The LCLS-II Precision Timing Control System

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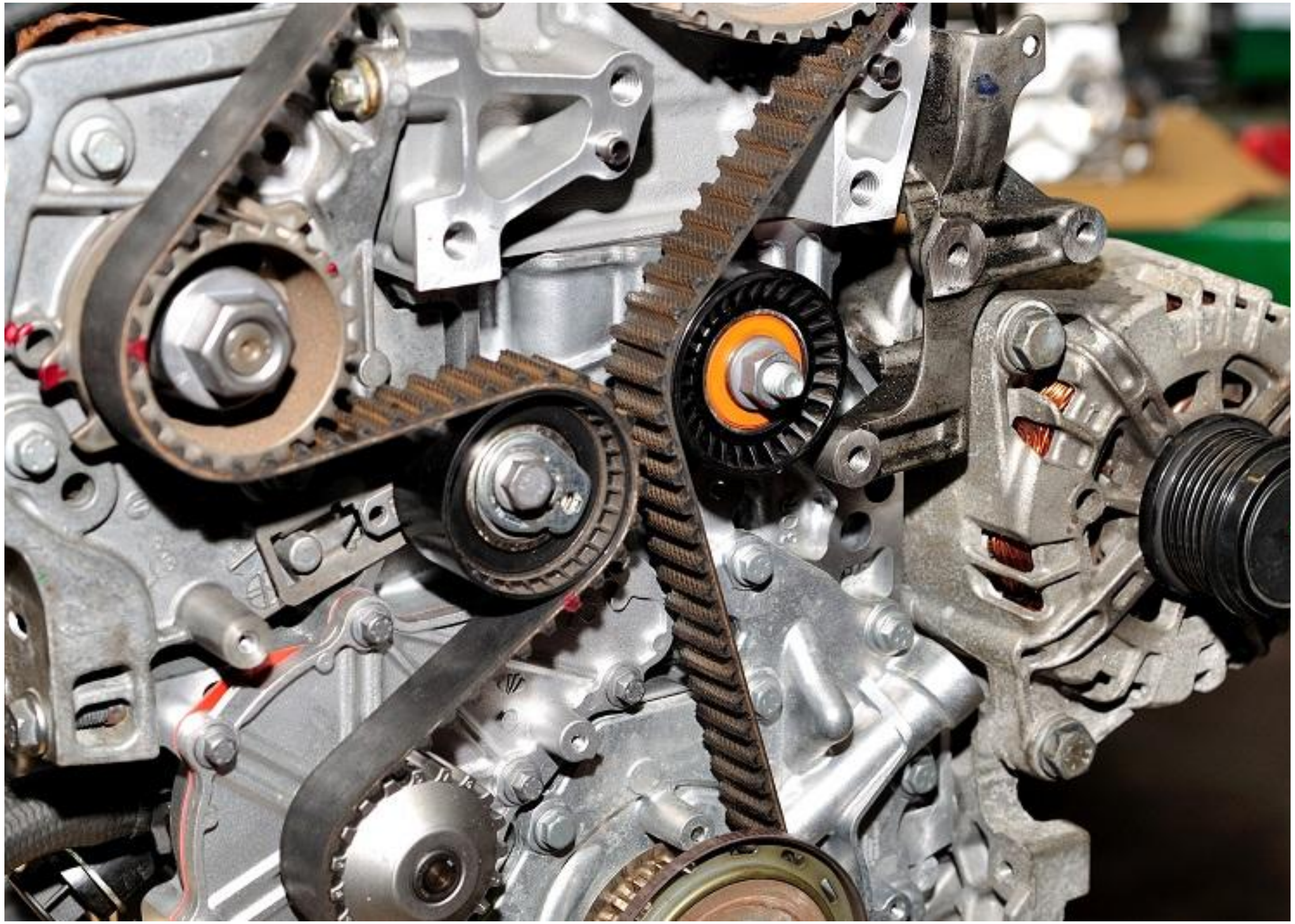
Why do we care about timing?



