Visible Diagnostic Beamline and Photon Beam Profile Monitor at PLS-II Storage Ring

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- **PLS-II BL1B Diagnostic Beamline**
  Interferometer Streak camera Online bunch length monitor

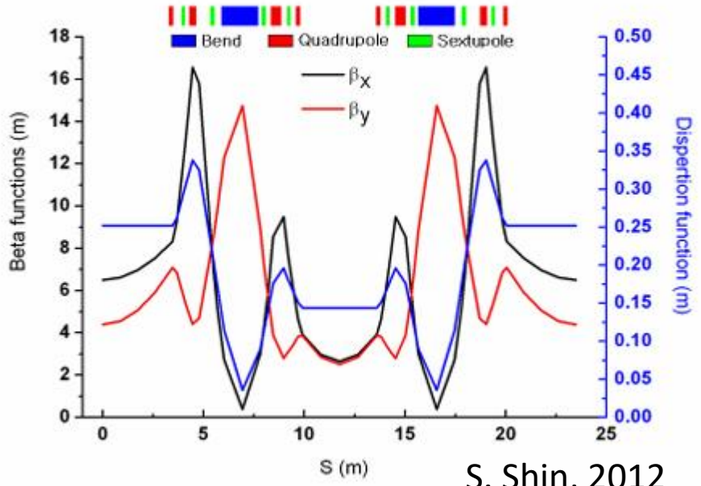
- **White Beam Profile Monitor**
- **Cherenkov Diffraction Radiation based Beam Profile Monitor**

Apr. 8, 2026

Pohang Light Source-II

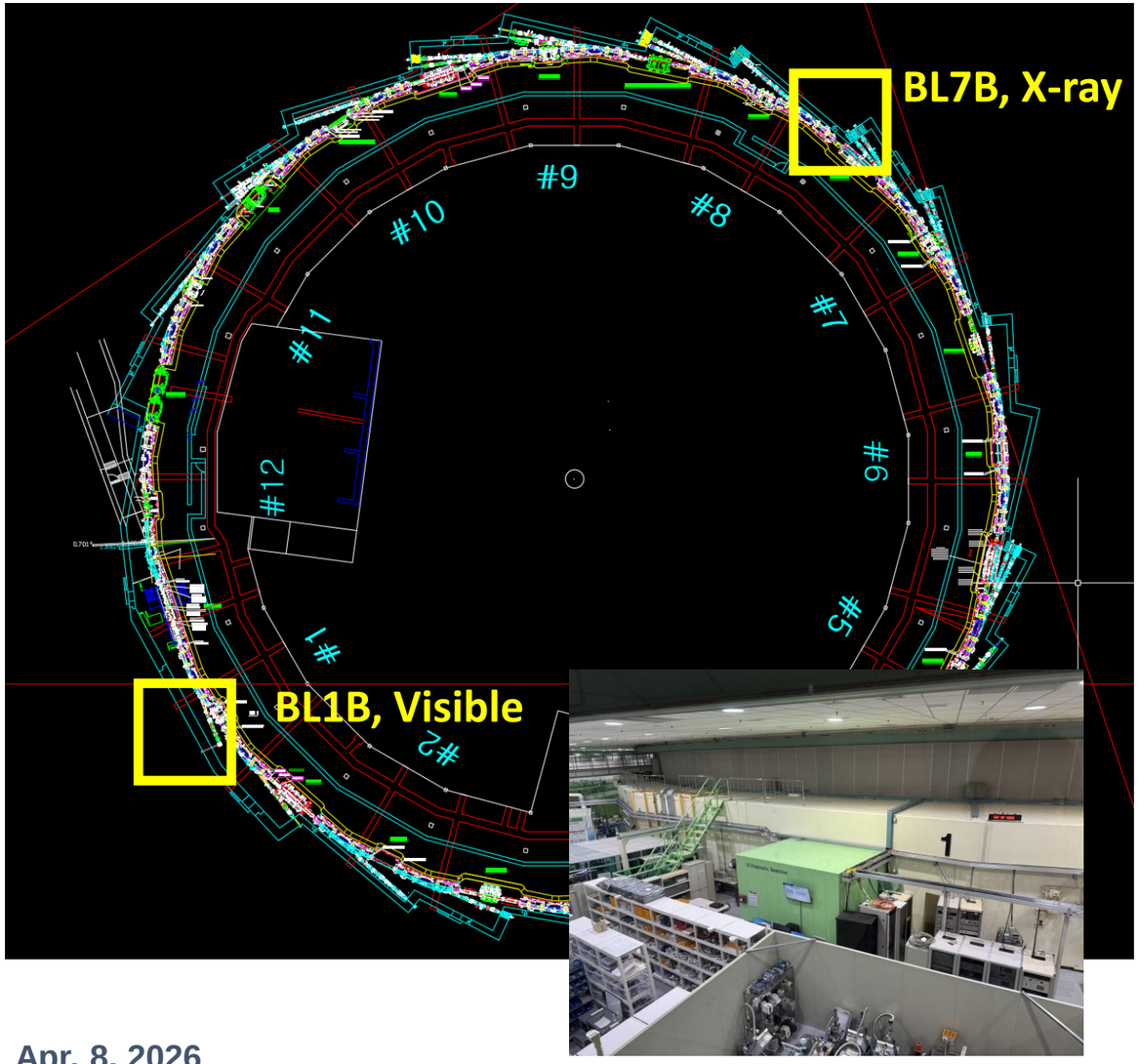
PLS-II Parameter	Value	Unit
Beam Energy	3	GeV
Beam Current	400	mA
Lattice Structure	DBA	
Emittance	5.8	nmrad
Circumference	281.82	m
RF Frequency	499.97	MHz
RMS Bunch Length	21.3	ps

- Pohang Light Source-II (PLS-II) is a third-generation synchrotron that stores electrons accelerated up to 3 GeV by a full-energy linac.
- The storage ring consists of 12 cells and adopts a DBA (Double-Bend Achromat) lattice.
- A total of 35 beamlines are in operation, using two insertion devices and two bending magnets as radiation sources.



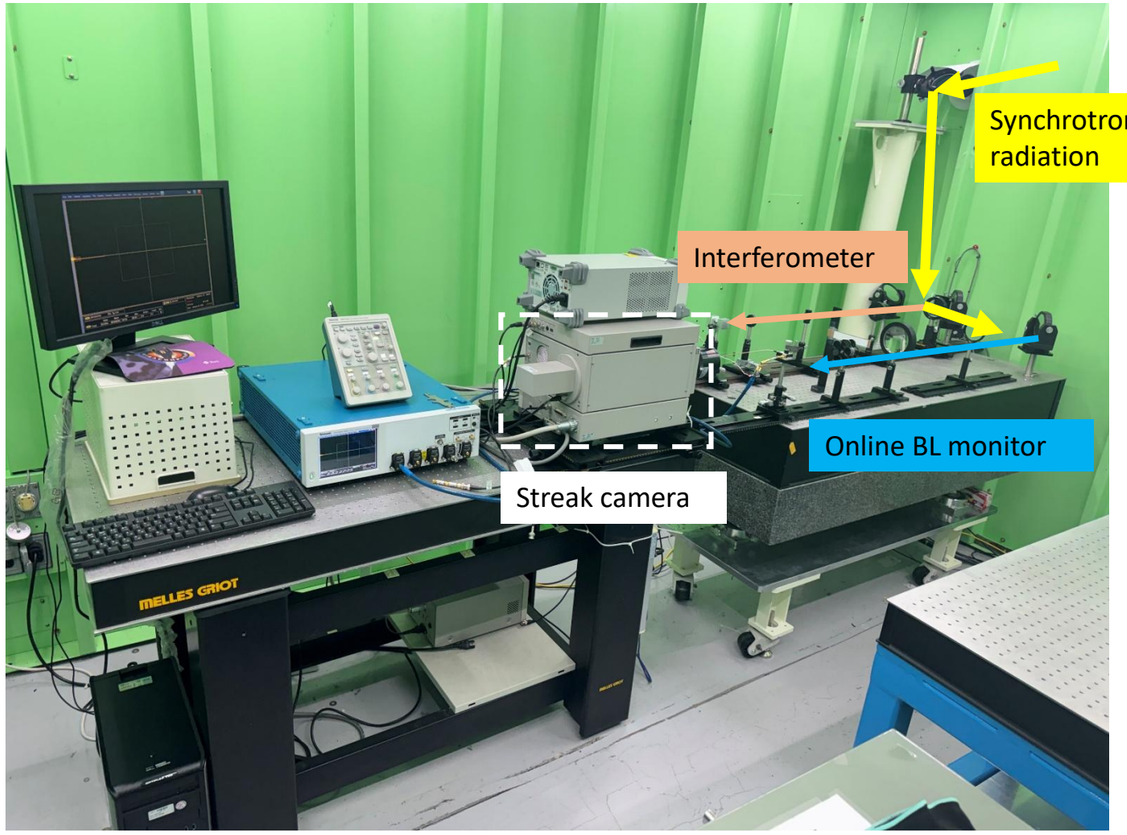
S. Shin, 2012

Diagnostic Beamline at PLS-II



- There are two diagnostic beamlines in the storage ring.
- Both beamlines use the first bending magnet of each cell as the radiation source.
- BL1B transports only visible light to the hutch using an optical system that includes an in-vacuum mirror.
- BL7B is configured similarly to a standard beamline, consisting of a Front End (FE) and a Photon Beam Transfer Line (PTL).
  - A pinhole camera is installed at the end of the PTL.

Visible Diagnostic Beamline



1. Interferometer (Beam Size Monitor)

   - Provides continuous vertical and horizontal beam size information using interference fringe patterns.

2. Streak Camera

   - Measures longitudinal beam information with high temporal resolution (~1 ps).

3. Online Bunch Length Monitor

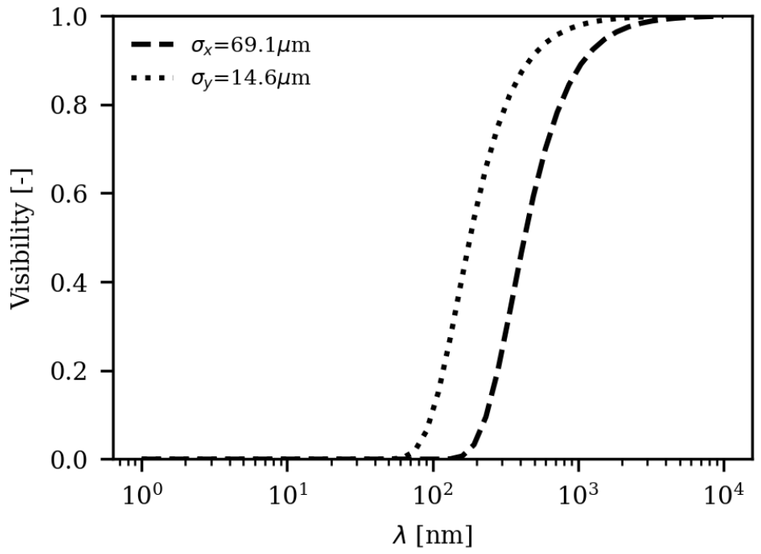
   - Measures bunch length, fill pattern, and bunch phase using a wide-bandwidth photodiode and a digitizer.

