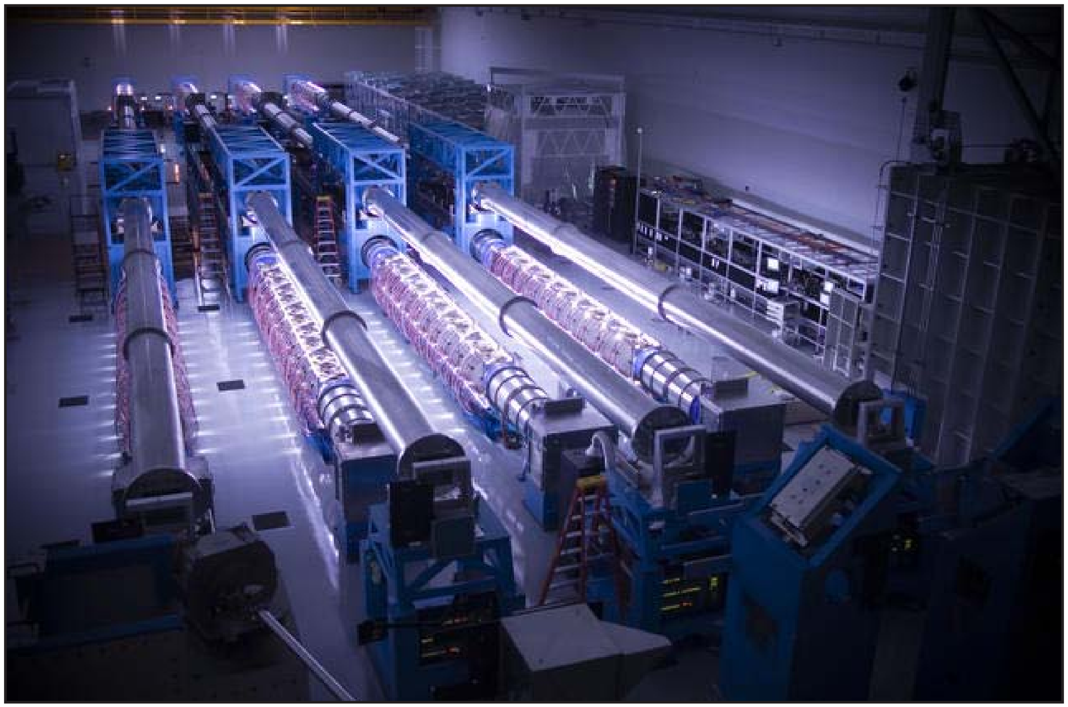
Performance of the OMEGA EP High-Energy Short-Pulse Laser System



B. E. Kruschwitz *et al*.
University of Rochester
Laboratory for Laser Energetics

International Conference on
Ultrahigh Intensity Lasers
Watkins Glen, NY
26 September – 1 October 2010

Summary

OMEGA EP is operational and advancing toward its rated performance level

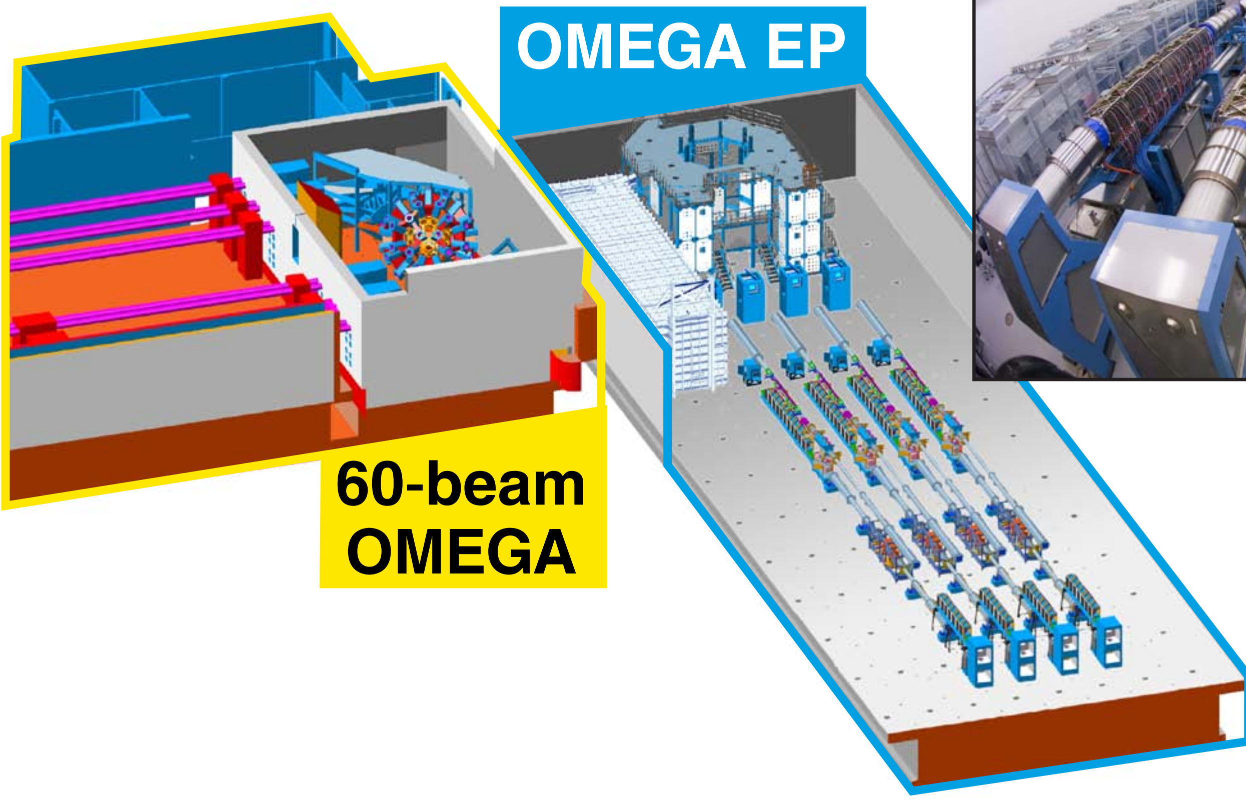
- OMEGA EP is a productive high-energy short-pulse laser enabling scientific advances
- LLE is working to extend the performance to full specifications
  - short-pulse optics performance is being improved–knowledge of safe operating limits is being developed
  - apodization is evolving to optimize beam uniformity–active beam correction is being implemented
- Advancements in short-pulse diagnostics have resulted in improved on-shot characterization capabilities and enhanced system performance

Collaborators

C. Dorrer, M. J. Guardalben, J. H. Kelly, M. D. Moore, J. Qiao, L. J. Waxer, I. A. Begishev, J. Bromage, S.-W. Bahk, L. Folnsbee, D. Irwin, S. D. Jacobs, R. Jungquist, T. J. Kessler, R. W. Kidder, S. J. Loucks, J. R. Marciante, R. L. McCrory, D. D. Meyerhofer, S. F. B. Morse, A. V. Okishev, J. B. Oliver, G. Pien, J. Puth, A. L. Rigatti, T. C. Sangster, A. W. Schmid, M. J. Shoup III, C. Stoeckl, K. A. Thorp, and J. D. Zuegel

