

Timing and DAQ for Beamlines and End-stations

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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

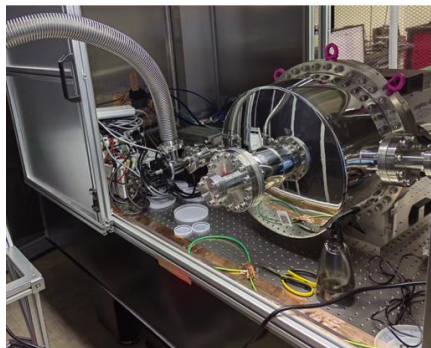
- ❑ Timing, pump-probe laser, optical diagnostics, end-stations
- ❑ **>24 types** of devices
- ❑ User-friendly integrated GUI for beamline devices
- ❑ High level control software for end-station instruments
- ❑ Integration of end-station scientific data and various diagnostics data with respect to Bunch-ID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

	sets of equipment	types of devices
Timing	WR Devices, 25sets	3types
Laser	Delay Line, 10sets	3types
Diagnostics	Imager, 17sets	3types
	PAM, 3sets	3types
	SERM, 1sets	4types
	PES, 1sets	1types
	WFS, 4sets	2types
	GMD&Hamps, 3sets	1types
	BPIM	
End-stations	SES	2types
	AMO	2types
	SSS	
	HSS	
	CDS	

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



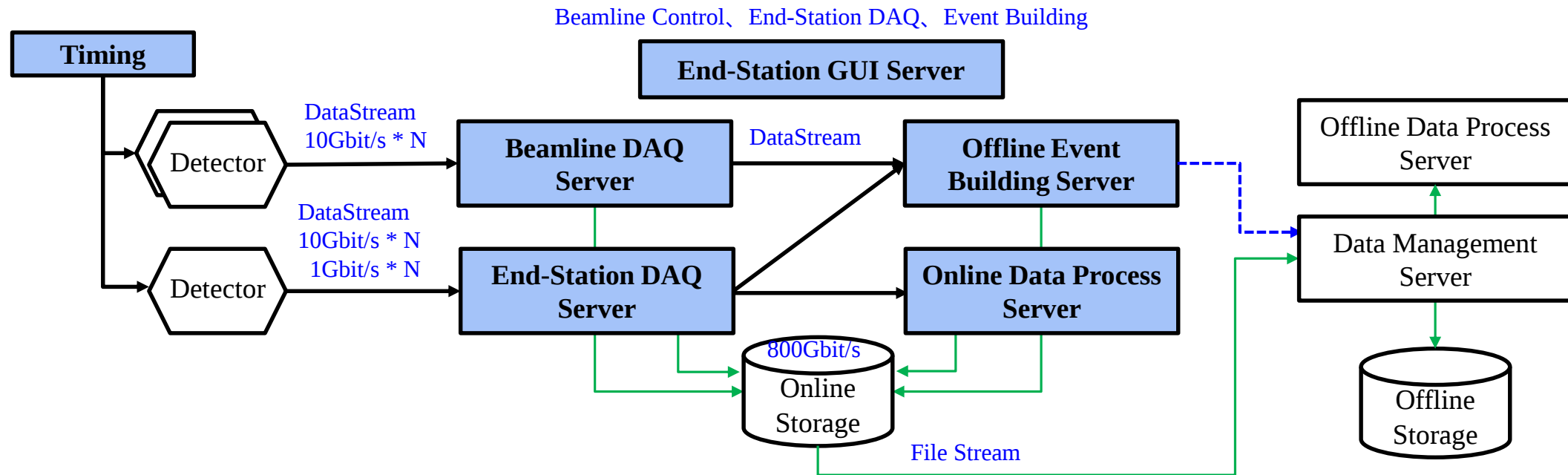
fADC



ML Camera

DAQ Design Principles

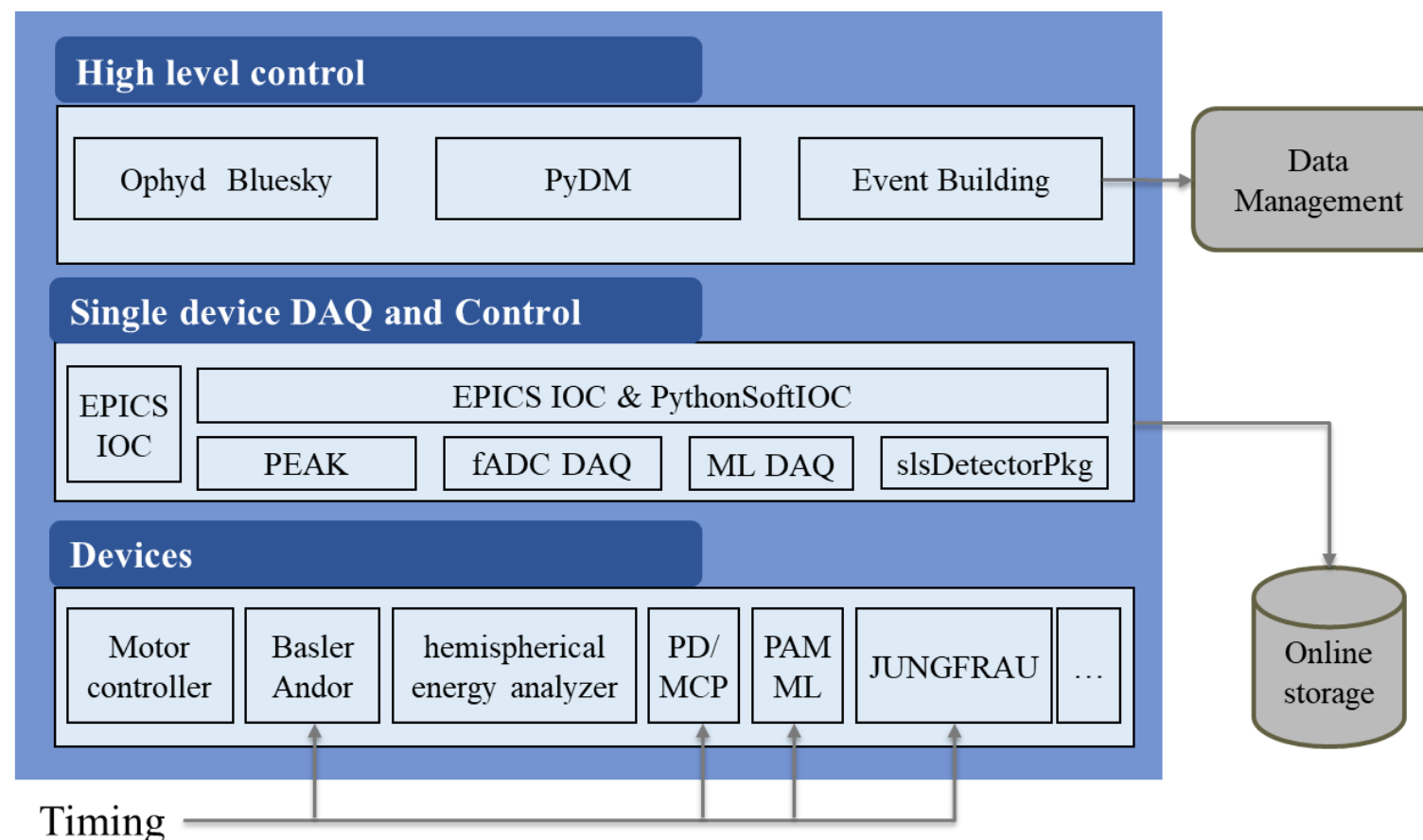
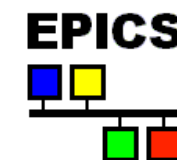
- ❑ **Trigger and Bunch-ID** provided by timing system
- ❑ **Each device** has its own DAQ server and GUI for diagnostic and end-stations
- ❑ All data are saved to **online storage simultaneously** during experiment in **HDF5 format**



