LCLS-II

LCLS-II Accelerator Control System Status

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MO1BCO03

SLAC NATIONAL ACCELERATOR LABORATORY

BERKELEY LAB Lawrence Berkeley National Laboratory

Argonne NATIONAL LABORATORY

Fermilab

Jefferson Lab

U.S. DEPARTMENT OF ENERGY

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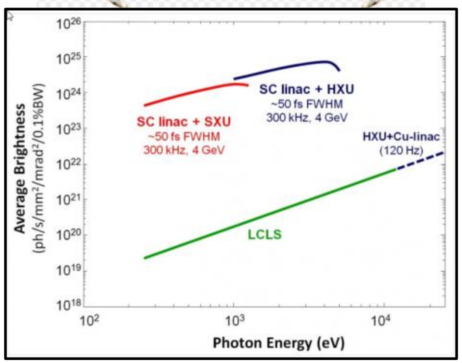
First Light achieved *a few weeks ago!!*

SLAC



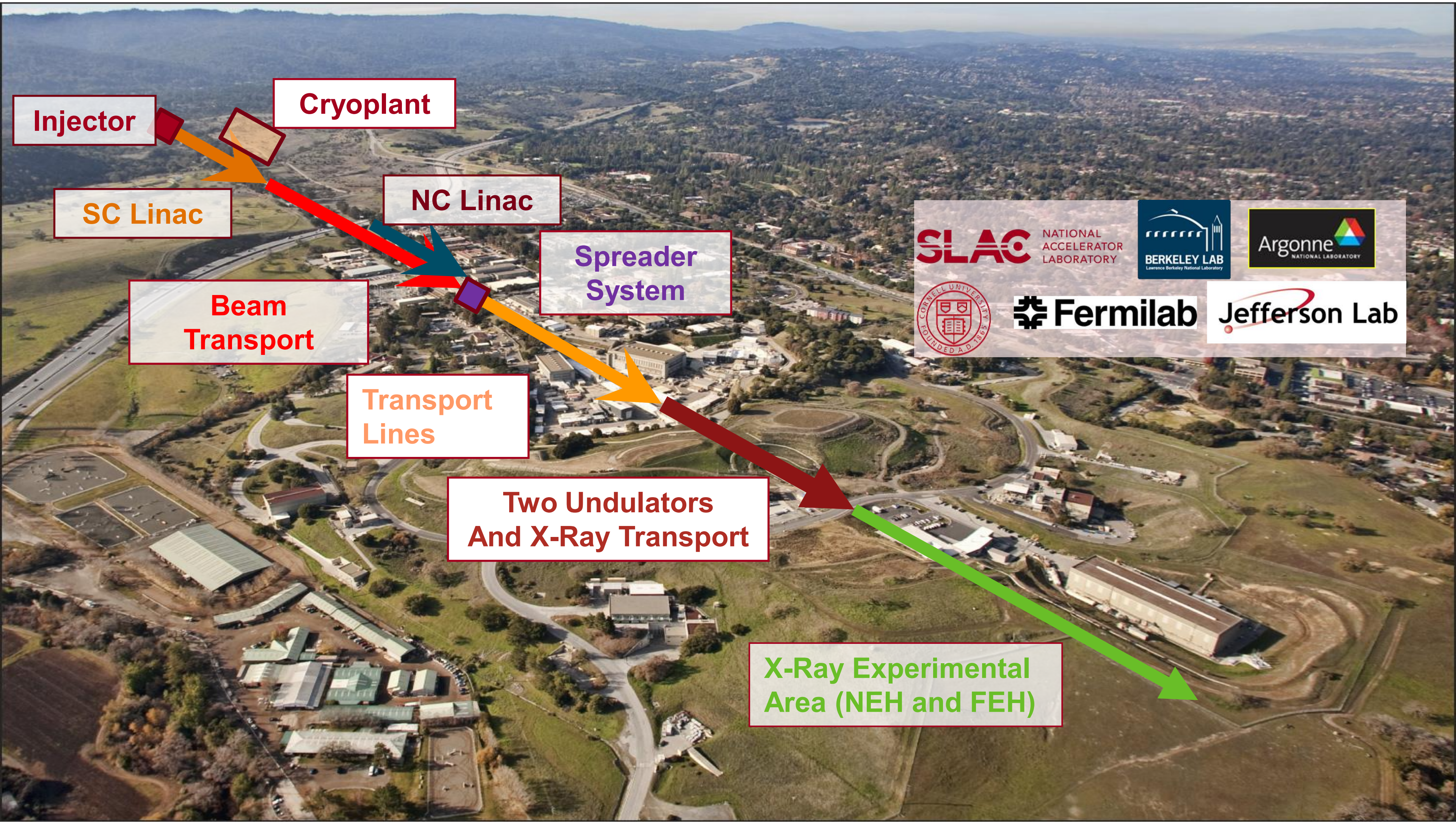
Compared to LCLS-I, LCLS-II delivers X-ray laser beams up to 10,000 times brighter with pulses that arrive nearly 10,000 times faster.

