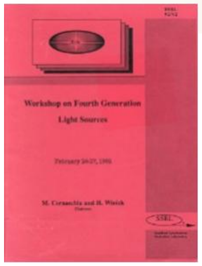
LCLS-II Update

John N. Galayda

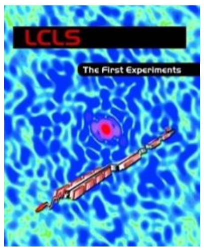
LCLS: 17 years from idea to first light



1992: Proposal (Pellegrini)

1997: BESAC (Birgeneau) Report

1999: BESAC (Leone) Report



2000: LCLS- the First Experiments (Shenoy & Stohr) SLAC-R-611<< for BES

2001: Critical Decision 0

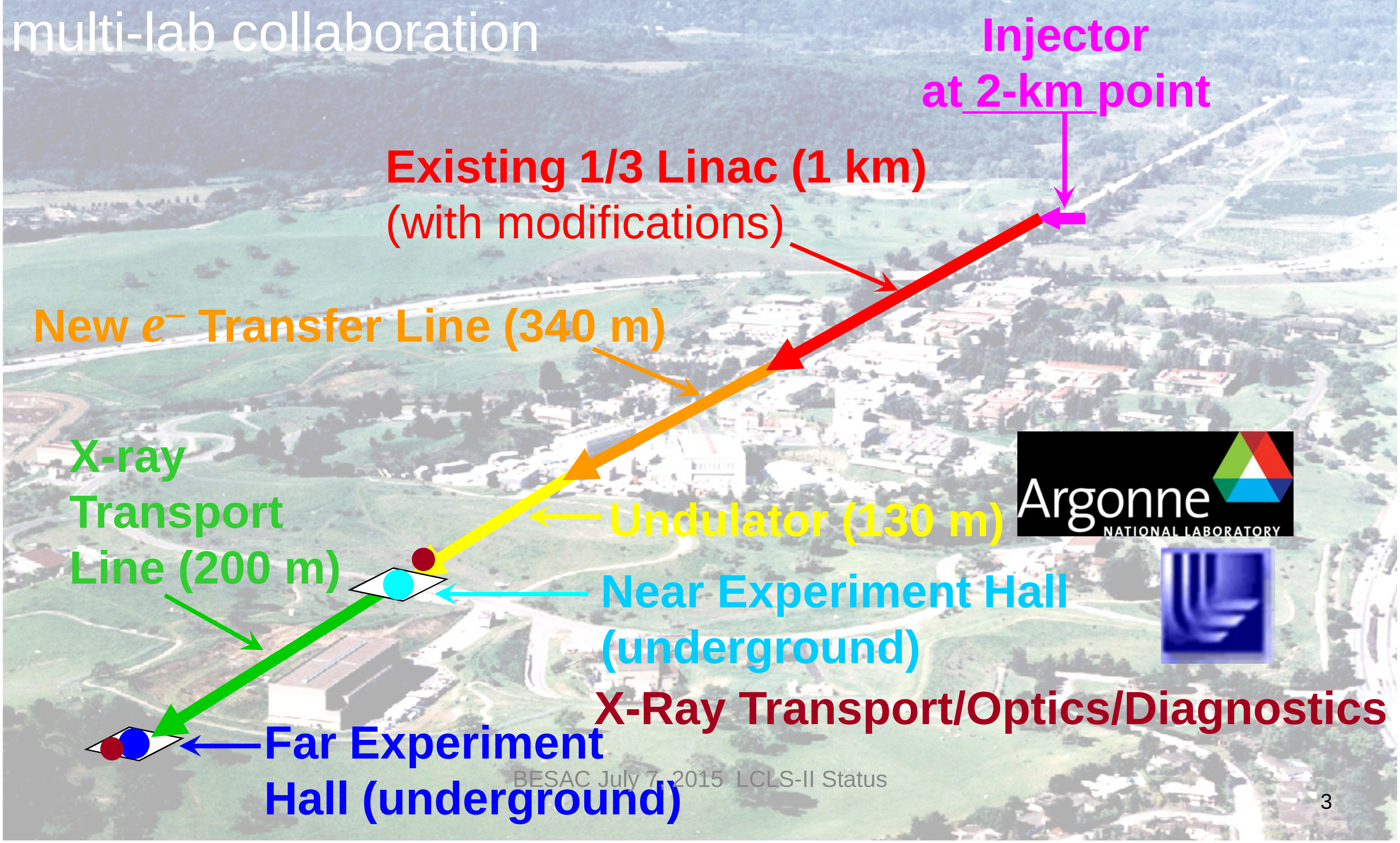
2002: Critical Decision 1

2005: Critical Decision 2
2006: Critical Decision 3

2009: First Light, 10 April
2010: Project Completion

LCLS Layout

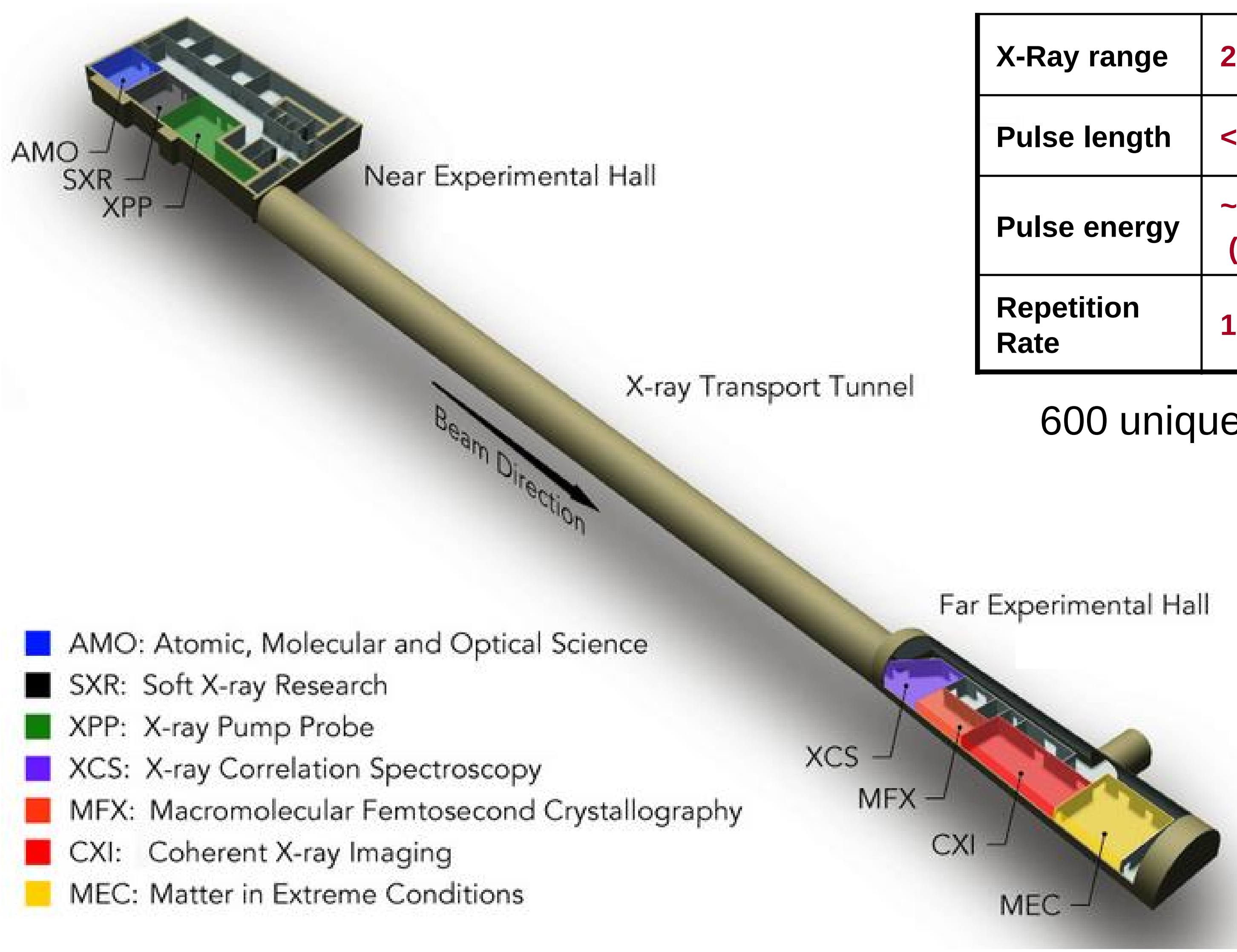
The LCLS Project was a successful multi-lab collaboration



