Conceptual Design of the Matter in Extreme Condition Upgrade (MEC-U) Rep-rated Laser Control System

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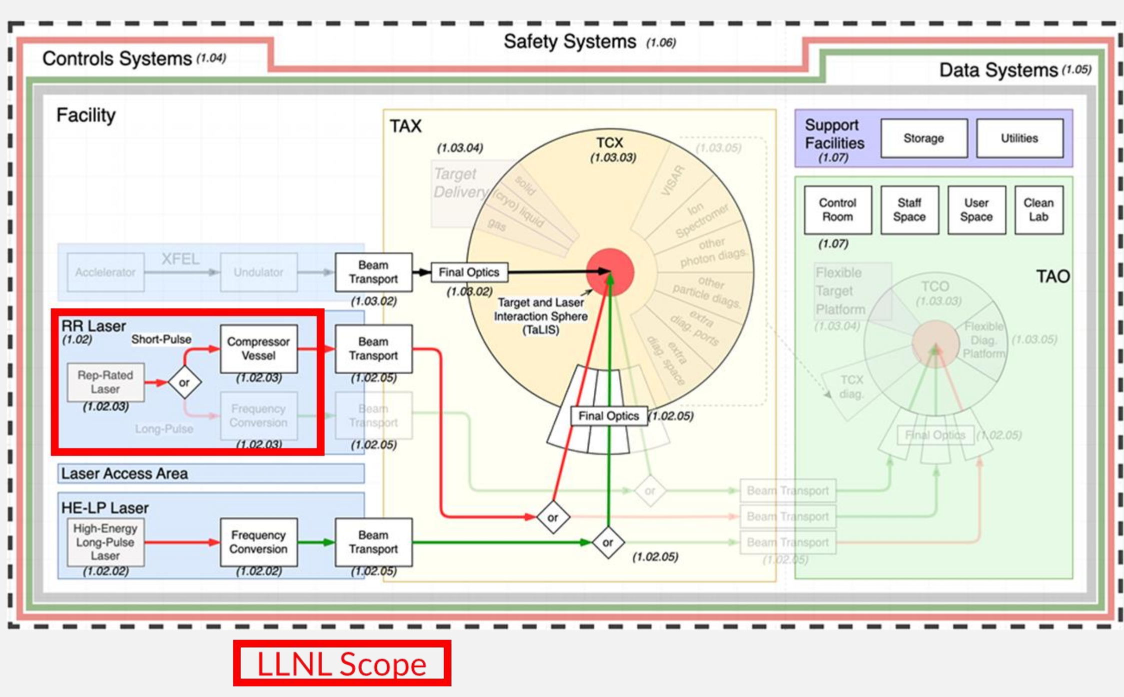
Abstract

The Lawrence Livermore National Laboratory (LLNL) is delivering the Dual-mode Energetic Laser for Plasma and High Intensity Science (DELPHI) system to SLAC as part of the MEC-U project to create an unprecedented platform for high energy density experiments. The DELPHI control system is required to deliver short and/or long pulses at a 10 Hz firing rate with femto/pico-second accuracy sustained over fourteen 12-hour operator shifts to a common shared target chamber. The MEC-U system requires the integration of the control system with SLAC provided controls related to personnel safety, machine safety, precision timing, data analysis and visualization, amongst others. To meet these needs along with the system's reliability, availability, and maintainability requirements, LLNL is delivering an EPICS based control system leveraging proven SLAC technology. This paper presents the conceptual design of the DELPHI control system and the methods planned to ensure its successful commissioning and delivery to SLAC.

