

Installation, Calibration and Commissioning of Beamline Diagnostics

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on behalf of diagnostic team

Oct 20th, 2026

Outline

1. Function of diagnostic tools

2. Diagnostics tools

- Pulse energy diagnostic: GMD + HAMPs
- Pulse arrival monitor (PAM)
- Talbot Wavefront Sensor
- Photo electron spectrometer (PES)
- Beam loss monitor (BLM)
- Imager
- Energy resolving power measuring for FEL-II beamline
- Beam position and Intensity monitor (BPIM)

3. Commissioning plan

Function of diagnostic tools

Provide diagnostic information of XFEL pulses (Intensity, Photon energy, position, wavefront, arrival time, beam loss signal, beam profile etc.) for the endstation, and provide them as on-line feedback signal for accelerator.

Atomic, **M**olecular and
Optical Science (AMO)

Soft X-ray **S**cattering
and **S**pectroscopy (SSS)

Spectrometer for
Electronic **S**tructure (SES)



Overview of FEL-II diagnostics system

	Diagnostic tool	Main Specification	Quantity
1	Pulse energy diagnostic (GMD + HAMPs)	$\leq 10\%$	3 (1 before M1, 2 before pink/mono KB)
2	Pulse arrival time monitor (PAM)	15 fs RMS	2 (1 pink, 1 mono)
3	Talbot Wavefront Sensor	$\lambda/50$	4 (1 after M2, 3 after 3 endstations)
4	Photon electron Spectrometer (PES)	0.5 eV	1 (before M1)
5	Imager	30 μm	14 (every limiting aperture)
6	Beam loss monitor (BLM)	Response time $\leq 10 \mu\text{s}$	4 (after mirrors)
7	Energy resolving power measurement	$E/\Delta E \geq 10,000$ @867eV	1 (after exit slit)

Overview of FEL-I diagnostics system

	Diagnostic tool	Main Specification	Quantity
1	Pulse energy diagnostic (GMD + HAMPs)	$\leq 10\%$	2 (1 in T3&4,140m, 1 in T4&5, 1110m)
2	Pulse arrival time monitor (PAM)	15 fs RMS	2 (for HXS and CDS)
3	Talbot Wavefront Sensor	$\lambda/50$	4 (1158)
4	BPIM	Position accuracy 10%@7keV	2 (for HXS and CDS)
5	Imager	30 μm	19
6	Beam loss monitor (BLM)	Response time $\leq 10 \mu\text{s}$	5 (downstream to mirrors)
7	Energy resolving power measurement	$\leq 5 \times 10^{-5} @ 8.9\text{keV}$	1 (downstream to exit slit)

On-line testing results of diagnostic tools in SXFEL and SSRF (Jan. 2024~Feb. 2026)



Pulse arrival time monitor(PAM)

Accuracy: 38 fs (RMS)



XGMD+HAMPs

Intensity accuracy: $\leq 3.8\%$
Position accuracy: 0.16mm



Imager

Spatial resolving power:
15 μ m (FWHM)



Beam lost monitor

response time: < 0.5 μ s



PES-eTOF

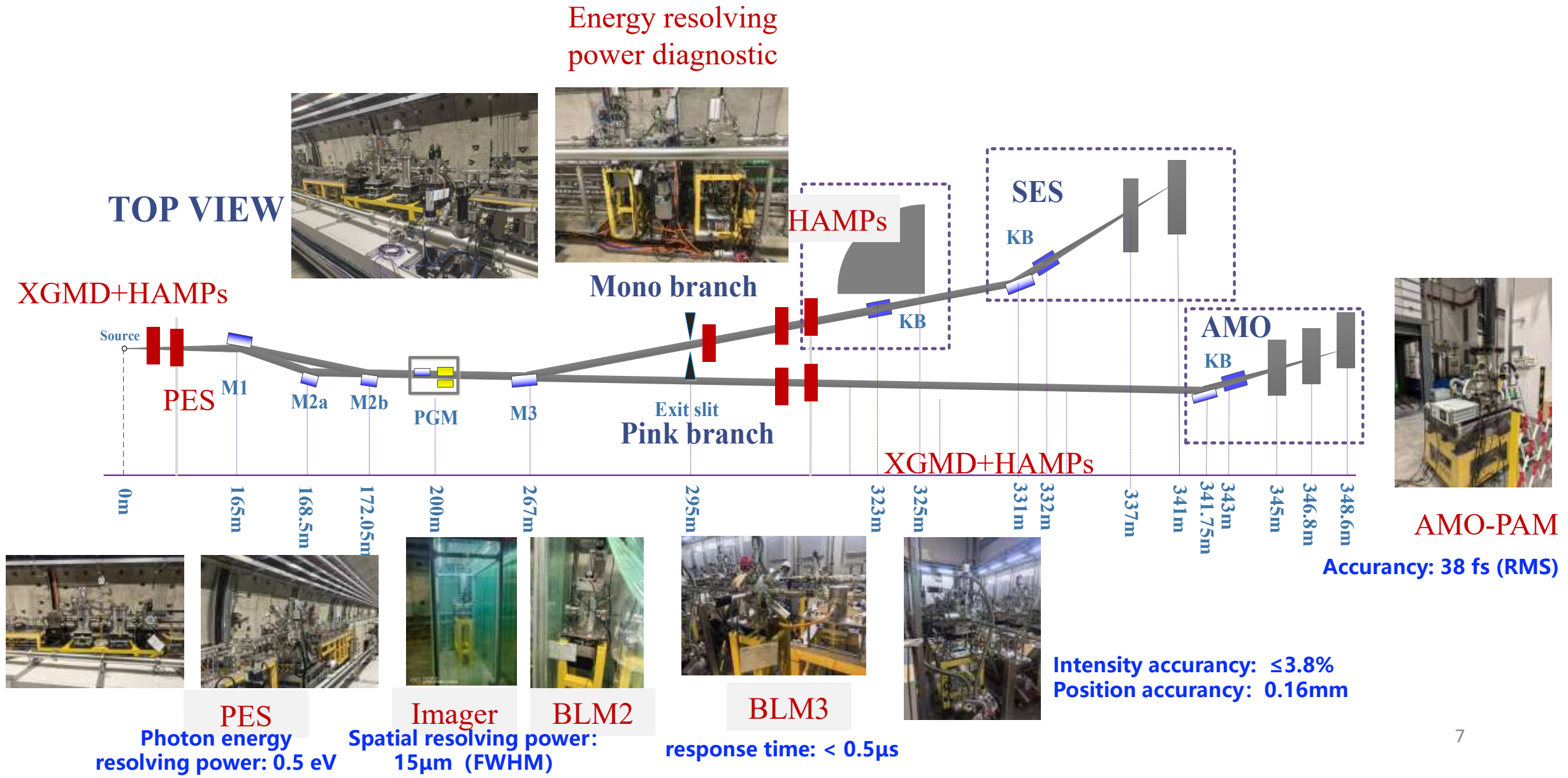


Photon electron spectrometer (PES)
Photon energy resolving power: 0.5 eV

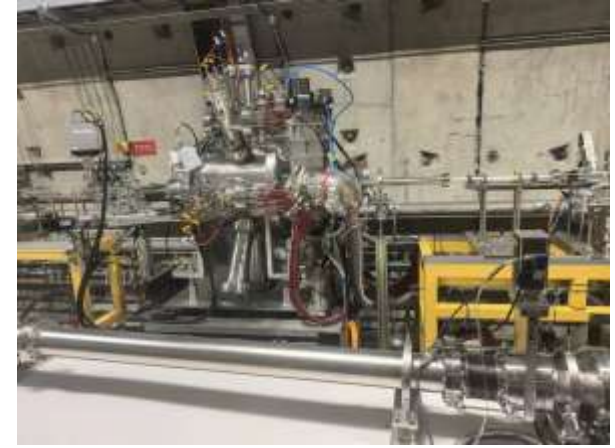


Backscattering Position and Intensity monitor
Position accuracy: $\leq 20\mu$ m

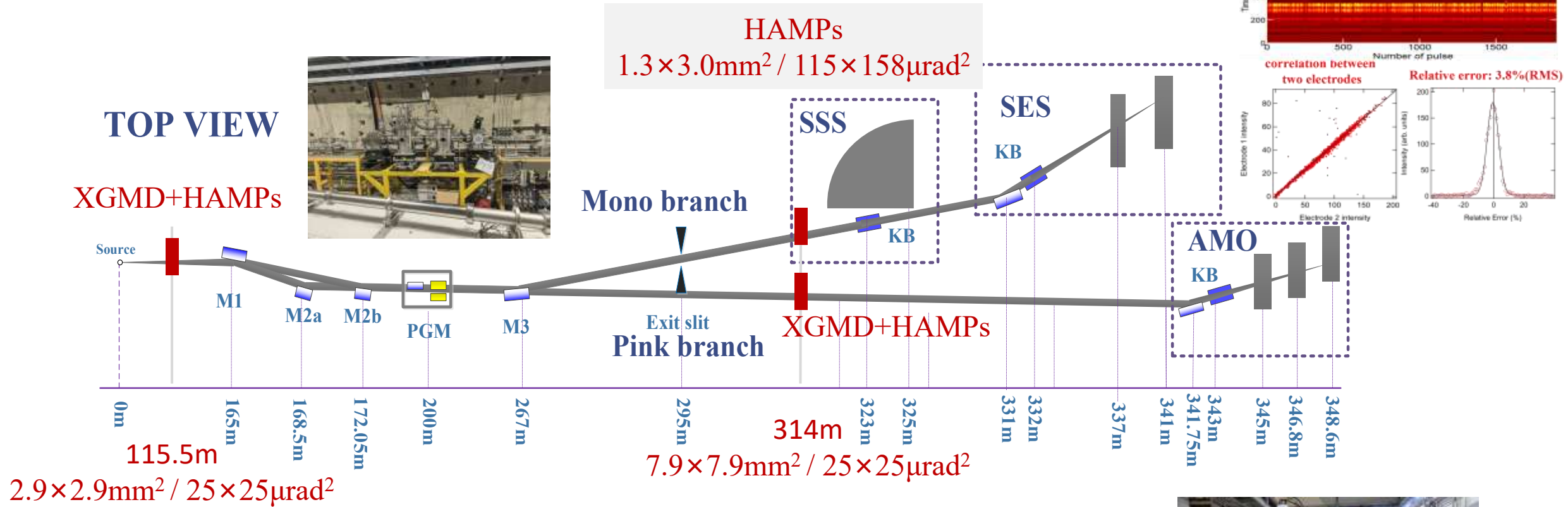
On-line assembly of diagnostic tools for FEL-II



Checking and testing of diagnostic tools before commissioning (Sep 16~17, 28 & Oct 14)



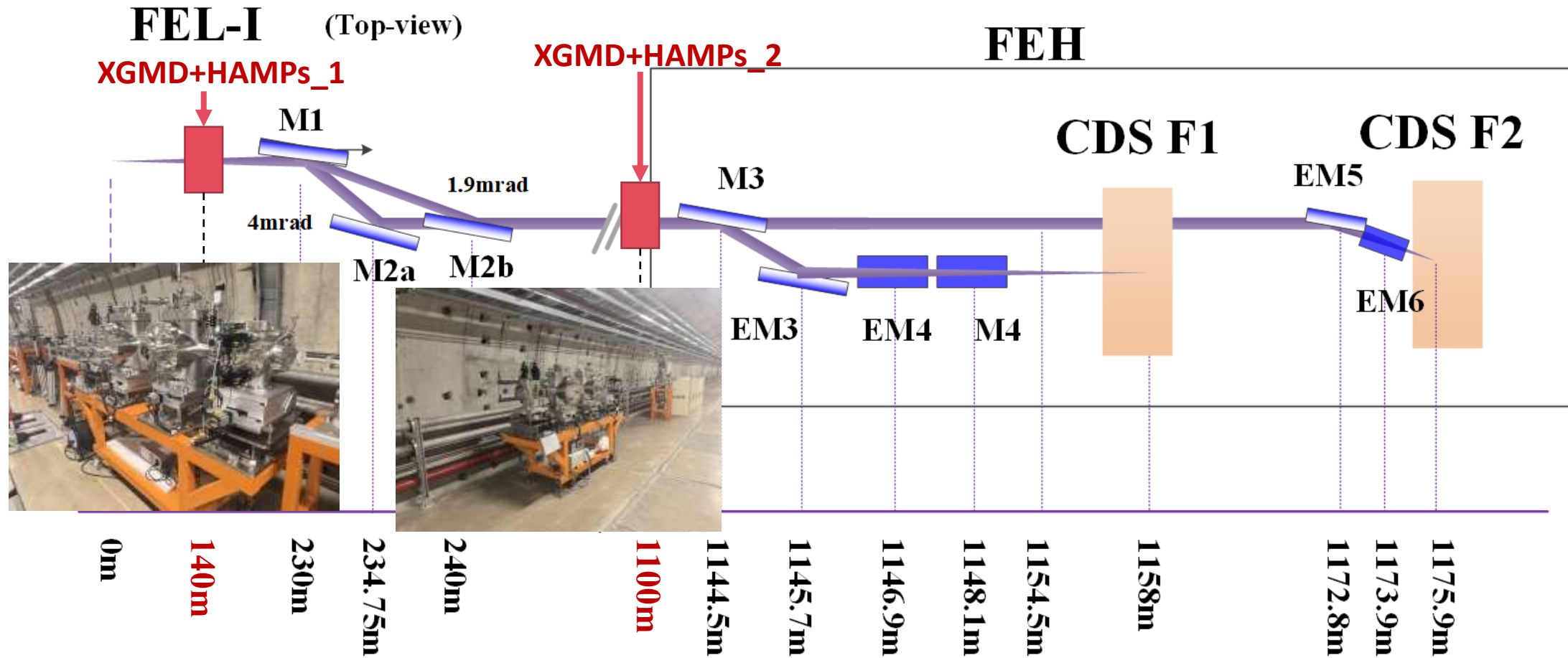
XGMD+HAMPs for FEL-II: location



- Monitoring the pulse photon energy and position.
- Measuring the reflectivity of M1 + M2 [+ M3] mirrors
- The HAMPs in pink branch is used to feedback M2 vibration



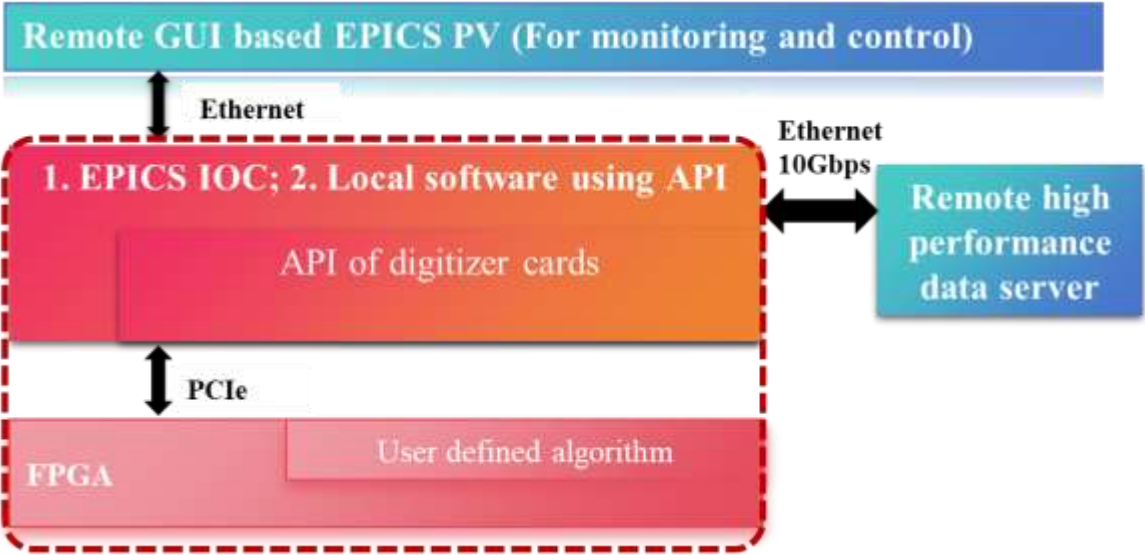
XGMD+HAMPs for FEL-I: location



- Monitoring the pulse energy and position
- Measuring the reflectivity of mirrors
- Feedback M2 vibration

