SHINE

Timing and DAQ
for Beamlines and End-stations

Speaker: Congcong Yin

On behalf of Data Acquisition and Analysis Group

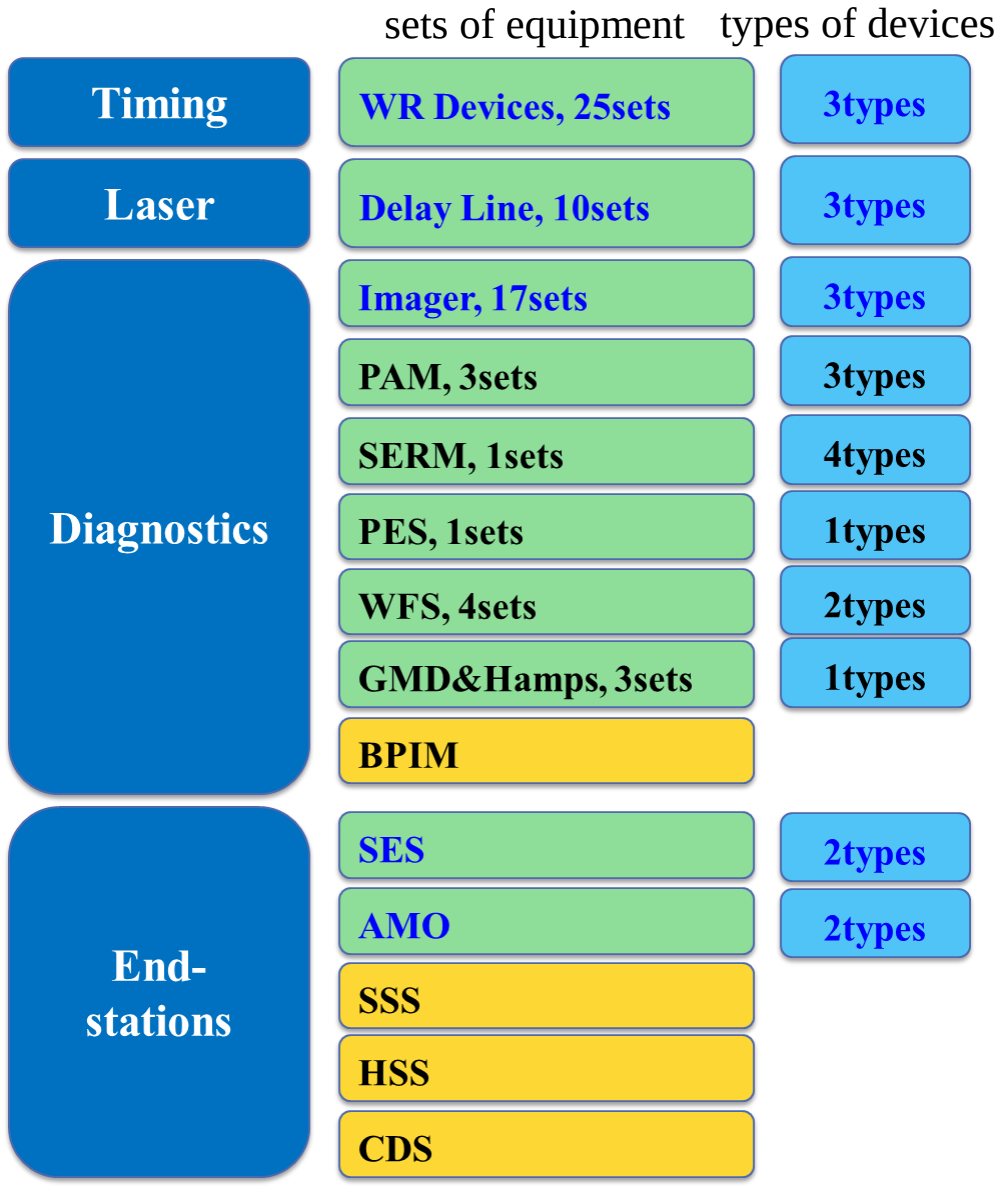
Oct. 23, 2025

Outlines

- Requirements & Design
- Timing System Progress
- DAQ Software Progress
- Commissioning Plan

DAQ Requirements for Beamlines and End-stations

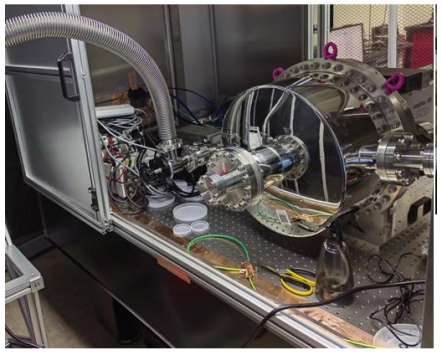
- Timing, pump-probe laser, optical diagnostics, end-stations
- **>24 types** of devices
- User-friendly integrated GUI for beamline devices
- High level control software for end-station instruments
- Integration of end-station scientific data and various diagnostics data with respect to Bunch-ID at rates up to **100kHz**
- EPICS interface to accelerator and environmental data

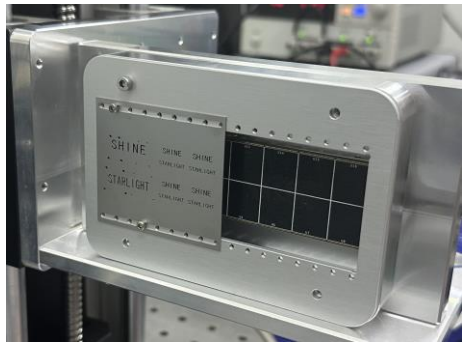


DAQ Requirements for Beamlines and End-stations

☐ Critical detectors

Type	Function	Frame size	Frame rate	Data rate
JUNGFRAU	Imaging & crystallography	2048×2048	2.2kHz	**18.4GB/s**
STARLIGHT (in progress)	Imaging & crystallography	1024×1024	10kHz	**~20GB/s**
CMOS Pixel Detector	Spectroscopy	2048×2048×2	70Hz	**~1.1GB/s**
fADC	MCP DAQ	10GSPS×4×2	**100kHz**	**~4GB/s**
ML camera	Photon Diagnostics (Pulse Arrival Monitor)	16k×4×2	**100kHz**	**~9.6GB/s**


