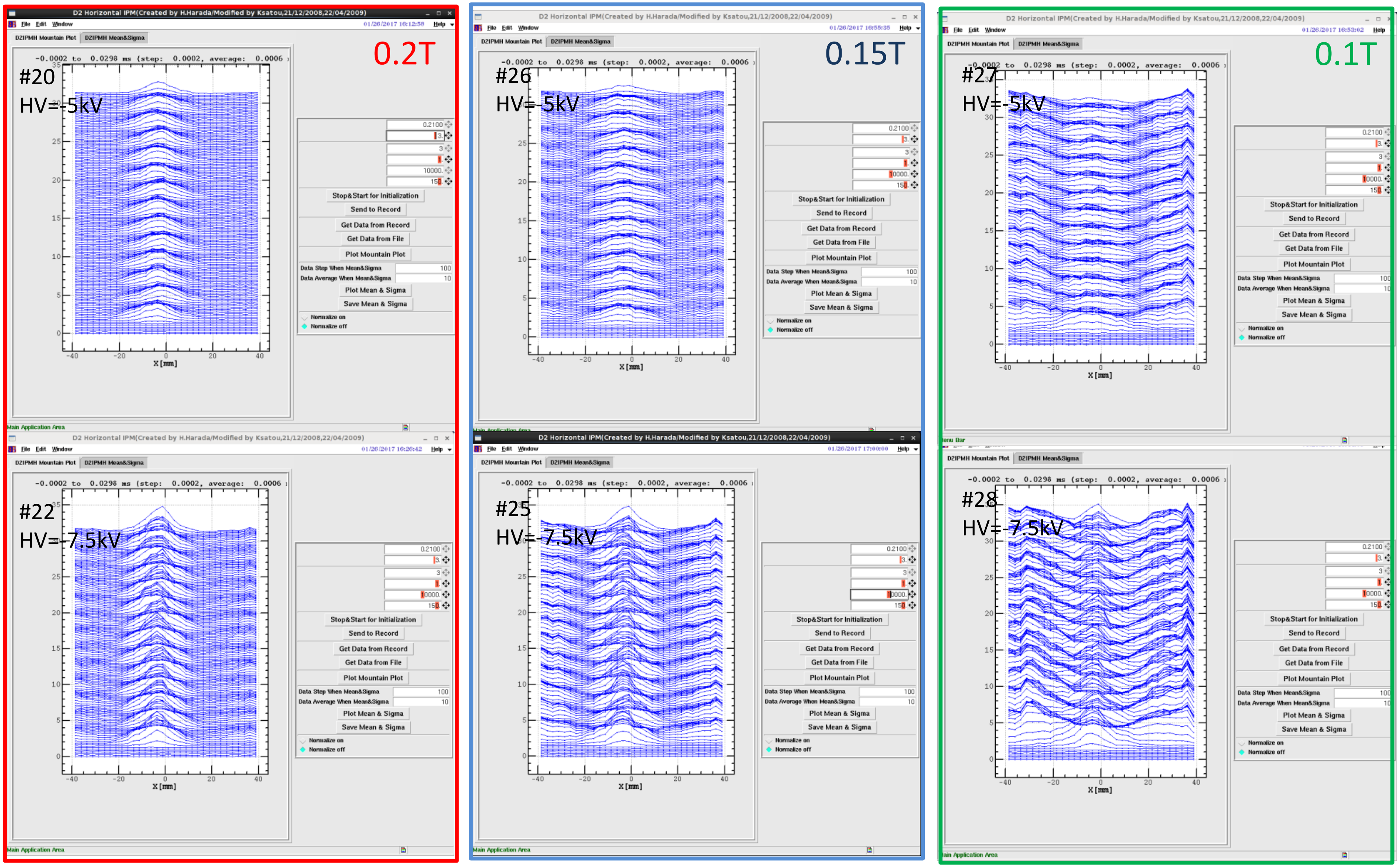
From where?



