LCLS Operation Experience and LCLS-II Design

Tor O. Raubenheimer
for the LCLS and LCLS-II teams

U.S. DEPARTMENT OF ENERGY
Office of Science
BERKELEY LAB
SLAC NATIONAL ACCELERATOR LABORATORY

SLAC@50

Two Mile Linac

1962: Start of accelerator construction

1967: 20-GeV electron beam achieved

Nobel Prizes

- **1976 Physics, J/psi, Richter and Ting**
- **1990 Physics, Deep inelastic scattering, Taylor, et al**
- **1995 Physics, Tau lepton, Perl**
- **2006 Chemistry, Eukaryotic transcription, Kornberg**
- **2008 Physics, broken symmetries, confirmed at SLAC & KEK**
- **2009 Chemistry, structure of the ribosome, early work at SSRL**

SPEAR 3.7 GeV Storage Ring and Synchrotron Radiation

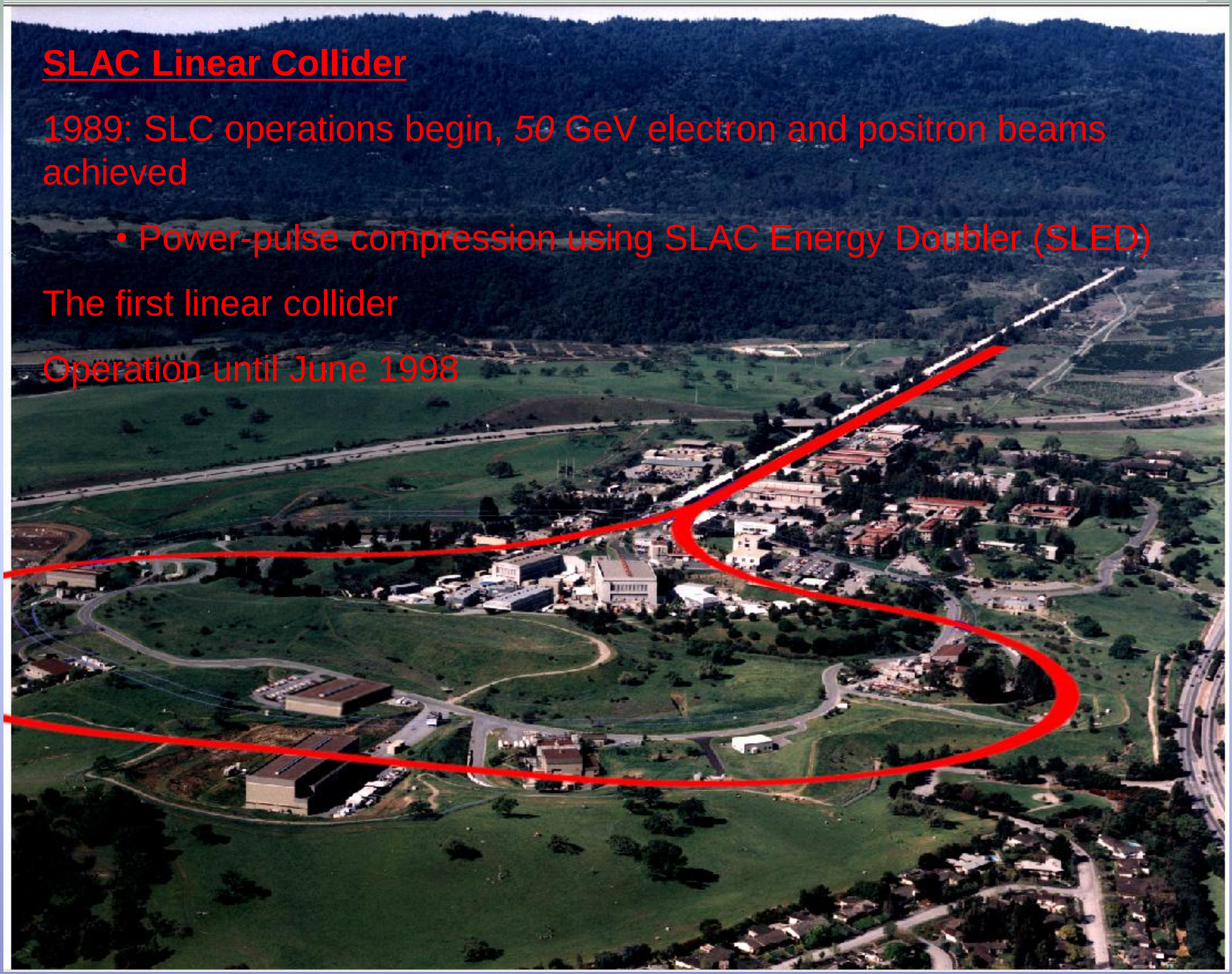
1972: SPEAR operations begin

1973: Stanford Synchrotron Radiation Project (SSRP) started – First Light

1977: SSRP becomes Stanford Synchrotron Radiation Laboratory (SSRL)

1990: SPEAR II - a dedicated synchrotron radiation facility

2003: SPEAR III synchrotron source



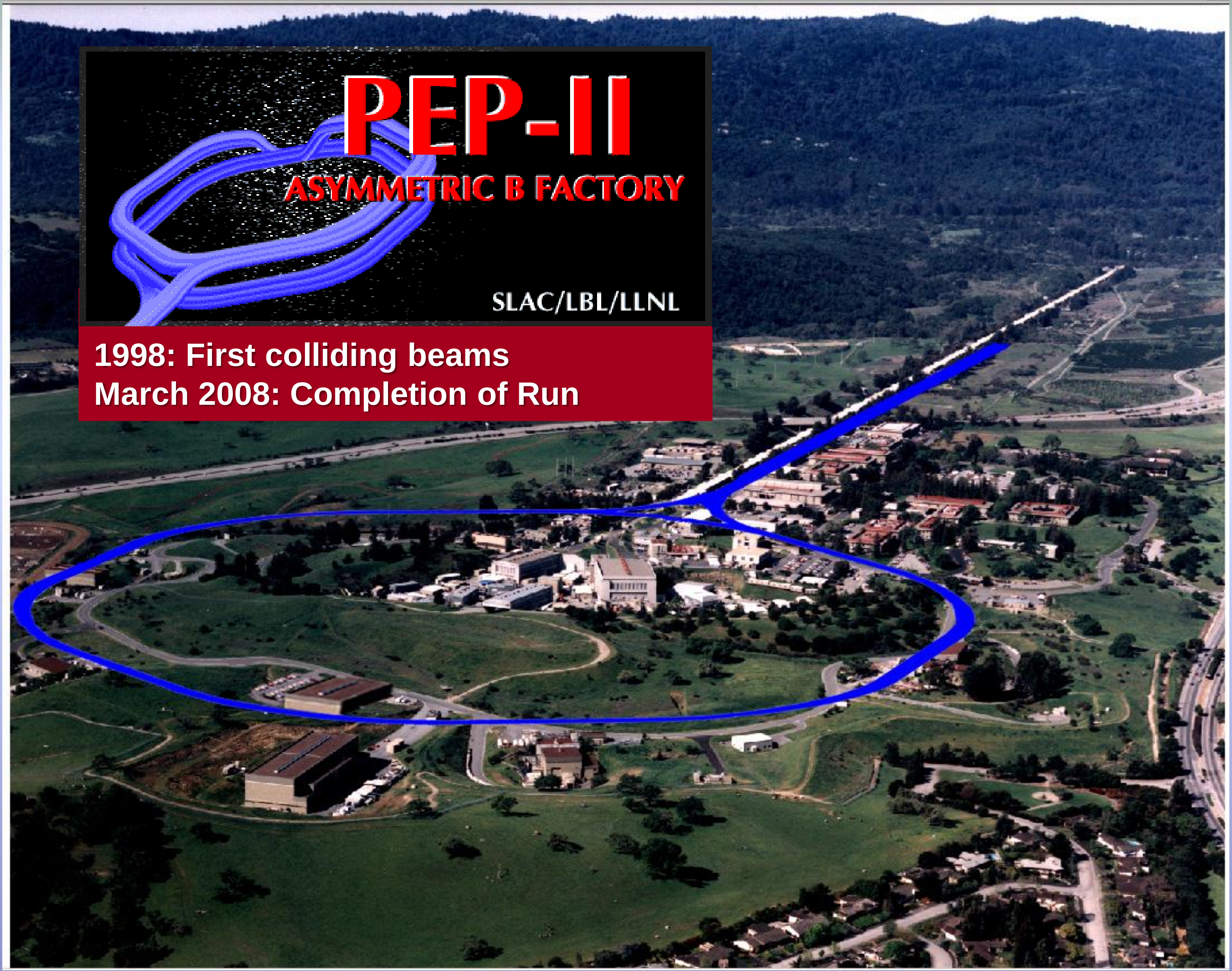
SLAC Linear Collider

1989: SLC operations begin, *50* GeV electron and positron beams achieved

- Power-pulse compression using SLAC Energy Doubler (SLED)

