LCLS-II Vacuum Design and Manufacturing

Guidelines and an Approach to Implementation

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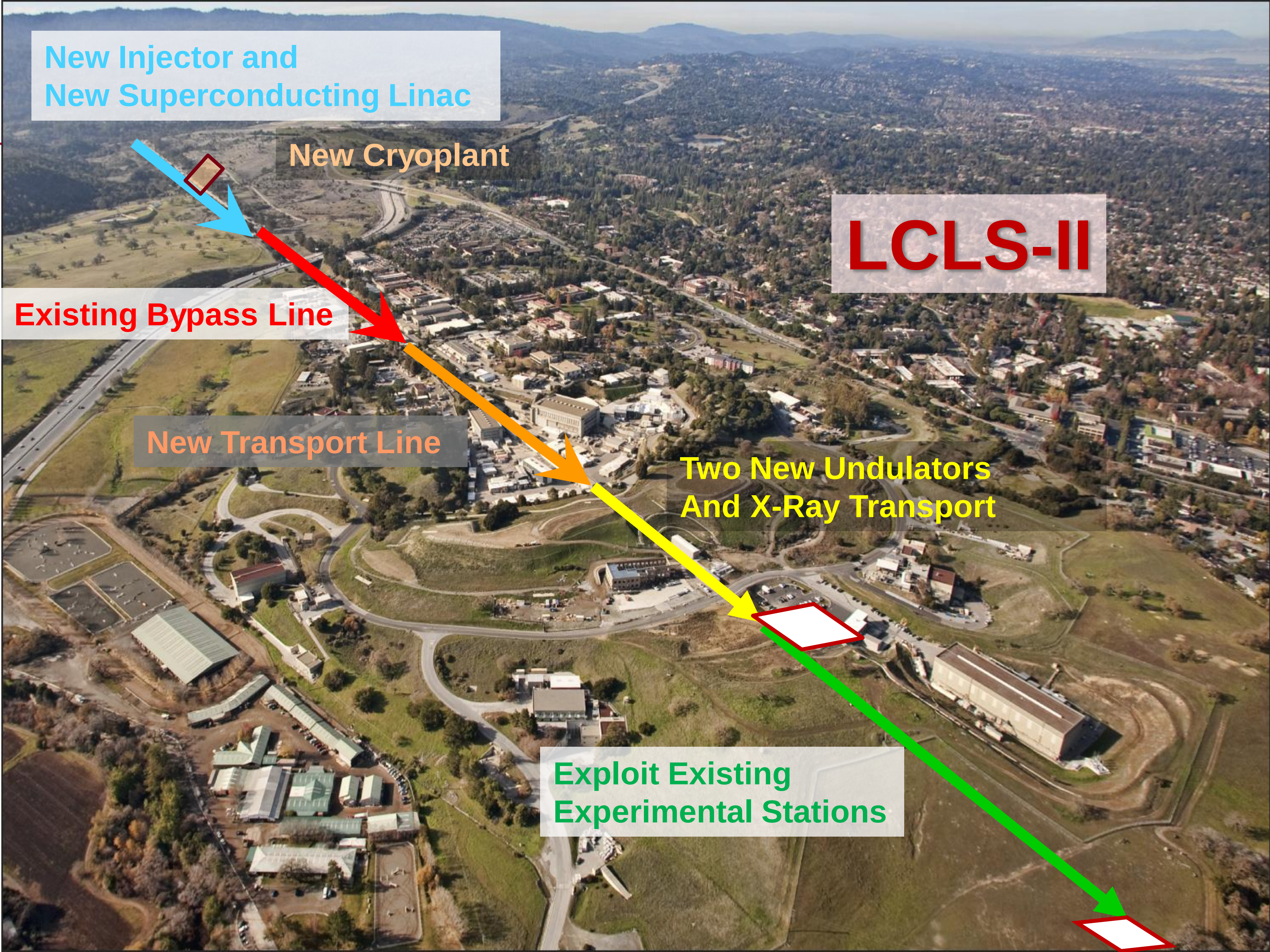
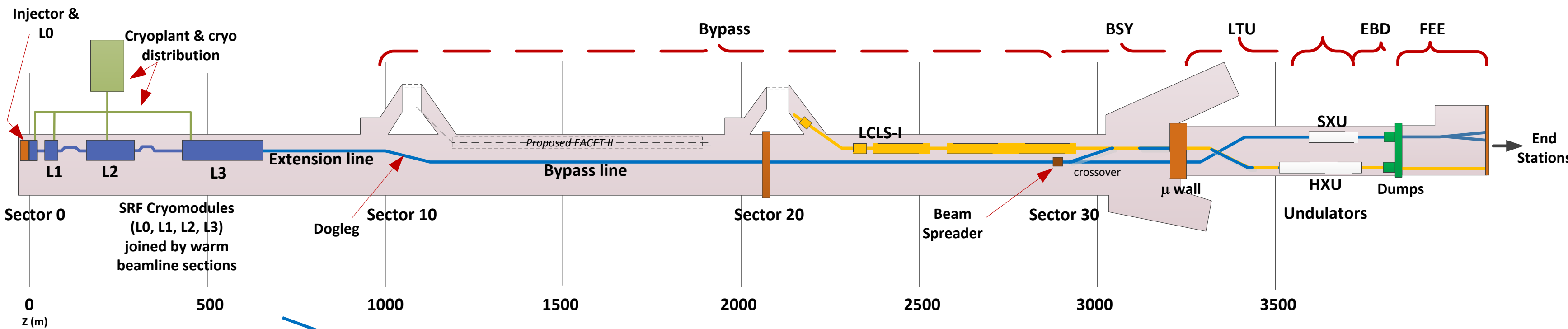
Overview

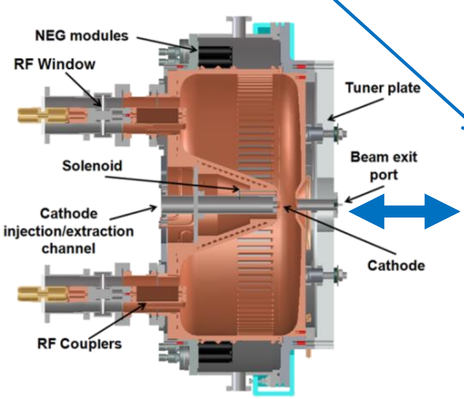
1. LCLS-II Project Background
2. Vacuum Systems and Challenges
3. Beam line vacuum
   - Design
   - Manufacturing
     - UHV
     - Particle Free
4. Beamline Failure Mode Analysis

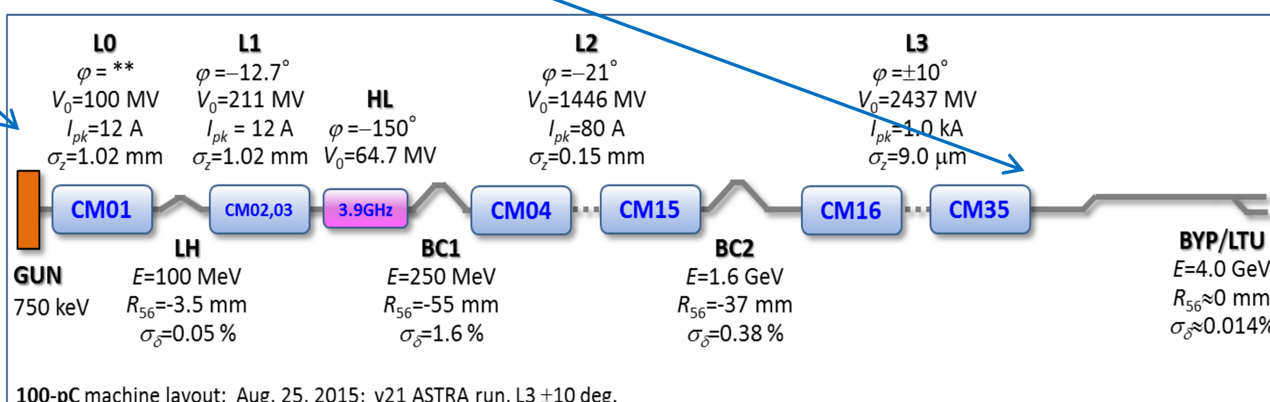

New Injector and
New Superconducting Linac
New Cryoplant
LCLS-II
Existing Bypass Line
New Transport Line
Two New Undulators
And X-Ray Transport
Exploit Existing
Experimental Stations