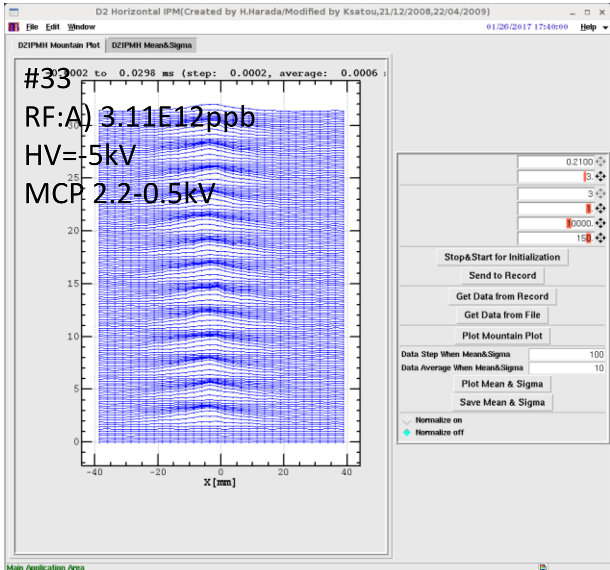


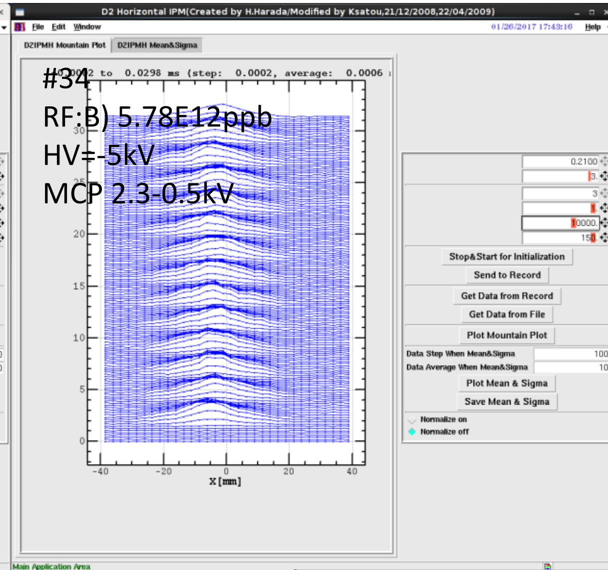
The time difference between a real beam signal of electrons and ions is about 500ns. This time difference is the result of the time of flight (TOF) to the MCP detector, a few ns in case of electrons and a few hundred ns for ions. The electron contamination shows somewhat broad structure and likely arrived on the detector surface at about 1.5μs after beam passage.

