

LCLS-II

LCLS-II Cryogenic System Instrumentation

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LCLS-II Cryogenic Instrum. & Elec. Lead

CEC-IMC23

- **LCLS-II Control System Architecture**
 - PLC Selection
 - PLC Number vs Remote I/O.
 - Lessons Learned
 - Future Improvement
- **Instrumentation Selection:**
 - Sensors Selection
 - Lessons Learned
 - Future Improvement
 - Experience
- **Commissioning:**
 - Number of I/O
 - Strategy [Instrum List / Loop Test]
 - Schedule / Resources

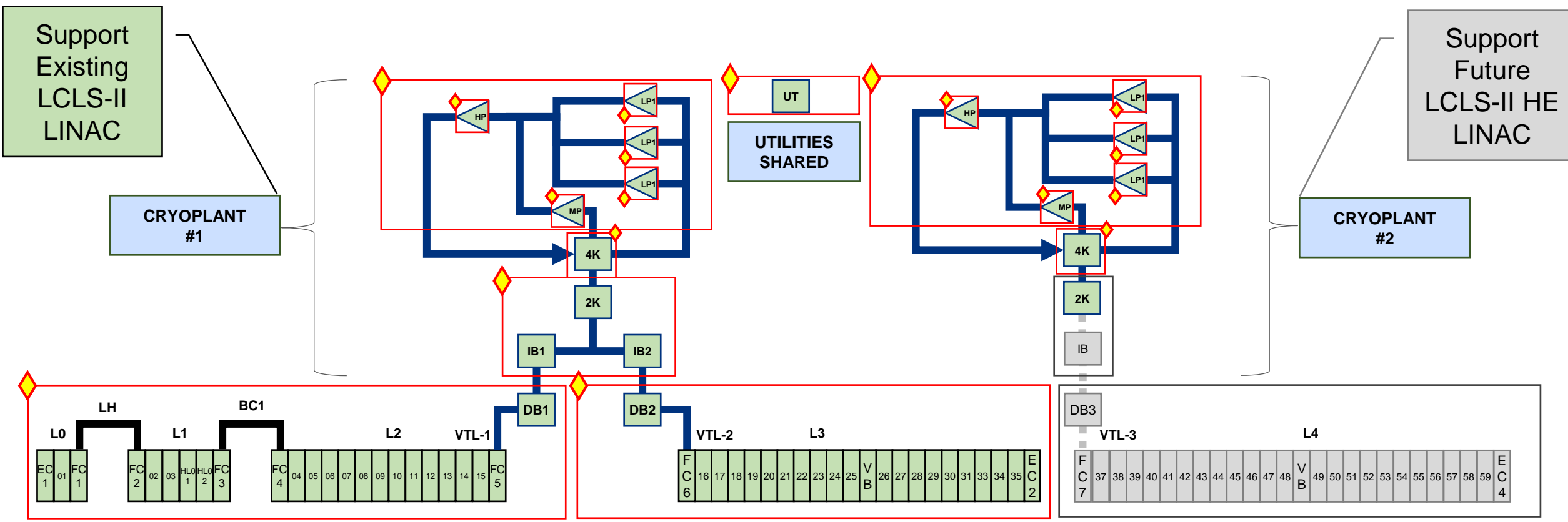
Systems Overview



CRYOPLANT VIEW: GHe & LN2 Storages, Cooling Water and Vertical Cold Boxes.

SLAC: Cryogenic System

- 2 identical 4kW @ 2K Cryoplants exists at SLAC

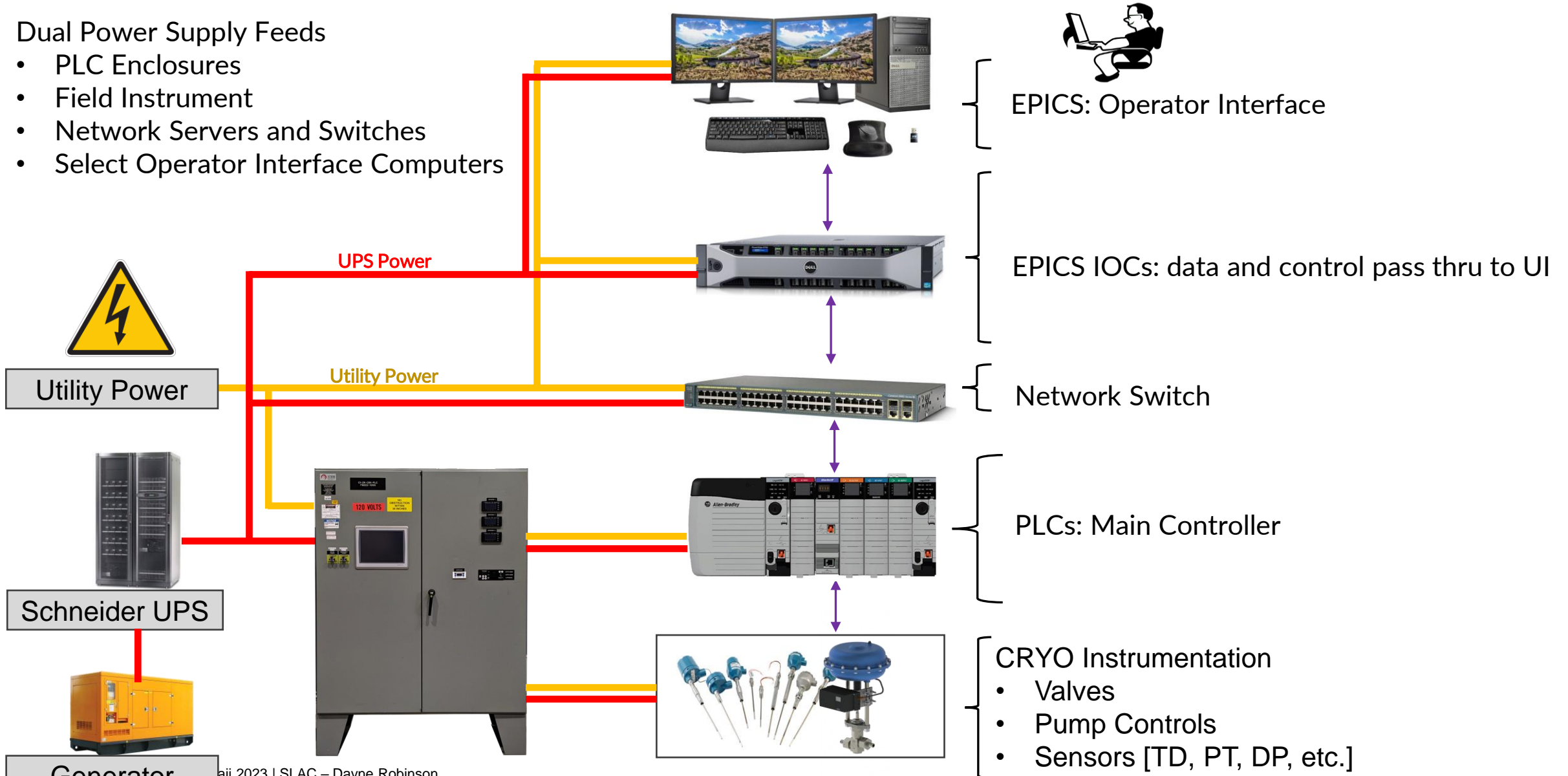


- Existing PLC Total PLCs : 22 – (Allen Bradley Controllers)
- Existing Equipment Total: #37 – Cryomodules, Distribution Boxes (DB) , Interface Boxes (IB), 2K Cold Box (2K), 4K Cold Box (4K), Compressors (LP , MP, HP)
- Future Equipment Total: #23 – Cryomodules, Distribution Box (DB) , Interface Boxes (IB)

