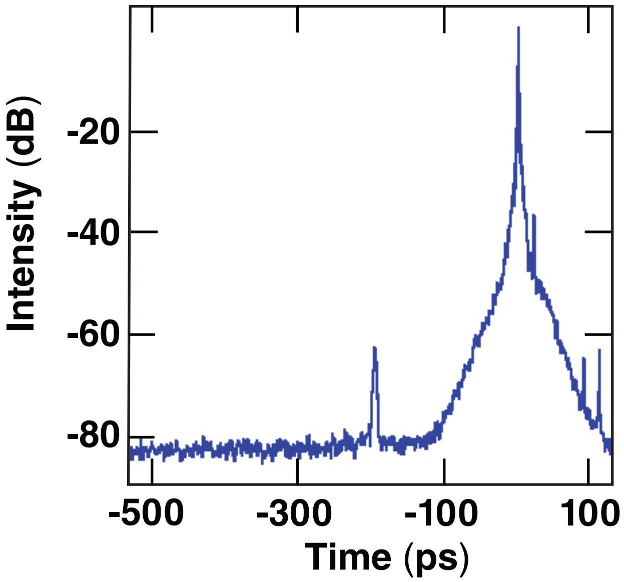
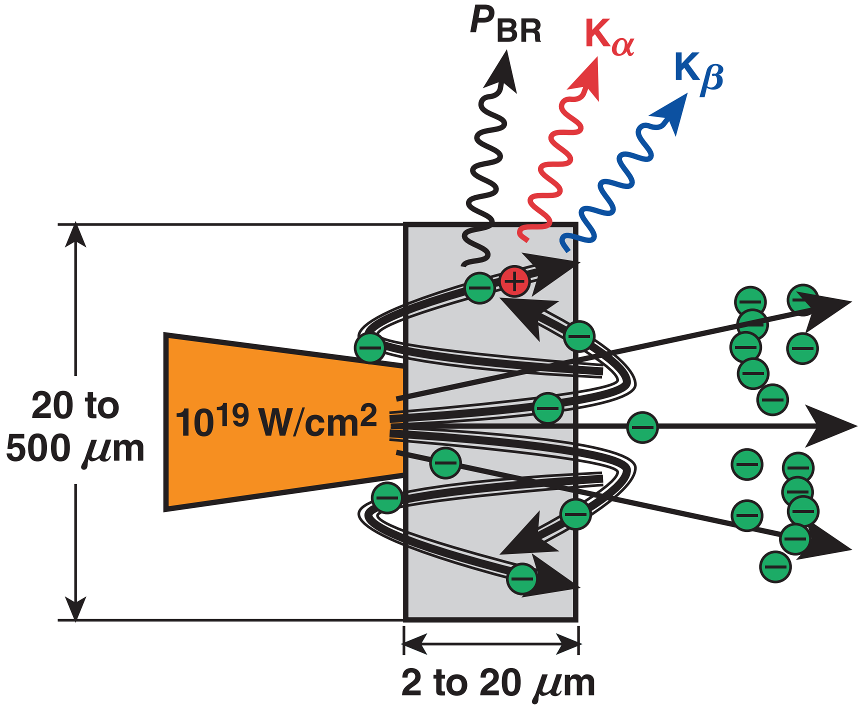
High-Temporal-Contrast Experiments Using a Hybrid OPCPA-Nd:Glass Multi-Terawatt (MTW) Laser System





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Summary

The MTW laser provides a unique facility to study ultrahigh-intensity laser and target physics

- The MTW laser enables important experimental campaigns:
  - high-temporal-contrast laser enhancements and diagnostic development
  - high temporal contrast enables solid-target experiments
  - high pointing stability makes it possible to use small, low-mass targets ($V_{target} \approx 10^{-6}$ mm^3)
  - high availability facilitates parametric studies with good statistics required to study important physics issues
- Laser-to-fast-electron conversion efficiency is 23% ± 8% when intense pulses are energy scaled with no observed pulse width dependence
- Low-density plasma generation from laser prepulses plays an important role in fast electron generation, so measuring and controlling temporal contrast is important

Collaborators

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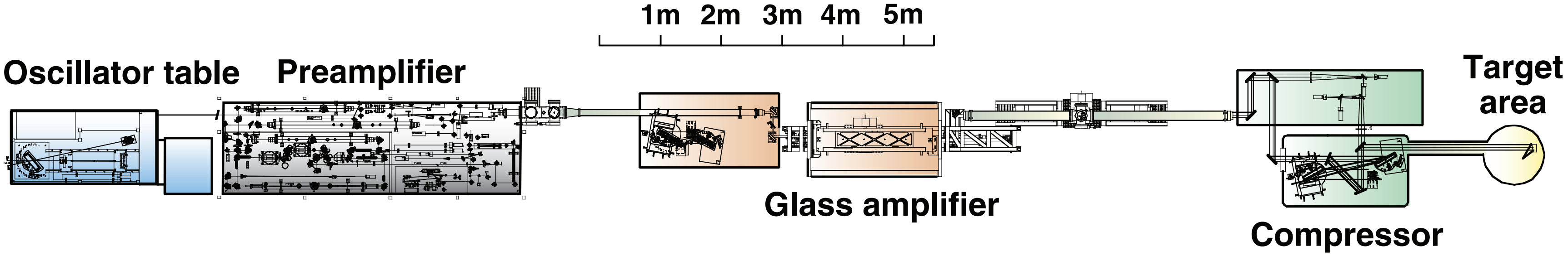
Outline