JUNGFRAU


STARLIGHT Single Module

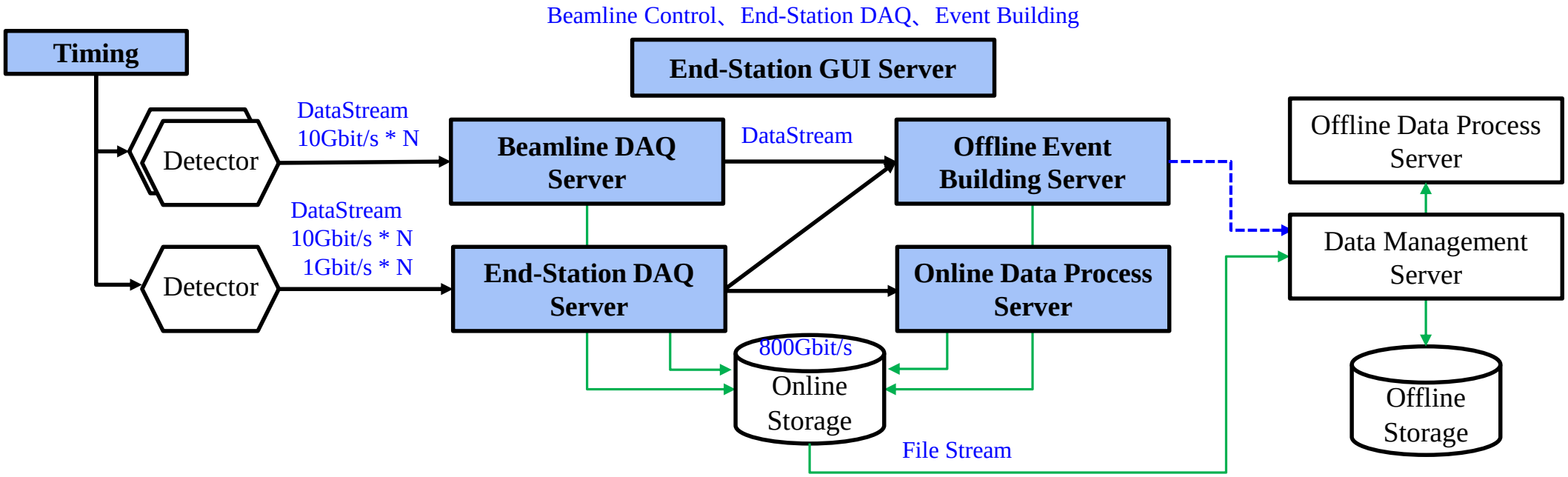
CMOS Pixel Detector


fADC


ML Camera

DAQ Design Principles

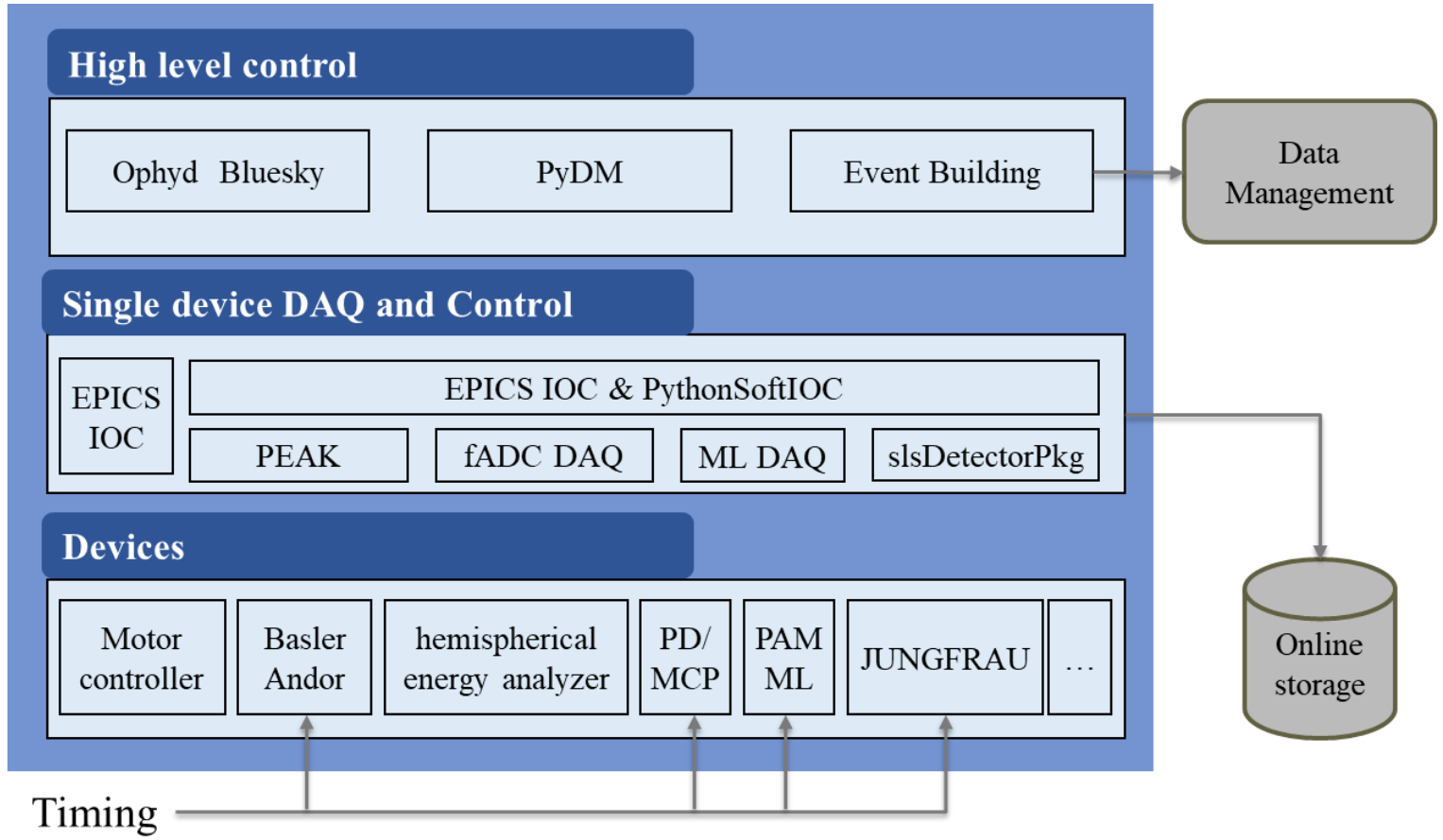
- **Trigger and Bunch-ID** provided by timing system
- **Each device** has its own DAQ server and GUI for diagnostic and end-stations
- All data are saved to **online storage simultaneously** during experiment in **HDF5 format**



DAQ server, Storage and Data Management are supported by Data Management System.

Architecture of DAQ Software

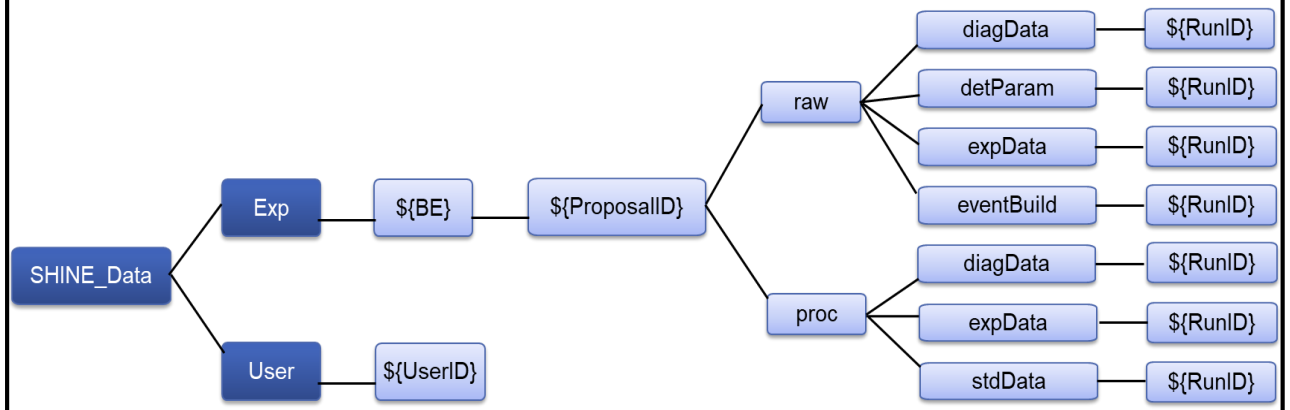
- All control parameters and online monitoring data in the form of **EPICS PVs**
- High level control software based on **Bluesky**
- **GUI** based on **PyDM**
- **Event building module** packages experimental and diagnostic data with respect to Bunch-ID and interfaces with Data Management



Unified Storage Standard

- Design a unified directory structure and file-naming to support data management
- Establish a unified control-signal naming scheme

unified directory structure



{BE}: AMO, SSS, SES, HSS, CDS, SEL, FEL1, FEL2
{ProposalID}: experimental ProposalID, beam tuning ProposalID
{RunID}: Each DAQ start-to-end cycle constitutes one run

file-naming:
${RAW/CORR/PROC}-${RunID}-${DeviceName}-${FileIndex}
For example:
RAW-R0001-JUNGFRAU00-S00000.h5

control-signal naming:
AA-CC-DD:EE-FF-NN:XXX-YYY-ZZZ
AA: Division code
CC: Beamline code
DD: System code
EE: Integrated-equipment code
FF: Device code
NN: Device sequence number
XXX-YYY: Specific signal name
ZZZ： Indicate signal type or function

Summary of Timing and DAQ

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Focus on FEL-II timing, pump-probe laser, diagnostics and end-stations in 2025

- Timing hardware and timing optical fibers have been deployed.
- Eight programs are developed according to plan, with most now at the deployment stage.
- Two company-developed diagnostic programs are underway and will be integrated into the DAQ system.

	software	requirements discussion	solution design	software development	testing	integration testing with timing	deployment	Progress
Timing	Timing Software	completion	completion	completion	completion	completion	completion	88%
Laser	Laser Delay Line Control	completion	completion	completion	completion	N.A.	in progress	70%
End-stations	SES TAP DAQ	completion	completion	completion	completion	completion	in progress	85%
	AMO TDC DAQ	completion	completion	completion	completion	completion with timing, in progress with Event Building	in progress	70%
	SSS DAQ	in progress						5%
	HSS DAQ	in progress				completion		5%
	CDS DAQ	in progress				completion		5%
Diagnostic	Imager DAQ	completion	completion	completion	completion	completion		80%
	PAM DAQ	completion	completion	extension development	in progress	completion		70%
	WFS DAQ	completion	completion	in progress		N.A.		10%
	SERM DAQ	completion	in progress			completion		10%
	BPIM DAQ	completion	in progress			completion		15%
	Spectrometer Control	completion	completion	in progress		N.A.		5%
	PES DAQ(support)	completion	completion	N.A.	N.A.	completion		80%
	GMD&Hamps DAQ(support)	completion	completion	N.A.	N.A.			50%
Integration	Event Building Software	completion	completion	completion	completion	in progress with endstation DAQ and DMS	completion	80%
	Integrated GUI for Beamline							0%
	Achive Application, Autosave, ProcServControl, IOCStats…	completion	completion	completion				60%

