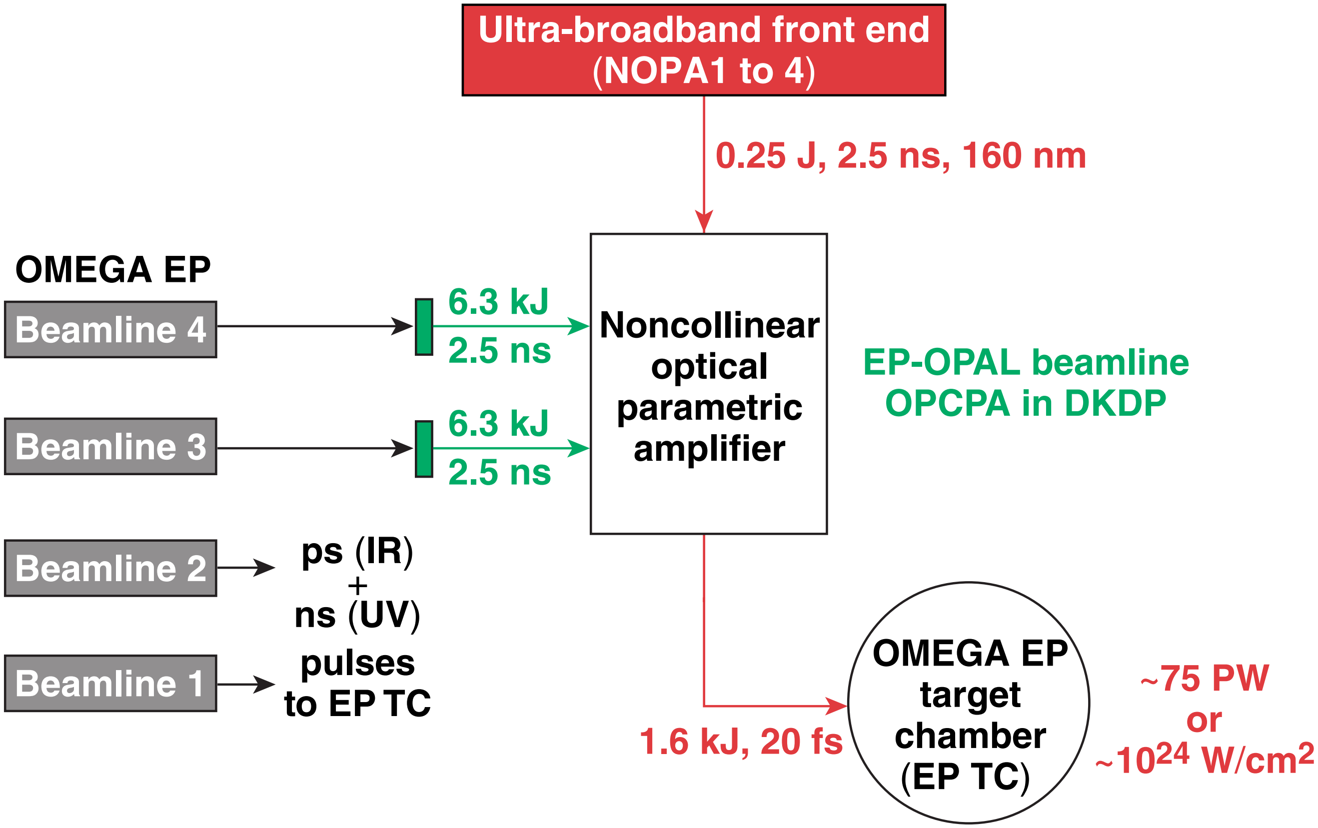
OMEGA EP OPAL: A Path to a 75-PW Laser System



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Summary

The Laboratory for Laser Energetics (LLE) is exploring the possibility of using OMEGA EP to pump an ultrahigh-intensity (10^{24} W/cm^2) laser beamline

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- Optical parametric chirped-pulse amplification (OPCPA)* makes it possible for solid-state lasers to pump ultrahigh-intensity lasers (tens of fs)
- Two OMEGA EP beams could be used to produce a 1.6-kJ, 20-fs (75-PW) OPCPA beamline—EP-OPAL (optical parametric amplifier line)
  - the two remaining beams would be available as ps or ns beams for target conditioning and pump–probe experiments
- EP-OPAL would extend the high-intensity frontier by two orders of magnitude

EP-OPAL's combination of high-energy fs, ps, and ns beams would provide a unique research environment.