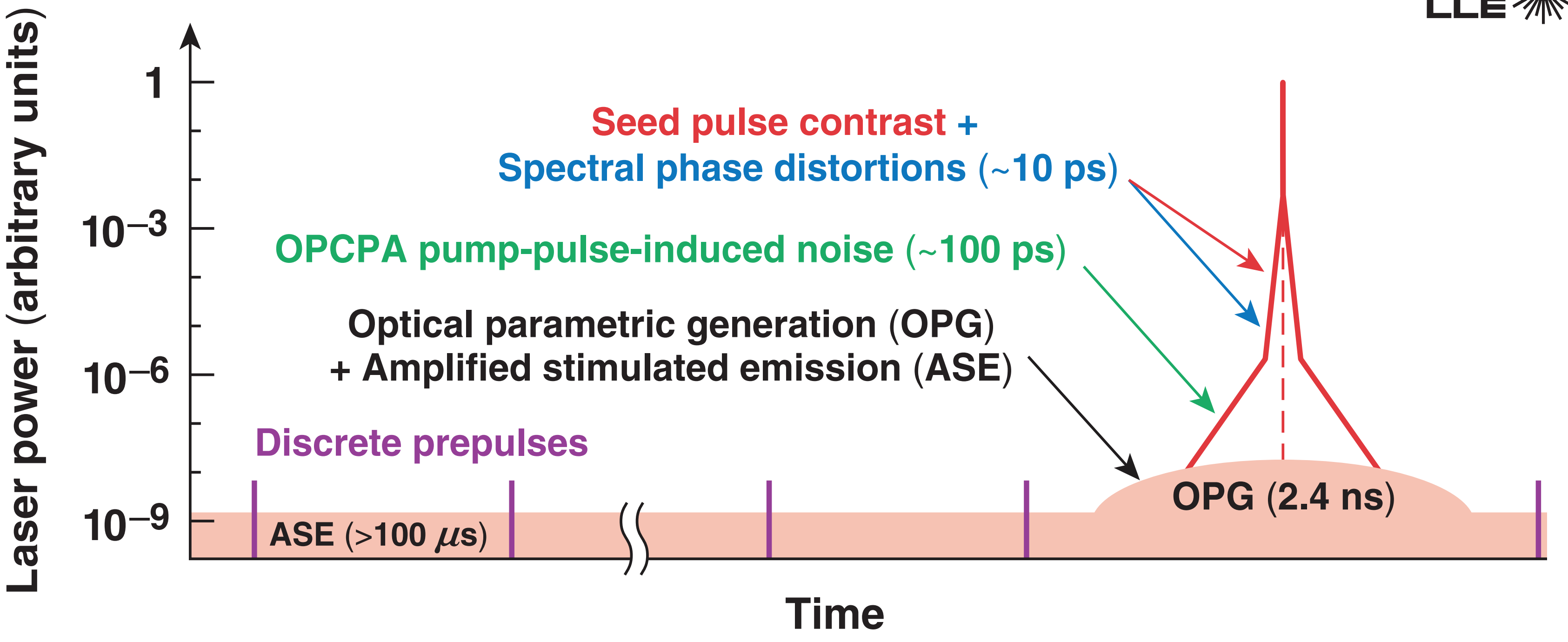
- Introduction: MTW laser description
- MTW contrast measurements
- Contrast enhancements tested on the MTW
    - ultrafast optical parametric amplifier
    - OPCPA pump filter with Volume Bragg grating
- MTW target experiments
    - isochoric heating of solid-density targets by relativistic electrons
    - laser-to-electron conversion efficiency for “bookend” targets

The front-end prototype for OMEGA EP is used for diagnostic development and target experiments



- The MTW laser is a single-beam, short-pulse laser facility.
- Pulse widths (0.5 to 100 ps) are adjustable using an Öffner grating pulse stretcher.
- OPCPA amplification provides high temporal contrast ($C > 10^8$).
- A four-pass Nd:phosphate glass disk amplifier delivers 10 J per shot (limited by compressor grating damage).
- An ~*f*/3 off-axis parabola focus (~4-μm FWHM) yields up to 4×10^{19} W/cm^2.
- Shot cycle time as short as 10 min; over 2300 system shots!

Producing and measuring ultrahigh pulse contrast for future OMEGA EP experiments is a significant challenge

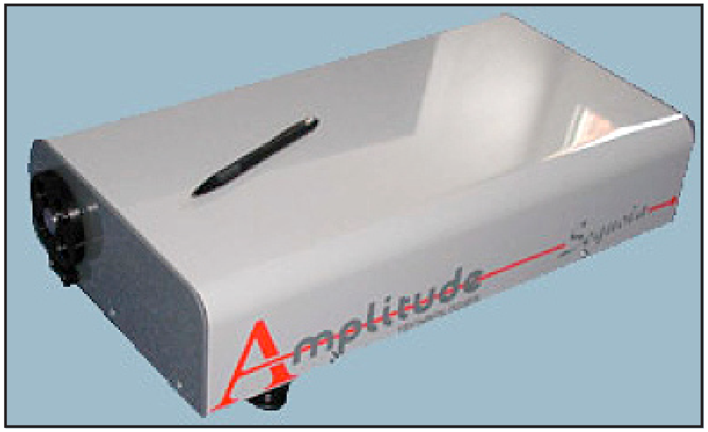


Known limits to CPA-system pulse contrast

- Seed pulse contrast – typical ML oscillator contrast is ~10^6:1
- Spectral phase distortions produce "picosecond pedestals"
- Incoherent noise on OPCPA pump pulse imprints on chirped-pulse spectrum that prevents full compression below ~100 ps
- OPG and/or ASE – incoherent radiation does not compress
- Discrete prepulses from ML pulse train and multipass amplification

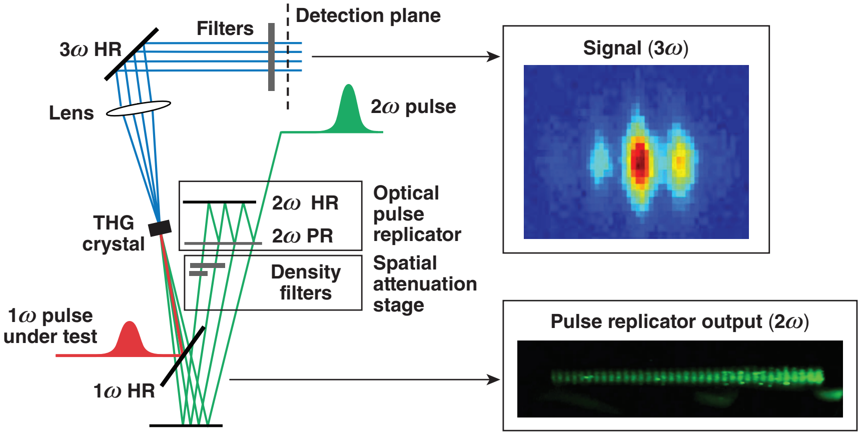
Scanning and single-shot cross correlators are used to measure temporal contrast

Sequoia* scanning cross correlator



- 660-ps range (–530/+130 ps)
- Estimated dynamic range = 91 dB for a 30 μJ Fourier-transform-limited pulse on MTW

Single-shot high-contrast diagnostic* (HCD)

