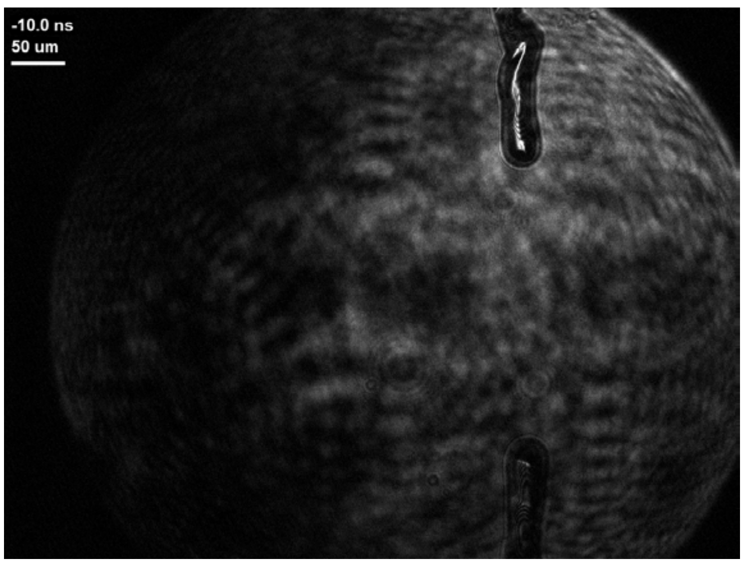
Death Star

Precision liquid target development for kHz relativistic laser-matter interaction studies



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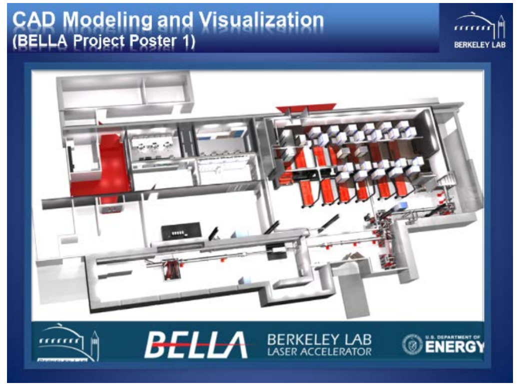
THE OHIO STATE UNIVERSITY

Outline

- Motivation
- AFRL Lab liquid target development
- Experiment: Relativistic electron generation with precision liquid targets
- Other efforts in target developments
  - Liquid crystals
  - Reduced mass

Motivation

SCARLET 500 TW, 0.0167 Hz



BELLA > 1 PW, 1 Hz

LLNL HAPLS laser ELI Beamline, > 1PW, 30 fs, 10 Hz

- Advent of High Rep rate lasers
- Applications:
  - High rep rate sources
    - Ions (Cancer Therapy, HZDR)
    - Neutrons (Karsch, Kitagawa, DARPA Pulse NE-OSU-UT)
    - Electrons, x-rays, positrons (many groups)
- Experiments
  - FEL/XFEL rep-rate high (LCLS 120 Hz, European XFEL, SASE, and others)

Kitagawa Nat. Phys. 2013
Neutron Generation 1 Hz

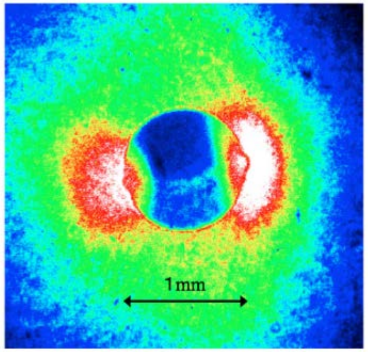


Figure 1 | Snapshot of a flying pellet at the instant of engagement by using a 2ω harmonic laser probe. The probe is perpendicular to the

Protein crystallography

*Solem 1986, Neutze...Hadju 2000, Chapman et al 2006 – first experiment, low resolution.
*Chapman, Fromme......Spence Nature 2011; Spence , Weierstall, Chapman Rep Prog Phys 2012 (Review).

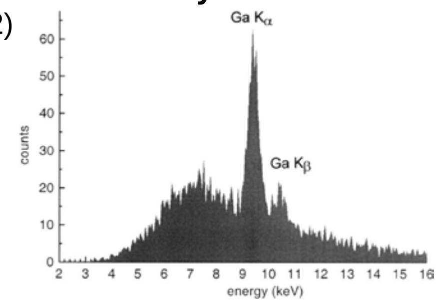
Why liquid target?

Liquid-jet target for laser-plasma soft x-ray generation
L. Malmqvist, L. Rymell, M. Berglund, and H. M. Hertz, RSI 67, 4150 (1996)

Ultrafast x-ray pulses emitted from a liquid mercury laser target
Christian Reich *et al.* Opt. Lett, 32, 427-429 (2007)

Ultrashort 1-kHz laser plasma hard x-ray source
Korn *et al.* Opt. Lett. 27, (2002)

MBI+MPQ

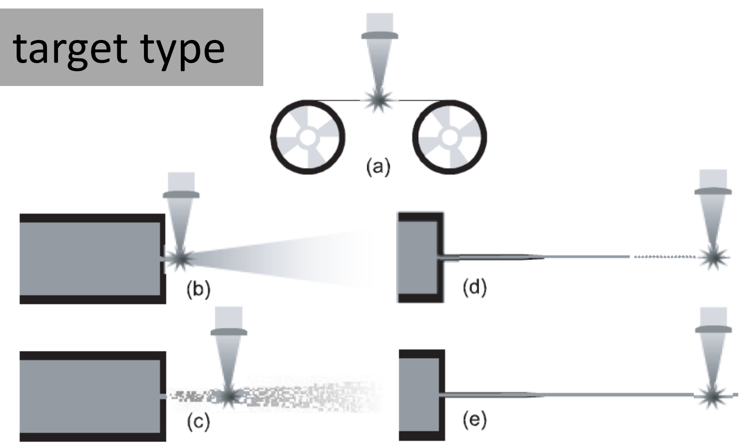


Individual solid target in Relativistic laser matter interaction cost $1 – $10,000 ea

- Pros
  - Cost effective
  - Potential to go to Multi-kHz
  - Alignment potentially easier than solid targets
  - Debris evaporates

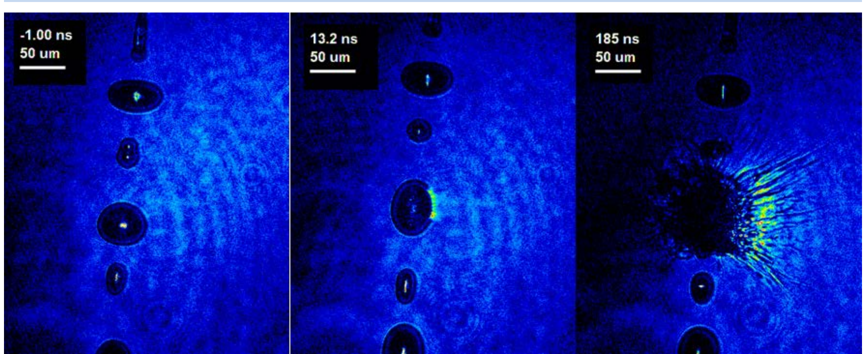
- Cons
  - Hard to produce very thin targets
  - High vapor pressure for some liquids
  - May cause corrosion inside chamber