XGMD+HAMPs: DAQ & Control system

1. Remote access to IOC sever of DAQ system



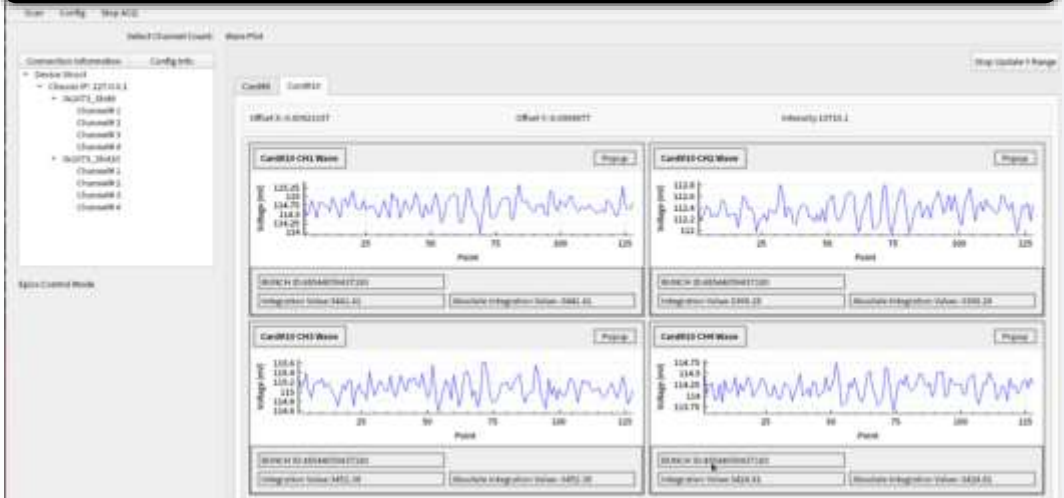
Online configuration of digitizer card



Setup of online data storage



Real-time display of data acquisition for all channels



Digitizer card	PXle-X1073 (EVERACQ TECHNOLOGIES)
Sampling rate	1GSPS
Resolution	16-bit
Channels	4 CH
Band width	DC-300MHz

PXle controller	EVERACQ TECHNOLOGIES
CPU/Memory/SSD	x86 Inter i7/16G/4T
System Bus	PCIe Gen3
OS	Anolis OS 8.8
Network	Dual 10 Gbps SFP+

XGMD+HAMPs: DAQ & Control system

2. Remote motion control



8-axis motion control system

Chamber position	XGMD electrodes motion
XGMD-H	XGMD_VS (Ion signal for vertical position)
XGMD-V	XGMD_VH (HV for vertical detector)
HAMPs-H	XGMD_HS (Ion signal for horizontal position)
HAMPs-V	XGMD_VH (HV for horizontal position)

3. Remote control of gas injection & differential pumping

Multi-inlet of gases



Online switch of gas type



Online control of gas type and pressure

Set up of gas type and pressure

Remote access to present gas type and pressure

Differential pump auto-start (@ gas pressure 5E-4 Torr)

Field test results

Succeed of remote setting: N₂, from UHV to 5E-4 Torr

Real-time reading the gas configuration via EPICS network

Up stream: 1.2 E-8 Torr
Down stream: 9.9 E-9 Torr

Principle of XGMD Pulse-Energy Calibration

Calibration procedure:

Photons per pulse N

↓ $\times k$ (C/photon, from synchrotron)

Accumulated charge Q_{acc}

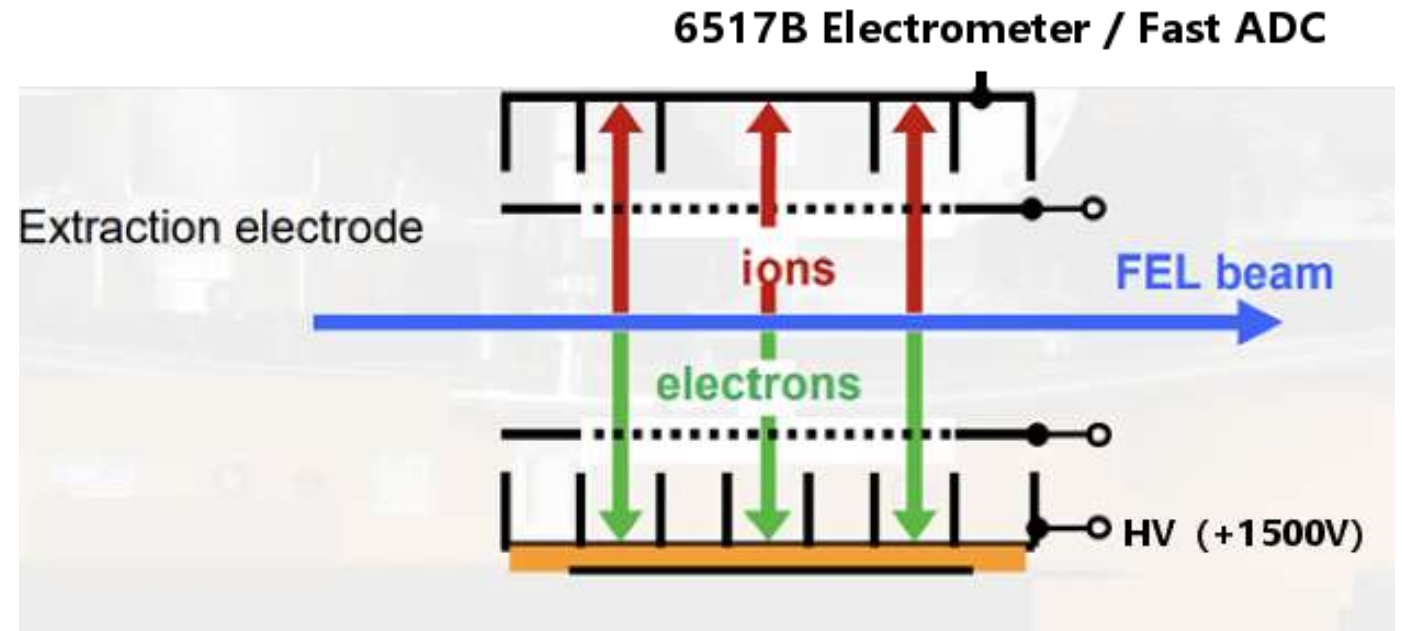
↓ $\times A$ (Ω , XFEL)

Fast ADC integrated voltage

$k = I / \Phi$ synchrotron-based

$A = \sum \int V dt / Q_{\text{acc}}$ on-site XFEL

$N_i = \int V_i dt / (A \cdot k)$ single pulse



X-rays ionize the gas; the bias collects the ions into an ion current.

The electrometer gives the **total photon count**; the Fast ADC resolves **each pulse**.

On-Site Calibration Procedure

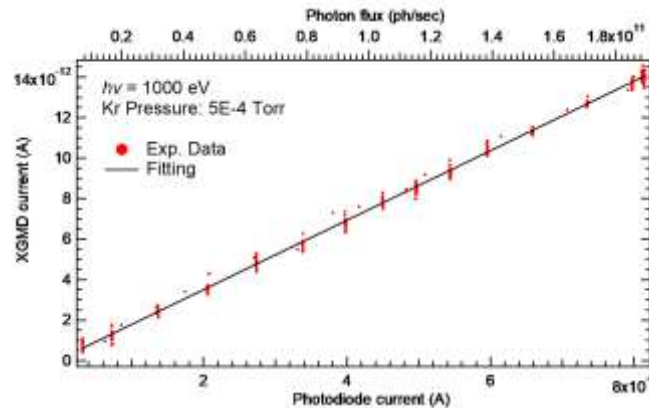
① Synchrotron calibration: coefficient k (C/photon)

CW: PD sets Φ , electrometer I

Fit: $k = I / \Phi$

BL02B measured

$k = 7.52 \times 10^{-23}$ C/photon



BL02B data and linear fit

② XFEL: transimpedance (A)

Electrometer: **charge** Q_{acc}

Fast ADC: waveform $V(t)$

$$A = \sum \int V dt / Q_{acc}, \hat{G} = A \cdot k$$



Fast ADC acquisition system

③ Single-pulse intensity

Integrate each pulse:

$$N_i = \int V_i dt / \hat{G}$$

Mean and **RMS jitter**



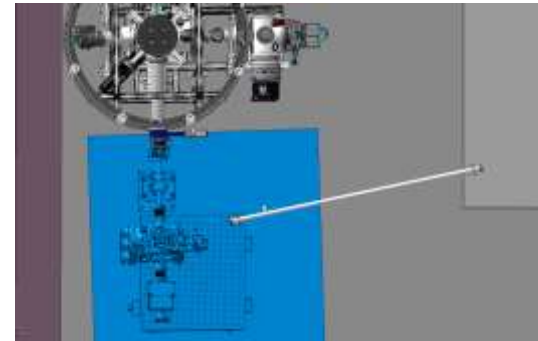
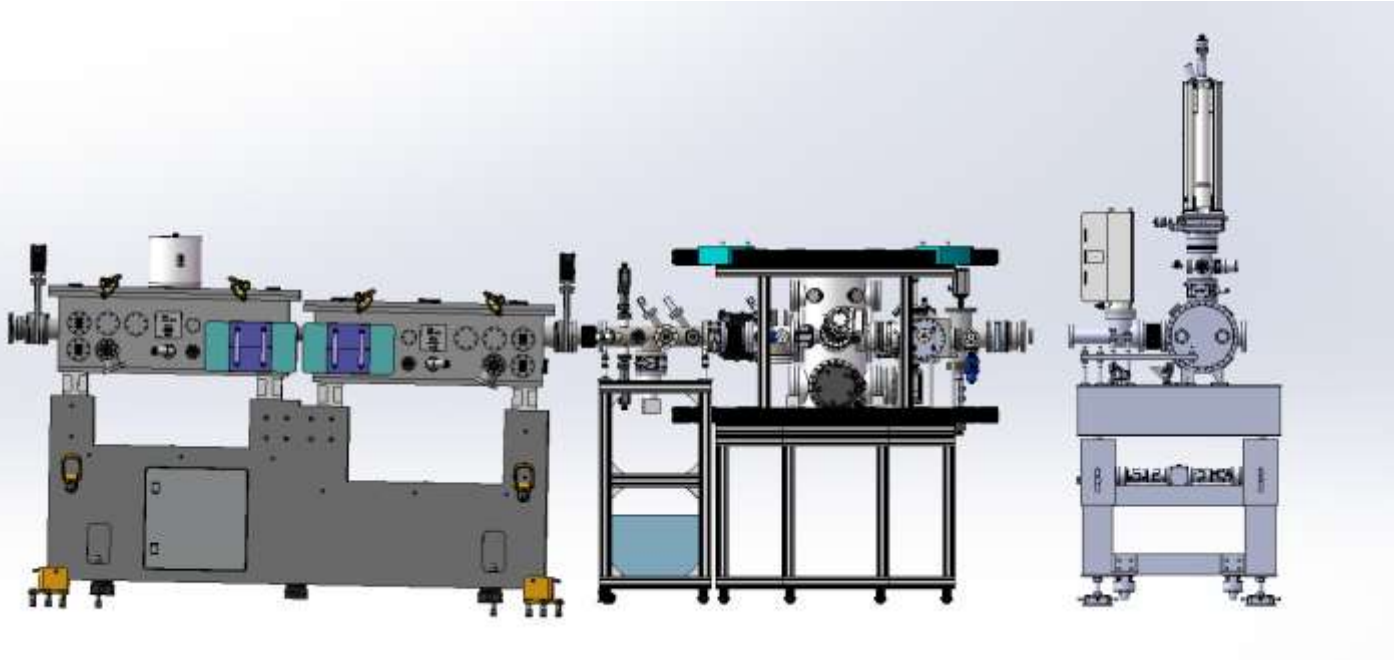
XGMD detector

Determine A and $\hat{G}$ at the FEL first, then move to per-pulse measurement.

Question: Which method is appropriate for the calibration of XFEL pulse absolute intensity in high repetition rate? PD or μ K temperature increasing of XFEL in Cu target?

PAM: the installation has completed

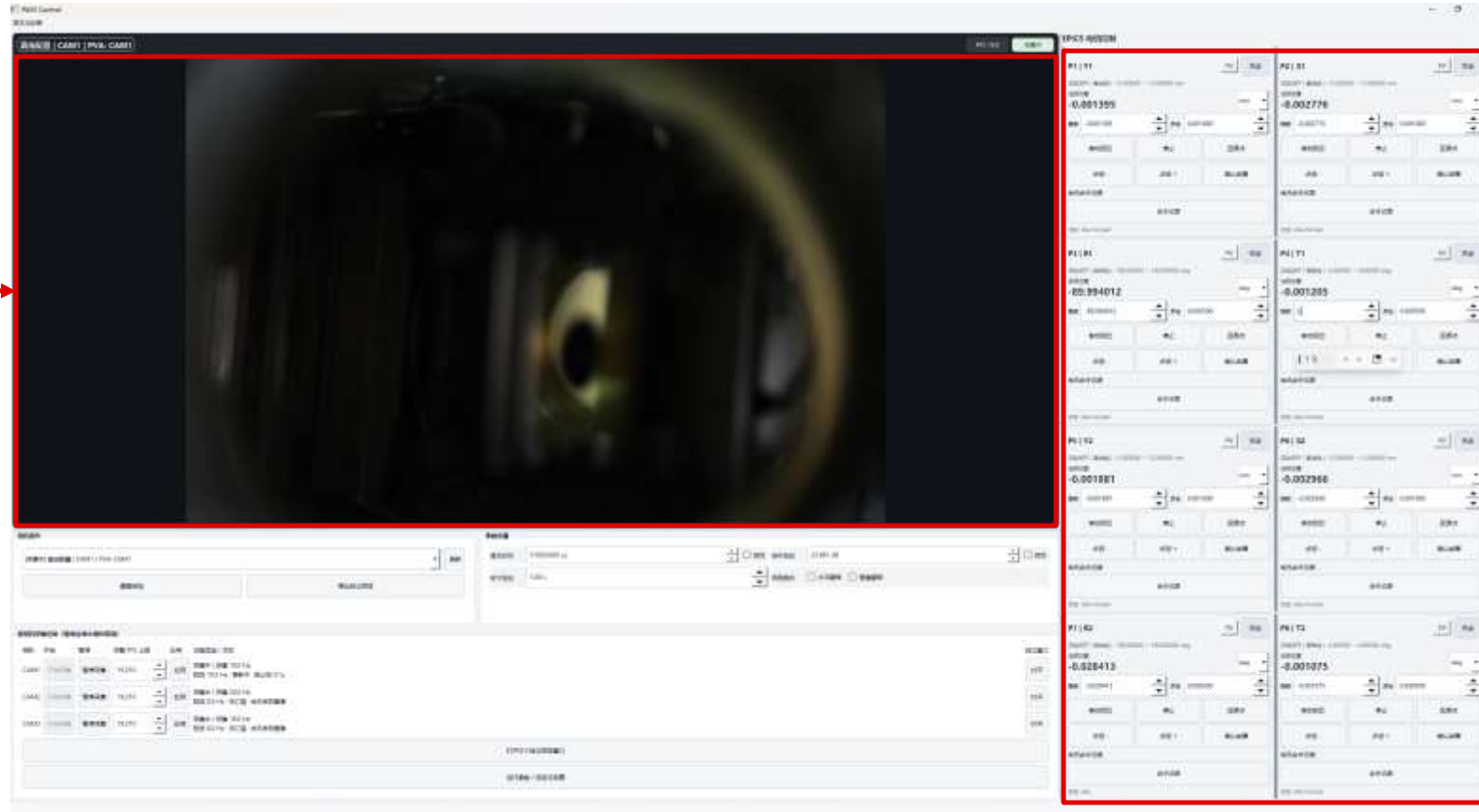
- ❑ The PAM will ben installed near the third focal point of AMO endstation.
- ❑ The PAM has been moved to Shaft #4, near AMO endstation.



PAM Software: Spatial Alignment

Camera
monitoring

Live observation
camera images



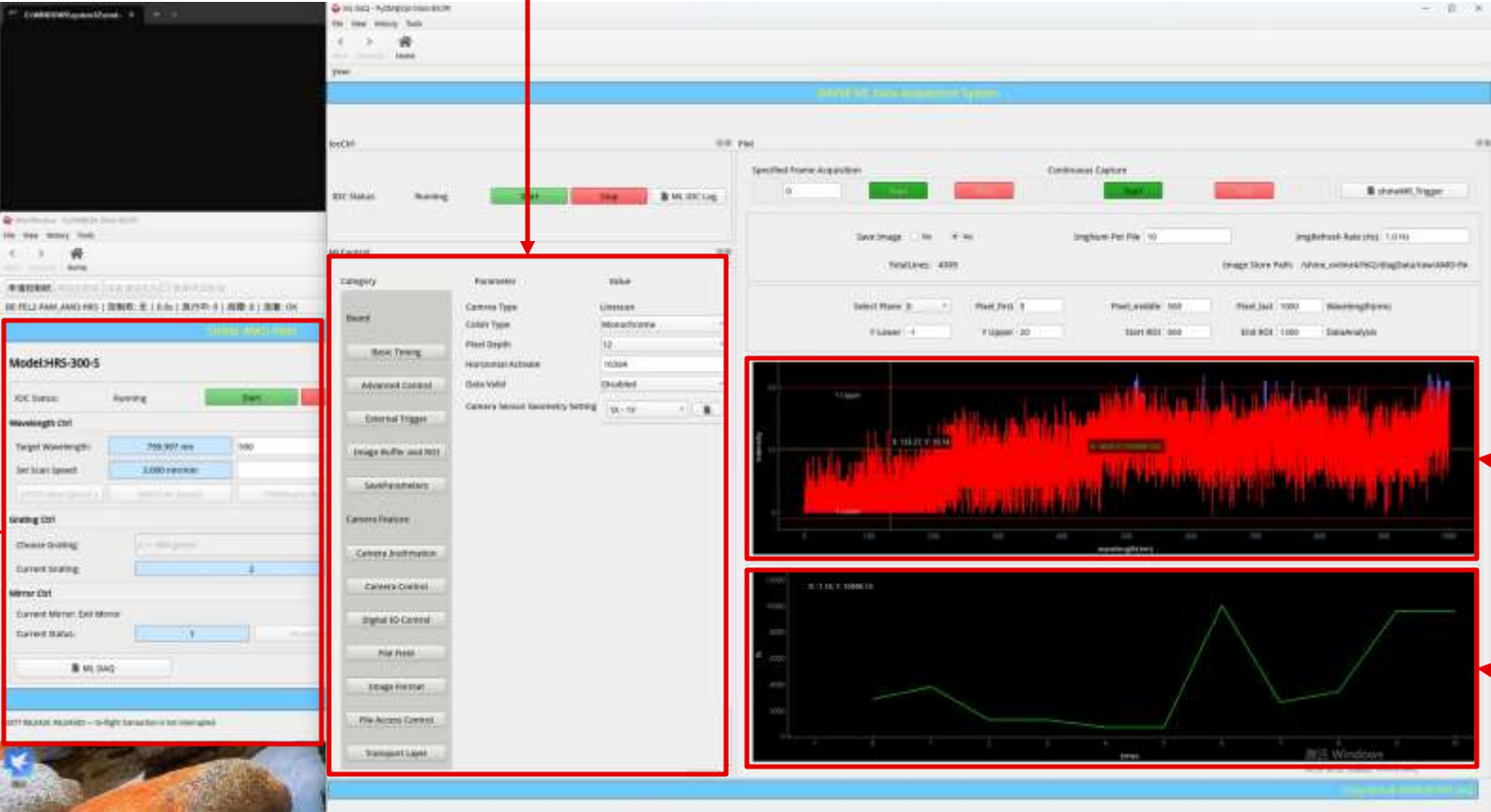
Motor
control

Adjust
positions
while viewing
live images

Integrated camera monitoring and motor control
simplify spatial overlap of the laser and XFEL beams.

