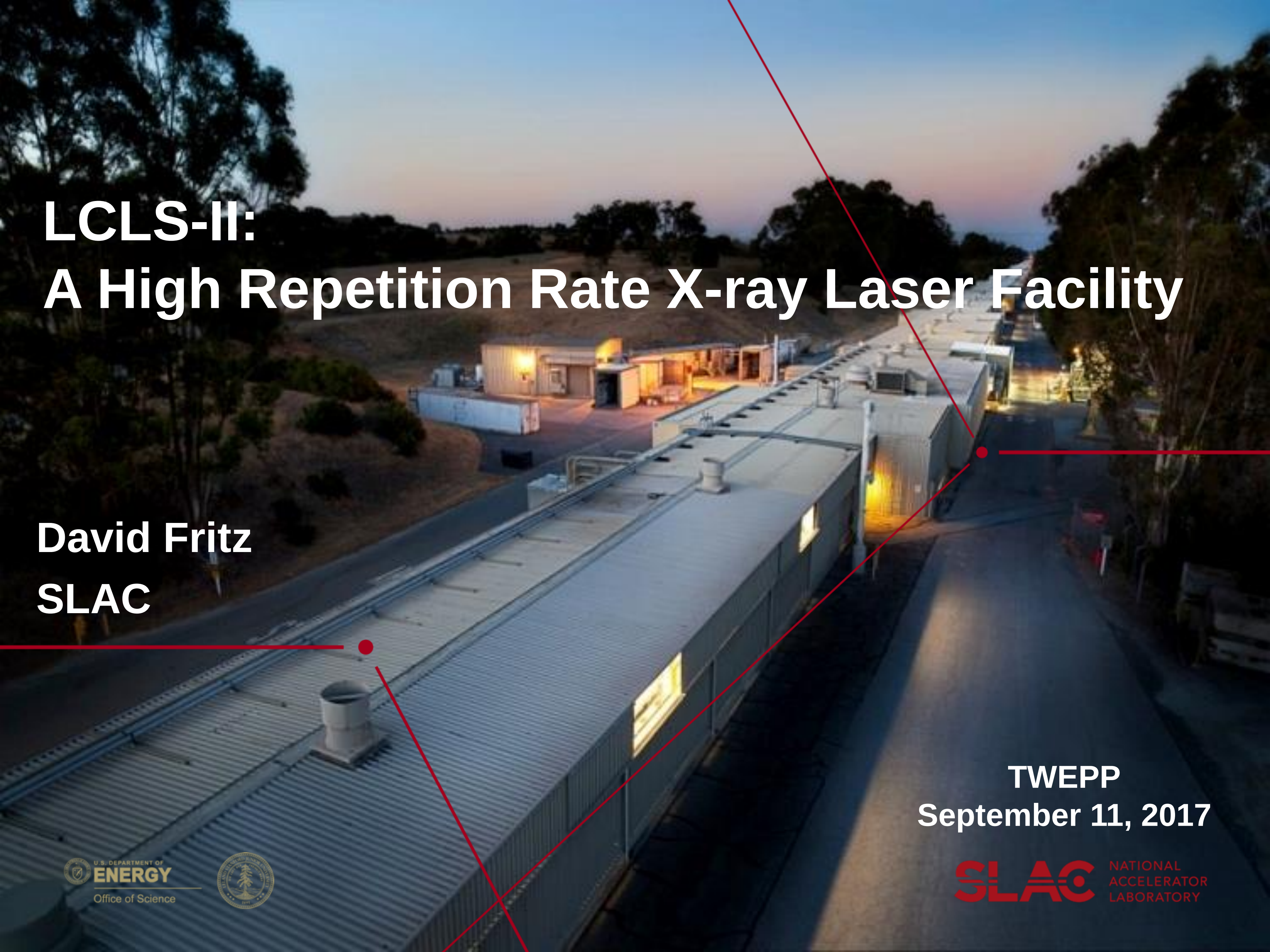


LCLS-II:
A High Repetition Rate X-ray Laser Facility

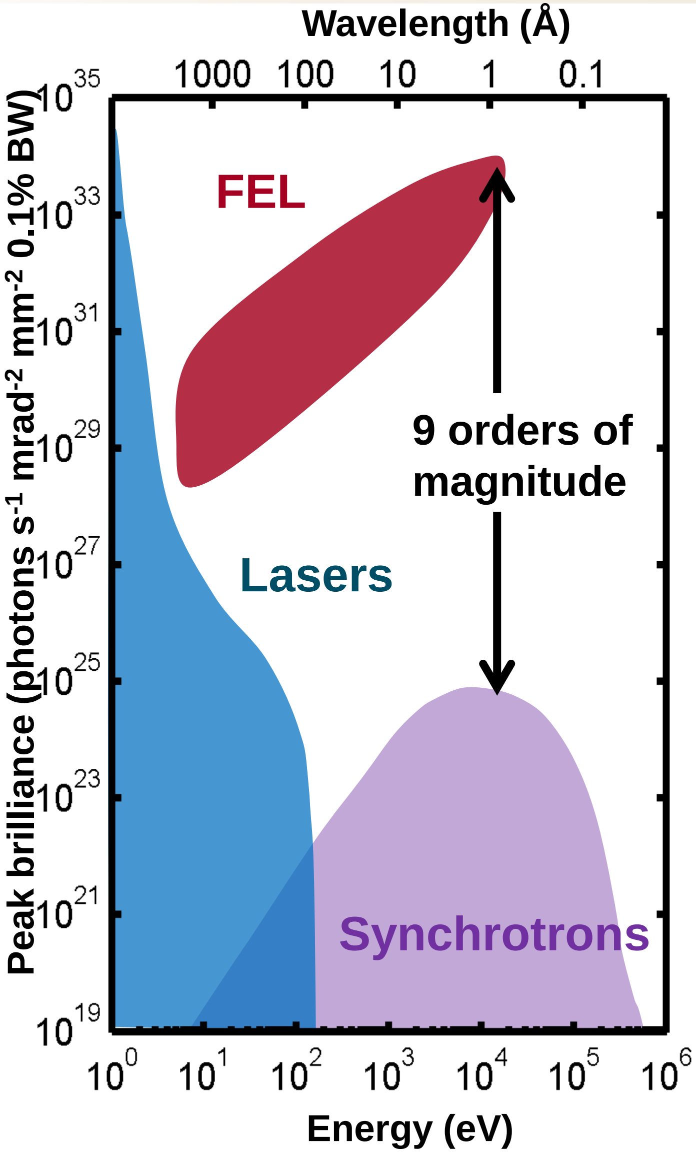
David Fritz
SLAC

TWEPP
September 11, 2017

Acknowledgments

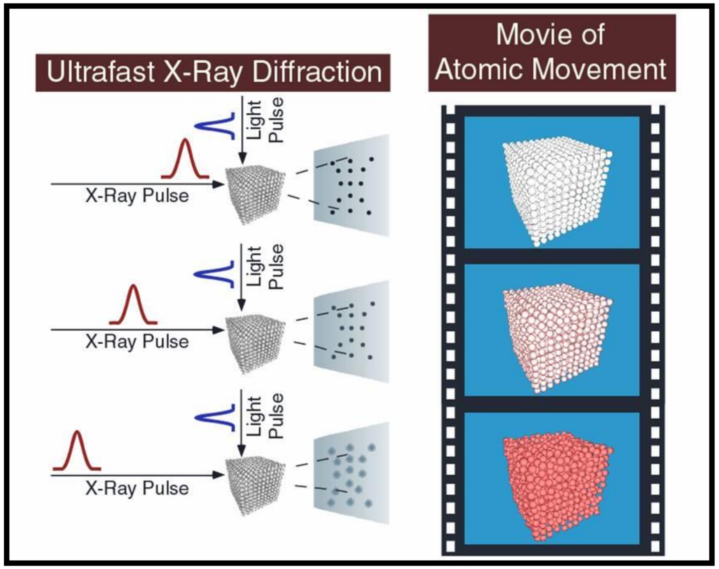
- The TWEPP Organizers
- DOE Office of Science
- The LCLS & LCLS-II Teams
- Partner Laboratories

X-ray FELs promise revolutionary capabilities



Exploiting the 9 orders of magnitude increase in x-ray peak brilliance

- **Pulse energy**
- **Pulse length**
- **Pulse coherence**
- **Spectral brightness**

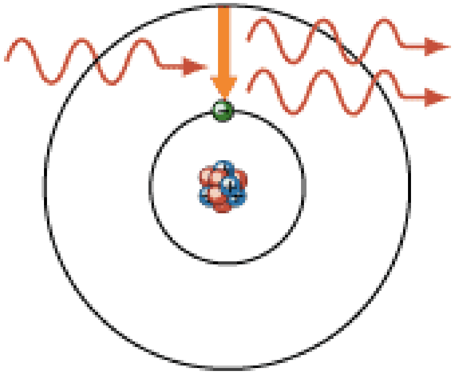


C. Siders

X-ray Free Electron Laser

Lot's of $$$$$$

Not like this:



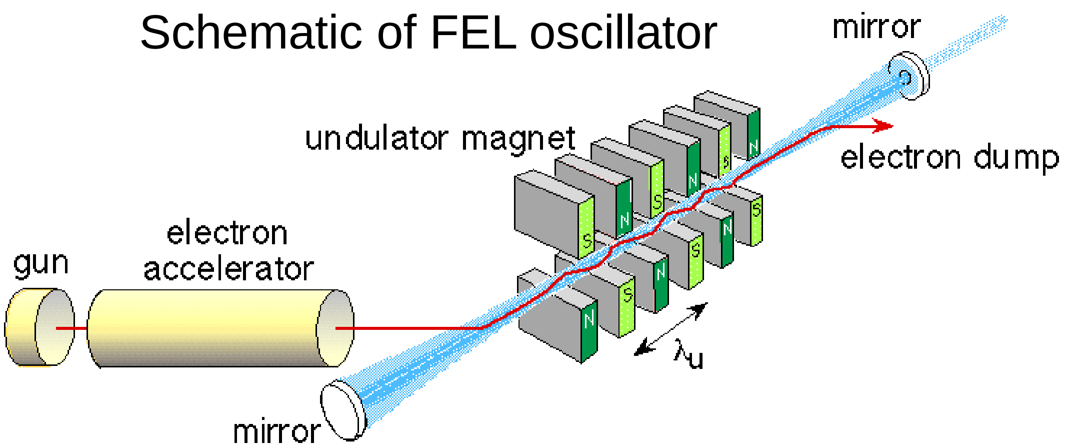
stimulated emission

Free electron laser (FEL) primer

3 main elements: **e- gun**, **accelerator**, & **undulator**

Two primary configurations:

low gain oscillator using mirrors or **high gain single pass amplifier**



FEL physics is relatively simple: transverse motion in undulator allows electrons to couple to light; light causes beam to bunch and radiate as N^2 rather than N.

T. Raubenheimer

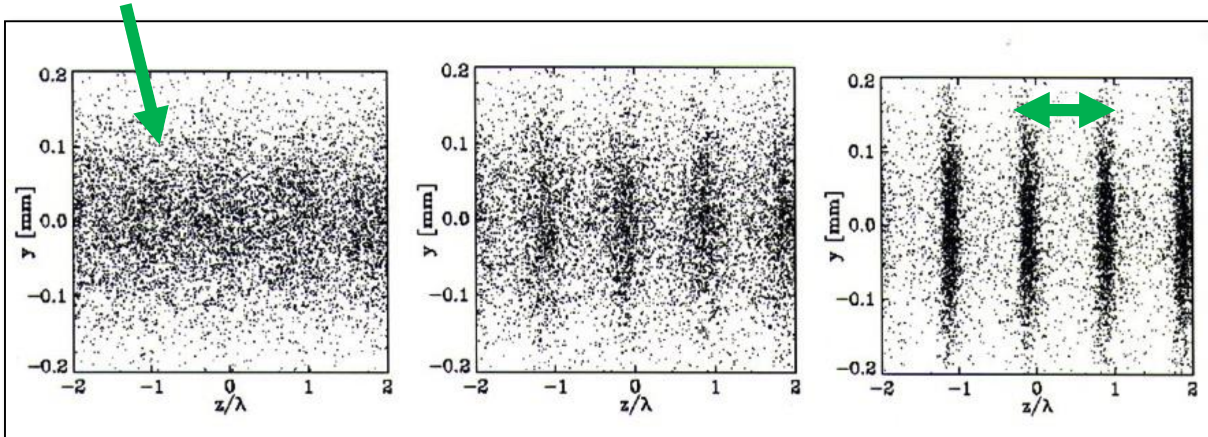
Getting the electrons to emit in phase

- X-rays push electrons into bunches, which then radiate coherently
- Self Amplified Spontaneous Emission (SASE)

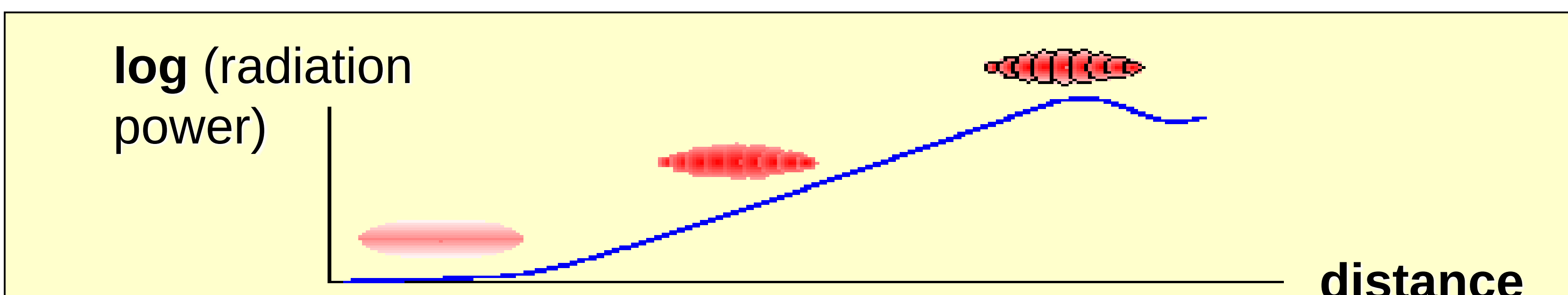
Electrons initially distributed randomly

Electrons are bunched at the special X-ray wavelength

SASE* FEL starts up from noise

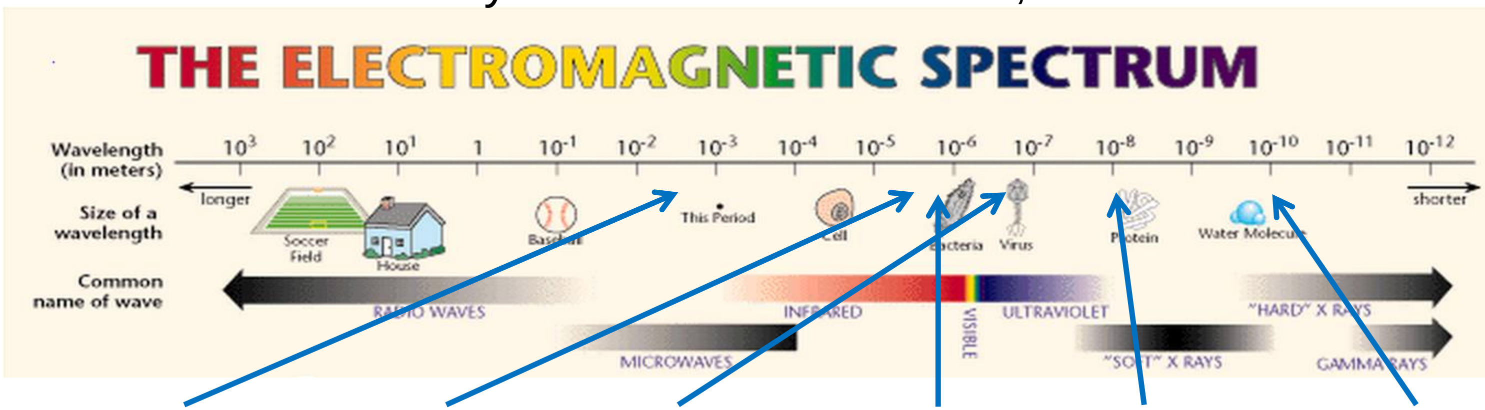


Computer simulation of electrons



Operating Free Electron Lasers

FEL History – Modified from Colson, 2006



Motz, Phillips 1950's | Madey 1970's | Duke Ring 1990's | JLAB 2000's | FLASH 2000's | LCLS, SACLA 2010

Over 50 FEL's operating around the world ranging from mm-wavelength to sub-Angstrom.