Liquid target type

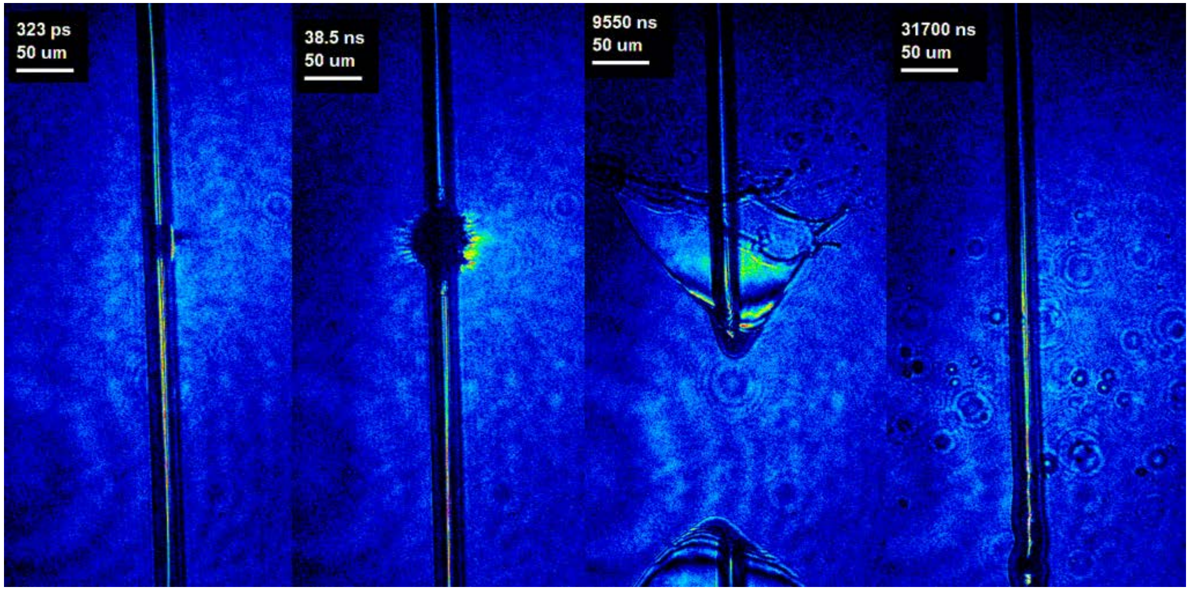


Hansson and Hertz, J. Phys. D: Appl. Phys. **37** (2004) 3233–3243

Imaging Methanol Droplet Interaction in AFRL Dayton



Precision Liquid targets at AFRL

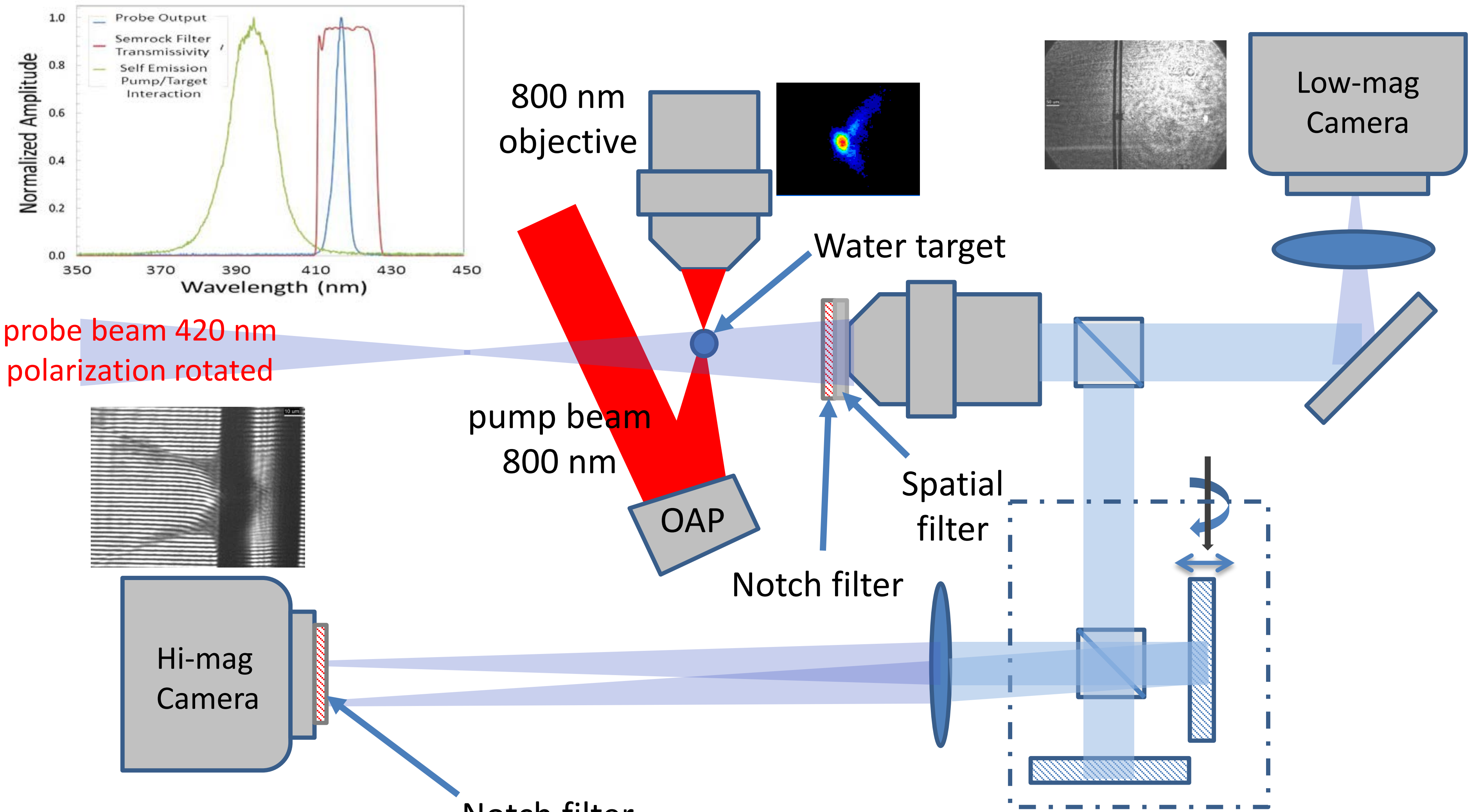


- Liquid targets produced in 0.9 – 20 Torr
- Target type
  - Jet column (30-200 µm),
  - droplets (> 5 µm),
  - Sheet (~300 nm)
- Positioning accuracy: 1 µm
- Healing time from 10 – 40 µs

Experiments at > 10^{18} Wcm^{-2} intensities with liquid targets

Liquid target interaction Probing system

Single oscillator splits into pump (780 nm) and shifted probe amplifier (830 nm)

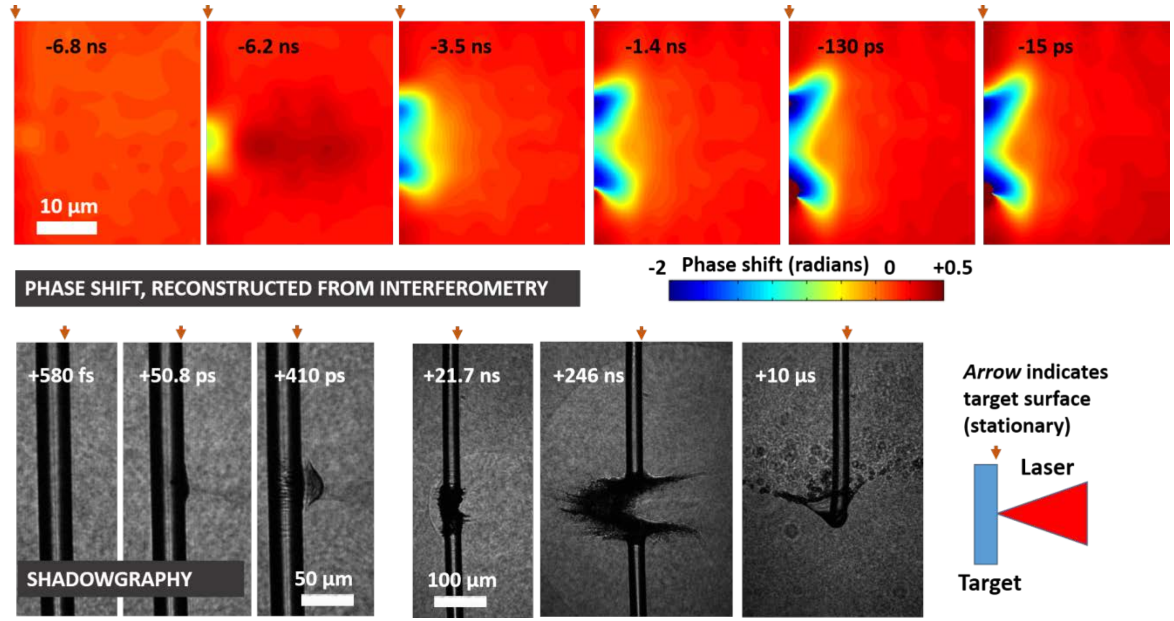


Shearing Michelson Interferometer (Nees, UM)