LCLS Capabilities

SASE	LCLS Project Goals	Now	
Tuning Range	800-8,000 eV	280-12,000 eV	280-10,000 is routine
Energy per pulse, mJ	2 mJ	up to 6 mJ	Dependent on pulse duration
Pulse duration	250 fs	<2 to 500 fs	Dependent on photon energy
Self-Seeded operation			
Tuning Range		5,500-9,500 eV	Diamond monochromator
Soft X-rays		500-1,000 eV	Grating monochromator
Pulse Energy		0.3 mJ	typical
Pulse BW		0.4-1.1 eV	2-4X brighter than SASE

6 LCLS instruments are now operational, with a 7th under construction this summer



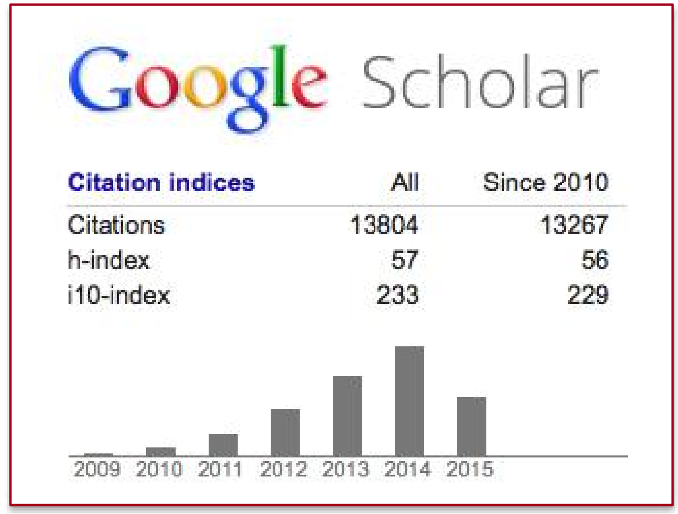
X-Ray range	250 to 11,300 eV
Pulse length	< 5 to 500 fs
Pulse energy	~ 4 mJ (2.5 * 10^{12} @ 10 keV)
Repetition Rate	120 Hz

600 unique users per year

Office of Science

LCLS scientific output since the instruments became operational in the 2009-2012 timeframe

	Total Publications	High Impact Publications
≤ 2010	91	16
2011	64	11
2012	125	38
2013	117	31
2014	128	33



138 high impact papers to date (2009-2015), including 25 in *Science* or *Nature*

See https://portal.slac.stanford.edu/sites/lcls_public/Pages/Publications.aspx

For an overview of science with x-ray FELs, see:

Nobel Symposium 158: Free Electron Laser Research is sponsored by the Nobel Foundation through its Nobel Symposia Fund and the Knut and Alice Wallenberg Foundation, and organised by Stockholm University.

The aim of the Nobel Symposium is to give an overview of free electron lasers from an accelerator physics point of view, and their use in research in the natural sciences.

Speakers from: USA, Italy, Germany, Switzerland, The Netherlands, Japan, UK

Special issue of J. Synch. Rad. w/intro: I. Schlichting, W. E. White and M. Yabashi

Scientific Achievement

A comprehensive description of the LCLS has been published, with 6 beamline papers, 9 research articles and 1 overview paper

Significance and Impact

This set of papers aims at providing detailed information on what the LCLS, as the first hard X-ray free electron laser user facility, offers to the scientific community in order to perform transformative science.

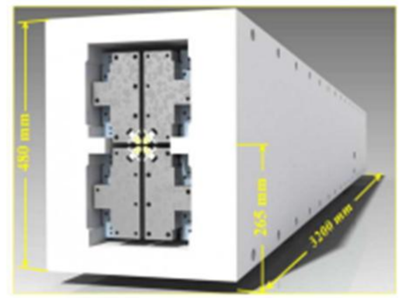
Research Details

- LCLS instruments: specifications of all soft X-ray (AMO, SXR) and hard X-ray end-stations (XPP, XCS, CXI, MEC)
- SLAC detectors: continuously improved towards LCLS II operation requirements
- Laser systems for pump-probe setups with high timing accuracy and control
- State-of-the-art X-ray characterization techniques

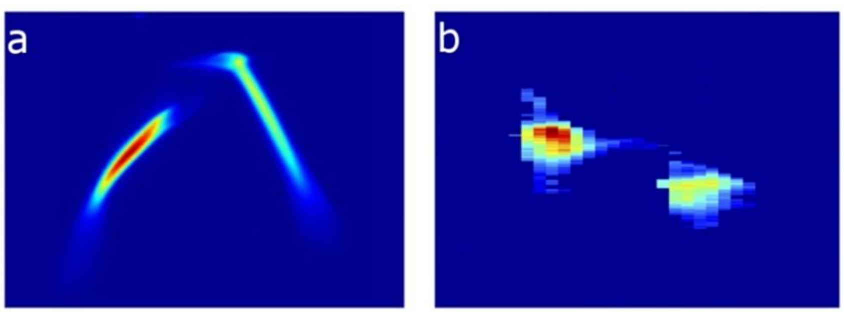
U.S. DEPARTMENT OF ENERGY
Office of Science

New operating modes

- Variable linear/circular polarization Delta Undulator)



- Multi-pulse operation (2-color, 2-pulse)



a) the energy profile of two electron bunches that are separated by about 6 picoseconds.
b) (b) two X-ray pulses of different energies separated by about 35 femtoseconds

By 2019, LCLS and SACLA will be joined by three new "Hard" X-ray FEL facilities

Name	Location	Electron sources	Undulator 1	Undulator 2	Undulator 3	First Light
LCLS	USA	17 GeV @ 120 Hz	0.28-12 keV			2009
SACLA: Spring-8	Japan	8.5 GeV @ 5x60Hz	to 20 keV	to 20 keV		2011 2014
European XFEL	Germany	17.5 GeV @ 3,000x10Hz	2.3 - 29 keV	2.3 - 29 keV	0.26-4.1 GeV	2016
PAL FEL	Korea	10 GeV @ 2x60Hz	to 20.6 keV	0.27-1.24 keV		2016
SwissFEL	Switzerland	5.8 GeV @ 2x100Hz	1.8-12.4 keV	0.18-1.8 keV		2017 2018
LCLS-II	USA	15 GeV @ 120 Hz 4 GeV @ 2x1 MHz	1-25 keV 1-5 keV	0.2-1.2 keV		2019 2019

Results from LCLS motivated plans to expand

- Starting in summer 2009

- Several alternatives considered
  - Existing SLAC linac was the starting point

- The 2013 BESAC subcommittee report provided crucial input:

BESAC Subcommittee Outcome: July 25, 2013

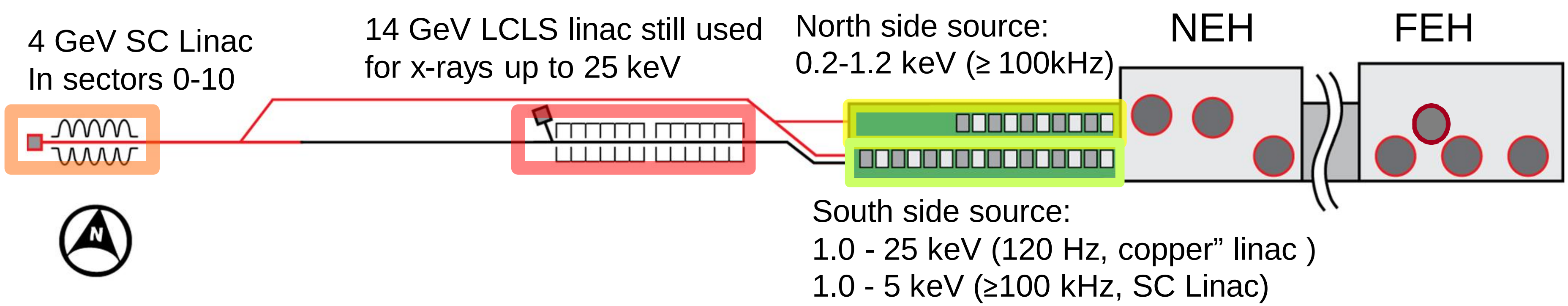
- Committee report & presentation to BESAC:
  - "It is considered essential that the new light source have the pulse characteristics and **high repetition rate** necessary to carry out a broad range of coherent "pump probe" experiments, in addition to a sufficiently broad photon energy range (**at least *~0.2 keV to ~5.0 keV***)"
  - "It appears that such a new light source that would meet the challenges of the future by *delivering a capability that is beyond that of any existing or planned facility worldwide is now within reach.* **However, *no proposal presented to the BESAC light source sub-committee meets these criteria*."**
  - "The panel recommends that a decision to proceed toward a new light source with revolutionary capabilities be accompanied by a robust R&D effort in accelerator and detector technology that will maximize the cost-efficiency of the facility and fully utilize its unprecedented source characteristics."

http://science.energy.gov/~/media/bes/besac/pdf/Reports/Future_Light_Sources_report_BESAC_approved_72513.pdf

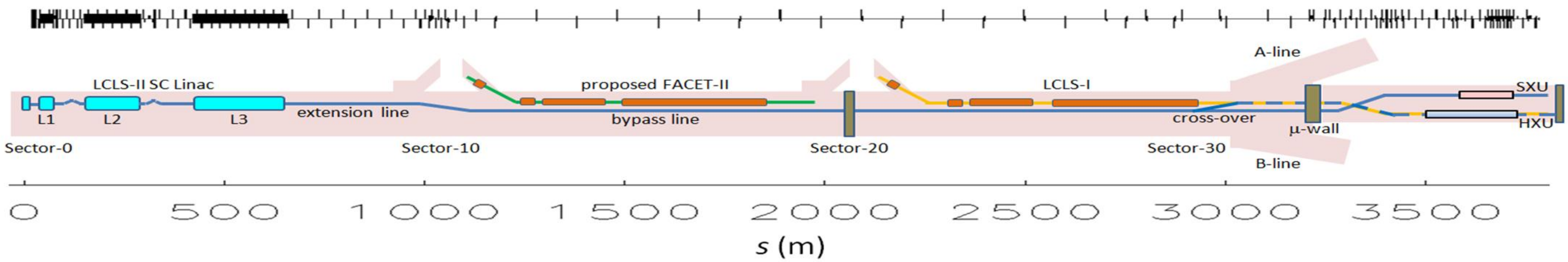
http://science.energy.gov/~/media/bes/besac/powerpoint/20130725/Hemminger_Presentation_July25.pptx

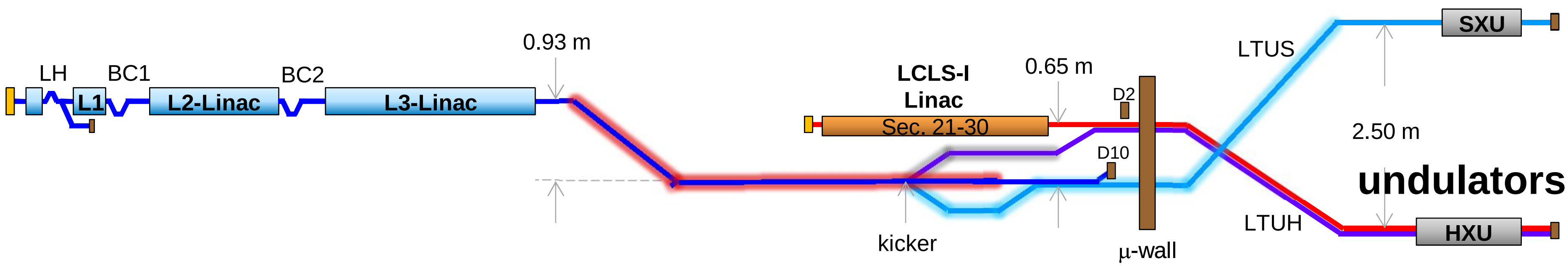
LCLS-II Concept by August 2013

To get "high repetition rate"	**Superconducting linac**: 4 GeV
To get "0.2-5 keV"photons with SC linac	New variable gap (north) undulator, 0.2-1.2 keV New variable gap (south), replaces existing fixed-gap und. 1-5 keV
Exploit existing LCLS linac	New variable gap (south) extends spectrum to 25 keV
Instruments	Re-purpose existing instruments (instrument and detector upgrades needed to fully exploit)



LCLS-II linac will occupy 700m of 3 km linac tunnel





The 1,000m "copper" linac in Sectors 0-10 will be replaced by a superconducting linac, occupying 700m(room to grow)

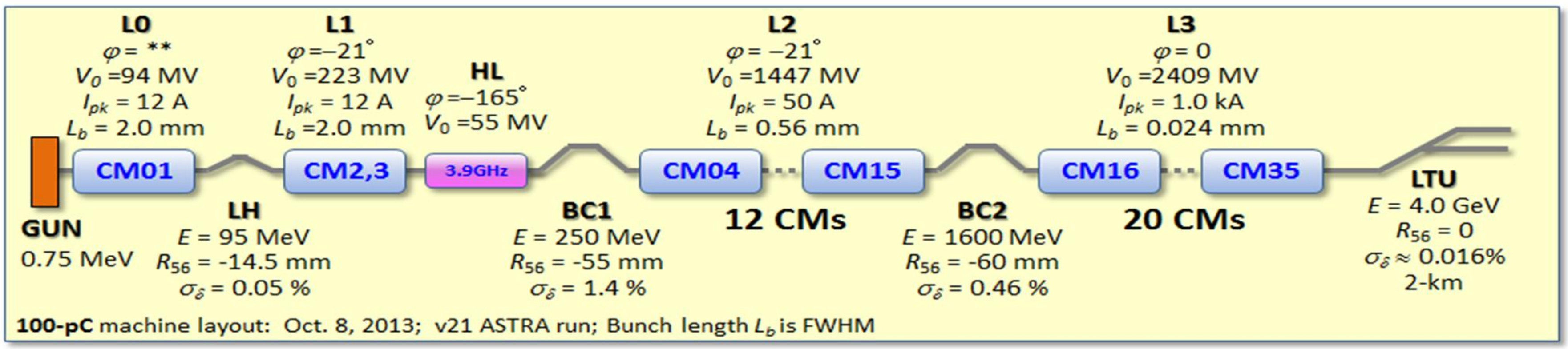
The SC linac will provide electrons to either or both undulators