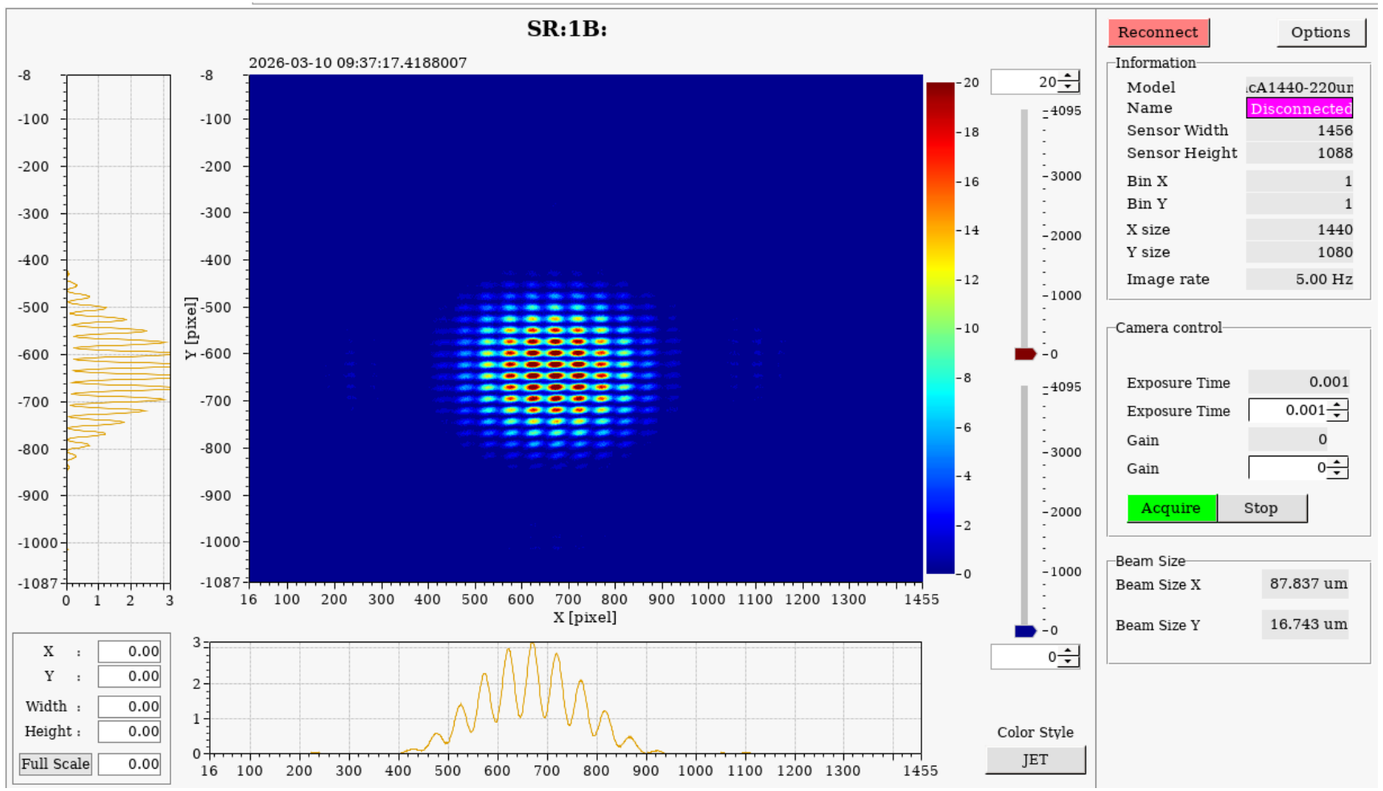
   - Enables turn-by-turn and bunch-by-bunch measurements, and is planned for continuous operation as a replacement for the streak camera.

   - Development was completed in 2023, and it is currently under testing to ensure stable service.

Fast Interferometer

- In the PLS-II storage ring, the electron beam size is measured using an interferometer.
- To measure the horizontal and vertical beam sizes simultaneously, a four-aperture slit is used.
- A wavelength of around 550 nm is used to suppress noise-induced errors and secure sufficient photon flux.
  - The expected visibility is 0.66 in the horizontal direction and 0.93 in the vertical direction.

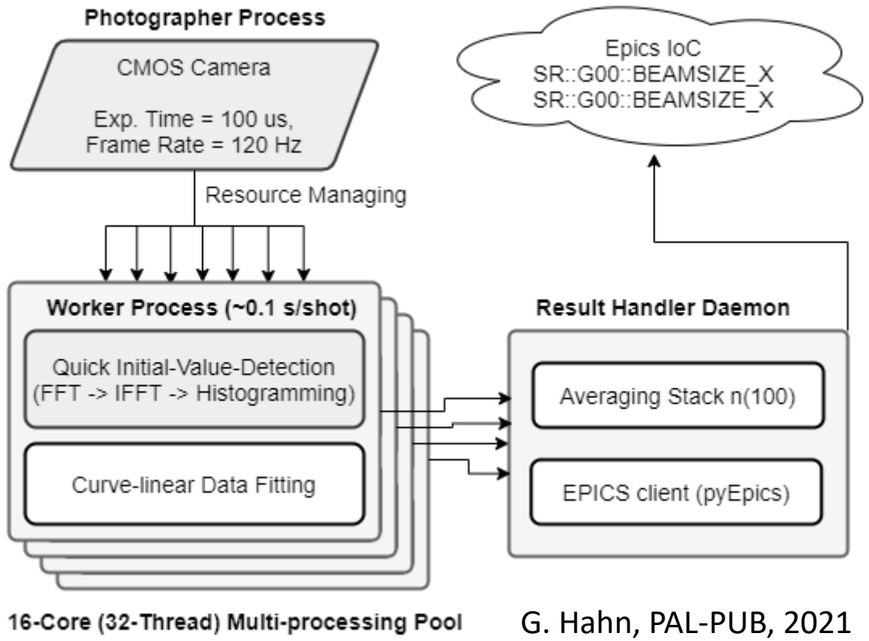




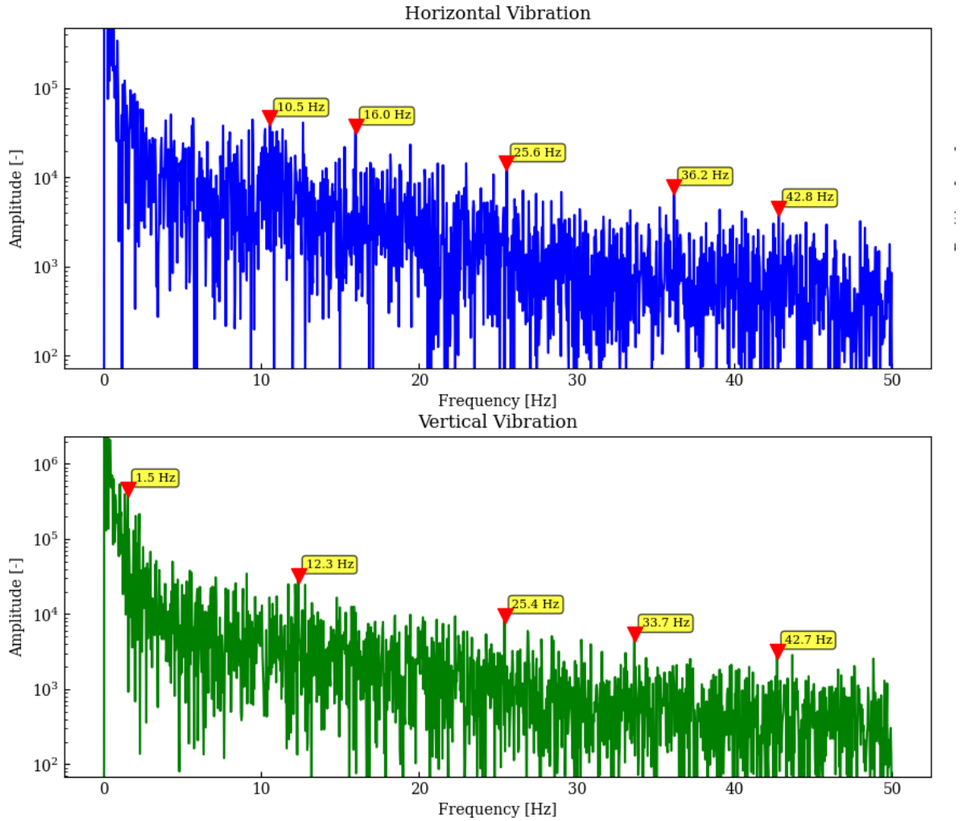
G. Hahn, PAL-PUB, 2021

Fast Interferometer

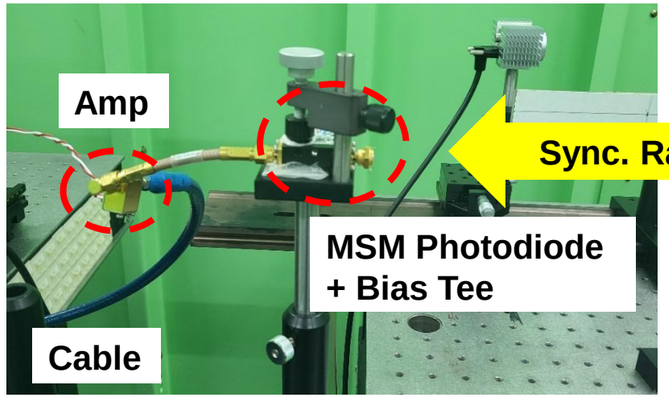
- The PLS-II interferometer was designed to operate at a high frame rate of up to 120 Hz.
- On the control and data-analysis PC, a multi-core CPU is used to process images at 120 Hz, and the results are written to the PV of the EPICS IOC.
- From the oscillation of the interference pattern center, mechanical vibrations up to ~60 Hz were observed.