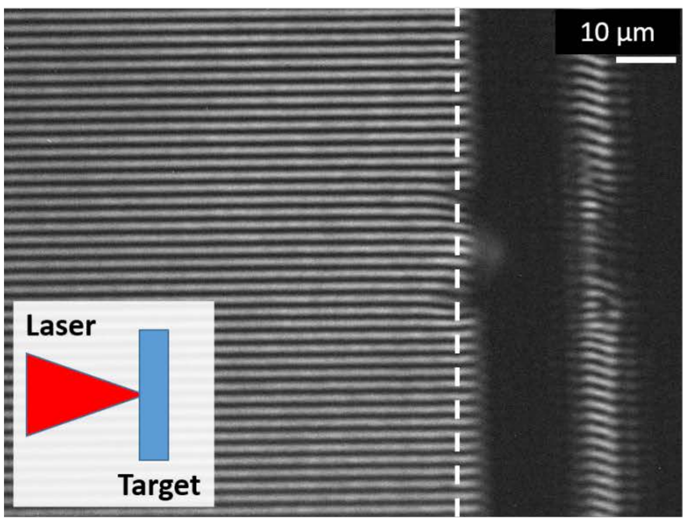
Target pre-plasma diagnostic

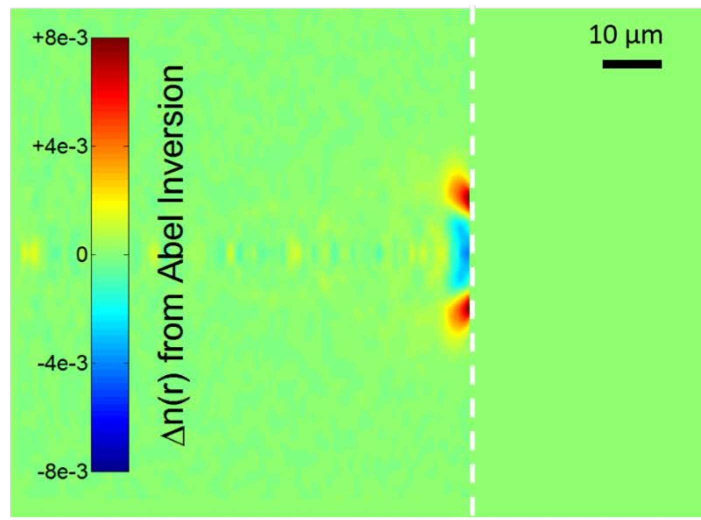
Interferometry and shadowgraphy

- Pre-pulse generated pre-plasma detection with 10^{18} Wcm^{-2} interactions in water
- Distinguish regions of *plasma* from *vacuum* and *neutral* regions

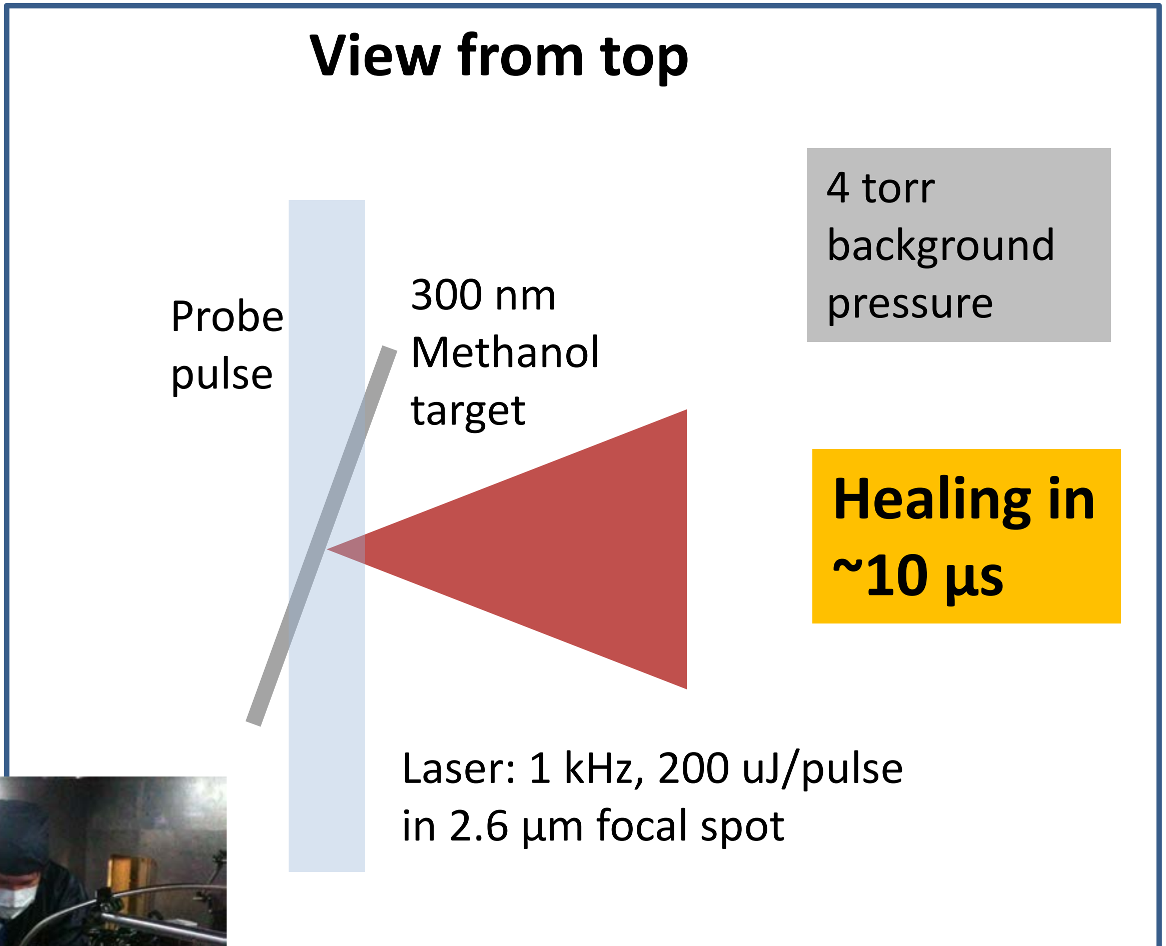


Feister et al.
Rev. Sci. Instruments, 85, 11D602 (2014)
A novel femtosecond-gated, high-resolution, frequency-shifted shearing interferometry technique for probing pre-plasma expansion in ultra-intense laser experiments

