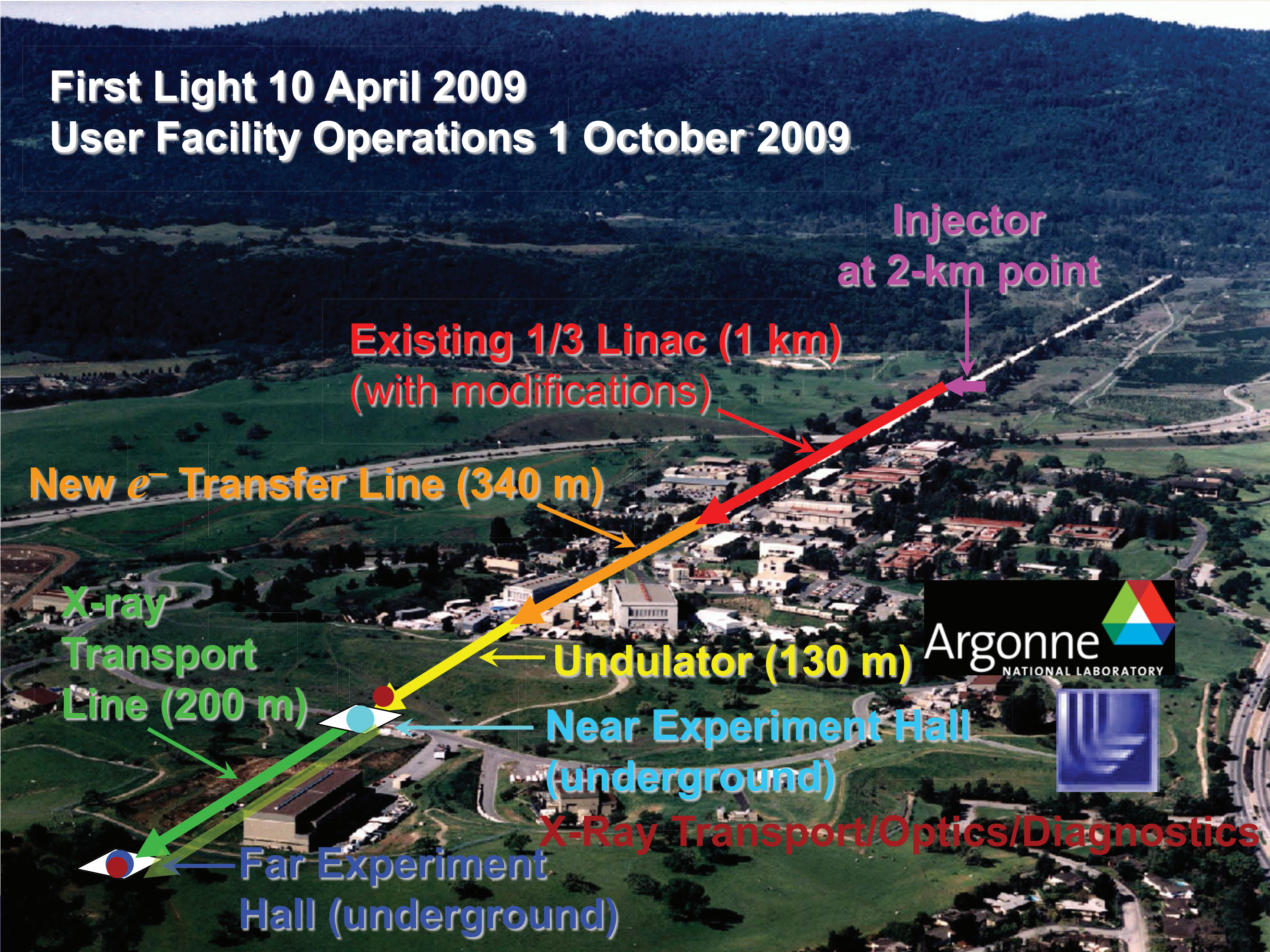
The 35th International Free-Electron Laser Conference

The Linac Coherent Light Source- Plans and Options for Future Development

John N. Galayda
representing the LCLS-II Team

SLAC NATIONAL ACCELERATOR LABORATORY

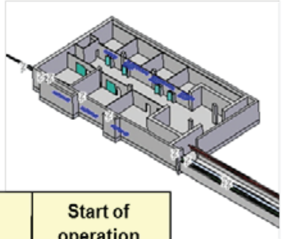
BERKELEY LAB


First Light 10 April 2009
User Facility Operations 1 October 2009
Injector
at 2-km point
Existing 1/3 Linac (1 km)
(with modifications)
New e^- Transfer Line (340 m)
X-ray
Transport
Line (200 m)
Undulator (130 m)
Argonne
NATIONAL LABORATORY
Near Experiment Hall
(underground)
X-Ray Transport/Optics/Diagnostics
Far Experiment
Hall (underground)

Six Experiment Stations Operational

Near Experimental Hall

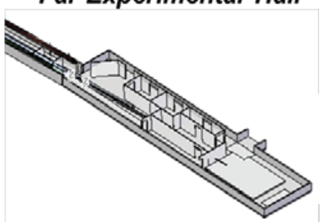
AMO
SXR
XPP

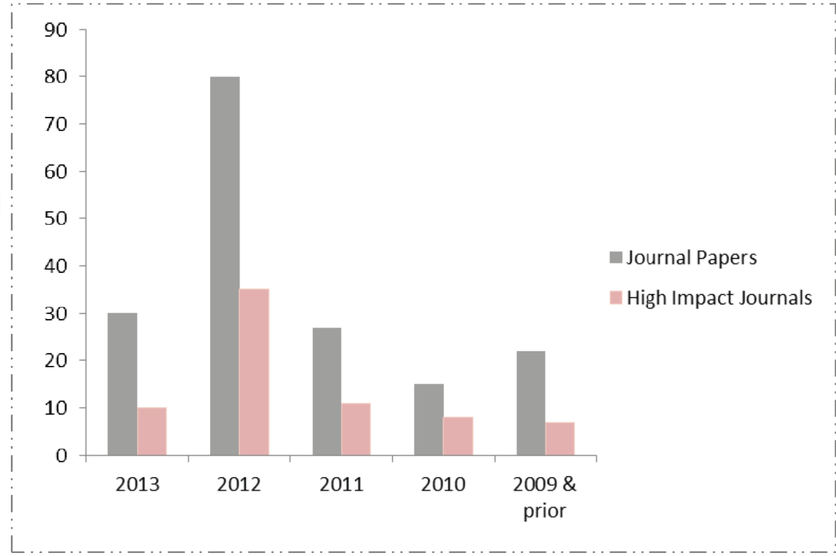


	Start of operation
AMO	Oct-09
SXR	May-10
XPP	October-10
CXI	February-11
XCS	November-11
MEC	April -12

