LCLS-II Controls System

Overview & Challenges

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16 June, 2014

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Linac Coherent Light Source Facility

First Light April 2009, CD-4 June 2010

Project Collaboration

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Fermilab
- 50% of cryomodules: 1.3 GHz
- Cryomodules: 3.9 GHz
- Cryomodule engineering/design
- Helium distribution
- Processing for high Q (FNAL-invented gas doping)

Jefferson Lab — Exploring the Nature of Matter
- 50% of cryomodules: 1.3 GHz
- Cryoplant selection/design
- Processing for high Q

Berkeley Lab
- Undulators
- e^- gun & associated injector systems

Argonne National Laboratory
- Undulator Vacuum Chamber
- Also supports FNAL w/ SCRF cleaning facility
- Undulator R&D: vertical polarization

Cornell University — Founded A.D. 1865
- R&D planning, prototype support
- processing for high-Q (high Q gas doping)
- e^- gun option

Requirements and Control System Challenges

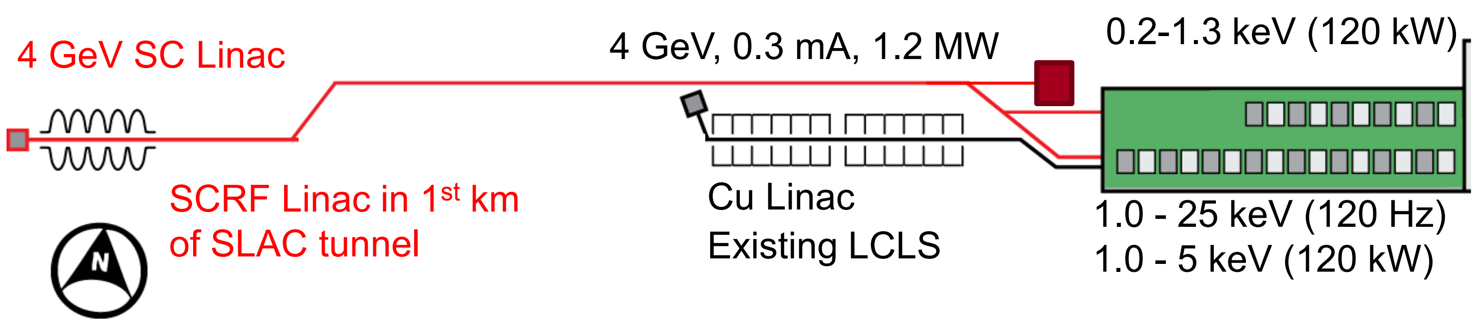
- Extend the successful EPICS Controls for LCLS to the new Super Conducting LCLS-II Project
- Preserve all the single-pulse control and readback features of a single-pass accelerator
- But do so for a CW machine with a bunch repetition rate up to 1 MHz
  - Maintain compatibility for the present 120 Hz LCLS
  - Technical challenge for very high repetition rate
  - Design in flexibility for an entirely new generation of accelerator based light source

LCLS-II Accelerator Layout
New Superconducting Linac → LCLS Undulator Hall

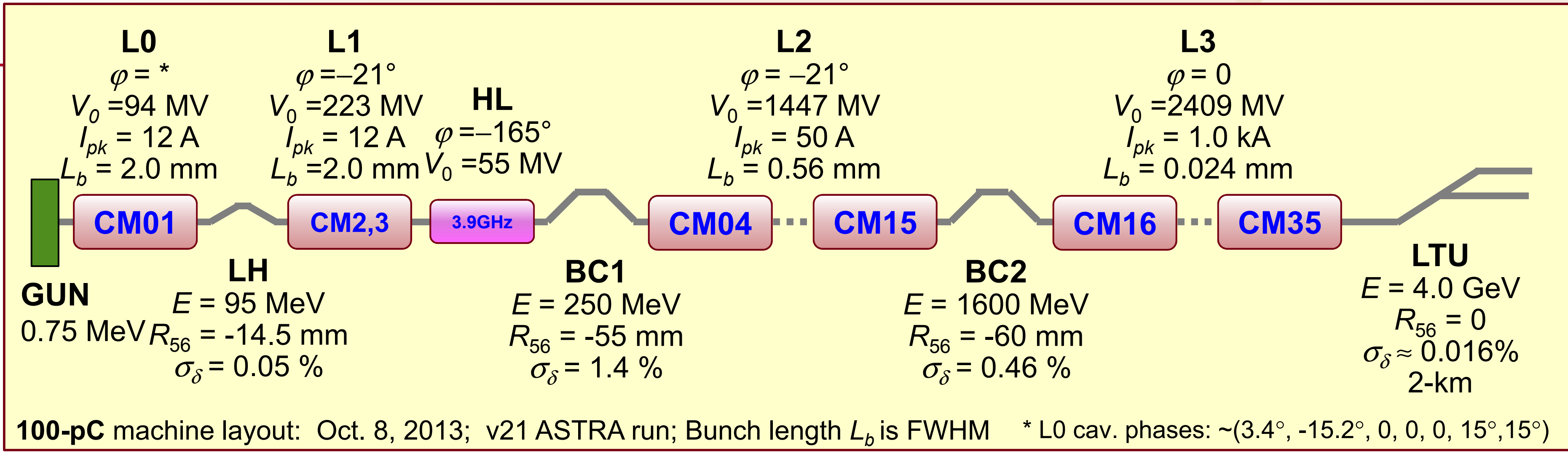
- Two sources: high rate SCRF linac and 120 Hz Cu LCLS-I linac
- North and South undulators can operate simultaneously in any mode

Undulator	SC Linac (up to 1 MHz)	Cu Linac (up to 120Hz)
North	0.25-1.3 keV	
South	1.0-5.0 keV	up to 25 keV higher peak power pulses

- Concurrent operation of 1-5 keV and 5-25 keV is not possible



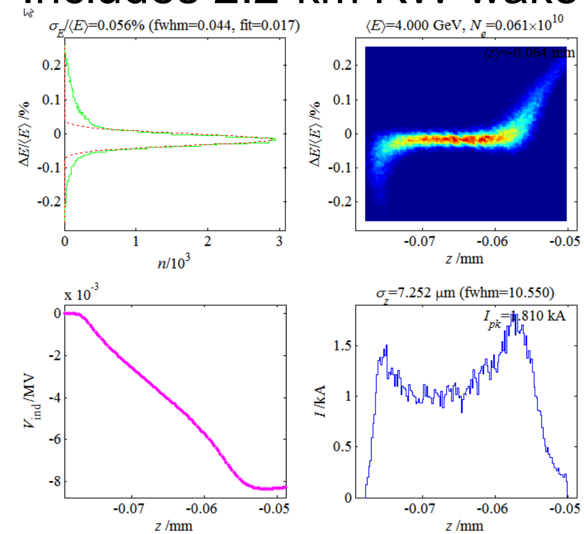
LCLS-II - Linac and Compressor Layout for 4 GeV



Linac Sec.	V (MV)	φ (deg)	Acc. Grad. (MV/m)	No. Cryo Mod's	No. Avail. Cav's	Spare Cav's	Cavities per Amplifier
L0	**94**	*	**13.2**	**1**	**8**	**1**	**1**
L1	**220**	**–21**	**14.3**	**2**	**16**	**1**	**1**
HL	**–55**	**–165**	**14.5**	**3**	**12**	**1**	**1**
L2	**1447**	**–21**	**15.5**	**12**	**96**	**6**	**48**
L3	**2409**	**0**	**15.4**	**20**	**160**	**10**	**48**

