PhotonMEADOW 2023

Development of X-ray Ionization Beam Position Monitor for PAL-XFEL Soft X-ray

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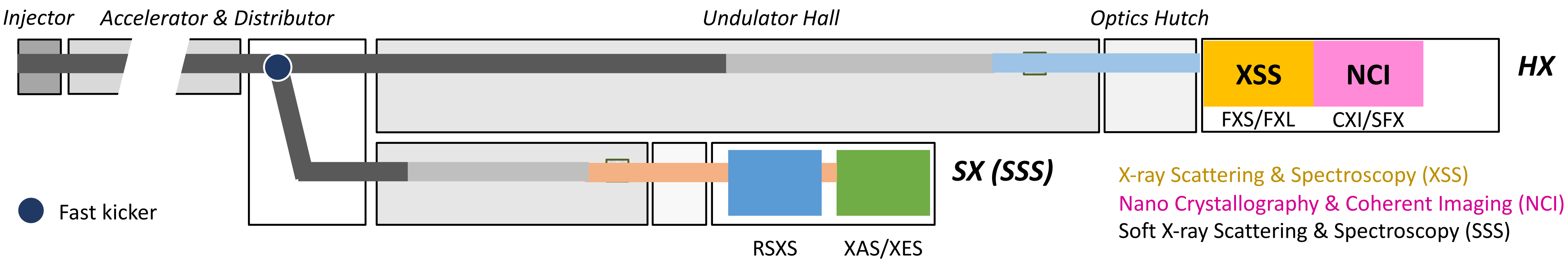
Pohang Accelerator Laboratory

Contents

Introduction of PAL-XFEL

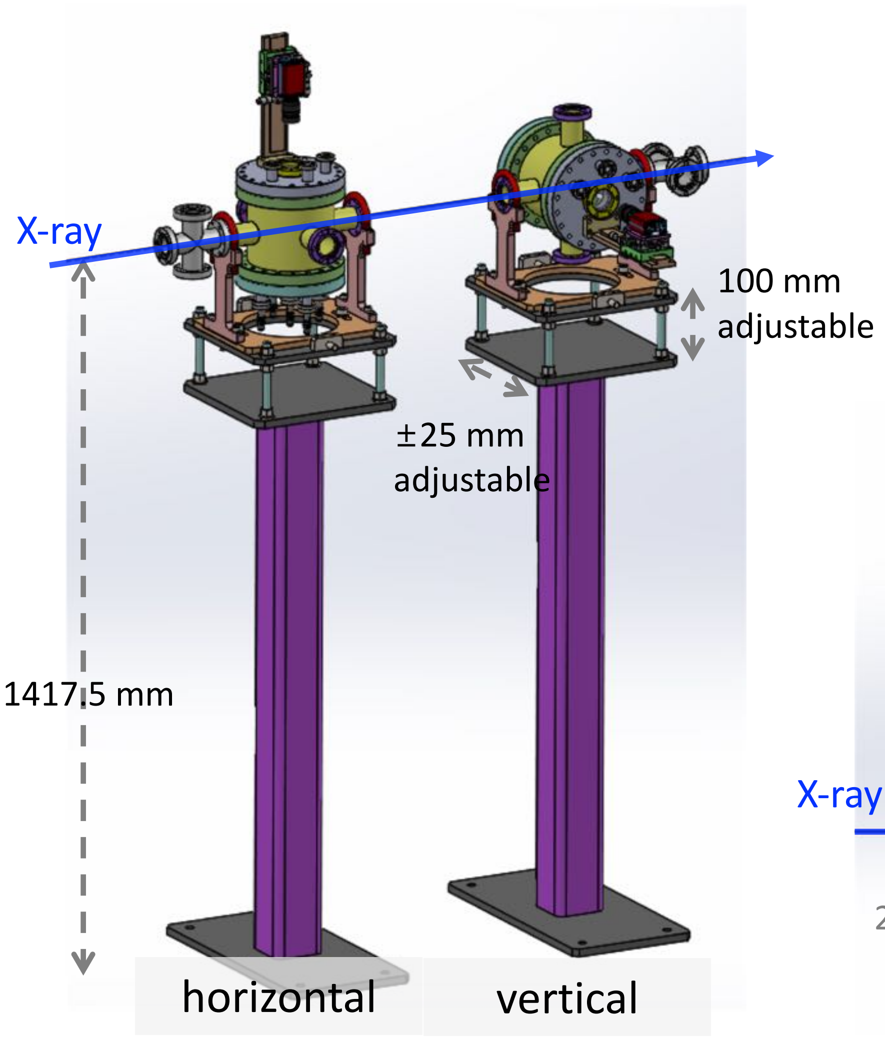


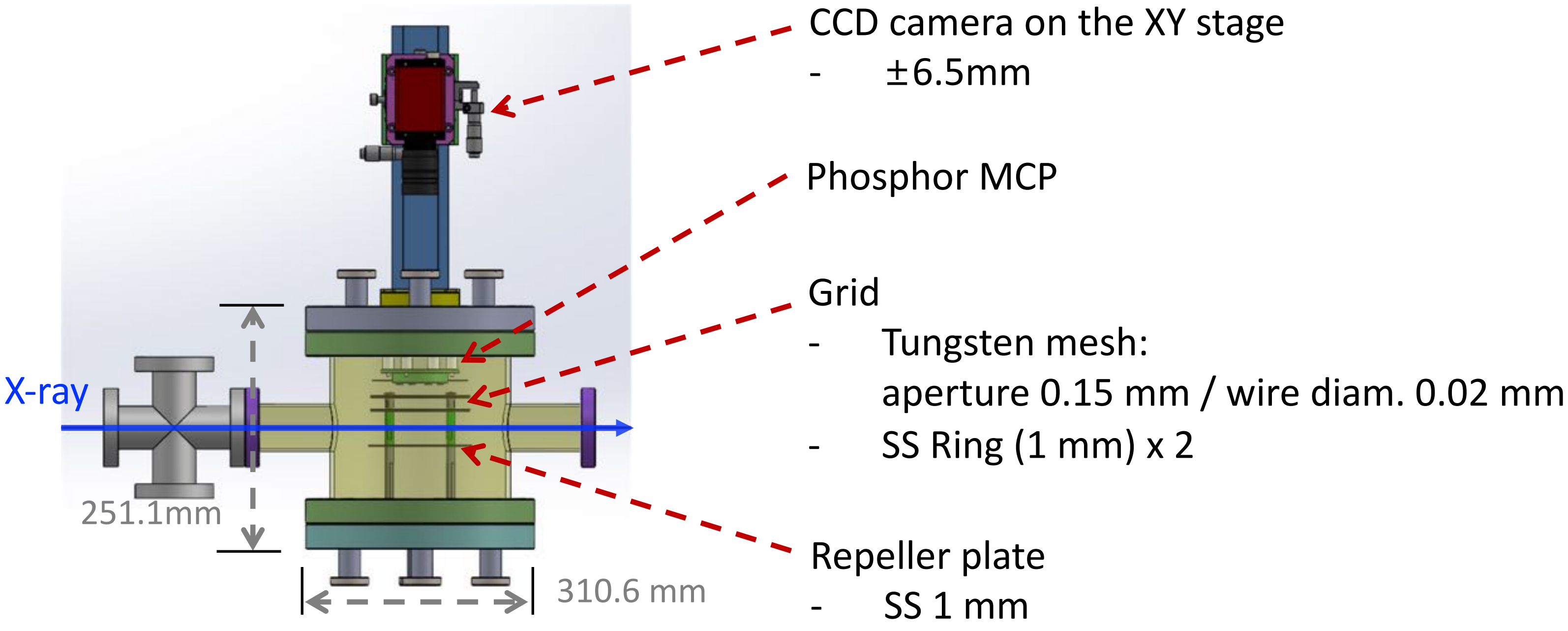
- The Pohang Accelerator Laboratory X-ray Free-Electron Laser (PAL-XFEL) is being operated
  - Provide intense ultrashort X-ray pulses based on the self amplified spontaneous emission (SASE) process
  - X-ray Free-Electron Laser (XFEL) is characterized by strong pulse-to-pulse fluctuations due to the SASE process
  - Online photon diagnostics are very important for the experiments