The existing linac in "middle" 1,000m of the tunnel will be left Intact (likely use: R&D on plasma wake field acceleration). Electrons from SC linac transported past this linac in a separate channel

The LCLS linac in sectors 21-30 will operate simultaneously with SC linac, providing electrons to the HXR undulator

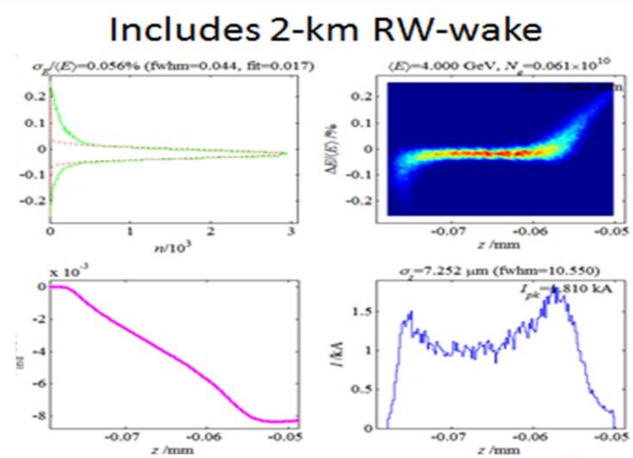
"glowing" sections indicate these are not in the vertical plane of either linac

SC linac requires 35 superconducting acceleration modules (1.3 GHz) and 2 higher-frequency (3.9 GHz) modules

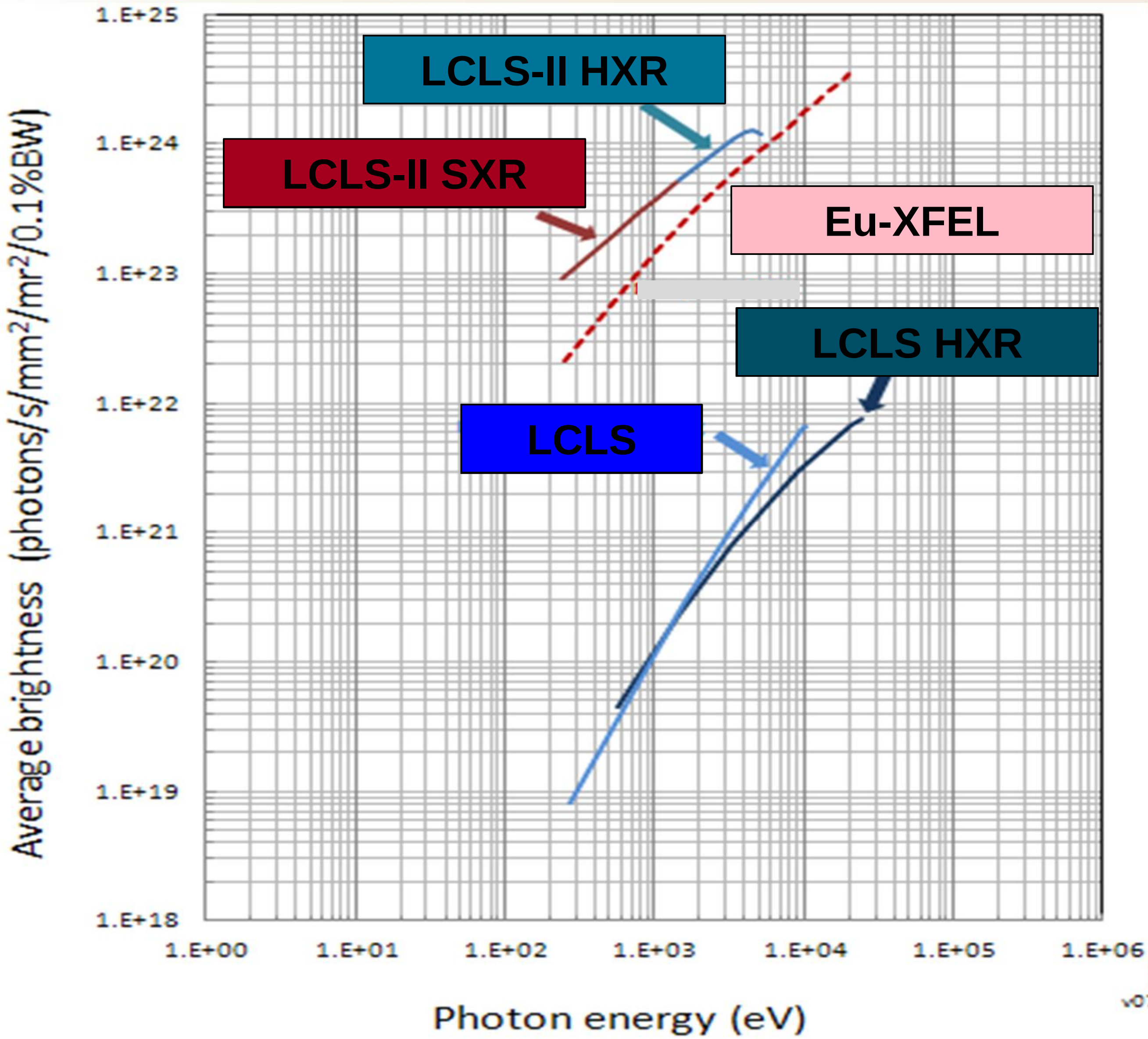


Accelerating module designs are based heavily on

ILC and European XFEL designs



Design Goals: Average Brightness for LCLS-II sources using the SC linac, compared to other sources



Based on production of 20W average x-ray power

FEL can produce higher power (>200W) at high repetition rate –

Collimation and control becomes challenging!

Project Collaboration: SLAC couldn't do this without…

Fermilab	• 50% of cryomodules: 1.3 GHz • Cryomodules: 3.9 GHz • Cryomodule engineering/design • Helium distribution • Processing for high Q (FNAL-invented gas doping)
Jefferson Lab — EXPLORING THE NATURE OF MATTER	• 50% of cryomodules: 1.3 GHz • Cryoplant selection/design • Processing for high Q
BERKELEY LAB	• Undulators • e^- gun & associated injector systems
Argonne NATIONAL LABORATORY	• Undulator Vacuum Chamber • Also supports FNAL w/ SCRF cleaning facility • Undulator R&D: vertical polarization
CORNELL UNIVERSITY FOUNDED A.D. 1865	• R&D planning, prototype support • processing for high-Q (high Q gas doping) • e^- gun option