Far Experimental Hall

XCS
CXI
MEC





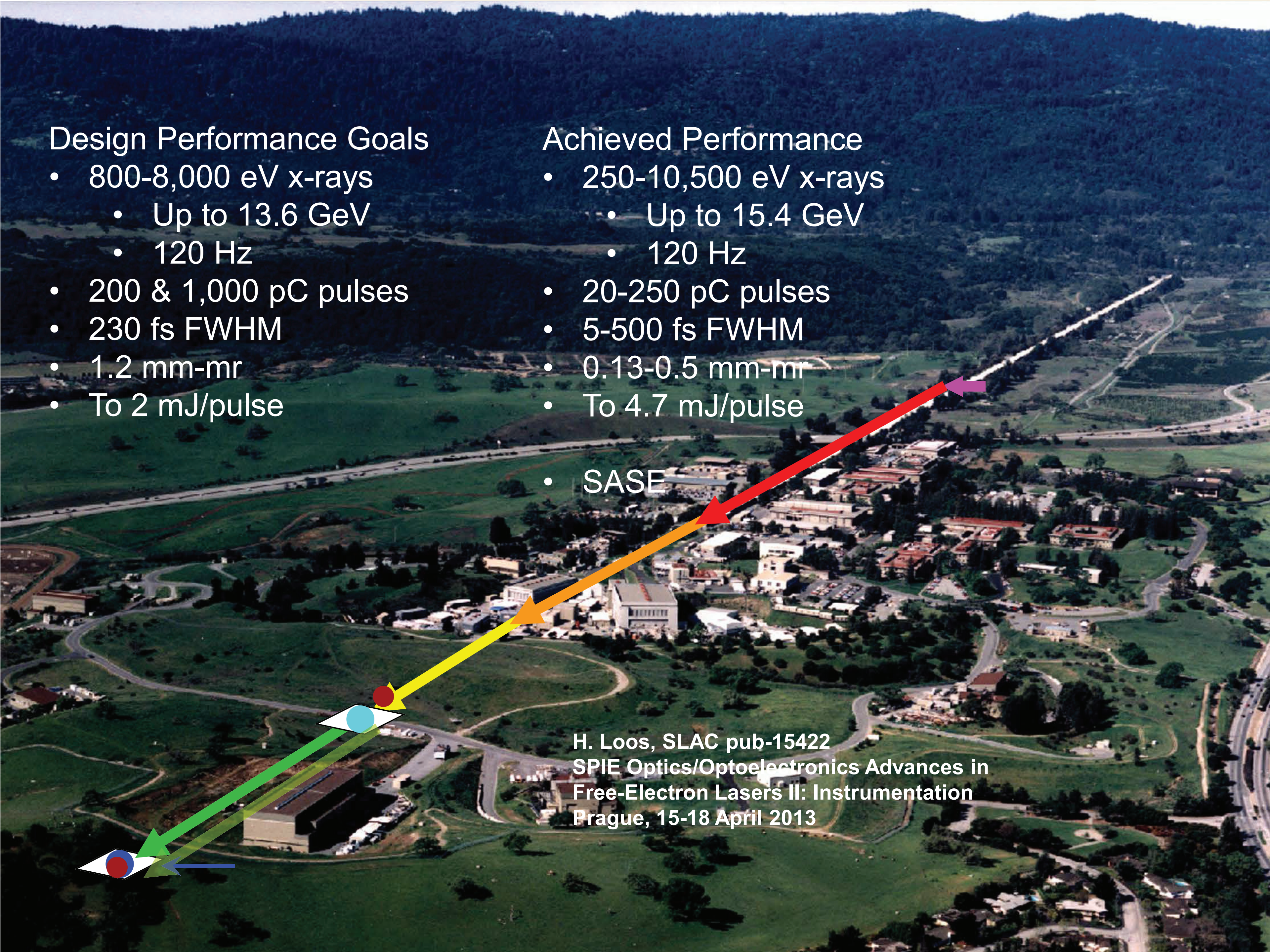
LCLS User	Call 1		Call 2		Call 3		Call 4		Call 5		Call 6		Call 7		Call 8		Call 9	
Summary	Sept. '08		May '09		Nov '09		June '10		January '11		September '11		July '12		Jan. '13		July '13	
	Scientists	Proposals	Scientists	Proposals	Scientists	Proposals	Scientists	Proposals	Scientists	Proposals	Scientists	Proposals	Scientists	Proposals	Scientists	Proposals	Scientists	Proposals
# Proposals	28	28	62	62	107	107	116	116	114	114	134	134	152	152	175	175	195	
# Scientists	219		473		672		710		850		953		1165		1215			
# Countries	16		15		22		19		23		24		14		26			
# Experiments Scheduled		11		23		26		26		39		33		43		37		
# Scientists	219	28	473	62	672	107	710	116	736	114	819	134	1013	152	1215	175		

Design Performance Goals

- 800-8,000 eV x-rays
  - Up to 13.6 GeV
  - 120 Hz
- 200 & 1,000 pC pulses
- 230 fs FWHM
- 1.2 mm-mr
- To 2 mJ/pulse

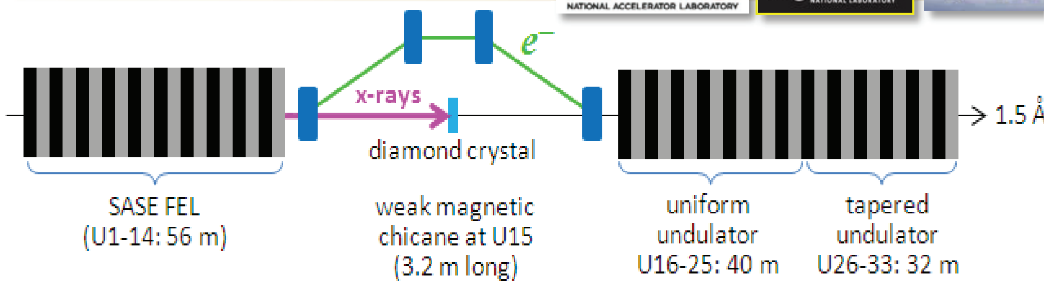
Achieved Performance

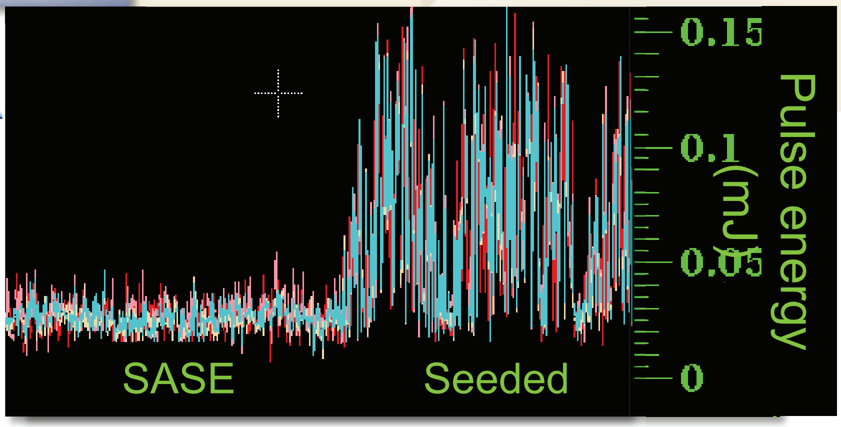
- 250-10,500 eV x-rays
  - Up to 15.4 GeV
  - 120 Hz
- 20-250 pC pulses
- 5-500 fs FWHM
- 0.13-0.5 mm-mr
- To 4.7 mJ/pulse
- SASE



H. Loos, SLAC pub-15422
SPIE Optics/Optoelectronics Advances in Free-Electron Lasers II: Instrumentation
Prague, 15-18 April 2013

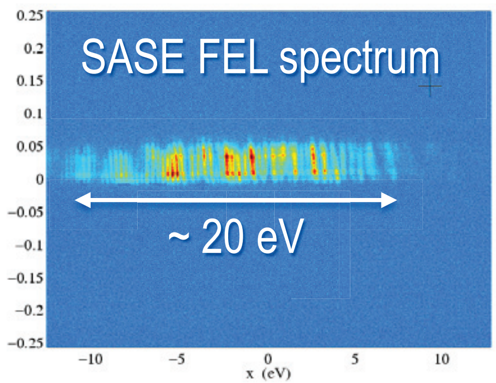
First Demonstration of Hard X-ray Self Seeding at LCLS

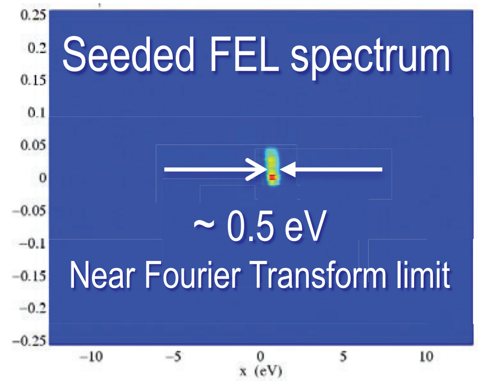


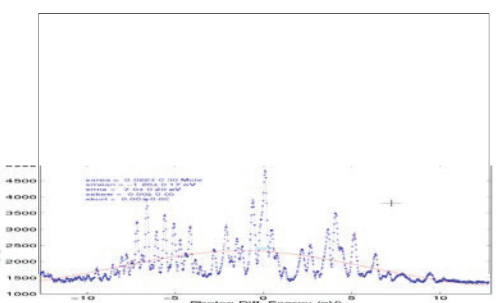


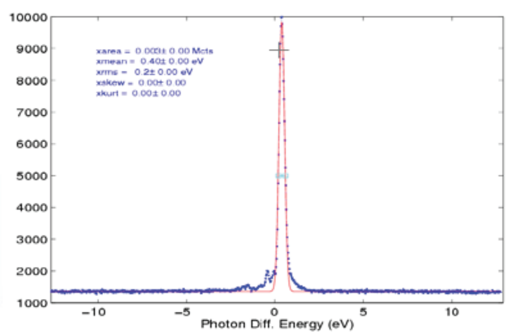
Single shot pulse energy from the gas detectors with 40pC charge