LCLS-II Project: Free Electron Laser

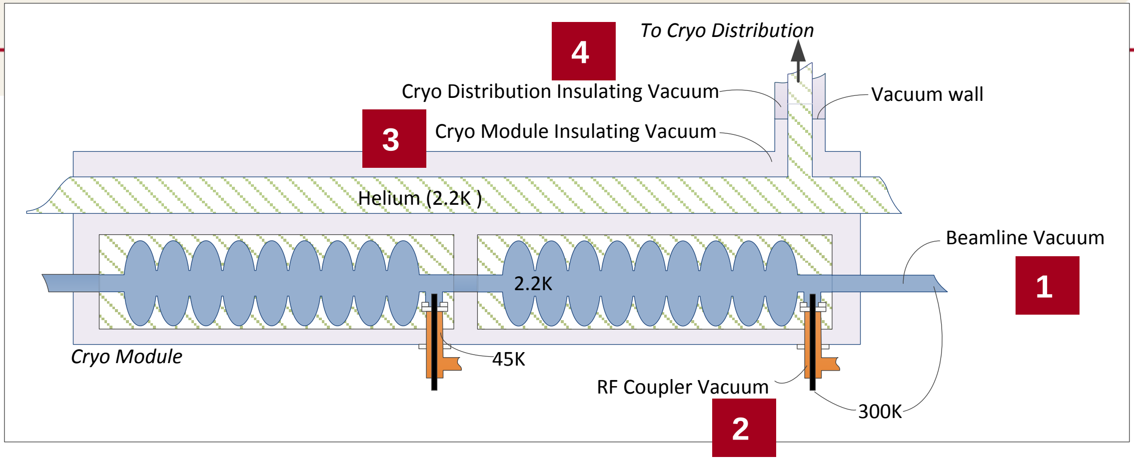


>3.5 km of beamline replaced or refurbished



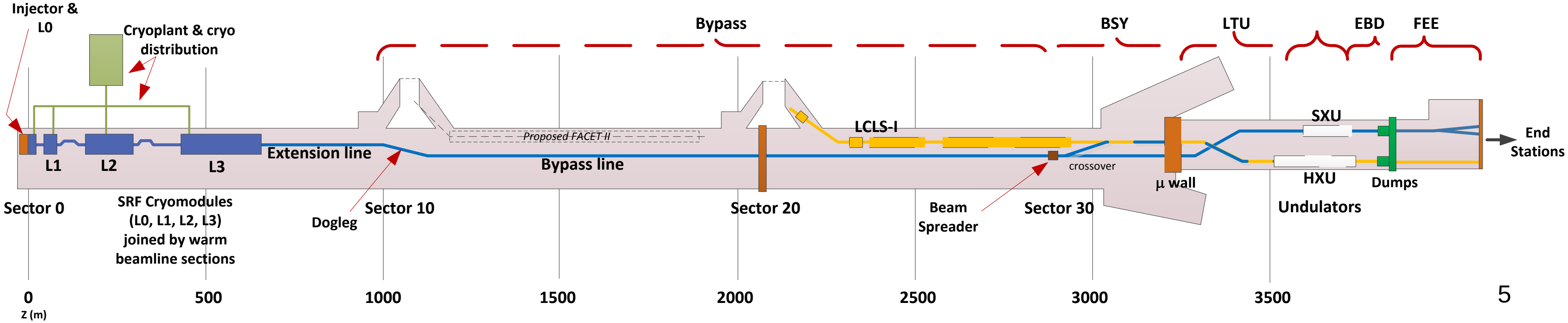


LCLS-II Vacuum Systems

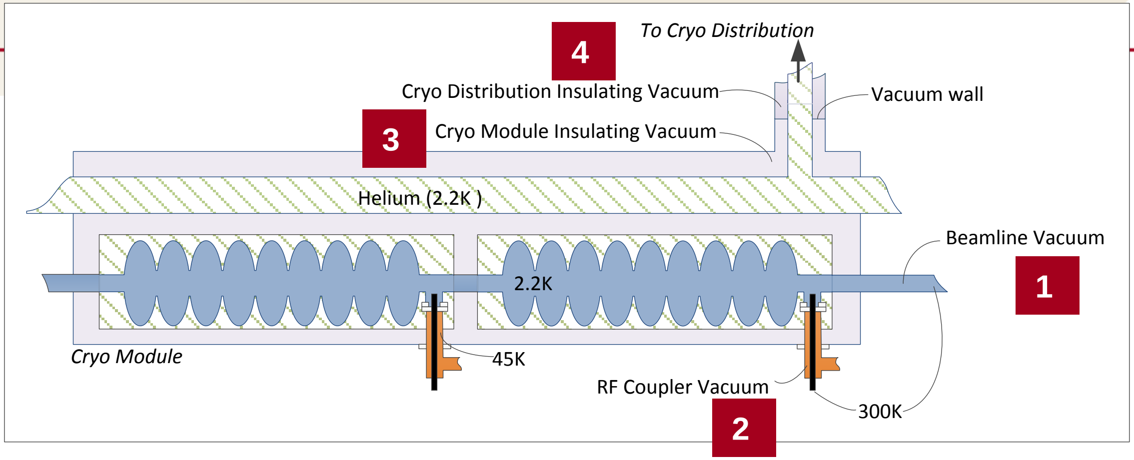


LCSL-II vacuum system consists of **4 independent** systems:

1. Beam line system: Vacuum in beam path from gun/injector, all cavities and instruments to dumps.
2. RF Coupler vacuum system
3. Thermal isolation system within the cryomodules
4. Thermal isolation of the Cryogenic Distribution System

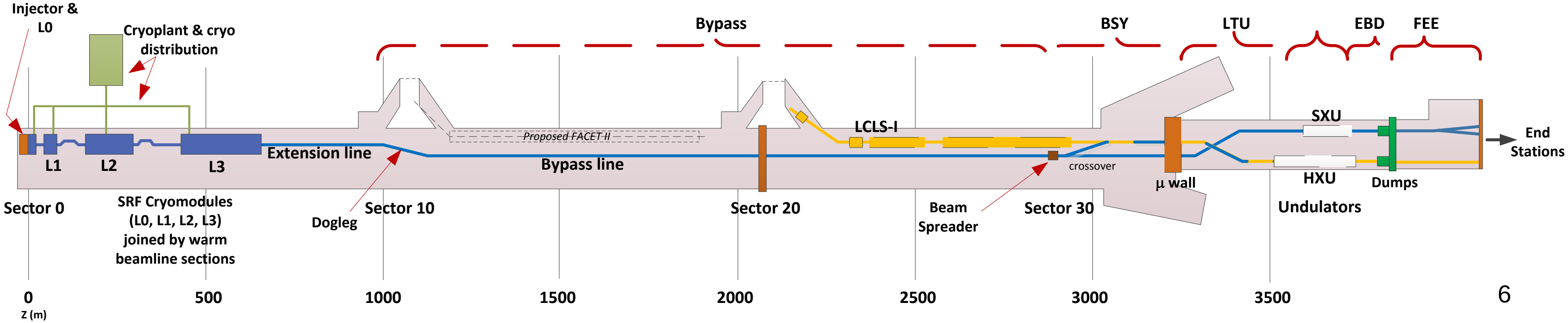


LCLS-II Vacuum Systems



LCSL-II Vacuum System is comprised of multiple environmental conditions:

- Ambient temperature, UHV pressure (most of downstream beamline)
- Ambient temperature, UHV pressure, particle-free (between cryomodules)
- Cryo temperature, UHV, particle-free (cryomodules)
- Cryo temperature, high vacuum (insulating vacuum)



SLAC Matrix Organization

Split of responsibilities between Responsible Engineers and Vacuum Engineering Expert

PROJECT

Design: Must meet the physics requirements

Execution: Guide buy, fab, build, install

Responsible Engineer

Responsible Engineer

Responsible Engineer

Responsible Engineer

Vacuum Engineering Experts

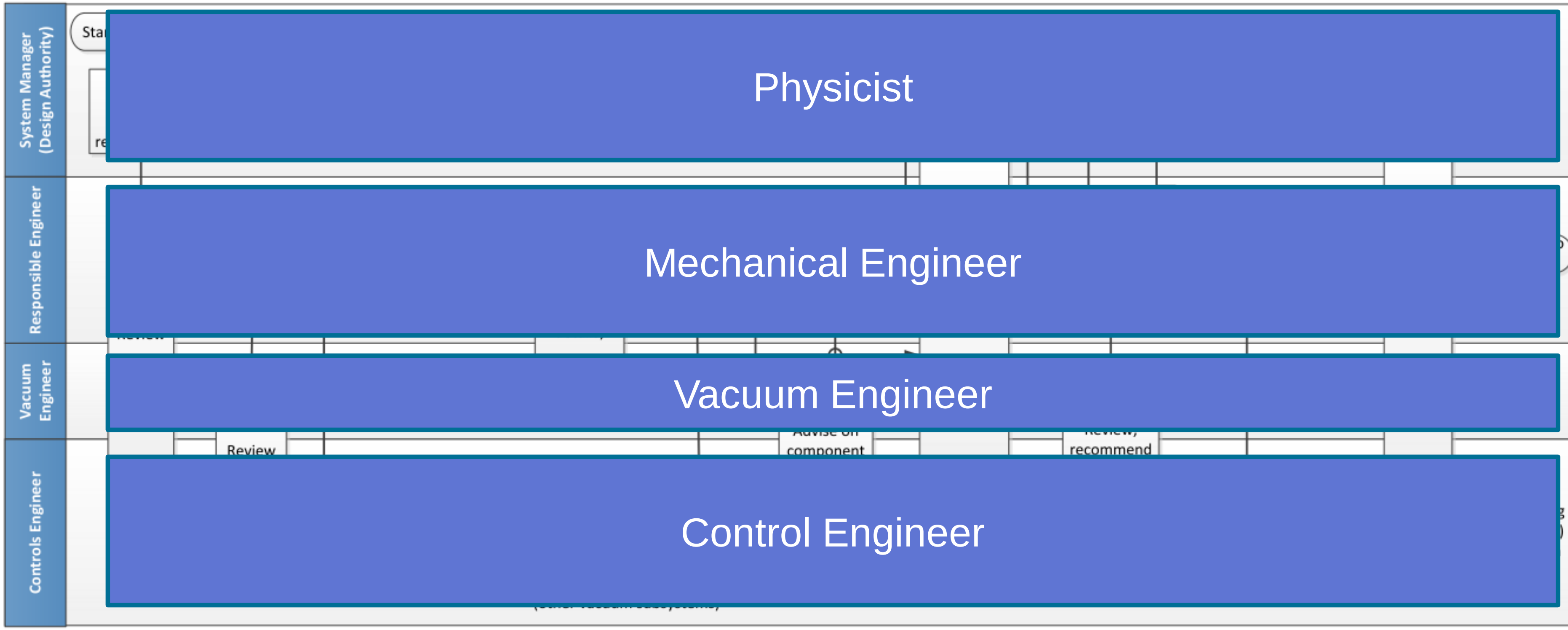
Set Requirements for:

UHV: Selection of components, materials, correct solutions

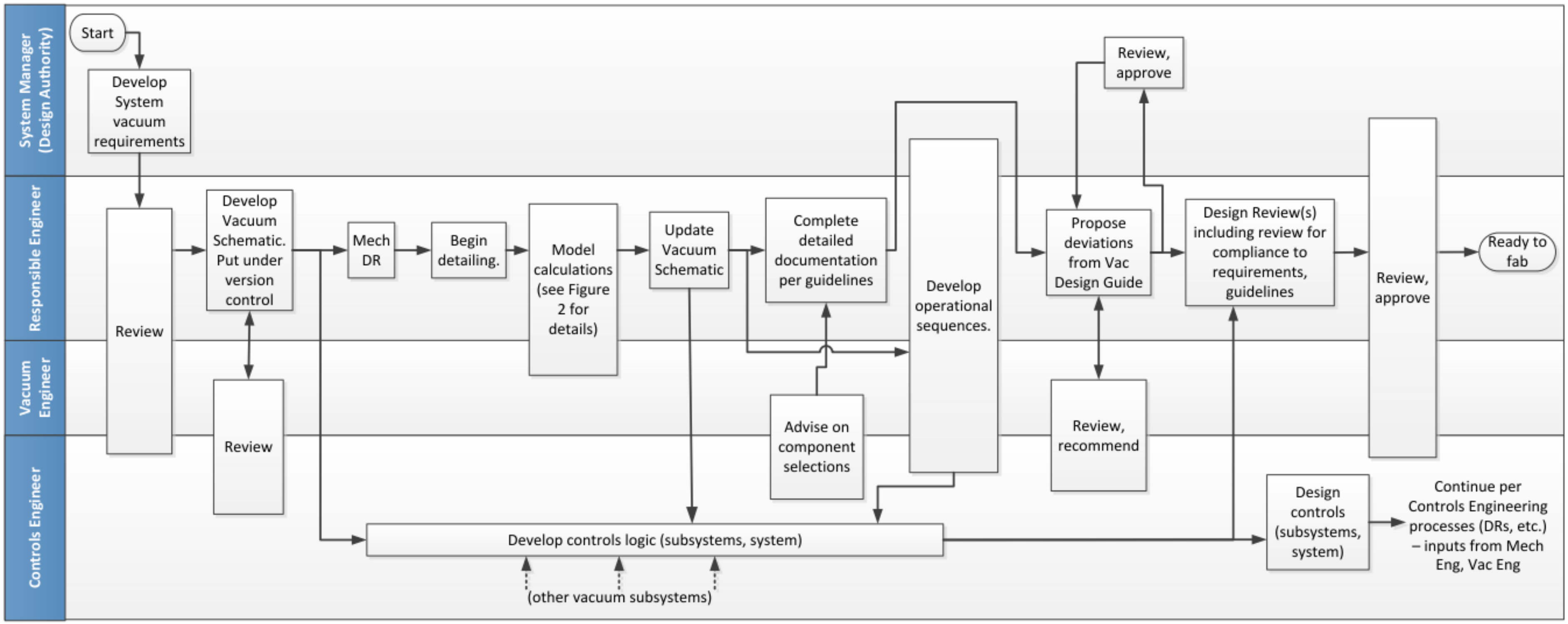
Particle Free: Manufacturing plan, cleaning and handling procedures

BEAM LINE VACUUM SYSTEM: DESIGN

Roles and Responsibilities for Design



Roles and Responsibilities for Design



- High level requirements are defined by physics.
- Vacuum Engineering converts to Vacuum Specifications
- Mechanical Engineering converts specs to design
- Control Engineer implement the system logic and protection

LCLS-II Beam Line Vacuum: Requirements

LCLSII-2.1-PR-0234-R1: Residual Gas

- A basis for design to insure the <u>properties of the electron beam</u> are not adversely <u>affected by residual gas in the beamline</u> and to protect the undulators from excessive <u>radiation damage</u>

LCLSII-1.1-ES-0231-R0: LCLS-II Vacuum Engineering Specifications

- Requirements and considerations for the design, build, installation, operation, and service/maintenance

LCLSII-1.1-TS-0147-R2: Vacuum Mechanical Design Guidelines

- Which design tasks must be accomplished for robust vacuum design
- Guidance on the split of responsibilities between a <u>responsible engineer</u> (usually mechanical) and a <u>vacuum engineering expert</u>.

Vacuum Requirements
Table 7.1, *Vacuum ESD*, LCLSII-1.1-ES-0231, rev. 1 (page 1)

	Project Major System	Vacuum Pressure – Design Requirement (Torr)	Vacuum Pressure Upper Operating Limit (Torr)	Vacuum Pressure (before cool-down) (Torr)	Outgassing Rate	Operating temperature	Particle-free requirement	Recovery risk if cross-contaminated? (high, med, low)	Downstream Neighbor differences
BL	Injector - Gun	1x 10^{-10}	*(See Note B)*	n/a	UHV	Ambient to 100 C	yes	*(See Note B)*	none
	Buncher cavity	1x 10^{-9}	*(See Note B)*	n/a	UHV	Ambient to 100 C	yes	*(See Note B)*	SC
	L0 (CM) *[Note 7.1.1.1.6]*	1x 10^{-10}	*(See Note B)*	7.5x 10^{-8} (ends)	UHV	2 K	yes	Very high	Ambient
	HTR-DIAG0-COL0	1x 10^{-8}	*See Note 7.1.1.1.2.1*	n/a	UHV	ambient	yes	*(See Note B)*	SC, particle
	L1 (CM) *[Note 7.1.1.1.6]*	1x 10^{-10}	*(See Note B)*	7.5x 10^{-8} (ends)	UHV	2 K	yes	Very high	Ambient
	BC1B-COL1	1x 10^{-8}	*See Note 7.1.1.1.2.1*	n/a	UHV	ambient	yes	*(See Note B)*	SC, particle
	L2 (CM) *[Note 7.1.1.1.6]*	1x 10^{-10}	*(See Note B)*	7.5x 10^{-8} (ends)	UHV	2 K	yes	Very high	Ambient
	BC2B-COL2	1x 10^{-8}	*See Note 7.1.1.1.2.1*	n/a	UHV	ambient	yes	*(See Note B)*	SC, particle
	L3 (CM) *[Note 7.1.1.1.6]*	1x 10^{-10}	*(See Note B)*	7.5x 10^{-8} (ends)	UHV	2 K	yes	Very high	Ambient
	Extension line	1 x 10^{-8}	*(See Note B)*	n/a	UHV	ambient	no	*(See Note B)*	none
	Dogleg – Bypass	1 x 10^{-7}	*(See Note B)*	n/a	UHV	ambient	no	*(See Note B)*	none
	BSY	1 x 10^{-8}	(physics input?)	n/a	UHV	ambient	no	*(See Note B)*	none
	Undulators	1 x 10^{-8}	1 x 10^{-6}	n/a	UHV	20 +/-1 °C	no	High	none
	X-ray self-seeding- *[Note 7.1.1.14]*	1 x 10^{-7} max (HXRSS) 1 x 10^{-9} max (SXRSS)	1x 10^{-7} (SXRSS chamber)	n/a	UHV	20 +/-1 °C	No	Very high	Max pressure
	Dumps	1 x 10^{-7} (before BYD) 1 x 10^{-6} (after BYD)	(physics input?)	n/a		ambient	no	*(See Note B)*	none
	XTES *[Note 7.1.1.15]*	1 x 10^{-6} (upstream) 1 x 10^{-8} (downstream)	1 x 10^{-6} (upstream) 1 x 10^{-8} (downstream)	n/a	UHV	ambient	no	Low (if outside of differential pumping to mirror section & contamination of < 1 level)	none
	End Stations *[Note 7.1.1.16]*	1 x 10^{-8} (upstream)	1 x 10^{-8} (upstream)	n/a	UHV	ambient	no	Depends on experimental setup. (See Note *7.1.1.16*)	none
Cryo	CM Insulating Vacuum *[Note 7.1.1.1.6]*	1x 10^{-6}	1x 10^{-4}	1x 10^{-4}	n/a	2 K to 80 K	no	low	n/a
	Distribution Insulating Vac	1x 10^{-6}	*(See Note B)*	7.5x 10^{-4}	n/a	2 K to 80 K	no	low	n/a
	Sub-atmospheric He line	(Out of scope of this ESD. See Cryo Distribution ESD)							

LCLS-II: Gas Density Simulation Programs

VacTran

- PEC Professional Engineering Computations, Livermore CA 94550, ©1996-2010
- Simulation of complete pumping system

CHEVRON

- Monte Carlo program, developed at CERN in 1988
- Simulates molecular trajectories in a series of consecutive tubes of uniform cross section

Pressur5

- Developed at CERN in 1992
- Pressure distribution and critical beam current for different gas

VACCALC

- “A Method for Calculating Pressure Profiles in Vacuum Pipes” Michael K. Sullivan (SLAC, Menlo Park) 1994
- program that utilizes the finite difference method

Molflow+

- a Monte-Carlo Simulator package developed at CERN

VACCALC input and output for the simulation of the beamline between the gun and the first cryomodule L0