Outlines

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- **Timing System Progress**
- DAQ Software Progress
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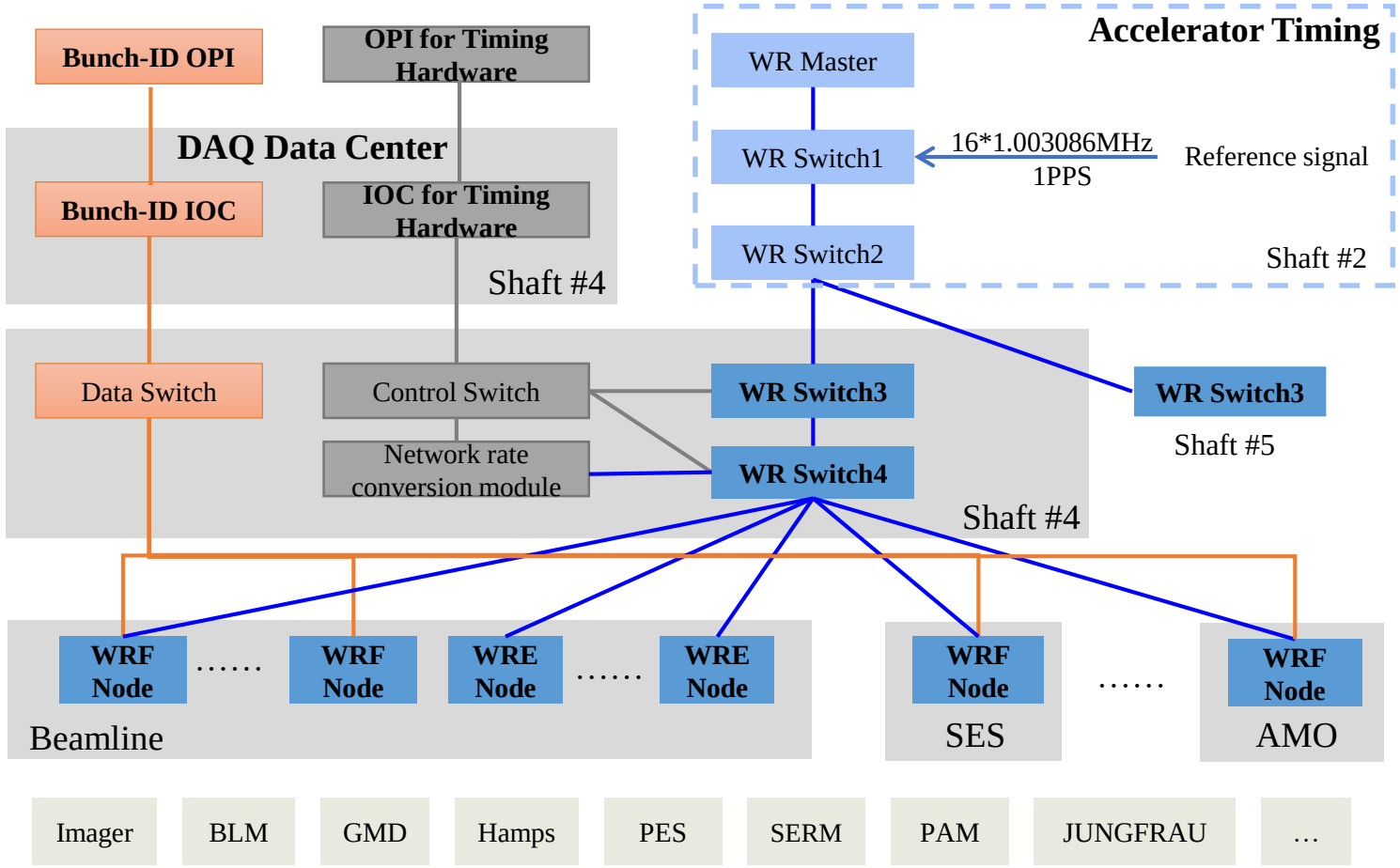
Architecture of Timing

- **White Rabbit(WR) Timing System**: synchronization with sub-nanosecond accuracy and picosecond jitter
- **Bunch-ID Data Acquisition**: supporting commercial detectors via **WR node firmware** and **an integrated software stack**
- **Timing Device Control**: providing comprehensive monitoring and parameter configuration



Timing Devices and Parameters

- **Timing Devices**: Due to SHINE special operating frequency, hetero-frequency WR devices have been co-developed, including WRS, WRF Node, WRE Node.
- **WRF Node:** SMA interface, 3VTTL@50Ω, 3VTTL@10kΩ, 5VTTL@50Ω, and 5VTTL@10kΩ.

WRS

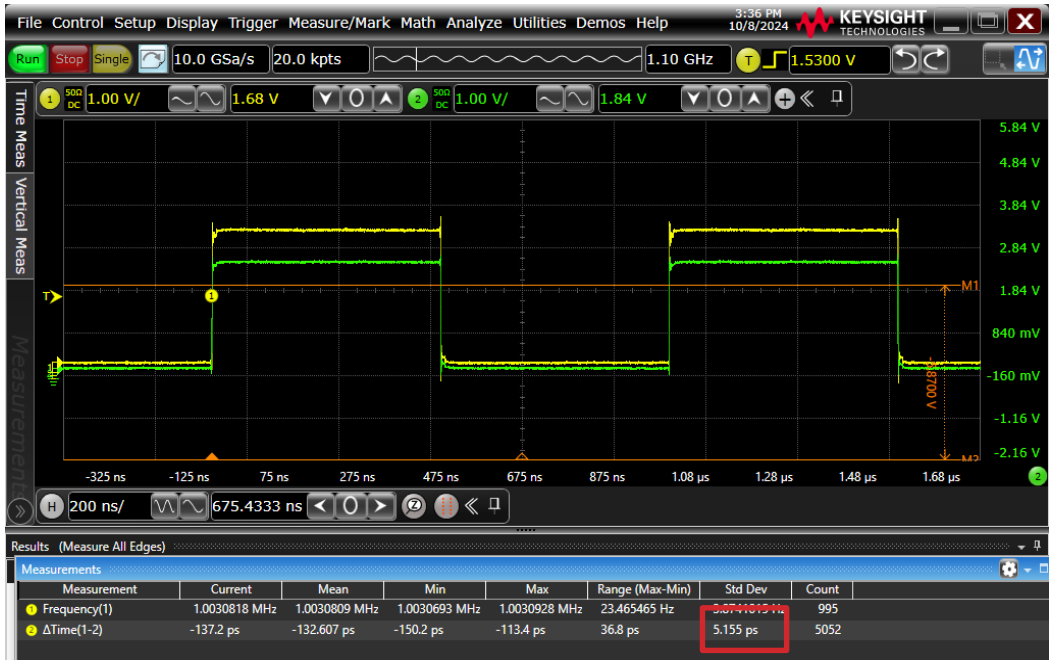
WRF Node

WRE Node

Parameters	Value
Maximum timing jitter w.r.t clock	**30ps rms**
Maximum trigger rate	**1Hz - 1MHz**
Width range, step size	**10ns - 10ms, 10ns**
Delay range, step size	**50ps - 1s, 50ps**

Hardware testing

- Timing system, deployed via a four-tier WRS network and about 5 km of fiber across the lab, **meets the design requirements.**
- FEL-II timing hardware and optical fibers have been deployed across the tunnel beamline and end-stations, more than 20 sites.



Jitter (WR Node4_1 Trigger Port and WR Switch1 SYNC Port) <30ps

Bunch-ID Transmission

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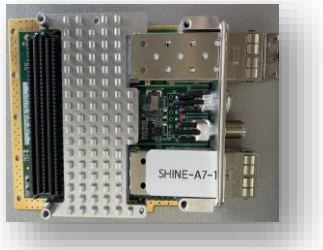
- **Three different modes of Bunch-ID transmission**



WRE Node

WRF Node

Timing Devices	Trigger and Bunch-ID transmission	Types of detectors supported
WRE Node	FMC	detectors with in-house developed electronics
WRF Node	SMA，Detail mode by UDP	JUNGFRAU, low-frequency commercial detectors, such as Basler, Andor…
WRF Node	SMA，Brief mode by UDP	High-frequency commercial detectors , such as PAM ML…

Three modes of Bunch-ID transmission

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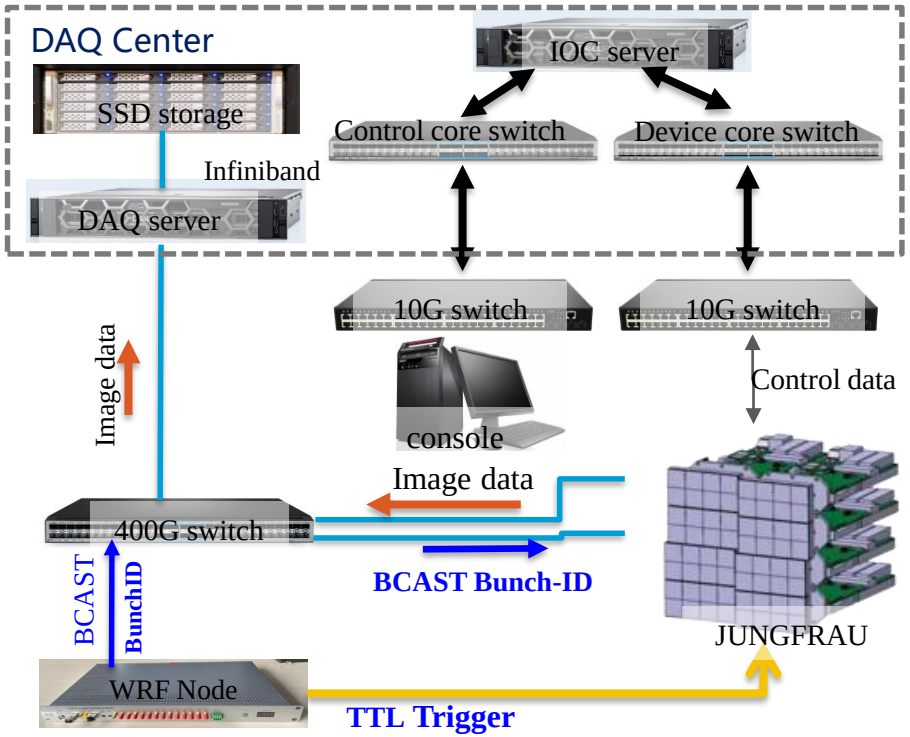
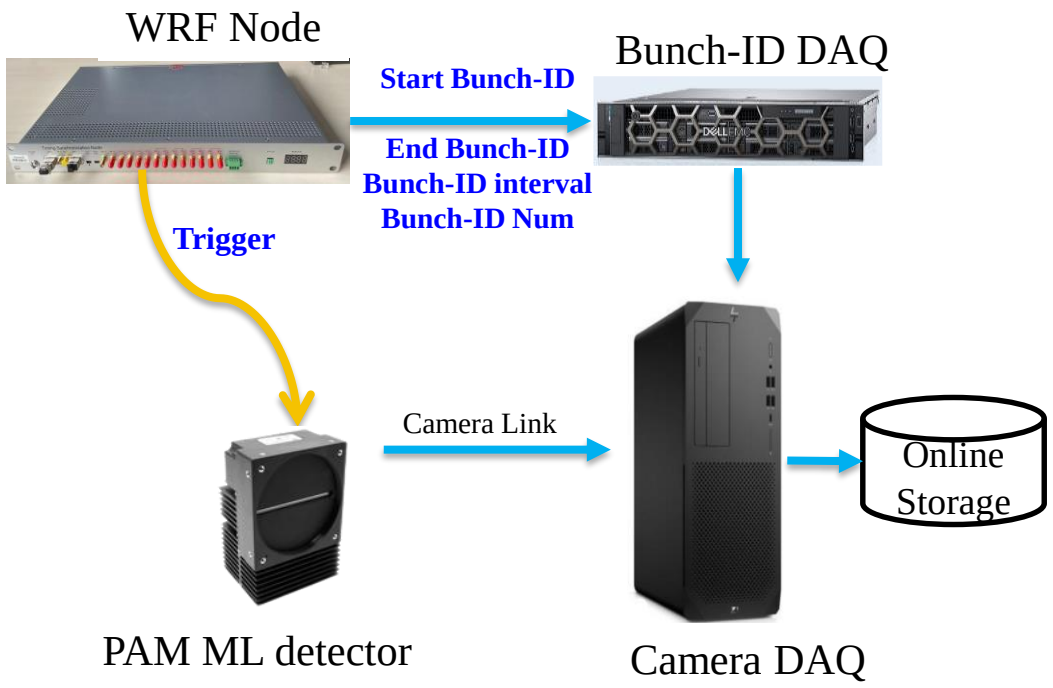
☐ Detail mode by UDP