- Concept developed by Geloni, Kocharyan and Saldin, DESY 10-053 (2010).
- The mean seeded FEL power is 8 GW with a 2.5 GW SASE background at 8 keV for 40 pC bunch charge.
- Peak seeded power is in excess of 15 GW, comparable to SASE but with a spectral bandwidth reduction by the factor of 40.
- Pulse energy jitter : SASE+ 10^{-3} e-beam energy jitter









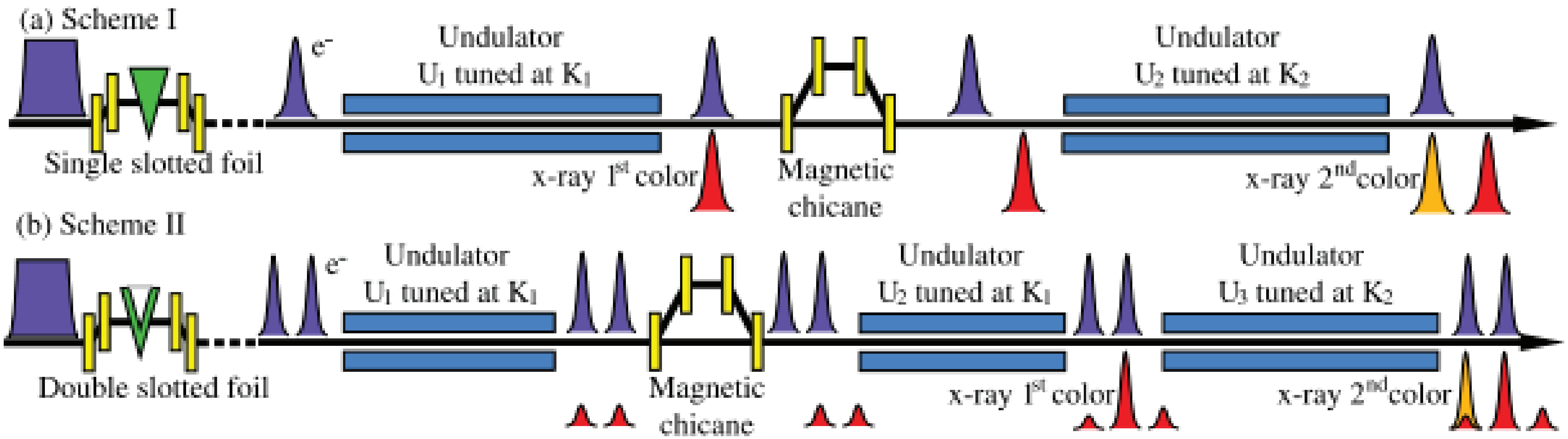
SASE and Seeded spectra recorded on single shots. The left panels are SASE with 150 pC, 3kA peak current, un-seeded. The FWHM of the SASE spectrum is 0.2 % Bandwidth. The right panels are the seeded beam with the same electron beam parameters. The FWHM of the seeded beam is 0.5 eV (5×10^{-5} bandwidth)

nature photonics
ARTICLES
PUBLISHED ONLINE: 12 AUGUST 2012 | DOI: 10.1038/NPHOTON.2012.180

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] and D. Zhu[1]

Two X-Ray Pulses, Two Colors:



Two-color FEL schemes tested at the LCLS. A single-slot (in scheme I) or double-slot (in scheme II) emittance spoiling foil was used to generate ultrashort single or double electron bunches. The emittance-spoiling foil is located in the second bunch compressor. A magnetic chicane, designed for hard x-ray self-seeding purpose, was adopted here to control the temporal delay between the two-color pulses.

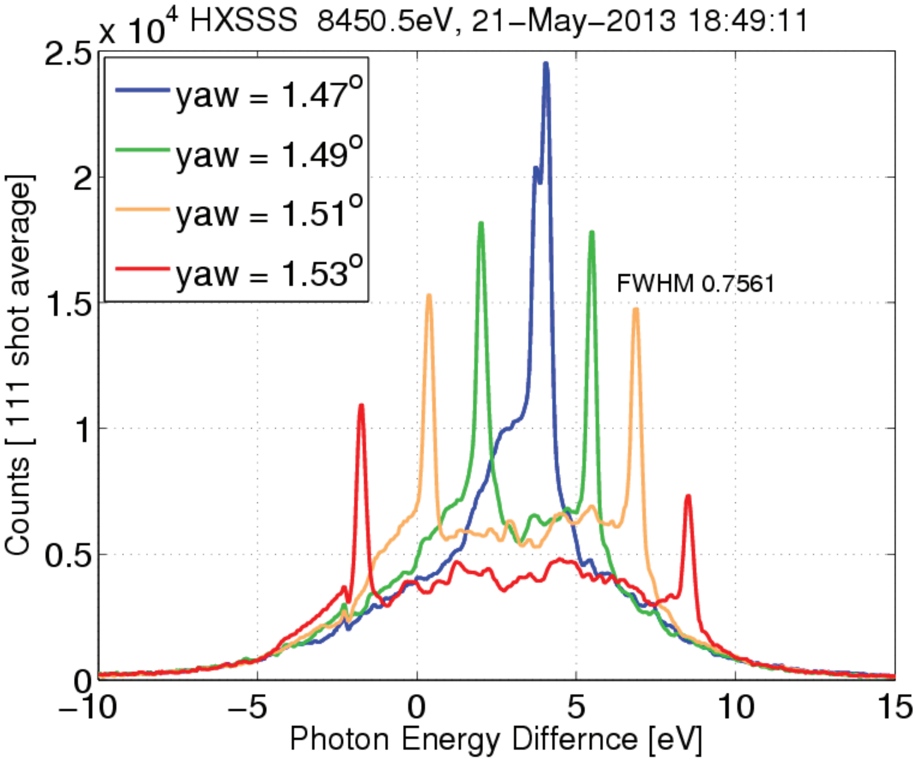
"A. Lutman, et al., **PRL 110**, 134801(2013)

- Start with 18 fs FWHM. 1.6 kA electron bunch
- "spoiler" foil @ BC2
- Produce 1 or 2 electron pulses capable of lasing
- Up to 25 fs delay between x-ray pulses
- ~1.5 keV, up to 20 eV energy separation

Two-color self-seeding

WEPSO09: *Two-Color Self-seeding and Scanning the Energy of Seeded Beams at LCLS,* F. J. Decker, Y. Ding, Y. Feng, M. Gibbs, J. B. Hastings, Z. Huang, H. Lemke, A. A. Lutman, A. Robert, J. L. Turner, J. J. Welch, D. H. Zhang, D. Zhu

"By adjusting the yaw angle in addition to the usual pitch angle of the seeding crystal, the authors demonstrated two-color seeded FEL with two different crystal diffraction planes at the hard x-ray photon energies. Each color has a spectral bandwidth of ~1eV and the color separation can be easily adjustable by the crystal yaw angle within the SASE bandwidth (about 20 eV)."



Continued development:

- Better understanding and control of soft x-ray performance
  - WEPSO27: *Recent LCLS Performance From 250 to 500eV* ,R.H. Iverson, J. Arthur, U. Bergmann, C. Bostedt, J.D. Bozek, A. Brachmann, W.S. Colocho, F.-J. Decker, Y. Ding, Y. Feng, J.C. Frisch, J.N. Galayda, T. Galetto, Z. Huang, E.M. Kraft, J. Krzywinski, J.C. Liu, H. Loos, X.S. Mao, S.P. Moeller, H.-D. Nuhn, A.A. Prinz, D.F. Ratner, T.O. Raubenheimer, S.H. Rokni, W.F. Schlotter, P.M. Schuh, T.J. Smith, M. Stanek, P. Stefan, M.K. Sullivan, J.L. Turner, J.J. Turner, J.J. Welch, J. Wu, F. Zhou (SLAC) P. Emma (LBNL) R. Soufli (LLNL)