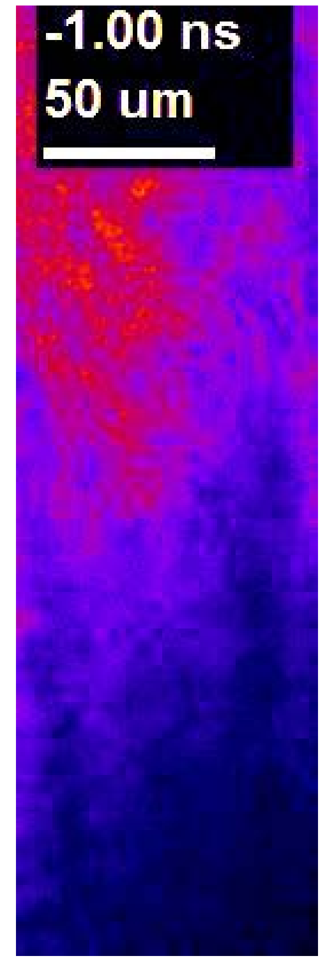




Submicron laminar sheet healing in vacuum



Side view

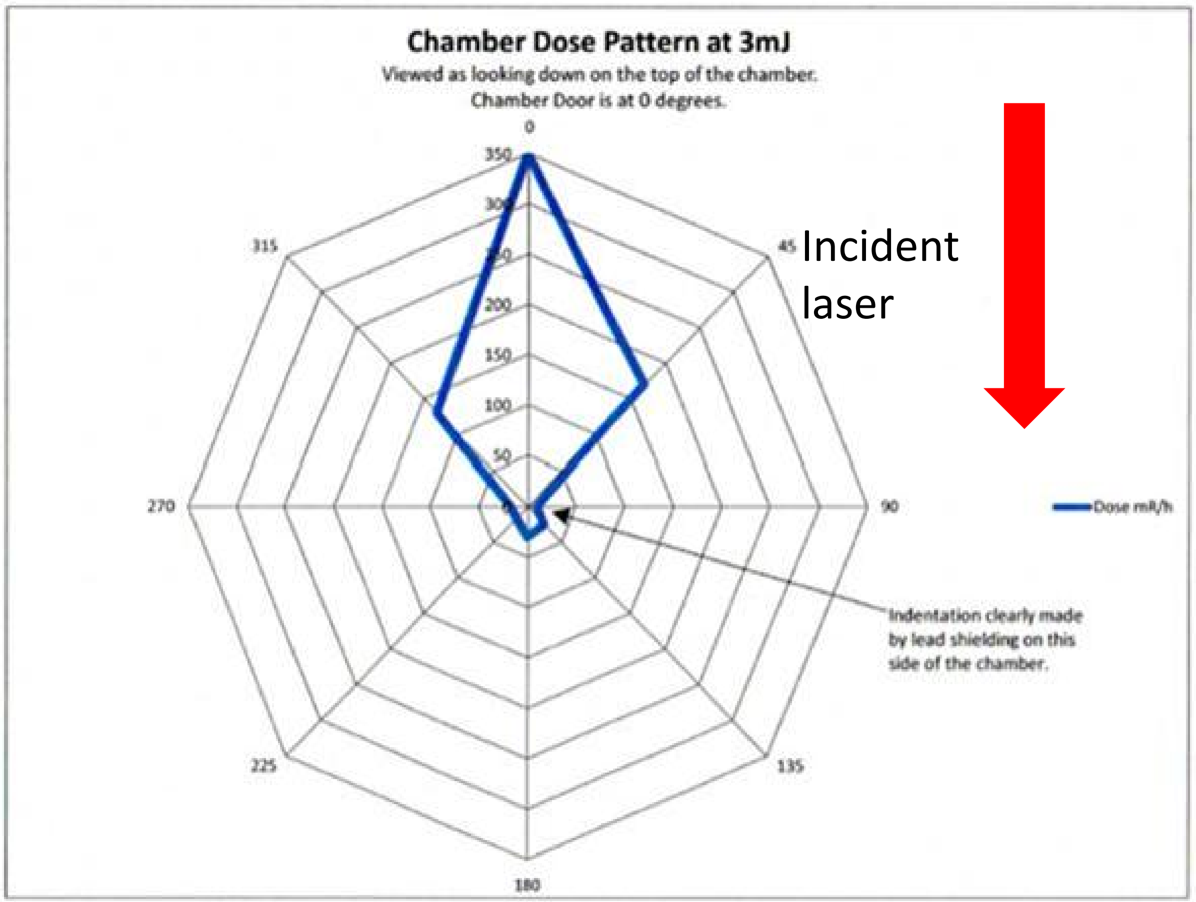


Morrison *et al.* RSI in preparation

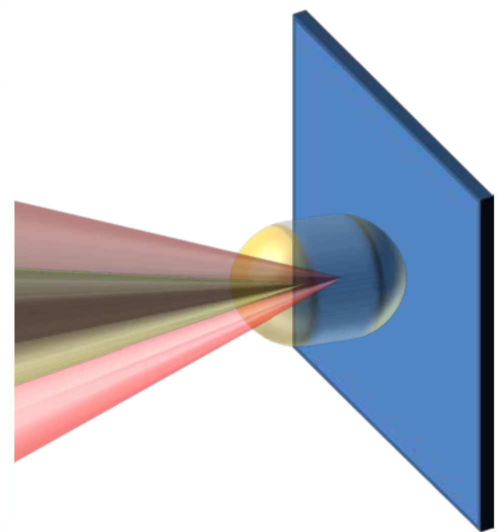
Experiment:

Relativistic electron generation with precision liquid targets

Conventional Wisdom: LPI

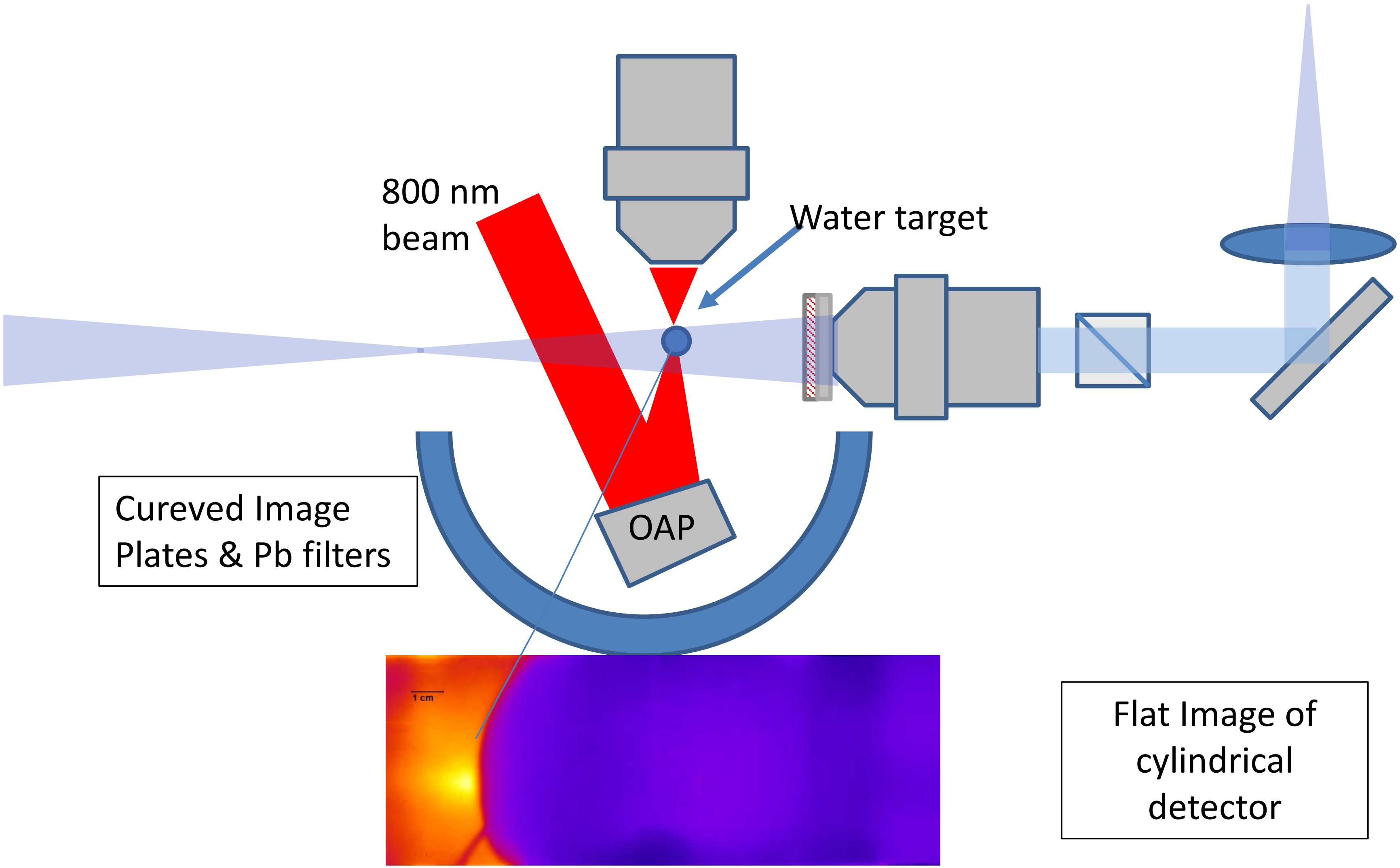


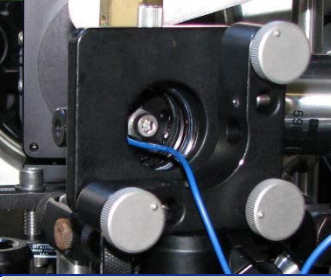
What we expected from
ional Ultra-intense LPI
sms: Ionized electrons
ed in the laser field
ropagates in forward
with significant energy