PAM Software: Acquisition and Timing

ML camera control



Spectrometer control

ML camera data

Real-time arrival time

100 kHz

Data acquisition and storage

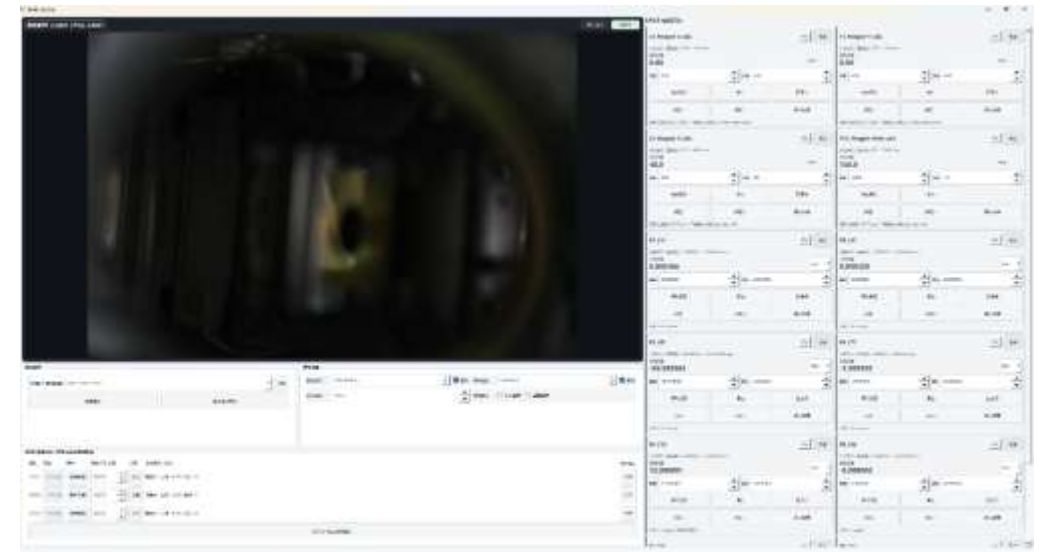
100 Hz

Real-time arrival-time fitting

Checking and testing of PAM2

1. vacuum motors (8)
2. stepping motors (5)
3. imager camera (3)
4. controlling of spectrometer.
5. linear stage for delay line
6. software for remote data acquisition and storage.

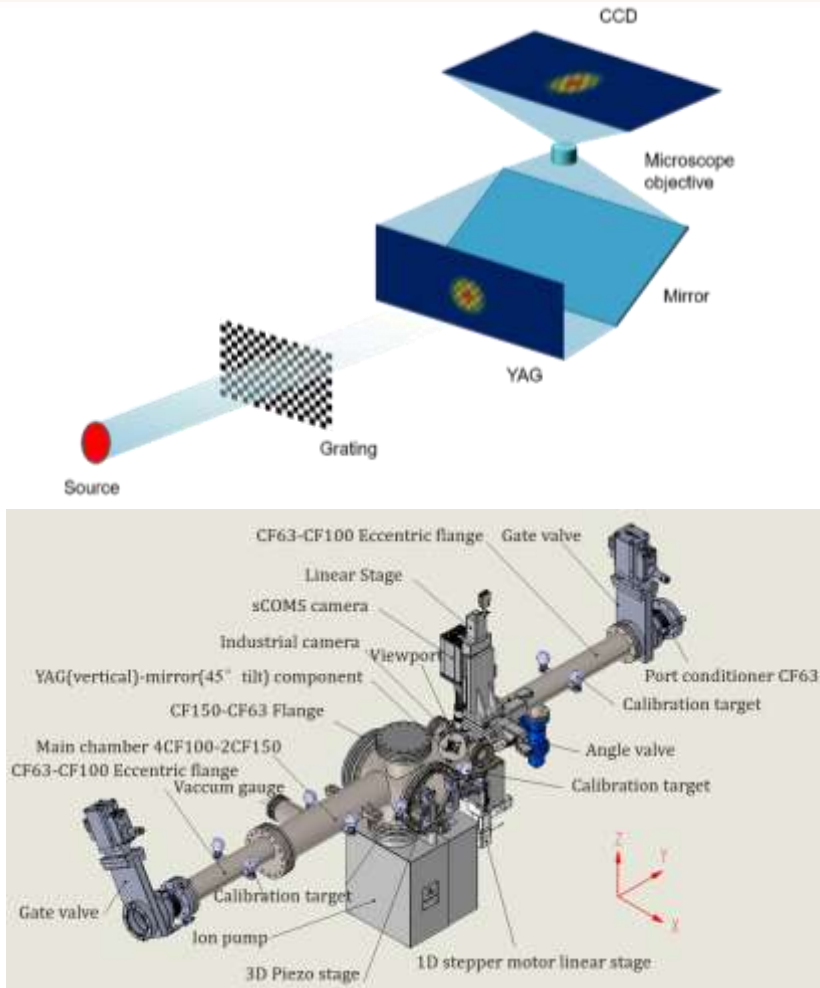
Highlights: the data acquisition up to 100kHz has been tested recently.



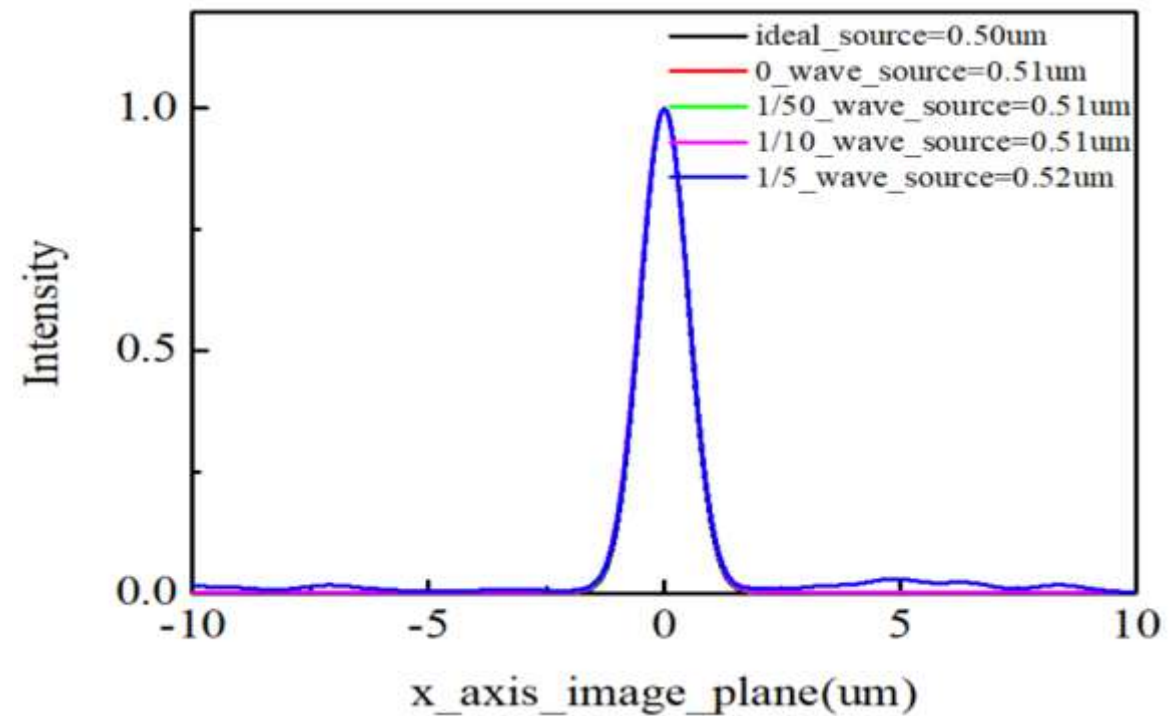
Wavefront Sensor

Experimental requirements: Measuring beam spot of $\sim 10\text{ }\mu\text{m}$

Repeatability: $\lambda/50$

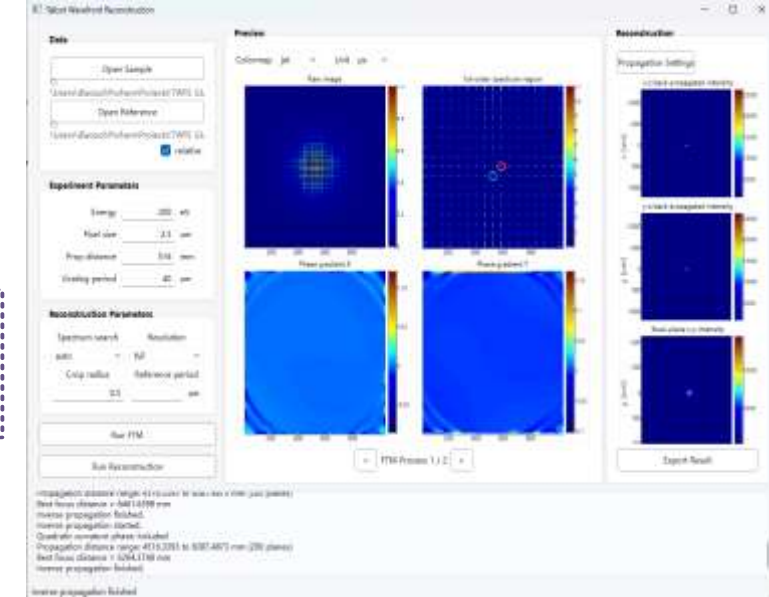
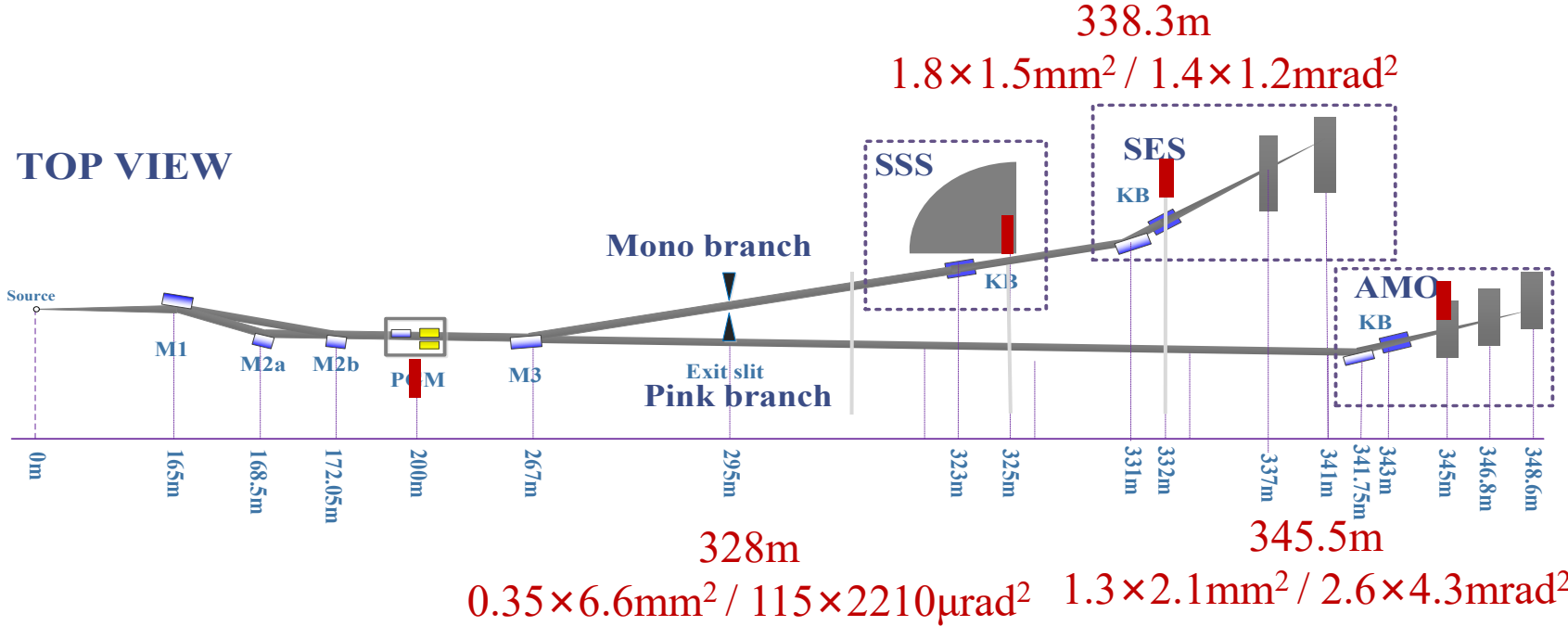


Simulation on beam reconstruction with wavefront errors



Wavefront measurement with $\lambda/50$ error is sufficient for $10\mu\text{m}$ spot

Wavefront Sensor



- Three wavefront sensors are installed, each located at the end of endstations in the beamlines.
- Firstly, KB alignment roughly with beam focal spot measurement using imager.
- Secondly, measurement using wavefront downstream to focal point.
- Reconstruction of focal spot for fine KB alignment

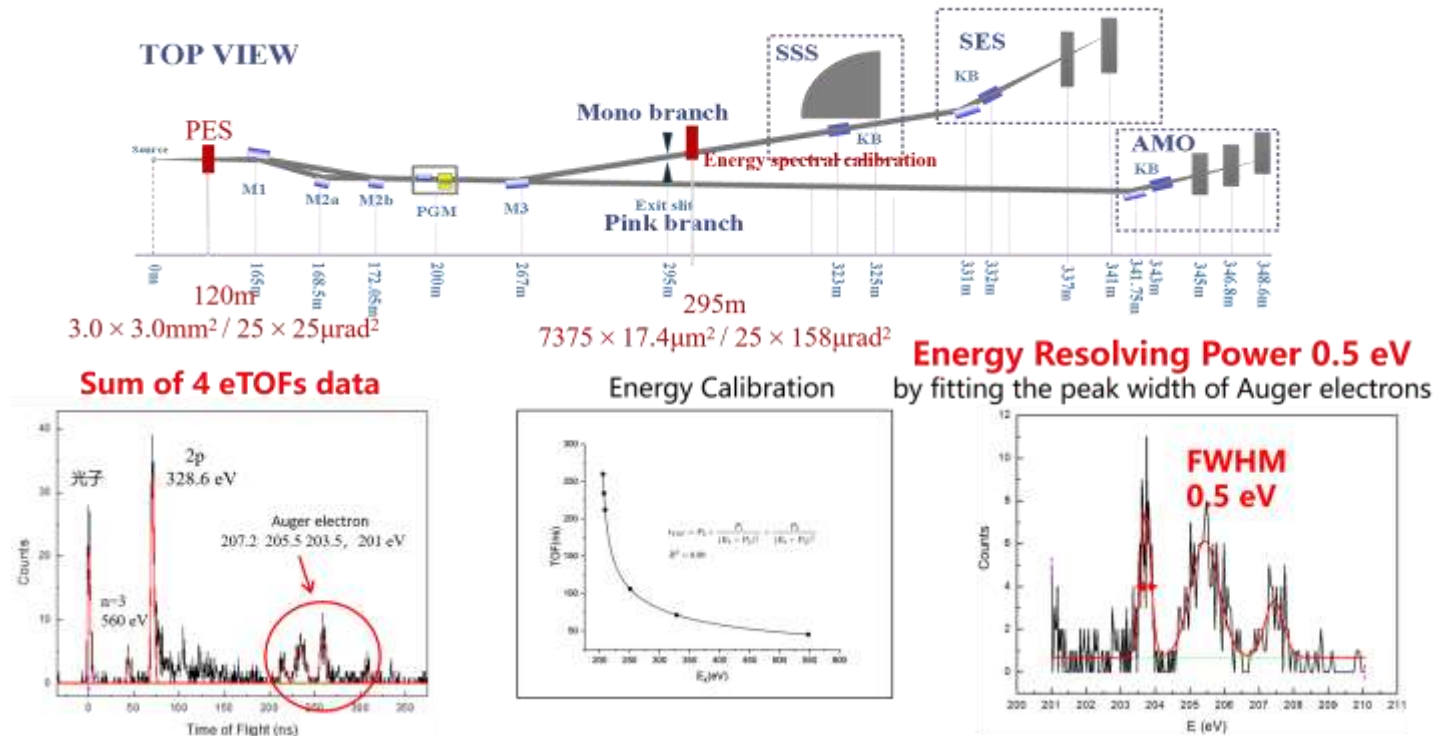
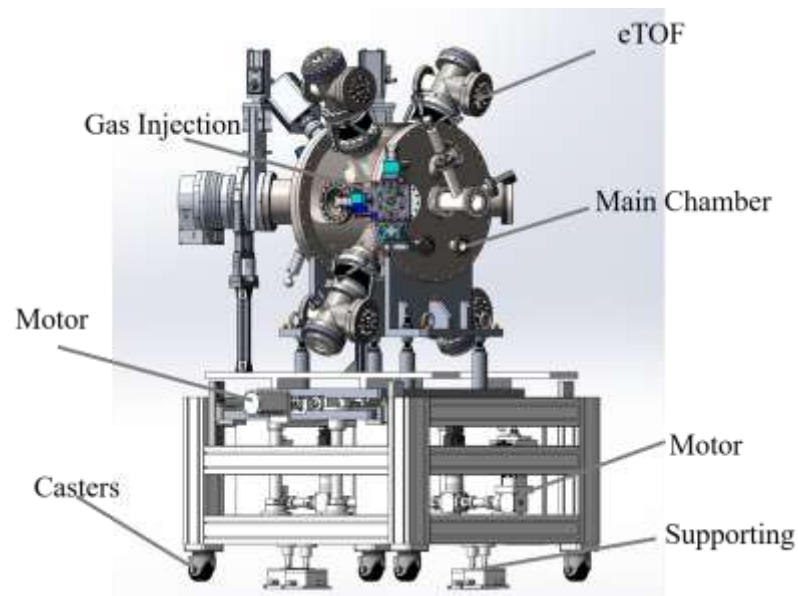
- WFS interface
- Input: Talbot image
 - Output: intensity at focal plane