DELPHI System Overview

MEC-U is a collaborative effort across three DOE facilities



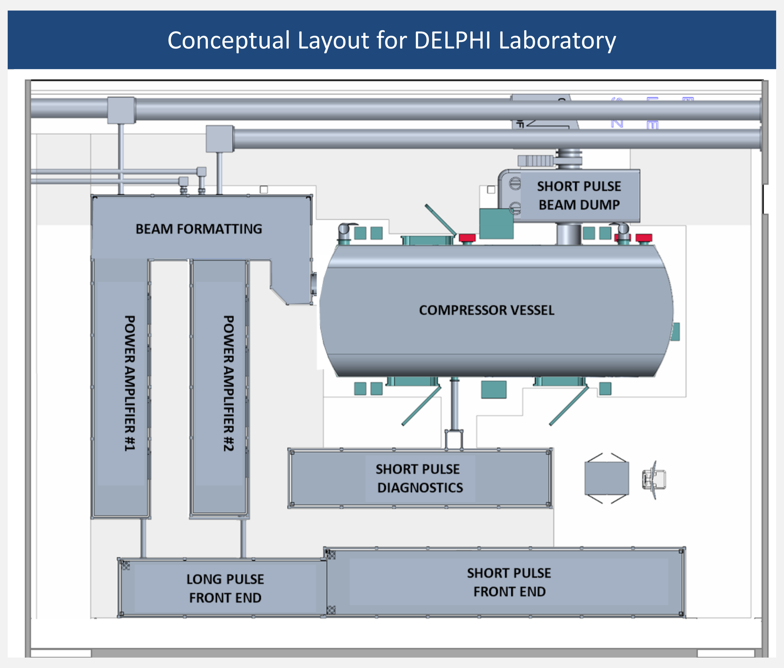
- DELPHI will be built at LLNL, and undergo final integration and site acceptance at SLAC as part of the MEC-U project
- Timed to the hard x-ray beam from SLAC's XFEL, LLNL rep-rated laser will deliver photons to a shared target chamber (TCX)

MEC-U will provide an unprecedented high energy density (HED) experimental platform

DELPHI layout supports dual mode, dual beamlines

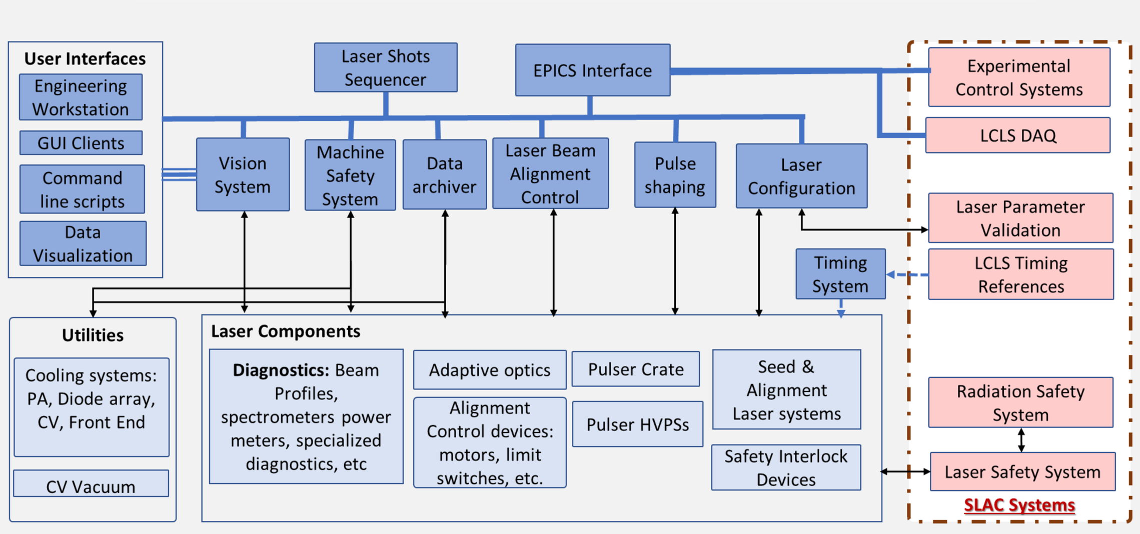
- Short pulse mode
  - 10 Hz, 150 J, 150fs, 1 PW, 1ω
- Long pulse mode
  - 10 Hz, 200J, 10ns, 2ω
- 2nd petawatt beamline and long pulse mode is do not preclude scope
- 12-hour operational shifts
  - -> 400,000 shots/shift
- Photons timed to arrive at shared target chamber with SLAC's XFEL
- Operated from remote control room by two trained personnel

Conceptual Layout for DELPHI Laboratory



Control System Architecture

EPICS based control system leveraging SLAC's technology baseline



EPICS provides the core communication framework and capabilities.
Python is used for supervisory software, GUIs (via PyDM), and visualization/analysis