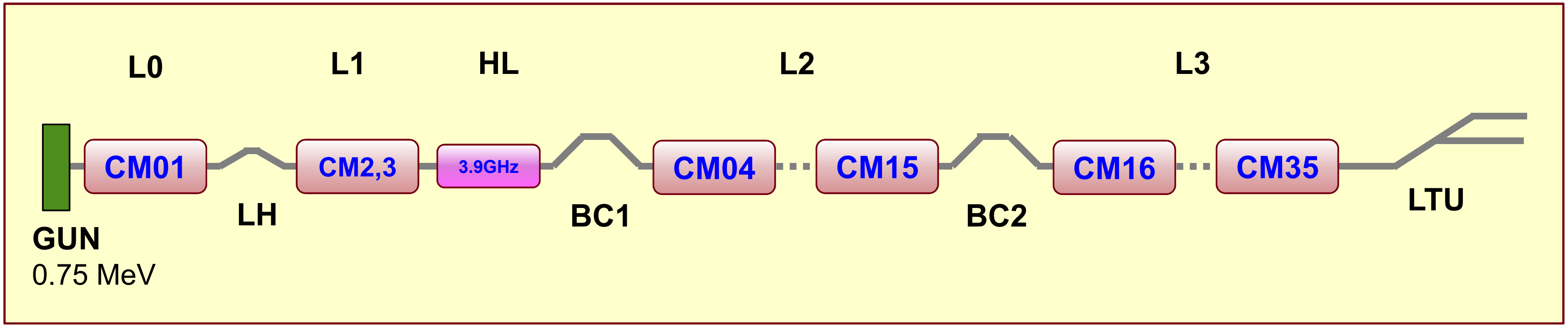
P. Emma, L. Wang, C. Papadopoulos

Includes 2.2-km RW-wake

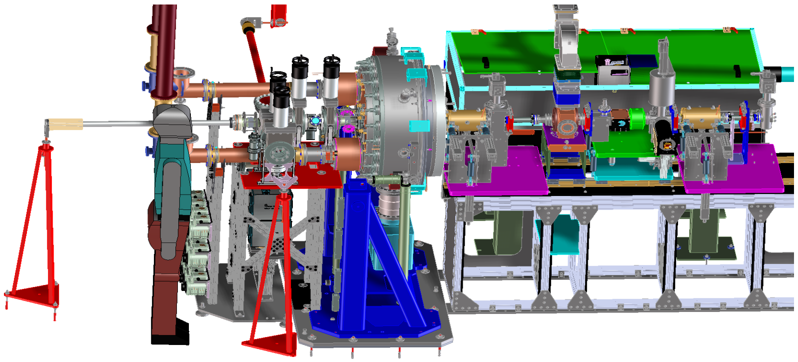


LCLS-II Controls System Scope

- Control & monitoring of beam line components
- Data acquisition and analysis for diagnostic systems
- Timing, synchronization and event systems
- Network and Controls computing infrastructure
- Operations and applications Software
- Low Level RF and Feedback systems
- Machine and personnel safety systems
- X-ray Transport and Experiment Systems controls
- Controls infrastructure, including racks & cables

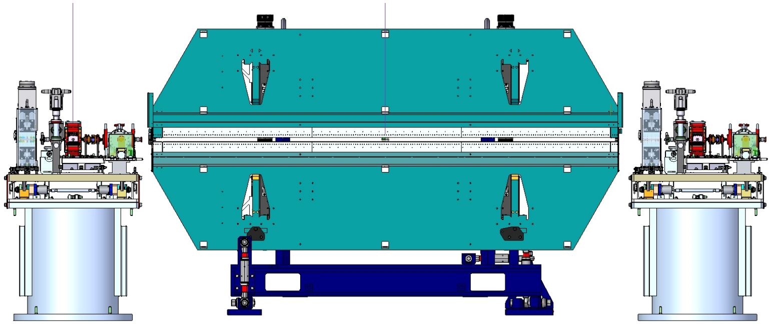


Controls Scope

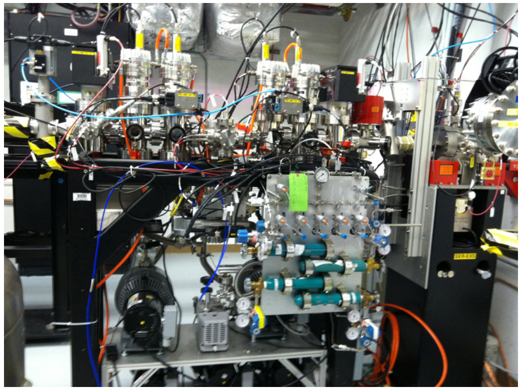


Injector – in collaboration with LBNL

SC Linac – in collaboration with JLab and FNAL



Undulator System



X-ray Transport & Experiment Systems

Controls Subsystems Designs

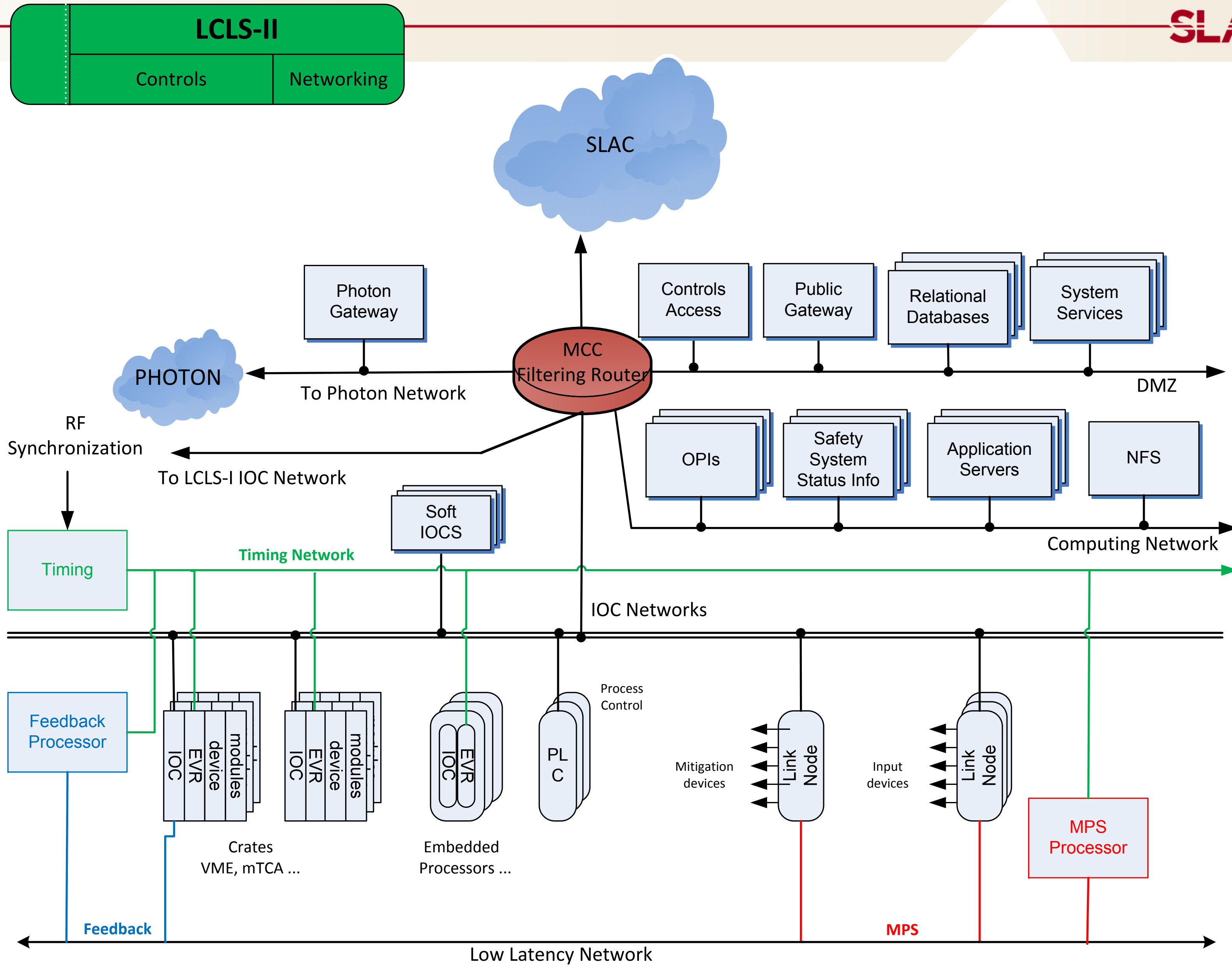
LCLS-I Proven Designs

- ✓ Network Architecture
- ✓ Controls Computing Infrastructure
- ✓ Vacuum Controls
- ✓ Magnet power supply
- ✓ Personnel Protection
- ✓ Warm LLRF
- ✓ High Level Applications
- ✓ Operations Software

Controls Design Challenges

- ❑ Timing & Synchronization
- ❑ SC Low Level RF
- ❑ Beam-based Feedback
- ❑ Beam Diagnostic Systems (BPM, charge monitor, etc.)
- ❑ Machine Protection
- ❑ Beam Containment System

