PLEIADES*: An ultra-fast Thomson x-ray Source at LLNL

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* **P**icosecond **L**aser **E**lectron **I**nter-**A**ction for the **D**ynamic **E**valuation of **S**tructures

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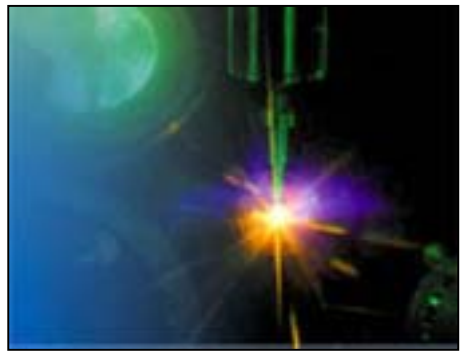
Arthur Kerman (MIT)

* Talk or poster at this workshop

>50 keV & <50 ps is a unique regime

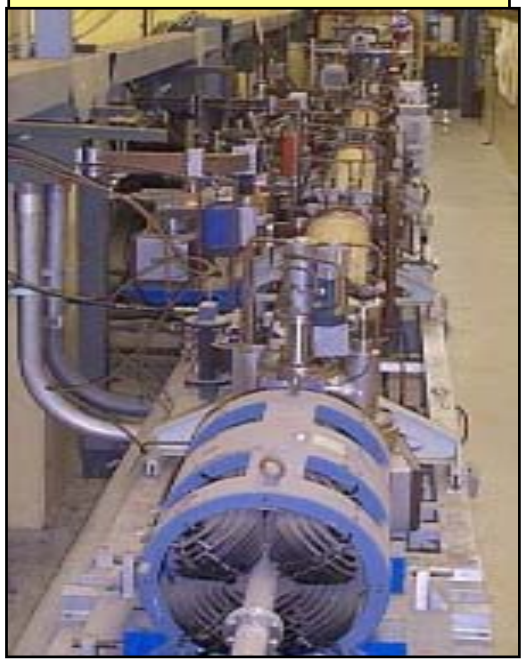
- 3rd-Generation: < 50 keV, > 50 ps
- LCLS: max. energy 24 keV
- K-α: energy limit ~ 100 keV, 4π



- PLEIADES: has already established very high brightness at 140 keV, fs hard x-rays and radiography studies >100 keV

PLEIADES combines a 120 MeV rf linac, photoinjector and two laser systems

120 MeV S-band RF Linac



UV Photoinjector Laser
350 μJ, 5 ps on cathode

10 TW, 55 fs
Ti:S FALCON Laser

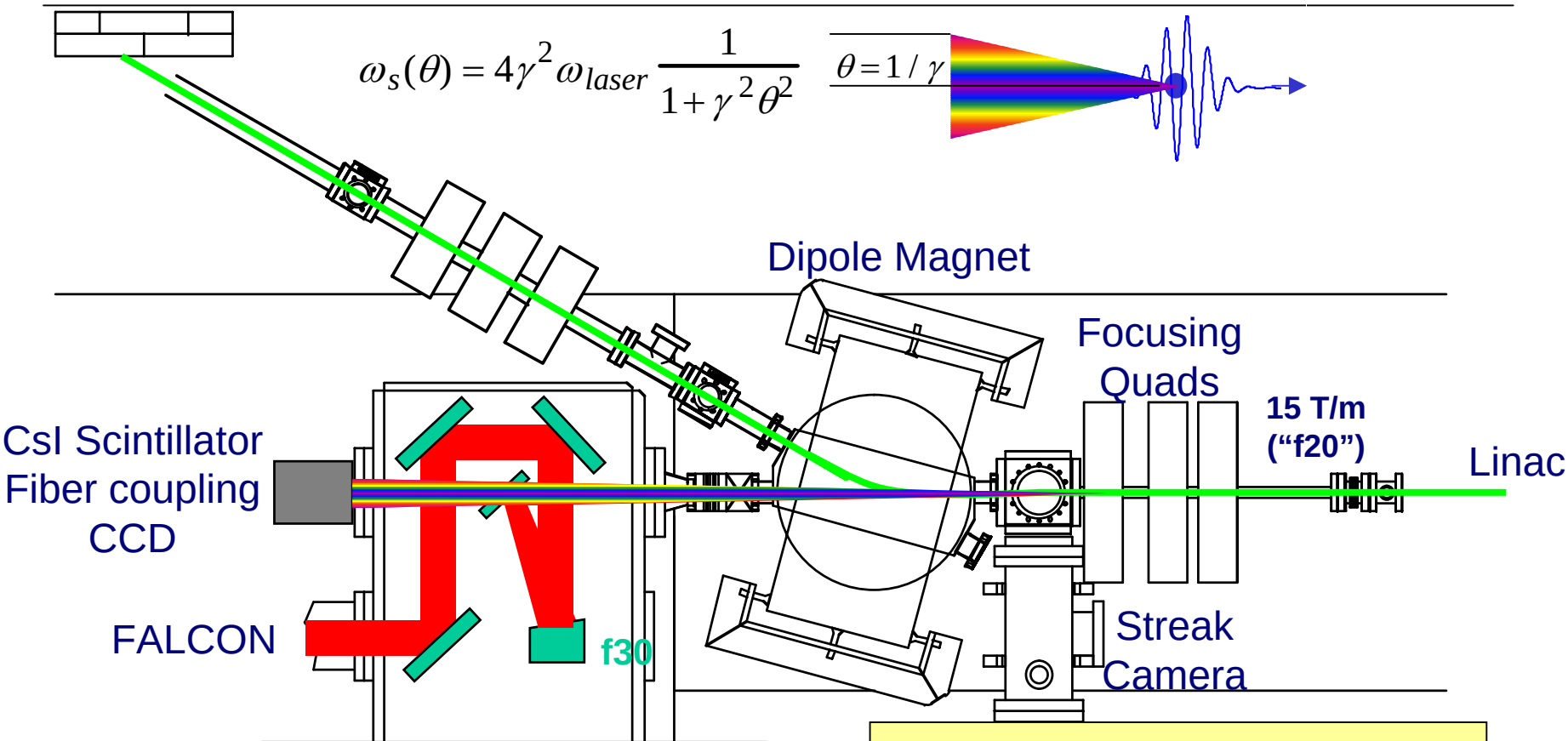
RF Photoinjector

All of these components must be synchronized to picosecond accuracy to maximize x-rays production

