LCLS-II

Update and Lessons Learned from LCLS-II CM Production

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SLAC NATIONAL ACCELERATOR LABORATORY

BERKELEY LAB Lawrence Berkeley National Laboratory

Argonne NATIONAL LABORATORY

Cornell University

Fermilab

Jefferson Lab

U.S. DEPARTMENT OF ENERGY Office of Science

Outline

What are we doing?

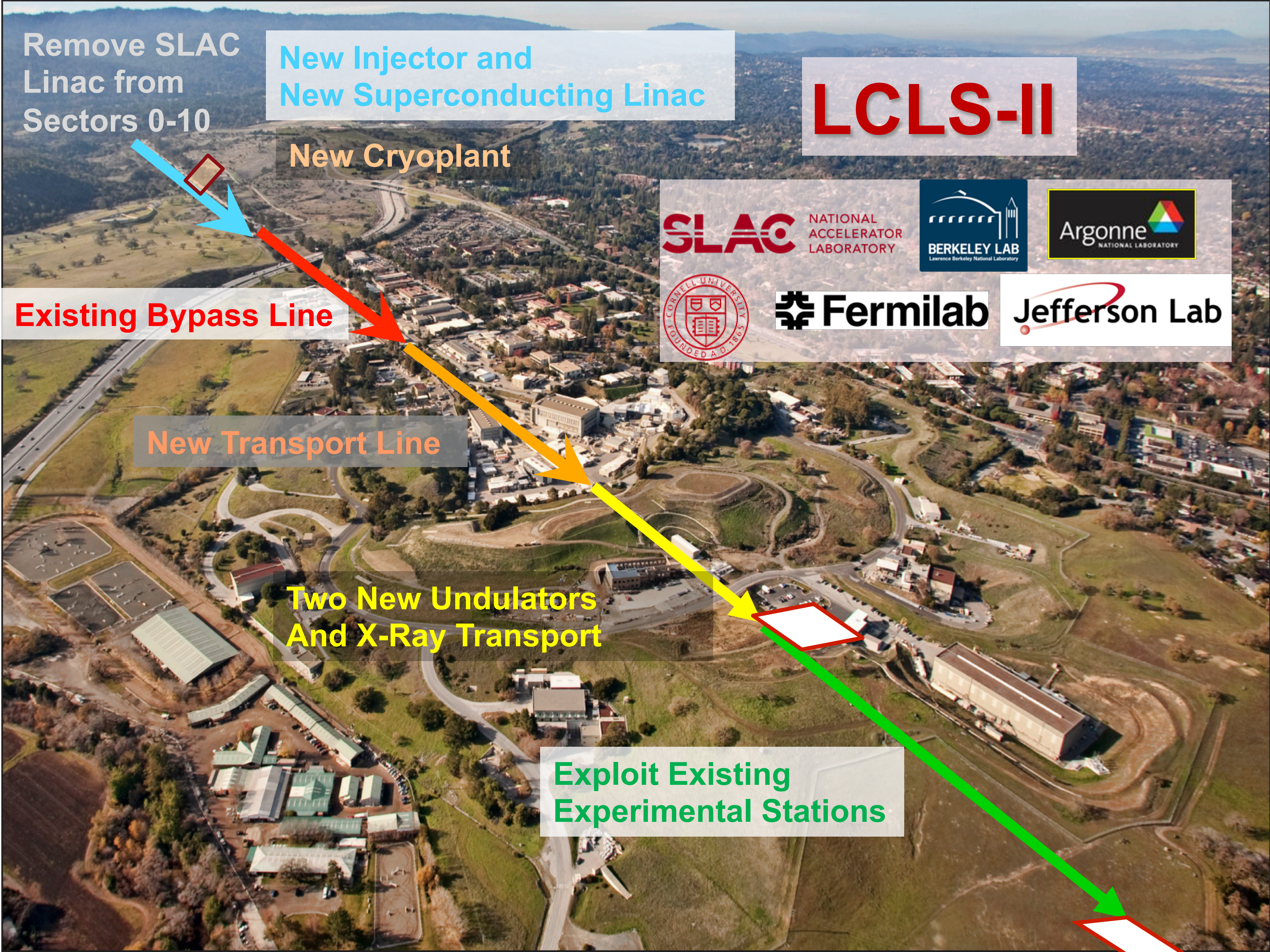
- LCLS-II Overview
- SRF Scope

How are we doing?