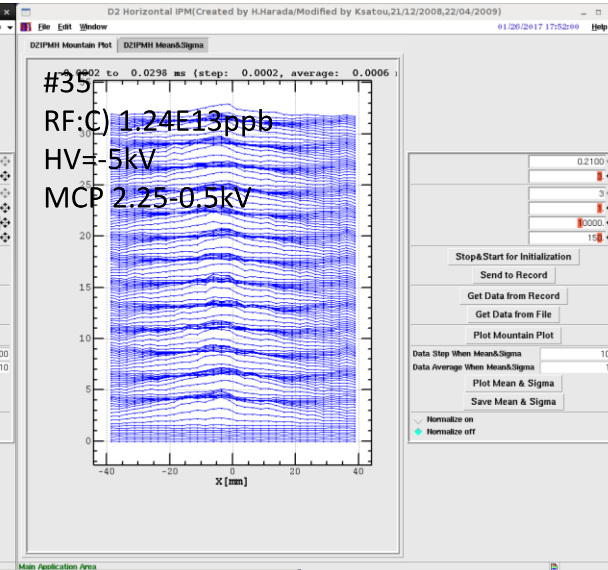
Contamination issue: B dependence

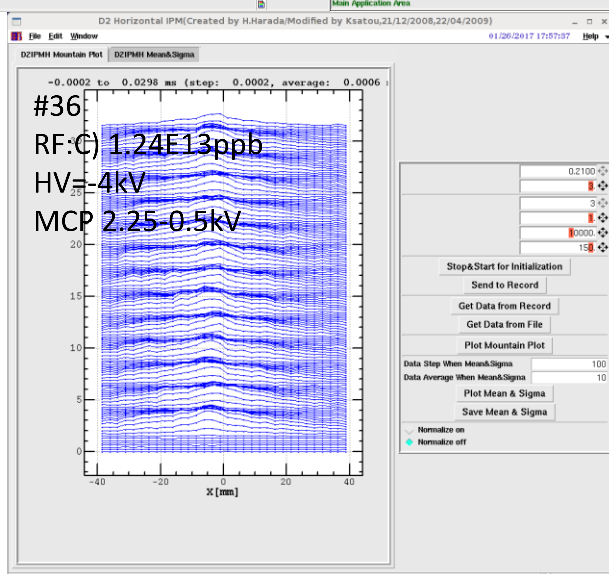


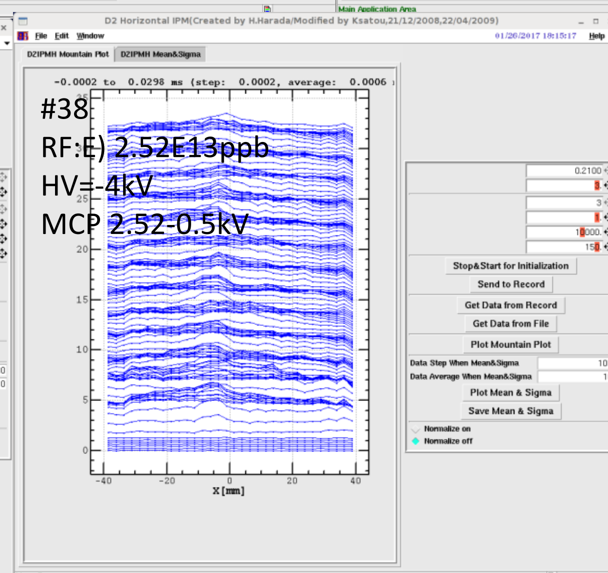
Contamination issue : Beam intensity dependence B=0.2T