180^0 Compton interaction region -Overlap the e-beam with the FALCON laser

$$\omega_s(\theta) = 4\gamma^2 \omega_{laser} \frac{1}{1+\gamma^2\theta^2}$$

$\theta = 1/\gamma$



FALCON Laser Parameters
❑ $\sigma_x \approx 18\ \mu m$
❑ Energy ≈ 500 mJ
❑ Pulse length ≈ 55 fs

Electron Beam
❑ $\sigma_x \approx 35\ \mu m$ (w/ PMQ <20 μm)
❑ Energy = 71 MeV
❑ Charge = 250 pC

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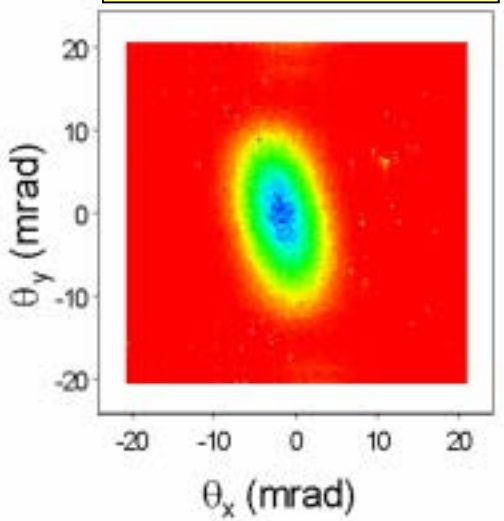
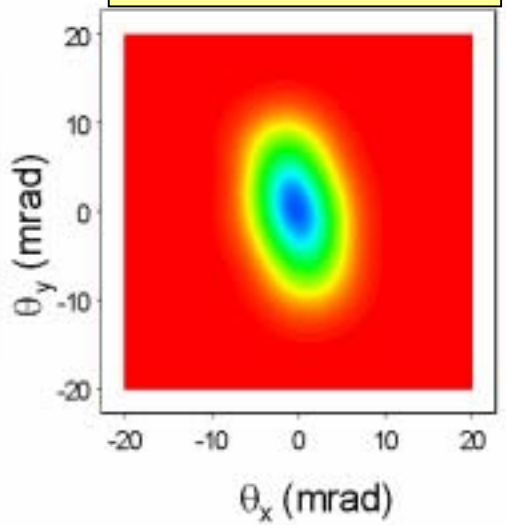
Measured x-rays agree well with simulation

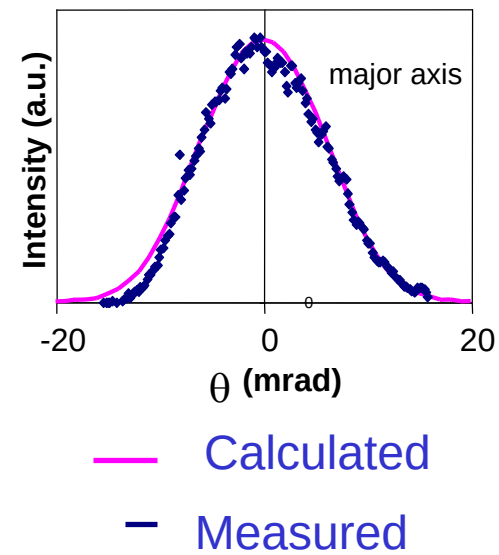
Measured Profile



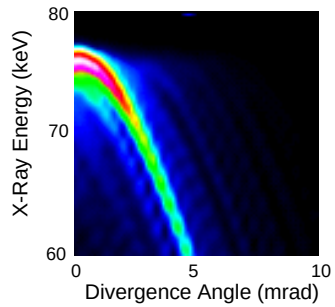
Calculated Profile



Comparison to Measurement



Simulated Spectral Dependence on Divergence



$E_{peak,x\text{-}ray} = 78$ keV

Consider the transmission of the x-rays and the sensitivity of detection

$B_x > 10^{16}$ photons/s/mm^2/mrad^2/.1%bw

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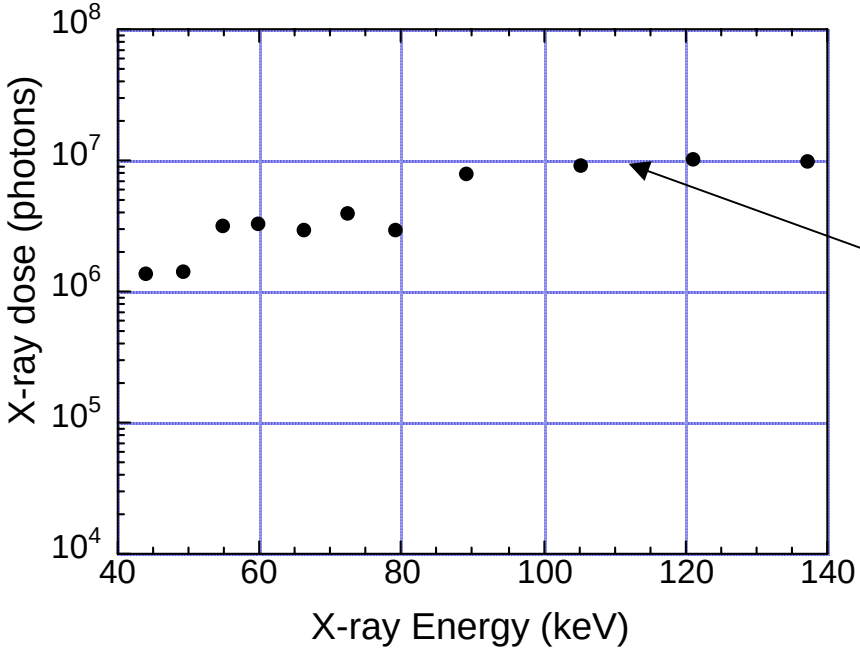
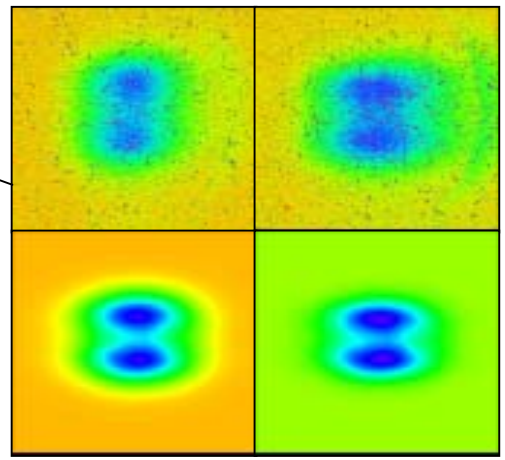
Currently produced LLNL x-ray parameters