- Partner Lab arrangement
- Cavity and CM progress and statistics
- CM Installation plan

What should we have done differently?

- Lessons Learned


Remove SLAC Linac from Sectors 0-10
New Injector and New Superconducting Linac
LCLS-II
New Cryoplant
Existing Bypass Line
New Transport Line
Two New Undulators And X-Ray Transport
Exploit Existing Experimental Stations

Mission Need, Scope & Key Performance Parameters

- LCLS-II adds a 4 GeV SC linac to the first kilometer of the SLAC linac tunnel.
  -The copper linac in that region will be removed
- The new beam will run CW at up to 1 MHz
  -The LCLS-1 linac is not altered, retains performance
- The new beam can be directed at either of two new undulators
  -The LCLS-1 beam can be directed to the new Hard X-ray Undulator

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MISSION NEED STATEMENT

for the

LINAC COHERENT LIGHT SOURCE-II (LCLS-II)

Major Acquisition Project

Office of Basic Energy Sciences

Office of Science

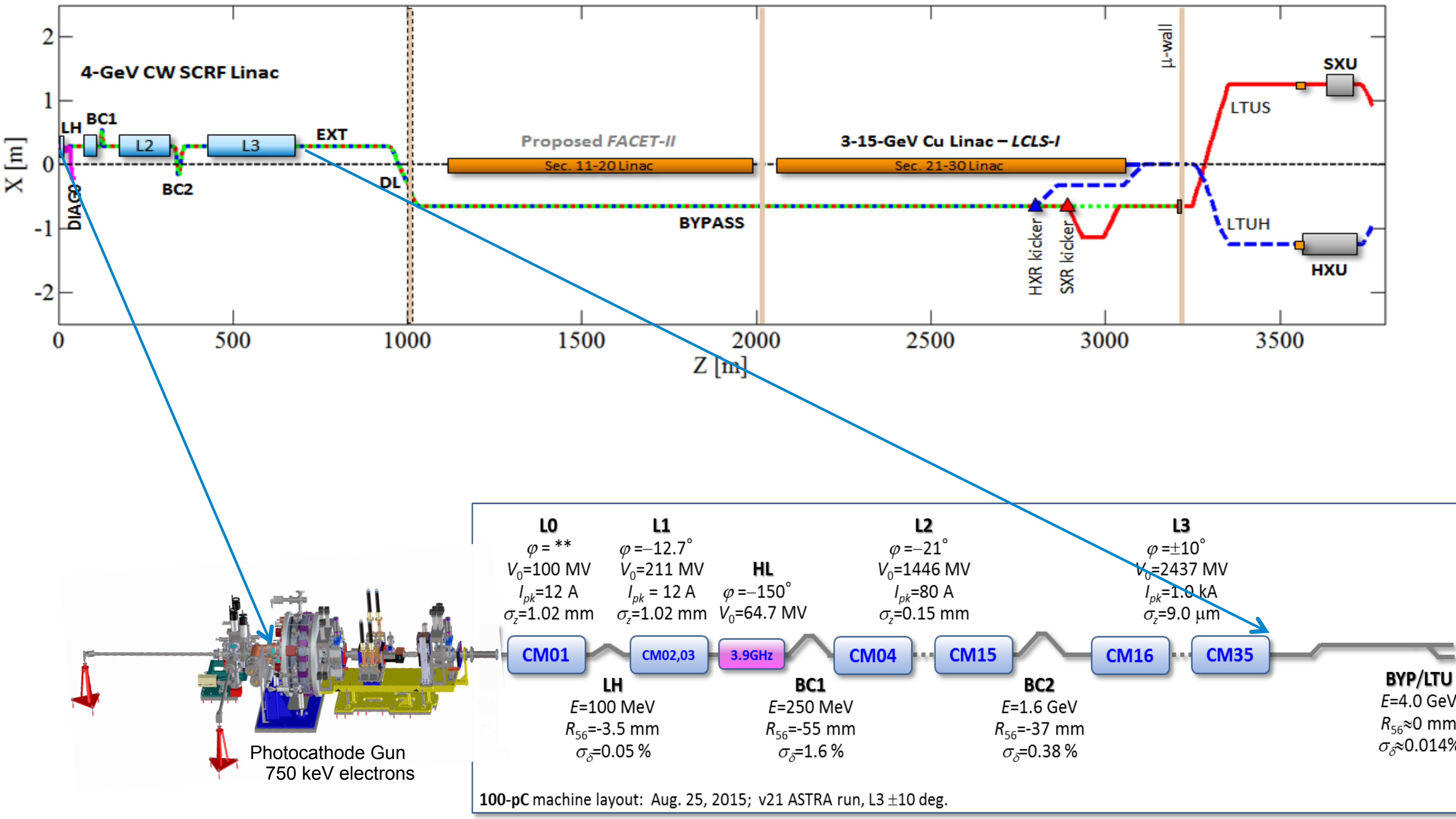