These brighter, faster X-rays will allow scientists to better:

- Understand how to naturally harvest solar energy for a new generation of clean fuels
- Invent sustainable manufacturing methods for industry
- Design new drugs based on being able to create molecular movies of how our bodies respond to disease

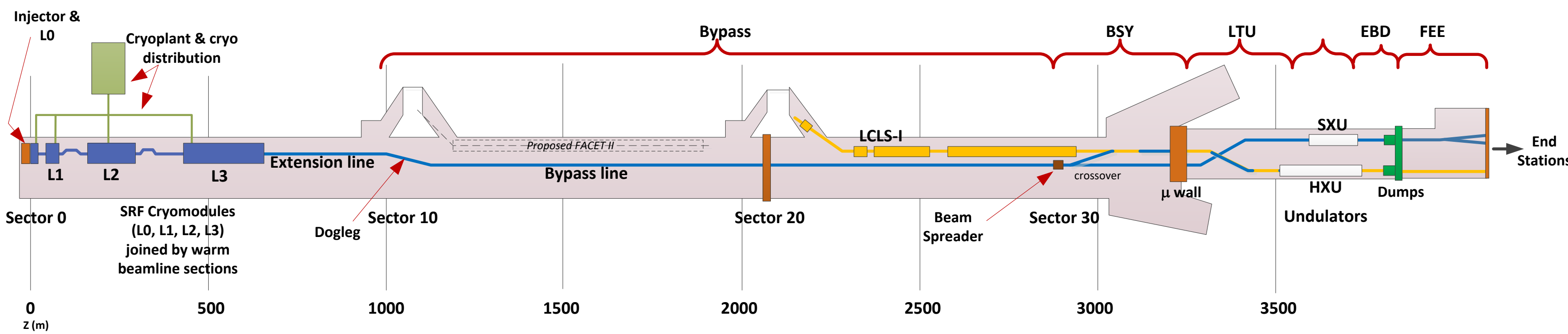
LCLS-II project is ending– now the real fun begins

LCLS-II Accelerator



Control System Scope

SLAC



- **Global Controls**: Racks & Cables, Network, Computing, SC Timing, SC Machine Protection (MPS), Common Platform (ATCA + diskless CPU)
- **Diagnostics**: Beam Position Monitor (BPM), Beam Current Monitor (BCM), Bunch Length Monitor (BLEN), General Motion (Wire Scanner, Collimator, Bunch Compressor), Profile Monitor, Undulator Motion
- **Instrumentation & Control**: Vacuum, Cryomodule and Distribution Control, Temperature & Facilities Monitoring, Laser (UV and IR), Power Supply (DC and Pulsed)
- **RF**: Low Level (LLRF) and High Power RF (HPRF)
- **Safety Systems**: Personnel Protection System, Beam Containment System, Oxygen Deficiency Monitor, Non-Ionizing Radiation Protection (new Divisions eventually created for Safety Systems and Cryogenics Plant)

25 Control Systems covering ~ 4 km of beamline have completed design, procurement, installation, checkout, and commissioning