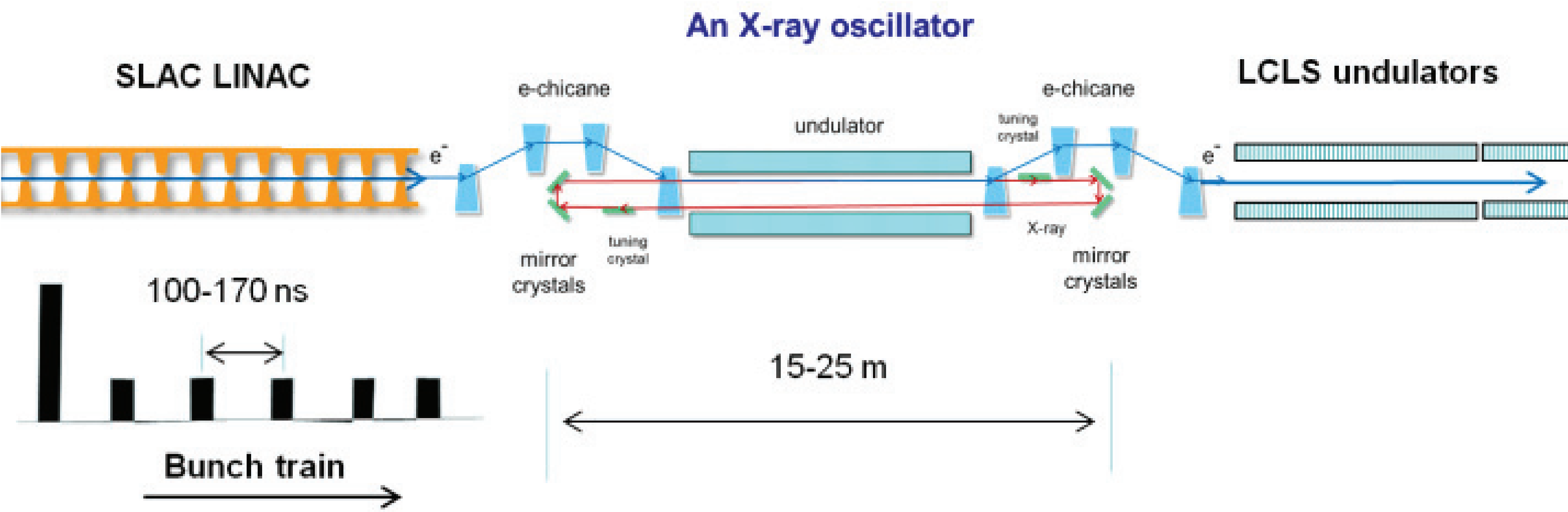
"For SXR operation typically we can provide 1-2 mJ x-ray pulses to the users, and recently we also established lasing down to 285eV ....."

- Soft X-Ray Self-seeding

  - WEPSO18: *The Soft X-ray Self-seeding Setup at the LCLS,* Y. Feng, P. Emma
  - WEPSO52: D.F. Ratner, J.W. Amann, D. Cocco, Y. Feng, J.B. Hastings, P.A. Heimann, Z. Huang, J. Krzywinski, H. Loos, S.P. Moeller, P.A. Montanez, H.-D. Nuhn, D.R. Walz, J.J. Welch, J. Wu (SLAC) K. Chow, P. Emma, L. Rodes (LBNL) U. Flechsig (PSI)

Continued development:

- WEPSO11, *Coherent X-Ray Seeding Source for Driving FELs,* F.-J. Decker, R.O. Hettel, Z. Huang, A. Novokhatski, H.-D. Nuhn, M.K. Sullivan (SLAC)
  - Concept for a cavity resonator for multi-bunch operation

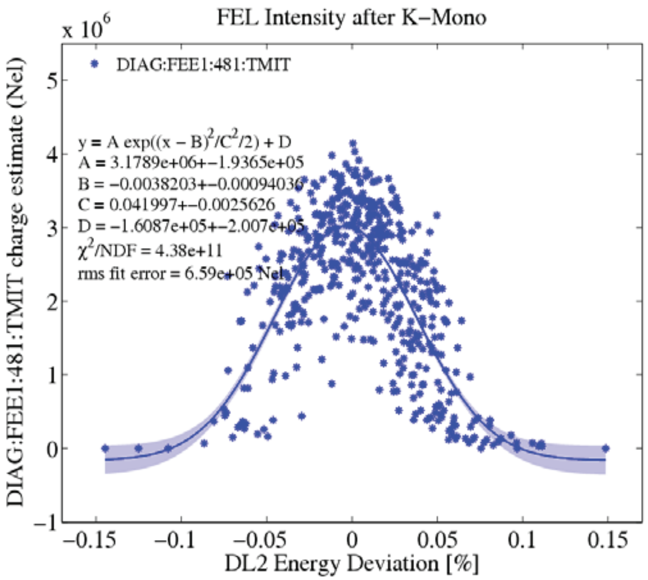


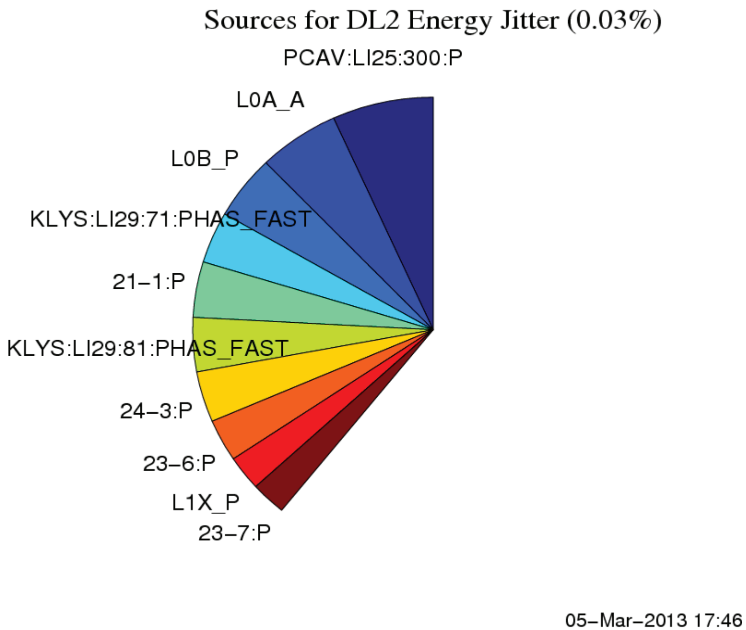
Continued development:

Improving energy stability for better seeded performance

WEPSO10: *Increased Stability Requirements for Seeded Beams at LCLS*, F.-J. Decker, W.S. Colocho, Z. Huang, R.H. Iverson,

A. Krasnykh, A.A. Lutman, M.N. Nguyen, T.O. Raubenheimer, M.C. Ross, J.L. Turner, L. Wang

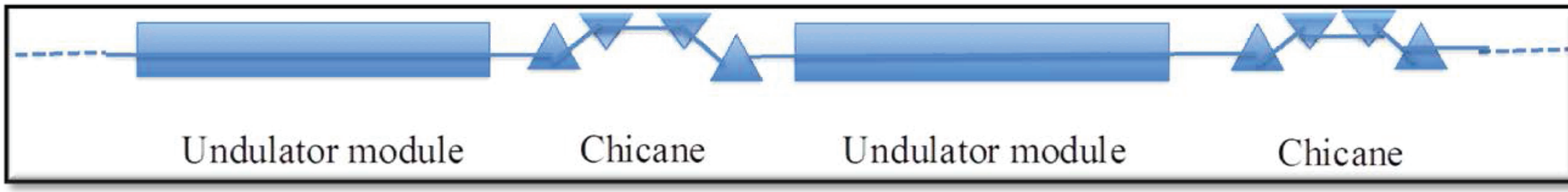


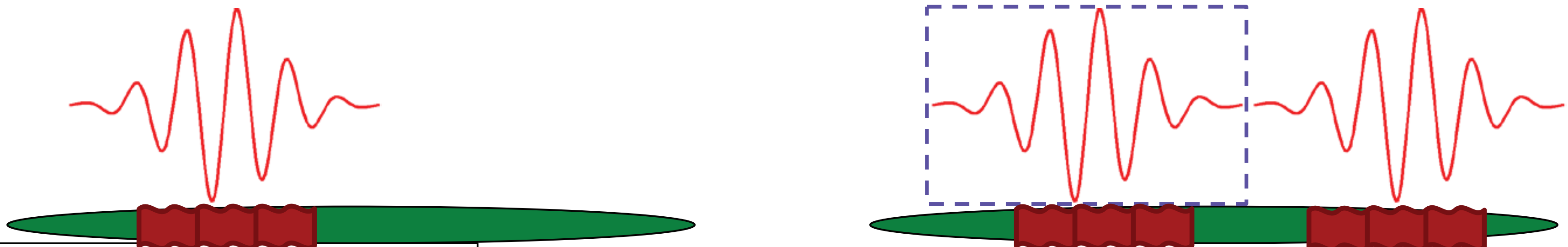


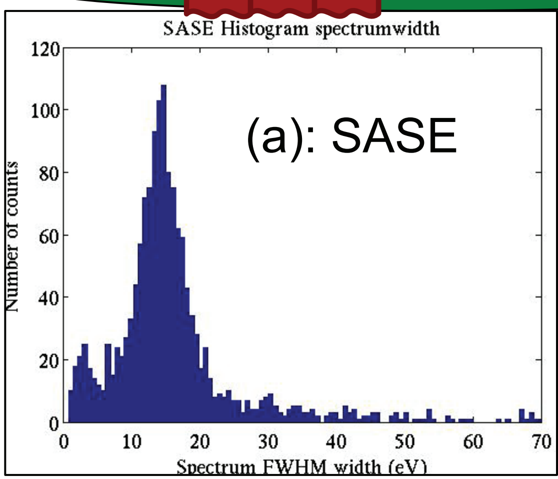
Reduce BW without use of a seeding monochromator:

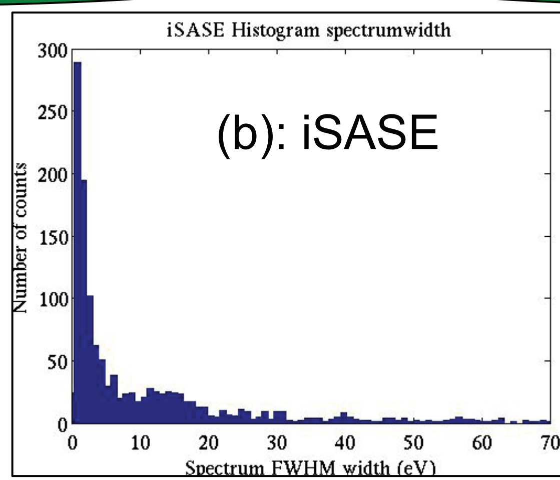
(c)

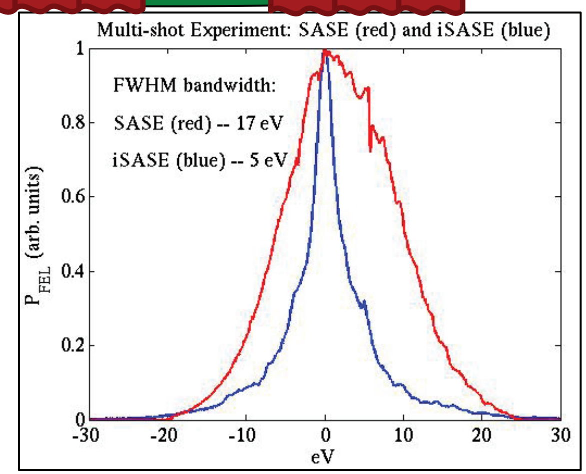
- THIBNO01: *Methods for Achieving Spectral Purity in SASE FELs,* J. Wu



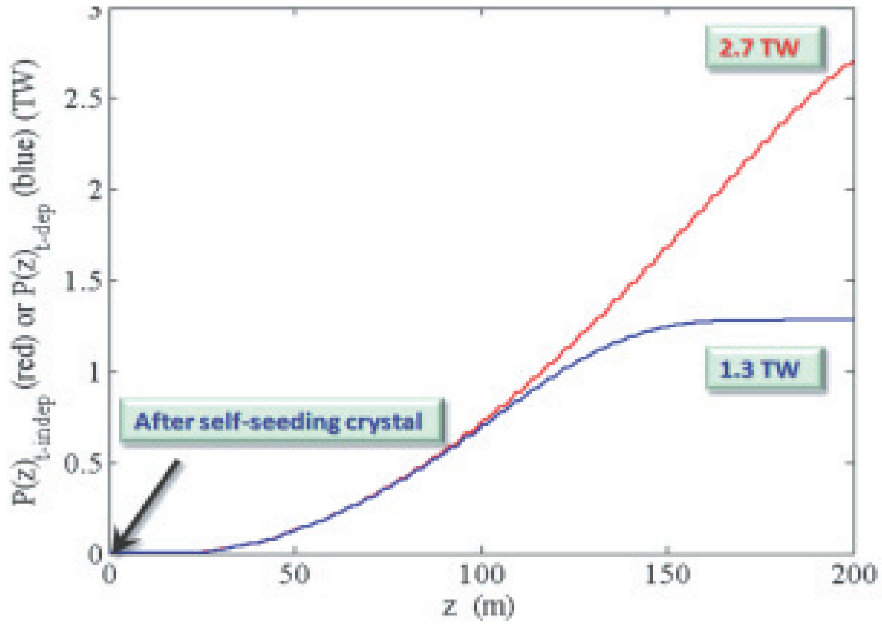








~TW Power from LCLS @ 8 keV should be achievable, if more undulators are installed in LCLS



TUOA4 Proceedings of FEL2011, Shanghai, China

TOWARD TW-LEVEL, HARD X-RAY PULSES AT LCLS*

W.M. Fawley[1], J. Frisch[1], Z. Huang[1], Y. Jiao[1], H.-D. Nuhn[1], C. Pellegrini[1,2], S. Reiche[3], J. Wu[1†]

[1]SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

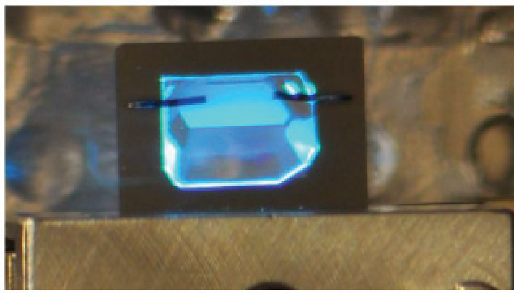
[2]Department of Physics and Astronomy, UCLA, Los Angeles, CA 90095-1547, USA

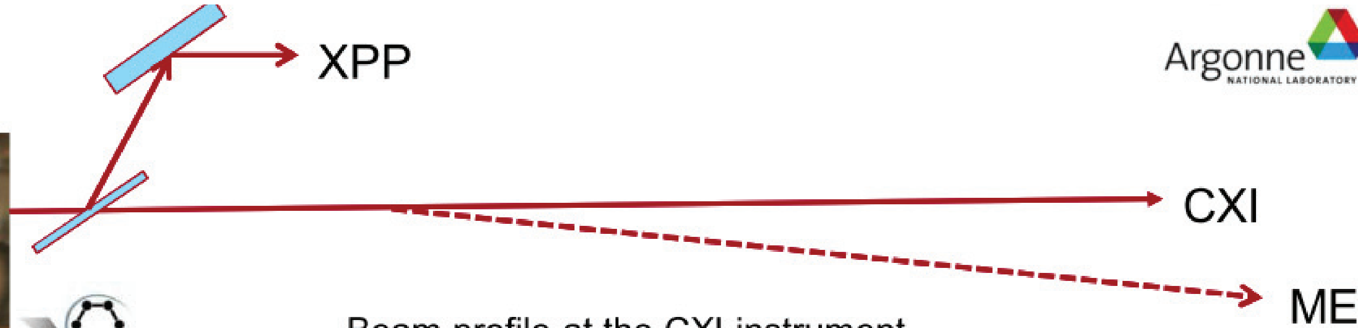
[3]Paul Scherrer Institute, Villigen PSI, 5232, Switzerland

http://accelconf.web.cern.ch/AccelConf/FEL2011/papers/tuoa4.pdf

HXR Beam Splitting at LCLS

Double Crystal
C*(111)

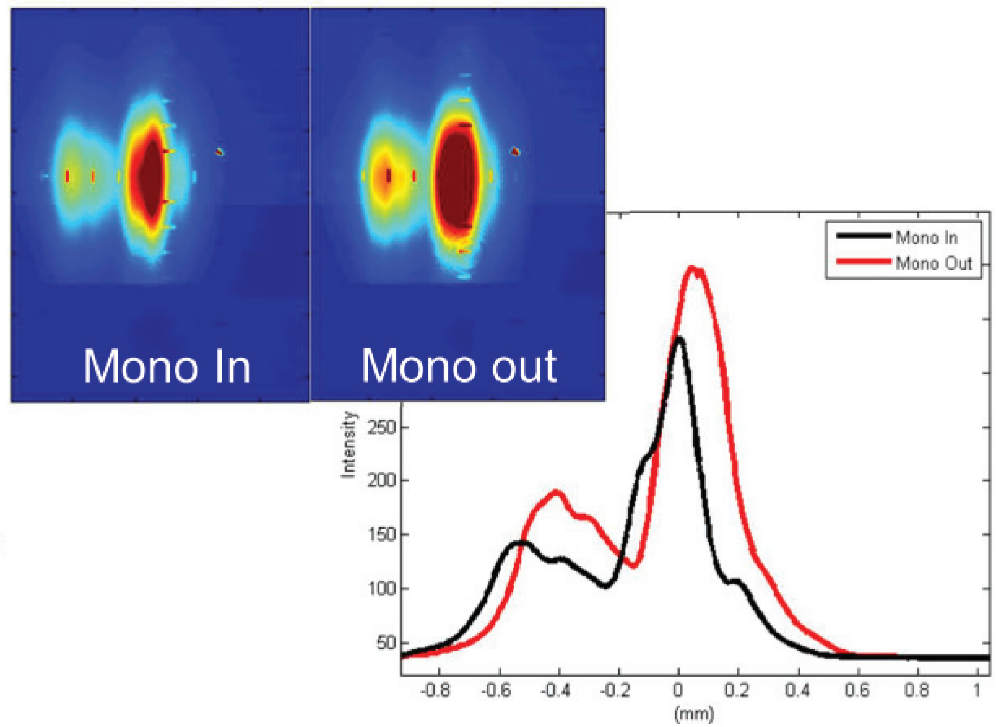




TISNCM

Technological Institute for Superhard and Novel Carbon Materials

Beam profile at the CXI instrument



First C*(111) crystal is 100μm thick

- Highly transmissive for X-rays outside Bragg reflection bandwidth)