SLAC hardware and controllers for high RAM

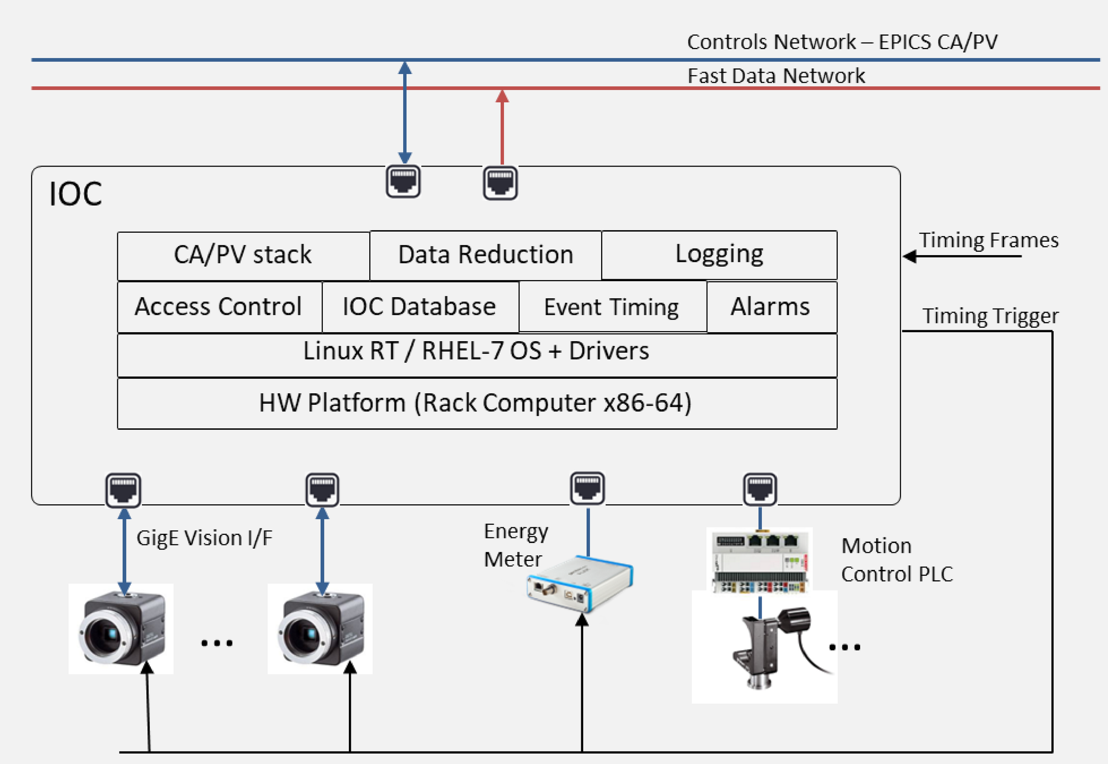
Laser System Devices	Count
Motor	216
Camera	114
Industrial Sensors	70
Large Motor	40
Photodiode	31
Inclinometer	24
Energy Meter	23
Spectrometer	21
MSS Position Switch	21
Laser Source	16
Plasma Cleaner	12
HV DC Power Supply	8
Pulser Crate	8
Wavefront Sensor	6
TEC	4
Power Sensor	4
Shutter	3
Energy Sensor	2
Quad Diode	2
Dazzler	1
Autocorrelator	1
Small Chiller	1
Total	**628**

Utility System Devices	Count
Temperature Transmitter	60
Pressure Transmitter	38
Control Valve	38
Flow switch	26
Flow Meter	32
Convectron Gauge	19
Total	**213**

- Where possible, using SLAC preferred hardware during control points device/controller selection
- CosyLab, a contracting company heavily involved in SLAC engineering and maintenance, is supporting the DELPHI design:
  - Identifying compatible hardware from SLAC
  - Seeking software solutions in SLAC and open-source EPICS baseline
  - Controller level software development
  - Hardware detailed design