The first linear collider

Operation until June 1998


PEP-II
ASYMMETRIC B FACTORY
SLAC/LBL/LLNL
1998: First colliding beams
March 2008: Completion of Run

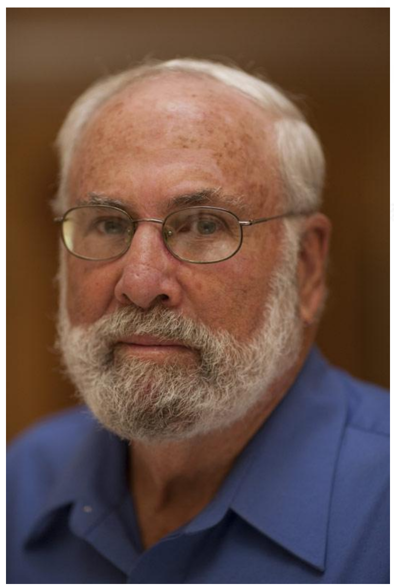
LCLS Concept: Fourth Generation Workshop 20 Years Ago

C. Pellegrini, A 4 to 0.1 nm FEL Based on the SLAC Linac,

Workshop on Fourth Generation Light Sources, February, 1992

Claudio Pellegrini

Herman Winick

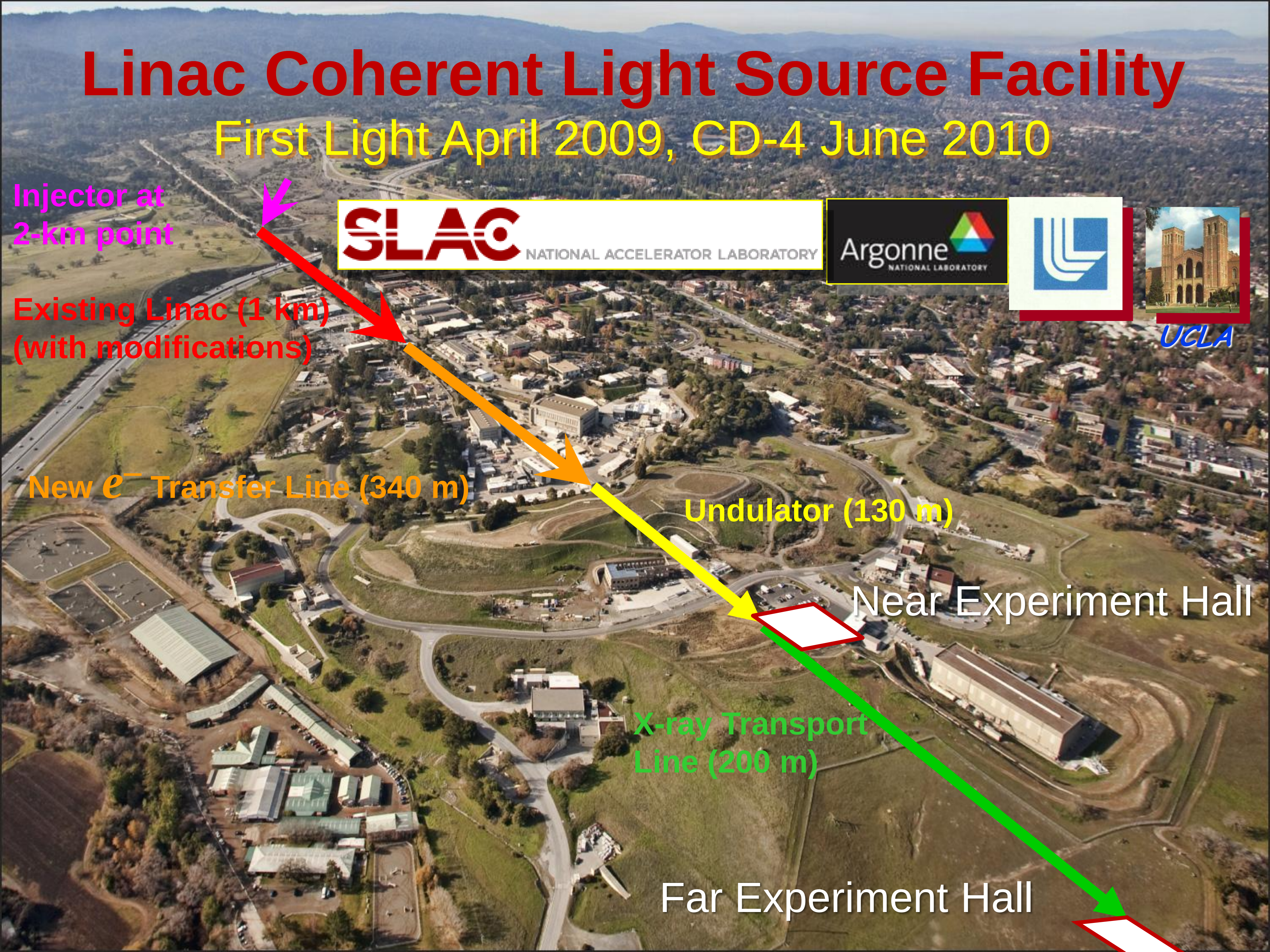


Herman Winick's Study Group

SHORT WAVELENGTH FELs at SLAC - STUDY GROUP

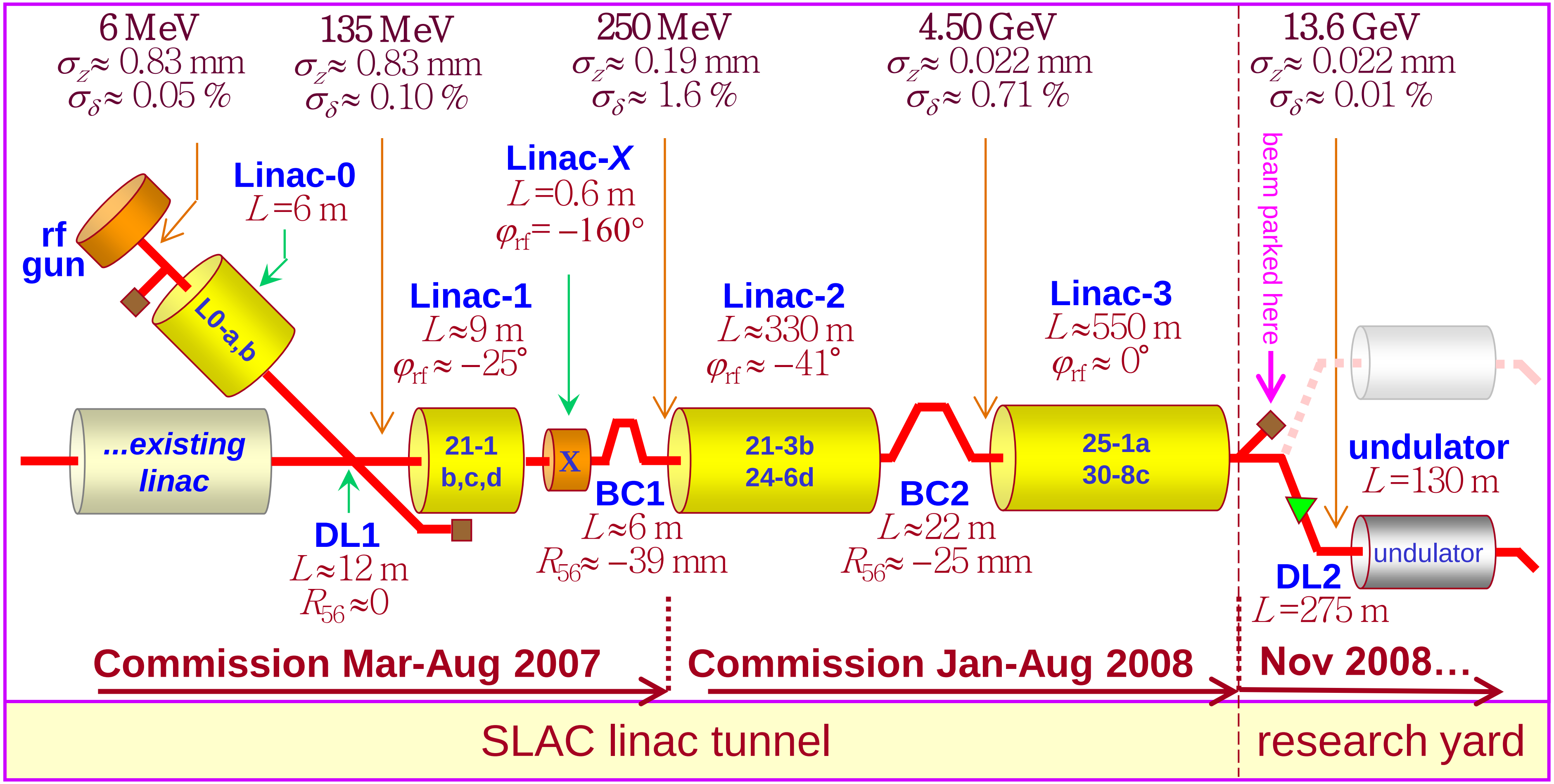
SOURCE	SCIENTIFIC CASE
Karl Bane	Art Bienenstock
Jeff Corbett	Keith Hodgson
Max Cornacchia	Janos Kirz (SUNY-Stony Brook)
Klaus Halbach (LBL)	Piero Pianetta
Albert Hofmann	Steve Rothman (UCSF)
Kwang-je Kim (LBL)	Brian Stephenson (IBM)
Phil Morton	
Heinz-Dieter Nuhn	
Claudio Pellegrini (UCLA)	
Tor Raubenheimer	
John Seeman	
Roman Tatchyn	
Herman Winick	

