Introduction to CBXFEL Controls

A. Montironi on behalf of the CBXFEL controls team

Apr 17, 2024

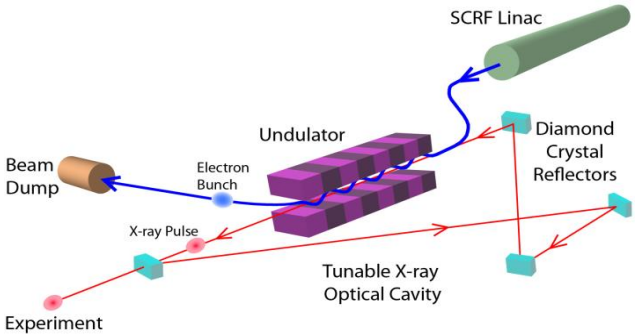
Overview

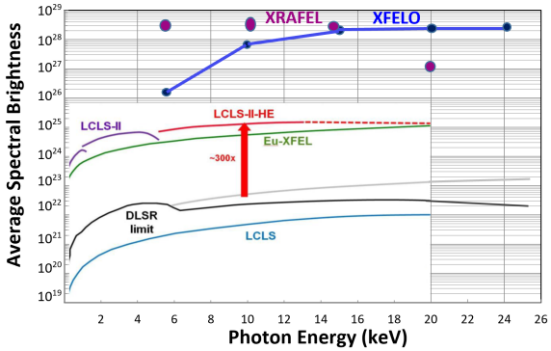
- What is CBXFEL?
- Controls overview
- Controls team
- Subsystems
  - Motion
  - Cameras
  - Digitizers
  - Temperature control
  - Vacuum
  - Timing, MPS, infrastructure
- Summary

What is CBXFEL

X-ray RAFEL: Z. Huang and R.D. Ruth, Phys. Rev. Lett. **96**, 144801 (2006).
X-ray Oscillator: K.-J. Kim, Y. Shvyd'ko, and Sven Reiche, Phys. Rev. Lett. **100**, 244802 (2008).

CB (cavity based) XFEL employs an X-ray cavity formed by crystal mirrors so that X-ray pulses receive periodic FEL-amplification and Bragg-monochromatization. CBXFEL can enhance hard XFEL brightness by another two-three orders of magnitude.





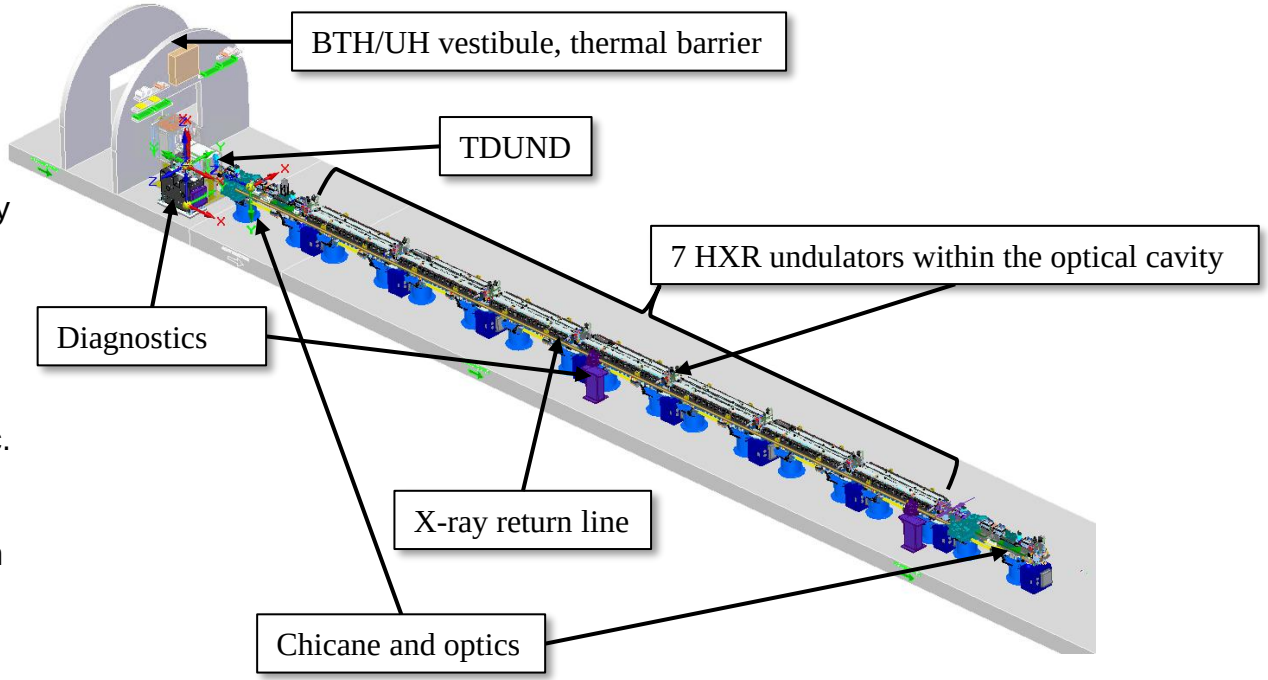
Two configurations:

- XRAFEL (X-ray Regenerative Amplifier FEL): High gain, CW or Q-switched for intense, ultra-short pulse
- XFELO (XFEL Oscillator): Low gain, CW operation for intense, ultra-fine spectral width

A. Cho, Science 373, 2068 (2021) " Tiny diamond mirrors could smooth out already revolutionary X-ray lasers"

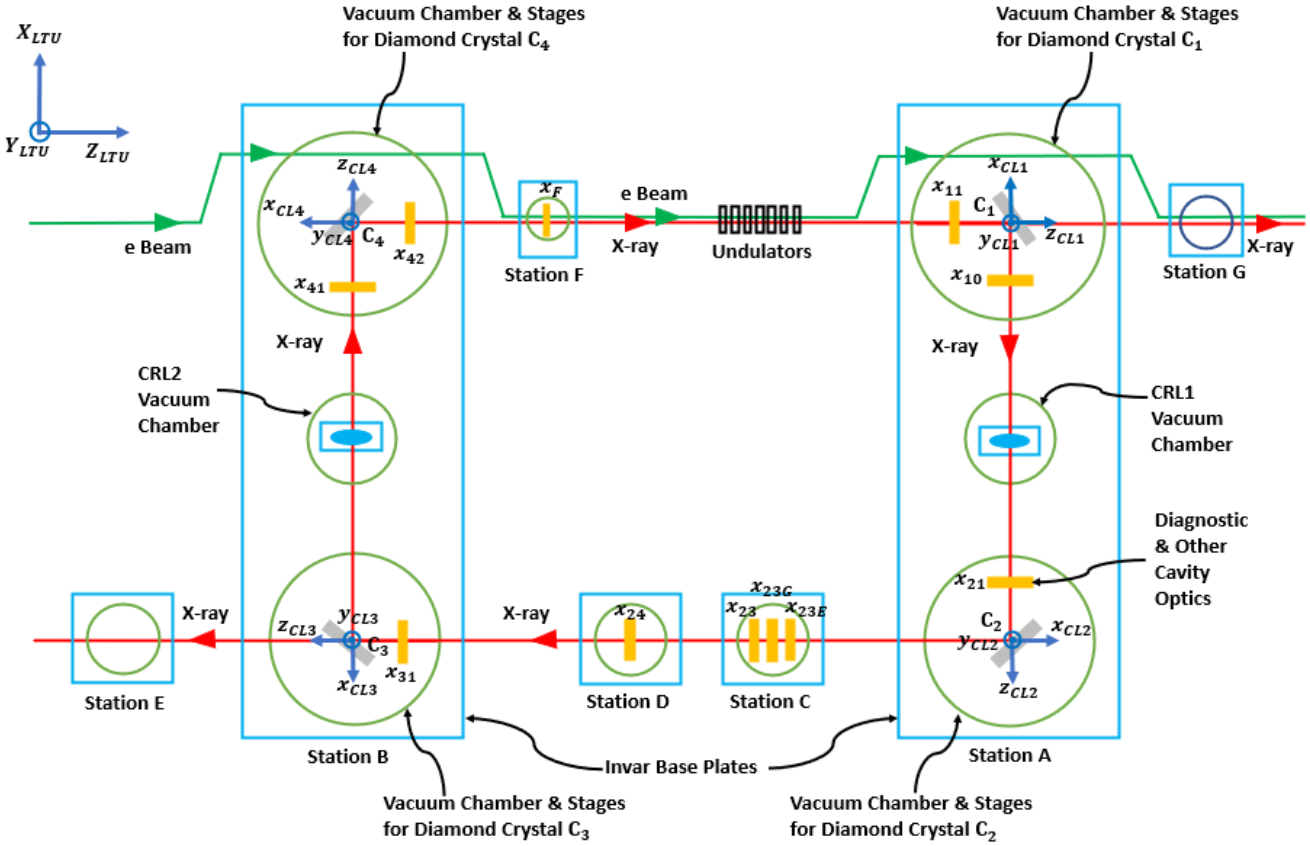
CBXFEL project – *ANL/SLAC/Spring-8 collaboration to conduct targeted R&D (**Phase 1**)*

- Design and construct a rectangular X-ray cavity that encloses the first 7 LCLS-II HXR undulator modules.
- Investigate crucial aspects related to CBXFEL physics using a pair of electron bunches from the SLAC copper RF linac.
- Demonstrate cavity tolerance and stability requirements necessary for both schemes.
- Perform 2-pass gain measurements and cavity ring-down measurements for low and high gain schemes.

