

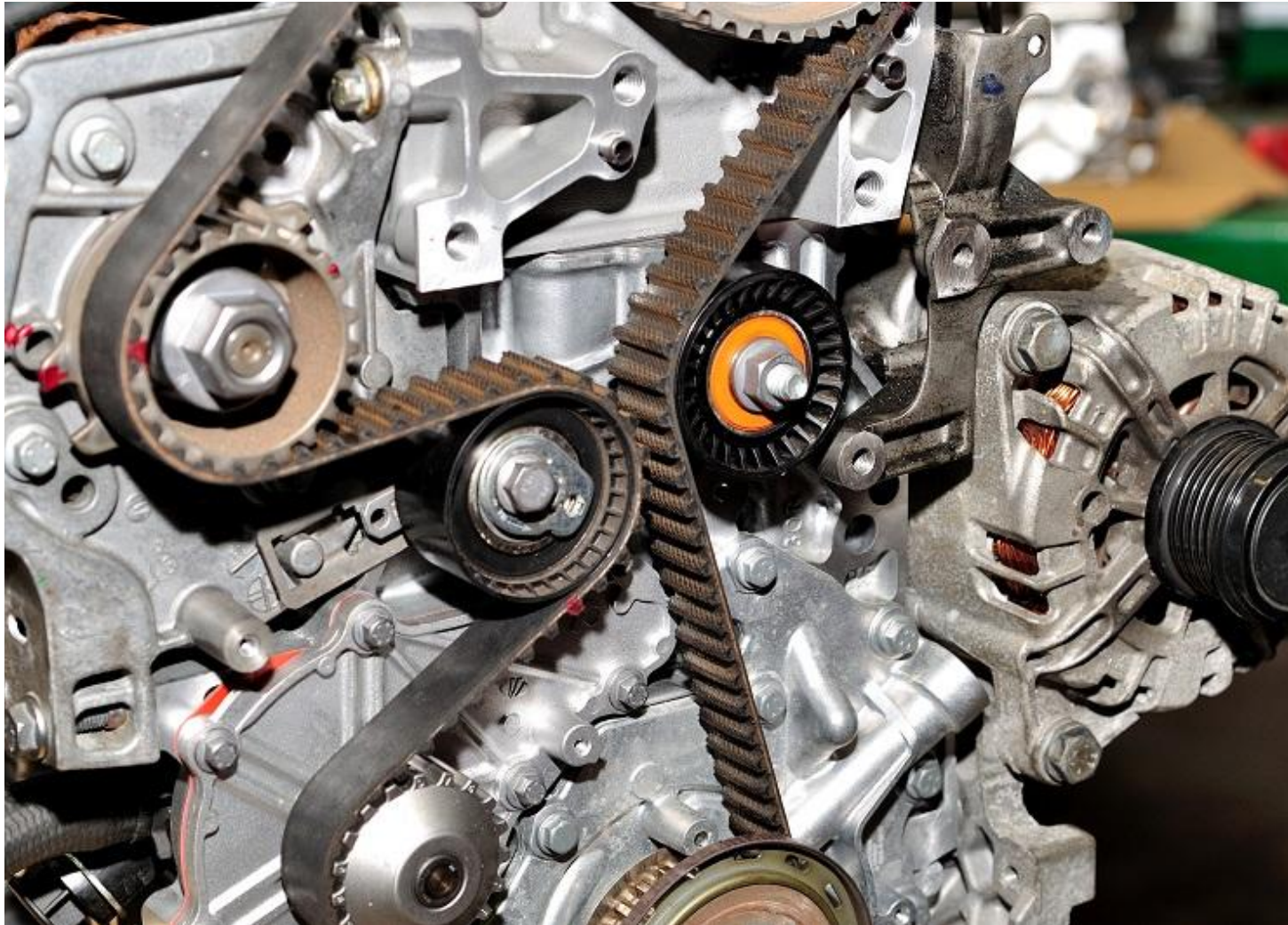
The LCLS-II Precision Timing Control System