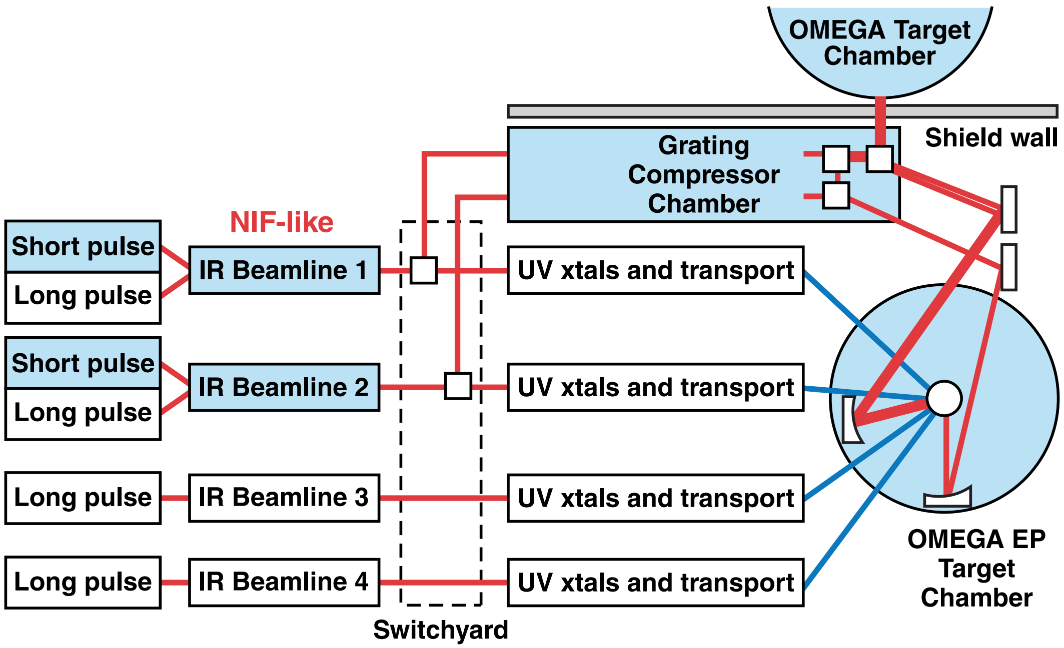
University of Rochester
Laboratory for Laser Energetics

The Extended-Performance (EP) addition to OMEGA is located adjacent to the OMEGA Laser System



E11888w

OMEGA EP is an exceptionally flexible high-energy, high-power laser facility



Beam 1 (IR)	2.6 kJ ($\tau > 10$ ps) 0.4 kJ ($\tau = 1$ ps)
Beam 2 (IR)	2.6 kJ ($\tau > 10$ ps) 1.0 kJ ($\tau = 1$ ps)
Beam 1 ~ 4 (UV)	2.5 kJ ($\tau = 1$ ns) 6.5 kJ ($\tau = 10$ ns)

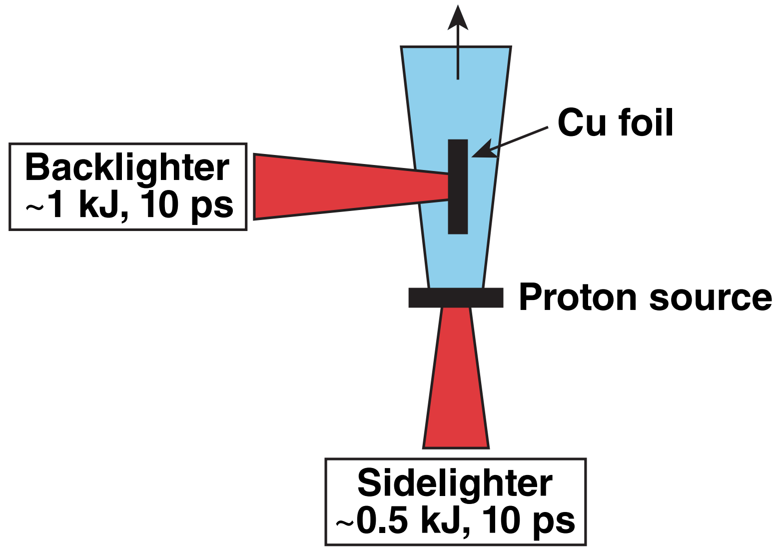
- OMEGA EP delivers two separate kilojoule-level, picosecond-pulse beamlines to the OMEGA EP target chamber
- The two short-pulse beams will be capable of co-propagating to either the OMEGA or OMEGA EP target chamber
- OMEGA EP delivers nanosecond UV pulses in four beamlines to the OMEGA EP target chamber
- The kilojoule-level, nanosecond UV beams can be used together with the short pulse beams

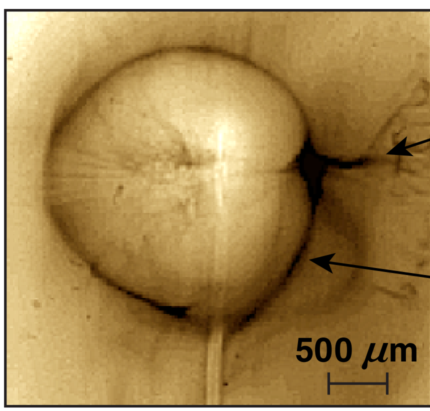
G7791h

OMEGA EP has performed >1000 target shots for a variety of experiments

- Target shots to date
  - 750 short pulse only (188 to Ω TC)
  - 200 long pulse only
  - 78 combined short and long pulse
- Scientific advances enabled
  - integrated fast ignition
  - positron production
  - proton radiography

Proton radiography measurements of target charging





Electron jet

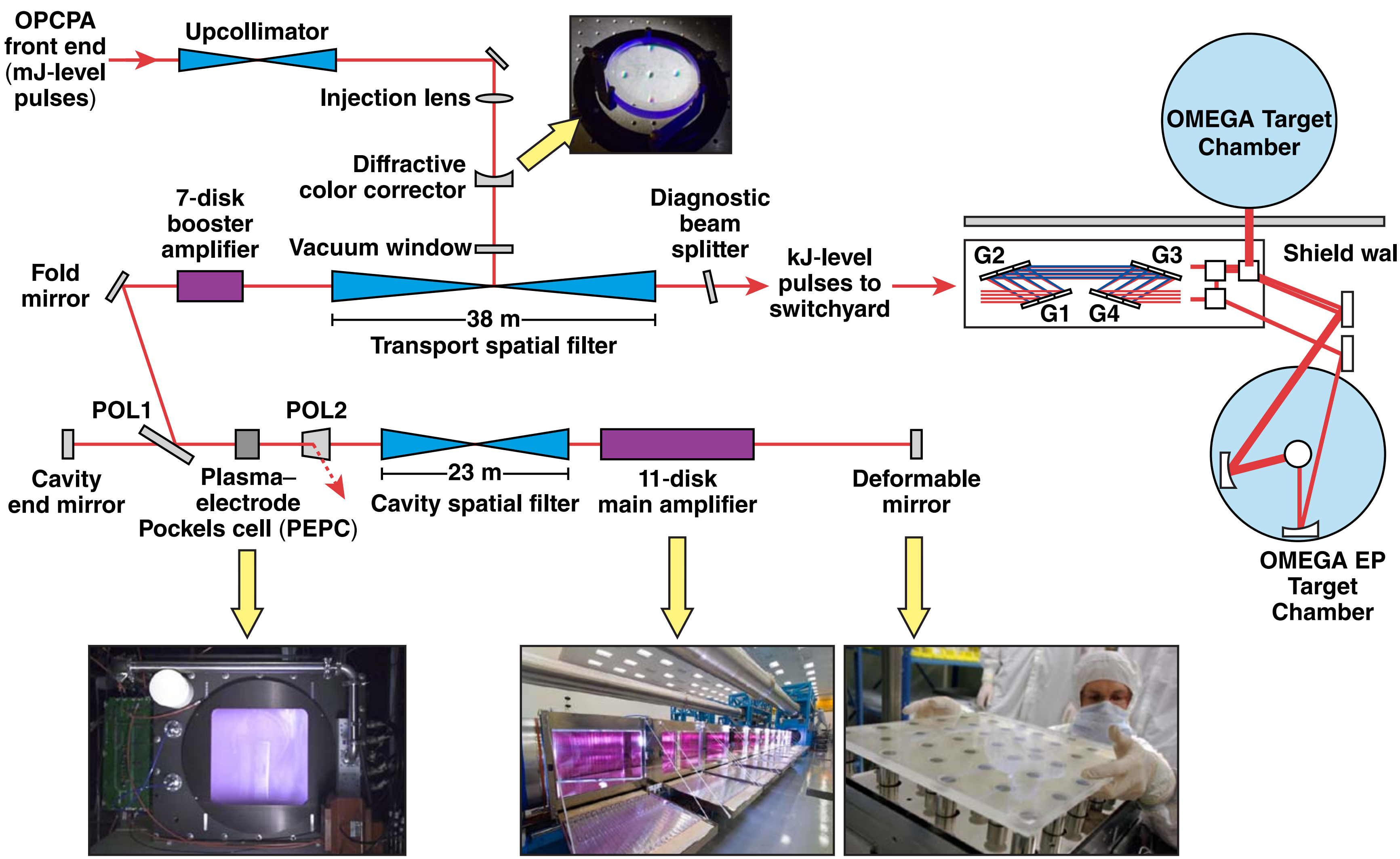
Expanding sheath field

P. M. Nilson *et al*., "Scaling Hot-Electron Generation to High-Power, Kilojoule-Class Laser–Solid Interactions," submitted to Phys. Rev. Lett.