LCLS-II: <7 years from BESAC subpanel report to first light

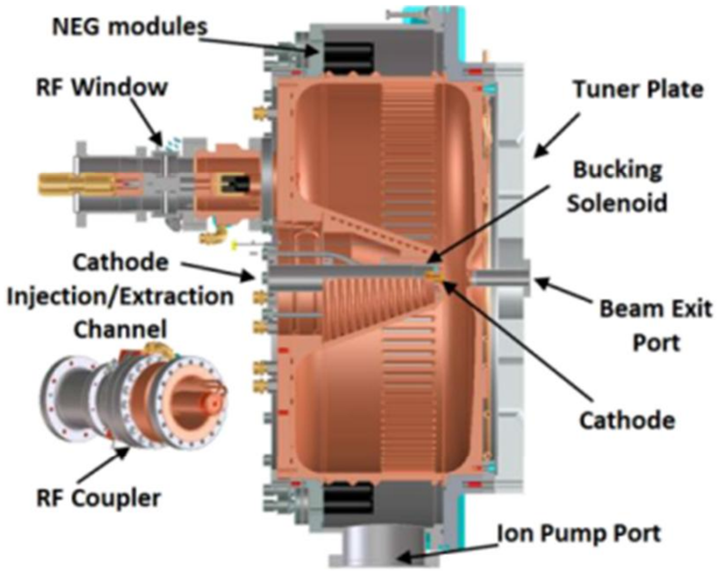
BESAC subcommittee report	25	July 2013
"Mission need" update CD-0 for new source	27	Sep 2013
First collaboration/planning meeting @ SLAC	9-11	Oct 2013
First complete cost estimate	28	Oct 2013
LCLS-II Collaboration Agreement signed	8	Nov 2013
Conceptual Design Report		Dec 2013
CD-1 - Approve Alt. Select. & Cost Range	26	Aug 2014
Advanced Procurement of Niobium Material	26	Aug 2014
CD-3b - Approve Long-Lead Procurements	28	May 2015
CD-2 – Approve Performance Baseline	2Q	FY 2016
CD-3 – Approve Construction Start	2Q	FY 2016
First light from Cu linac	1Q	FY 2019
First Light from SC linac	4Q	FY 2019
CD-4 - Project Complete/Start of Operations	4Q	FY 2022

LCLS-II can make rapid progress because:

- LCLS-II Project makes maximal use of designs developed for
  - **ILC & XFEL:**
    - Cryomodule, Cavities, Fundamental & higher mode couplers
  - **LBNL** 186 MHz gun, undulators
  - **FNAL:** Active in ILC design effort and SCRF R&D
  - **JLAB:** Cryoplant, cryomodule manufacturing for 12 GeV upgrade, SCRF R&D
  - **Cornell:** experience with CW operation, accelerator physics
  - **LCLS-II staff at SLAC** are experienced in project planning and execution: >90% are alumni of LCLS project

- LCLS-II project deriving full benefit from LCLS:
  - **Ongoing R&D and operational experience** in
    - Hard x-ray self-seeding
    - Soft x-ray self-seeding
    - X-ray detectors & data acquisition
    - X-ray instrumentation development for LCLS science
  - Use of **existing infrastructure** (e.g. tunnels, facilities, …)

Gun based on design developed/tested at LBNL

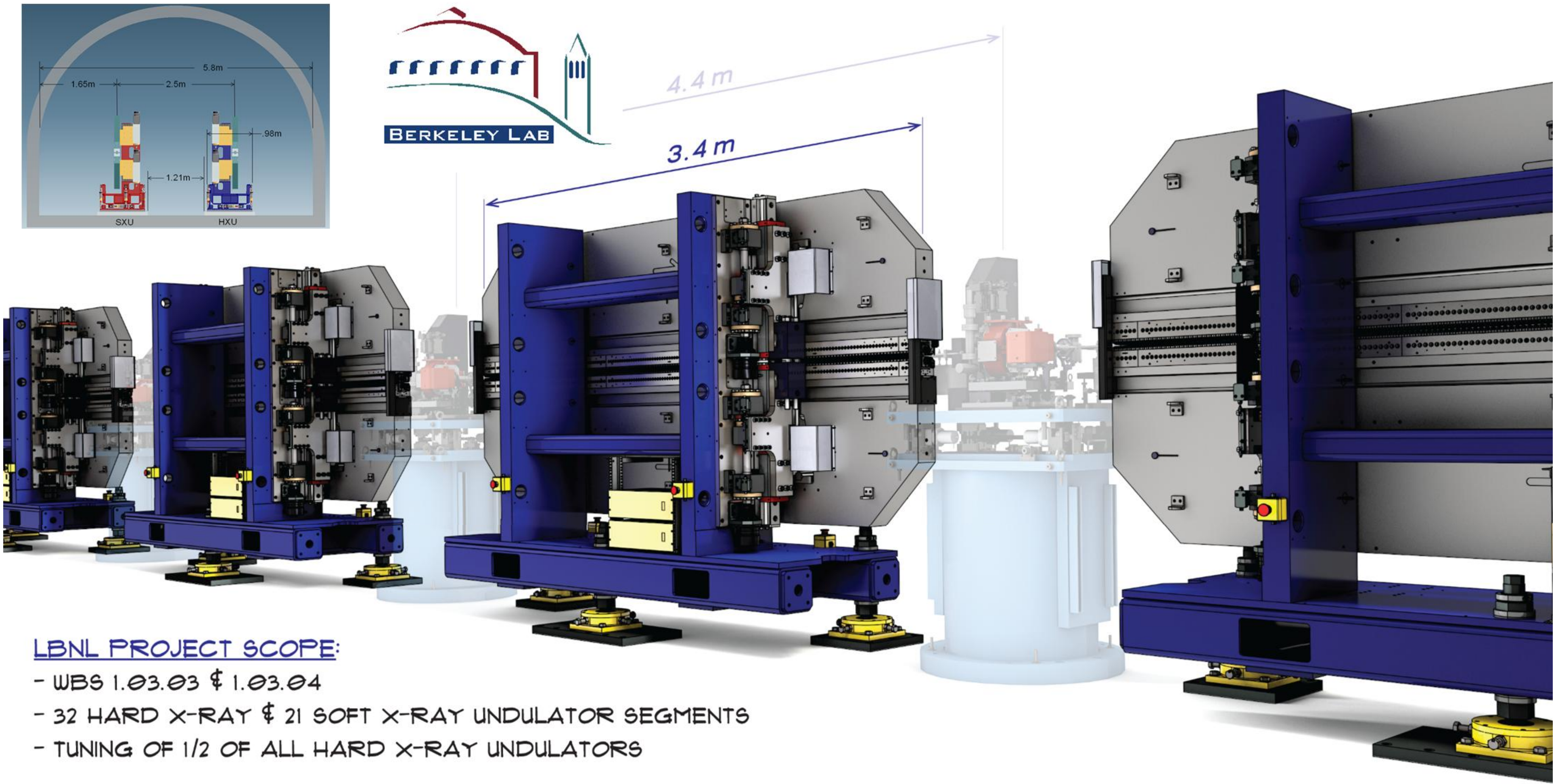


Frequency	186 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19.47 MV/m
Q_0 (ideal copper)	30887
Shunt impedance	6.5 MΩ
RF Power @ Q_0	87.5 kW
Stored energy	2.3 J
Peak surface field	24.1 MV/m
Peak wall power density	25.0 W/cm^2
Accelerating gap	4 cm
Diameter/Length	69.4/35.0 cm
Operating pressure	~ 10^{-10}-10^{-9} Torr

J. Staples, F. Sannibale, S. Virostek, CBP Tech Note 366, Oct. 2006
K. Baptiste, et al, NIM A 599, 9 (2009)
F. Sannibale, et al., PRST-AB 15, 103501 (2012)

- QE > 10%
- Lifetime > 10 days
- $\varepsilon_{thermal}$ < 1 μm/mm
- Exceeds LCLS-II specs

LBNL providing 21 Soft X-Ray And 32 Hard-X-Ray Undulator Segments: Variable Gap



LBNL PROJECT SCOPE:

- WBS 1.03.03 & 1.03.04
- 32 HARD X-RAY & 21 SOFT X-RAY UNDULATOR SEGMENTS
- TUNING OF 1/2 OF ALL HARD X-RAY UNDULATORS

What does it take to build a superconducting linac?