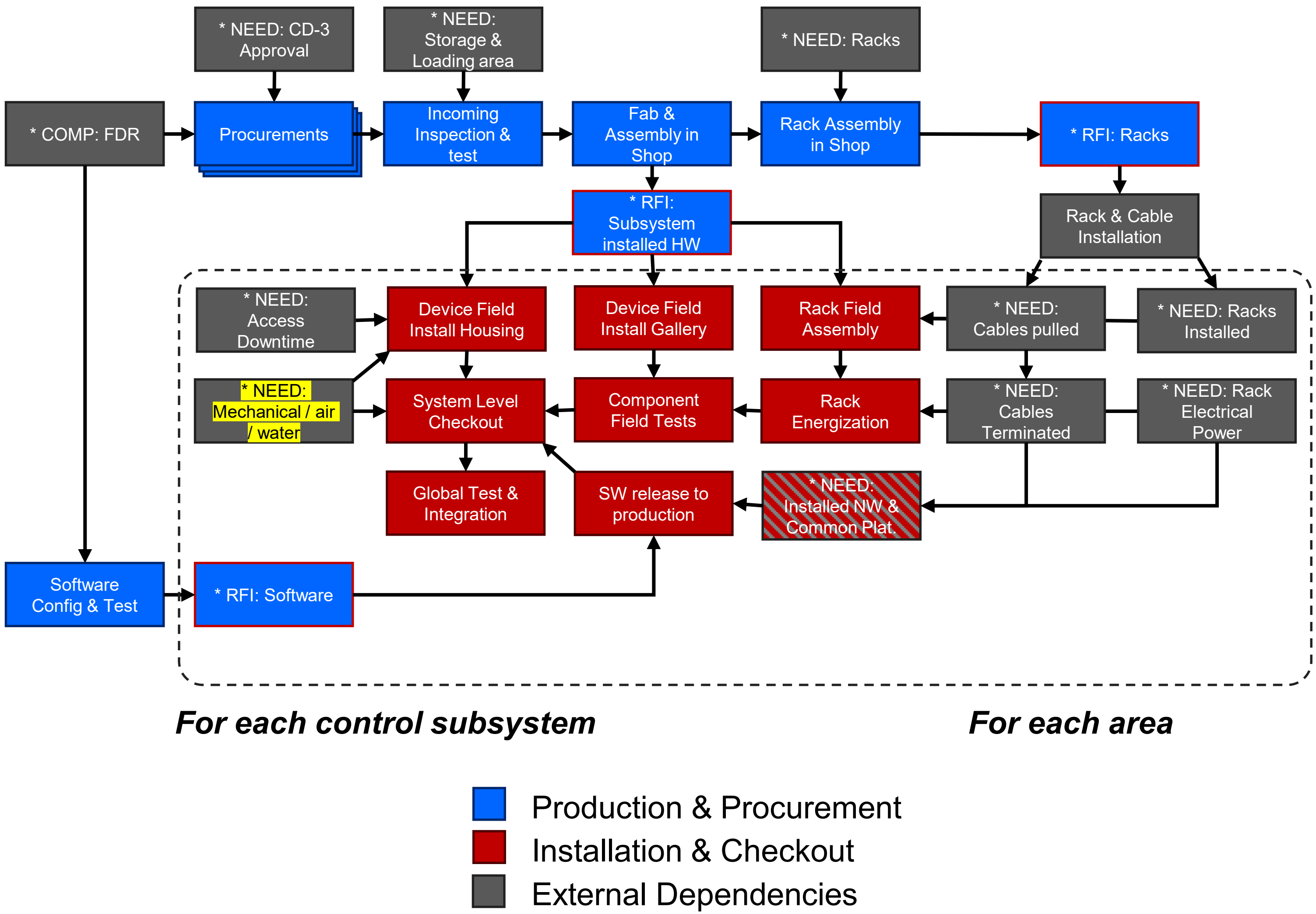
Impressive Controls Installation

SLAC

Some highlights…

- ~15,000 cables, (1.6 million LF), ~30,000 cable ends terminated
- 573 new & 106 existing racks wired, loaded, powered, checked out
- 88 ATCA crates for 1 MHz systems and 144 rack mounted Industrial PCs (CPUs)
- ~ 300 new or upgraded diagnostics using Common Platform
- ~4 km of dedicated fiber optic network for Network, for Timing, for MPS
- ~4 km of warm and particle free beamline vacuum (65 racks; 18 PLCs)
- Cryomodule (CM) controls for 37 CMs
- HPRF controls 294 SSAs; LLRF 294 cavity tuners & has 600 chassis total
- 22 variable gap Soft X-Ray, 35 Hard X-Ray undulator cells that can receive either SC or NC beam in parallel
- 901 DC and Pulsed Magnet power supplies

Installation & Checkout Sequence



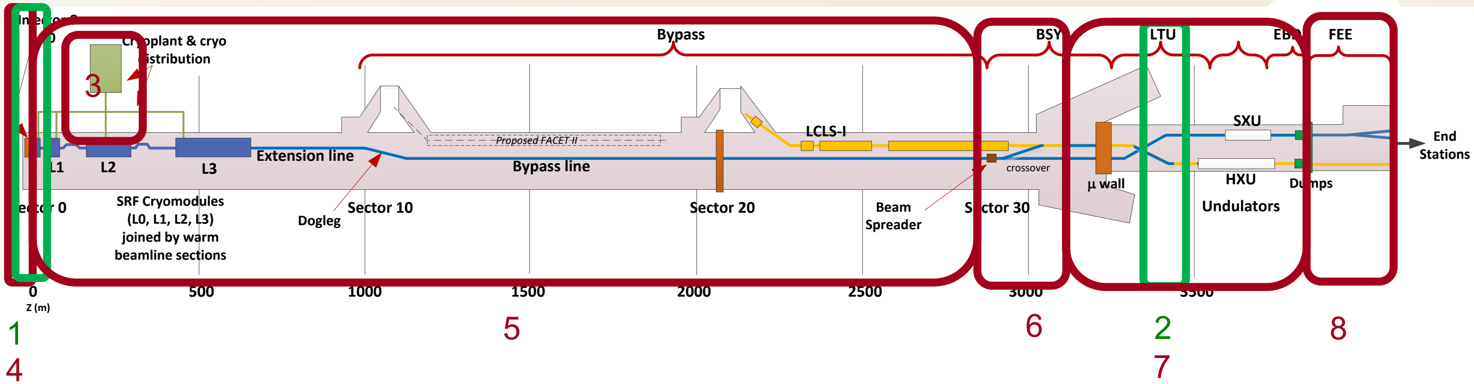
Multi-year (2017-2022) field installation required a detailed schedule integrated with other groups & projects along with NC LCLS and FACET-II operational runs.