G9112

OMEGA EP IR beamlines use a folded architecture based on the NIF

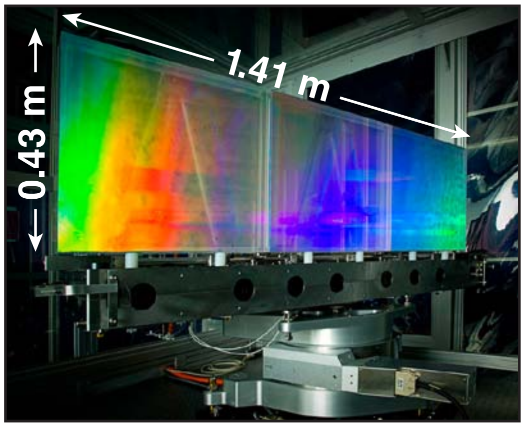
UR LLE



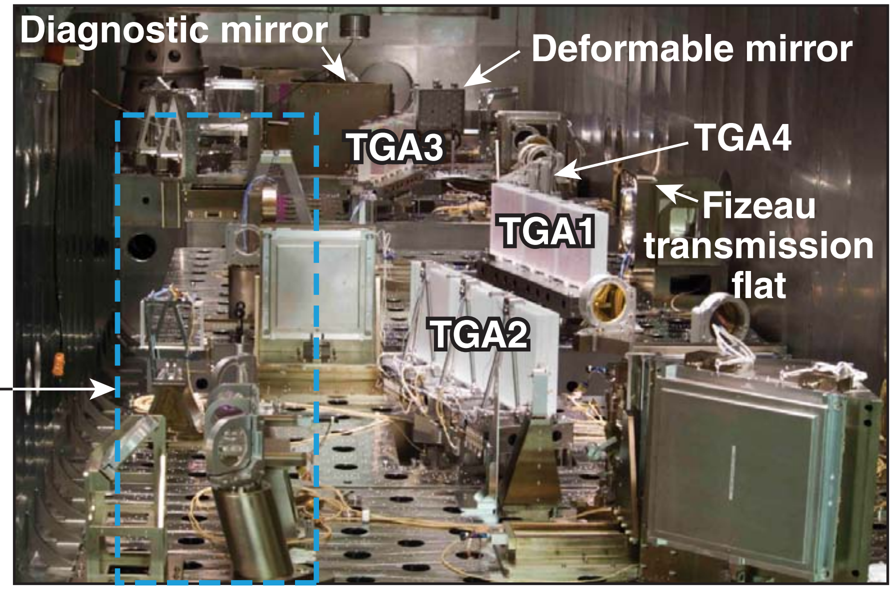
G7793g

Each compressor is comprised of four tiled-grating assemblies (TGA’s)

Tiled-grating assembly



Short-pulse diagnostic path



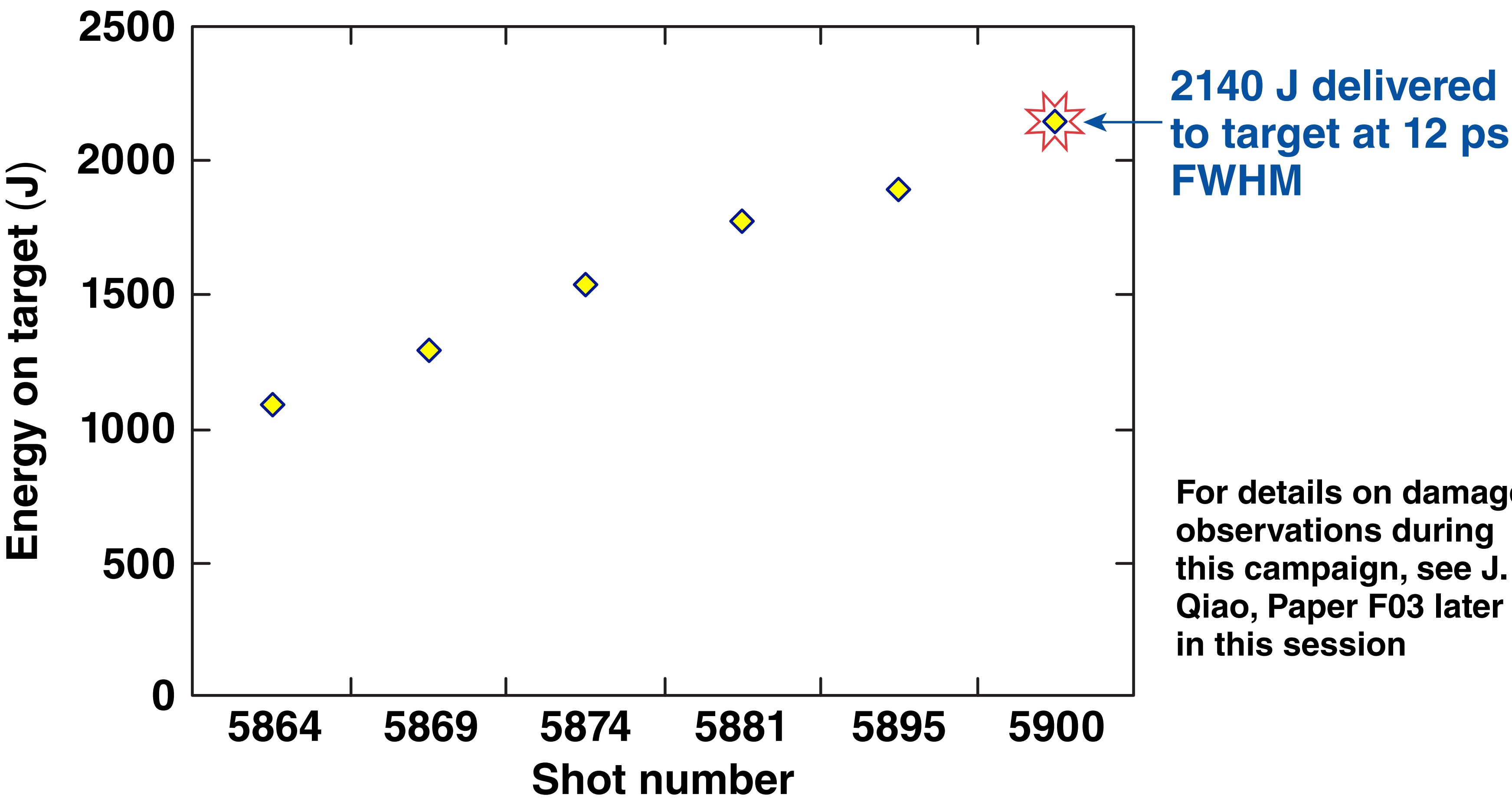
- The TGA’s are interferometrically tiled inside the grating compressor chamber at vacuum
- Fourier fringe analysis is used to tile the TGA’s and to retrieve TGA wavefront
- Differential piston, tip, and tilt are automatically calculated and removed for initial tiling
- Tiled positions are maintained by closing the actuator control-loop with feedback of position displacement sensors
- Submicroradian angular stability is achieved

G9114

J. Qiao *et al*., Opt. Express 15, 9562 (2007).

An energy ramp to >2.1 kJ at ~12 ps was performed in September 2009

UR LLE



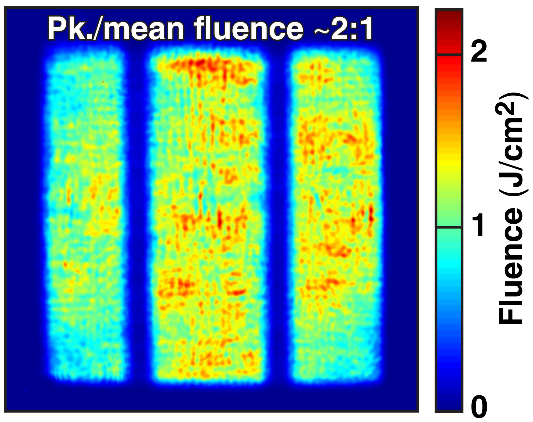
For details on damage observations during this campaign, see J. Qiao, Paper F03 later in this session

Damage was observed on the final grating and downstream optics. Energy is currently limited to 1 kJ at ≥ 10 ps as a result.