*A. Dubietis, G. Jonusauskas, and A. Piskarskas, Opt. Commun. 88, 437 (1992).
**I. N. Ross *et al*., Opt. Commun. 144, 125 (1997).

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Collaborators

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An ultra-intense OPCPA extension to OMEGA EP would reach focused intensities approaching 10^{24} W/cm^2

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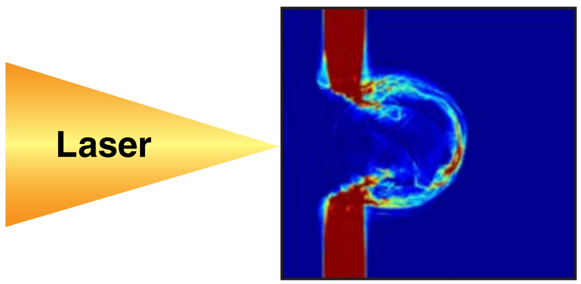
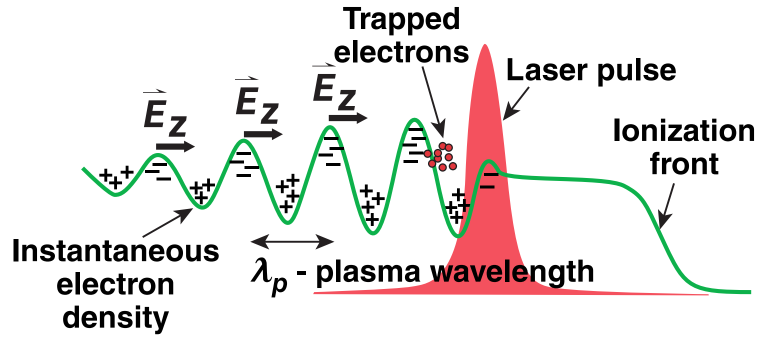
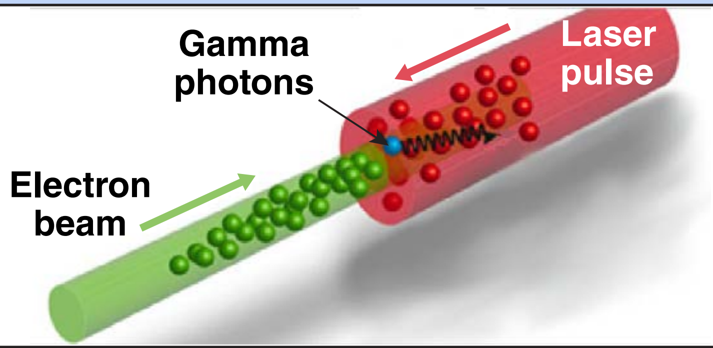
Protons – relativistic above 10^{21} W/cm^2



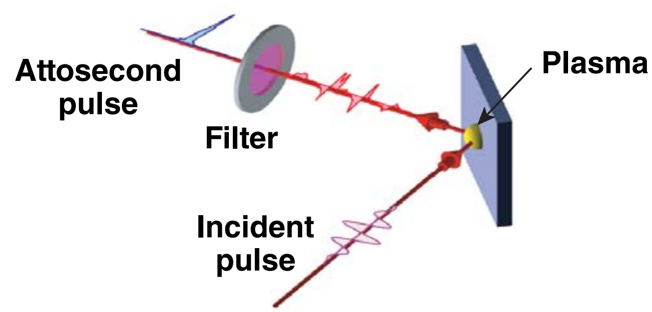
Electrons – accelerated to $\gg$1 GeV



Monoenergetic γ for nuclear science



Attosecond pulses from relativistic mirrors for quantum electrodynamic studies



This laser would be a world-class tool for fundamental science at new intensity regimes.