U.S. Department of Energy

Revised and Approved:
September 2013

Key Performance Parameters for LCLS-II

Performance Measure	Threshold	Objective
Variable Gap Undulators	2 (SXR & HXR)	2 (SXR & HXR)
Super Conducting Linac Based FEL System		
Super Conducting Linac Energy	3.5 GeV	$\geq$ 4 GeV
Electron Bunch Repetition Rate	93 kHz	929 kHz
Super Conducting Linac Charge per Bunch	0.02 nC	0.1 nC
Photon Beam Energy Range	250-3,800 eV	200-5,000 eV
High Repetition Rate Capable End Stations	$\geq$ 1	$\geq$ 2
FEL Average Power (10^-3 BW)	5×10^{8} (10x spontaneous @2,500 eV)	$>10^{11}$ @ 3,800 eV
Normal Conducting Linac Based FEL System		
Normal Conducting Linac Electron Beam Energy	13.6 GeV	15 GeV
Electron Bunch Repetition Rate	120 Hz	120 Hz
Normal Conducting Linac Charge per Bunch	0.1 nC	0.25 nC
Photon Beam Energy Range	1,000-15,000 eV	1,000-25,000 eV
Low Repetition Rate Capable End Stations	$\geq$ 2	$\geq$ 3
FEL Photon Energy (10^{-3} BW[a])	10^{10} (lasing @ 15,000 eV)	$> 10^{12}$ @ 15,000 eV