Network-based Overview of the Controls System



Timing and Event System

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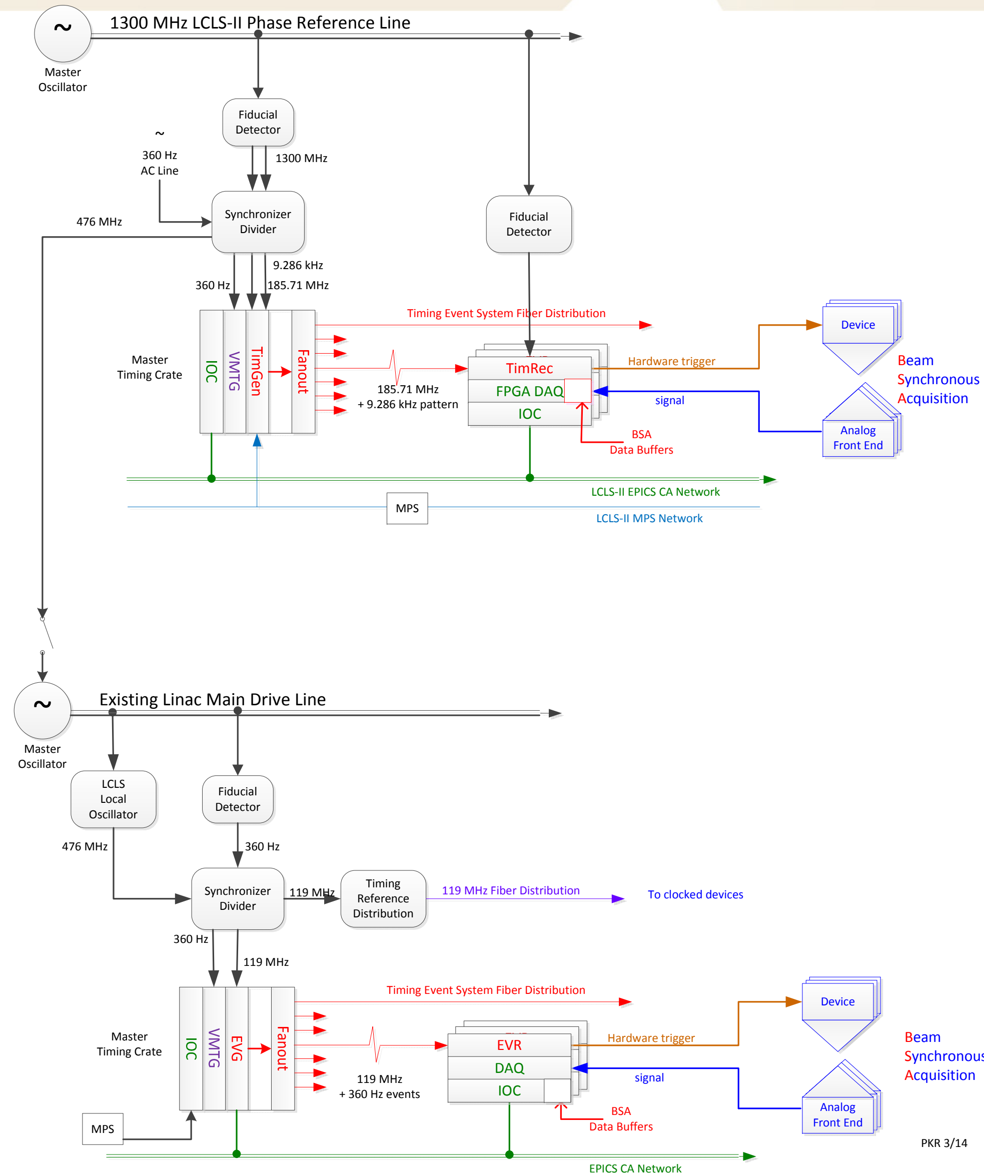
- Timing system will still be based on the successful Event Generator (EVG) and Event Receiver (EVR) commercial components from Micro Research Finland.
- EVG clock rate will be scaled up from 360 Hz to 1 MHz
- LLRF will be tied to the timing system through the 1300 MHz reference line.
  - The reference line also includes a timing fiducial.

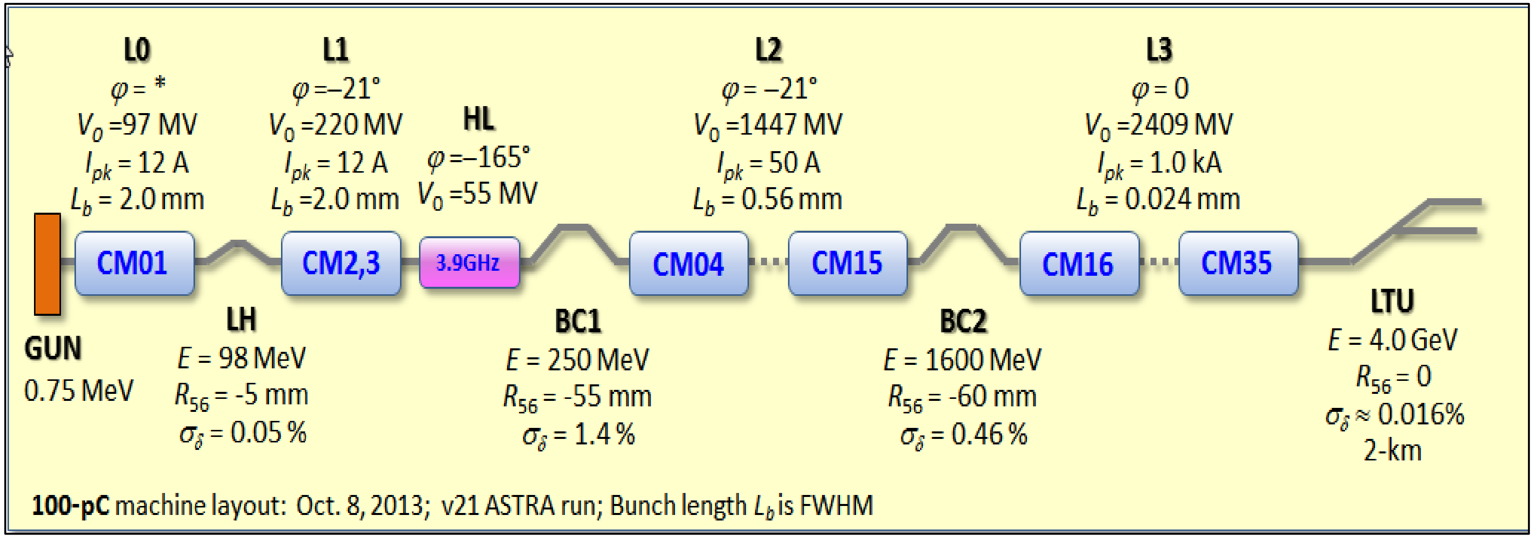


IPAC 2014, 16 June 2014

Low Level RF Control

Required Field Control to meet accelerator performance:

0.01° rms. phase and 0.01% rms. gradient ….pulse to pulse



LCLS-II LINAC

- ***Single Source Single Cavity Control can meet the cavity field control specification***
- ***48 cavity vector sum will meet it, but not the cavities in the sum …….***

LCLS-II LLRF Systems

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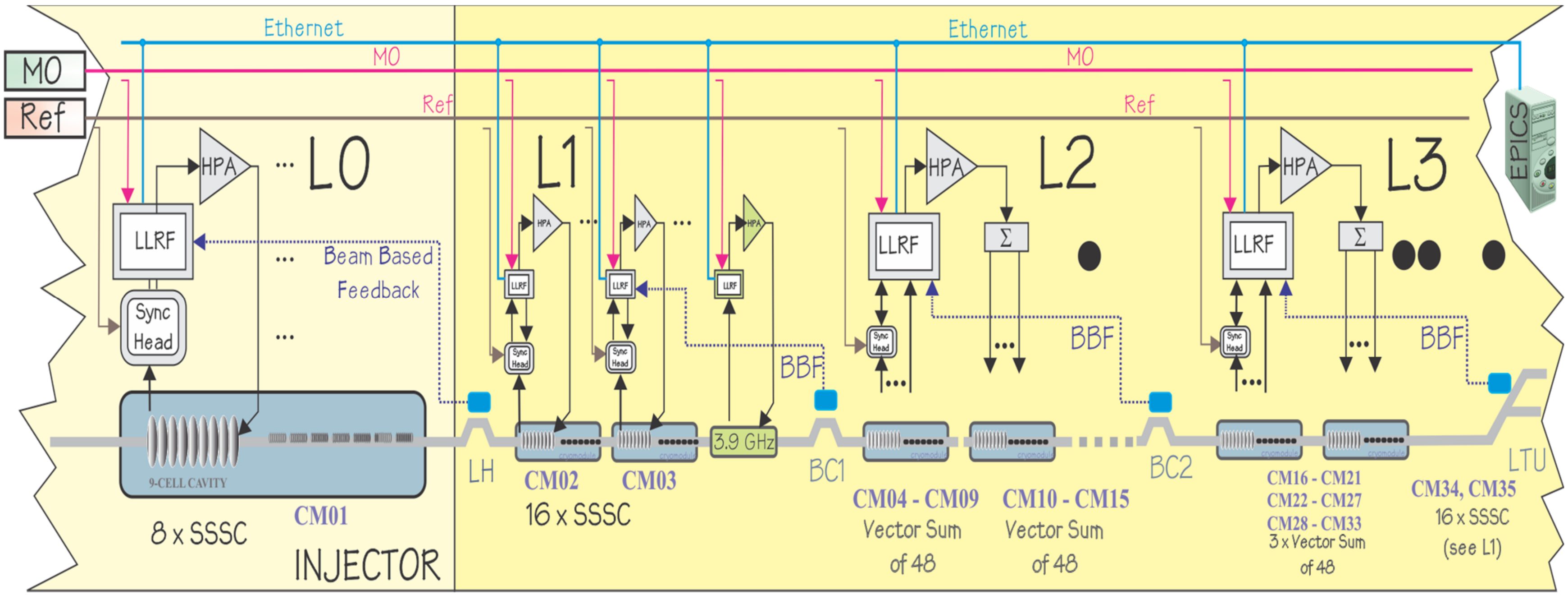
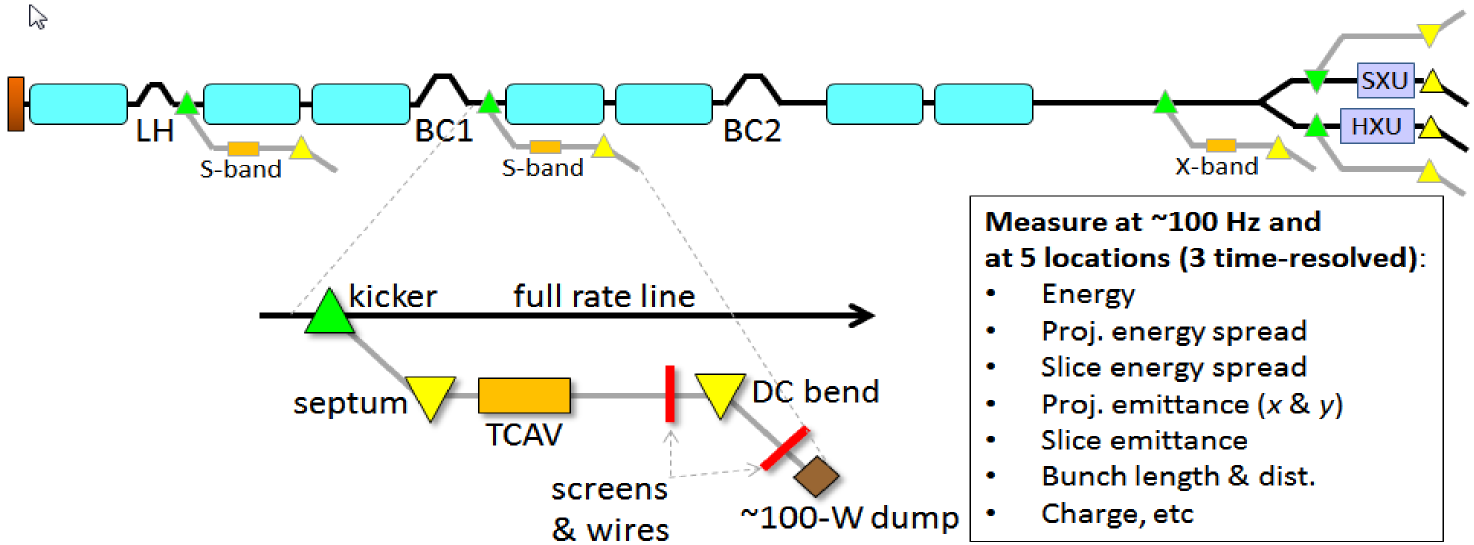