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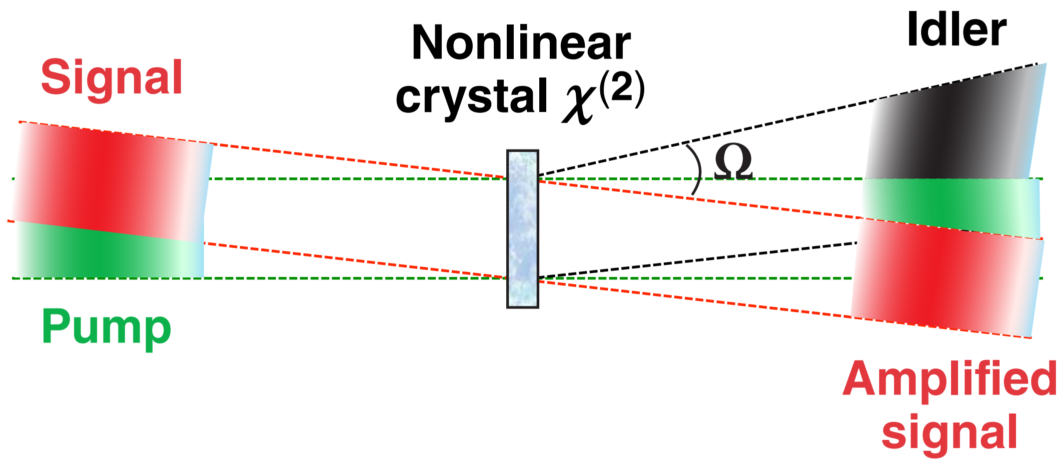
Noncollinear optical parametric amplifiers (NOPA's) use a three-wave process



- **Energy conservation:** $\hbar\omega_P \rightarrow \hbar\omega_S + \hbar\omega_I$
- **Momentum conservation:** $\hbar\vec{k}_P \rightarrow \hbar\vec{k}_S + \hbar\vec{k}_I$ "phase matching"
  (use crystal birefringence)

