Status of the LCLS-II-HE Upgrade

Dan Gonnella

LCLS-II-HE Installation & Commissioning System Manager

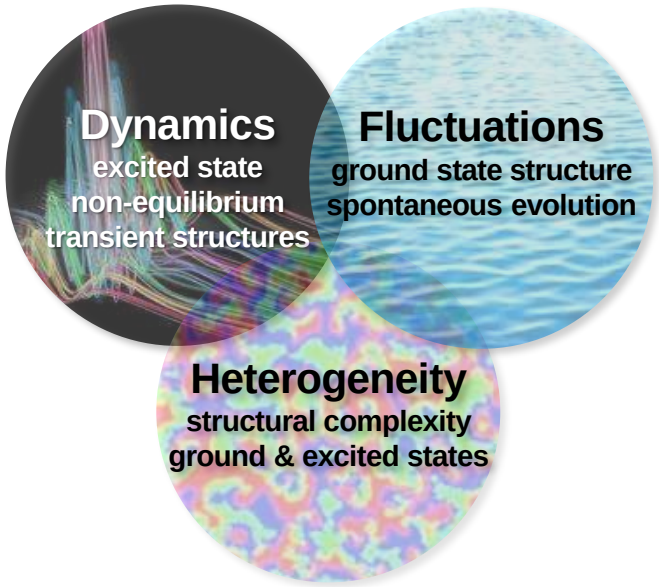
17 Aug 2026

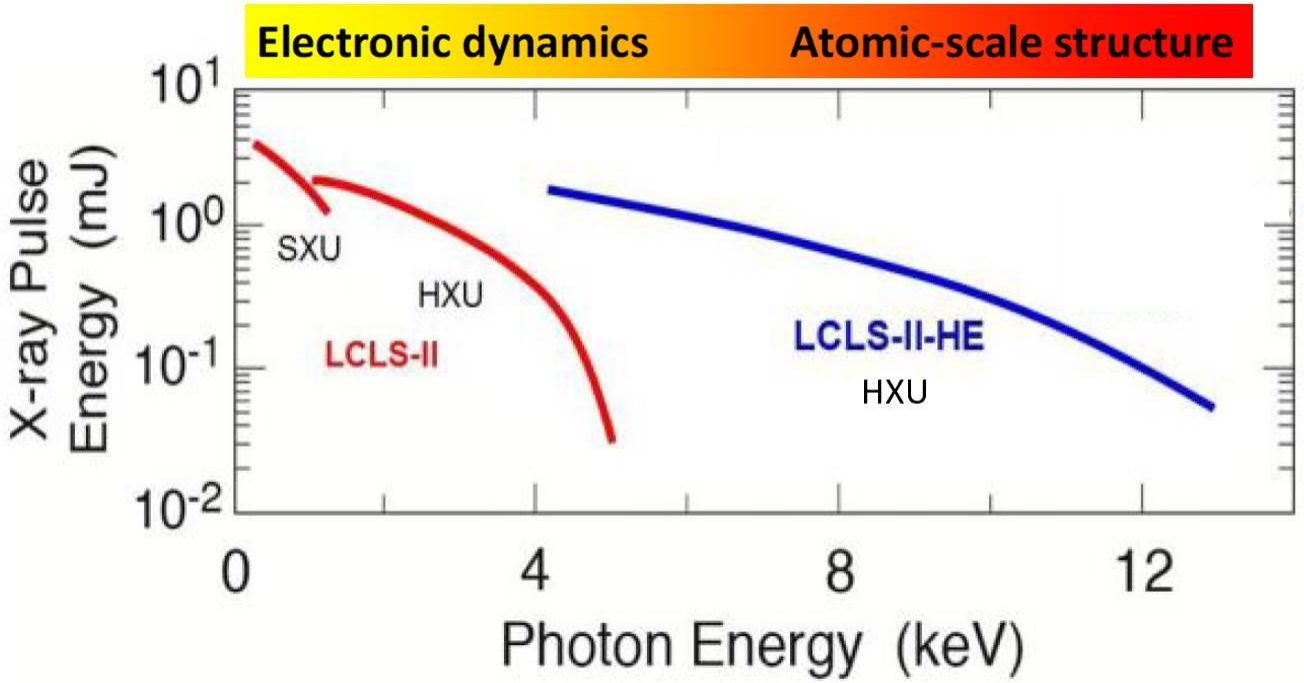
DAEJEON LINAC 2026

BERKELEY LAB · Fermilab · FACILITY FOR RARE ISOTOPE BEAMS · Jefferson Lab · SLAC NATIONAL ACCELERATOR LABORATORY · Stanford University · U.S. DEPARTMENT OF ENERGY

LCLS-II-HE: Ultrafast, High Average Power, Hard X-rays

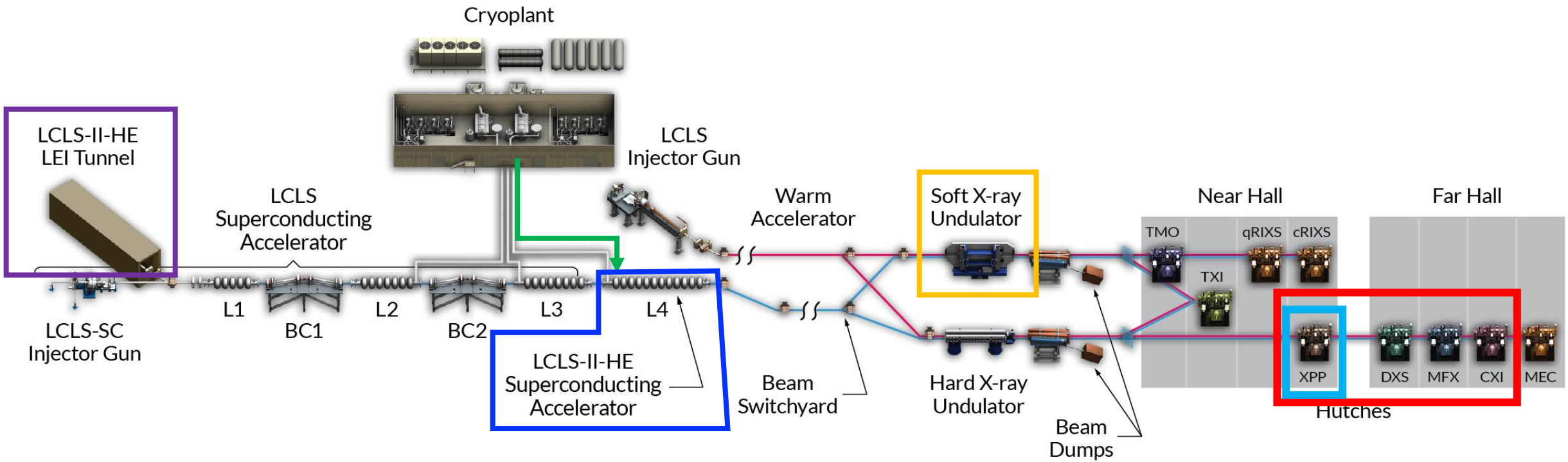
Deliver the ability to observe and understand the structural dynamics of complex matter at the atomic scale with hard x-rays, at ultrafast timescales, and in operational environments.





LCLS-II-HE provides high-rate, FEL radiation at Ångstrom wavelengths

LCLS-II-HE Scope Overview



1. Add 23 additional cryomodules (L4 linac) to double the LCLS-II accelerator energy: 4 GeV to 8 GeV
2. Install new cryogenic distribution box and transfer line between the cryoplant and the new L4 linac
3. New long period soft X-ray undulator
4. Upgrade XPP instrument & enable upgrades of DXS, MFX, and CXI beamlines for MHz beam.
5. Construct new tunnel for future Low Emittance Injector (LEI)
6. Develop prototype SRF gun for the LEI

Performance Goals Compared with LCLS-II

Parameter	LCLS-II	LCLS-II-HE
Beam Energy	4 GeV	8 GeV
# CMs	35	58
Rep. Rate	929 kHz	929 kHz
Photon Energy	200 – 5,000 eV	200 – 12,800 eV
Photon Pulse Energy	$>10^{11}$ @ 3.8 keV	20 µJ @ 12.8 keV

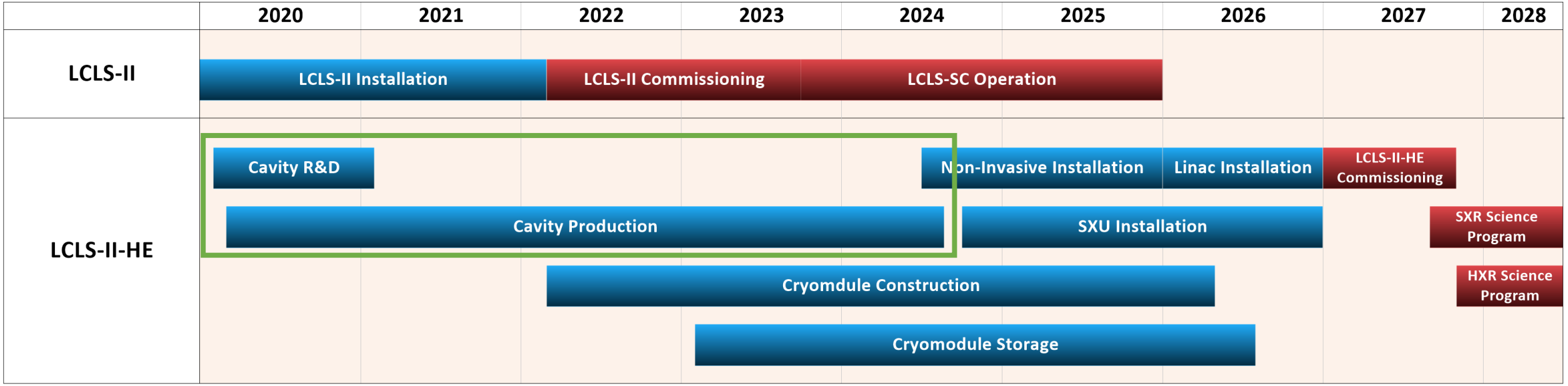
1. **Increase the hard x-ray reach** → **More CMs = Higher Beam energy**
2. **Maintain capability in the soft x-ray regime** → **New SXR Undulators for 8 GeV Operation**

Performance Goals Compared with LCLS-II

Cryomodule Parameter	LCLS-II	LCLS-II-HE
Beam Energy	4 GeV	8 GeV
# CMs	35	35 (old) + 23 (new)
Operating Gradient	16 MV/m	21 MV/m
Q_0 (2 K, Op. Grad.)	2.7×10^{10}	2.7×10^{10}

1. Increase the hard x-ray reach → More CMs = Higher Beam energy
2. Maintain capability in the soft x-ray regime → New SXR Undulators for 8 GeV Operation

LCLS-II & LCLS-II-HE Timeline

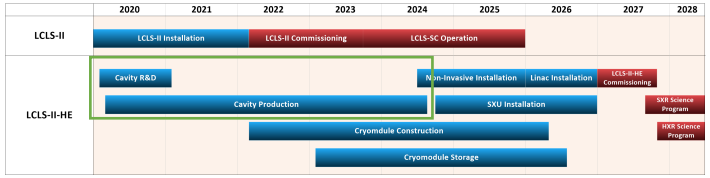


Significant overlap between LCLS-II & LCLS-II-HE:

- Cavity & Cryomodule construction were well underway before LCLS-II commissioning
- HE Installation in part in parallel with linac operations

Nearly all equipment was required to be stored at SLAC prior to the main installation period

SRF Cavity Improvements from LCLS-II



LCLS-II

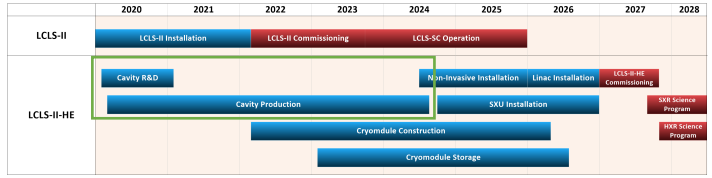
- Bulk EP
- High Temperature Furnace Treatment
- 2N6 Doping
- Final EP

LCLS-II-HE

- Bulk EP 1
- High Temperature Furnace Treatment
- Bulk EP 2 (cold)
- 2N0 Doping
- Final EP (cold)
- Material Sorting for Flux Expulsion
- Continuous Temperature Monitoring During EP
- RGA Monitoring During Furnace Run

For LCLS-II-HE, improvement and consistency in cavity performance would be required

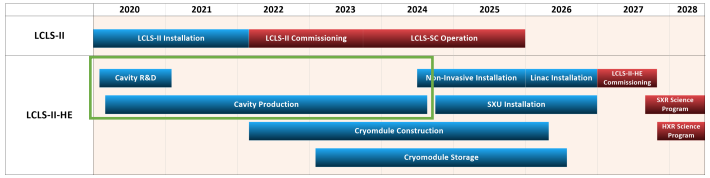
SRF Cavity Improvements from LCLS-II



Increase Gradient Reach	Consistent High Q_0	Quality Control
Bulk EP 2 (cold)	High Temperature Furnace Treatment	Bulk EP 1
Final EP (cold)	Material Sorting for Flux Expulsion	Continuous Temperature Monitoring During EP
2N0 Doping		RGA Monitoring During Furnace Run

For LCLS-II-HE, improvement and consistency in cavity performance would be required