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

Architecture of DAQ Software

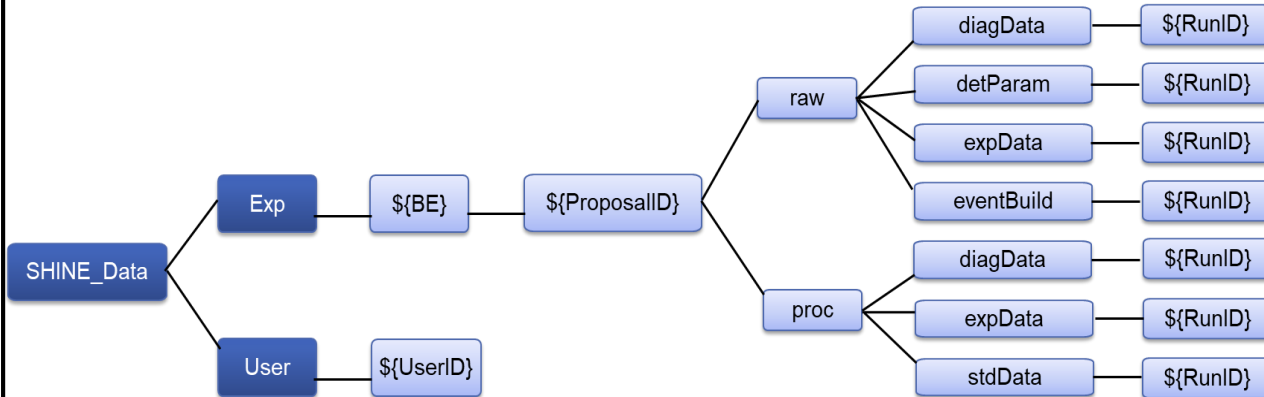
- ❑ All control parameters and online monitoring data in the form of **EPICS PVs**
- ❑ High level control software based on **Bluesky**
- ❑ **GUI** based on **PyDM**
- ❑ **Event building module** packages experimental and diagnostic data with respect to Bunch-ID and interfaces with Data Management



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:

$\{\text{RAW/CORR/PROC}\}-\{\text{RunID}\}-\{\text{DeviceName}\}-\{\text{FileIndex}\}$

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

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.

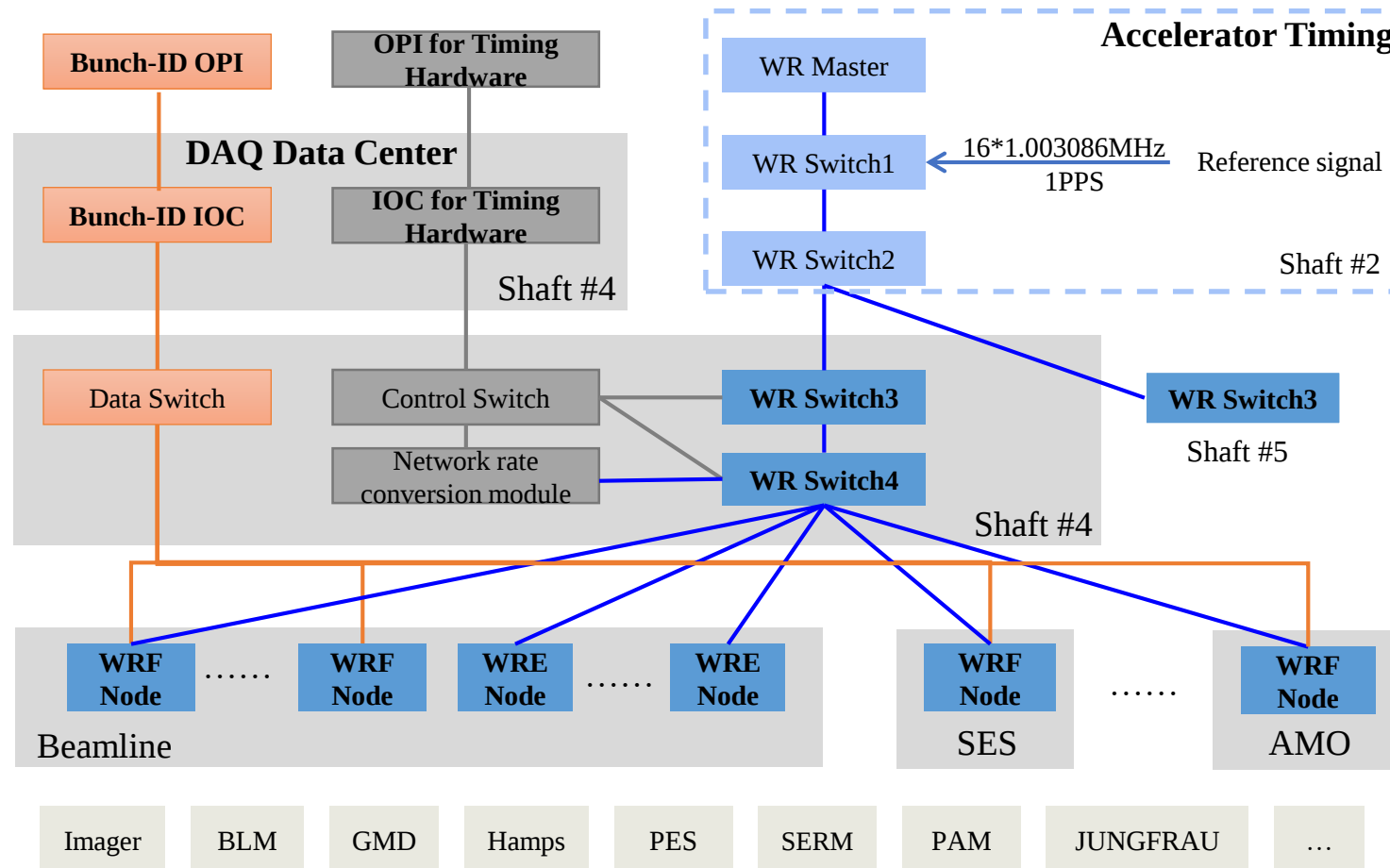
	software	requirements discussion	solution design	software development	testing	integration testing with timing	deployment	Progress
Timing	Timing Software	completion	completion	completion	completion	completion	completion	88%
Laser	Laser Delay Line Control	completion	completion	completion	completion	N.A.	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%

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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



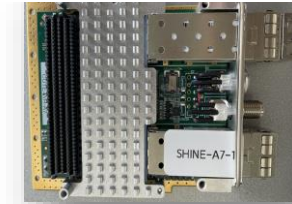
- ❑ **Timing Devices:** Due to SHINE special operating frequency, hetero-frequency WR devices have been co-developed, including WRS, WRF Node, WRE Node.
- ❑ **WRF Node:** SMA interface, 3VTTL@50 Ω , 3VTTL@10k Ω , 5VTTL@50 Ω , and 5VTTL@10k Ω .