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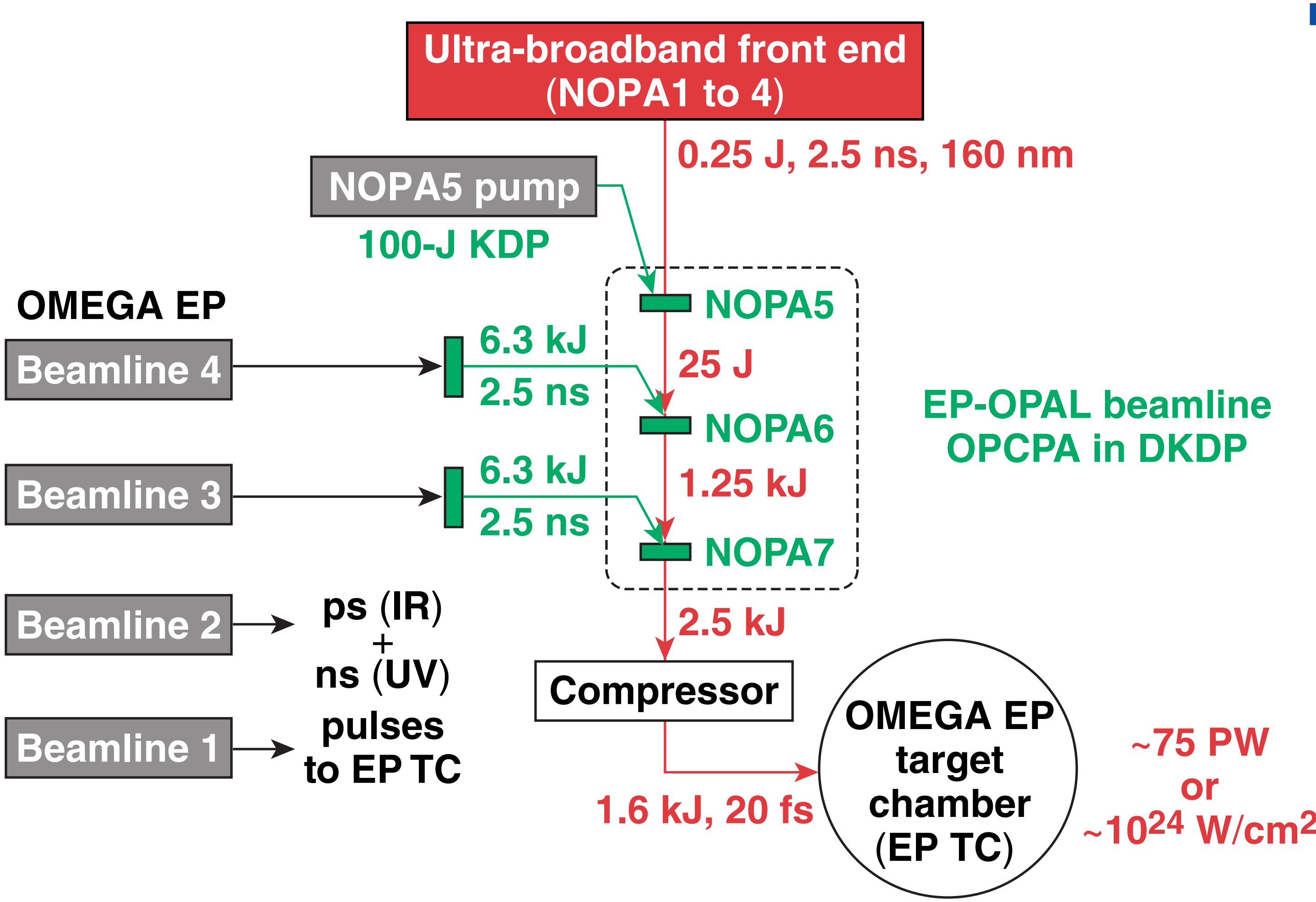
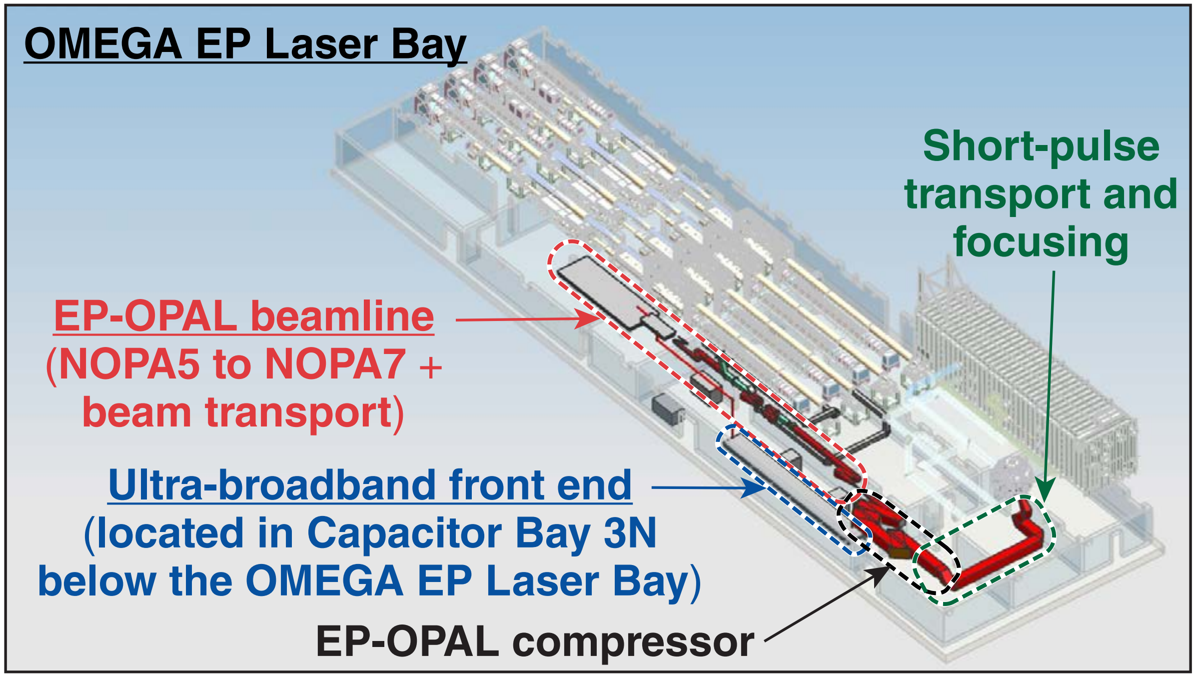
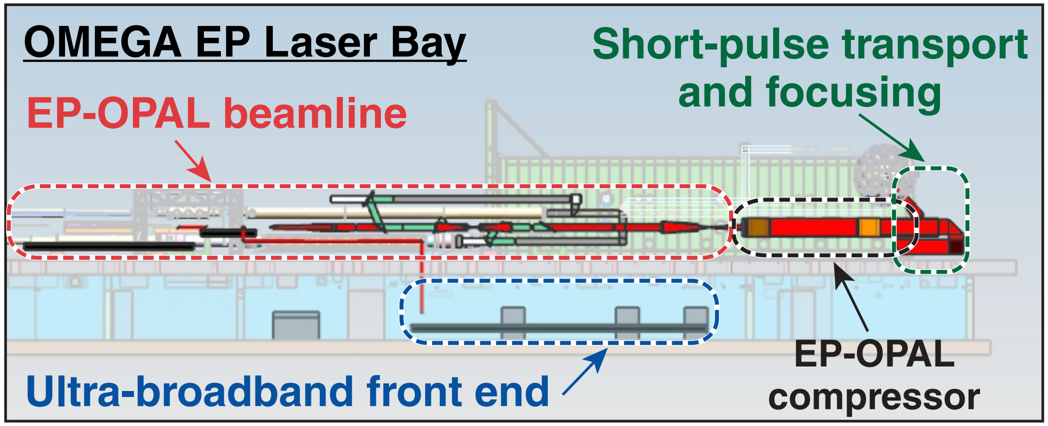
The OMEGA EP Laser System could be used to pump a 75-PW, 20-fs OPCPA beamline: EP-OPAL