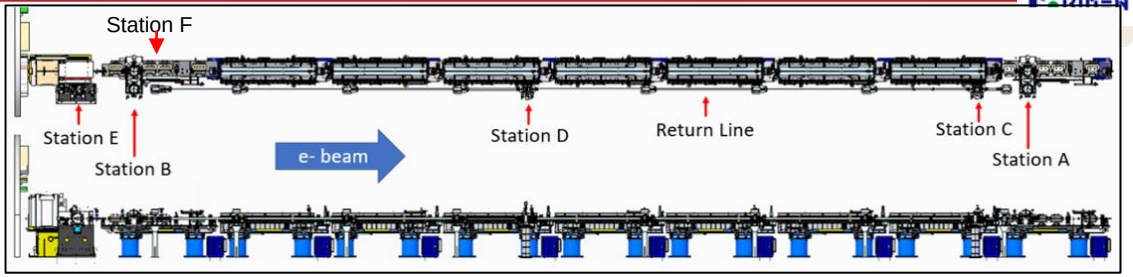


From Z. Huang CBXFEL Mechanical Delta FDR Nov. 30 2022

CBXFEL Project Components Overview



CBXFEL Controls Overview - Subsystems



Subsystem	Device type	Quantity
Magnets	Chicanes	2 chicanes
Motion	Diamond crystal nanopositioning flexure stages	24 axes
Motion	Diamond crystal alignment (above flexures)	12 axes
Motion	Diagnostic alignment, camera focus, etc.	43 axes
Vacuum	Ion pumps, vacuum gauges, valves	25 pumps, 8 gauge pairs, 3 pneumatic valves
Diagnostics	Cameras (USB, GigE)	5 USB, 12 GigE
Diagnostics	Digitizers	4 digitizers, 12 signals
Temperature Control	Diamond crystal heaters and T sensors	4 heaters
MPS	Component position, chicane current	6 switches, 2 chicanes
Timing	Timing receivers, timing distribution	
Network infrastructure	Controls network distribution	
Power infrastructure	AC power	

- All devices controlled using standard SLAC controls hardware and software.
- Standard SLAC EPICS implementations used across all subsystems, including displays, archiving, and alarming.
- High-level applications are in physics scope.

CBXFEL Controls Team

Technical Leads
SLAC
A. Montironi
ANL
J. Stein

Motion
SLAC
A. Montironi
W. Lewis
C. Andrews
D. Caltabiano
N. Balakrishnan
T. Thayer
ANL
J. Stein

Vacuum
SLAC
S. Saraf
S. Karimian
S. Nguyen

Cameras
SLAC
C. Curtis
ANL
P. Liu

Temperature
SLAC
N. Balakrishnan
Z. Huang
S. Karimian
ANL
P. Liu

Digitizers
SLAC
A. Le
M. Dunning
J. Mock
M. Urbina
V. Tang
ANL
P. Liu
Y. Shvyd'ko

Magnets
SLAC
B. Lam

Timing
SLAC
C. Bianchini
Mattison
D. Sanchez

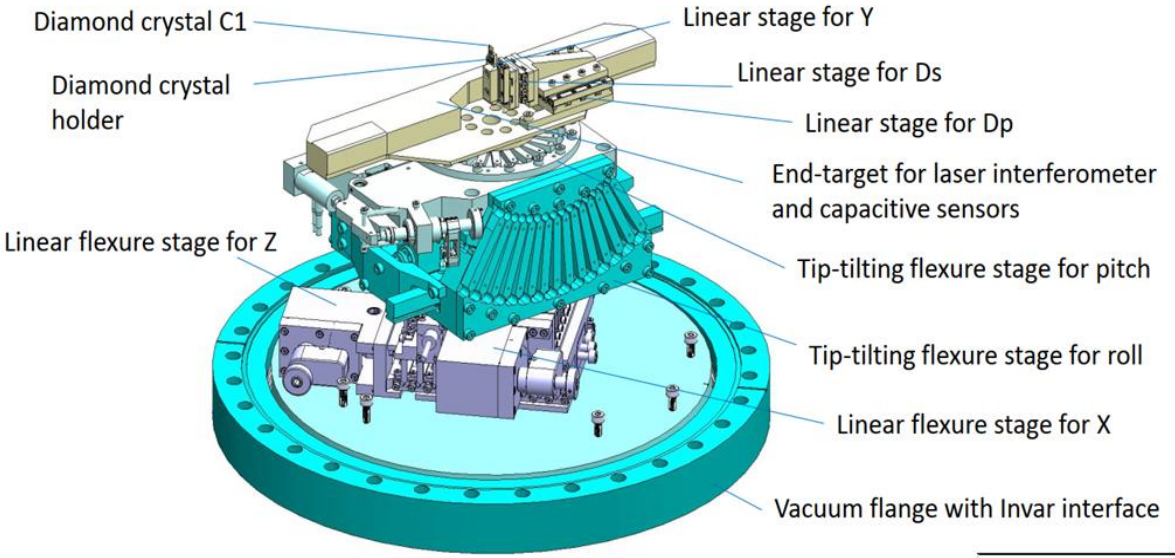
MPS
SLAC
J. Mock
K. Leleux

Network
SLAC
A. Shetty
C. Granieri
K. Brobeck

Scope
ANL (Stations A, B, C, D)
- Controls component specification and procurement
- Device and system checkout prior to shipping
- PMAC configuration