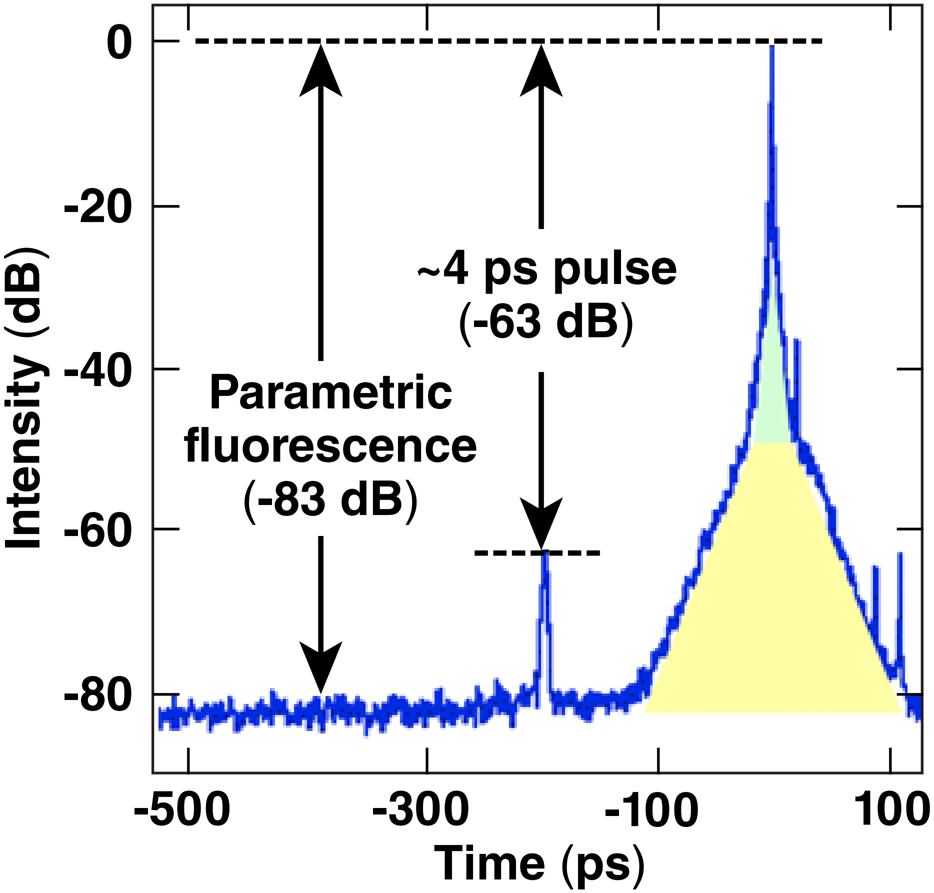


- 85 replicas with ~6-ps delay between replicas yields ~ 510 ps temporal range

A prototype HCD is now deployed on the MTW laser for target shots.

see C. Dorrer talk session 10-4.

"Baseline" MTW contrast is measured using the 5-Hz OPCPA front end with the Sequoia cross-correlator



Two-component pedestal

- Spectral phase distortions*
- OPCPA pump-induced noise†

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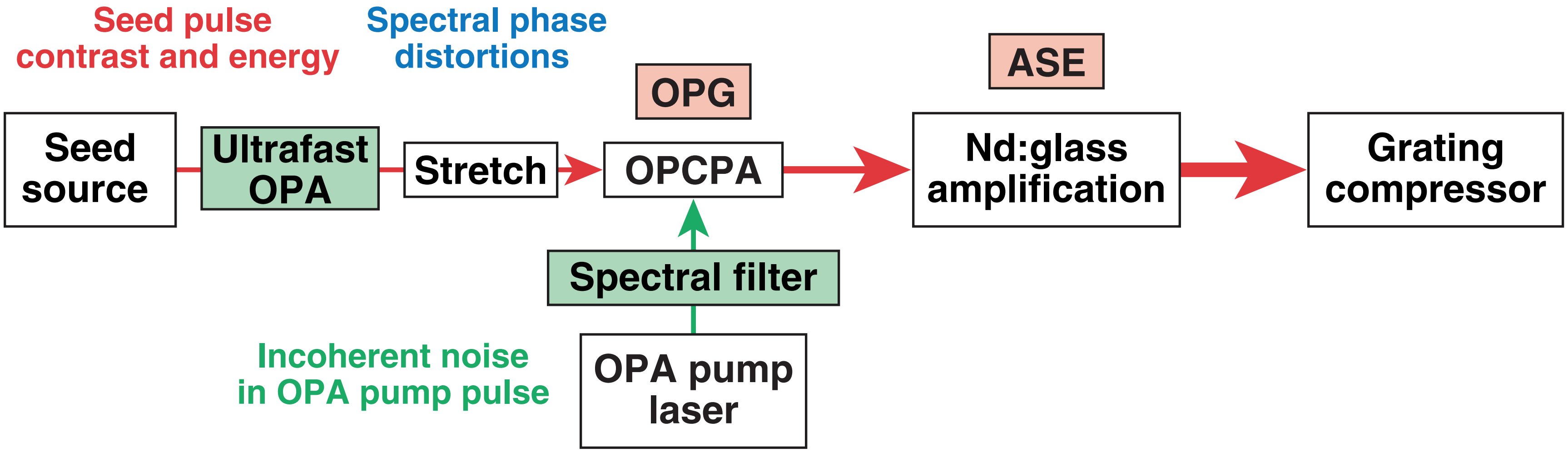
*C. Dorrer et al., JOSA B 24, 3048 (2007).

†C. Dorrer et al., Opt. Express 16, 3058 (2008)

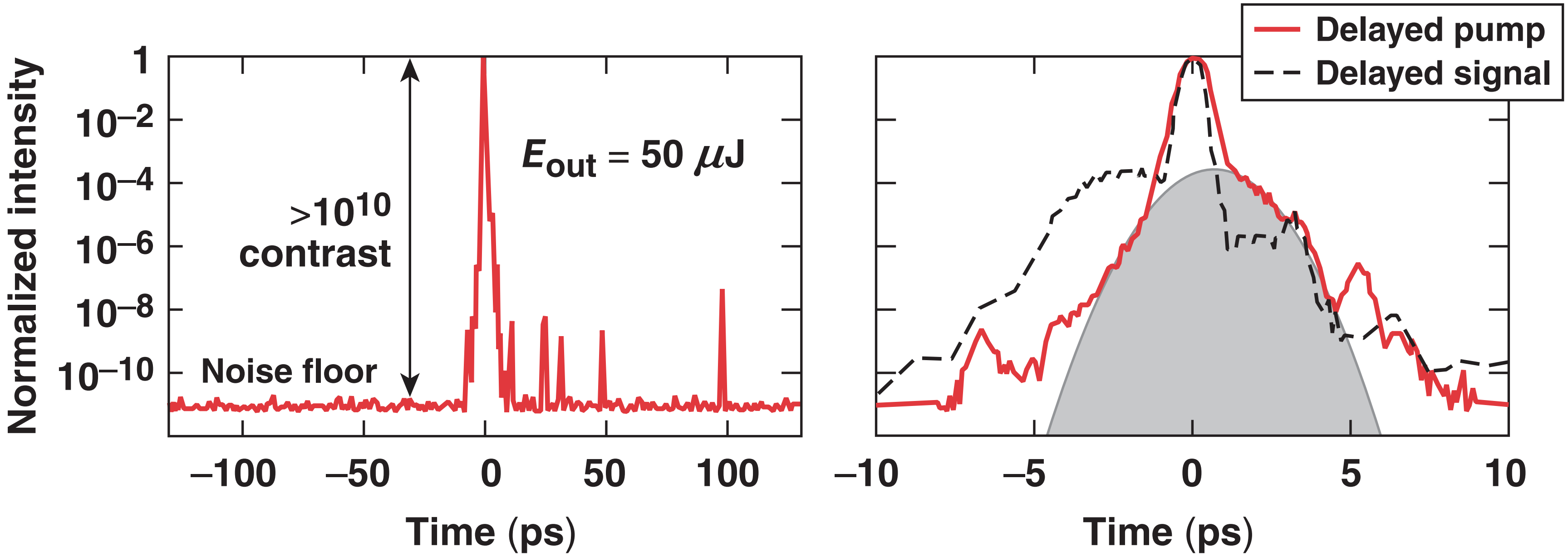
High-contrast technologies are being tested in the MTW laser system before being deployed in OMEGA EP.