Measured x-ray flux vs. energy



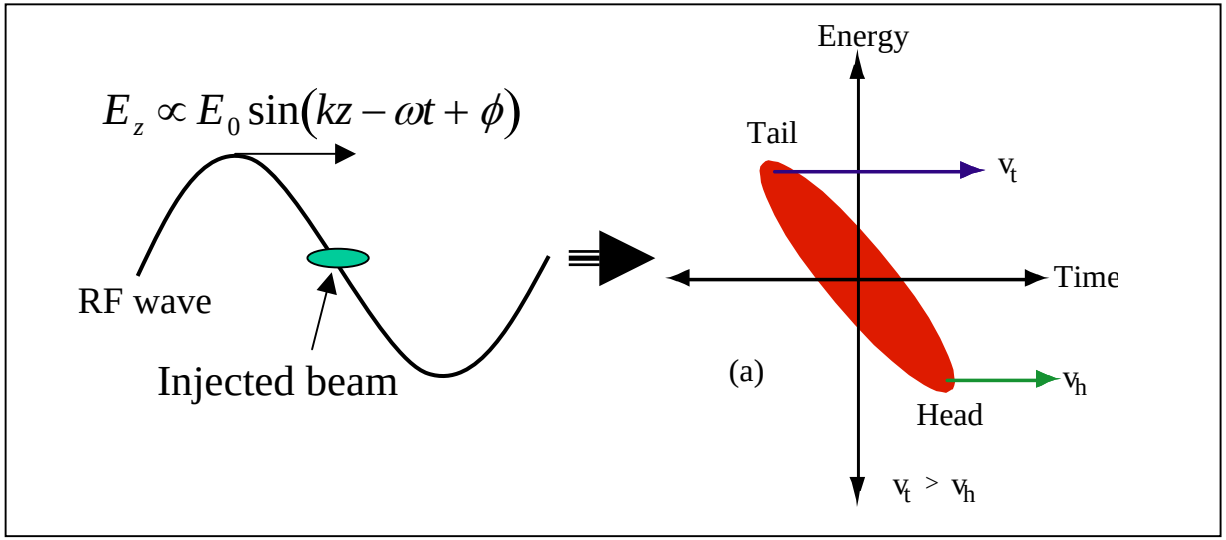
Uranium K-edge at 116 keV

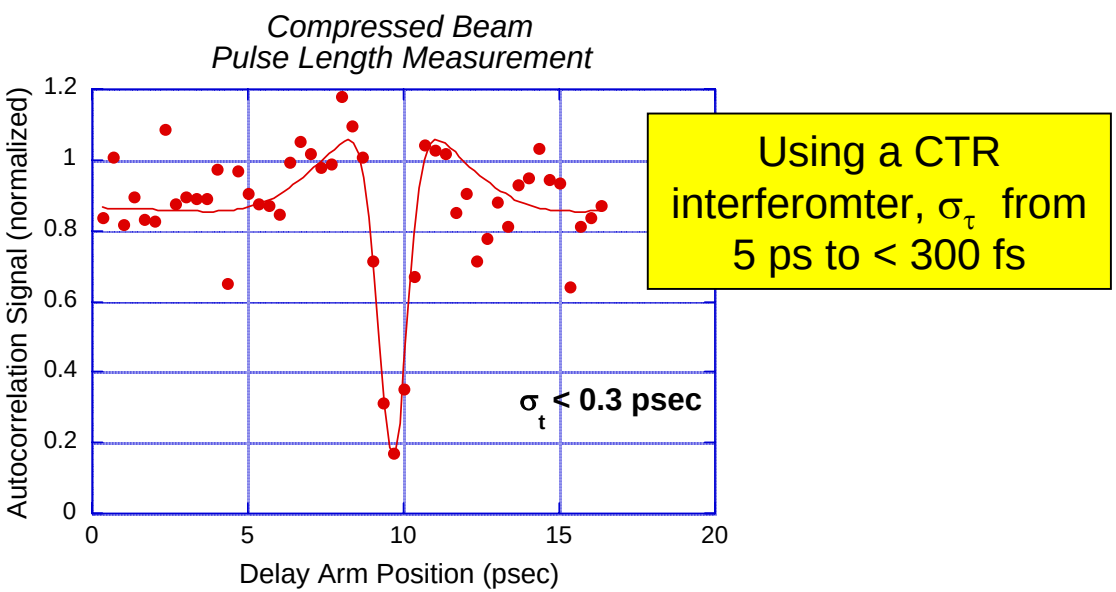


Currently produced LLNL X-ray parameters

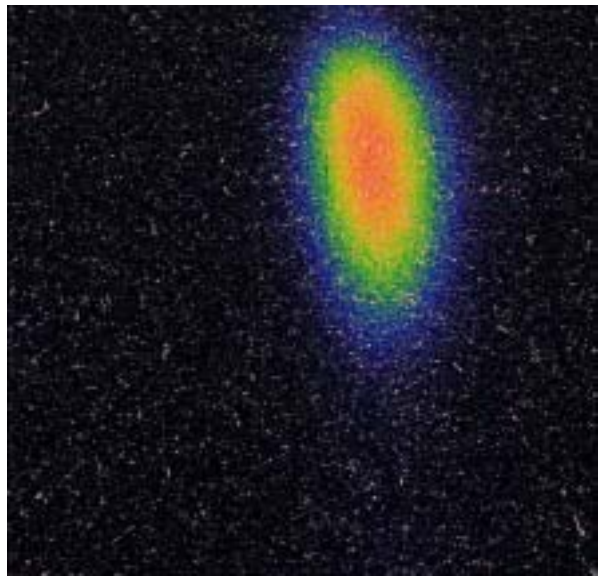
- **Tunable 40 - 140 keV**
- **Short pulse, .3-5 ps**
- **Well collimated (<10mrad)**
- **Reasonably narrow bandwidth ($\Delta\lambda/\lambda$~ 10%)**