Engaged Bjorn Wiik and Gerd Materlik during sabbaticals at SLAC



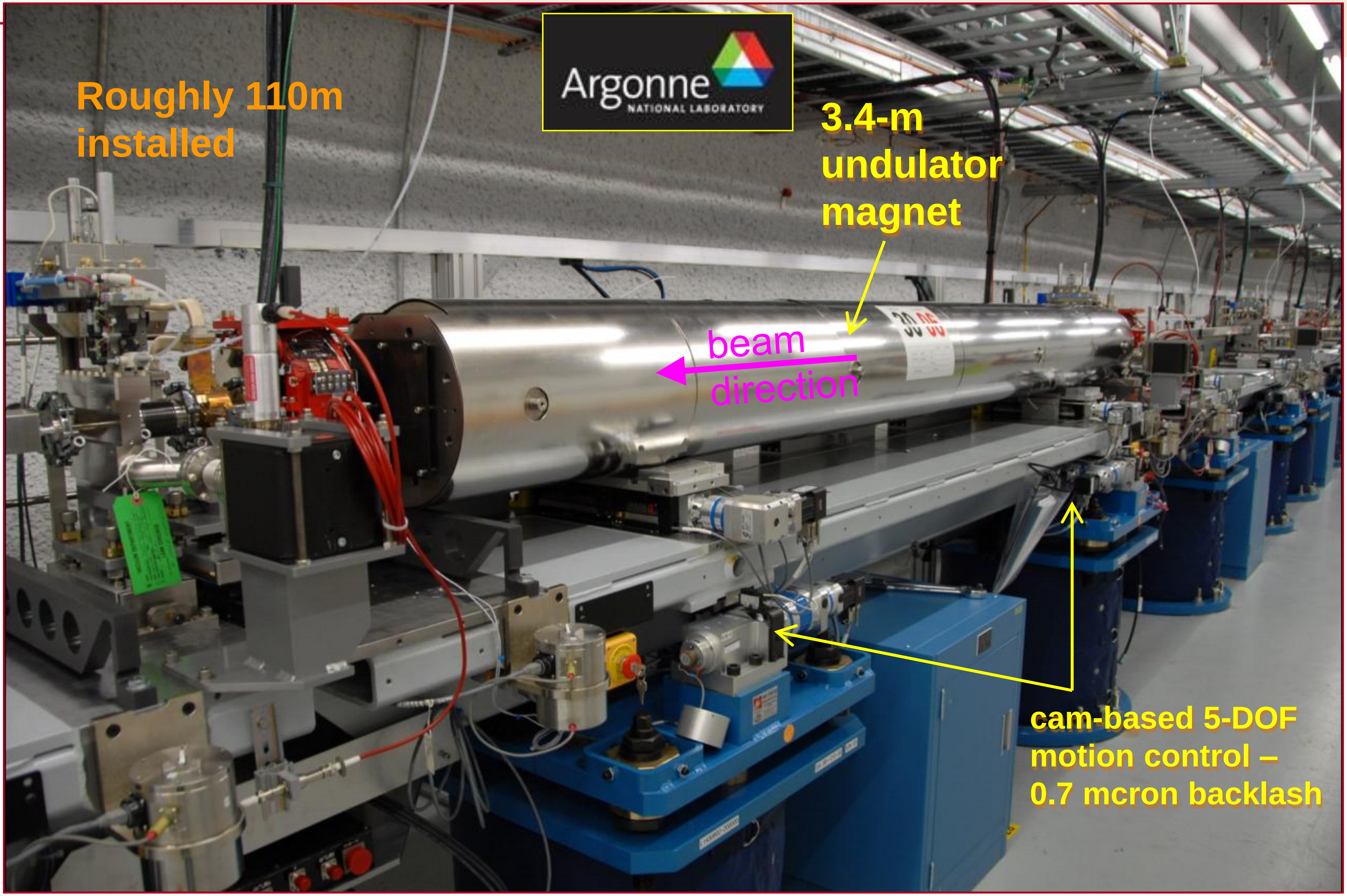
Linac Coherent Light Source Facility
First Light April 2009, CD-4 June 2010
Injector at 2-km point
SLAC NATIONAL ACCELERATOR LABORATORY
Argonne NATIONAL LABORATORY
UCLA
Existing Linac (1 km) (with modifications)
New e^- Transfer Line (340 m)
Undulator (130 m)
Near Experiment Hall
X-ray Transport Line (200 m)
Far Experiment Hall

LCLS commissioning ended Oct. 2009



- **Generation of low emittance beam**
- **Preservation of 6D brightness in accelerator and compressors**
- **Undulators meeting tolerance and trajectory control**

LCLS Undulators



SLAC/LCLS Main Control Center (MCC)