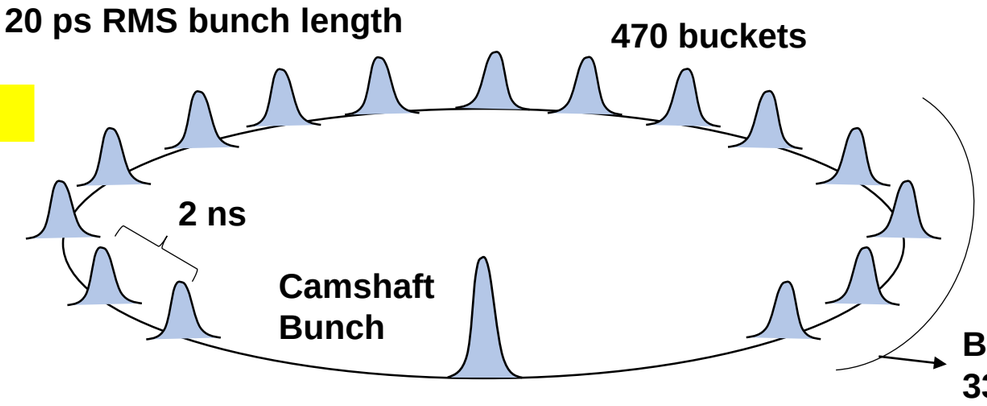


G. Hahn, PAL-PUB, 2021



Online bunch length monitor

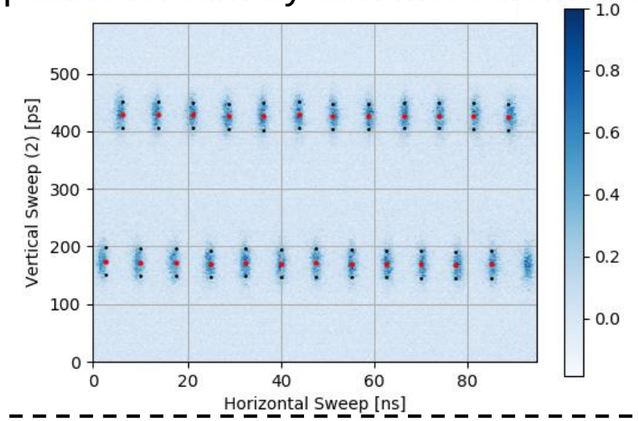




Bunch Length

Streak Camera

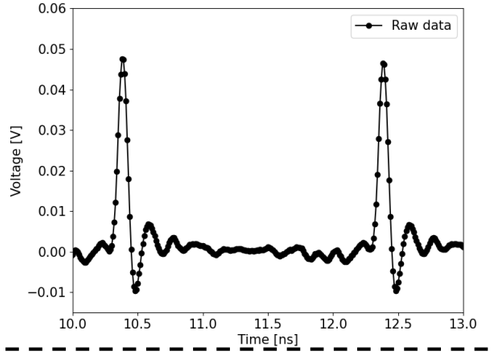
- High temporal resolution (< RMS 1 ps)
- Slow acquisition rate
- Incompatible for turn-by-turn measurements



Bunch Length + Fill-Pattern

Fast Photodiode

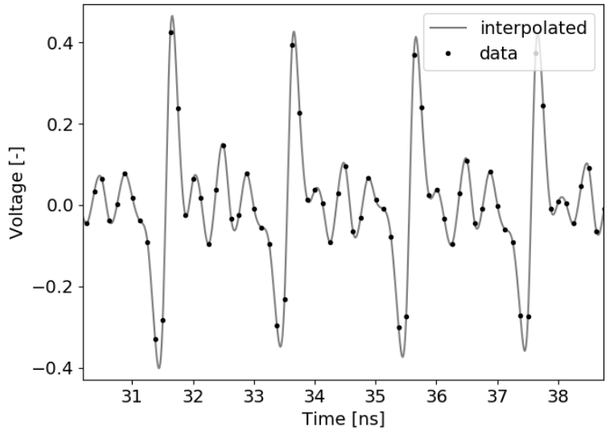
- Intermediate resolution (~2 ps)
- Bunch length and fill-pattern real-time measurement



Fill-Pattern

BPM pick-up / FCT

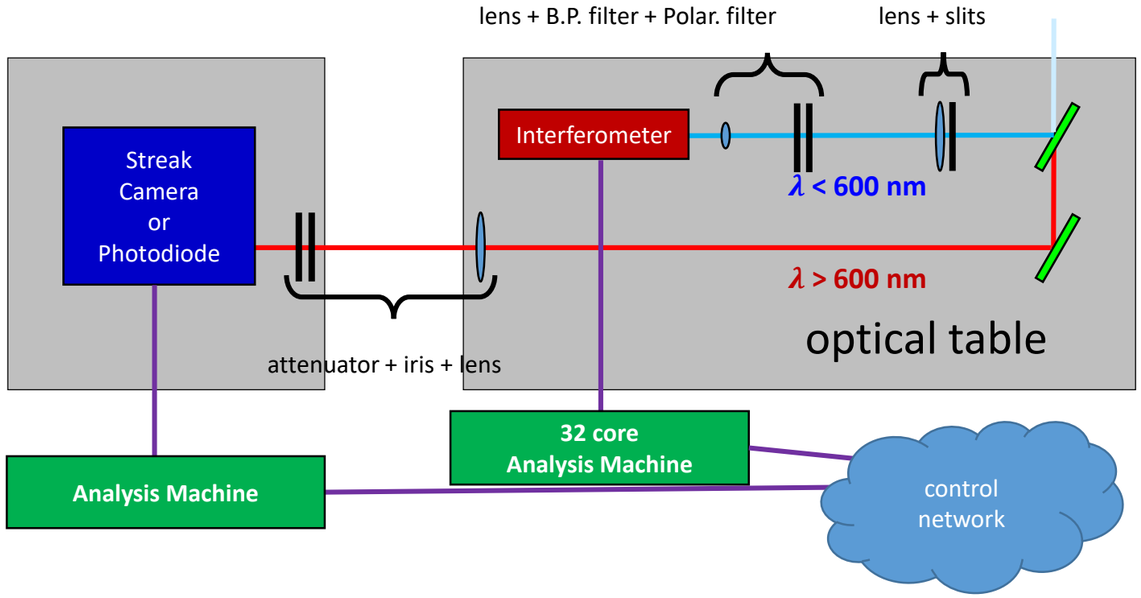
- Limited bandwidth, Moderate accuracy
- Non-linear behavior causes an intolerable error

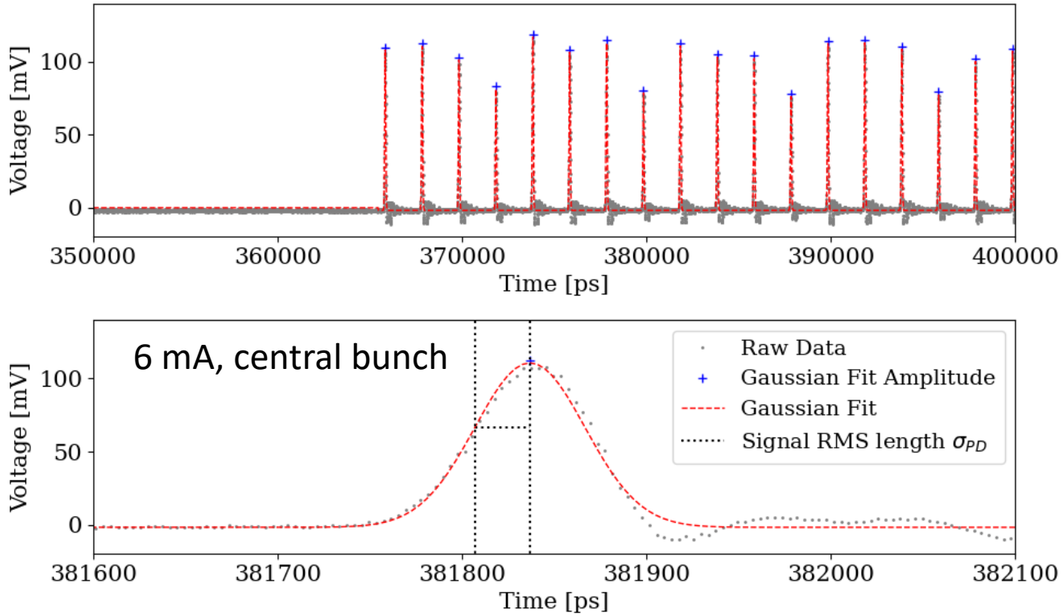


G. Hahn and W Song, IEEE-TIM, 2023

Online bunch length monitor

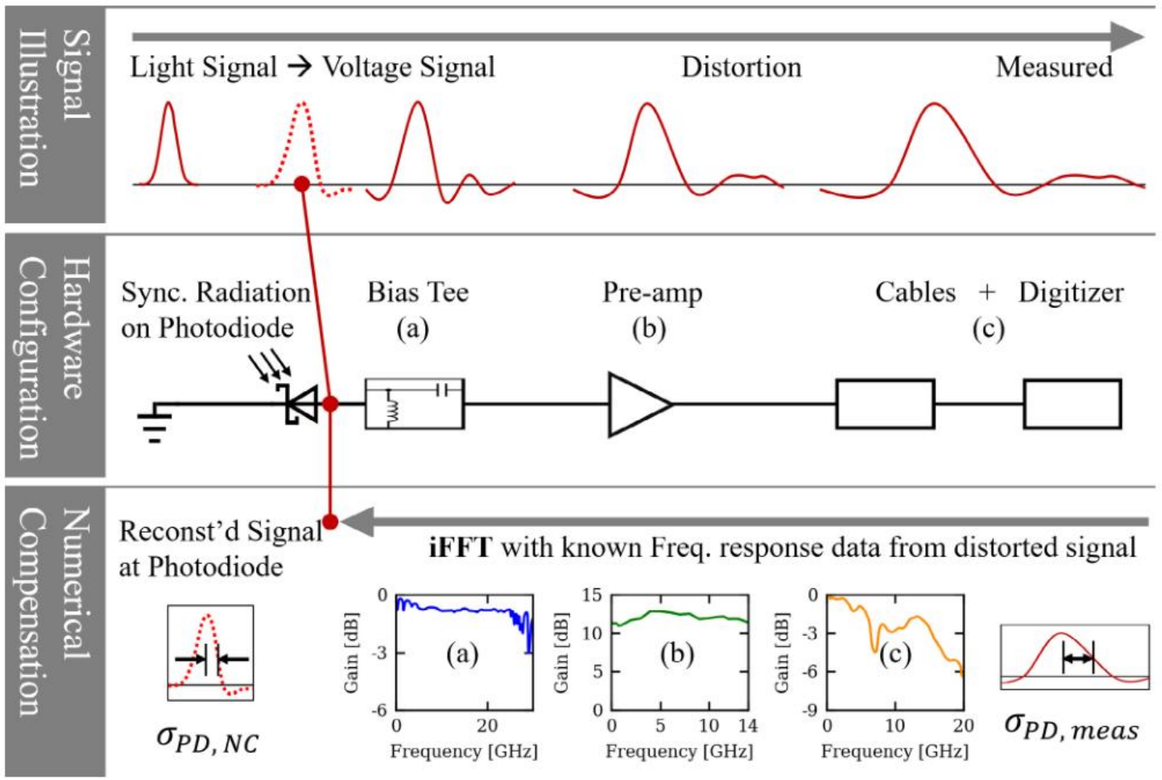
Visible Light Beam Diagnostic Hutch (BL1B)