Two OMEGA EP beamlines would be used, leaving two ns/ps beamlines for pump–probe and other experiments.

There is room in the OMEGA EP Laser Bay for EP-OPAL





- There are technical challenges
  - gratings: size and damage
  - large KDP crystals
  - fs optics damage threshold
  - dispersion management
- LLE is developing a 7-J, 15-fs beamline to address these challenges

Existing technologies would allow for 10 PW.

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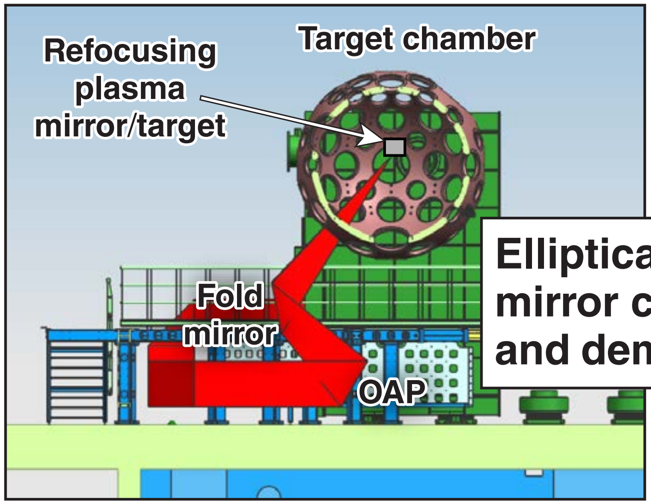
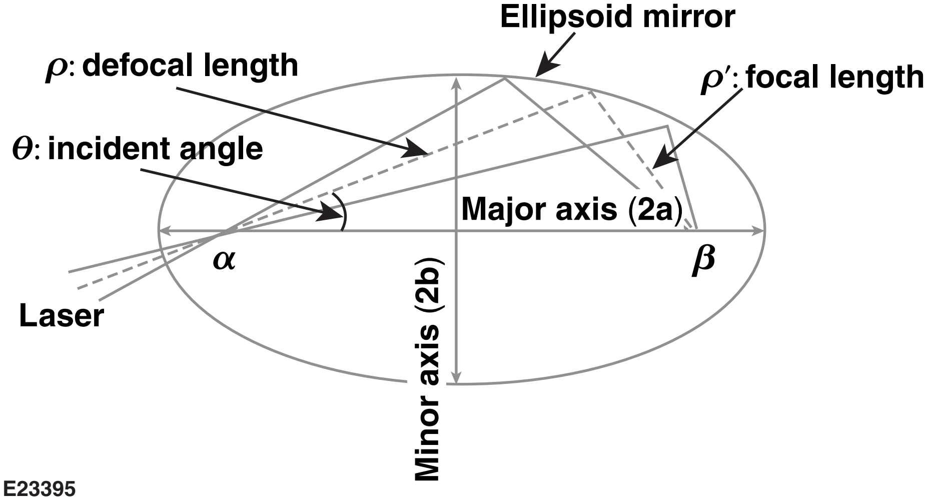
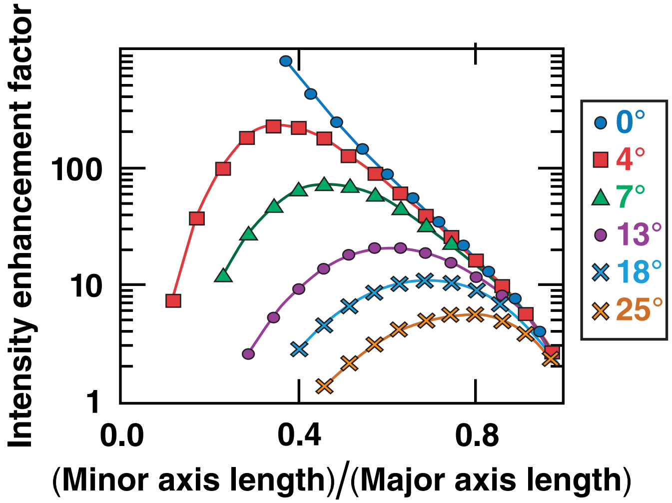
EP-OPAL will use a two-element focusing system to provide experimental flexibility