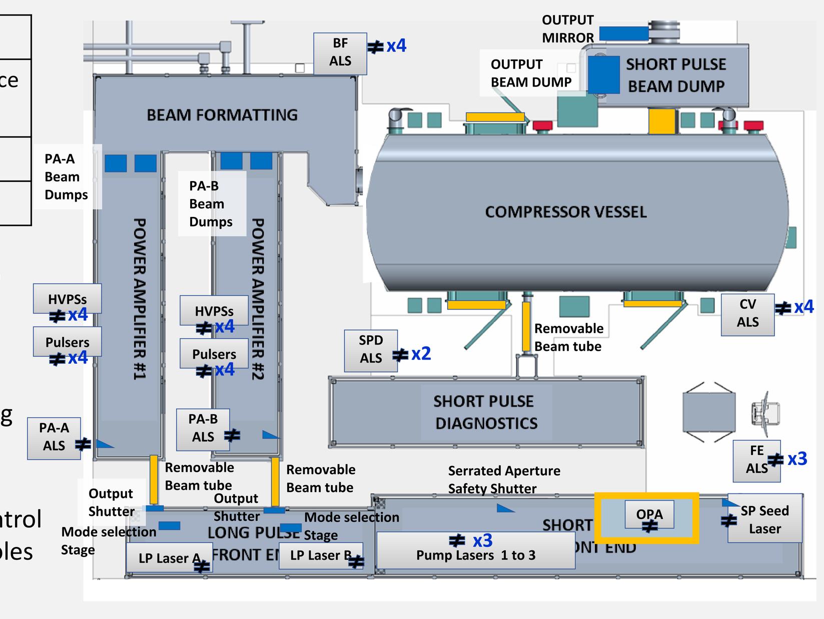
Subsystem Design Concepts

Standard SLAC IOC Controller



Independent Personnel Safety Interlock System (SIS)

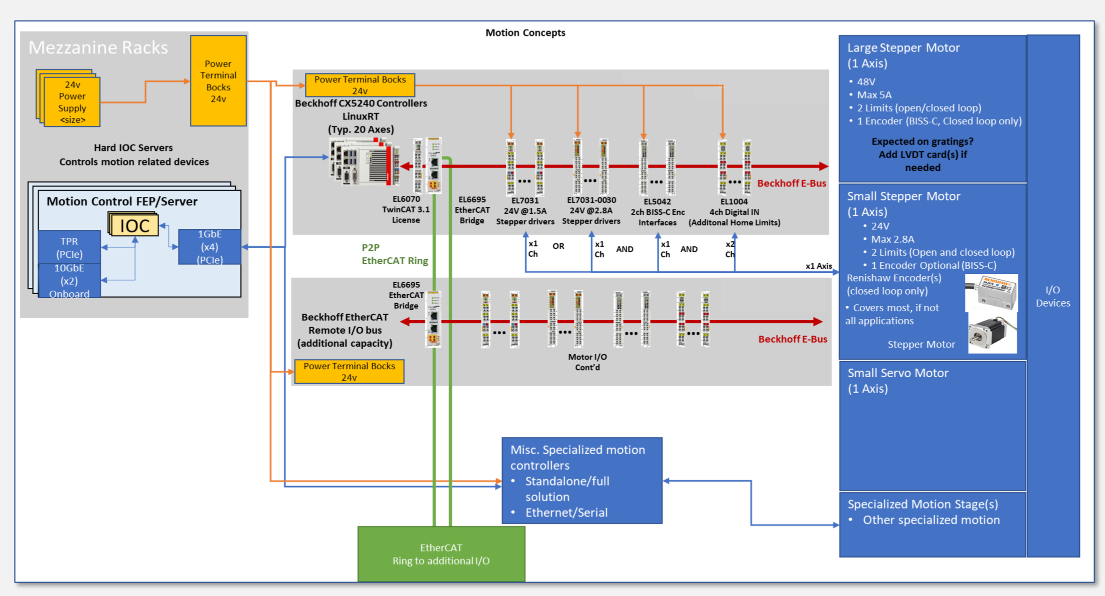
- SIS monitored safety shutter
- SIS monitored beamline device
- SIS monitored enclosure
- SIS Interlocked device



- LLNL will provide interfaces to laser devices, and build LLNL site SIS for FAT
- SLAC is responsible for building and integrating own SIS
- Dedicated safety interface control document (ICD) documents roles and responsibilities

Safety system and interfaces are compliant to SIL-2 standards, as well as SLAC and LLNL's engineering design standards for safety