- JLAB generated 14 kW in IR in oscillator configuration
- LCLS generated 6 mJ in single pulse at a few keV
- SACLA has lased at sub-Angstrom wavelengths

T. Raubenheimer

SLAC National Accelerator Laboratory

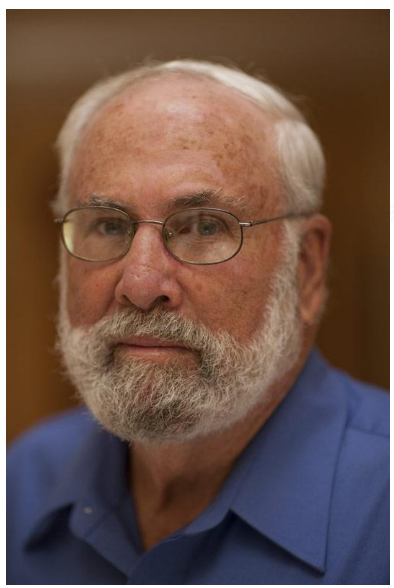
- A high energy, high brightness electron accelerator is a main ingredient to create an x-ray FEL

LCLS Concept:
Fourth Generation Workshop, 25 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

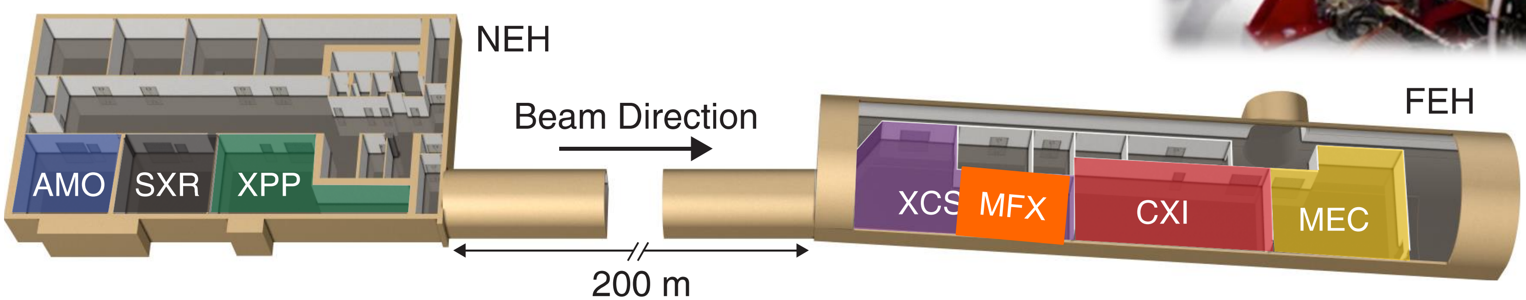


Herman Winick's Study Group

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	

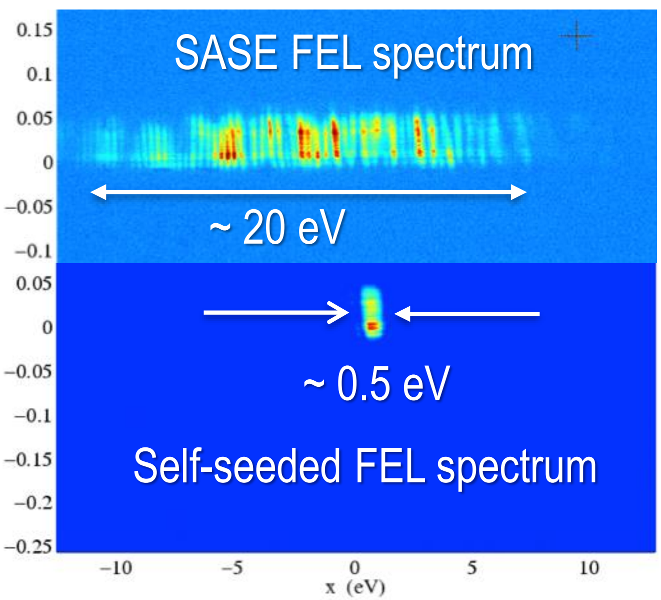
… and 17 years later LCLS was realized and started user operations (2009)



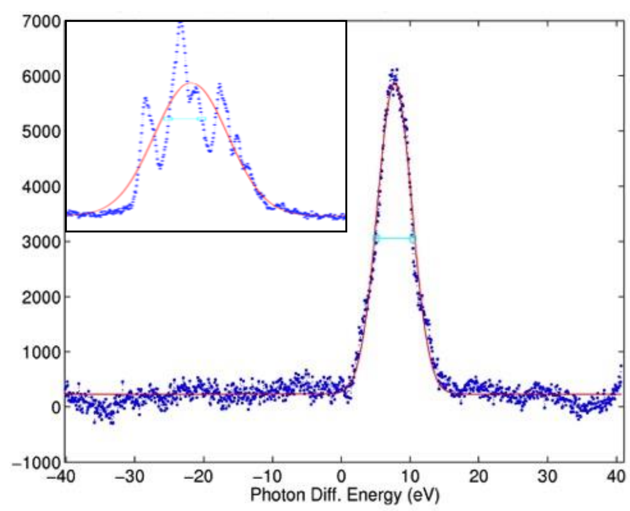
■ AMO:	Atomic, Molecular and Optical	[0.22 ; 2.0]	■ XCS:	X-ray Correlation Spectroscopy	[4.0 ; 24.0]
■ SXR:	Soft X-ray Research	[0.22 ; 2.0]	■ CXI:	Coherent X-ray Imaging	[5.0 ; 11.0]
■ XPP:	X-ray Pump Probe	[4.0 ; 24.0]	■ MEC:	Matter in Extreme Conditions	[4.0 ; 24.0]

LCLS performance parameters

	Current performance
Photon energy range	280 to 12,800 eV
FEL pulse length	< 5 – 500 fs
FEL pulse energy	~ 4 mJ (2.5 * 10^{12} @ 10 keV)
FEL coherence	SASE, Seeding (hard x-ray)
Repetition Rate	120 Hz



Hard X-ray self-seeding



Near transform limited soft x-ray pulses

Rapid International Growth of x-ray FELs

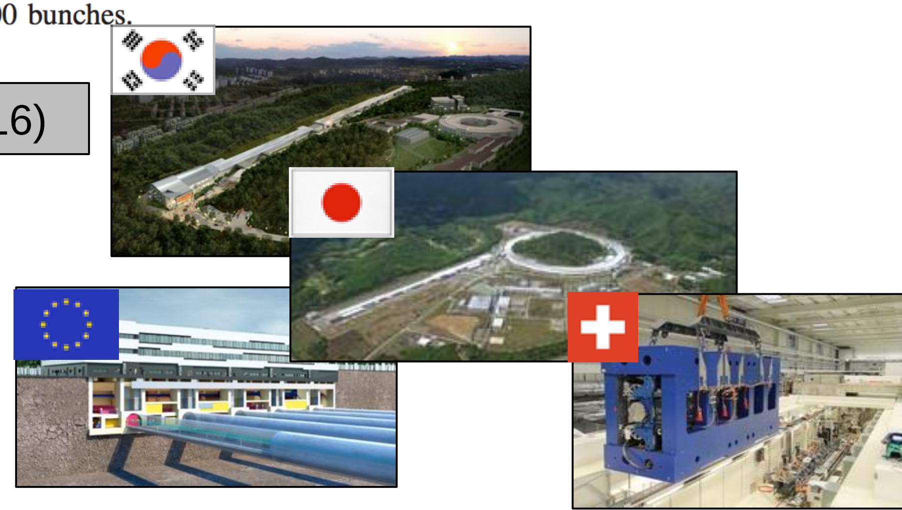
SLAC

Location	Name	Linac type	*E* energy (GeV)	Photon energy (keV)	Rep. rate (Hz)	Start ops.
Germany	FLASH FLASH-II	SC SC	1.2	0.03–0.3	(1 – 500) × 10[a]	2005 2015
	XFEL	SC	17.5	3–25 0.2–3	(1 – 2800) × 10[b]	2017
Italy	FERMI-FEL1 FERMI-FEL2	NC	1.5	0.01–0.06 0.06–0.3	10–50	2012 2014
Japan	SACLA	NC	8	4–15	30–60	2011
Korea	PAL-XFEL	NC	10 3	1–20 0.3–1	60	2016
Switzerland	SwissFEL	NC	5.8 3	2–12 0.2–2	100	2017
USA	LCLS LCLS-II LCLS-II	NC NC SC	16 16 4	0.25–11 1–25 0.2–5	120 120 10^6	2009 2020 2020

[a]Pulsed mode operation at 10 Hz, with each macropulse providing up to 500 bunches.
[b]Pulsed mode operation at 10 Hz, with each macropulse providing up to 2800 bunches.

Rev. Mod. Phys., Vol. 88, No. 1, January–March 2016)

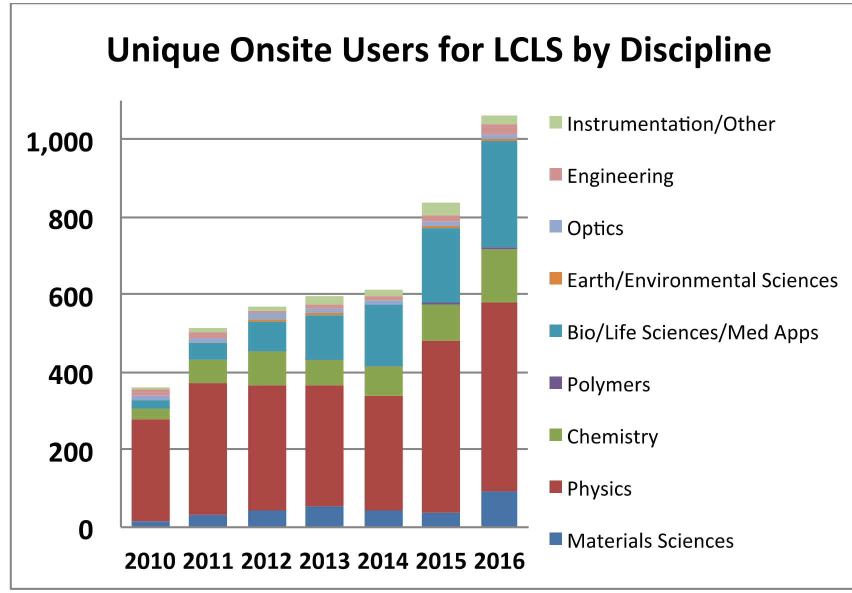
VUV: below 0.2 keV
Soft X-ray: 0.2-2.0 keV
Hard X-ray: 4-25keV

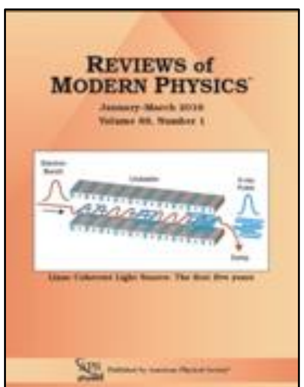


The Early Years of LCLS have Exceeded Expectations

	Total Publications	High Impact
<2010	91	16
2011	64	11
2012	125	38
2013	117	31
2014	134	37
2015	178	33
2016	174	25

883 papers,
with 191 in high impact journals to date
(~450 experiments performed to date)

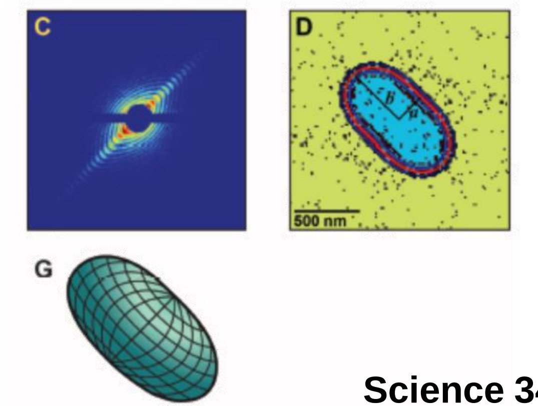




“Linac Coherent Light Source: The first five years”
Rev. Mod. Phys., Vol. 88, No. 1, January–March 2016)

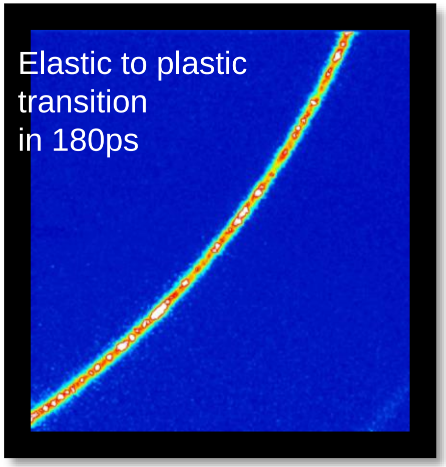
A broad range of science results: from novel techniques, to fundamental discovery, to precision studies

First direct evidence of superfluidity in nanometer sized quantum systems



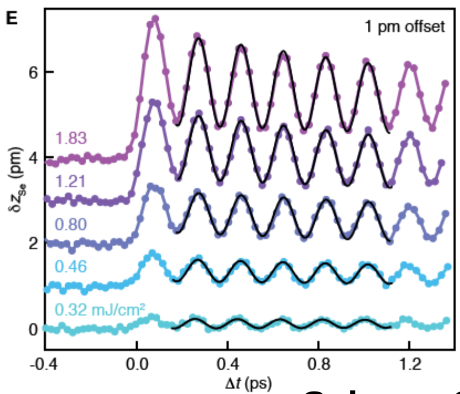
Science 345, 907 (2014)

Imaging materials under extreme stress



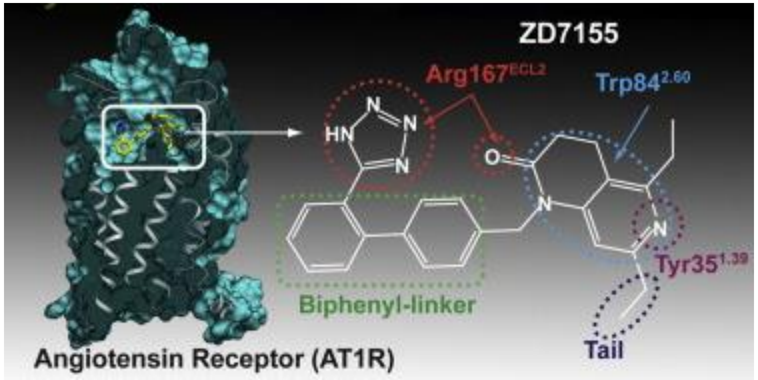
Science 342, 220 (2013)

Direct quantification of electron phonon coupling strength in a superconductor



Science 357, 71 (2017)

High resolution structure of blood-pressure regulating compound

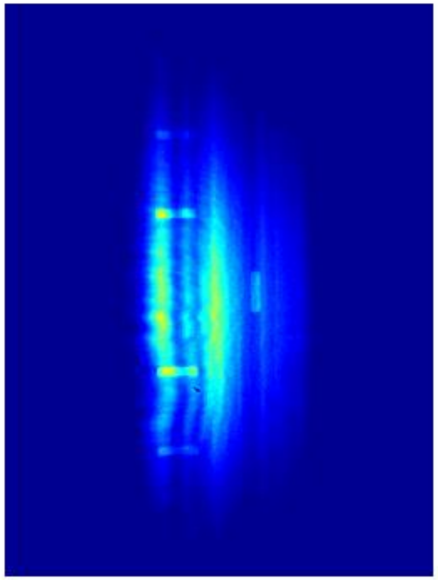


Cell 161, 1-12 (2015)

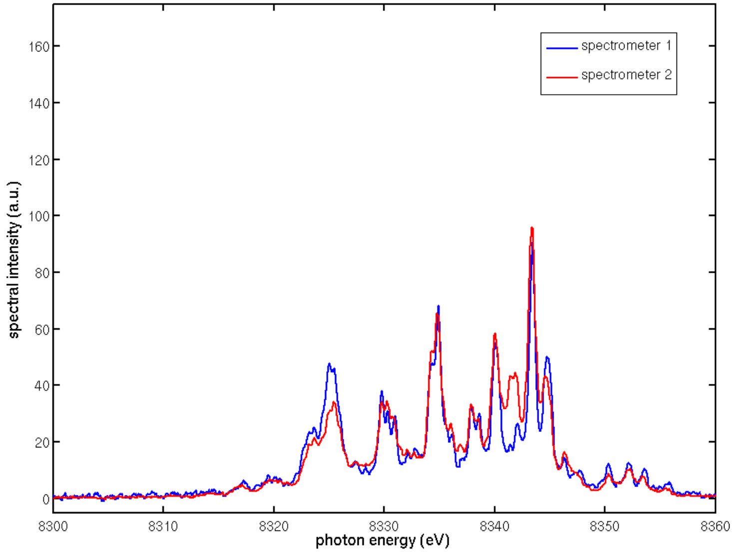
Limitations with SASE and pulsed accelerator