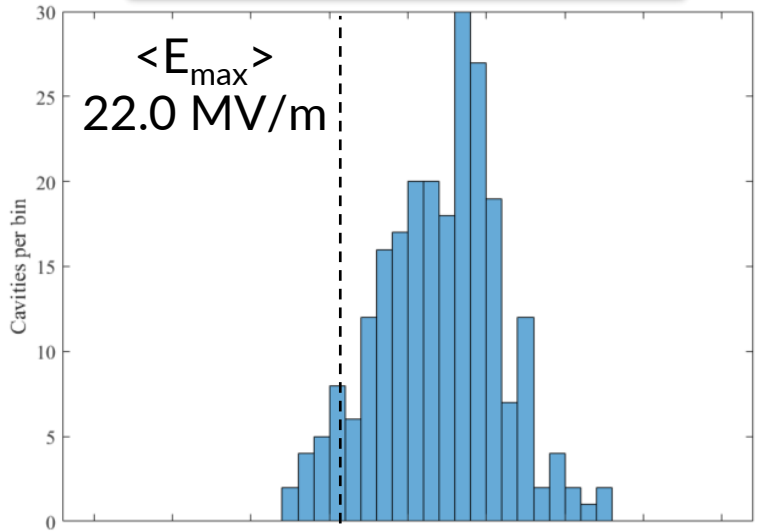
SRF Cavity Performance

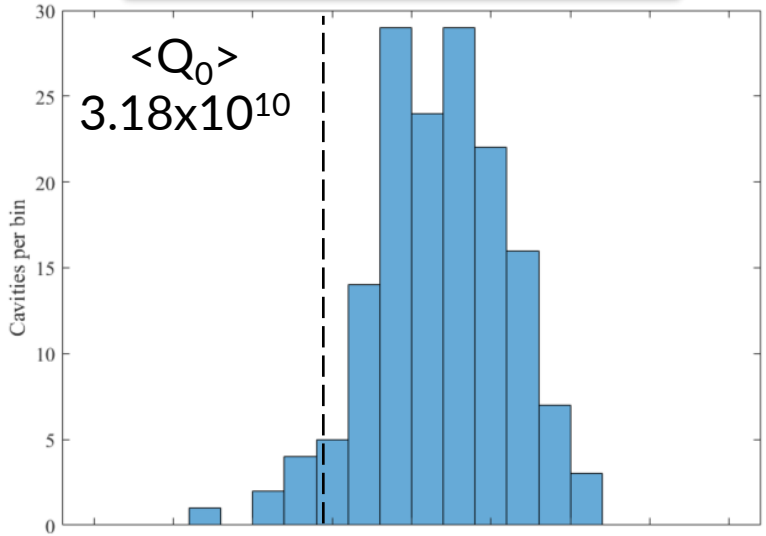


Maximum Gradient

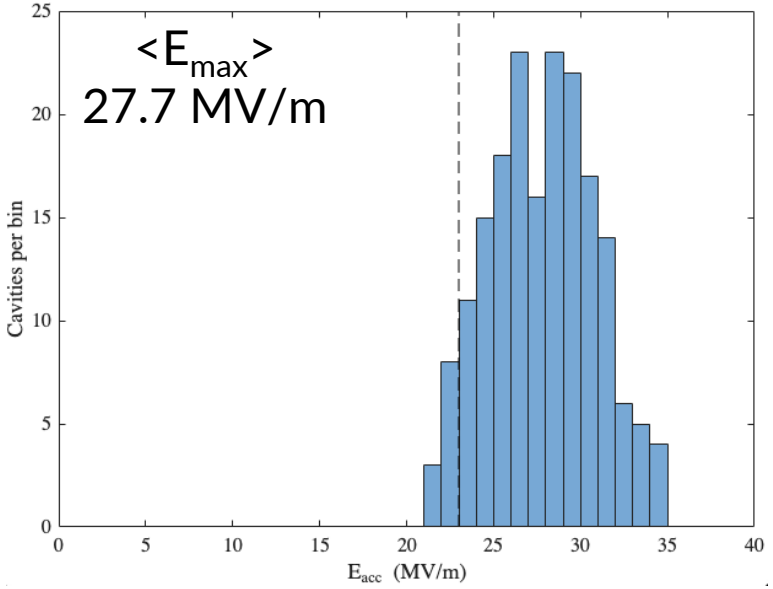
Q_0

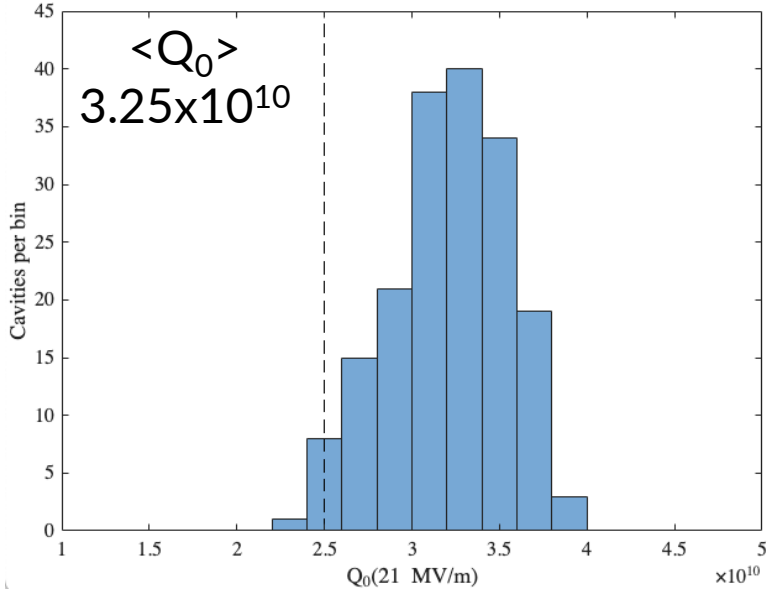
LCLS-II





LCLS-II-HE

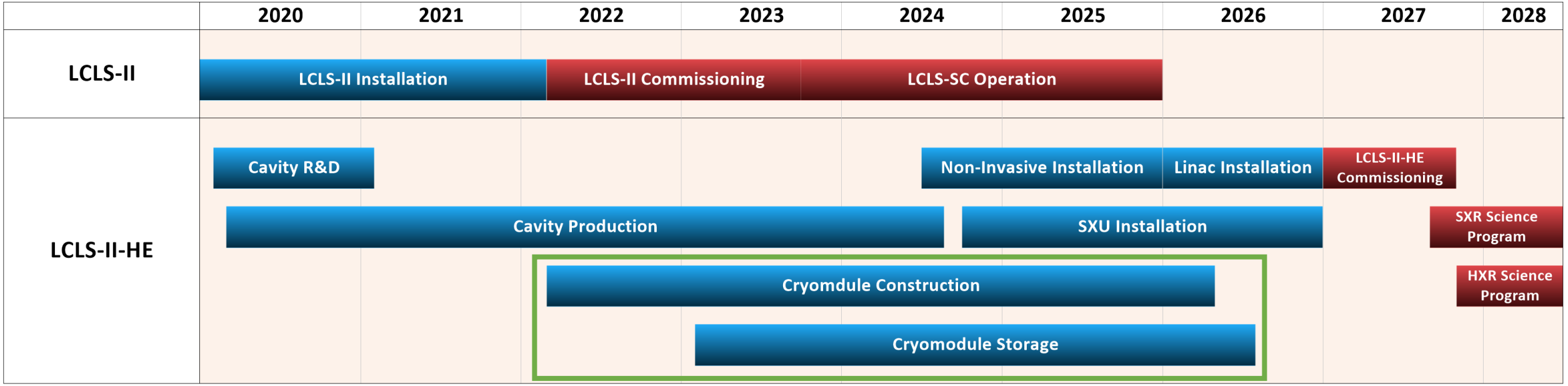




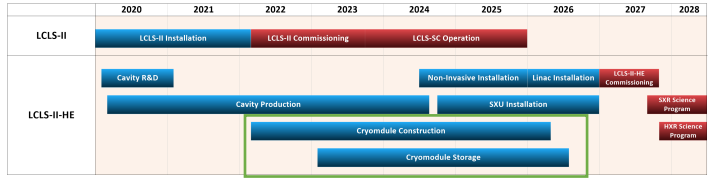
5 MV/m increase in the average maximum gradient!

Average Q_0 unchanged with fewer poor performers

Cryomodule Production



Cryomodule Production at FNAL and JLab



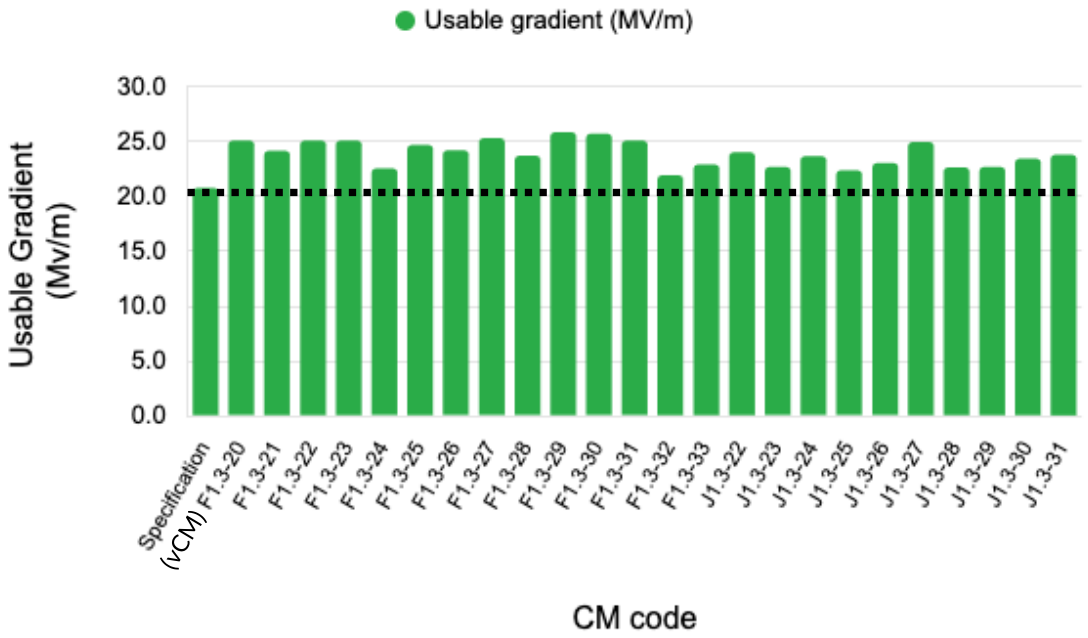
JLab: 10 CMs, 1 rebuilt

FNAL: 13 CMs (+vCM), 1.5 rebuilt

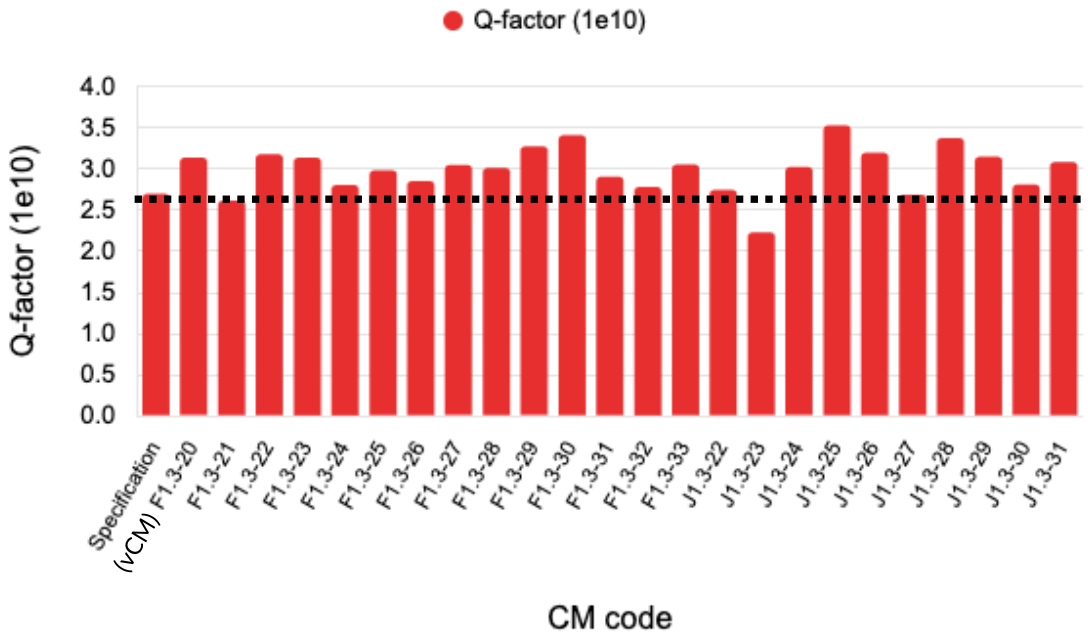
Cryomodule Performance

Average Usable Gradient (MV/m)	Average Usable Voltage (MV)	Average Q-factor (1e10)
24.0	199	3.0

