LCLS-II

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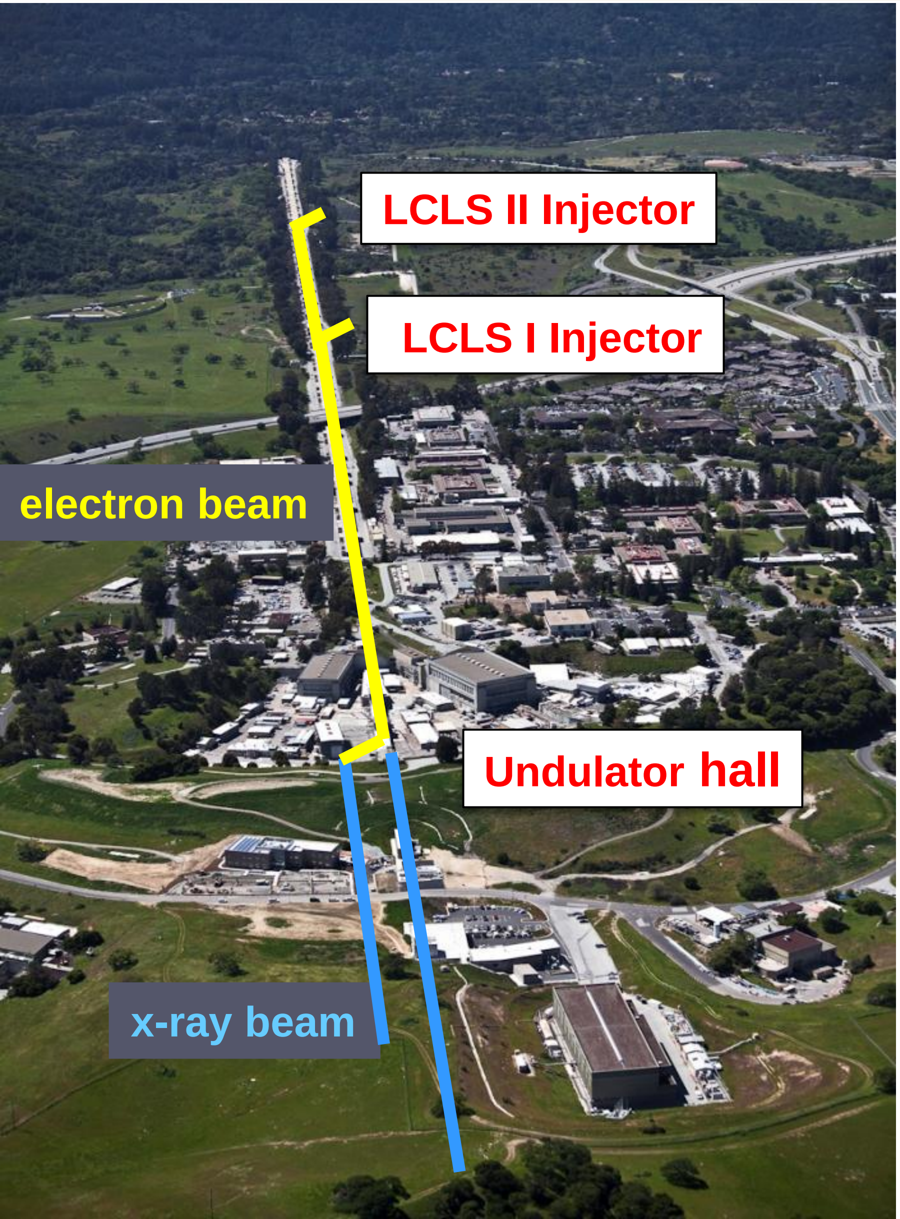
BESAC

Feb. 27, 2014

Outline

- BESAC recommendations
- Revised LCLS-II proposal
- Status of the new LCLS-II project
- Experimental capability development

Rationale for the LCLS-II project and the original LCLS II



- LCLS is leading the world into a new era of x-ray science
- Rapid increases in scientific productivity and demand
- Increasing competition worldwide

- Second independent 1-km Cu linac
- 3 simultaneous FEL undulator sources
- Operating at 120Hz
- Photon energy range: 250 eV –18 keV

July 2013 BESAC Subcommittee recommendations

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- 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."