observed: Backward going MeV electron beam

Added Panoramic Image Plate



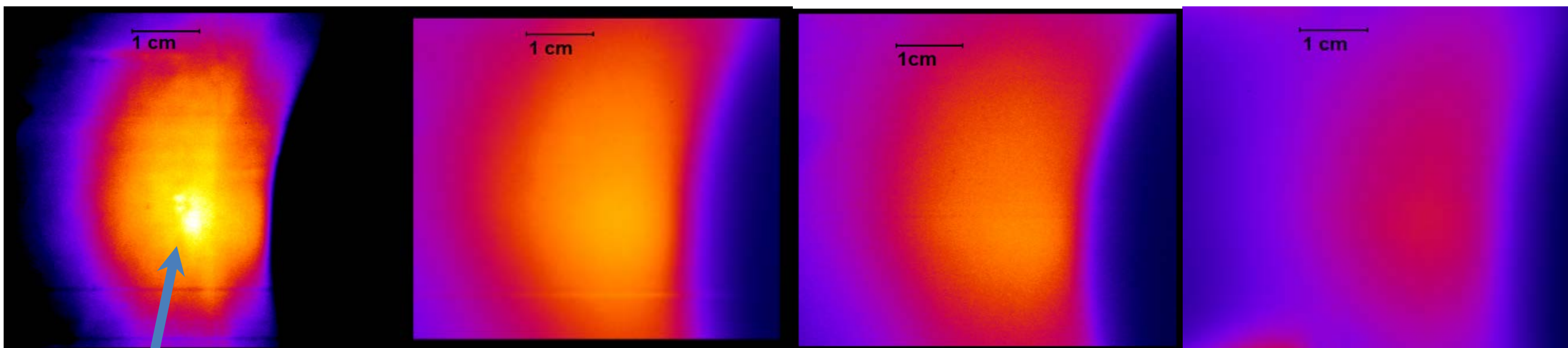


X-ray Dose Through Pb Filters

Image Plate's View of OAP & mount

Beamlike dose through 4mm of Lead Implies spectral components > 200keV

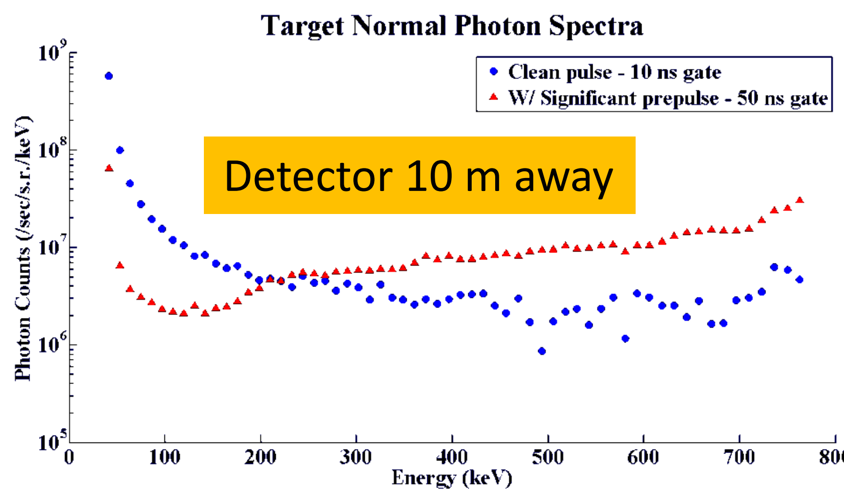
1 mm Pb | 2 mm Pb | 3 mm Pb | 4 mm Pb



Central Feature 3-5° apparent divergence

Integrated over ~ 10^5 shots

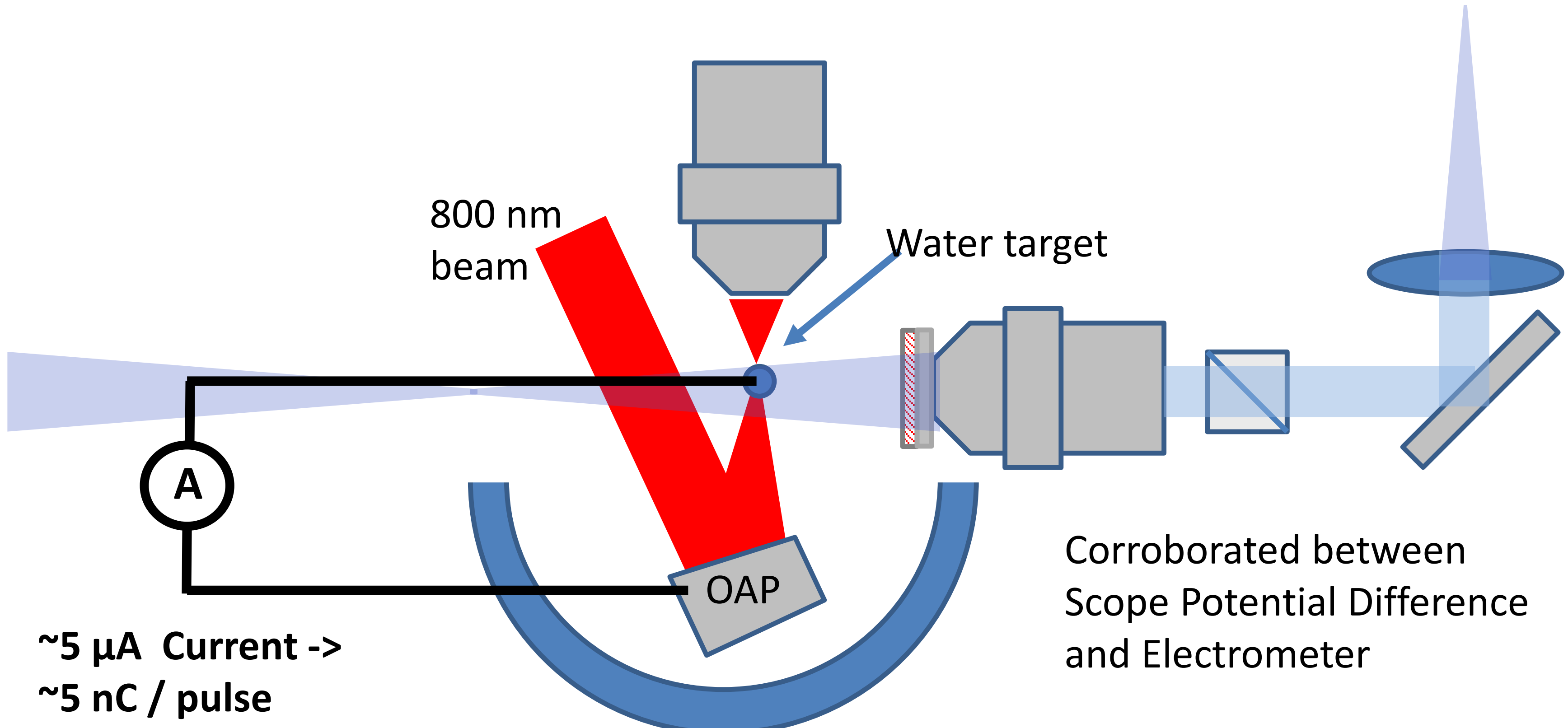
We then decided to observe single hit x-ray spectra



Detector 10 m away

Backward-propagating MeV electrons from 10^{18} Wcm^{-2} laser interactions with water Morrison et al. PoP (2015)