Installation Challenges

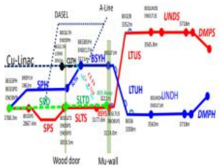
Challenge	Mitigation
Magnitude of Cable Plant	• Rigorous QA of cable plant design & during installation • Phone app was developed to track field cable pulling, termination, QA status in real-time
Running machines	• Limits time – no org. can handle all requests • Prioritize small projects along with LCLS-II
Hand-offs drive controls schedule	• Checkout at much as possible to be ready when predecessors complete
Schedule Pressure	• Manage expectations with realistic durations and add float- the unexpected usually happens

Controls is continuously under scrutiny since we are last in the sequence to checkout

Commissioning



1. 2018: Injector Electron Gun
2. 2020: Cu Line to Soft – commissions new SXR Unds with NC beam



3. 2021: Cryoplant #1 and Cryogenic Distribution
4. 2022: SC Injector Commissioning

   Re-establish Electron Gun operation

   100 MeV injector including diagnostics beamline

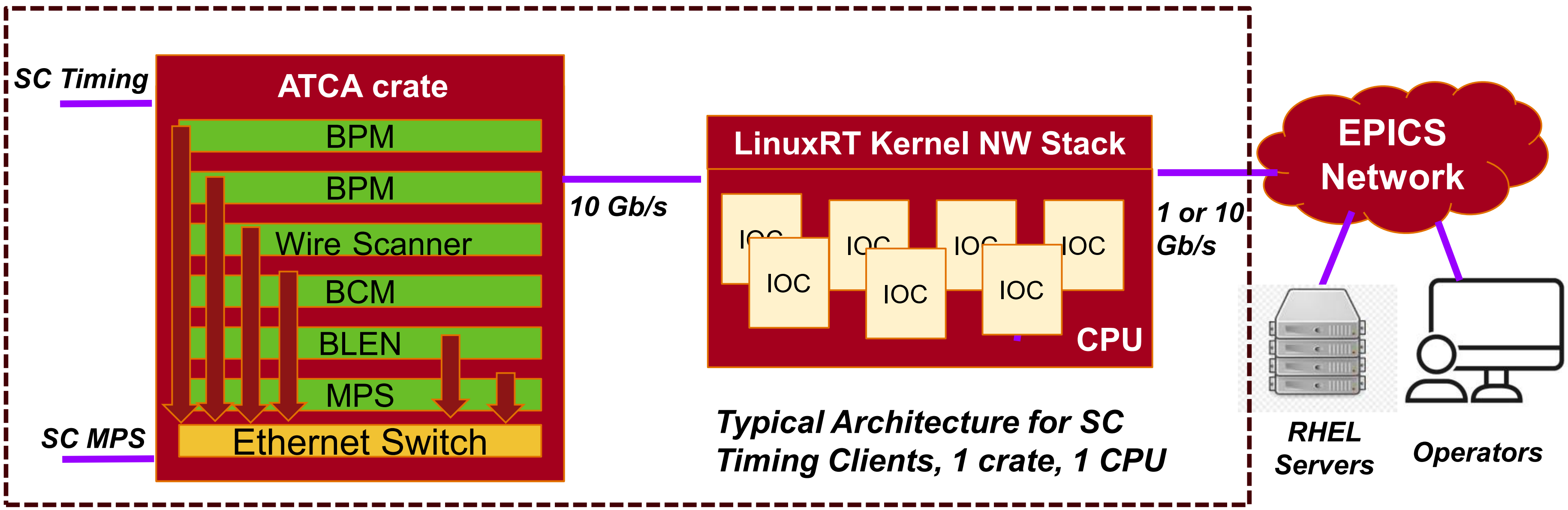
5. 2022: SC linac and transport beamlines
6. 2023: Spreader system with SC beams

7. 2023: SXR and HXR undulators with SC beams, including dumps
8. 2023: X-Ray transport beamlines