The Revised LCLS-II Project in Response to BESAC recommendations

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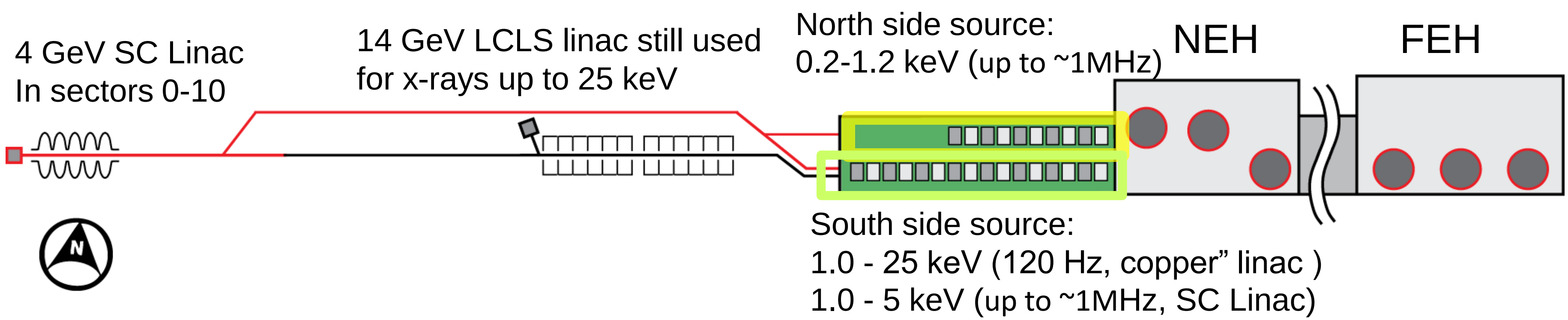
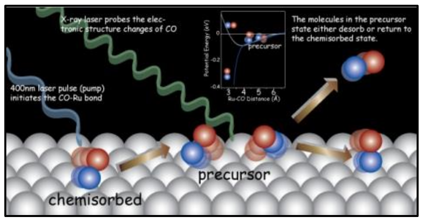
Accelerator	<u>**Superconducting linac**</u>: 4 GeV
Undulators in existing LCLS-I Tunnel	New variable gap (north) New variable gap (south), replaces existing fixed-gap und.
Instruments	Re-purpose existing instruments (instrument and detector upgrades needed to fully exploit)

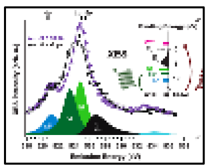


FEL Science opportunities

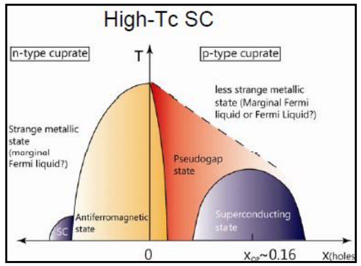
High repetition rate science: between 0.2 - 5keV

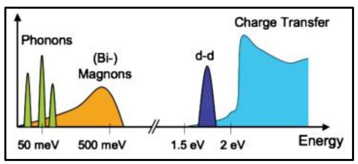
Catalysis (CO on Ru)



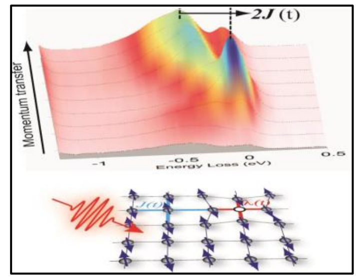


High T_C Superconductors



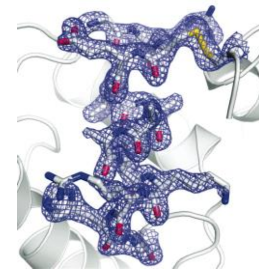


Correlated Electron Systems



Time resolved RIXS

de novo phasing using
Single Wavelength Anomalous Diffraction
from Sulfur: 4-5 keV



C K edge
0.284 keV

Cu L_{III} edge
0.932 keV

Ru L_{III} edge
2.838 keV

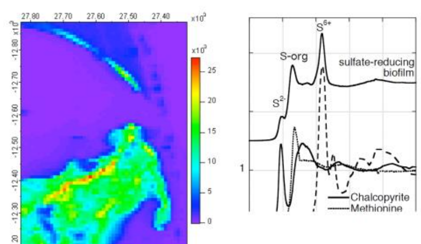
0.2 keV

Gd M_V edge
1.190 keV

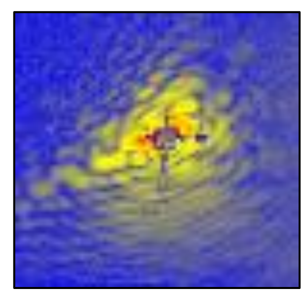
S K edge
2.472 keV

5.0 keV

Coherent X-ray Imaging of
magnetic domain in Gd/Fe



Sulfur spectro-microscopy in
bio/environmental science



Non-periodic
imaging: 2-5 keV

FEL Science opportunities (Cont.)

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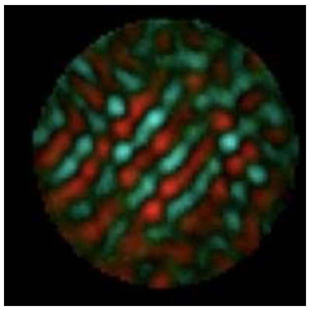
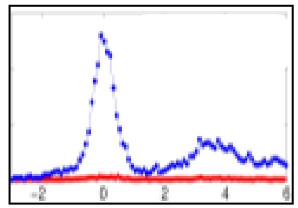
High energy per pulse science 5.0-25.0 keV

Magnetic polarities of a cobalt alloy

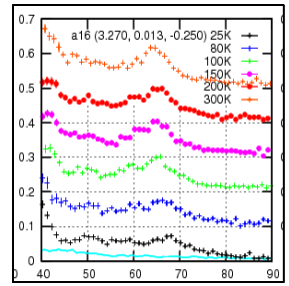


Iridates: model strongly correlated materials

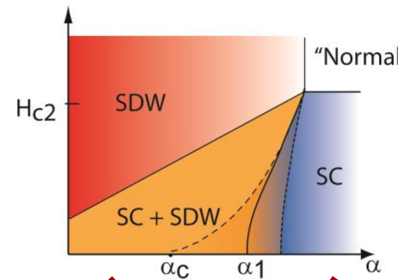


Energy Loss (eV)