	Hard X-ray	Soft X-ray
Photon energy	**2.0 ~ 15 keV** (0.6 ~ 0.08 nm)	**250 ~ 1250 eV** (5 ~ 1 nm)
Repetition rate	10 Hz, 30 Hz, 60 Hz	10 Hz, 30 Hz, 60 Hz
Band width of pink beam (ΔE/E)	~ 0.4 %	~ 0.5 %
Photon flux (pink beam)	> 1.0 × 10^{11} phs/pulse	> 1.0 × 10^{12} phs/pulse @ 800eV

X-ray Ionization Beam Position Monitor (XIBPM) : Design

- To monitor the beam position at the soft X-ray beamline of the PAL-XFEL, a prototype **online X-ray ionization beam position monitor (XIBPM)** is developed
  - Uses ionization of either residual gas in the vacuum or added Kr gas
  - Photo-ions move following electric field, and are detected by microchannel plate (MCP) with phosphor screen and CCD camera

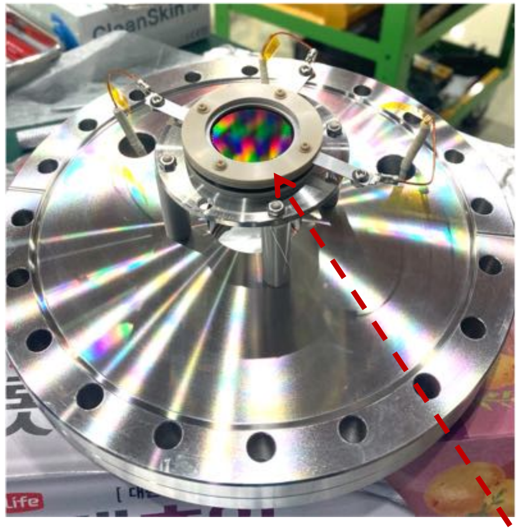


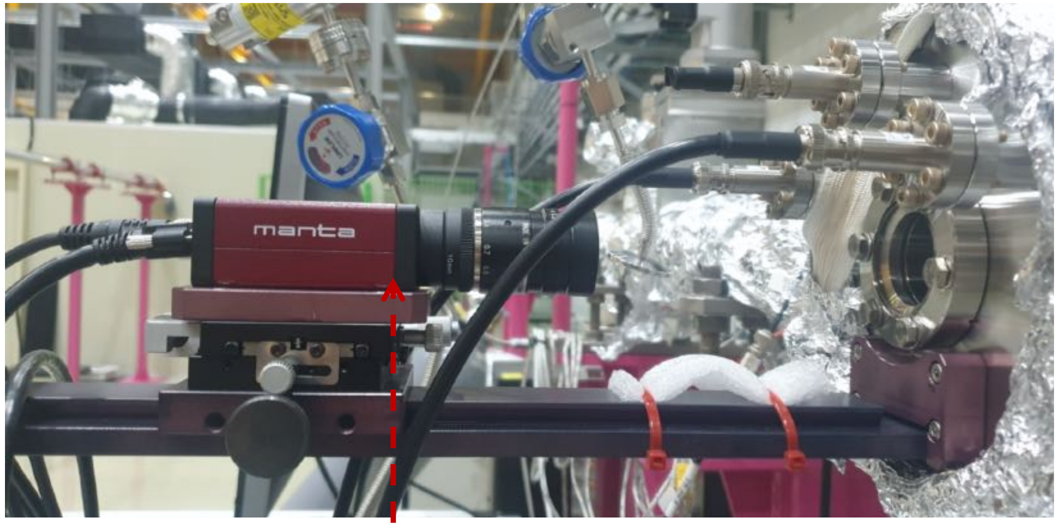


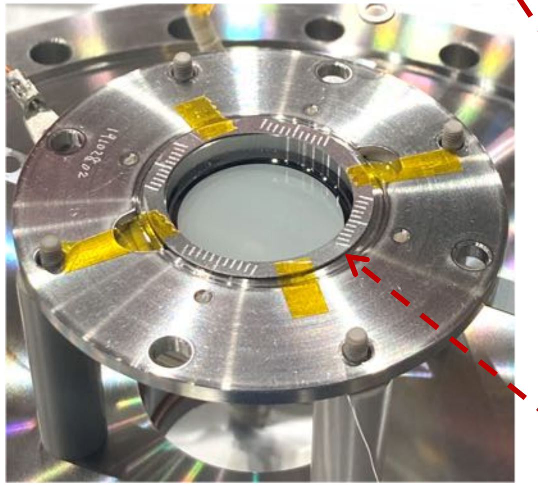
X-ray Ionization Beam Position Monitor (XIBPM) : Manufacture and Assembly

____________________________ Detector side ___________________________

______ E-field creation side ______



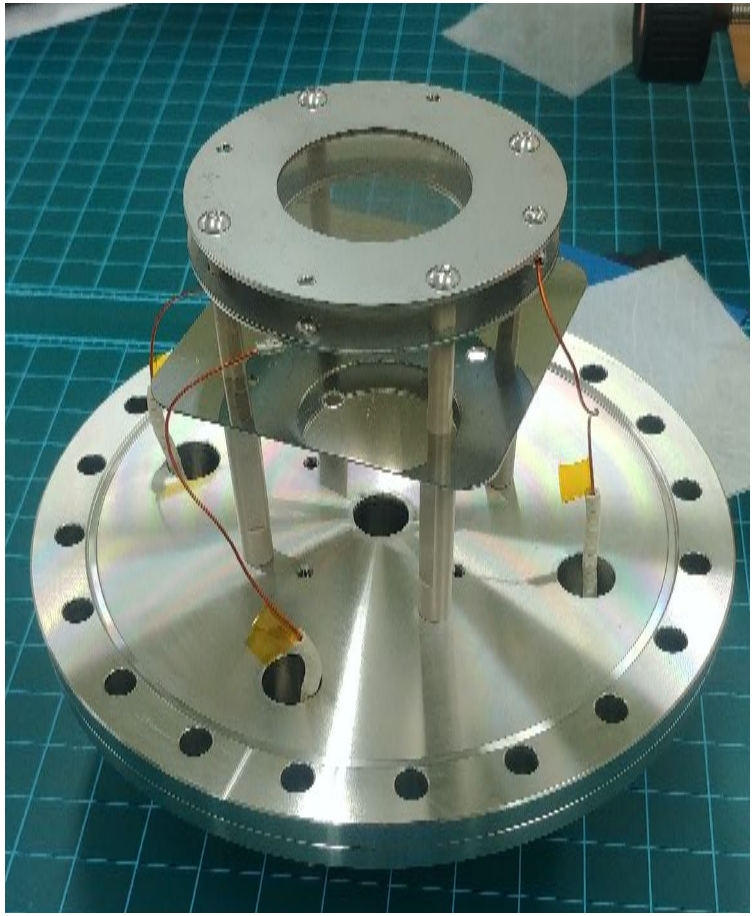




CCD camera with Lenz
(Manta G046)

Phosphor MCP
(F2223-21P including P43 Phosphor screen)