CMs Gradient Summary

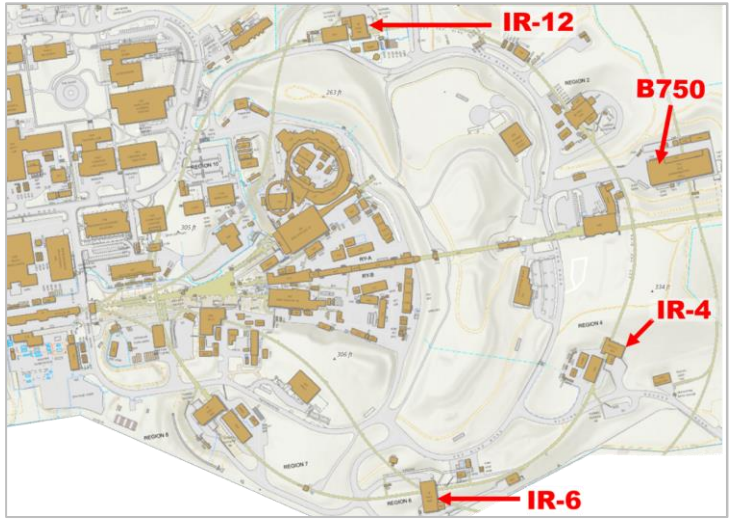


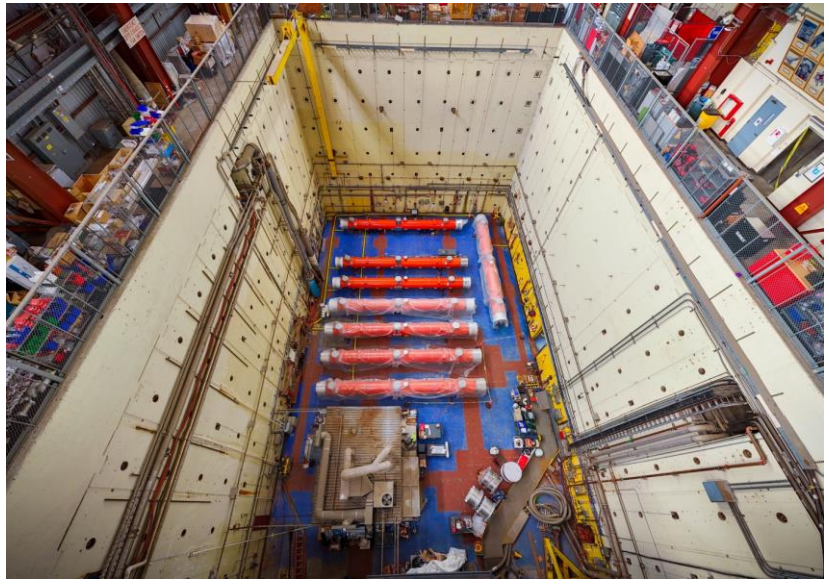
CMs Q-factor Summary



Cryomodule Performance Exceeds Spec with a Comfortable Margin

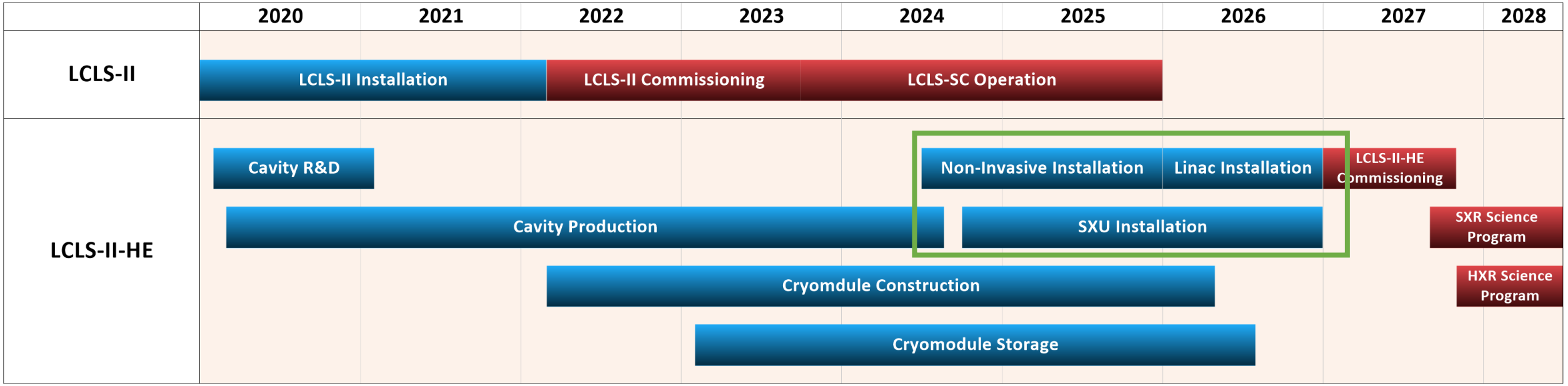
Cryomodule Storage



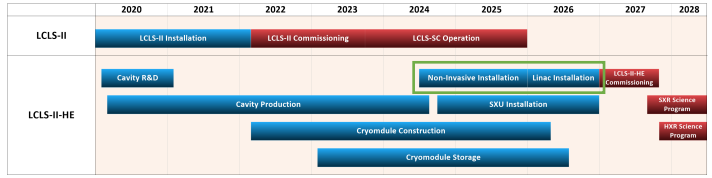


23 Cryomodules Stored at SLAC for up to 4 years prior to installation

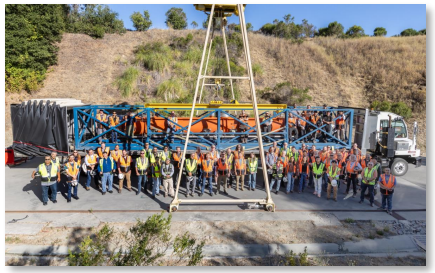
LCLS-II-HE Installation



Installation Progress

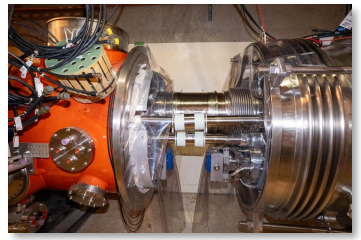


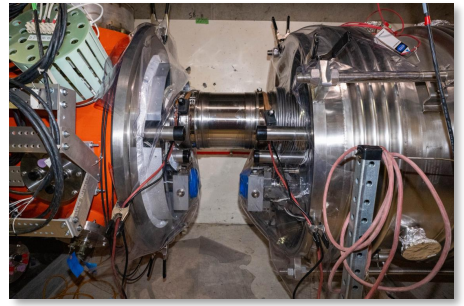
All 23 Cryomodules Installed

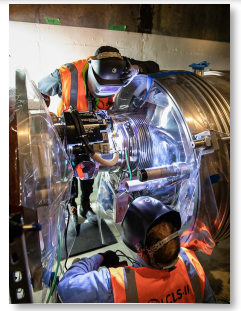


All CDS Components Installed

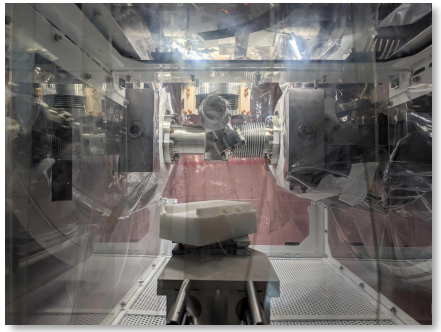
20/25 Interconnect Welds Complete

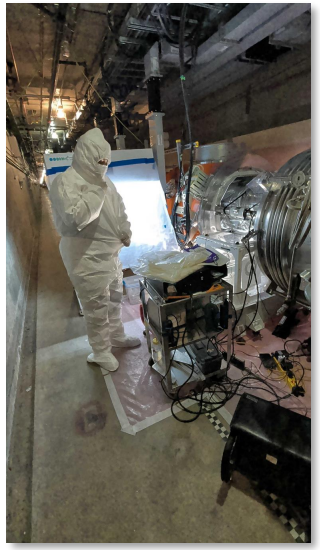




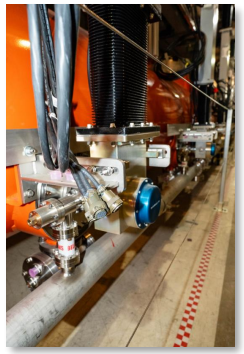


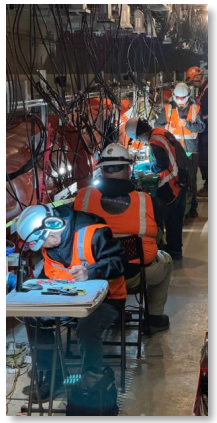
13/25 Particle Free Connections Complete





100% Controls Cables and Racks Installed



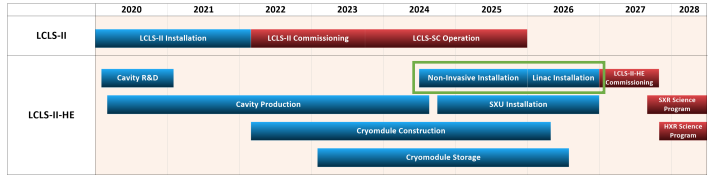


100% Waveguides Installed

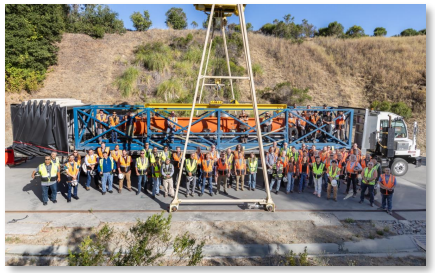
Installation P

All 23 Cryomodules Installed

Installation Progress

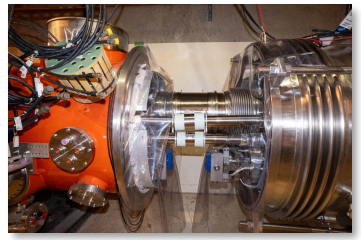


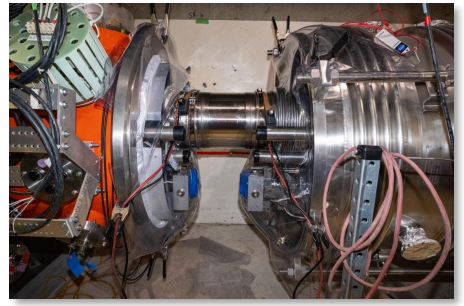
All 23 Cryomodules Installed

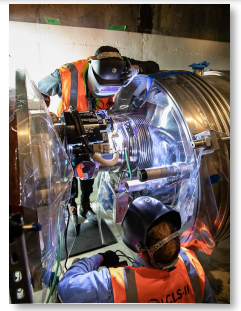


All CDS Components Installed

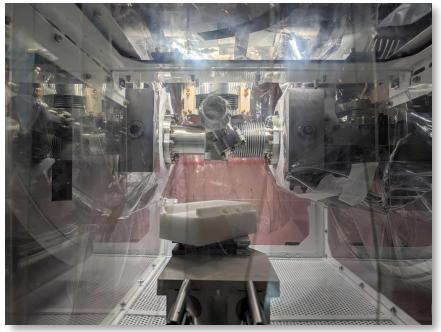
20/25 Interconnect Welds Complete

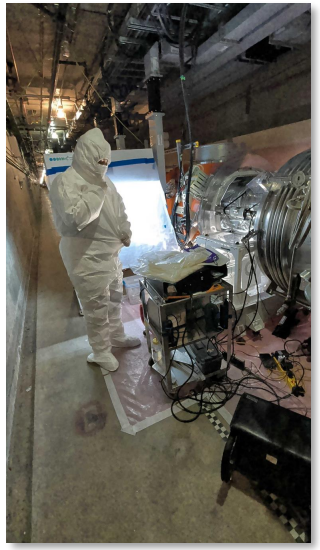




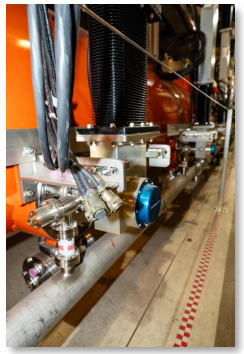


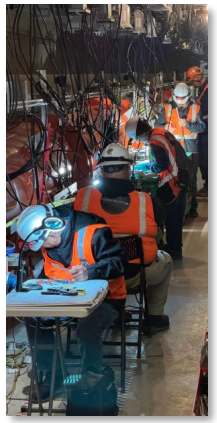
13/25 Particle Free Connections Complete





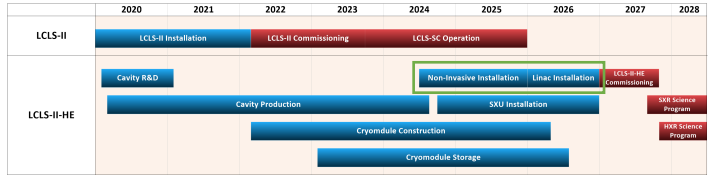
100% Controls Cables and Racks Installed



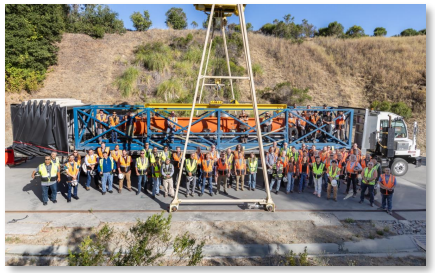


100% Waveguides Installed

Installation Progress

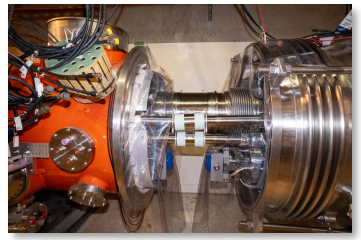


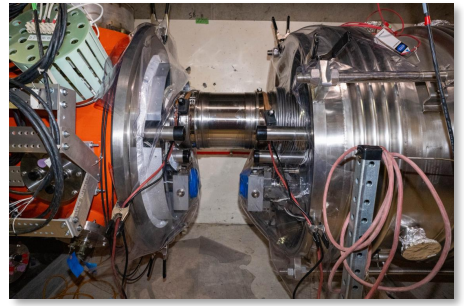
All 23 Cryomodules Installed

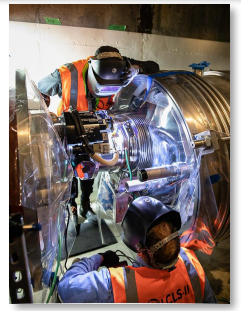


All CDS Components Installed

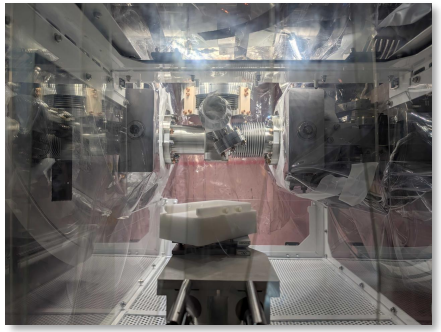
20/25 Interconnect Welds Complete

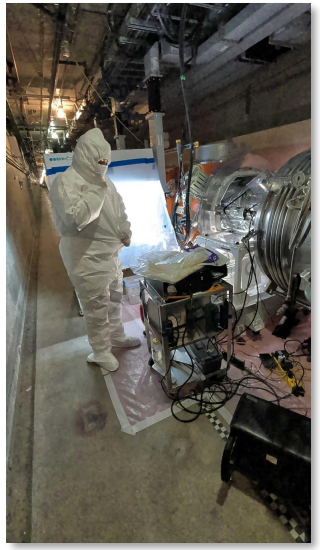




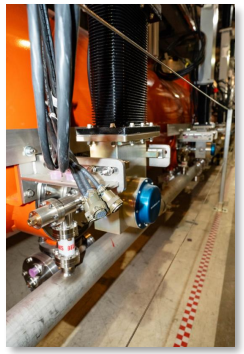


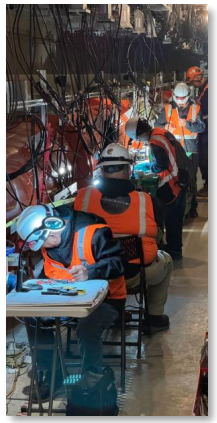
13/25 Particle Free Connections Complete