ICALEPCS 2023

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October 11, 2023

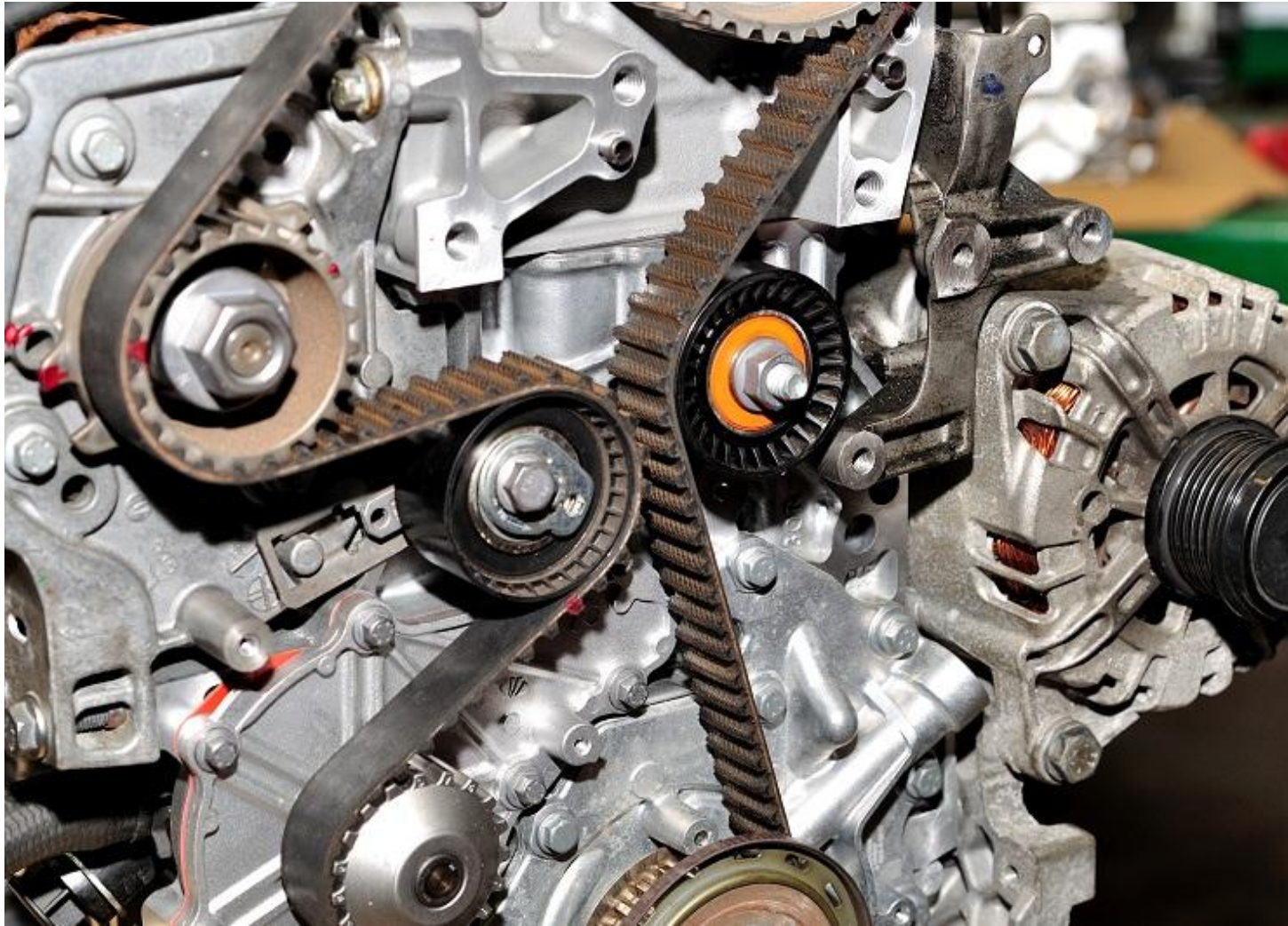
Why do we care about timing?



Timing is everything

- >75% of LCLS experiments require optical lasers
 - Pump-probe
 - “Molecular Movies”, etc.
- LCLS X-ray pulses are 100’s to 10’s of fs long
- LCLS optical laser pulses are of the same order
- Need to **establish, maintain,** and **control** the temporal overlap of these two very short pulses

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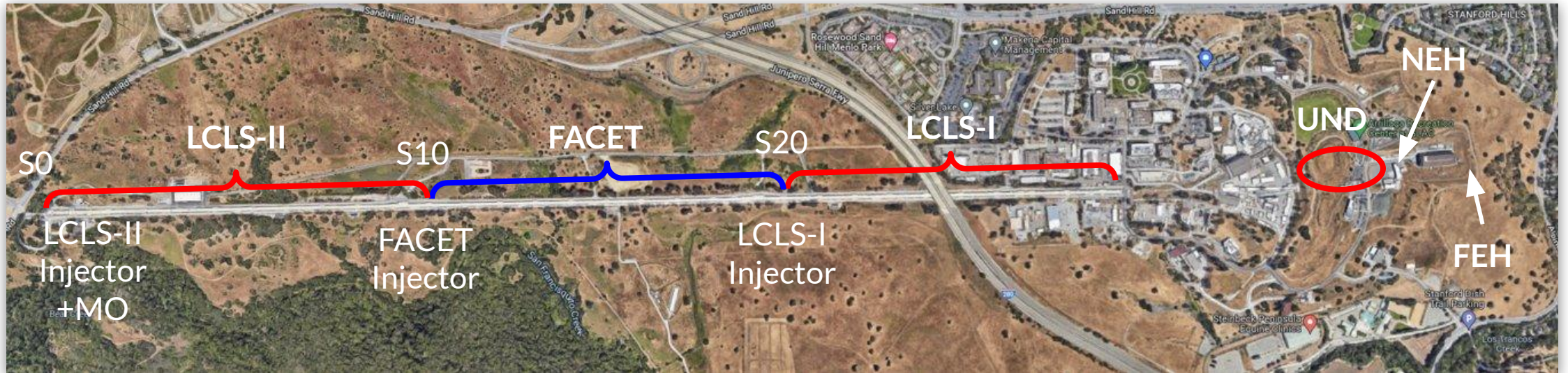
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*Requires precise phase locking
and phase control!*

A 10,000 ft (3 km) view of LCLS

Multiple facilities, different needs



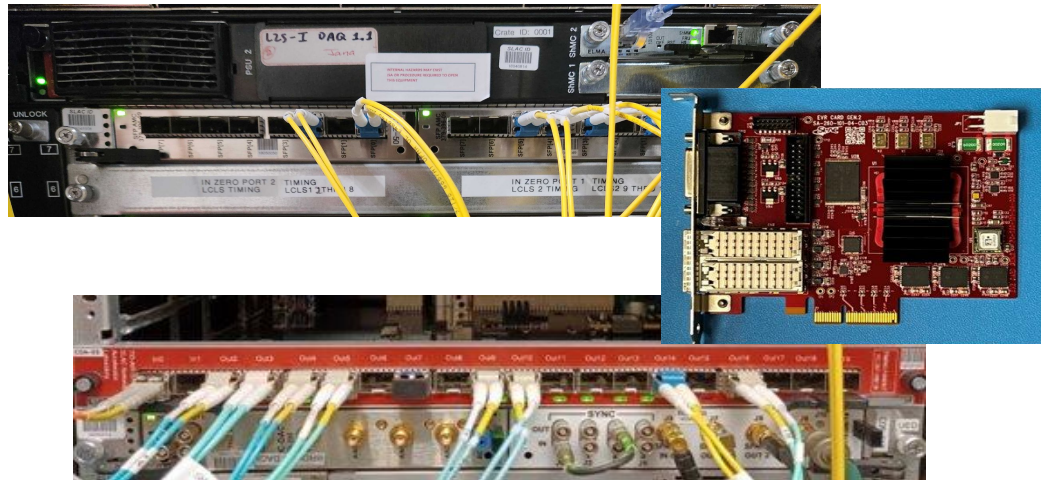
Event and RF timing is distributed to multiple facilities (AD/LCLS)