Ruller for calibration

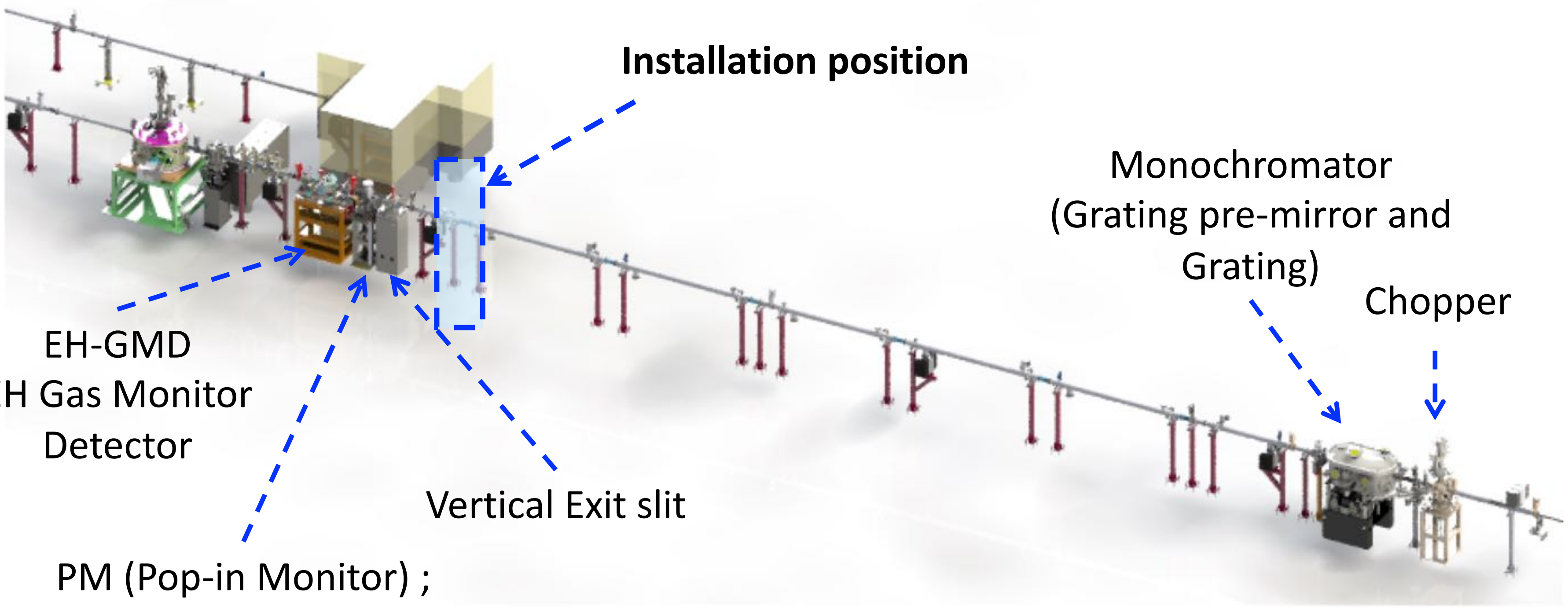


Tungsten mesh pairs and repeller plate
for electric field creation

X-ray Ionization Beam Position Monitor (XIBPM) : Installation

RSXS
(Resonant Soft X-ray Scattering)
end-station

Installation position



Monochromator
(Grating pre-mirror and
Grating)

Chopper

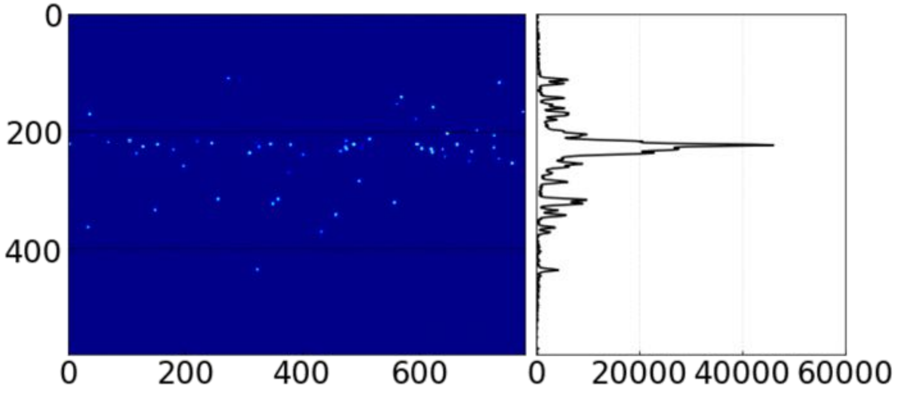
EH-GMD
EH Gas Monitor
Detector

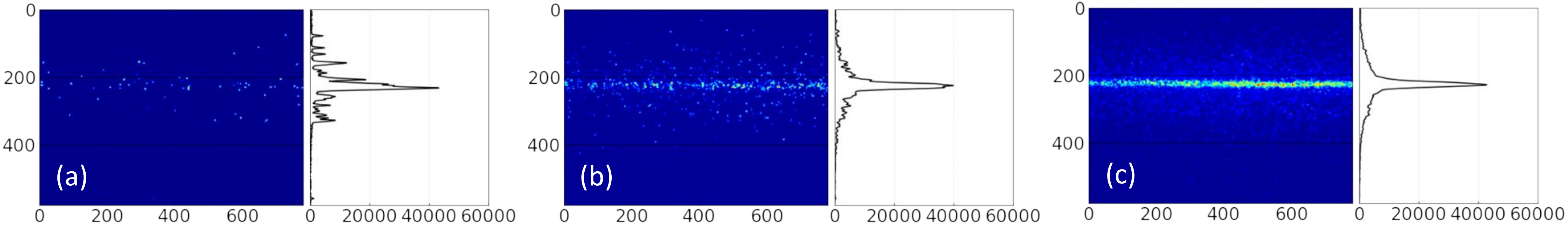
Vertical Exit slit

PM (Pop-in Monitor) ;
YAG screen + CCD camera

Tests at PAL-XFEL Soft X-ray Beamline

- The XIBPM was tested with various conditions as changing beam energy, electric field, MCP gain, and etc.
  - Pink and monochromatic X-ray : 500 eV – 1100 eV
  - Exit slit size in mono-beam mode : 0.2 mm, 1 mm
  - Residual gas mode (10^{-8} Torr) and Kr gas mode (10^{-6} Torr)
  - Grid (Mesh1 & Mesh2) voltage adjusted depending on voltages for MCP gain and Repeller plate

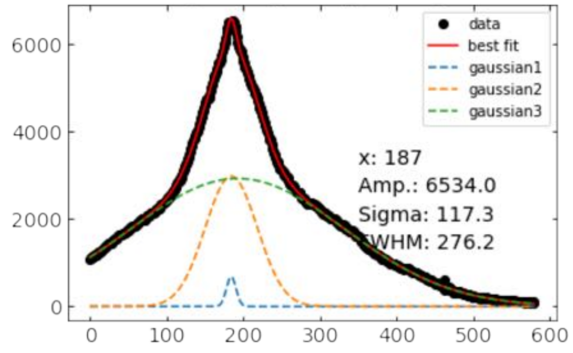




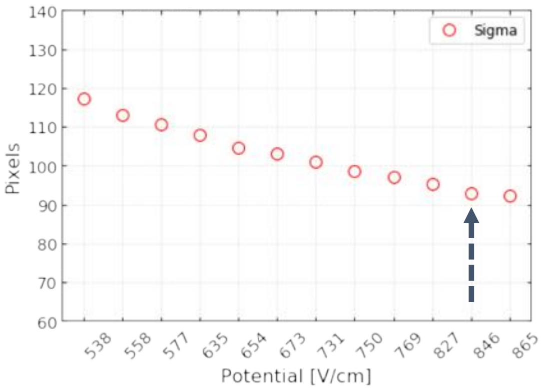
Trajectory of the beam at 500 eV mono-beam w/ 1 mm exit slit, residual gas mode, & E-field 885 V/cm : (a) one pulse, (b) 10 pulses averaged, and (c) 100 pulses averaged