Velocity compression in the linac has further increased the x-ray brightness





<300 femtosecond, 78 keV x-ray pulse



~1.5 times brighter than uncompressed x-ray beam

$$B = \frac{N_\gamma}{(2\pi)^{5/2}\sigma_t \sigma_x^2 \sigma_y^2 \sigma_{x'} \sigma_{x'} BW}$$

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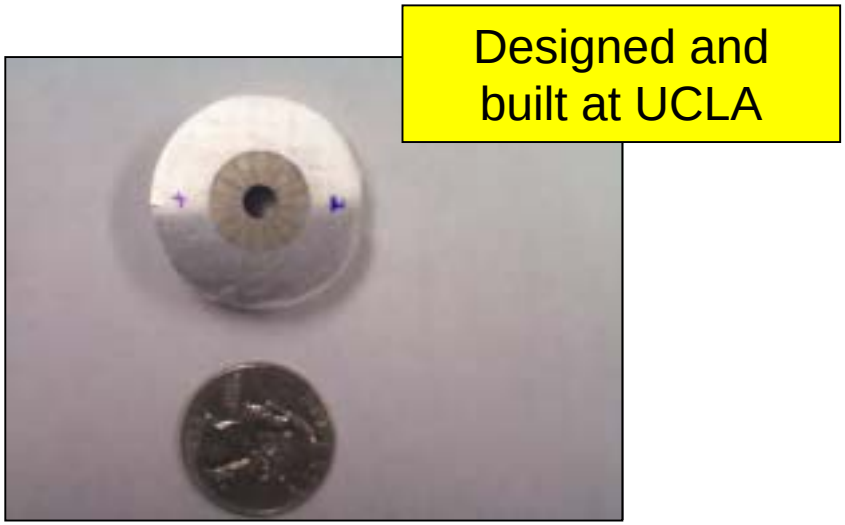
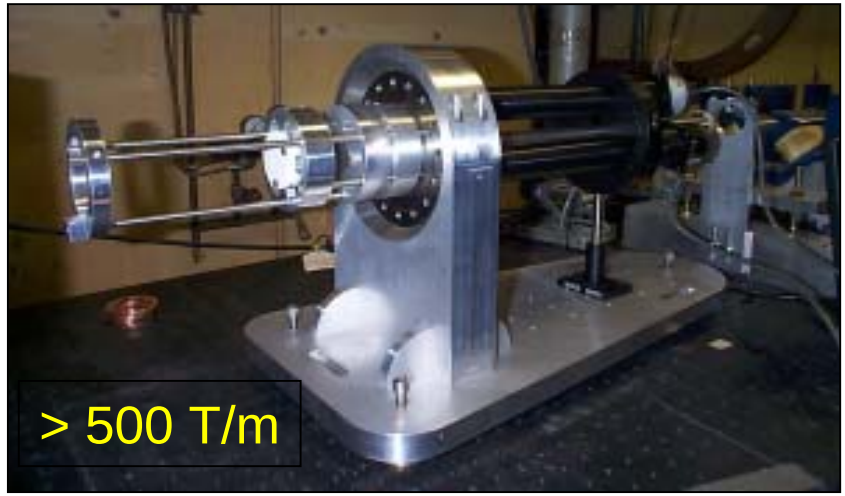
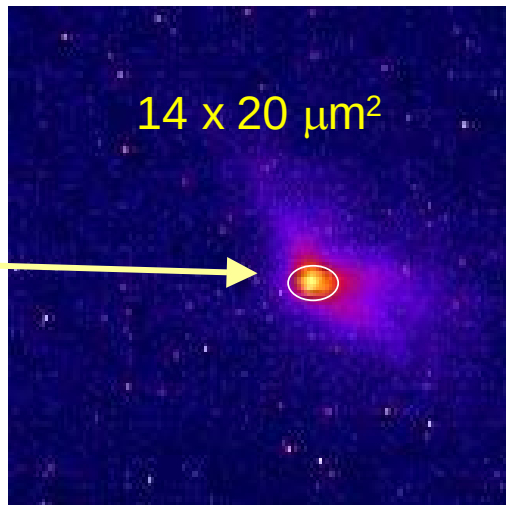
Increase the x-ray flux by stronger final focusing -permanent magnet quadrupoles