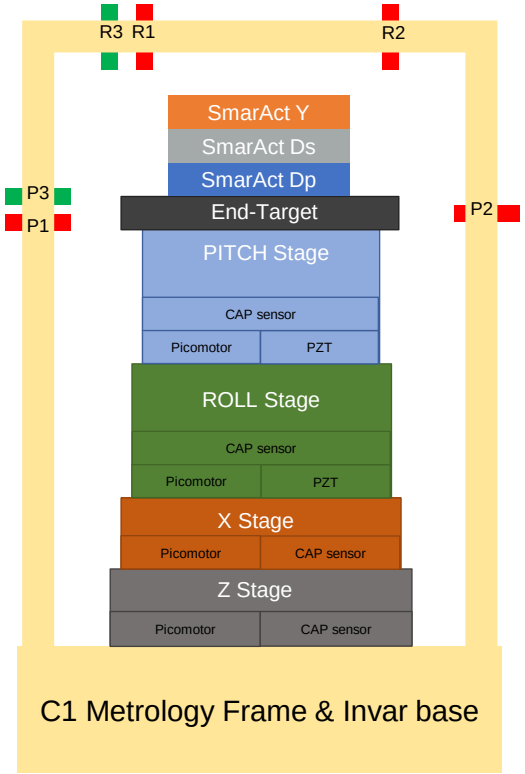
SLAC
- Site acceptance testing
- SLAC integration design and execution
- EPICS integration and driver development
- All Station E and F controls
- Installation planning and execution

Diamond Crystal Nanopositioners Control



Stage name	Travel Range	Resolution
Linear flexure stage for X and Z (coarse)	1000 micron	50 nm
Linear flexure stage for X and Z (fine, optional)	15 micron	5 nm
Tip-Tilt flexure stage for around Y and Ds (coarse)	26 mrad	350 nrad
Tip-Tilt flexure stage for around Y and Ds (fine)	0.1 mrad	20 nrad
Linear miniaturized stage for Dp, Y, and Ds	12 mm	50 nm

Diamond Crystal Nanopositioners Control



Axis	Count	Actuator/Sensor	Controller
X, Z, Roll (coarse), Pitch (coarse)	4	PicoMotor/Capacitive	PMAC
Roll (fine), Pitch (fine)	2	PI PZT/Interferometer	PMAC
Roll, Pitch	2	-/Capacitive	-
Dp, Ds, Y	3	SmarAct	SmarAct

- 7 motion axes with 9 actuators per diamond crystal
- PMAC integrates all instrumentation (except SmarAct axes) and implements closed loop control for flexure coarse and fine movement
- SmarAct controller provides single-axis control
- Redundant sensors (capacitive, interferometer) on end-target bar for pitch and roll absolute measurement
- PMAC will implement crosstalk compensation by sequencing axis movements using coordinate system/motion program
- EPICS interfaces to PMAC and SmarAct individual motion axes and PMAC coordinate system using standard motor records

Other Motion Control

Device	Actuator/Sensor	Controller
Diagnostics (XBPM, XBIM, etc.)	SmarAct	SmarAct
Lenses	SmarAct	SmarAct
Interferometer collimator alignment	SmarAct	SmarAct
Photodiodes	NewFocus/None	NewFocus
Camera focus/iris	NewFocus/None	NewFocus
Station E camera and diagnostics	Stepper motor/encoder	PMAC
Station F camera and diagnostic	Stepper motor/encoder	PMAC

- 43 motion axes
- All controllers already in use in SLAC EPICS environment
- All motion axes interface to SLAC control system via standard EPICS IOCs and motor records