Tests at PAL-XFEL Soft X-ray Beamline : Vacuum Quality Control

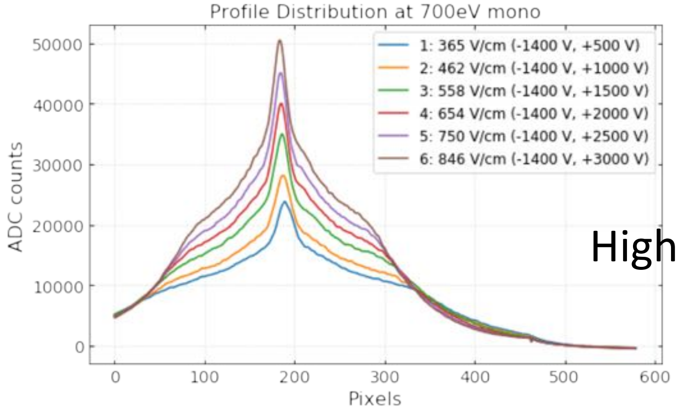
700 eV Mono (residual gas)



Profile fitting results



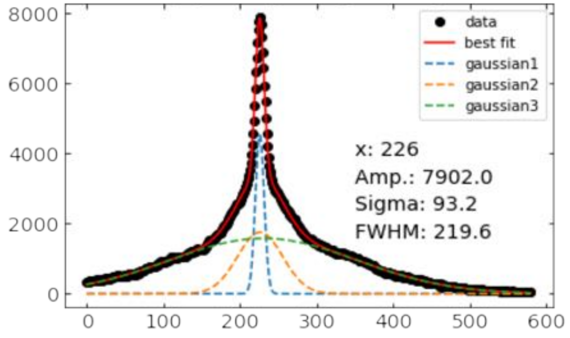
Adding Kr gas



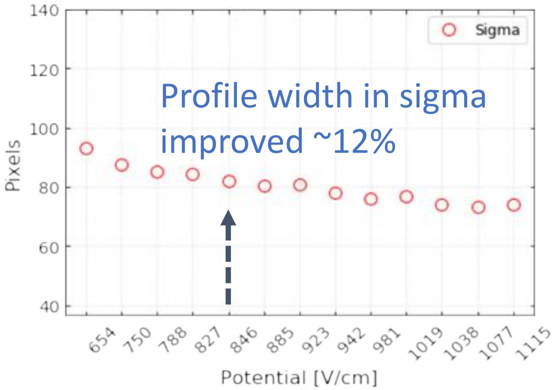
Highest peak at N_2

Bake-out & flushing

700 eV Mono (residual gas)

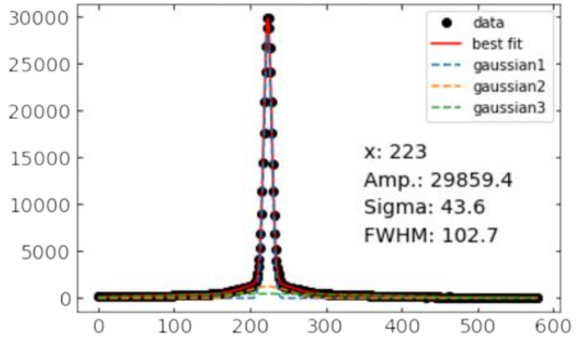


Profile fitting results

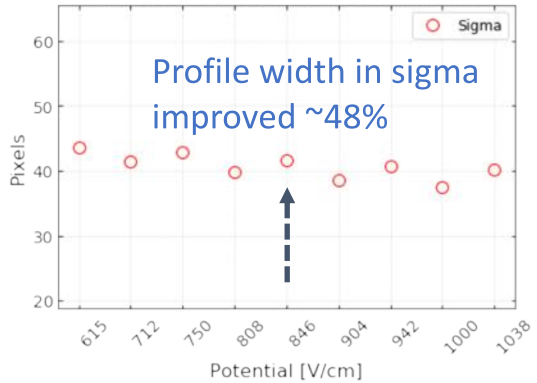


Adding Kr gas

700 eV Mono (adding Kr gas)



Profile fitting results

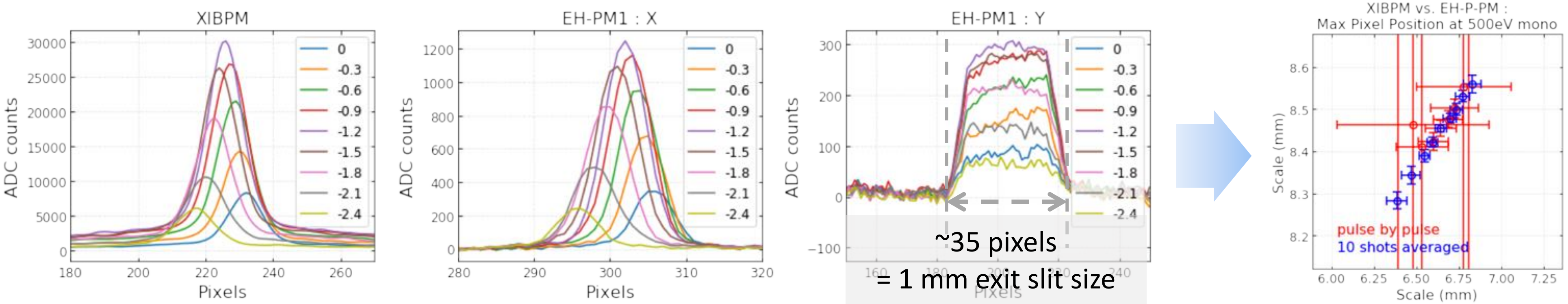


Tests at PAL-XFEL Soft X-ray Beamline : Displacement Comparison

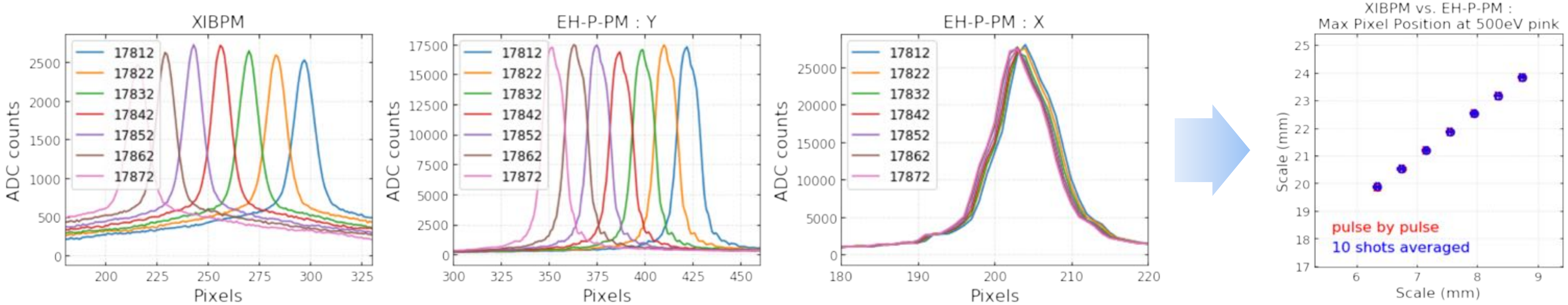
- Beam position change mimic
  - Horizontal : using chopper at mono-beam mode
  - Vertical : using grating pre-mirror at pink-beam mode

− For each step, data for 600 shots saved
− Each profile obtained via averaging 600 shots