- ✓ Sender: WRF node, Bunch-ID synchronized with trigger signal
- ✓ Receiver: **JUNGFRAU electronic firmware** or EPICS IOC
- ✓ Bunch-ID integration between **JUNGFRAU** and timing system at **1kHz trigger**

☐ Brief mode by UDP

- ✓ Sender: WRF node, **Start Bunch-ID and End Bunch-ID**
- ✓ Receiver: EPICS IOC
- ✓ Precise **one-to-one mapping** between data of **commercial detectors and timing Bunch-IDs** at rates up to 10 kHz





Timing Progress

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- Validation of three Bunch-ID transmission modes

Detectors	Bunch-ID transmission	Data packaging	Result
SERM fADC	FMC	Firmware	**Ok**
BPIM fADC	FMC	Firmware	**Ok**
PES fADC	FMC	Firmware	**Ok**
JUNGFRAU	Detail mode by UDP	Firmware	**Ok**
Basler detector	Detail mode by UDP	Software	**Ok**
Blaze detector	Brief mode by UDP	Software	**Ok**
ML detector	Brief mode by UDP	Software	**Ok**
AMO TDC	Brief mode by UDP	Software	**Ok**

Outlines

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AMO DAQ Architecture

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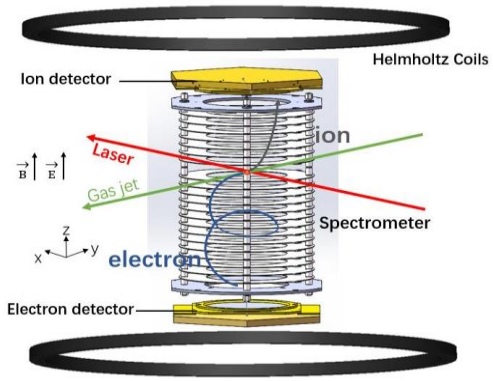
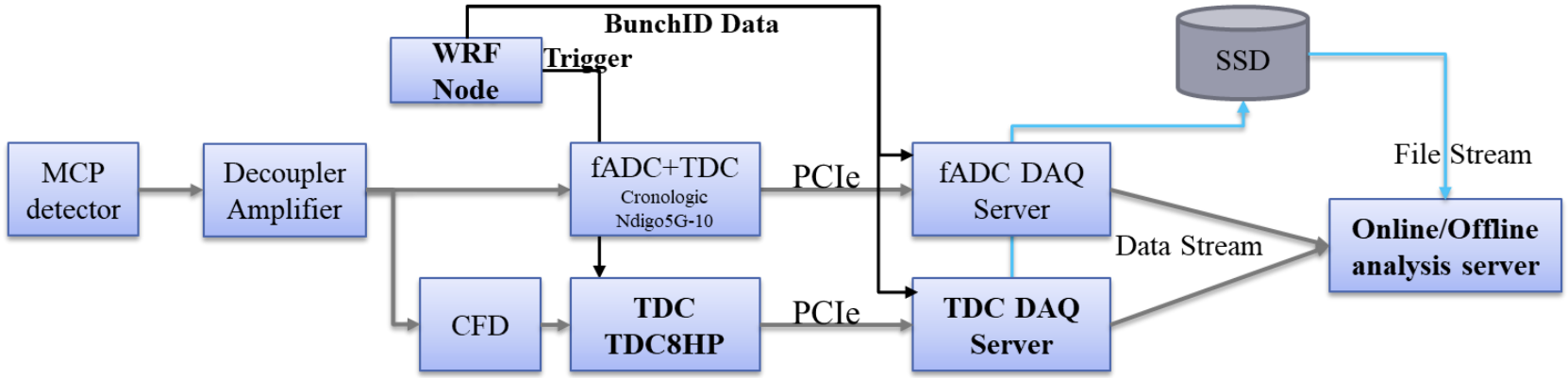
- **Single-pulse experiment, pump–probe, Time-to-Digital Converter (TDC) DAQ**



from AMO



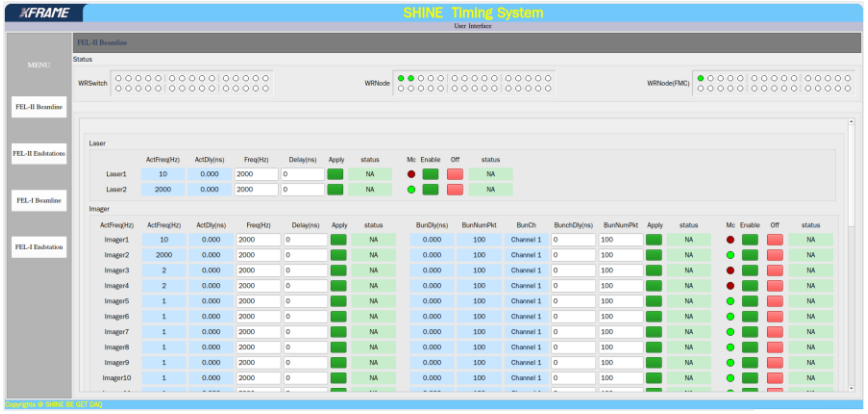
	Software requirements	Devices	Software
1	Timing control and Bunch-ID integration	WRF Node	**Timing IOC**
2	Laser delay line control	Laser Delay line	**Delay line IOC**
3	Beamline diagnostic data acquisition	PAM, PES, HAMPs, Imager	**Diagnostic DAQ**
4	Beamline motion control	KB, Imager, etc	**Motion IOC**
5	AMO DAQ for TDC and fADC, with Timing Bunch-ID	AMO TDC、fADC	**End-station DAQ**
6	A data stream pipeline with online analysis software		
7	Integration of diagnostic and experimental data	PAM, PES, HAMPs, KB	**Event building**