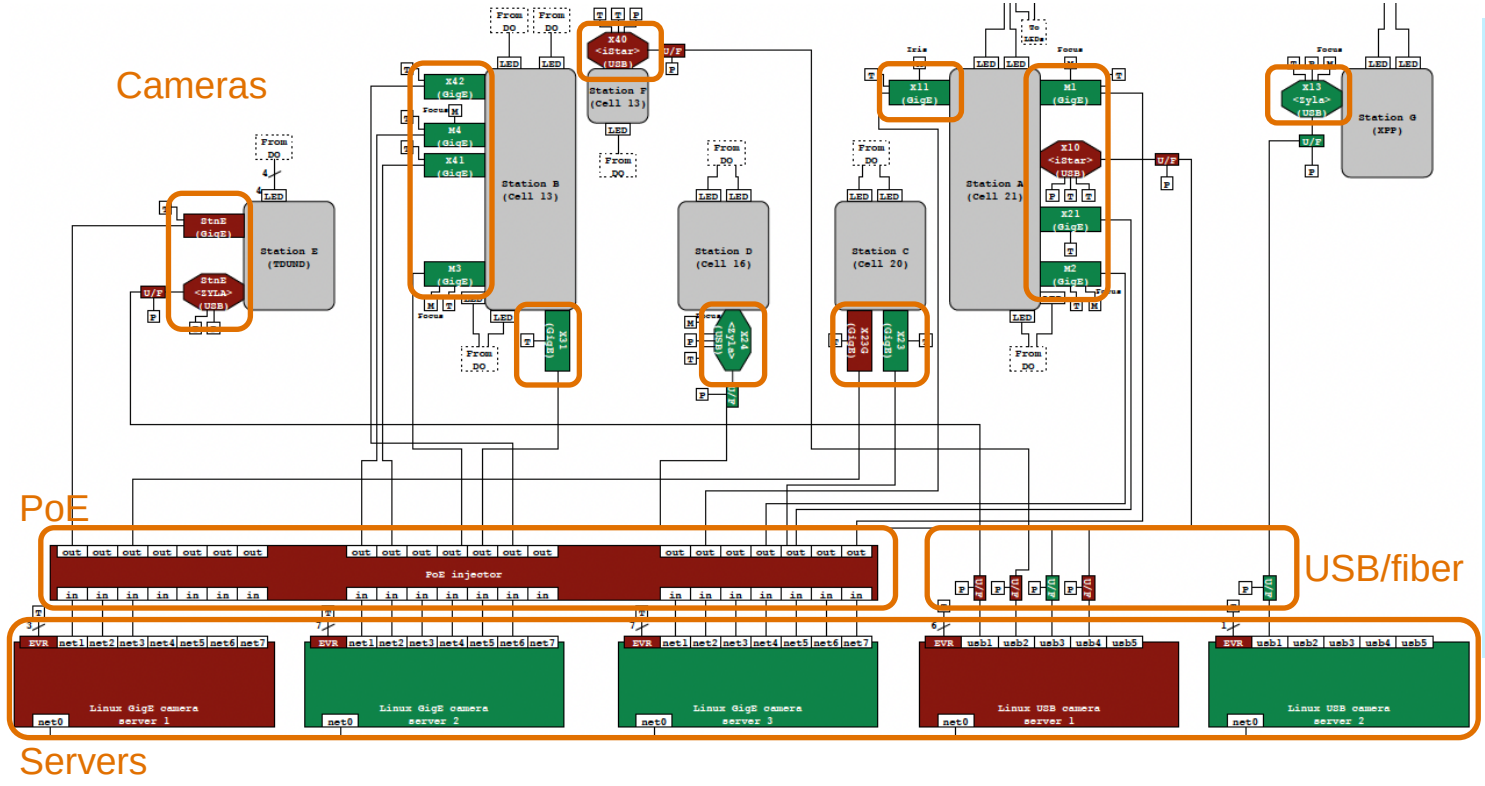
Motion Controllers

One motor controller we have introduced with this project with very positive results

PMAC CK3M

- High-performance modular motion controller
- Station E configuration: 8 axes for step-and-direction motion control, 8 axes for BiSS-C encoder readback
- Interface with actuator-specific amplifiers (steppers, piezo…)
- EPICS interface over Ethernet/IP

Diagnostic Cameras Controls

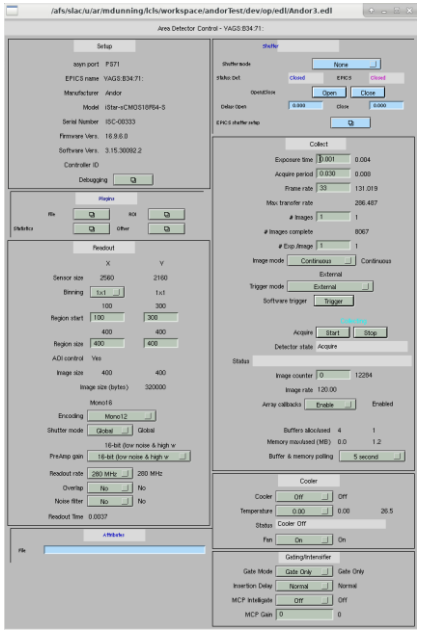


- 5 USB cameras, 12 GigE cameras
- 5 servers in support building
- Standard SLAC EPICS areaDetector implementation for all cameras
- Motorized focus and iris control handled by motion control
- Timing receiver in each server to provide triggers to cameras
- Illuminator control using Beckhoff