- Maximizing input signal-to-noise ratio (contrast) at every amplification stage minimizes degradation from OPG and ASE.
- Spectral amplitude and phase of amplified pulse must be maintained for best pulse compression.

Contrast levels greater than 10^{10} within ~10 ps have been achieved in the MTW seed source

Ultrafast OPA using a seed pulse with zero dispersion (no stretch) and ~2-ps (FWHM) pump pulse at 2ω



C. Dorrer *et al.*, Opt. Lett. 32, 2143 (2007).

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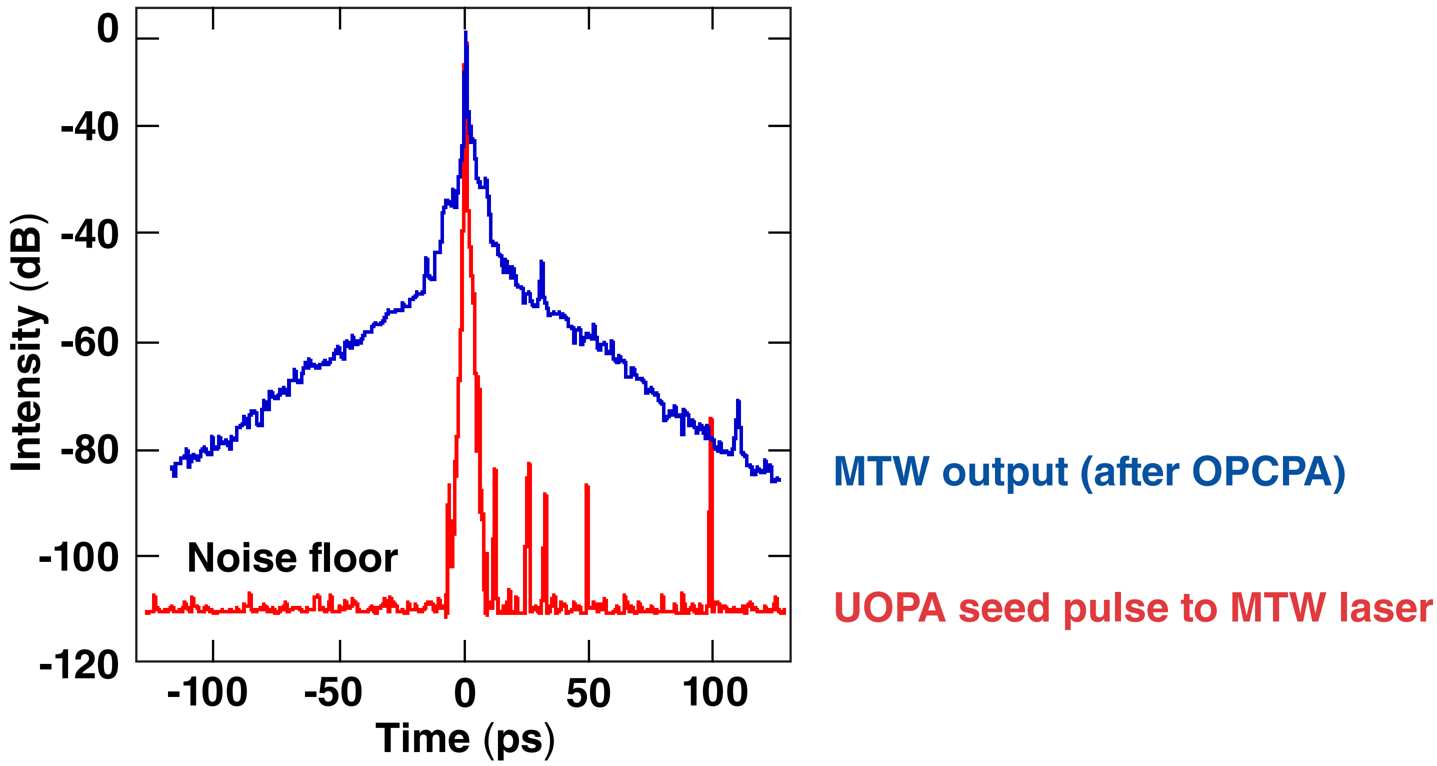
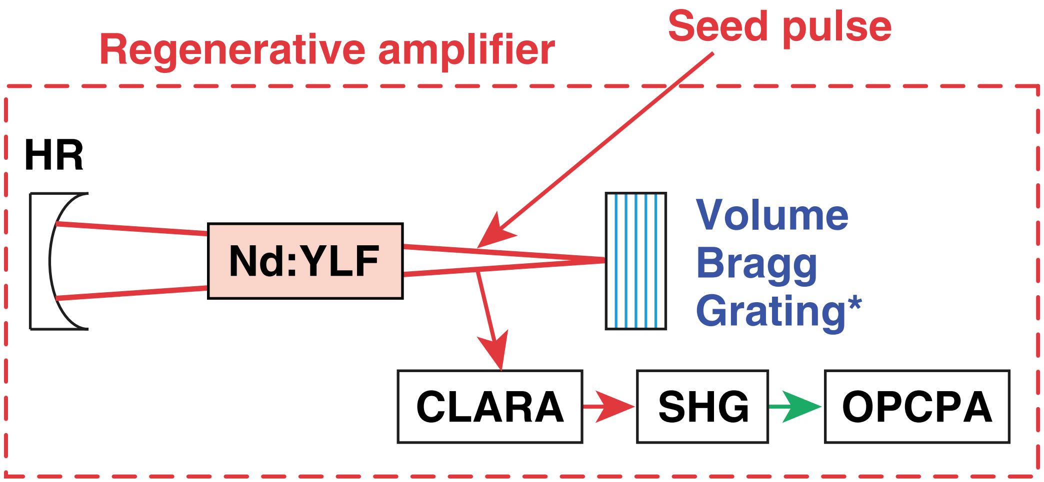
OPCPA amplification degrades the extreme contrast delivered by the UOPA seed source



- Temporal contrast appears to be dominated by phenomena like
  - OPCPA pump-induced noise
  - spectral phase noise?