Timing Software

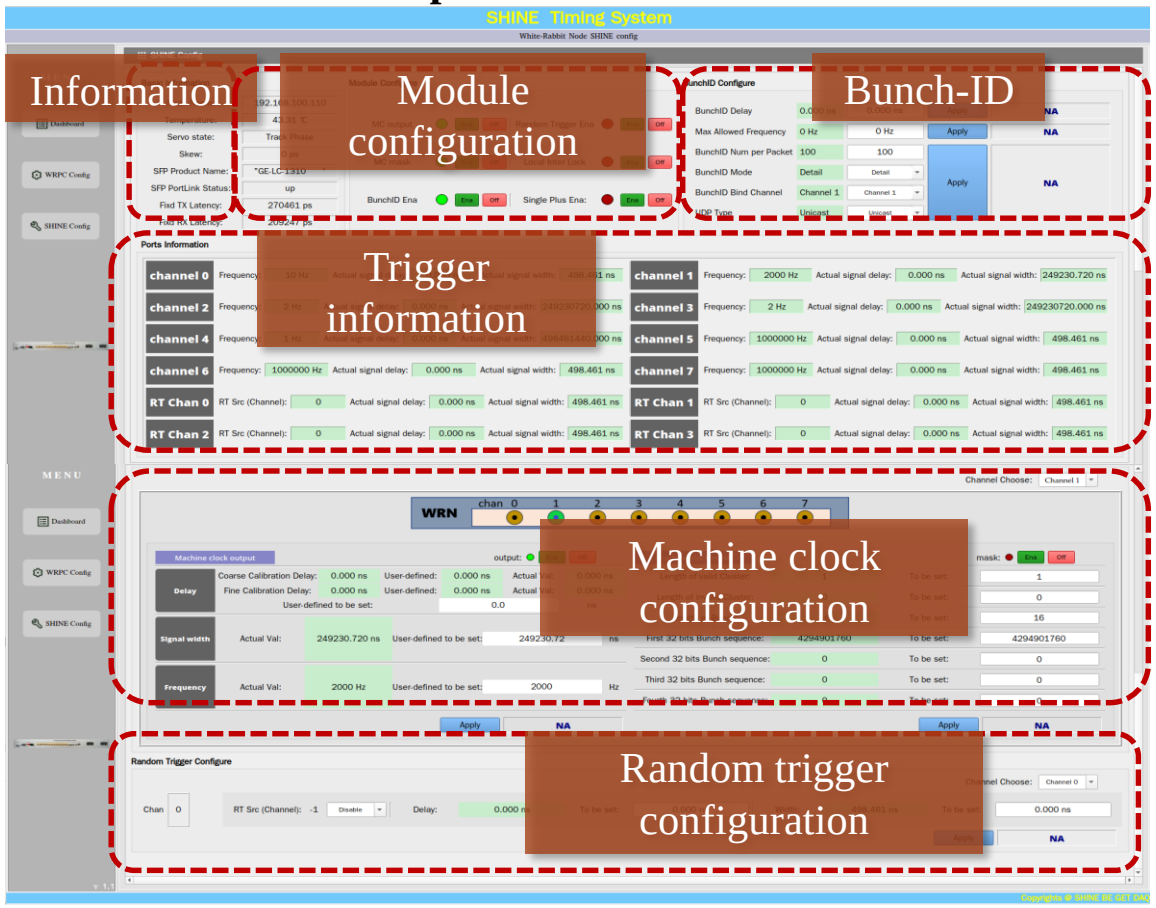
- Shared control virtual machine (VM)
- Three EPICS IOCs for WRS, WRF and WRE node; Two GUIs, including expert GUI and User GUI
- **Complete the development, testing, and deployment of all FEL-II timing software**

Overall Expert GUI

User GUI for FEL-II Beamline

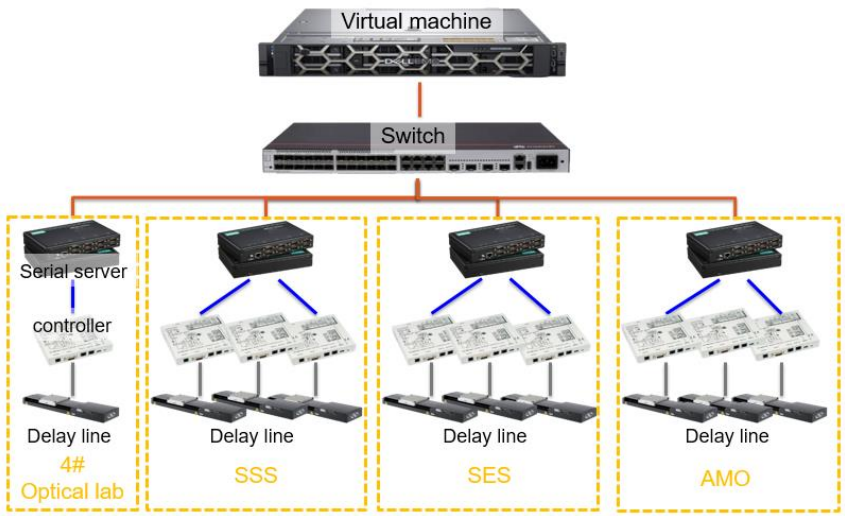


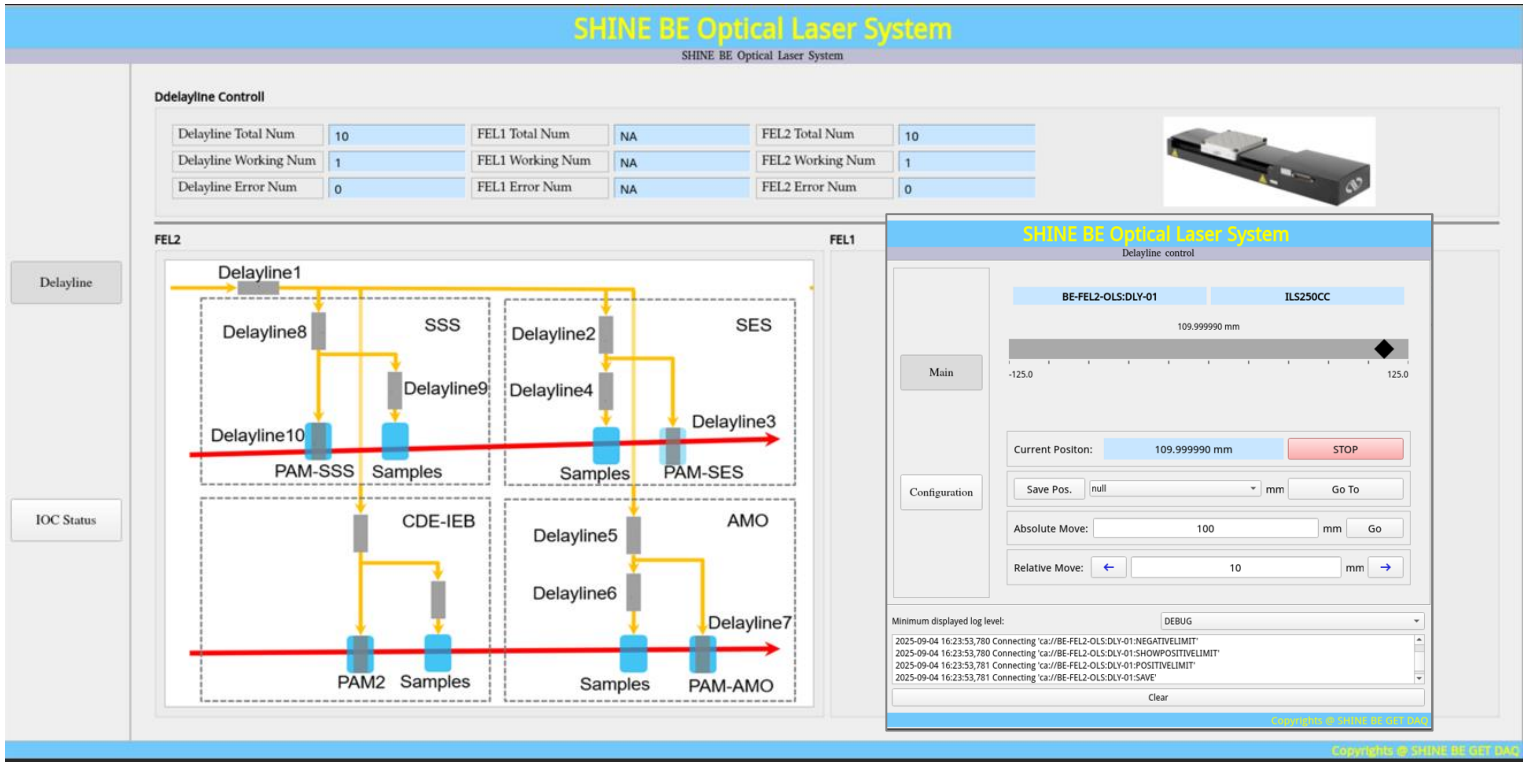
Expert GUI for WRF Node



Laser Delay Line Software

- Shared control virtual machine (VM)
- EPICS for three Newport delay-line models, maximum travel 325 mm, minimum incremental motion 75 nm
- **Complete software deployment**