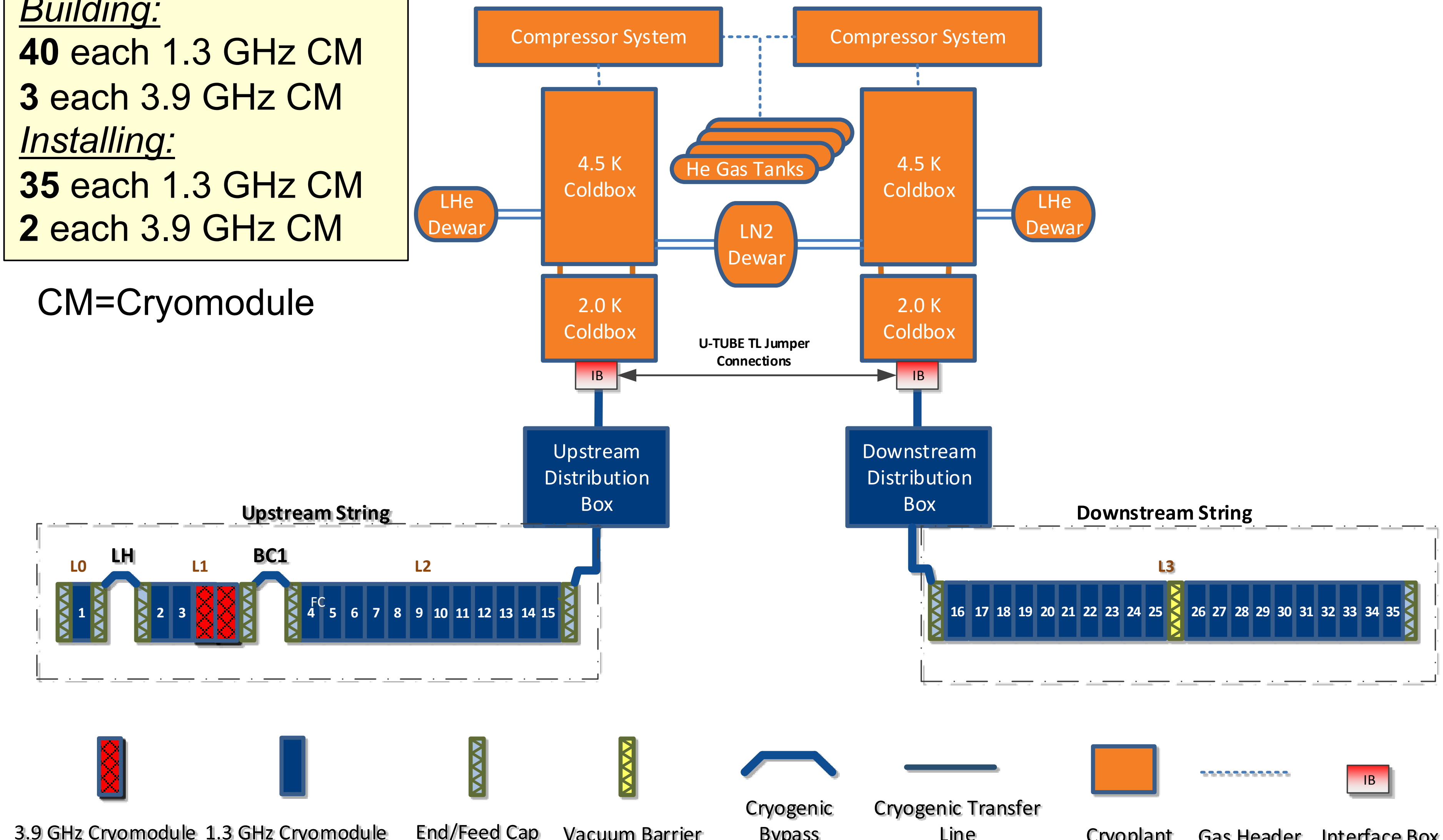
Linac Layout



Cryogenic Systems overview:

Building:
40 each 1.3 GHz CM
3 each 3.9 GHz CM
Installing:
35 each 1.3 GHz CM
2 each 3.9 GHz CM

CM=Cryomodule



Partner Lab Scope

JLab

- **Assemble 21 – 1.3 GHz CM's**
  - 20 production + 1 spare
  - Cryomodule15 string assembly is complete.
  - 9 additional CM strings must be built (includes 3 rebuilds)
- **Test 14 additional CM's**
  - 9 CM tests complete
  - 13 additional JLab CM's to test
  - 2 FNAL CM's
    - F1.3-03 and F1.3-06 will be tested at JLab to improve overall project schedule.*
  - Testing complete March 2020
- **Ship 19 CM's to SLAC for operations**
  - 18 – 1.3 GHz for installation, 1 spare
  - 2 CM's are ready to ship now
  - CM shipments for installation complete **Late 2019**

FNAL

- **Assemble 19 – 1.3 GHz CM's and 3 – 3.9 GHz CM's**
  - Cryomodule 14 string assembly is complete
  - 11 additional CM strings must be built (includes 3 rebuilds)
- **Test 11 additional CM's**
  - 12 CM tests complete. (3 must be re-tested)
  - 10 – 1.3 GHz CM tests
  - 3 – 3.9 GHz CM tests
  - Testing complete August 2019*
- **Ship 20 CM's to SLAC for operations**
  - 17 – 1.3 GHz, 3 – 3.9 GHz (1 spare)
  - 3 CM's are ready to ship now
  - CM shipments for installation complete **Late 2019**