9-cell cavity

Inside jacket

8 cavities per cryomodule

Nitrogen Doping for CW linac performance: LCLS-II will be first facility to exploit this phenomenon

Fermilab Today

Tuesday, June 3, 2014

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Feature

Anna Grassellino receives $2.5 million DOE award for research on SRF cavities

A. Grassellino, et al.,
"New insights on the physics of RF surface resistance",
TUIOA03
2013 SRF Conference
Paris, France

For a pulsed linac (ILC, XFEL) heat load comes mostly from outside the module

For a CW linac, heat load is from BCS resistance @ 2K + surface resistance

For a given acceleration V: Power dissipation ~ $V^2/(Q_o R_g)$

R_g depends on cavity geometry
Q_o depends on BCS and residual resistivities

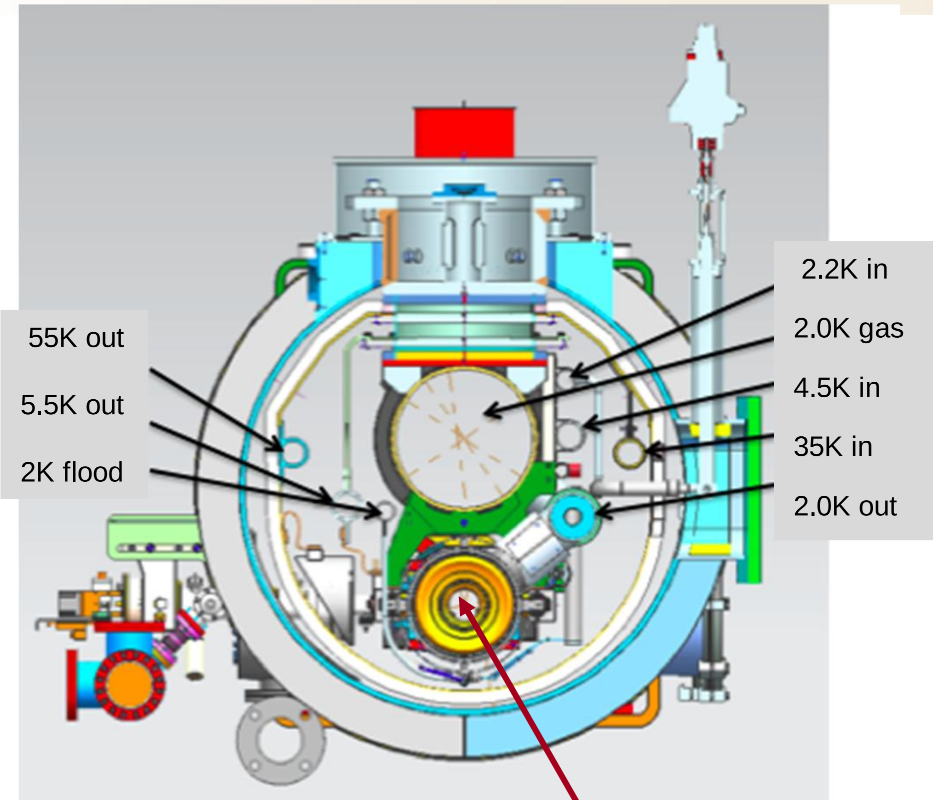
Nitrogen doping reduces BCS resistance at moderate gradient, increasing Q_o 2X-4X

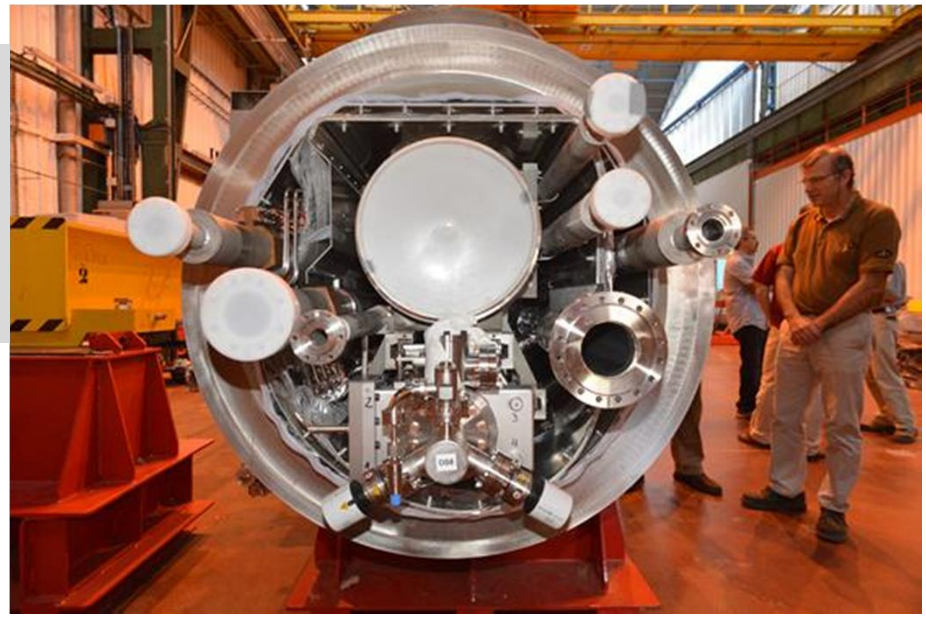
Enables lower power bill at a given gradient Or a higher gradient at a given power level

LCLS-II has planned for sufficient refrigeration to handle the "new technology" risk: 8 kW at 2K