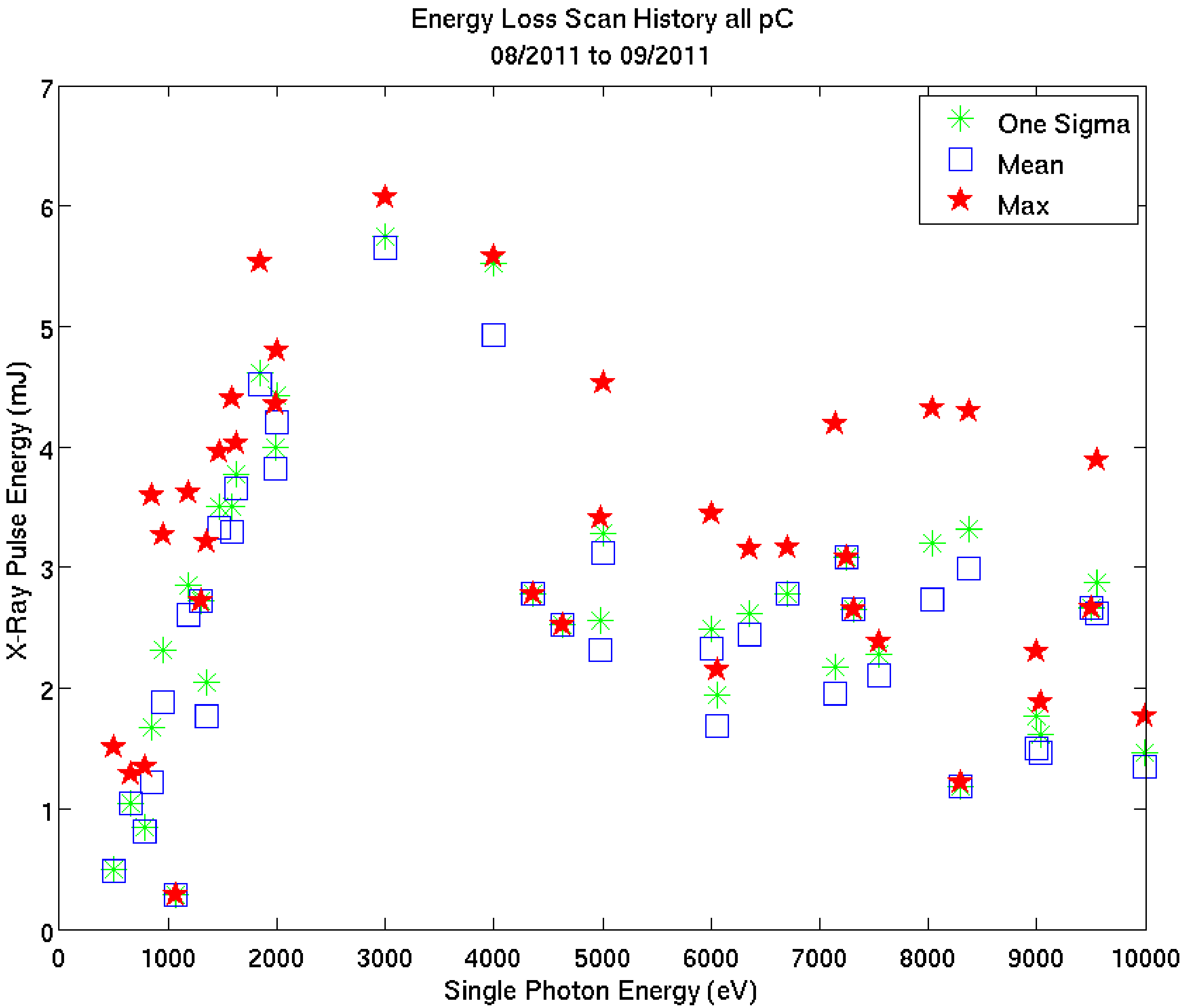
LCLS Experiment Stations

AMO
SXR
XPP

XCS
CXI
MEC

	Start of User Operation
AMO	Oct., 2009
SXR	June, 2010
XPP	Oct., 2010
CXI	Feb., 2011
XCS	Nov., 2011
MEC	April, 2012

LCLS Operational Performance (480 eV – 10 keV)



LCLS Experimental Program

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
Proposals Received	Sept'08	May '09	Nov'09	Jun'10	Jan'11	Sept'11	Jul'12
AMO	28	24	16	25	15	15	17
SXR		38	32	31	18	28	23
XPP			59	35	34	27	35
CXI				25	29	36	45
MEC					12	18	19
XCS					6	10	13
Total Proposals Received	28	62	107	116	114	134	152

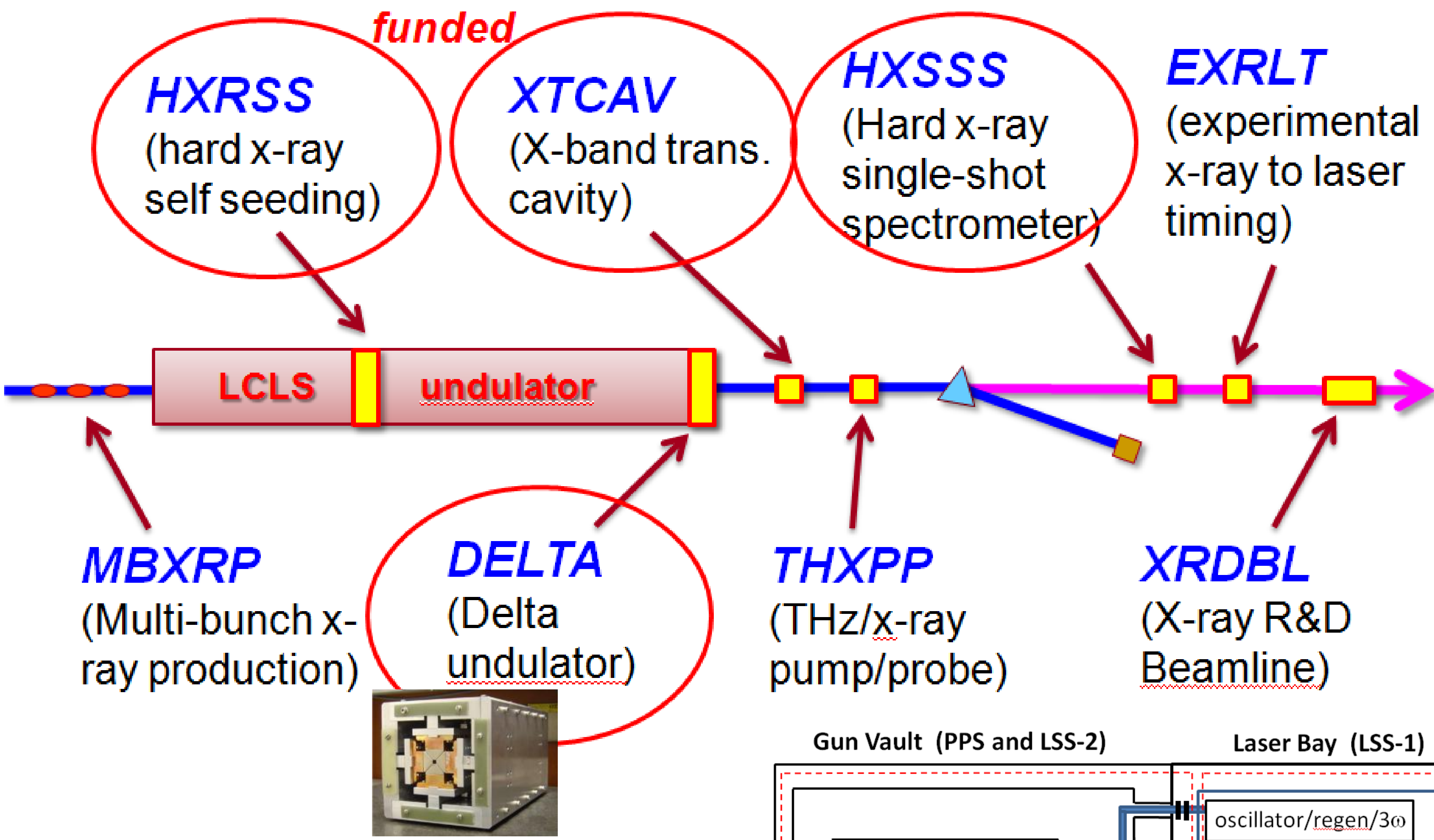
	"User Assisted Commissioning"			Dedicated User Facility > August 2010			
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
Proposals Scheduled	Oct-Dec'09	May-Sep'10	Oct-Mar'11	Jun-Oct'11	Nov-May'12	Jun-Dec'12	Jan-May'13
AMO	11	13	5	8	4	7	
SXR		10	5	7	4	5	
XPP			16	6	10	8	
CXI				6	11	2	
MEC					3	8	
XCS					5	4	
Total Proposals Scheduled	**11**	**23**	**26**	**27**	**37**	**34**	

LCLS Achievements

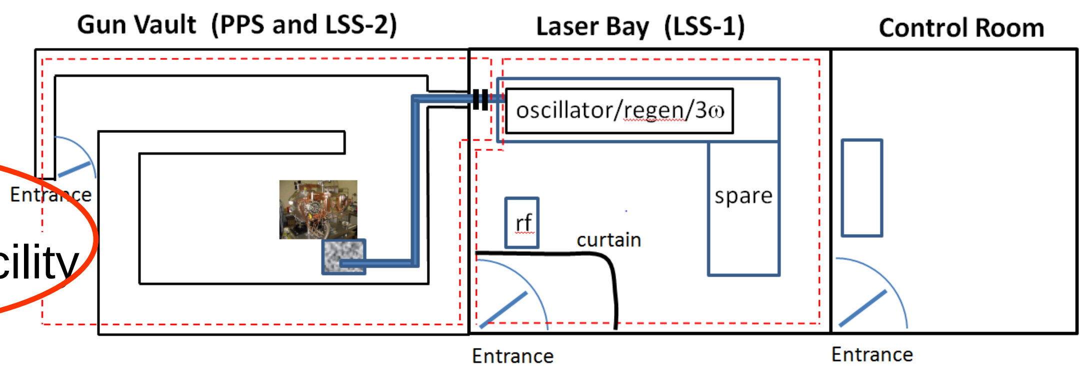
- Exceptional e^- beam quality from RF gun ($\gamma\varepsilon_{x,y} \approx \mathbf{0.4}\ \mu\mathrm{m}$)
- Pulse length *easily* adjustable for users (**60 - 500** fs FWHM) with <<**10** fs pulses at low charge (20 pC)
- Wider photon energy range: **480 - 10000** eV (design was: 830 - 8300 eV)
- Peak FEL power >**70** GW (10 GW in CDR)
- Pulse energy up to **6** mJ (2 mJ in CDR)
- **96.7**% accelerator availability, **94.8**% photon availability
- Total of 133 pubications, 35 in high impact journals