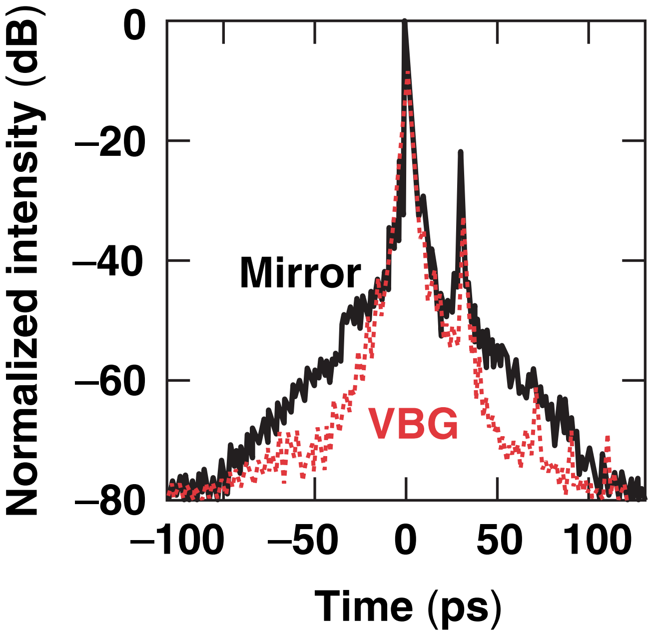
Regenerative filtering shows promise for limiting OPCPA pump laser noise transferred to the signal

OPCPA pump laser



*Collaboration with Optigrate and UCF/CREOL

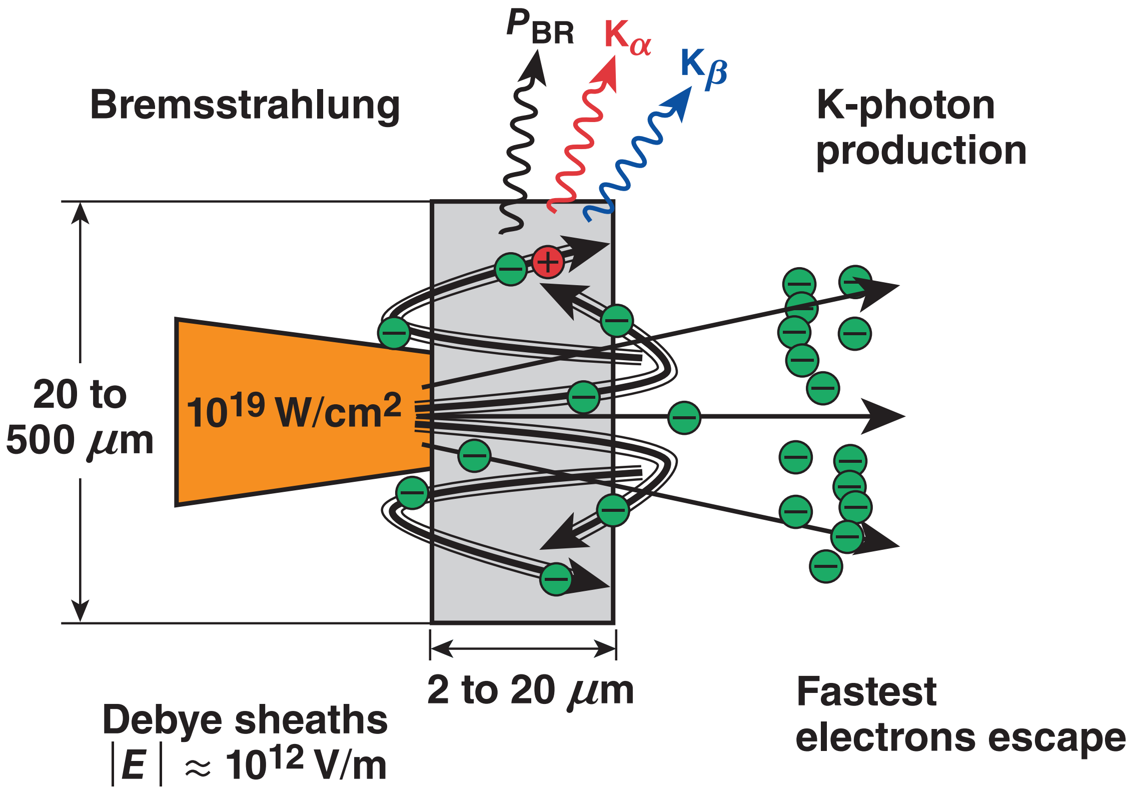
Saturated OPCPA preamp



Extremely narrowband filtering is achieved by filtering ASE on each regenerative amplifier round trip with a volume Bragg grating (VBG).

C. Dorrer *et al*., Opt. Lett. 32, 2378 (2007).

Fast-electron refluxing in small-mass targets allows access to high-energy-density phenomena



- Refluxing is caused by Debye sheath field effects[1,2]
- Majority of fast electrons are stopped in the target
- Provides a simple geometry for testing laser-coupling, electron-generation, and target-heating models[3,4]
- High temporal contrast is required to achieve refluxing

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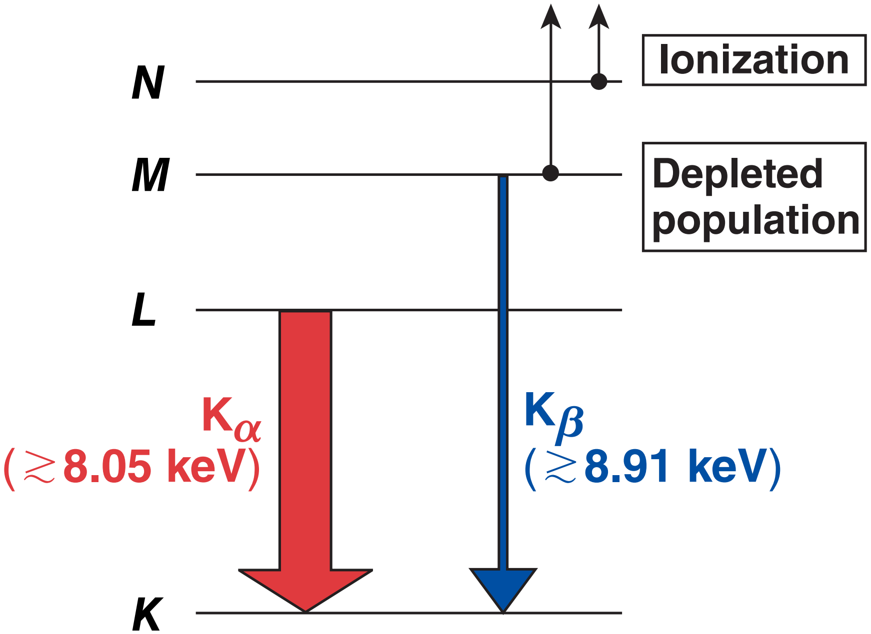
[1] S. P. Hatchett *et al.*, Phys. Plasmas 7, 2076 (2000).
[2] R. A. Snavely *et al.*, Phys. Rev. Lett. 85, 2945 (2000).
[3] W. Theobald *et al.*, Phys. Plasmas 13, 043102 (2006).
[4] J. Myatt *et al.*, Phys. Plasmas 14, 056301 (2007).

