LCLS-II and the future

April 10, 2019

Mike Dunne
Director, LCLS
SLAC National Accelerator Laboratory
DOE Office of Basic Energy Science is driving a wealth of ambitious new science programs

“Grand Challenges” from BESAC

“Round Table” assessments identifying new opportunities

FOA in Ultrafast Science, targeting LCLS-II

LCLS development is being targeted to respond to these scientific challenges
Over the past 5 years, the community has identified a broad suite of specific scientific opportunities for LCLS.

Much is owed to those who devote their time to LCLS, including:

- **SAC** and subcommittees: Strategic direction
- **SPC**: Integration into SLAC/Stanford
- **UEC**: User community requirements
- **PRP**: Experiment priorities
- **Annual Users Meeting**: Broad engagement

Thank you! to all who have served on our PRP, SAC, UEC, SPC, workshops, …
LCLS-II was devised to open up a new era of precision science, and enable entirely new modes of experiment.

The leap from 120 pulses per second to 1 million pulses per second will be transformative.
LCLS-II is being designed and delivered by a national partnership, with international collaboration from DESY and many others.

- 50% of cryomodules: 1.3 GHz
- Cryomodules: 3.9 GHz
- Cryomodule engineering/design
- Helium distribution, including valve boxes
- Processing for high Q (FNAL-invented gas doping)

- 50% of cryomodules: 1.3 GHz
- Cryoplant selection/design/installation/commissioning
- Processing for high Q

- Undulators
- e⁻ gun & associated injector systems
- Accelerator physics support

- Undulator Vacuum Chamber
- Also supports FNAL w/ SCRF cleaning facility
- Undulator R&D: vertical polarization

- R&D planning, accelerator physics & prototype support
- Processing for high-Q
- e⁻ gun option

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**LCLS-II Partners**

**Fermilab**

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**Jefferson Lab**

- 50% of cryomodules: 1.3 GHz
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**Berkeley Lab**

- Undulators
- e⁻ gun & associated injector systems
- Accelerator physics support

**Argonne National Laboratory**

- Undulator Vacuum Chamber
- Also supports FNAL w/ SCRF cleaning facility
- Undulator R&D: vertical polarization

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John Galayda,
Project Director

Jeff Sims
Project Manager

Tom Peterson
Technical Director
LCLS-II performance represents a huge leap in capability

Doubles the hard x-ray energy reach of the high peak power beam (120 Hz)

Delivers unprecedented average power for 0.25 to 5 keV

(soft and tender x-rays)
LCLS-II will transform our understanding of dynamics in real-world materials and chemical science systems

**Charge dynamics on fundamental timescales**
- Reveal coupled electronic and nuclear motion in molecules
- Capture the initiating events of charge transfer chemistry with sub-fs resolution

**Molecular dynamics with exquisite resolution**
- Measure element-specific, local chemical structure and bonding
- Study efficient, robust, selective photo-catalysts

**Emergent phenomena in quantum materials**
- Connect spontaneous fluctuations, dynamics and heterogeneities on multiple length- and time- scales to bulk material properties
- Study interacting degrees of freedom (e.g. unconventional superconductors)

**Ultrafast**

**High repetition rate**

**Extreme brightness**
The LCLS-II cryogenic plants
LCLS-II cryomodules are now being installed in the tunnel
LCLS-II variable gap hybrid undulators from the teams at LBNL and ANL

Variable gap undulators used in LCLS-II to provide greater wavelength tuning flexibility

Horizontally polarized undulator for soft x-ray branch

Vertically polarized undulator for hard x-ray branch
The Near Experimental Hall will have a new instrument suite (nominally 5 end-stations in 3 hutches – now on 2 levels)

- 7 instruments fed by a single undulator at present
- 8 instruments available for LCLS-II (new soft & tender instruments)

Near Hall

- NEH 1.1: Atomic, Molecular and Optical
- NEH 2.2: Soft X-ray Research
- NEH 1.2: Tender X-ray Instrument
- XPP: X-ray Pump Probe
- XCS: X-ray Correlation Spectroscopy
- MFX: Macromolecular Femtosecond Crystallography
- CXI: Coherent X-ray Imaging
- MEC: Matter in Extreme Conditions

Far Hall

- SXU: 2 Soft X-ray
- HXU: 2 “tender” x-ray
- 5 Hard X-ray

~ 50 m

~ 70 m
Equipment removal is complete from the Near Hall and FEE
The design of the new instruments for LCLS-II is now mature

Large team effort, building from the success of LCLS Instruments to date
The leap to high repetition-rate drives step-changes across all aspects of our work, engaging the whole lab.