71% beam transmission at 8.33 keV

Wavefront distortion is minimal

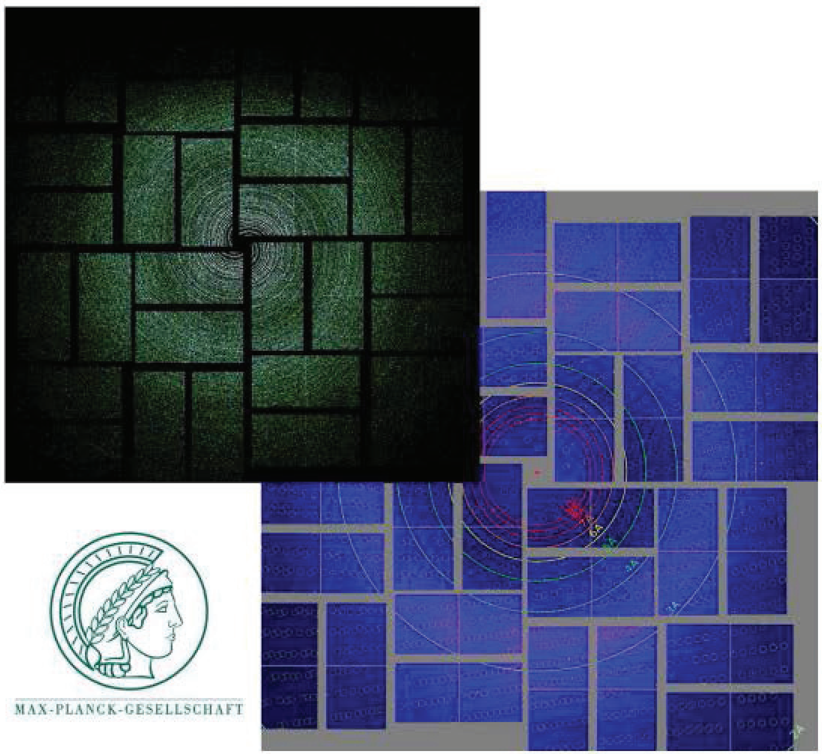
First simultaneous experiments performed Feb. 6

HXR Beam Splitting at LCLS

- Two simultaneous benchmark experiments successfully performed on February 6:
  - CXI: Protein nanocrystallography (lysozyme)
  - XPP: Femtosecond spin-crossover dynamics in Fe(II) complex

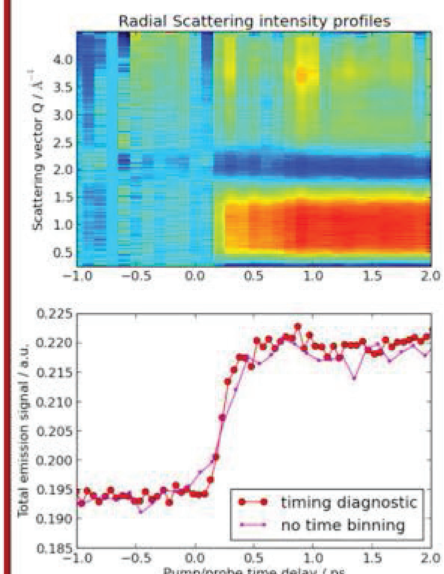
    Femtosecond structural dynamics in bismuth

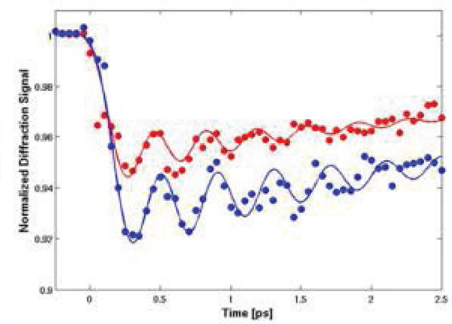
CXI



MAX-PLANCK-GESELLSCHAFT

XPP



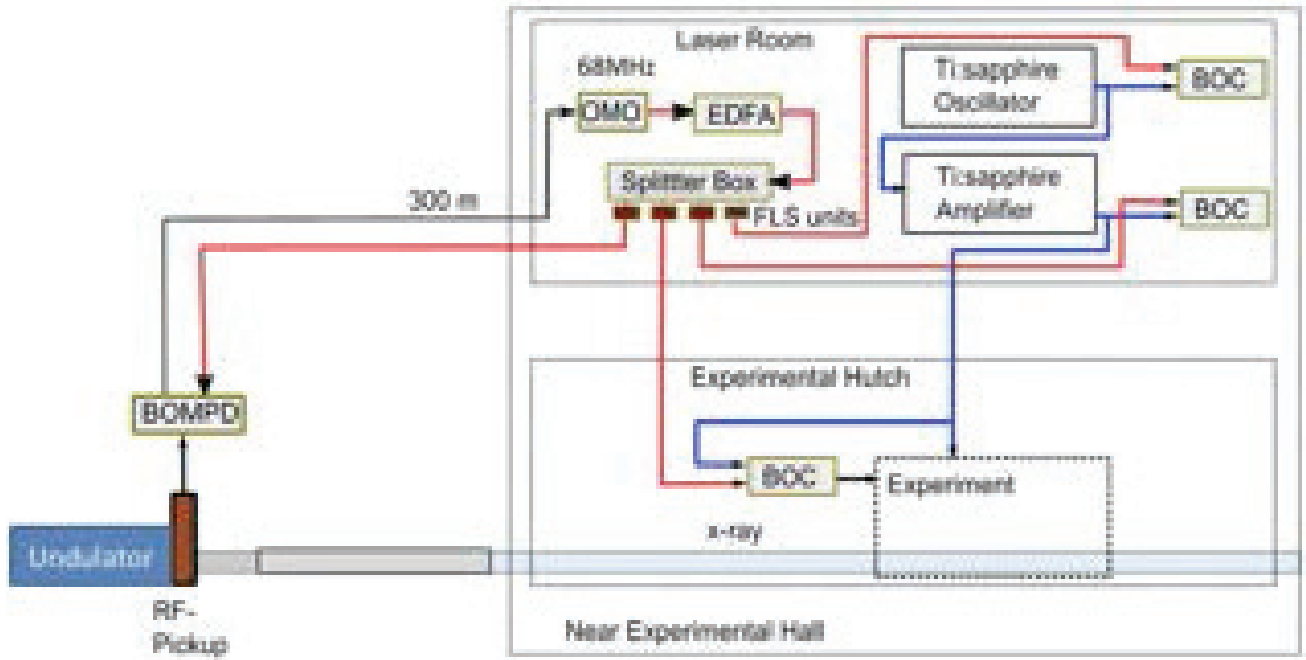


3

What's Next: Continue Diagnostics Development and Reduce Jitter

WEPSO37: **Femtosecond Fiber Timing Distribution System for the Linac Coherent Light Source,** H. Li, P.H. Bucksbaum, J.C. Frisch, A.R. Fry, J. May, K. Muehlig, S.R. Smith (SLAC) L. Chen, H.P.H. Cheng (Idesta Quantum Electronics) F. Kärtner (CFEL)

"A critical aspect of pump/probe experiments to explore time resolved dynamics with X-ray FELs is the timing stability between the x-rays and optical laser pulses. Our research project with an SBIR-funded small business is developing methods for timing distribution and synchronization at femto second resolution."