Diagnostic DAQ--PAM

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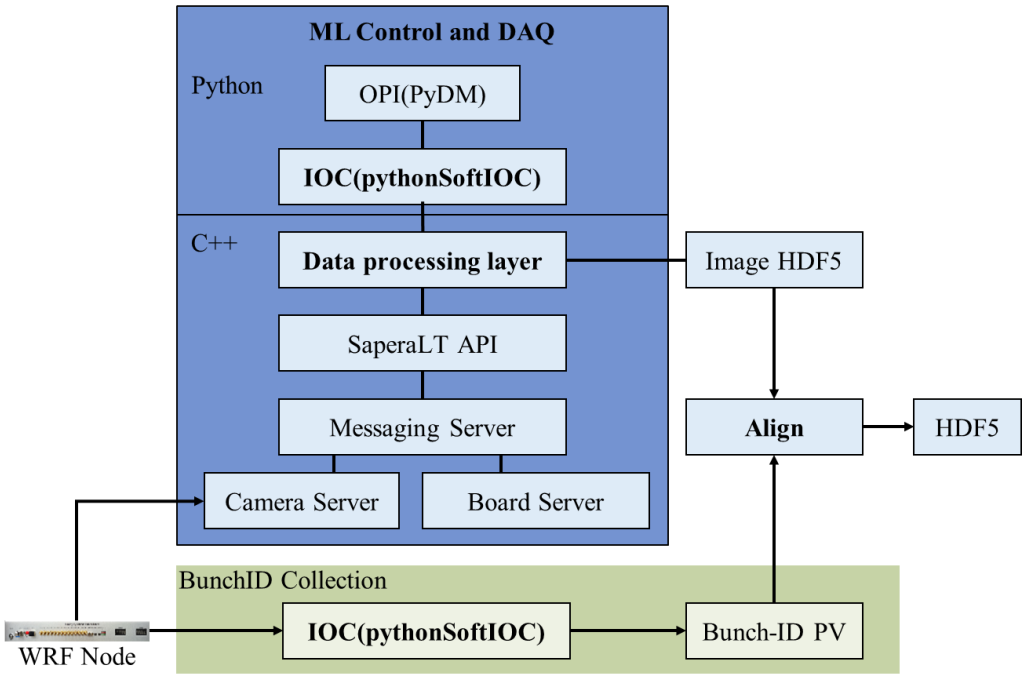
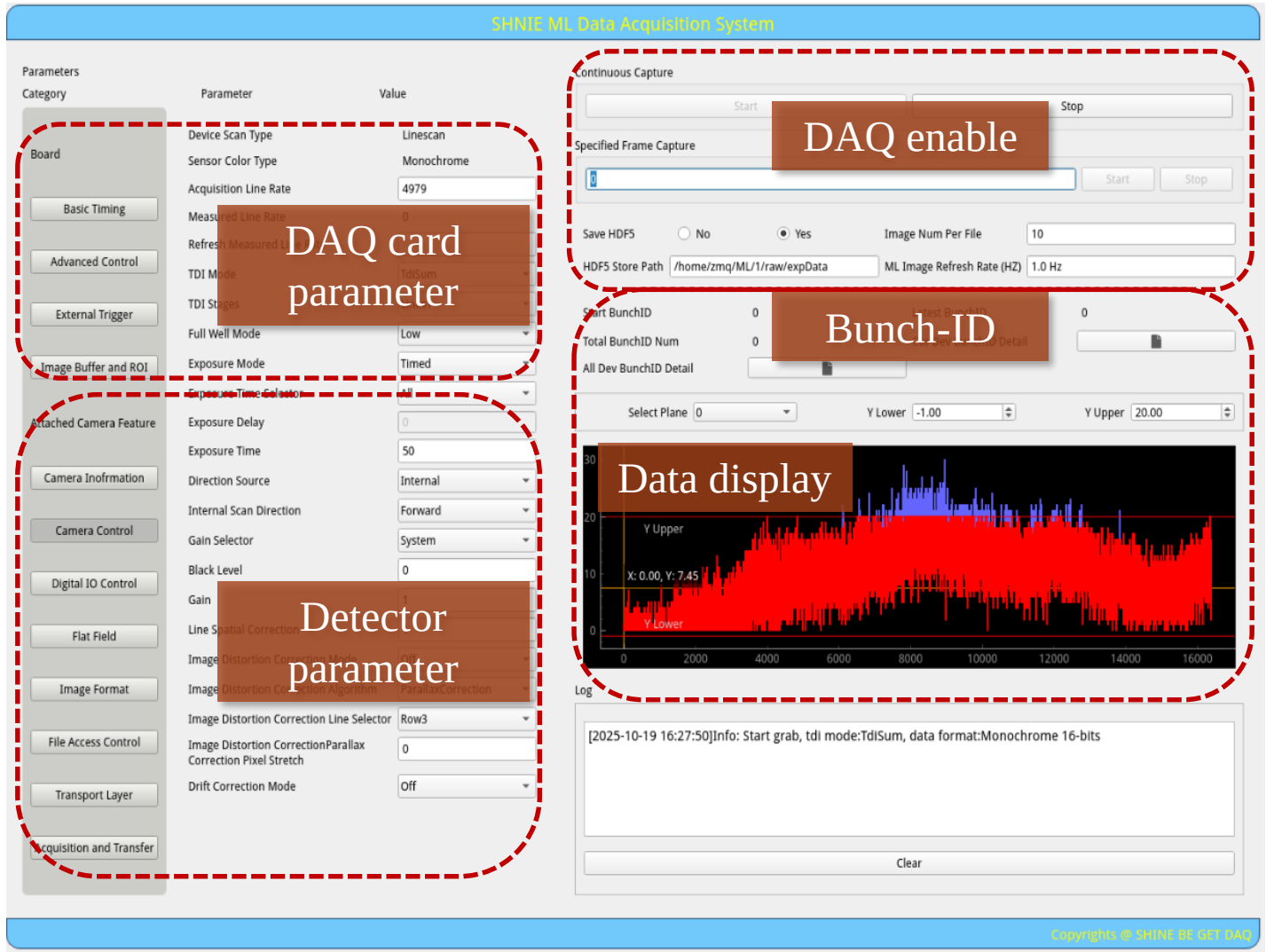
- **Back-end Software**:
  - IOC1: control PAM ML detector
  - Data processing layer: PAM ML detector DAQ
  - IOC2: Bunch-ID DAQ
  - Align: integration of ML data and Bunch-ID



ML-HM-16K30H-00-R camera
16384 × 4 pixel, 100kHz, 9.6GB/s



The system achieves a **10 kHz data acquisition.**

AMO DAQ

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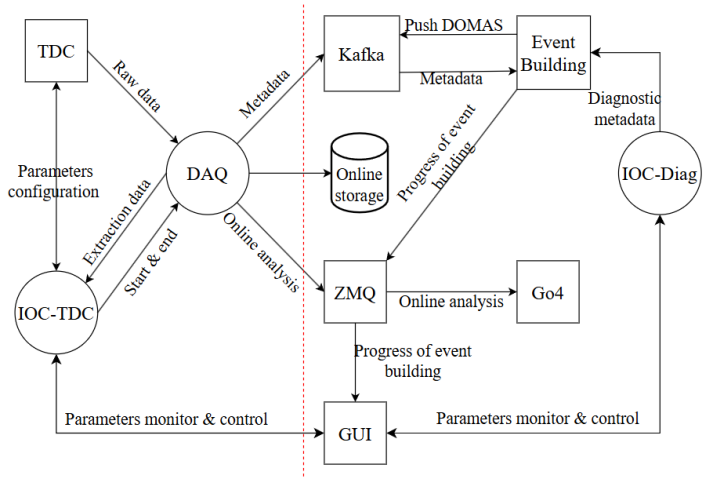