Remaining work is the SC linac and high rep rate beam commissioning

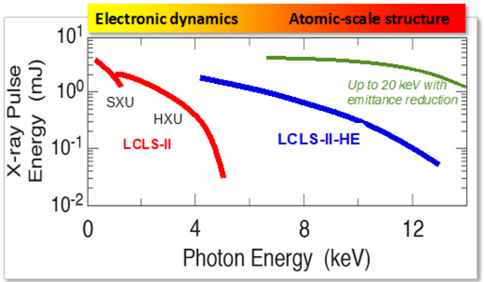
SC Commissioning Challenges

Challenge	Improvements
Commissioning new technologies, IOC crashing & latency issues when time stamped orbit / fault buffers requested	~5 months troubleshooting/modifying/testing in PRODUCTION • Additional error handling after QA of code • Addition of diagnostics and stress testing for bug analysis • Utilization of jumbo frames, CPU to ATCA crate to reduce latency • Prioritization of threads for optimizing network stack throughput • Optimize BSA-related software code (API and device support) to reduce CPU load • GUI modifications to request data at slower rates • CPU RAM upgrades (64 Gb to 128 Gb)

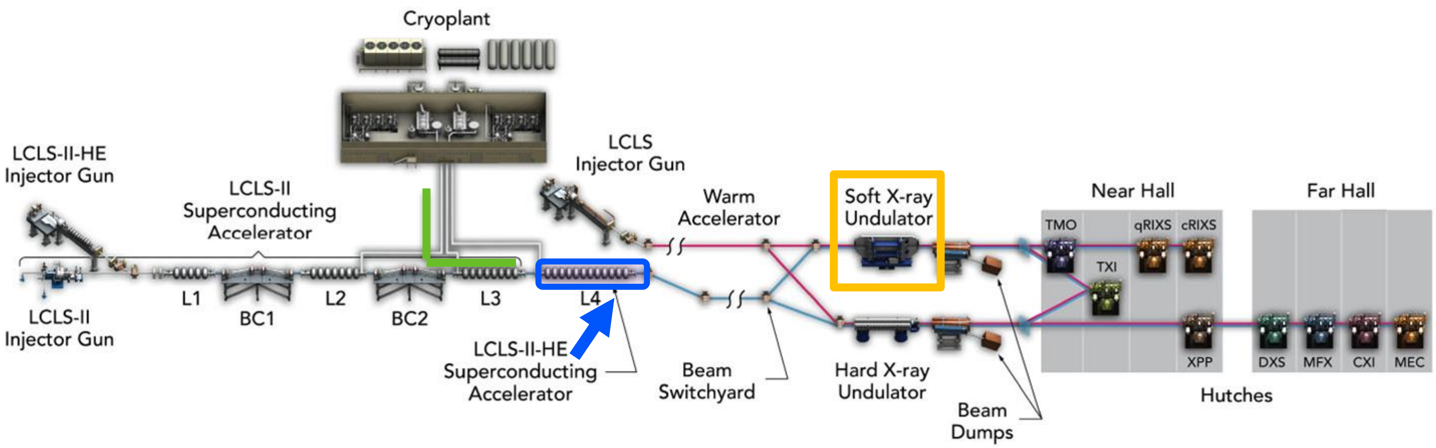


Typical Architecture for SC Timing Clients, 1 crate, 1 CPU

Road Ahead: LCLS-II High Energy (HE) upgrade



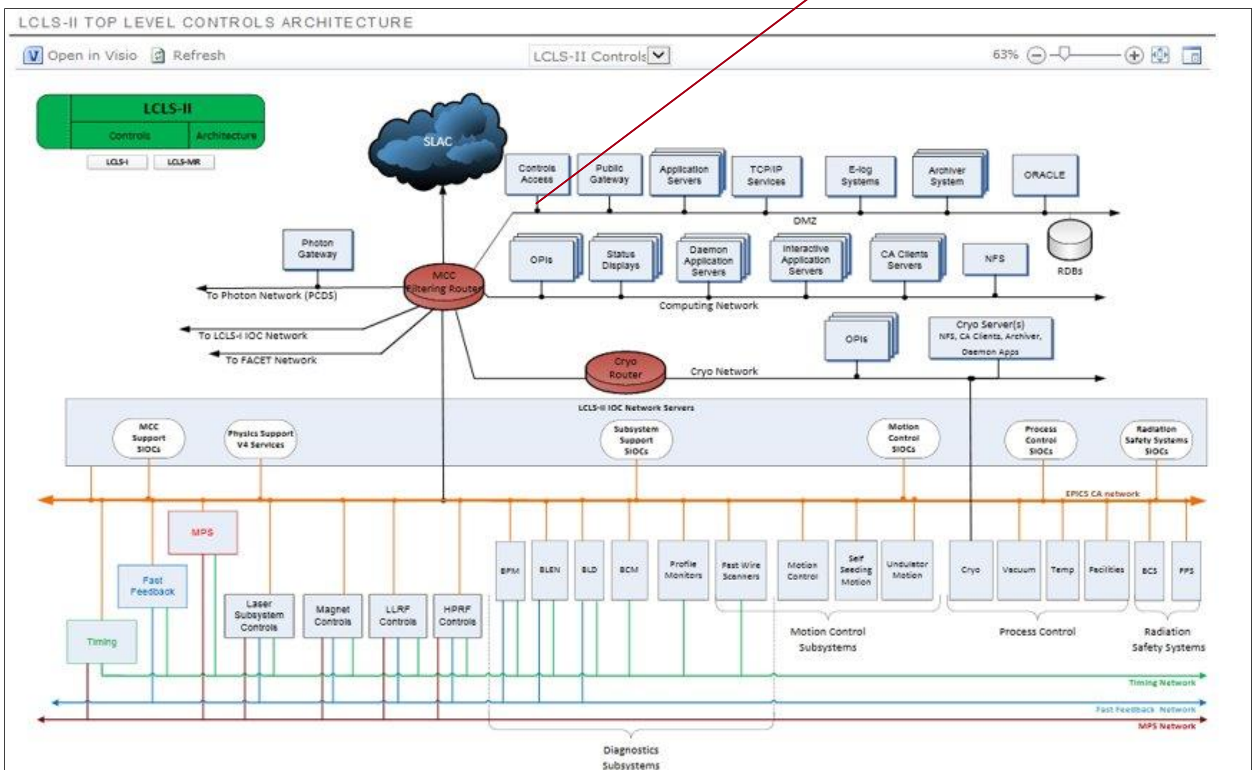
Allows deeper penetration into materials with enhanced resolution.



1. **Install 23 additional cryomodules (L4 Linac) to increase the LCLS-II accelerator electron energy (4->8 GeV); X-ray energy range from 5 to 12.8 keV**
2. **Install new cryogenic distribution system between Cryoplant-2 and new L4 Linac.**