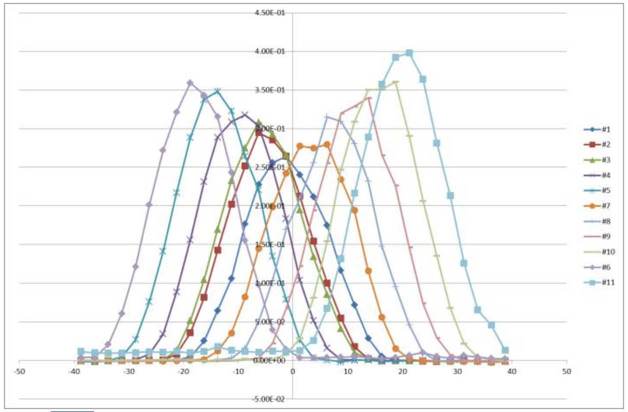


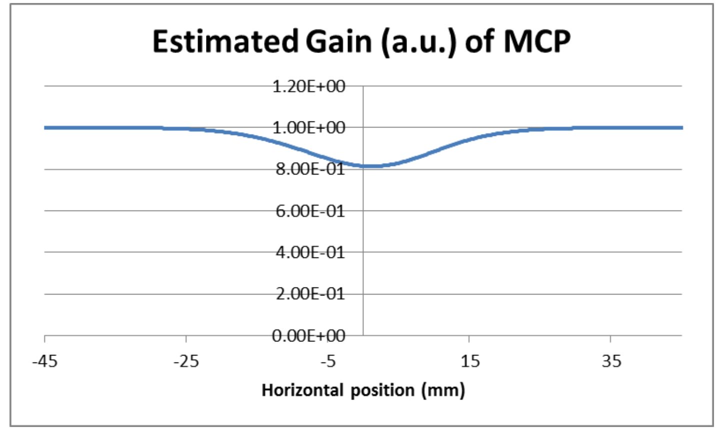






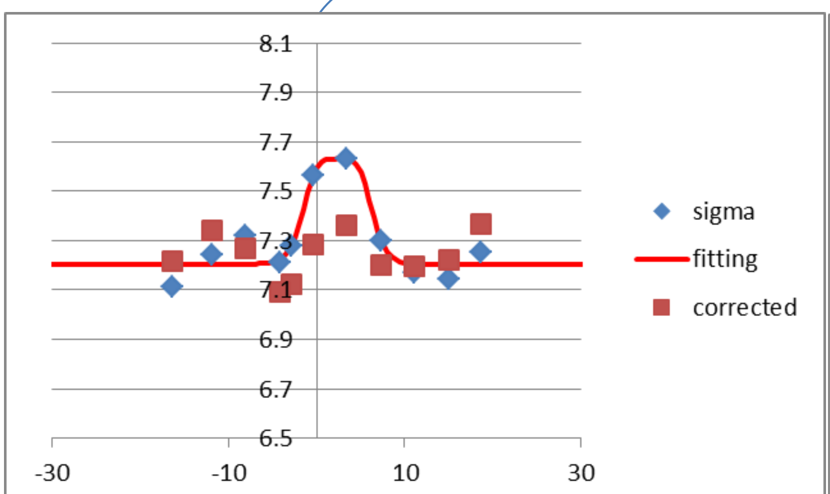
How to calibrate MCP without source?