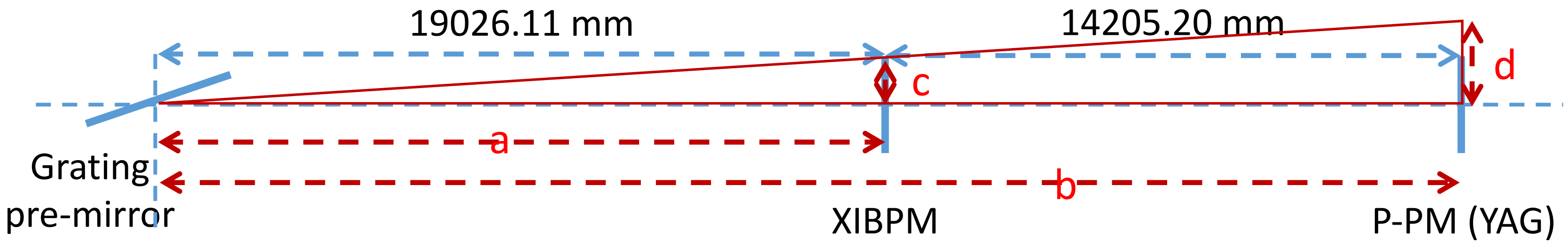
HORIZONTAL
500 eV Mono
Residual gas mode &
885 V/cm
(R +3000 V, G -1600 V)



VERTICAL
500 eV Pink
Residual gas mode &
885 V/cm
(R +3000 V, G -1600 V)



Tests at PAL-XFEL Soft X-ray Beamline : Displacement Comparison

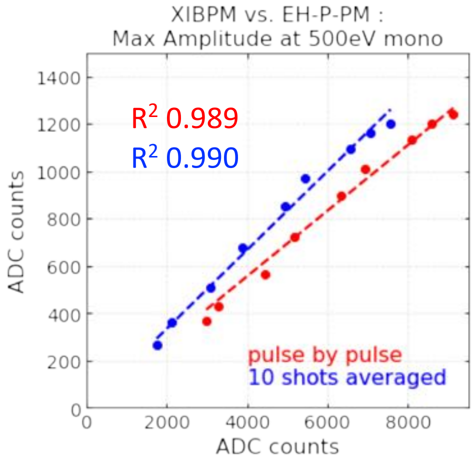


$$\frac{b}{a} = \frac{d}{c} \qquad \frac{b}{a} = 1.75$$

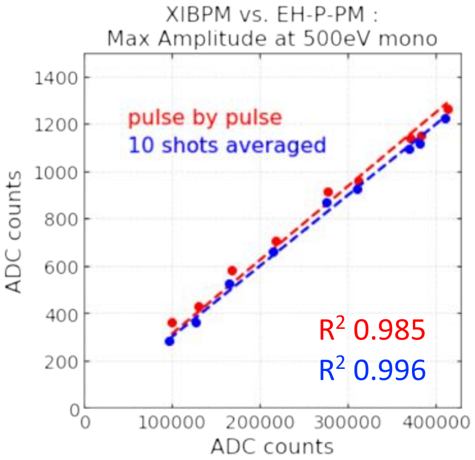
Ratio $\frac{d}{c}$ (relative % error)		864 V/cm (R +3000 V, G -1400 V)	885 V/cm (R +3000 V, G -1600 V)	923 V/cm (R +3000 V, G -1800 V)
500 eV Pink	Shot-to-shot	1.86 (6.29 %)	1.66 (5.14 %)	1.67 (4.57 %)
	Every 60 shots averaged	1.66 (5.14 %)	1.66 (5.14 %)	1.66 (5.14 %)
	All shots averaged	1.64 (6.29 %)	1.66 (5.14 %)	1.66 (5.14 %)
900 eV Pink	Shot-to-shot	3.73 (113 %)	1.63 (6.86 %)	1.67 (4.57 %)
	Every 60 shots averaged	1.65 (5.71 %)	1.66 (5.14 %)	1.65 (5.71 %)
	All shots averaged	1.66 (5.14 %)	1.62 (7.43 %)	1.62 (7.43 %)

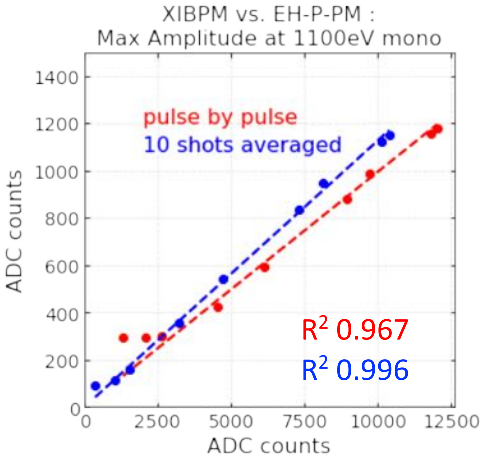
Tests at PAL-XFEL Soft X-ray Beamline : Linearity

Residual gas mode & 846 V/cm
(R +3000 V, G -1400 V)



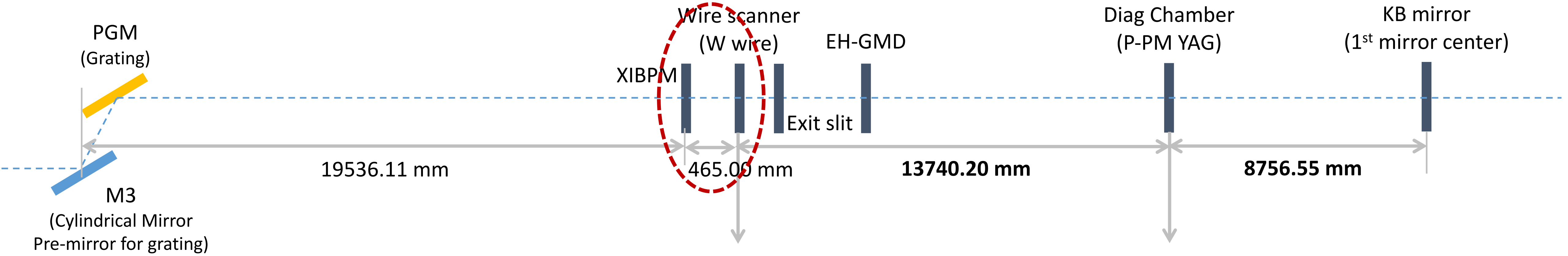
Kr gas mode & 846 V/cm
(R +3000 V, G -1400 V)





- From the chopper scan data, linearity of the XIBPM could be checked
  - The data points are obtained by either averaging maximum amplitude of pulse by pulse or averaging every 10 pulses' profile grouped
    - ✓ They are fitted using linear function ; $y = ax$
  - At 700 eV and 900 eV mono-beams, PM shows saturation feature
  - At 500 eV and 1100 eV mono-beams, XIBPM and PM shows linear correlation