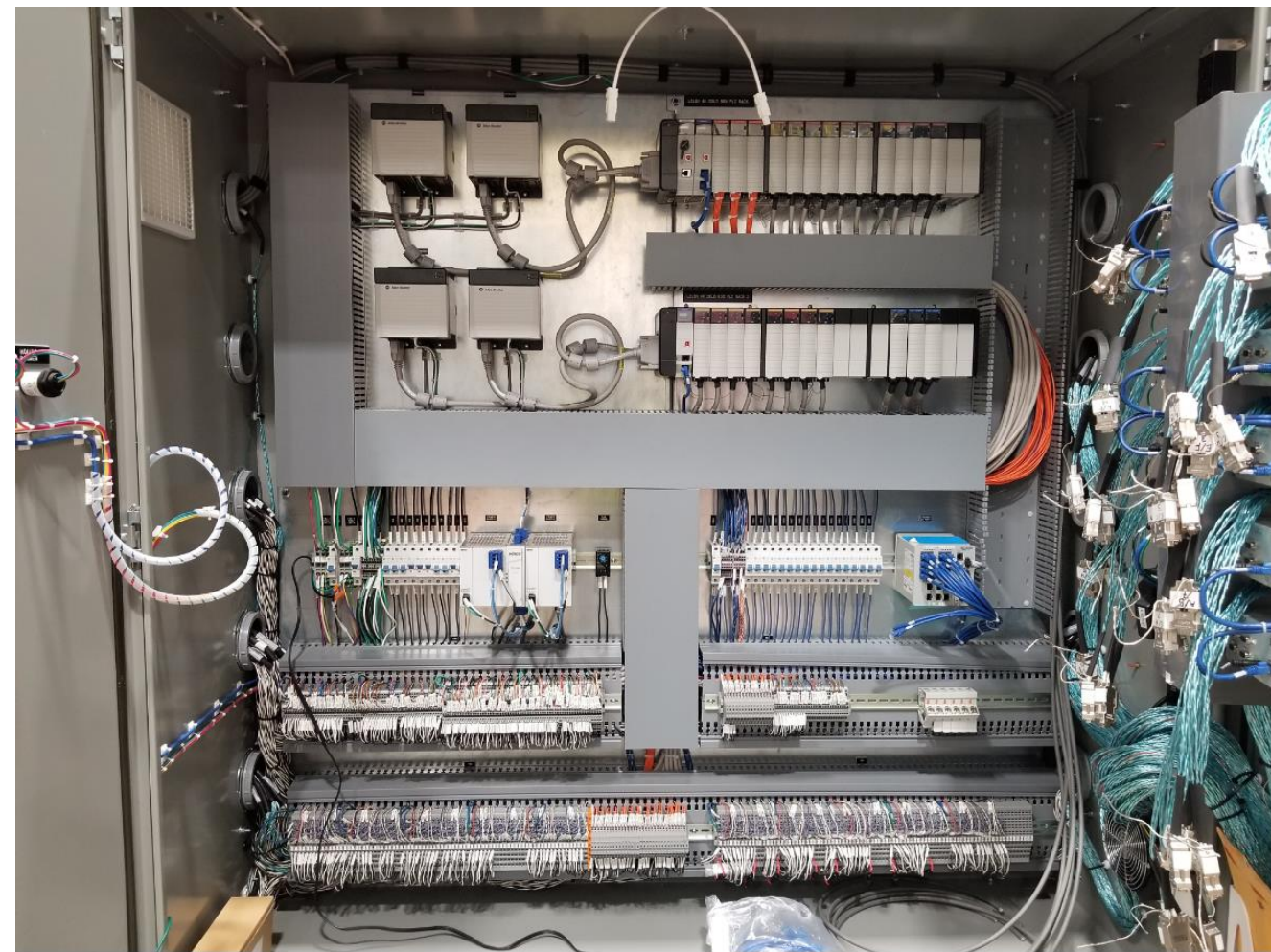
PLC / Instrumentation Architecture

Dual Power Supply Feeds

- PLC Enclosures
- Field Instrument
- Network Servers and Switches
- Select Operator Interface Computers



PLC / Instrumentation Enclosures



PLC Instrumentation Enclosures

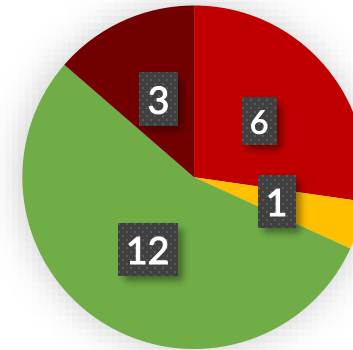
Instrumentation Enclosures

- Built to Print
- UL Listed
- Dual Power Supply [Utility & UPS]
- Redundant PLC Power Supply
- Redundant Field Instrument Power Supply
- Field Instrument
- Local Panelview Touchscreen
- Network Switches
 - PLC-PLC Controls network
 - EPICS network

PLC / Selection

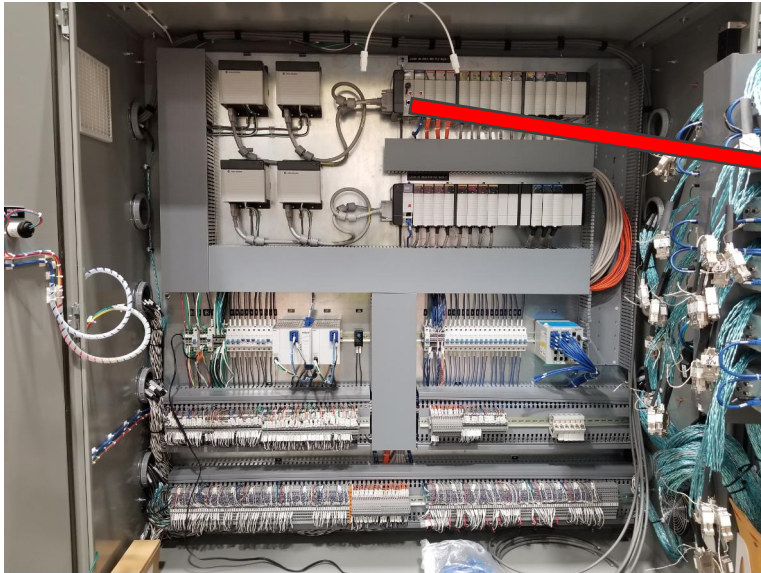
PLC Model	Application	No. of PLCs
Rockwell 1756-L81E	CP1-2K, CP1-4K, CP2-4K Cold Box, Utility, C1-GMGT, C2-GMGT	6
Rockwell 1756-L85E	CP1 2K, DB1, DB2	3
Rockwell 1756-L71	Warm Compressors	12
Rockwell 1769-L30ERM	Oil Processor	1

CryoPlant PLCs



The 1756-L71, 1756-L81E/L85E all belong to the ControlLogix 5580 family. Main features of 5580:

- Most powerful Rockwell processors
- Clock speed of 2.5 GHz
- 40 MB user memory
- Support for up to 128,000 digital I/O points
- Support for up to 4,000 analog I/O points
- Built-in 1-gigabit Ethernet port
- Support for controller redundancy
- CP1 2K-CBX-PLC exchanges over 4000 Produced – Consumed tags with the Cryo Distribution System for Integrated Controls.