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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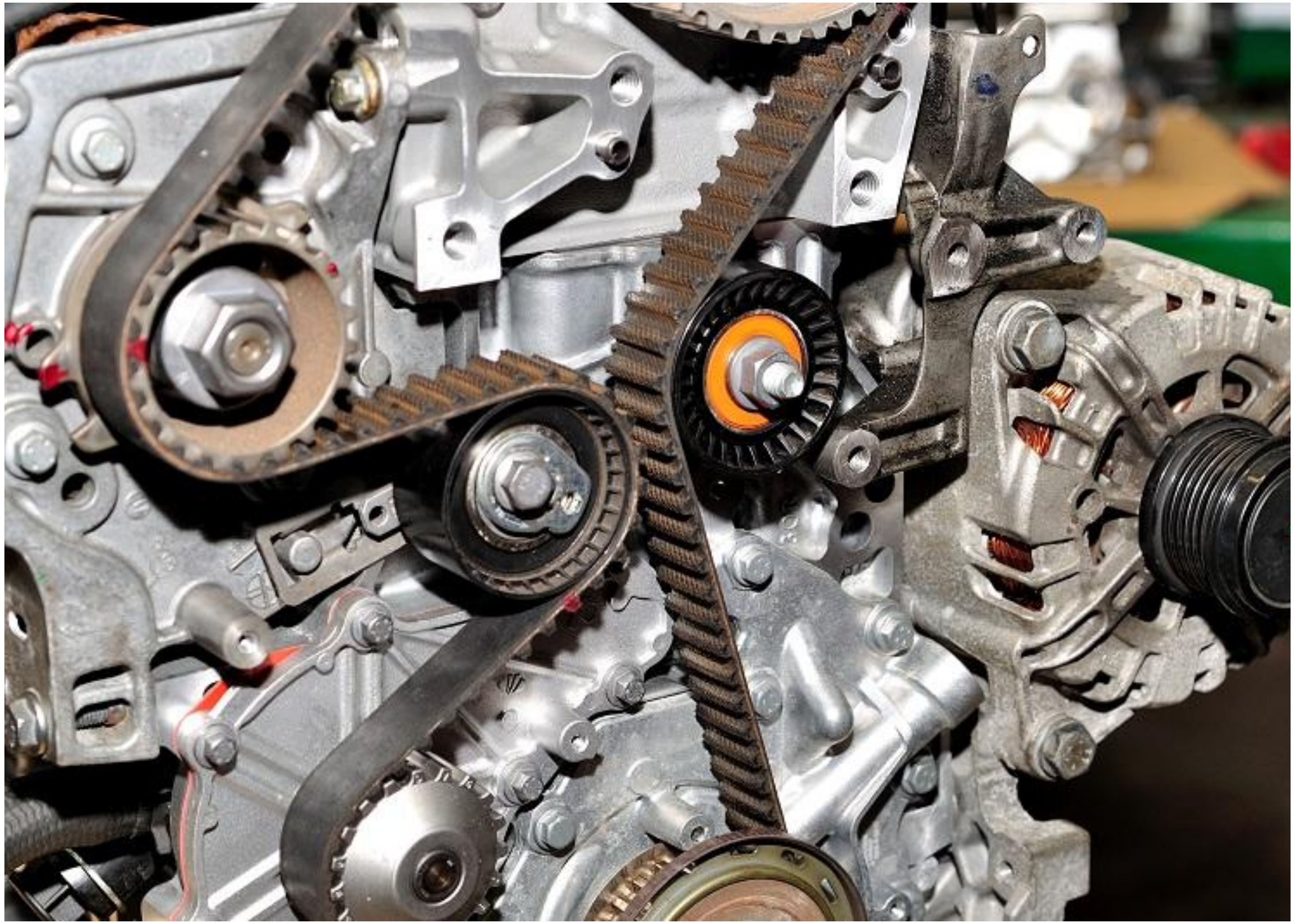

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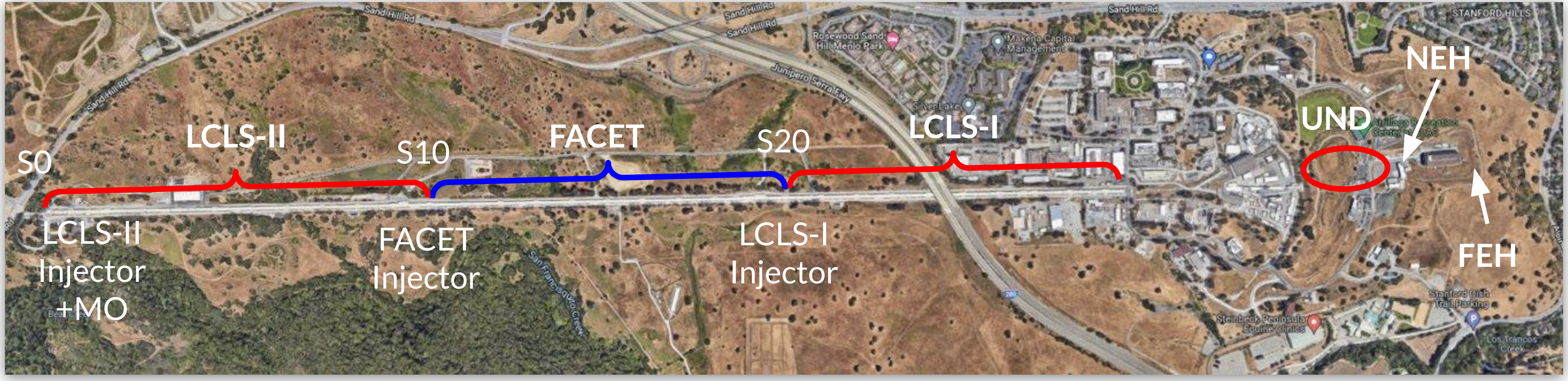
Requires precise phase locking and phase control!