Phonons in superconductivity



High magnetic fields 14-25 KeV disentangle competing orders



Fe K edge 7.112 keV

Co K edge 7.712 keV

Ir L_{III} edge 11.215 keV

Si(777) backscatter 13.84 keV

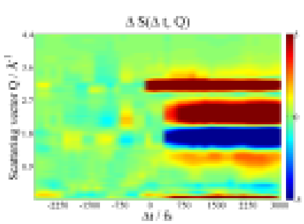
Se K edge 12.658 keV

5 keV

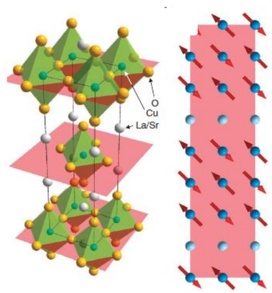
Cu K edge 8.979 keV

25 keV

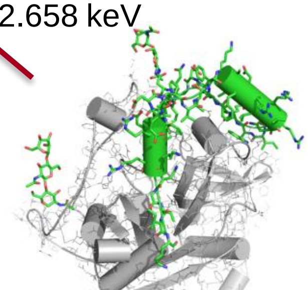
Solute-solvent interactions in photo-excited reactions



Time resolved Resonant solution scattering



Charge-stripe ordering in LSCO superconductor

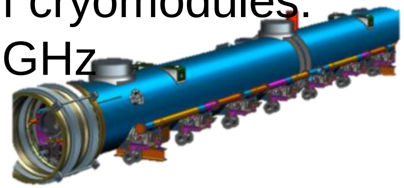


Serial Femtosecond Crystallography *de novo* phasing using Multiple Wavelength Anomalous Diffraction from Selenium