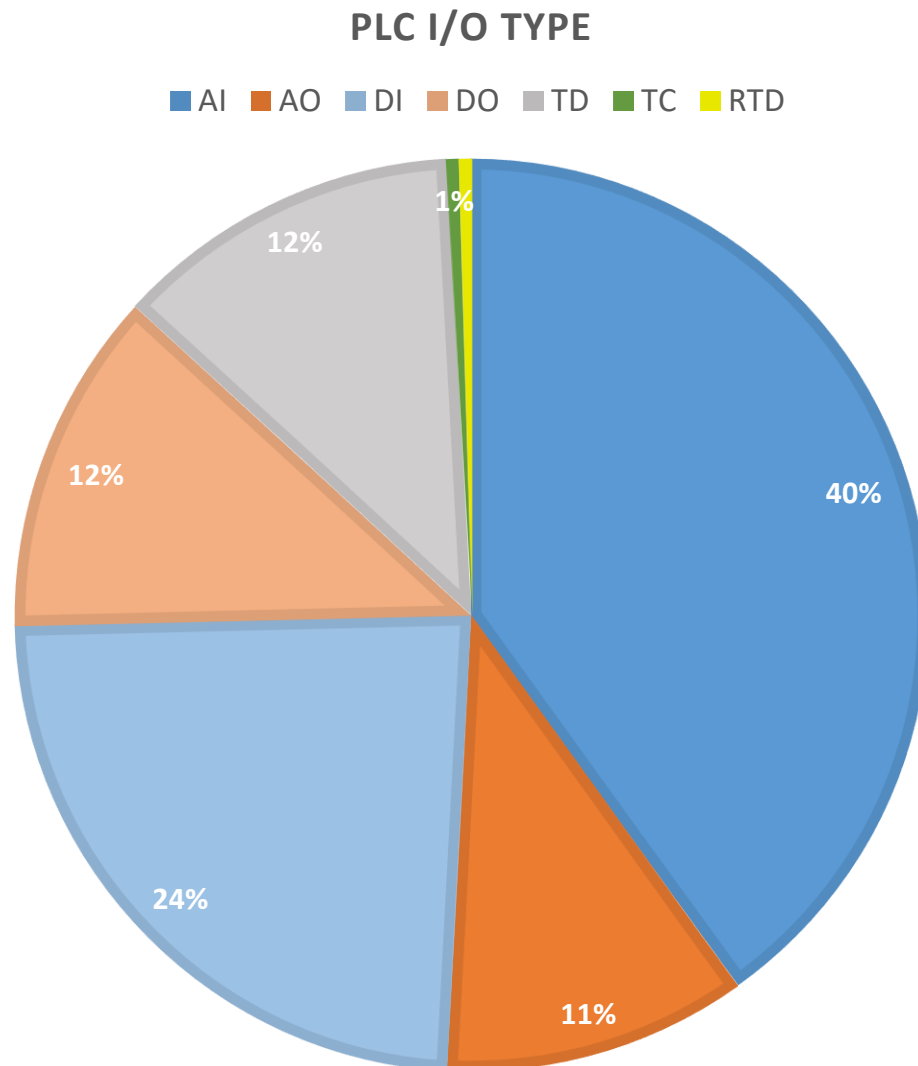


PLC Enclosure

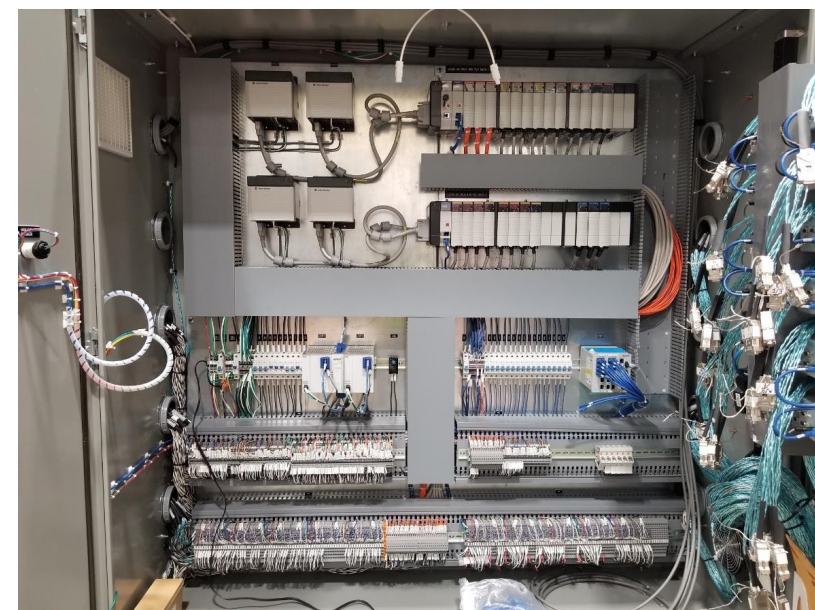
ControlLogix 5580:1756-L85E

PLC / Architecture

CryoPlant I/O Type	Count
AI	829
AO	223
DI	492
DO	252
TD	255
TC	9
RTD	9
TOTAL	2069



2 x Compact 5069 Remote I/O



PLC Enclosure

Cryogenic Distribution System:
~ 4,000 I/O

Instrumentation selected based on the following criteria:

- Type of measurement
- Application
- Accuracy and reliability requirements
- Safety requirements
- Cost

CryoPlant has ~50 different instruments

Top performing Instruments @ SLAC

- Pressure Transmitters
 - GE UNIK 5000
 - Rosemount DP 3051
 - Endress+Hauser
 - Kurt Lesker 3000 Series
- Temperature Transmitters
 - Omega TX-12
 - Lakeshore DT670 Sensor
 - Lakeshore 240-8P: RTD
 - Cryocon Temperature Monitor
- Pneumatic Valves
 - Fisher Controls DVC6200
 - Flowserve Positioner
 - Samson 3730-3
- Level Transmitter
 - AMI Level probe
 - Rosemount 3051 DP

INSTRUMENTATION / Pressure Sensor

- Sensor: Silicon Diaphragm [Piezoresistance]
- Pressure Transmitter: GE UNIK 5000
- Unit: bara
- PT most used > 60%



GE UNIK 5000

Other pressure transmitters used at SLAC:

- Dwyer
- Omega
- Rosemount

Pros	Cons
Accuracy $\pm 0.2\%$	Less Accurate Compared with Rosemount 3051
Available in Absolute and Gauge	Not as sensitive as other types of pressure sensors
Durable, rugged construction	
Less expensive compared to Rosemount	
Easy to install and use	Only $\pm 5\%$ Zero Offset and Span Setting
Easy to calibrate sensor	Not HART Compatible

Recommendation:

The GE UNIK 5000 was selected for general application pressure readings: Cost Effective, Reliable, Sufficient accuracy.