- LCLS-I S20 through S30 (approx. 100m/sector)
- FACET S10 through S20
- LCLS-II S0 through S10

Two flavors of timing at LCLS

Event Timing

- LVTTTL triggers and CPU interrupts for data acquisition and/or PV processing
- Generator: synchronous timestamps & control on fiber optic distribution system
- Receiver: decodes messages, generates triggers for device control & acquisition



Precision Timing

- Precise (~ 10 's fs) synchronization with XFEL
- RF synchronization of devices via hardware: PLL, FPGA, etc.
- Used for optical drive laser synchronization and delay control w.r.t. the XFEL

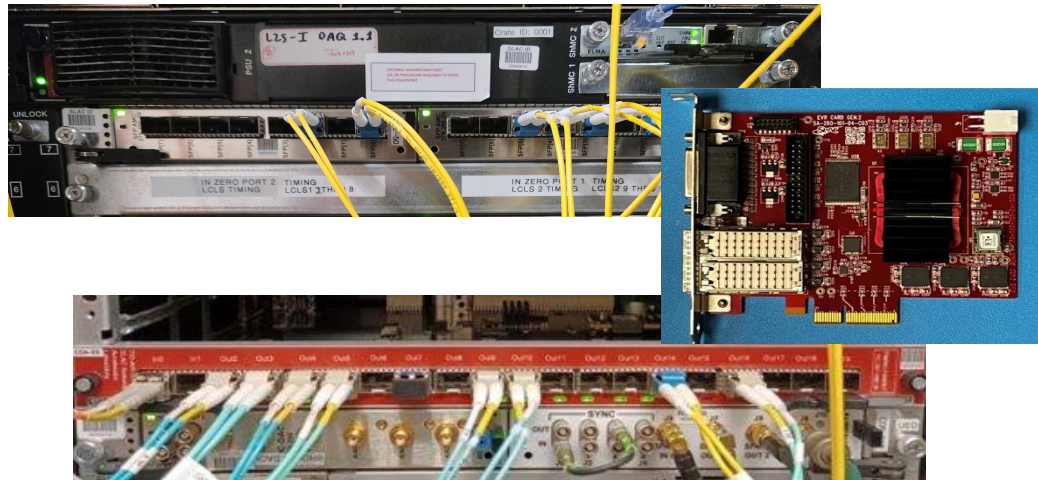


Two flavors of timing at LCLS

Focus for today

Event Timing

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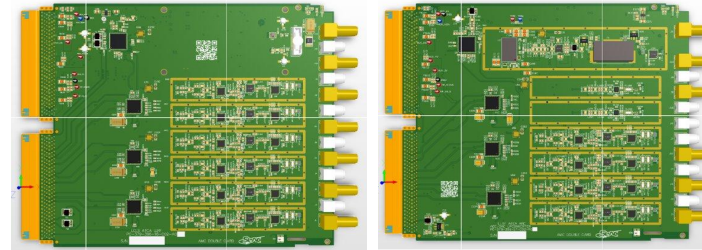
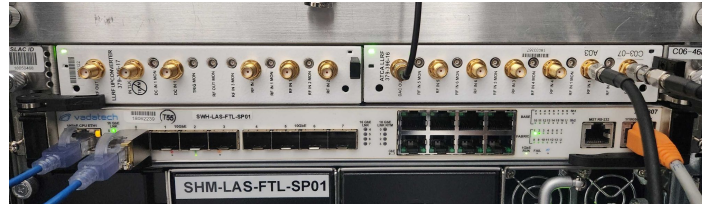
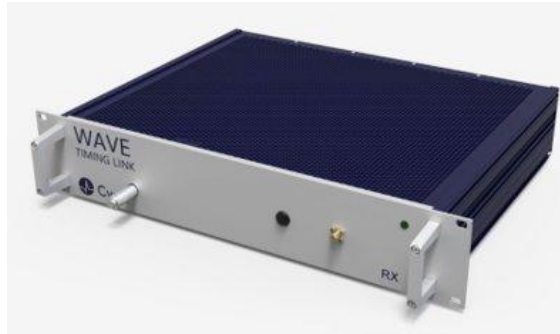


Precision Timing

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How do we do precision timing?



RF Distribution

- RF-Over-Fiber technology
- Commercial systems
- Transmit LCLS RF reference across >5km optical fiber
- Low jitter, low drift