- **40 Single Source Single Cavity Controllers**
- **Five Vector Sum Multi-Cavity Controllers (240 cavities)**
- **12 3.9 GHz Single Source Single Cavity Controllers**

Beam Diagnostic Systems

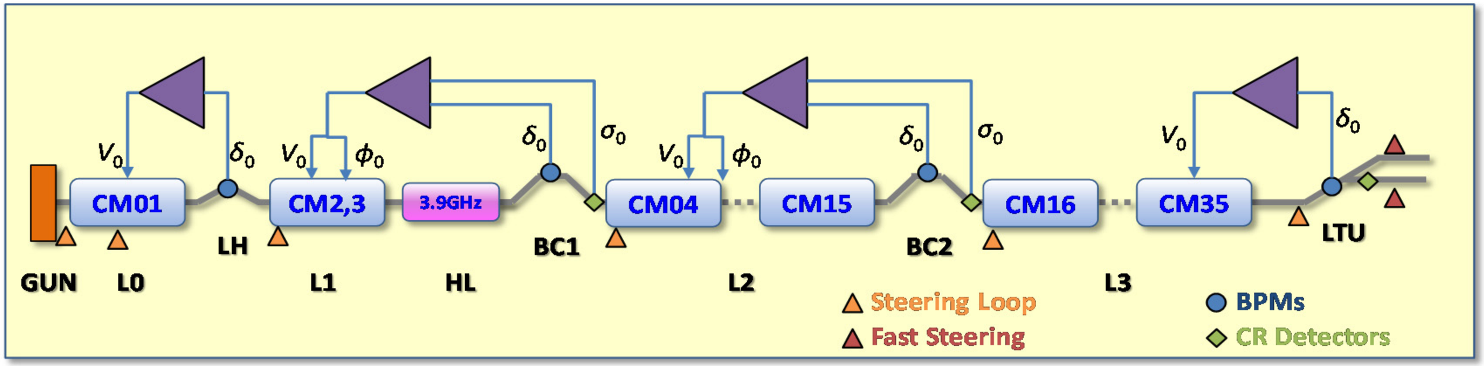
- Full beam rate monitors
  - BPMs, Loss monitors, current monitors
  - Relative bunch length monitors.
- Single bunch, low readout rate
  - Longitudinal & transverse profile monitor
- Time average
  - beam loss, beam halo
  - average current including dark current.

- Standard ADC + FPGA Electronics
  - 4-10 channels of 120-250 MHz >11 effective bit ADC's.
  - FPGA with hundreds of thousands of cells capable of doing LLRF or feedback algorithms including calibrations and diagnostics.
  - Memory to buffer several million consecutive readings.
  - Computer interface for setup/read-back.



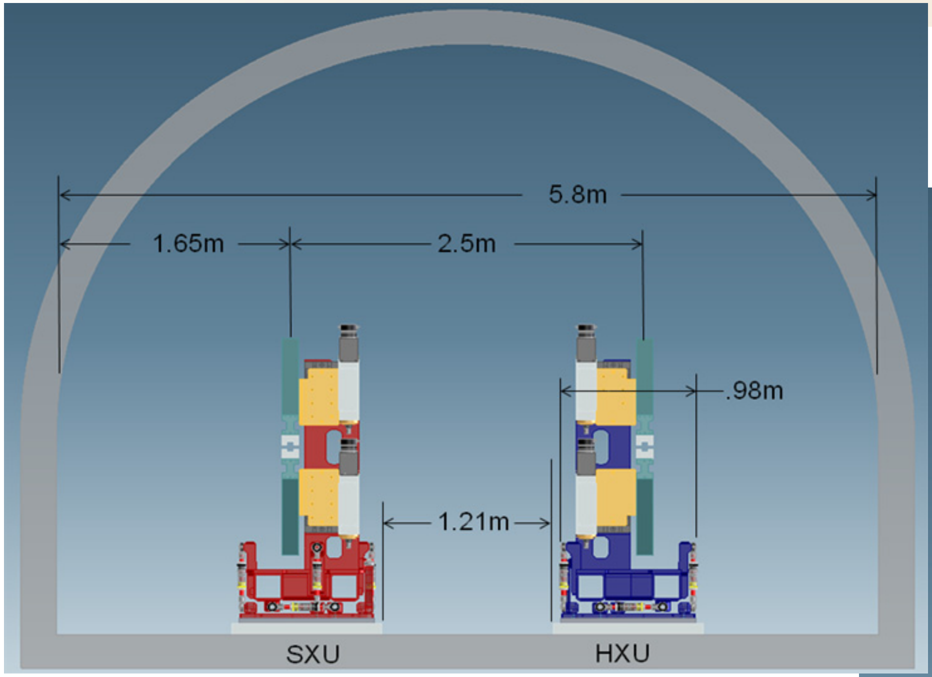
Measure at ~100 Hz and at 5 locations (3 time-resolved):
- Energy
- Proj. energy spread
- Slice energy spread
- Proj. emittance (*x* & *y*)
- Slice emittance
- Bunch length & dist.
- Charge, etc

