

X-ray science at Arizona State University CXLS and CXFEL

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Arizona State University

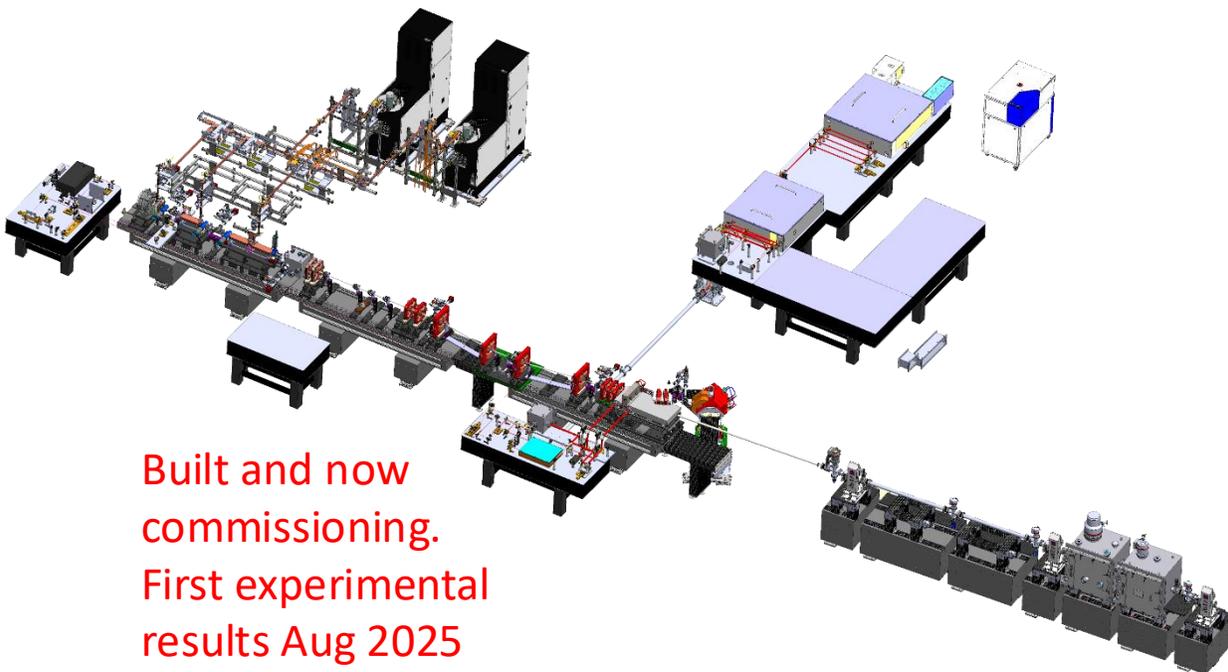


This work supported by the
National Science Foundation grants 2153503, 1935994

A two-phase project to build a compact fully coherent x-ray laser

Compact X-ray Light Source (CXLS)

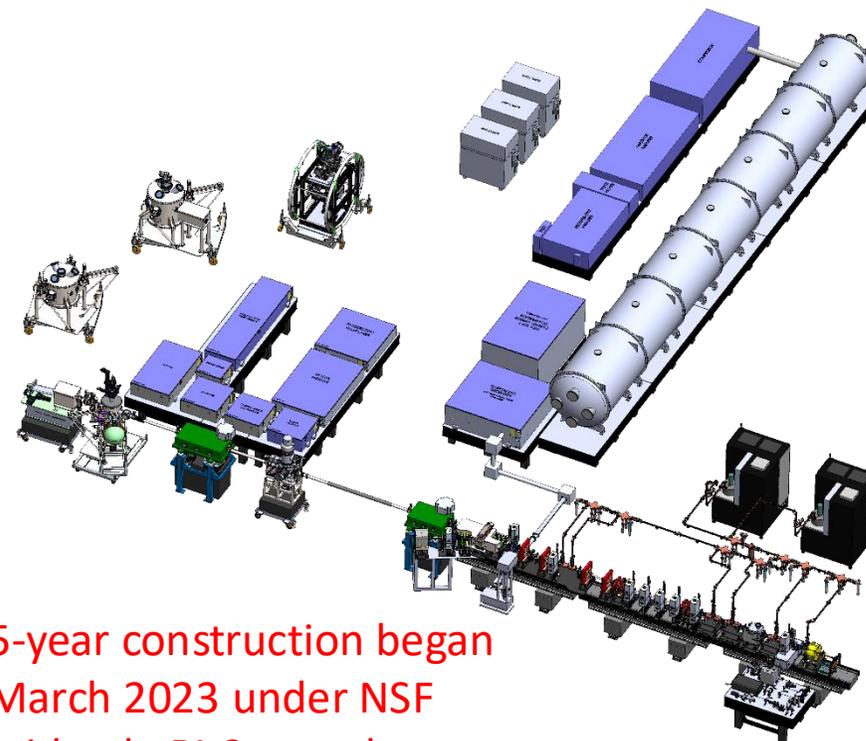
Phase 1 : Hard X-ray ICS Source



Built and now commissioning. First experimental results Aug 2025

Compact X-ray Free Electron Laser (CXFEL)

Phase 2 : Soft X-ray Coherent Laser



5-year construction began March 2023 under NSF midscale RI-2 award

XFELs* worldwide



Why do XFELs need to be so large?

~ 20 mm, $\sim 1,500$ periods = 30 m

$$\lambda_{XFEL} \sim 0.1 \text{ nm} \rightarrow \lambda_{XFEL} = \frac{\lambda_{und}}{2\gamma^2} \left(1 + \frac{K^2}{2} \right)$$

$$\gamma = 25,000 = 12 \text{ GeV}$$

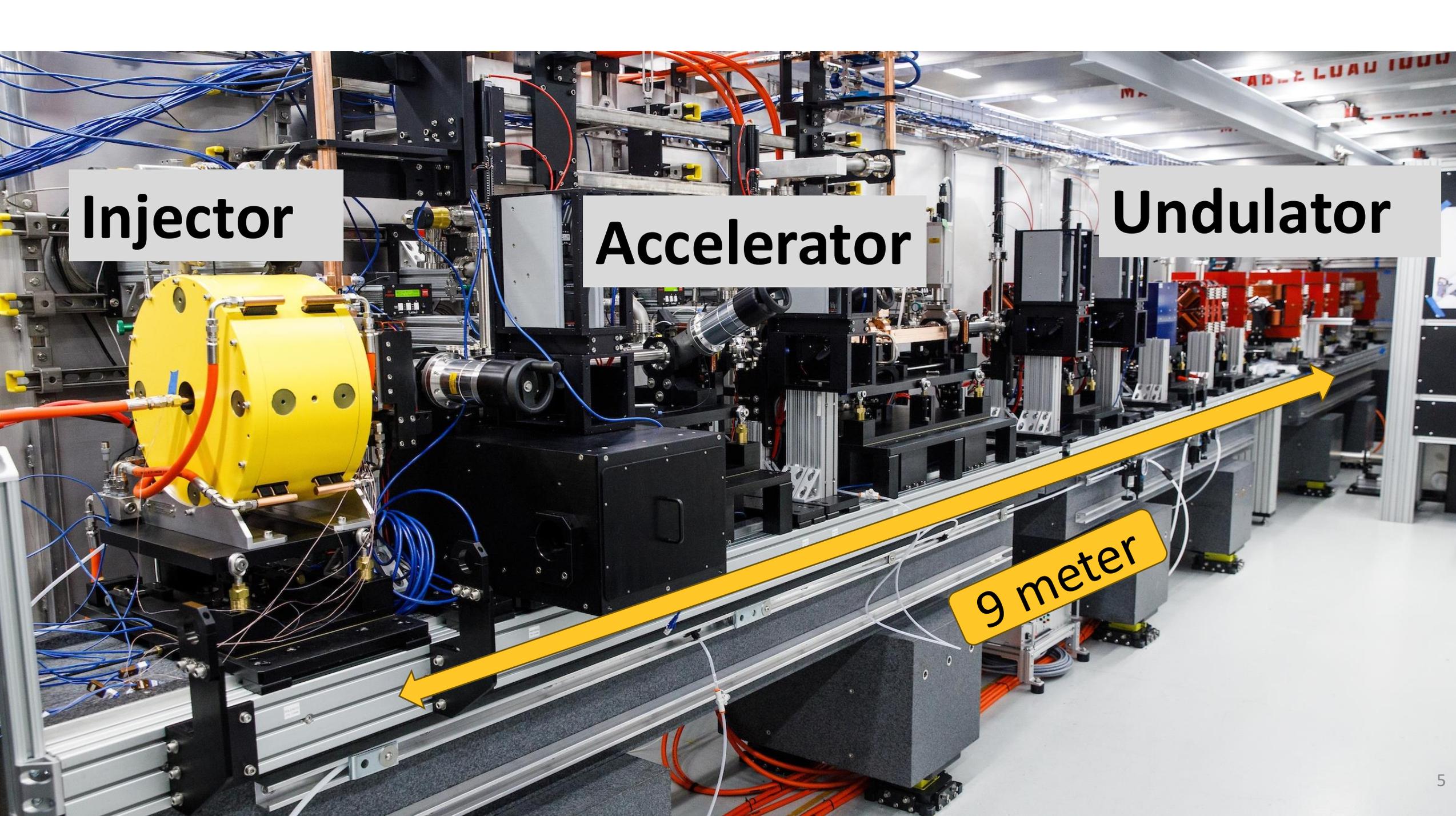
Modern accelerating gradients are ~ 30 MV/m.
Total accelerator length is at least **400 m**, plus
interfaces, optics, injector, etc.