WRS



WRF Node



WRE Node

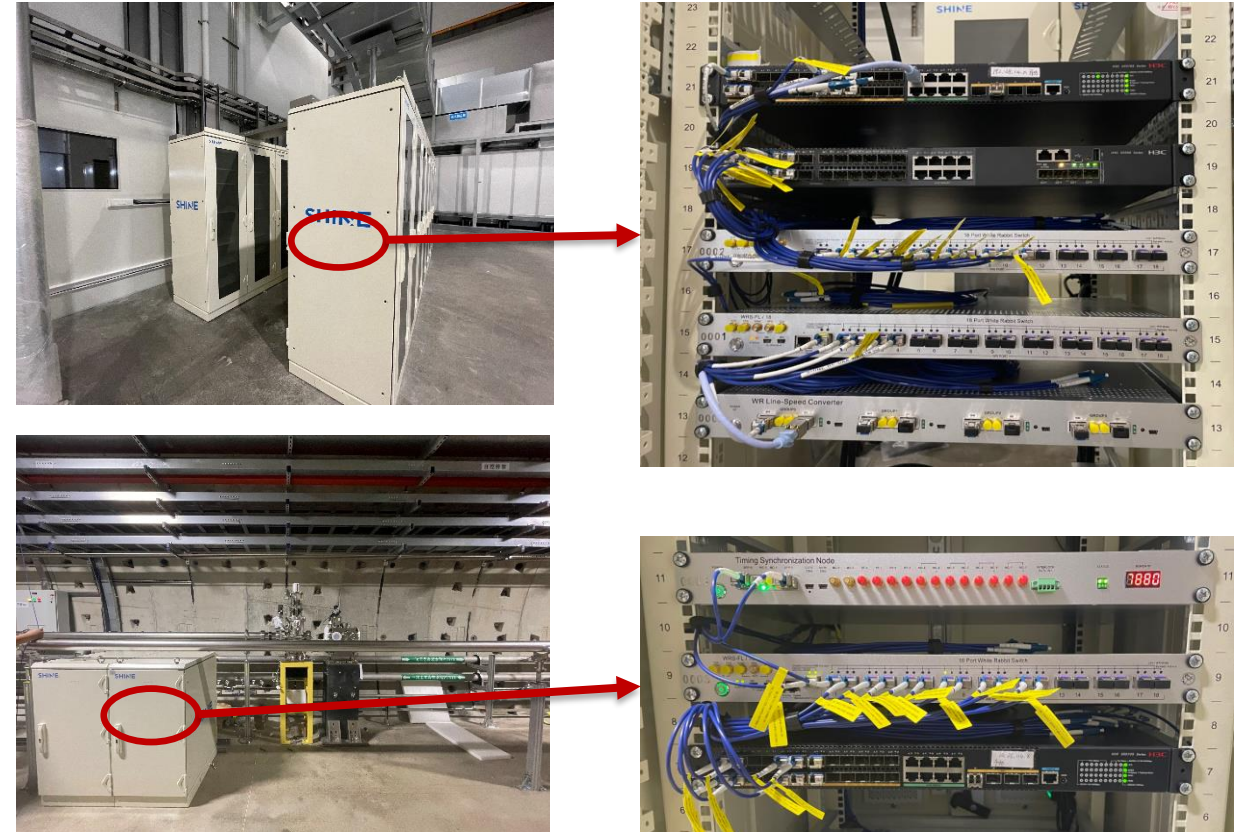
Parameters	Value
Maximum timing jitter w.r.t clock	30ps rms
Maximum trigger rate	1Hz - 1MHz
Width range, step size	10ns - 10ms, 10ns
Delay range, step size	50ps - 1s, 50ps

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

□ 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...

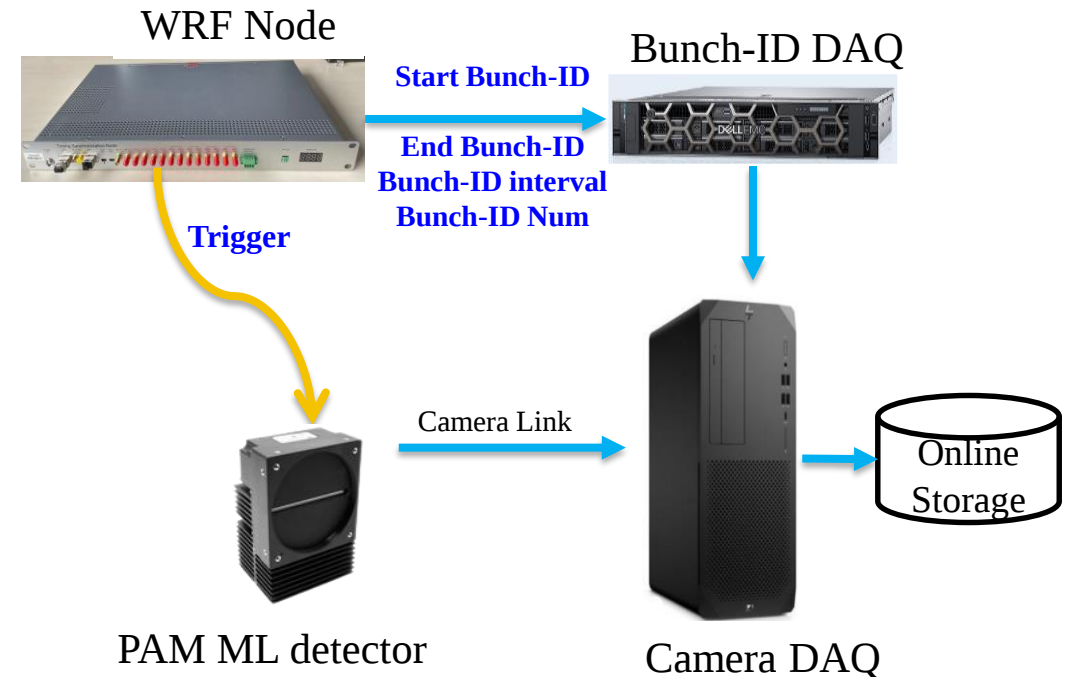
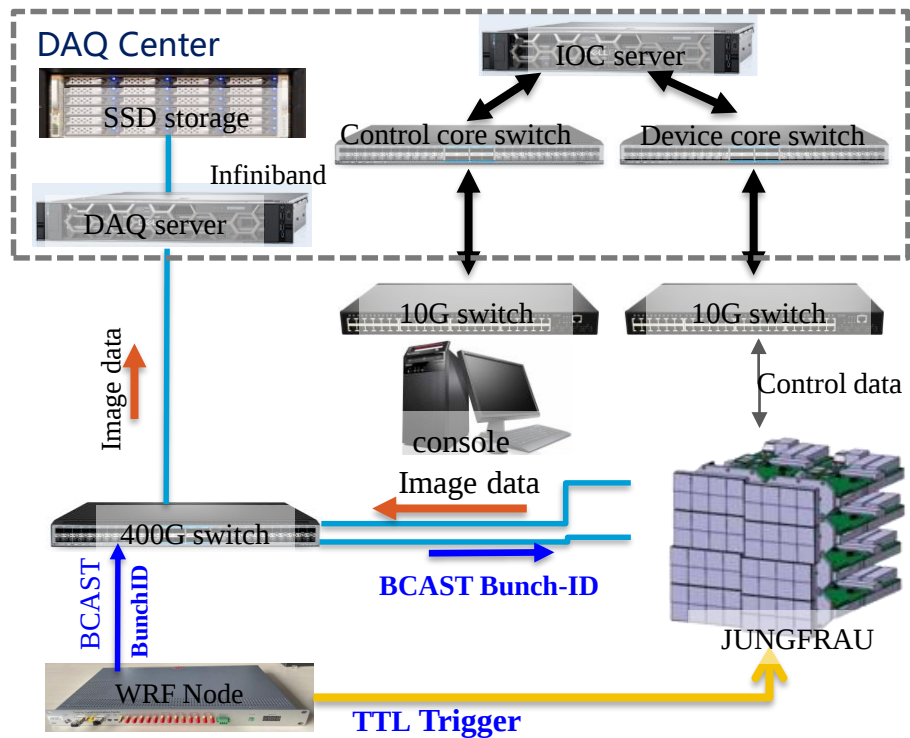
Three modes of Bunch-ID transmission