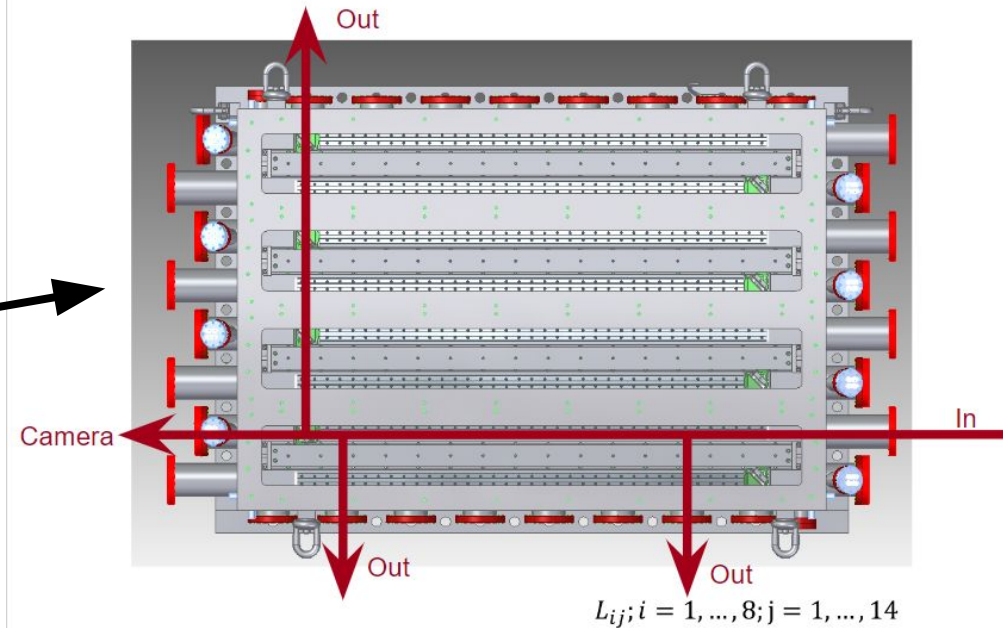
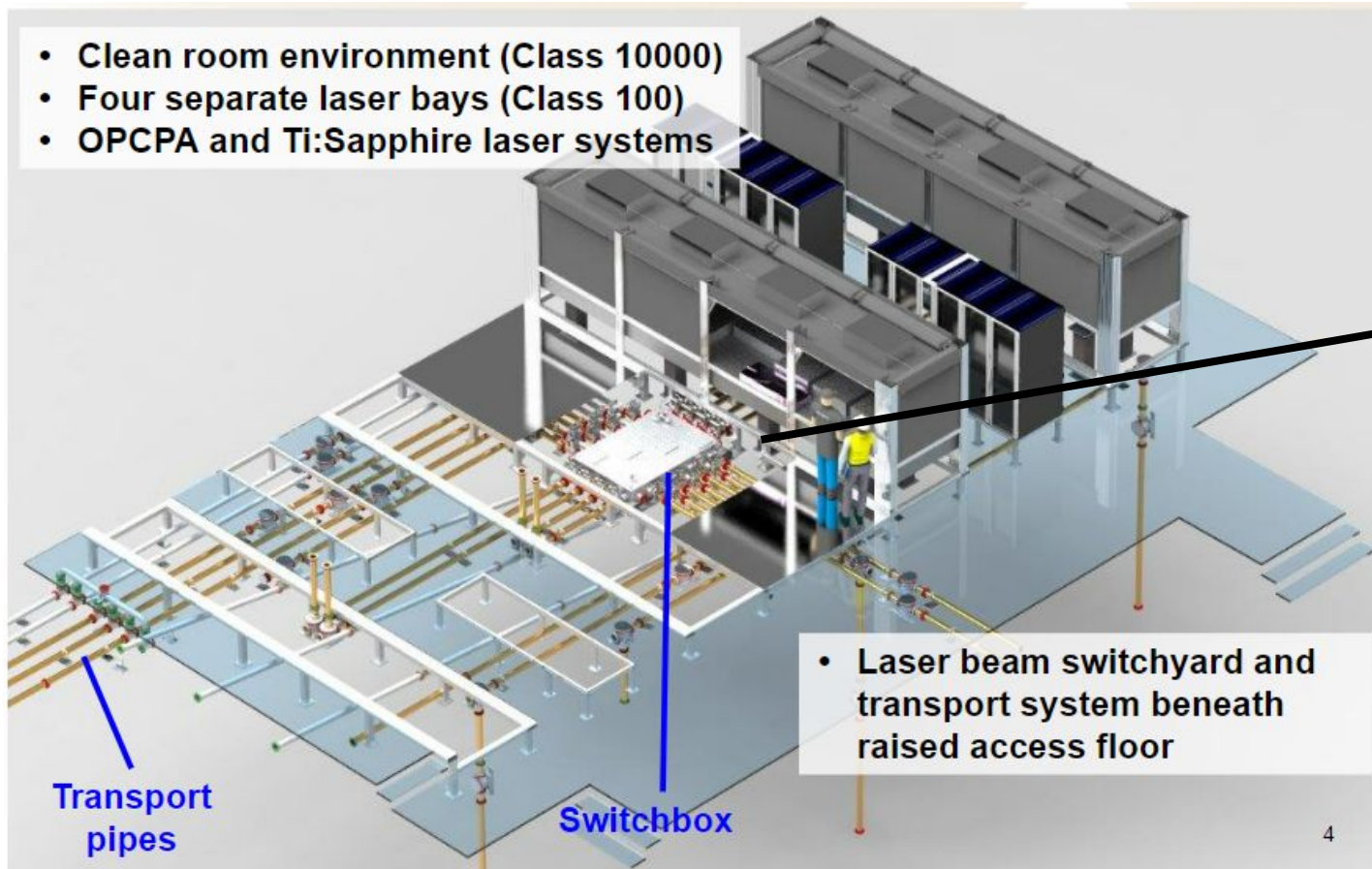
RF Locking

- Phase lock to RF reference
- Based on ATCA Common Platform developed for LCLS-II LINAC
- Delay control for pump-probe experiments

Optical Locking

- Based on commercial optical timing system
- Uses optical, rather than RF, phase comparison
- Provides sub-fs delay control and measurement