Time-tagging LCLS pump/probe data with new diagnostics: Dynamics with ~10 fs resolution

SLAC

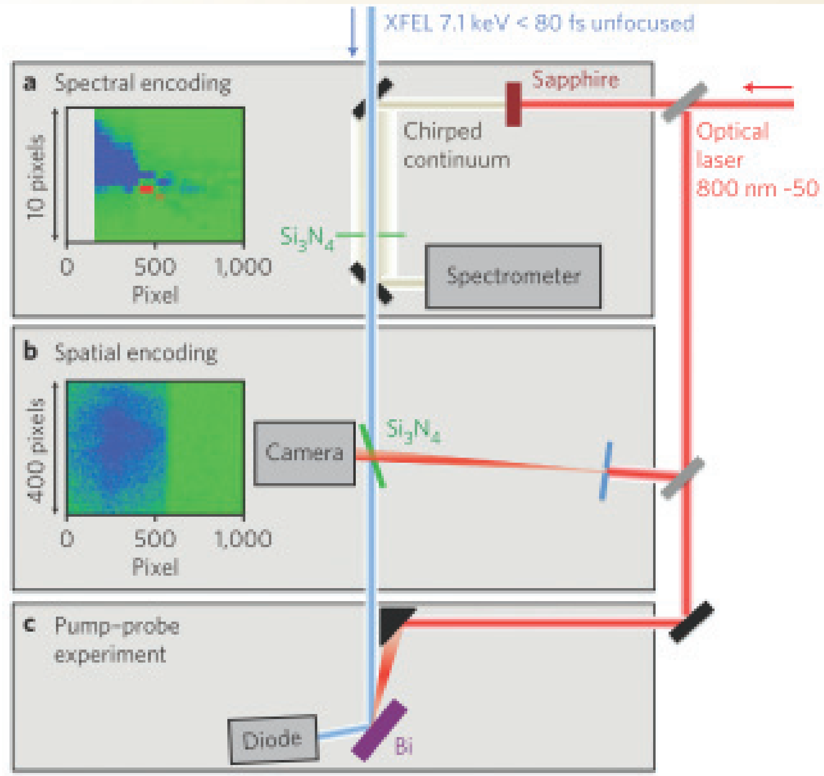


Figure 1 | Sketch of the experimental set-up. The FEL beam propagates from top to bottom. **a–c**, The same laser beam is split into three beams: with the first the relative delay between laser and X-ray is encoded into wavelength by using a broadband chirped supercontinuum (**a**); in the second, the temporal delay is spatially encoded (**b**); in the third, coherent phonon motion in bismuth provides an experimental test of time-sorting with the timing tools (**c**). The presented images are already background subtracted (without X-ray excitation).

- Pump laser-to-LCLS jitter ~200fs rms
- Jitter is measurable to <10fs
- Data can be retrospectively sorted
- Confirmed by using 3 cross-correlation monitors:
  - 6.1 keV LCLS x-rays modulate reflection of 200nm BW chirped light pulse in a thin Si_3N_4 film
  - Tilted Si_3N_4 film encodes TOA of FEL pulse across width of film
  - 3rd measurement using laser disruption of Bragg scattering of x-ray pulse from Bi

nature photonics LETTERS
PUBLISHED ONLINE: 17 FEBRUARY 2013 | DOI: 10.1038/NPHOTON.2013.11

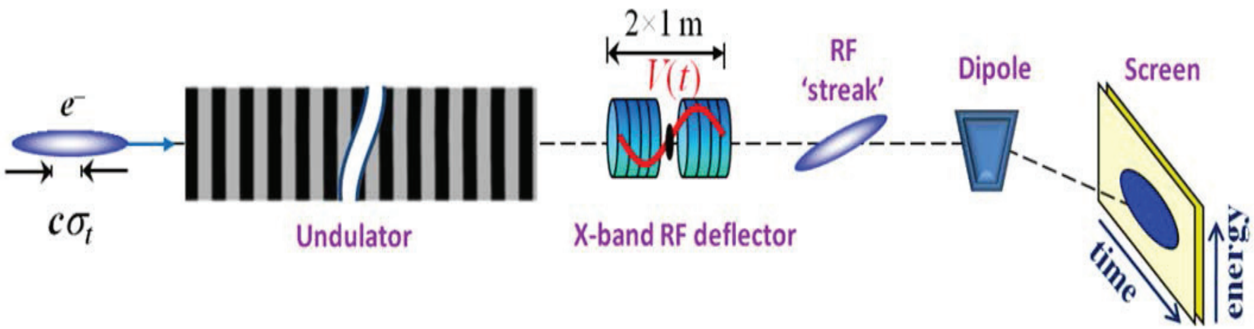
Achieving few-femtosecond time-sorting at hard X-ray free-electron lasers

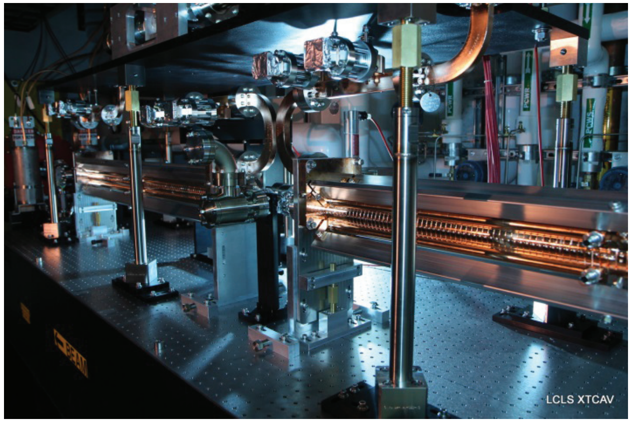
M. Harmand[1†]*, R. Coffee[2], M. R. Bionta[2,3], M. Chollet[2], D. French[2], D. Zhu[2], D. M. Fritz[2], H. T. Lemke[2], N. Medvedev[4], B. Ziaja[4,5], S. Toleikis[1] and M. Cammarata[6]*

Inference of x-ray pulse structure from e-beam measurements

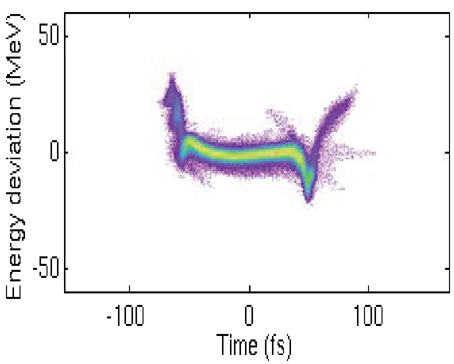
SLAC

TUOBNO04: *Femtosecond Electron and X-ray Beam Temporal Diagnostics Using an X-band Transverse Deflector at LCLS,* Y. Ding, C. Behrens, J.C. Frisch, Z. Huang, P. Krejcik, H. Loos, T.J. Maxwell, J.W. Wang, M.-H. Wang, J.J. Welch (SLAC)