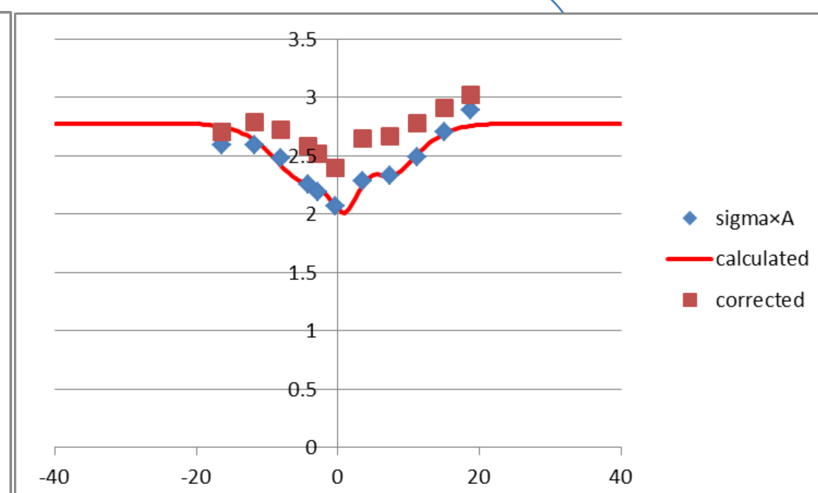




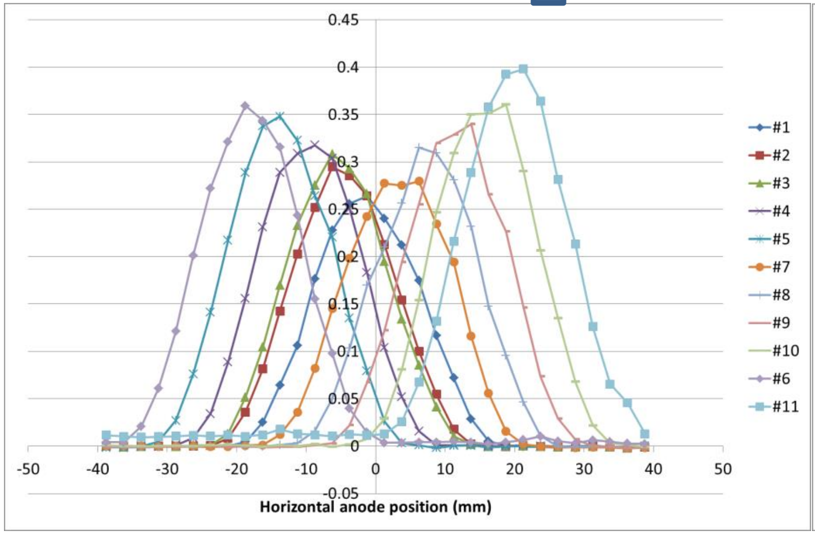
Gauss fitting

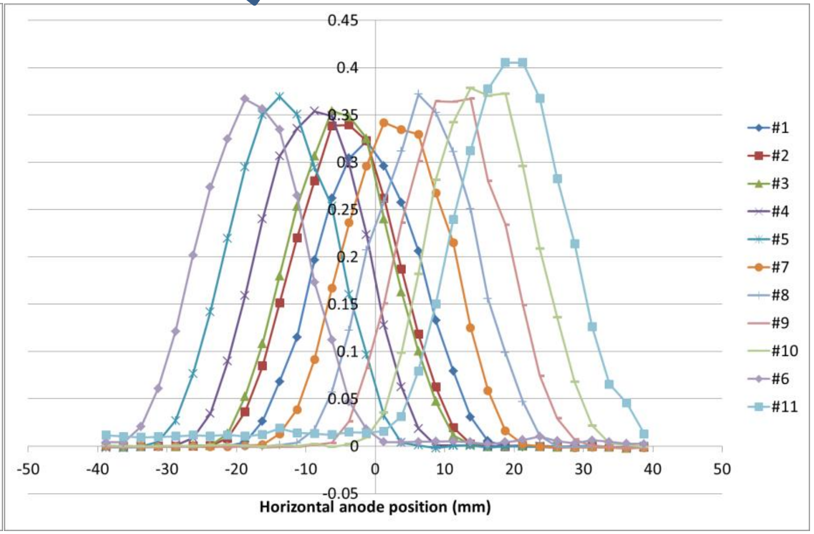
Fitting functions





Before and after gain correction





The profile widths are corrected well, however small intensity gaps are remained

Some iterations may improve the situation

Solution: HV DC -> Pulse mode operation

Local gain decrease can be expressed as

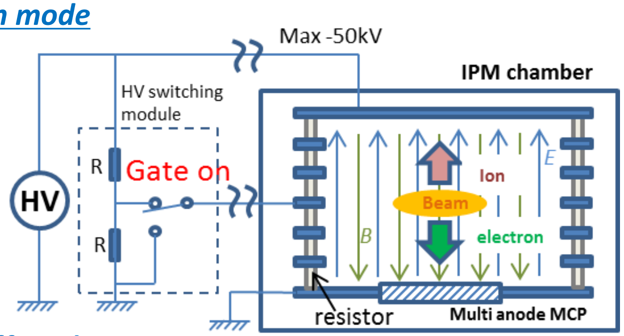
$$\Delta G(x) \propto Q(x) \propto G_0(V_{bias}) \cdot \tilde{\rho}(x - f_{x0}(x)) \cdot \tilde{I}_0 \cdot T \cdot D_{beam} \cdot D_{IPM}$$

- $\Delta G(x)$: Local gain change
- $Q(x)$: Integrated output charge
- $G_0(V_{bias})$: MCP gain set
- $\tilde{\rho}(x - f_{x0}(x))$: Averaged profile measured
- $f_{x0}(x)$: Beam center fluctuation
- $\tilde{I}_0$: Averaged intensity
- T: Integrated time of measurement
- D_{beam}: Beam on ratio
- D_{IPM}: Duty of IPM operation