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

Multiple facilities, different needs



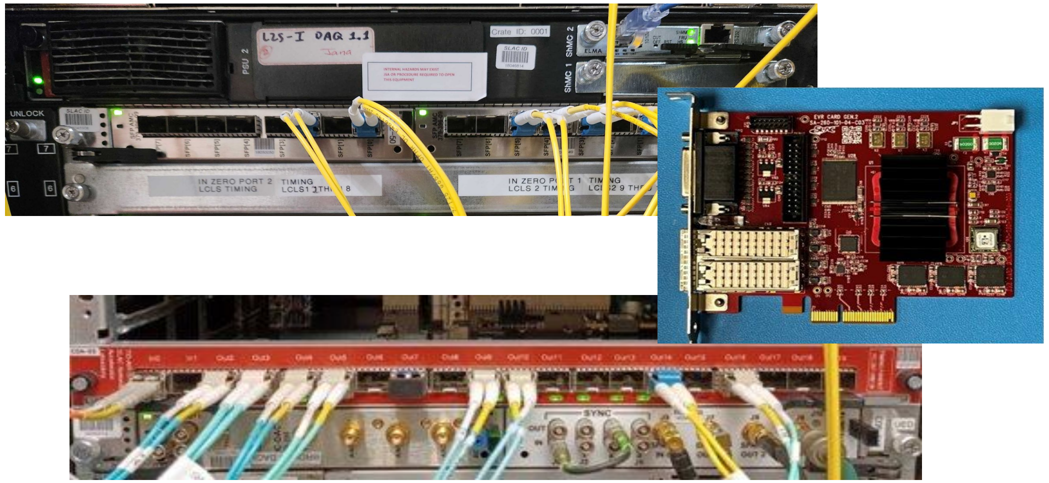
Event and RF timing is distributed to multiple facilities (AD/LCLS)

- 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

- LVTTL 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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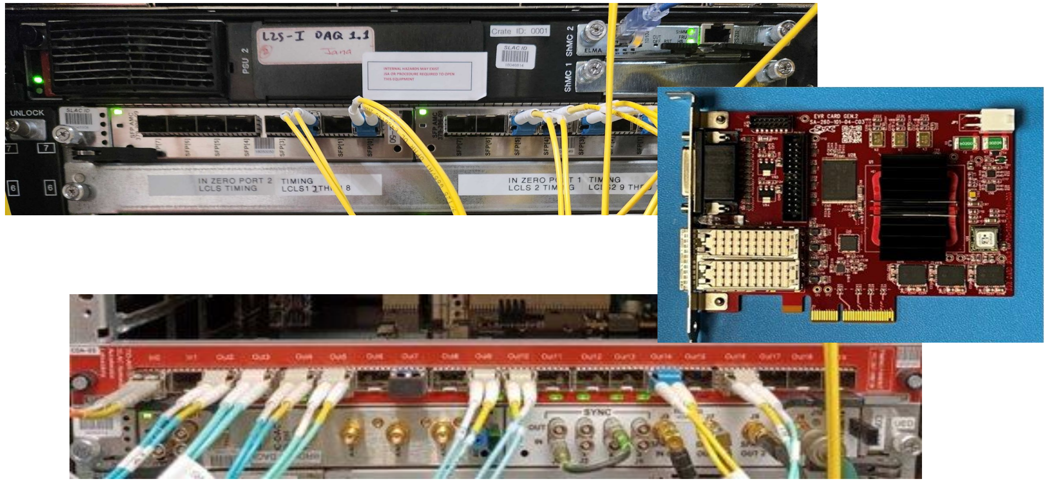

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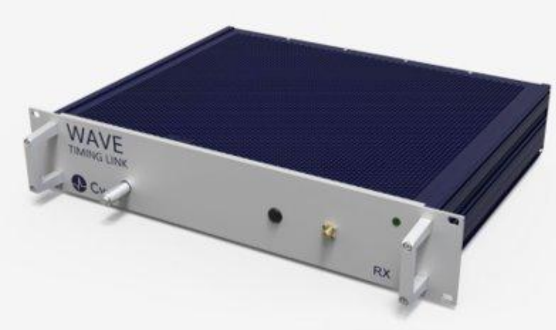
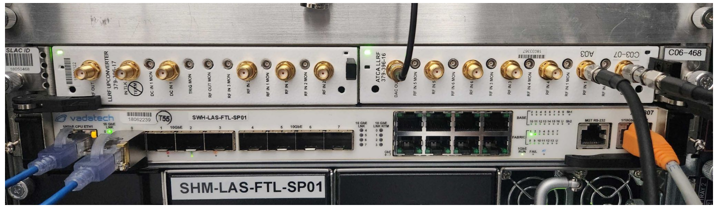
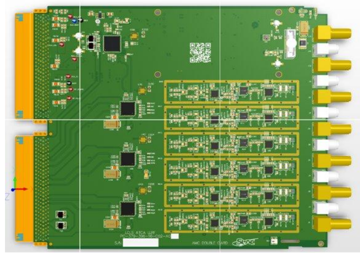
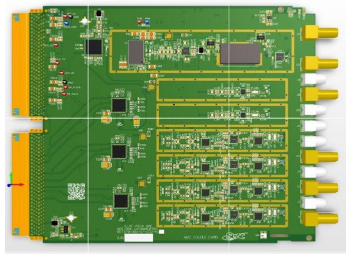
How do we do precision timing?