Tests at PAL-XFEL Soft X-ray Beamline : Beam Size Estimation from Profile Width



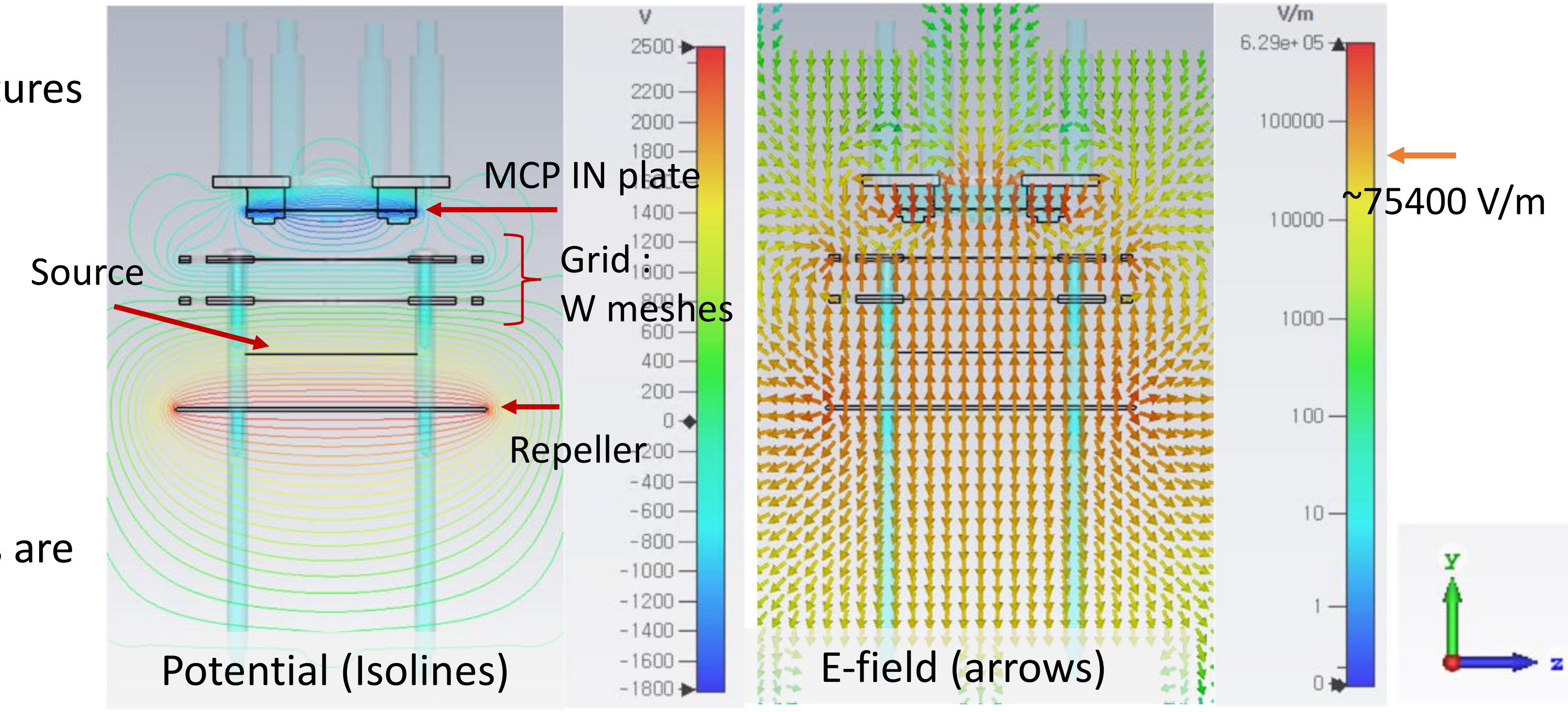
500 eV pink (vertical)	**60.7 ± 5.7 um (FWHM)**	766.8 ± 4.0 um (FWHM)
900 eV pink (vertical)	**46.7 ± 0.8 um (FWHM)**	638.3 ± 3.0 um (FWHM)

- Wire scanner with W wires of 500 um & 200 um diameters is recently installed just before the exit slit
- We could compare width of the Y profile obtained from the XIBPM and beam size measured by knife edge method via wire scanner
- The widths of the XIBPM's Y profile at the residual gas mode are about 7 times and 20 times larger than beam size measurement results for 500 eV pink and 900 eV pink beams, respectively

Simulation Study

- Electrostatic field-map of the XIBPM and multiparticle tracking studies on the obtained filed-map is ongoing **using the CST (Computer Simulation Technology) Studio Suite**
  - To quantitatively analyze and identify error components such as a non-flat mesh electrodes or protruded connectors for the potential setup, in order to improve a measurement precision

- Ideal case
  - No miss-aligned between structures
  - W meshes in Grid so flat
  - No lead for MCP IN plate
  - Almost equipotential
    → R +2500 V, G -1800 V
- Source is assumed to be Kr^{1+} ion in a cylinder of 1 um radius, and Kr^{1+} ions are in rest at the source point

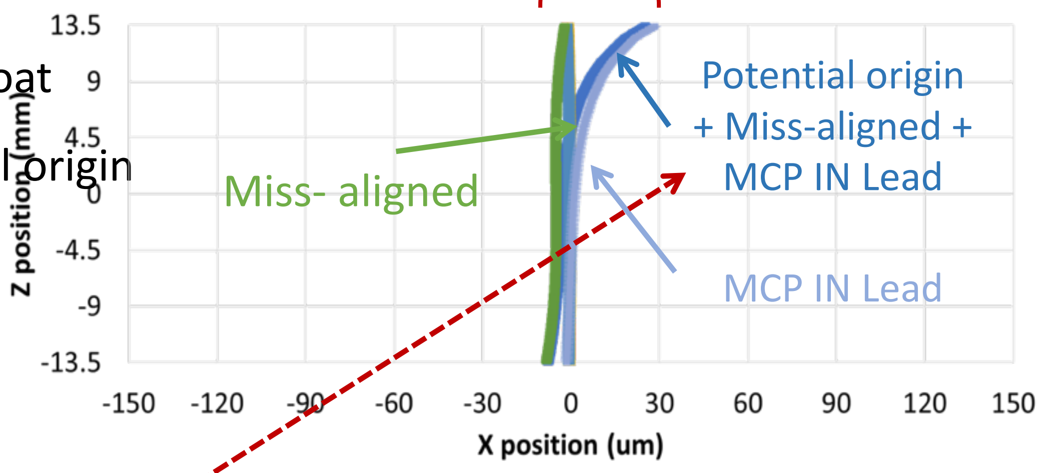


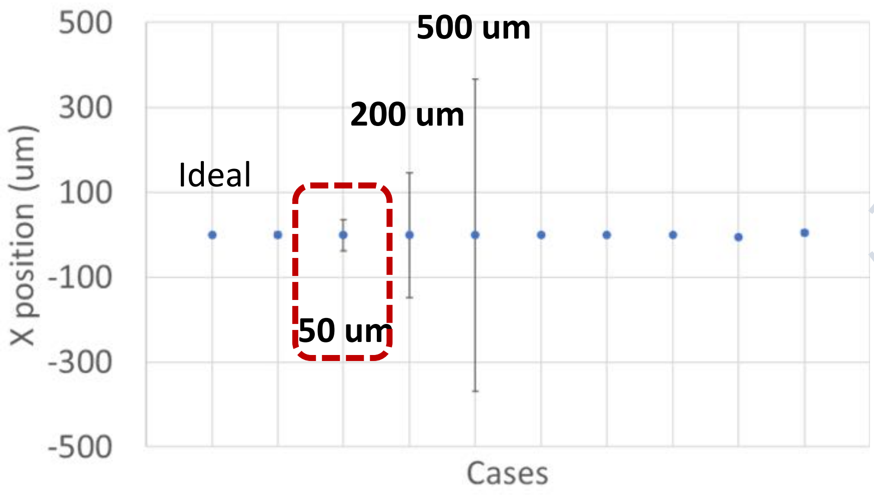
Simulation Study

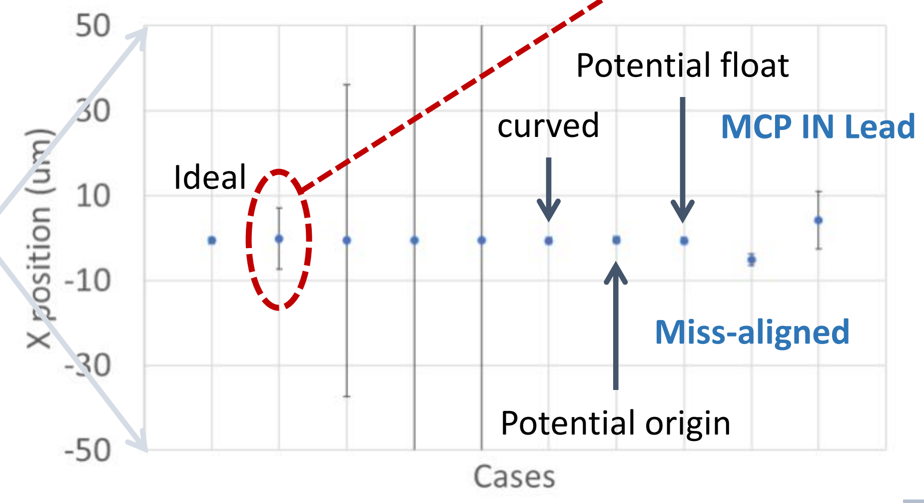
- From the Ideal case
  - Voltages not applied to W meshes of the grid → Potential float
  - Wrong voltages applied to W meshes of the grid → Potential origin
  - **Structure slightly miss-aligned → Miss-aligned**
  - One of the W meshes not flat → Curved
  - **Make a lead for MCP In plate → MCP IN Lead**
  - Source size increased to be **50 um, 200 um, and 500 um**