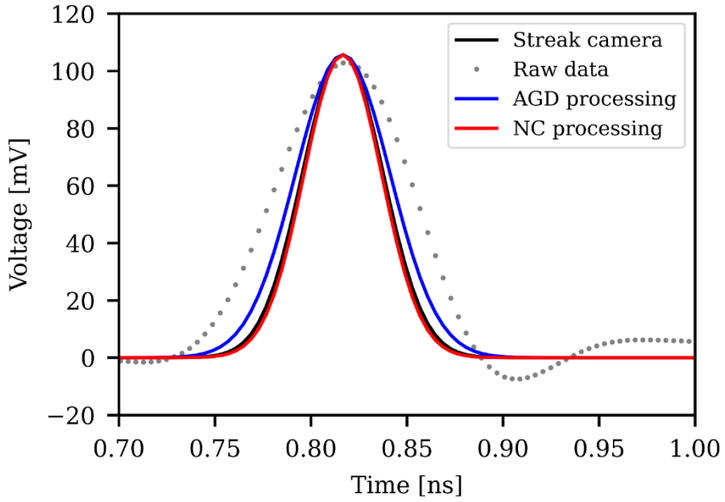


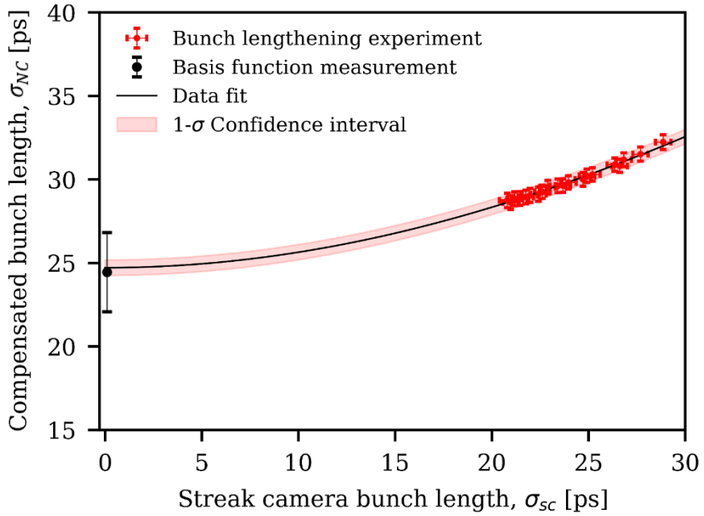


- **To maximize gain and efficiency, dichroic mirror was used.**
  - Higher than 600 nm for photodiode, lower for interferometer.
- **Simultaneous measurement of transverse beam size and longitudinal information.**
  - Monitoring the fill pattern, phase, and single bunch length of the entire 940 ns bunch train.

Online bunch length monitor



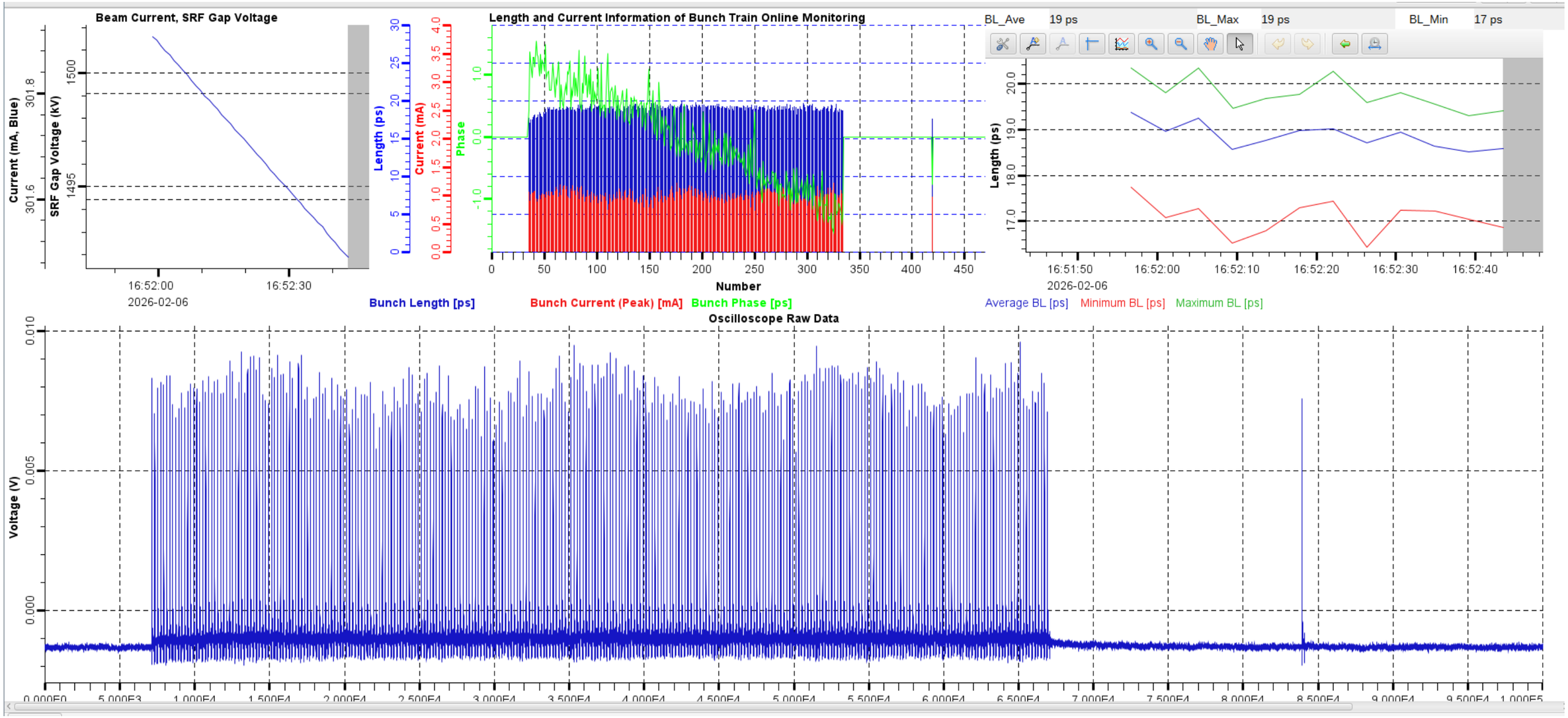




- Experimentally demonstrated a compact monitor that enables filling pattern and bunch length monitoring at the PLS-II.
- A numerical compensation method to restore the original signal was shown.

→ Achieved better resolution (bunch length ~ 1.2 ps, current ~ 9 μA) than the conventional method.

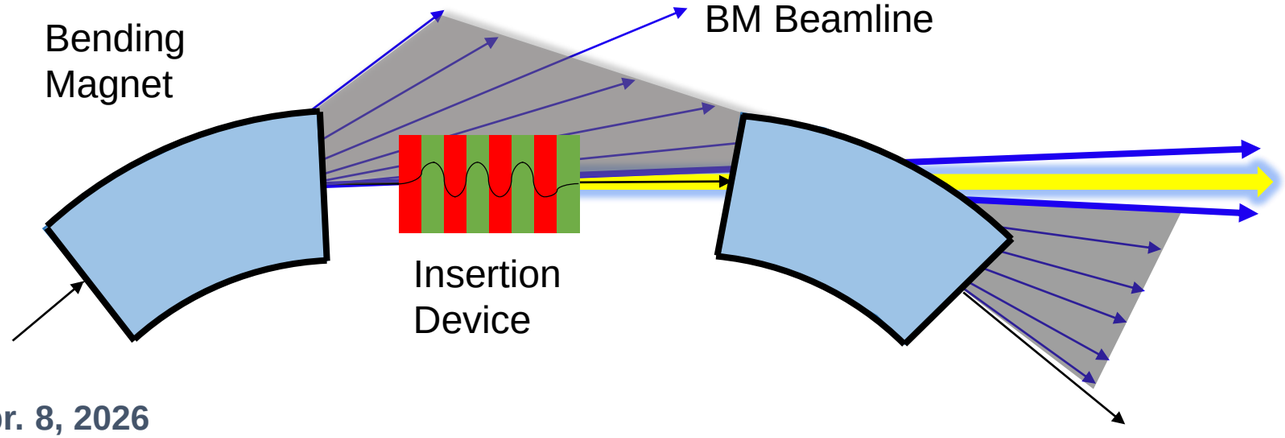
Online Bunch Length Monitor



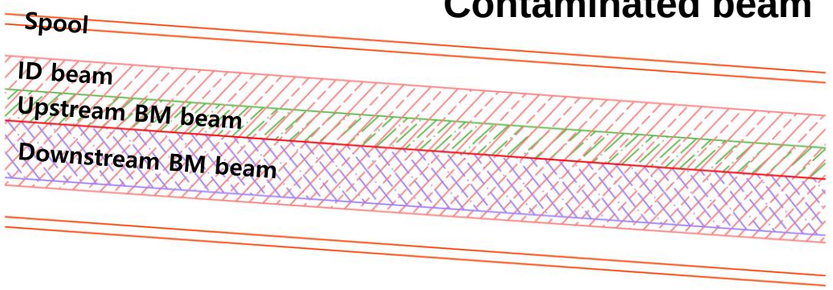
White Beam Profile Monitor

- **Photon beam profile measurement** is required to identify the on-axis radiation in the white beam and to align optical components in IVU beamlines.
- Photon beam contamination
  - Contamination from the bending magnet can cause measurement errors in blade-type PBPM.
- Higher photon power density
  - Conventional diagnostic for profiles measure through direct interaction, making it difficult to withstand the high heat load.

→ It is necessary to measure the profile of the photon beam in a non-invasive way.