Element	Pipe Length	Conductance	Outgassing	Pump Speed
Units	m	litres/s	nTorr	(l/s)/m
VALV	0.07	107.54	0.18	0
PIPE	0.06	22.91	0.08	0
DPS1	0.2	7500	3.65	35
PPIE	0.35	3.74	0.49	0
DPS2	0.2	7500	3.65	35
PIPE	0.35	3.74	0.49	0
DPS3	0.2	7500	3.65	35
PIPE	0.46	2.86	0.64	0
VALV	0.07	107.54	0.18	0
PIPE	1.04	4.9	2.27	0
BELL	0.06	24.6	0.1	0
PUMP	0.12	40.79	0.27	40
PIPE	0.87	5.86	1.9	0
BELL	0.06	24.6	0.1	0
PIPE	0.47	2.78	0.65	0
BPM2	0.25	5.11	0.35	0
PIPE	0.31	4.23	0.43	0
WS01	0.2	6.81	0.27	0
PIPE	0.07	19.65	0.09	0
OTR1	0.14	8.26	0.18	0
PIPE	0.04	31.54	0.06	0
BLM0	0.07	57.54	0.13	0
PIPE	0.15	8.51	0.21	0
BPM3	0.25	5.11	0.35	0
PIPE	0.97	1.35	1.35	0
VALV	0.07	107.54	0.18	0

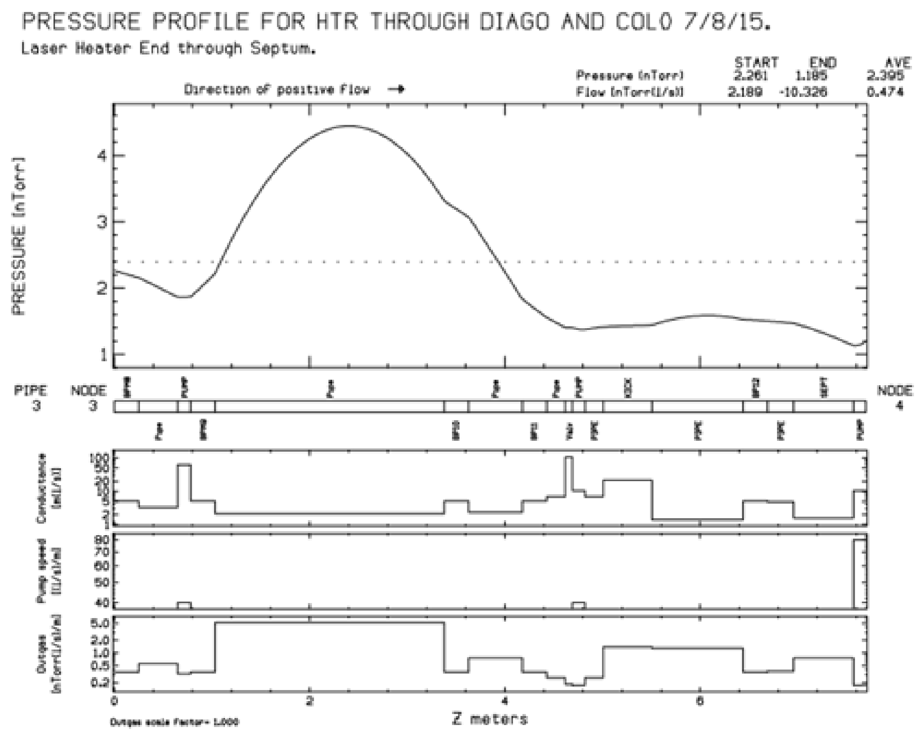
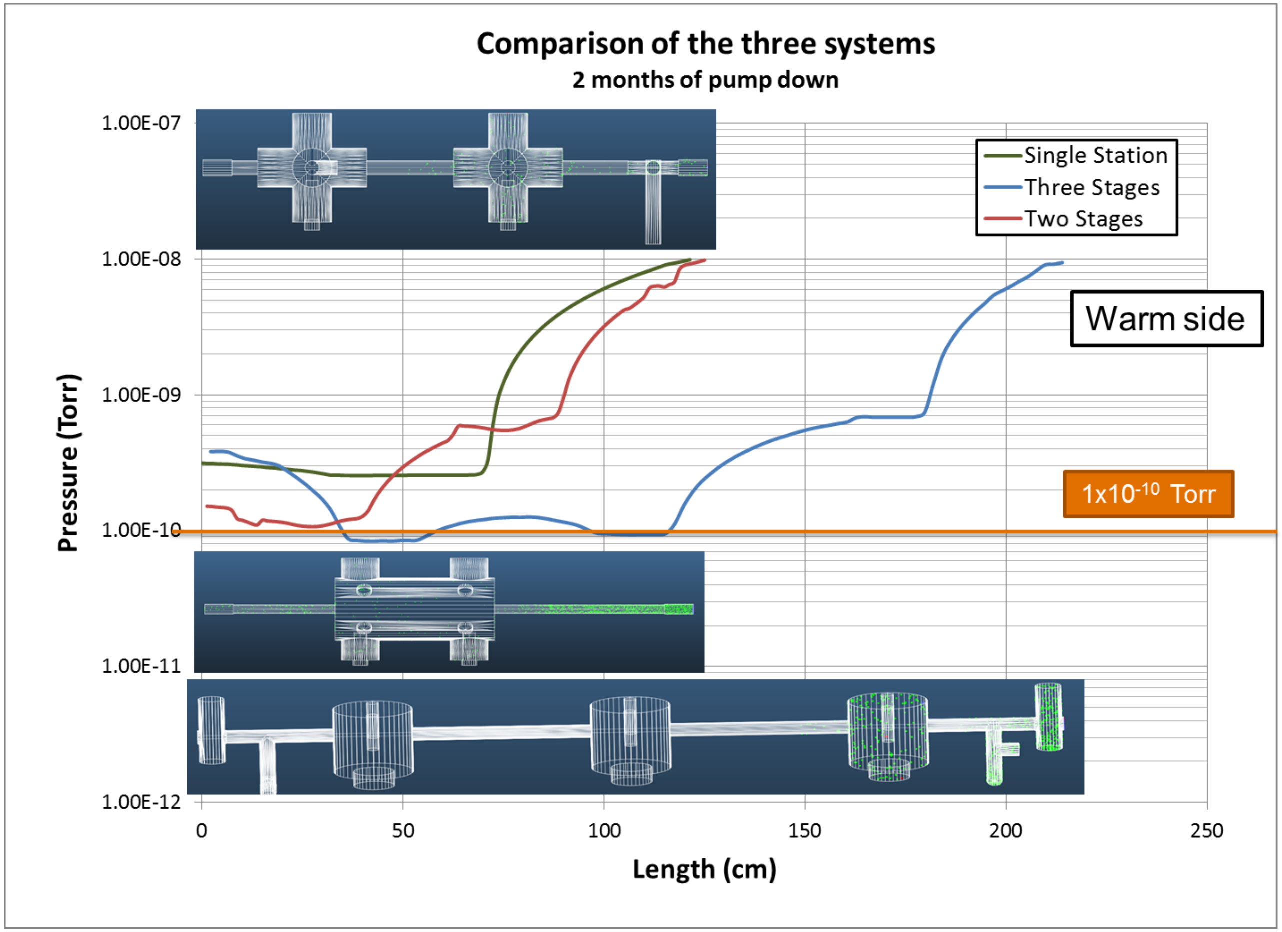
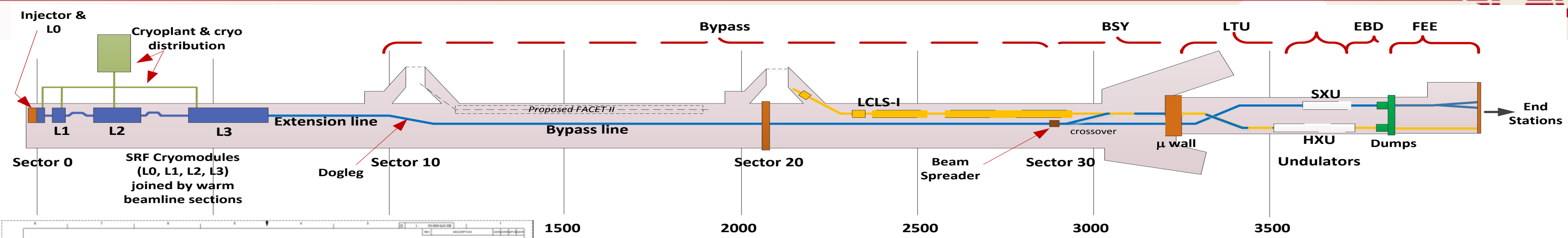