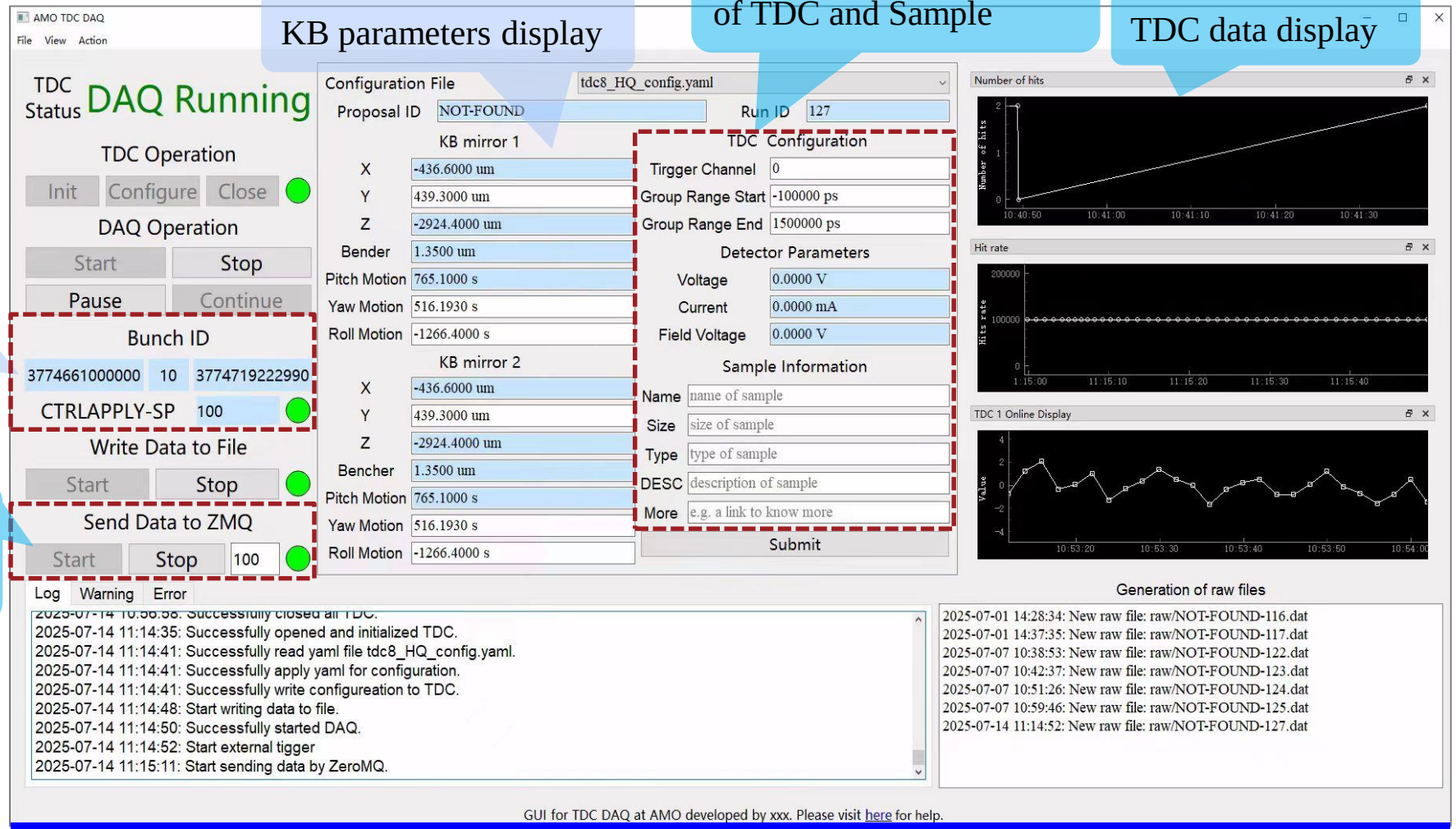
Timing Bunch-ID integration

Pipeline of data streams with online analysis software

KB parameters display

Parameters configuration of TDC and Sample

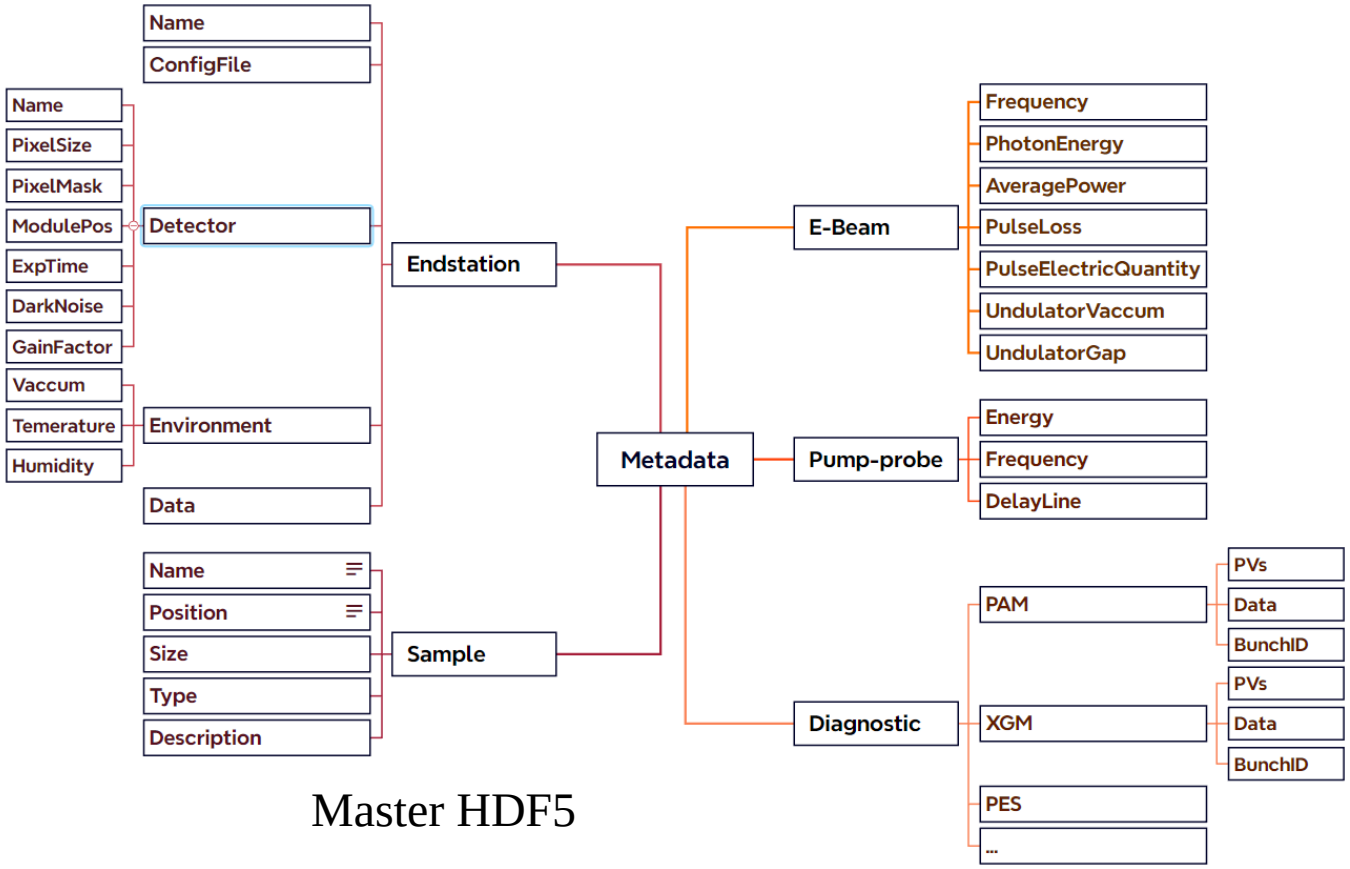
TDC data display



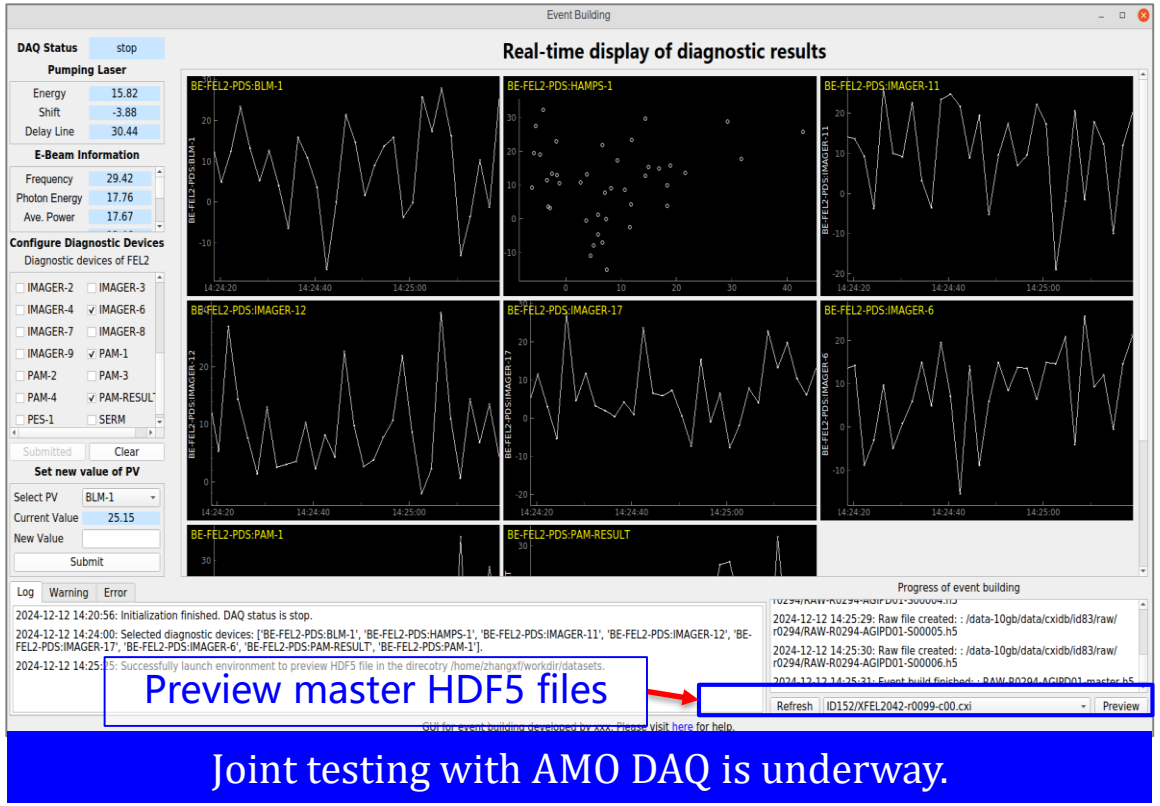
Complete Two-Channel 200 kHz DAQ Extreme Performance Test.

Event Building

- Supporting three interfaces: **EPICS, ZeroMQ, and Kafka**
- Design **master HDF5 file**, including the parameters of control, laser, diagnostic, experiment, etc.