PLC based Motion and Utilities Control

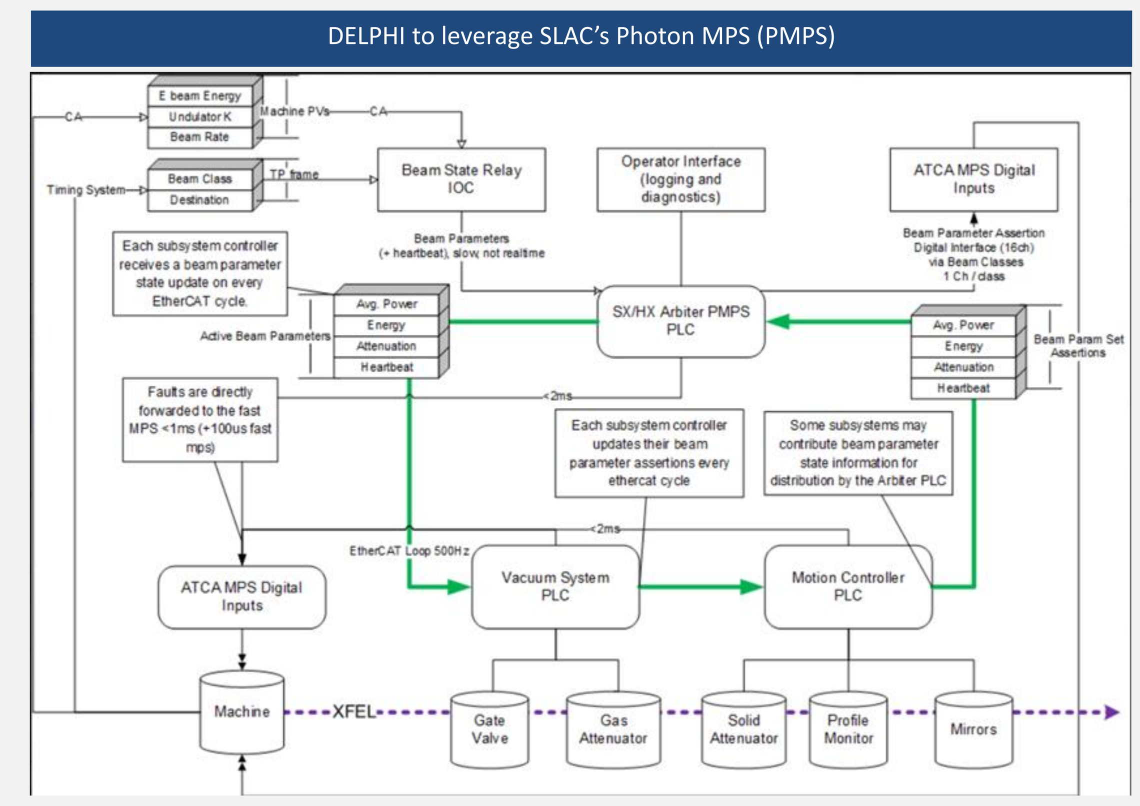


- Beckhoff PLCs is SLAC's common platform for motors and standard industrial sensor I/O
- Standardizing on 4-20mA for sensor I/O to support longer cable distances, and noise resilience.
- ~20-25m cable runs will require appropriate shielding to minimize EMI effects for motor control
- EtherCAT network ties PLCs directly into PMPS network for fast response time to machine safety issues

Leveraging SLAC's Beckhoff technology will ease the integration effort and associated risk into the EPICS based control system

Integrated Machine Protection System (MPS)

DELPHI to leverage SLAC's Photon MPS (PMPS)