SLAC

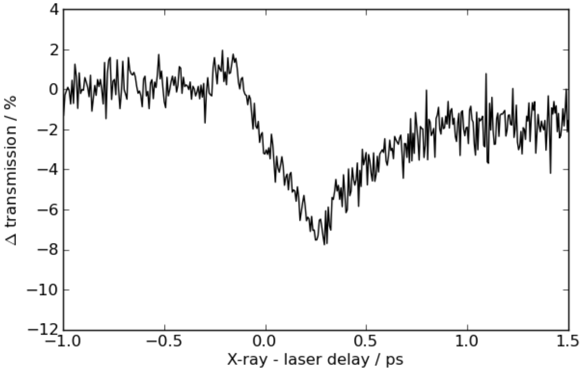
Spatial



Spectral

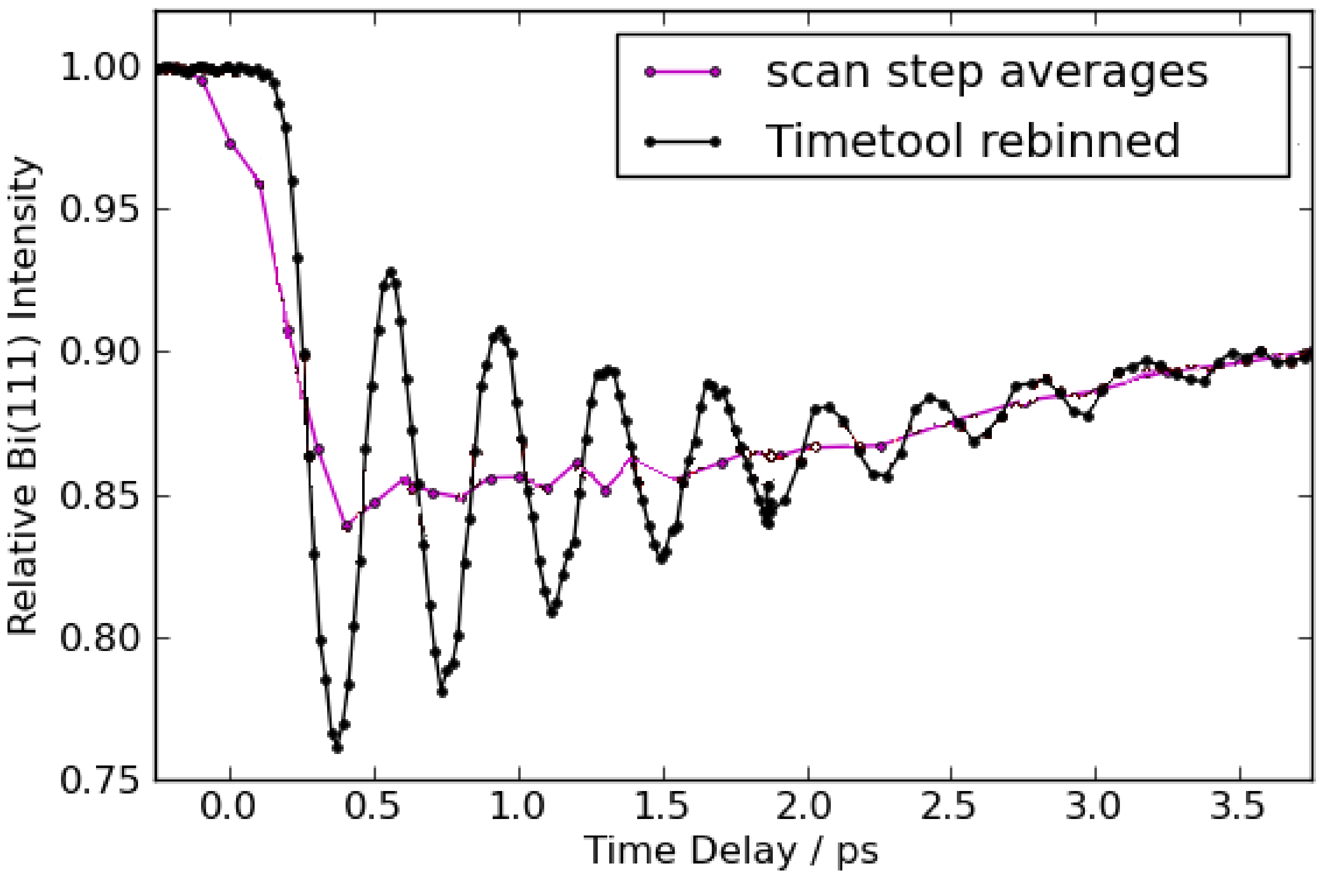


Temporal



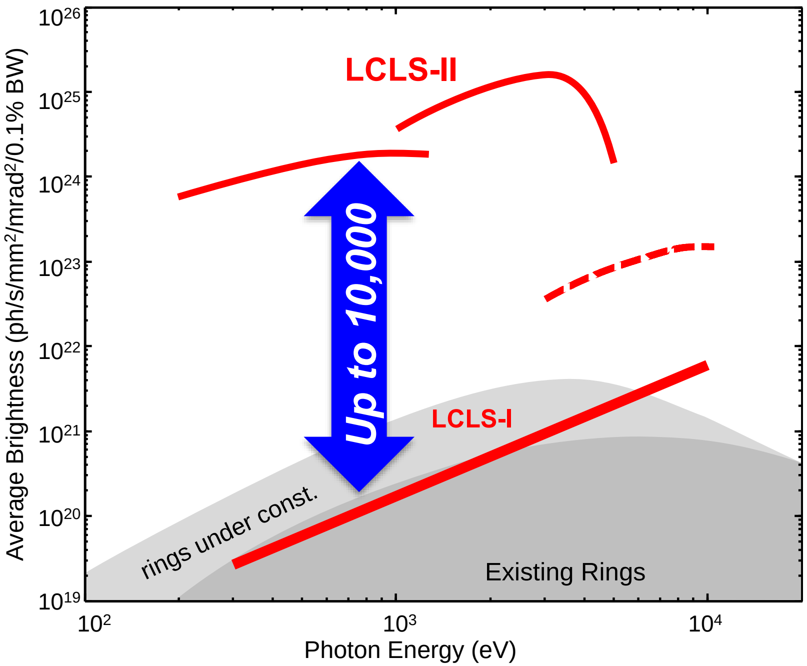
- Currently, every pulse is sufficiently different that it must be diagnosed individually
- These fluctuations can be a limiting factor for many experiments
- Significant improvements would be realized with a “CW” machine

Some fluctuations can be corrected but

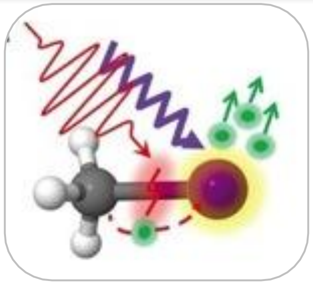


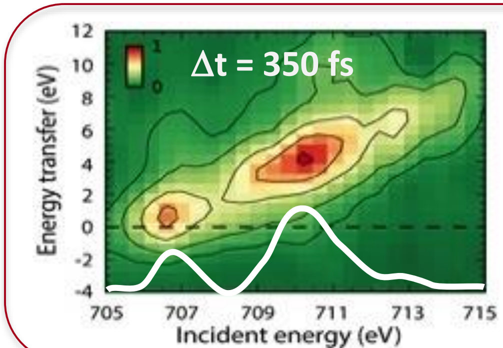
What else does a MHz repetition rate do for us?

SLAC

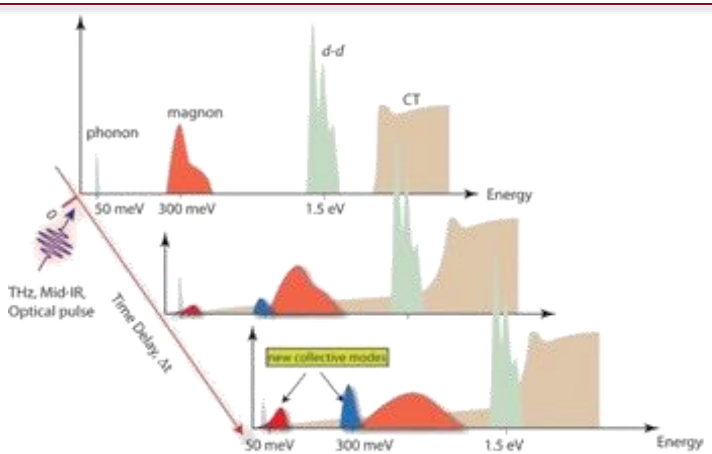


Entanglement and correlation dynamics in isolated molecules



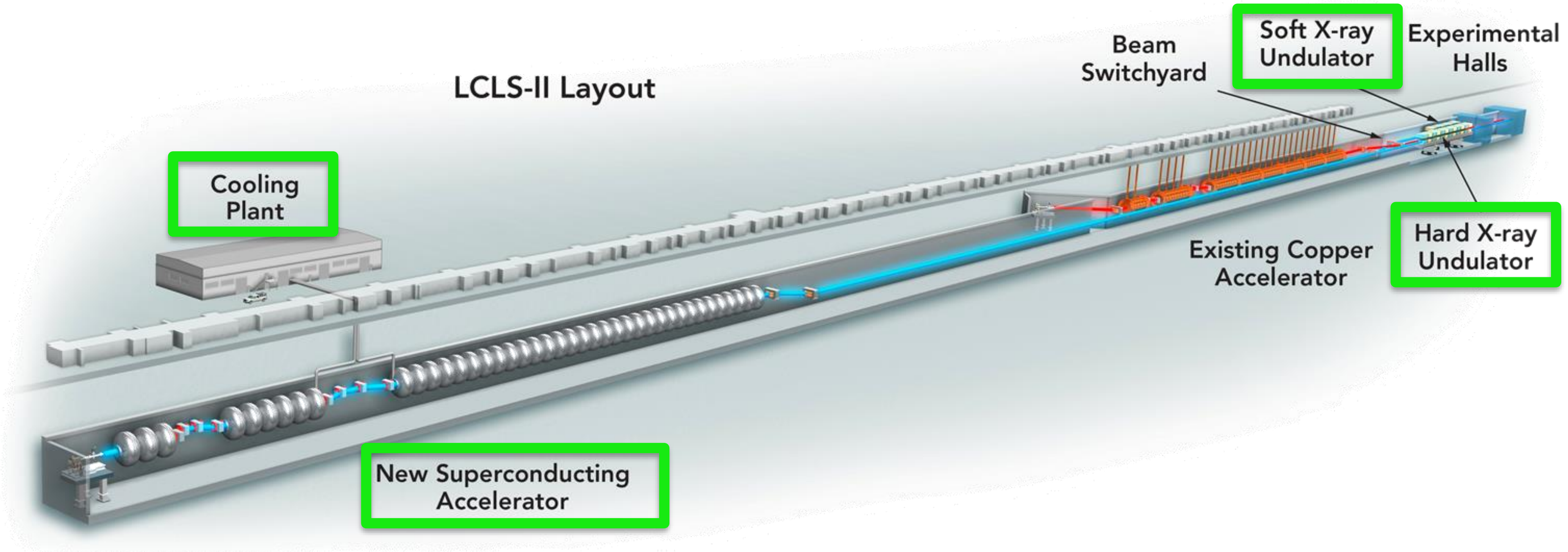


Local chemical structure and bonding: Element specific maps of frontier molecular orbitals and their evolution



Understand and control emergent phenomena in quantum systems with interacting degrees of freedom

Linac Coherent Light Source II (LCLS-II)

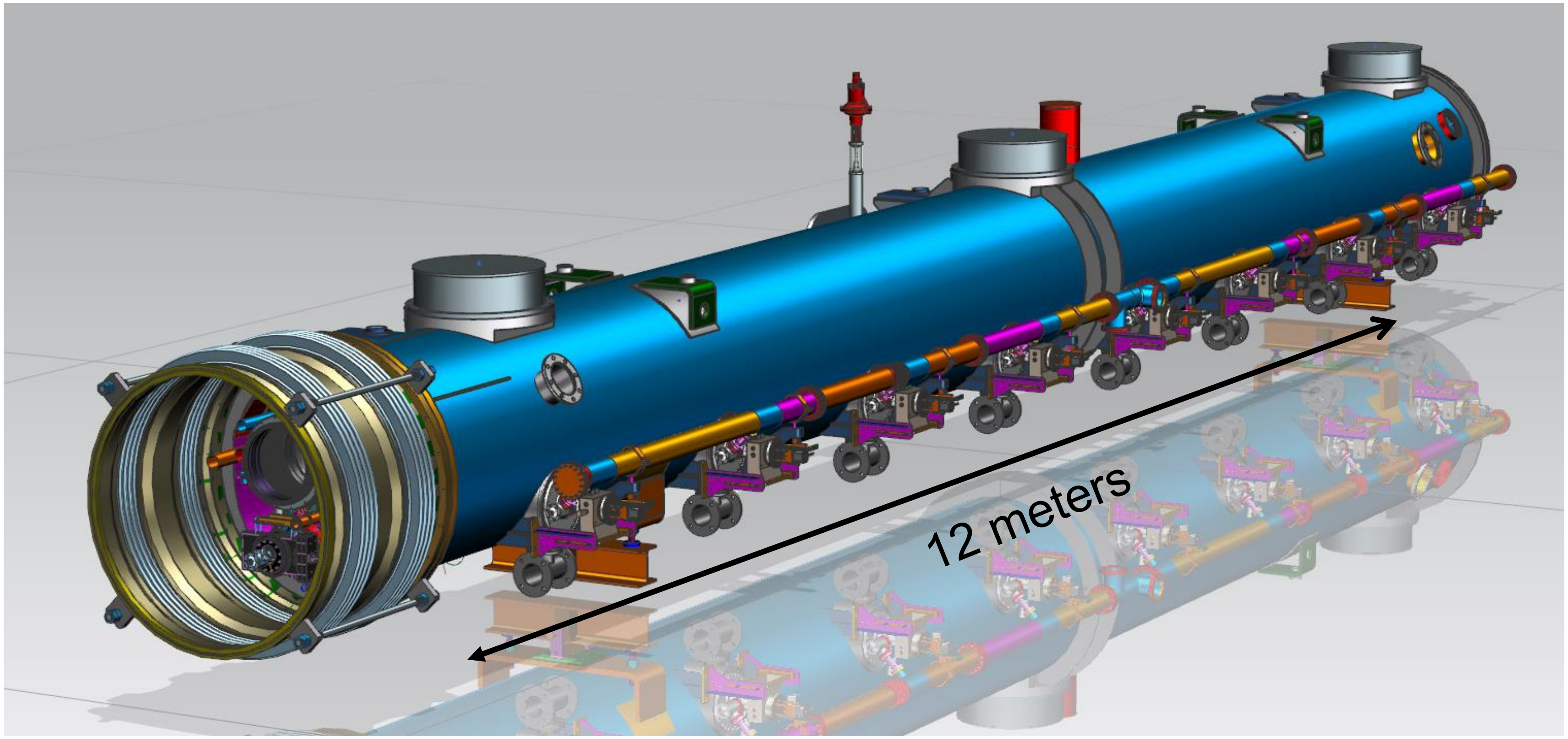


	Now	HXU - Cu	SXU – Cu	HXU - SC	SXU - SC
Photon Energy Range (keV)	0.25 -12.8	1 - 25	0.25 - 6	1 - 5	0.25 - 1.6
Repetition Rate (Hz)	120	120	120	929,000	929,000
Per Pulse Energy (mJ)	~ 4	~ 4	~ 8	~ 0.2	~ 1
Photons/Second	~ 10^{14}	~ 10^{14}	~ 10^{14}	~ 10^{16}	~ 10^{17}

LCLS Electron Accelerator Comparison

	LCLS-I	LCLS-II
Accelerator technology	Normal conducting or "warm" 	Superconducting or "cold" 
RF frequency	2.8 GHz	1.3 GHz
Ave. RF gradient	~ 25 MV / m	~ 16 MV / m
Electron energy	15 GeV	4 GeV
Cavity Q	~ 10^4	~ 10^{10}
RF "pulse" duration	~ 1 μs	CW
Bunch repetition rate	120 Hz	930,000 Hz

LCLS-II cryomodule
1.3 GHz, designed for CW operation



- Modification of EuXFEL design
- CM being fabricated at Fermilab and JLab

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

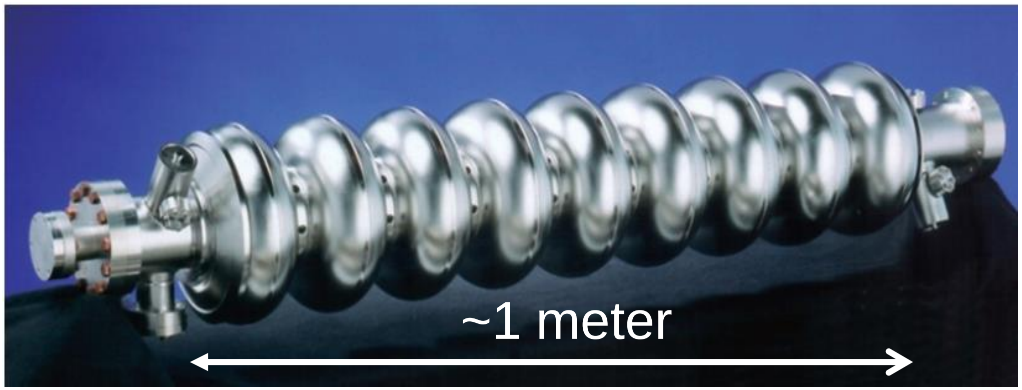
A. Grassellino, et al., "New insights on the physics of RF surface resistance", TUIOA03
2013 SRF Conference
Paris, France