Collect back-scattered electrons using isolated OAP as Faraday Cup



Corroborated between Scope Potential Difference and Electrometer

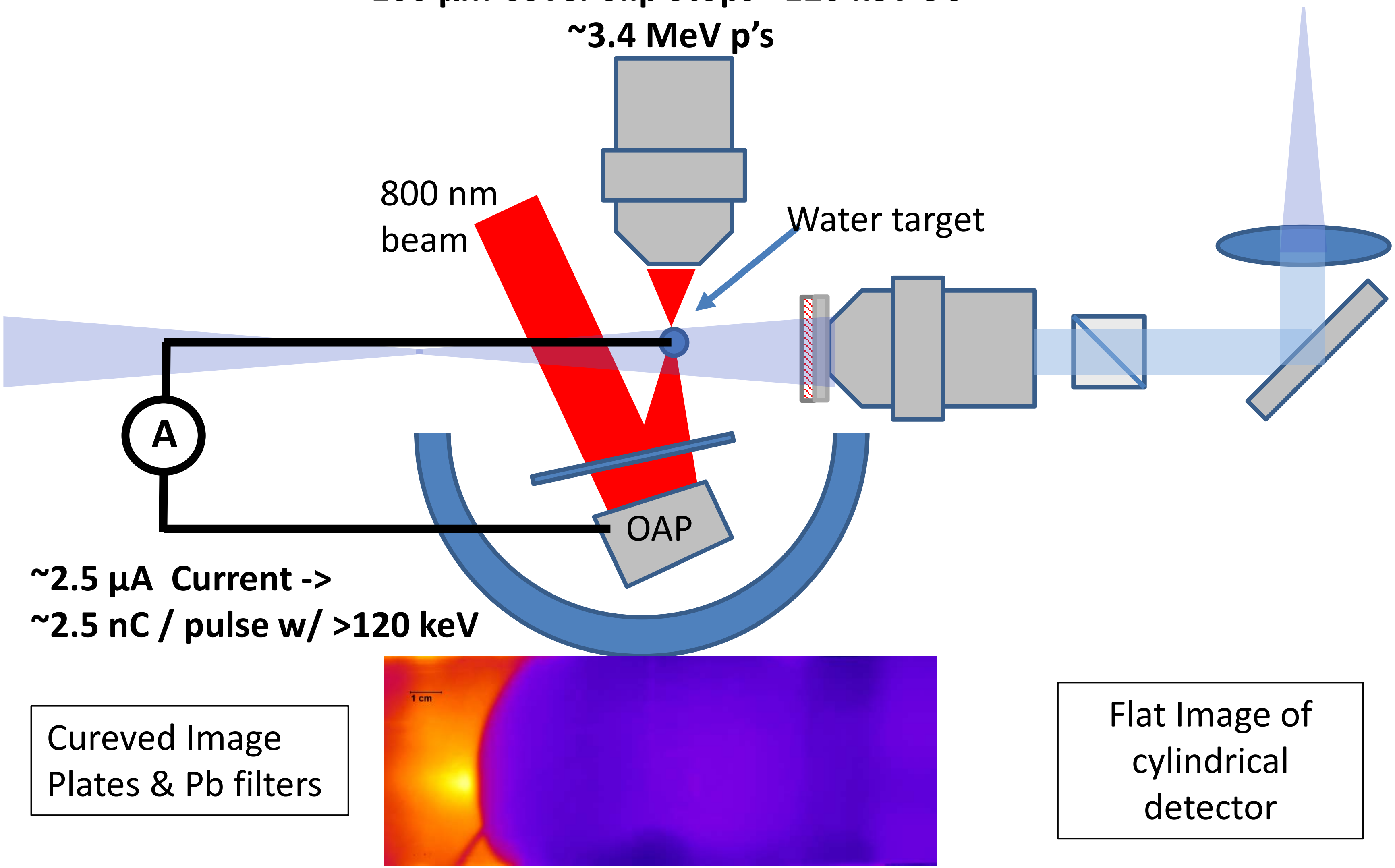
~5 µA Current ->
~5 nC / pulse

Cureved Image Plates & Pb filters

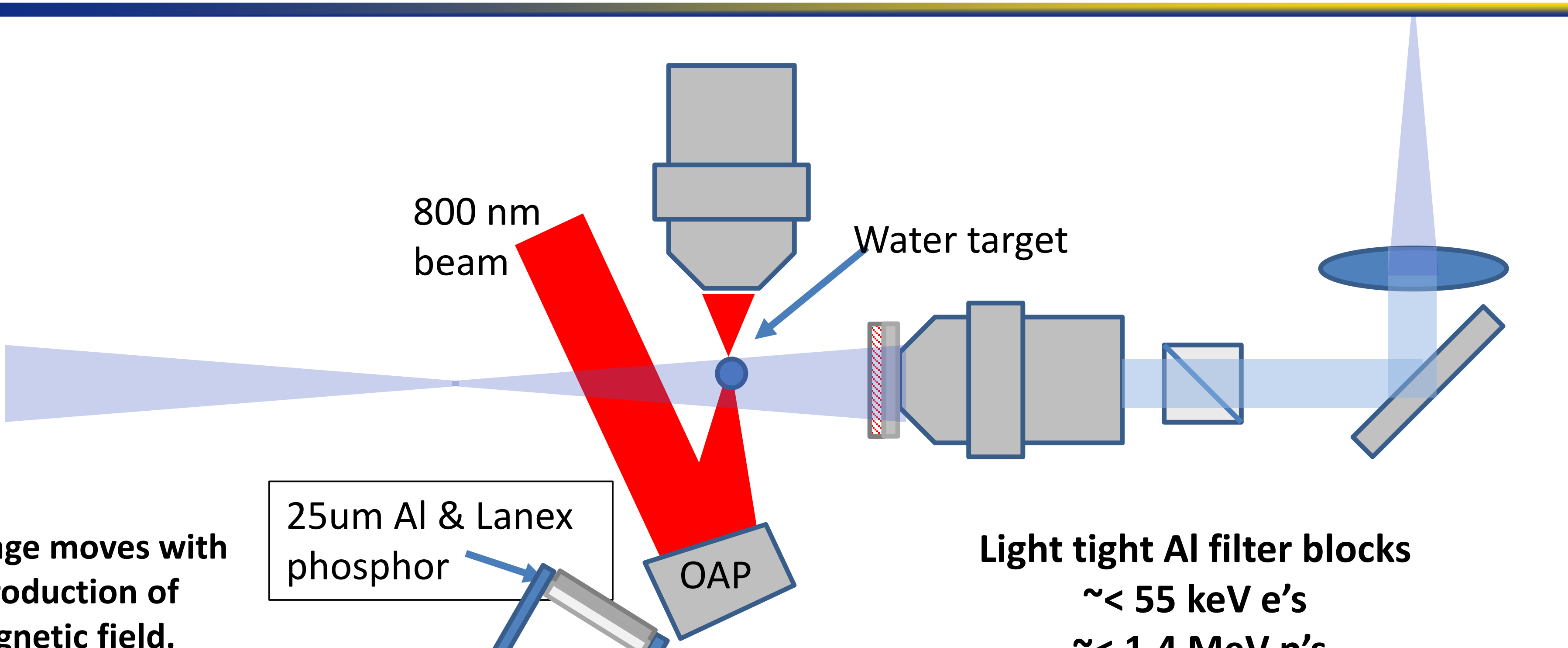
Flat Image of cylindrical detector

Current Measurement Through 100 µm BK7 Glass

100 µm Cover Slip Stops ~120 keV e's
~3.4 MeV p's



Backscattered electrons on Imaged Lanex Screen



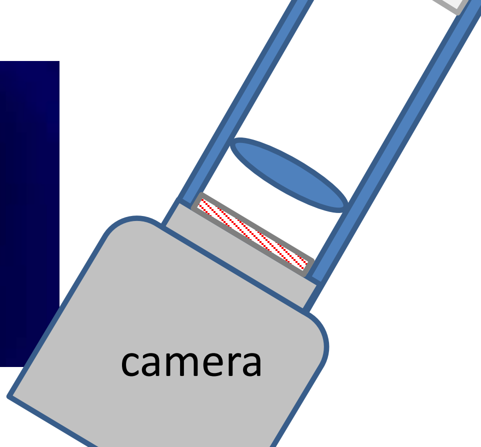
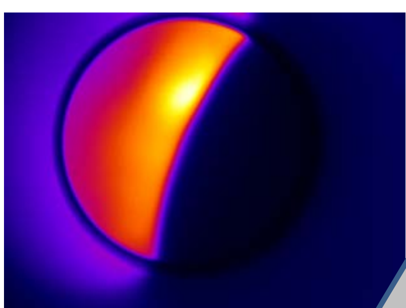
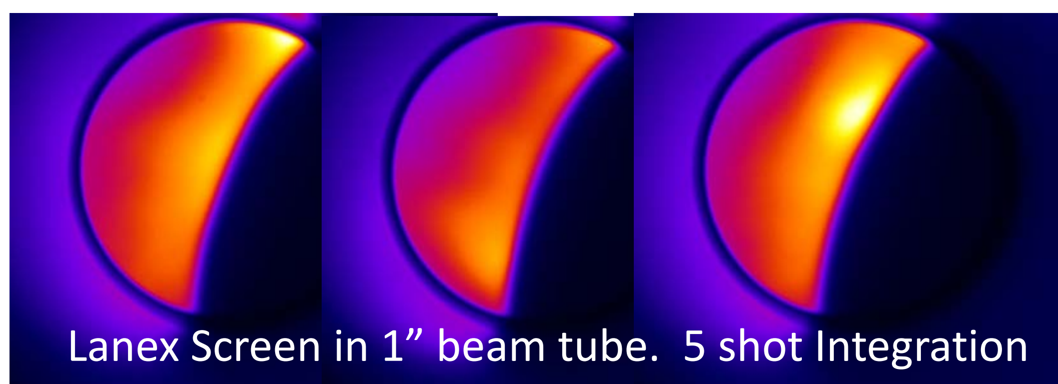


Image moves with introduction of magnetic field.

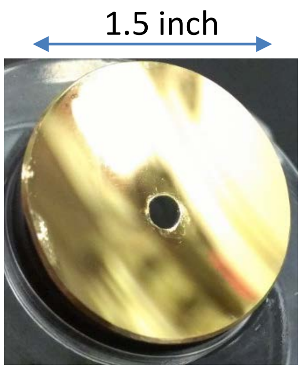


Light tight Al filter blocks
~< 55 keV e's
~< 1.4 MeV p's

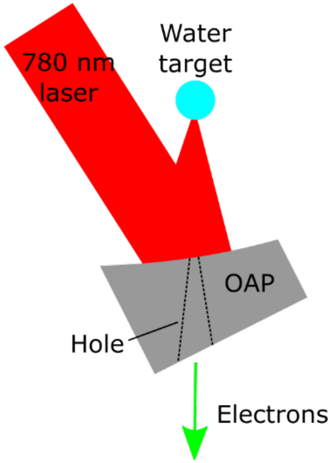


Direct Electron Measurement with H-OAP

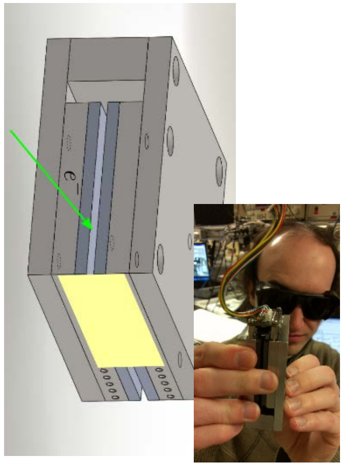
- Hole is 3-mm, 10 degree cone.



The "Holey OAP"

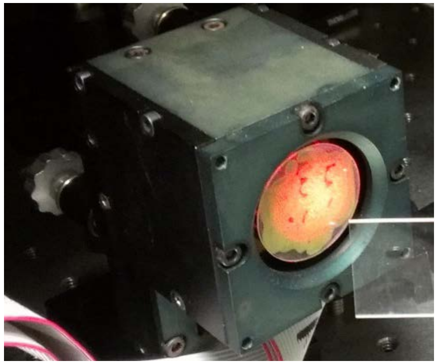


Electron diagnostics

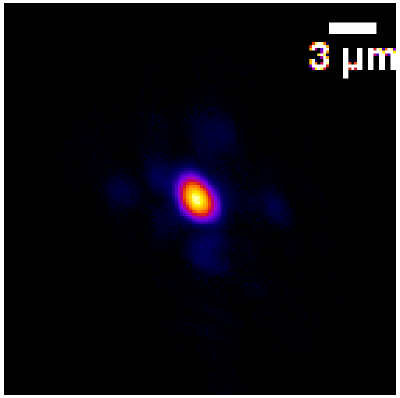


- Energy calibrated using 2D particle-tracking code in conjunction with measured magnetic fields
- Electron angle of incidence at each energy can also be determined.