ILC module at Fermilab: Same size as LCLS-II

LCLS-II will be very similar to ILC/XFEL Cryomodule





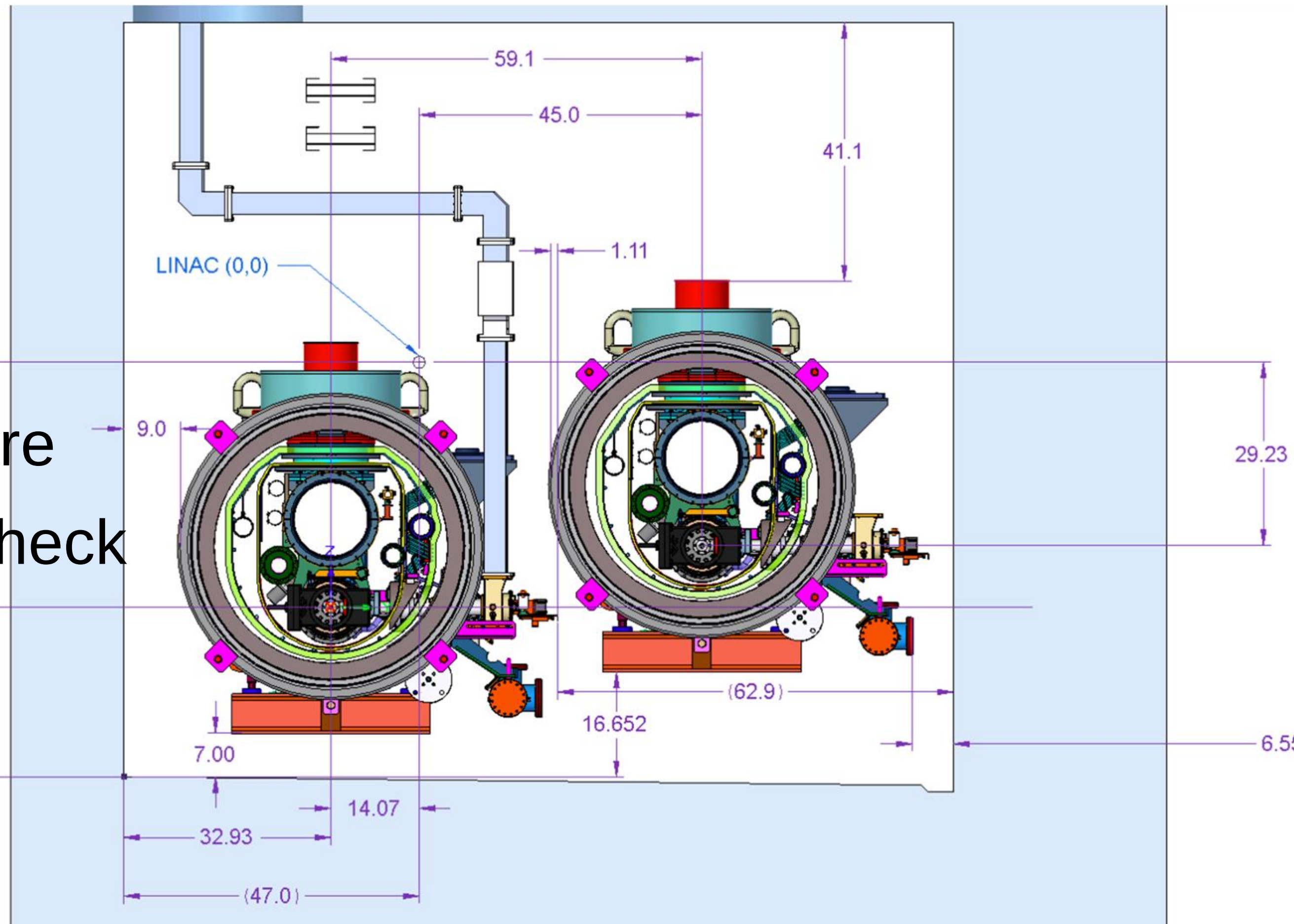
Electrons go here!