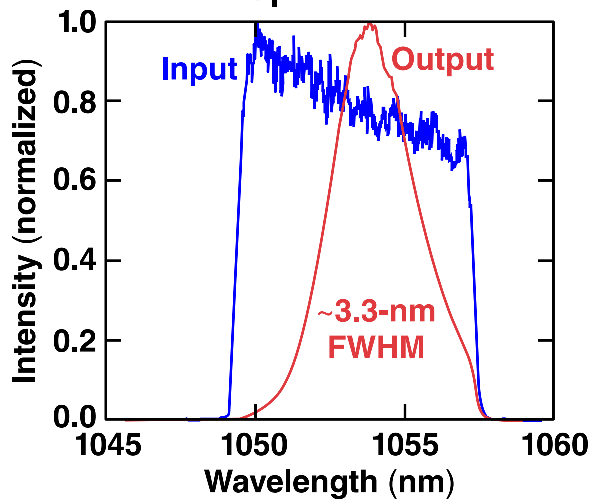
G9144

Typical performance of a BL2 1-kJ shot (need to come up with a sentence title)

Near field



Spectrum

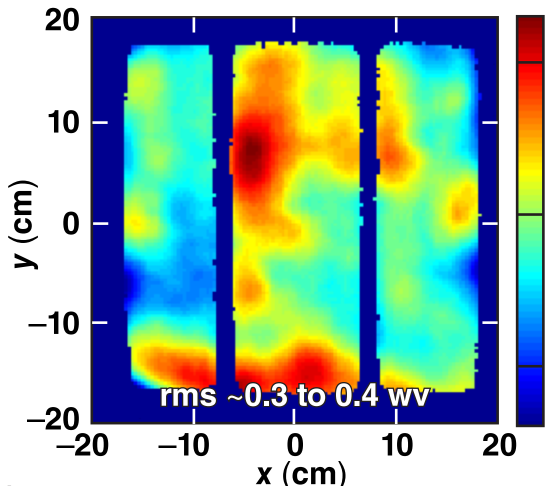


Pointing ~15-μm rms

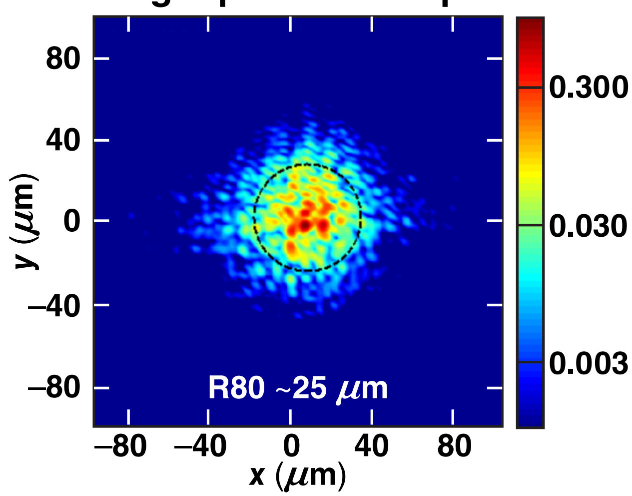
Energy contrast ~10^4

Power contrast ~10^6 for 10-ps pulses

Wavefront



Target-plane focal spot



G9145

OMEGA EP is aggressively working to meet its design specifications

Design Energy Performance	Current Energy Performance
1 PW (600 J at 0.6 ps)	0.5 PW (300 J at 0.6 ps)
2.6 kJ for $\tau \geq$ 10 ps	1.0 kJ for $\tau \geq$ 10 ps

Challenges

- Increase short-pulse damage threshold of gratings and transport optics
- Optimize beam fill factor and minimize beam modulation
- Minimize on-target focus-spot size
- Minimize prepulse

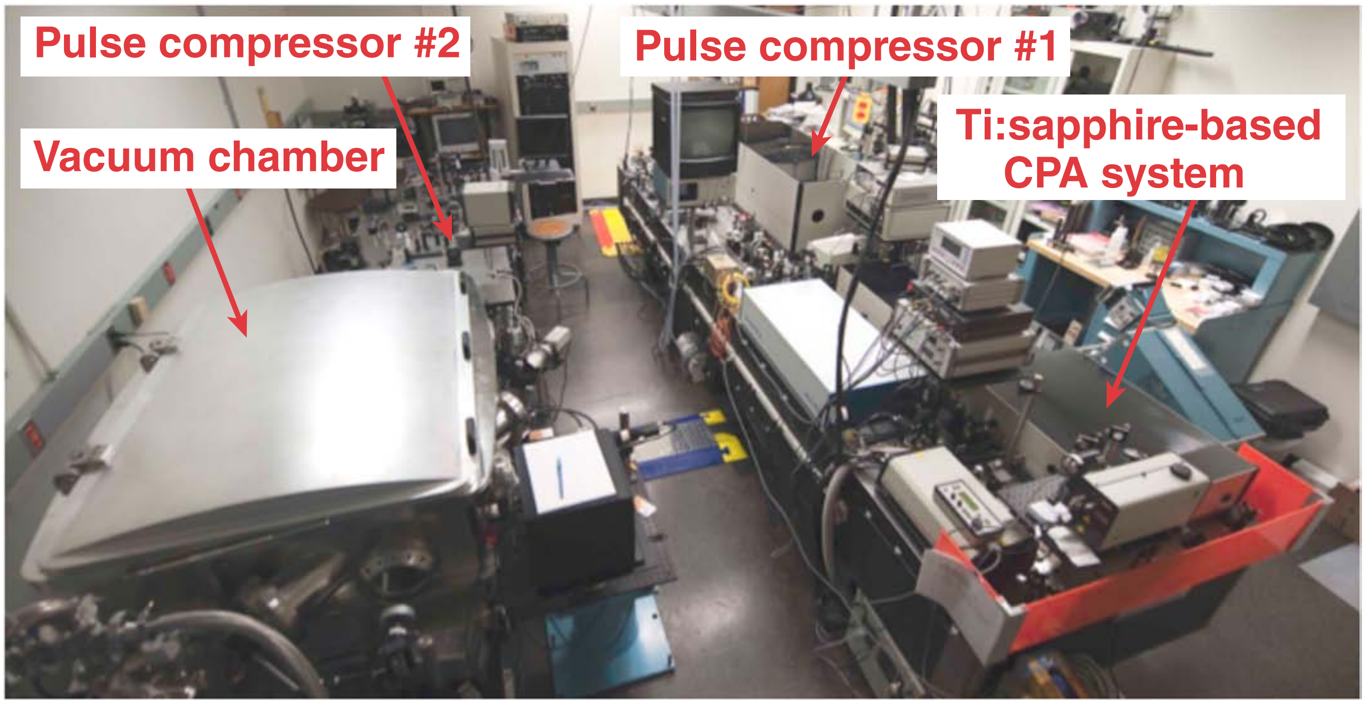
G9115

LLE has a comprehensive program to improve the performance of short-pulse optics

- **Dedicated short-pulse vacuum damage-testing facility**
- ***In-situ* grating damage detection**
- **MLD coating facility with electron-beam or plasma-assist deposition on large OMEGA EP size optics (~0.9-m diagonal), which provides options for environmental stability and/or film stress control**
- **Metrology**
  - **AFM and Nomarski microscopes that allow evaluation of full-scale OMEGA EP optics**
  - **high-resolution SEM for witness-sample assessment**
- **Theoretical modeling of electric-field enhancement to guide grating design**
- **Analytical support for cleaning chemistry studies**