INSTRUMENTATION / Pressure Sensor

- Sensor: Silicon Diaphragm [Piezoresistance]
- Pressure Transmitter: Rosemount 3051S
- Unit: bara
- Critical Application: 2K Cold Compressor Suction



Rosemount 3051S

Other pressure transmitters used at SLAC:

- GE UNIK 5000
- Dwyer
- Omega

Pros	Cons
Ultra High accuracy $\pm 0.025\%$	More expensive compared to GE UNIK 5000
Durable, rugged construction	
Resistant to vibration and shock	
HART Compatible	Complex, can be difficult to configure and use
Easy to calibrate sensor	

Recommendation:

The Rosemount 3051S was selected for a specific critical application. This transmitter is pricier than most however it provides ultra high accuracy, reliability and is very robust.

INSTRUMENTATION / Vacuum Pressure Sensor

- Sensor: Hot Filament Ion Gauge & Convection Enhanced Pirani Gauge
- Multi Gauge Controller: Kurt J. Lesker [MGC3200]
- Unit: mbar



Convection Gauge



Ionization Vacuum Gauge



KJL MC Controller

	Ionization Gauge	Convection Gauge
Range	1.330 x 10 ⁻⁴ – 1333 mbar	1.3 x 10 ⁻⁹ to 6.7 x 10 ⁻² mbar
Resolution	1.3 X 10 ⁻⁴ mbar	
Durable, rugged construction	Less susceptible to mechanical shock and vibration	Dual hot filament design, rugged and compact metal construction

Other vacuum pressure transmitters used at SLAC:

- MKS
- TeleVac

Recommendation:

The KJL Ionization and Convection Gauges along with the MGC controller are Cost Effective, Reliable, Sufficient accuracy. It is a good choice for a wide range of applications that require accurate vacuum pressure measurement.

INSTRUMENTATION / Solenoid Valves

- General-purpose valve used in a variety of applications
- Fast acting valves used for quick shut-off of PV Instrument Air only



ASCO Solenoid Valve

Other solenoid valves used at SLAC:

- Continental Hydraulics [Compressor Load/Unload]
- Magnatrol [Compressor Oil Return]

Pros	Cons
High quality	Relatively expensive
Versatile	Not suitable for all applications
Reliable, Long Life	

Recommendation:

ASCO solenoid valves are known for their reliability and durability. They work well for quick shut-off of Instrument Air applications.

INSTRUMENTATION / Cryogenic Temperature Sensor

- Sensor: Lakeshore DT-670



DT-670 Silicon Diode

- Best accuracy across temperature range: 1.4 K to 500K any silicon diode in the industry
- Rugged, reliable designed to withstand repeated thermal cycling and minimize sensor self-heating
- Standard Curve DT-670 temperature response curve
- 4-wire diode for high precision

- Temperature Controller: Cryocon 18i



Cryocon temperature Controller

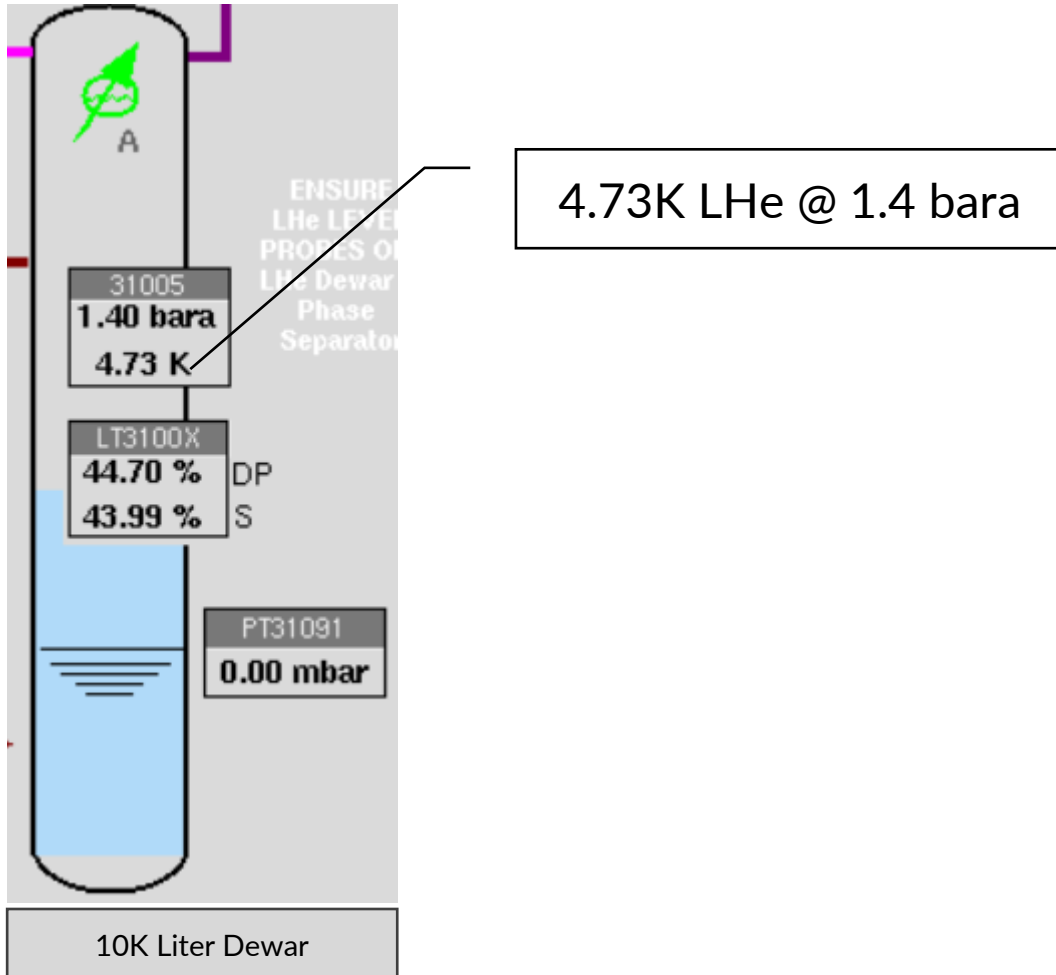
- Supports cryogenic temperature sensor
- Consolidate signals using 8 channel input
- Ethernet connectivity allows interfacing with PLC
- Industrial grade security: Configurable firewall, HTTPS encryption and authentication

After more than 25 years of providing innovative instrumentation to the low-temperature industry, Cryogenic Control Systems Inc. ceased operations on February 28, 2023.

Cryo-con's product line has been discontinued and customer support for it is no longer available. The web page at www.cryocon.com will continue to provide links to product archives for the near future. These archives contain all of the information that is available.