3. **Upgrade soft X-ray undulator for 8 GeV operation.**

EPICS Controls

EPICS	Total
IOCs	1274
PVs	10 M
Archived PVs	800k; 1.2M upgraded capacity

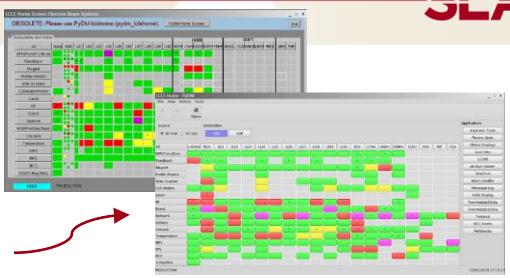


Version	Ratio
EPICS 3*	23%
EPICS 7*	77%

IOC OS	Ratio
RHEL	29%
linuxRT	45%
RTEMS	26%

LCLS Accelerator Complex

Additional Developments



EPICS 7

- Channel Access -> PV Access
- Display Manager edm -> PyDM dynamic display
- Orbit data through Beam Synch. Acq. Service (BSAS) for ML
- Beamline Data (BLD) via multicast network used by experimental side

Computing Infrastructure

- Linux upgrade: RHEL6 -> RHEL7 -> RHEL8 -> RHEL9
- Web applications front & back-end migration

Development and Deployment Environment

- Configuration management CVS & bare git repos -> GitHub enterprise
- Group accounts> Individual logins on production servers
- Development Environment workflow

RTEMS

- Preparation for NFS V4

Thank you

Huge thank-you to all of the Controls Engineers too numerous to mention by name who are contributing to the success of LCLS-II and HE

BERKELEY LAB Fermilab Argonne NATIONAL LABORATORY Jefferson Lab EXPLORING THE NATURE OF MATTER SLAC NATIONAL ACCELERATOR LABORATORY Stanford University U.S. DEPARTMENT OF ENERGY