Project Collaboration

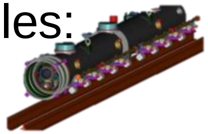
Fermilab

½ of cryomodules:
1.3 GHz

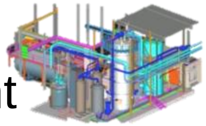


Jefferson Lab
EXPLORING THE NATURE OF MATTER

½ of cryomodules:
1.3 GHz

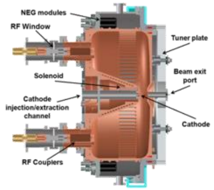


Cryoplant

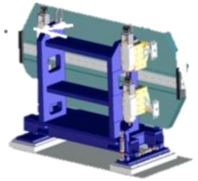


BERKELEY LAB

e$^-$ gun & associated injector systems



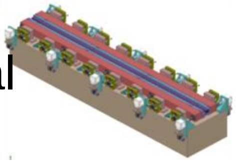
Undulators



Argonne NATIONAL LABORATORY

Undulator Vacuum Chamber

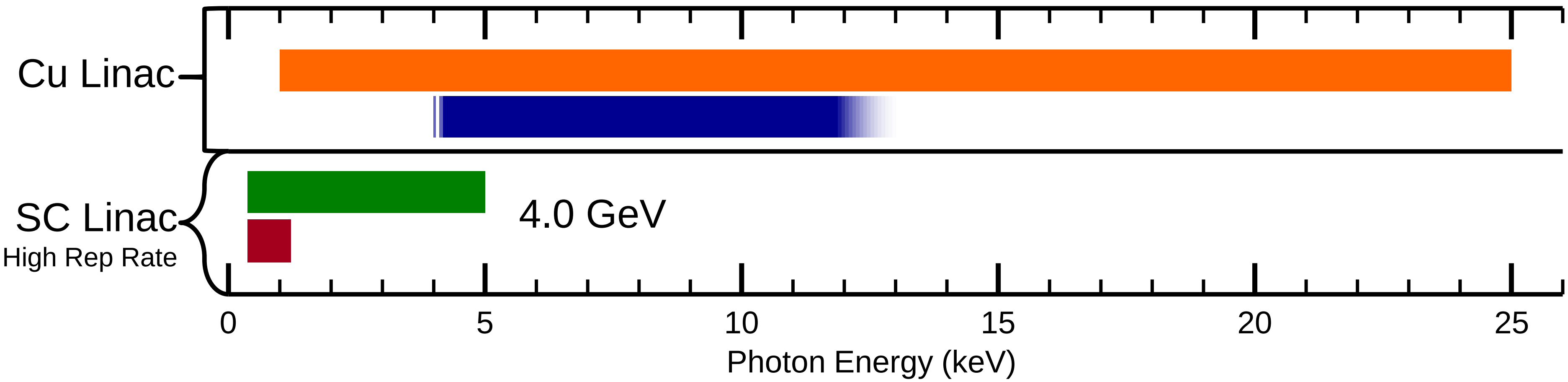
Undulator R&D: vertical polarization



CORNELL UNIVERSITY FOUNDED A.D. 1865

R&D planning, prototype support
e$^-$ gun option

Baseline Deliverables

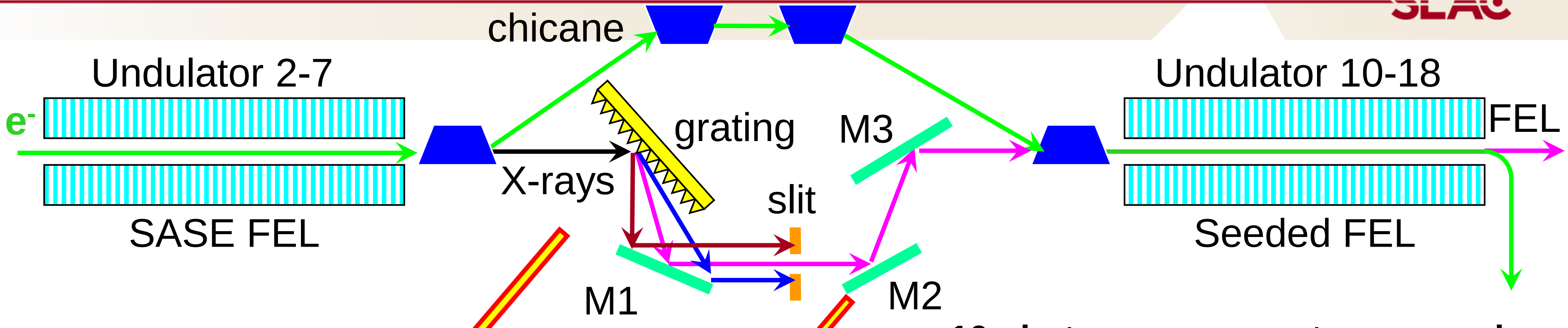


Legend

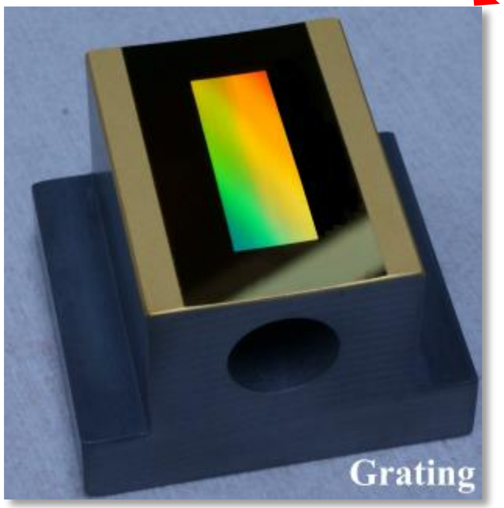
- Cu SASE
- Cu Self Seeded
- High Rep Rate SASE
- Self Seeded (Grating)

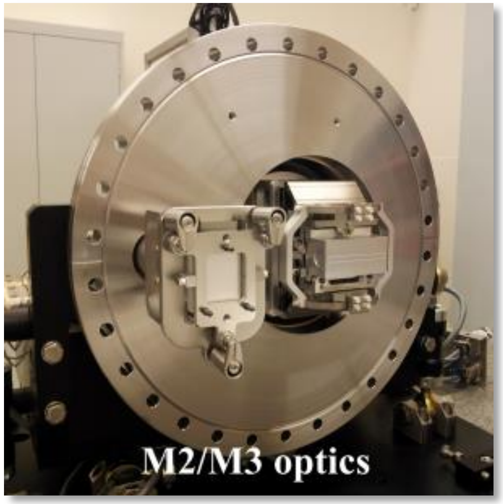
- Hard X-Ray Source:
  - 1-5 keV w/ 4 GeV SC linac
  - Up to 25 keV with LCLS Cu Linac
- Soft X-Ray Source:
  - 250 eV-1.2 keV w/ 4 GeV linac

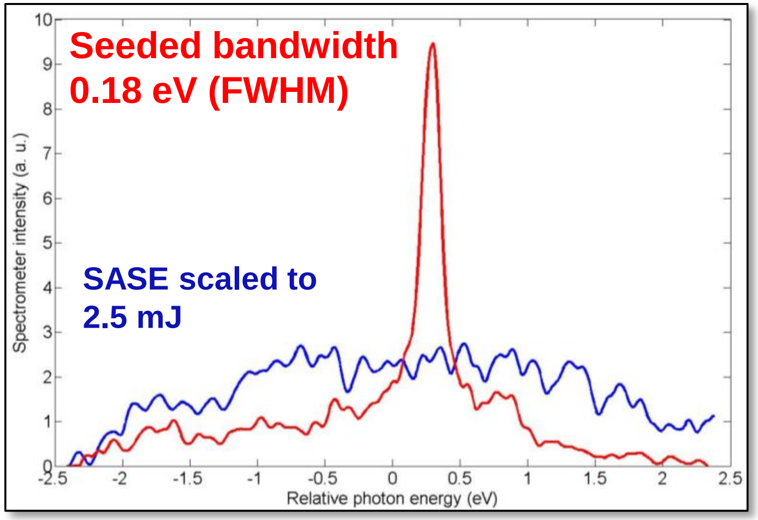
First Demonstration of Soft X-Ray Self Seeding