Any laser, any hutch

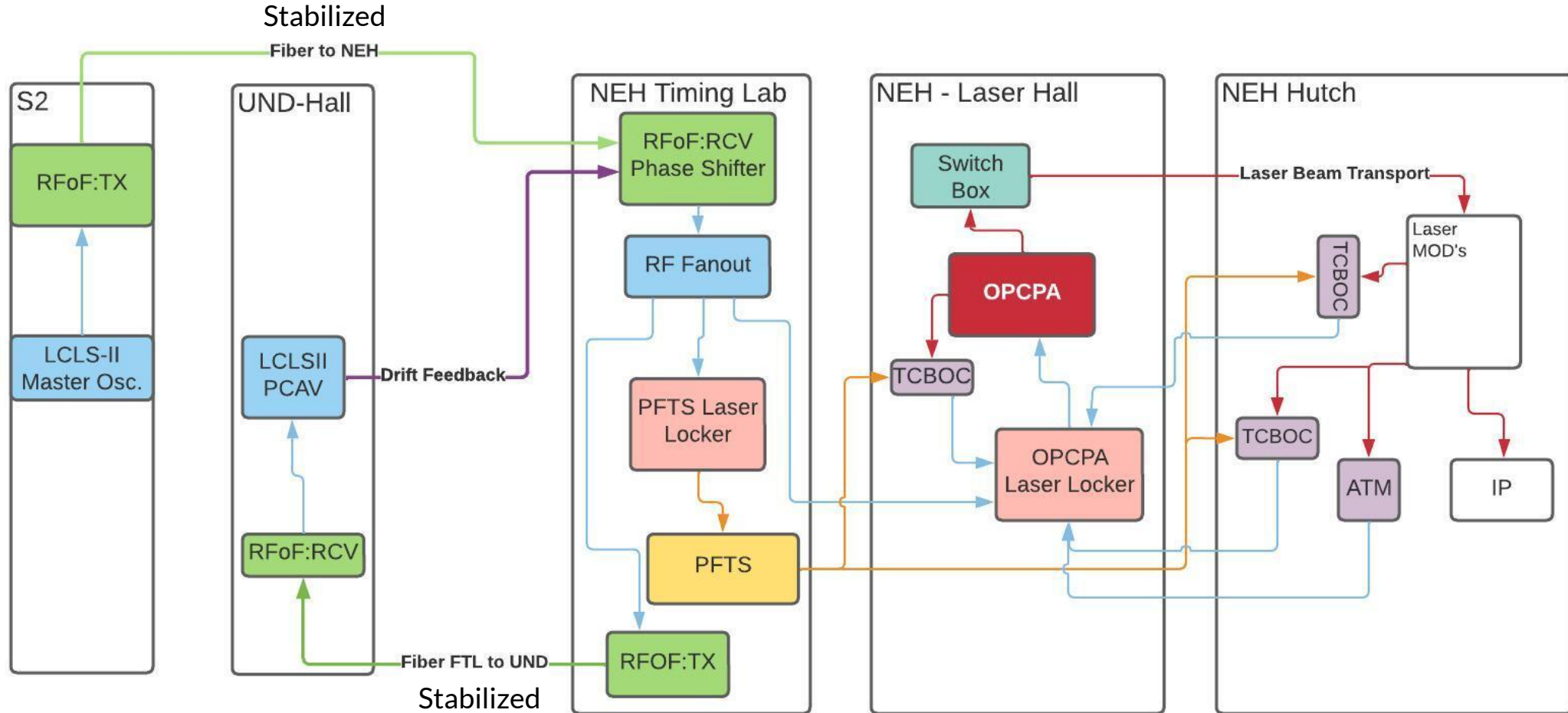


NEH Beam Transport System

- Optical laser switch box (8 in, 14 out)
- Evacuated transport lines to every IP
- Supplies optical laser for entire Near Expt. Hall

N:M relationship between hutches and the laser and timing systems!