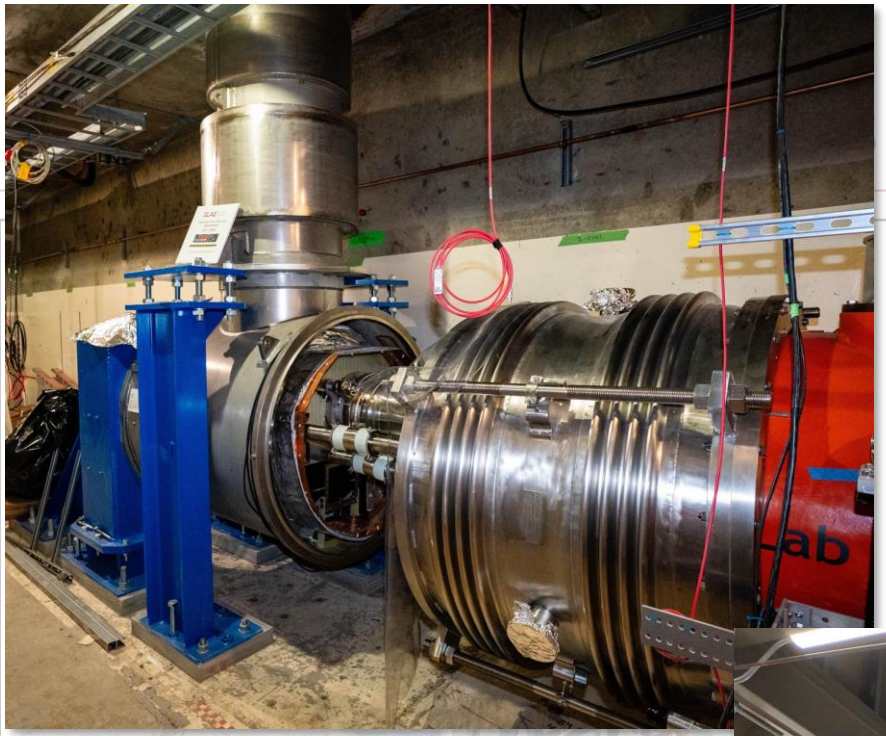


100% Controls Cables and Racks Installed





100% Waveguides Installed

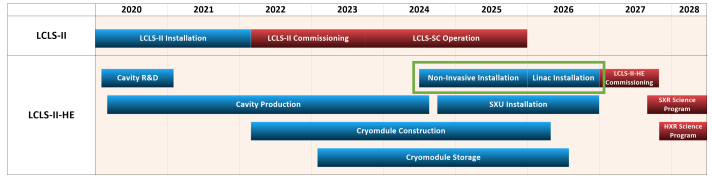


All CDS Components Installed

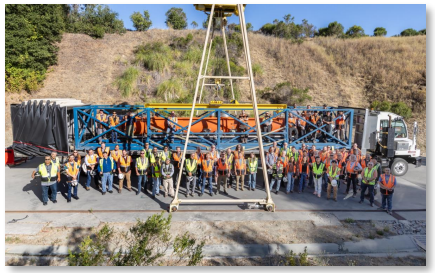
13/25 Particle Free Connections Complete

100% Waveguides Installed

Installation Progress

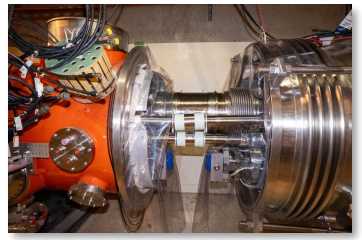


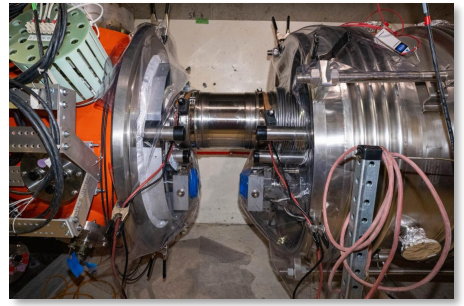
All 23 Cryomodules Installed

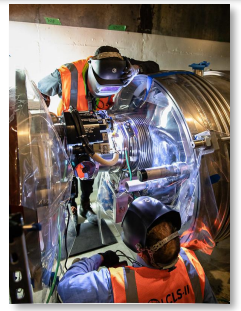


All CDS Components Installed

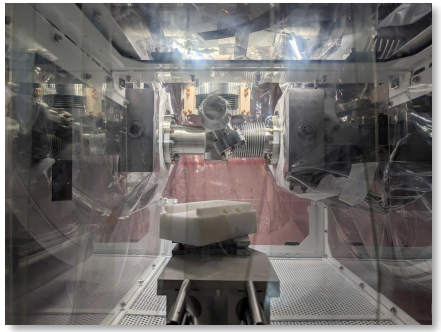
20/25 Interconnect Welds Complete

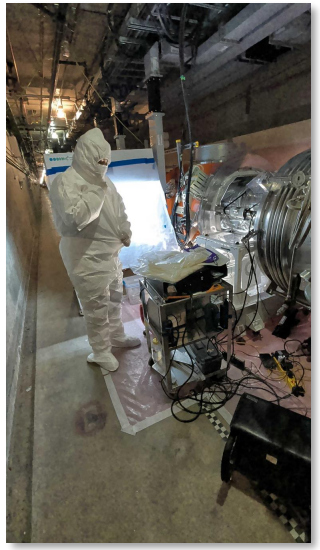




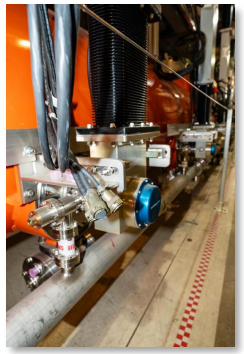


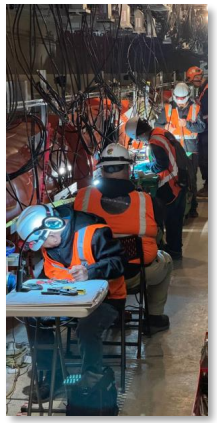
13/25 Particle Free Connections Complete





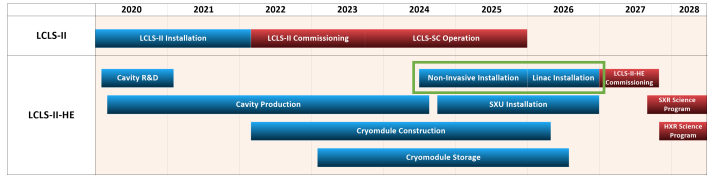
100% Controls Cables and Racks Installed



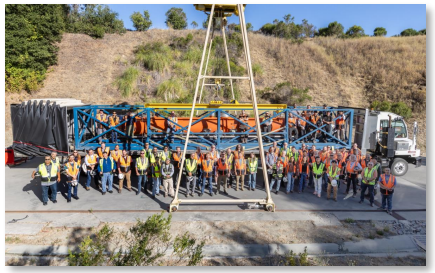


100% Waveguides Installed

Installation Progress

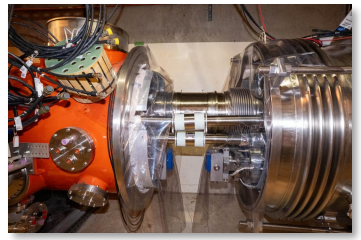


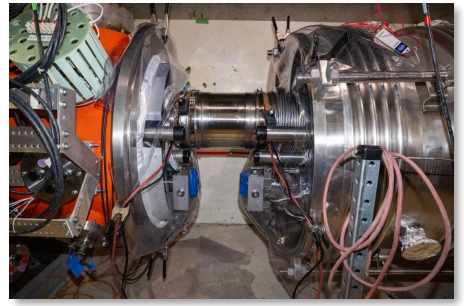
All 23 Cryomodules Installed

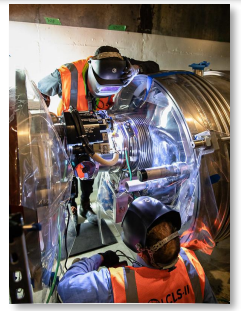


All CDS Components Installed

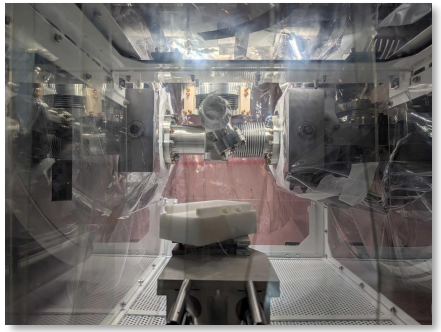
20/25 Interconnect Welds Complete

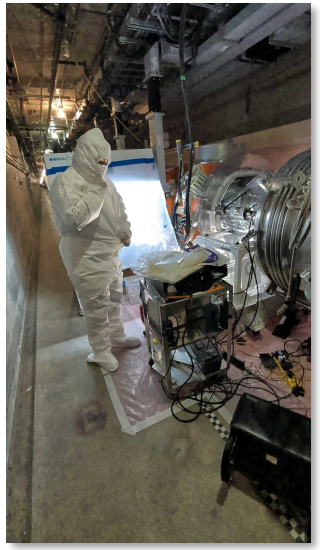




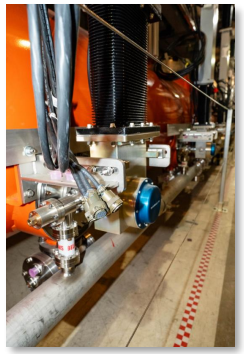


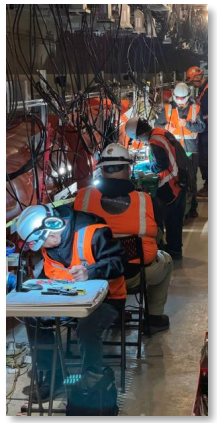
13/25 Particle Free Connections Complete





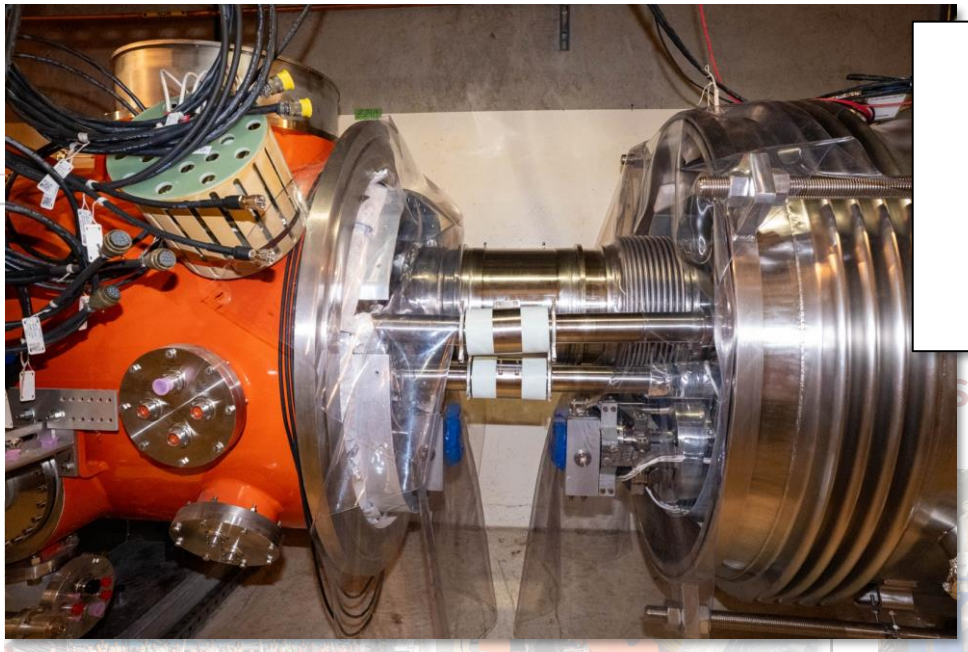
100% Controls Cables and Racks Installed