LCLS-I FEL R&D Program
Exploring new capabilities for X-ray FELs

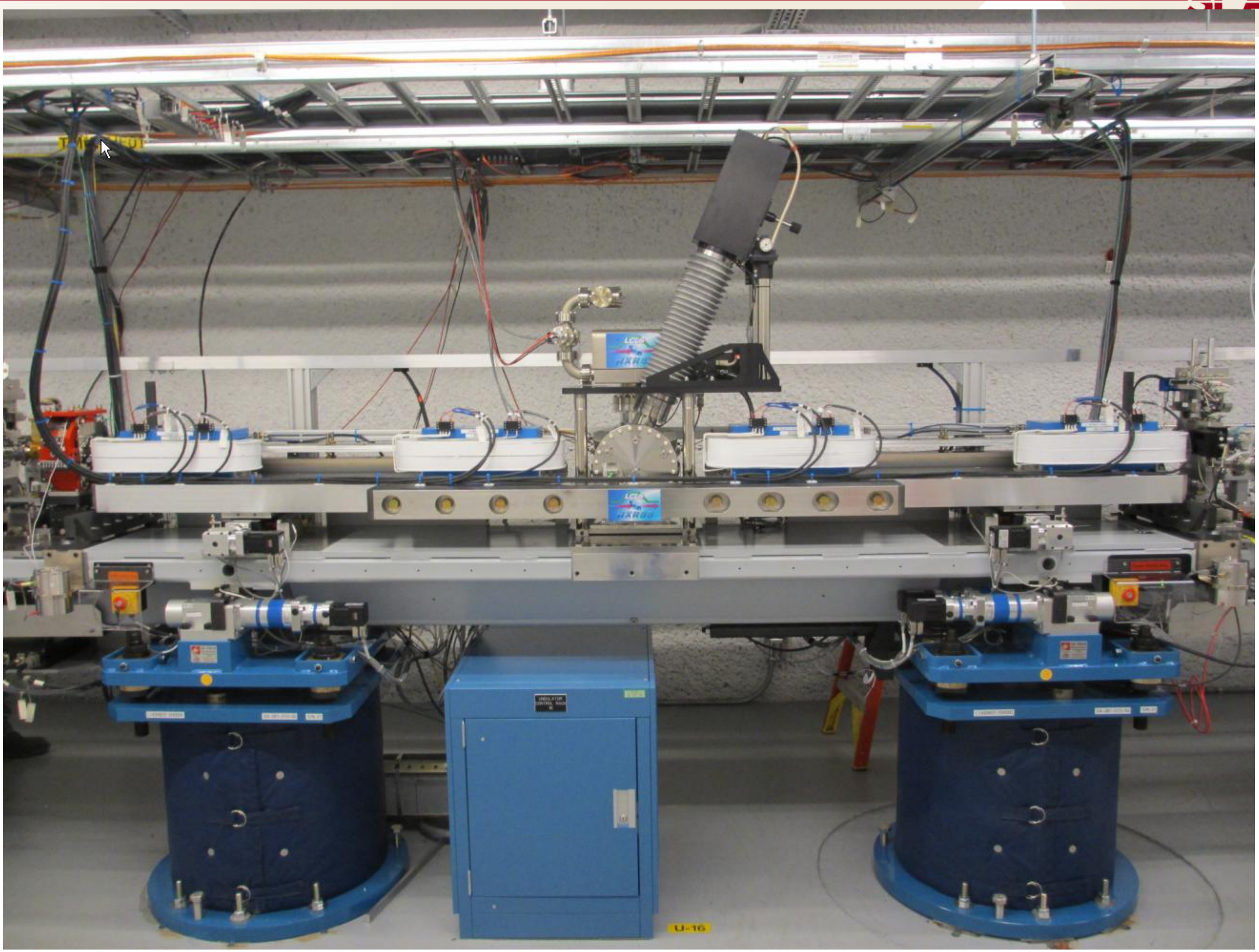
SLAC



CTF
Cathode Test Facility



Hard X-ray Self-Seeding



Hard X-Ray Self-Seeding
New Capability in LCLS Operation

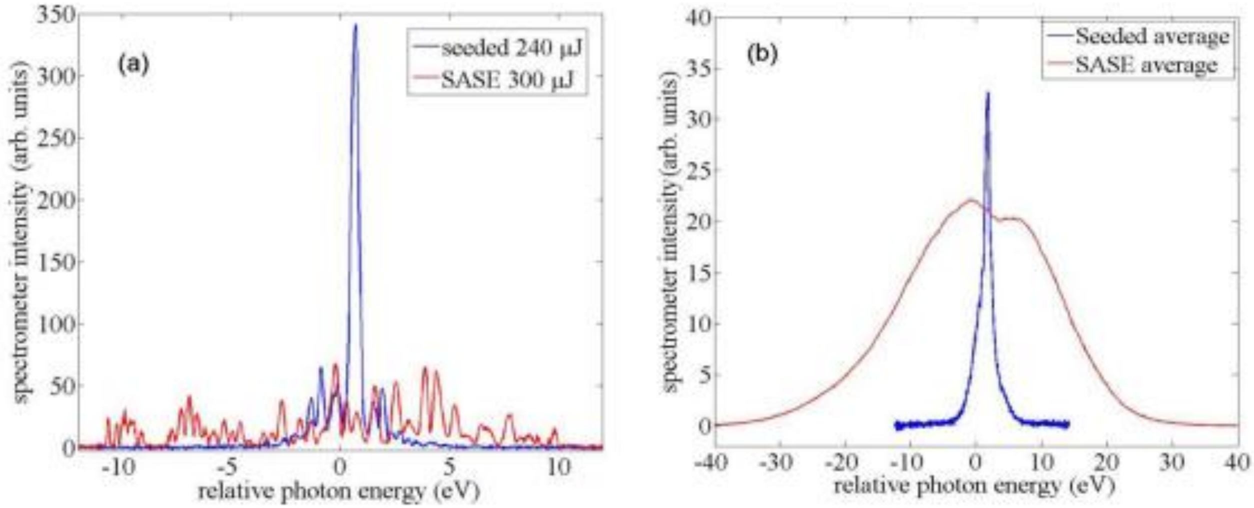


Figure 5. Single-shot (a) and averaged (b) x-ray spectrum in SASE mode (red) and self-seeded mode (blue). The FWHM single-shot seeded bandwidth is 0.4 eV, whereas the SASE FWHM bandwidth is approximately 20 eV. Vertical scales have the same arbitrary units in both plots (a) and (b). The chicane is turned off for the SASE measurements, but necessarily switched on for the self-seeded mode.