Injector and accelerator capabilities

High power optics & precision diagnostics

High rate detectors

High power lasers and synchronization

Theory and modeling

Massive scale data analytics and real-time controls
Looking beyond LCLS-II, the science impact of the MEC instrument (funded by DOE-FES) has been very impressive.

Wide-ranging research in the “extreme materials” and “dense plasma” states
The success of MEC has underpinned a major new project to expand to the “petawatt” power level

CD-0 (“mission need”) approved by DOE in January. Funds provided to LCLS for CD-1 (“design selection”). Specific building and laser options now being evaluated.
LCLS-II-HE (“High Energy”) will extend the high average power from 5 keV to a limit of at least 13 keV, and possibly up to 20 keV.

Early investment and foresight has provided SLAC with a flexible platform for future growth.
LCLS-II-HE will enable structural dynamics at the atomic scale

**Heterogeneity & complexity in ground & excited states**
- Correlate catalytic reactivity and structure
- Real-time evolution with chemical specificity and atomic resolution

**Dynamics of biomolecules & molecular machines**
- Study large scale conformational changes via solution scattering
- Physiological conditions
- Dynamics ties structure to function

**Ground State Fluctuations & spontaneous evolution**
- Characterize statistically dynamic systems without long-range order
- Inform directed design of energy conversion and storage materials

LCLS-II-HE provides the ability to study non-equilibrium phenomena and move beyond idealized materials and systems
... and beyond ??

- 3.7 GeV SCRF beam
- SXR Farm
- 4-7 GeV at 1 MHz
- SCRF, km-1

- 8 GeV ESA XFEL-O
- 25 GeV at 120 Hz
- SCRF, km-2, km-3

- 17 GeV at 360 Hz
- SCRF beam
- SXR Farm

- 50-200 eV
- 50-200 eV
- ESB VUV, PMU

- +24.5°
- +24.5°
- HPSXR, PMU

- -12.5°
- -12.5°
- -12.5°

- 25-100 keV
- UHXR, SCU
- 5-15 keV
- HPHXR, SCU

- +0°
- +0°
- 1-12 keV (1-50)

- +4°
- +4°
- 0.25-4 keV PMU

- -4°
- -4°
- 0.25-4 keV PMU

- 0.25-4 keV HPSXR, SCU
- 5-15 keV HPSXR, SCU

- +2°
- +2°

- 5-15 keV HPHXR, SCU
- 25-100 keV UHXR, SCU

- +0°
- +0°

- +12.5°
- +12.5°

- HX: 1-12 keV (1-50)
- HX: 1-12 keV (1-50)
Key to the success of LCLS is being embedded in the wider capabilities of SLAC National Accelerator Laboratory, …

… with amazing teams from Facilities, Communications, ES&H, Business, IT, Legal, HR, CACM, and the Director’s Office
... along with our integration into Stanford University, ...
... coupled to extensive collaboration with our international partners, ...
... the vision, support, and broad network of the DOE Office of Science, ...

Largest Supporter of Physical Sciences in the U.S.

Funding at >300 Institutions including all 17 DOE Labs

Over 22,000 Scientists Supported

Nearly 32,000 Users of 26 SC Scientific Facilities

Research to Universities

Research Programs

Facility Operations

Major Projects
... the thousands of ‘unique users’, students and interns...
... and, of course, our wonderful staff ...

... from across SLAC

... LCLS staff, attentively listening to a lecture...

... Accelerator Directorate ...

... LCLS-II groundbreaking ...
From initial vision

.... to early scientific impact,

... unprecedented measurements,

... accessing critical new regimes,

... and exploration of new frontiers.