Plan at SLAC

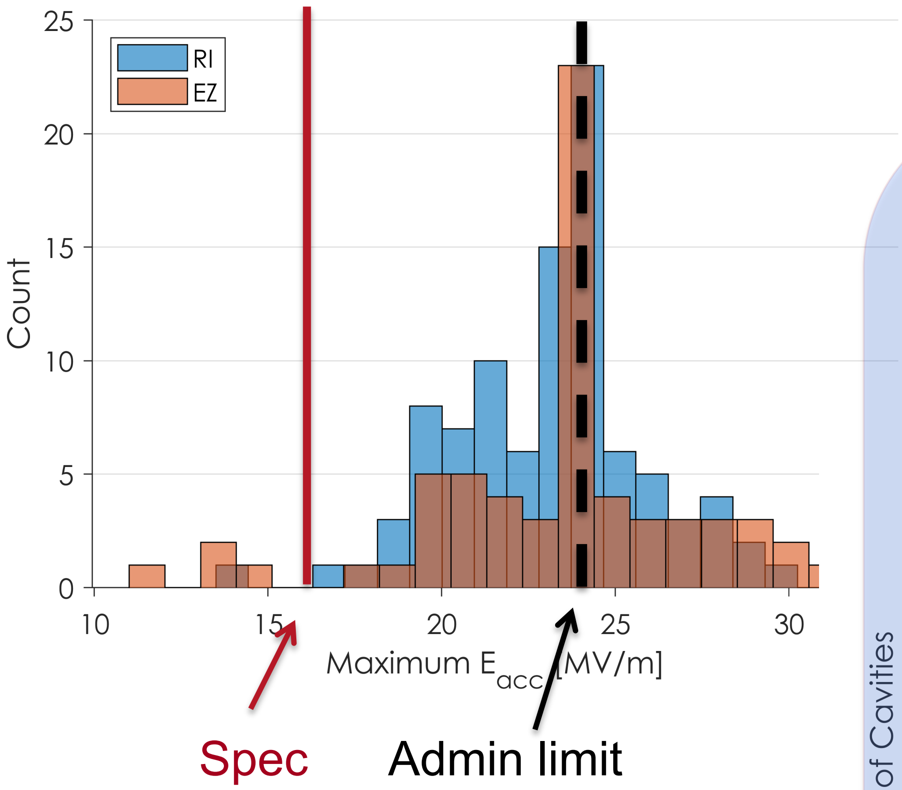
- SLAC is ready for receipt of CM's at the sector 10 adit
- Receive and install 37 CM's (35 – 1.3 GHz, 2 – 3.9 GHz)
- Safely store spare CM's
- Weld cryogenic interconnect piping between all CM's, end-caps and feed-caps in the linac
- Particle free installation of beamline higher order mode dampers between cryomodules
- Prepare commissioning documentation, databases and procedures
- Continue to participate in CM testing at partner labs
- Ensure smooth integration of CMs with the cryogenic plant

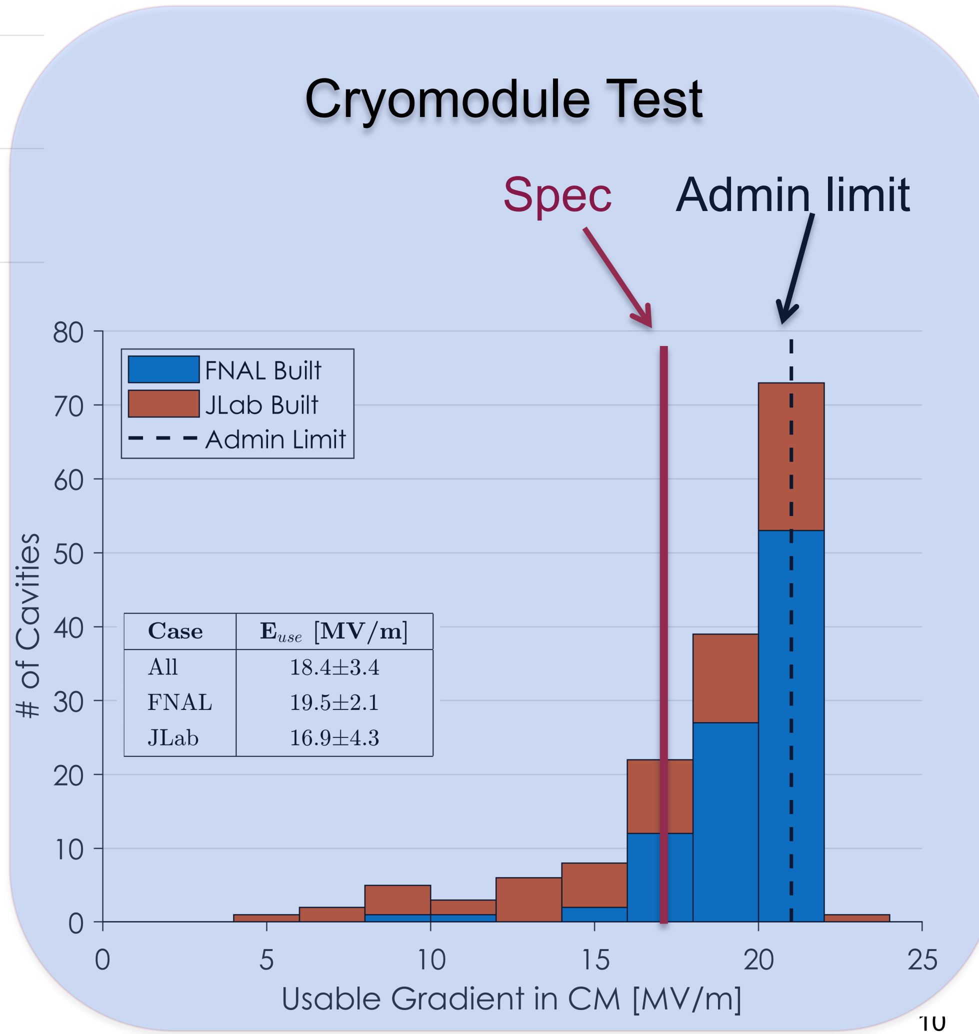
Commissioning at SLAC will be a team effort. SLAC, JLab, FNAL