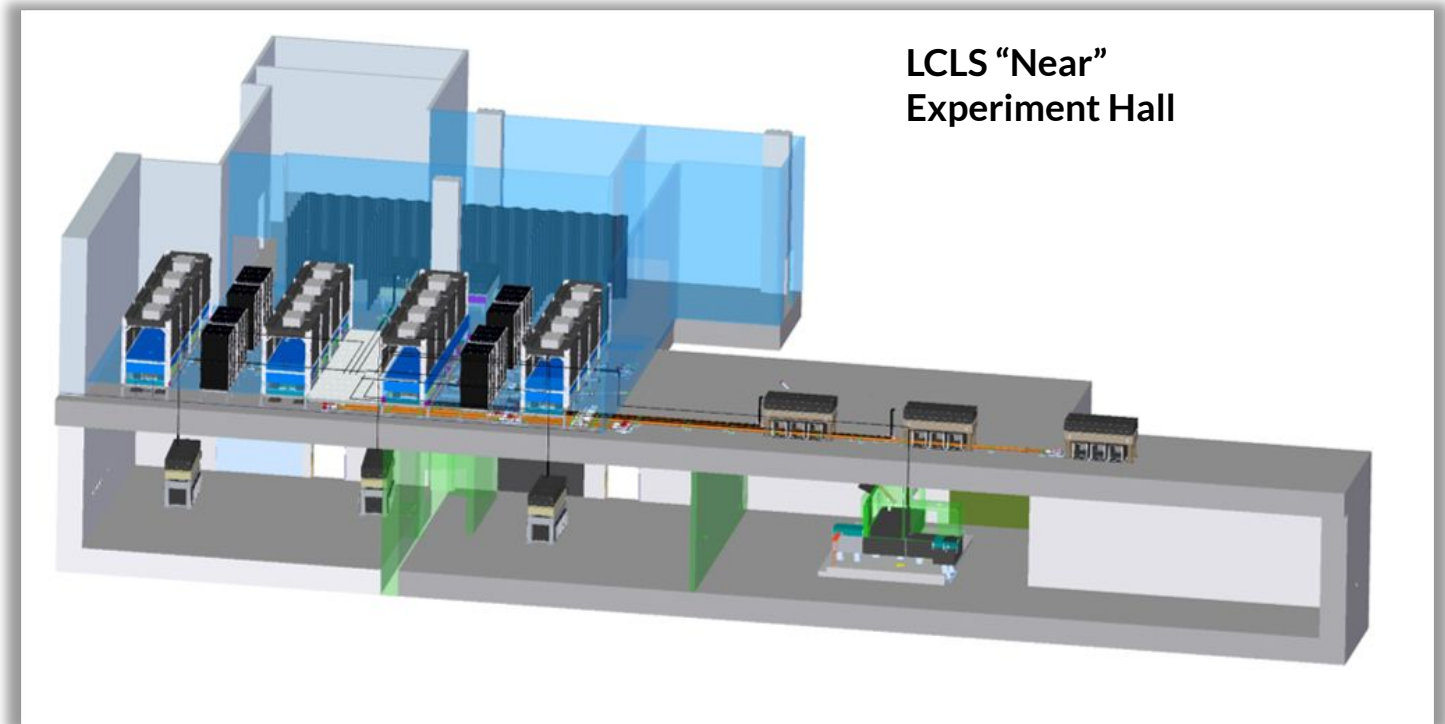
Putting it all together



What challenges do we face?

Multi-user systems

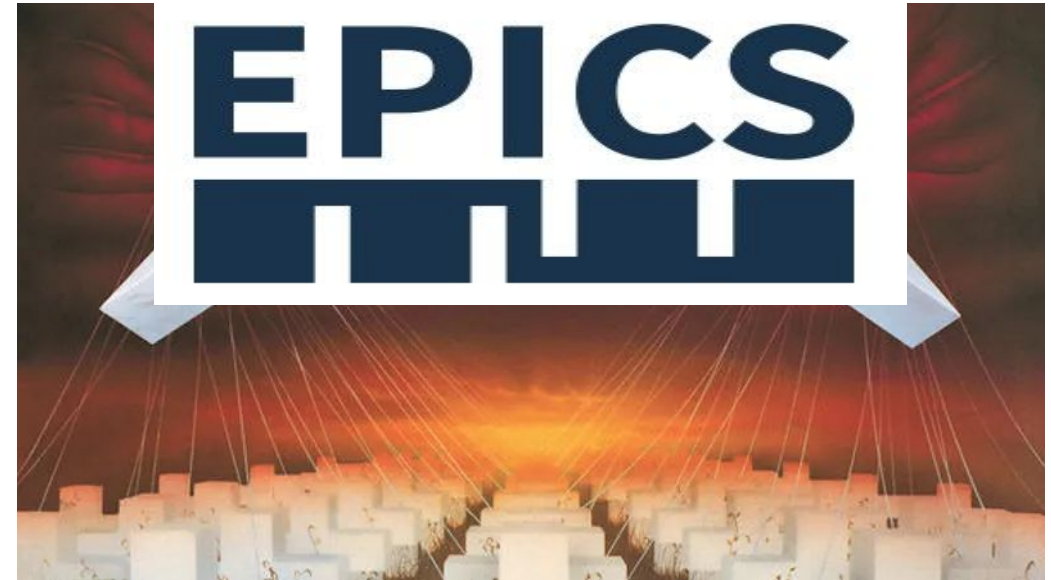
- LCLS-I lasers and laser lockers are 1:1
 - No “sharing”
- LCLS-II OPCPA laser can be delivered to up to 7 different interaction points
- Up to 4 experiment changes per day
- **Goal:** allow beamline operators to changeover laser and timing w/out expert assistance
- Need to deconflict shared resources
 - Drive laser
 - Laser locker
 - Stabilized timing links



From Python to EPICS

All EPICS, all the time

- Most beamline automation at LCLS is done via Python
 - ophyd, bluesky, etc
- LCLS-I: EPICS IOC + Python script
 - IOC: basic functions, frequency locking, EPID record
 - Python: high level interface PVs, calibration routine, delay calculations and delay control
- LCLS-II: Why not 100% EPICS?
 - Most of the LCLS-I locker could be handled by EPICS
 - Can have an all in one system application
- Missing capabilities:
 - Mutual exclusion
 - Easy automation procedures



Resource arbitration at the record level

The arbiter record

- 30 separate request lines (potential owners)
- Reports current owner and owned status
- Requests can be cleared and arbiter released
- Used in global and local contexts throughout the PFTS automation system

FIELD	Summary
REQ0 to REQ29	30 long inputs. Write a non-zero value to request the arbiter, and zero to release it (or cancel the request).
OWN0 to OWN29	30 string input links. These describe the thirty input requests.
OWNER	A string value giving the name of the current owner using the OWNx field. If OWNx is not defined, this will be "REQn" if the owner is n, or "None" if the arbiter is not owned.
VAL	A long value indicating the current owner, or -1 if it is not currently owned.
CLEAR	Writing a non-zero value will clear all requests and release the arbiter. This field is cleared after handling the request.

Example: Global PFTS arbiter record

```
record(arbiter, $(P):GLOBAL:ARB) {  
  field(OWN0, "$(P):OWN0 NPP NMS")  
  field(OWN1, "$(P):OWN1 NPP NMS")  
  field(OWN2, "$(P):OWN2 NPP NMS")  
  field(OWN3, "$(P):OWN3 NPP NMS")  
  field(OWN4, "$(P):OWN4 NPP NMS")  
  field(OWN5, "$(P):OWN5 NPP NMS")  
  field(OWN6, "$(P):OWN6 NPP NMS")  
  field(OWN7, "$(P):OWN7 NPP NMS")  
  field(OWN8, "$(P):OWN8 NPP NMS")  
  field(OWN9, "$(P):OWN9 NPP NMS")  
}
```