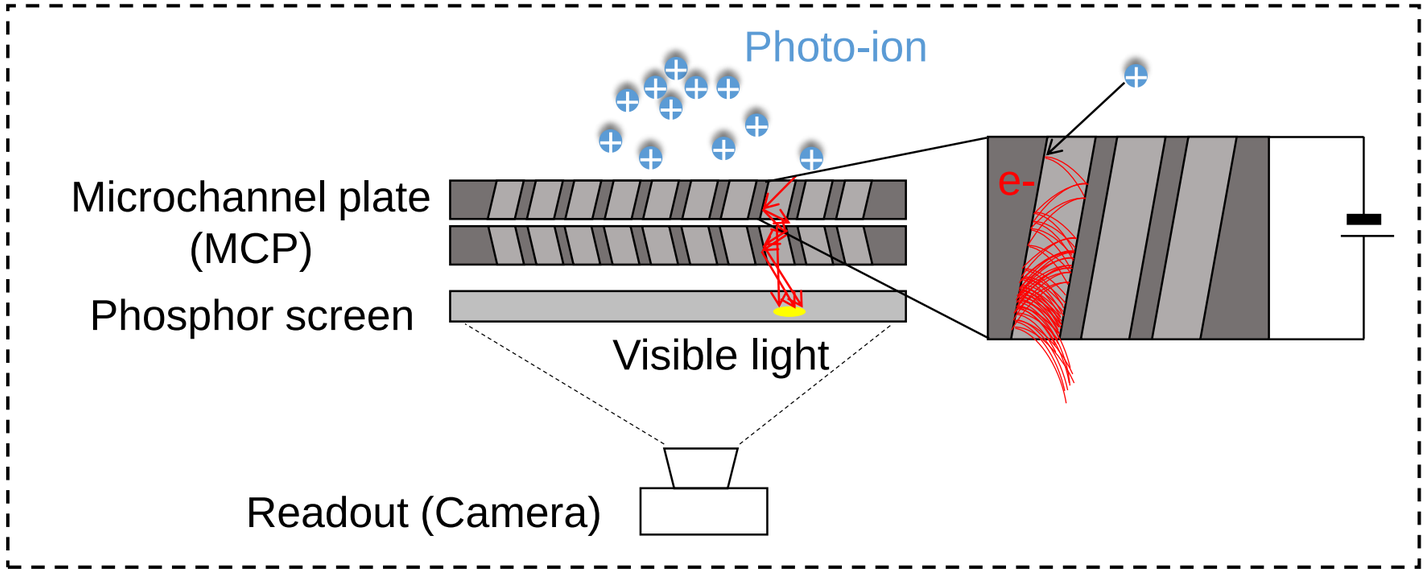
Contaminated beam

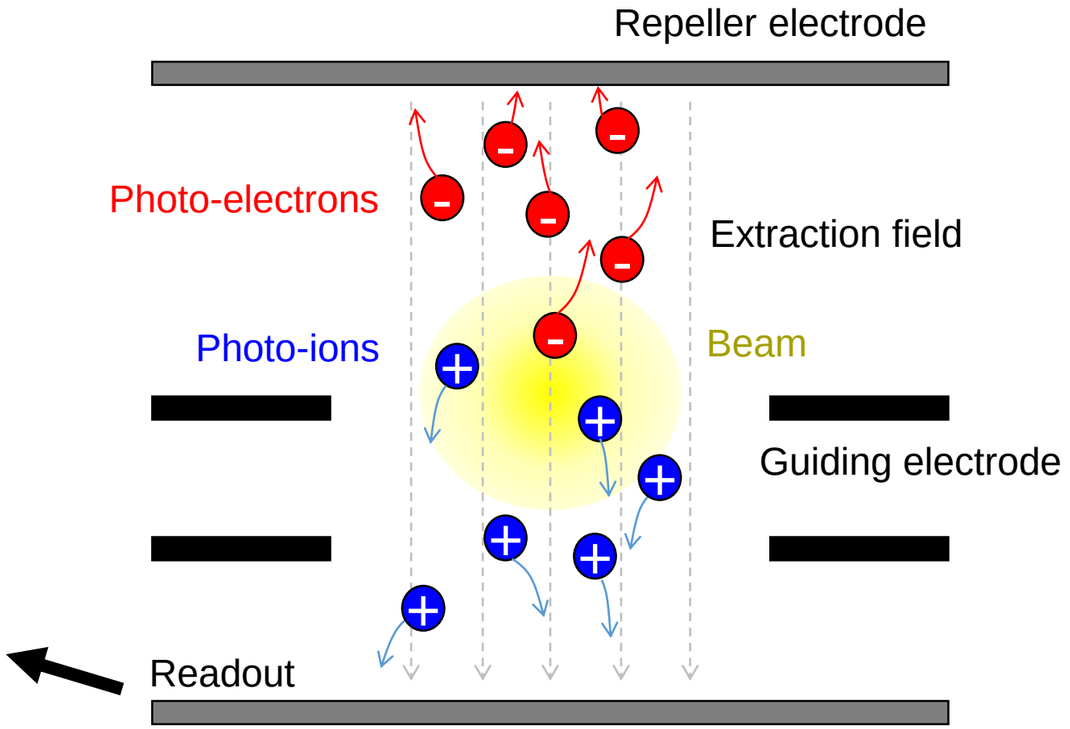


ID Beam Power	Total Power	Power Density
PLS-II IVU20	2.95 kW	22.9 kW/mrad^2
Korea-4GSR IVU24	17.94 kW	165.5 kW/mrad^2

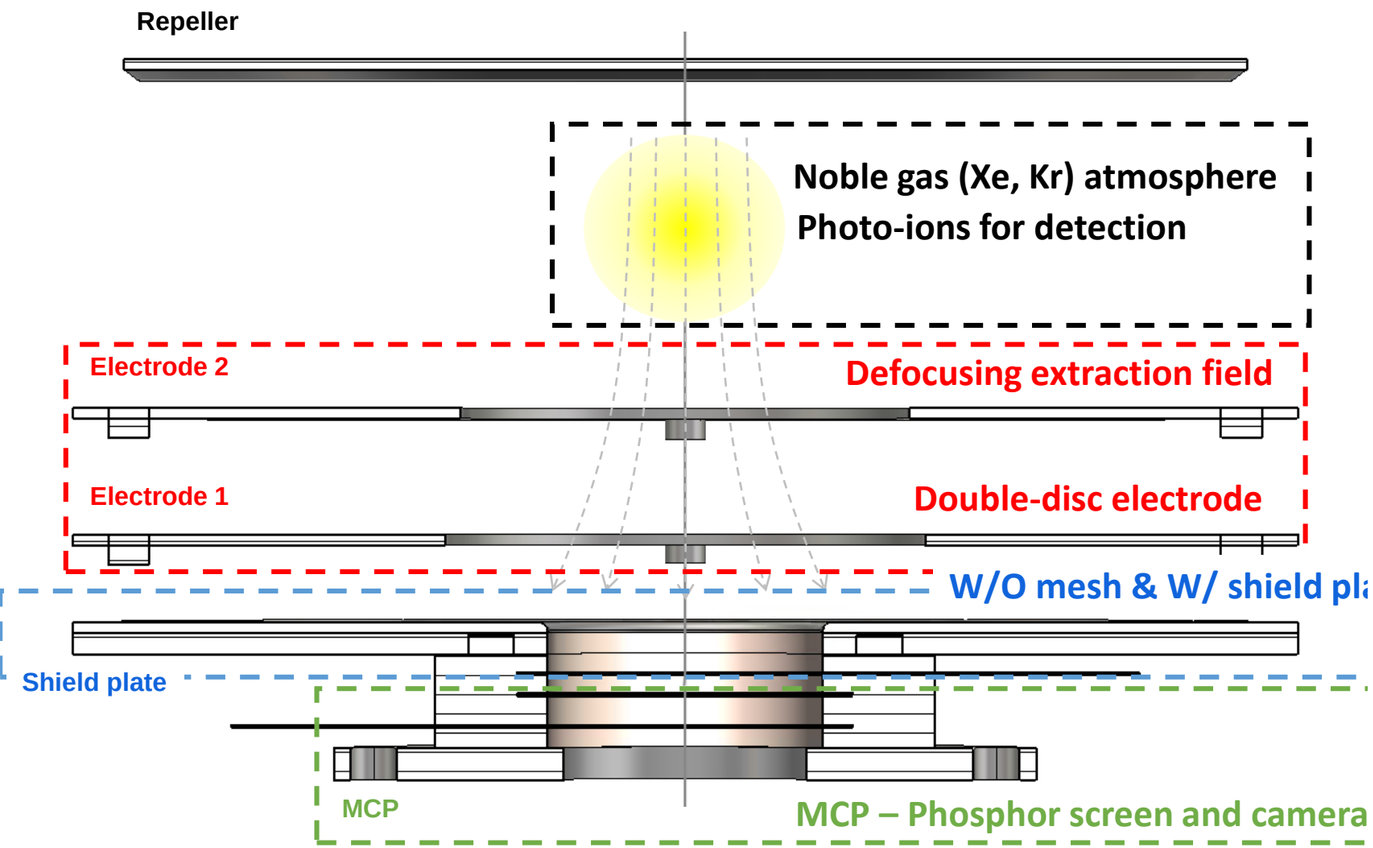
White Beam Profile Monitor

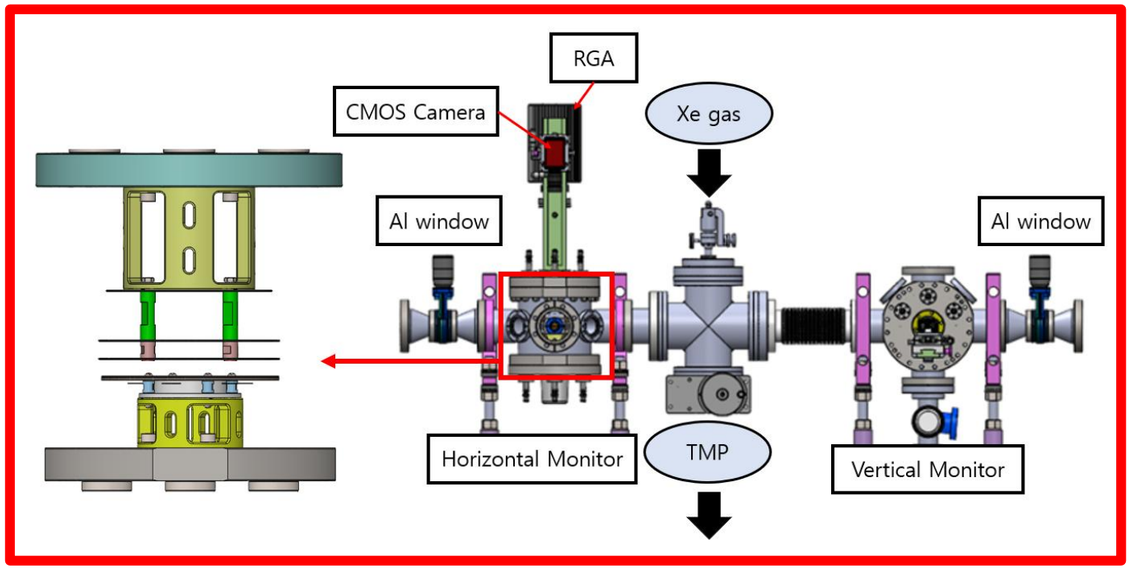
- To non-destructively monitoring the photon beam profile, a proven technique is employed.
  - Ionization Profile Monitor (IPM)
- X-rays or charged particles ionize the residual gas within the chamber.
  → Creating ion–electron pairs.
- These pairs are extracted before recombination occurs.
- Ion distribution at the readout is used to measure the beam profile.