INSTRUMENTATION / Cryogenic Temperature Sensor

- Sensor: Lakeshore DT-670
- Temperature Controller: Cryocon 18i



INSTRUMENTATION / Cryogenic Temperature Sensor

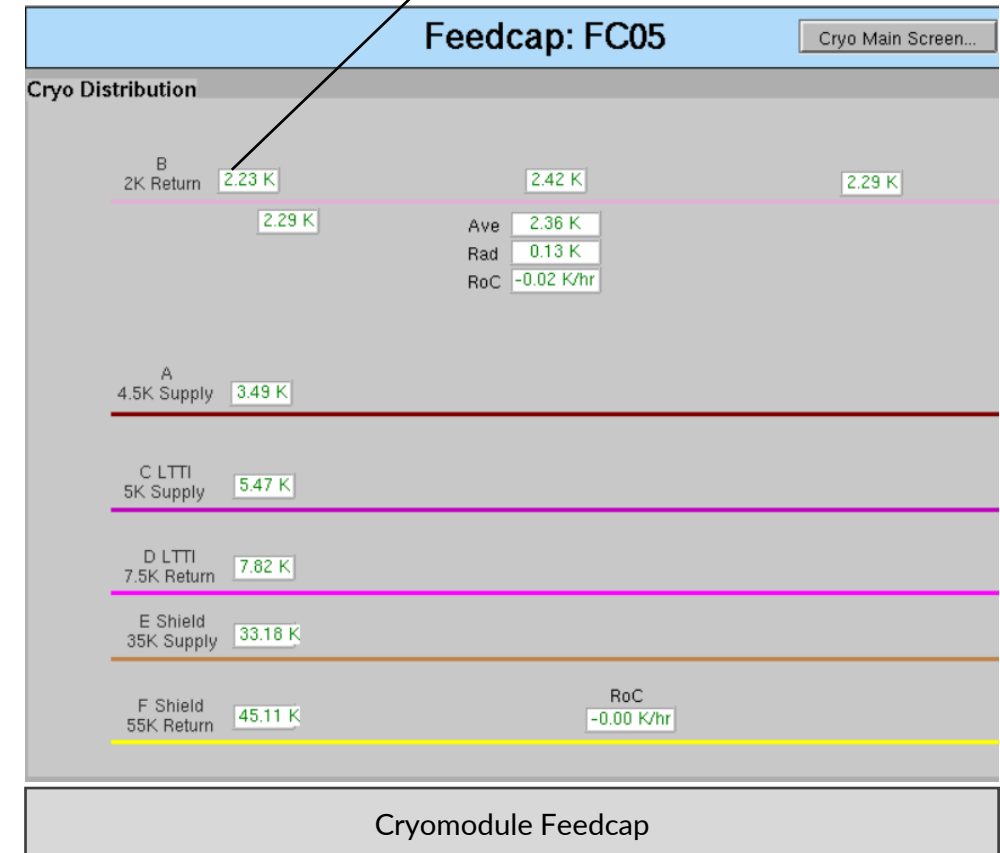
- Sensor: Cernox RTD
- Temperature Module: Lakeshore 240-8P



Lakeshore 240-8P

- Eight cryogenic temperature sensor inputs with specific curves
- Integrates Lake Shore Cernox[®] RTDs, and DT-670 silicon diodes
- Signals communicated to PLC via Profibus-Ethernet/IP Gateway
- Precision measurement with conversion to calibrated temperature

2.23K @ 31 mbara



Cryomodule Feedcap

INSTRUMENTATION / Cryogenic Temperature Sensor

- Sensor: Cernox RTD vs DT-670



Recommendation:

Cernox:

Good sensitivity over entire range, low magnetoresistance and best choice for applications with magnetic fields up to 30T and temperatures greater than 2K. Resistant to ionizing radiation and are available in robust mounting packages.

Silicon Diodes:

Best choice for general-purpose cryogenic use. Sensors follow a standard curve and are interchangeable. Robust mounting packages. Easy and inexpensive to instrument, wide variety of cryogenic applications such as cryo-coolers, laboratory cryogenics, cryo-gas production and space satellites.

Characteristic	DT-670 Silicon Diode	Cernox
Temperature Range	1.4K to 500K	0.10k to 420K
Typical Reproducibility	± 10 mK	± 3 mK
Interchangeability	Yes [Sensor follows a standard curve]	Has a specific curve
Use in Radiation	Not recommended for B > 5 tesla. Above 60K SD package has magnetic leads	Recommended. Excellent for use in magnetic fields 1K and up SD package with non-magnetic leads.
Number of wires	4-wire for accurate sensor measurements	4-wire for accurate sensor measurements
Package	Rugged and versatile	Robust mounting packages and probes
Applications	Cryo-coolers, laboratory cryogenics	Particle Accelerators, and cryogenic systems

INSTRUMENTATION / Cryogenic Liquid Level Sensor

- Sensor: Superconducting level probe
- Level Transmitter: AMI Model 1700



AMI Model 1700

- Superconducting level sensor measures 2K or 4.2K
- Used for 10 LHe Dewar and Cryomodules
- Simplify and intuitive touch-screen user interface
- Remote operation via TCP/IP connection
- Variety of packaging options

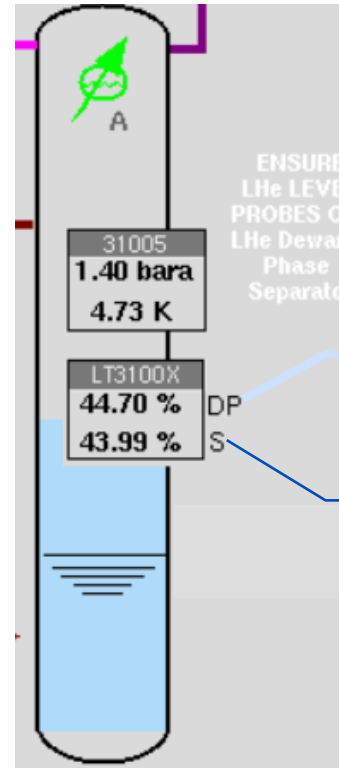
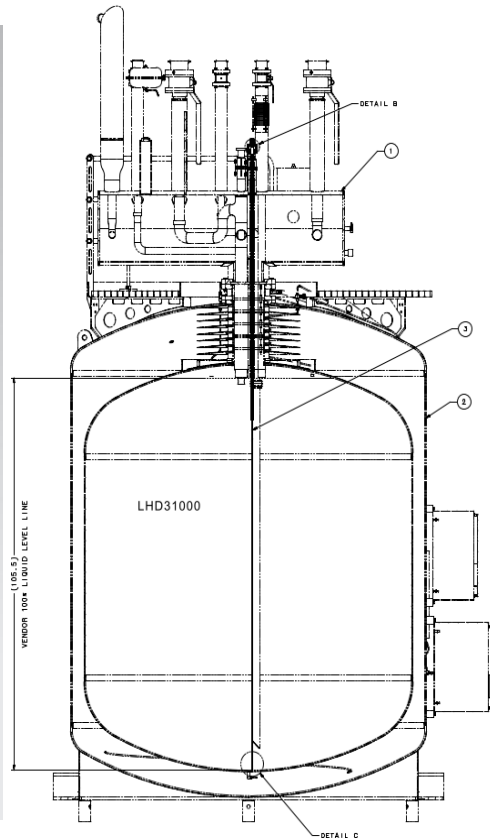
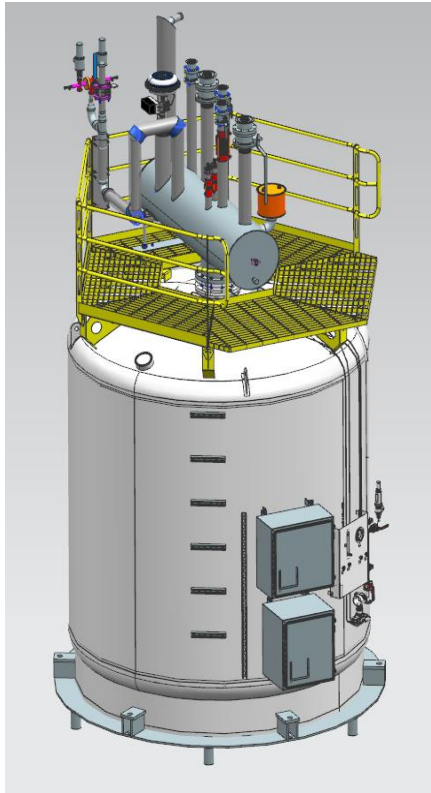
- Sensor: Diaphragm Seal Differential Pressure
- Level Transmitter : Rosemount 3051