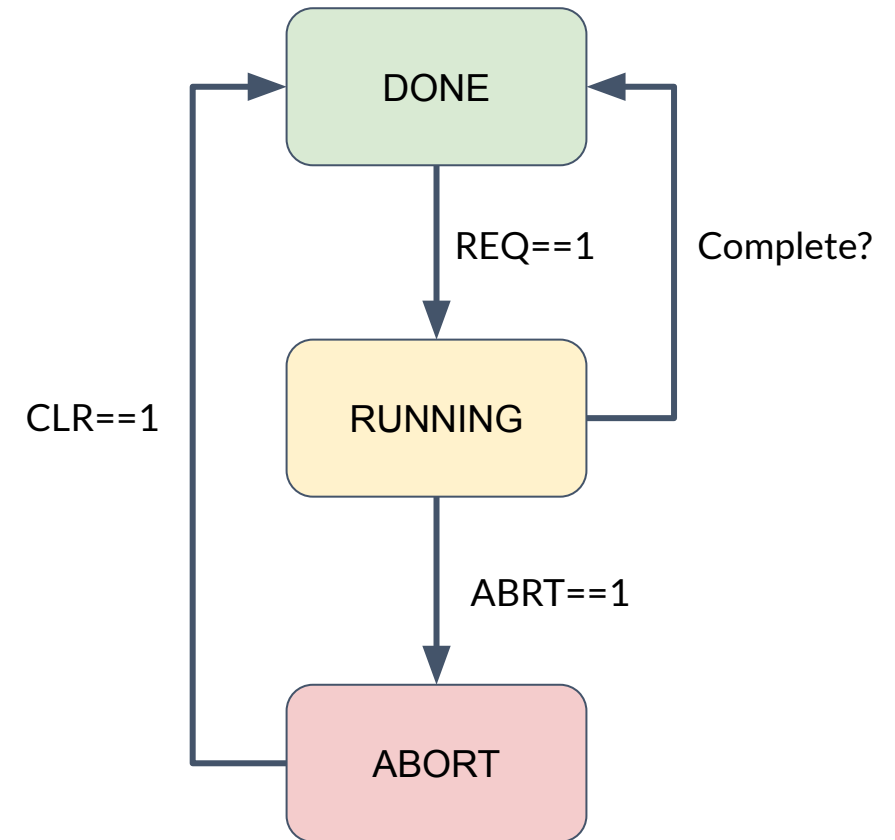
Example: Hutch interface PVs accessing global lock

```
# Global action lock.  
  
# Write 1/0 to lock/unlock the global lock.  
record(longout, $(P):QRIX:ACTREQ) {  
  field(VAL, "0")  
  field(PINI, "YES")  
  field(FLNK, "$(P):QRIX:ACTREQ_ASUB")  
}  
  
# Write $(P):QRIX:ACTREQ to $(P):GLOBAL:ARB.REQ0.  
record(longout, $(P):QRIX:ACTREQ_ASUB) {  
  field(OMSL, "closed_loop")  
  field(DOL, "$(P):QRIX:ACTREQ NMS NPP")  
  field(OUT, "$(P):GLOBAL:ARB.REQ0 NMS PP")  
}
```

How do we do procedures in EPICS?

stepSequence Record

- What do we want in a procedure?
 - Start, Stop, Status
 - Clear, consistent interface
- “stepSequence” record: simple FSM interface
- stepSequence provides 5 main interface fields:
 - **REQ**: Set to 1 to ask the stepSequence to start.
 - **ABRT**: Set to 1 to ask the stepSequence to abort.
 - **STATE**: Indicates whether the stepSequence is DONE (0), RUNNING (1), or ABORTED (2).
 - **CLR**: Inlink. Set to 1 to move from ABORT to DONE
 - **STEPNAME**: Description of current step.
Concatenation of step prefixes and step names.



We automate the use of the stepSequence record!

Database Preprocessor

- Provides a simple, consistent method for generating stepSequence records
- Preprocessor is applied to any .dbs files found during compilation
- Recognizes sequence { ... } macros
- Decodes simple macros into stepSequence records and supporting EPICS records
- “Normal” records are left untouched
- StepSequence records can be chained together, or used as steps *within* other stepSequences!

Example

```
sequence($(P):$(H):R$(N):REQ_SRC) {  
  SET_INT("Start Operation", $(P):$(H):R$(N):LAST_REQ, 0)  
  SET_INT("Src ownership", $(P):$(H):R$(N):SRC_REQ, 1)  
  WAIT("Waiting for src ownership", $(P):$(H):R$(N):SRC_OWNED, 5)  
}
```

.dbs file

stepSequence Preprocessor

.db file

```
record(stepSequence, $(P):$(H):R$(N):REQ_SRC) {  
  field(PRE0, "Start Operation")  
  field(REQ0, "$(P):$(H):R$(N):REQ_SRC:_V0.PROC")  
  field(PRE1, "Src ownership")  
  field(REQ1, "$(P):$(H):R$(N):REQ_SRC:_V1.PROC")  
  field(PRE2, "Waiting for src ownership")  
  field(REQ2, "$(P):$(H):R$(N):REQ_SRC:ST2.PROC")  
  field(ABRT2, "$(P):$(H):R$(N):REQ_SRC:AB2.PROC")  
  field(STATE2, "$(P):$(H):R$(N):REQ_SRC:_S2_CPP")  
}
```

Automated optical reference distribution

PFTS Manager

- Provides arbitration of shared resources
- Makes heavy use of the stepSequence and Arbiter records
- Provides facility for requesting/releasing control of up to 3 PFTS stabilized links for TCBOCs
- Automatically performs signal routing via fiber matrix switch
- Performs stabilized link locking and unlocking as needed for fiber routing
- Displays current system status
- Provides both “user” and “expert” interfaces to subsystems