RF Distribution

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

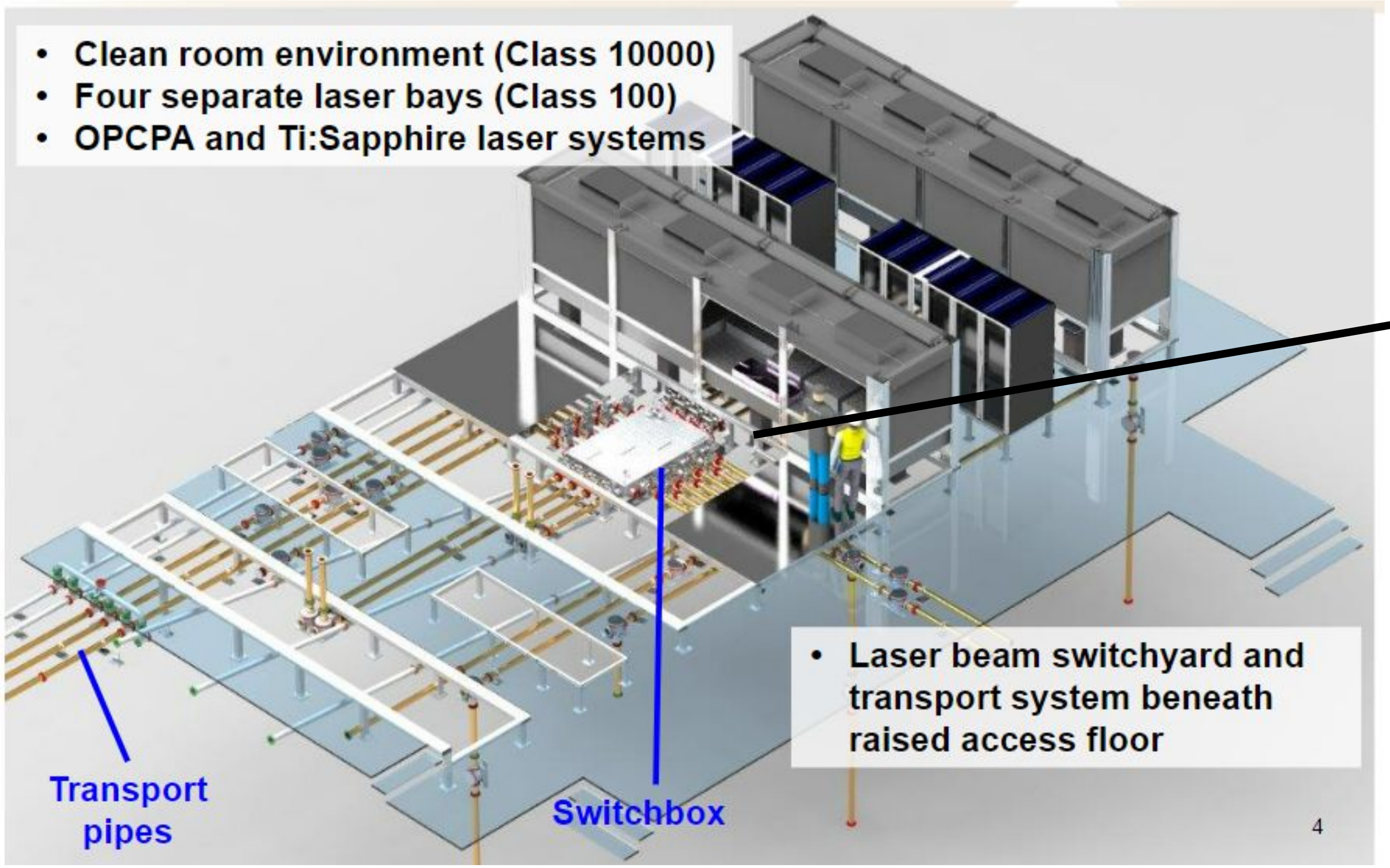
RF Locking

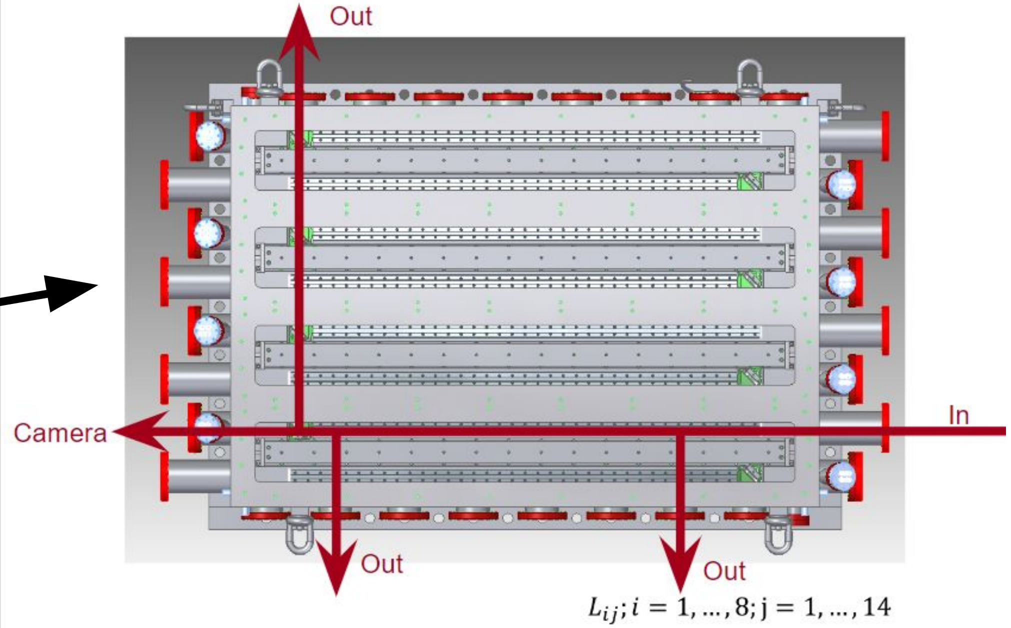
- Phase lock to RF reference
- Based on ATCA Common Platform developed for LCLS-II LINAC
- Delay control for pump-probe experiments