Rosemount 3051 Differential Pressure Transmitter

- Redundant 10K Dewar Level reading using DP Transmitter
- DP used for large volume vessel [10K Liter Dewar]
- Reliable measurements and wide application flexibility
- Easy to configure using HART

INSTRUMENTATION / Cryogenic Liquid Level Sensor



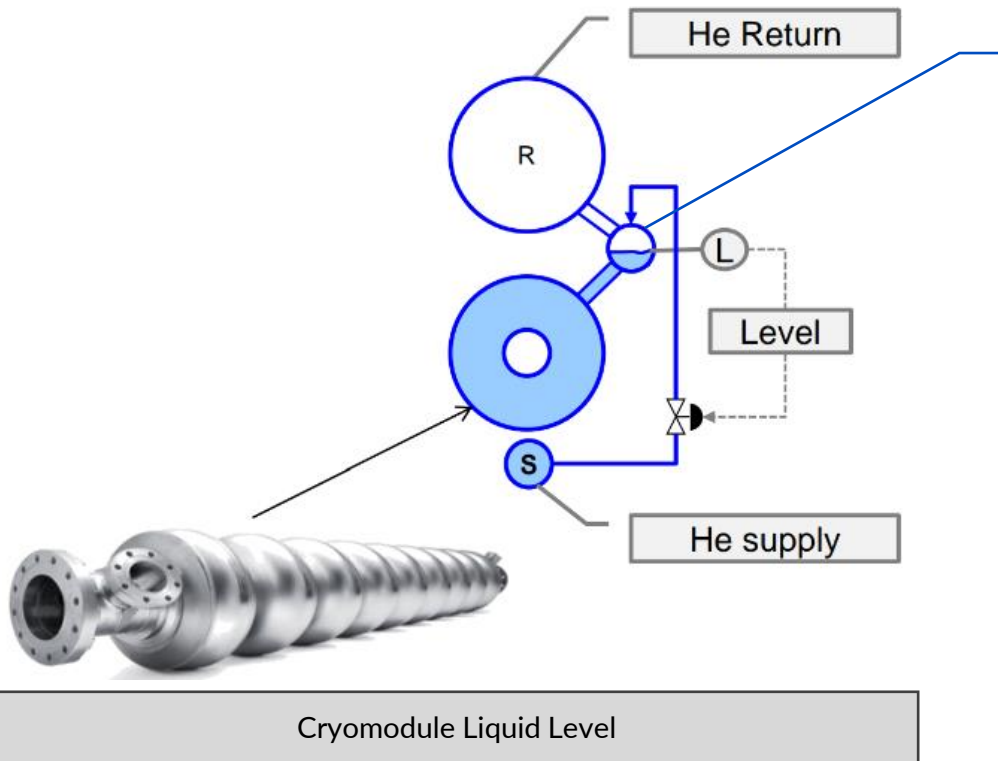
10K Liter Dewar

Differential Pressure [DP]

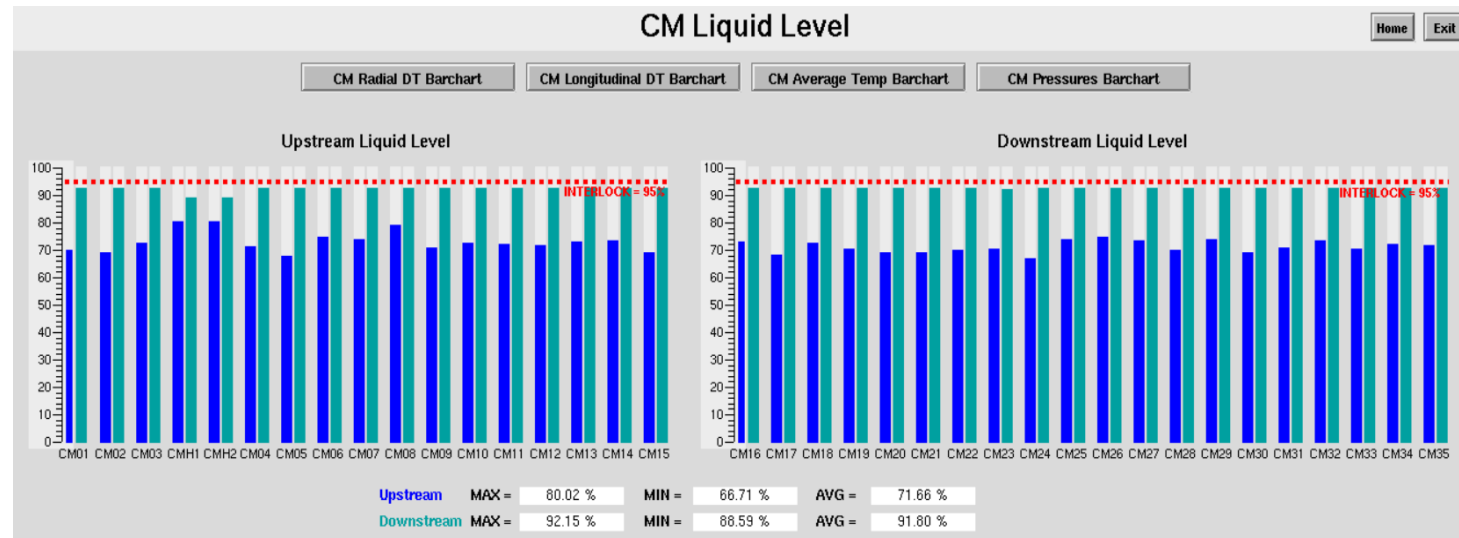
Superconducting Probe [SC]

- Both used in LHe Dewar
- SC used with AMI Controller in continuous mode.
- DP impacted by density change during Cooldown [False readings during CD].
- DP reading more stable at 4K and preferred for automated controls
- DP reading converted to level using formulae