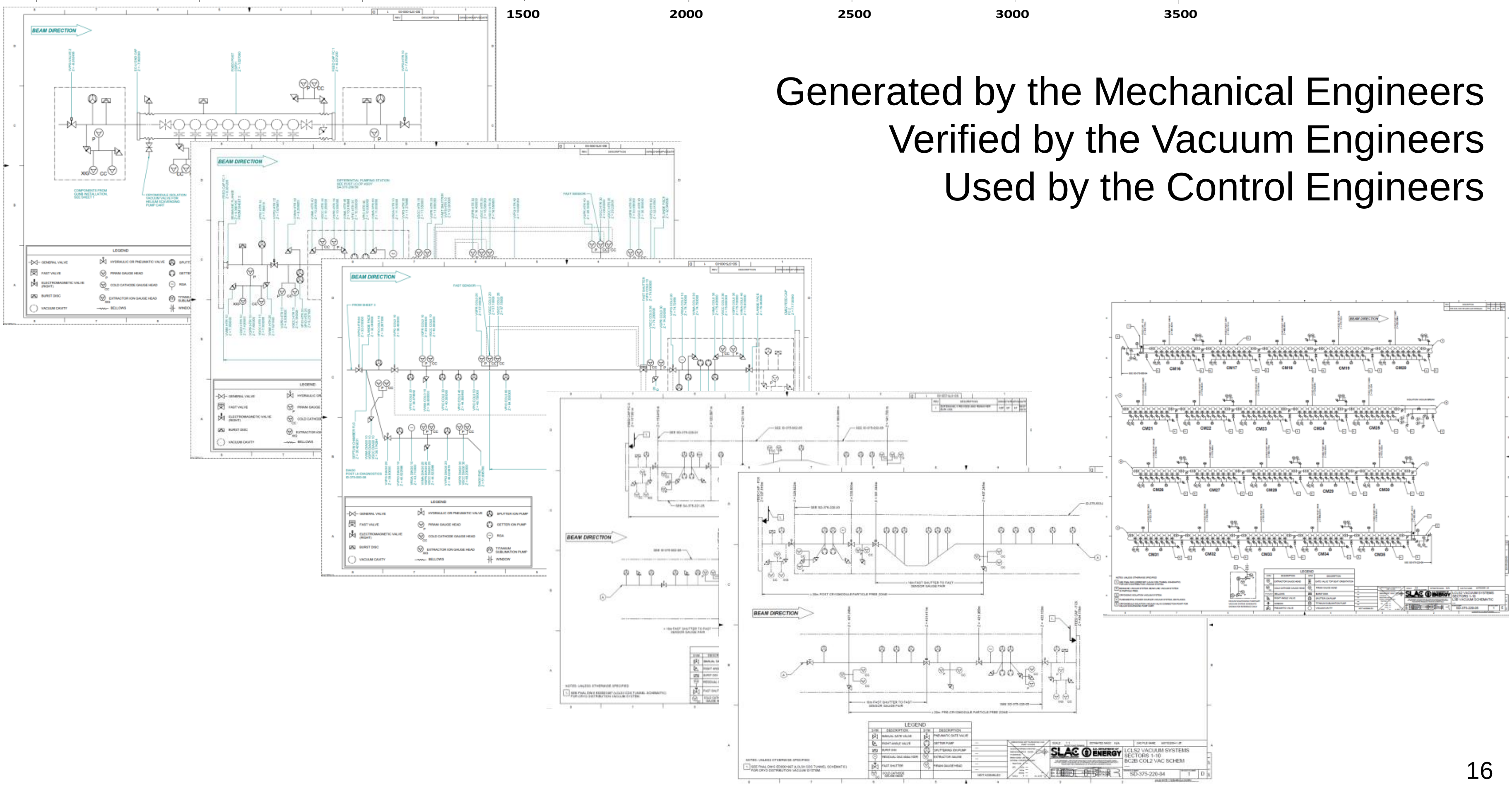
Figure 4: Pressure Profile for Laser Heater End through Septum

Molflow+ study of the **Differential Pumping System** between the room temperature and cryogenic beam line



LCLS-II: Vacuum Schematics





Generated by the Mechanical Engineers
Verified by the Vacuum Engineers
Used by the Control Engineers

BEAM LINE VACUUM SYSTEM:
SLAC MANUFACTURING - UHV REQUIREMENTS

SLAC UHV Acceptance Test Criteria

FP-202-631-14-REV8

1. **Leak Tight:** Helium leakage rate of < 2×10^{-10} std. cc/sec helium.

2. **RGA Acceptance**: Mass spectrometer scan performed at 150°C on each lot of components in the same test chamber

Conditions/Criteria	Limits SLAC AD UHV
Temperature of entire vacuum system and RGA head ionizer	150°C
Ratio of partial pressures of water vapor, (18 AMU) to hydrogen (2 AMU)	$P_{18} < \frac{P_2}{2}$
Partial pressure from sum of all peaks >44 AMU	P < 1×10^{-11} Torr
Maximum single-peak partial pressure for >44 AMU	P < 5×10^{-12} Torr

3. **Total Outgassing:** As specified by component/assembly drawing, if present, otherwise a value < 2×10^{-12} Torr-L/sec-cm^2 of surface area exposed to vacuum shall be demonstrated (standard method like aperture or rate of raise method)

SLAC's Process for UHV Assembly and Verification

If executed properly, this sequence has many SLAC years' proof of success to achieve < $1x10^{-8}$ Torr levels.

Fabricate & Clean Parts: Per UHV spec FP-14

→

Assemble: UHV best practices that keep UHV Parts clean!

→

Bake: 250C 48 hrs

→

Verify Outgassing Spot checks & vendor qualifications

Verify Hydrocarbons RGA @150C

→

RFI

For LCLS-II there won't be any beamline in-situ bakeout after installation

BEAM LINE VACUUM SYSTEM:
SLAC MANUFACTURING - PARTICLE FREE REQUIREMENTS

LCLS-II: Particle Free Requirements

SLAC

Particle-Free Engineering Specifications

LCLSII-1.1-ES-0476-R1

The approach to achieve an acceptable cleanliness versus consequence for the design, fabrication, installation and operation of the LCLS-II SRF Accelerator components.

More critical

Less critical

Cleanliness Region	Description
A	• SRF cavity, cathode, mirrors, and surfaces in the same vacuum region when vented. (Internal Surfaces)
B	• Warm Beamline Vacuum Surfaces, within "Particle-Free Length" of Cleanliness Region A. (Internal Surfaces)
C	• Warm Beamline Assembly parts and tools. (External Surfaces) • External surfaces of Cryo Beamline components. (External Surfaces) • Cleanliness Region A assembly parts and tools. (External Surfaces) • Cleanliness Region A assembly jigs and fixtures. (External Surfaces)
D	• Warm Beamline Assembly Jigs and Fixtures. (External Surfaces)
E	• Warm Beamline Components and Assemblies, within cleanrooms and clean zones during beamline connections. (External Surfaces)