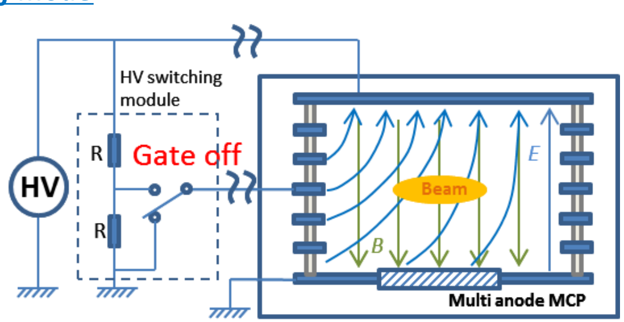
Gated IPM system can optimize this parameter

Gated system

On mode

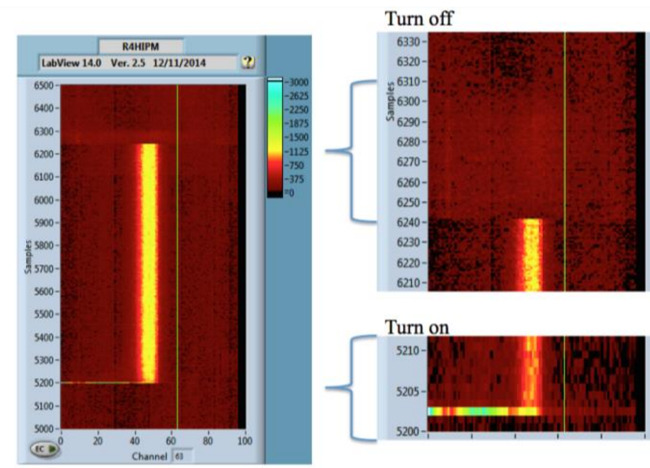


Off mode



$E \times B$ ($v_z = E_x B_y$) drift sweeps the charged particle away from the area of MCP detector

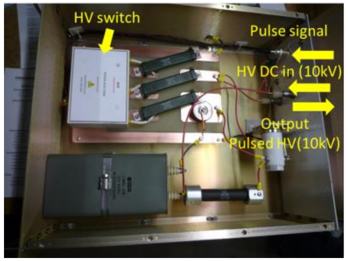
Original idea comes from FANL IPM



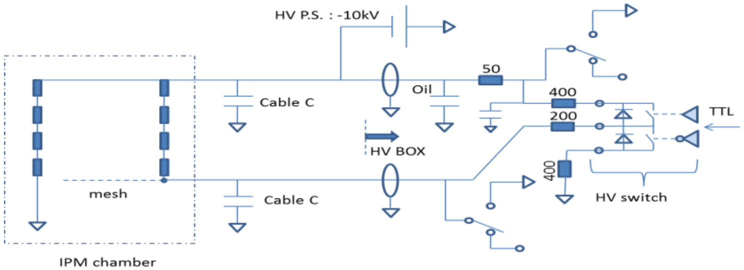
Courtesy of Randy Thurman-Keup, profile measured by the IPM @ FNAL with pulsed HV: From the presentation file of US/Japan monitor meeting at FNAL, 2015.

When 100Hz 1% duty switching operation is used ($D_{IPM}: 1 \rightarrow 0.01$), only 20 turn profiles will be selected for each pulse. MCP life will be extended to 100 times longer than that in the case of non-gated system.