INSTRUMENTATION / Cryogenic Liquid Level Sensor



Superconducting Probe



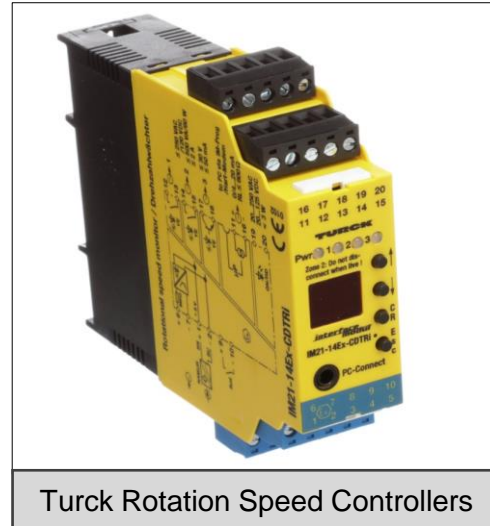
SC Probe accurate for small volume [2 liters] in Cryomodules compared with 10K Liter Dewar

INSTRUMENTATION / Turbine Speed Sensor

- Sensor: Frequency Converter
- Units: Frequency [Hz]
- Speed Sensor: Pepperl+Fuchs KFD2-UFC-1.D



Phoenix Contact



Turck Rotation Speed Controllers



Pepperl+Fuchs

- Phoenix Contact sensors has low precision at low speeds
- Turk Controller not UL Listed

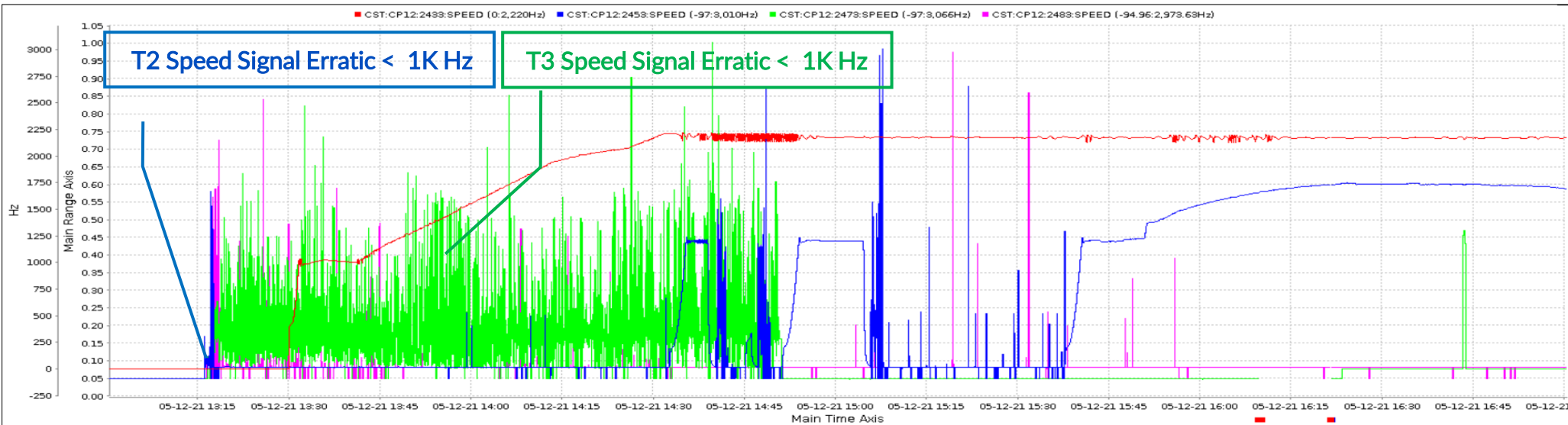
- Speed Sensors are UL listed
- High precision readings at low speeds

INSTRUMENTATION / Turbine Speed Sensor

Low precision at low speeds
TRIP on High-Speed Variation



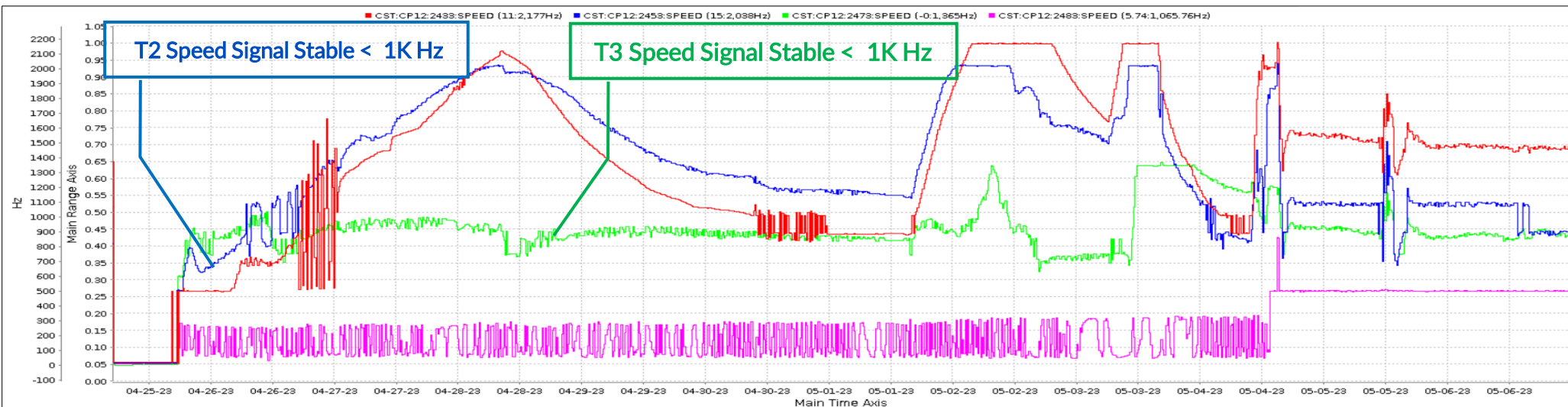
Phoenix Contact



High precision at low speeds



Pepperl+Fuchs



Phoenix Contact sensors replaced with Pepperl+Fuchs

INSTRUMENTATION / Cryogenic Valve Actuators

- Equipment: Cryogenic Control Valve
- Flowserve Valtek, Weka
- Piston Type



Cryogenic Valves on Lower 4K Cold Box

Other pressure transmitters used at SLAC:

- Fisher Controls
- Weka
- Samson



Failed CRYO Valve Positioner

- Faulty Valve Positioners
 - Cleaned
 - Rebuilt
 - Replaced
- IA System blown down