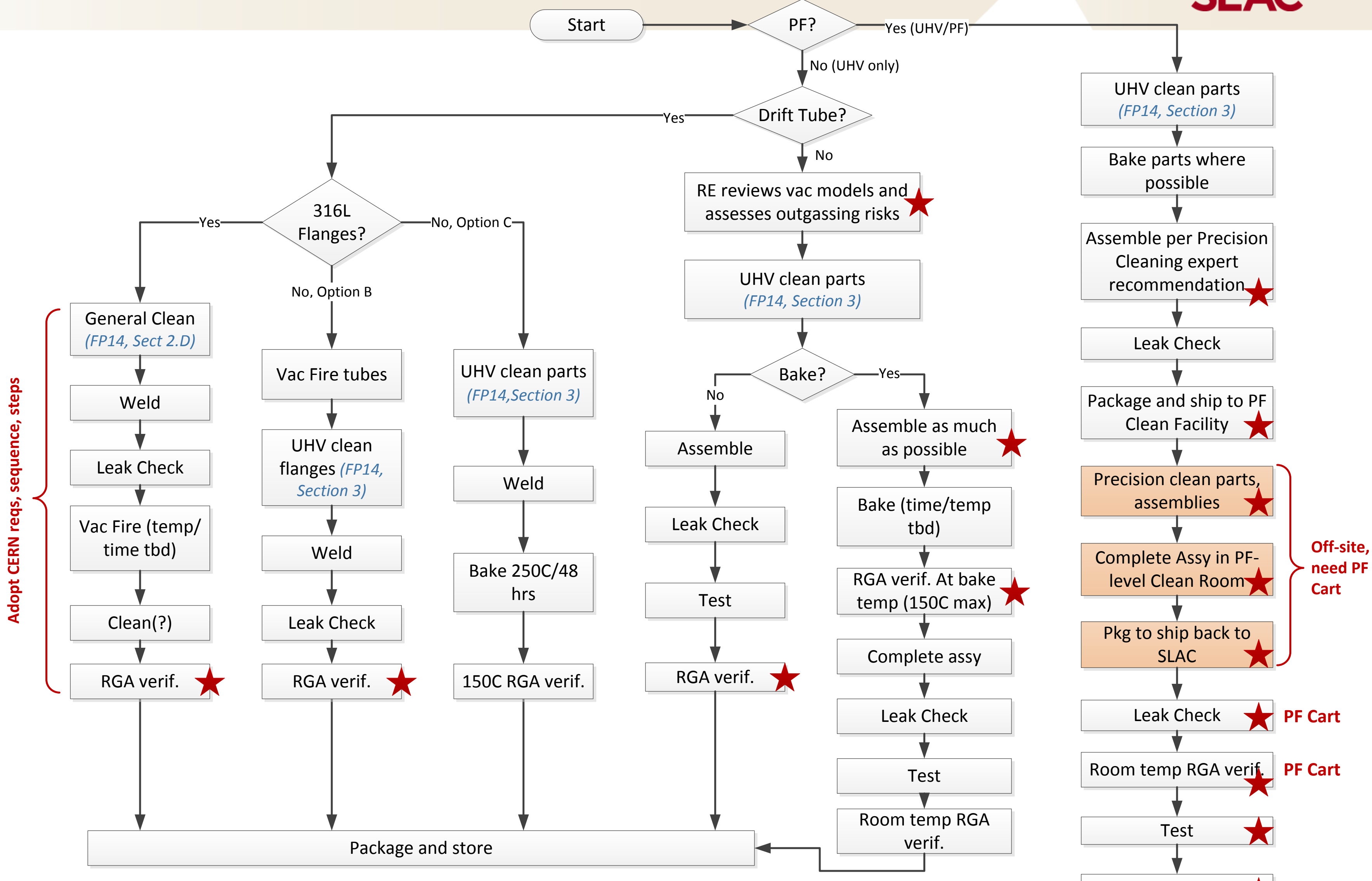
LCLS-II: Particle Free Requirements

Table 6-2: Cleanroom Class per Assembly Step or Usage

Assembly Step	**ISO 4/ Class 10**	**ISO 5/ Class 100**	**ISO 6/ Class 1000**	**ISO 7/ Class 10,000**
Preliminary Cleaning (removal of majority of particles due to parts being fabricated, inspected, or handled in non-Cleanroom environments, purpose of this cleaning is to minimize transport of particulates into cleanroom.)				X
Final Cleaning		X		
Parts Drying	X			
Cleanliness Verification	X			
Cryo Beamline Component Assembly	X			
Cryo Beamline Interconnection	X			
Warm Beamline Component Assembly		X		
Warm Beamline Interconnection		X		
Cryo Beamline Assembly Jigs and Fixture Final Cleaning and Assembly		X		
Warm Beamline Assembly Jigs and Fixture Final Cleaning and Assembly			X	
Particle-Free Turbo Cart Cleaning and Assembly, except final filters, valves and vacuum interconnect. (External Surfaces and Internal Surfaces).			X	
Particle-Free Turbo Cart Cleaning and Assembly of final filters, valves and vacuum interconnect. (Internal Surfaces)	X			

Graded approach

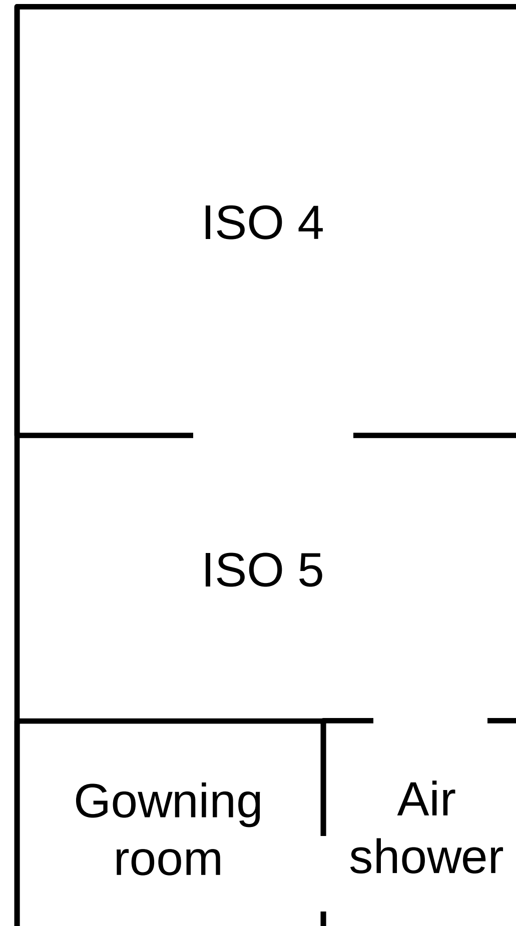
SLAC Process:
Vacuum Fabrication Decision Tree



★ = Need specs, procedure, validation, and/or other

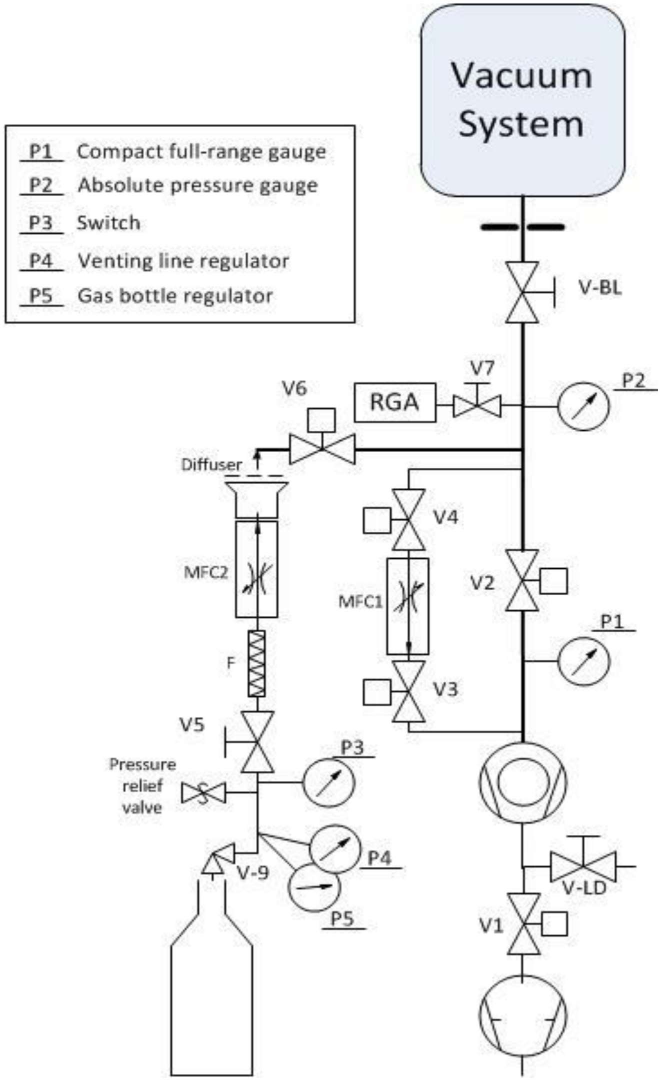
SLAC Facilities for Particle Free Manufacturing Clean Rooms

- Clean room for components assembly
- Cleaning station
- Rinsing station



LCLS-II: Particle Free Pump Cart

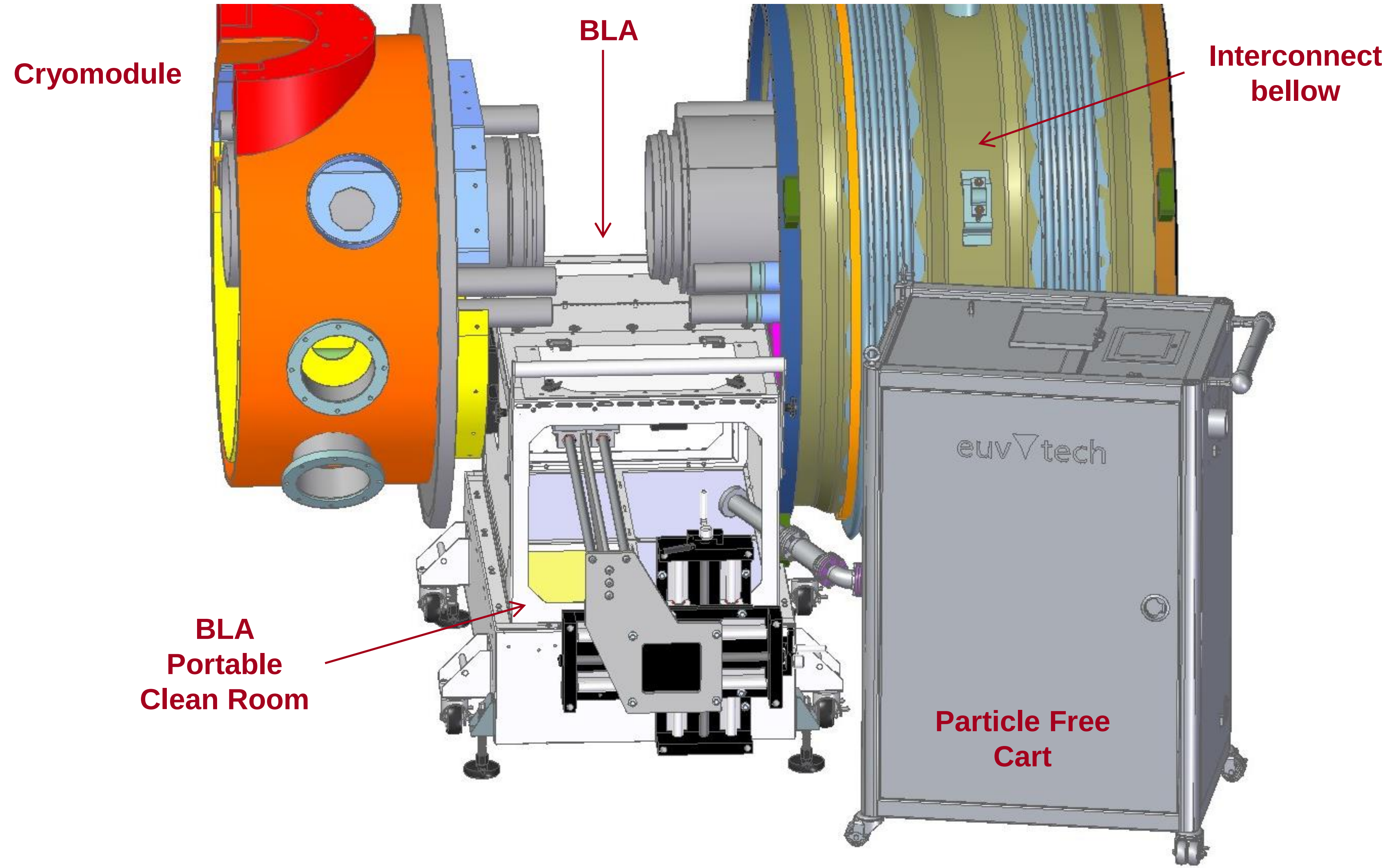
- LCLS-II installation Particle Free zones:
  - Venting
  - Pumping
  - Leak detection
- Prior to installation, every component designated for the LCLS-II Particle Free zone will be pumped and tested with the Particle Free cart, following specific procedures
- For pumping and venting the Mass Flow Controller is set up at 3 l_N/min (~40 Torr l/s)