K-photon radiation reveals hot electron production and bulk heating of small-mass targets*



Copper energy levels

- Intense laser-plasma interaction produces energetic electrons that leave K-shell vacancies
- K_α yield indicates hot electron conversion efficiency
- Inelastic collisions heat the target and ionize outer shell electrons
- Collisional ionization with thermal background plasma occurs
- $T_e > 100$ eV causes significant M-shell depletion, which affects K_β yield
- Target heating is inferred from K_β/K_α

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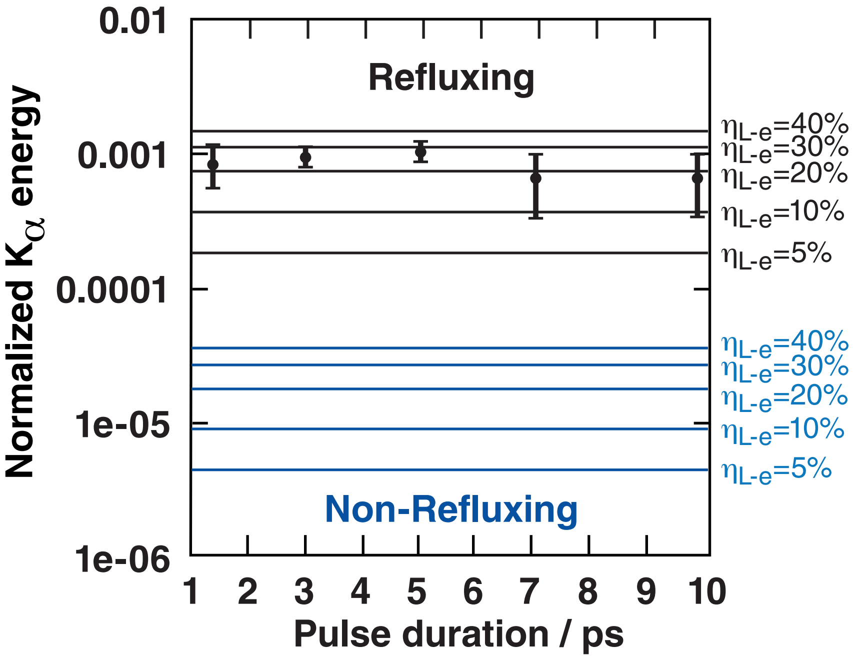
*J. Myatt *et al*., Phys. Plasmas 14, 056301 (2007).
*G. Gregori *et al*., Contrib. Plasma Phys. 45, 284 (2005).

Normalized K_α yield is approximately constant for 1-10 ps pulses with the same peak intensity

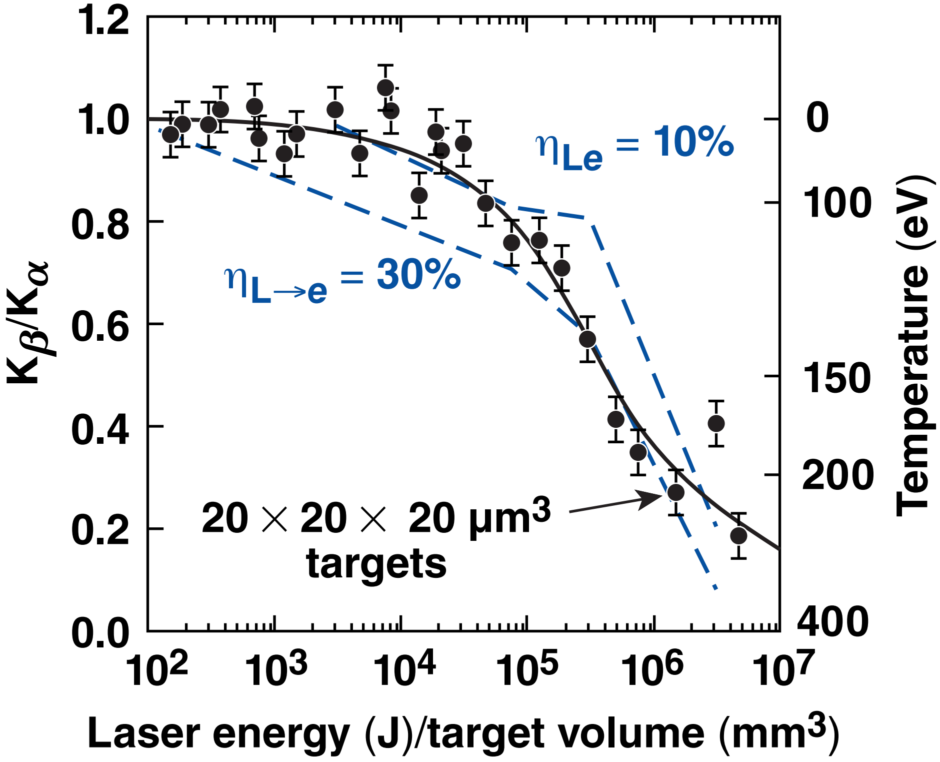


- **Laser-to-electron energy-conversion efficiency ($\eta_{L\text{-}e}$) is inferred using a K_α production model**
- **Planar Cu targets ($500 \times 500 \times 20\ \mu m^3$)**
- **1 to 10 ps laser pulses are energy scaled (constant at ~ 10^{18} W/cm^2)**

K_α yields are consistent with a refluxing electron model assuming $\eta_{L\rightarrow e} = (23\pm8)\%$ with no observed pulse width dependence.