10-shot average spectra comparison

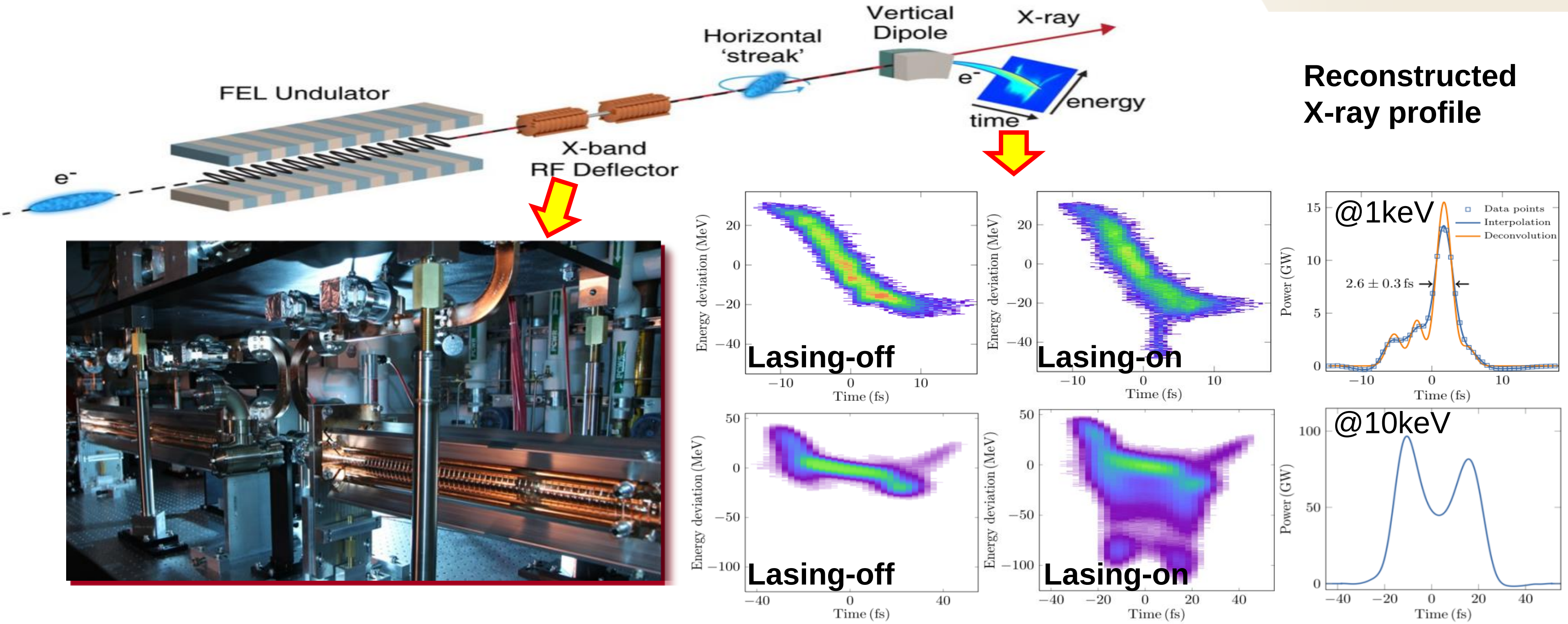






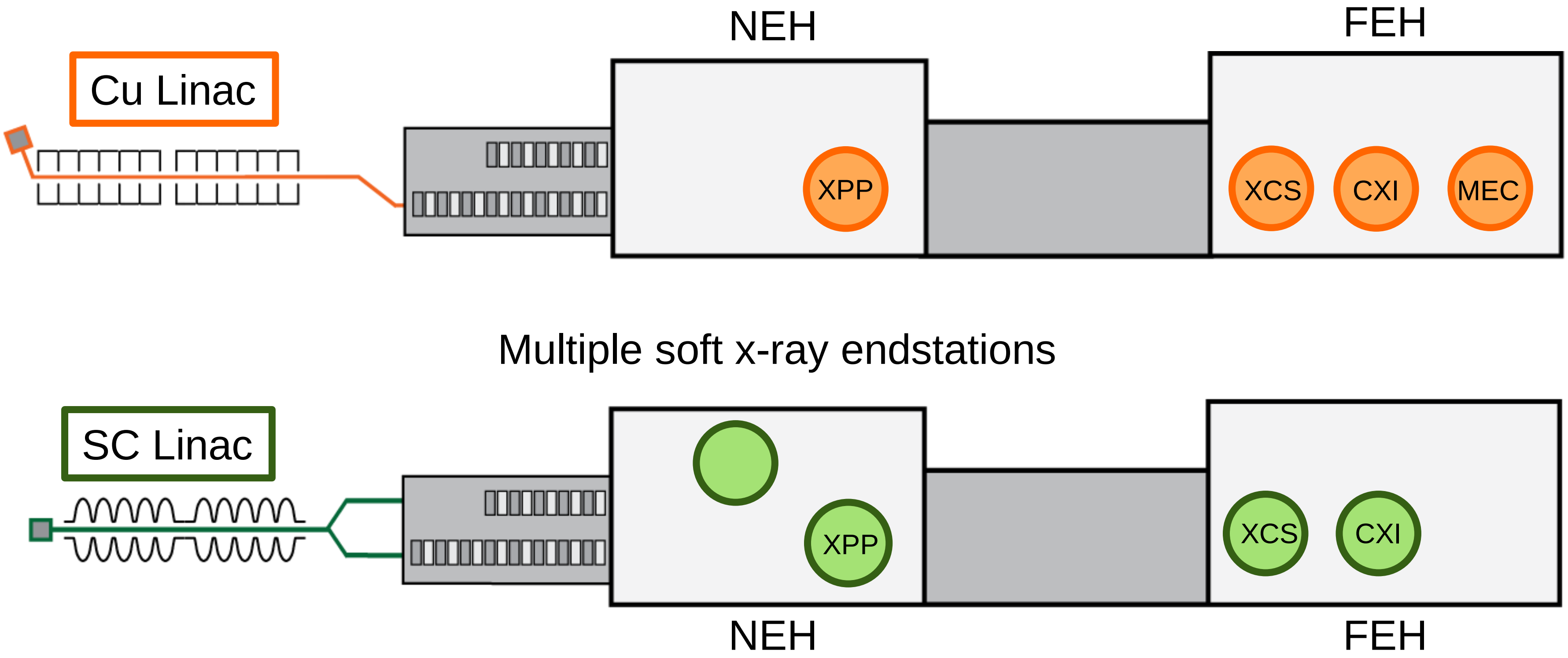
- Seeded bandwidth is **a factor of ~30 narrower than SASE** at photon energy 860 eV
- Seeded beam has a **resolving power exceeding 5000**.
- 10-shot averaged spectral brightness is a factor of ~4 higher than 2.5 mJ SASE.