Injector

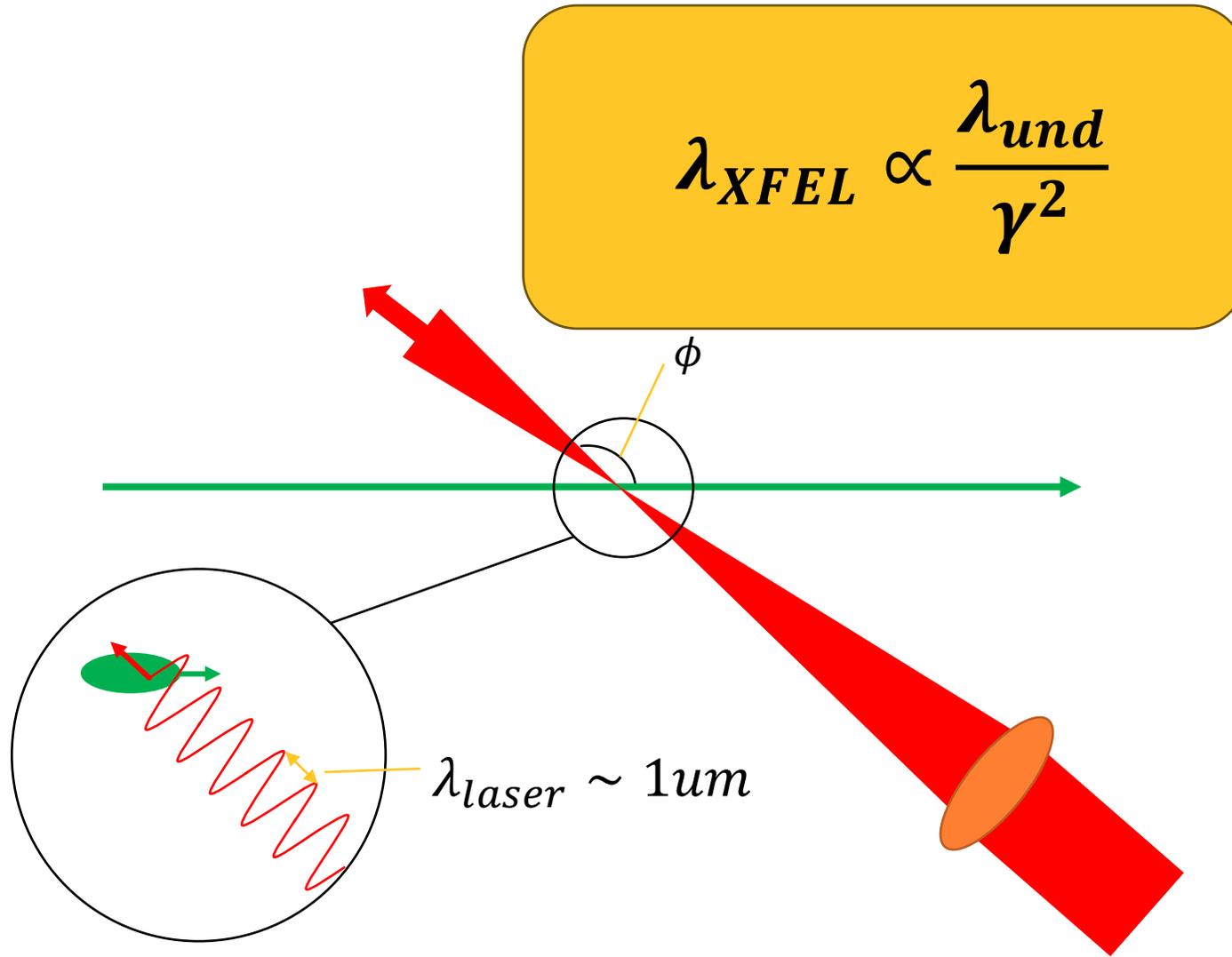
Accelerator

Undulator

9 meter



Laser undulator: Inverse Compton Scattering (ICS)



$$\lambda_{laser} \approx 1\mu m$$

$$E \approx 20 \text{ MeV}$$

X-ray wavelength can be reached
with lower-energy electrons
→ **Compact device (~10m)**

Estimate of Flux

Thompson cross section

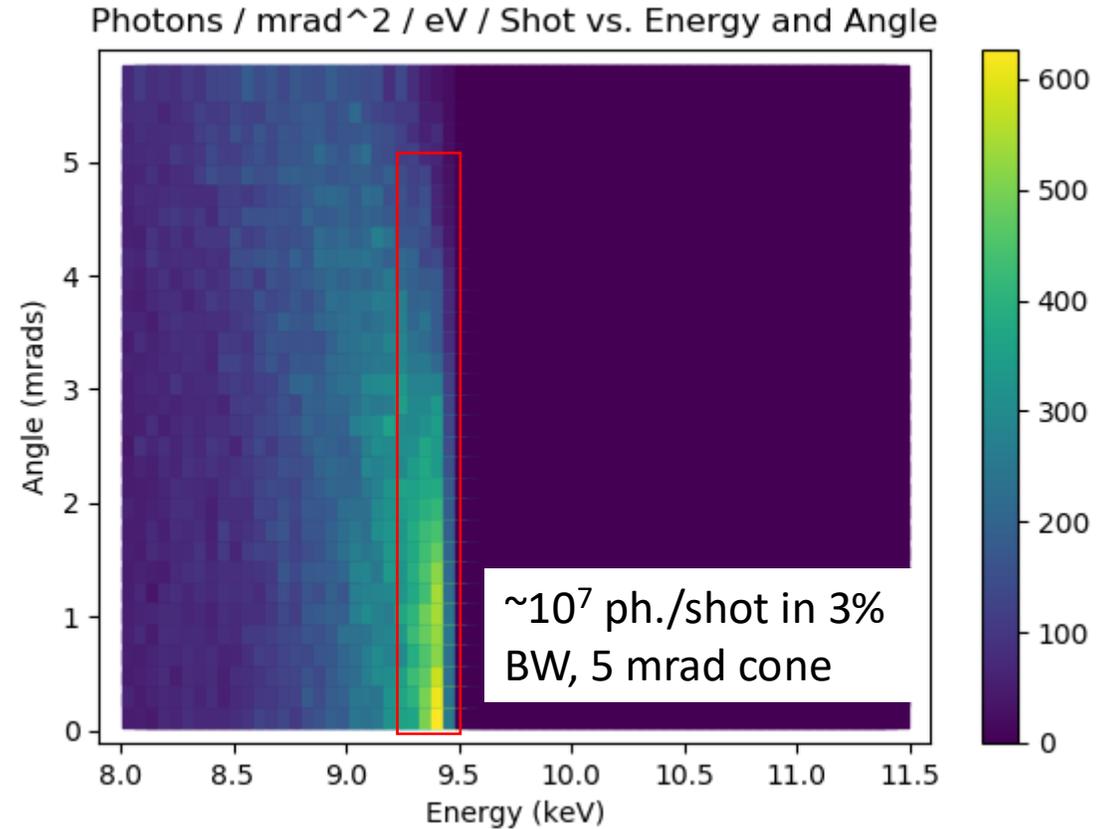
Number of electrons

Number of photons

Interaction area

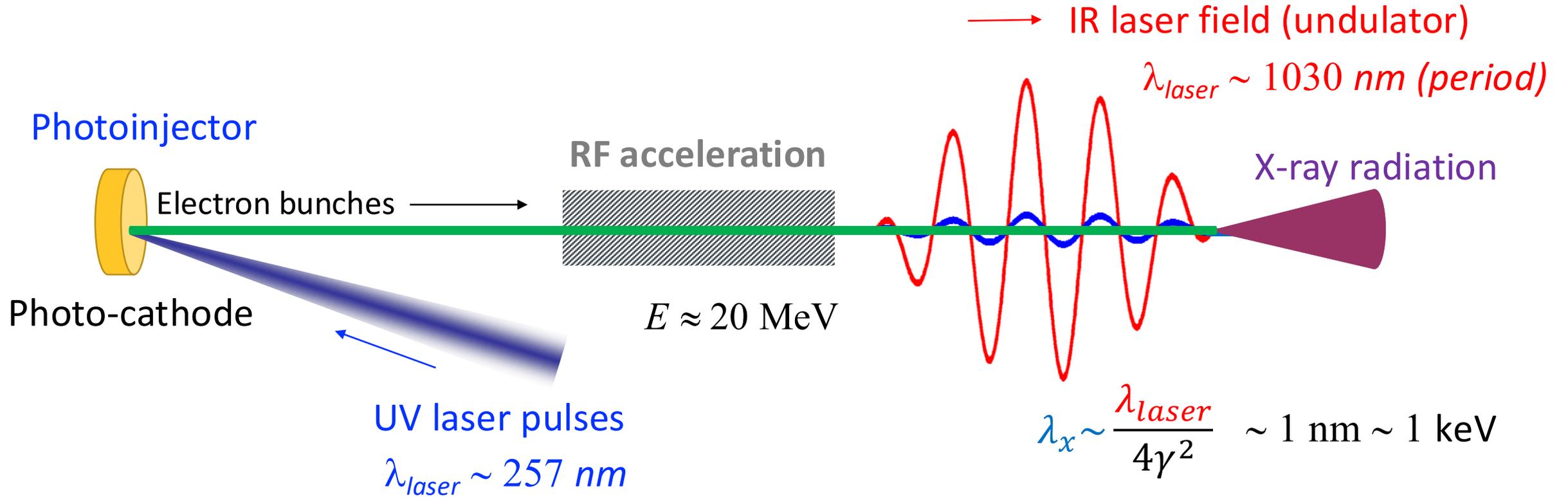
$$N_{ph} \approx \sigma_t \frac{N_e N_l}{\sigma_x \sigma_y}$$

100 pC 200 mJ



$$N_{ph} \approx 10^{-29} m^2 \frac{(6 \times 10^8)(1 \times 10^{18})}{(10 \mu m)^2} \approx 7 \times 10^7 \text{ ph./shot} \approx 7 \times 10^{10} \text{ ph./sec}$$

CXLS Schematic



Inverse Compton Scattering (ICS)

Photons mugging electrons!!