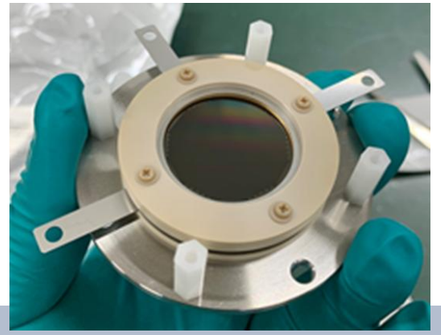


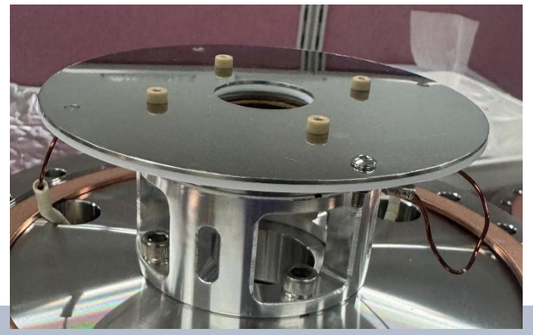


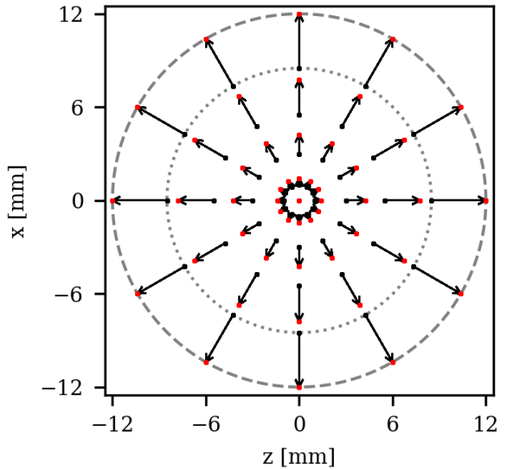
White Beam Profile Monitor



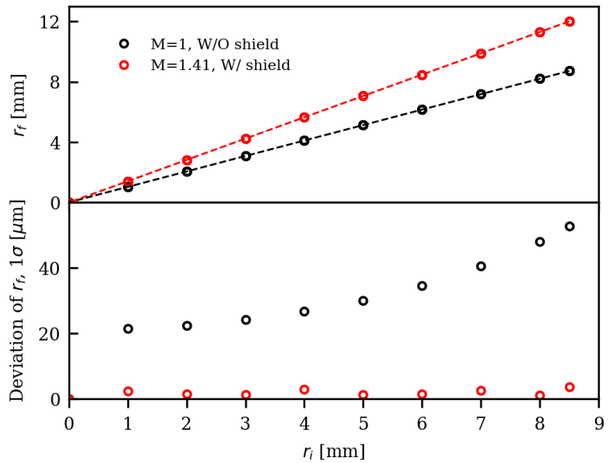








- Ionization position, r_i
- Detection position, r_f



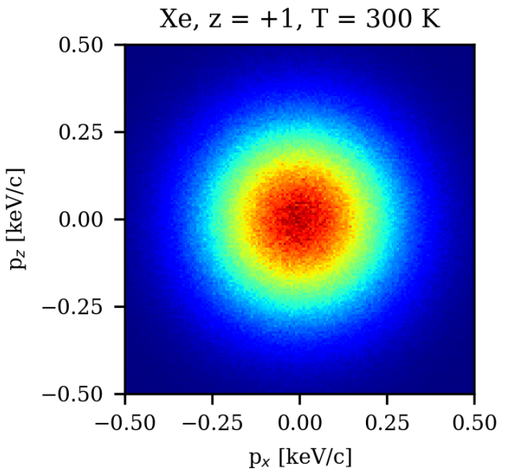
Active area (12 mm)

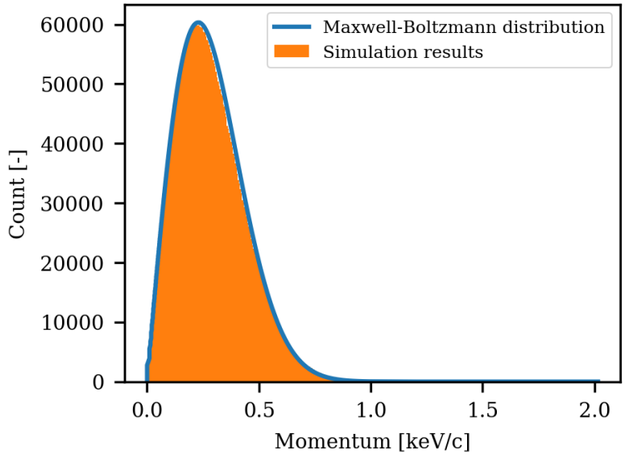
Ionization region (8.5 mm)

White Beam Profile Monitor

- The expected point spread function was calculated for each facilities.
- The thermal-energy-induced spread is analyzed to explain the measurement results.

Factors	Sources	Quantity (σ_i)		
		PAL-XFEL SX	Korea-4GSR IVU	**PLS-II BL6C**
Field quality	Non-linearity	Under 4 μm		
	Defocusing field	$\sigma_{tot} \times M$ (Magnification)		None
Transverse spread	**Thermal energy**	Kr, 70 – 120 μm (Dep. on beam E)	Xe, 55 μm (IVU20)	**Xe, 51 μm (MPW)**
	Momentum transfer	Under 0.1%		
	Space charge effect	None		
Readout device	MCP resolution	80 (~ 100) μm		
Data processing	Calibration method	None (single axis)	10 μm (±3 mm)	None ($M = 1$)
Point Spread Function $\sigma_{tot} = \sqrt{\sum_i \sigma_i^2}\,/M$		100 – 145 μm	97.68 μm	**94.96 μm**

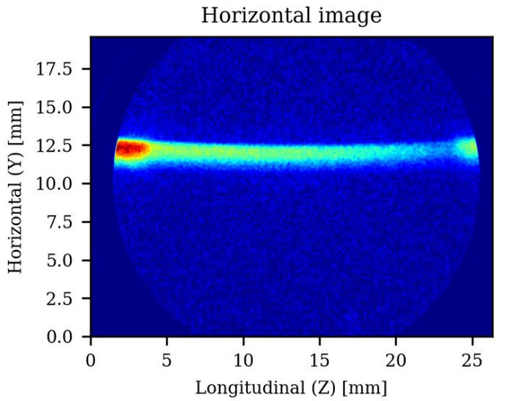


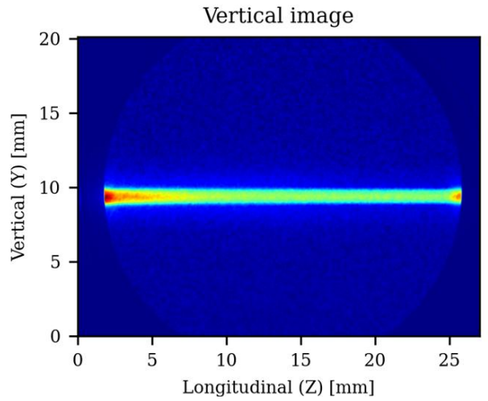


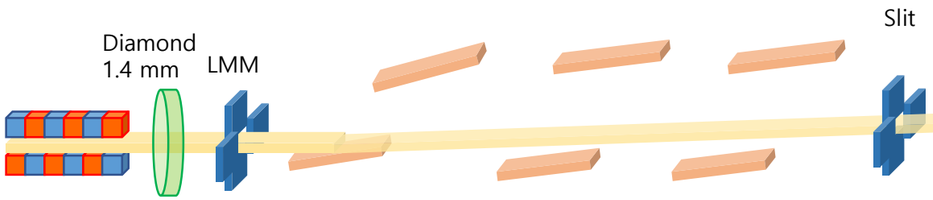
White Beam Profile Monitor

- The WBPM test was conducted at the 6C Biomedical Imaging beamline of the PLS-II.
- The WBPM was installed inside the experimental hutch, positioned directly in front of the screen monitor.
- The photon beam from the MPW passes through a diamond window and a Al window.

  → To increase ionization reactions, Xe gas was injected.







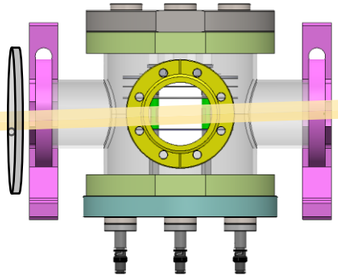
Multi-Pole Wigger
- E_c = 12 keV
- Normal source size : 500 um x 30um
- Total power : 10kW

Double Multilayer Monochromator
- Ru/C, 4.0 nm : 10 – 20 keV
- W/B4C, 2.6 nm : 20 – 55 keV

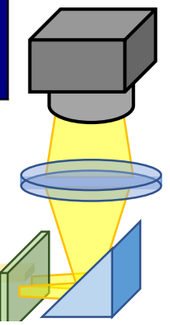
DCM 1
- Si (220) : 30 – 50 keV

DCM 2
- Si (111) : 12 – 33 keV

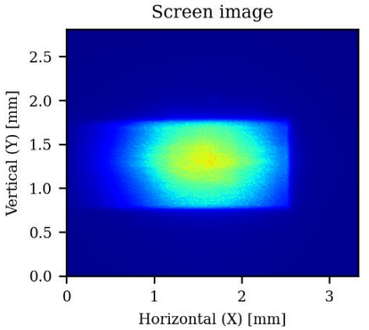
Al window
0.1 mm



WBPM

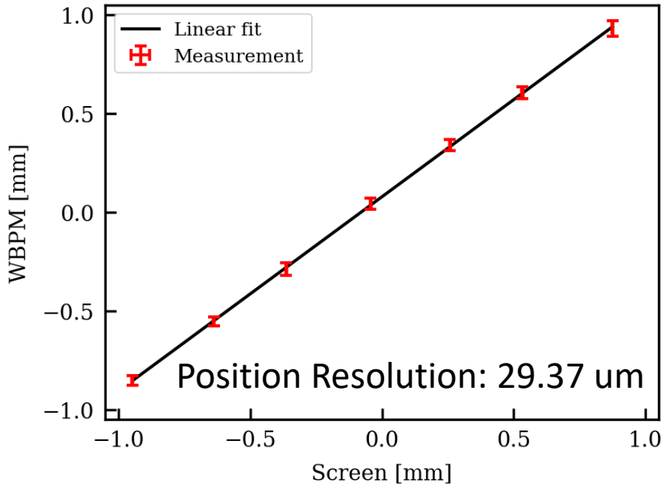


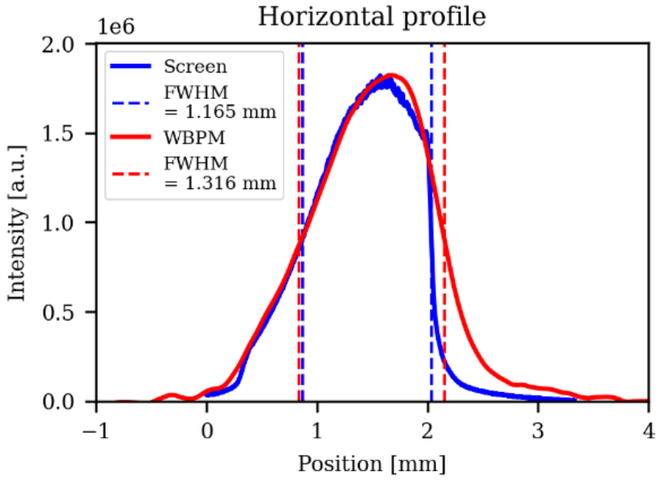
sCMOS Camera
- Pco.Edge 5.5
- Hamamatsu Fusion
- 2x ,4x, **5x**, 10x, 20x, 40x