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



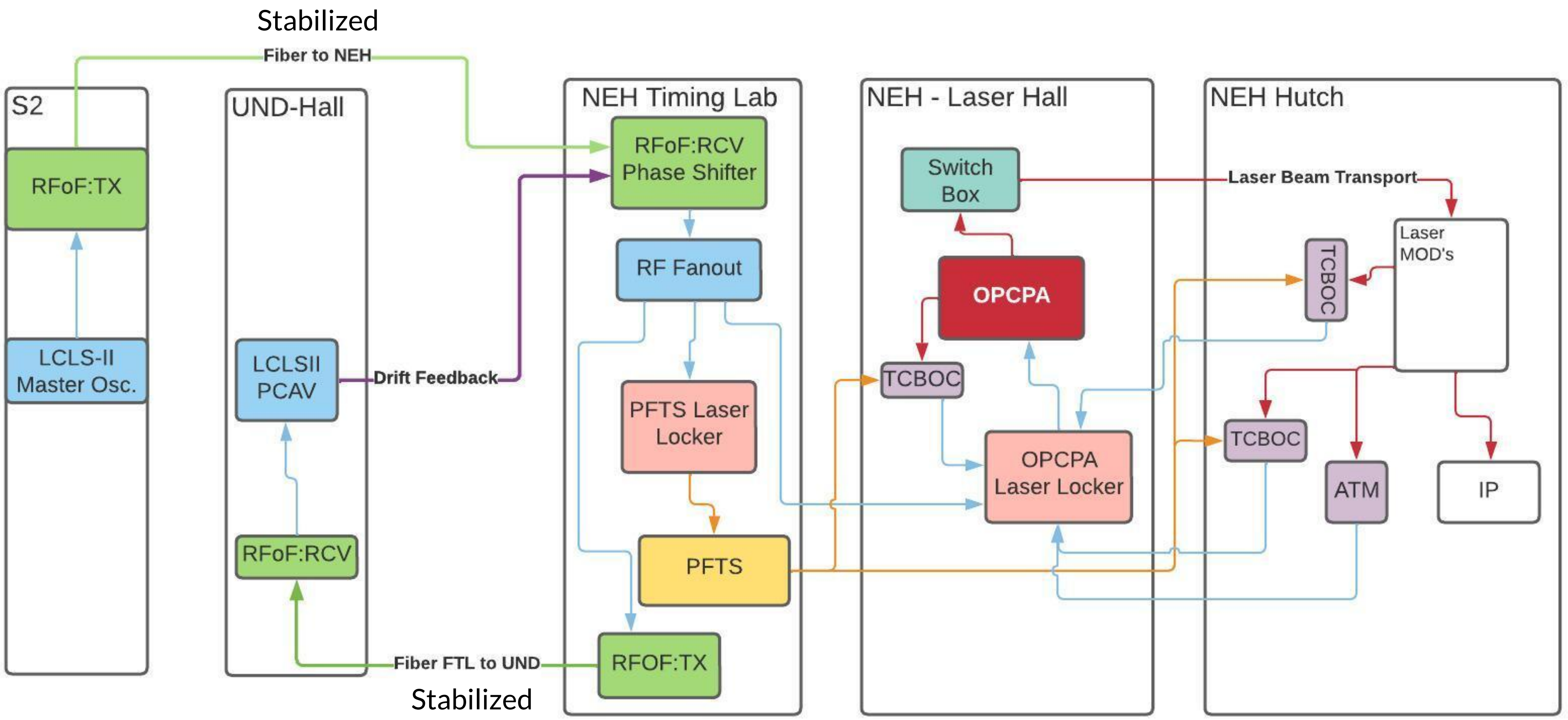


NEH Beam Transport System

- 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!