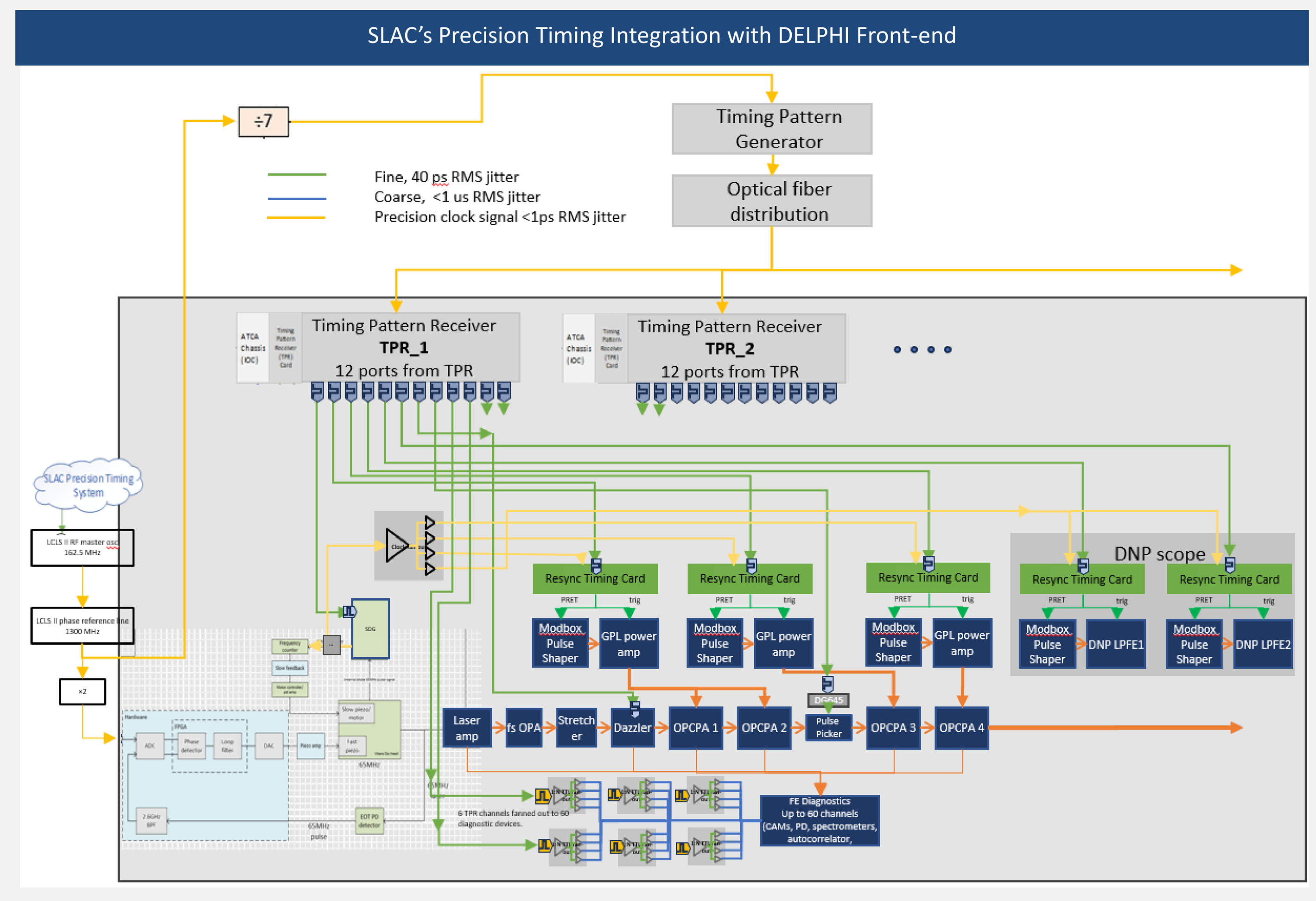


- DELPHI PMPS requires segmentation to support shutdown of individual subsystems/beamlines
- PMPS controls fire permissives for the front-end pulse picker and pulsed power system.
- Fire permissives are inputs into DG645
- Operator feedback on threshold status and bypasses to carry over to DELPHI PMPS system