Comparison of K_β/K_α ratios to simulations are consistent with the absolute K_α yields

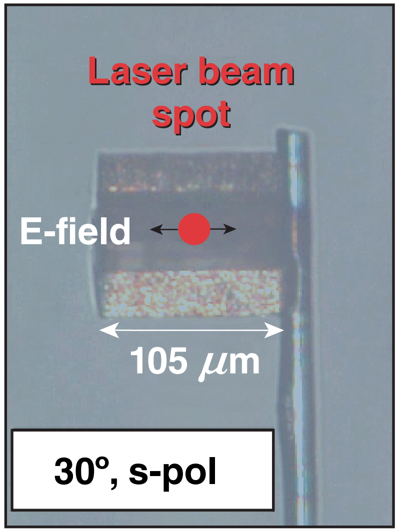
- Provides a self-consistency check on $\eta_{L\rightarrow e}$
- Provides a detailed data set for comparison to future OMEGA EP experiments at higher energy densities
- High pointing stability enables the smallest targets ($V = 10^{-6}$ mm^3)
- Measured K_β/K_α for the smallest targets is consistent with $T_e \approx 200$ eV



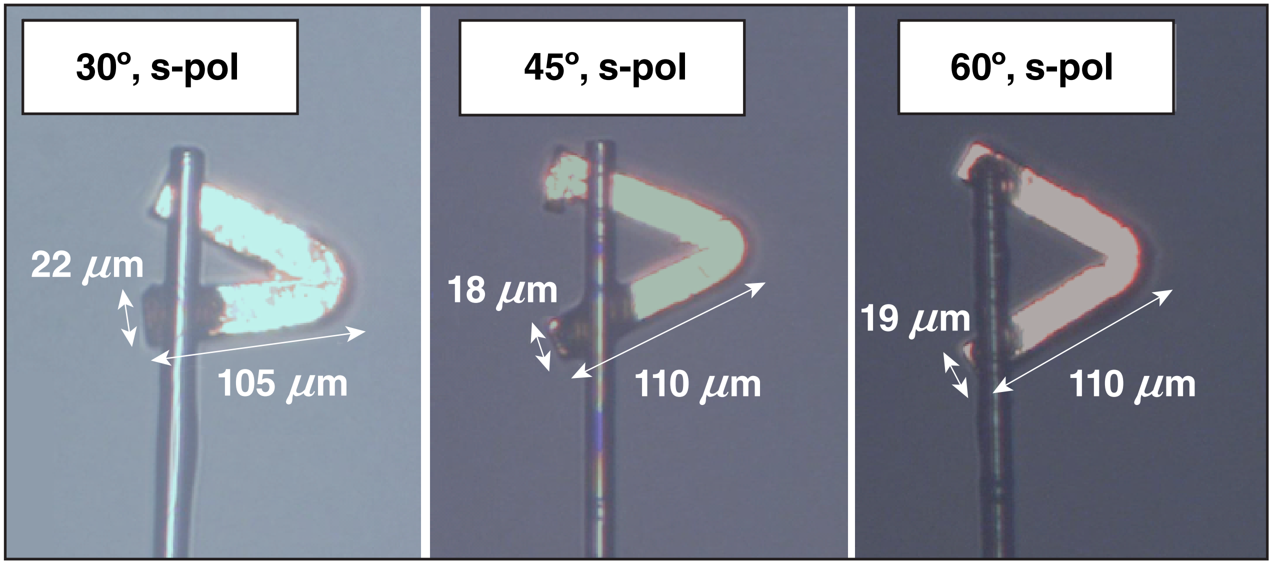
P. M. Nilson *et al.*, Phys. Plasmas 15, 056308 (2008).

"Bookend" targets are used to study the fast-electron-conversion efficiency for cone-like target geometries

Front view



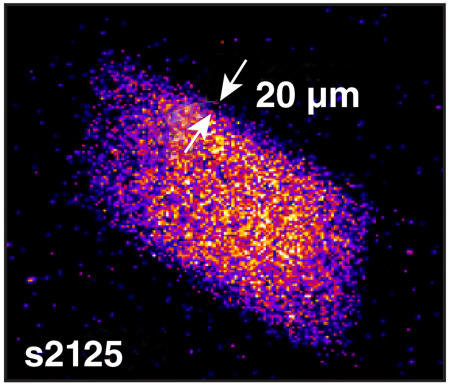
Side view



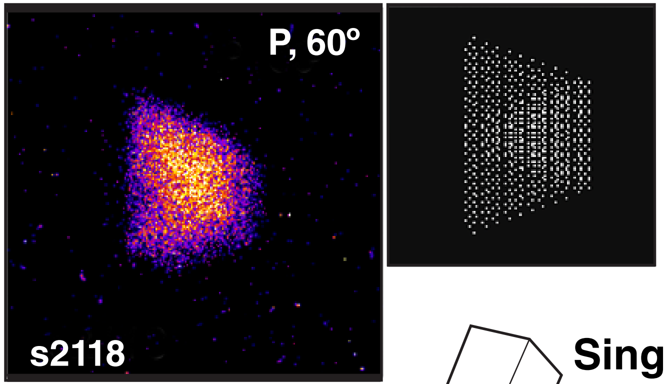
- One-piece Cu targets (~100 × 100 × 20-μm^3 plates joined at 30°, 45°, and 60°)
- Radius of curvature (~1 μm) smaller than the focal-spot diameter
- Bookend orientation sets laser polarization

K_α emission was recorded using a narrowband spherical crystal imager and two spectrometers