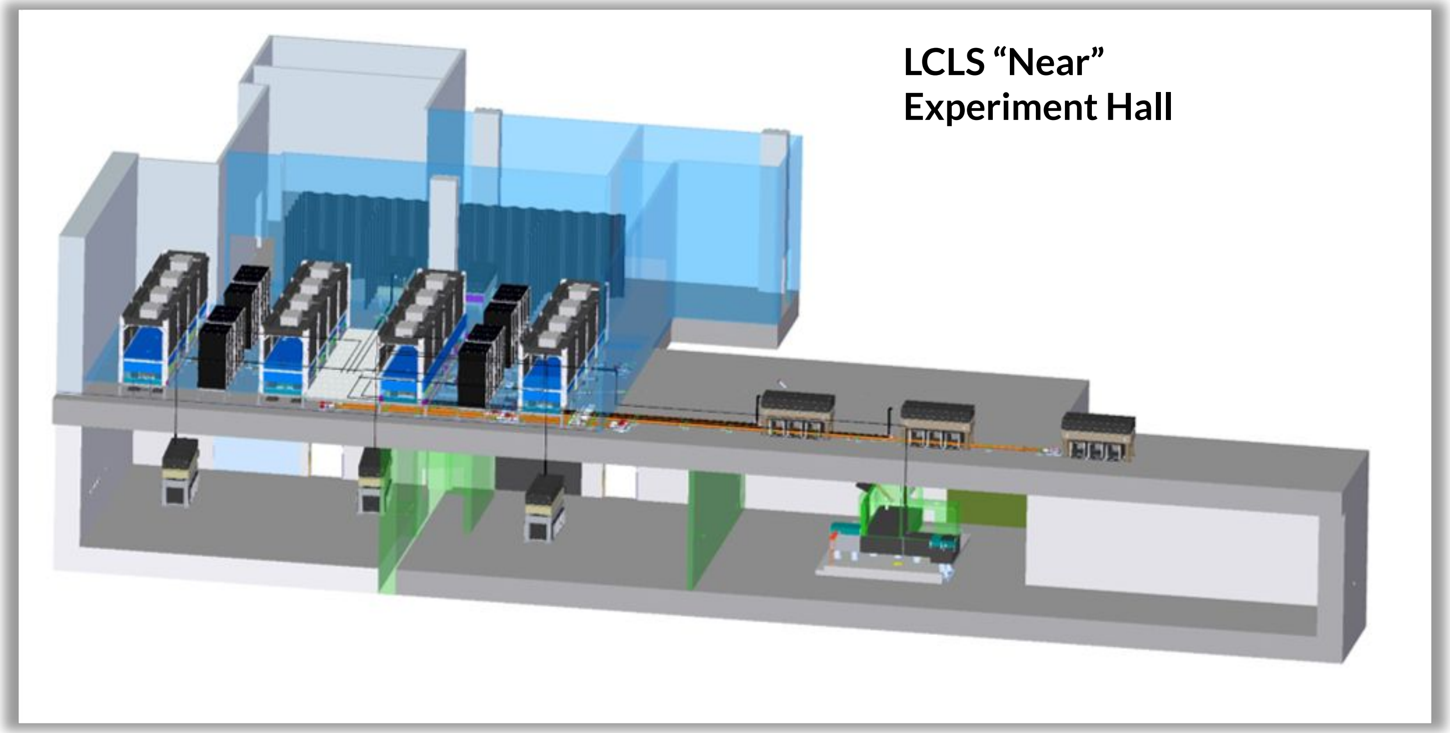
Putting it all together



What challenges do we face?

Multi-user systems

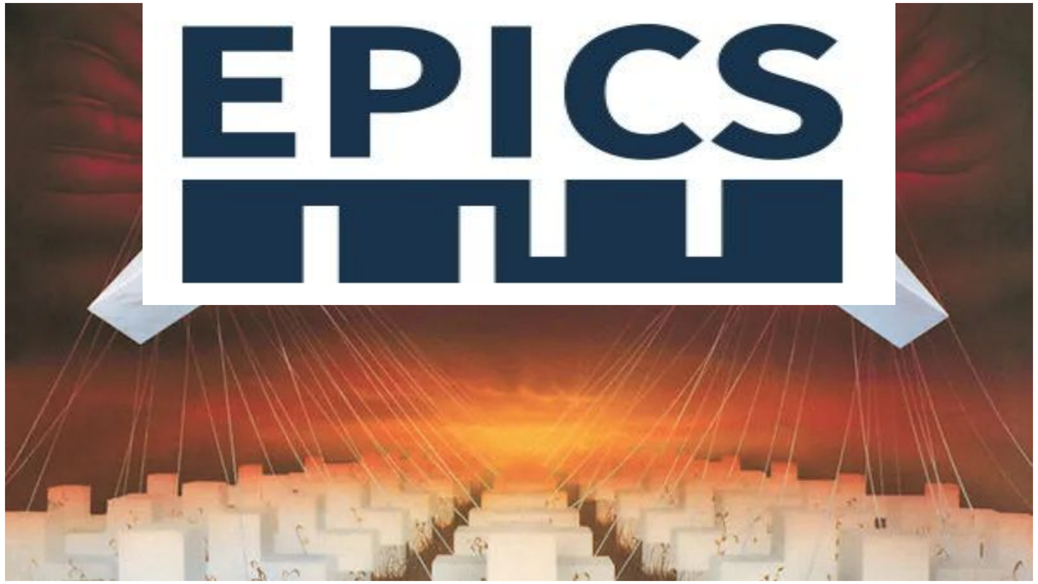
- LCLS-I lasers and laser lockers are 1:1
  - No "sharing"
- LCLS-II OPCPA laser can be delivered to up to 7 different interaction points
- Up to 4 experiment changes per day
- **Goal:** allow beamline operators to changeover laser and timing w/out expert assistance
- Need to deconflict shared resources
  - 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
- <u>Missing capabilities</u>:
    - 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 “REQ*n*” 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")
```

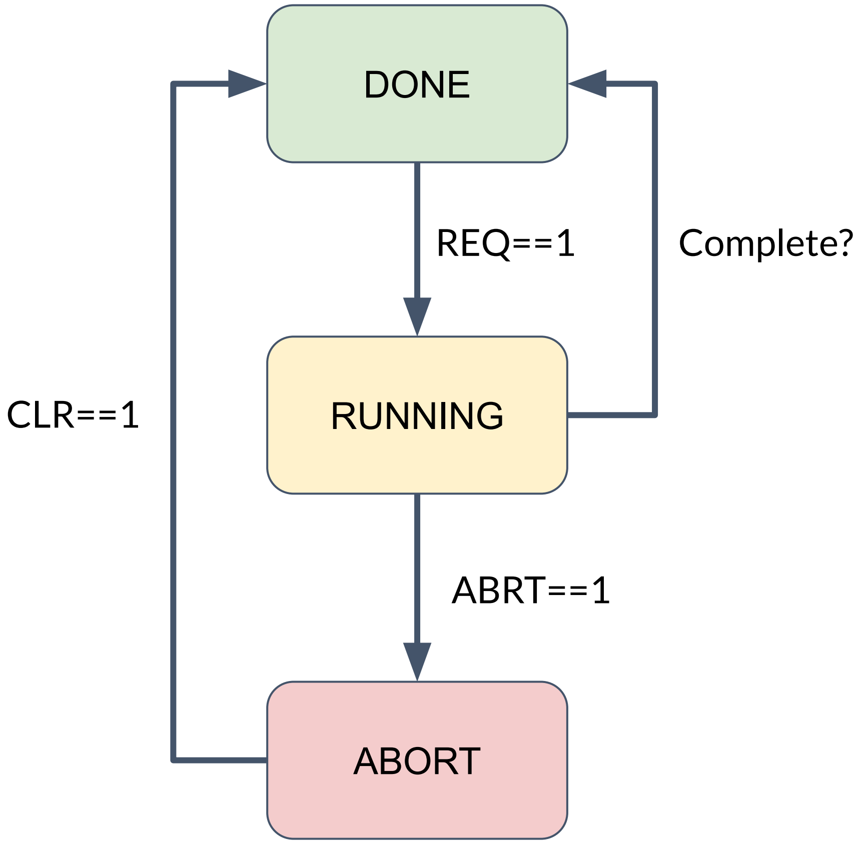
Example: Hutch interface PVs accessing global lock