$$N_x = \frac{\sqrt{2} N_e N_\gamma \sigma}{\pi \left(2 r_b^2 + w_o^2\right)}$$

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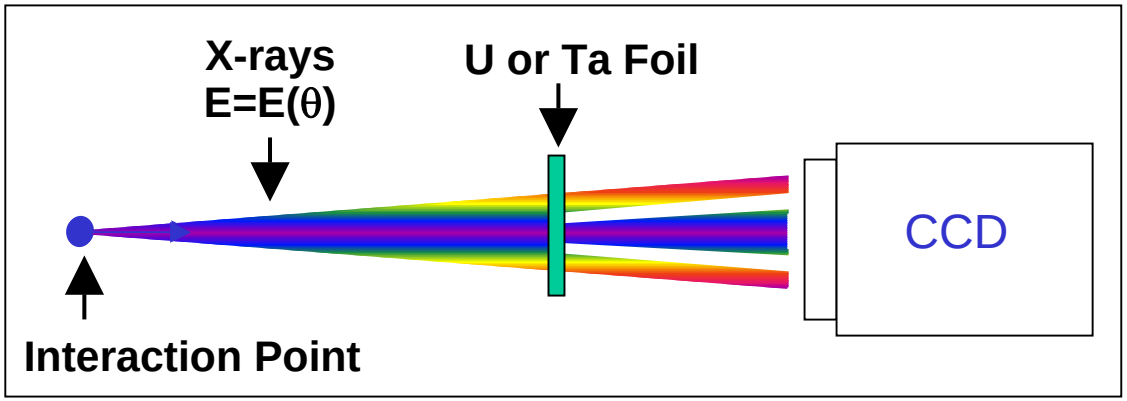
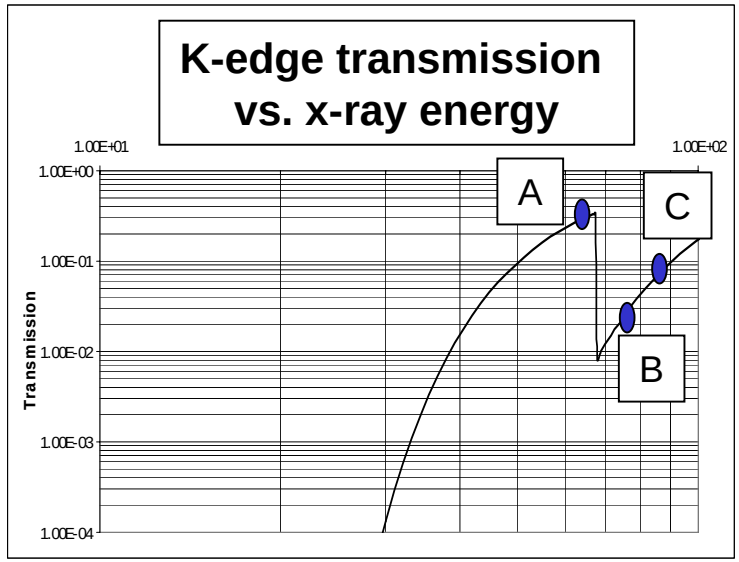
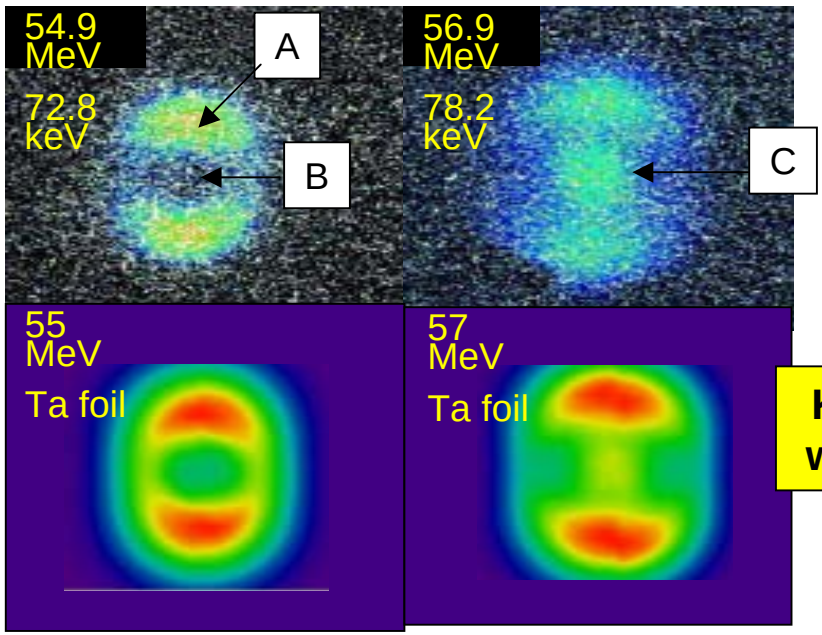
K-edge absorption/radiography demonstrates the high energies and tunability of the source





Tantalum



K-edge data agrees well with simulation

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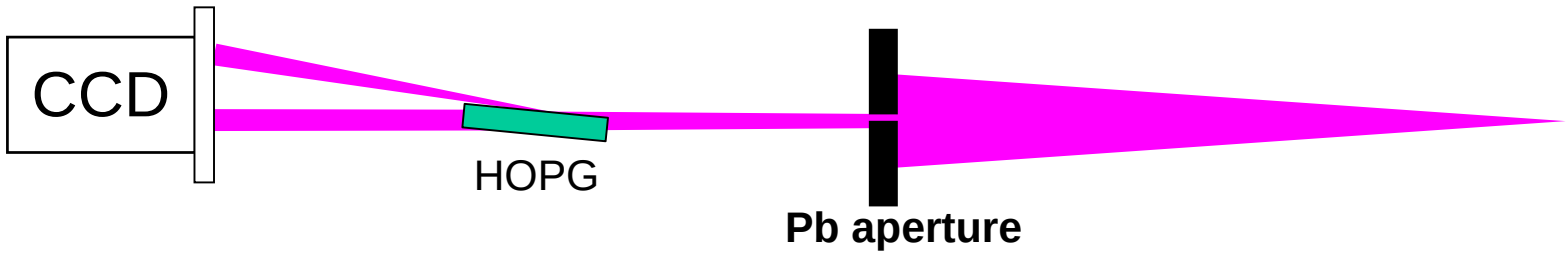
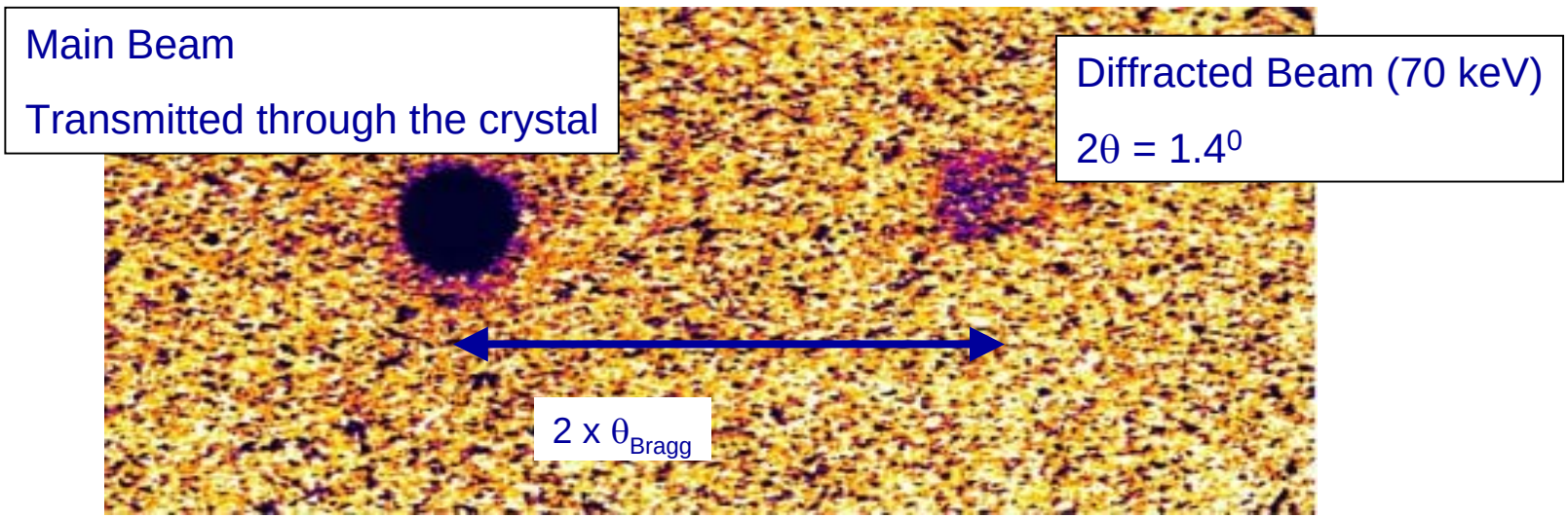
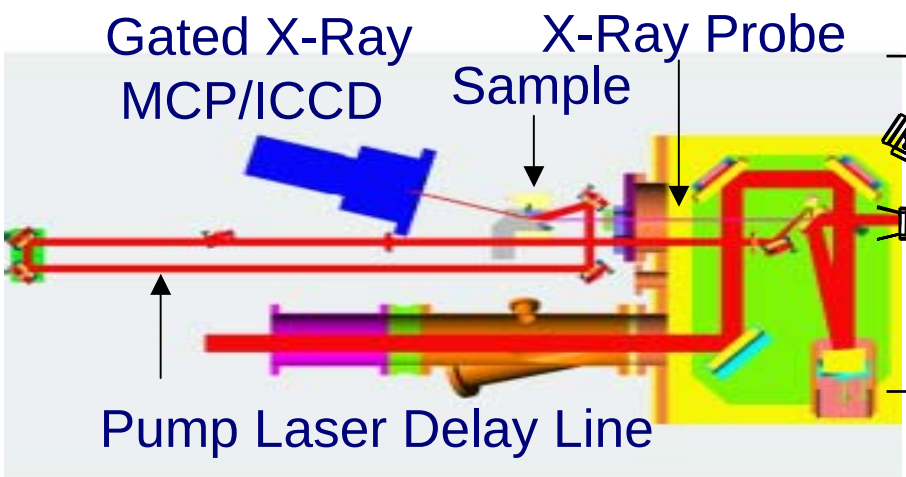
Diffraction demonstrated from HOPG (Graphite)