Cryomodule Usage Plan

- Install 35 – 1.3 GHz and 2 – 3.9 GHz CM's that meet the acceptance testing criteria.
- Select CM's that will allow for long term operation with 1 cryoplant
  - Commissioning and early operation will utilize both cryoplants
  - **Goal to keep 2K load below 4 kW.**
- Done by optimizing operating gradient of each cavity in each CM.
- Goal of the optimization is to minimize the heat load to 2K while providing an average CM voltage of 128 MV **(required for Objective KPP of 4 GeV beam)**

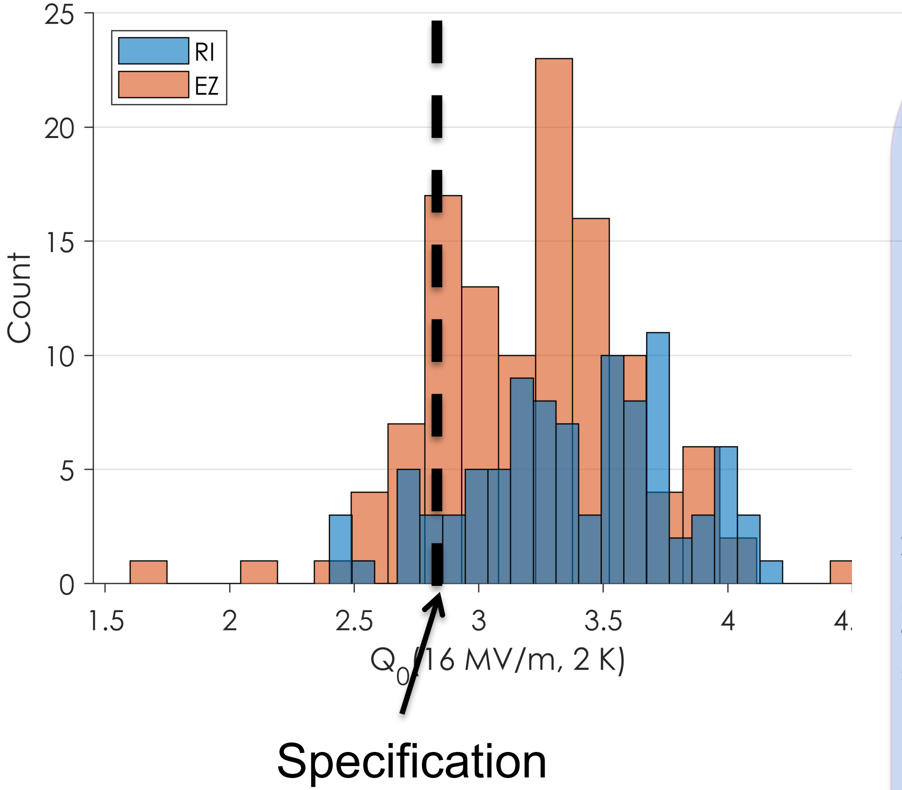
Cavity Gradient Reach VT and CM

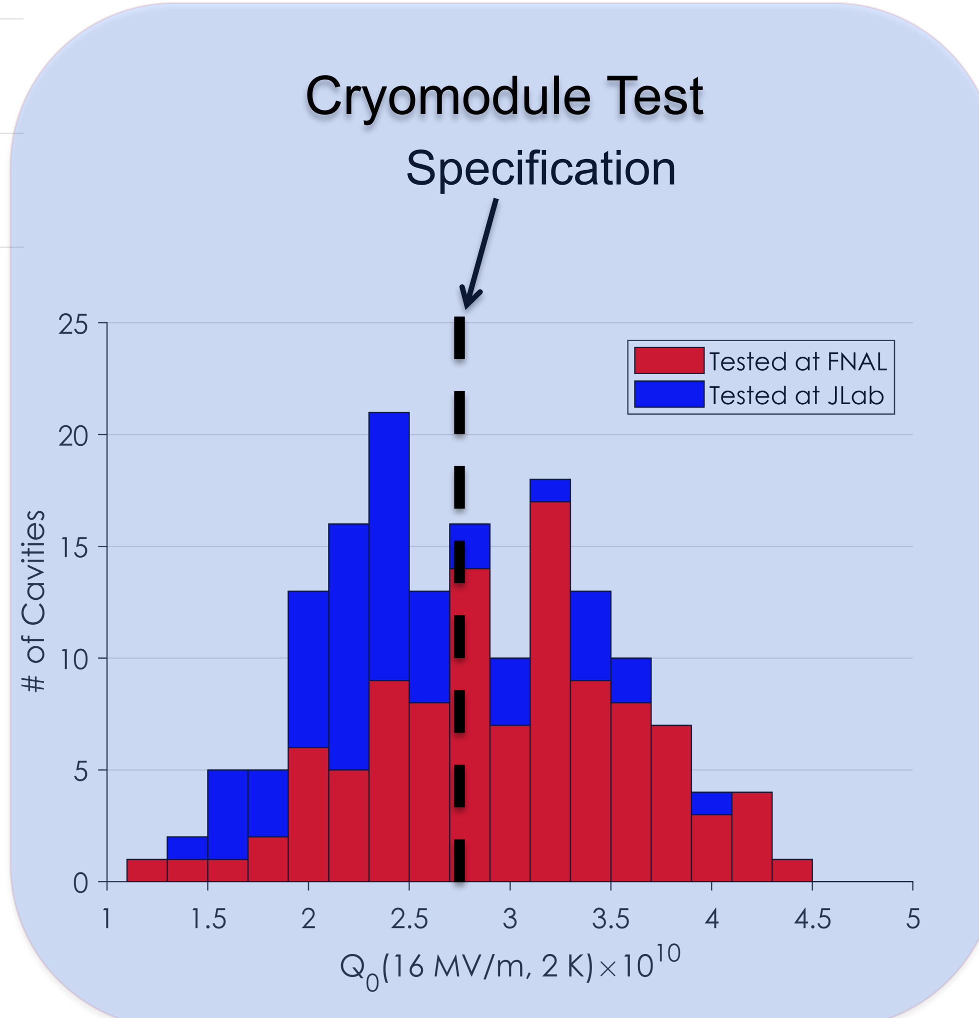




Case	E_{use} [MV/m]
All	18.4±3.4
FNAL	19.5±2.1
JLab	16.9±4.3

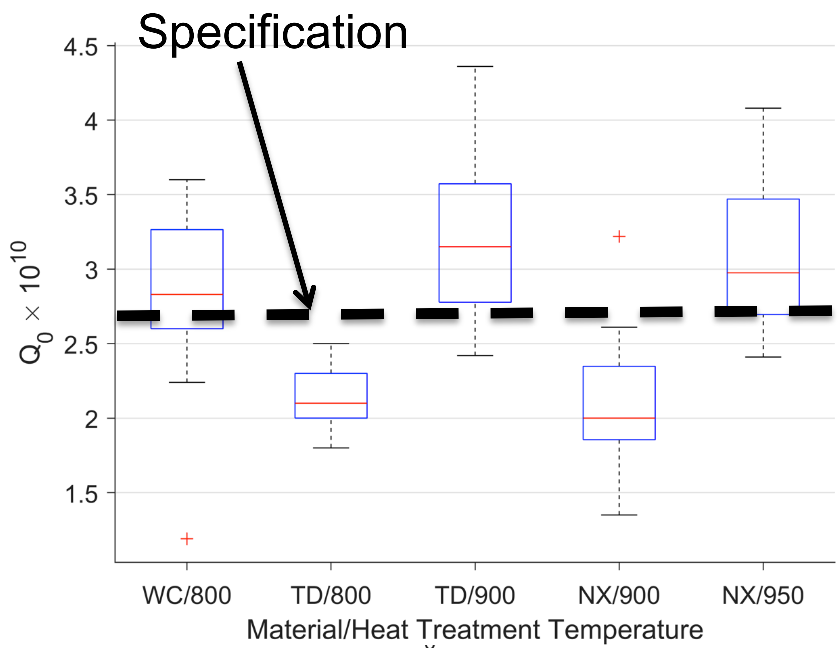
Cavity Q_0 Performance VT and CM





Cryomodule Gradient Optimization

- Flux trapping and thus Q depression varies based on material type and cavity preparation.
- Required "fast" cooldown rate varies based on material
  - 30 g/sec – spec
  - 80 g/sec required for some material
  - Some material simply traps 100% of trapped flux.
- JLab only recently achieved ~30 g/sec cooldown
  - Early JLab CM test had low measured Q due to slow cooldown rate