LCLS-II Beam-based Feedback Requirements

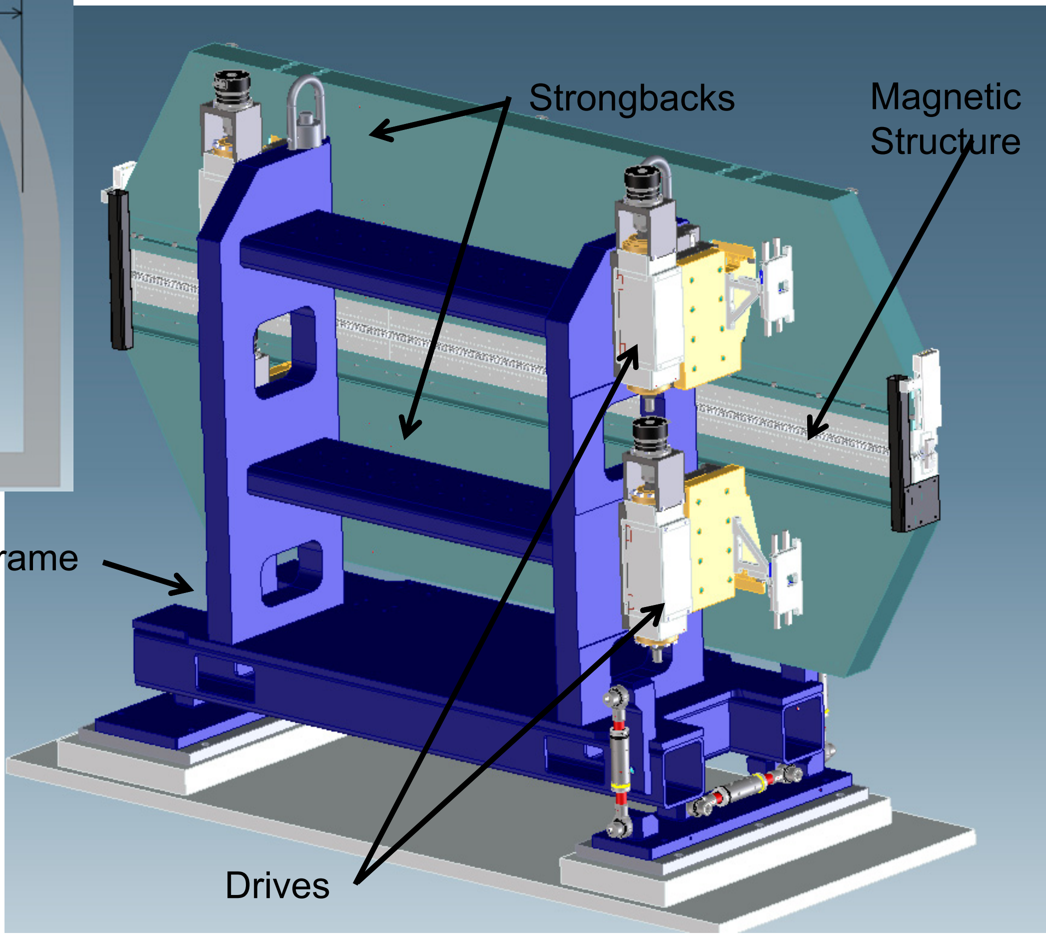


- Charge Feedback (<30Hz)
- Transverse feedbacks for steering at linac accelerator sections (<30Hz)
- Faster steering before undulator sections (100 kHz)
- Beam-rate Longitudinal feedback for stability (1 MHz)

Two Variable-Gap Undulators for Hard and Soft x-ray



LBNL VG Undulator Design

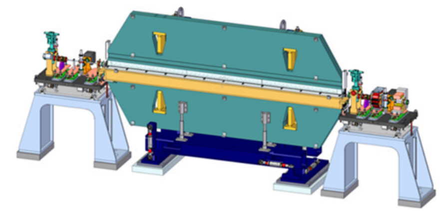


Well on our way to a full scale prototype as part of LCLS-II$_{\text{Phase I}}$

D. Bruch, S. Marks, M. Rowen

Safety Systems Overview: PPS, BCS, MPS

Radiation Safety System

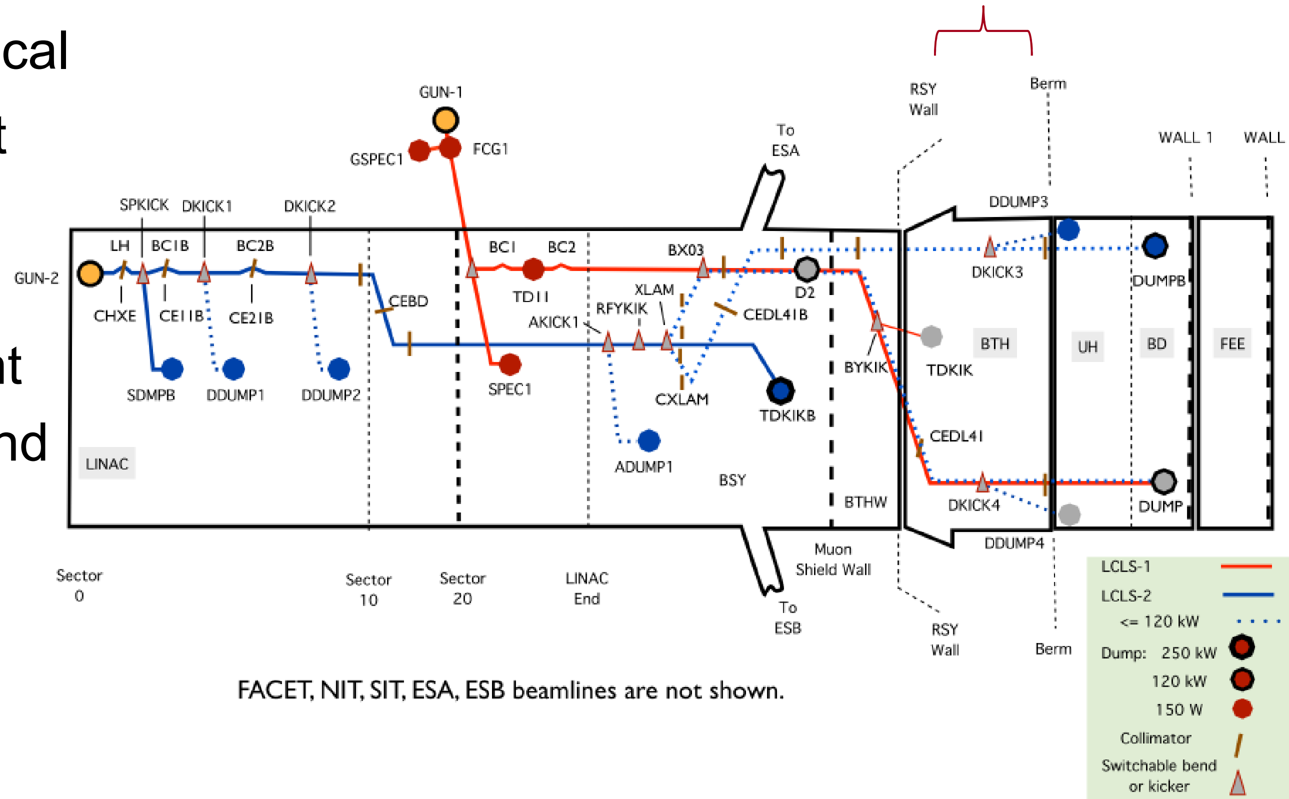


Personnel Protection System (PPS)	Beam Containment System (BCS)	Machine Protection System (MPS)	
Detect presence of personnel.	Measurements of beam current, repetition rate, energy, and beam losses.		Input Sensors
up to ~5 sec	as fast as 25 – 100 µs	25 – 150 µs or rate limit	Response Times
Beam Shut-off devices			Output Devices
		Power Limiting Devices	

Tuning Dumps and Diagnostic Lines

- Beam power and beam loss issues are critical
- Beam Containment & Machine Protection are especially important in Undulator Hall and down stream

Enclosure across Research Yard



FACET, NIT, SIT, ESA, ESB beamlines are not shown.

J. Welch

Beam Containment System (BCS) Response Time Requirement

- Shut off time requirements

Initiative Device	Response Time (maximum)	Shutoff Path
Ion chamber	100 μs	Fast shutoff + PLC
Average Current Monitor /Current Comparator	20 ms	Fast shutoff + PLC
Vacuum Sensor	1 ms	Fast shutoff + PLC
Magnet current Sensor	600 ms	PLC
Other slow sensors	600 ms	PLC

- LCLS-II shut off Actions
  - Abort Kicker upstream of undulator hall
  - Pockels Cells/AOM, Laser Shutter, Gun Phase Shift at the injector
- Targeted shut off
  - Trip off SXR or HXR source or both depending on a specific BCS fault

Machine Protection System – Scope and Requirements

- Protect LCLS-II machine components from beam based damage by shutting off beam or reducing beam rate.
  - LCLS-II Respond within 1 msec for slow type faults and 25 usec for fast type faults
  - LCLS-I: Respond within 8.3ms LCLS MPS, actually responds within 2.78ms
  - Beam Loss Prevention Absolutely Critical