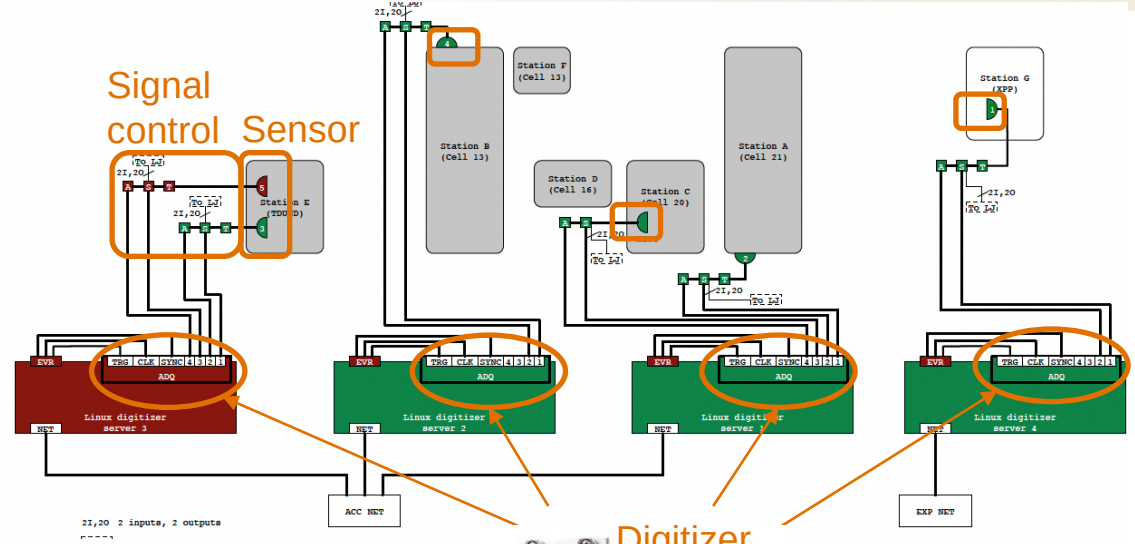
Diagnostic Cameras Control

Mike D, Courtney, and Jeremy integrated USB cameras driver from the community into EED supported version of AreaDeterctor EPICS module

Testing and development 90% complete



Diagnostic Photodiodes and XBIM Controls



- 5 photodiodes, 1 XBIM
- 12 signals distributed across 4 digitizers
- Digitizers and timing receiver installed in server chassis
- Server chassis installed close to detectors to minimize cable length
- Channel switching control using LabJack digital IO

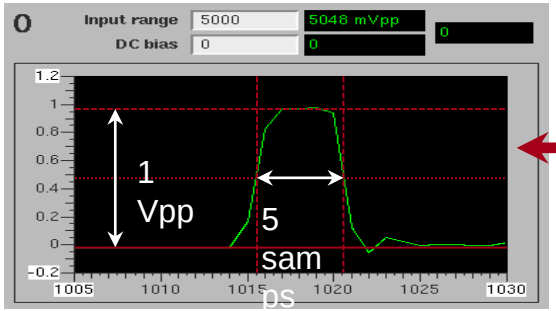
Digitizer

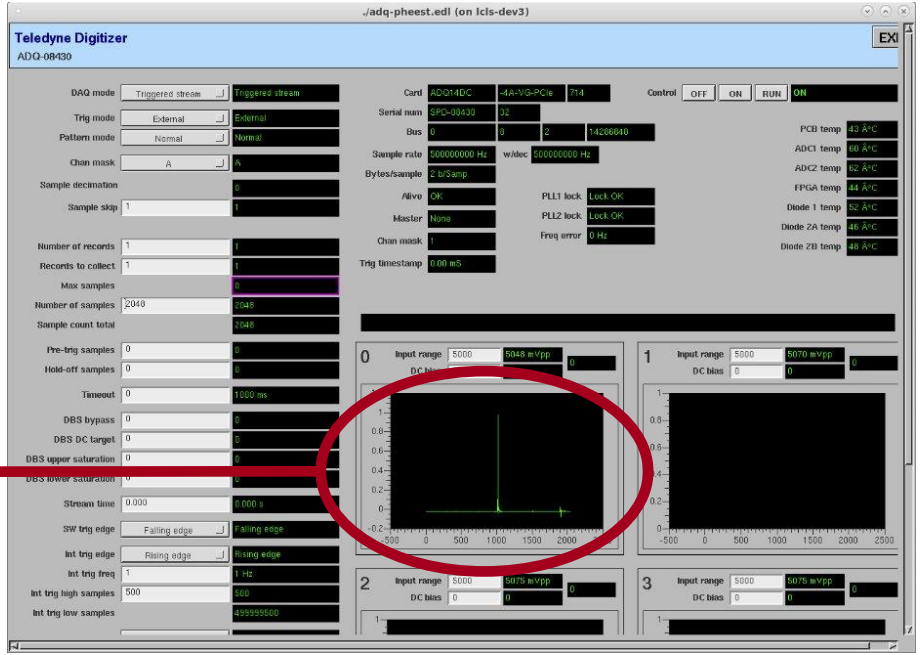
- Teledyne ADQ14
- New digitizer at SLAC
- Driver development completed