PFTS Manager - PyDM@las-console

FLS (Source) Status									
Name	Description	Enable	Dicon Routing		Owner	Lock Status			
FLS1	TCBOC OPCPA 1	<input checked="" type="checkbox"/>	5	5	CRIX	Release	Unlocked	Lock	Unlock
FLS2	MODS TCBOC	<input checked="" type="checkbox"/>	17	17	CRIX	Release	Unlocked	Lock	Unlock
FLS3	ATM TCBOC	<input checked="" type="checkbox"/>	15	15	CRIX	Release	Unlocked	Lock	Unlock
FLS4	N/A	<input type="checkbox"/>	0	0	None	Release	Unlocked	Lock	Unlock
FLS5	N/A	<input type="checkbox"/>	0	0	None	Release	Unlocked	Lock	Unlock
FLS6	N/A	<input type="checkbox"/>	0	0	None	Release	Unlocked	Lock	Unlock
FLS7	N/A	<input type="checkbox"/>	0	0	None	Release	Unlocked	Lock	Unlock
FLS8	N/A	<input type="checkbox"/>	0	0	None	Release	Unlocked	Lock	Unlock

Destination Status									
Name	Description	Enable	Fiber	Name	Description	Enable	Fiber		
LH:1	Bay 1 Optical Table	<input checked="" type="checkbox"/>	5	Switch	ES3:MODS	ES3 MODS	<input type="checkbox"/>	21	Switch
LH:2	Bay 2 Optical Table	<input checked="" type="checkbox"/>	6	Switch	TMO:LMP:ATM	TMO LAMP ATM	<input type="checkbox"/>	23	Switch
LH:3	Bay 3 Optical Table	<input checked="" type="checkbox"/>	3	Switch	TMO:LMP:MODS	TMO LAMP MODS	<input type="checkbox"/>	25	Switch
LH:4	Bay 4 Optical Table	<input type="checkbox"/>	1	Switch	TMO:DRM:ATM	TMO DREAM ATM	<input type="checkbox"/>	27	Switch
LL:1	Las Lab Optical Table	<input type="checkbox"/>	9	Switch	TMO:DRM:MODS	TMO DREAM MODS	<input type="checkbox"/>	29	Switch
QRIX:ATM	qRIX ATM	<input checked="" type="checkbox"/>	11	Switch	TXI:HXR:ATM	TXI HXR ATM	<input type="checkbox"/>	31	Switch
QRIX:MODS	qRIX MODS	<input checked="" type="checkbox"/>	13	Switch	TXI:SXR:ATM	TXI SXR ATM	<input type="checkbox"/>	33	Switch
CRIX:ATM	ChemRIX ATM	<input checked="" type="checkbox"/>	15	Switch	TXI:MODS	TXI MODS	<input type="checkbox"/>	35	Switch
CRIX:MODS	ChemRIX MODS	<input checked="" type="checkbox"/>	17	Switch	XPP:ATM	XPP ATM	<input type="checkbox"/>	37	Switch
ES3:ATM	ES3 ATM	<input type="checkbox"/>	19	Switch	XPP:MODS	XPP MODS	<input type="checkbox"/>	39	Switch

Hutch View: QRIX Edit Mode

QRIX									
Route	Source	Destination	FLS Owned	FLS Routed	FLS Lock	Dicon Dest	FLS Owner		
Route 1	FLS1 TCBOC OPCPA 1	LH:1 5	●	●	●	5	CRIX	Request All	Release All
Route 2	FLS2 MODS TCBOC	QRIX:MODS 13	●	●	●	17	CRIX		
Route 3	FLS3 ATM TCBOC	QRIX:ATM 11	●	●	●	15	CRIX		

Current Operation: Request Release DONE Run AQL 0.00000

Auto Overlap: Run AQL 0.00000

Automated pump-probe delay control

Form - PyDM@ctl-las-lhn-sp01

File View History Tools

Back Forward Home

Laser Locker Manager - LAS:LHN:LLG2:01

Calibration Phase Shifter TPR Controls HLA Delay Control Bucket Jump Lock Control

PID Loop - Piezo Stabilization System State: Found Expert Screen

Setpoint	Readback	Error	User Enable	PID Active	Error?
0.00000000e+00	6.361278115e+00	-6.690878e+00	Enable	●	●

Override Automation? Auto RF Lock?

PID Loop - Frequency Lock System State: Idle Expert Screen

Setpoint	Readback	Error	User Enable	PID Active	Error?
6.50000000e+07	6.49999999e+07	4.395202e-03	Disable	●	●

HLA Control Enabled? Enabled

RF Lock	HLHN:LLG2:01:AUTO_RF_LOCK_E
Target Time (ns)	2610.000000 2610.124794
Counter Time (ns)	2610.119000
RF Power	0.517075
Diode Power	0.643178
DAC Output	6.690878
Laser Phase Error (deg)	-0.021973
RF Bucket Error	Correct Disabled 7319.000000
Calibration Status	DONE Calibrated

Laser Locker Manager

- Primarily EPICS record primitives
 - stepSequence for calibration
- Single “Target Time” delay control
- Automated system calibration, locking, and RF/laser bucket jump corrections
- TODO: PFTS-style arbitration

Form - PyDM@ctl-las-lhn-sp01

File View History Tools

Back Forward Home

Configuration/Monitors

Calib. Status	DONE
Calibrated?	Calibrated
Calib. Control	Start Calib. Stop Calib.
Calib. Points	20.0 20.0
Calib. Range (ns)	35.0 35.0
Calib. Step Size (ns)	1.8
Calib. Setpoint (ns)	-149.4
Calib. Step Counter	20.0
Steps <= Counter?	● 0.0
TIC Measurement	2.610121e-06
Avg. TIC Measurement	2.610121e-06
TIC Meas. for Calib.	2.570085e-06
Phase Meas. for Calib.	-1.494422e+02
TIC Reference Value	2.573959e-06
Phase Reference Value	-1.686922e+02
Calib. Edge 1	-1.765672e+02
Calib. Edge 2	-1.608172e+02
Calib. Center	-1.686922e+02

TIC Time (s)

Phase Shift (ns)

Acknowledgments

LCLS Control Systems

- Mike Browne
- Christina Pino

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- Dring Xiang
- Charlie Xu



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.... And all of you!



Questions?