  - **This does not represent true CM performance**



Boxplot by Material Type
- Red line is Median for each type
- Blue box is 25th – 75th quartile
- Whiskers are min and mix
- + and * are outliers

Cryomodule Operation Plan

SLAC

- Minimize 2K heat load through optimization of operating point of each cavity.
- Done based on CM test performance at partner labs
- Ensure linac ensemble average produces 4 GeV beam
- Limit maximum operating gradient to 18.2 MV/m to remain within available RF power limit

Case	P_{diss}/CM [W]	Extrapolated Total CP Load [kW]
JLab Q's Estimated	76.4	3.67
JLab Q's as Measured	81.8	3.85

Single cryoplant operation is achievable

CM Q_0 Performance

SLAC

Cryomodule Heat-Load (Average Q_0) Test Results

	X 10^{10}		X 10^{10}	
FNAL pCM	2.9	Jlab pCM	2.7 *	
F1.3-02	2.1	*J1.3-02*	*1.7*	Estimated Q_0's
F1.3-03	3.4	*J1.3-03*	*3.3*	
F1.3-04	3.1	*J1.3-04*	*3.3*	
F1.3-05	3.0	*J1.3-05*	*2.3*	
F1.3-06	1.9	*J1.3-07*	*2.6*	
F1.3-07	2.6	J1.3-08	2.5	
F1.3-08	2.3	J1.3-10	3.0	
F1.3-09	3.3			
F1.3-10	2.7			
F1.3-11	3.6			
F1.3-12	3.1	* tested at Fermilab		

- With fast cool down, most JLab CMs will have higher Q_0 than measured in CM test
- Expected performance with fast cool down based on cavity material makeup shown

Both 1.3-02 modules with low heat-treat cavities

Lessons Learned

1. Adopting a proven design is not a guarantee things will be trouble free.
2. Cavity material specification must be fully understood
    1. Especially important for doped cavities, or when material from different vendors is used
3. Engagement with vendors before and during production is key.
4. Open collaboration is required
5. Finish all prototyping before beginning production. Otherwise many of the lessons learned from the prototype cannot be implemented in production
6. Utilize multiple suppliers and partners wherever possible.

Summary

- SRF Cavity and CM performance is going well.
- Nitrogen doped cavities exceeds Q specification.
- Magnetic hygiene and shielding in the CM works very well.
- Deliveries to SLAC will start at the end of this month.
- Regular communication with vendors is critical.
- Discussions with labs who have done similar projects in the past is indispensible.

LCLS-II made possible on current timescale thanks to XFEL.