SCRF Linac in SLAC Tunnel

<u>SLAC Linac Tunnel: 3.53m wide x 3.05 m high</u>

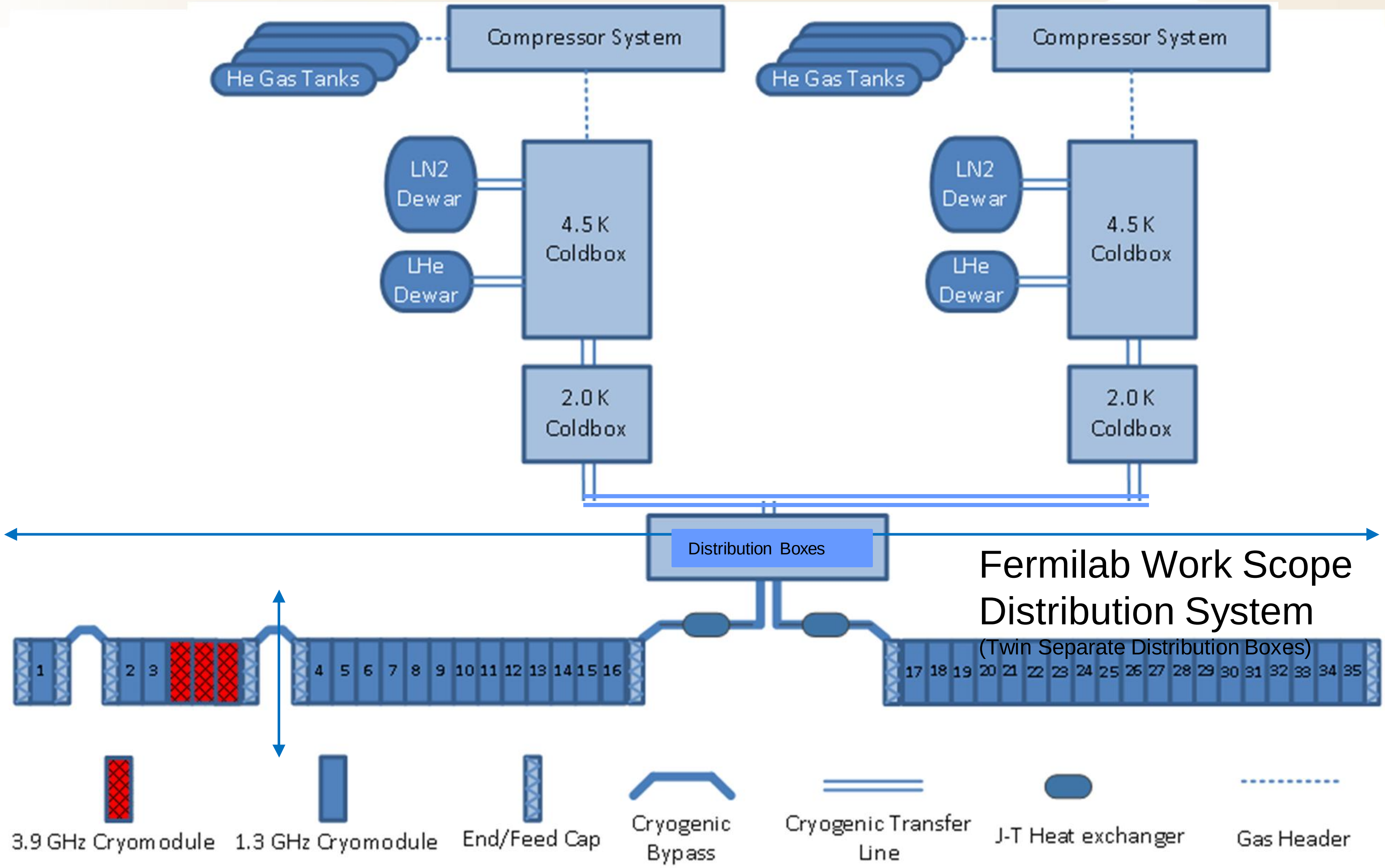
Yes, it fits…

A mock-up of the tunnel and hardware has been built to check clearances

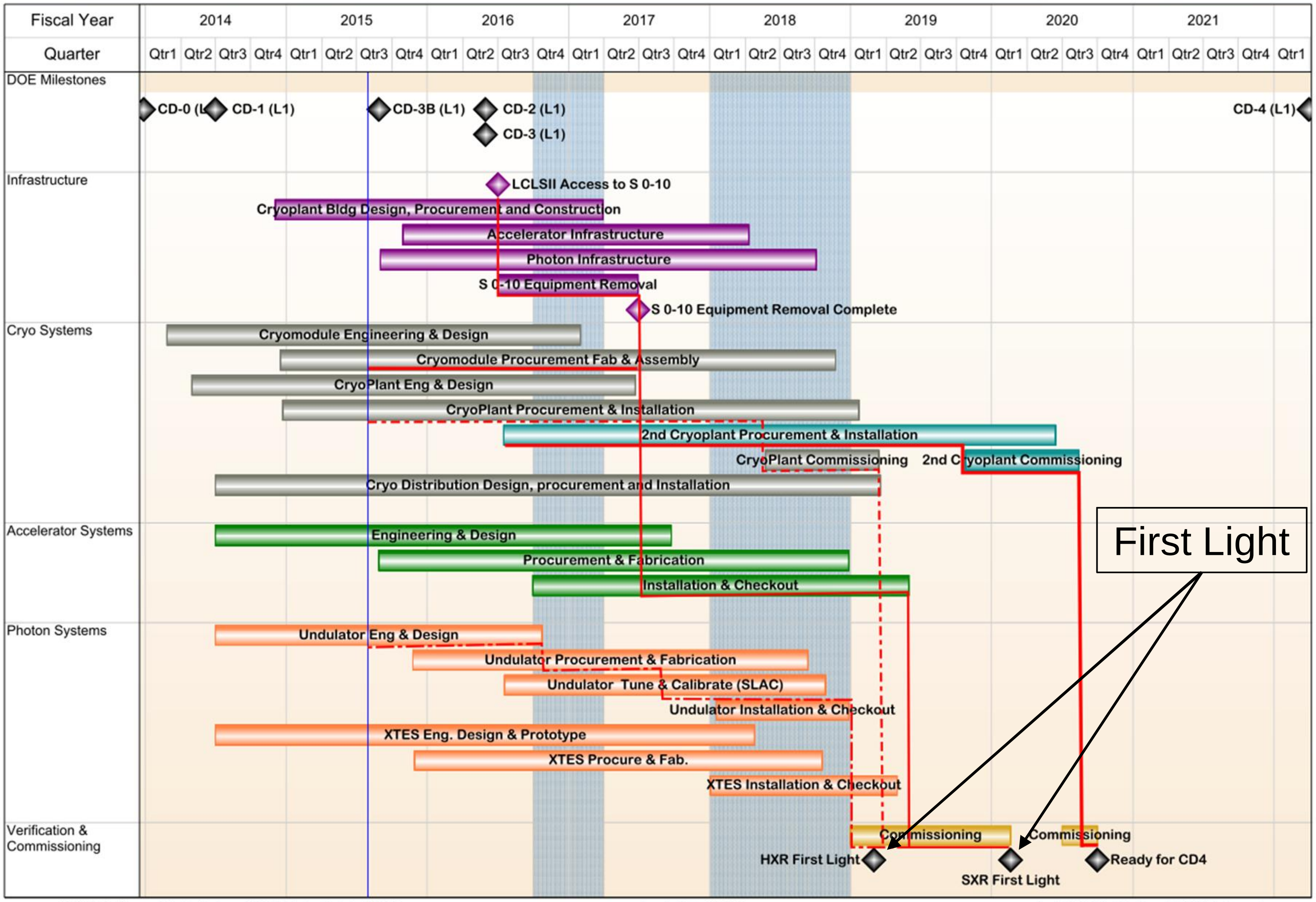


S. Boo, J. Chan

Cryogenic refrigeration makes use of existing JLAB design



Schedule



Fiscal Year
2014
2015
2016
2017
2018
2019
2020
2021
Quarter
Qtr1 Qtr2 Qtr3 Qtr4
DOE Milestones
CD-0 (L
CD-1 (L1)
CD-3B (L1)
CD-2 (L1)
CD-3 (L1)
CD-4 (L1)
Infrastructure
LCLSII Access to S 0-10
Cryoplant Bldg Design, Procurement and Construction
Accelerator Infrastructure
Photon Infrastructure
S 0-10 Equipment Removal
S 0-10 Equipment Removal Complete
Cryo Systems
Cryomodule Engineering & Design
Cryomodule Procurement Fab & Assembly
CryoPlant Eng & Design
CryoPlant Procurement & Installation
2nd Cryoplant Procurement & Installation
CryoPlant Commissioning
2nd Cryoplant Commissioning
Cryo Distribution Design, procurement and Installation
Accelerator Systems
Engineering & Design
Procurement & Fabrication
Installation & Checkout
Photon Systems
Undulator Eng & Design
Undulator Procurement & Fabrication
Undulator Tune & Calibrate (SLAC)
Undulator Installation & Checkout
XTES Eng. Design & Prototype
XTES Procure & Fab.
XTES Installation & Checkout
Verification & Commissioning
Commissioning
Commissioning
HXR First Light
SXR First Light
Ready for CD4
First Light

LCLS-II Science Workshops (February 2015) provided the framework for facility planning

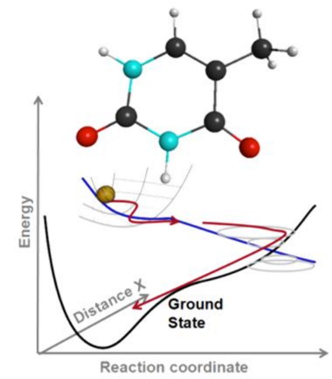
- Excellent attendance (414 registered)
- Huge amount of material. This has been condensed into a summary “opportunities” document, available online
- Focused on the baseline capability of LCLS-II
- Informing LCLS strategy for facility developments

LCLS-II Science Opportunities:
Translating into LCLS facility strategy

SLAC

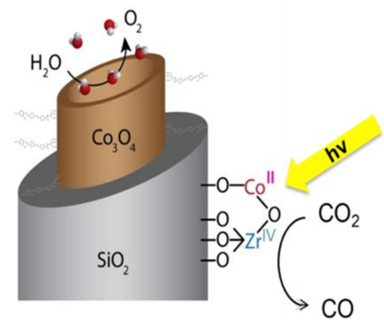
1. Fundamental charge migration & redistribution

Dynamic reaction microscope	High rep rate
Stimulated X-ray Emission Spec.	Coherence (few fs), 2-color
Photoemission	Soft, tender X-rays
X-ray scattering	Hard X-rays



2. Predictive understanding of photo-catalysis

Time-resolved X-ray Raman	High rep rate
(X-ray absorption/emission)	Soft, tender X-rays
Time-resolved photoemission	Coherence (FT limit), 2-color

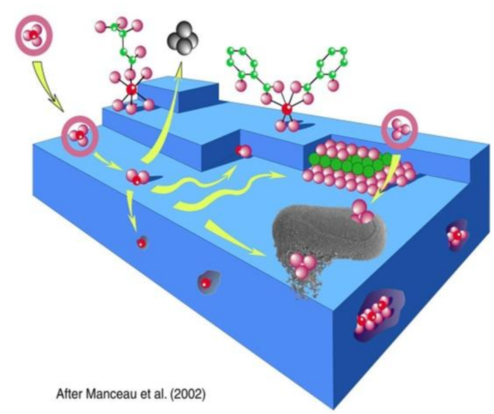


3. Heterogeneous catalysis - in real time & operando

Time-resolved photoemission	High rep rate
(ambient pressure)	Soft, tender X-rays
Res. coherent X-ray scattering	Hard X-rays + soft X-rays

4. Combustion & aerosol chemistry

Flash tomography	High rep rate
Stimulated X-ray Emission Spec.	Soft, tender X-rays
Coherent X-ray scattering	2-color


After Manceau et al. (2002)

Longer-term opportunities, requiring R&D

- We've just scratched the surface of what can be done with an x-ray FEL
- Future possibilities
  - 10X-100X increases in peak power
    - Superconducting undulator
    - Brighter electron gun
  - Control of electron beam properties on micron scale
    - ~1 femtosecond timing/synchronization
    - Temporal characteristics of intensity, wavelength and polarization
    - Lasing wavelength & chirp
  - Controlled modulation of color, amplitude, phase of x-ray pulse

Conclusions

- LCLS-II design responsive to BESAC subpanel report
- The project is moving fast with help of partner labs
- Several ongoing accelerator R&D efforts have set the stage for LCLS-II
- LCLS-II is proposing to first light by end of 2019
- LCLS Facility is accumulating experience and new capabilities at 120 Hz that prepare the way for LCLS-II science

- LCLS+LCLS-II will continue to provide groundbreaking capabilities and enable groundbreaking science

Thank you for your Attention!