Photon electron spectrometer: PES

Function: Measure the spectrum of XFEL pulses

Energy resolution: 0.5 eV

To measure the kinetic energy of photoelectrons to get the FEL spectrum.

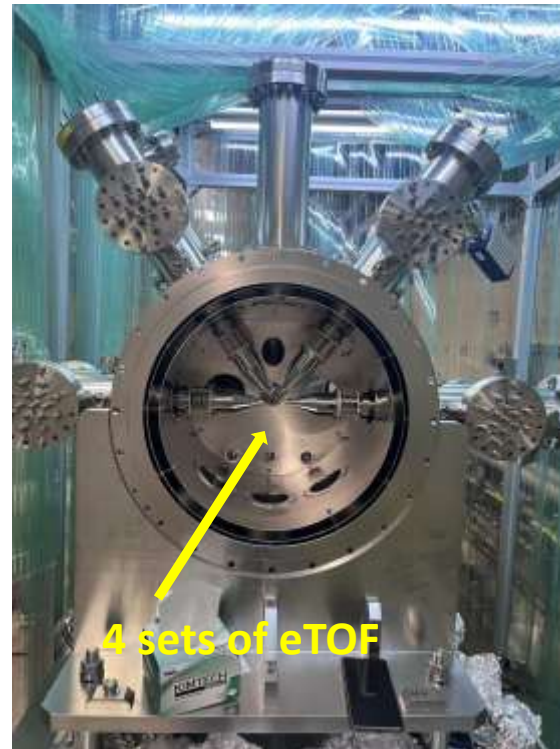
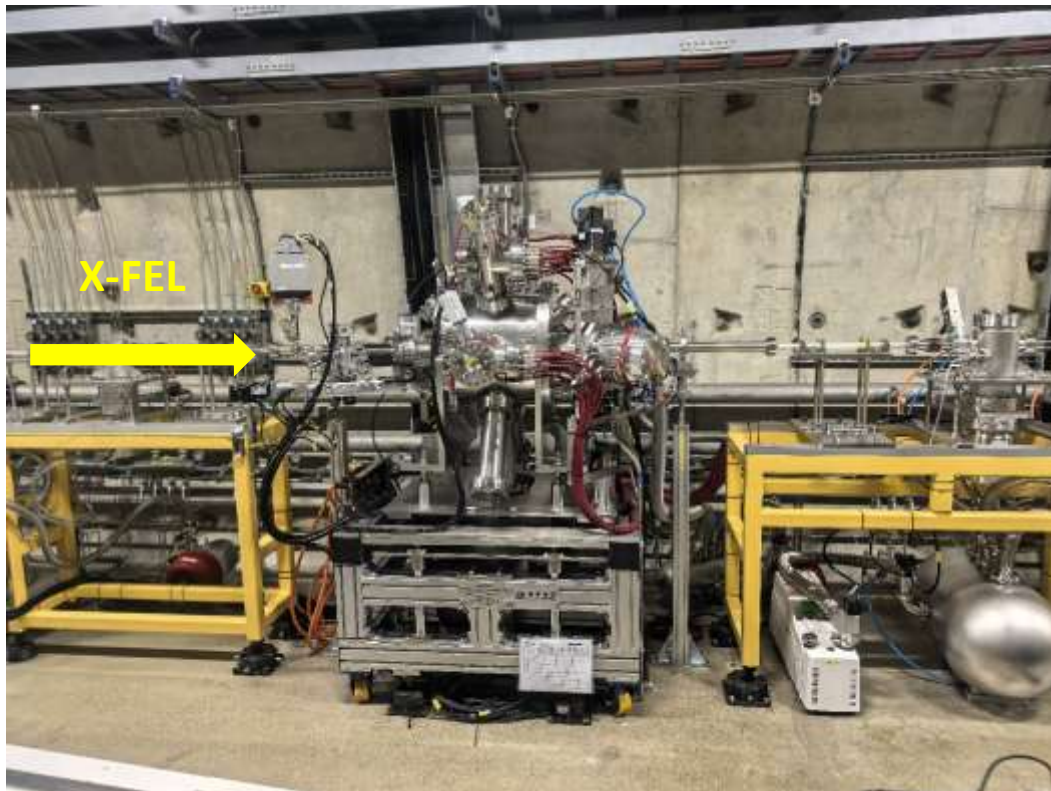


- ❑ The PES locates as upstream as possible to get small spot (4~10mm) to increase energy resolution
- ❑ Measure the average spectra of multiple pulses.
- ❑ A YAG imager downstream the exit slit (295m) is used as a calibration tool in combination with PES.

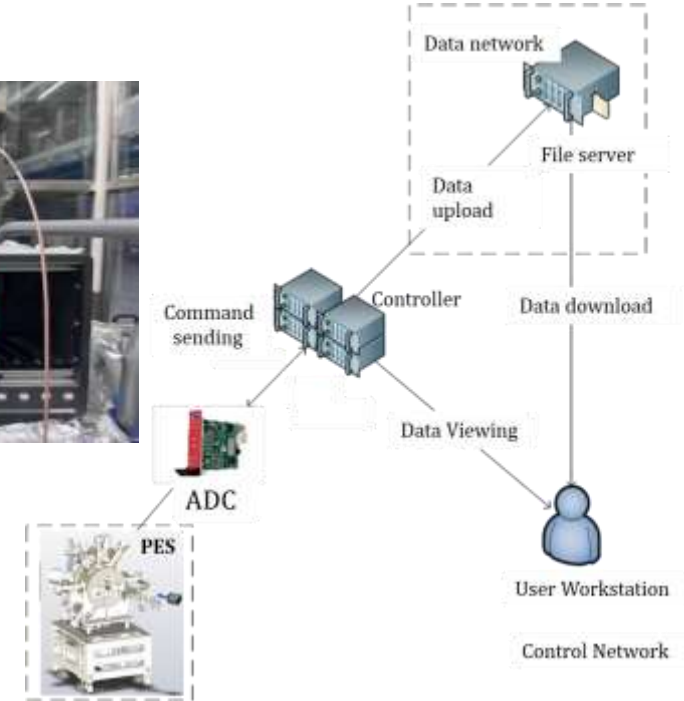
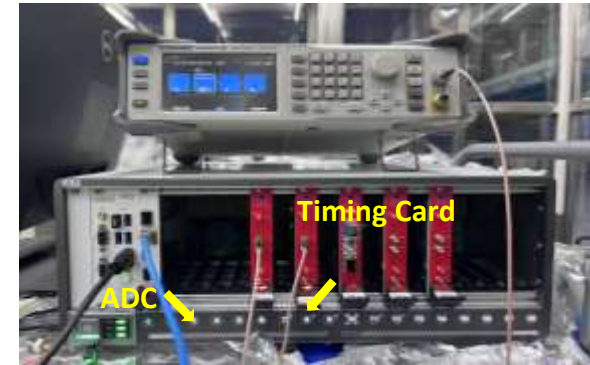
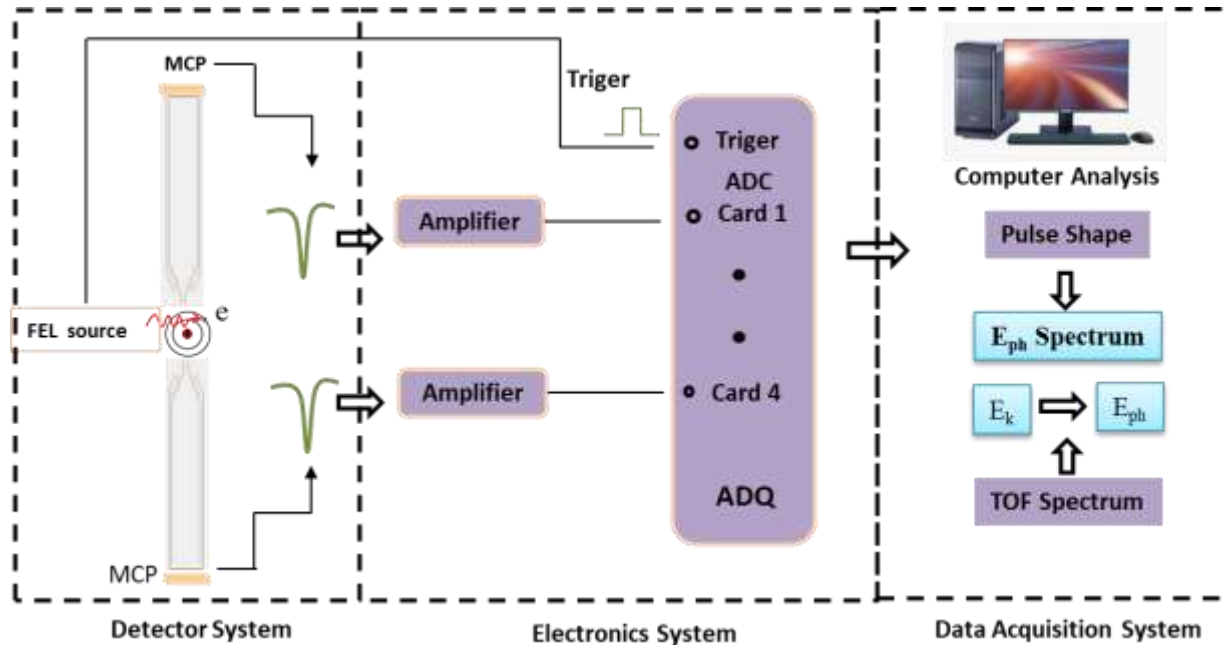
PES: Installation @SHINE has been finished

Two eTOFs are installed in the horizontal direction.

The axes of the other two eTOFs form a 54.7° angle with another two eTOFs in horizontal direction.



PES: Data Acquisition System



Parameters of the Data Acquisition System

- 4 ADC acquisition cards;
- The **sampling rate** of each ADC card: **10 GSPS**;
- Bandwidth: **3 GHz**;
- Data transfer rate: Maximum up to **4 GB/s**;
- Data storage: **4TB** local SSD and Remote Storage Server

Difficulties encountered and corresponding solutions

- Solve the **4 ns random error** between the **trigger signal** and the **acquisition clock**.
Adding a **fine delay unit in the firmware**, the random error is **reduced to 60 ps**.
- Adding **signal threshold-crossing detection** to prevent **false acquisition** caused by noise.

PES Data Acquisition Software

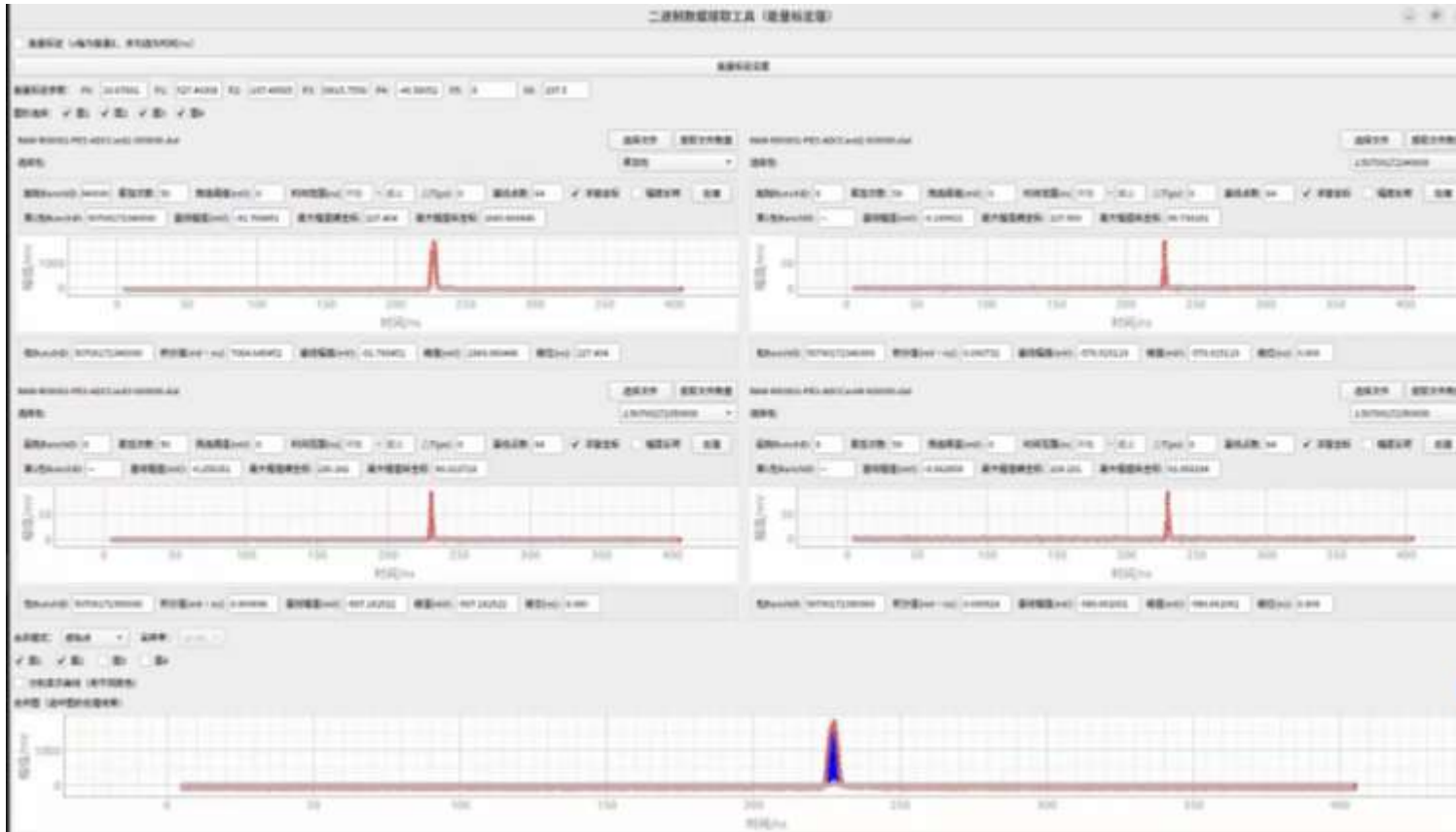


Main Functions

1. **4-channel ADC synchronous acquisition**
10 GS/s sampling rate; waveforms and energy spectra; feature values bound with BunchID; recording of key experimental parameters.
2. **Parameter configuration Support**
configuration of trigger source, trigger threshold, sampling rate, acquisition length and other parameters.
3. **Multiple acquisition modes**
Continuous, single-shot, multi-pulse accumulation and other modes
4. **Local & remote data storage**
100 kHz repetition rate, 180 ns acquisition length per shot.

PES Data Acquisition Software

Post-processing Interface



Software Operation Procedure

- 1. Configure system parameters:**
Set acquisition parameters, acquisition mode and data storage path.
- 2. Enable raw waveform reception:**
Check the ****Receive Raw Waveform**** option.
- 3. Enable waveform plotting:**
Click ****Plot Waveform****.
- 4. Start data acquisition:**
Click ****Start Acquisition****.