CXLS Overview

RF Power (Klystrons + Modulators)
X-band, 9300 MHz
6 MW for 1 us at 1 kHz
<100 ppm stability

Photoinjector Laser
~200 fs

Photoinjector

X-band linac (ASU)

diagnostics and
matching quads

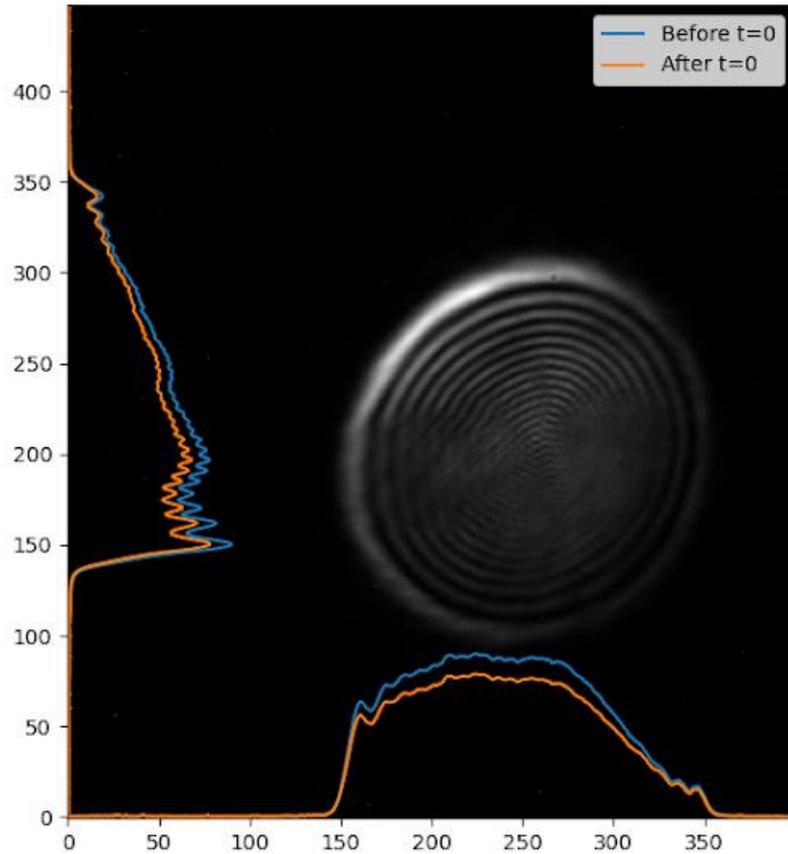
chicane
compressor

Final focus and
interaction
point

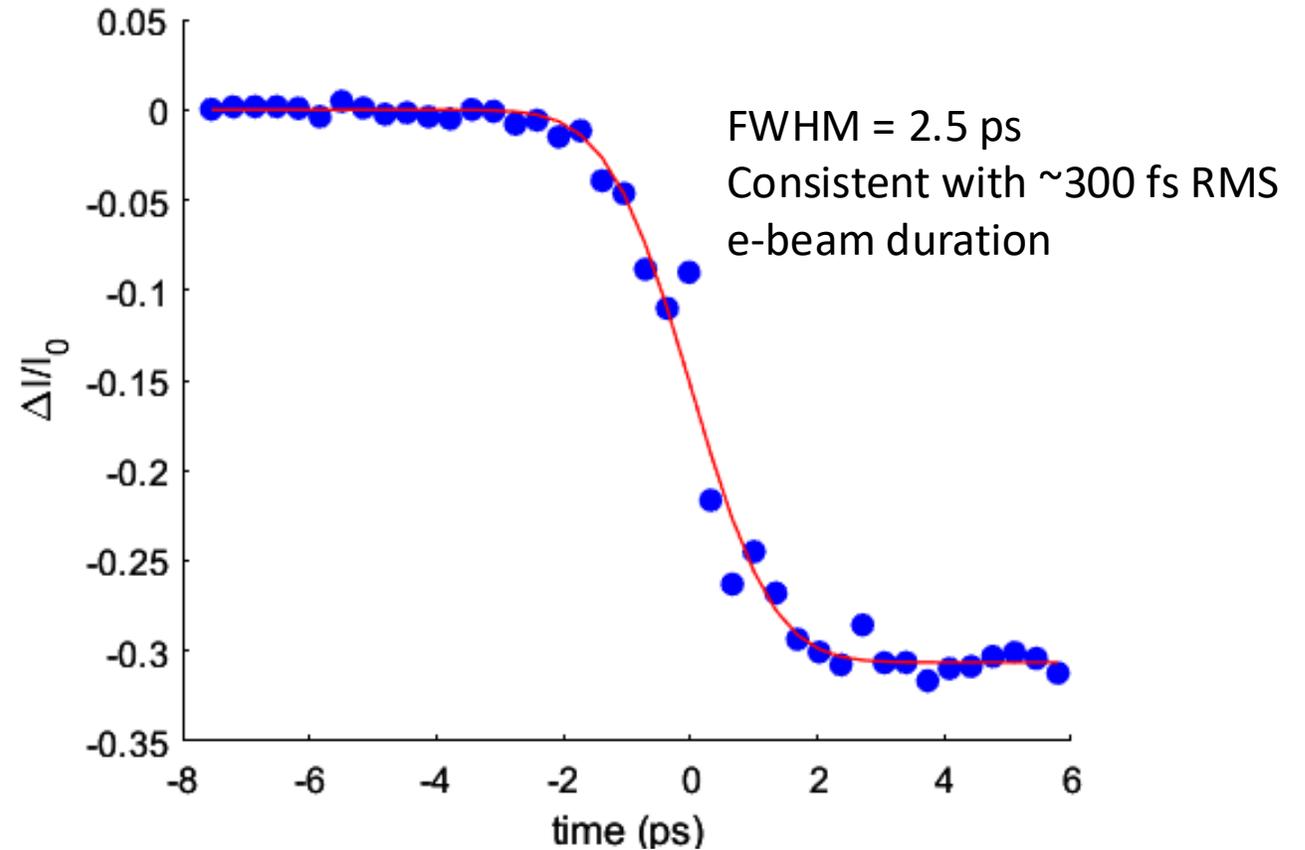
ICS Laser
Yb-YAG Thin-disk
1030 nm
200 mJ/pulse
1.5 ps
1 kHz
 $M^2 > 1.2$

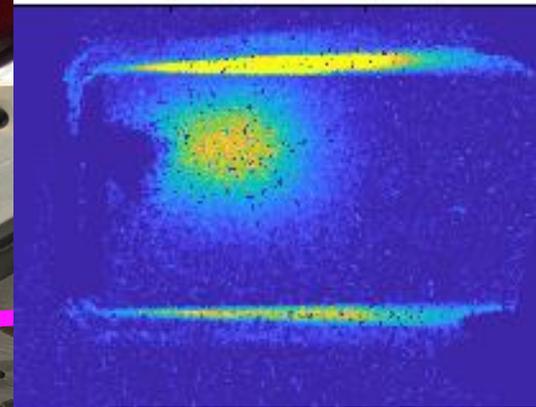
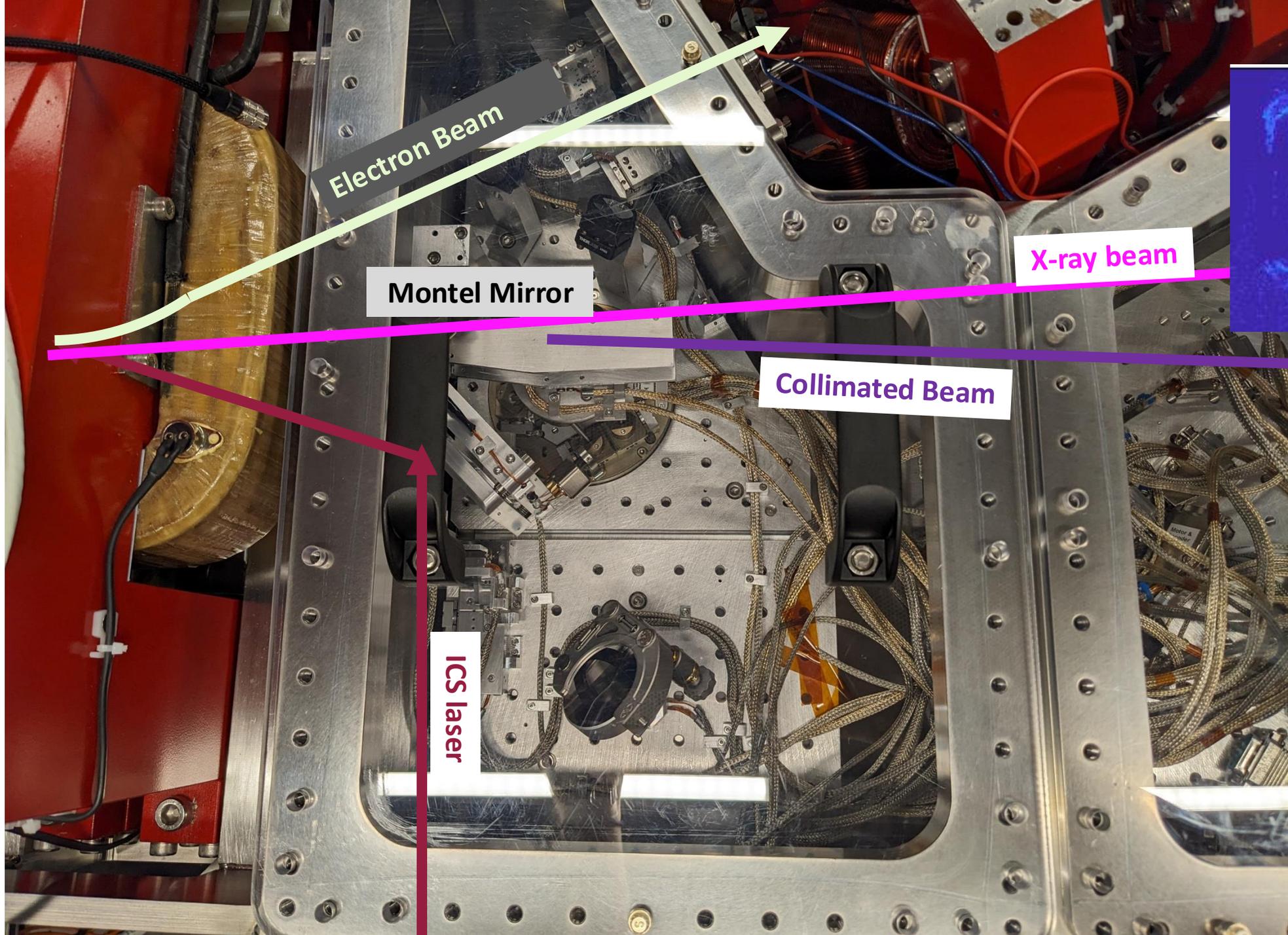
Endstations
~ 10^7 photons/shot
6-17 keV
300 fs
1 kHz