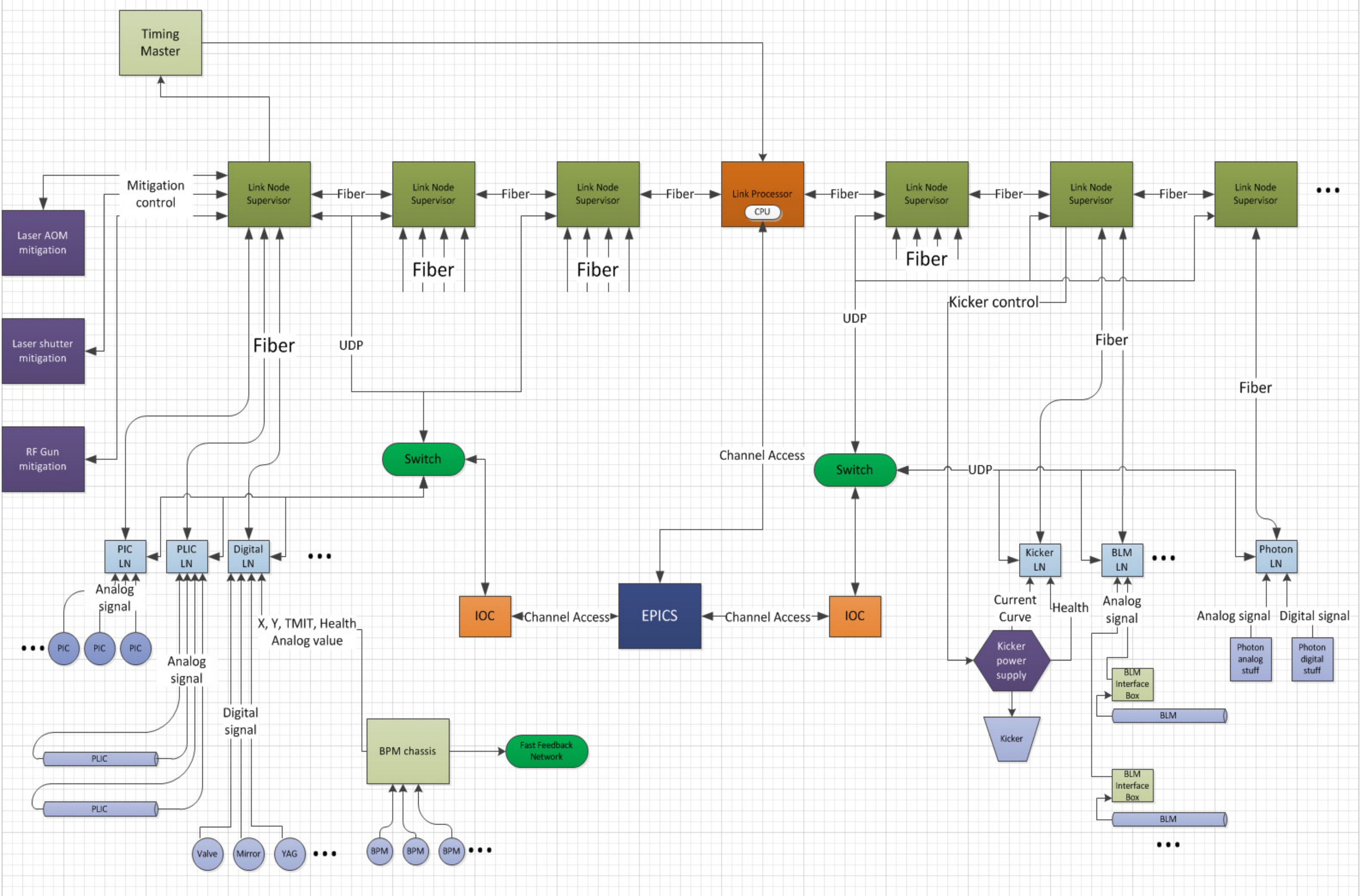
- System must support multiply sources (new LCLS-II Injector and current LCLS-I Injector)
- Simultaneous Beam Destination each with varying allowed rates
  - MPS must monitor a Beam Spreader that switches beam between two undulator beam lines and pulsed magnet kickers that pulse steal into diagnostic beam lines
  - LCLS-II MPS must be capable of independently rate-limiting the beam in either of its two undulator beam lines.

- Design based on existing LCLS-I design and includes:
  - Machine obstruction and electron beam monitoring
  - Mitigation device control
  - MPS Configuration
  - MPS History
  - Full integration of MPS into the LCLS-II EPICS control system
  - MPS communication with the timing Event Generating source

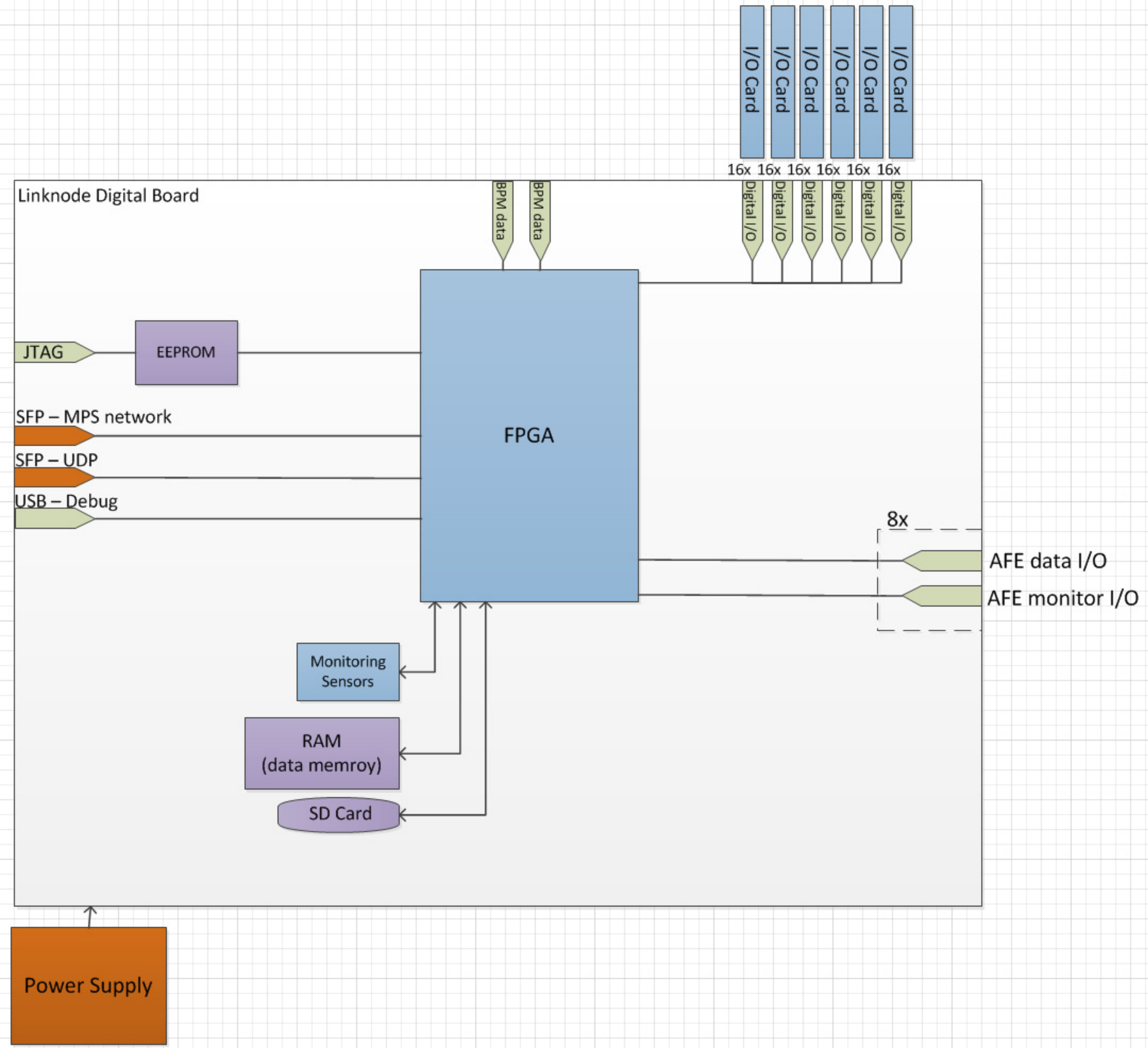
MPS Scope of Work – Assumption

- Maximum 90 μs response time to MPS faults
- Use of beam spreader as a rate limiting/mitigation device
- All beam position monitors will be connected to MPS
- The acoustic optical modulators (AOM) in the laser system will be used as a rate limiting/mitigation device.
- Ion chambers and loss monitors will be able to resolute 1MHz beam rate
- Slow status report via EPICS control system.

Conceptual Design



FPGA Linknode module for Fast MPS



Conclusion

- The new LCLS-II provides a number of engineering challenges for the design of the control system
- 1 MHz beam rate requires the “business logic” for many systems such as BPMs, LLRF, MPS, etc. to be migrated from processors to FPGAs
- A new timing system has to be developed to meet the complex needs of LCLS-I & LCLS-II in concurrent operation
- Beam power and beam loss issues are critical in the design of the safety systems