Post-processing Capabilities

- 1. Load and plot 4-channel raw waveform data;**
- 2. Fit and calculate feature values (peak position, peak amplitude, peak area);**
- 3. Perform cumulative averaging for four-channel waveforms;**
- 4. Time-energy parameter fitting and energy-spectrum visualization.**

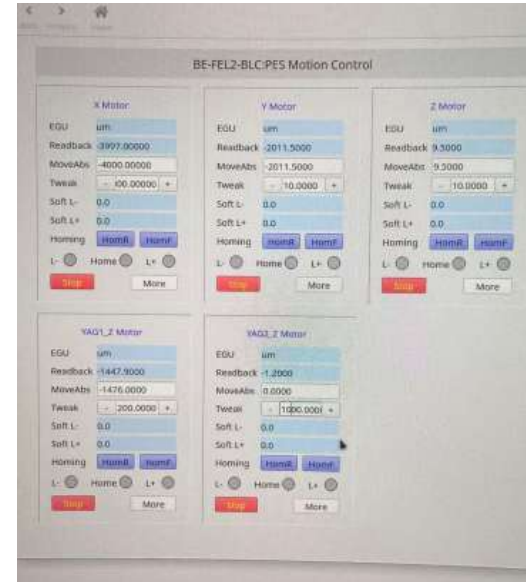
Checking and testing of PES

➤ Checking and testing of PES:

1. Checking and testing of the motors.
2. Checking of YAG screen.
3. Controlling of gas injection.
4. Remote controlling of eTOFs and high voltage for detectors.
5. Data acquisition for PES.

The testing has been completed and can fulfill the requirements of on-line testing (Sep. 16, 2026).

motor controlling



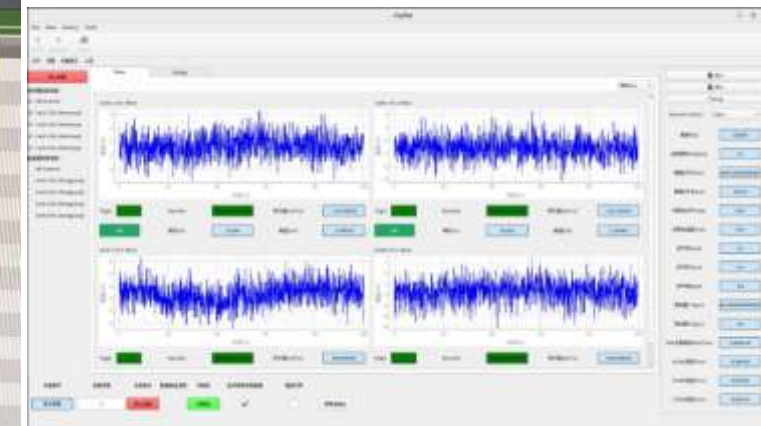
YAG screen



High voltage controlling

Custom	Name	IOSet	VOSet	Mon	VMon	Per
01.000	CHANNEL00	50.0 uA	0.0 V	-0.9 uA	-0.2 V	On
01.001	CHANNEL01	50.0 uA	-23.0 V	-0.5 uA	-22.6 V	On
01.002	CHANNEL02	50.0 uA	-40.0 V	-1.1 uA	-39.8 V	On
01.003	CHANNEL03	50.0 uA	-68.0 V	-0.7 uA	-65.6 V	On
01.004	CHANNEL04	50.0 uA	-91.0 V	-1.0 uA	-90.7 V	On
01.005	CHANNEL05	50.0 uA	-116.0 V	-0.8 uA	-116.2 V	On
01.006	CHANNEL06	50.0 uA	-112.0 V	-1.0 uA	-111.8 V	On
01.007	CHANNEL07	50.0 uA	-117.0 V	-0.8 uA	-116.8 V	On
04.000	CHANNEL00	50.0 uA	-124.0 V	-0.8 uA	-124.1 V	On
04.001	CHANNEL01	50.0 uA	-124.0 V	-1.3 uA	-124.0 V	On
04.002	CHANNEL02	50.0 uA	-130.0 V	-1.3 uA	-130.2 V	On
04.003	CHANNEL03	50.0 uA	-134.0 V	-0.8 uA	-133.7 V	On
04.004	CHANNEL04	50.0 uA	-114.0 V	-0.9 uA	-113.8 V	On
04.005	CHANNEL05	50.0 uA	-141.0 V	-0.7 uA	-140.7 V	On
04.006	CHANNEL06	50.0 uA	-141.0 V	-41.8 uA	-140.7 V	On
04.007	CHANNEL07	500.0 uA	0.0 V	-0.6 uA	0.1 V	On

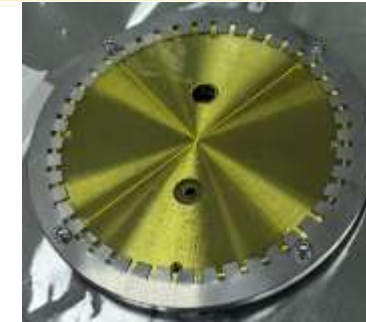
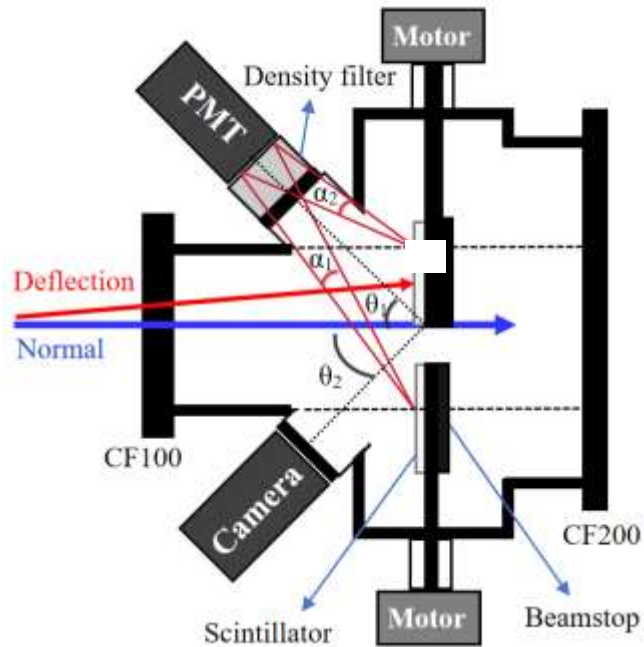
Data acquisition of PES



Beam Lost Monitor (BLM): Principle

Function: Response on the lost photon beam and notify the machine protection system

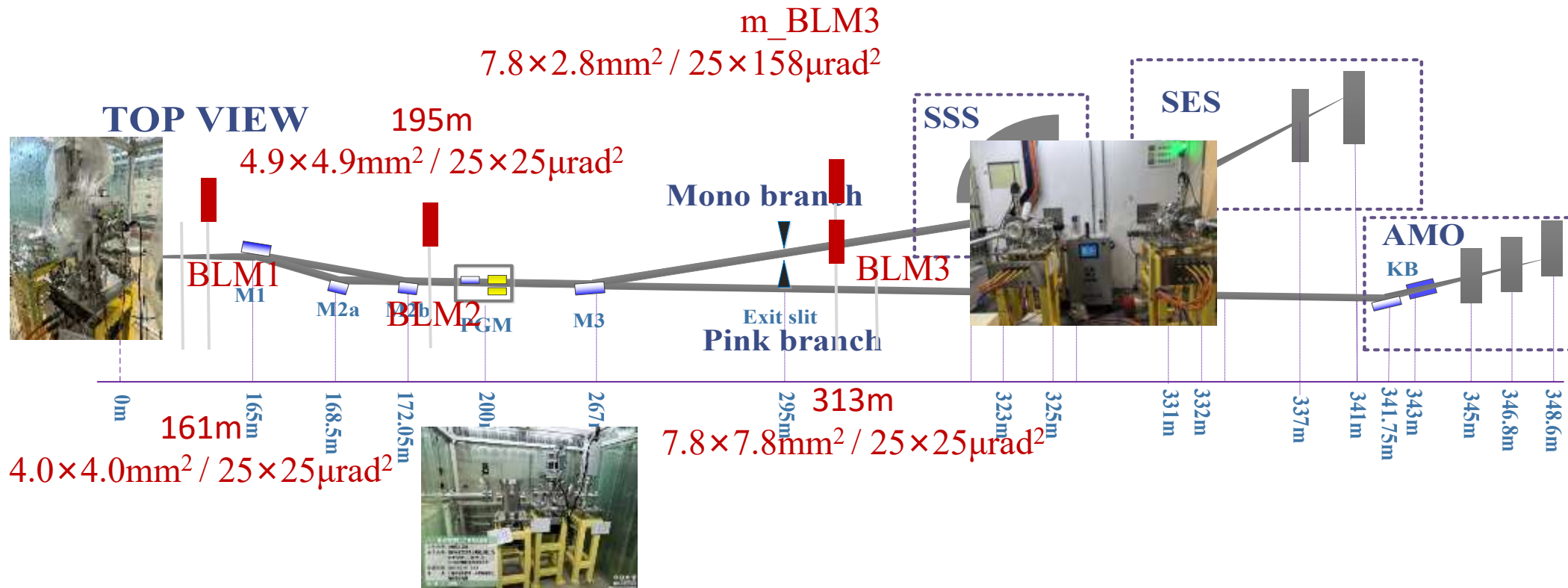
Response time: detecting fluorescence from diamond and response within $10\mu\text{s}$



Schematic diagram of the overall optical design of the BLM system.

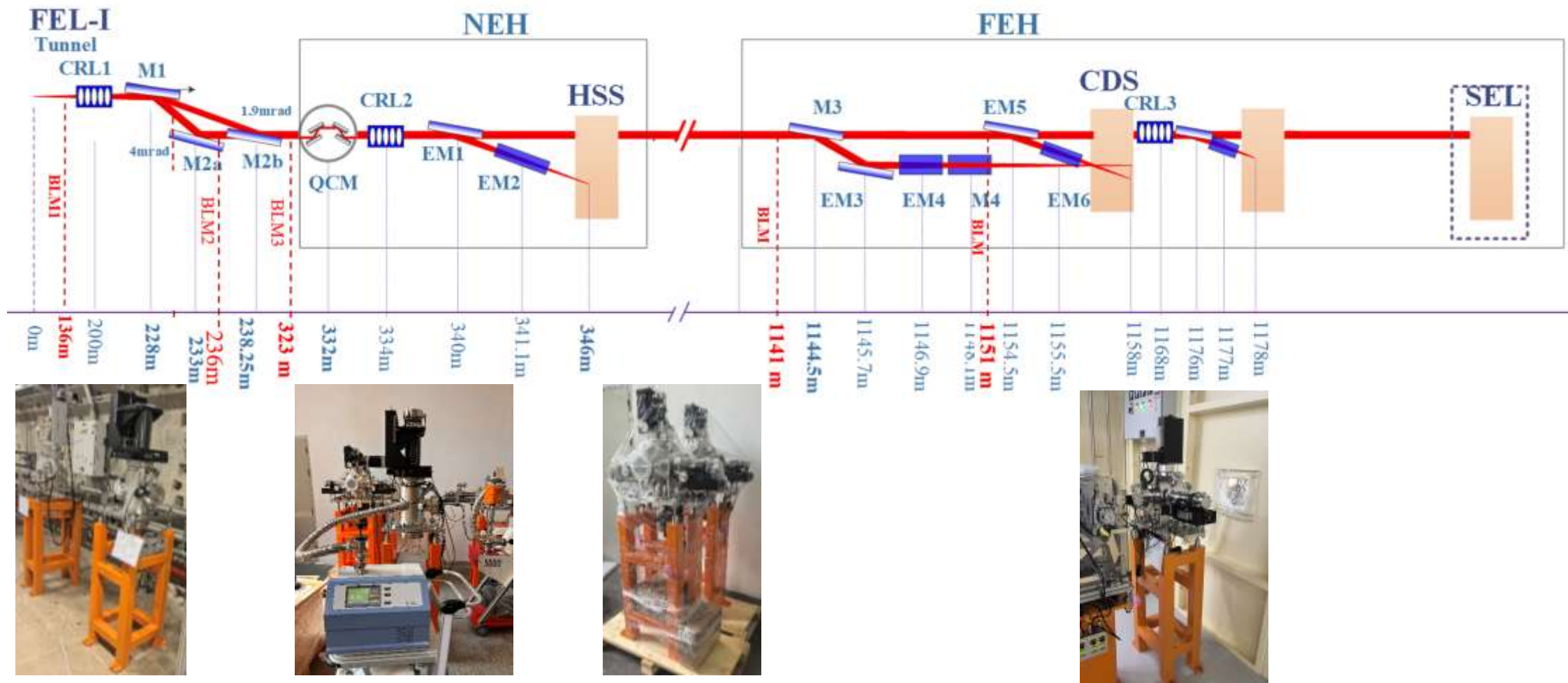


Beam Lost Monitor (BLM): Location



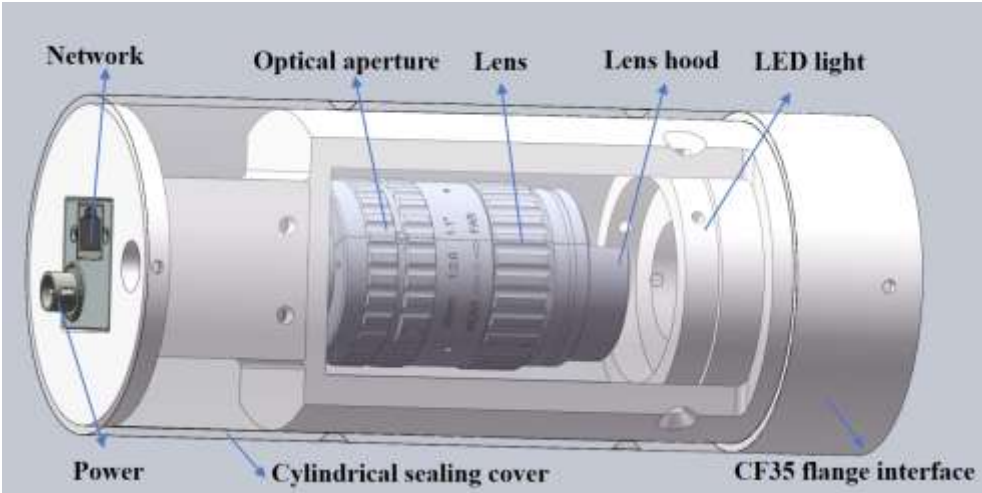
- Four BLMs are installed to monitor the possible lost photon beam in FEL-II in respective.
- The threshold will be measured during beamline commissioning

Beam Lost Monitor (BLM): FEL-I-Location



- Five BLMs are installed to monitor the possible lost photon beam in FEL-I in respective.

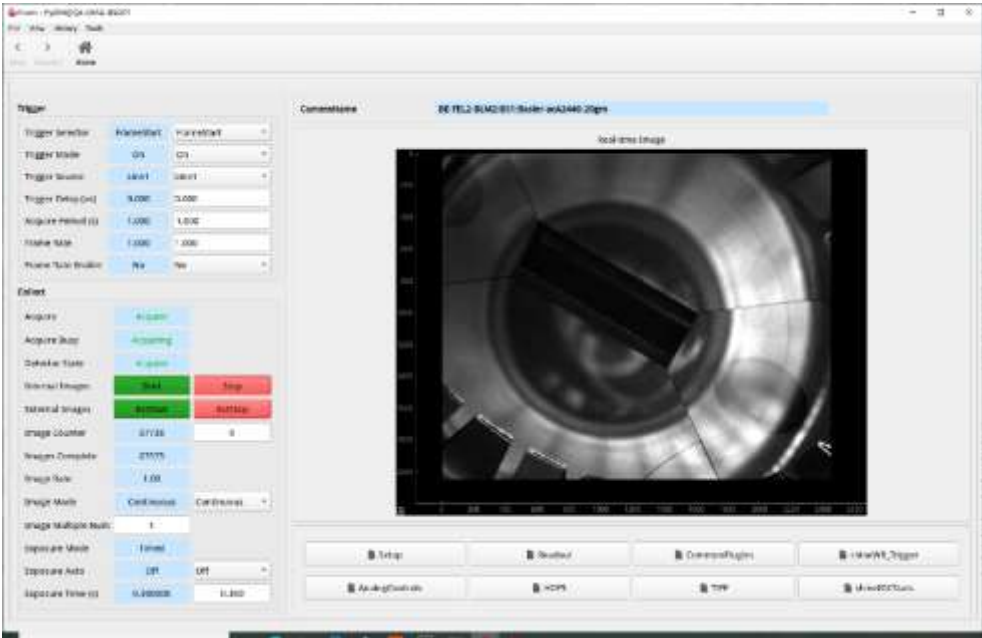
Beam Lost Monitor: FEL-II test



The Baler camera installation bracket.



Neutral attenuator and PMT installation bracket.