Spatial and Temporal Overlap

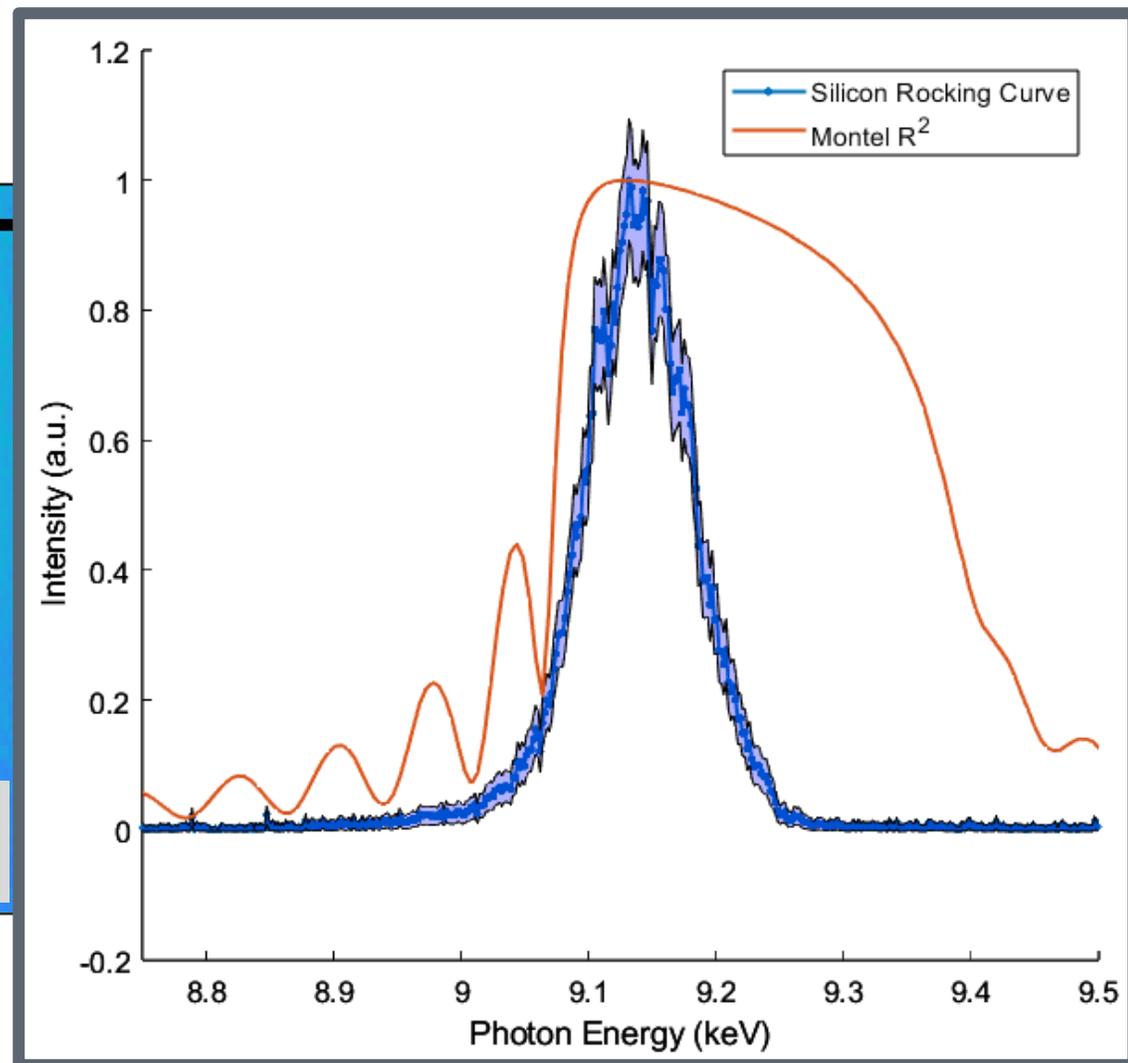
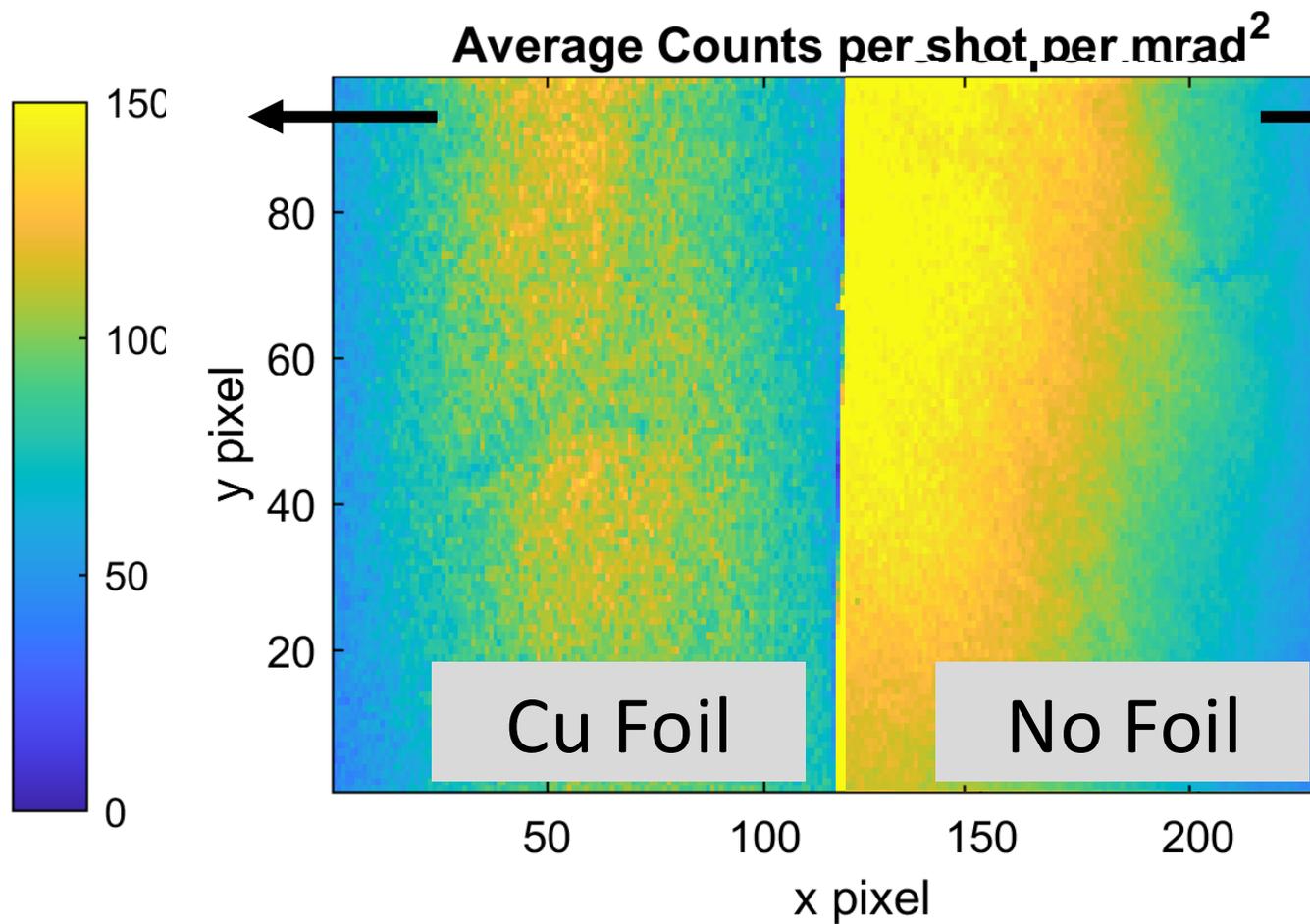