Master HDF5

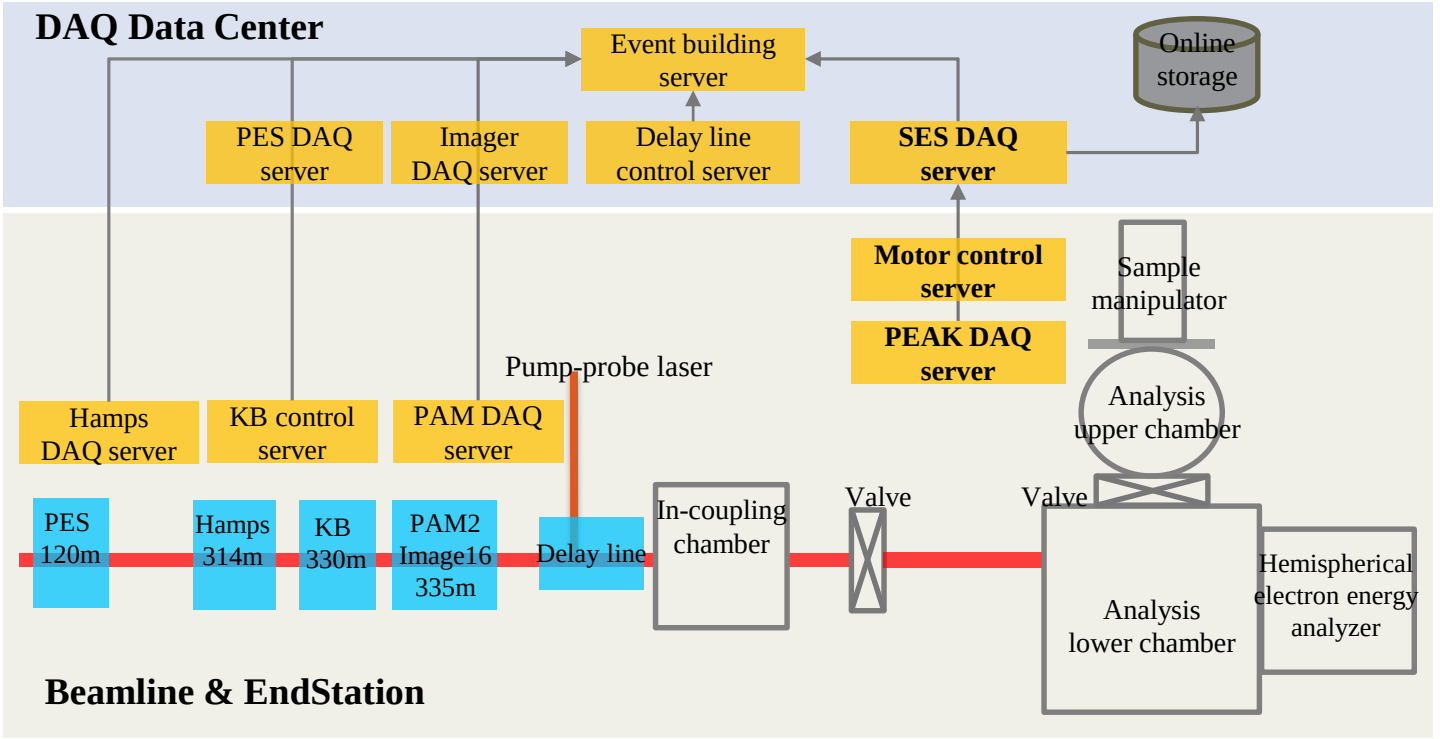


Joint testing with AMO DAQ is underway.

SES DAQ

- **Spectrometer for Electronic Structure(SES)** utilizes spin-space-resolved photoelectron spectroscopy to conduct multiple degrees of freedom and high-resolution measurements of electronic structure.
- The first end-station to come online
- The primary experimental method is pump–probe technique

Software requirements	Devices	Software
Motion control of beamline devices	Imager, KB, etc	Motion control interface
Diagnostic data view	PAM, PES, HAMPs, Imager	Event building
Laser delay line control	Laser Delay line	Delay line IOC
SES motor and detector monitor and DAQ	**Sample manipulator, Hemispherical electron energy analyze**	**End-station DAQ**



SES DAQ Progress

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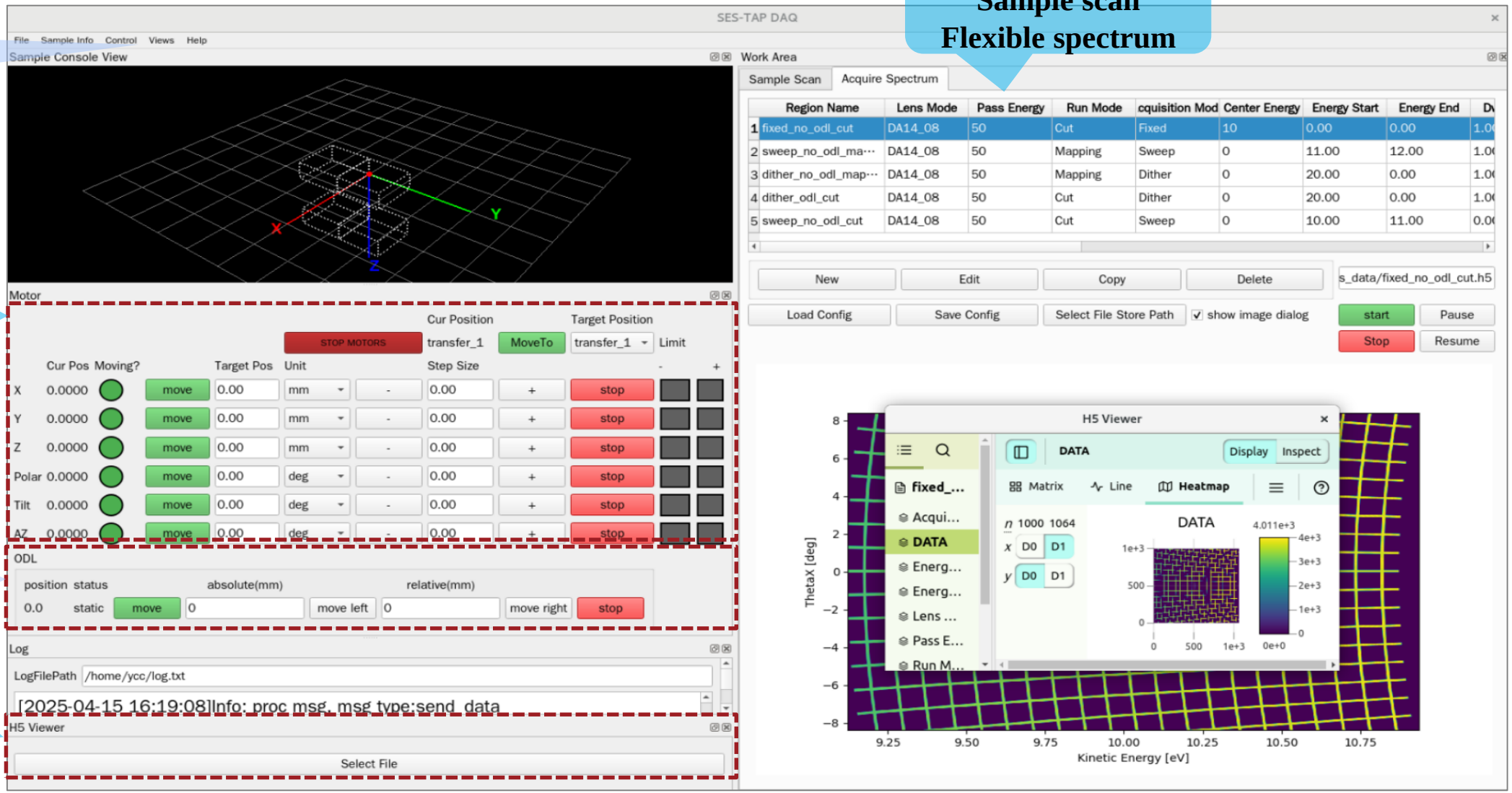
Control diagnostics detectors

Control sample manipulator

Laser delay line control

HDF5 storage

SES detector DAQ
Sample scan
Flexible spectrum



Complete all software feature development and laboratory testing, ready for software deployment and go-live

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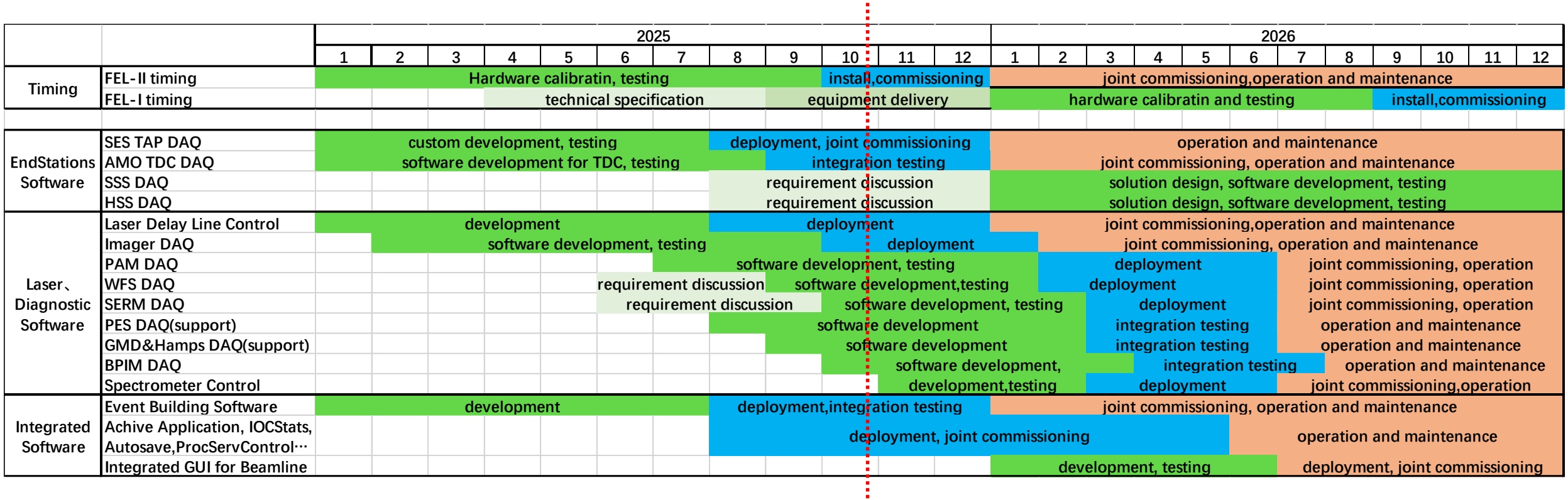
DAQ CPM for Beamlines and End-stations

- Timing, Laser, SES DAQ and AMO DAQ software are scheduled to be available by the end of this year.
- Development of all diagnostic software and integrated GUI will be completed by mid-next year.
- SSS, HSS and CDS DAQ are planned for delivery by the end of next year.



Questions

- In addition to basic functions, does the DAQ software offer any key features that enhance experimental efficiency or capabilities?
- Based on previous experience with XFEL or similar facilities, how long does it typically take to test and verify the functionality of DAQ software during the commissioning of beamlines and end-stations?
- Is there a better solution for integrating the Bunch-ID into DAQ with a commercial detector whose original firmware does not support it?

Thank you for your attention!