End of Presentation

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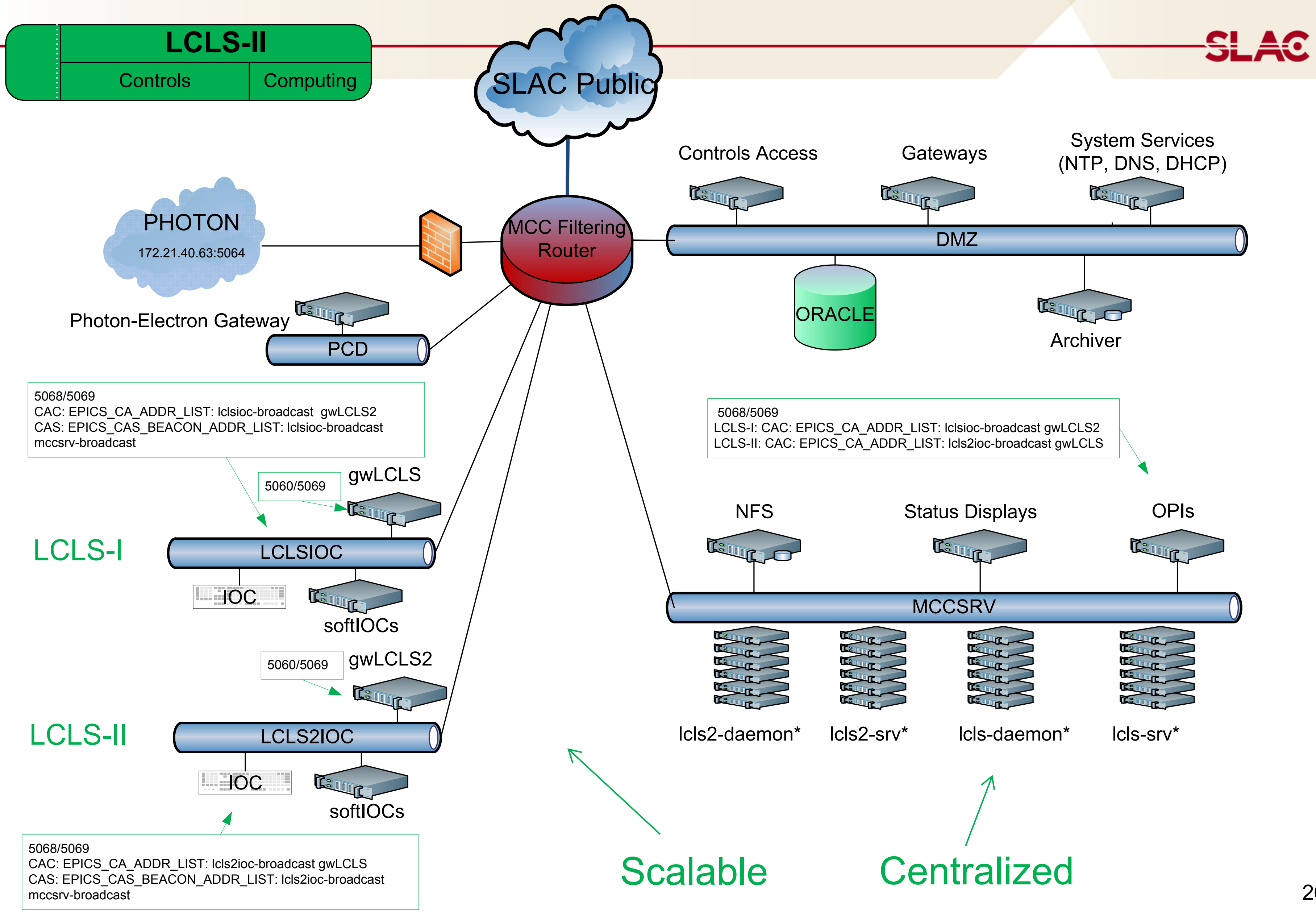
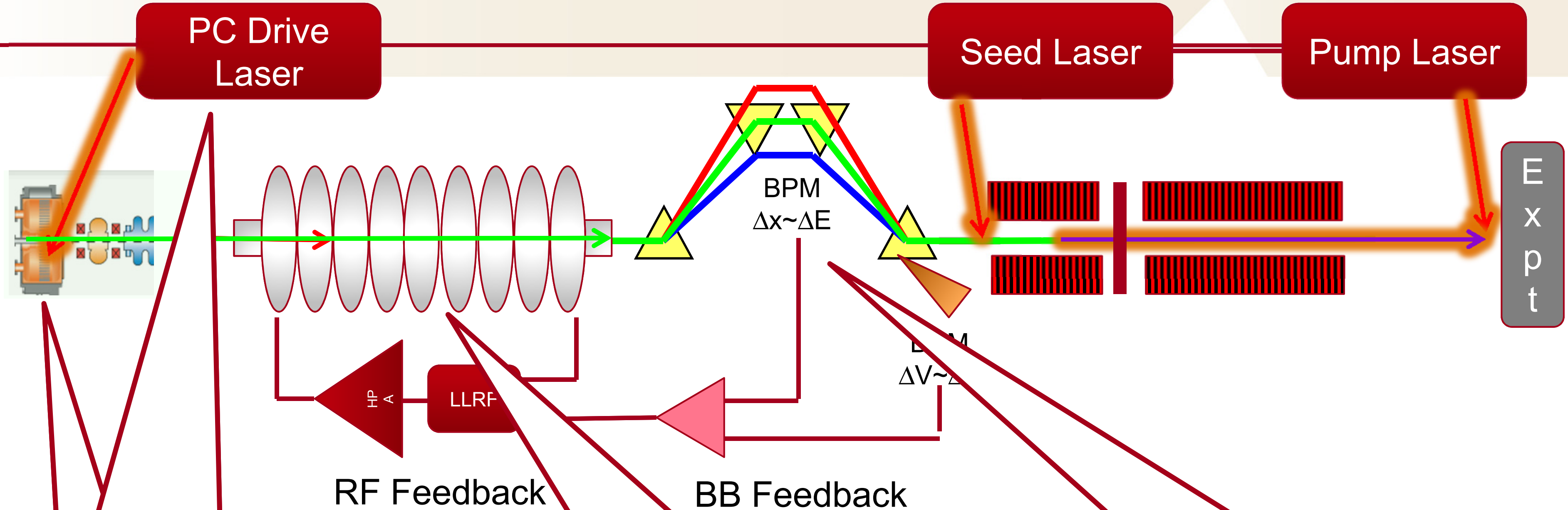
Controls Computing Architecture



EPICS Channel Access Traffic Control

- Controls largely based on EPICS Channel Access Protocol
- Channel Access traffic control
  - Channel Access traffic is separated between LCLSIOC (for LCLS-I) and LCLS2IOC (for LCLS-II) to avoid networks impacting each other
  - Use EPICS PV gateways to control communication between LCLS-I and LCLS-II
    - LCLS-I gateway: serve LCLS-I PVs to LCLS-II applications
    - LCLS-II gateway: serve LCLS-II PVs to LCLS-I applications
  - LCLS-I applications: have direct access to LCLS-I PVs and can access to LCLS-II PVs via gateway
  - LCLS-II applications: have direct access to LCLS-II PVs and can access to LCLS-I PVs via gateway

Jitter Sources



PC Drive Laser:
- Pulse energy
- Time jitter
- Pulse length

Gun + Injector:
- RF Amp + Phase
- Bunch Charge

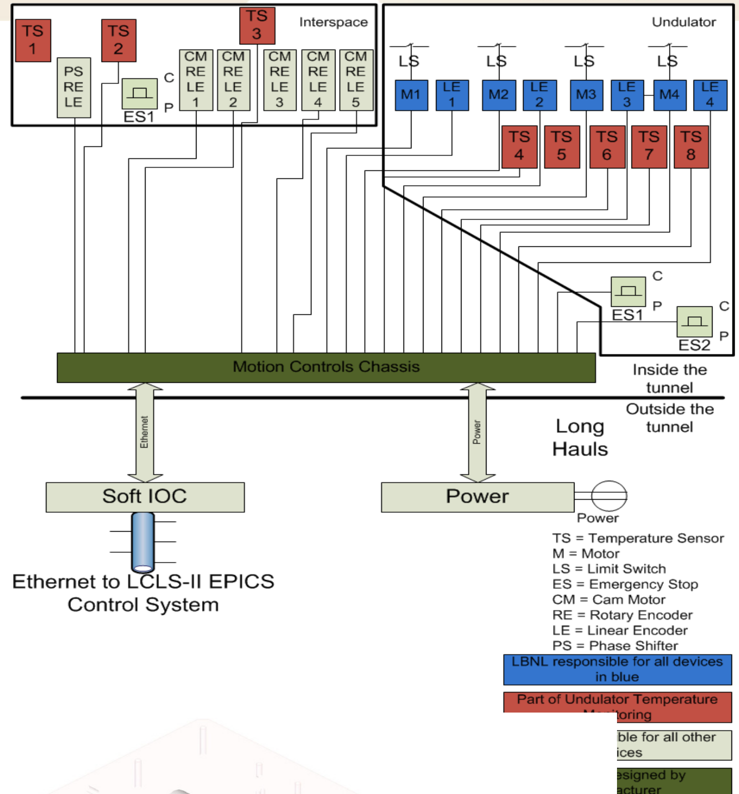
Linac:
- RF Amplitude + Phase
- ADC noise
- Klystron noise
- Beam loading modulation