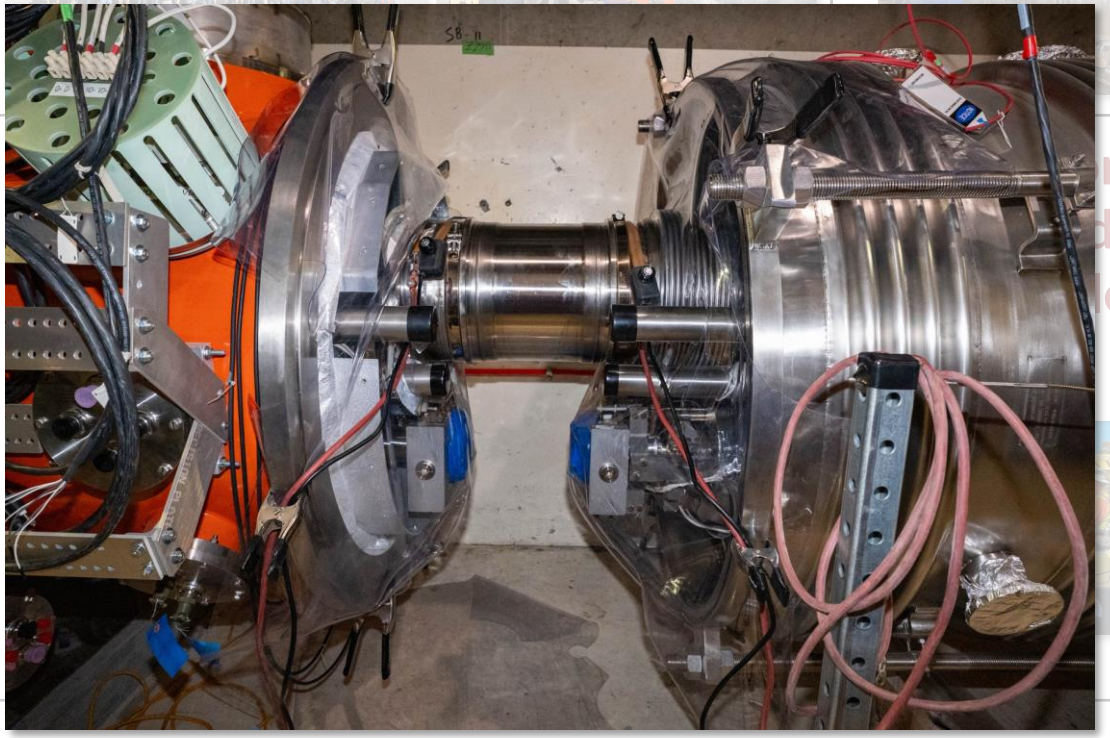




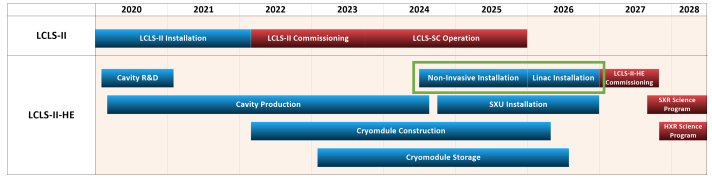
100% Waveguides Installed

20/25 Interconnect Welds Complete

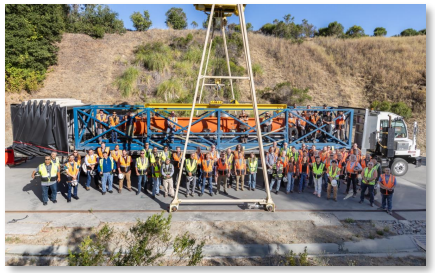




Installation Progress

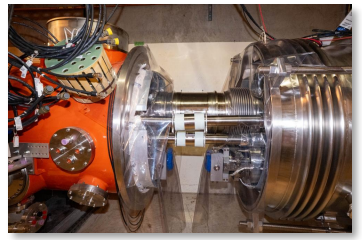


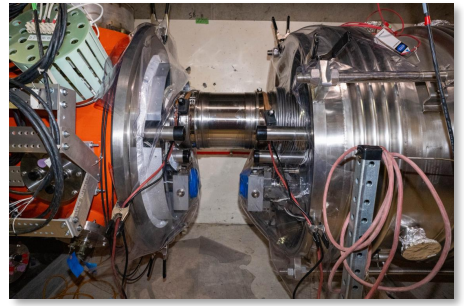
All 23 Cryomodules Installed

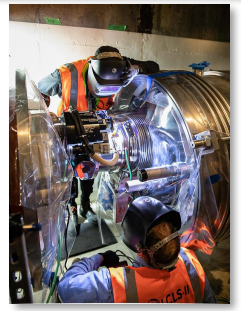


All CDS Components Installed

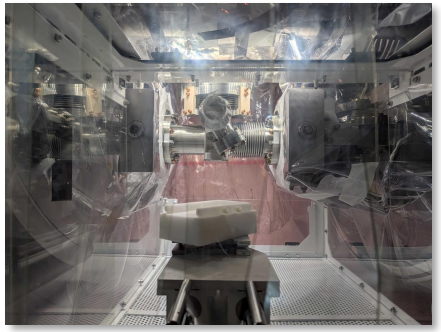
20/25 Interconnect Welds Complete

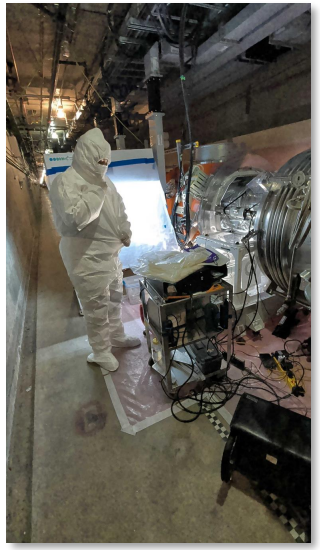




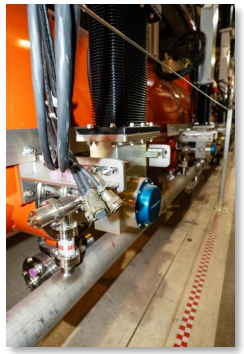


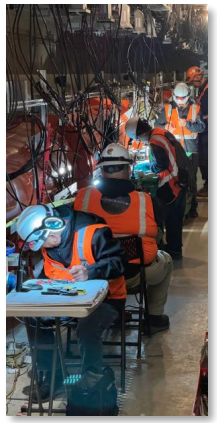
13/25 Particle Free Connections Complete





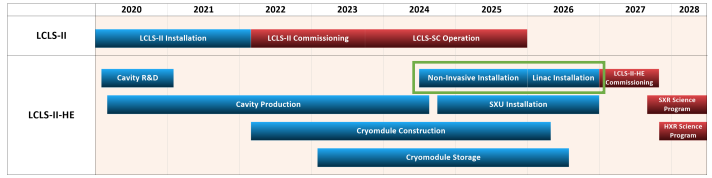
100% Controls Cables and Racks Installed



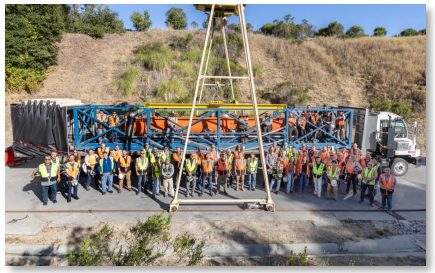


100% Waveguides Installed

Installation Progress

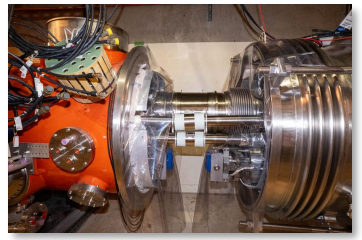


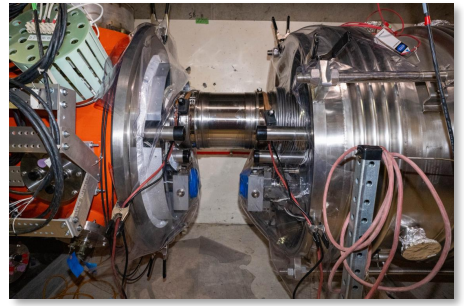
All 23 Cryomodules Installed

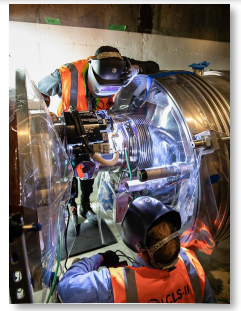


All CDS Components Installed

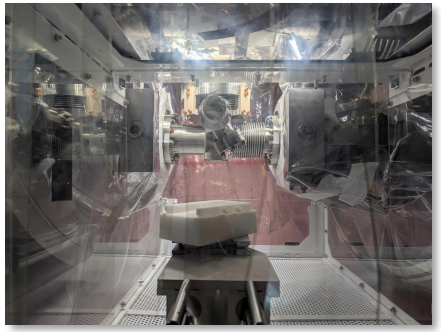
20/25 Interconnect Welds Complete

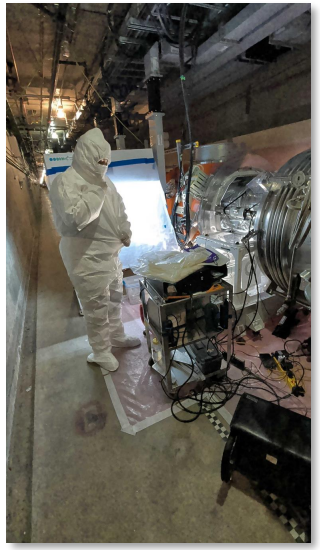




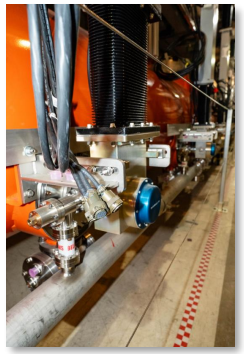


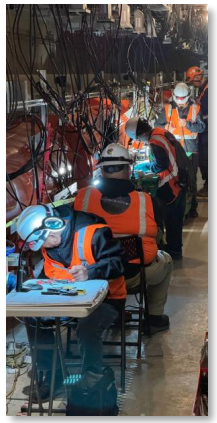
13/25 Particle Free Connections Complete





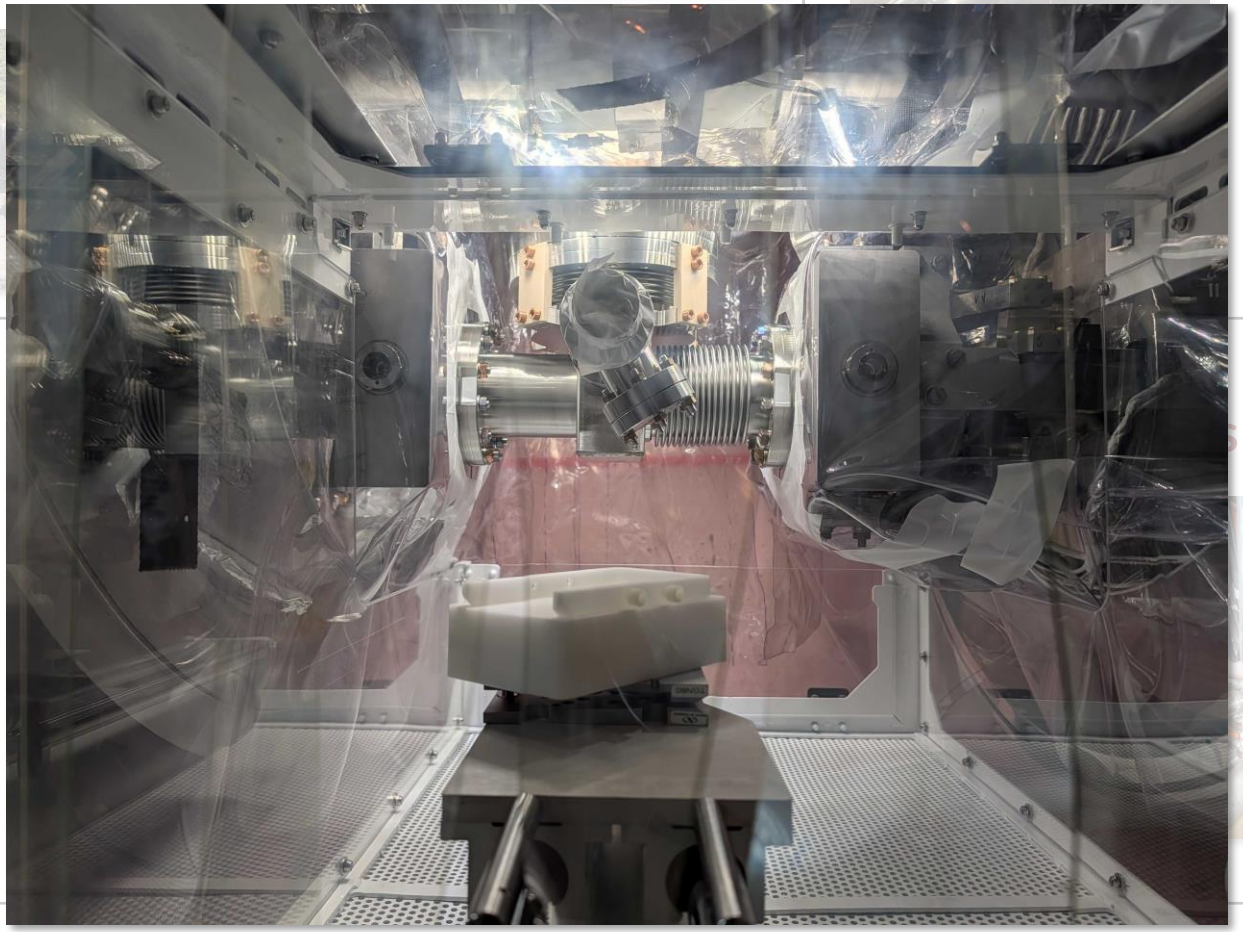
100% Controls Cables and Racks Installed



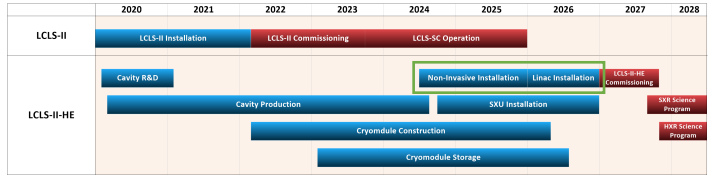


100% Waveguides Installed

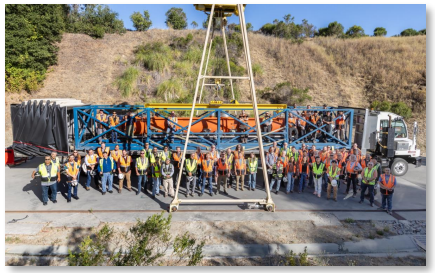
13/25 Particle Free Connections Complete