System	Processor	Response Time
PMPS	PLC	2 ms
MPS	FPGA	80 µs

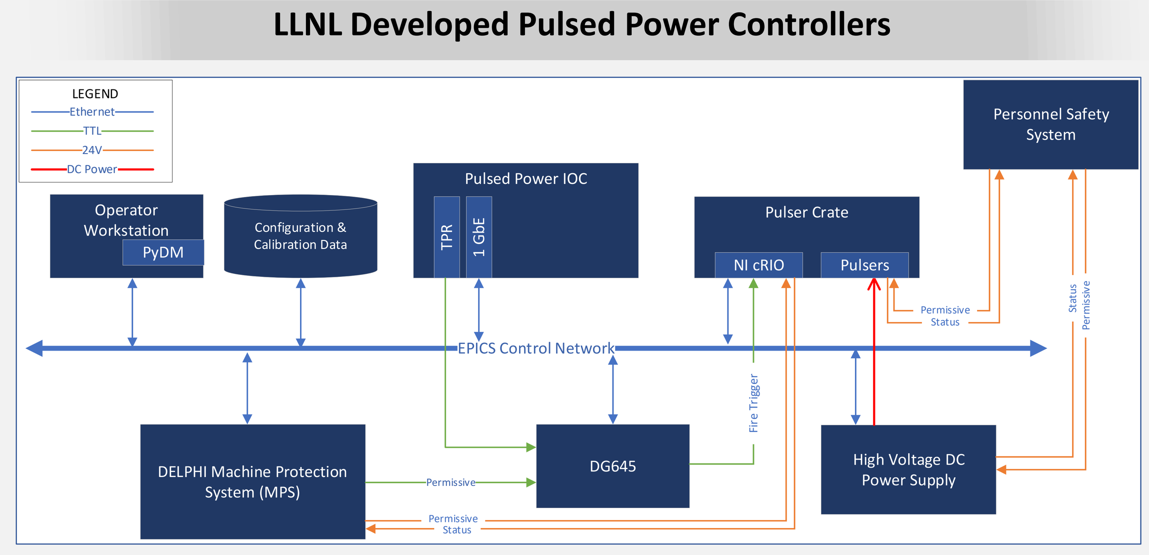
SLAC Precision and Event Timing System

SLAC's Precision Timing Integration with DELPHI Front-end



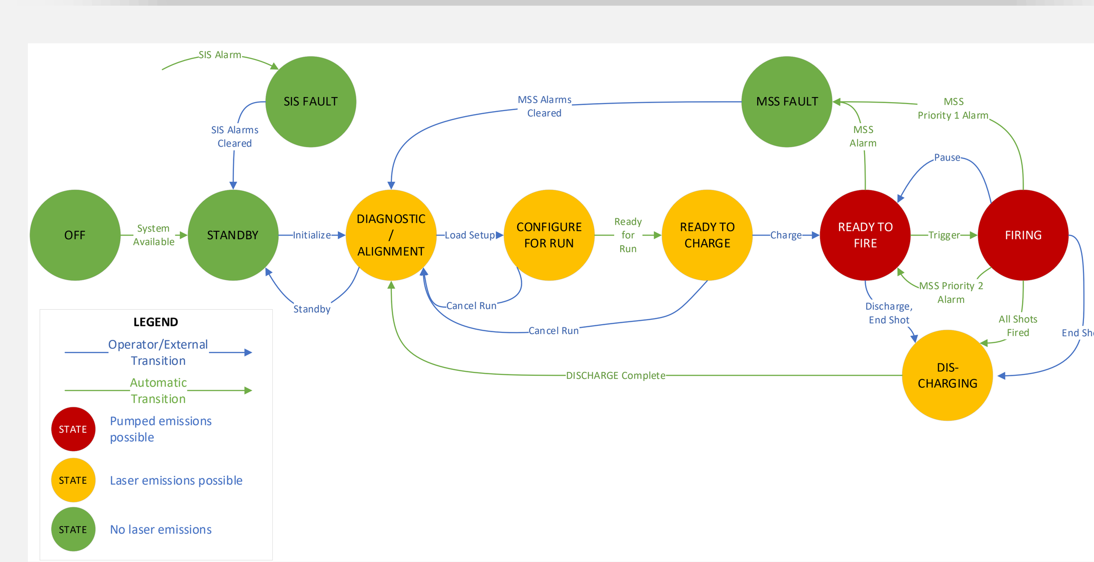
- 10Hz/10.2Hz Heart-beat from MEC-U runs DELPHI front-end timing system for LCLS/LCLS-2 sources for XFEL
- Dedicated Timing Pattern Generator (TPG) for DELPHI
  - Supports programming to provide independent timing/firing of DELPHI without relying on MEC-U
- Precision timing used for synchronizing DELPHI seed pulse to master RF source with high stability
- Event timing system is used for down stream diagnostics and main amplifier
  - Timing Pattern Receiver + optical distribution, or DG645 are options to distributing timing
- SLAC to provide timing system to LLNL for onsite acceptance testing

LLNL Developed Pulsed Power Controllers



- Pulser crates are a custom LLNL hardware design for the safe power delivery to the amplifier diode systems
- Embedded controller is an NI cRIO running LabVIEW.
  - Communication protocol uses the Simple Messaging (STM) Communication Library
- Emulator/Simulator to be provided for system integration testing

High Level Shot Sequencer/Director



- LLNL and SLAC are collaborating on a software framework to support the definition and execution of state machines and associated sequences
- The framework will be Python based, and applied across the SLAC, LLNL, and LLE systems on MEC-U

Summary

- Thanks to the DELPHI design team, SLAC collaborators, and international review committees for their contributions to the conceptual design
- Leveraging SLAC technology for deployment to their site is a necessary step to ensure a maintainability system with high availability, while reducing overall engineering effort
- Next design phase will be the detailed design of the hardware and software using CosyLab/SLAC contractors to best leverage SLAC technology and standards

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