G9116

LLE built a dedicated vacuum, short-pulse-laser damage-test facility

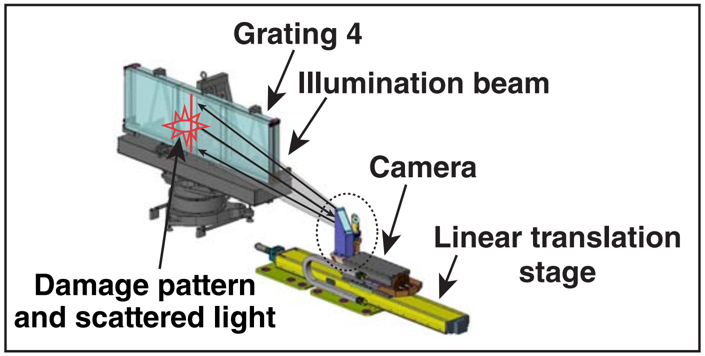


- 1.053-μm ultrafast laser system provides tens of millijoules at a 0.1-Hz repetition rate with a 0.6- to 100-ps pulse-width range
- Vacuum vessel provides damage testing at 10^{-6} Torr

G9117

OMEGA EP uses a grating inspection system (GIS) to detect damage on the final grating assembly

Grating inspection system



Scanned image of TGA4

Contrast enhanced to emphasize damage features

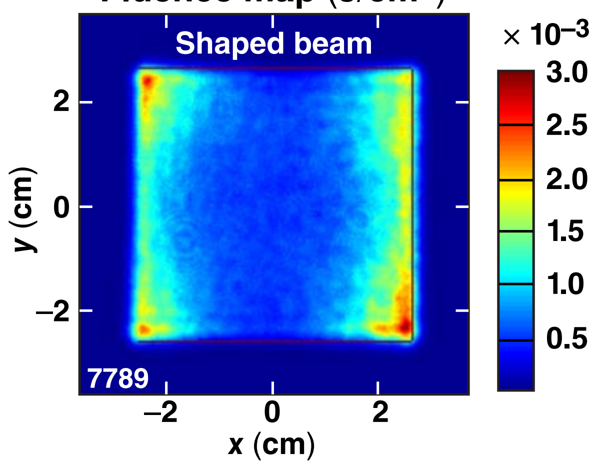
- A line-shape illumination generator projects a focused line onto the grating surface
- A 10-bit linear charge-coupled device (CCD) measures the scattered light from any features on the grating surface
- The line-shape generator and the CCD are scanned across the grating to generate a composite two-dimensional image of the entire grating surface
- Features ≥250 μm in size are detected

J. Qiao, this conference (Paper F03).

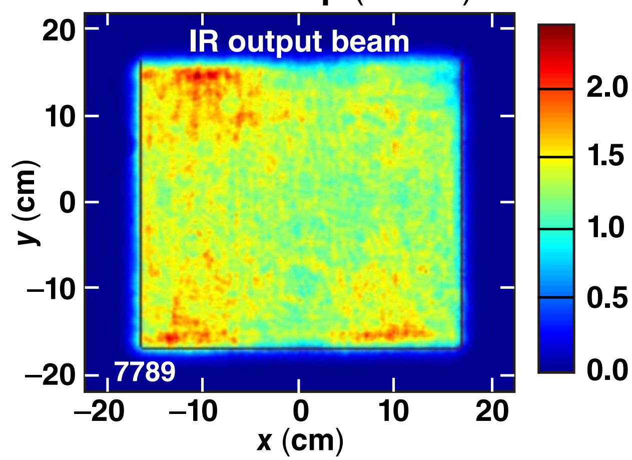
OMEGA EP is evolving its capability to compensate gain nonuniformity and optimize beam quality

Current approach: static beam shaping with an apodizer

Fluence map (J/cm^2)



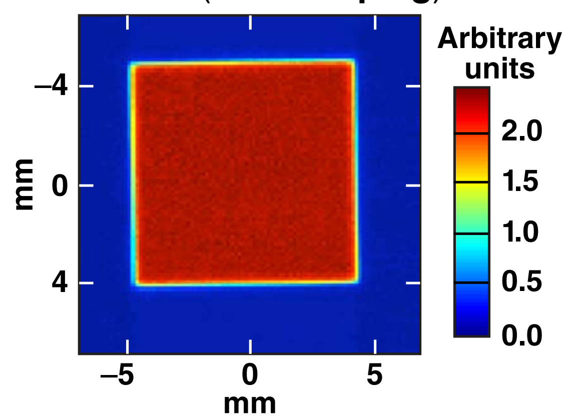
Fluence map (J/cm^2)



Future enhancement: a programmable spatial-light modulator will refine the statically shaped beam

Hamamatsu LCOS-SLM
Area: 12 × 16 mm^2
Resolution: 600 × 792 (20-μm pixel)
Dynamic range: 2 waves

Fluence (after shaping)

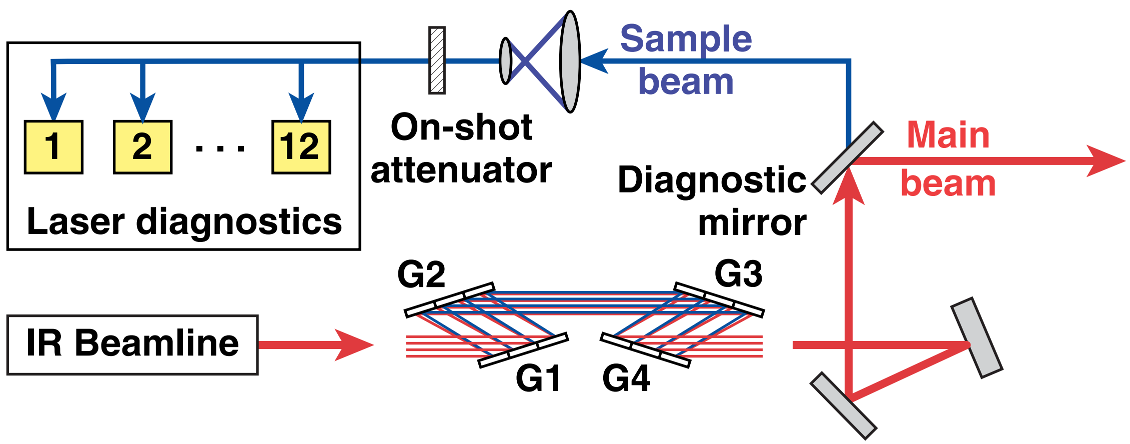


Beam-shaping results from prototype testing

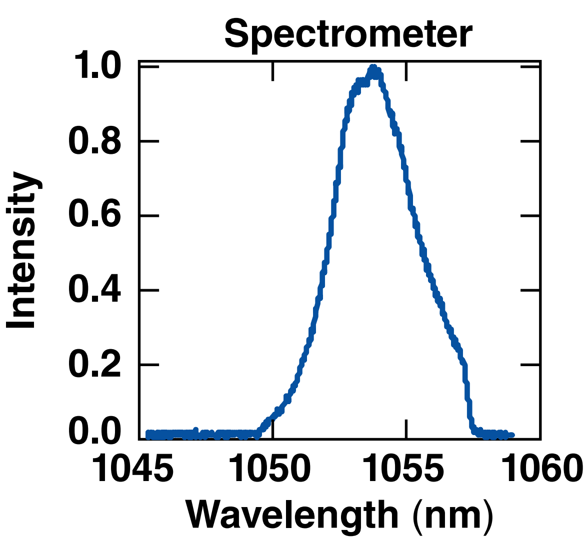
S.-W. Bahk, this conference (F04).