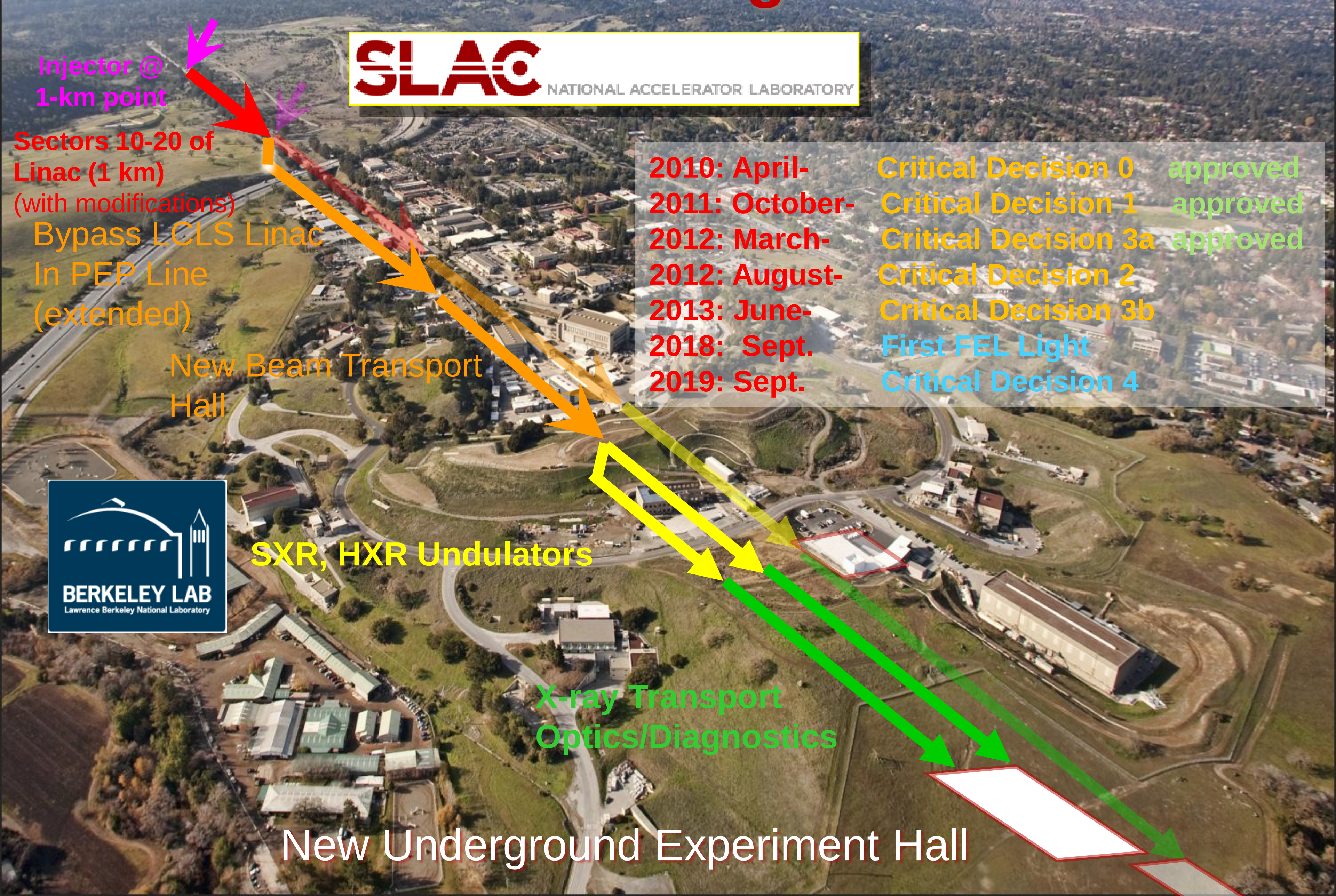
Demonstration of self-seeding in a hard x-ray free-electron laser

J. Amann[1], W. Berg[2], V. Blank[3], F.-J. Decker[1], Y. Ding[1], P. Emma[4], Y. Feng[1], J. Frisch[1], D. Fritz[1], J. Hastings[1], Z. Huang[1], J. Krzywinski[1], R. Lindberg[2], H. Loos[1], A. Lutman[1], H.-D. Nuhn[1], D. Ratner[1], J. Rzepiela[1], D. Shu[2], Yu. Shvyd'ko[2], S. Spampinati[1], S. Stoupin[2], S. Terentyev[3], E. Trakhtenberg[2], D. Walz[1], J. Welch[1], J. Wu[1], A. Zholents[2], D. Zhu[1]

Affiliations for authors: [1]SLAC National Accelerator Laboratory, Stanford, CA 94309, USA; [2]Argonne National Laboratory, Argonne, IL 60439, USA; [3]Technical Institute for Superhard and Novel Carbon Materials, Troitsk, Russia 142190; [4]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Nature Photonics (2012)

Linac Coherent Light Source II



LCLS-II Enhanced Capability

LCLS-II will provide expanded spectral range using two beamlines and variable gap undulators

- Up to 13 keV (above Selenium K-edge) @ 10.5-13.5 GeV
- Down to 250 eV (Carbon K-edge) @ 7-10 GeV

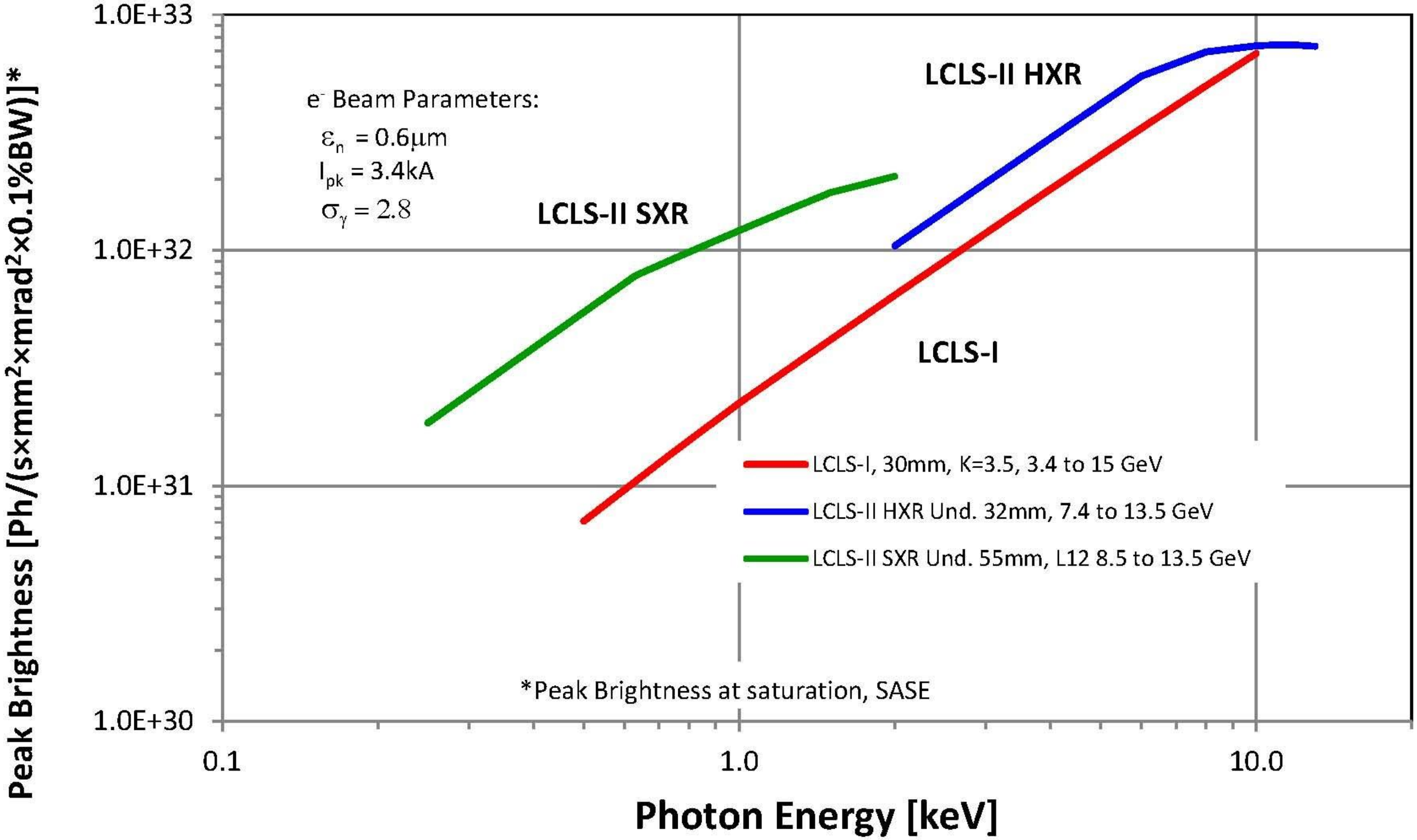
- <u>300 meter undulator tunnel</u>
  - Adequate space to accommodate future enhancements:
    - Seeding
    - Two-color generation
    - Polarization control
    - TW peak power
  - Details will be determined by ongoing LCLS R&D program