- *f*/4.6 off-axis parabola outside the target chamber
- Elliptical plasma mirror inside the target chamber*
  - part of the experimental design/target
  - disposable
  - could be concave or convex to tune the *f*/#



Elliptical plasma mirror concept and demonstration*





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*A. Kon *et al*., J. Phys., Conf. Ser. 244, 032008 (2010).

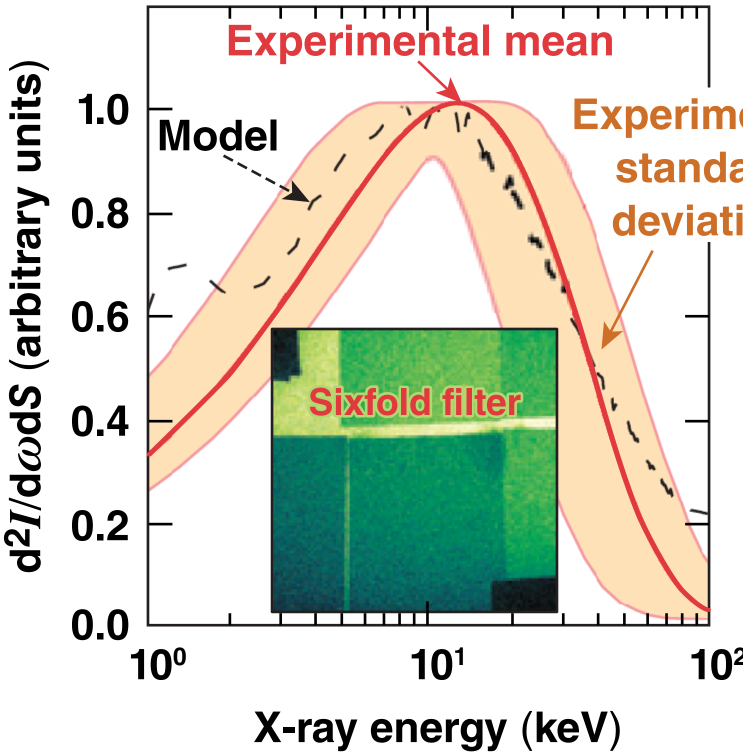
EP-OPAL will provide a variety of beams for high-energy-density-physics research

- EP-OPAL should be able to generate a wide array of photon/particle beams, many with unprecedented fluences
  - THz
  - intense x rays up 100 keV
  - gamma ray
  - >10-GeV electron beams
  - multi-GeV proton beams (and other ions)
- The two remaining OMEGA EP beamlines can provide
  - 1- to 10-ns UV beams with up to 6.5 kJ
  - 1- to 100-ps IR beams with up to 2.5 kJ

EP-OPAL should extend K-shell extended x-ray absorption fine structure (EXAFS) measurements to high-Z materials

- Implosion-based continuum EXAFS sources* are not available above ~20 keV
  - researchers are developing more complicated L-shell EXAFS**
- Betatron sources show promise to produce tens of keV quasi-continuum x-ray sources†
- A spatially coherent quasi-continuum 10-keV x-ray source with a 2-J, 30-fs laser was recently demonstrated‡

Experimental betatron x-ray spectrum‡



*B. Yaakobi *et al.*, Phys. Rev. Lett. 95, 075501 (2005).
**Y. Ping *et al.*, Rev. Sci. Instrum. 84, 123105 (2013).
†E. Esarey *et al.*, Phys. Rev. E 65, 056505 (2002).
‡S. Kneip *et al.*, Nat. Phys. 6, 980 (2010).