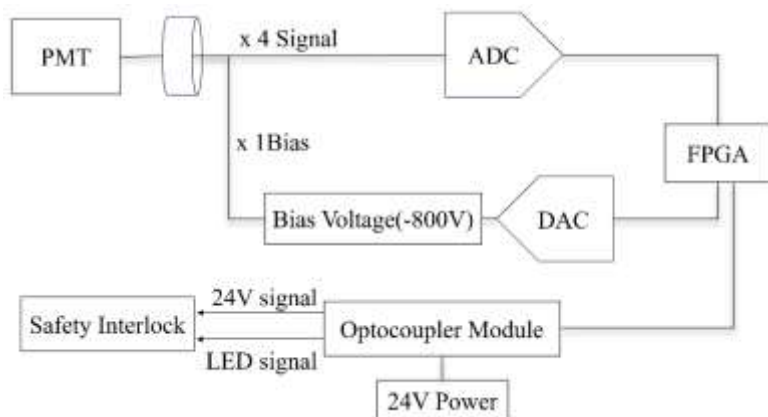


The Basler camera display in control computer.



Neutral attenuator control interface

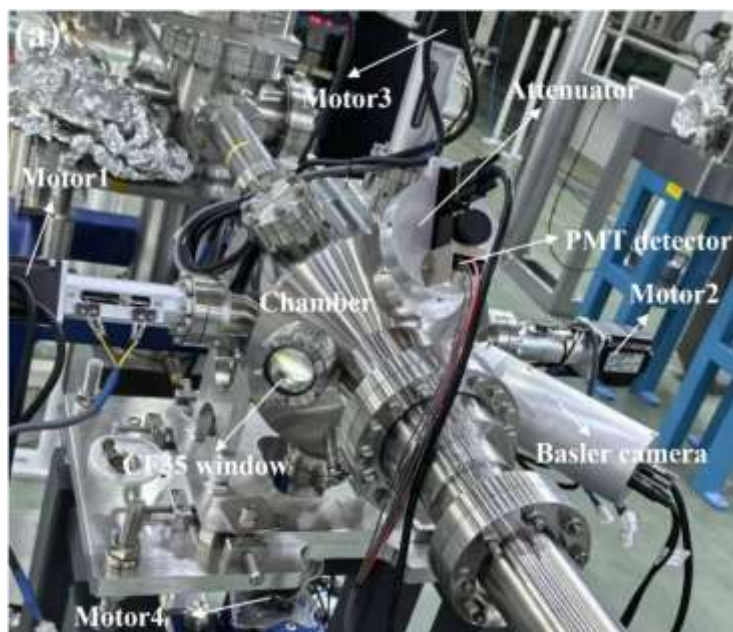
Beam Loss Monitor: SXFEL test



Overview of the BLM ultrafast electronics system.



Electronic system control interface



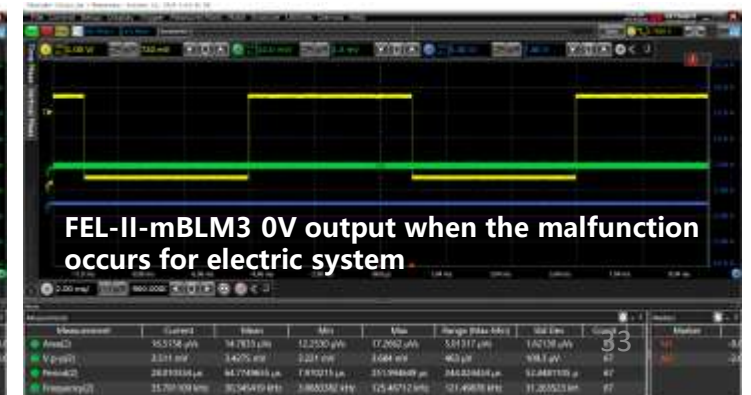
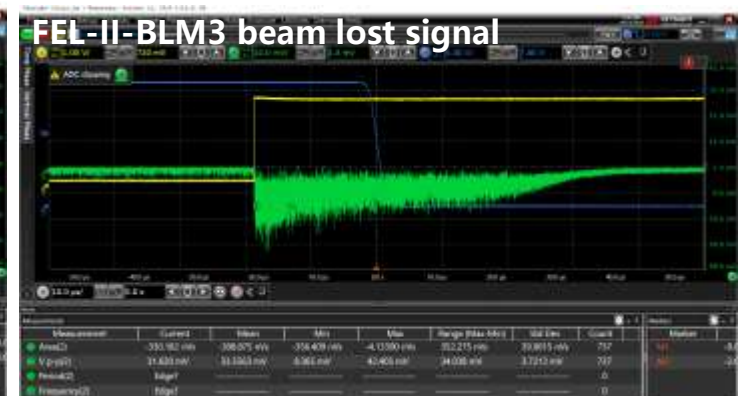
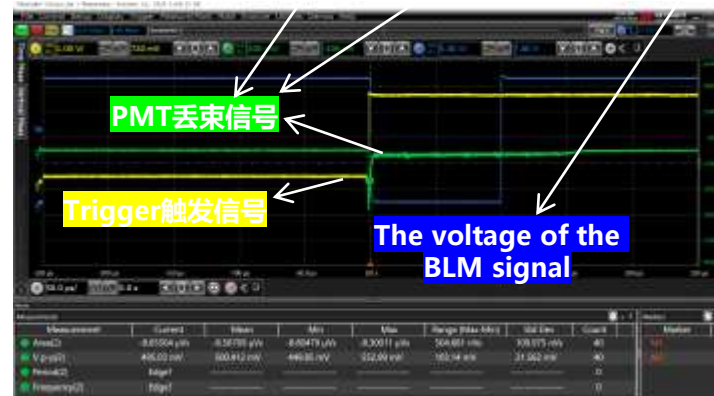
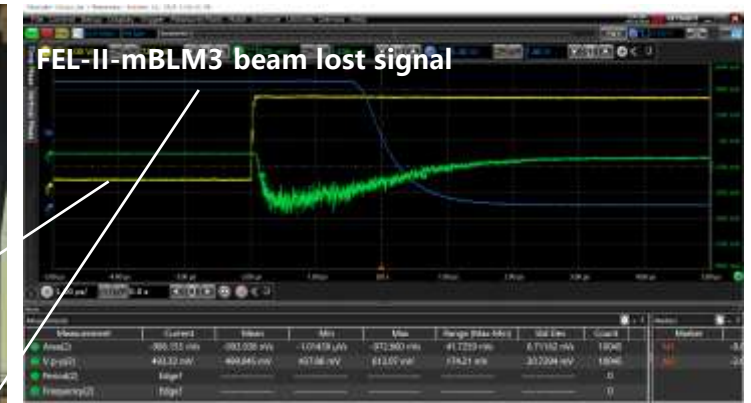
The BLM photo installed at SXFEL beamline.



Test results: Delay time is $[0.50 - 0.55] \mu\text{s}$

Checking and testing of Beam loss monitor (BLM)

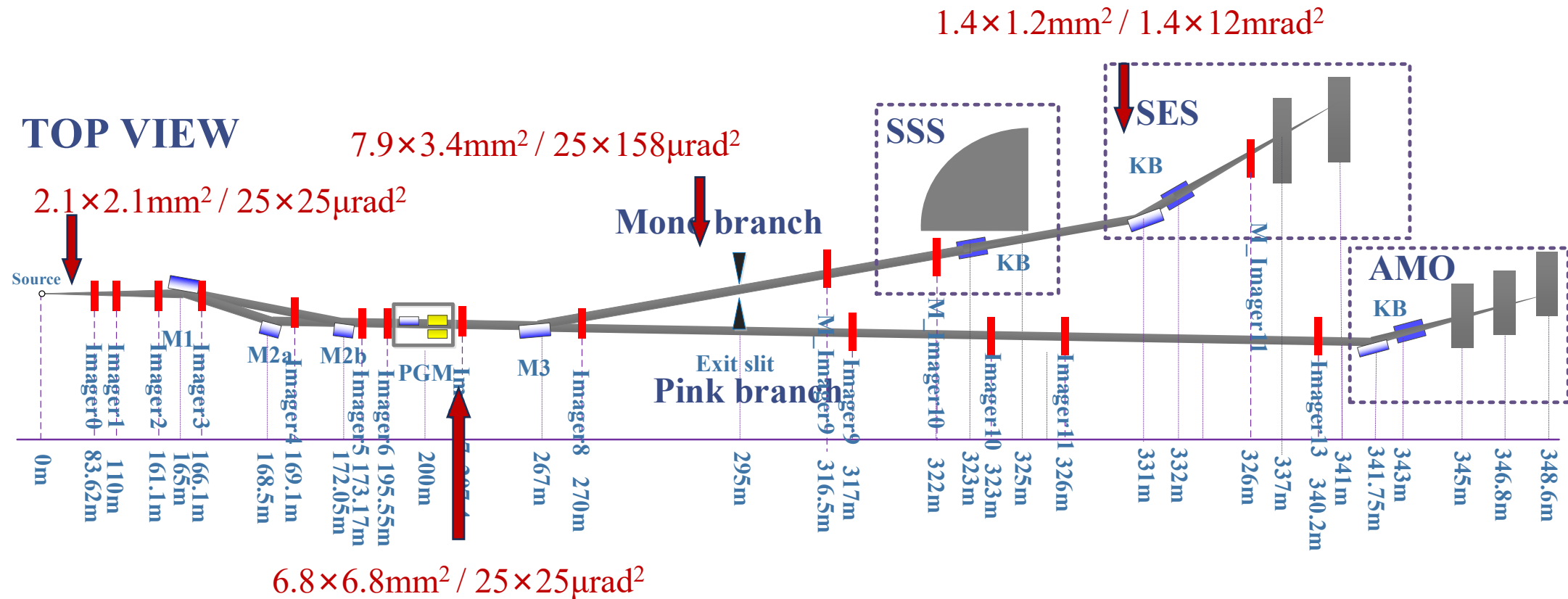
The checking and testing of BLM(1,2,3,m3) of FEL-II beamline includes the motors, the PMT detector, the electronic system and the attenuator etc. have been conducted.



Beam Loss Monitor: Function Test Question

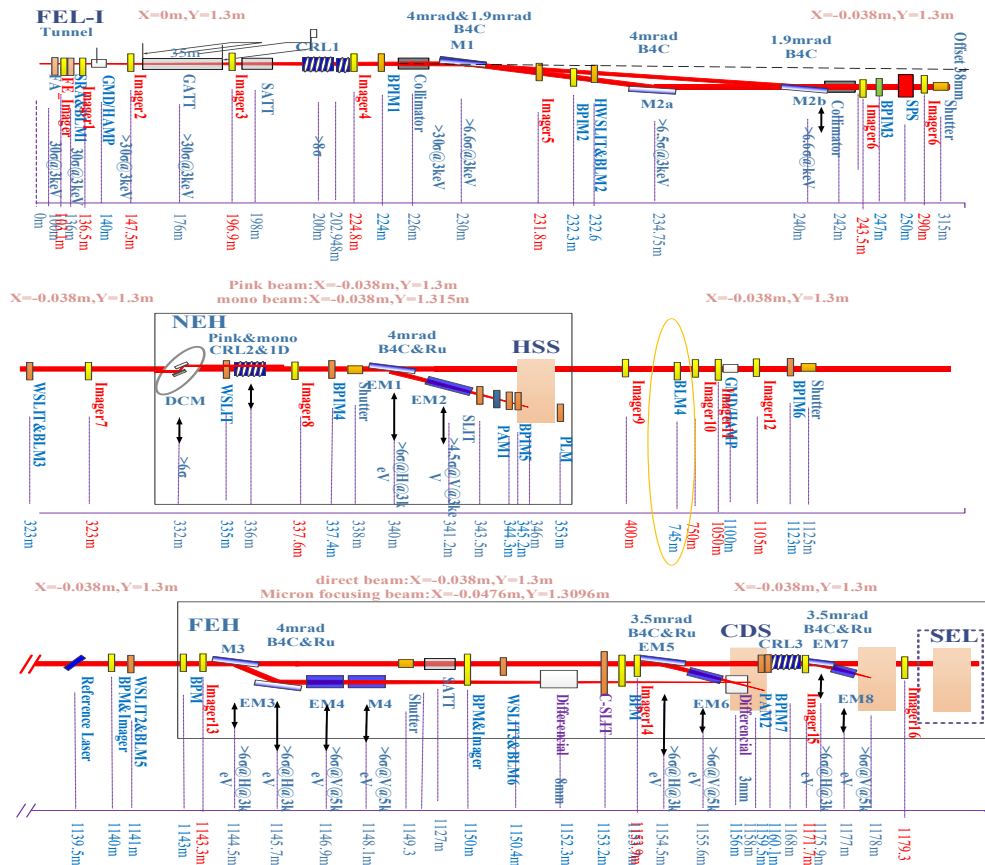
- ◆ What protective means should be typically implemented when the beam lost signal is transmitted to the accelerator via the safety interlock, such as **shut down the photon shutter, lower the repetition rate** etc.?
- ◆ How should the beam lost electronics system provide **the real-time operating status**, including **abnormal PMT readings, high voltage status, and FPGA and 24V beam loss module faults** be displayed?
- ◆ How often should the beam loss monitor function be **self-tested**, and what specific measures should be taken: slowly **inserting the scintillator** into the optical path, or **deflecting the upstream mirror** for trigger detection?

Imager: Location



- ❑ There are 14 imagers in the beamline, There are 19 imagers in the FEL-I beamline
- ❑ There is an imager after every mirror and aperture which may cut beam

Imager@FEL-I beamline: Location



Installed @ FEL-II



Installing scintillator
inside clean hutch

- ❑ The Installation of Imagers in FEL-II has been completed.
- ❑ Imagers of FEL-I will be commissioned in this year.

Checking and testing of Imager

➤ Checking and testing of Imager:

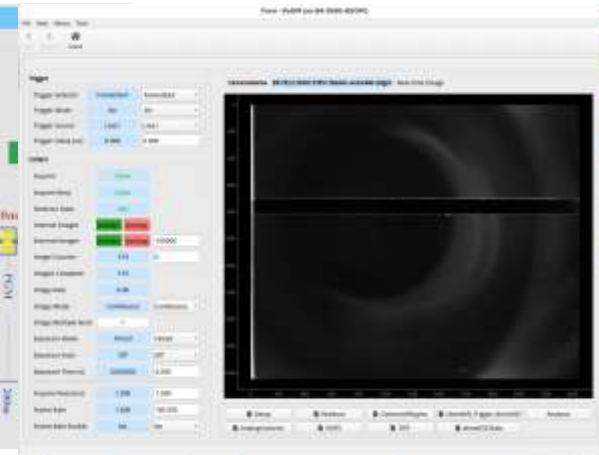
1. Checking and testing of the motors.
2. Checking of YAG screen.
- 3, Checking of Remote Camera & Lighting Switch Control.
5. Data acquisition for Imager

Functional testing has been completed for FE Imager 1, 2, 3, 4, 5, 6, 7, 8, and 10, with data acquisition confirmed normal. Some imagers require field-of-view adjustment; additionally, the X and Y coordinates should be swapped during display to standardize the imaging orientation across all imagers.