LCLS-II Greater Capacity

SLAC

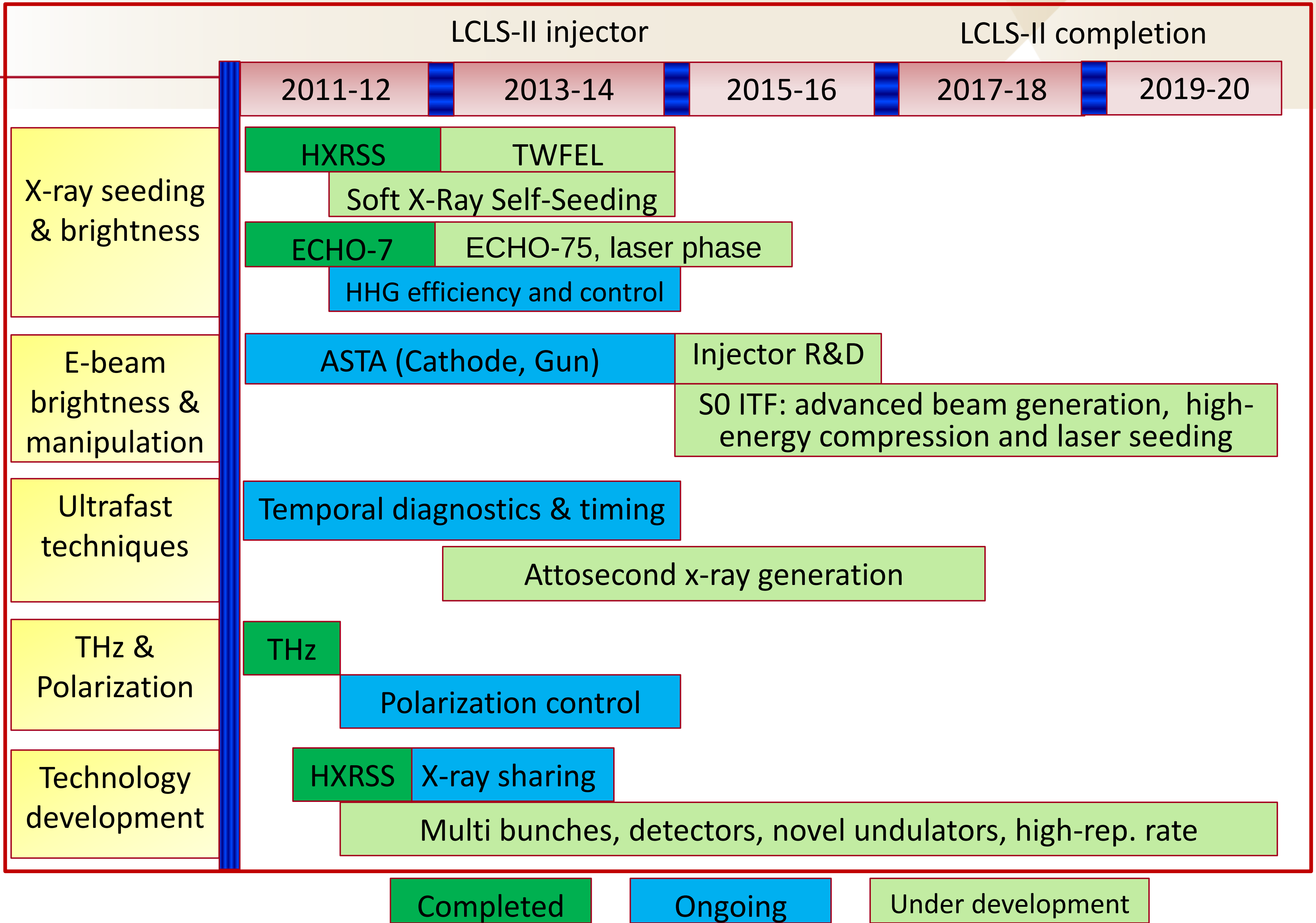
- Dedicated new injector at Sector 10
- Two new SASE undulator x-ray sources, both variable gap
- High Field Physics Soft X-Ray Experiment Station
- Immediately:
  - 4X increase in operations hours for soft x-rays
  - Generally, soft x-ray experiments run one-at-a-time
- Immediate 20% increase in operations hours for hard x-rays
  - Since hard x-ray instruments will someday run simultaneously, perhaps 2 or even 3 at a time, this can mean nearly 20% more time <u>per station</u>
- Future: Room in new experiment hall for at least 3 more new instruments with new scientific capabilities
- Future: 4^{th} undulator in existing tunnel, 2 more instruments

Two New FEL Sources with Expanded Spectral Range



Tuning the X-Rays with both undulator gap and Electron Beam Energy
Maintain the flexible beam format vital to the LCLS success

SLAC X-ray FEL R&D roadmap



Summary

- LCLS has been a great success
  - Very flexible beam operations allows for wide range of photon science studies
  - R&D program is defining new capability
    - Short fs-scale bunches
    - Wide photon energy range
    - Self-seeding with >0.01% BW
    - Two color operation
    - Polarized x-rays
    - Strongly tapered operation
- LCLS-II will be the next addition to the SLAC photon science portfolio → expands LCLS capability and capacity greatly

LCLS-II

End of Presentation

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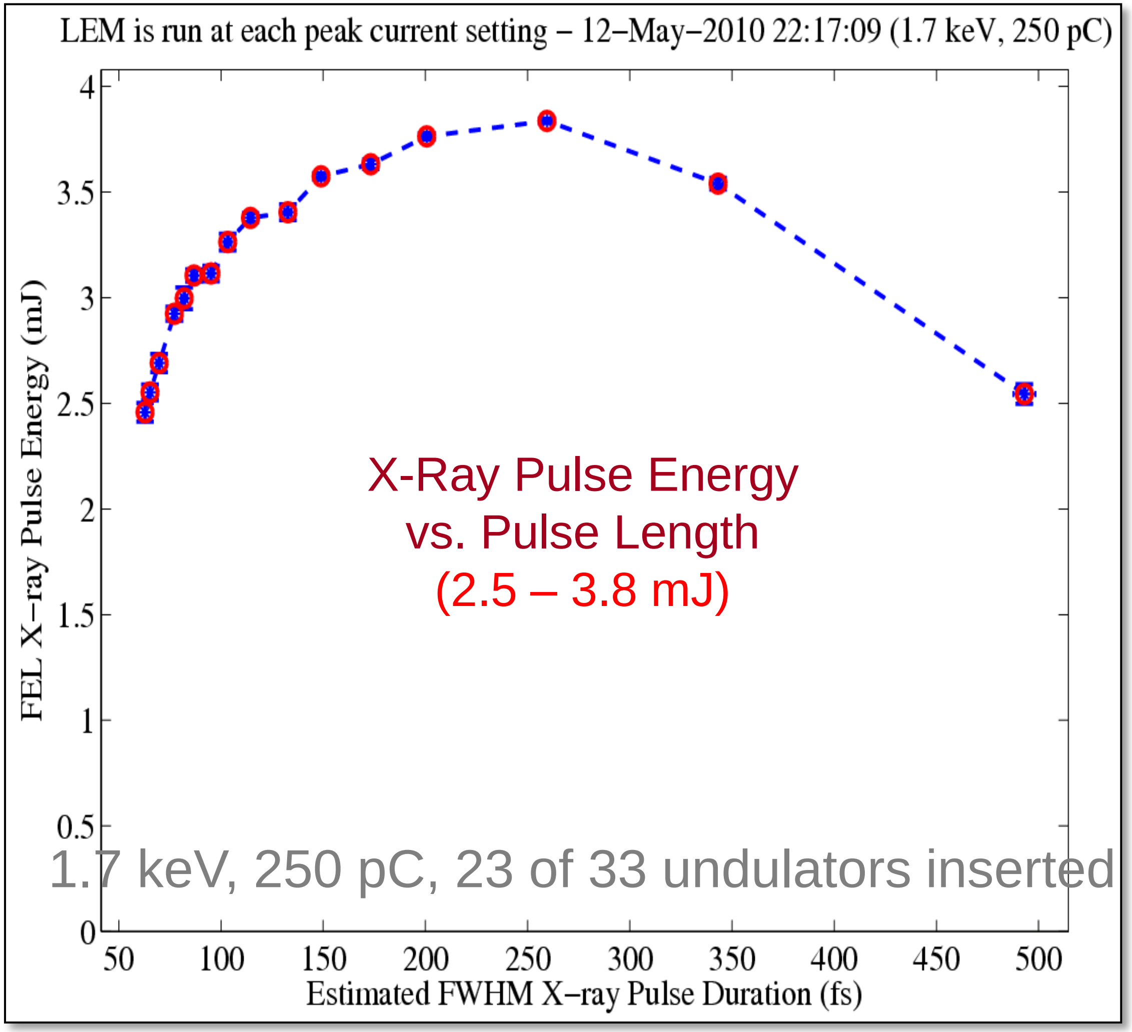
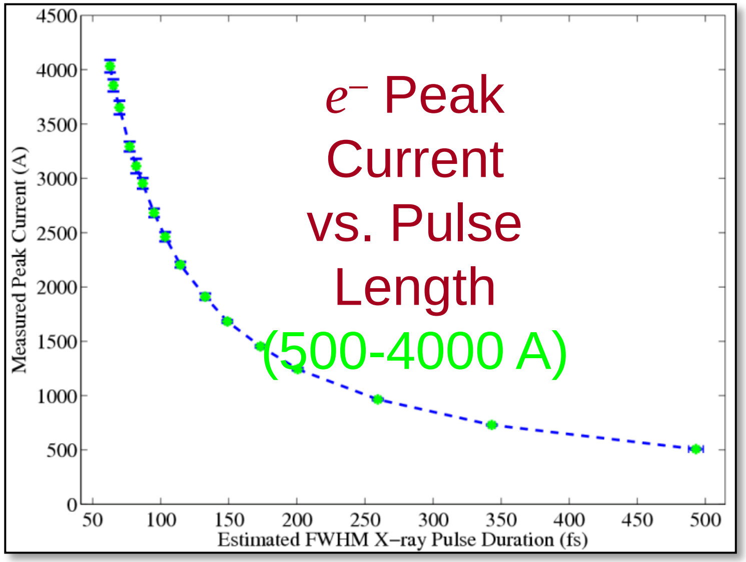
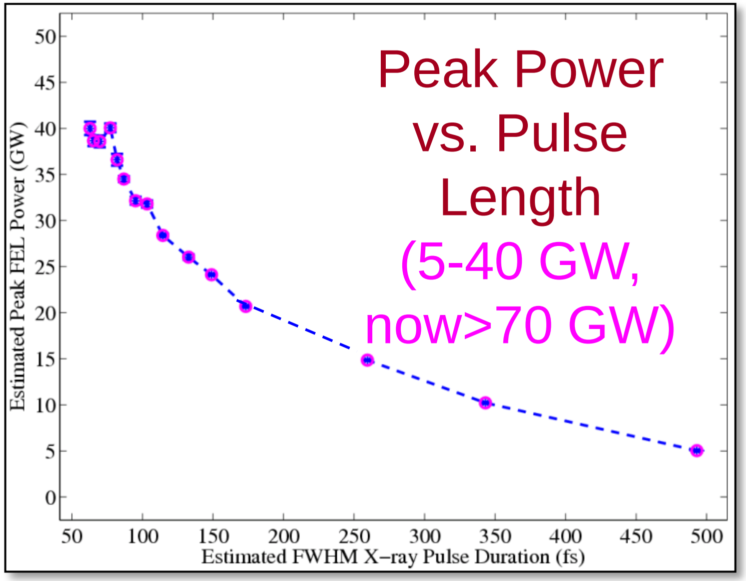
Pulse Length Easily Adjusted (500-60 fs)*