```
# 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

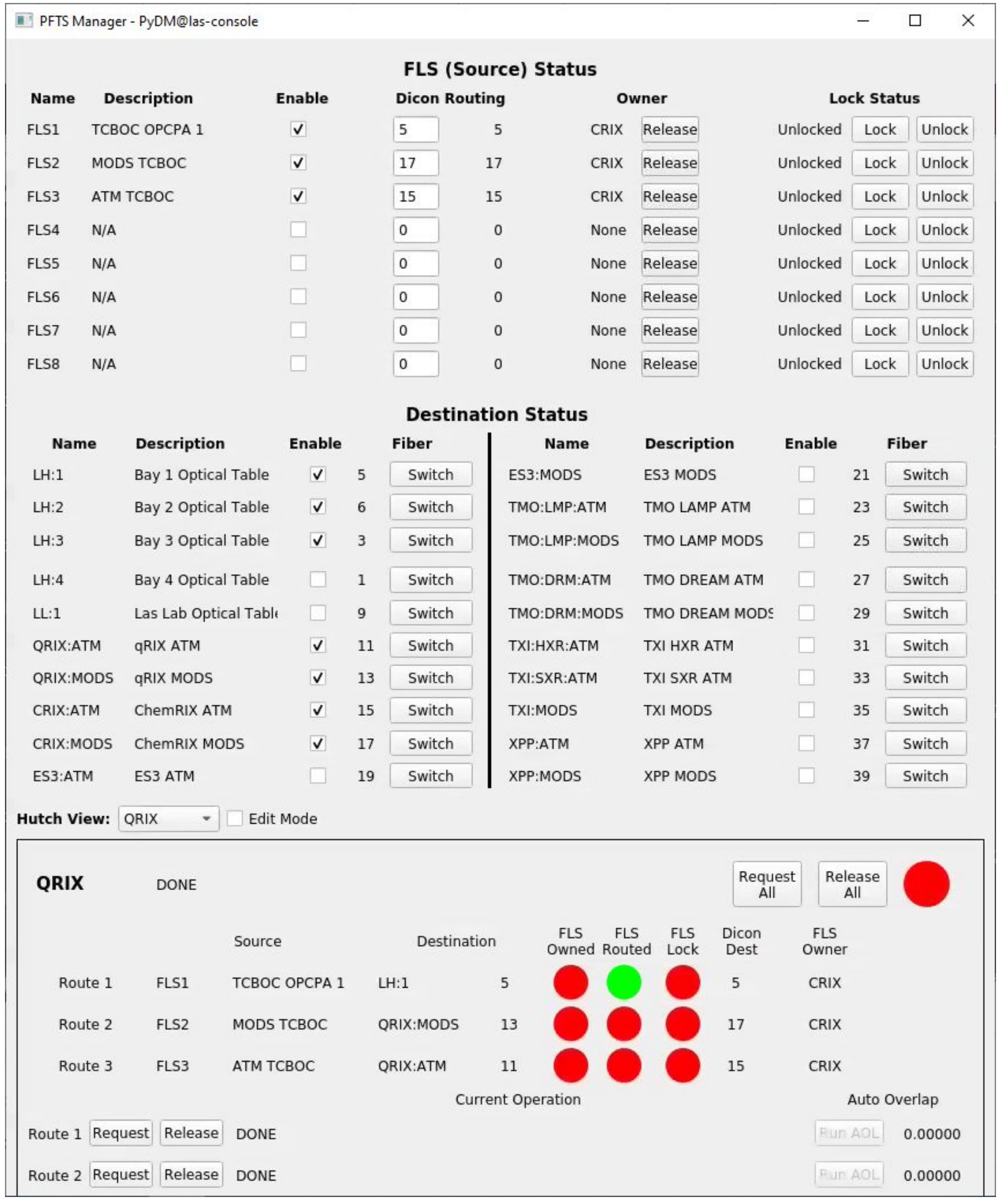
.db file

```
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")
}
```