Transient YAG transmission

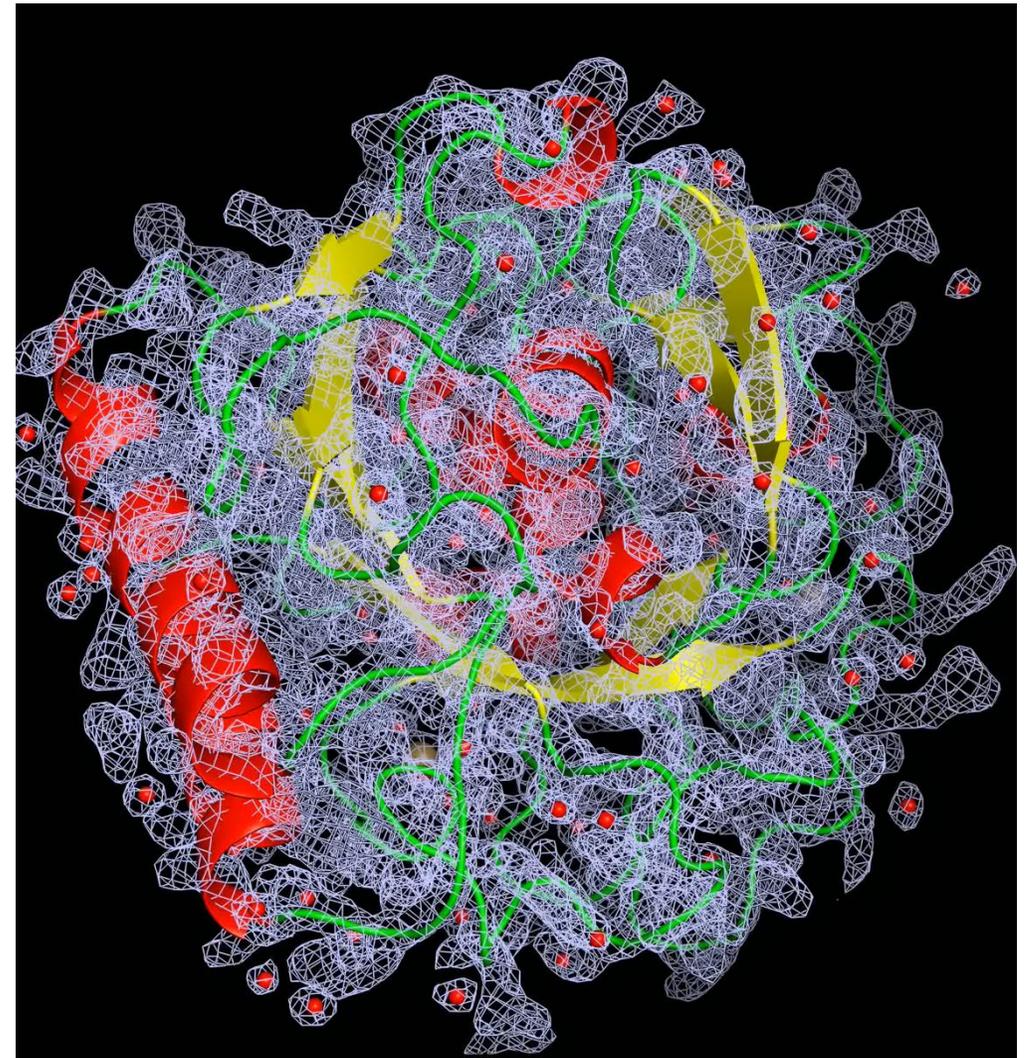
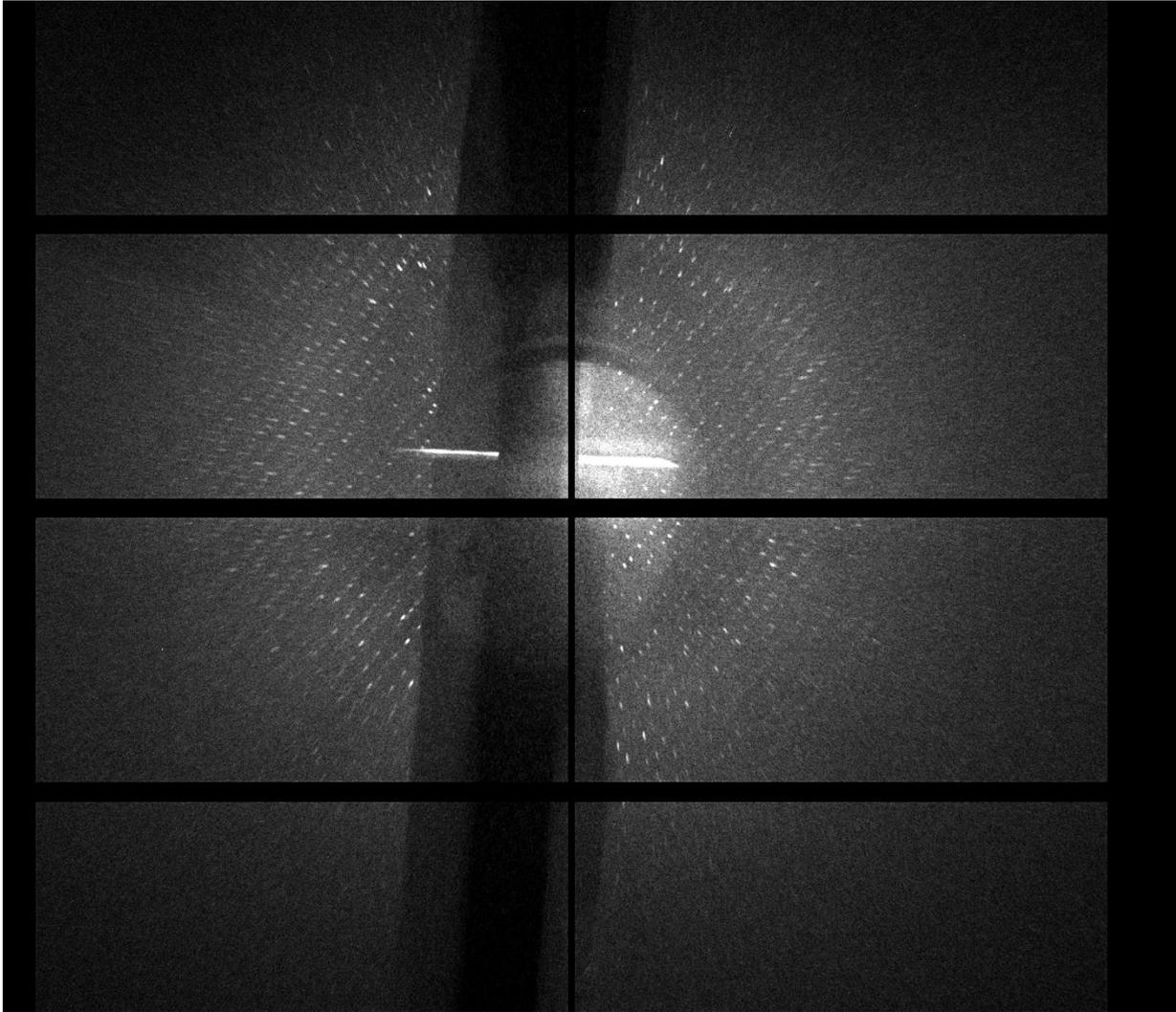




X-ray Results: Validated Flux, Spectrum

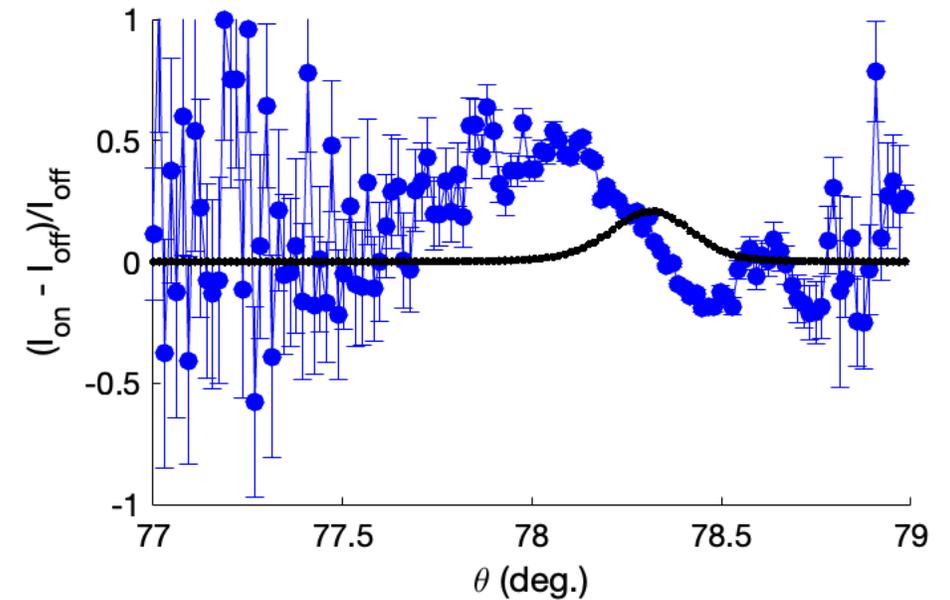
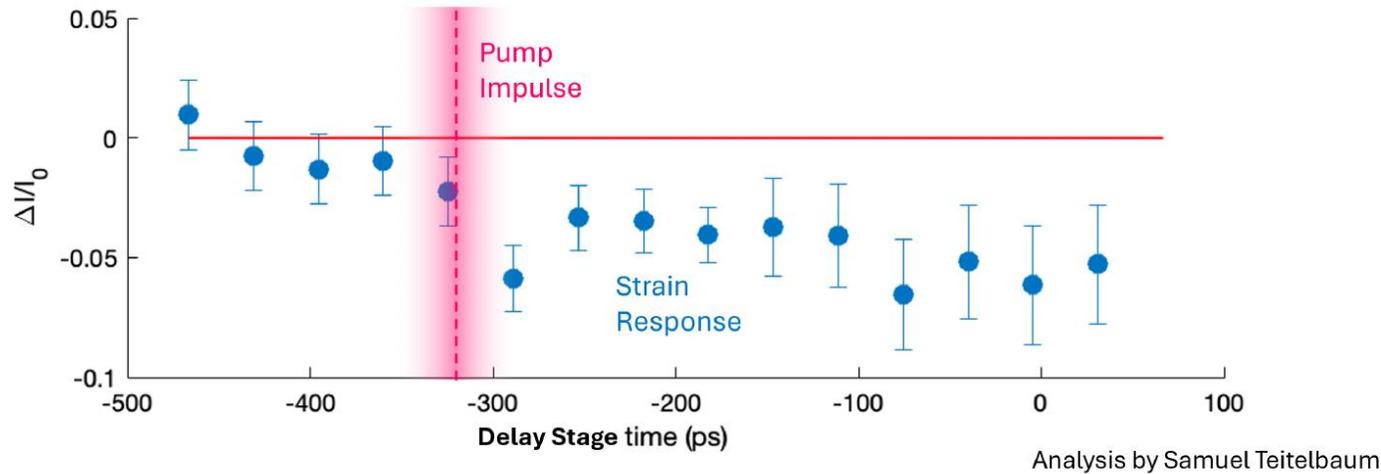
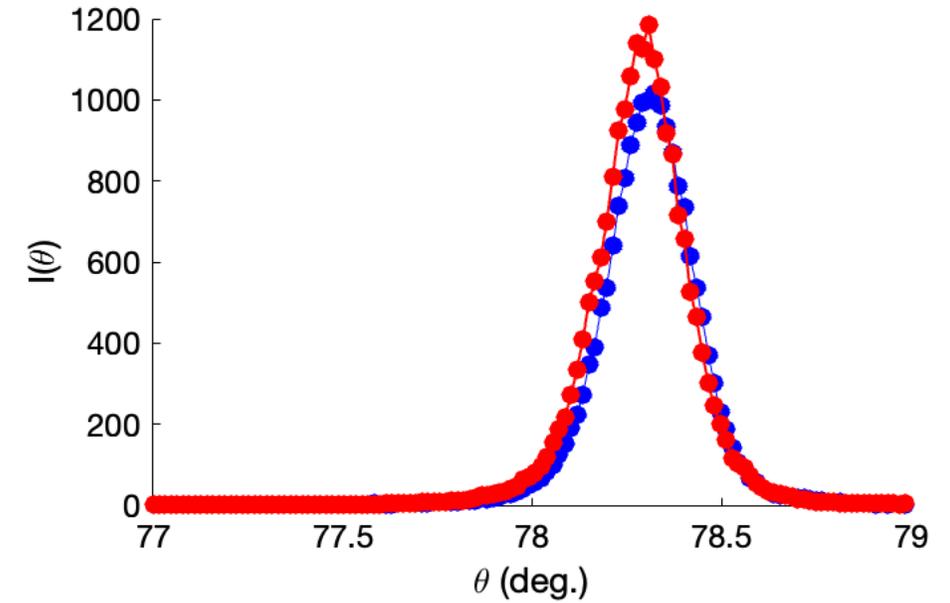