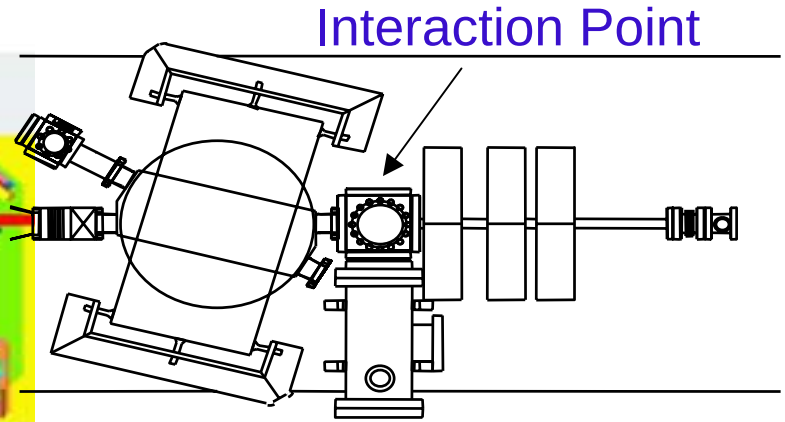


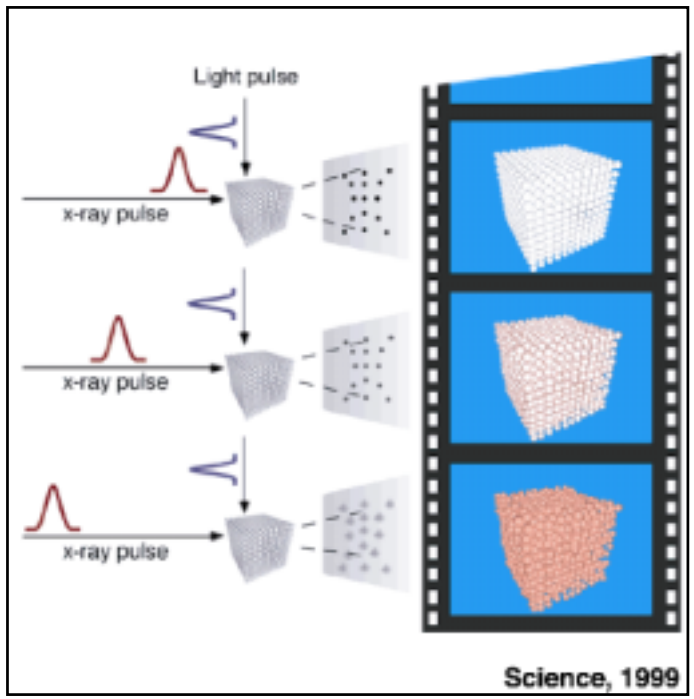


- **Measured on axis peak x-ray energy agrees with theory**
- **Use of gated ICCD will enable more detailed information to be obtained.**

We are currently implementing a dynamic diffraction experimental setup







Temporal dynamics of a physical events can be mapped out

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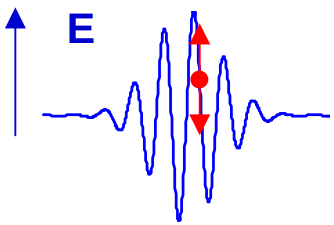
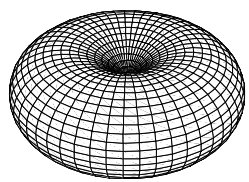
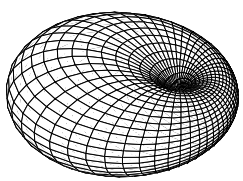
PLEIADES is capable of exploring nonlinear Compton scattering