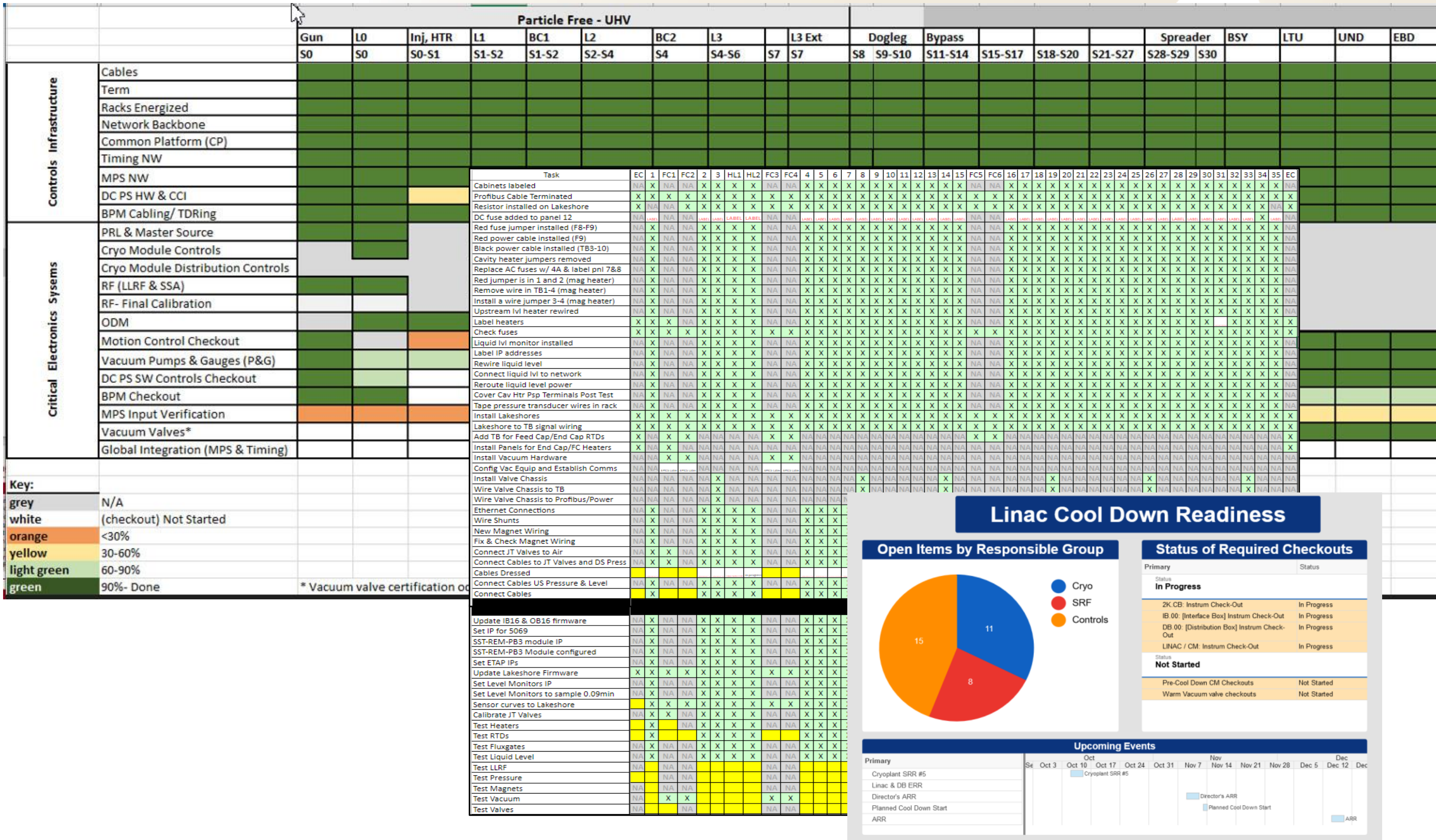
Related Accelerator Contributions

- **1978 - TU2BCO04** Accelerator Systems Cyber Security Activities at SLAC
- **1488 - TUPDP123** SLAC ATCA Scope - Upgrading the EPICS Support Package
- **1676 - TUPDP125** Design and Implementation the LCLS-II Machine Protection System
- **1852 - TUPDP127** SLAC LINAC Mode Manager Interface
- **1790 - TUPDP130** PyDM Archive Viewer
- **2106 - TUPDP131** Longitudinal Feedback for the LCLS-II Superconducting Linear Accelerator at SLAC
- **1788 - WE3AO06** Deployment and Operation of the Remotely Operated Accelerator Monitor (ROAM) Robot
- **1625 - TH2AO02** High Availability Alarm System Deployed With Kubernetes
- **1917 - THMBCMO19** LCLS-II Cryogenic System Instrumentation Commissioning
- **1261 - THPDP086** LCLS-II Cryomodule Isolation Vacuum Pump System
- **1405 - THPDP087** LCLS-II Controls Software Architecture for the Wire Scan Diagnostics
- **1487 - THPDP088** Beamline Data Software for the New SLAC Timing System
- **1626 - THPDP090** LCLS-II Vacuum Control System Design, Installation and Checkout
- **1122 - THSDSC03** Integrate EPICS 7 with MATLAB Using PVAccess for Python (P4P) Module