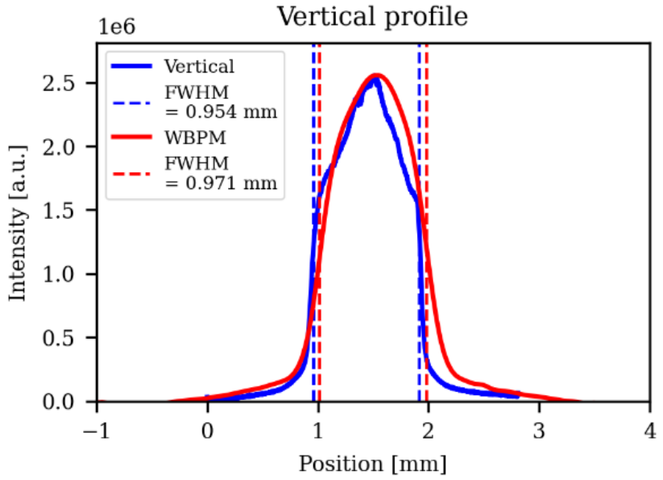


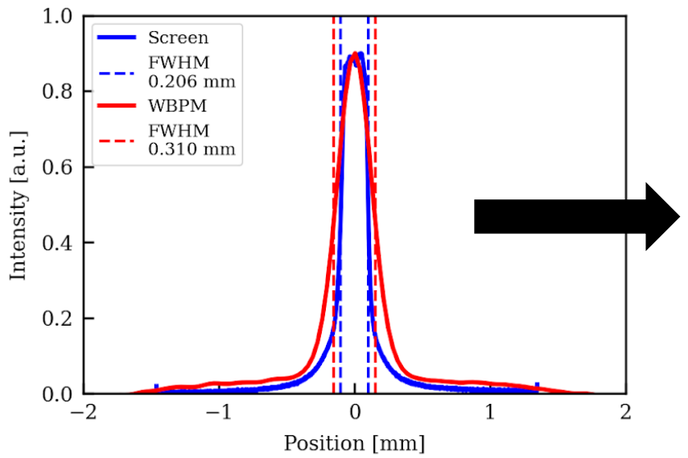
White Beam Profile Monitor

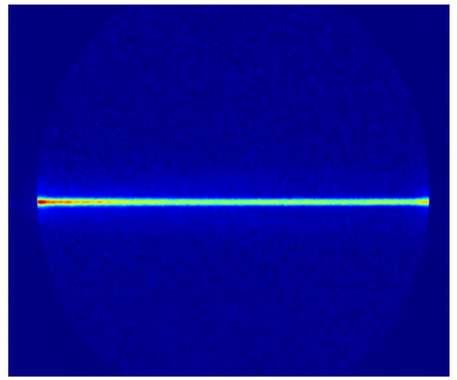
- **Beam Profile Measurement**
  - By changing the position of the slit, the distribution of the photon beam visible in the screen image was generated. (Exposure time: 75 sec)
  - Meas. PSF: **98.33 um** vs Numerical Cal.: **94.96 um**
- **Beam Position Measurement**
  - By adjusting the pinch of the DMM, the position of the beam reaching the WBPM and the slit was varied. (Exposure time: 0.3 sec)







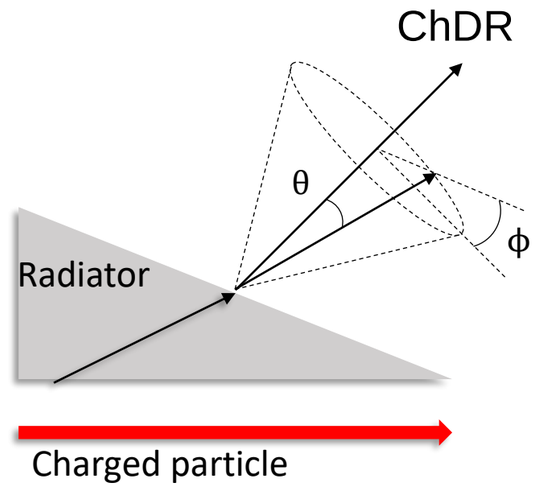


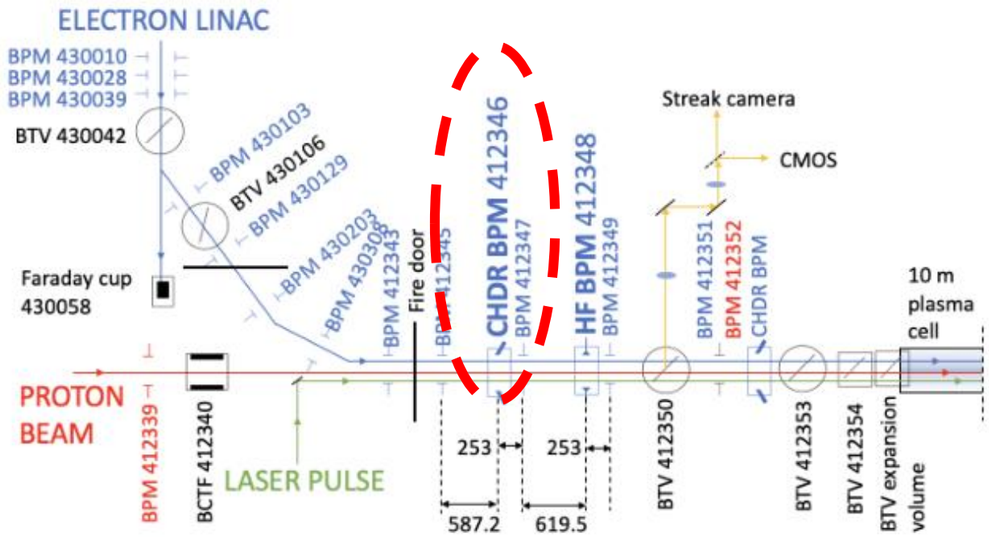


Cherenkov diffraction radiation based beam profile monitor

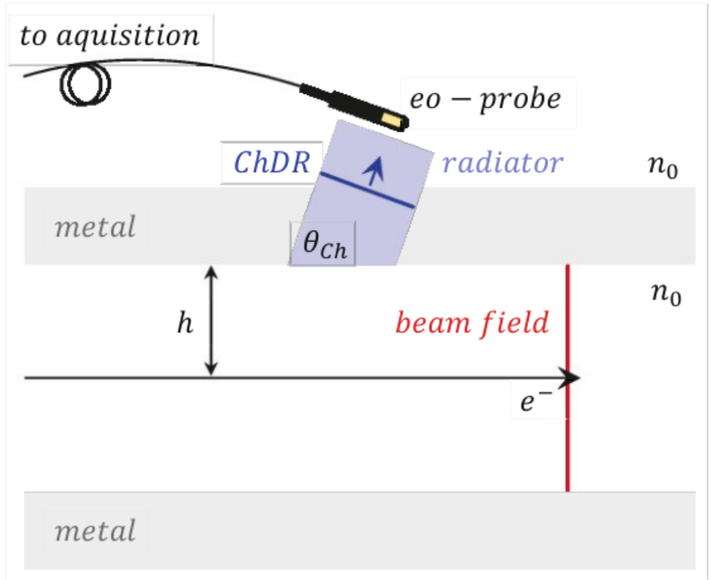
Cherenkov Diffraction Radiation (ChDR)

- Charged particles emit radiation even when they pass in the **vicinity of a dielectric medium**.
- Since its introduction in 2018, it has been studied at CERN, DLS, and Cornell.
- It has demonstrated applicability to various measurements, including position, profile, and bunch length.

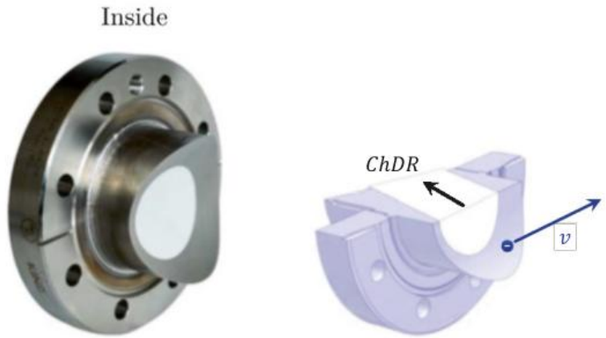




Advanced WAKEfield Experiment (AWAKE)



Future Circular Collider (FCC-ee)



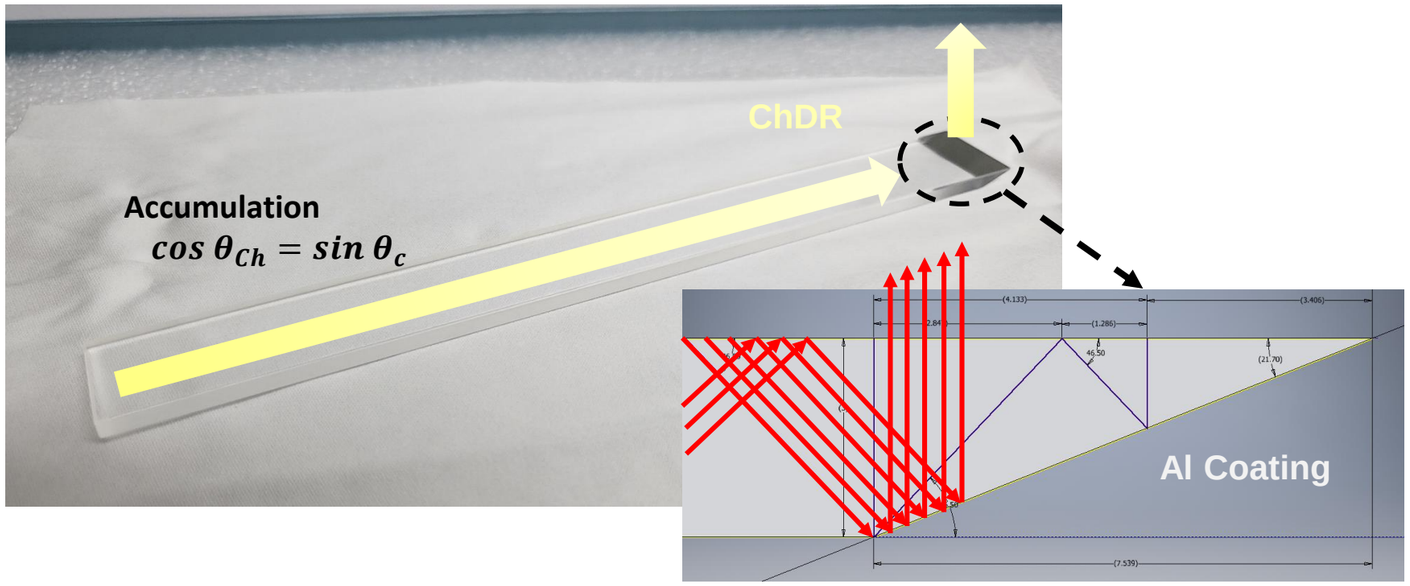
E. Senes et. al, PRR, 2024
A. Schlögelhofer, Diss. Tech. Univ. Wien, 2024