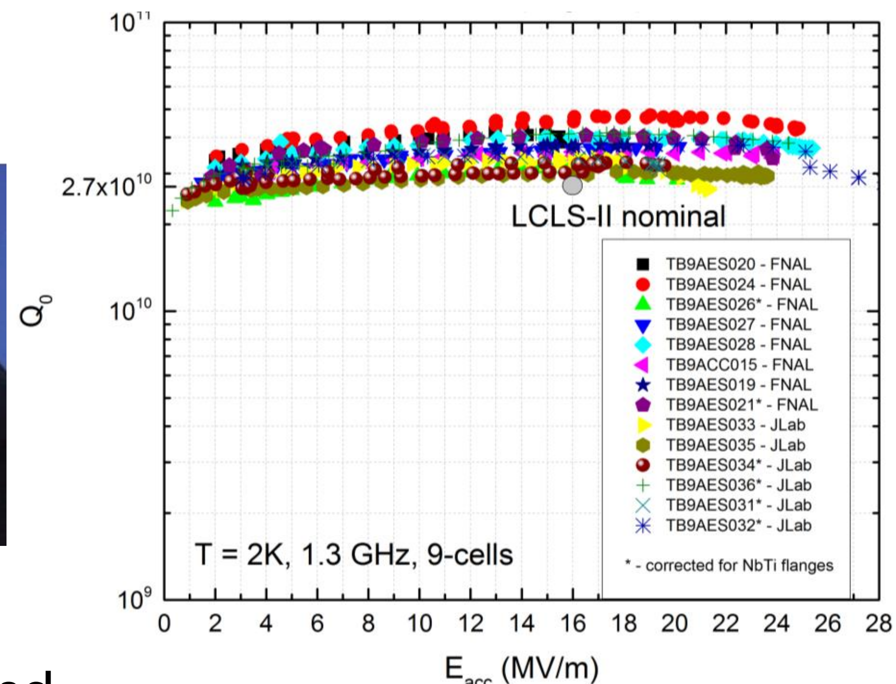
- For a pulsed linac (ILC, XFEL) heat load comes mostly from outside the module
- For a CW linac, heat load is from BCS resistance @ 2K + surface resistance
- For a given acceleration gradient: Power dissipation ~ $V^2/(Q_o R_g)$ cavity geometry
- Q_o depends on BCS and residual resistivities
- **Nitrogen 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

Superconducting RF cavities

Eight 1-m 1.3 GHz cavities within each CM for 280 cavities total

- Backbone of the LCLS-II accelerator are the 9-cell 1.3 GHz superconducting rf cavities



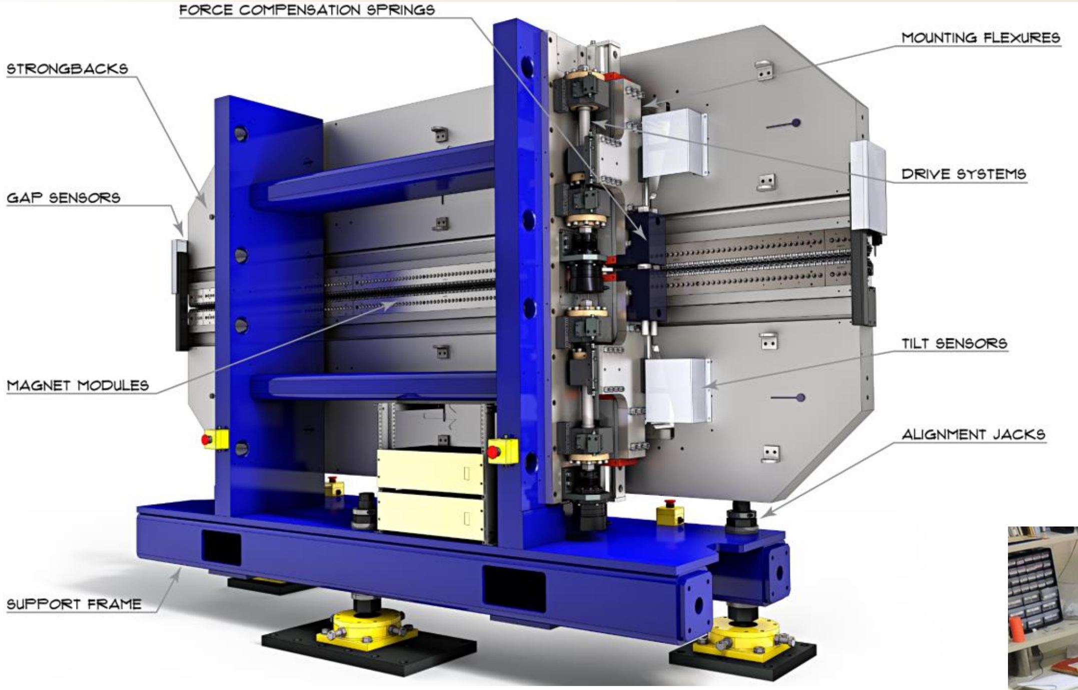


- Technology developed in Europe and transferred around world. Hundreds have been fabricated in US, Japan, Europe.

$\langle Q \rangle$ = 3.0e10
$\langle E_{max} \rangle$ = 22.2 MV/m

Variable gap hybrid undulators

Ongoing development at LBNL and ANL



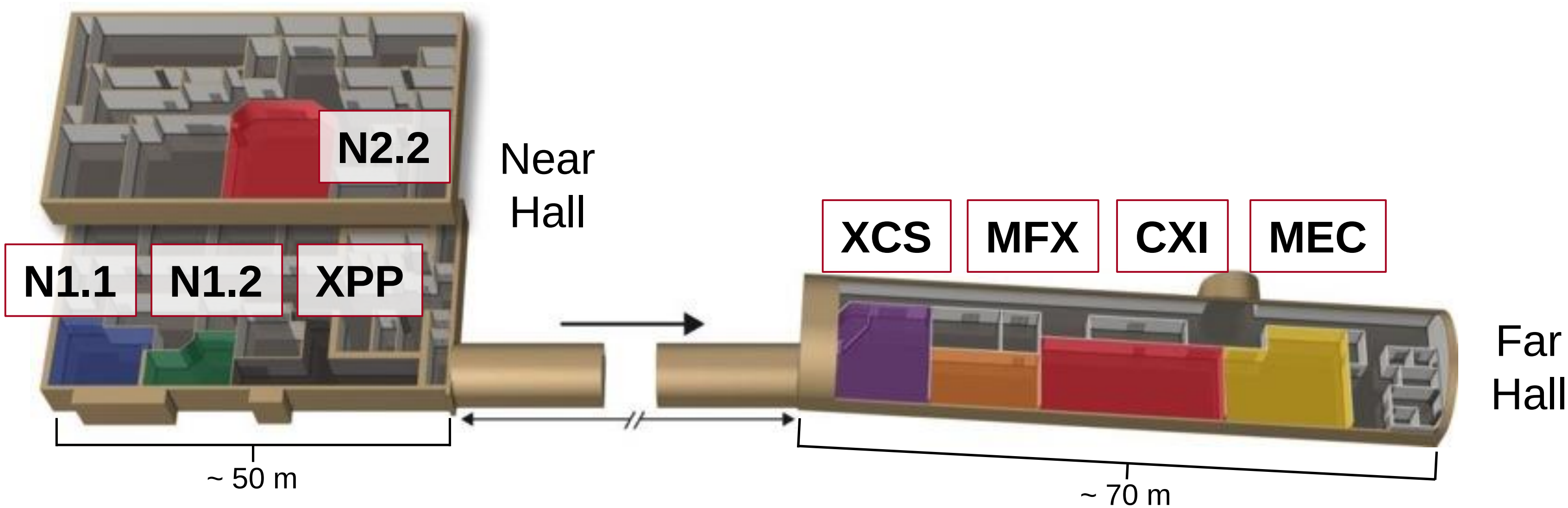
Variable gap undulators used in LCLS-II to provide greater wavelength tuning flexibility

- Vertical gap horizontally polarized undulator for soft x-ray branch
- Horizontal gap vertically polarized undulator for hard x-ray branch

X-ray instrument plans for LCLS-II

SLAC

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



SXU	NEH 1.1:	Atomic, Molecular and Optical	2 Soft X-ray
SXU	NEH 2.2:	Soft X-ray Research	
SXU, HXU	NEH 1.2:	Tender X-ray Instrument	1.5 “tender” x-ray
HXU	XPP:	X-ray Pump Probe	4.5 Hard X-ray
HXU	XCS:	X-ray Correlation Spectroscopy	
HXU	MFX:	Macromolecular Femtosecond Crystallography	
HXU	CXI:	Coherent X-ray Imaging	
HXU	MEC:	Matter in Extreme Conditions	

Experimental layout for LCLS-II consolidates functionality into 3 new instruments (5+1 endstations)

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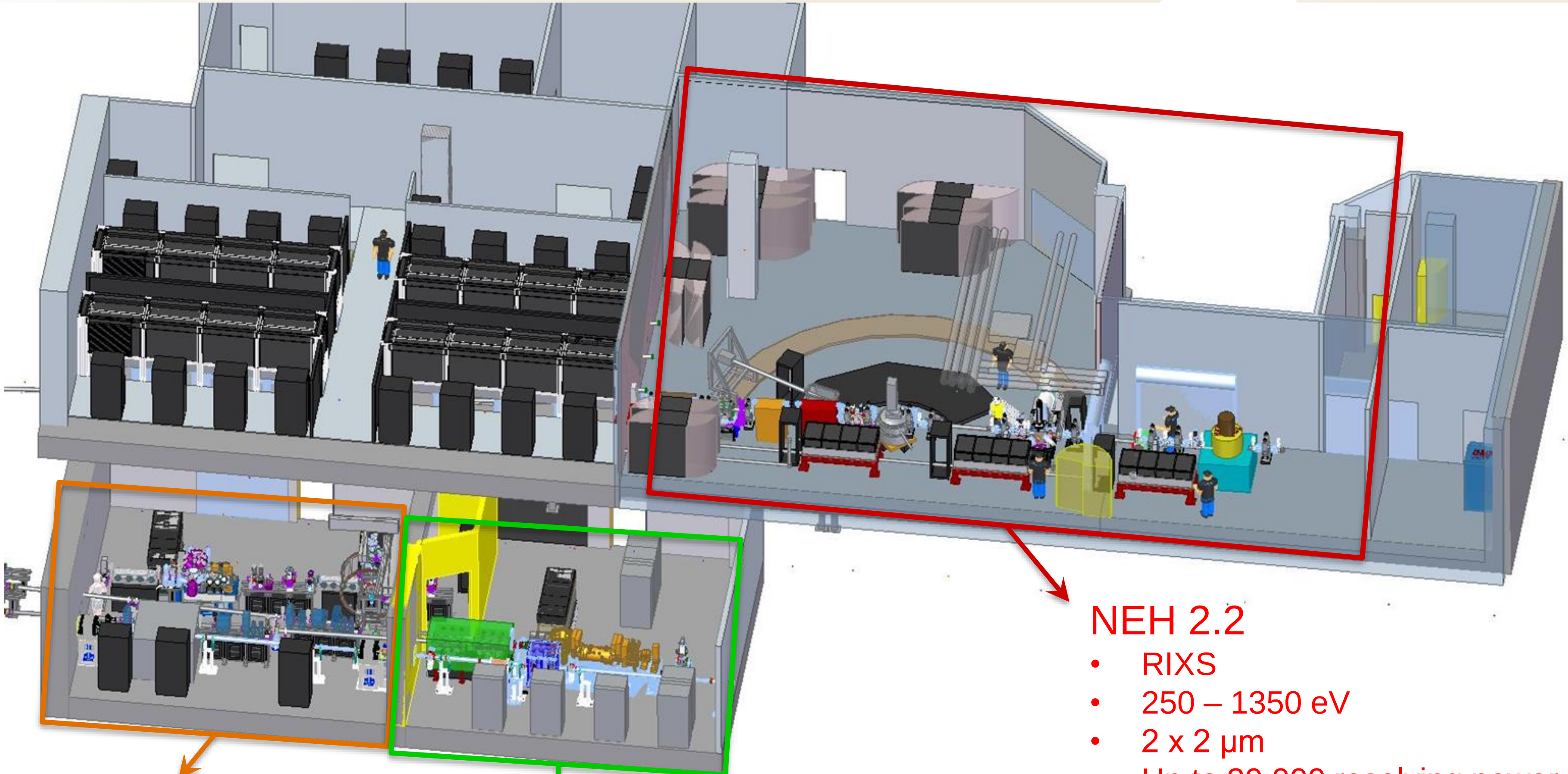
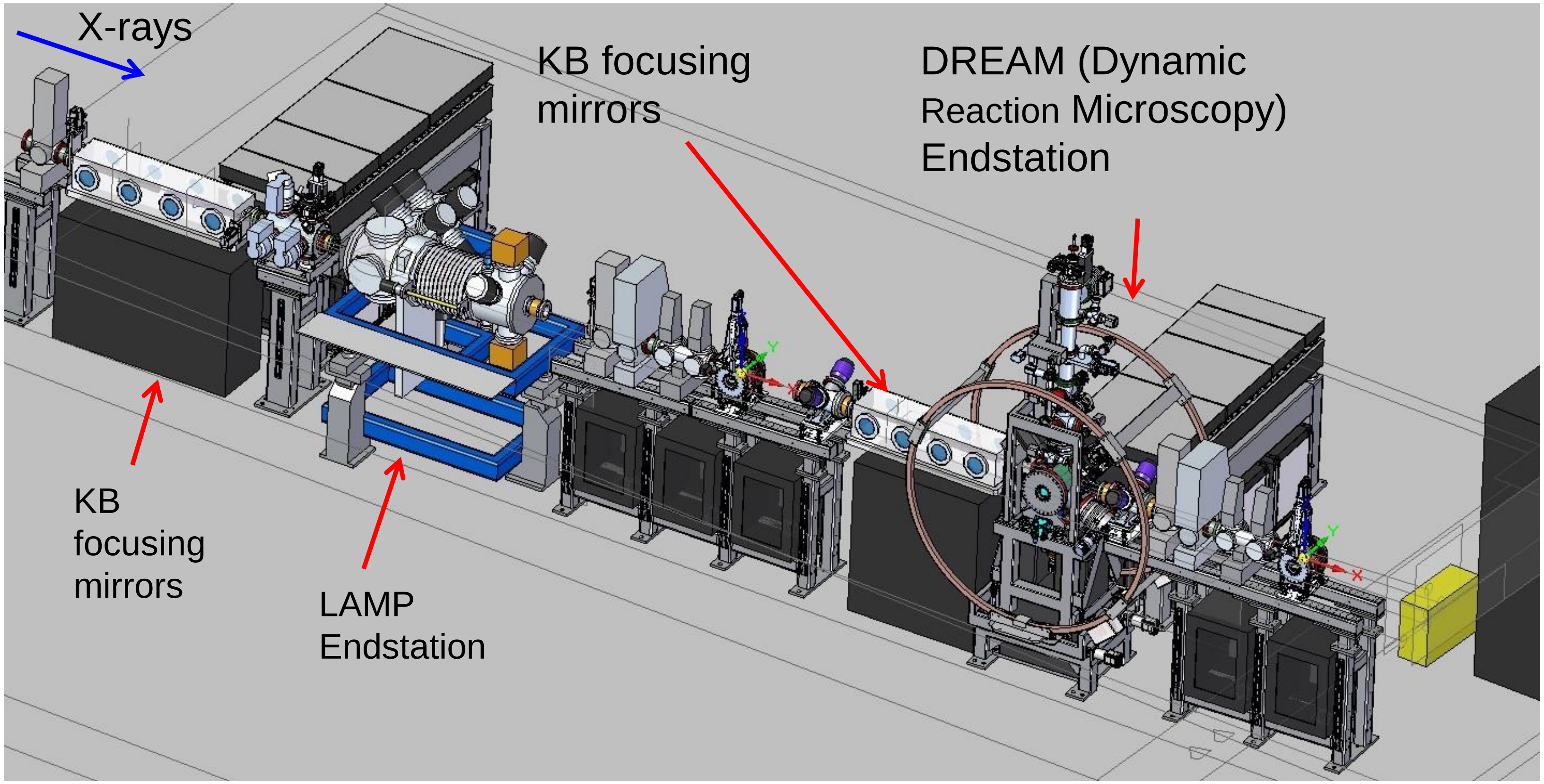