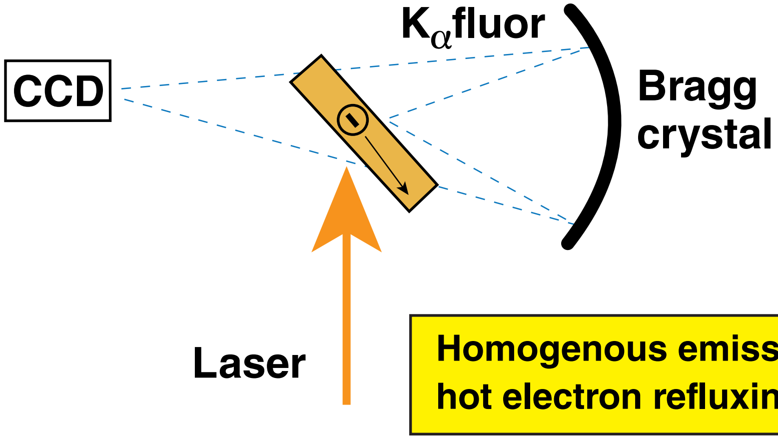
Flat foil target

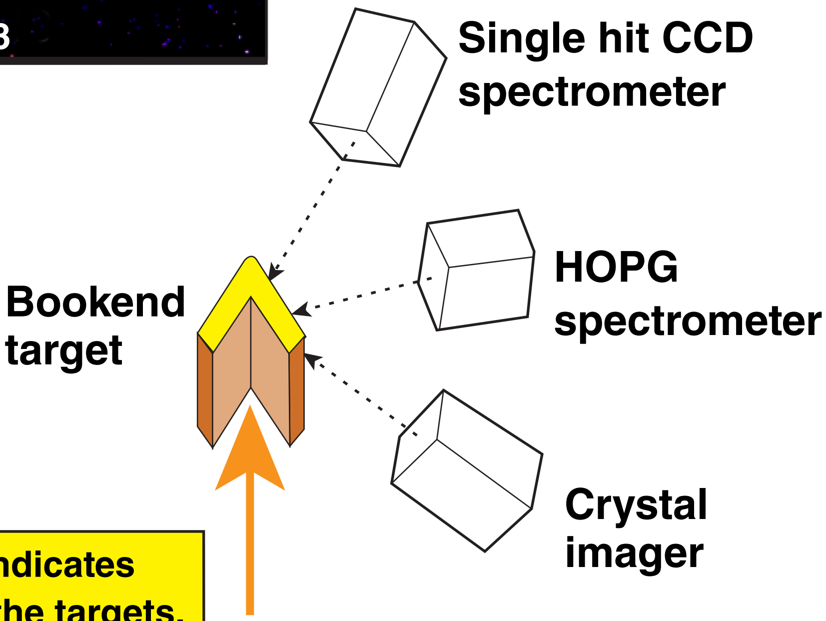


Bookend target



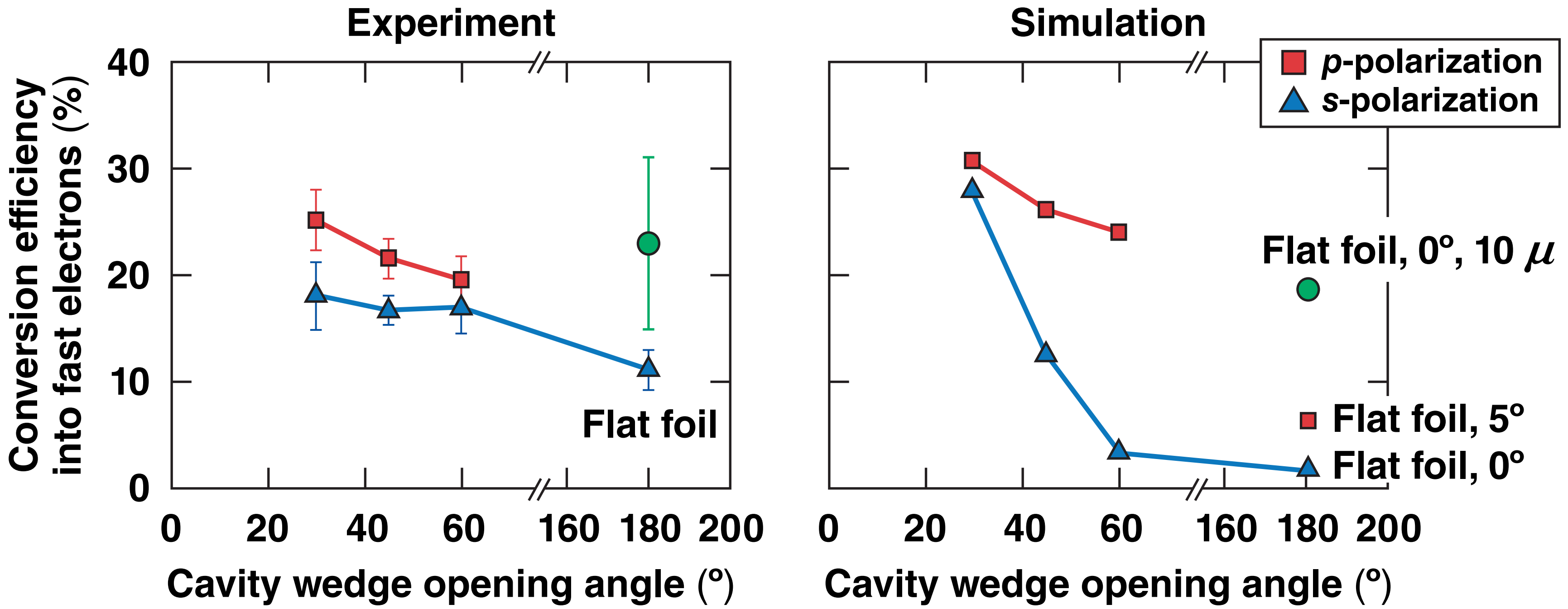
Refluxing electrons create x-ray emission





Homogenous emission indicates hot electron refluxing in the targets.

Bookend target experiments show similar trends as *OSIRIS* (2-D PIC) simulations

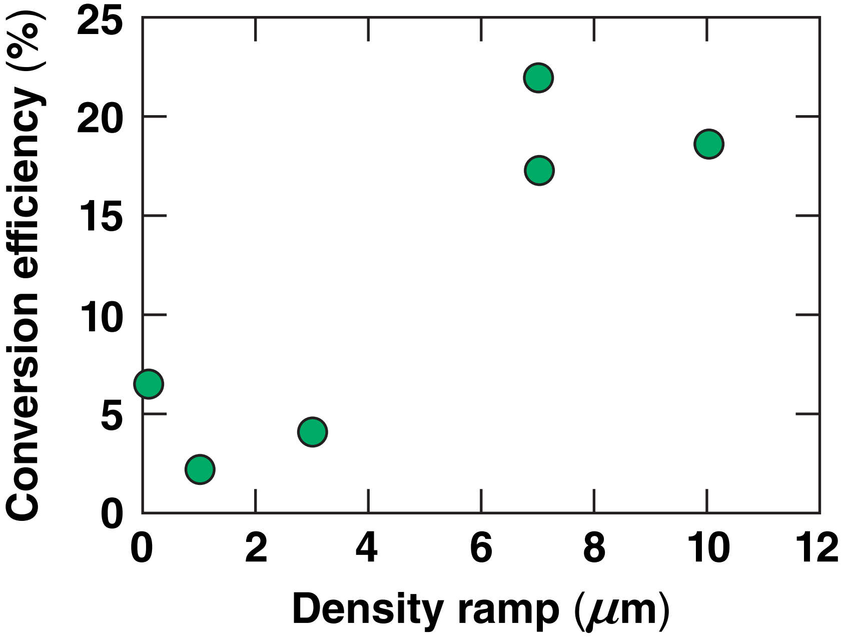


- Fast-electron conversion efficiency increases for the narrow bookend targets compared to flat foils.
- Resonance absorption increases *p*-polarization absorption compared to *s*-polarization (but strong *s*-pol angle dependence is not observed).

A large discrepancy is observed between flat foil targets in this campaign with earlier refluxing targets that may be explained by contrast variations.

Low-density plasma generation from laser prepulses plays an important role in fast-electron generation

Simulated conversion efficiency versus density ramp



- 1-D *LILAC* simulations estimate the low density plasma:
  - measured prepulse contrast
  - does not account for 3-D effects of bookend targets

- 1-D *OSIRIS* simulations calculated absorption for different density gradients:
  - longer density ramps (more low density plasma) yield higher conversion efficiency
  - angle of incidence affects the plasma profile between critical and tenth critical density

Pre-plasma plays an important role in fast-electron generation, so measuring and controlling temporal contrast is important.

Summary/Conclusions

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