Femtosecond X-ray diagnostics with an X-band radio-frequency transverse deflector



- ➢ Electron beam is streaked horizontally and viewed on a screen in a vertically resolved energy spectrometer, revealing time-energy phase space **after the FEL undulator**.
- ➢ The upper right plots show an example of an ultra-short soft x-ray pulse with a measured **2.6-fs pulse duration**.

Instrumentation Plan (Work in progress)



Nonadiabatic Molecular Dynamics
- X-ray Emission Spectroscopy

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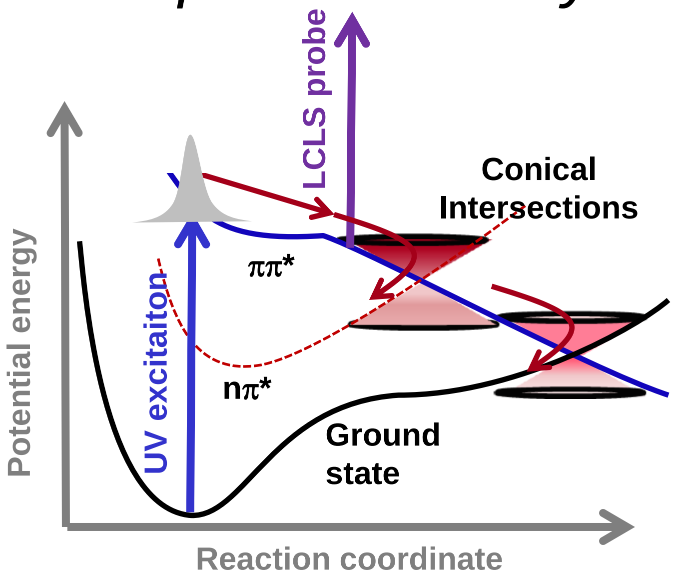
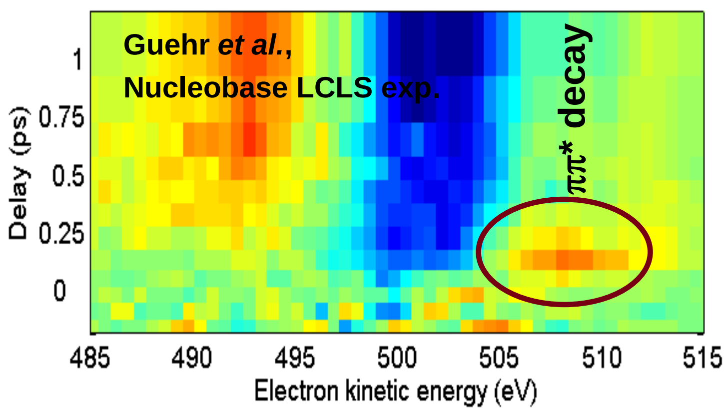
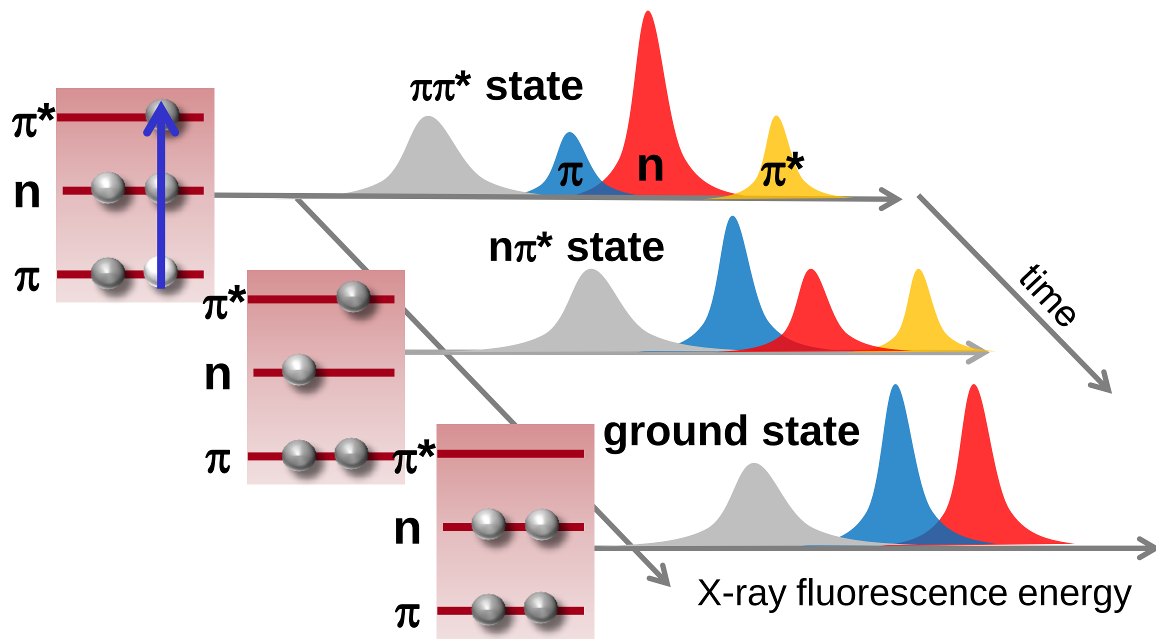
XES probes directly the electronic structures of excited states