NEH 2.2
- RIXS
- 250 – 1350 eV
- 2 x 2 μm
- Up to 30,000 resolving power

NEH 1.1
- High Flux Soft X-ray
- 250 – 2000 eV
- 1 μm / 0.3 μm
- Minimal Optics

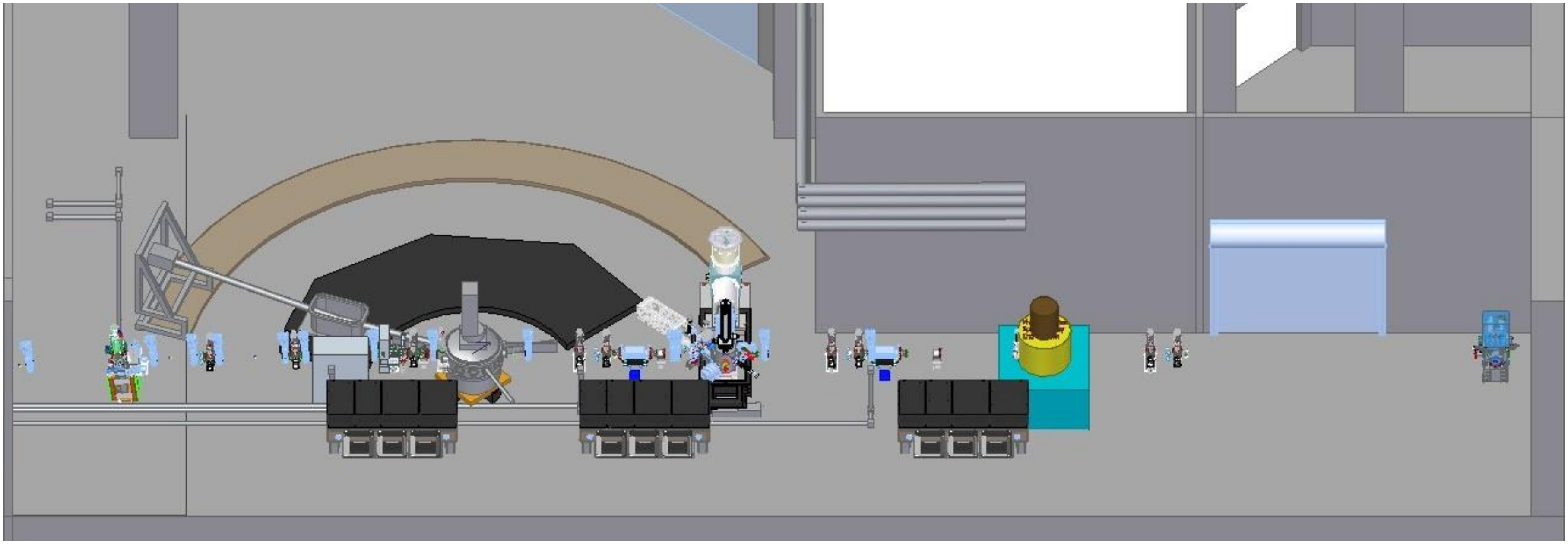
NEH 1.2
- Tender X-ray Instrument
- 400 – 7000 eV
- 1 μm
- 2x XFELs

NEH 1.1: Atomic & Molecular Physics



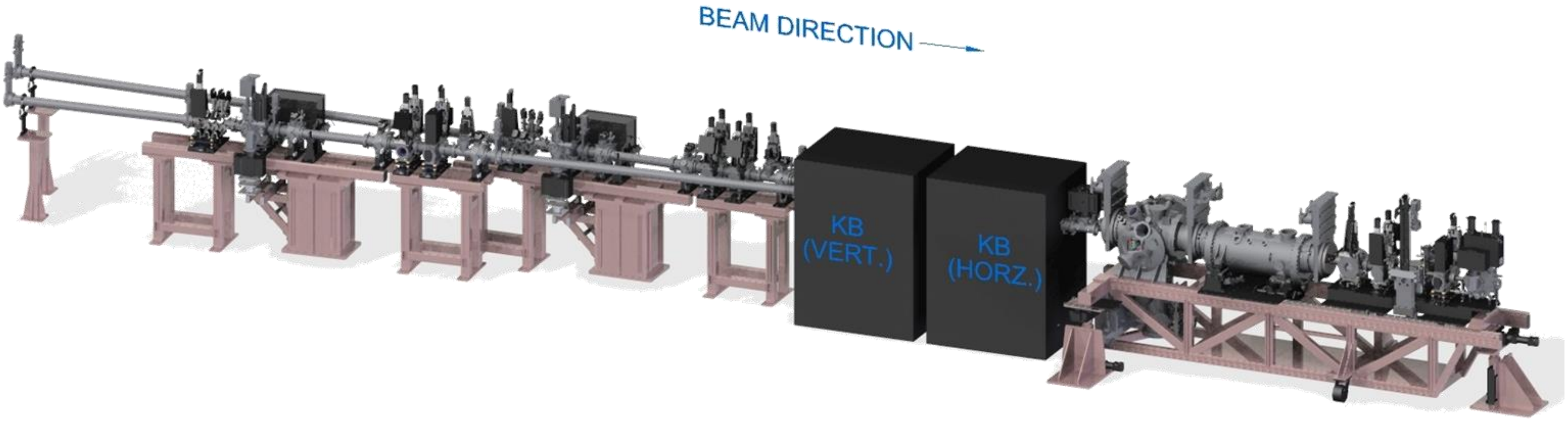
Science	Method	XFEL Parameters	Detectors
Fundamental excited state dynamics of atomic and molecular systems Charge and energy transfer	Dynamic molecular reaction microscope	250 – 1500 eV >= 100kHz	2D ToF Charged Particle (1 MHz) TES (≤1 eV, ≥10 kHz)
High field physics Photophysics & photochemistry	Ion/Electron Spectroscopy	250 – 2000 keV	2D ToF Charged Particle (1 MHz) Hemispherical analyzer

NEH 2.2: Materials Science & Liquid Phase Photochemistry



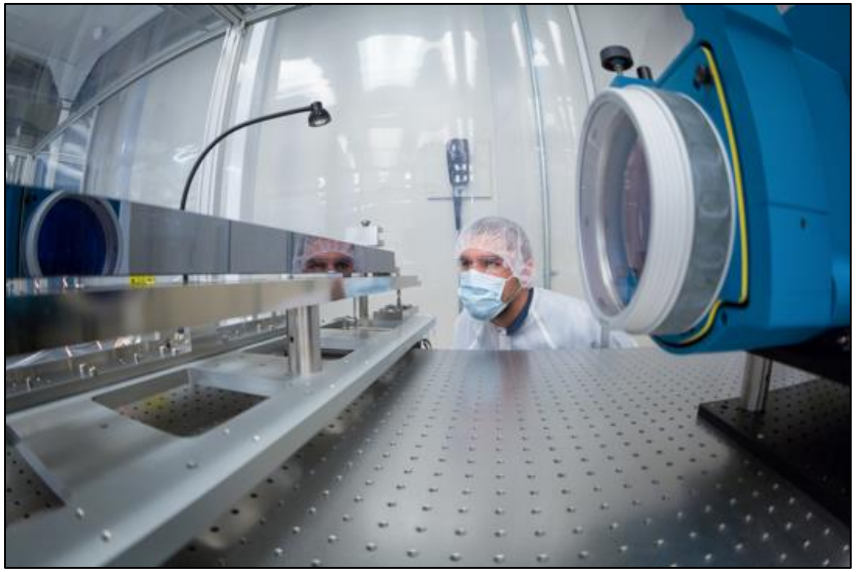
Science	Method	XFEL Requirement	Detectors
Emergent phenomena and collective modes in correlated materials	Resonant inelastic X-ray scattering Resonant diffraction	250 – 1600 eV, $>10^{14}$ ph/s with 50,000 resolving power	2D High Spatial Resolution (5 µm) Soft X-ray Area (≥ 5 kHz, 0.5 MP)
Heterogeneous catalysis Interfacial chemistry Photo-catalysis	X-ray Absorption Spectroscopy X-ray Emission Spectroscopy	250-1600 eV, ≥ 100 kHz, 1000-5000 res. Power	2D High Spatial Resolution (5 µm) TES (≤ 0.5 eV, ≥10 kHz)
Nanoscale material dynamics	X-ray photon correlation spectroscopy	250 – 1600 eV, 5,000 resolving power	Soft X-ray Area (≥ 5 kHz, 0.5 MP)

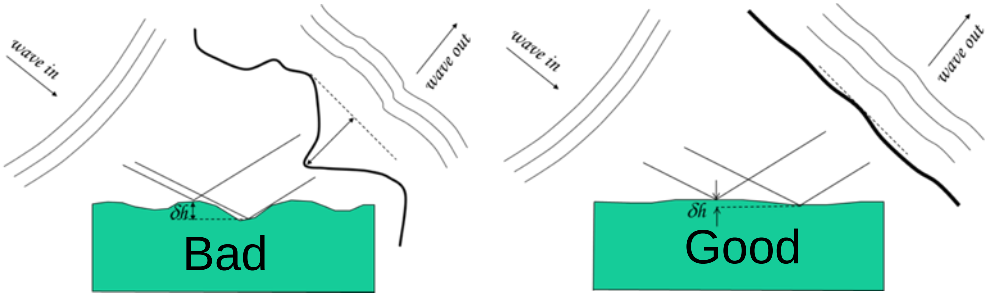
NEH 1.2: Stimulated Spectroscopy & imaging

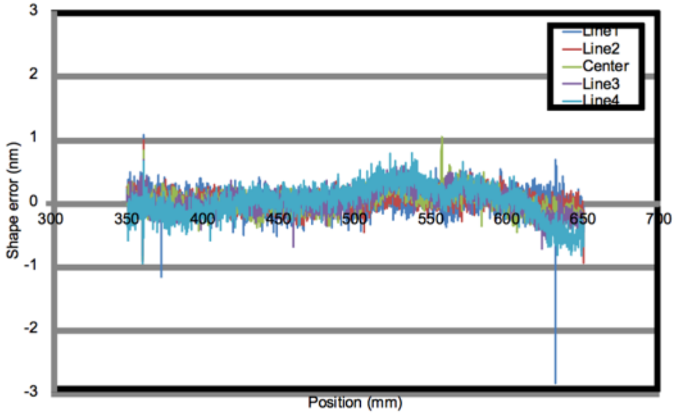


Science	Method	XFEL Requirement	Detectors
Fundamental dynamics of energy & charge - excited state	X-ray Pump / X-ray Probe	~1 μm focus, 400-5000 eV	Tender X-ray Area (≥ 5 kHz, 0.5 MP) Soft X-ray Area (≥ 5 kHz, 0.5 MP)
Bio-imaging (Revealing biological function)	CDI/SPI	~1 μm focus, 1500-5000 eV	Tender X-ray Area (≥ 5 kHz, 2x2.4 MP) Tender X-ray Area (≥ 5 kHz, 0.5 MP)
Protein dynamics and SAD phasing (Revealing biological structure)	Protein Crystallography	1-5 μm focus, 3000 to 5000 keV	Tender X-ray Area (≥ 5 kHz, 2x2.4 MP)
Revealing biological function and time scales	TR-SAXS/fSAXS	~10 μm focus, 1500-5000 keV	Tender X-ray Area (≥ 5 kHz, 2x2.4 MP)
Catalysis Photo-catalysis Bio-spectroscopy	Absorption & emission spectroscopy	~10 μm focus, 250-1500 eV, ≥100 kHz	Soft X-ray Area (≥ 5 kHz, 0.5 MP)

Technical challenges: X-ray distribution mirrors







Property	Requirement	Measured value
Tangential shape error (full-length)	< 1.0 nm RMS	0.154 nm RMS
Tangential shape error (central region)	< 0.3 nm RMS	0.143 nm RMS
Tangential radius	> 500 km	1515.15 km

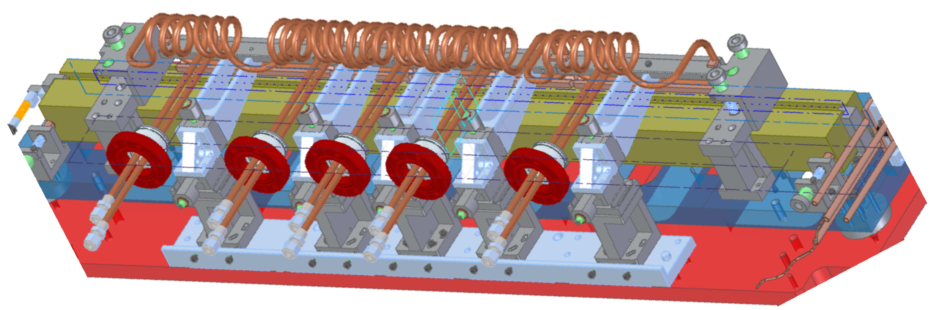
- The best meter-class x-ray mirrors ever produced

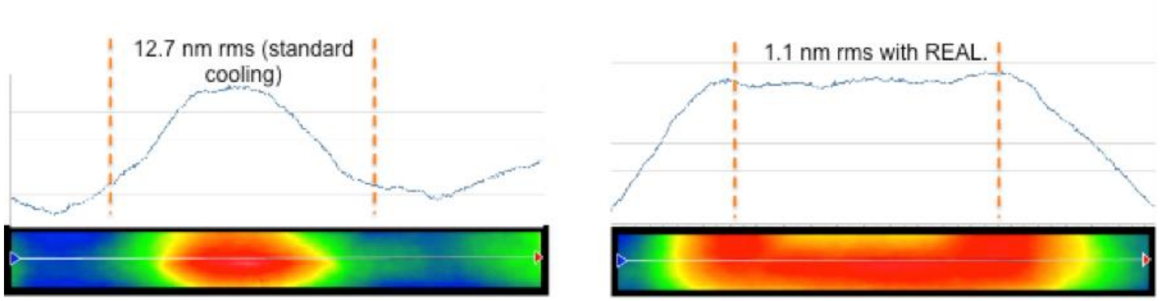
Technical challenges: X-ray distribution mirrors

HXR; 1.35 mrad, 13 keV → **0.56 nm rms**

SXR; 12.0 mrad, 1.3 keV → **0.6 nm rms**

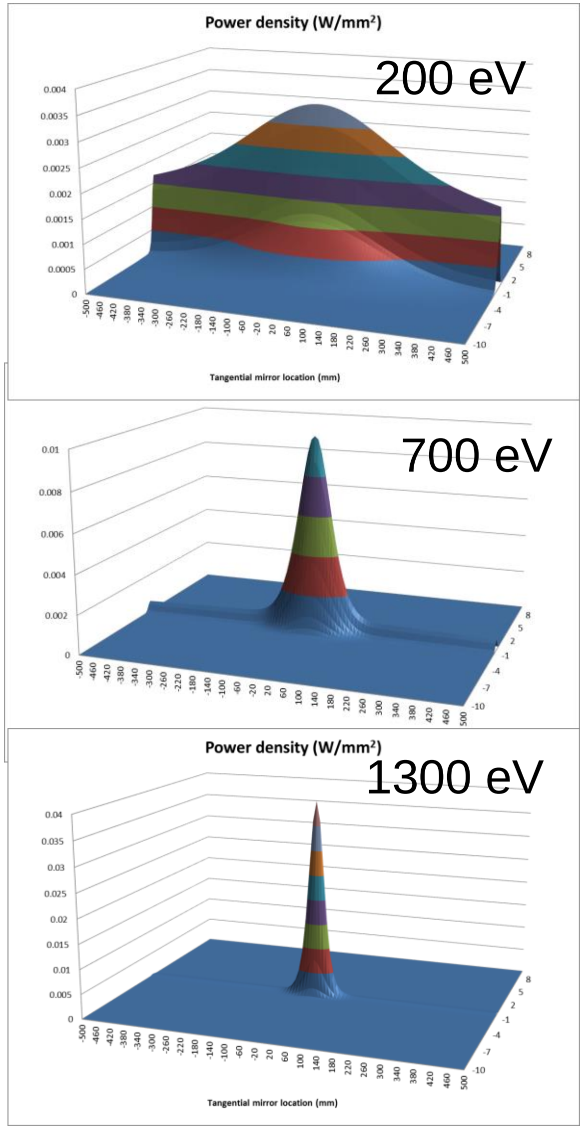
Challenge is to preserve figure under variable profile heat load





Heat Load induced by an IR laser (15W)

Combined effect (REAL + heat Load)