Beam size: 1 um in radius

Projection → profile





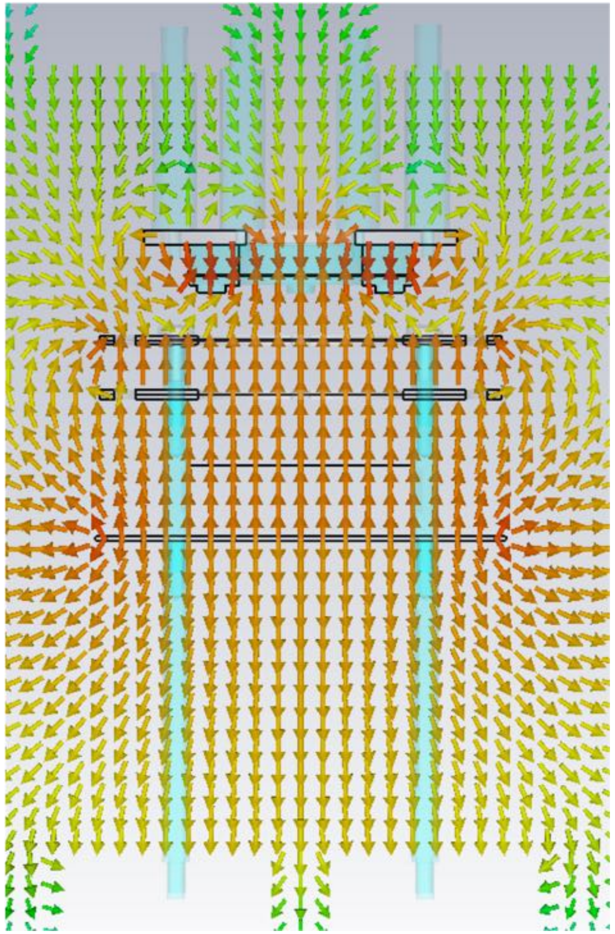


→ about 88 um in FWHM

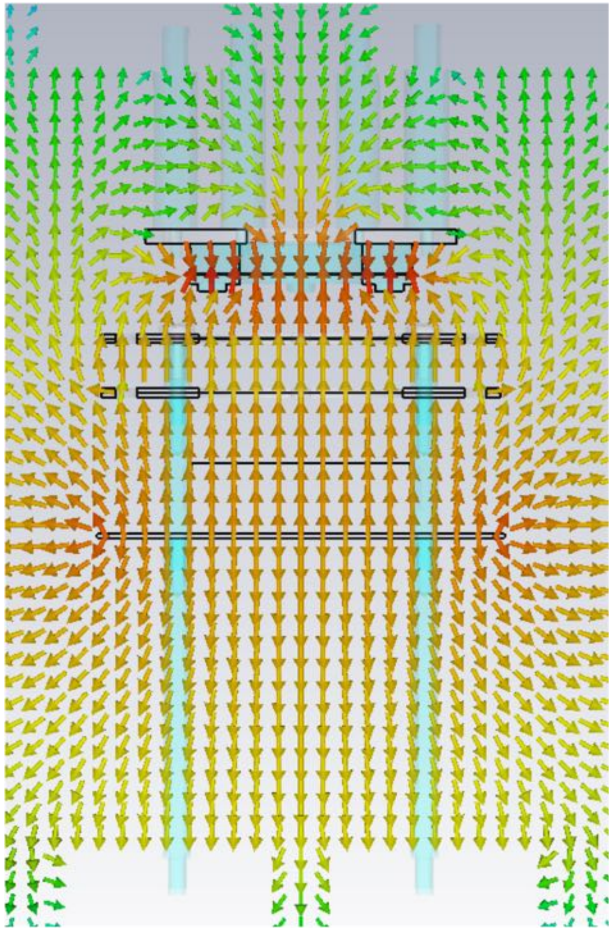
Simulation is ongoing about source variations such as >Kr^{2+} and N^{n+}, and including kinetic energy of the photo-ions