Understand efficiency and selectivity in molecular photo-energy conversion

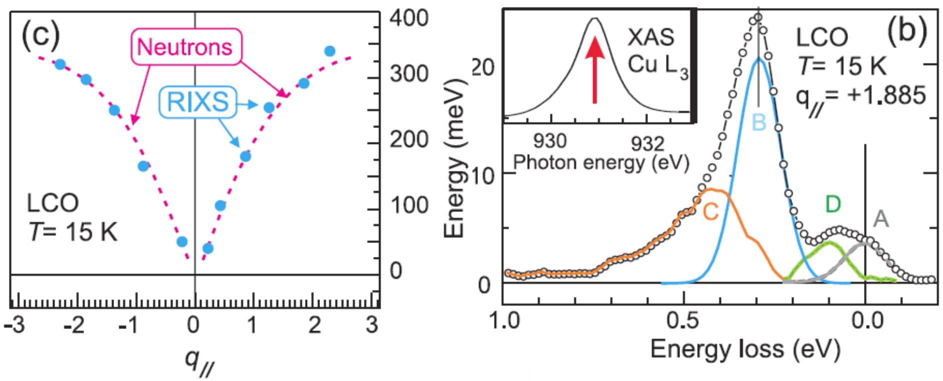




Required: Tailored pump sources, emission spectrometer/detector

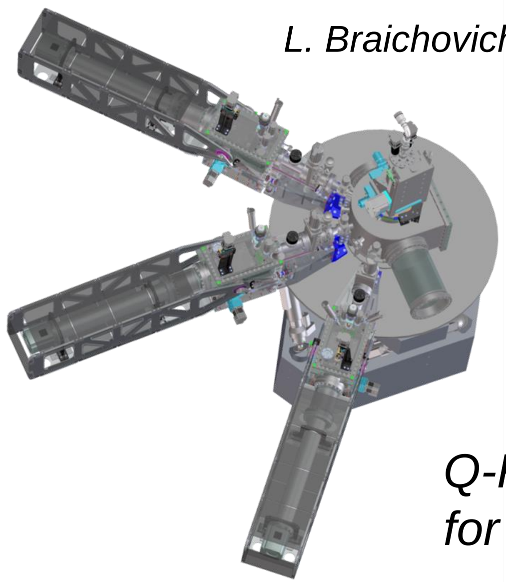
Tracking Bosonic Excitations:
- Resonant Inelastic X-ray Scattering