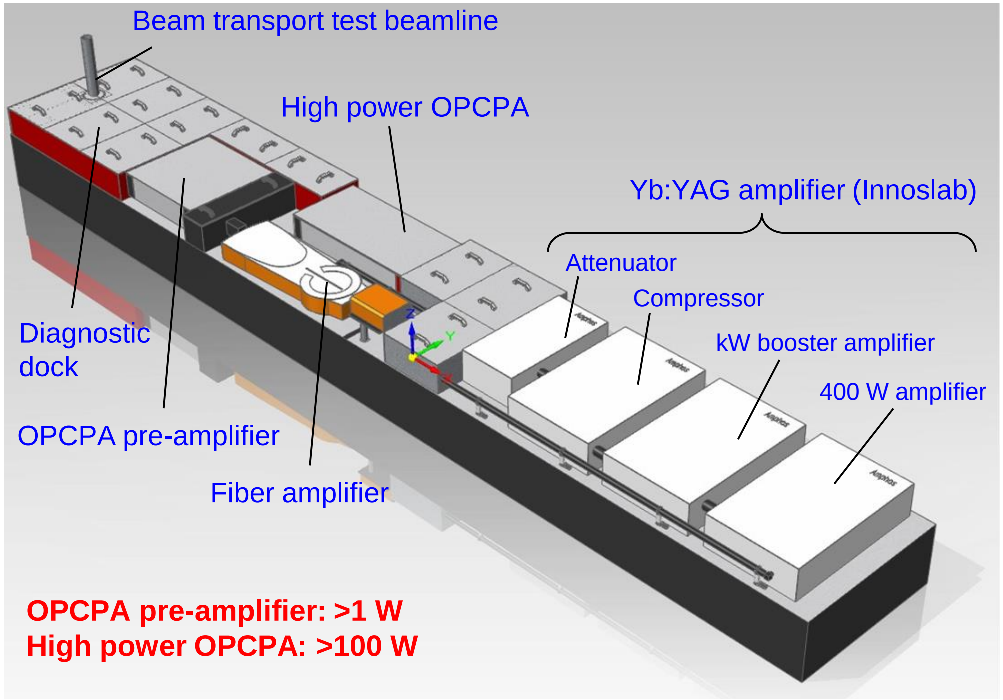
D. Cocco

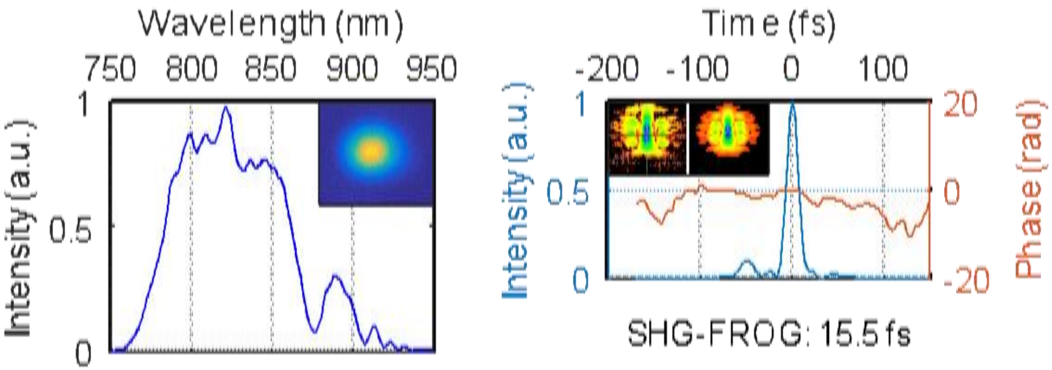
Technical challenges:
High average power femtosecond pump laser

SLAC

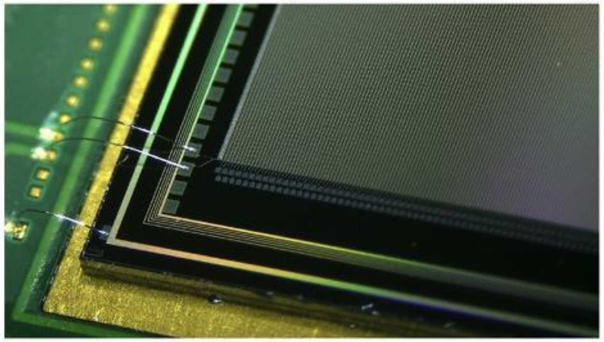
OPCPA	
pulse energy	1 mJ, 100 W (signal)
wavelength range	0.7-1 μm
pulse duration	15 fs
	<5 fs, 60 W with spectral broadening
pulse energy	1.5 mJ, 150 W (signal)
wavelength range	1.4-1.7 μm
pulse duration	50 fs
	<10 fs with spectral broadening
pulse energy	1 mJ, 100 W (idler)
wavelength range	2.6-3.8 μm
pulse duration	70 fs
	<15 fs with spectral broadening
pump laser	
pulse energy	15 mJ, 1.5 kW
wavelength range	1.03 μm
pulse duration	1.5 ps
	<200 fs with spectral broadening
other secondary sources	
Harmonics (OPCPA and pump)	SHG, THG and FHG
tunable OPA	(pumped with 1 mJ, 50 fs, 800 nm)
pulse energy	μJ-tens of μJ
wavelength range	200 nm-20 μm
pulse duration	> 40 fs
THz source	DFG or Optical rectification
pulse energy	to be investigated
wavelength range	0.1-100 THz

Table 2. Overview on basic parameters and alternative parameter for the LCLS-II PP-laser amplifier (at 0.1 MHz repetition rate). Color code reflects the current development time as follows; black: available day-1; blue: upgrade level-1; magenta: upgrade level-2.

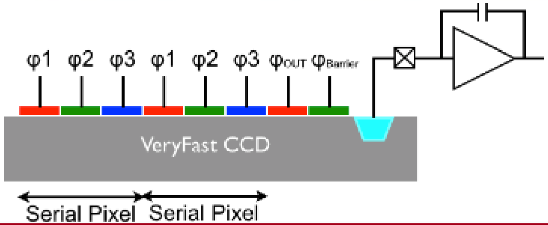


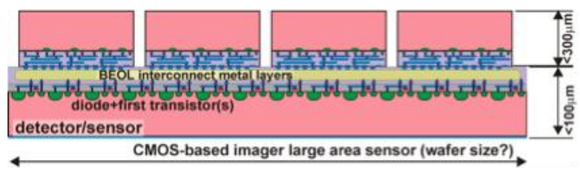


Technical challenges: Advanced detectors

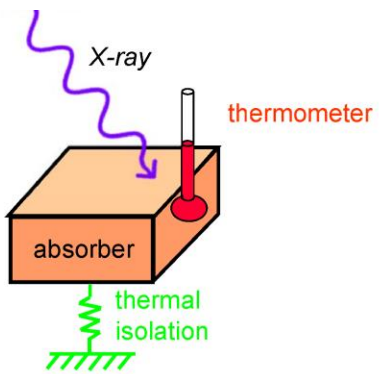


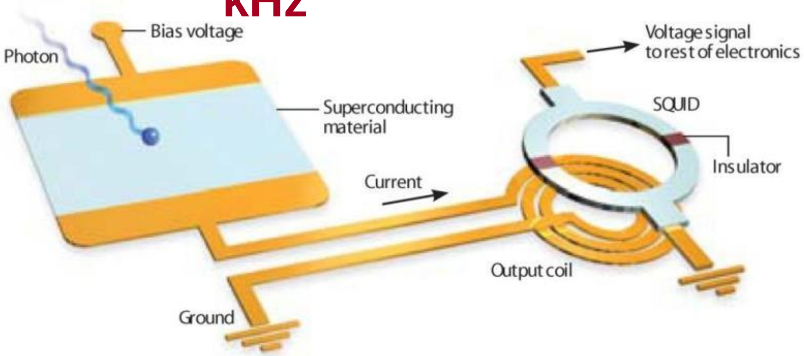
High Speed Imaging
≥ 5-10 kHz

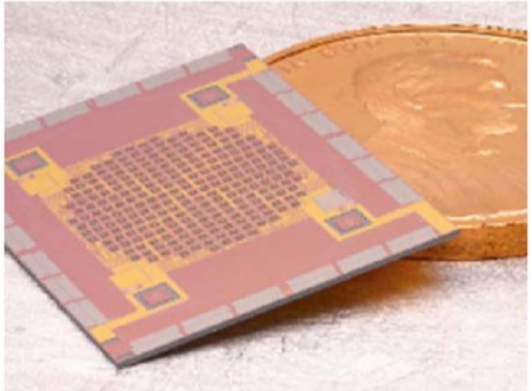




Spectroscopic
~ 0.5 eV @ 1 keV, 10 kHz



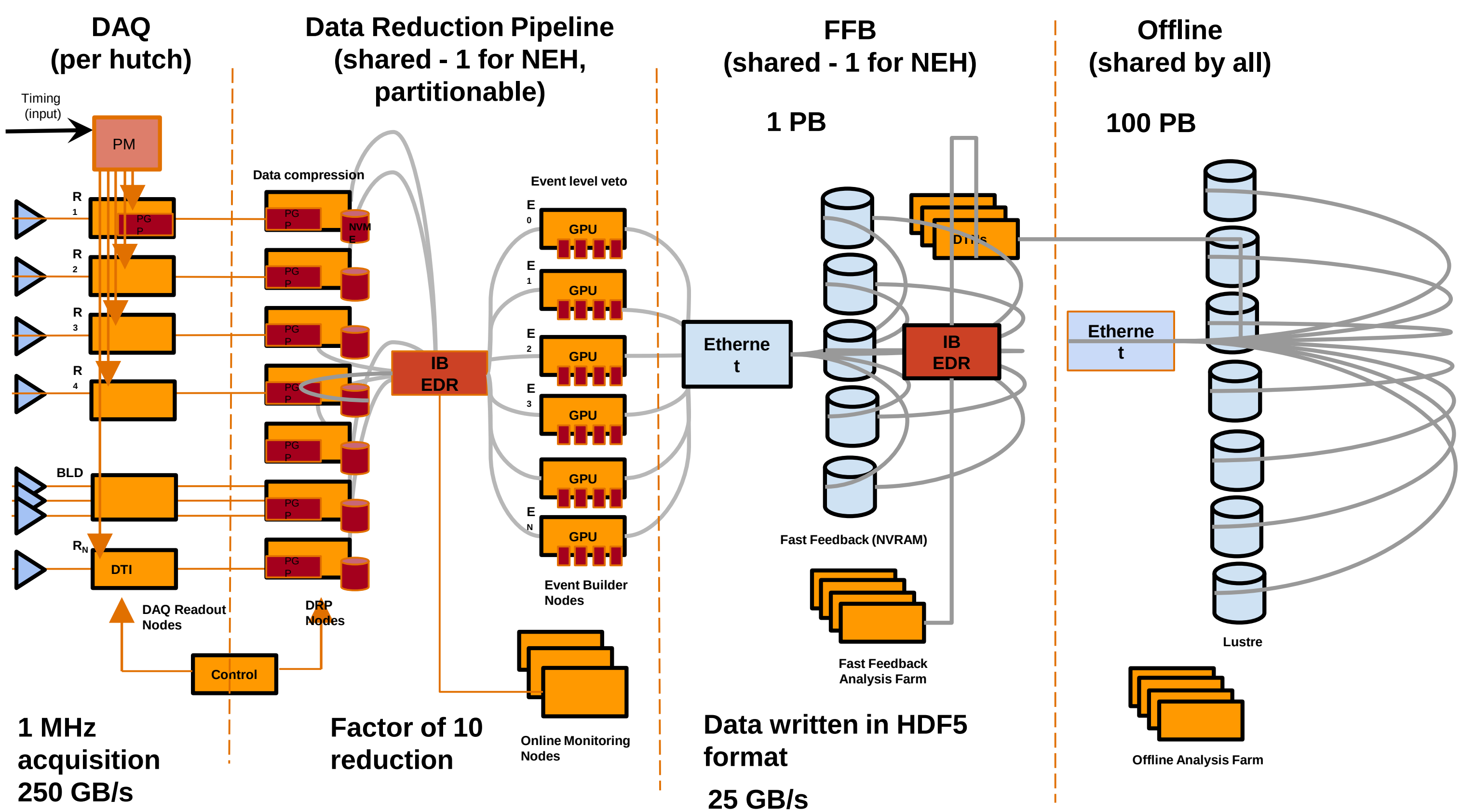




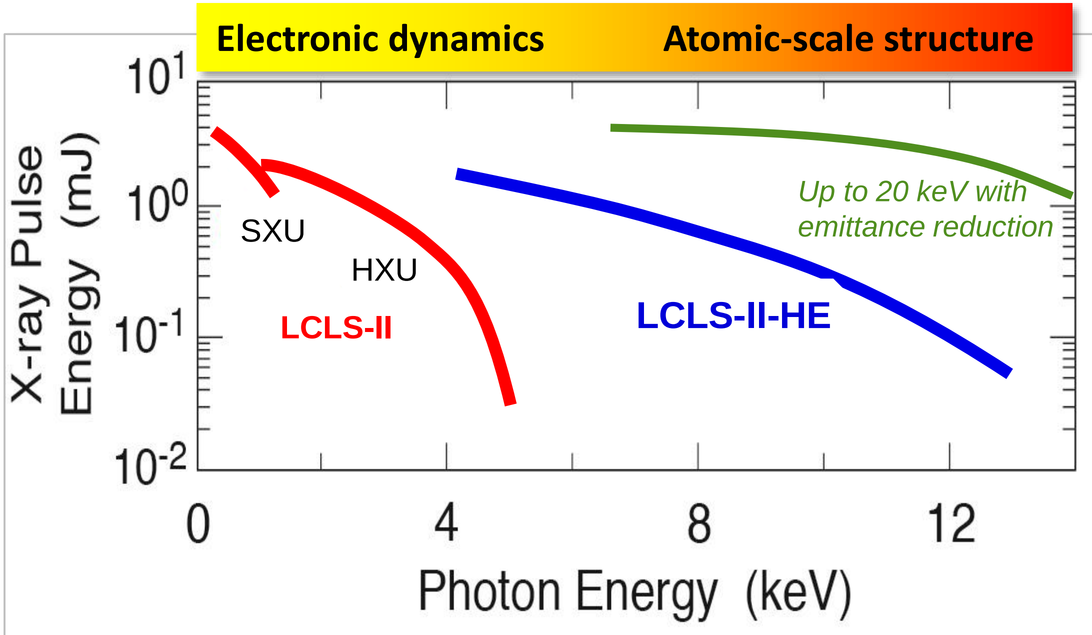
Technical challenges:
High throughput data systems

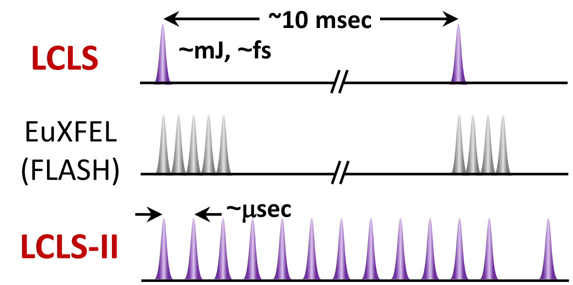
SLAC

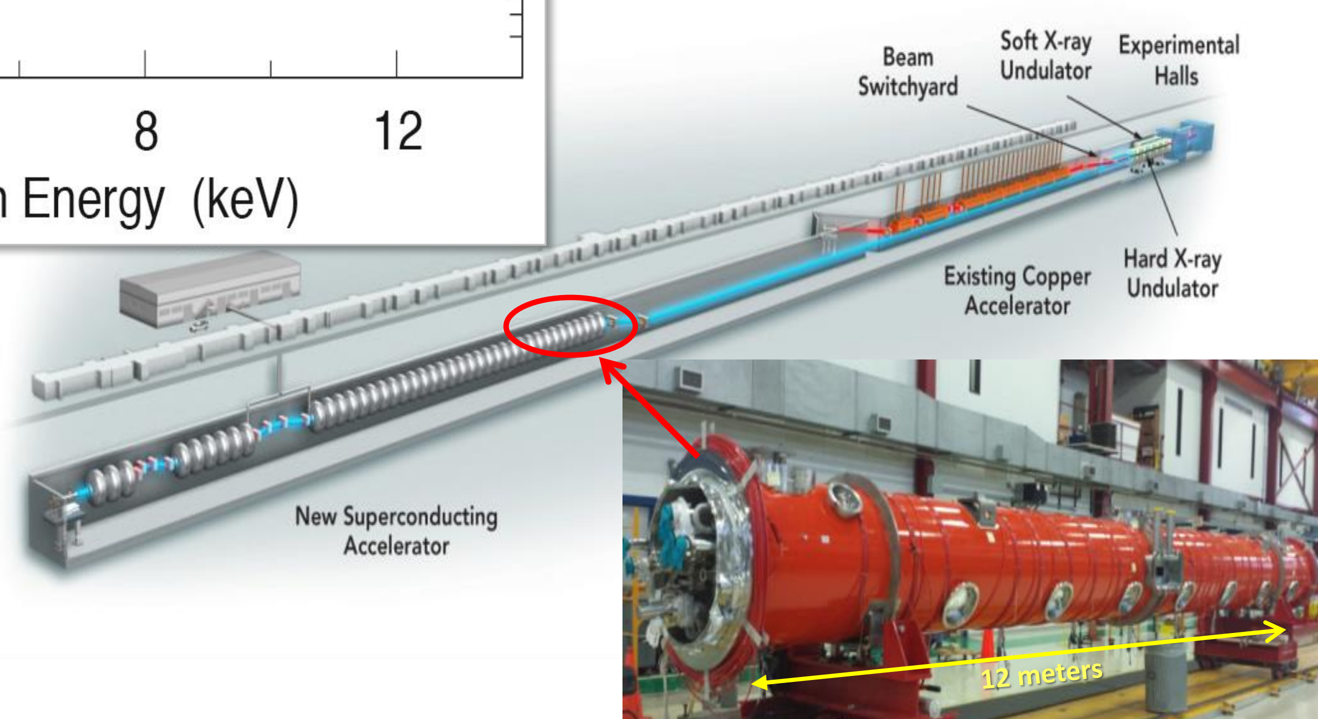
- High Throughput DAQ (250 GB/s)
- Data Reduction Pipeline (10x)
- Fast Feedback System
- Data Management System (100 PB)
- Data Analysis