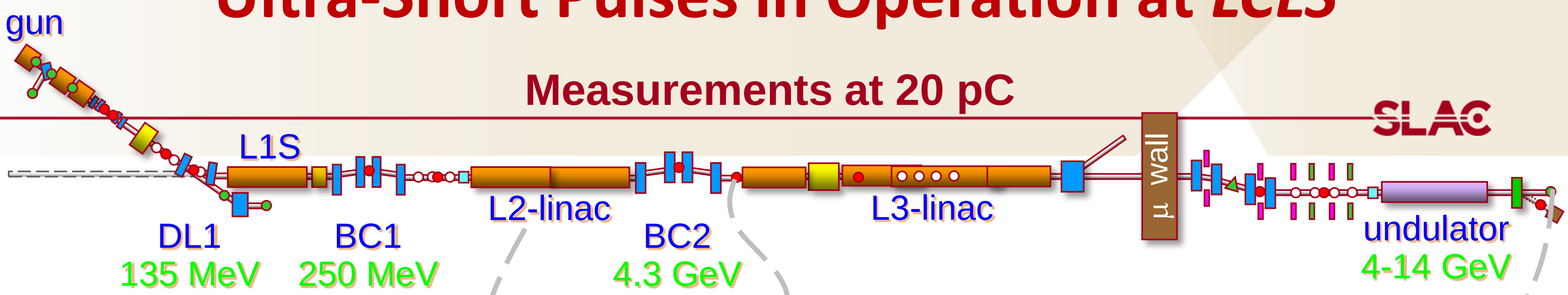


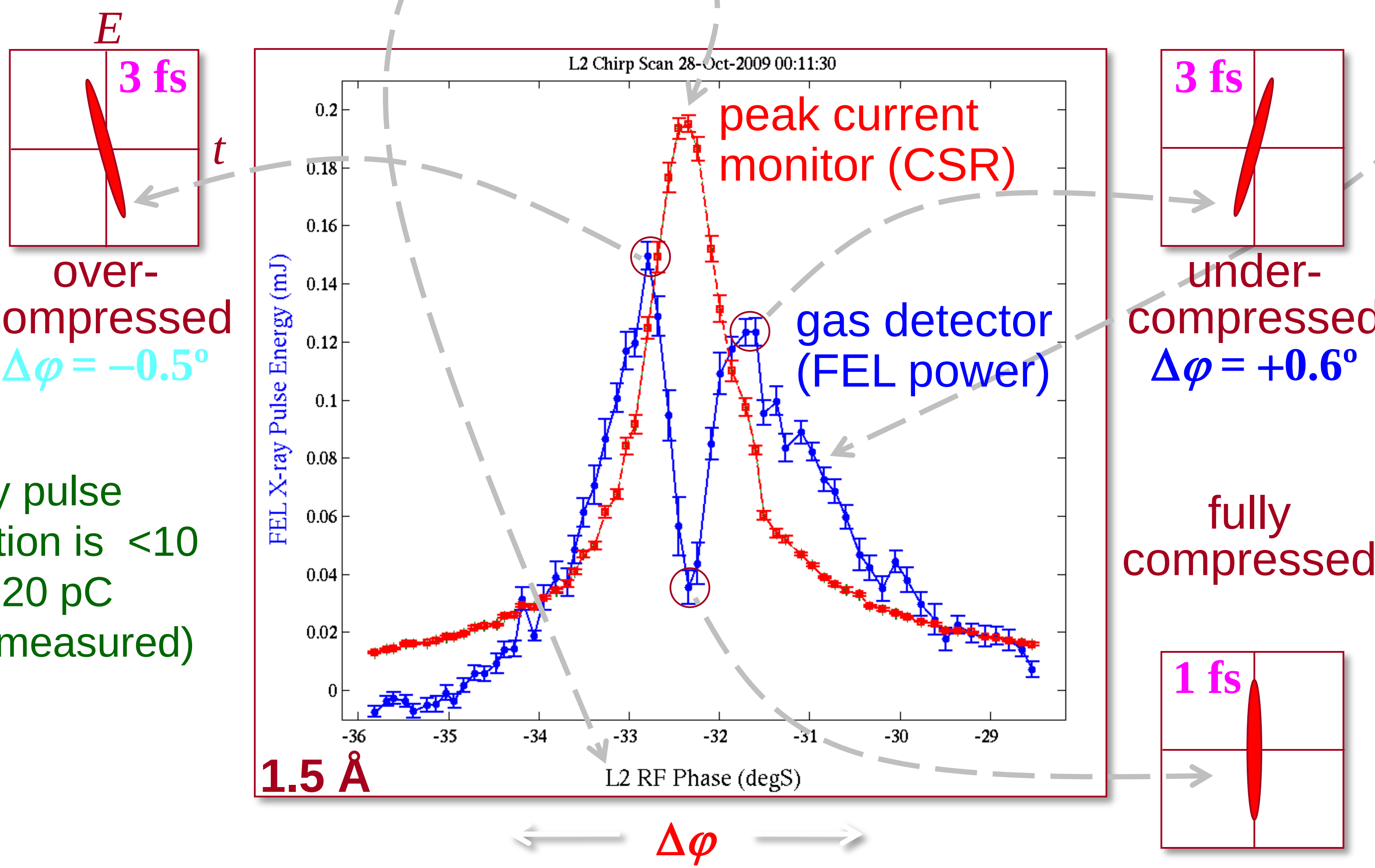
e^- bunch length is quickly adjustable (<1 min) from 60 to 500 fs (hard x-rays: 60 to 100 fs)

*** for soft x-rays (0.5-2 keV)**

Ultra-Short Pulses in Operation at *LCLS*

Measurements at 20 pC





X-ray pulse duration is <10 fs at 20 pC (not measured)

Ultra-short bunch length measurement

- Transverse deflector lacks resolution to measure ultra-short low charge bunch (< 10 fs)
- A technique is developed to map time to energy, which can be measured with a high-resolution spectrometer (**~1 fs** resolution)