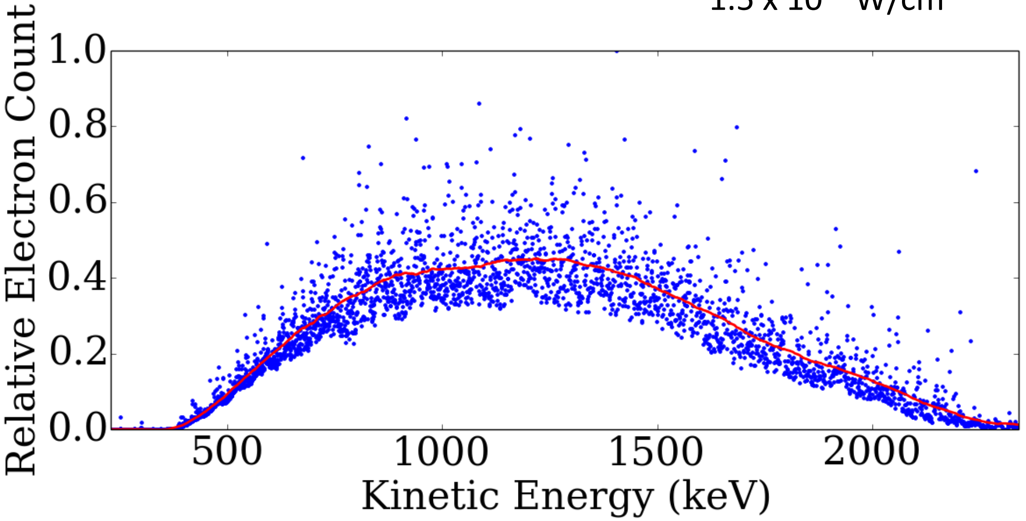
Deformable mirror
Optimization of focal pot



"Best focus" optimization



1.5 x 10^{18} W/cm^2

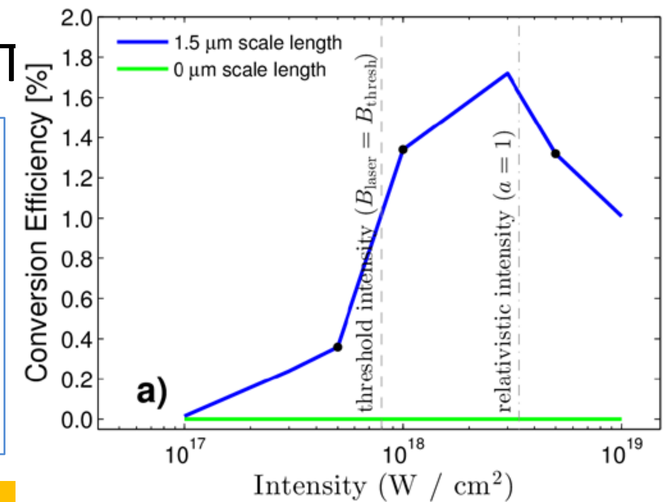


- 10 shot integration
- working on absolute calibration

Particle-in-Cell (PIC) Simulations

Particle T

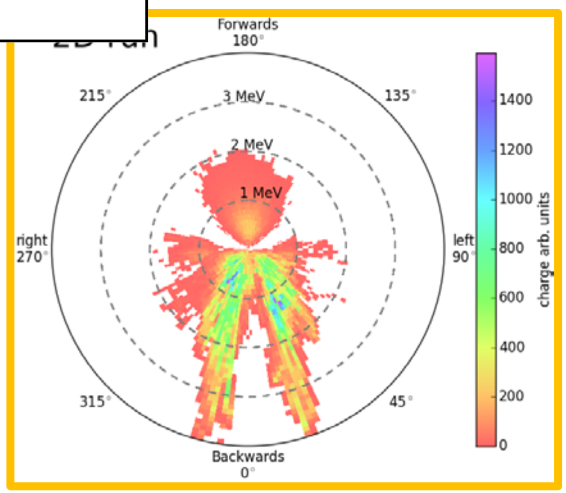
Particle-in-Cell (PIC) simulations using the LSP code indicate strong electron beams if a pre-plasma is present

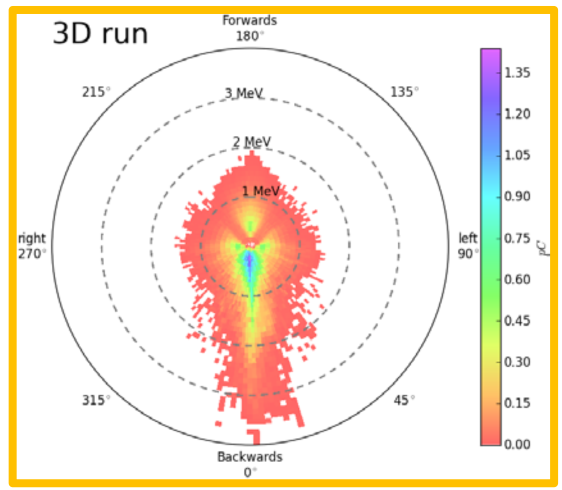


3 10^{18} W/cm^2, 1.5 µm pre-plasma scale length

w/o pre-pulse, MeV electrons disappear

Laser



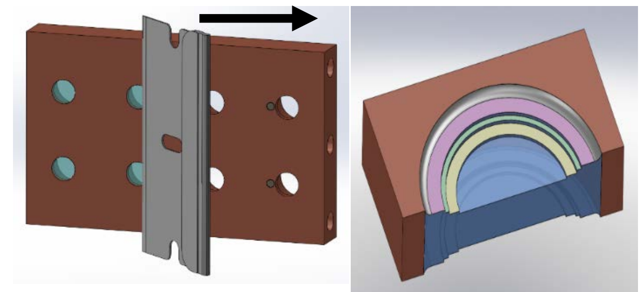


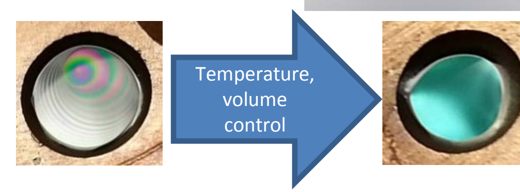
Backward-Propagating MeV Electrons in Ultra-Intense Laser Interactions: Standing Wave Acceleration and Coupling to the Reected Laser Pulse Orban *et al.* Phys. Plasmas (2015)

Other HEDP target work at OSU

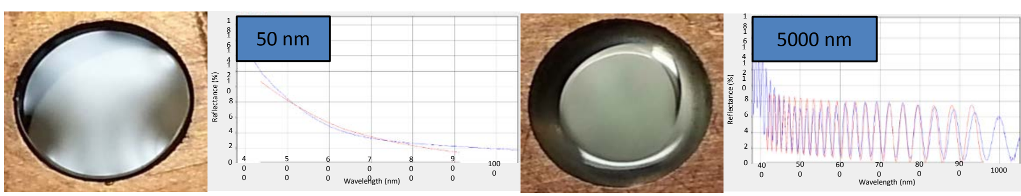
Liquid crystal films are variable thickness, on-demand, inexpensive targets

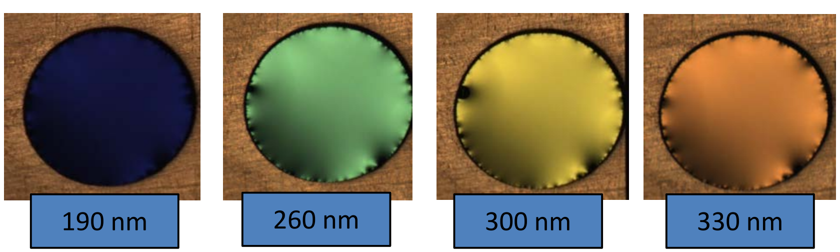
- Thicknesses between 10 nm and 10 µm can be made in real time
- Thickness variation possible via temperature, volume control
- Volume per target is small: << 1 cent each
- Films formed outside of target chamber survive installation and alignment and maintain initial thickness below 10^{-6} Torr
- In-situ rep-rated film formation possible at 0.33 Hz with < 2 µm RMS positioning repeatability, faster rates under development