LCLS-II-HE (High-Energy upgrade)







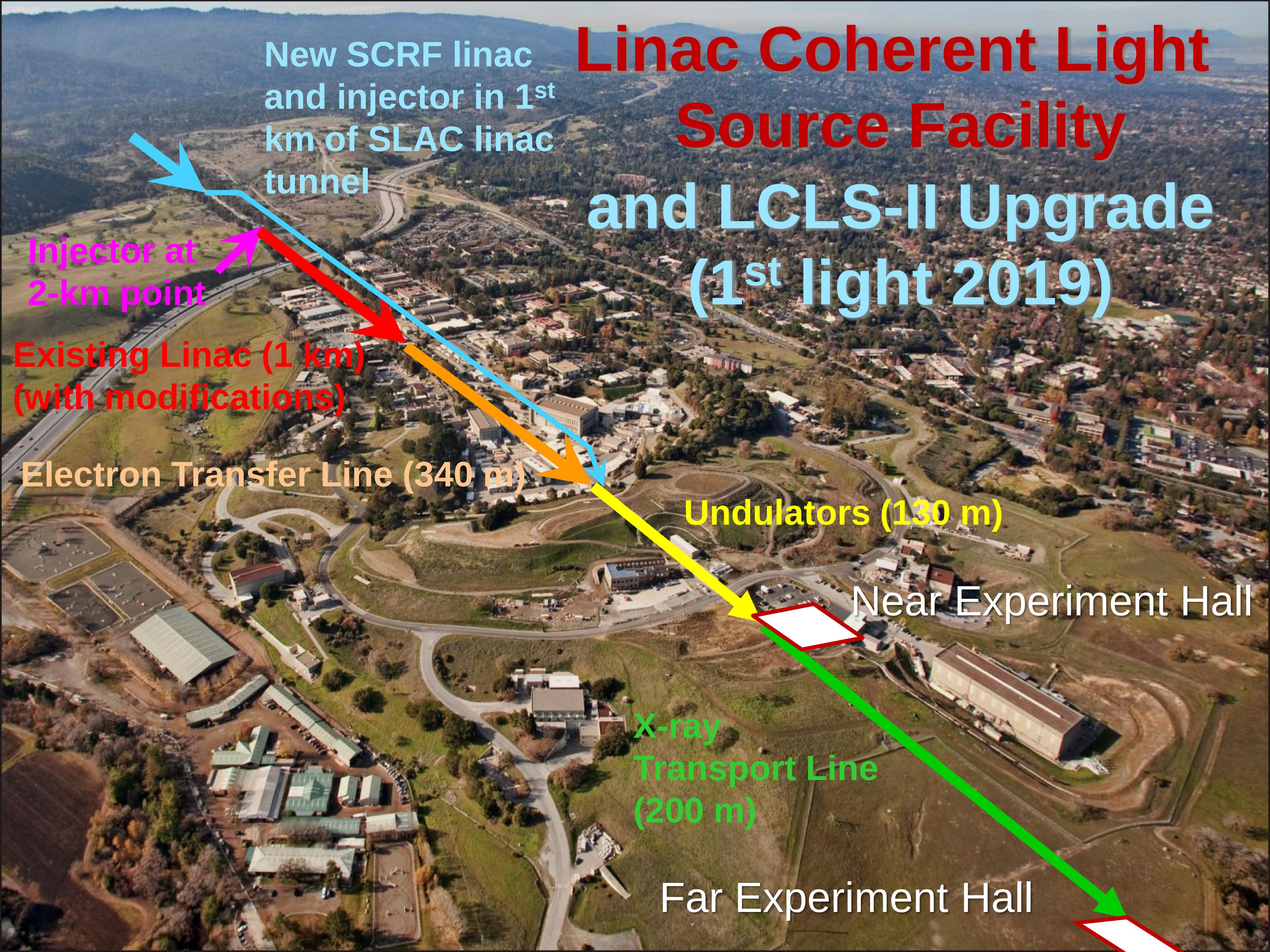
- **+20 cryomodules**
- **4 GeV ⇒ 8 GeV CW-SCRF linac**

Summary

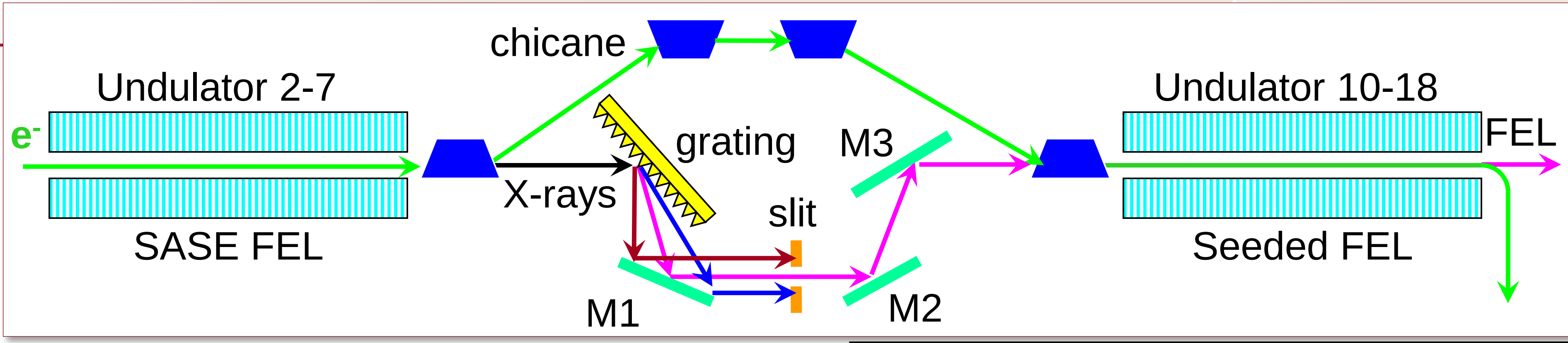
- The LCLS-II construction project, with strong US collaboration and support from international partners, is underway to deliver:
  - 4 GeV CW SCRF accelerator
  - High brightness CW injector
  - Two variable gap undulators
  - High power beams and optics

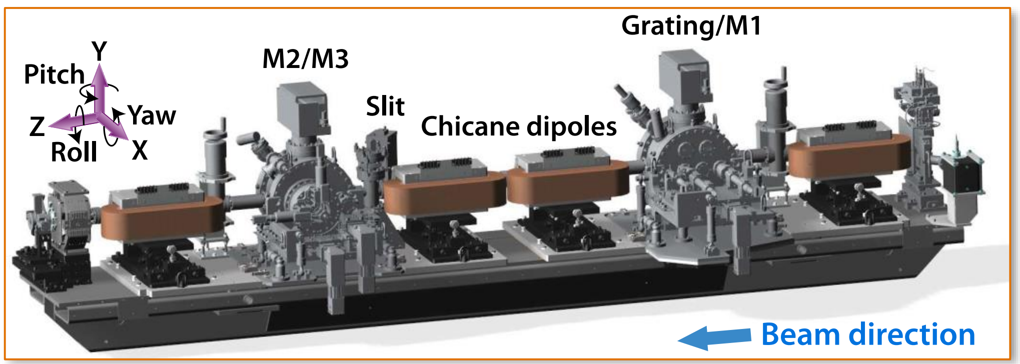
- X-ray instruments are being designed to take advantage of this new MHz, mJ-class x-ray laser

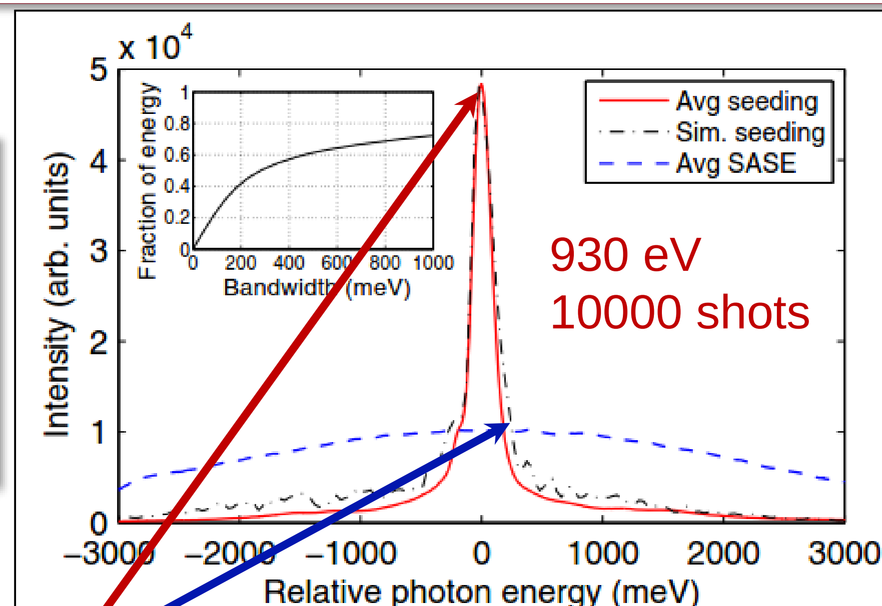
- First light is anticipated in 2020


Linac Coherent Light Source Facility
and LCLS-II Upgrade
(1st light 2019)
New SCRF linac and injector in 1st km of SLAC linac tunnel
Injector at 2-km point
Existing Linac (1 km) (with modifications)
Electron Transfer Line (340 m)
Undulators (130 m)
Near Experiment Hall
X-ray Transport Line (200 m)
Far Experiment Hall

Soft x-ray self-seeding







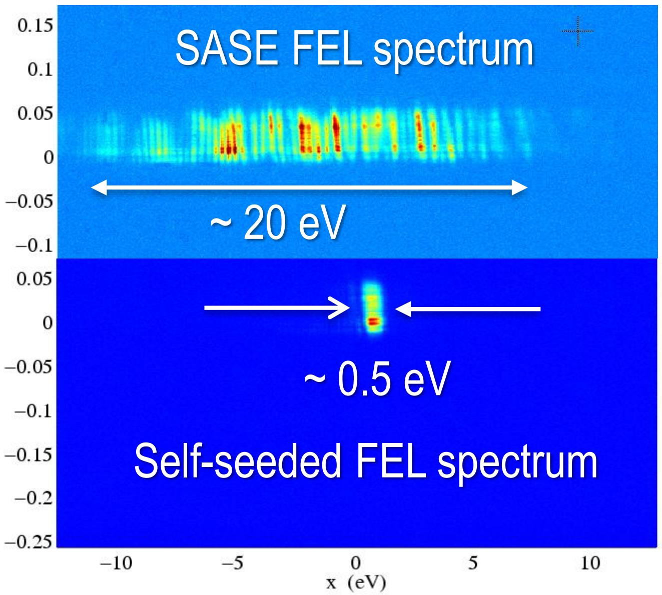
- Spectral brightness ~5x higher than SASE
- Observed spectral pedestals (may degrade certain applications w/o a mono).

D. Ratner et al., PRL 114, 054801 (2015)

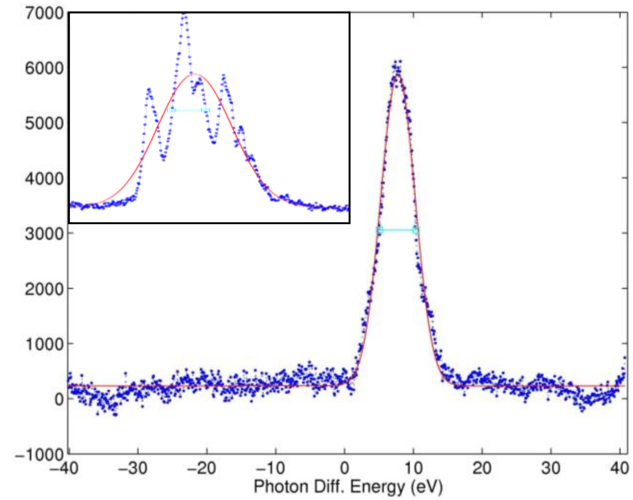
BERKELEY LAB
PAUL SCHERRER INSTITUT PSI
SLAC NATIONAL ACCELERATOR LABORATORY

LCLS performance parameters

	Current performance
Photon energy range	280 to 11,500 eV
FEL pulse length	< 5 – 500 fs
FEL pulse energy	~ 4 mJ (2.5 * 10^{12} @ 10 keV)
FEL coherence	SASE, Seeding (hard x-ray)
Repetition Rate	120 Hz

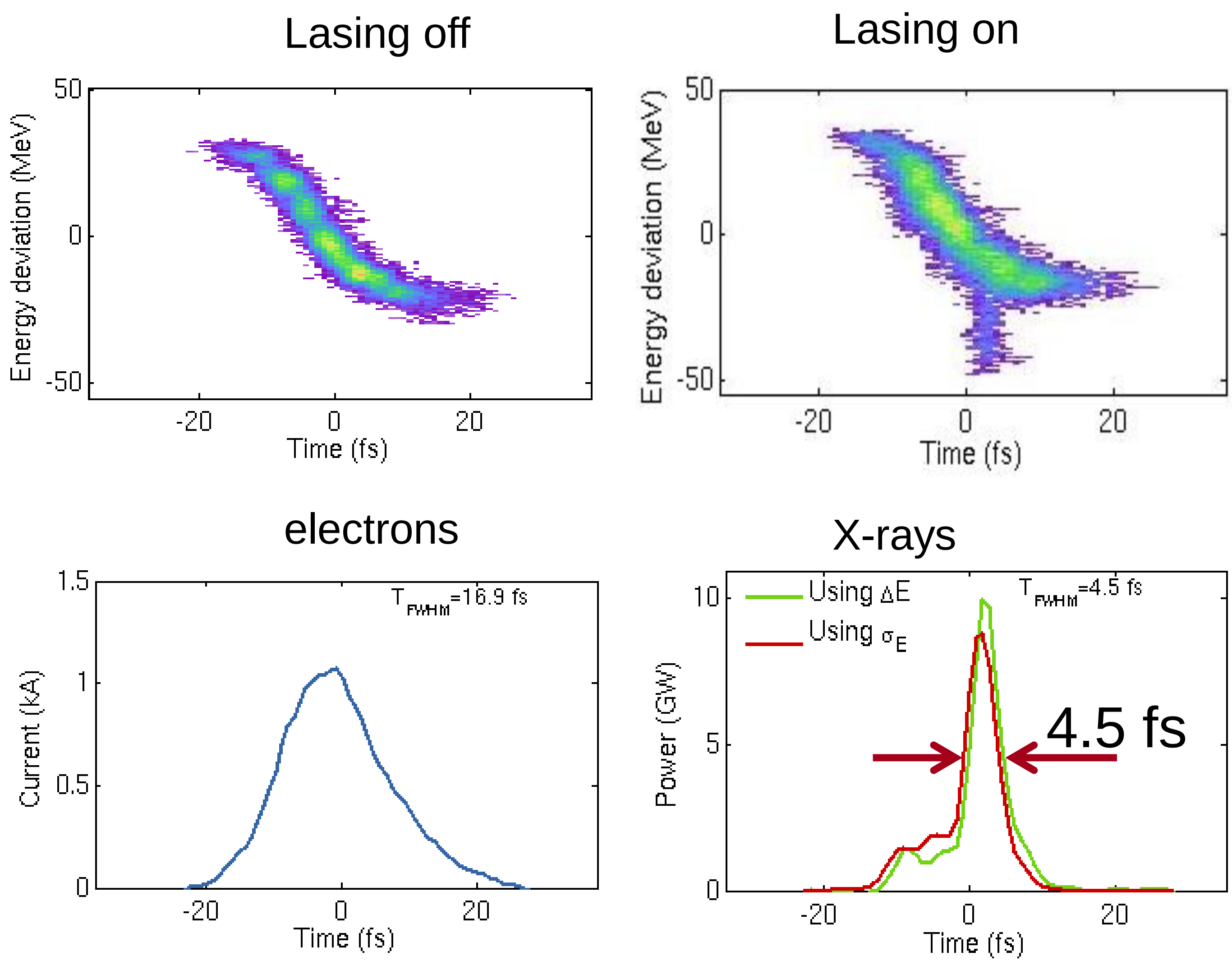


Hard X-ray self-seeding



Near transform limited soft x-ray pulses

X-band Transverse Cavity



Y. Ding, P. Krejcik et al.

Resolution corrected 2.6 fs FWHM

Liquid explosions induced by X-ray laser pulses

Scientific Achievement

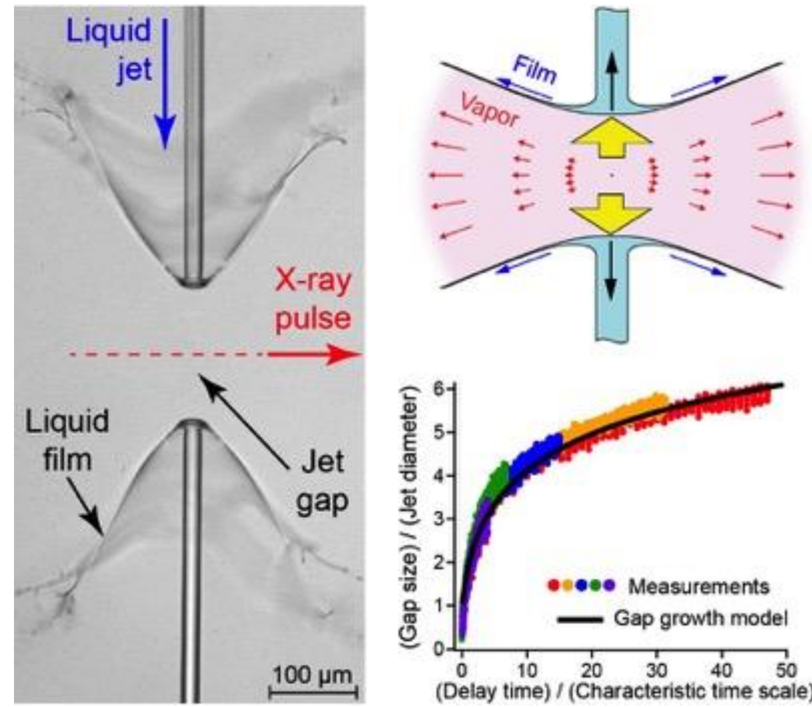
Observation and characterization of explosions induced by X-ray lasers in liquids.