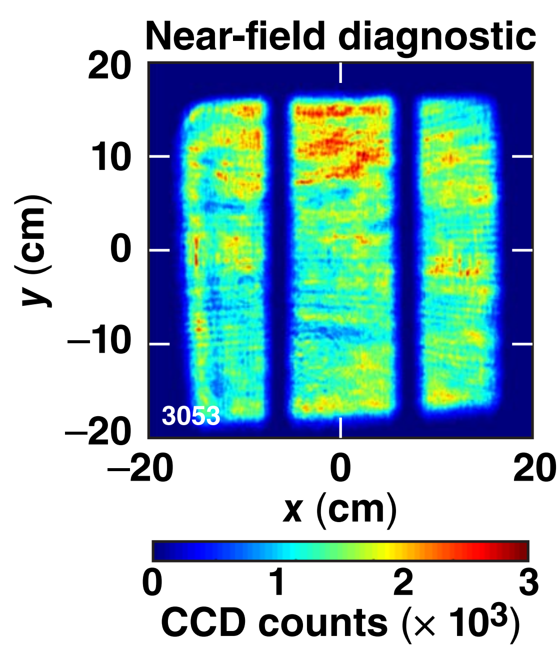
G9119

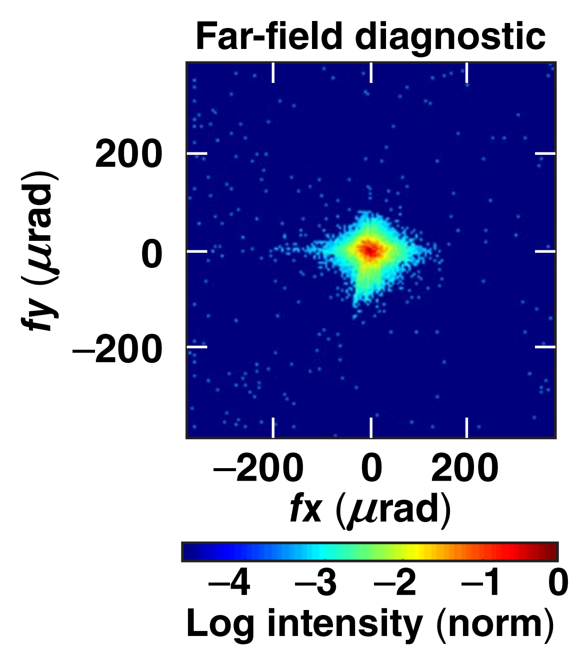
The short-pulse diagnostics package (SPDP) is used for pre-shot and on-shot pulse characterization



- Temporal diagnostics
- Spectrometer
- Near field
- Far field
- Wavefront
- Energy
- On-target focal spot
- Contrast

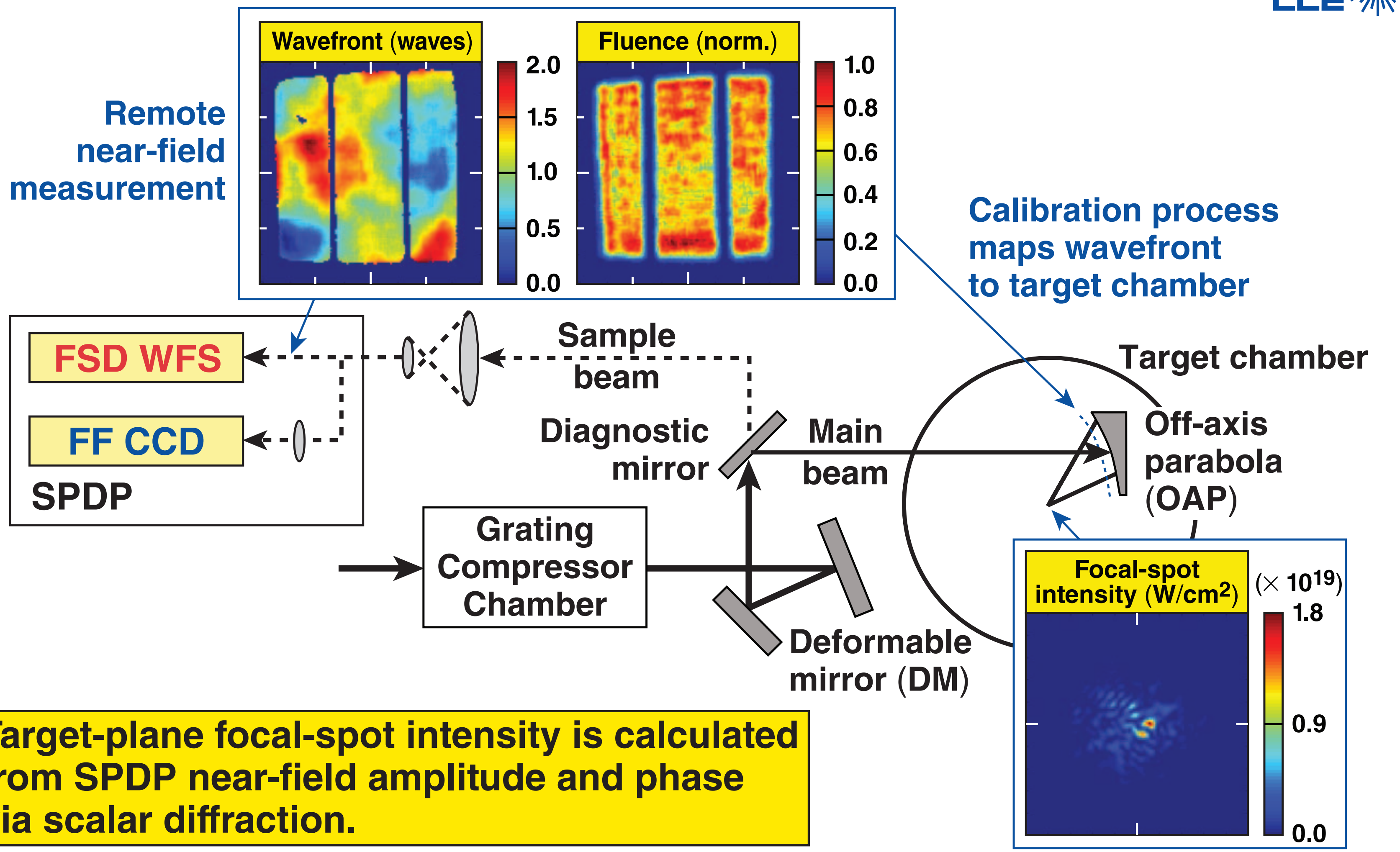






G8236d

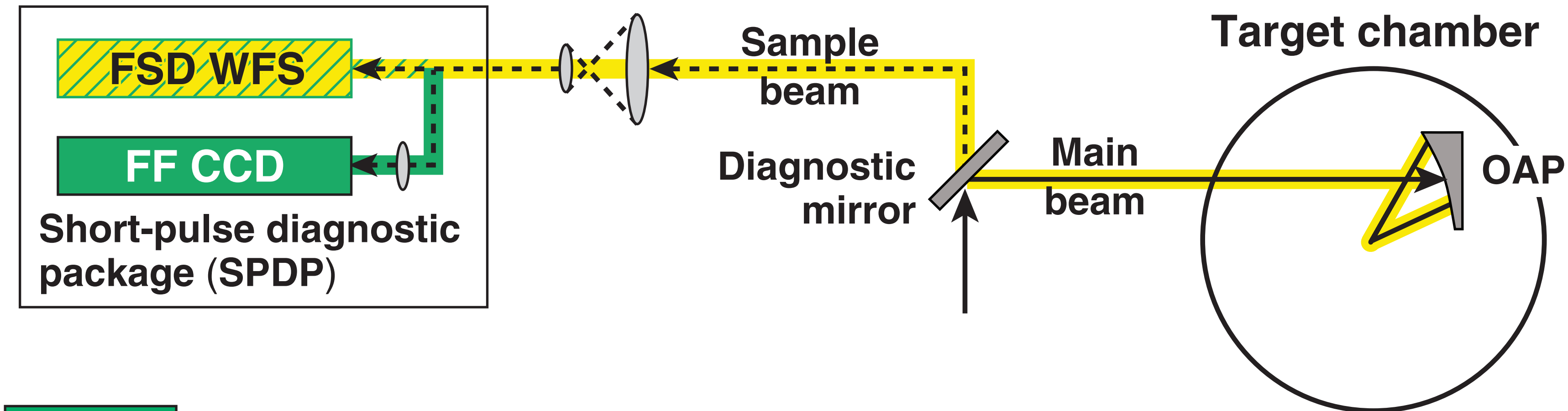
The focal-spot diagnostic (FSD) uses remote, on-shot near-field characterization to determine the on-target energy density



Target-plane focal-spot intensity is calculated from SPDP near-field amplitude and phase via scalar diffraction.