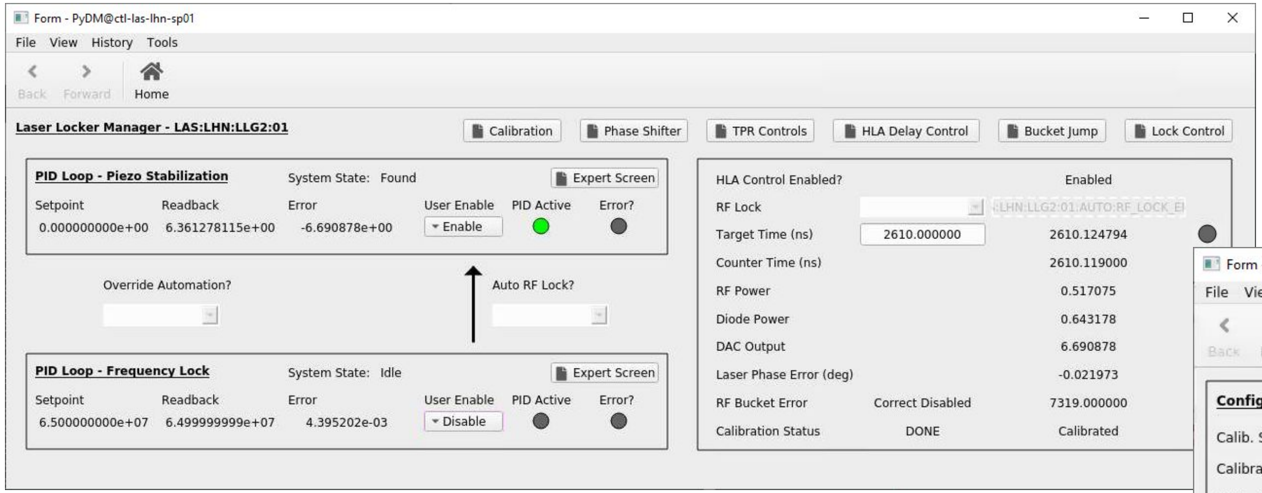
Automated optical reference distribution

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

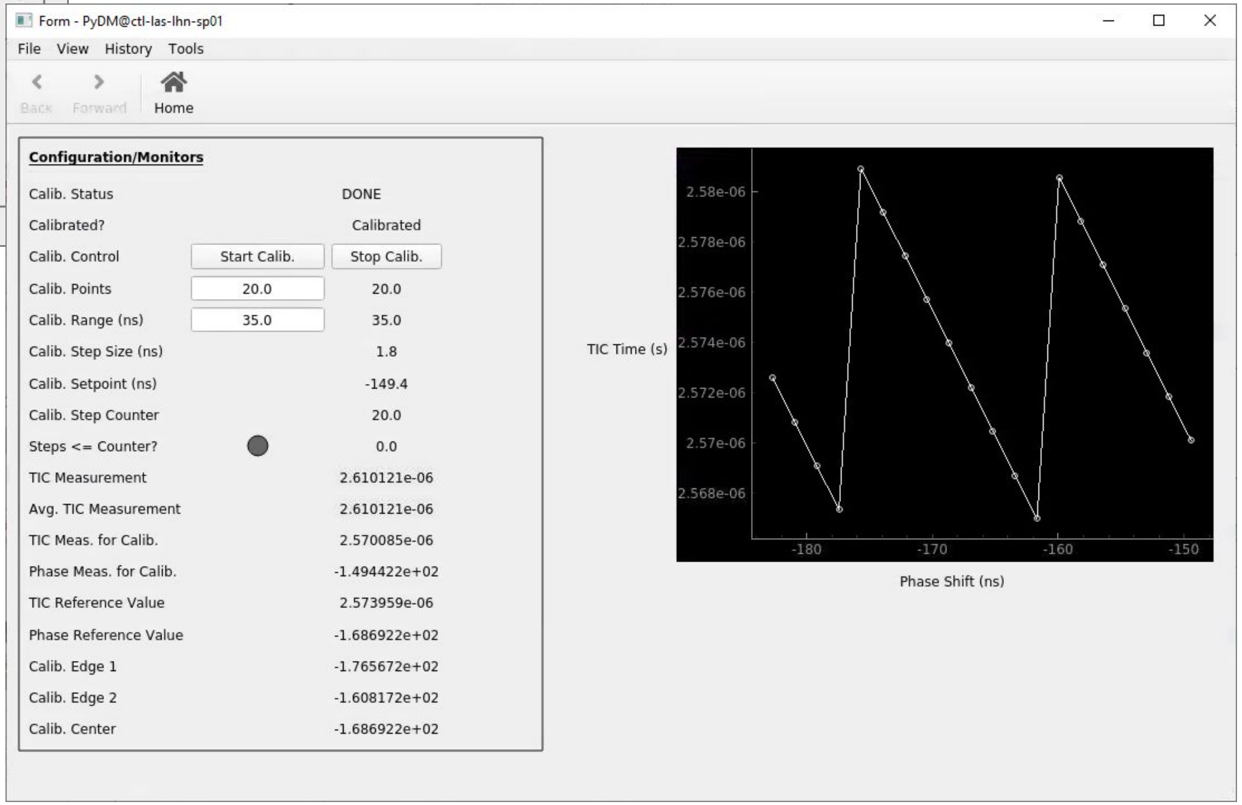


Automated pump-probe delay control



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



SLAC

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…. And all of you!

Questions?