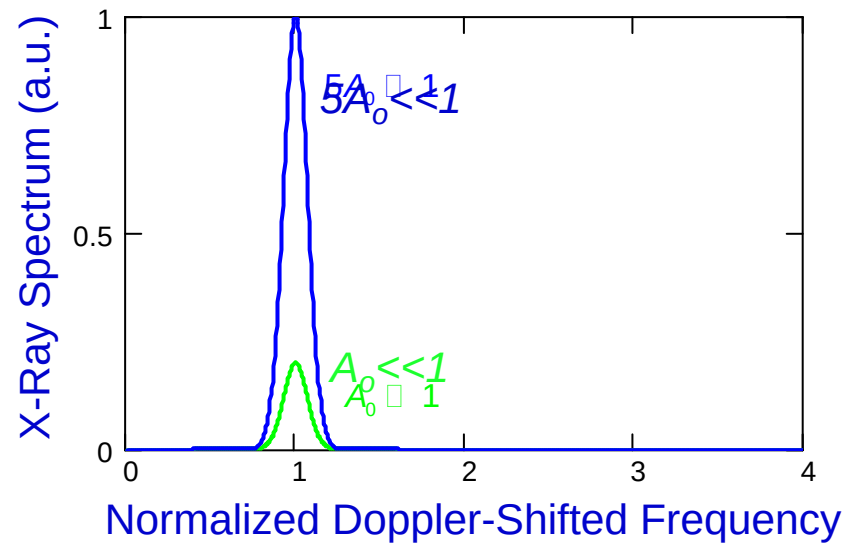
Linear







$$A_0 = \frac{eE}{\omega m_o c} \Leftrightarrow K \Leftrightarrow \frac{eB_w}{m_o k_w c}$$



Nonlinear

Analogy: Strong Wiggler Field

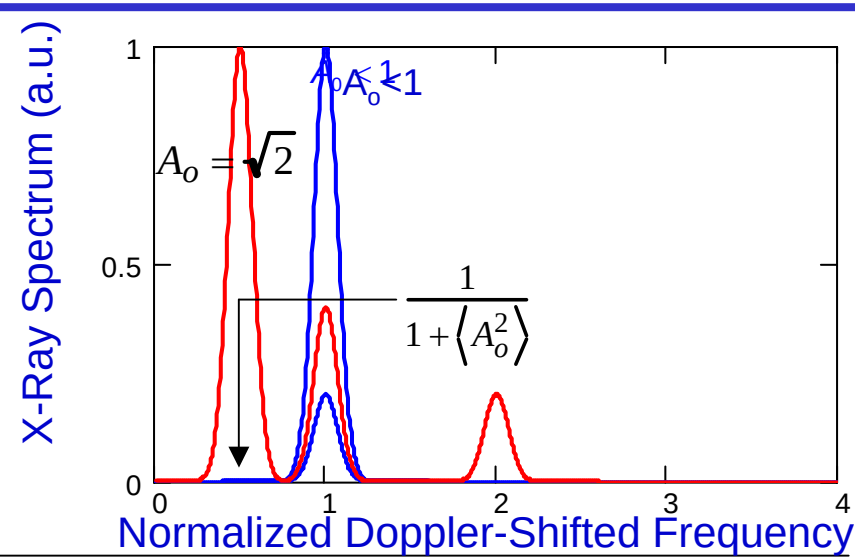
X-Ray Harmonic Production

$$E \propto A_0 \rightarrow v_\perp \approx c$$

$$\mathbf{E} \propto A_0 \rightarrow \mathbf{v}_\perp \approx c$$

$$B \propto A_0 \rightarrow F \propto v \times B$$

$$\mathbf{B} \propto A_0 \rightarrow \mathbf{F} \propto \mathbf{v}_\perp \times \mathbf{B} \propto A_0^2$$



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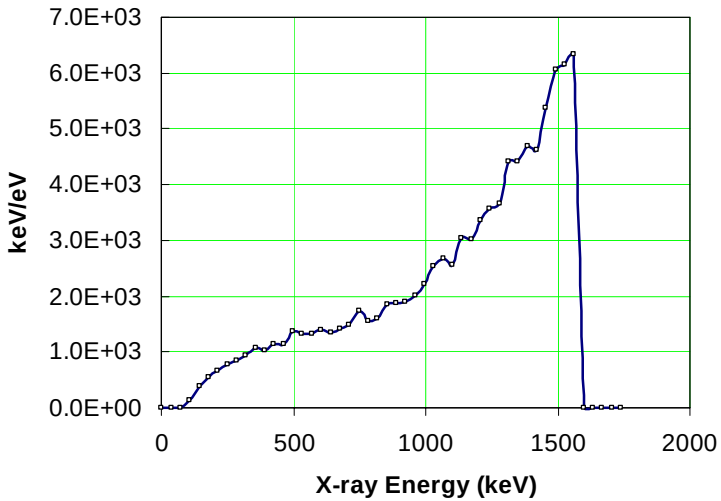
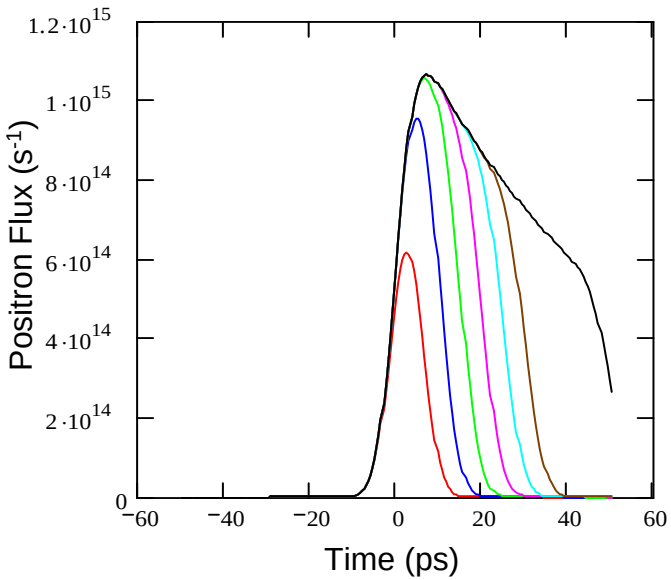
Picosecond positron pulse production





Linac Beam at 150 MeV
FALCON at 3 ω, 10%
Pb Target

- **Time-Resolved Positron Annihilation Spectroscopy**

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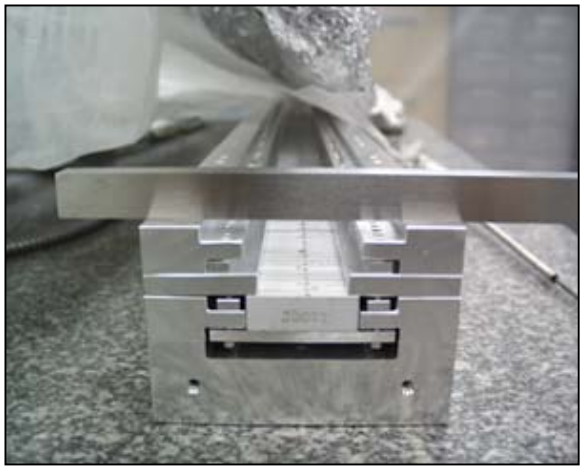
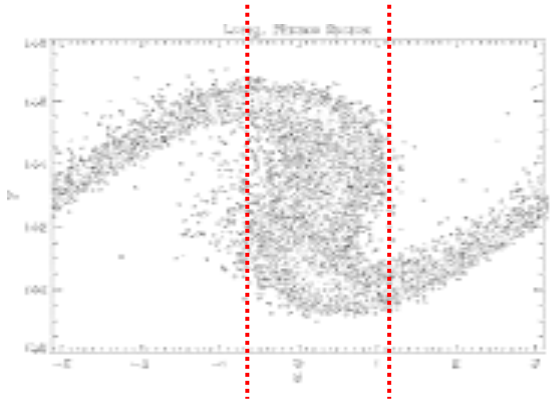
Plans to introduce undulator based physics: Seeded FEL, laser acceleration & atto x-rays