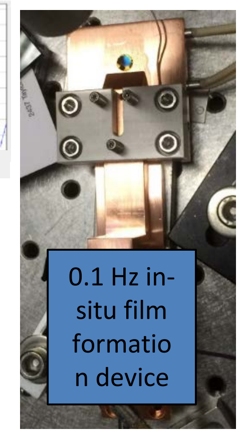


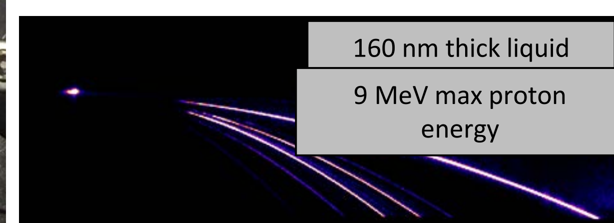


P. L. Poole *et al. Phys. of Plasmas* ***21***, *063109 (2014)*





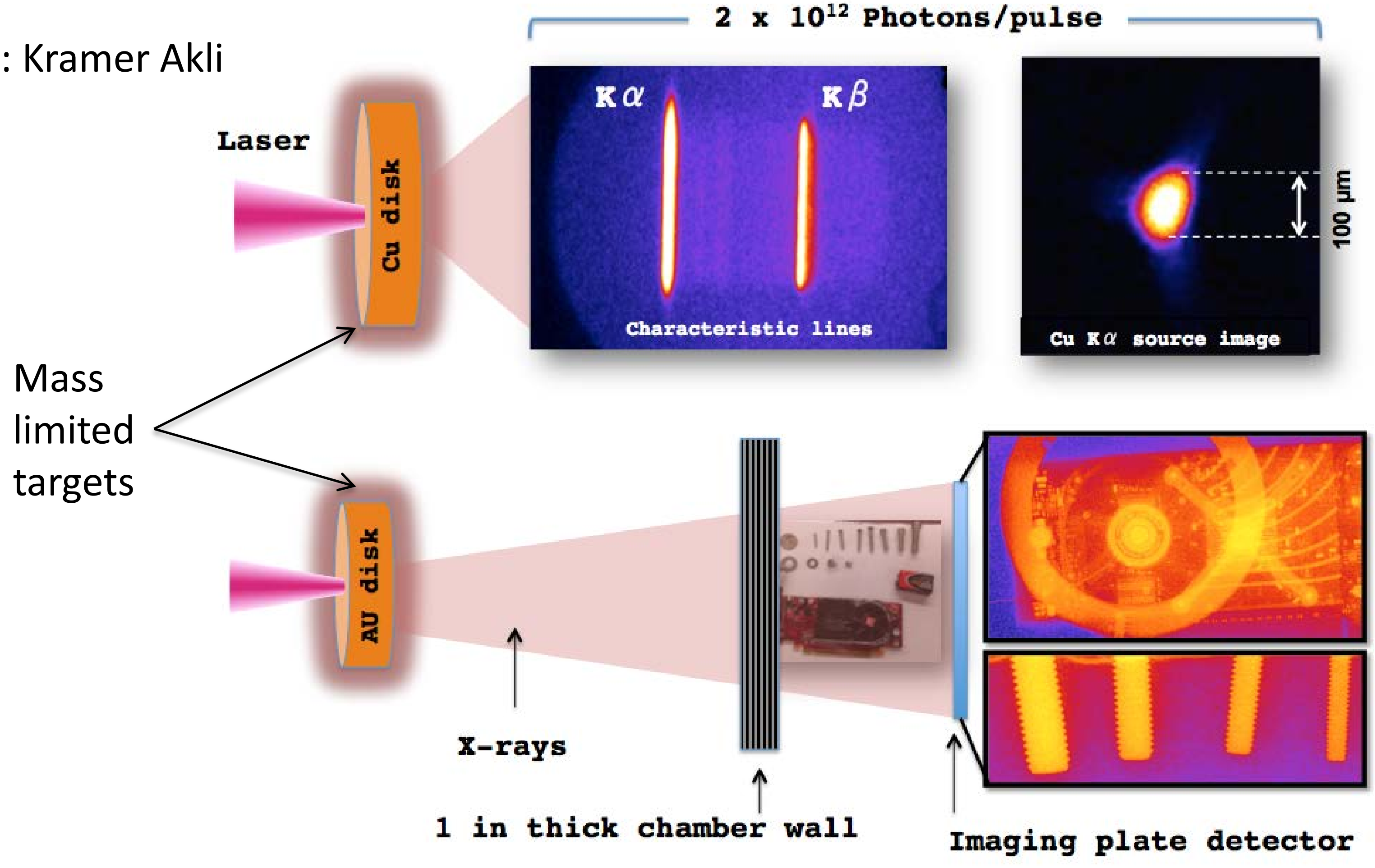




PI: Douglass Schumacher

Short pulse produced plasmas are bright sources of radiation

PI: Kramer Akli



High fluxes and small sources required for high-resolution point projection radiography and Thomson scattering

Summary

- AFRL Lab liquid target development for kHz rep-rate experiments
  - Jet
  - Droplet
  - Sub-micron sheet
- Experiment: Relativistic electron generation with precision liquid targets
  - Backward MeV electrons/x-rays with mJ-1kHz laser
  - Presence of pre-plasma crucial for backward propagating electron acceleration
- **Currently working on kHz neutron generation**

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Chris Orban (ISSI; OSU)

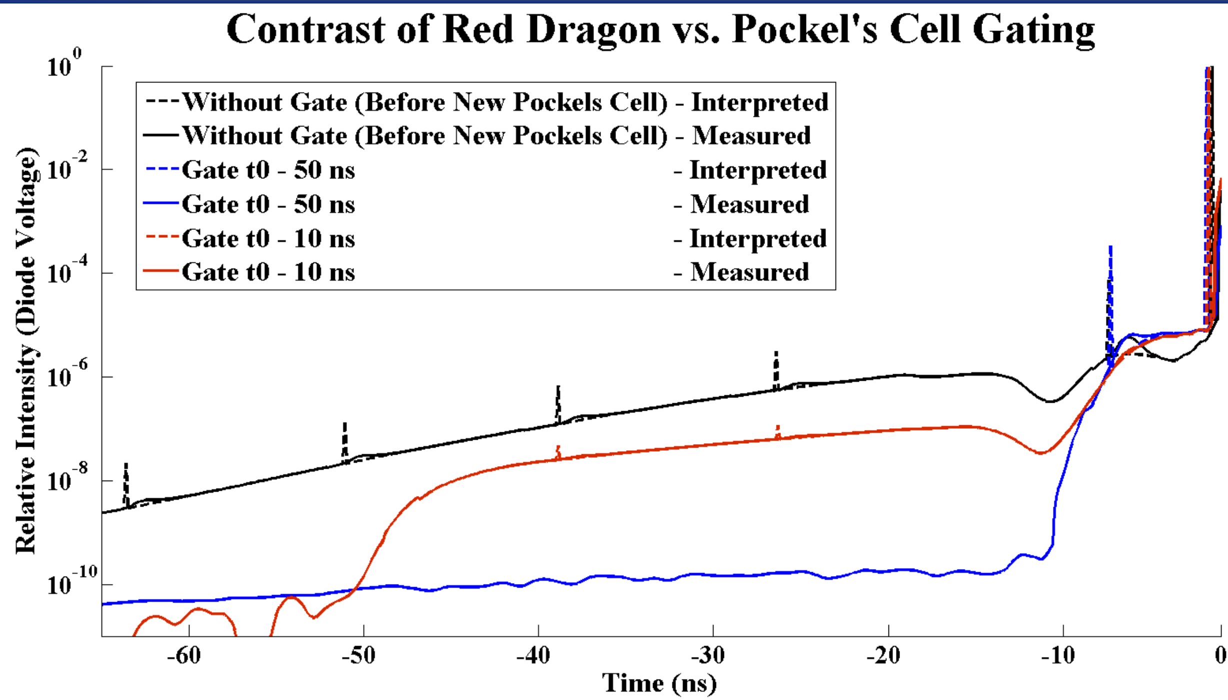
Gregory Ngirmang (OSU; ISSI)

John Nees (ISSI, UM)

Group Leader:Mel Roquemore (AFRL/RQ)

- Air Force Office of Scientific Research Quantum and Non-equilibrium Processes Division, Program Manager: Dr. Enrique Parra
- DoD supercomputer SPIRIT
- Ohio State Supercomputer center storage

Suppressed ns Pre-Pulse Amplitude and ASC by Controlling Pockels Cell Gating



- Diodes and calibrated filters were used to measure ns pre-pulses up to 60 ns prior to the main pulse arrival
- The measurement shows that the pre-pulses constitute of satellite short pulses from oscillator, separated by oscillator period, which rides over the broad 12 ns FWHM
- Calibrating against TOCC measurement of ASE, we have been able to determine what the ns level ASE contrast is. These parameters can then be put into LPI simulations