July 2025: First Protein Diffraction (Proteinase K)



Time-resolved X-ray diffraction

Bismuth film pumped by femtosecond laser

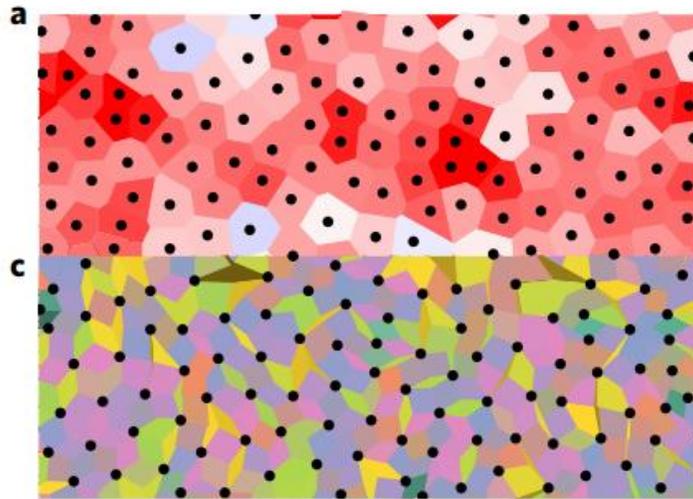


Applications in Material Science

Femtosecond hard x-ray pulses for XRD, Scattering

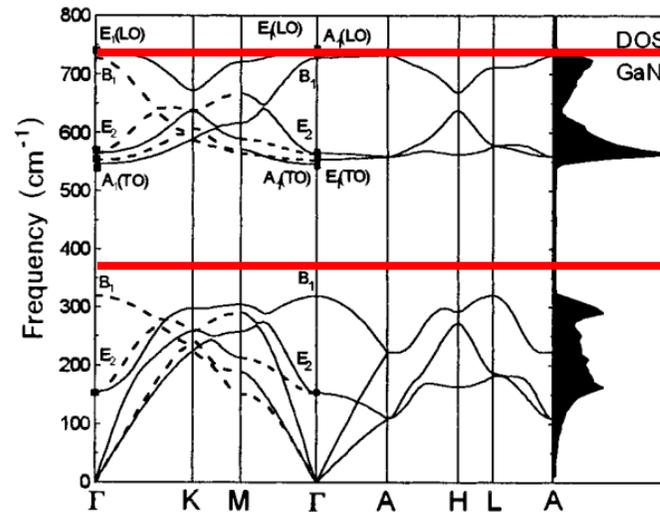
Circular polarization–magnetic materials!

Disorder in correlated quantum systems



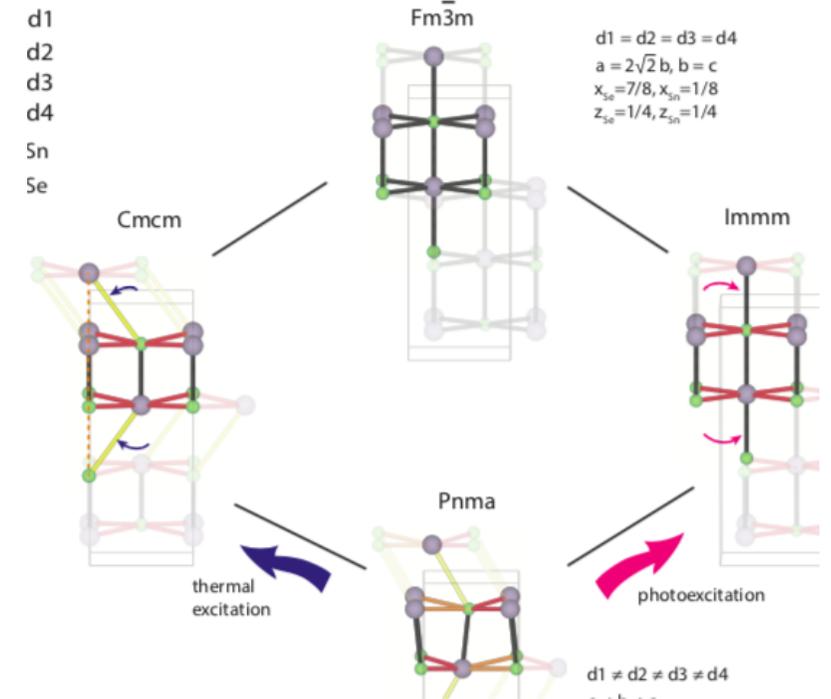
Nat. Mater. 18, 1078–1083 (2019)

Thermal and Electronic transport in semiconductors



PRB 98, 214105 (2018)

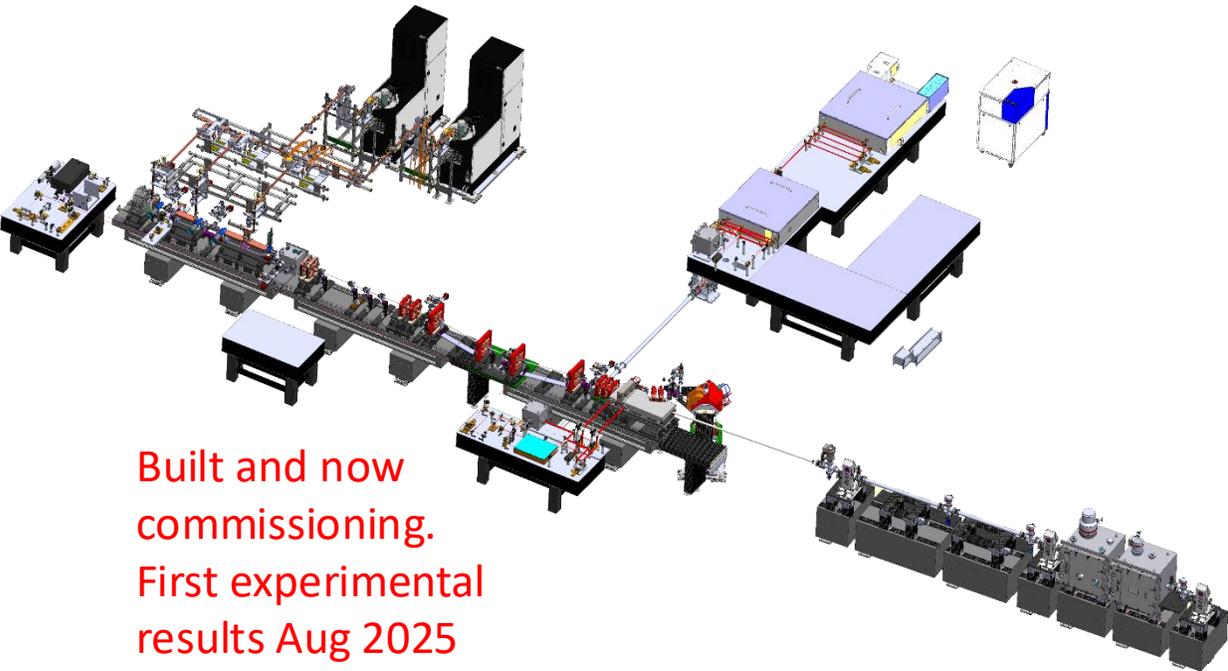
Manipulating phase diagrams and electronic topology



PRX 12, 011029 (2022)

Compact X-ray Light Source (CXLS)

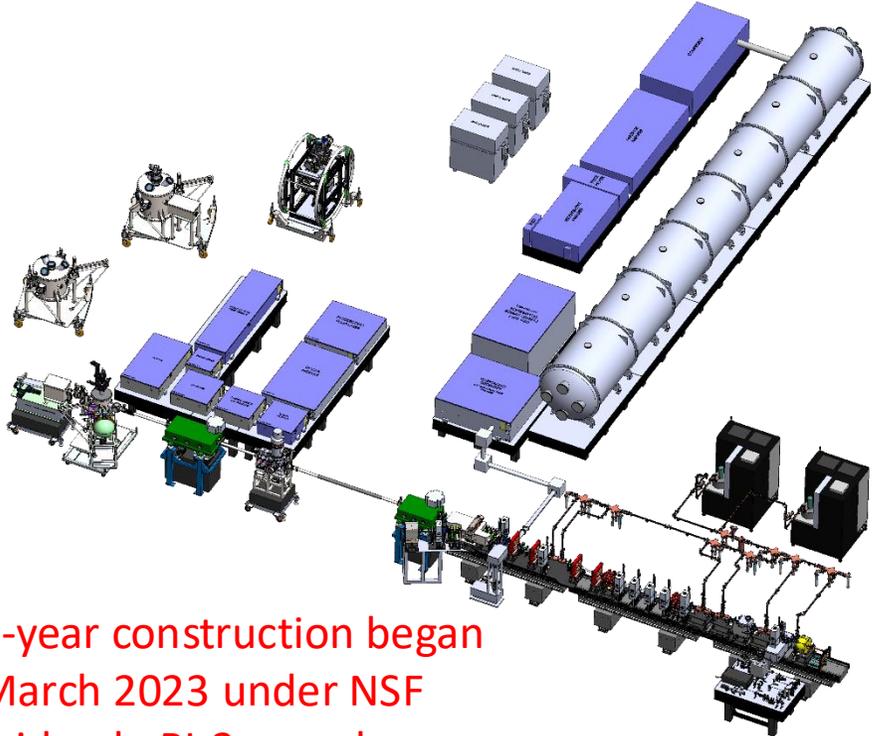
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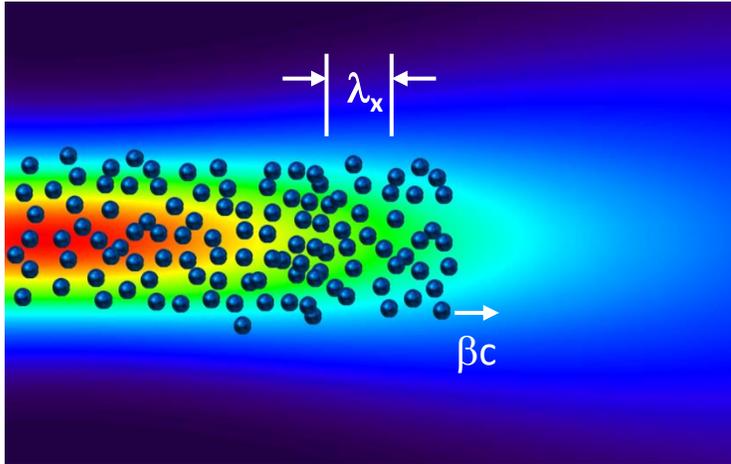
Compact X-ray Free Electron Laser (CXFEL)