❑ 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



▣ Validation of three Bunch-ID transmission modes

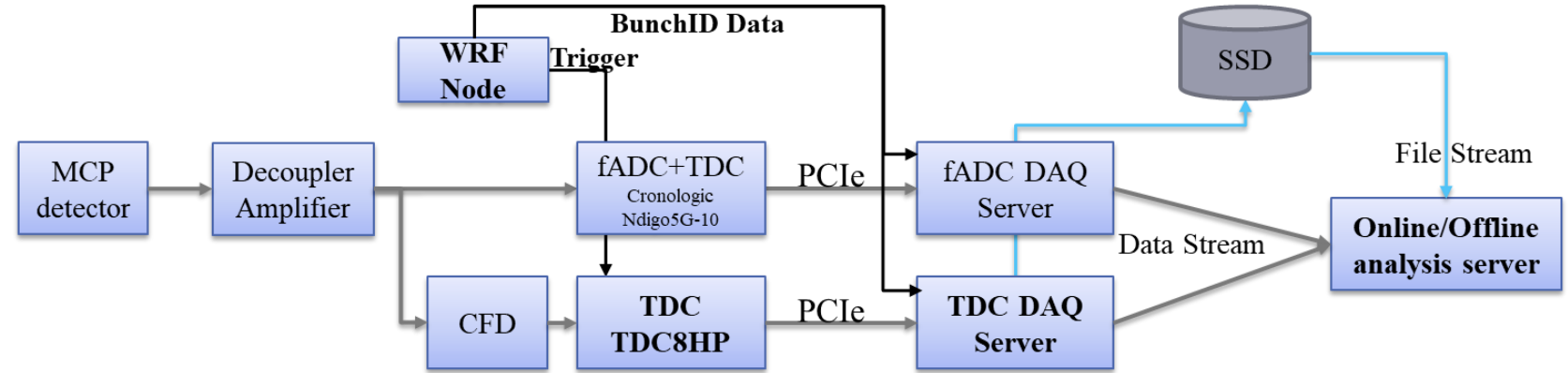
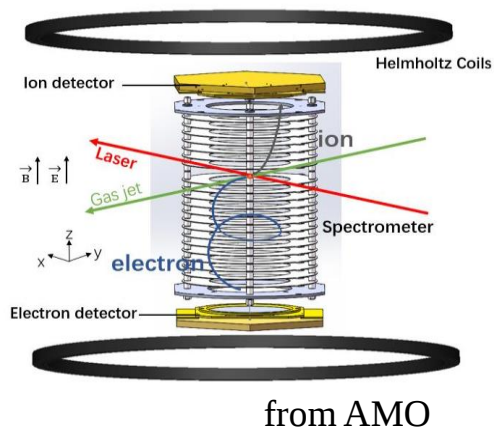
Detectors	Bunch-ID transmission	Data packaging	Result
SERM fADC	FMC	Firmware	Ok
BPIM fADC	FMC	Firmware	Ok
PES fADC	FMC	Firmware	Ok
JUNGFRAU	Detail mode by UDP	Firmware	Ok
Basler detector	Detail mode by UDP	Software	Ok
Blaze detector	Brief mode by UDP	Software	Ok
ML detector	Brief mode by UDP	Software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

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AMO DAQ Architecture

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



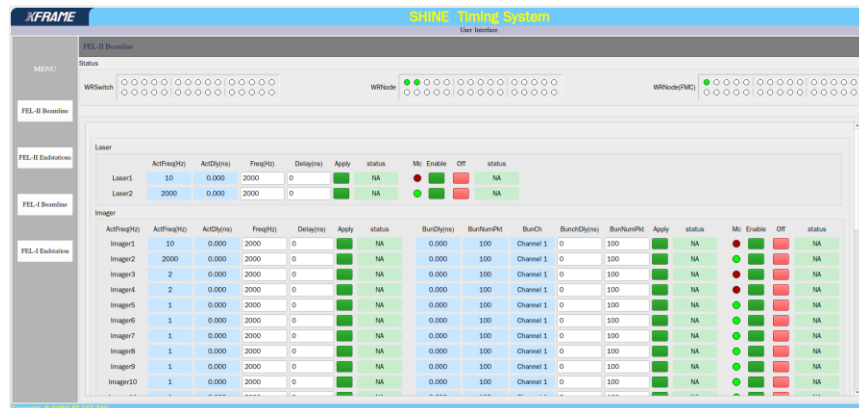
	Software requirements	Devices	Software
1	Timing control and Bunch-ID integration	WRF Node	Timing IOC
2	Laser delay line control	Laser Delay line	Delay line IOC
3	Beamline diagnostic data acquisition	PAM, PES, HAMPs, Imager	Diagnostic DAQ
4	Beamline motion control	KB, Imager, etc	Motion IOC
5	AMO DAQ 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