Installation Progress

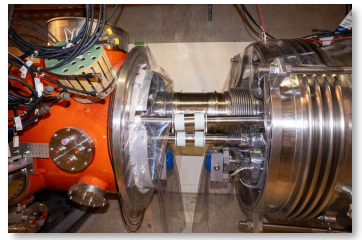


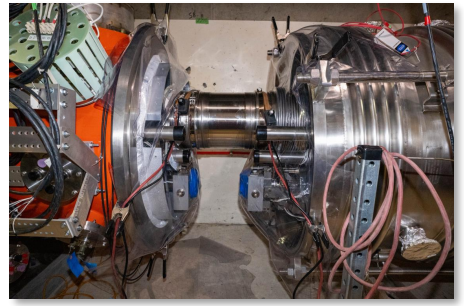
All 23 Cryomodules Installed

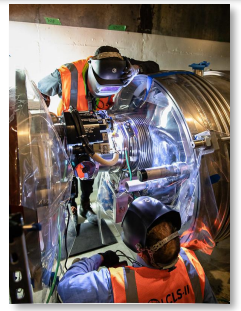


All CDS Components Installed

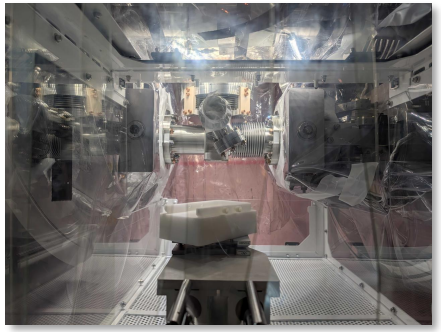
20/25 Interconnect Welds Complete

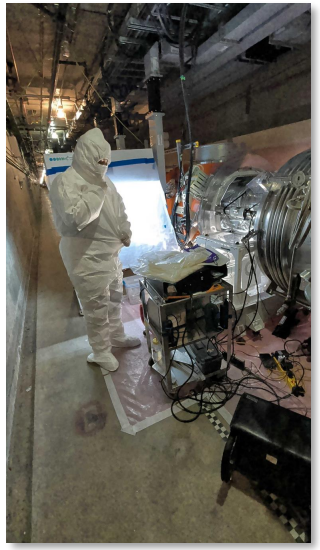




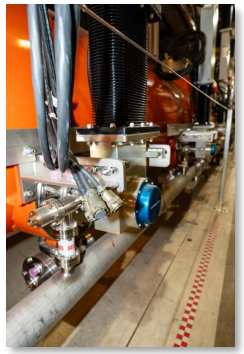


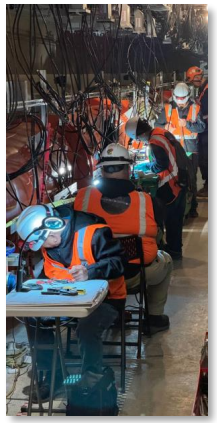
13/25 Particle Free Connections Complete





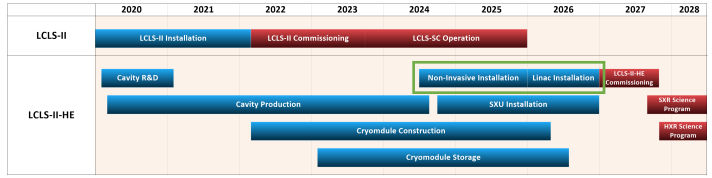
100% Controls Cables and Racks Installed



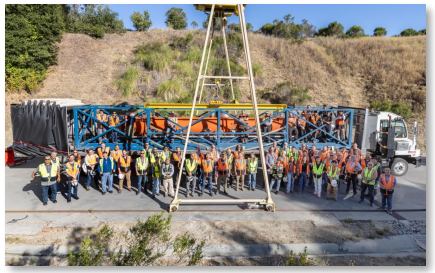


100% Waveguides Installed

Installation Progress

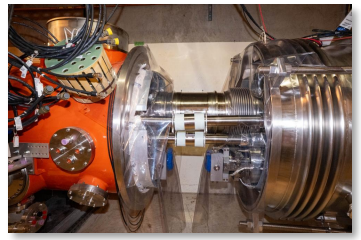


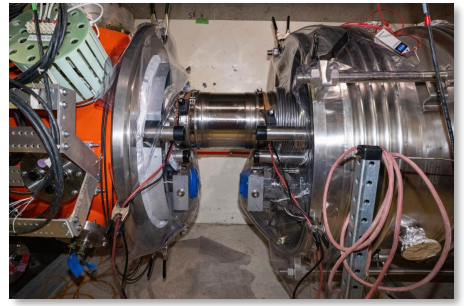
All 23 Cryomodules Installed

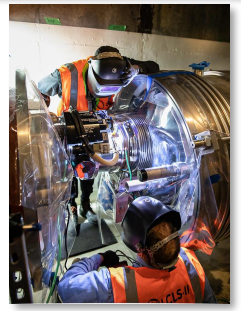


All CDS Components Installed

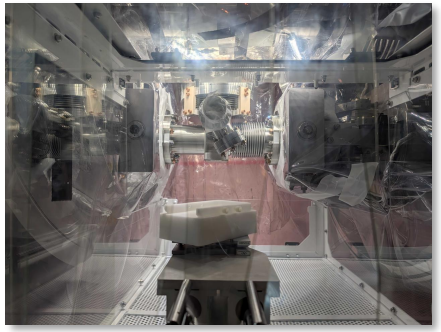
20/25 Interconnect Welds Complete

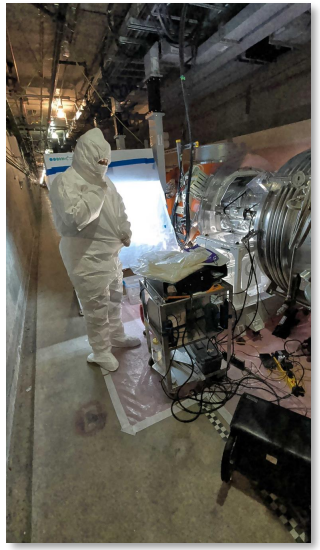




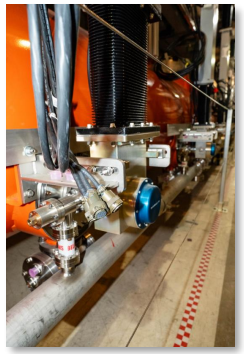


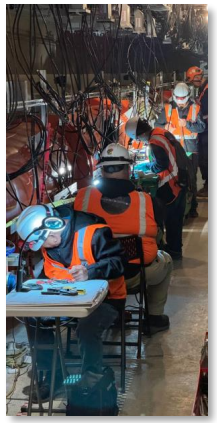
13/25 Particle Free Connections Complete





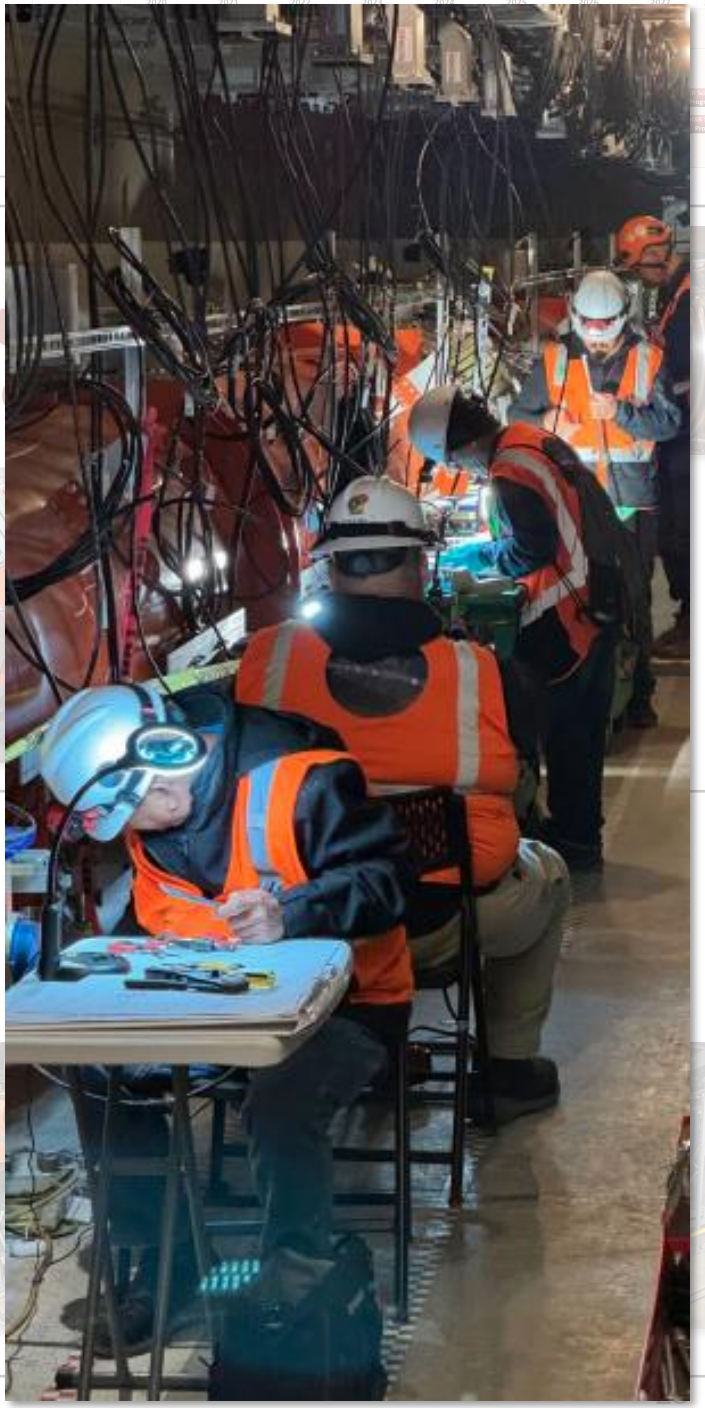
100% Controls Cables and Racks Installed



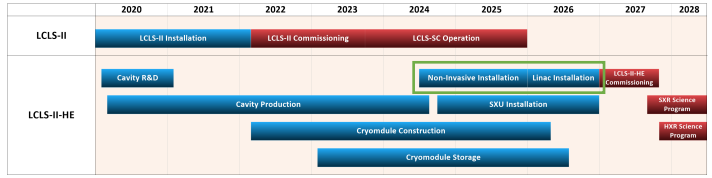


100% Waveguides Installed

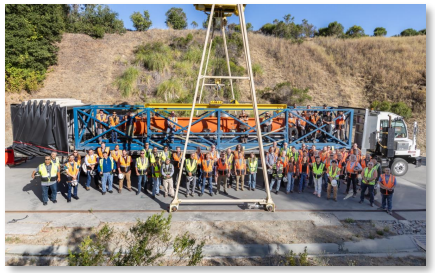
100% Controls Cables and Racks Installed



Installation Progress

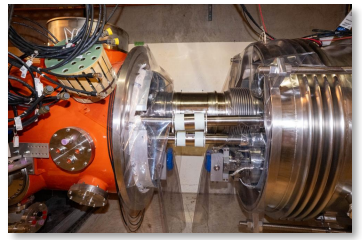


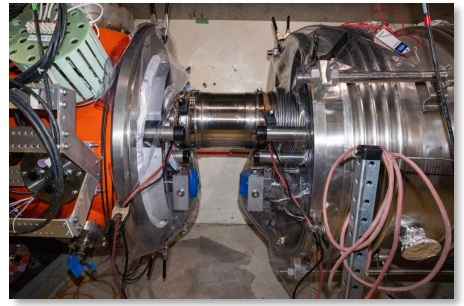
All 23 Cryomodules Installed

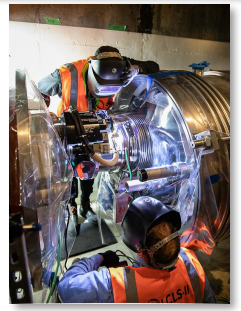


All CDS Components Installed

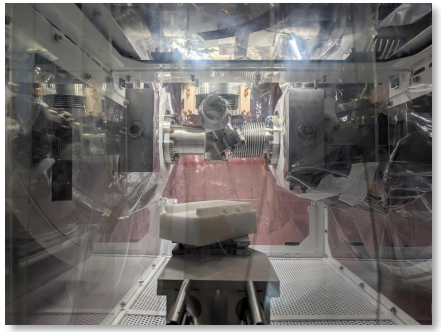
20/25 Interconnect Welds Complete

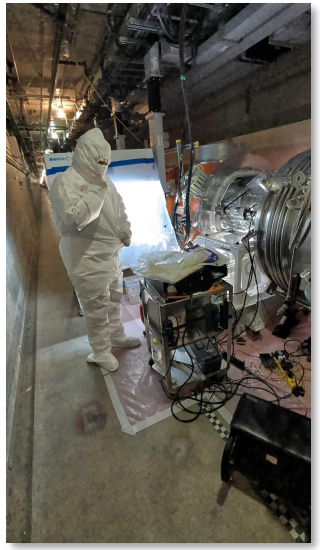




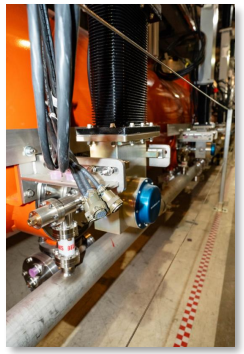


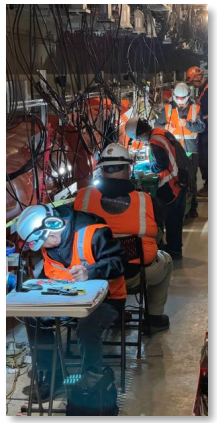
13/25 Particle Free Connections Complete





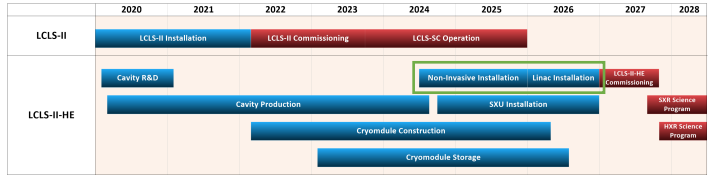
100% Controls Cables and Racks Installed