Diagnostic Diodes and XBIM control

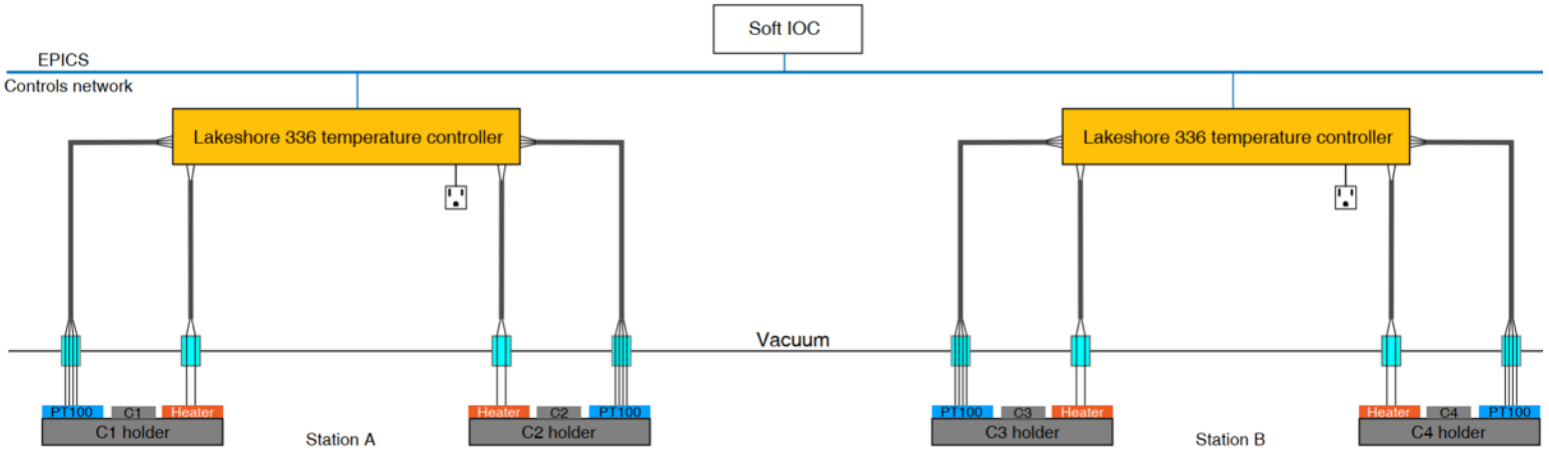
Mike D, and An took Teledyne digitizer driver from the community and ported it to our EPICS environment. Plus added features needed for CBXFEL and triggering from timing system.

Testing and development 90% complete





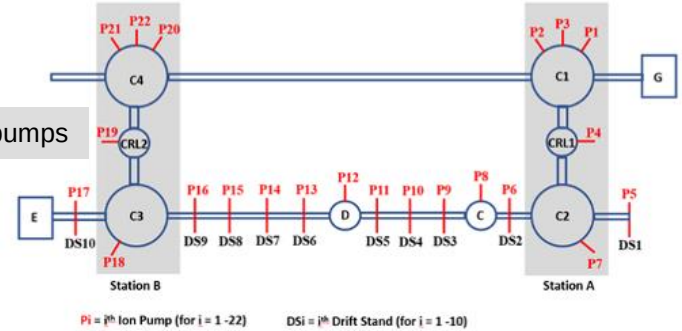
Temperature Control and Monitoring



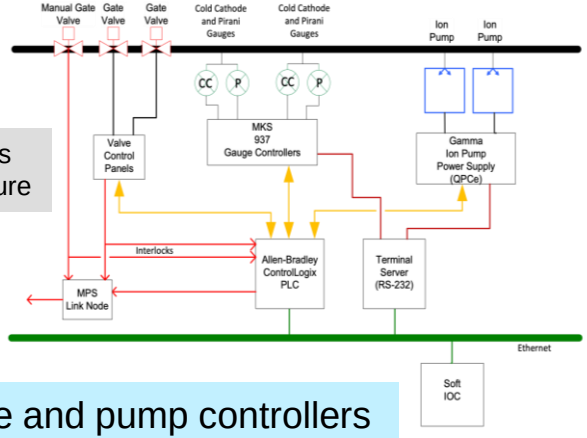
- 4 temperature control loops
- 2 Lakeshore 336 controllers
- Controller integrated using standard SLAC EPICS support
- Girder temperature monitoring implemented using existing undulator infrastructure

Vacuum Control

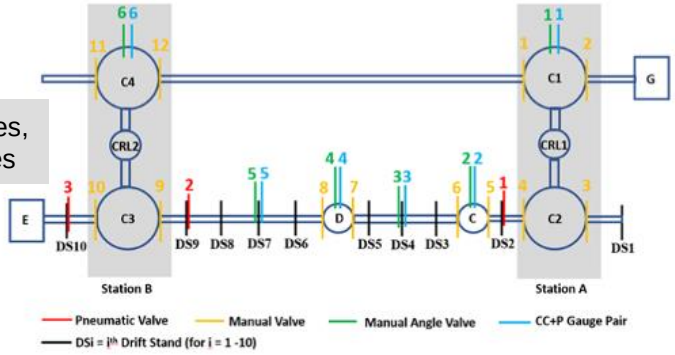
Ion pumps



Controls architecture



Gauges, valves



- Standard SLAC gauge and pump controllers
- Standard SLAC vacuum PLC
- Standard SLAC EPICS integration