- ❑ 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

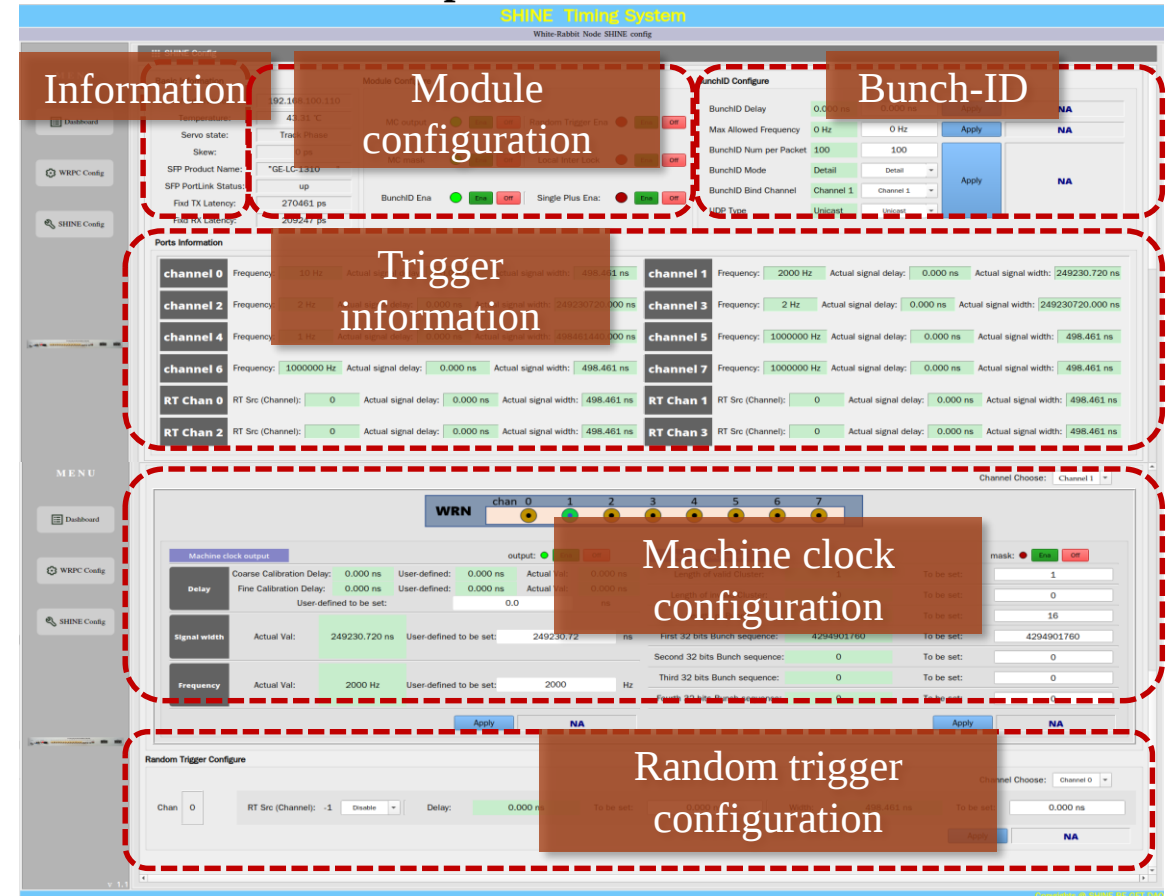
Overall Expert GUI



User GUI for FEL-II Beamline

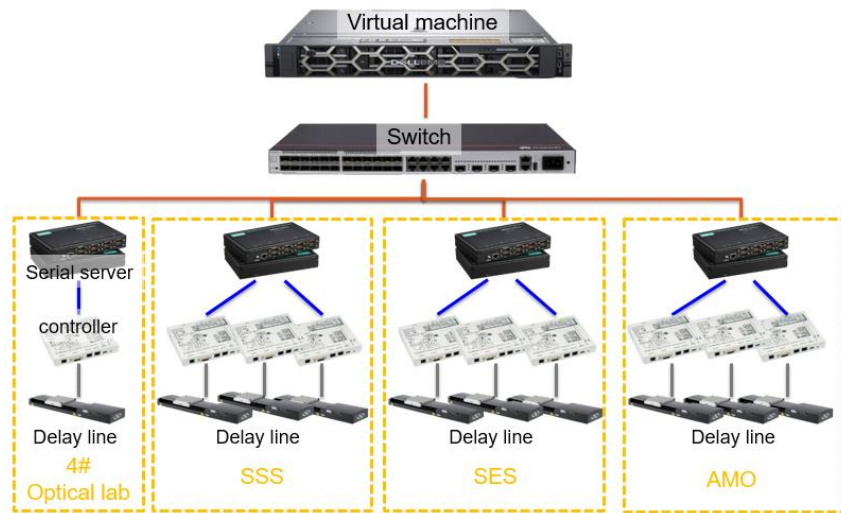


Expert GUI for WRF Node



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



The screenshot shows the 'SHINE BE Optical Laser System' interface. At the top, a title bar reads 'SHINE BE Optical Laser System'. Below it, a 'Delayline Control' section contains a table with status information for FEL1 and FEL2.

FEL2		FEL1	
Delayline Total Num	10	FEL1 Total Num	NA
Delayline Working Num	1	FEL1 Working Num	NA
Delayline Error Num	0	FEL1 Error Num	NA

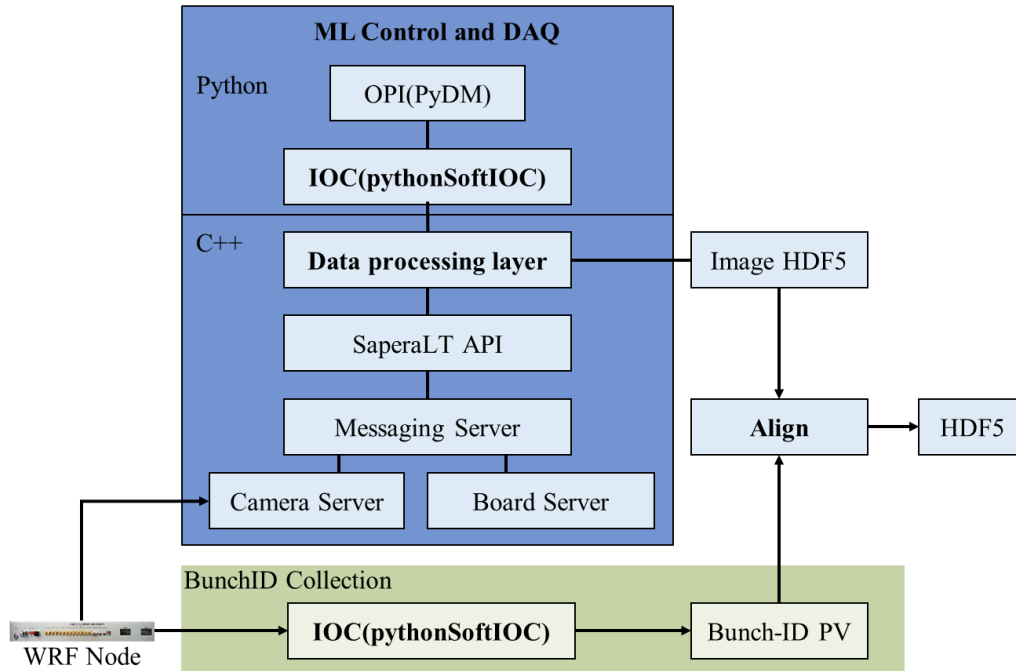
Below the table, a schematic diagram shows the layout of delay lines (Delayline1 to Delayline10) and sample positions (PAM-SSS, Samples, PAM-SES, PAM-AMO) for FEL2 and FEL1. The diagram includes labels for SSS, SES, CDE-IEB, and AMO sections.

On the right, a 'SHINE BE Optical Laser System' window displays 'Delayline control' for 'BE-FEL2-OLS:DLV-01' and 'ILS250CC'. It features a position slider ranging from -125.0 to 125.0 mm, with the current position set to 109.999990 mm. Below the slider are buttons for 'STOP', 'Save Pos.', 'Go To', 'Absolute Move', and 'Relative Move'. A log window at the bottom shows system messages.