Imager DAQ



Imager screen



Camera and Lighting Control

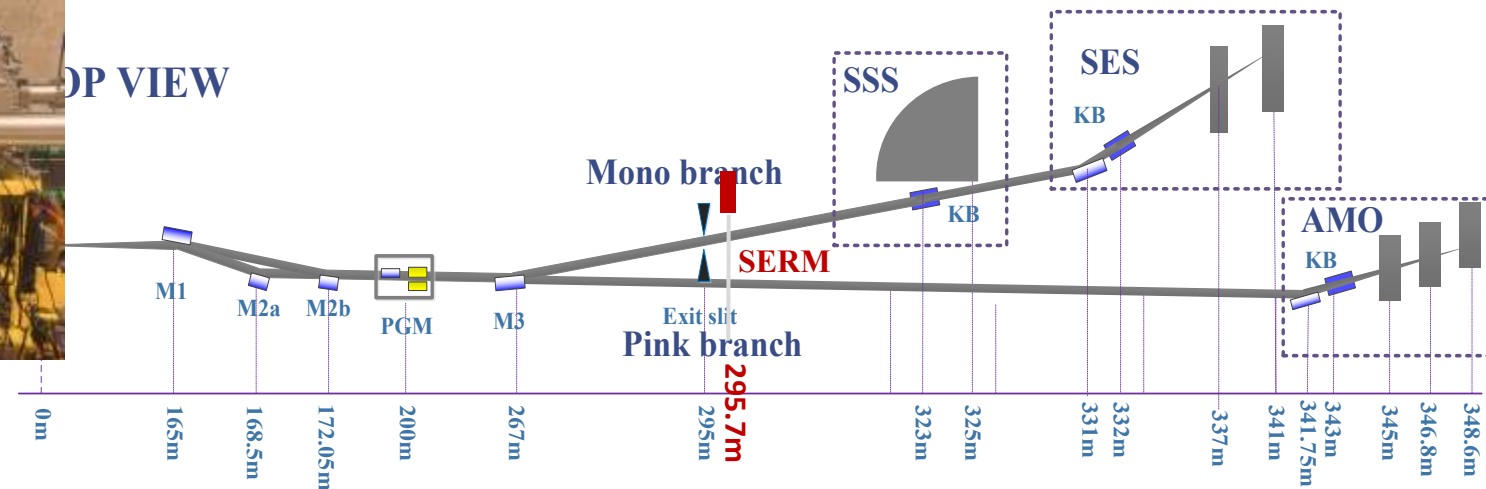
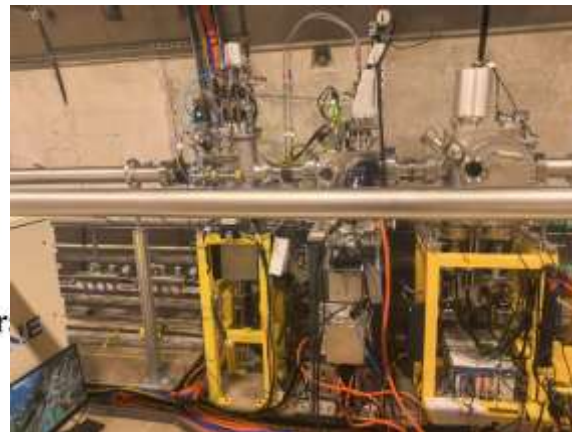
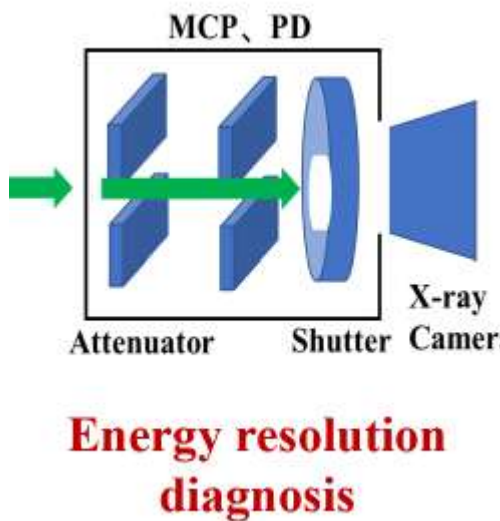


Soft X-ray Energy resolution diagnosis (SERM)

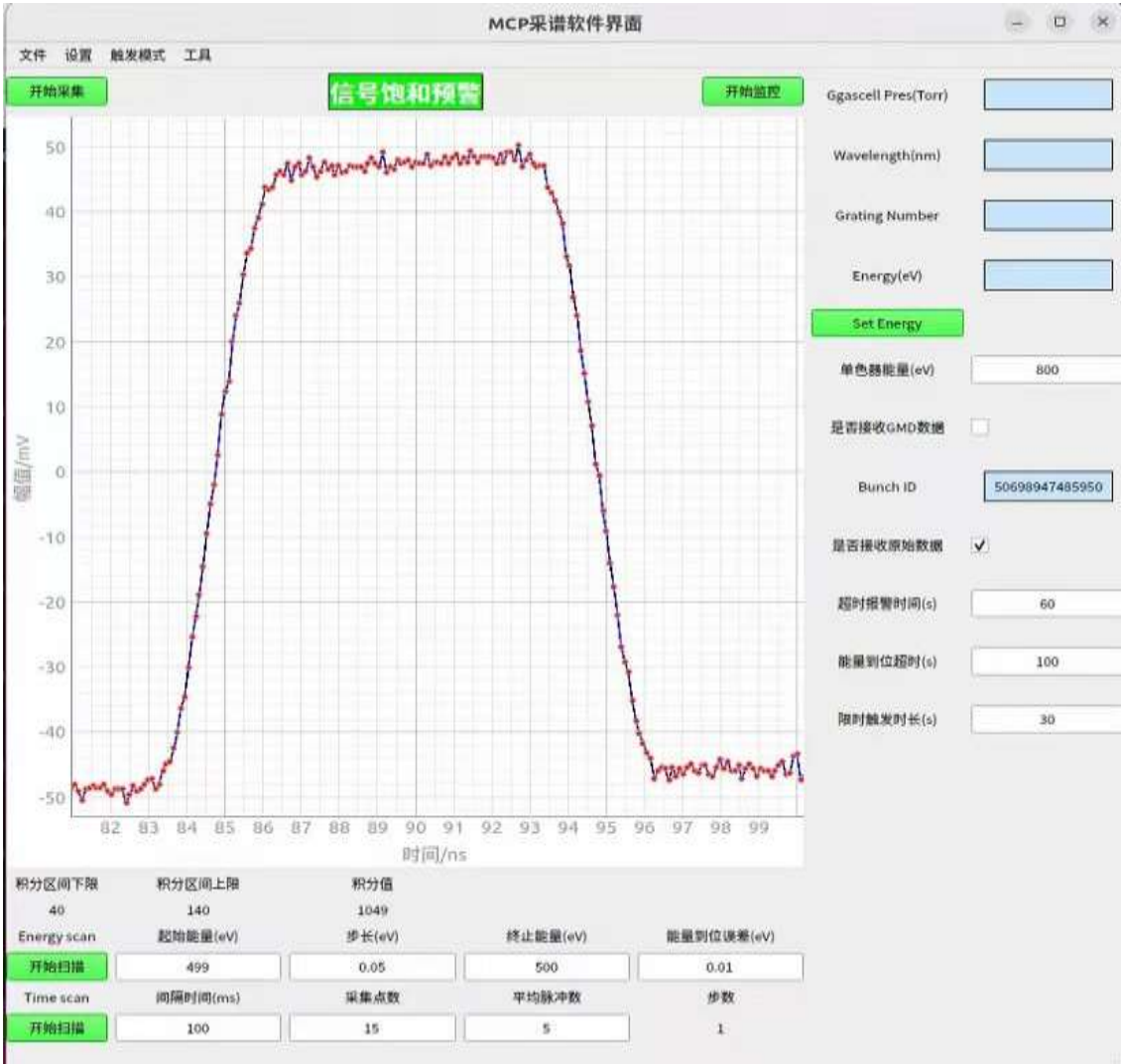
Function: Measuring the beamline energy resolution

Specification: $E/\Delta E = 10000 @ 867\text{eV}$

- ❑ Fill Ne gas (pressure~10.5 mTorr, length 20m, transmission~80%) into the gas attenuator
- ❑ Measure the Ne absorption spectra using MCP adjacent to the exit slit
- ❑ Fit the absorption spectrum to obtain energy resolution $E/\Delta E$, assuming Ne natural width is 0.25eV



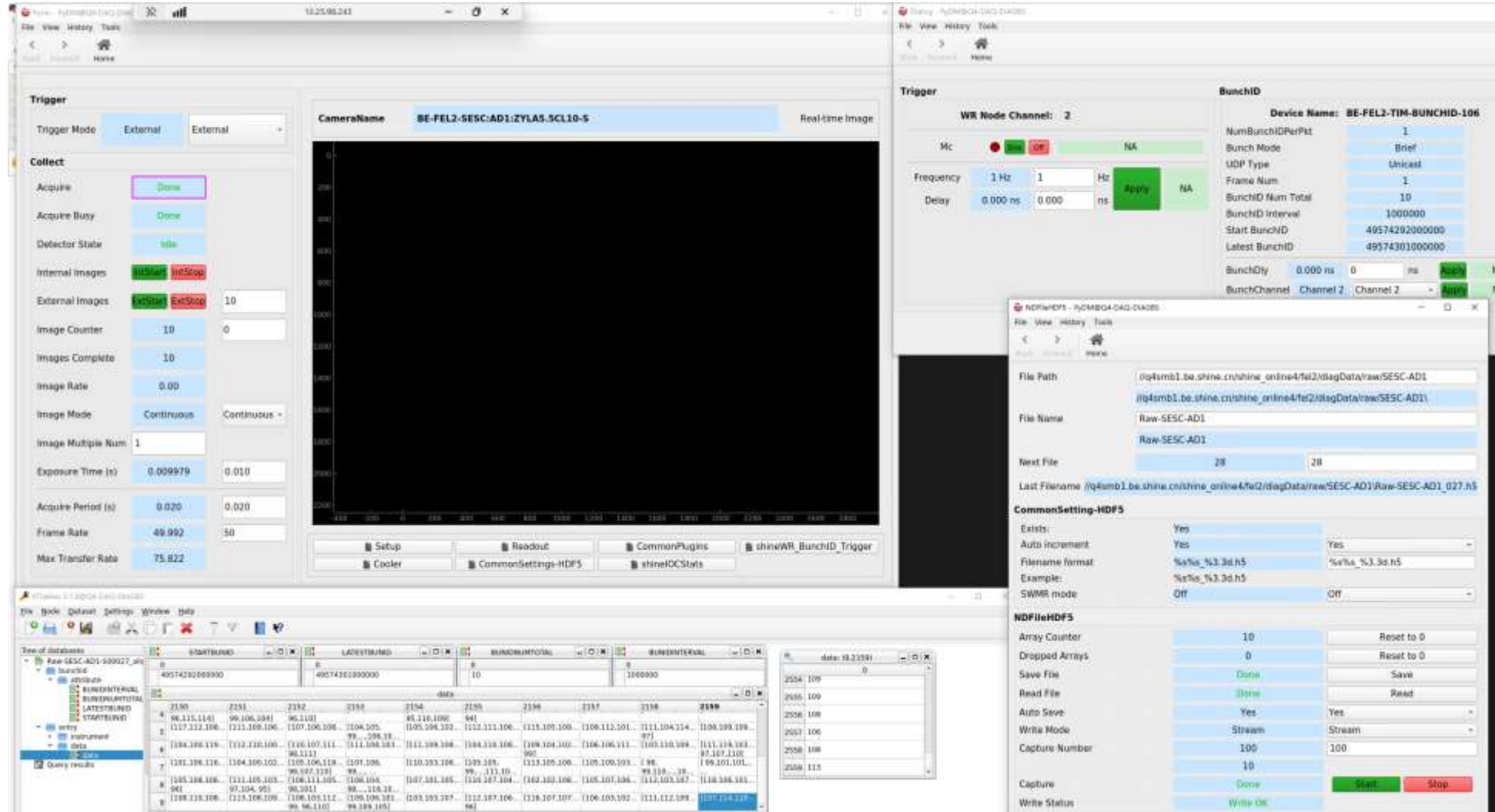
Soft X-ray Energy Resolution diagnostics (SERM) software



Including two modes: **energy scanning** and **time scanning**. Raw waveform acquisition is available

A YAG crystal and an Basler camera are used to determine the Beam position.

Soft X-ray Energy Spectrum Calibration (SESC) software



Function: Single-pulse energy spectrum and multi-pulse energy spectrum acquisition

Checking and testing of Soft X-ray Energy Resolution diagnostics (SERM)

➤ Checking and testing of SERM:

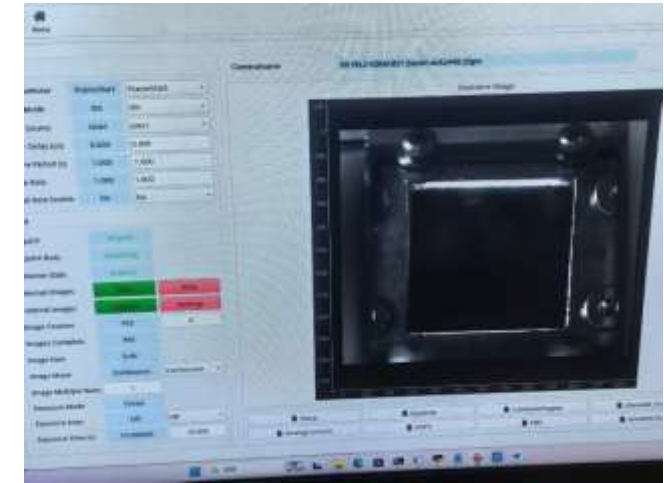
1. Checking and testing of the motors.
2. Checking of YAG screen.
3. Remote controlling of high voltage for MCP detector.
4. Data acquisition for SERM.

The testing has been completed and can fulfill the requirements of on-line testing (Sep. 17, 2026).

Motor controlling



YAG screen



Remote controlling of high voltage



Data acquisition of SERM



Checking and testing of Soft X-ray Energy Spectrum Calibration (SESC)

➤ Checking and testing of SESC:

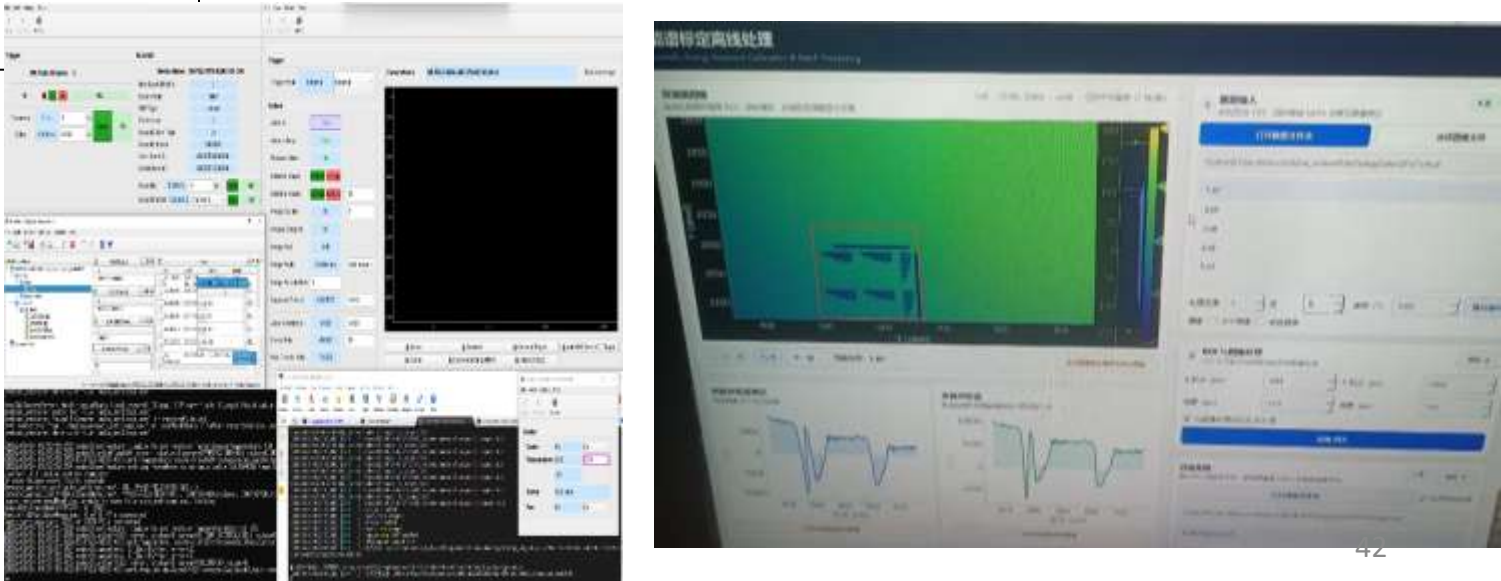
- 1. Checking and testing of the motors.
- 2. Checking of YAG screen.
- 3. Data acquisition for SESC.

The testing has been completed and can fulfill the requirements of on-line testing (Sep. 17, 2026).