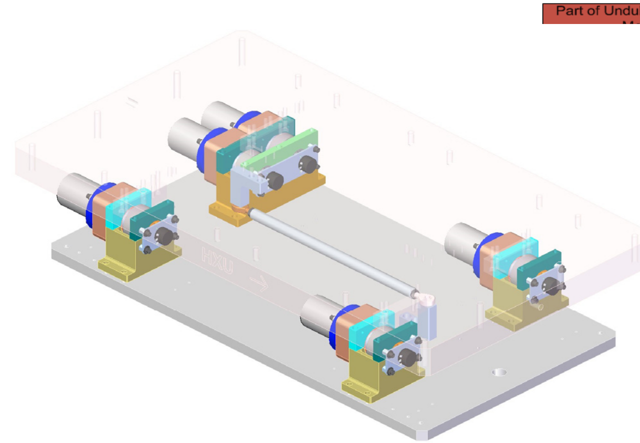
Beam-based Feedback:
- Energy measurement (BPM)
- Arrival time (BAM)
- Bunch shape (BCM)

John Byrd (LBNL)

Variable Gap Undulator Motion Control System

- Undulator gap control using 4 motors, position encoders & limit switches
- Interspace control using 5 cam system, 5 contact points at four corners
- Controls for each undulator and interspace will be integrated into a single system that interfaces to an EPICS IOC
- Prototype assembly is complete
- A temperature monitoring system is also integrated into each control chassis, with sensors on the undulator and interspace

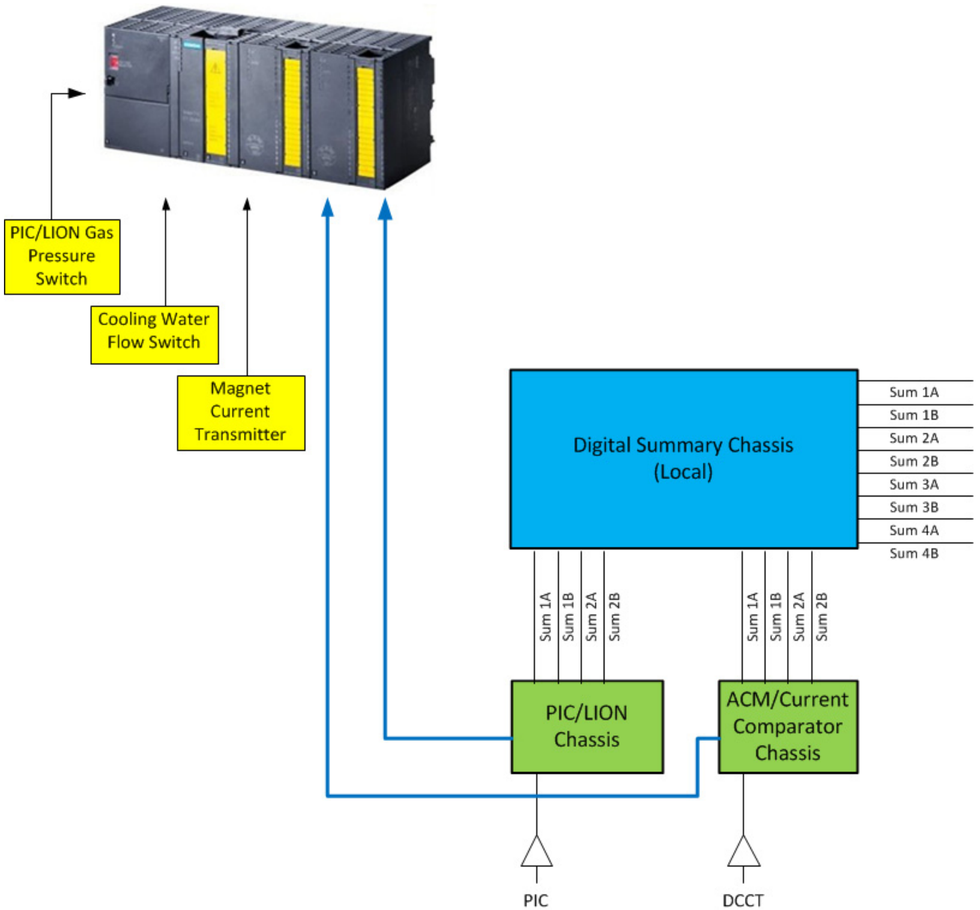




Typical BCS Location

Remote I/O drop acts as a data hub

- Use Siemens S7 safety PLC as the backbone for BCS
- Slow sensors directly connect to PLC
- Custom chassis for fast sensors
- Chassis will exchange information with PLC
- Chassis provide “fault” information to local Digital Summary chassis
- Local digital summary chassis uses fiber to transfer “OK/Fault” signal to avoid cost of long haul cable
- Global Digital Summary chassis for fast shut off of output devices
- PLC provides diagnostics and configuration control



Key Performance Parameters

Performance Measure	Threshold	Objective
Variable Gap Undulators	2 (SXR & HXR)	2 (SXR & HXR)
Super Conducting Linac Based FEL System		
Super Conducting Linac Electron Beam Energy	3 GeV	≥ 4 GeV
Super Conducting Linac Repetition Rate	50 kHz	1,000 kHz
Super Conducting Linac Charge per Bunch	0.02 nC	0.1 nC
Photon Beam Energy Range	250-2,800 eV	200-5,000 eV
High Repetition Rate Capable End Stations	≥ 1	≥ 2
FEL Photon Quantity (10^-3 BW)	10X spontaneous @ 2.5 keV	>10^11
Normal Conducting Linac Based FEL System		
Normal Conducting Linac Electron Beam Energy	13 GeV	15 GeV
Normal Conducting Linac Repetition Rate	120 Hz	120 Hz
Normal Conducting Linac Charge per Bunch	0.1 nC	0.25 nC
Photon Beam Energy Range	1-13,000 eV	1-25,000 eV
Low Repetition Rate Capable End Stations	≥ 2	≥ 3
FEL Photon Quantity (10^-3 BW)	10X spontaneous @ 13 keV	>10^12 @ 13 keV

Schedule

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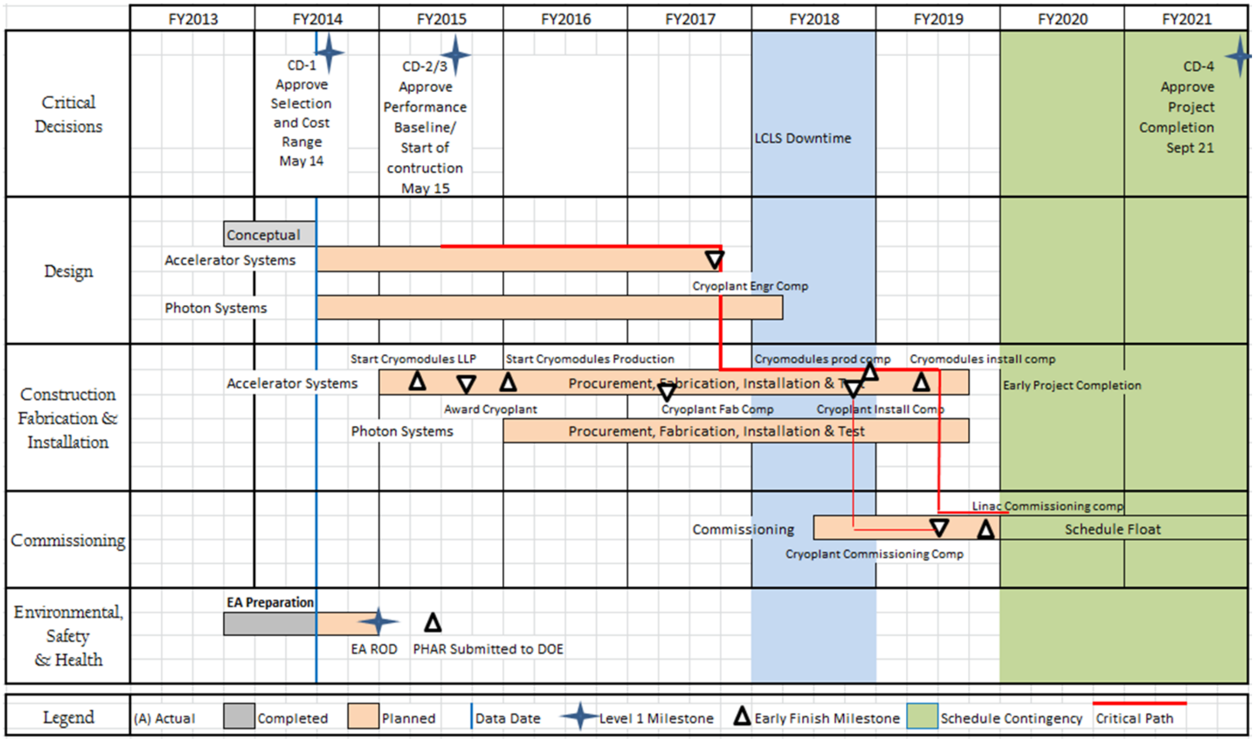

Level I Baseline Milestones	Schedule
CD-0, Approve Mission Need	4/22/10 (actual)
Approve Mission Need Statement (Revised)	9/27/13 (actual)
CD-1, Approve Alternative Selection and Cost Range (Revised)	3QFY2014
CD-2, Approve Performance Baseline	3QFY2015
CD-3, Approve Start of Construction	3QFY2015
CD-4, Approve Project Completion	4QFY2021