Device counts and locations defined by ANL, integration by SLAC

- 25 ion pumps
- 8 gauge pairs
- 3 pneumatic valves
- 12 manual valves

Other Subsystems and Infrastructure

Timing
- Additional timing fanout added to provide capacity for timing receivers for cameras and digitizers

MPS
- Out-of-beam position indication for components that can be inserted into the nominal electron beam path
- Chicane current monitoring to determine CBXFEL operation status

Cabling
- CAPTAR submitted for all subsystems
- Cable tray installation in progress

Network
- Required network ports have been requested

Power
- Adequate AC power is available in tunnel
- Each controls rack will have network-connected PDU

Racks
- Controls rack locations have been assigned under undulator girders or in support buildings

Next few months (SLAC)

- Finish building controls infrastructure (cables)
- **Summer 2024**: motion, cameras, digitizers, and vacuum testing – Stations D and E
- **Fall 2024**: motion, cameras, digitizers, and vacuum testing – Stations C and F
- **Early Summer 2024**: receive first nanopositioner stack and chamber (C1)
- **Winter Down 2024/2025**: Nanopositioners stack chambers installation
- **Winter 2025**: final controls testing and commissioning

- Lots of software work to do!
- Lots of coordination and lab testing

Summary

- Interfaces between ANL and SLAC scope have been defined and documented
- Controls has worked closely with mechanical to define control system device counts and performance requirements
- Required controls infrastructure has been identified and is being installed
- Actively developing PMAC controls for nanopositioning flexure stage control
- All devices have existing EPICS support and EPICS applications have been prototyped
- Standard SLAC EPICS environment will be used, including standard control system services
- Stations A through E controls FDRs have been completed
- Station F FDR scheduled for next Monday, April 22

THANK YOU!

QUESTIONS?

BACKUP SLIDES

Relevant Documentation - Motion

Document Number	Document Title	Version	Document Status
SLAC-I-120-065	CBXFEL Motion Control FRS	R2	IN APPROVAL
SLAC-I-120-067	CBXFEL Motion Control ESD	R2	RELEASED
ANL-SPEC-CTL-000-A840-CBXM01 (SLAC-I-120-183)	CBXFEL Motion Control Hardware ESD	R1	IN REVIEW
ANL-SPEC-CTL-000-A840-CBXM02	CBXFEL Nanopositioning and Mechanical System ESD	R0	IN DRAFT
SLAC-I-120-178	CBXFEL Motion Block Diagrams	R1	RELEASED
SLAC-I-120-174	CBXFEL Motion Control ESD Supporting Data	R2	RELEASED
SLAC-I-120-098	CBXFEL Control System ICD – SLAC to ANL	R2	IN APPROVAL
SLAC-I-120-181	CBXFEL Motion Control Site Acceptance Test Procedure	R1	IN APPROVAL
SLAC-I-120-257	CBXFEL Nanopositioning System Characterization and Test Procedure	R0	IN DRAFT
SLAC-I-120-022	Planning of CBXFEL X-ray Cavity MAD Device	R3	IN APPROVAL
SLAC-I-120-190	CBXFEL Station A and B Vacuum Chamber In-Air and In-Vacuum Electrical Wiring Schematic	R1	IN EARLY DRAFT
SLAC-I-120-242	Record of Decision on CBXFEL – Addition of Tip-Tilt Stage in C2 for Etalon Collimator	R0	RELEASED
SLAC-I-120-225	Record of Decision on CBXFEL – Piezo Arcing Risk Assessment	R0	RELEASED
SLAC-I-120-244	CBXFEL Venting Checklist	R0	RELEASED
SLAC-I-120-245	CBXFEL Pumpdown Checklist	R0	RELEASED

Relevant Documentation - Subsystems

Document Number	Document Title	Version	Document Status
SLAC-I-120-112	CBXFEL Subsystem Control FRS	R1	IN APPROVAL
SLAC-I-120-103	CBXFEL Subsystem Control ESD	R0	RELEASED
SLAC-I-120-159	CBXFEL Subsystem Diagnostic Camera Engineering Specifications	R1	IN DRAFT
SLAC-I-120-249	CBXFEL Digitizer Block Diagram	R0	RELEASED
SLAC-I-120-182	CBXFEL Diamond Crystal Mirror Temperature Control ESD	R0	RELEASED
SLAC-I-120-248	CBXFEL Station A Diamond Holder Temperature Control Schematic	R0	IN DRAFT
SLAC-I-120-258	CBXFEL Undulator Hall Power Requirements Engineering Note	R0	RELEASED