HV switching module design

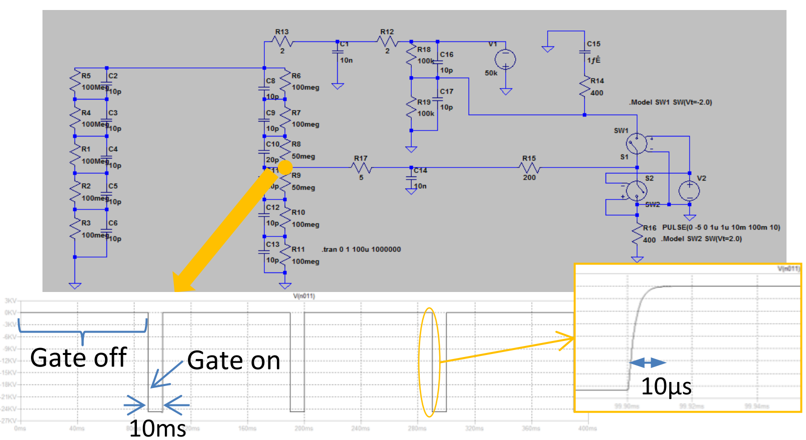


Courtesy of James R Zagel: Photo and block diagram of the HV switching module for FANL IPM



New HV switching module for J-PARC is now under design

Same design as FNAL IPM cannot be used due to the higher voltage of 50kV



Proposed circuit for gated IPM system of J-PARC and its simulated results

Schedule

- FY2016
  - Design of the HV switching module
  - Component procurement
  - Performance check with test circuit
  - Particle tracking simulation of gated IPM system
- FY2017
  - Component procurement
  - Construction
    - HV switching module
    - New faraday cage
  - Performance check of the HV switching module
  - Particle tracking simulation of gated IPM system

FY2018
  - Install
    - New faraday cage
    - HV switching module
  - Performance check of the new gated IPM system

At each stage, **the discussion with the team at FNAL** is required to get their expertise on the construction of the gated system, and to **share the new knowledge from the new system of J-PARC**

IPM Data set for simulation works from J-PARC MR

As for the ion&electron collection mode, the data set for IPM simulation were measured.

- **A)3.11E12 ppb**
  - **RF para**
    - **100us, 228ns, delay1010ns, 32/32**
  - **MRPM data: Shot#266392, WCM data:wfm170126_09(and 15)_wcm.tekwfm**
- **B)5.78E12 ppb**
  - **RF para**
    - **300us, 228ns, delay1010ns, 20/32**
  - **MRPM data: Shot#266393, WCM data:wfm170126_10_wcm.tekwfm**
- **C)1.24E13 ppb**
  - **RF para**
    - **300us, 456ns, delay896ns, 20/32**
  - **MRPM data: Shot#266393, WCM data:wfm170126_11_wcm.tekwfm**
- ~~**D) 2.96E13 ppb**~~
  - ~~**RF para**~~
    - ~~**500us, 462ns, delay896ns, 28/32**~~
  - ~~**MRPM data: Shot#266455, WCM data:wfm170126_13_wcm.tekwfm**~~
- **E) 2.52E13 ppb**
  - **RF para**
    - **500us, 462ns, delay896ns, 24/32**
  - **MRPM data: Shot#266458, WCM data:wfm170126_14_wcm.tekwfm**

Wil be ready in June.

Summary

- 3 IPM systems are now operating in J-PARC MR, only one system has magnet system to collect electrons.
- The magnet installed and start operation after 2016 summer long shut-down.
- The current balance tuning between the PS of the main (C type) magnet and the PS of the two correction (H type) magnet was made by checking the CODs from BPMs, and the balance tuning is now reasonably well within the uncertainties of BPM resolution and magnet installation error.
- The electron contamination issues were found in electron collection mode with magnetic field, and these contaminant depends on HV, B, as well as the beam intensity -> Further study will needed to clear the source of the contaminations.
- The beam based MCP gain calibration was made.
- Development of Gated IPM system for J-PARC MR, with helps from FNAL group, was proposed for one of the projects of Japan-US collaboration framework for upgrade of neutrino beams and accepted recently.
- Some sets of data was measure for IPM simulation for both ion and electron collection mode and will be be ready in next month.