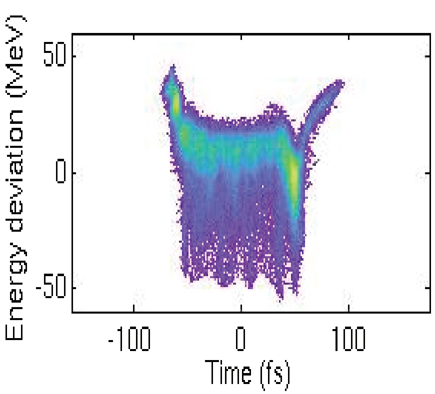




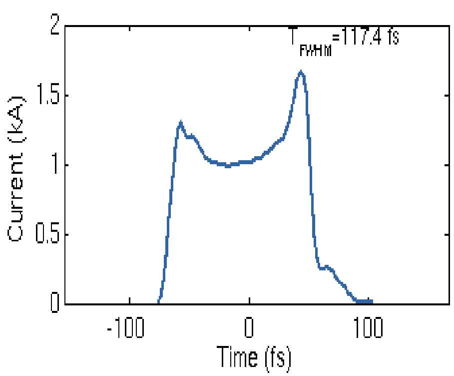
Lasing off



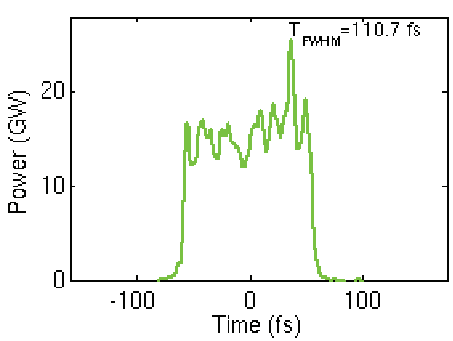
Lasing on



Electrons 4.7 GeV



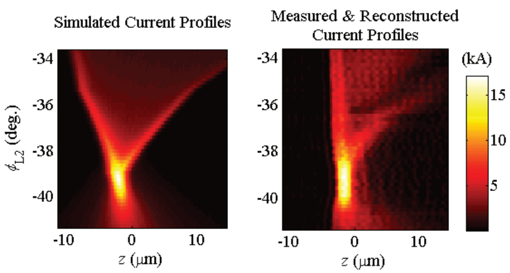
X-rays 1 keV

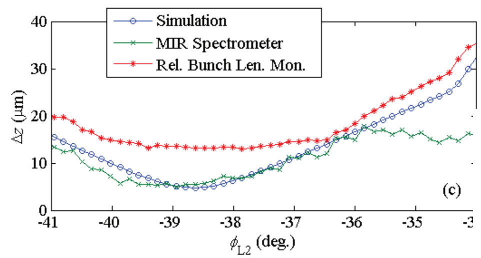


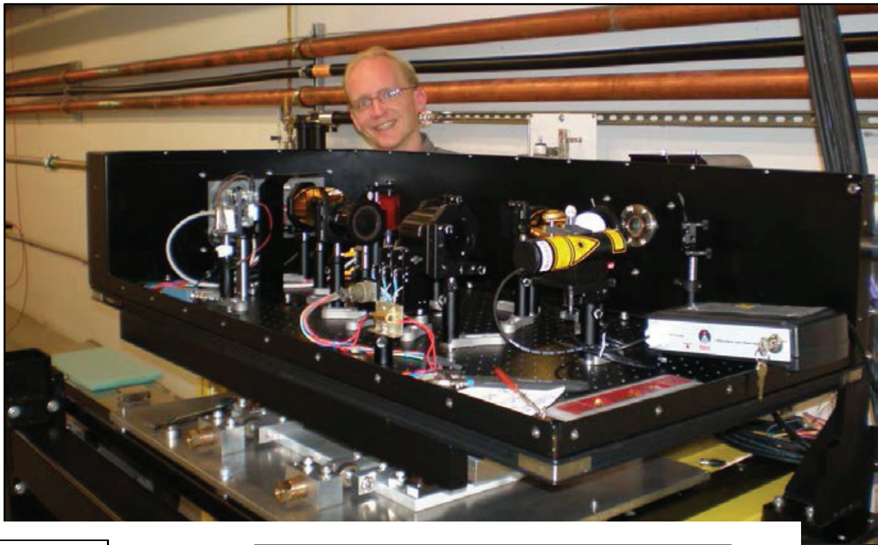
TUOANO03

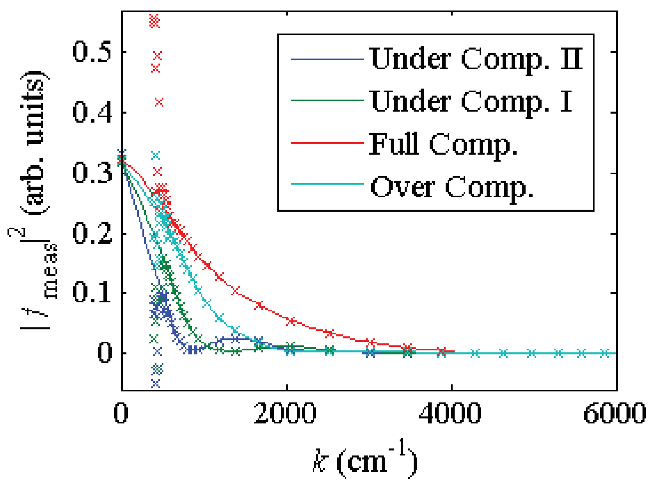
Bunch Profile Measurement of the LCLS Electron Beam via Mid-IR Spectroscopy

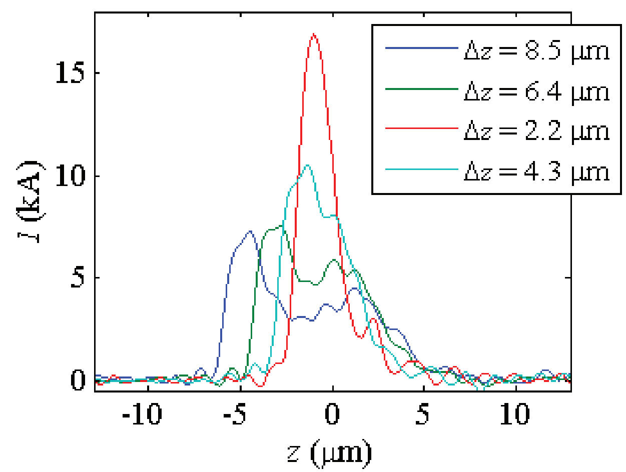
T.J. Maxwell, Y. Ding, A.S. Fisher, J.C. Frisch,
H. Loos (SLAC) C. Behrens (DESY)












Linac Coherent Light Source II
SLAC NATIONAL ACCELERATOR LABORATORY
Injector @ 1-km point
Sectors 10-20 of Linac (1 km) (with modifications)
Bypass LCLS Linac In PEP Xport Line (extended)
New Beam Transport Hall
SXR, HXR Undulators
X-ray Transport Optics/Diagnostics
New Underground Experiment Hall
BERKELEY LAB
Lawrence Berkeley National Laboratory

Undulator Prototype Assembly Has Begun

SLAC

BERKELEY LAB

Department of Energy Office of Basic Energy Sciences

- Basic Energy Sciences Advisory Committee called for a review of the scientific capabilities of future x-ray light sources. The review concluded that

  "Given the impressive advances in accelerator technologies during the last five years, it is likely that the best approach for a light source with the characteristics just enumerated would be a linac-based, seeded, free electron laser (FEL). To meet theanticipated high demand for this linear device, the linac should feed multiple, independently tunable undulators each of which could service multiple endstations. It is considered **essentia**l 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 subcommittee meets these criteria."

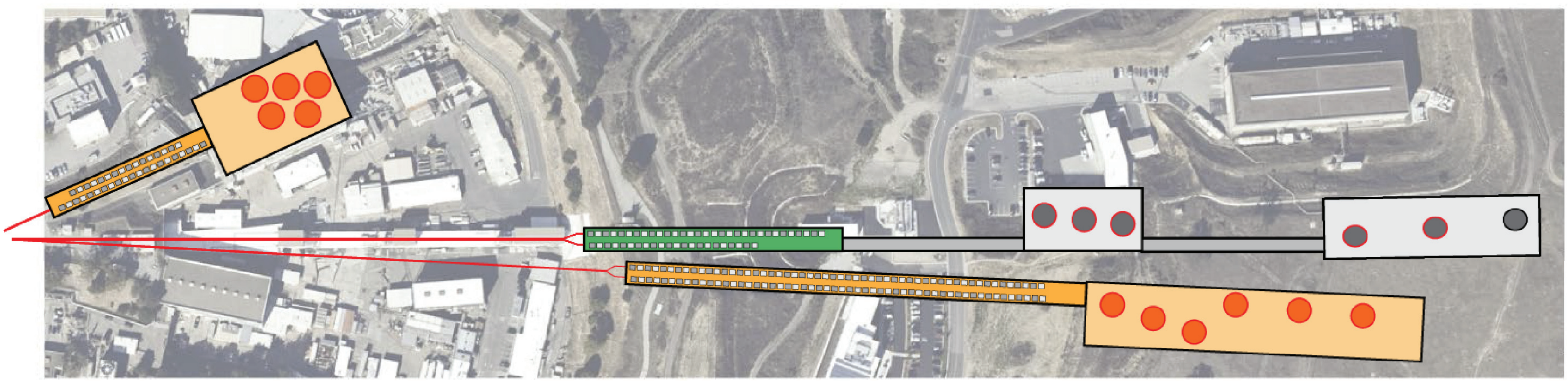
- That "no proposal" included LCLS-II.

SLAC Director Chi-Chang Kao announced today at SLAC:

"Over the last few weeks, we have developed a modified plan for the upgrade that we believe fulfills the recommendations from BESAC and leverages the significant existing infrastructure at SLAC. We recently presented this concept to the Office of Science. I will update you on our progress moving forward. "

We may be changing direction now- But our long-term goal has never changed

- Use the entire Linac
- Linac repetition rate Upgrade
- More x-ray sources Using SLAC facilities



- LCLS-I
- Upgrade Path
- Long Term Plan

Then What?

SLAC

- Maybe the research presented at this conference will point to a new direction…
- Thank you for listening
- Thank you to the people at SLAC who I have the privilege to represent
- Thank you to the attendees at FEL conferences whose research, past/present/future has inspired me

The 35th International Free-Electron Laser Conference

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For the presentation materials they have allowed me to show today

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