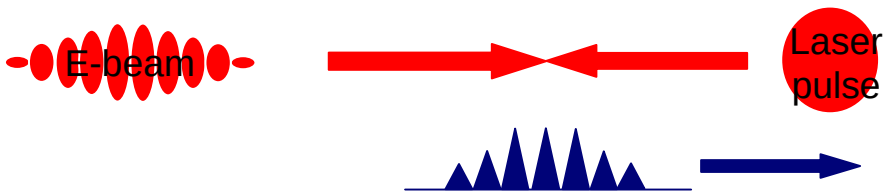


Seeding wiggler with small fraction of FALCON bunches electron beam



700 attoseconds bunches (after 30 cm of wiggler!)

<u>Compton back scatter off microbunched e-beam</u>



Attosecond X-ray strobe

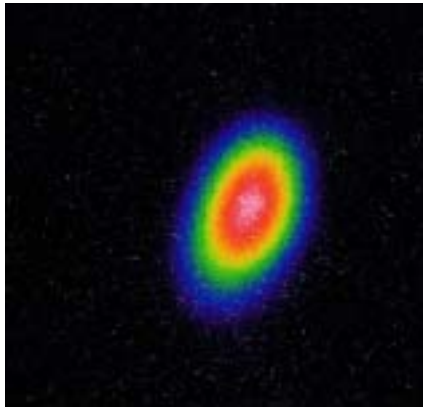
GENISIS simulation by S. Reiche

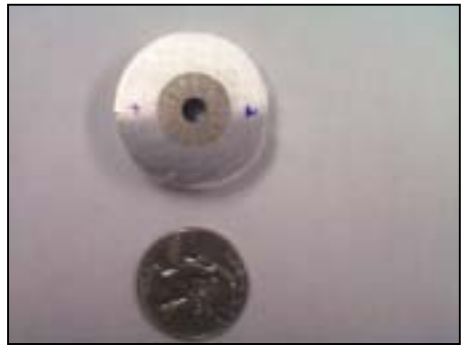
Our success leads to a broader research program

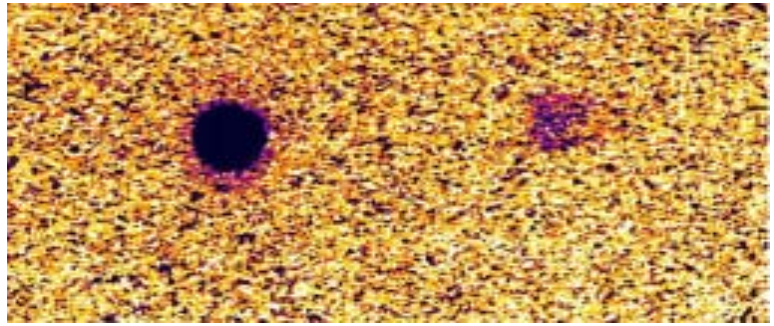
- **Reliable e-beam delivery to increasing number of physics programs**
  - Users/experimental programs request run time
- **Materials studies with x-rays and positrons**
  - X-ray optics testing
- **On-site light source and development: Hard x-ray**
- **Physics of short (and coherent) wavelength production**
- **Laser acceleration (IFEL)**
  - Using the FALCON
- **Compton Scattering**
  - Continue hard x-ray production
  - Extendable to future light sources

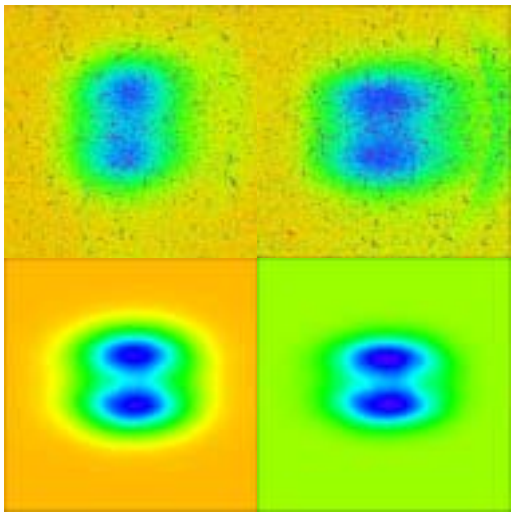
Expand group, collaborations and student representation

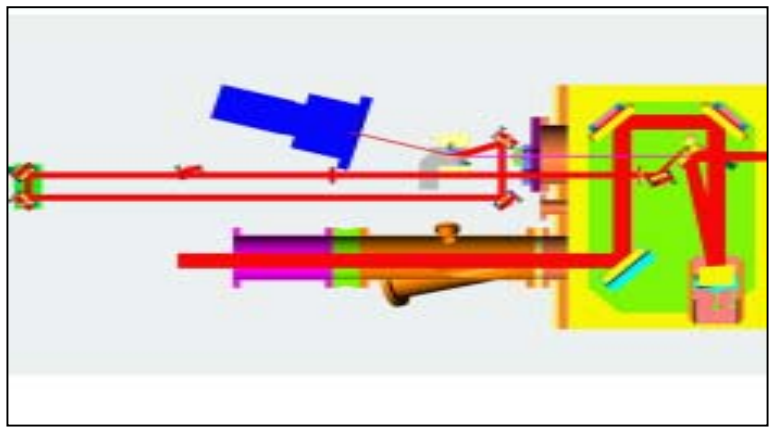
PLEIADES: The LLNL ultra-fast X-ray Source and Accelerator Facility











End of presentation

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