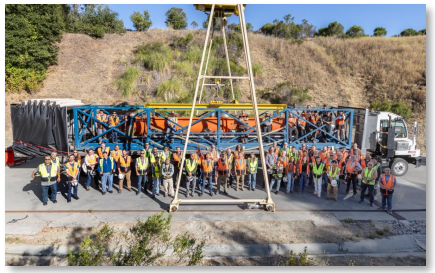


100% Waveguides Installed

Installation Progress

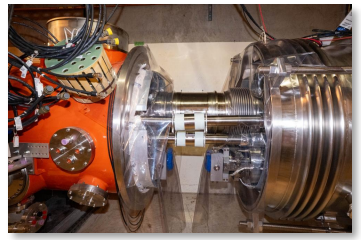


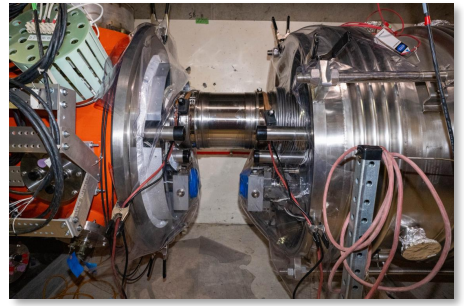
All 23 Cryomodules Installed

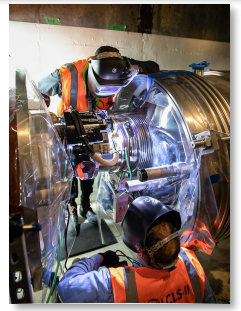


All CDS Components Installed

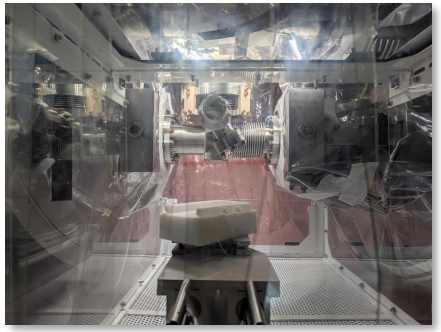
20/25 Interconnect Welds Complete

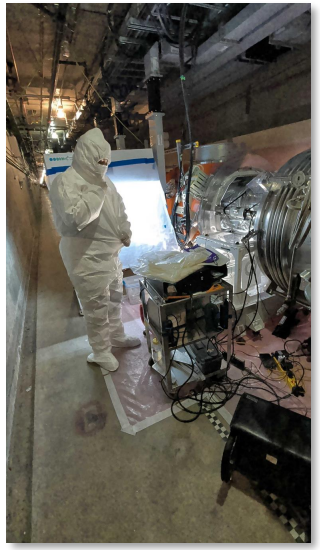




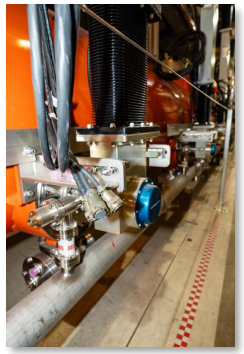


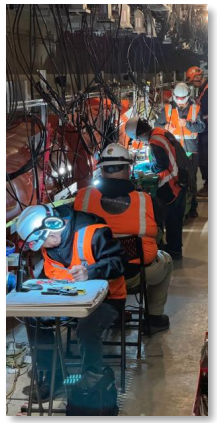
13/25 Particle Free Connections Complete





100% Controls Cables and Racks Installed





100% Waveguides Installed

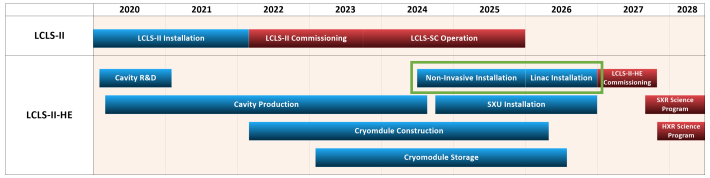
100% Waveguides Installed

A
Co
Installed

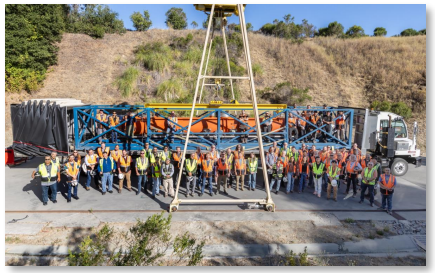
20/25
Interconnect
Welds Complete

13/25 Particle
Free Connections
Complete

Installation Progress

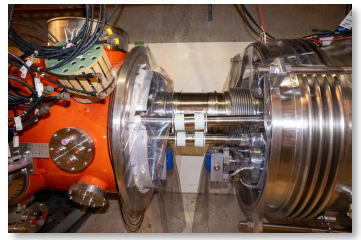


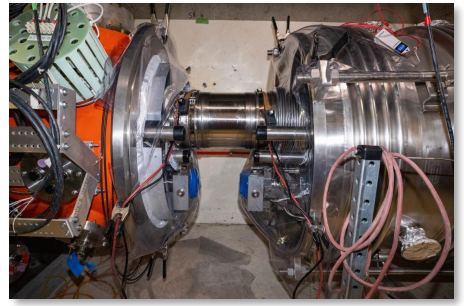
All 23 Cryomodules Installed



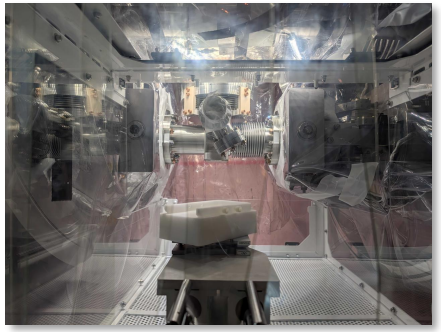
All CDS Components Installed

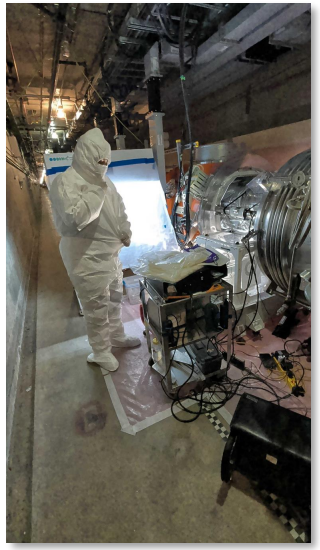
20/25 Interconnect Welds Complete



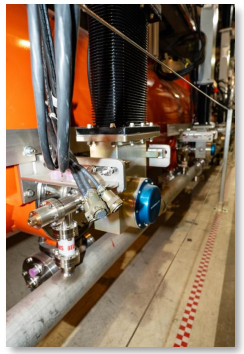


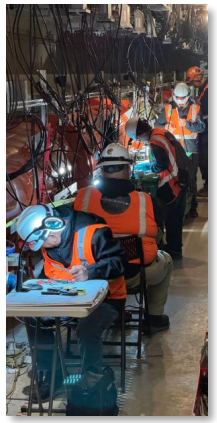
13/25 Particle Free Connections Complete





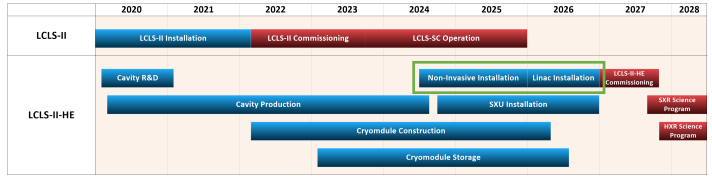
100% Controls Cables and Racks Installed





100% Waveguides Installed

CM Repair Work in Upstream Linac

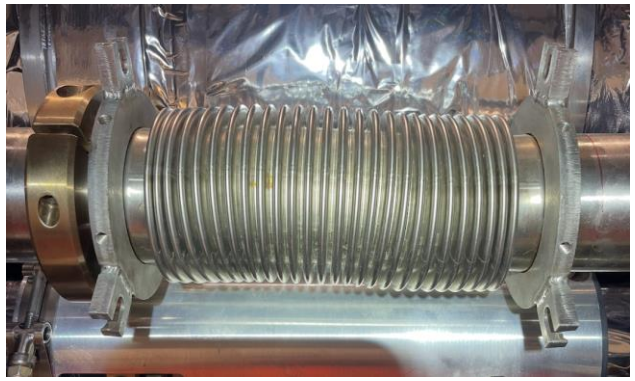


Cryomodule Replacements

2 cryomodules replaced:

- Excessive field emission limiting cavity gradients
- Suspected helium leaks to insulating vacuum:
  100-200 W of additional static heat load at 2 K

CDS Repair

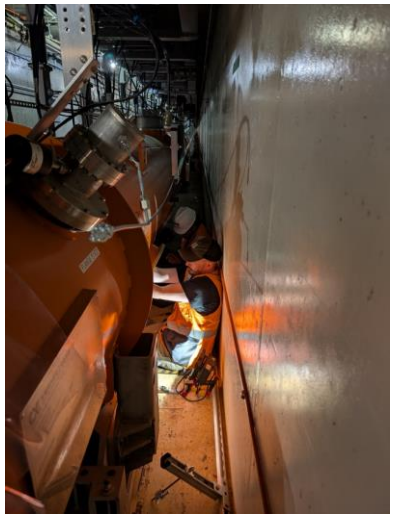


Bellows replaced at Line A interconnect

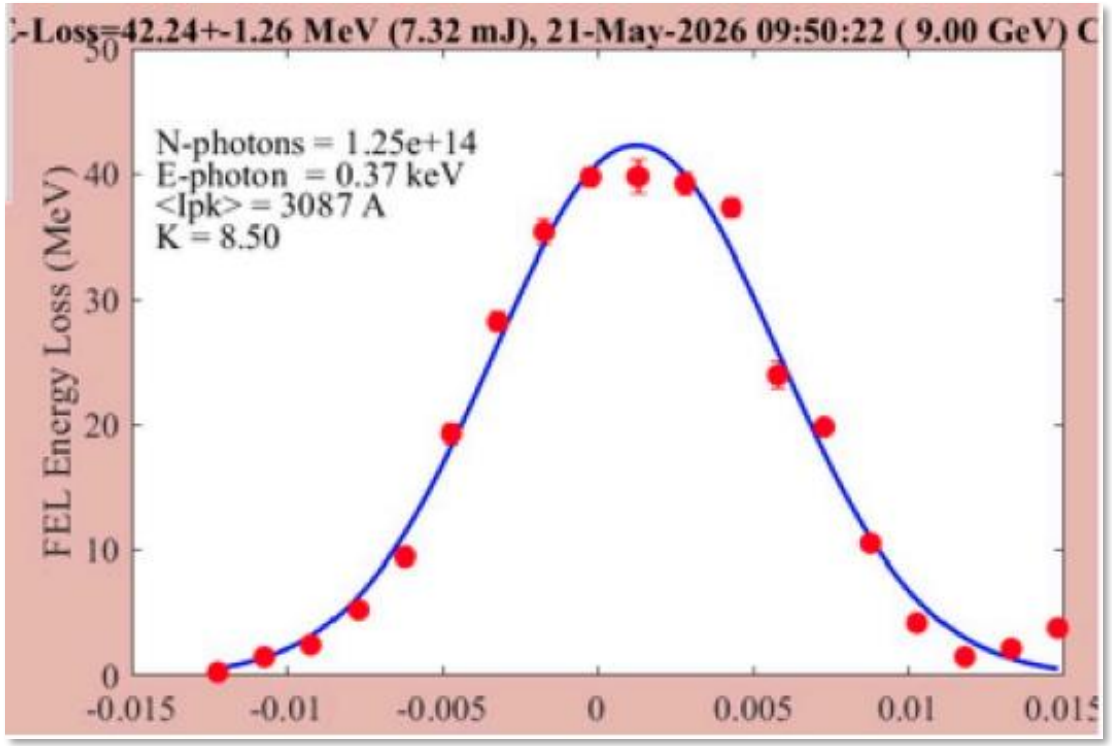
- Helium leak identified
- Expected 300 W of additional static heat load at 2 K