J. Bromage *et al.*, "A Focal-Spot Diagnostic for On-Shot Characterization of OMEGA EP," ICUIL 2008, Shanghai-Tongli, China, 27 October 2008.

A two-step strategy using phase retrieval from far-field image data is used to improve measurement accuracy



Step 1: Produce accurate prediction of the focal spot measured by the nearby far-field CCD camera

1. Phase retrieval of static lens errors
2. Phase retrieval of average relative phase among beam segments
3. Fourier analysis to estimate effects of polychromatism

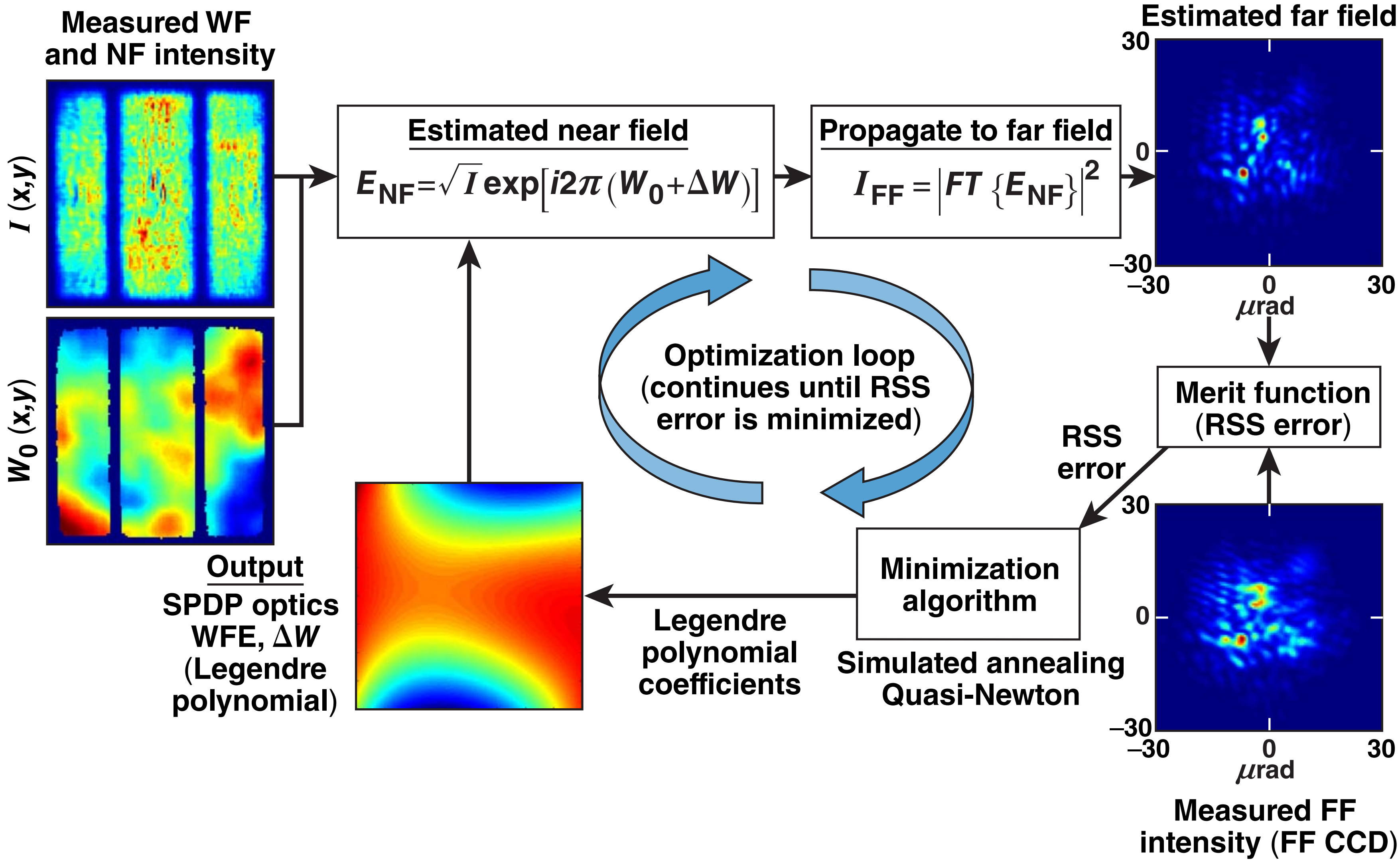
Step 2: Obtain accurate focal-spot measurements in the distant target chambers

1. Phase retrieval of static calibration errors

G8963a

B. E. Kruschwitz *et al.*, this conference (Poster MP3).

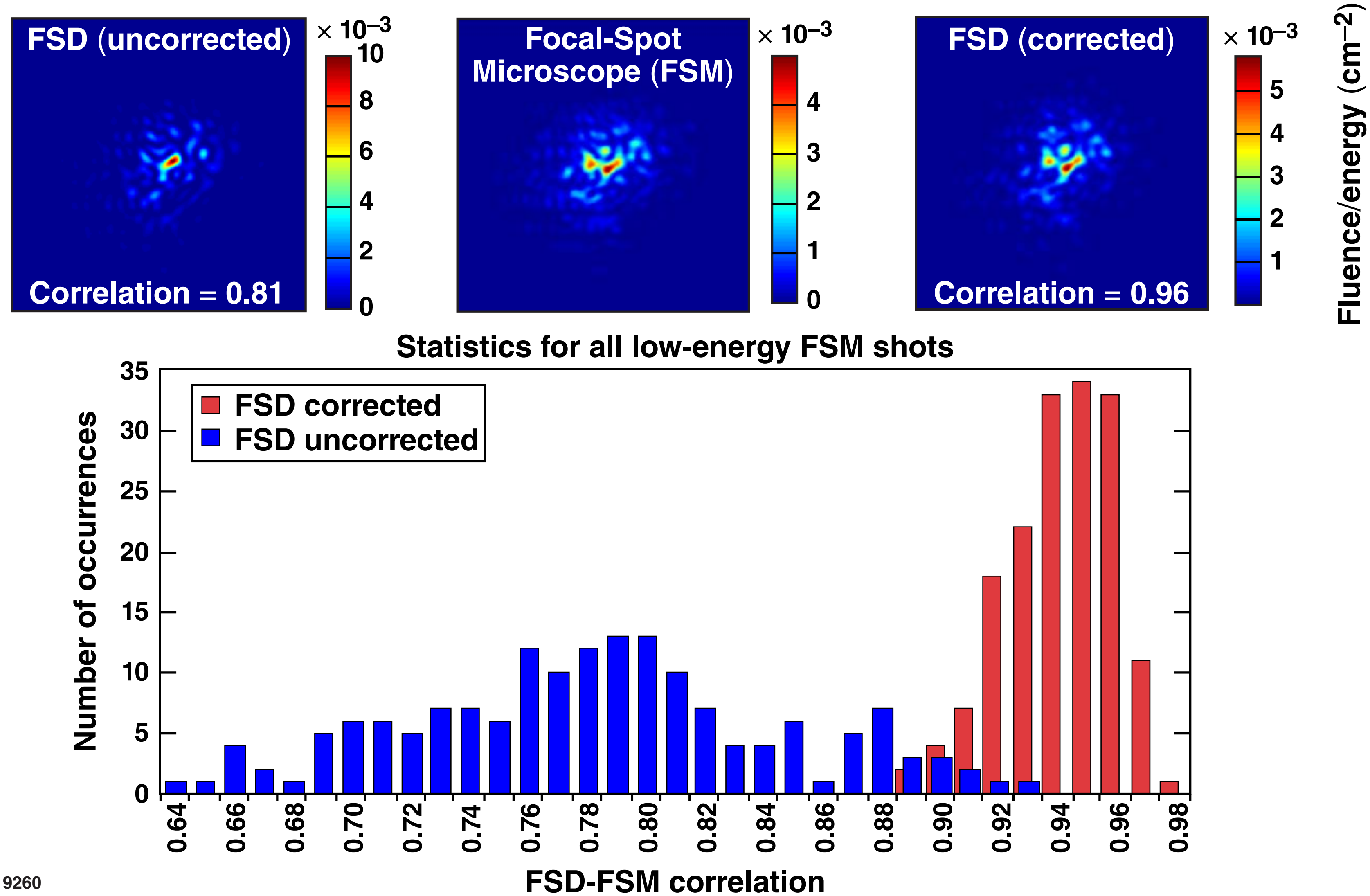
A modal phase-retrieval algorithm is used to retrieve wavefront information from focal-spot images