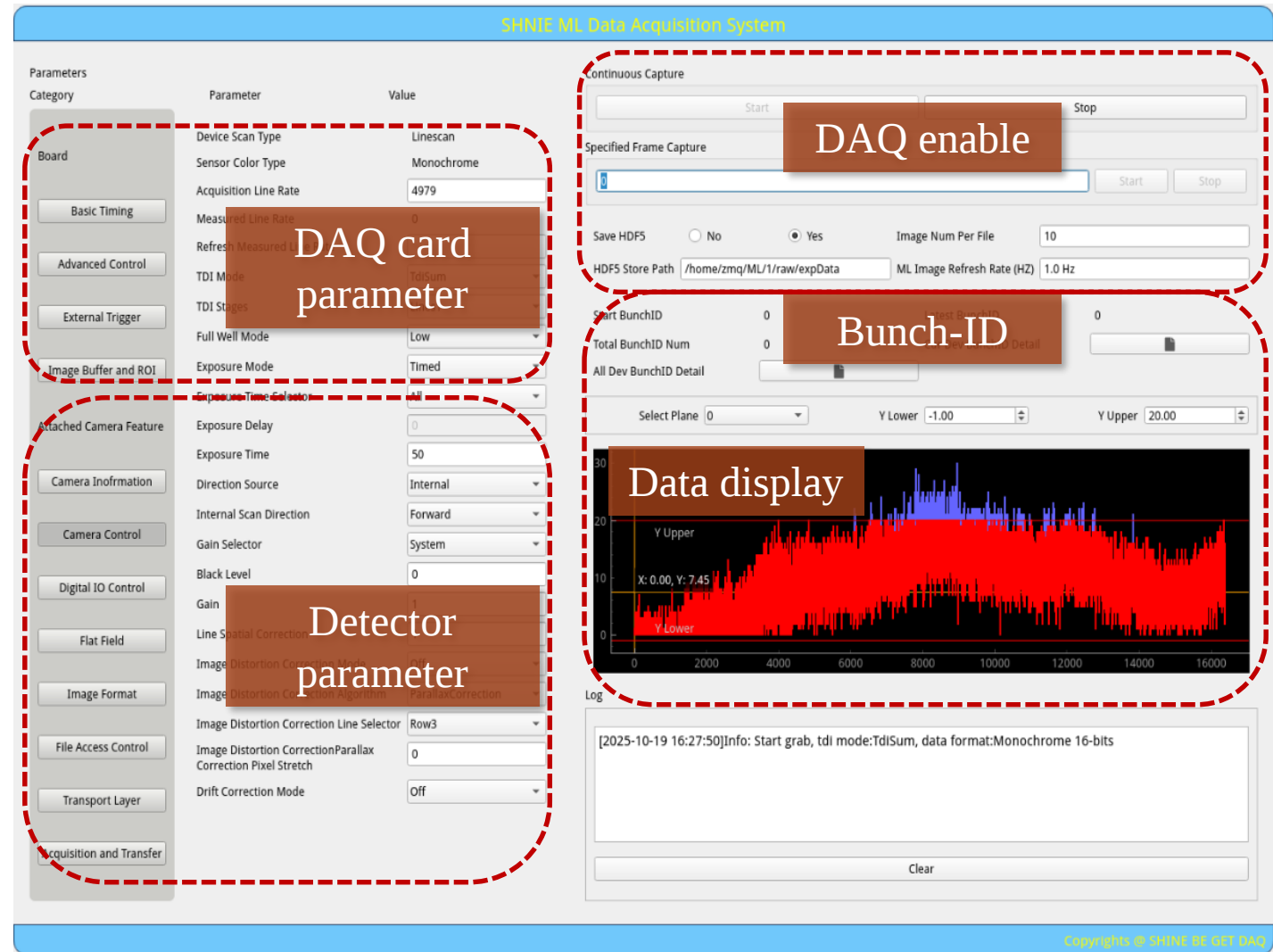
Diagnostic DAQ--PAM

❑ Back-end Software:

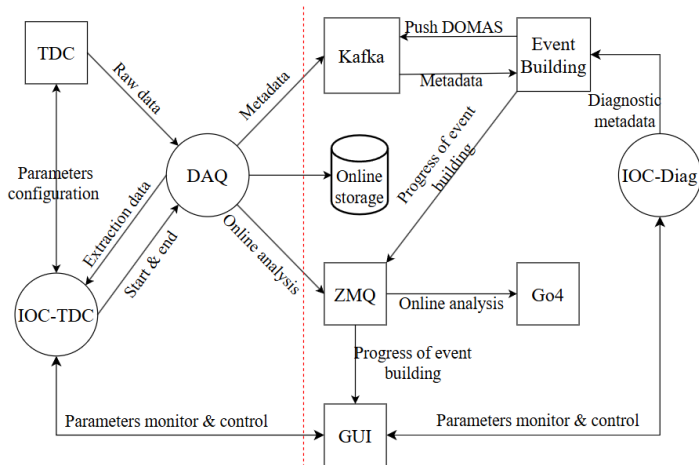
- IOC1: control PAM ML detector
- Data processing layer: PAM ML detector DAQ
- IOC2: Bunch-ID DAQ
- Align: integration of ML data and Bunch-ID



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



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



Timing Bunch-ID integration

Pipeline of data streams with online analysis software

KB parameters display

DAQ Running

TDC Status

TDC Operation: Init, Configure, Close

DAQ Operation: Start, Stop, Pause, Continue

Bunch ID: 3774661000000 10 3774719222990

CTRLAPPLY-SP: 100

Write Data to File: Start, Stop

Send Data to ZMQ: Start, Stop, 100

Log Warning Error

```

2025-07-14 10:56:56: Successfully closed all TDC.
2025-07-14 11:14:35: Successfully opened and initialized TDC.
2025-07-14 11:14:41: Successfully read yaml file tdc8_HQ_config.yaml.
2025-07-14 11:14:41: Successfully apply yaml for configuration.
2025-07-14 11:14:41: Successfully write configuration to TDC.
2025-07-14 11:14:48: Start writing data to file.
2025-07-14 11:14:50: Successfully started DAQ.
2025-07-14 11:14:52: Start external trigger
2025-07-14 11:15:11: Start sending data by ZeroMQ.
                
```