Simulation Study : Electric Field Distributions

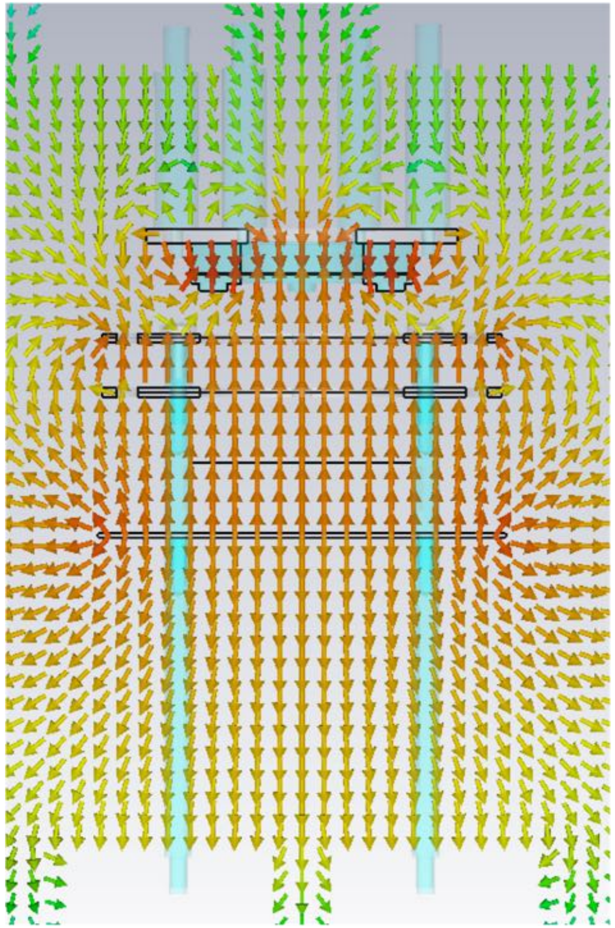
Ideal



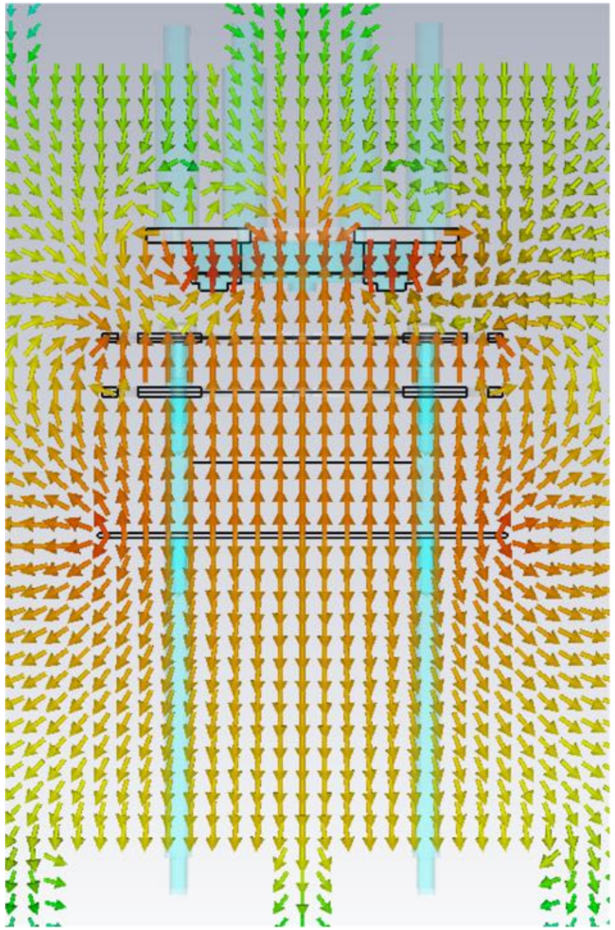
Potential float



Miss-aligned



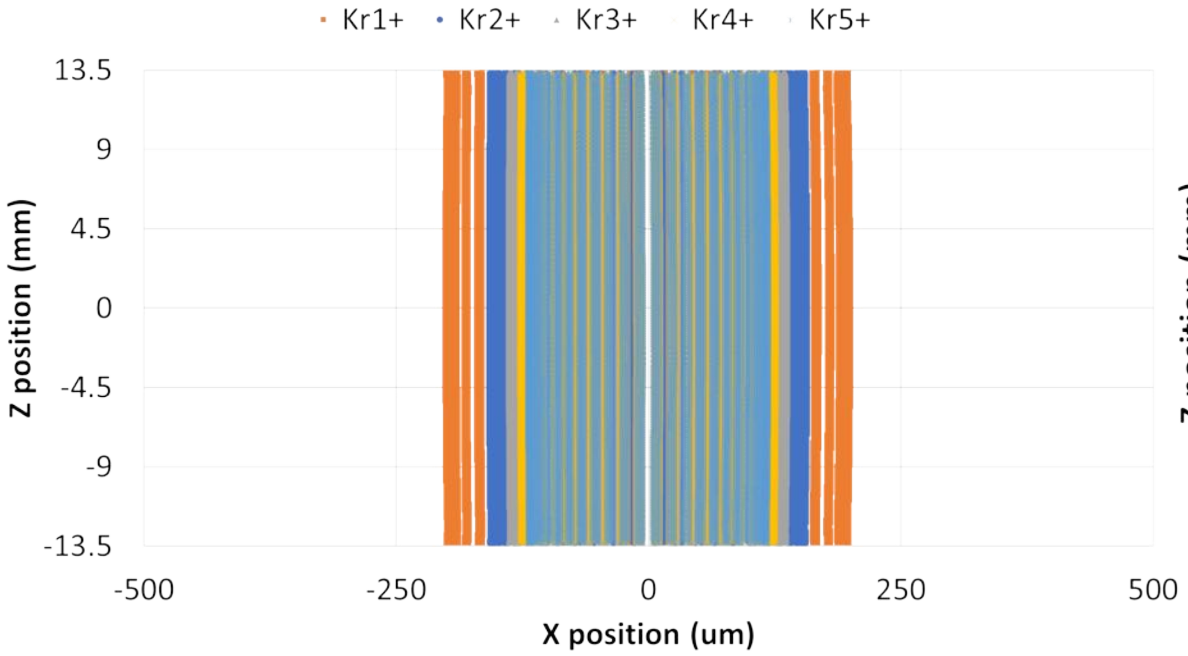
MCP IN Lead



Simulation Study : Example - Source Variations

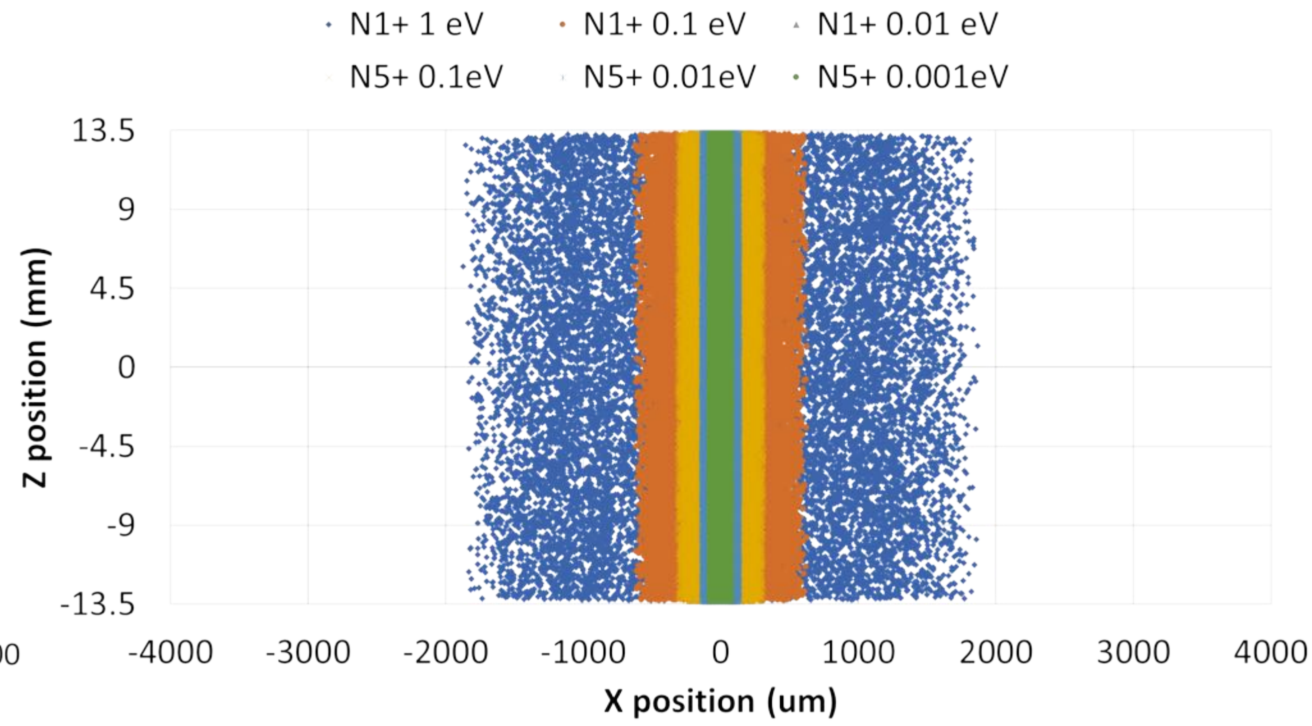
$Kr^{1+ \sim 5+}$

(K.E. 0.01 eV with energy spread 0 %)



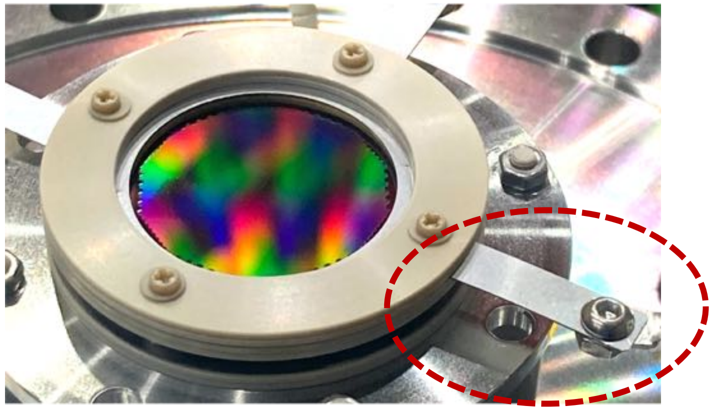
$N^{1+, 5+}$

(with energy spread 100 %)



Summary and Plan

- The XIBPM using ionization of residual gas or added Kr and the MCP with phosphor screen developed
- The XIBPM was tested using soft X-ray FEL beams
  - Trajectory of the beam was detected apparently
  - The change of the beam center position was also measured
- The particle tracking study was done to figure out field error sources
  - MCP In plate’s lead is most significant systematic error component



- The simulation with various source condition will be followed
- And also, additional test of the XIBPM at PAL-XFEL soft X-ray beamline is scheduled in next week
- The length of the lead will be made shorten to improve the performance

Acknowledgements

Diagnostic group at PAL-XFEL:

Seonghan Kim (Mechanical engineer)

Sunmin Hwang (Electronic engineer)

Seungcheol Lee (Post-doctor)

SSS beamline – RSXS endstation :

Hoyoung Jang (PhD. Beamline staff)

Thank you for your attention!