CM *In Situ* Repairs

- 12 of 13 faulty tuners repaired
- 1 of 2 coupler issues resolved



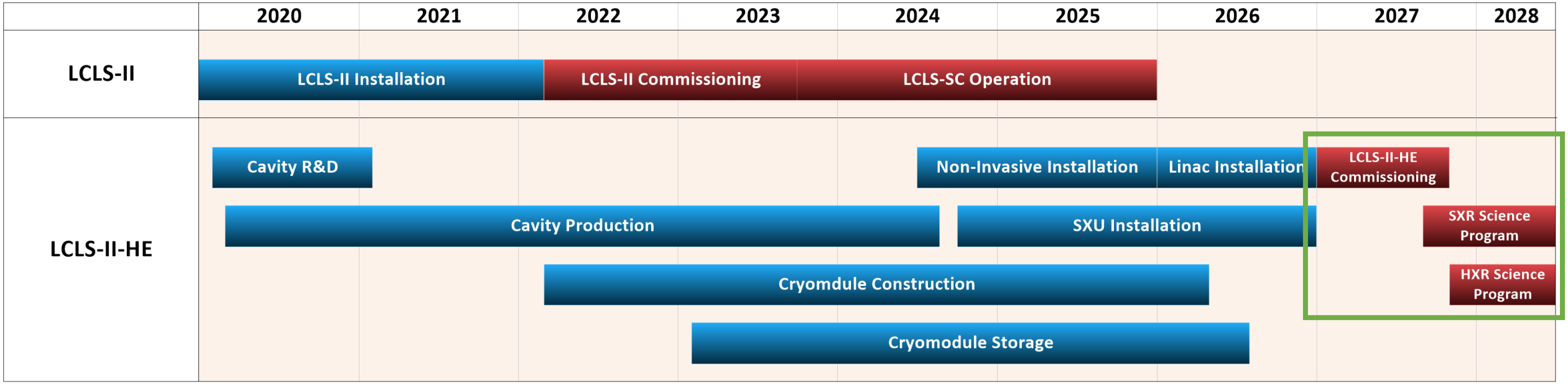
Undulator Installation & Experience

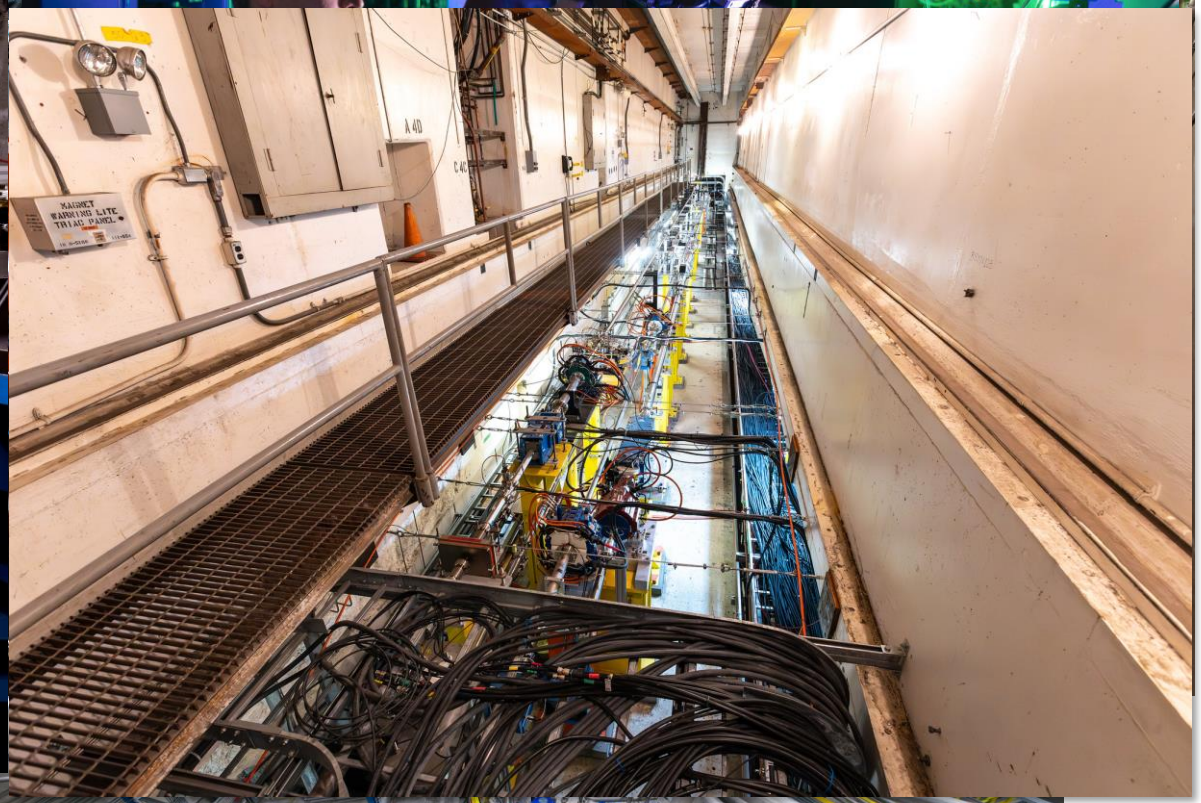


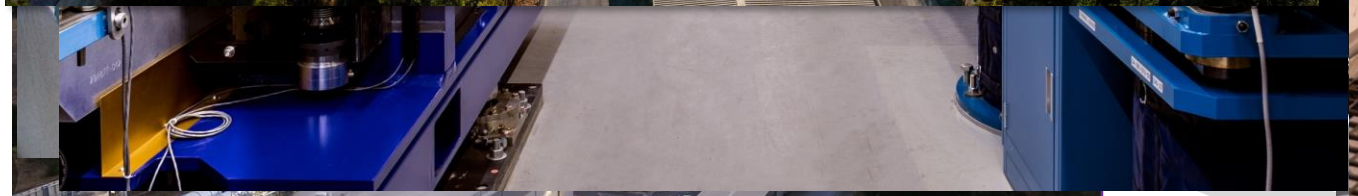
Record 7.3 mJ with the Cu Linac and LCLS-II-HE undulators!

- 26 of 30 new long-period undulators installed and in operation with the copper linac
- Remaining undulators will be installed this fall

Commissioning





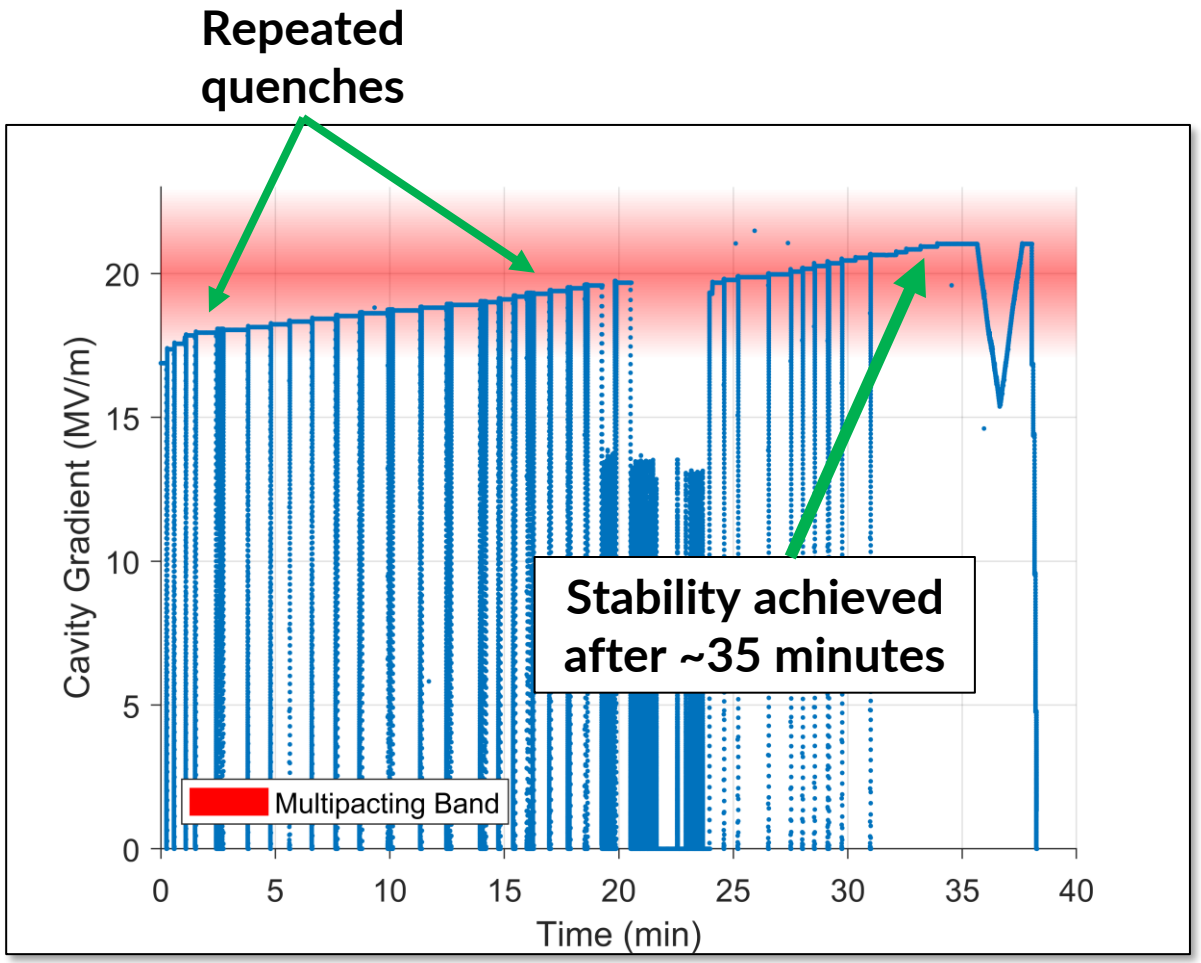


sioning

– Aug '27

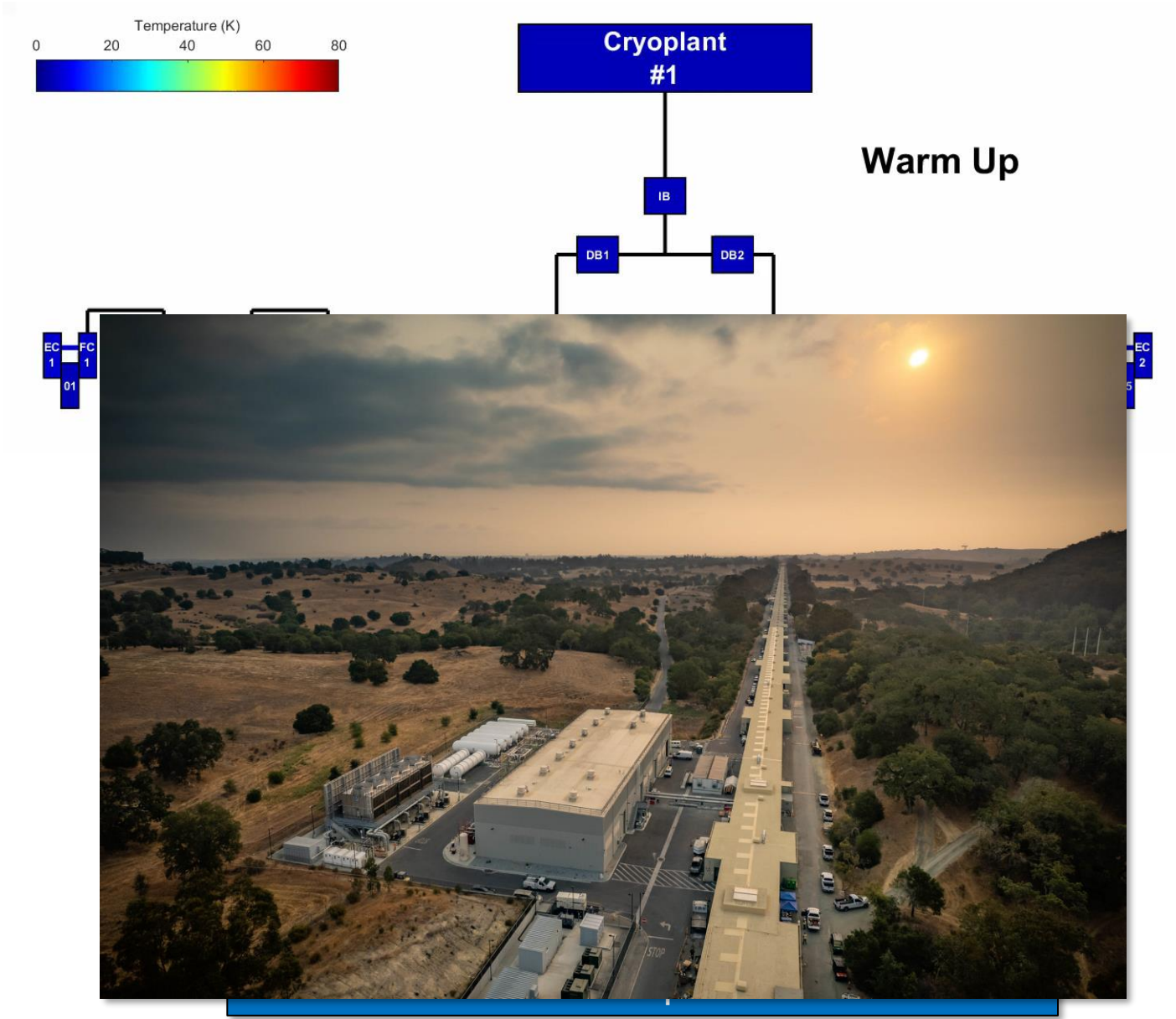
Expected Challenges: Multipacting Processing

- Multipacting identified as a gradient limitation for LCLS-II cavities late in CM production
- Observed as a short term stability at gradient in the band of 17-23 MV/m
- Processing techniques developed and tested during LCLS-II-HE cryomodule testing
- Requires significant time during the CM checkout process
- Was carried out during all HE CM test and is planned as part of cavity commissioning

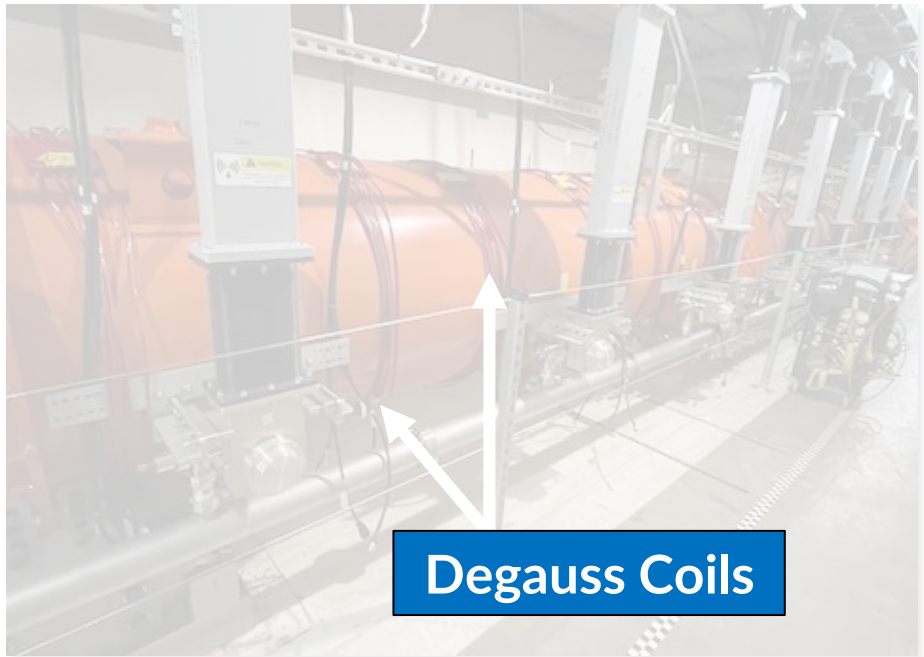


Multipacting processing is required to operate at HE gradients

Expected Challenges: Cryoplant Overhead



Running at 8 GeV on the two available cryoplants will be challenging



Summary

- LCLS-II-HE will double the electron beam energy of the LCLS SC Linac from 4 to 8 GeV, enabling up to 12.8 keV x-rays
- Installation is well underway with physical installation nearing completion and controls checkouts starting
- 2 of the existing cryomodules have been replaced and multiple cavities have been repaired during this down time
- Cool down and commissioning is expected to begin in January and last the majority of 2027

LCLS-II-HE Will Begin Delivering X-Rays to Users in Mid-2027!


Thank you
BERKELEY LAB
Fermilab
FACILITY FOR
RARE ISOTOPE BEAMS
Jefferson Lab
SLAC
NATIONAL
ACCELERATOR
LABORATORY
Stanford
University
U.S. DEPARTMENT OF
ENERGY