Reference:

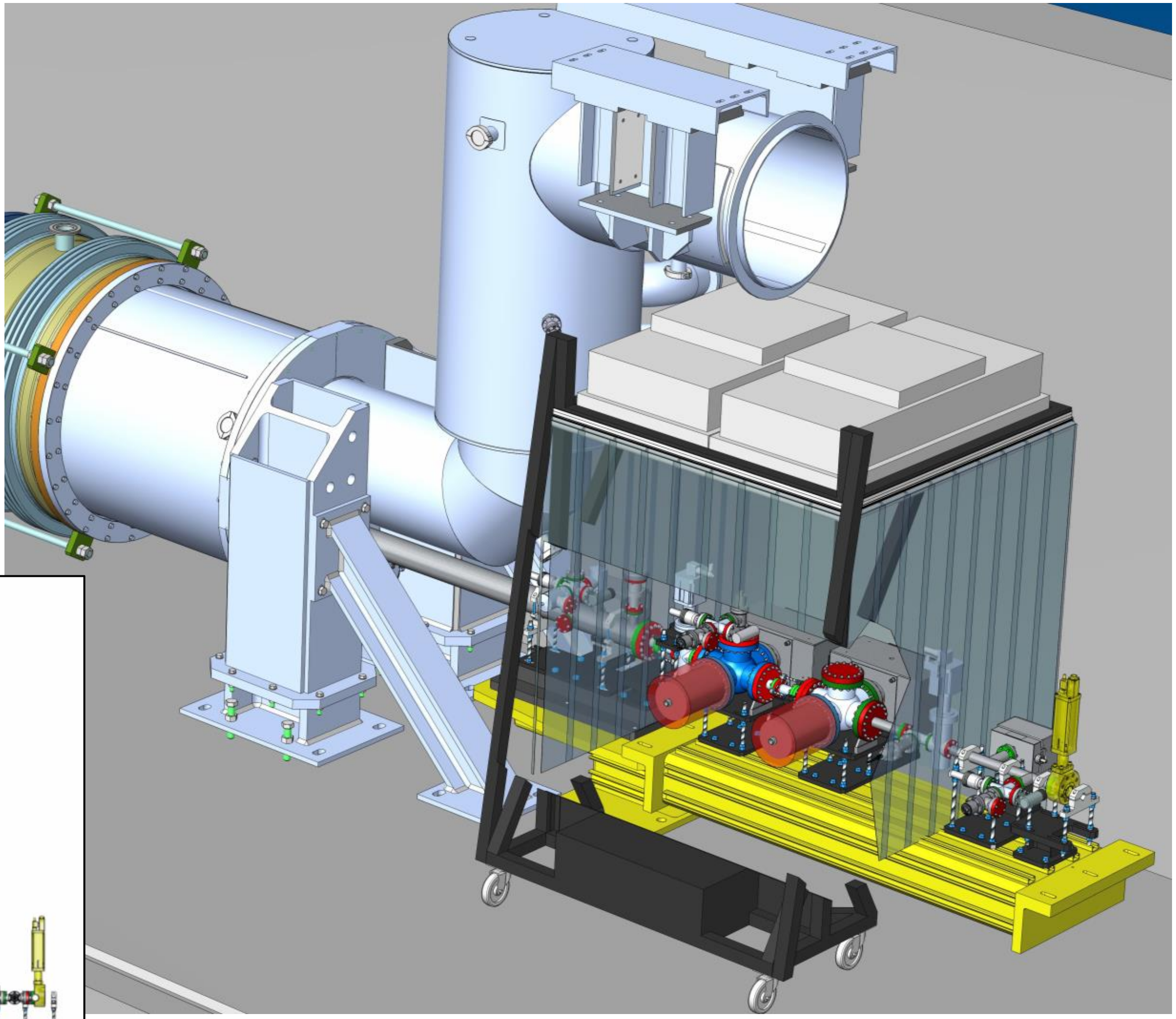
- "Particle Free Pump Down and Venting of UHV Vacuum Systems" by K. Zapfe and J. Wojtkiewicz, SRF2007

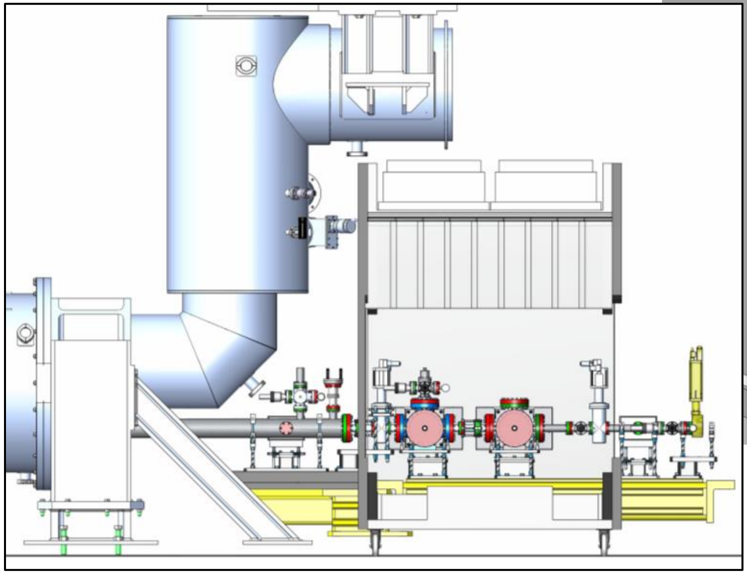
LCLS-II: Field Installation
Portable BLA Clean Room



LCLS-II: Field Installation
Portable Overhead Clean Room

Used for interconnection of the room temperature beam line





BEAM LINE VACUUM SYSTEM:
FAILURE ANALYSIS

LCLS-II: Component failures with control system mitigation

Gauges	Potential Failure Mode	Potential Effect(s) of Failure	Recommended action
Pirani	loss of connection	No pressure information when the system is vented. No information about high pressure if the system has a leak. The paired cold cathode switches off or doesn't switch on and triggers a fault on the PLC (TO CHECK THE 937B manual)	Alarm condition Treat as a fault condition for the controller
	Controller power failure	No information about pressure rise or sector status (vented or under vacuum)	Alarm condition Treat as a fault condition for the controller
	Setpoint Failure	The pressure is too high for the cold cathode to switch on. The cold cathode stay on at high pressure and get damaged	program the gauge controller so the setpoint failure trigger the cold cathode switch off or stop the cold cathode ignition
Cold Cathode Gauge	Loss of connection	No information about pressure rise or sector status (vented or under vacuum)	Alarm condition, Treat as fault condition for the interlock
	Controller power failure	No information about pressure rise or sector status (vented or under vacuum)	Alarm condition, Treat as fault condition for the interlock
	Setpoint Failure	Pressure spike or pressure rise due to a leak	Alarm condition, Treat as fault condition for the interlock
Extractor	Filament Failure		Alarm
	Setpoint Failure		Alarm if a setpoint is in place
Hot cathode gauge	Filament Failure	No information about pressure rise or sector status (vented or under vacuum)	Alarm condition, Treat as fault condition for the interlock Switch to the second filament if available
	Loss of connection	No information about pressure rise or sector status (vented or under vacuum)	Alarm condition, Treat as fault condition for the interlock
	Controller power failure	No information about pressure rise or sector status (vented or under vacuum)	Alarm condition, Treat as fault condition for the interlock
	Setpoint Failure	Pressure spike or pressure rise due to a leak	Alarm condition, Treat as fault condition for the interlock

Based on the usual failures and experience

Answer the question: what can possibly go wrong?

Gauges (example)

The tables are available for
- Automatic valves,
- Pumps,
- RGA

[see LCLSII-1.1-EN-0943]

Tables and documents handed over to the control group to implement the automatic actions

LCLS-II: Alerts and automatic actions: rules and logic (1)

The logic of the operating system for gate valves

General Rules:

- Interlock sensors are Pirani, Cold Cathode gauges and Ion pumps
  - Reliable pressure measurement in the range we use them
  - More tolerant of high pressure than filament gauges
- Hot Filament Ion gauge are used for interlock only when there is no other choice (CC or IP) available
  - The filament is sensitive to sudden pressure variation
- The Particle Free (PF) area has an interlock redundancy, coincidence detection of at least 2 of 3
  - To make sure the gate valves don't close due to electric glitch
- Each PF sector has at least two interlock sensors per sector
  - If the sector is vented two of three sensors will be interlocking the gate valves to stay close
- Each triplet closes the two valves of the sector
  - The problem arising in one sector will stay confined in that sector
- Fast shutters are triggered by coincidence of two cold cathode gauges

LCLS-II: Alerts and automatic actions: rules and logic (2)

- Fast shutters close the two adjacent gate valves
  - Fast shutters do not completely seal the sector
- In the non-PF areas each sector has two interlock sensors
  - Sectors in the non-PF areas are long
  - Having two sensor in one sector helps if one of the sensor has problem and needs to be bypassed
- In the non-PF area the interlock sensors are the gauges or ion pumps closest to the gate valves
  - To monitor the sector pressure on each end
- In the non-PF areas each interlock sensor triggers the two valves of its sector
  - The problem arising in one sector will stay confined in that sector

LCLS-II: Particle Free Areas

Considerations Driving Controls and Design

Cavity performance degradation

Particles present on the cavity surface cause field emission.