Configuration File: tdc8_HQ_config.yaml

Proposal ID: NOT-FOUND Run ID: 127

KB mirror 1

X: -436.6000 um

Y: 439.3000 um

Z: -2924.4000 um

Bender: 1.3500 um

Pitch Motion: 765.1000 s

Yaw Motion: 516.1930 s

Roll Motion: -1266.4000 s

KB mirror 2

X: -436.6000 um

Y: 439.3000 um

Z: -2924.4000 um

Bender: 1.3500 um

Pitch Motion: 765.1000 s

Yaw Motion: 516.1930 s

Roll Motion: -1266.4000 s

TDC Configuration

Trigger Channel: 0

Group Range Start: -100000 ps

Group Range End: 1500000 ps

Detector Parameters

Voltage: 0.0000 V

Current: 0.0000 mA

Field Voltage: 0.0000 V

Sample Information

Name: name of sample

Size: size of sample

Type: type of sample

DESC: description of sample

More: e.g. a link to know more

Submit

Parameters configuration of TDC and Sample

TDC data display

Number of hits

Hit rate

TDC 1 Online Display

Generation of raw files

```

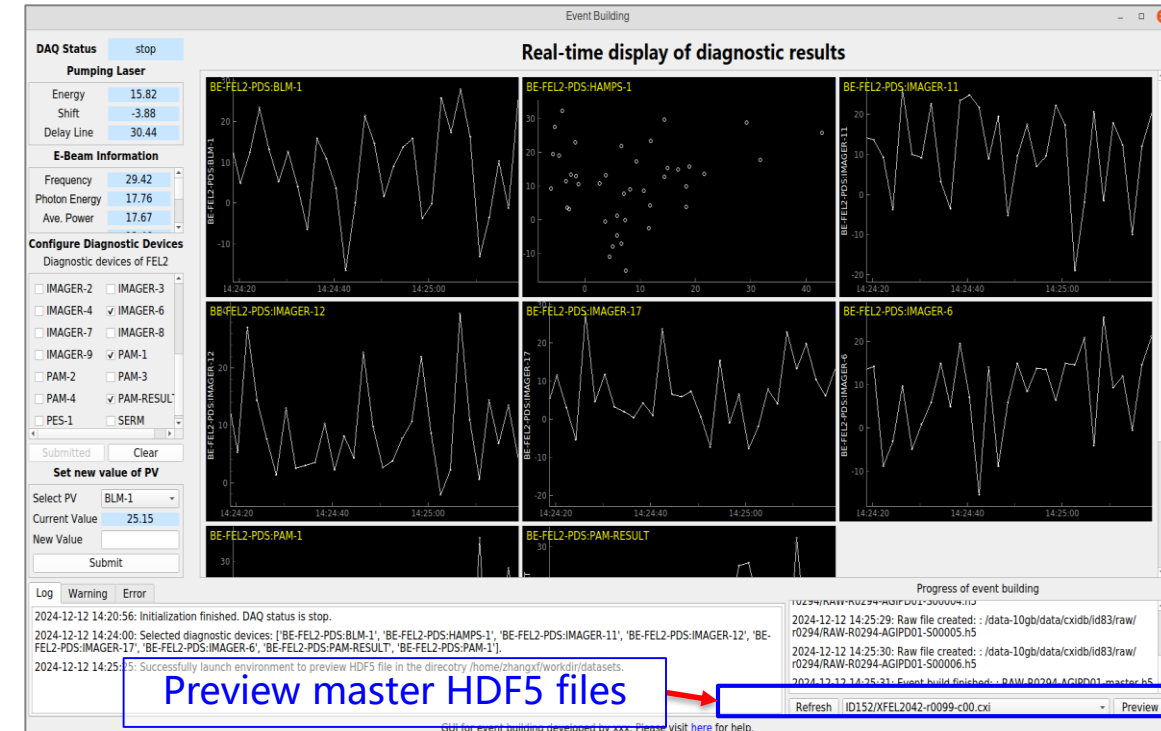
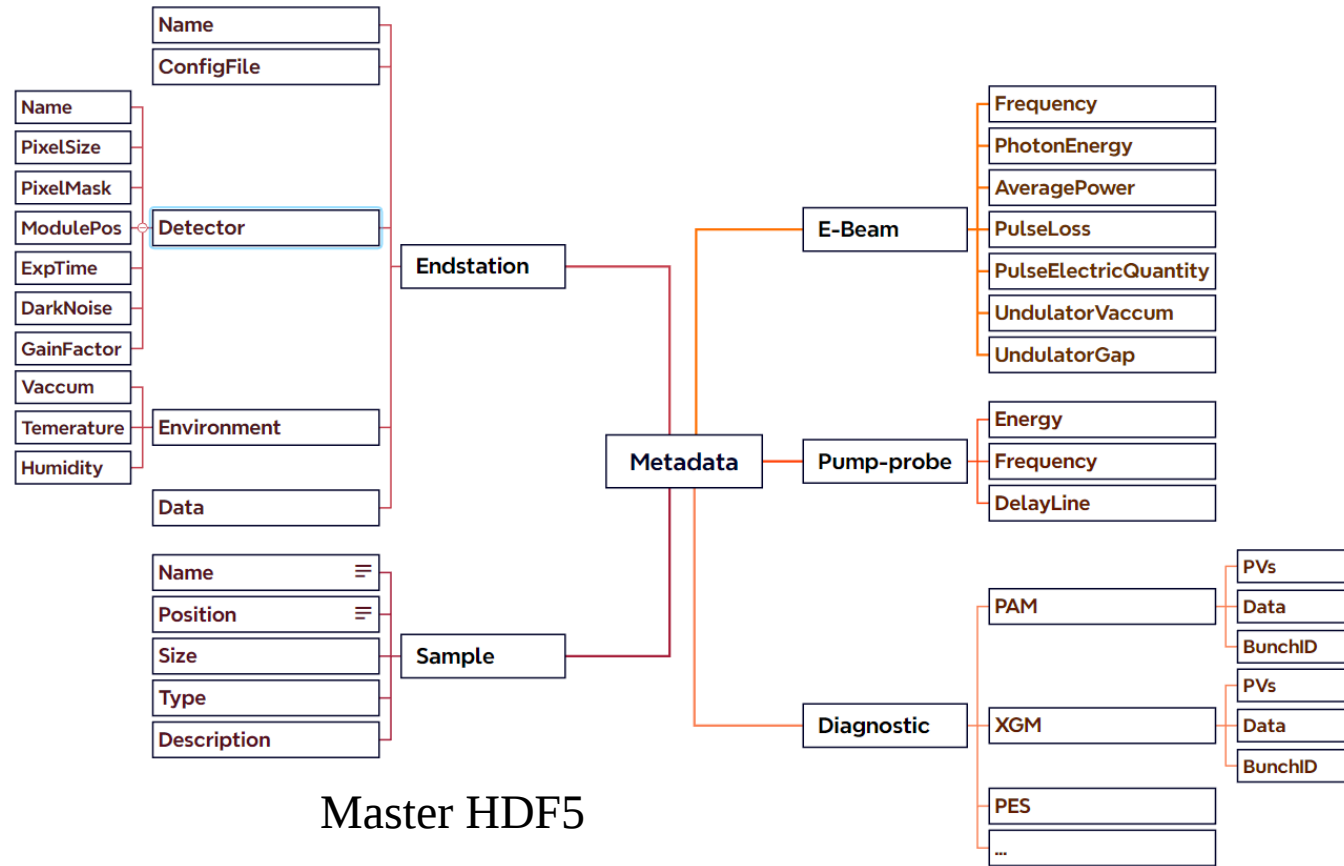
2025-07-01 14:28:34: New raw file: raw/NOT-FOUND-116.dat
2025-07-01 14:37:35: New raw file: raw/NOT-FOUND-117.dat
2025-07-07 10:38:53: New raw file: raw/NOT-FOUND-122.dat
2025-07-07 10:42:37: New raw file: raw/NOT-FOUND-123.dat
2025-07-07 10:51:26: New raw file: raw/NOT-FOUND-124.dat
2025-07-07 10:59:46: New raw file: raw/NOT-FOUND-125.dat
2025-07-14 11:14:52: New raw file: raw/NOT-FOUND-127.dat
                
```

GUI for TDC DAQ at AMO developed by xxx. Please visit [here](#) for help.

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.