Phase 2 : Soft X-ray Coherent Laser

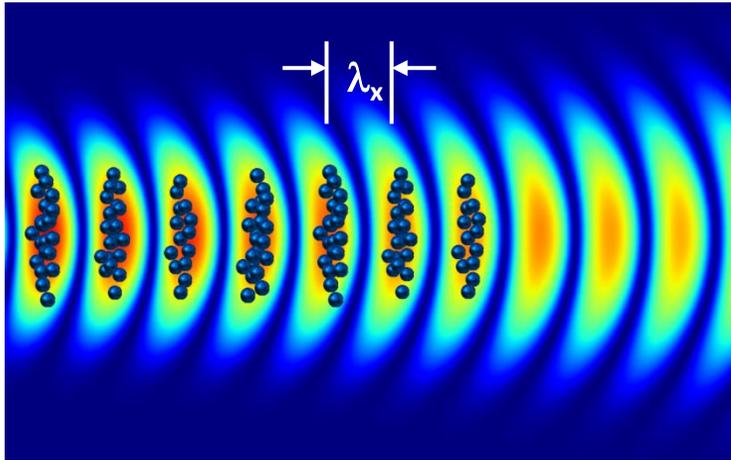


5-year construction began March 2023 under NSF midscale RI-2 award

CXFEL: Coherent x-rays require coherent electron bunching



Random electron positioning for Undulator radiation through Inverse Compton Scattering (ICS)

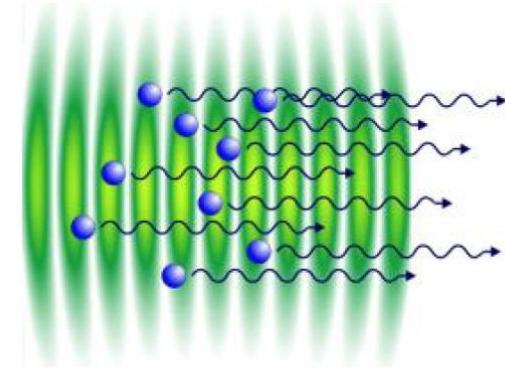


Coherently bunched electrons for **XFEL** radiation through coherent ICS
→ Compact **CXFEL**

$$\lambda_d = \lambda_{x-ray}$$

$$E_{x-ray} = 1 \text{ keV} \quad \lambda_d = 1.24 \text{ nm}$$

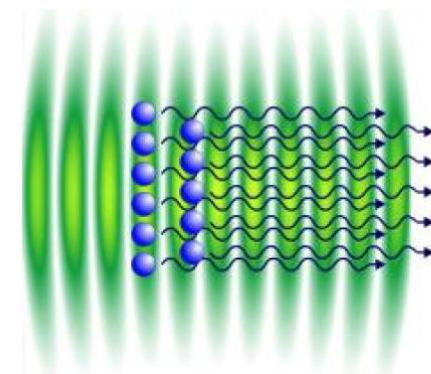
- Randomly distributed electron beam



Regular:

$$I_{x-ray} \sim N$$

- Bunched electron beam

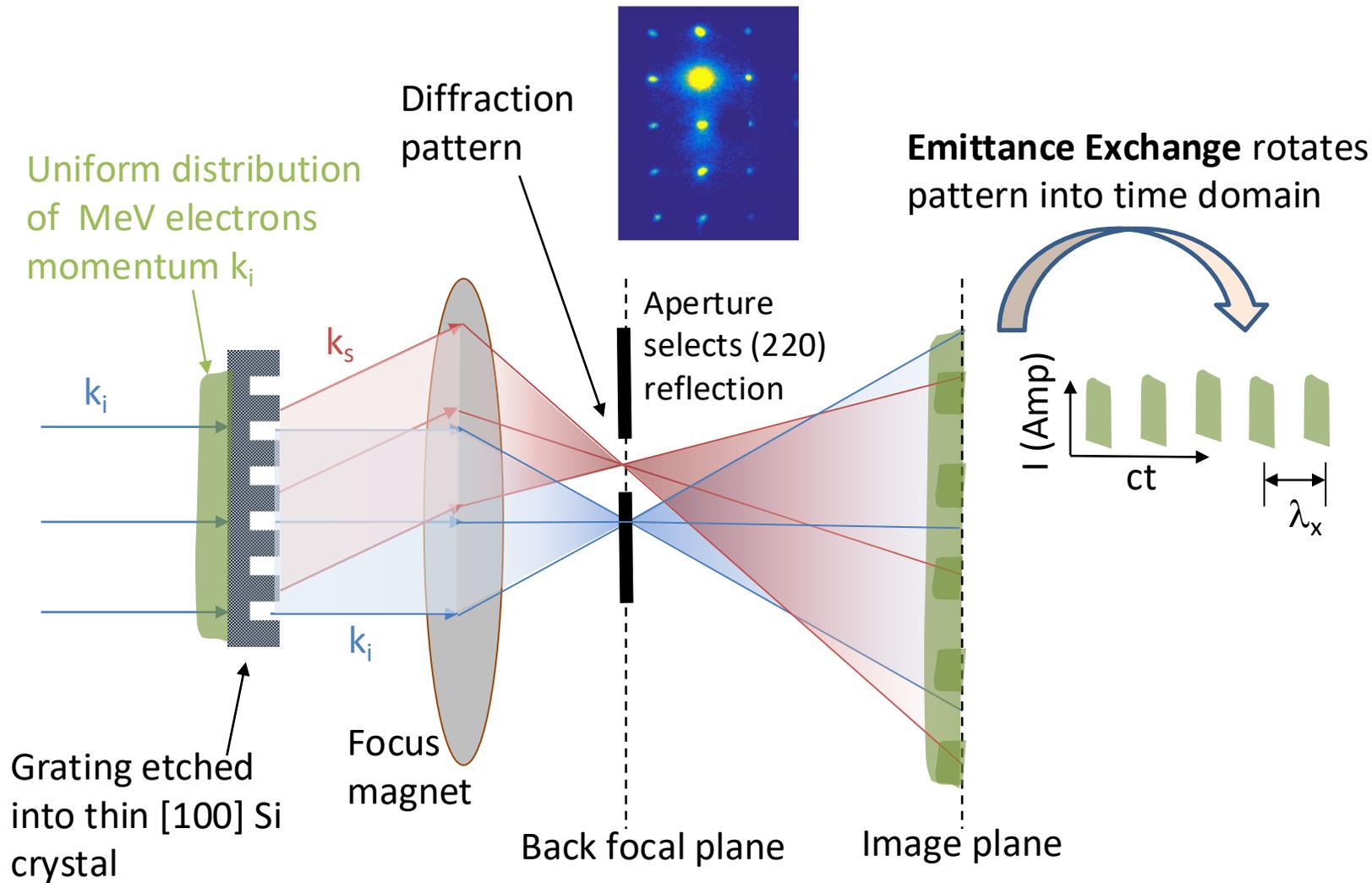


Coherent:

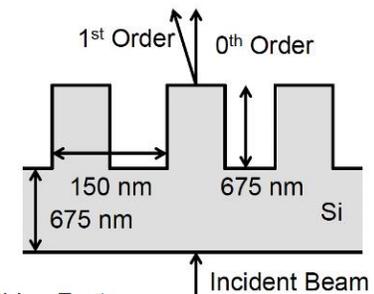
$$I_{x-ray} \sim N^2$$

$$N > 10^6$$

Nanopatterning Electrons via Diffraction

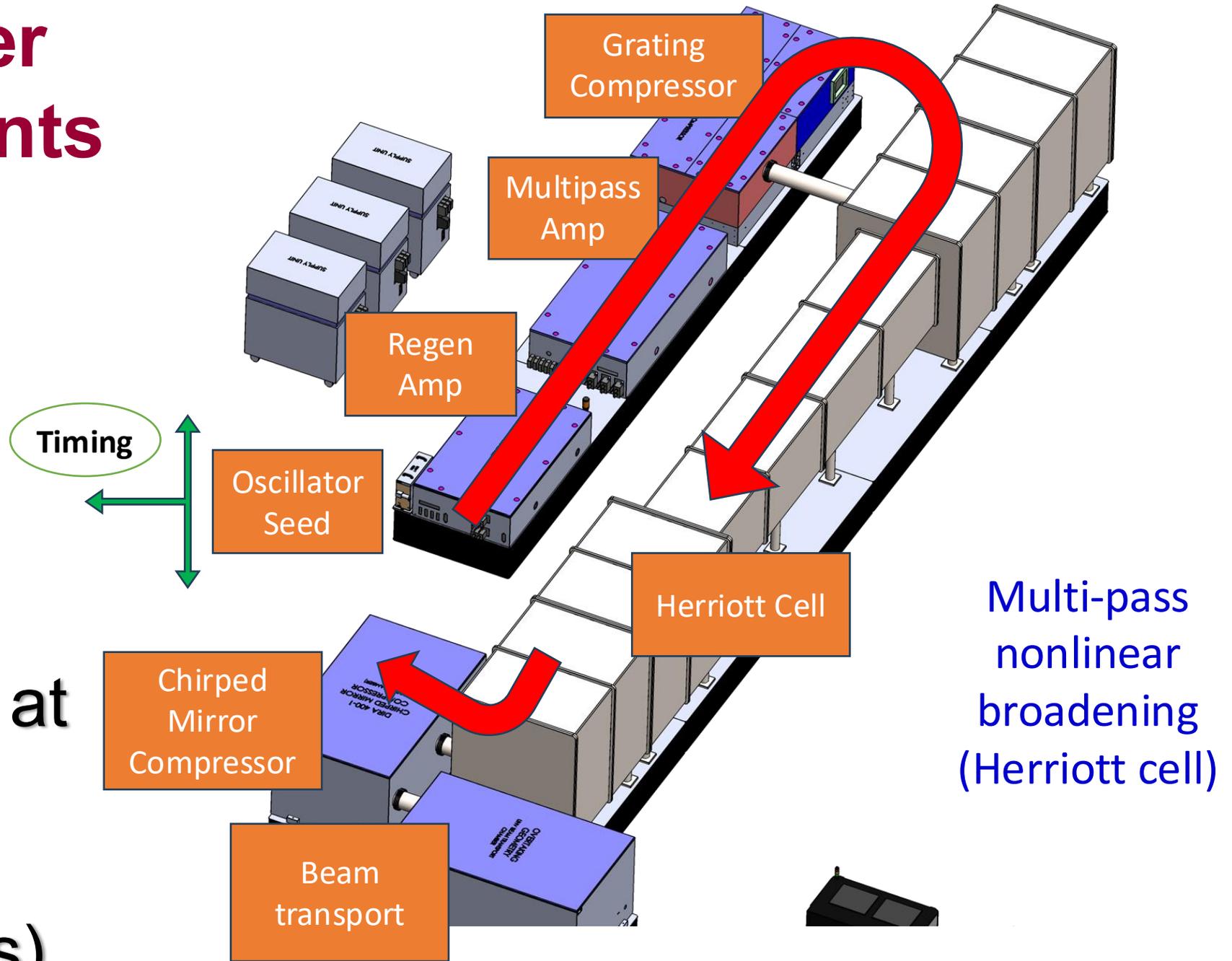


- Tune the modulation spacing of the diffracted beam with patterned Si substrate



Phys. Rev. Acc. Beams **21**, 014401 (2018)

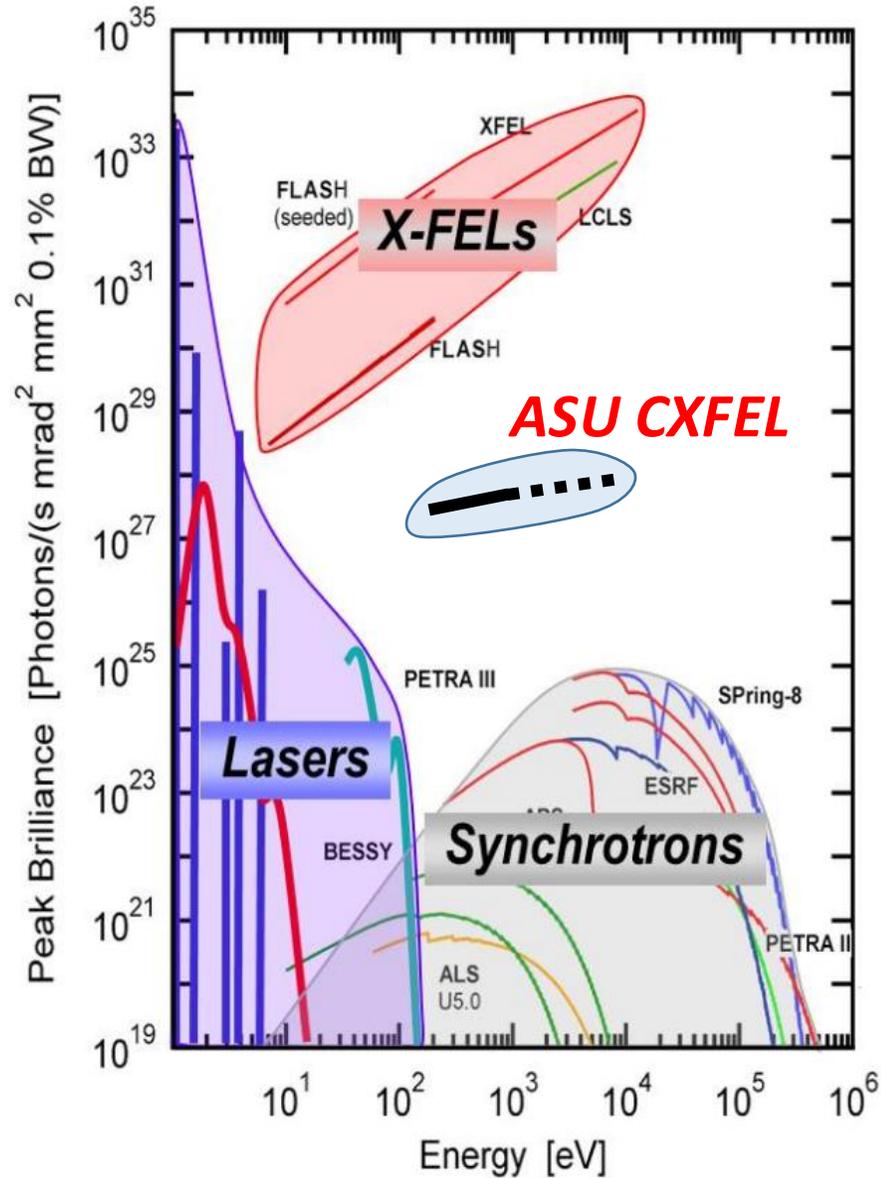
ICS Laser Components



10 TW Pulses at
1 kHz

(500 mJ, 50 fs)

CXFEL Estimated Performance



Full coherence in temporal and transverse dimensions, but lower power than large XFELs.

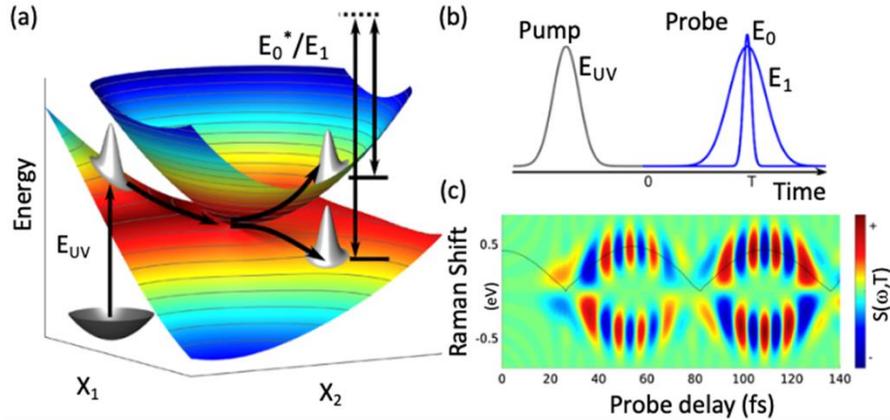
The ASU CXFEL uniquely controls the x-ray phase and amplitude.

CXFEL can seed large XFELs to increase their brilliance X100

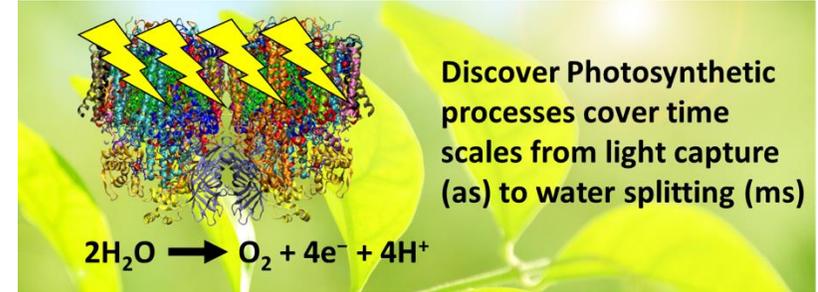
CXFEL and Attosecond Science

AMO: Attosecond charge migration and conical intersections dynamics

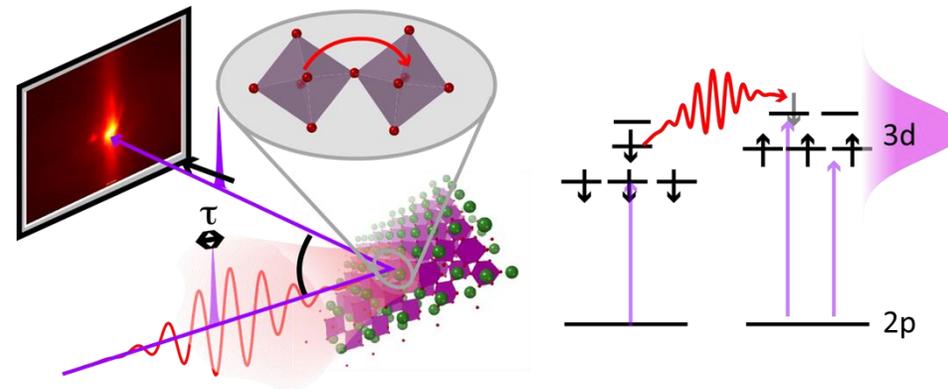
Phys. Rev. Lett. 115, 193003 (2015)



Bio: Study the dynamics of structural, electronic and oxidation changes



QM: Manipulate and track coherences in correlated electron materials



ASU CXFEL TEAM



Bill Graves, Petra Fromme, Sam Teitelbaum, Nicholas Matlis, Sami Tantawi, Robert Kaindl, Arvinder Sandhu
Sabine Botha, Alexandra Ros, Aaron LaForge, Islam Shalaby, Siyang Wang, Adil Ansari
Mark Holl, Deanna Clarke, Engineering team, Graduate students, Undergraduate students