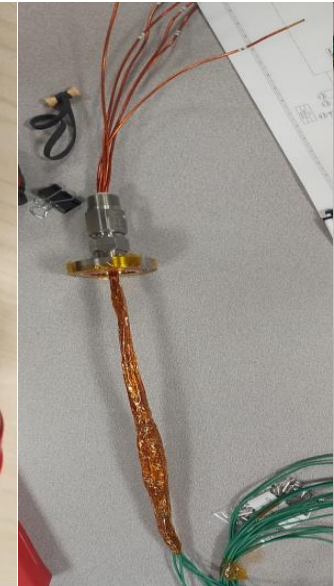
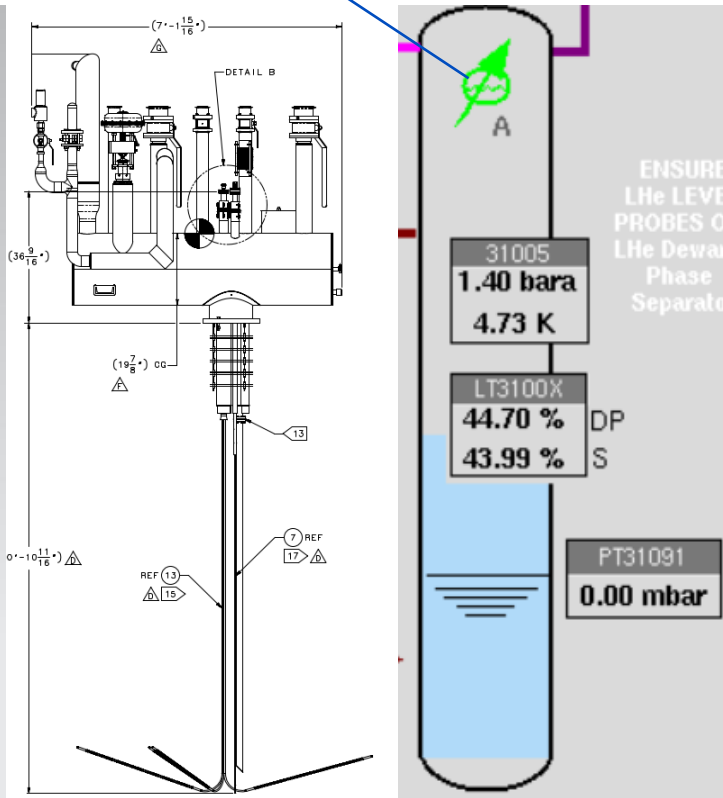
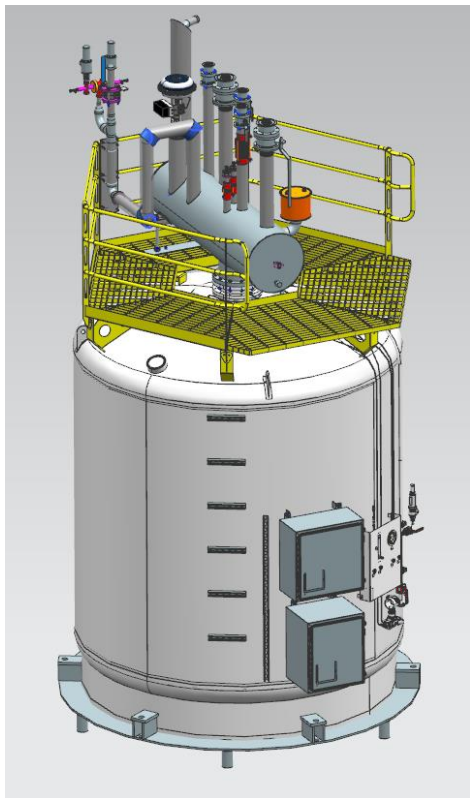


Debris found in Air Filters

- Debris & Oil in Instrument Air Manifold during start-up
- Failure of numerous CRYO valve positioners
- Recommendation
 - Use filter on each valve!
 - Blow down IA System to remove contaminants

INSTRUMENTATION / Liquid Helium Dewar Heater

Dewar Heater



ENSURE LHe LEVEL PROBES ON LHe Dewar Phase Separator

31005
1.40 bara
4.73 K

LT3100X
44.70 % DP
43.99 % S

PT31091
0.00 mbar

Issues with LHe Dewar Heater:

- Heating elements shorted together
- Heater controller fuses blown repeatedly
- Solution:
 - Replaced heaters
 - Insulated heater wires

10K Liter Dewar Electrical Heater

Future:

- Develop and implement I&C Program and Training, Critical spares inventory management
- Manual Valves readback
 - Adding position feedback sensor to manual valves which currently no feedback
- Add Vibration Monitoring on Compressor Station
- Automation of Helium Purifier
- Selectively implement redundant sensors to improve CRYO System robustness

Difficult to determine position of manual valve



Oil Coalescers



Helium Purifier

Manual valves can be automated on purifier

COMMISSIONING / Instrumentation

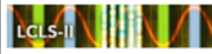
What we did well:

Careful planning of Pre-Commissioning:

- Detailed Instrumentation List
- Detailed Test Plan
- Instrument Calibration
- Careful verification [Loop Test]
- Documentation

Resources:

- 1 Instrumentation Engineer
- 3 Technicians
- ~2000 Signals
- 10 – 15 minutes

	Plans and Procedures		
	Document Title: HRS.CT.HD.OM.SLAC-Instrument Loop Test		Page 12 of 12
Document Number: LCLSII-4.5-PP-1545-R0			

4.2 INSTRUMENT WORKSHEET

TECHNICIAN		DATE	
TAG NAME		PLC NAME	
INSTRUMENT RANGE		WIRING DWG #	
MODEL NUMBER		ENCLOSURE DWG #	
SERIAL NUMBER		P&ID #	
CONFIGURATION COMPLETED?		INSTRUMENT TUBING CHECKED?	

CALIBRATION STANDARD MANUFACTURER, MODEL, SERIAL NUMBER:
 Druck DPI 880 / Fluke 787-789 / Hart 475/ EPICS

APPROXIMATE TEST POINT	STANDARD READING	TEST TRANSDUCER READING	TEST TRANSDUCER READING	TEST TRANSDUCER READING
	Calibrator			
	Druck/Fluke	Fluke787/789	EPICS	Local HMI
0% OF CAL RANGE				
25% OF CAL RANGE				
75% OF CAL RANGE				
100% OF CAL RANGE				

COMMENT

The only official copy of this file is located in the LCLS-II Controlled Document Site. Before using a printed/electronic copy, verify that it is the most current version.

What worked well:

- Lakeshore DT-670 and Cryocons provide reliable temperature readings
- AMI Level probes work well in Cryomodules with small height [$\sim 100\text{mm}$] of LHe
- ROSEMOUNT 3051-DP for 10,000L LHe Dewar Level
- GE UNIK 5000

Issues during commissioning:

- Intermittent spikes on temperature signals caused nuisance TRIPS. A time delay was added to PLC code
- Liquid Level Heaters in the Dewar failed and had to be replaced
- Endress Hauser DP [0 - 100mbar] used for flow calculation was undersized for the application and was replaced with Rosemount 3051 transmitters [0 - 600mbar]
- Installed Dual DP Transmitters to better monitor high and low ranges for critical flows [4K & LTTI Supply]
- Moisture due to condensation in outdoor instrument cabinets

- LCLS-II Cryogenic Instrumentation was successfully loop tested and accurately documented
- Loop Tests detected ~ 10% of total installed instruments had issues related to mis-wiring errors
- Choose high quality instruments for reliability
- Develop and implement I&C Program and Training at SLAC
- Plan spares inventory management at an early stage [10% spare].
- Categorize and label sensors in the field: monitoring, alarms, interlocks, trips and control loops.
- Selectively implement redundant sensors to improve CRYO System robustness



Thank you