Significance and Impact

Explosions induced by X-ray lasers could enable studies of matter in extreme conditions. The phenomena that may affect experiments at higher repetition rates such as at LCLS-II were quantified and modeled.

Research Details

- The nanosecond-to-microsecond dynamics of X-ray laser explosions in jets and drops was determined at LCLS using time-resolved optical imaging.
- Femtosecond X-ray pulses induce a multistep dynamics that can last up to tens of microseconds, leading to the formation of a gap in the jets.
- A fluid dynamics model was developed to predict the gap growth and the recovery time of the jets.



Explosions induced by X-ray lasers in jets: The picture shows a water microjet, several microseconds after it was hit by an X-ray laser. The liquid in the path of the X-rays is vaporized, and the vapor pushes the liquid films from the jet. The growth of the gap is modeled analytically to predict how quickly the jets will recover in X-ray laser experiments.

Claudiu A. Stan, *et al.*, Nat. Phys. (2016). DOI: 10.1038/nphys3779.

Project Collaboration: SLAC couldn't do this without…

SLAC

Fermilab

- Cryomodule engineering/design
- Manufacture 50% of cryomodules: 1.3 GHz
- Design and manufacture 2 Cryomodules: 3.9 GHz
- Design and acquisition of helium distribution
- Processing for high Q (FNAL-invented gas doping)

Jefferson Lab — EXPLORING THE NATURE OF MATTER

- Manufacture 50% of cryomodules: 1.3 GHz
- Design and acquisition of two 4 kW Cryoplants
- Processing for high Q

Berkeley Lab

- Undulators
- e^- gun & associated injector systems

Argonne NATIONAL LABORATORY

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

Cornell University — Founded A.D. 1865

- R&D planning, prototype support
- processing for high-Q (high Q gas doping)
- e^- gun option

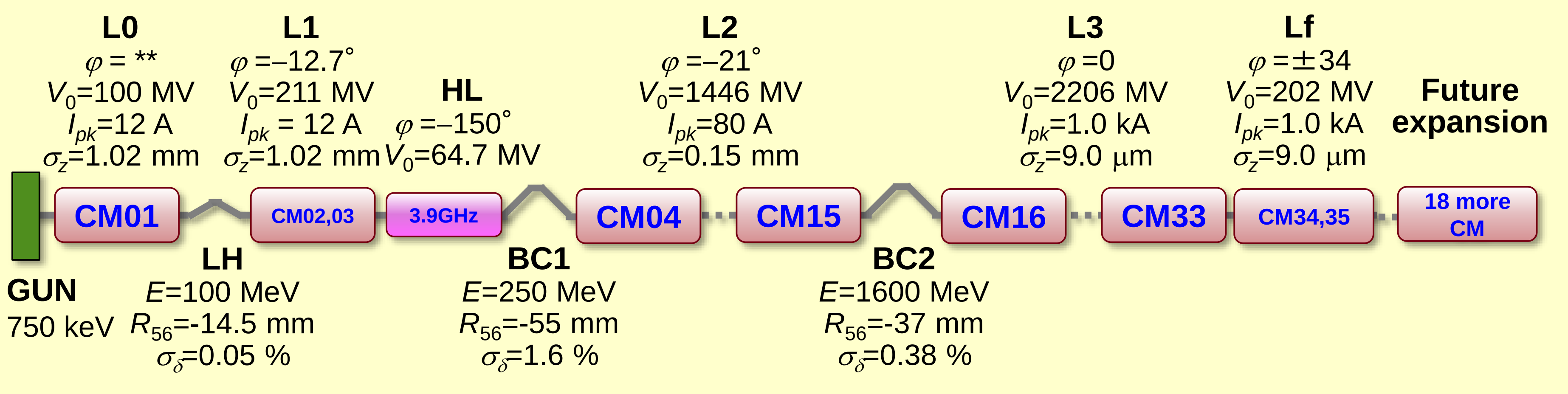
LCLS-II (SCRF) Baseline Parameters

Parameter	symbol	nominal	range	units
Electron Energy	E_f	**4.0**	2.0 - 4.5	GeV
Bunch Charge	Q_b	**100**	10 - 300	pC
Bunch Repetition Rate in Linac	f_b	**0.62**	0 - 0.93	MHz
Average e^- current in linac	I_{avg}	**0.062**	0.0 - 0.3	mA
Avg. e^- beam power at linac end	P_{av}	**0.25**	0 - 1.2	MW
Norm. rms slice emittance at undulator	$\gamma\varepsilon_{\perp\text{-}s}$	**0.45**	0.2 - 0.7	μm
Final peak current (at undulator)	I_{pk}	**1000**	500 - 1500	A
Final slice E-spread (rms, w/heater)	σ_{Es}	**500**	125 - 1500	keV
RF frequency	f_{RF}	**1.3**	-	GHz
Avg. CW RF gradient (powered cavities)	E_{acc}	**16**	-	MV/m
Avg. Cavity Q_0	$Q0$	**2.7e10**	1.5 - 5e10	-
Photon energy range of SXR (**SCRF**)	E_{phot}	-	**0.2 - 1.3**	keV
Photon energy range of HXR (**SCRF**)	E_{phot}	-	**1 - 5**	keV
Photon energy range of HXR (**Cu-RF**)	E_{phot}	-	**1 - 25**	keV

LCLS-II SCRF Linac Layout

Layout similar to LCLS (except SCRF)

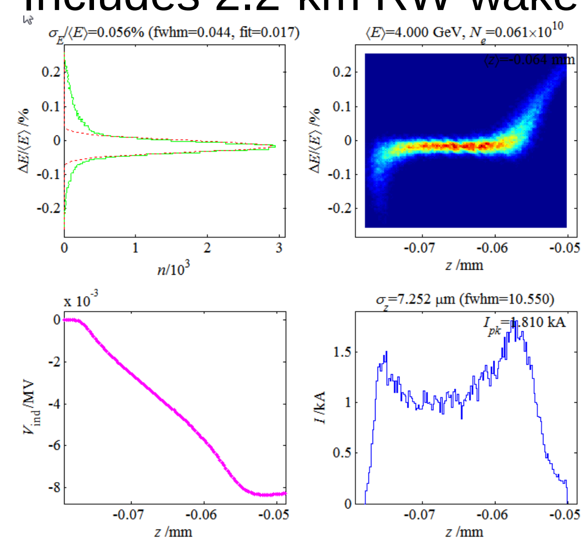
SLAC



100-pC machine layout: April 24, 2014; v21 ASTRA run; Bunch length L_b is FWHM ** L0 cav. phases: ~(3°, -15°, 0, 0, 0, 0, 15°,0°)

- Two-stage BC w/ linearizer plus laser heater
- Uses (35) 1.3 GHz and (2) 3.9 GHz CM
  - CM design adopted from ILC/XFEL design and adapted for CW operations
  - EuXFEL producing 1 module/per week; LCLS-II is planning on ~1 CM/month

Includes 2.2-km RW-wake



Jlab CEBAF 12 GeV Upgrade 4.5 K cold-box (Linde) 'CHL 2'

LCLS-II 2x4kW 2°K Cryoplants will be based on JLAB CHL2 design

2.1 Expected flux on the sample

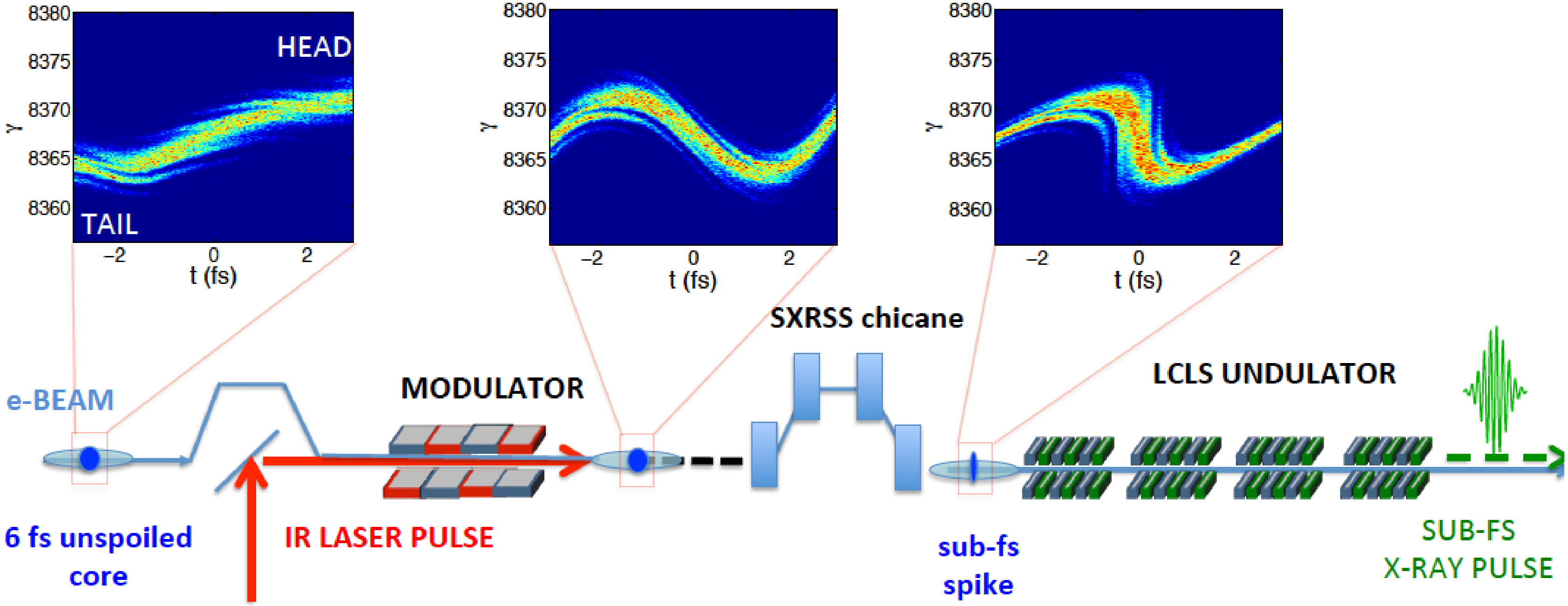
- Does RIXS at an FEL make sense?
  - A safe x-ray energy density is ~ 1 mJ/cm^2
  - For a spot size of 10 x 400 μm^2, 10^8 ph/pulse result in this fluence
  - At 1 MHz rep rate this gives 10^{14} ph/s
  - Beamline delivers ~10^{15} ph/s at resolving power of 50,000

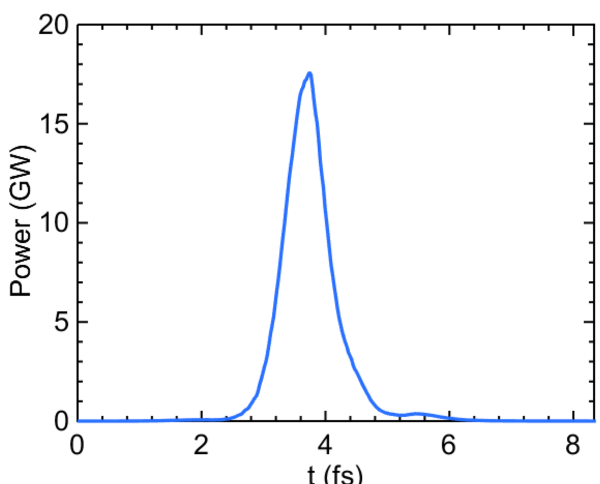
RIXS Resolution	30 meV @1 keV
LCLS-II	**10^{14} ph/s**
SLS ADRESS BL	10^{11} ph/s
NSLS-II SIX BL	10^{12} ph/s

Unmatched performance for high spectral resolution, combined with a unique capability for time-resolved experiments

30 meV ⇔ 66 fs
100 meV ⇔ 20 fs

A method for producing sub-fs pulses is under development now





E_{photon} = 500 eV – 1300 eV

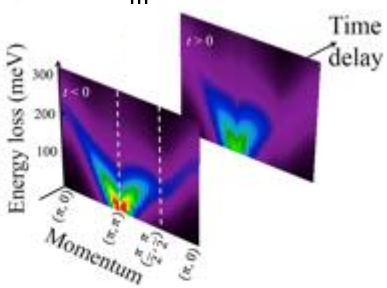
~0.75 fs duration
~3 eV coherent bandwidth
30-40 uJ/pulse

A. Marinelli (SLAC)

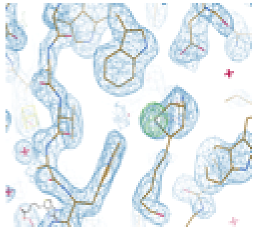
Recent LCLS beam developments

Extended photon energy range: from 0.8–8 to 0.25–12.8 keV

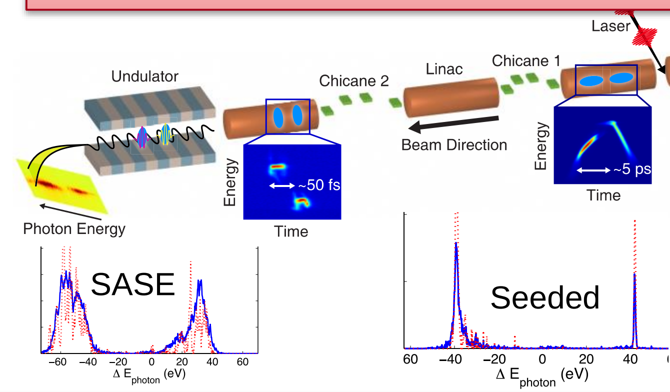
Ir L_{III} RIXS



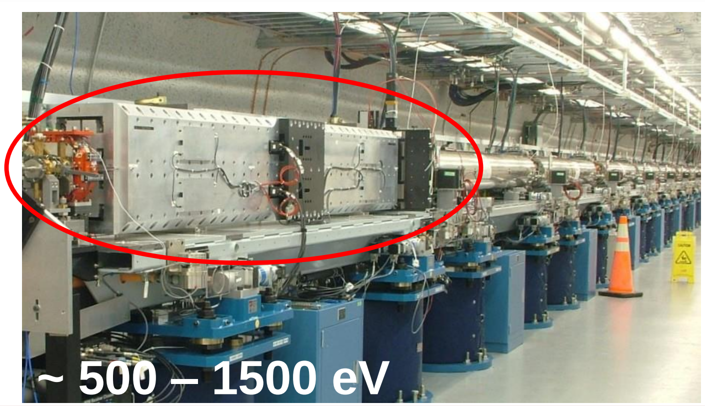
Se K-edge SAD



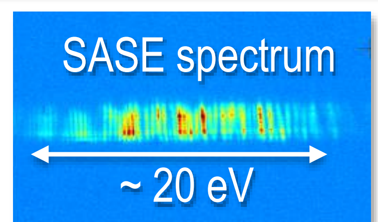
Creation of multiple options for 2-pulse, 2-color x-rays

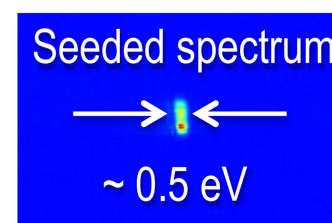


From linear to controlled polarization



From SASE fluctuations to controlled pulse width and spectrum (seeding)





40x increase in spectral brightness

LCLS has moved far beyond its baseline parameters and we aim to continue this trend with LCLS-II

An example instrument:
AMO (atomic, molecular and optical science)