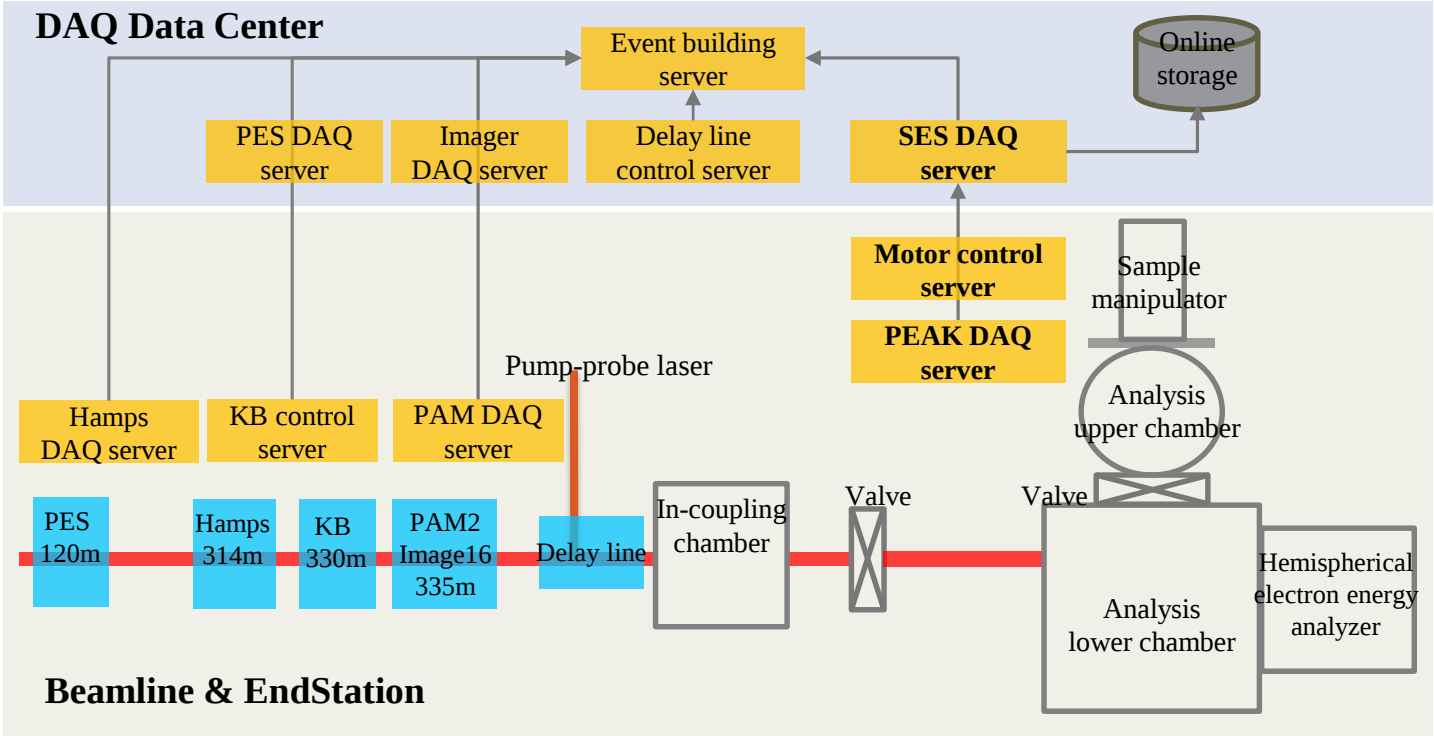
Joint testing with AMO DAQ is underway.

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

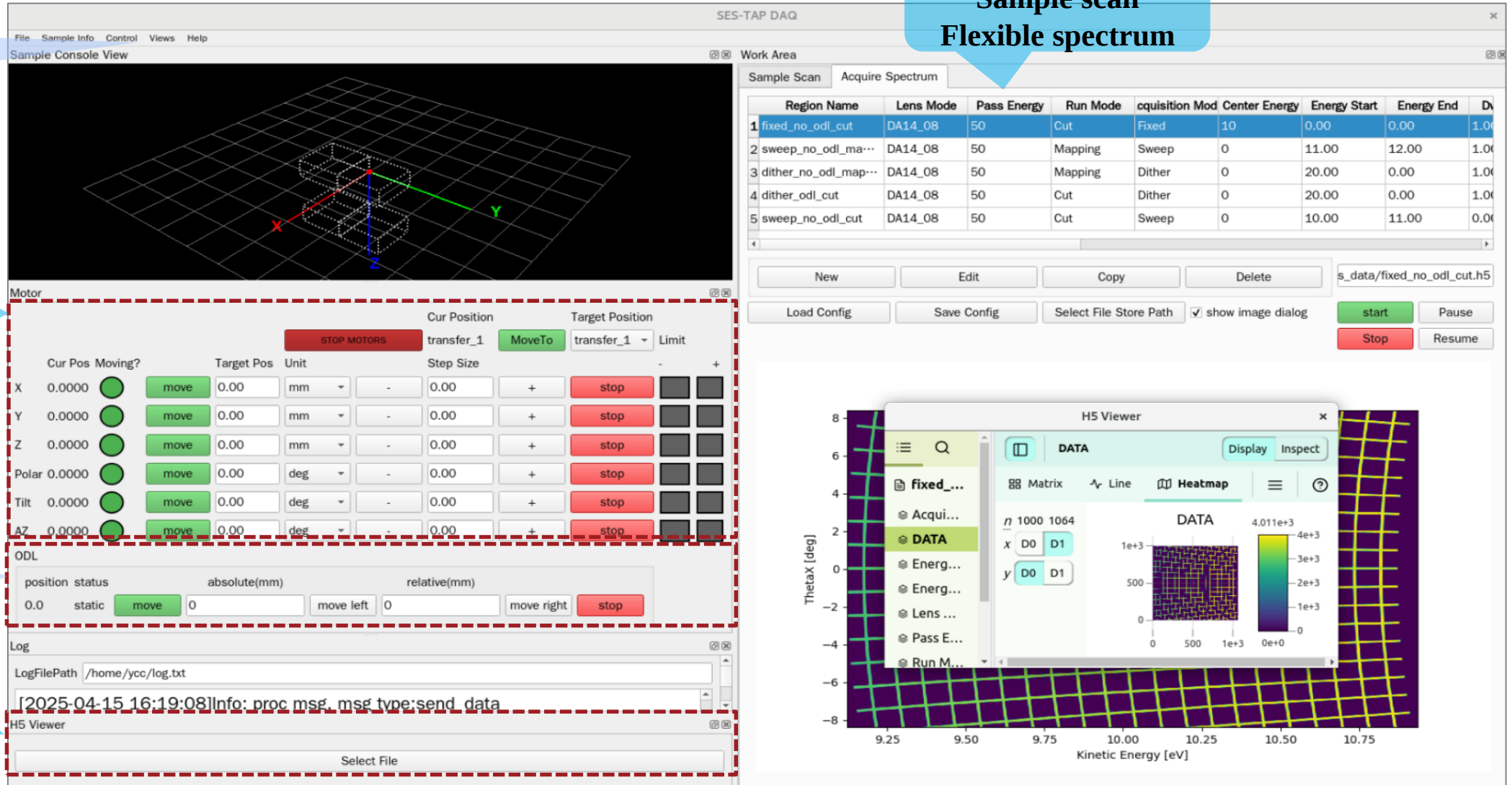
Control
diagnostics
detectors

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.

		2025												2026														
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12			
Timing	FEL-II timing	Hardware calibratin, testing										install,commissioning		joint commissioning,operation and maintenance														
	FEL-I timing				technical specification				equipment delivery				hardware calibratin and testing								install,commissioning							
EndStations Software	SES TAP DAQ	custom development, testing							deployment, joint commissioning					operation and maintenance														
	AMO TDC DAQ	software development for TDC, testing							integration testing					joint commissioning, operation and maintenance														
	SSS DAQ								requirement discussion					solution design, software development, testing														
	HSS DAQ								requirement discussion					solution design, software development, testing														
Laser、Diagnostic Software	Laser Delay Line Control	development							deployment					joint commissioning,operation and maintenance														
	Imager DAQ		software development, testing							deployment					joint commissioning, operation and maintenance													
	PAM DAQ								software development, testing					deployment					joint commissioning, operation									
	WFS DAQ							requirement discussion		software development,testing					deployment					joint commissioning, operation								
	SERM DAQ							requirement discussion			software development, testing					deployment					joint commissioning, operation							
	PES DAQ(support)									software development					integration testing					operation and maintenance								
	GMD&Hamps DAQ(support)										software development					integration testing					operation and maintenance							
	BPIM DAQ											software development, development,testing					integration testing					operation and maintenance						
	Spectrometer Control												development,testing					deployment					joint commissioning,operation					
Integrated Software	Event Building Software	development							deployment,integration testing					joint commissioning, operation and maintenance														
	Achive Application, IOCStats, Autosave,ProcServControl...									deployment, joint commissioning								operation and maintenance										
	Integrated GUI for Beamline													development, testing					deployment, joint commissioning									

- ❑ 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!