Cherenkov diffraction radiation based beam profile monitor

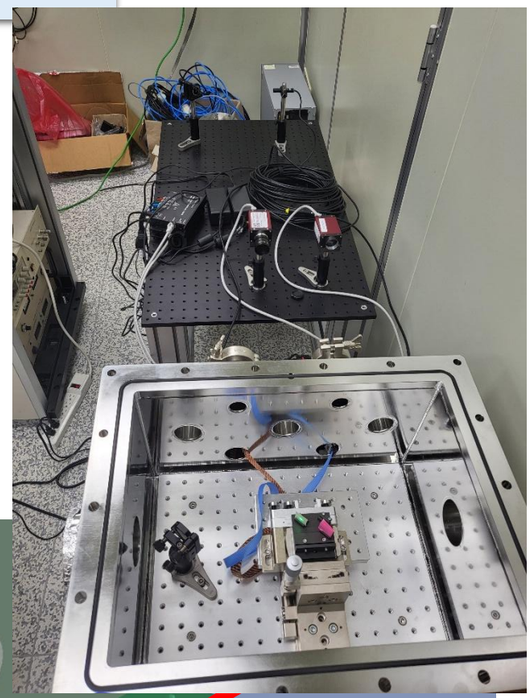
1. Electron beam profile monitor

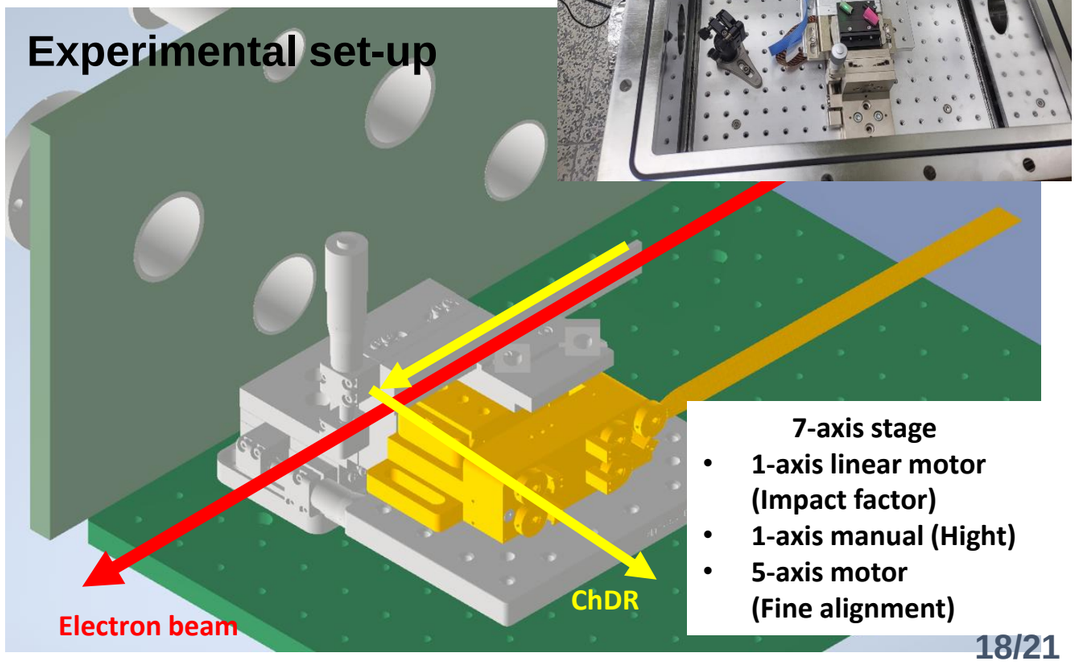
- **Non-invasive**
  → Online measurement (↔OTR and YAG screens, even in storage rings).
- **Directional**
  → Intuitive profile measurement, simple structure.

→ Profile measurement experiments planned at low energy electron Linac (e-LABs) and PLS-II Linac.



Accumulator radiator for low energy beam
Fused silica, 157 mm length

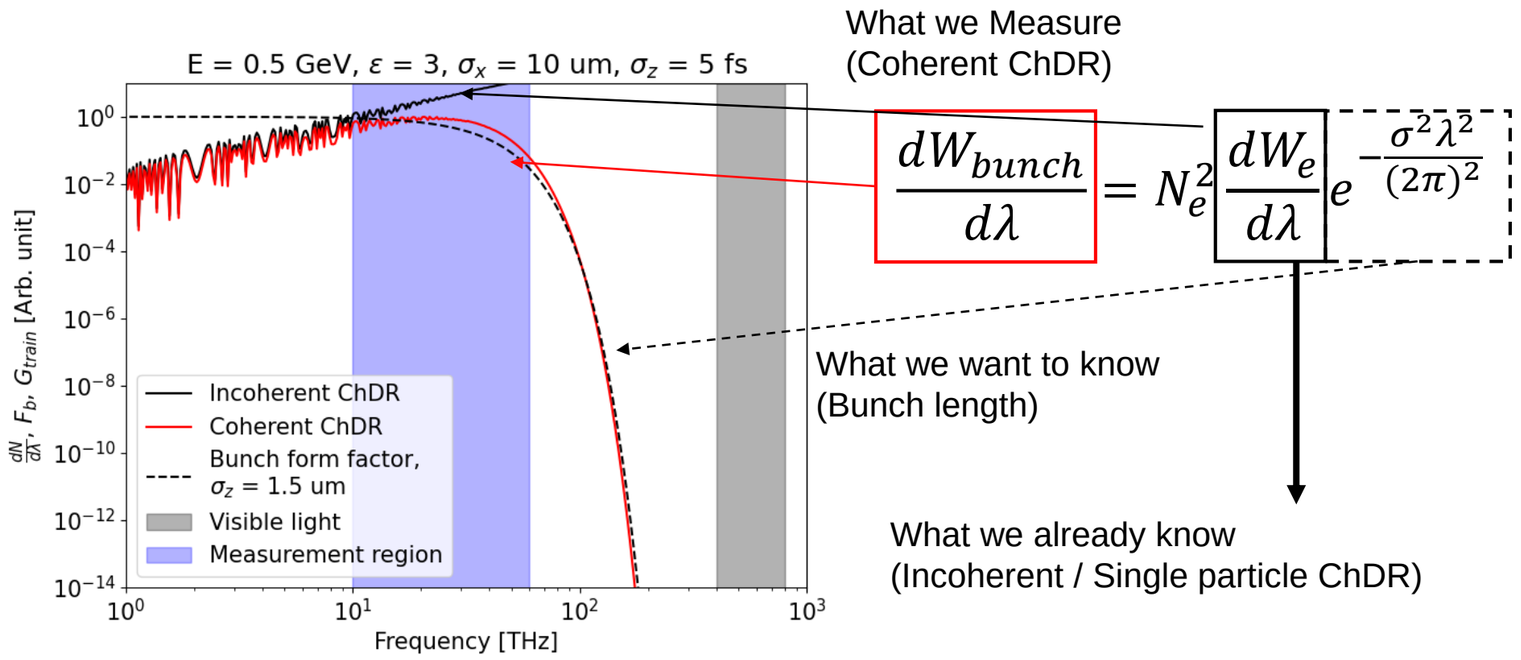


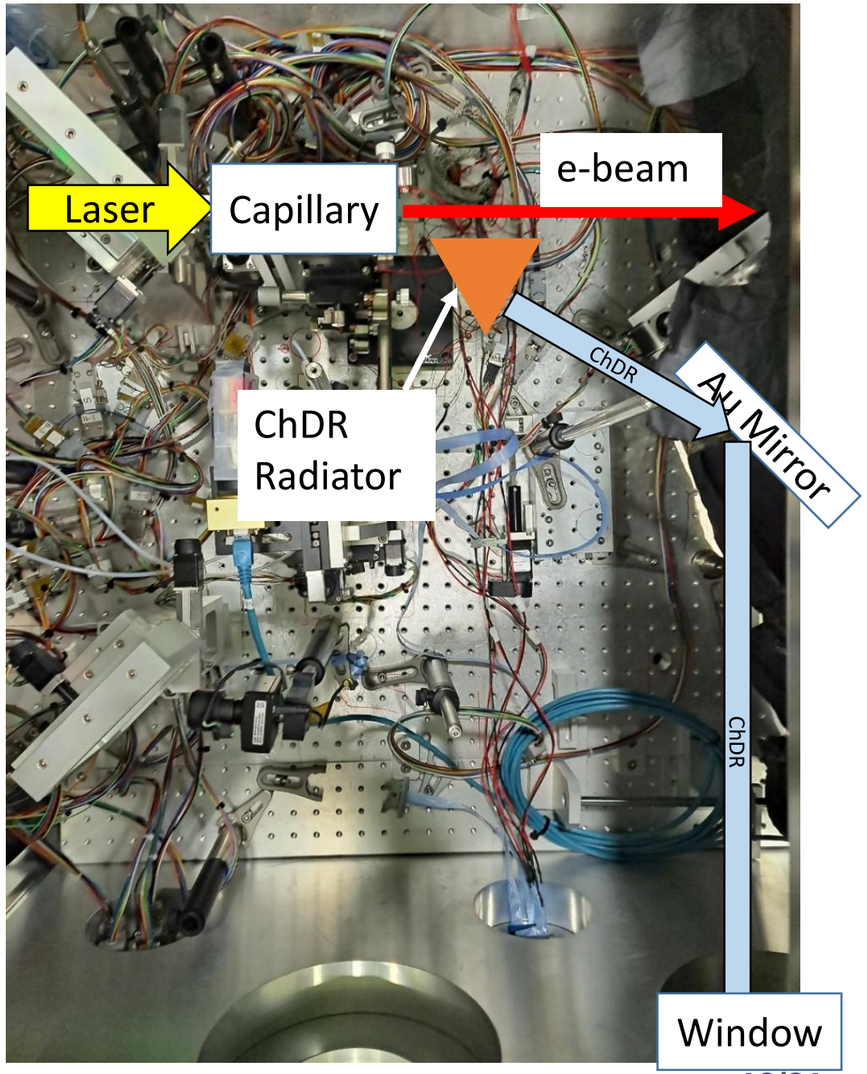


Cherenkov diffraction radiation based beam profile monitor

2. Sub-picosecond bunch length measurement

- **Broad spectrum, High intensity** (↔ Coherent Transition Radiation)
  → Non-invasive bunch length measurement using Coh. ChDR spectrum.
- An experiment to measure LWFA beam is planned.
  (LWFA experiment using IBS 150 TW Laser)





Summary

- The PLS-II storage ring operates two diagnostic beamlines: BL1B and BL7B.
- BL1B diagnoses the beam using visible light with,
  - Interferometer
  - Streak camera
  - Online bunch length monitor
- Recently, a WBPM has been developed and tested to measure the photon beam profile non-destructively.
- Advanced studies are being planned using Cherenkov diffraction radiation.

Thank you for your attention