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Summary/Conclusions

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EXAFS is modulations in x-ray absorption caused by interference of the ejected electron wave function with reflections from neighboring atoms

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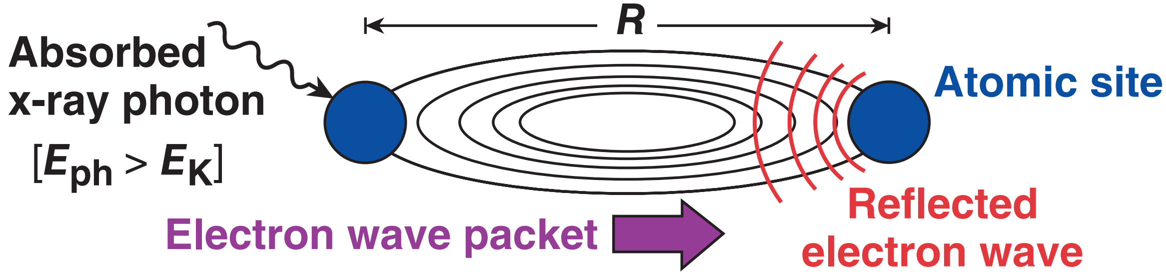
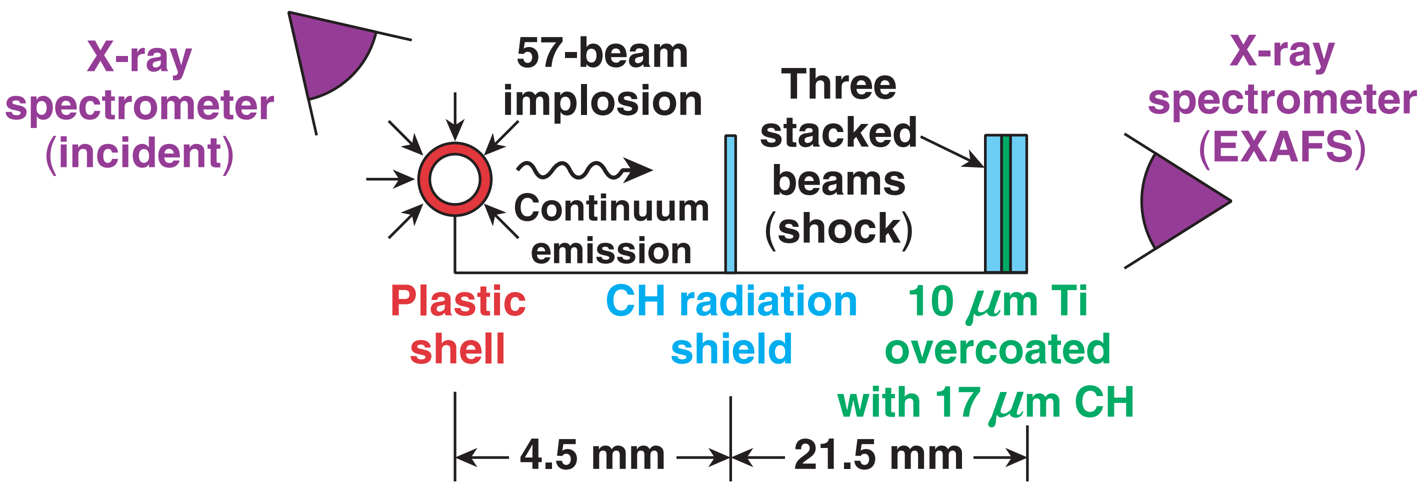


$$\hbar^2 k_e^2 / 2m = E_{ph} - E_K\text{, phase is } k_e R$$

- If the two electron waves are
  - in phase: maximum absorption
  - out of phase: minimum absorption



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