Motor controlling



Data acquisition and processing of SERM



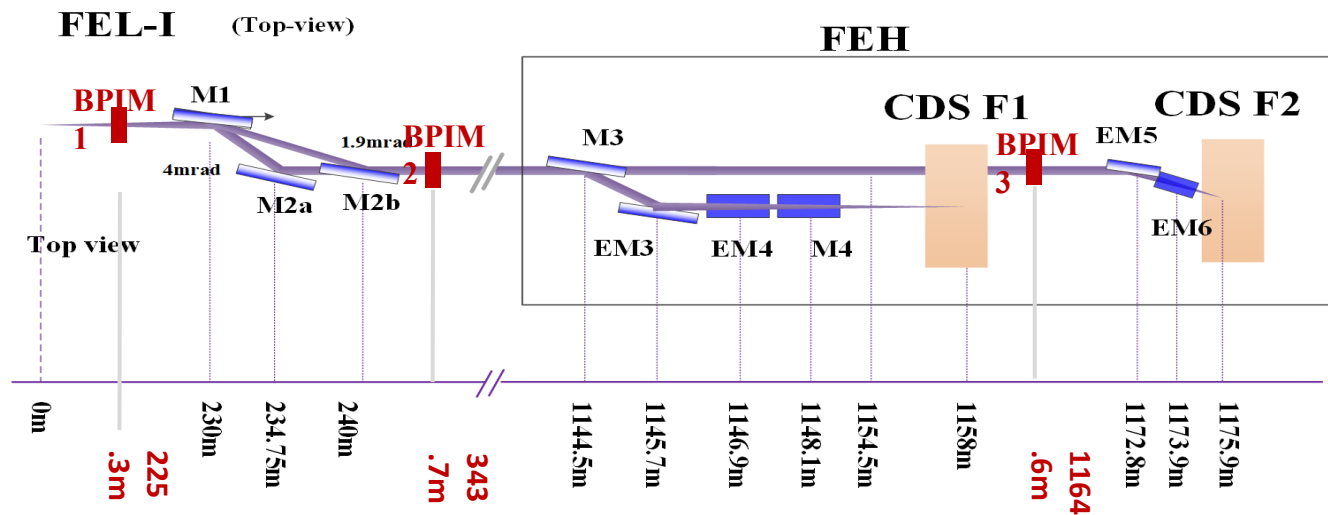
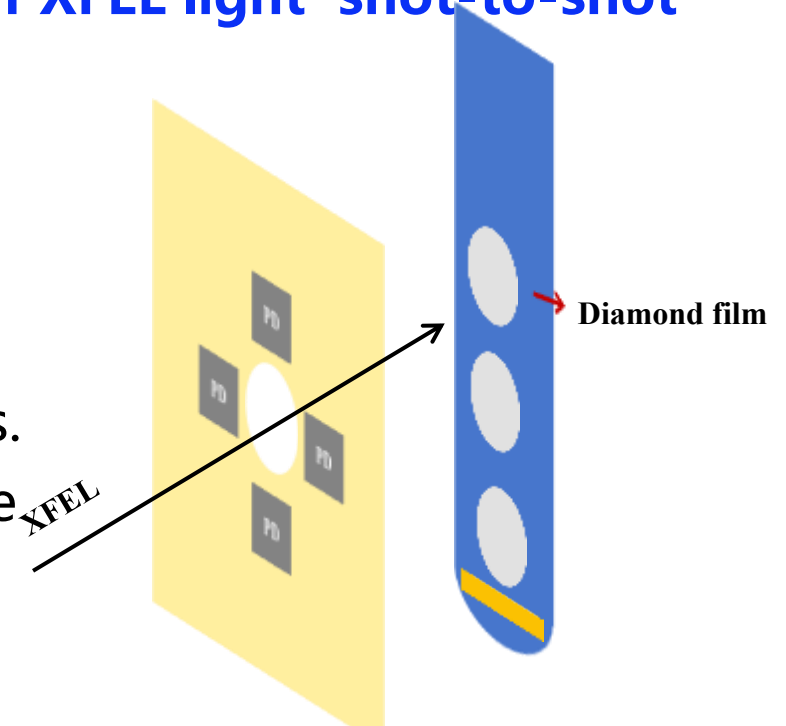
Beam-position and Intensity monitor (BPIM)

Function: Measuring the position and the relative pulse flux of XFEL light shot-to-shot

Specification: Position measurement accuracy $\leq 30\mu\text{m}@7\text{keV}$

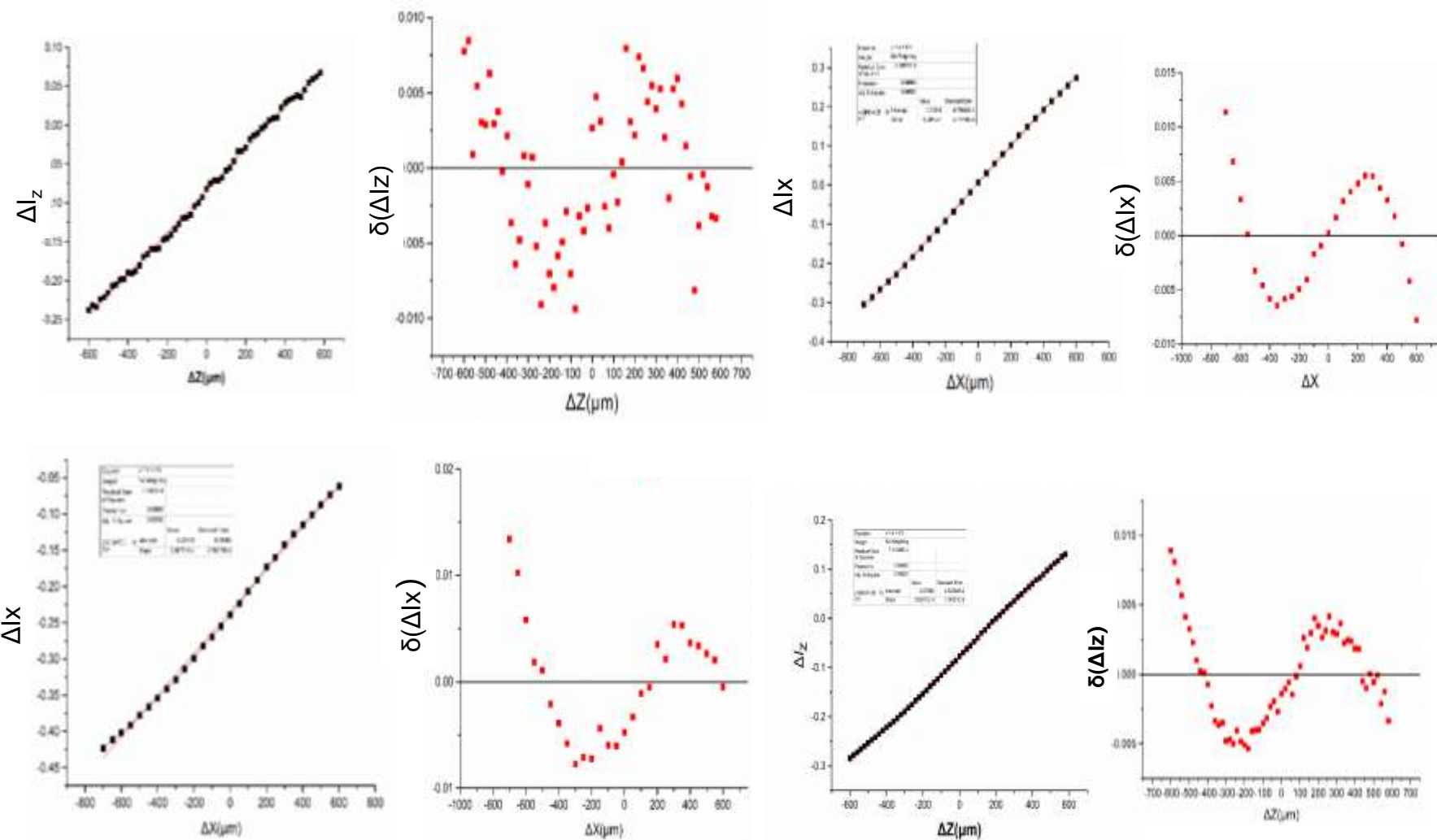
Principle:

1. BPIM uses a thin membrane made of diamond to incoherently backscatter a portion of the photons in a pulse onto four diodes.
2. The signal on the four diodes is used to measure the relative pulse flux, beam position on a shot-to-shot basis



BPIM: Installation and Testing @SSRF

Position measurement
accuracy $<20\mu\text{m}@7\text{keV}$



Microcrystalline diamond

Nanocrystalline diamond

BPIM Software: Beam Position and Relative Intensity monitor



Beam position

Commissioning plan of the diagnostic tools(11 days)

Beamline (26 days)

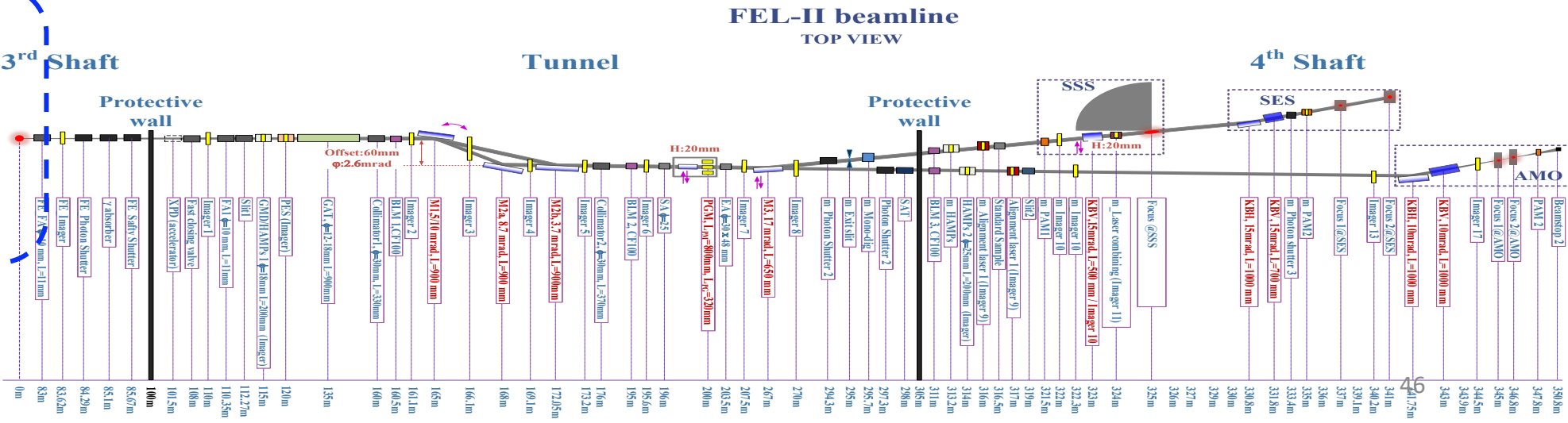
Front-end	2 days	The beam passes through FE_Imager, Imager1, GMD/Hamps, and GAT to reach Imager2	Spot can be observed on Imager2
M1/M2a+ AMO-KB	1 day	The beam reaches AMO-KB through M1, M2a. The PGM will be moved out of the beam path here.	Spot can be observed at AMO
PGM(ECM) + M3	2 days	The beam passes through the PGM and M3. The ECM in the PGM will be moved in the beam path.	Spot can be observed on Imager 7/8
SES-KB	1 days	The beam reaches SES-KB	Spot can be observed at SES
AMO-KB	8 days	Commissioning of AMO-KB	Spot size < 50 μm @F2 & F1
SES-KB	4 days	Commissioning of SES-KB	Spot size < 50 μm @F1
GAT	3 days	Test the proportional relationship between gas pressure and attenuation factor.	
Energy resolution	4 days	Measure the energy resolving power of the monochromator at the Ar edge.	

Diagnostic Equipment

Imager	11 days
GMD / HAMPs	
PES	
BLM	

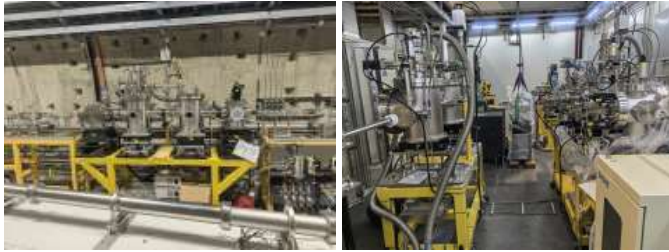
Endstation (9 days)

AMO	5 days
SES	2 day

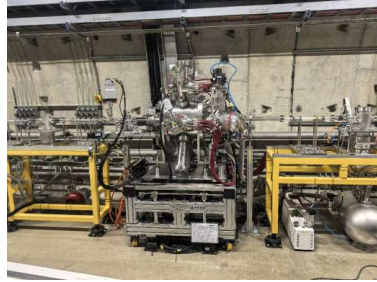


Test of diagnostic tools will be conducted and fullfill the requirements of beamline comissioning

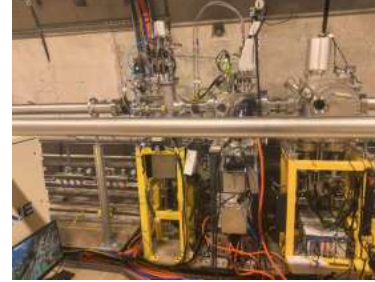
XGMD+HAMPs



PES



SERM&SECS



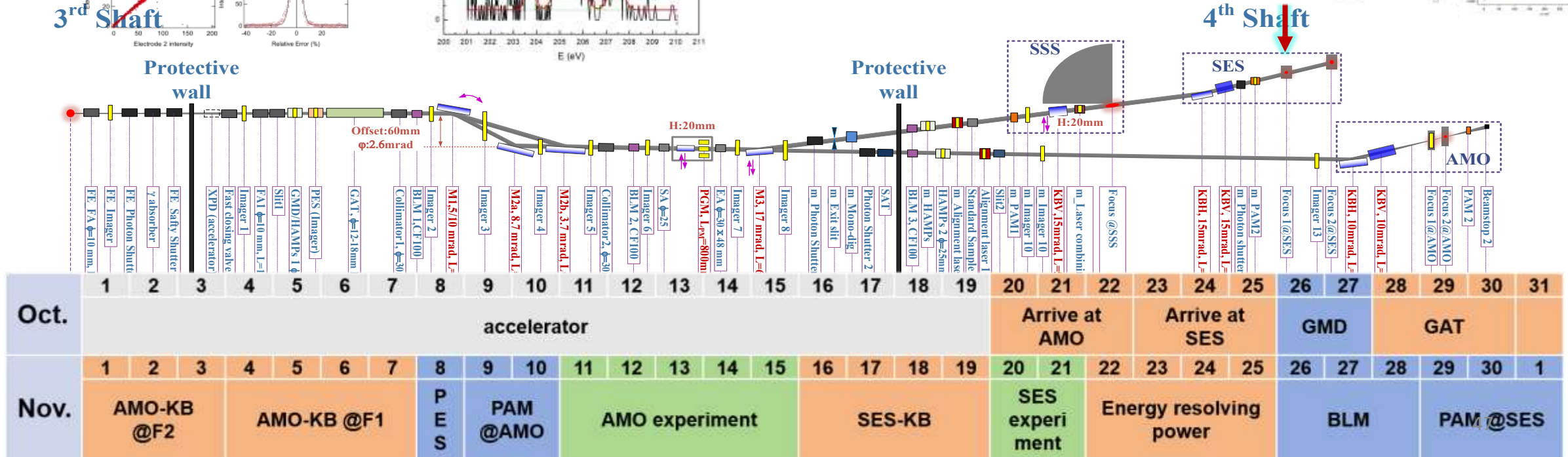
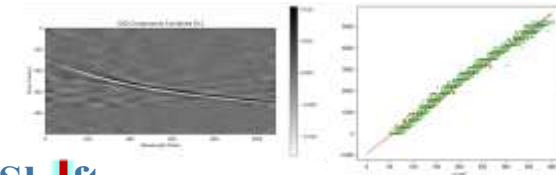
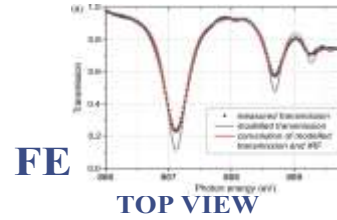
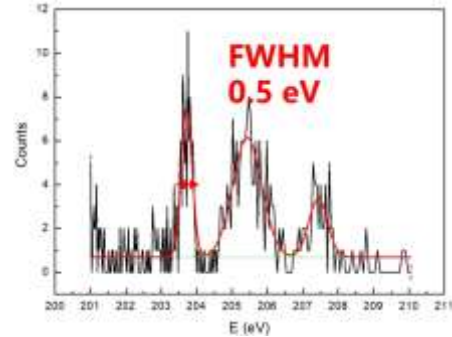
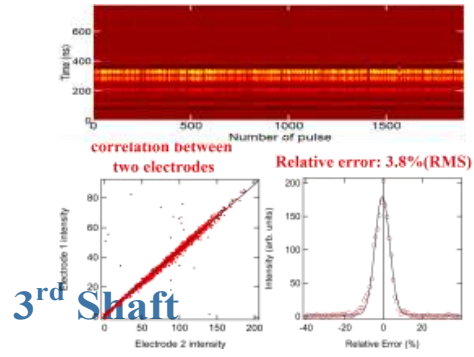
Imager



BLM



PAM



Summary

- There are 9 types of diagnostic tools pulse energy and time, beam position and size, energy spectrum and wavefront.
- The installation of diagnostic system for FEL-II has been finished in Sep. 2026.
- The installation of diagnostic tools for FEL-I will be completed in Oct. 2026.
- Checking and testing of the diagnostic tools show that the capabilities for their hardware and software can fulfill the requirements.

	Diagnostic tool	Experimental requirements	Main Specification	installation progress
1	Pulse energy diagnostic (GMD + HAMPs)	Pulse energy: 1-3000 μJ	$\leq 10\%$	completed for FEL-II off-line testing for FEL-I
2	Pulse arrival monitor (PAM)	Jitter: ≤ 35 fs	≤ 15 fs RMS	completed for FEL-II
3	Talbot Wavefront Sensor	Beam size: ≤ 10 μm	$\leq \lambda/50$	will be completed in Feb. 2027
4	Photoemission Spectrum (PES)		≤ 0.5 eV	completed
5	Imager		≤ 30 μm	completed for FEL-II
6	Beam loss monitor (BLM)		Response time ≤ 10 μs	will be completed in April
7	Energy resolution measurement	ΔE : ~ 150 meV	$\Delta E \leq 86.7$ meV @867 eV	will be completed in April

Acknowledgement

□ Team members

Dr. Yong Wang, leader of beamline and diagnostic technology.

- PAM: Zhi Guo, Xiangzhi Zhang, Chi Zhang
- Wavefront Sensor: Xiangyu Meng, Junchao Ren, Zhi Qiao, Yajun Tong
- GMD + HAMPs: Mao Ye, Jishan Liu
- Imager: Huachun Zhu
- BLM: Haigang Liu
- PES: Junqin Li, Yamei Wang
- Energy resolution diagnosis: Huaina Yu, Fangyuan Zhu

□ Thank Engineer Department (Jiahua Chen, et. al.) and Experimental Assistant Department (Ping Huai, et.al.)

□ Control, alignment, vacuum, etc.

□ Data management, network, etc.

□ Thank a lot for the assistance from Prof. Jan. Gruenert, Prof. Kai Ji, Dr. Liu Jia et.al.



Thank you for your attention!