There are several experiments which show that condensed gases can activate field emission, presumably by adsorbing on the surface of dormant particulate site.

Field emission is amplified by a superficial layer of absorbed gas.*

Catastrophic event

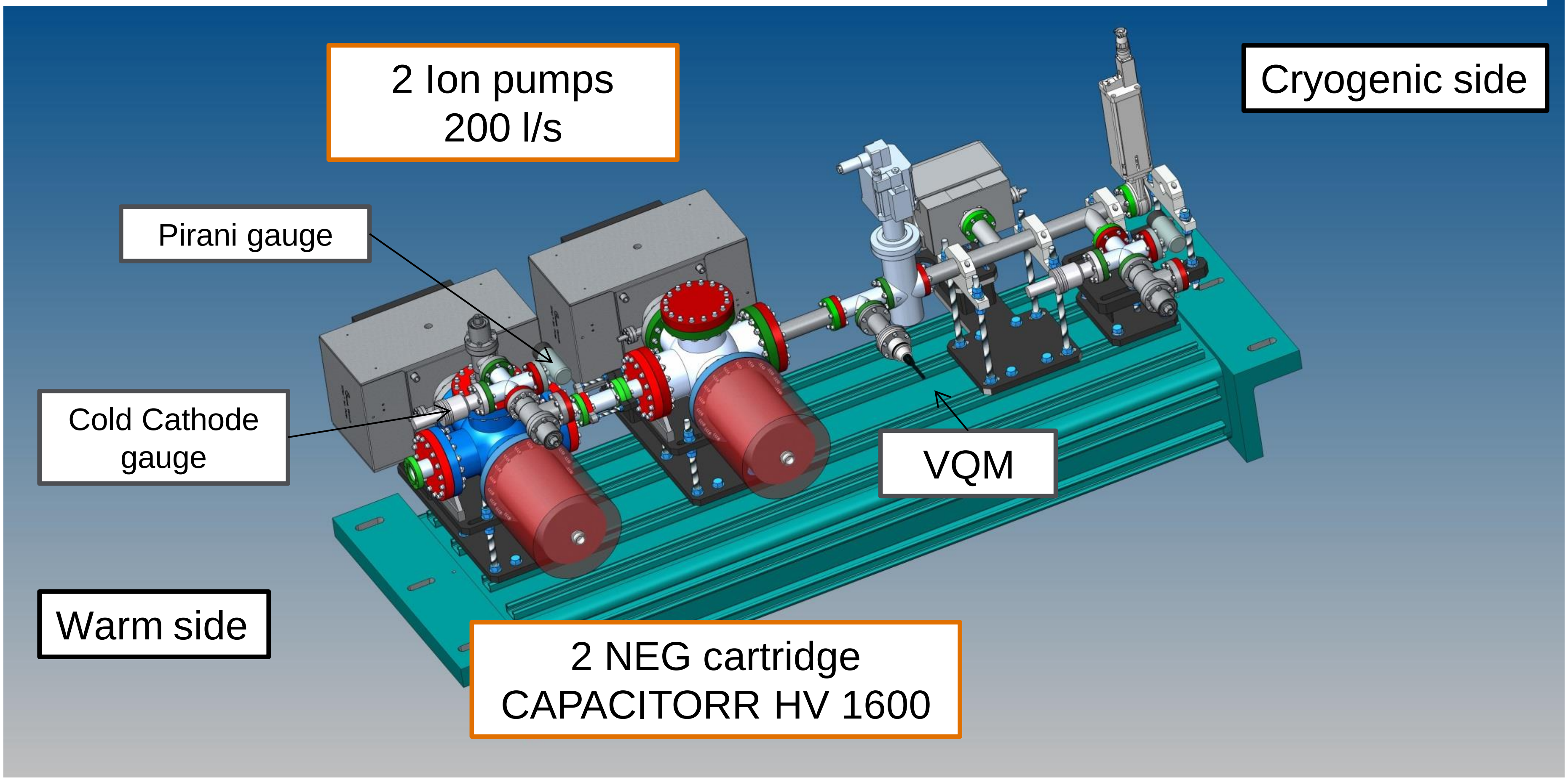
Various leak scenario that leads to

- Loss of vacuum in the particle free area
- Loss of vacuum in the cryostat beam line at operating temperature
- Loss of particle free cleanliness in the particle free area at room temperature
- Loss of particle free cleanliness in the cryostat beam line

*H. Padamsee, J. Knobloch, T. Hays, RF Superconductivity for Accelerators, 2nd Edition

Managing Cryo-to-Warm Transitions
Differential pumping system

Reduce the amount of gas cryo-pumped by the RF cavities

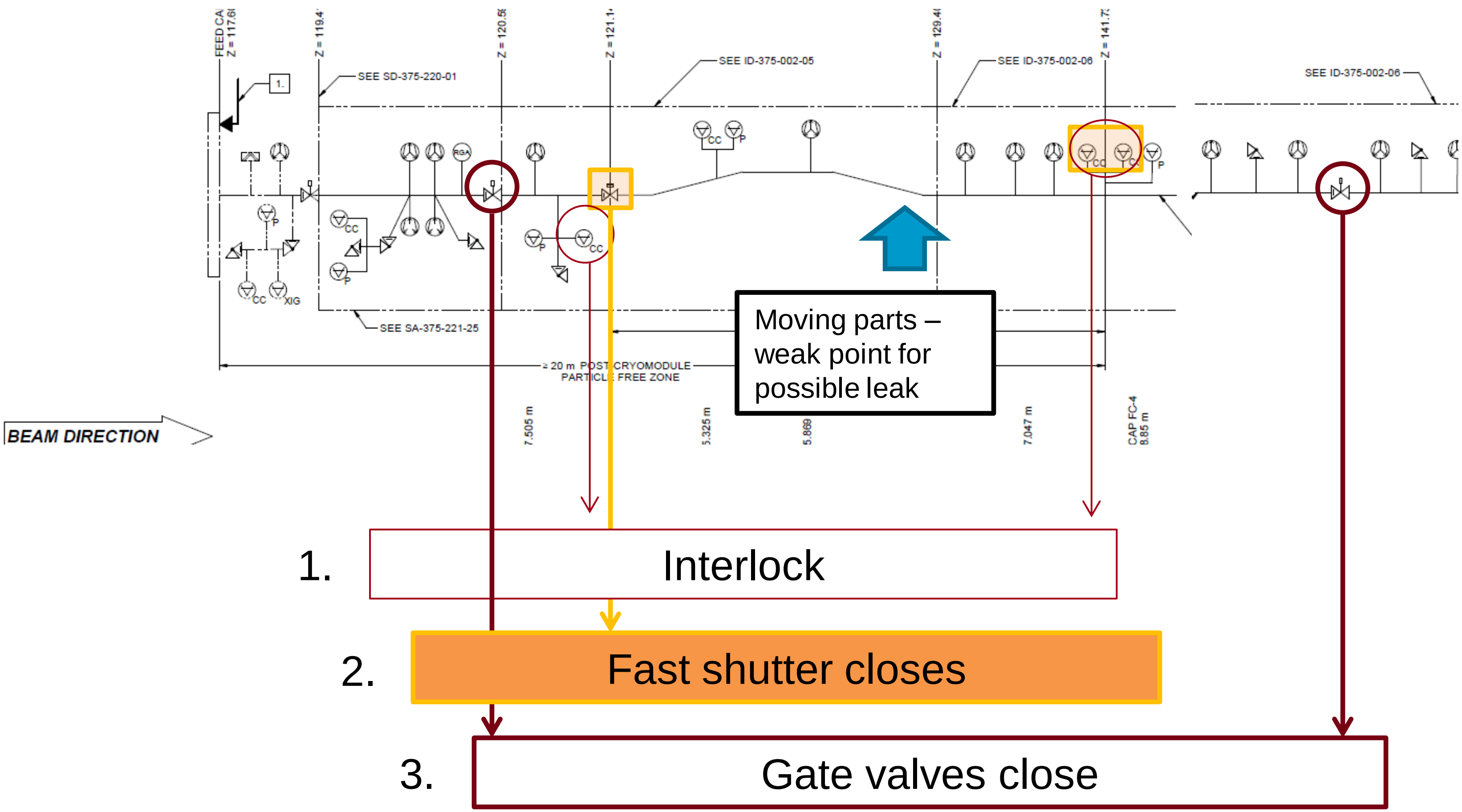


TOTAL LENGTH: L=1250mm Ø=34.8mm

Engineering Note: LCLSII-1.1-EN-0658: A differential pumping system for LCLS-II beam pipe cold-warm transitions

Managing Cryo-to-Warm Transitions: Example of leak in BC2B

Fast shutters are intended to <u>limit the propagation of acoustic shock waves</u>, such as from a thin window break or accidental opening of an isolation valve to a vented volume



Summary

LCLS-II Project`

LCLS-II beam line design is completed

To support the mechanical engineers in their work the vacuum group set the new SLAC standards for:

- design and manufacture UHV vacuum system
- Test and accept the UHV components
- clean for particle free

The effort for preparing the infrastructures (bakeout stations, clean rooms, pumping carts, …) to accommodate the LCLS-II incoming activities is ongoing.

Next Steps:

- Test/validate the external companies
- Train our technicians for clean room work

END

Thank you