E18819

J. R. Fienup, Appl. Opt. 21, 2758 (1982).

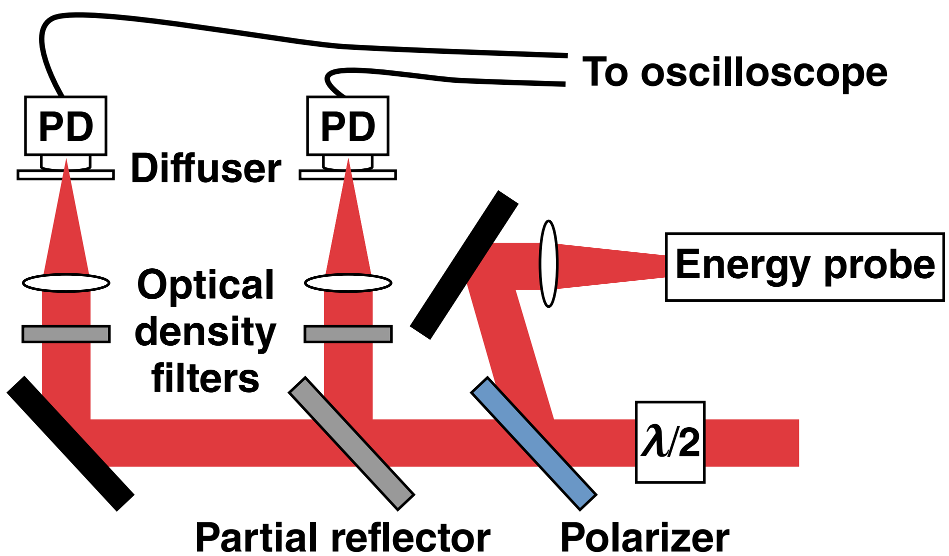
FSD accuracy was confirmed with direct target-plane microscope images in low-energy qualification testing



E19260

OMEGA EP currently uses two diagnostics to measure temporal contrast

- Two operational diagnostics
  - scanning cross-correlator for 5-Hz OPCPA front-end characterization (Sequoia, Amplitude Technologies)
  - fast photodiodes and oscilloscope for on-shot nanosecond contrast characterization of BL1 and BL2



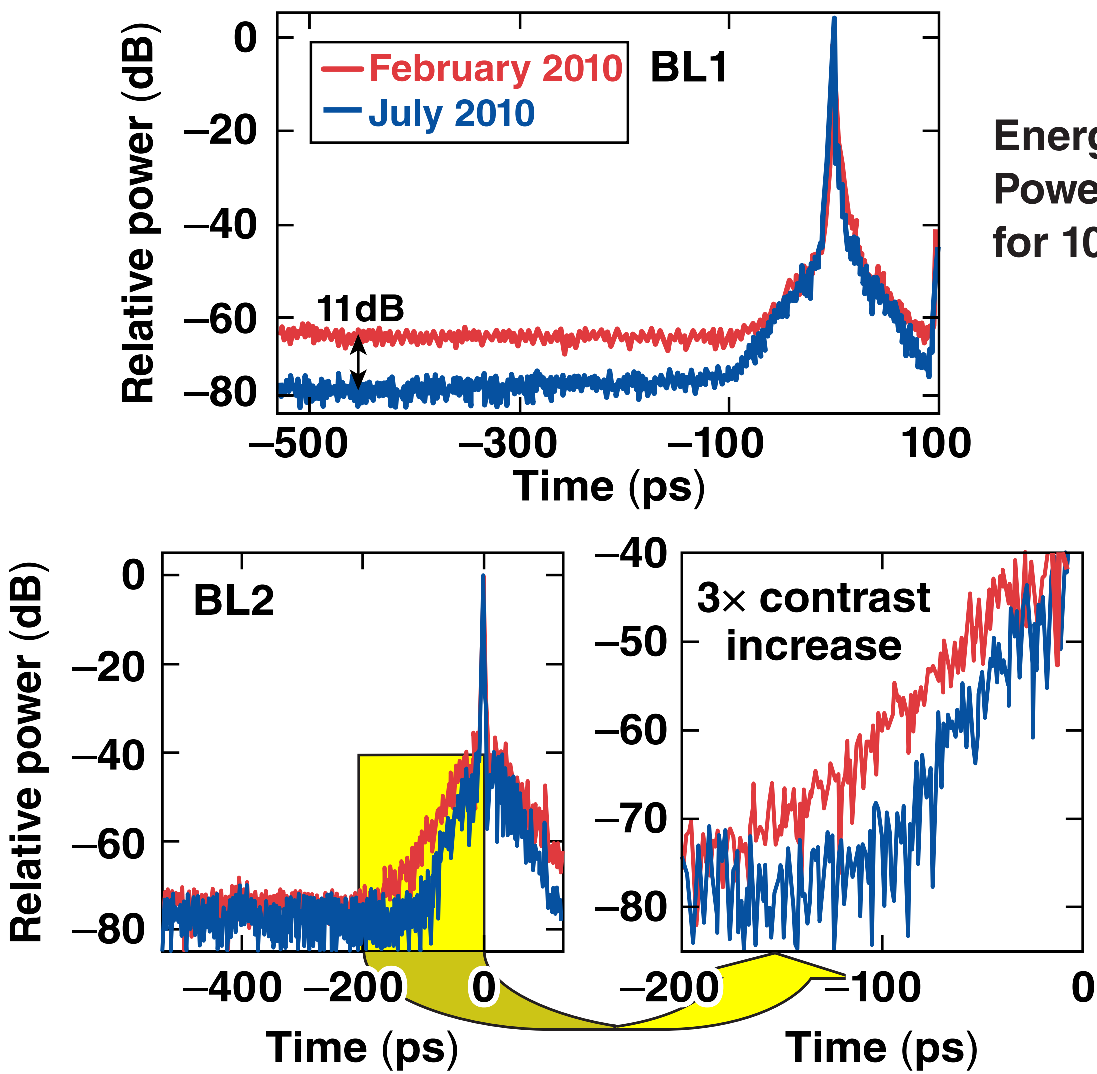
- One diagnostic under development: on-shot cross-correlator for contrast measurement in the 500-ps window before the main pulse

G9120

C. Dorrer, this conference (Paper Th03).

The contrast diagnostics have contributed to improved pulse contrast on both beamlines

Contrast of OPCPA at best compression



Energy contrast ~10^4
Power contrast ~10^6
for 10-ps pulses

G9121

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