RIXS probes charge, orbital, lattice and spin excitations

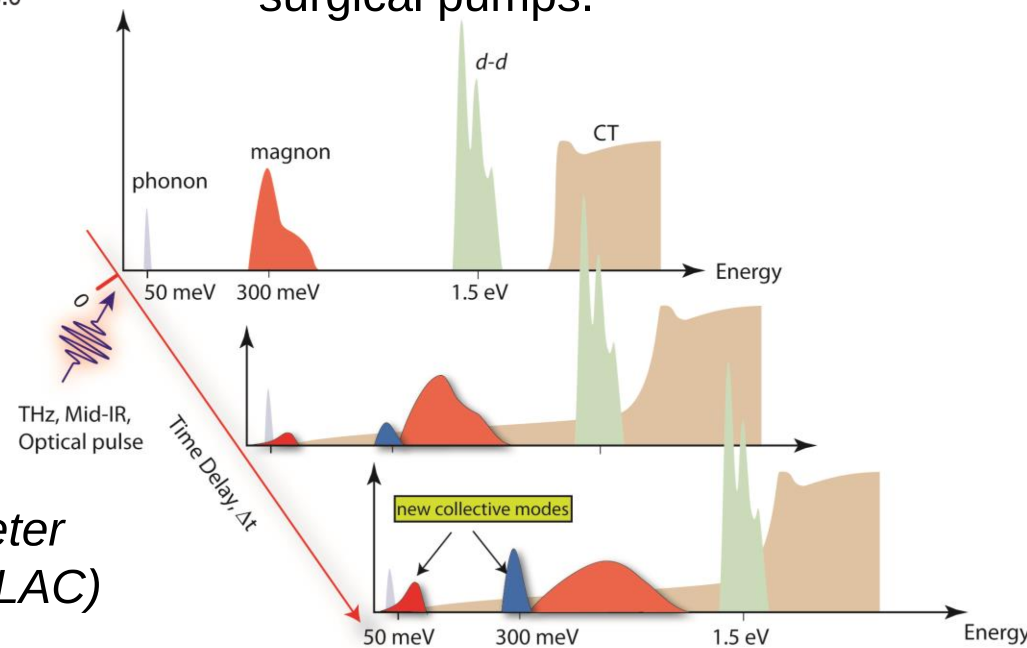


L. Braichovich et al., (SLS/ESRF)

- Emergence of new collective modes as signatures of new states of matter.
- Evolution of elementary excitations when stimulated by surgical pumps.



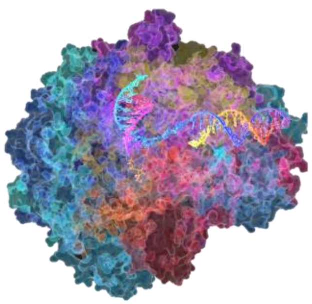
Q-RIXS spectrometer for LCLS (LBNL-SLAC)

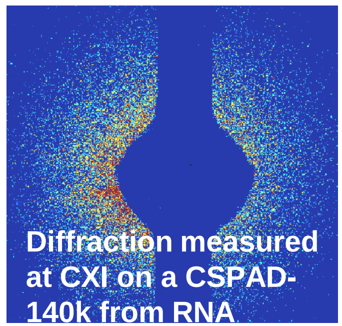


Required: THz pump sources; small pixel, low noise detector

Structural analysis of macromolecular complexes
- Single Particle Imaging

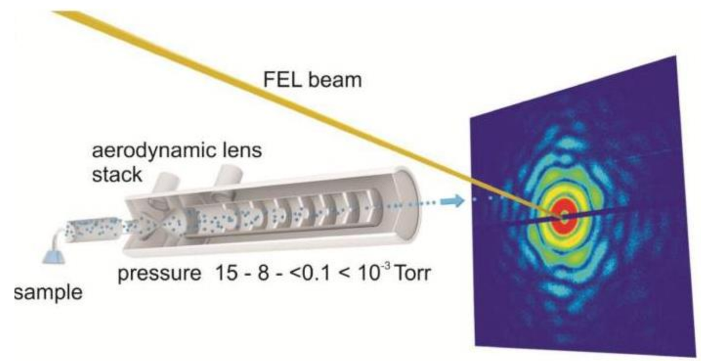
Coherent diffraction imaging using 2-5 keV X-ray



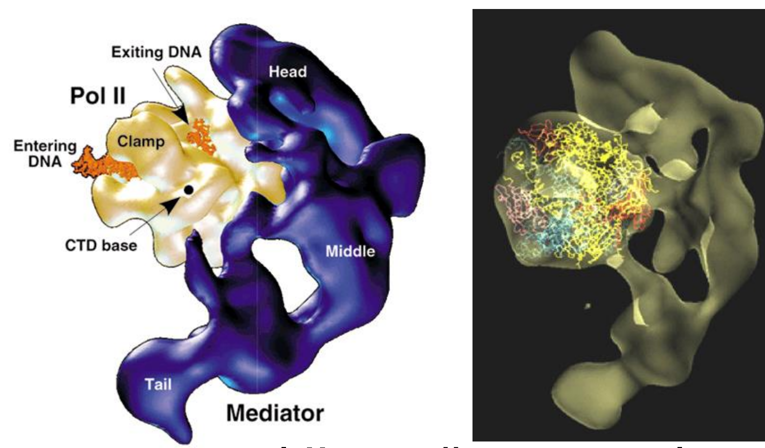


RNA polymerase II complex & RNA polymerase II-mediator complex: critical step in gene expression

J. Hajdu and F. Maia, LCLS experiment L730



Single particle delivery and diffraction data acquisition system LCLS



Pol II−mediator complex

Required: Single particle jet, high rep. rate area detector

Laser Development

Science Target	Pump Laser Needs
Nonadiabatic Molecular Dynamics	• ≥ 100 kHz ; <50 fs pulse duration vis-UV
Tracking Bosonic Excitations	• ≥ 100 kHz ; <200 fs pulse duration THz
Requirements can be met by a scalable laser architecture based on optical parametric chirped pulse amplification (OPCPA) employing commercial kilowatt-class laser modules	

Detectors for imaging experiments

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'Accumulating'

- Detector requires
  - Stable performance
  - Large dynamic range
  - Small pixel size
  - Scalability for large cameras

'Single pulse readout'

- Detector requires
  - Single photon resolution
  - 'Smaller' pixel size (XPCS)
  - Scalability for large cameras
- Data sorting and binning

- The next generation of LCLS detectors are under development
- Leverage investment and expertise within SC and beyond

Summary

- LCLS-II design revised in response to BESAC recommendations
- An Office of Science wide multi-lab collaboration has been formed for the project
- Cost and schedule are under development
- The R&D program will be focused to meet the high repetition rate science needs
- Engage LCLS users and wider scientific community to exploit the extraordinary capabilities of LCLS-II