Other SLAC ICALEPCS contributions

- **1676 - TUPDP125** The LCLS-II Experiment Controls Preemptive Machine Protection System
- **2142 - WE1BCO04** The LCLS-II Experimental System Vacuum Controls Architecture
- **2021 - WE1BCO07** The LCLS-II Precision Timing Control System
- **2140 - TH2BCO03** The LCLS-II Experiment Control System
- **1917 - THMBCMO19** The LCLS-II Cryogenic System Instrumentation Commissioning
- **2064 - MO4BCO06** ATEF, an Automated Test Execution Framework for System Configuration Checkout
- **1624 - TUPDP124** Design and Integration of the Laser Control Systems for MEC-U
- **1432 - THPDP089** Centralized Logging and Alerts for EPICS-based Control Systems With Logstash and Grafana

Dashboards



Particle Free - UHV
Gun S0
L0 S0
Inj, HTR S0-S1
L1 S1-S2
BC1 S1-S2
L2 S2-S4
BC2 S4
L3 S4-S6
S7
L3 Ext S7
Dogleg S8
S9-S10
Bypass S11-S14
S15-S17
S18-S20
S21-S27
Spreader S28-S29
S30
BSY
LTU
UND
EBD
Controls Infrastructure
Cables
Term
Racks Energized
Network Backbone
Common Platform (CP)
Timing NW
MPS NW
DC PS HW & CCI
BPM Cabling/ TDRing
Critical Electronics Sysems
PRL & Master Source
Cryo Module Controls
Cryo Module Distribution Controls
RF (LLRF & SSA)
RF- Final Calibration
ODM
Motion Control Checkout
Vacuum Pumps & Gauges (P&G)
DC PS SW Controls Checkout
BPM Checkout
MPS Input Verification
Vacuum Valves*
Global Integration (MPS & Timing)
Key:
grey N/A
white (checkout) Not Started
orange <30%
yellow 30-60%
light green 60-90%
green 90%- Done
* Vacuum valve certification o
Task
Cabinets labeled
Profibus Cable Terminated
Resistor installed on Lakeshore
DC fuse added to panel 12
Red fuse jumper installed (F8-F9)
Red power cable installed (F9)
Black power cable installed (TB3-10)
Cavity heater jumpers removed
Replace AC fuses w/ 4A & label pnl 7&8
Red jumper is in 1 and 2 (mag heater)
Remove wire in TB1-4 (mag heater)
Install a wire jumper 3-4 (mag heater)
Upstream lvl heater rewired
Label heaters
Check fuses
Liquid lvl monitor installed
Label IP addresses
Rewire liquid level
Connect liquid lvl to network
Reroute liquid level power
Cover Cav Htr Psp Terminals Post Test
Tape pressure transducer wires in rack
Install Lakeshores
Lakeshore to TB signal wiring
Add TB for Feed Cap/End Cap RTDs
Install Panels for End Cap/FC Heaters
Install Vacuum Hardware
Config Vac Equip and Establish Comms
Install Valve Chassis
Wire Valve Chassis to TB
Wire Valve Chassis to Profibus/Power
Ethernet Connections
Wire Shunts
New Magnet Wiring
Fix & Check Magnet Wiring
Connect JT Valves to Air
Connect Cables to JT Valves and DS Press
Cables Dressed
Connect Cables US Pressure & Level
Connect Cables
Update IB16 & OB16 firmware
Set IP for 5069
SST-REM-PB3 module IP
SST-REM-PB3 Module configured
Set ETAP IPs
Update Lakeshore Firmware
Set Level Monitors IP
Set Level Monitors to sample 0.09min
Sensor curves to Lakeshore
Calibrate JT Valves
Test Heaters
Test RTDs
Test Fluxgates
Test Liquid Level
Test LLRF
Test Pressure
Test Magnets
Test Vacuum
Test Valves
Linac Cool Down Readiness
Open Items by Responsible Group
Cryo
SRF
Controls
11
8
15
Status of Required Checkouts
Primary
Status
In Progress
2K CB: Instrum Check-Out In Progress
IB 00: [Interface Box] Instrum Check-Out In Progress
DB 00: [Distribution Box] Instrum Check-Out In Progress
LINAC / CM: Instrum Check-Out In Progress
Not Started
Pre-Cool Down CM Checkouts Not Started
Warm Vacuum valve checkouts Not Started
Upcoming Events
Primary
Cryoplant SRR #5
Linac & DB ERR
Director's ARR
Planned Cool Down Start
ARR
Oct 3
Oct 10
Oct 17
Oct 24
Oct 31
Nov 7
Nov 14
Nov 21
Nov 28
Dec 5
Dec 12

Lessons Learned

Cable Plant Design & Installation

- Have efficiency tools ready ahead of time (Cables, Inventory, travelers, etc)
- Need for proven process to deliver cable plant. Use of 3D design and routing tools

Schedule

- Lab-wide integrated installation schedules are key
- Manage expectations for Controls

Technical

- Stress test new designs on test stands, QA code, include diagnostics

Strategic

- Maintain dedicated resources to upgrade computing infrastructure and applications