LCLS-II

X-ray Diagnostics

Yiping Feng, LCLS and LCLS-II

8th Hard X-ray FEL Collaboration Meeting

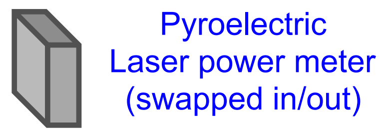
24-26 October 2016

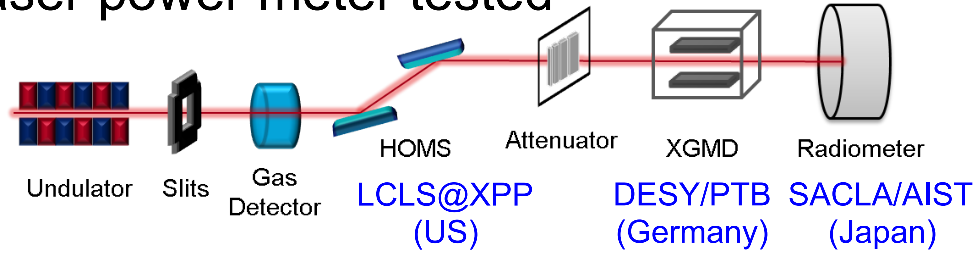
Outline

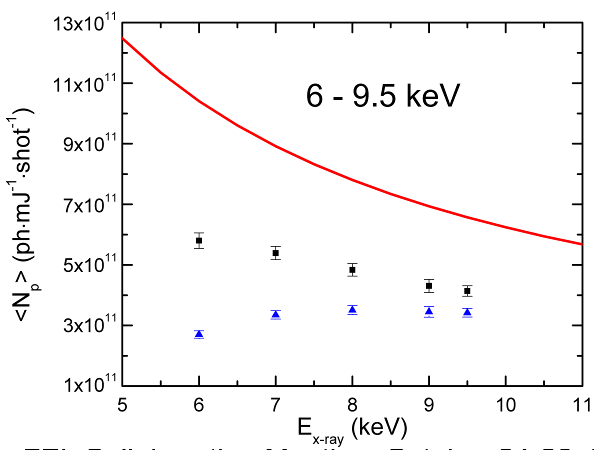
- R&D on X-ray power meter
- Timing diagnostics
  - High resolution time tool
  - R&D on high sensitivity time tool
- R&D on wavefront sensors (see B. Schlotter's X-ray optics presentation)
- Gas filamentation studies
  - Thermodynamic and hydrodynamic simulations
  - Recent experimental results
- Gas fluorescence imaging

X-ray Absolute Intensity Measurements at XPP

- In-house beamtime for absolute hard x-ray intensity measurements at XPP - multi-lab collaboration (2015)
  - Large foot print, requires differential pumping
  - Not practical for routine operation
  - Pyroelectric laser power meter tested







Measurement of the absolute number of photon of the hard X-ray beamline At the Linac Coherent Light Source

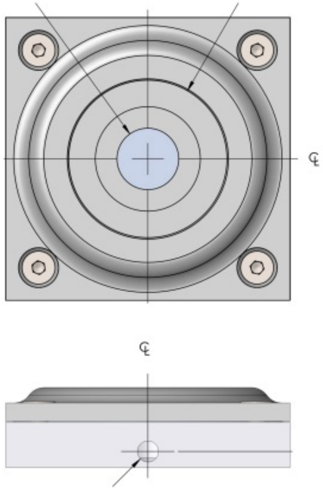
Sanghoon Song,[a]* Roberto Alonso-Mori,[a] Matthieu Chollet,[a] Yiping Feng,[a] James M. Glownia,[a] Henrik T. Lemke,[a] Marcin Sikorski,[a] Diling Zhu,[a] Stefan Moller,[a] Haeja Lee,[a] Mark Hunter,[a] Gabriella Carini,[a] Kai Tiedtke,[b] Ulf Jastrow,[b] Mathias Richter,[c] Murakami Toshiyuki,[d] Owada Shigeki,[d] Tanaka Takahiro,[e] Kato Masahiro[e] and Aymeric Robert[a]

[a]Linac Coherent Light Source, SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, U.S.A., [b]Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany, [c]Physikalisch-Technische Bundesanstalt, Abbestrae 2-12, 10587 Berlin, Germany, [d]RIKEN SPring-8 Center, 1-1-1 Kouto, Sayo-cho, Sayo-gun, 679-5148, Hyogo, Japan, and [e]National Institute of Advanced Industrial Science and Technology (AIST), NMIJ, 305-8568 Tsukuba, Japan. Correspondence e-mail: sanghoon@slac.stanford.edu

Courtesy of S. Song, et al

R&D on X-ray Power Meters

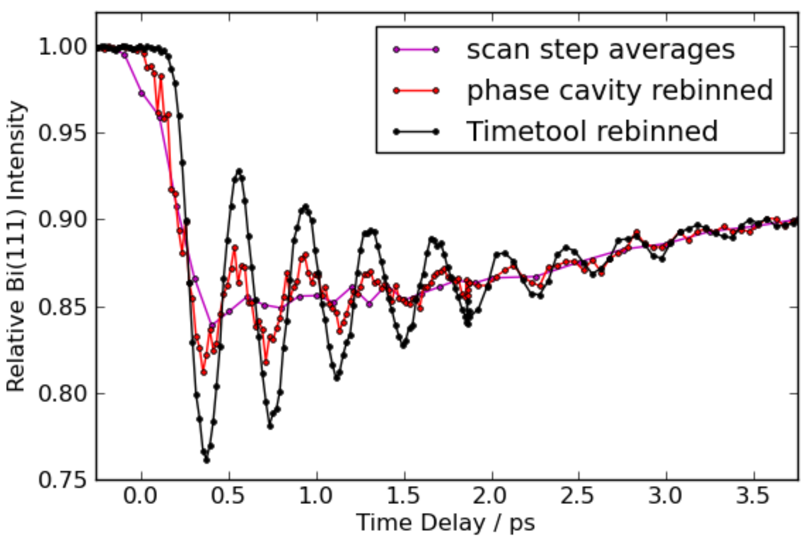
- Goal: develop portable, compact, possible commercially available FEL power meter
  - Measure absolute X-ray intensity
  - Possibly single-shot capable
- Solutions being evaluated
  - Thermopile sensors
    - Average measurement from temperature change
    - Al absorber
  - Pyroelectric sensors
    - Single-pulse measurement
    - Maximum repetition rate limited to few kHz
  - Testing using in-house LCLS@SXR, Nov. 16-17, 2016
    - Compare thermopile, pyroelectric power meters with GMD
    - Photon energy range: 500 – 2000 keV



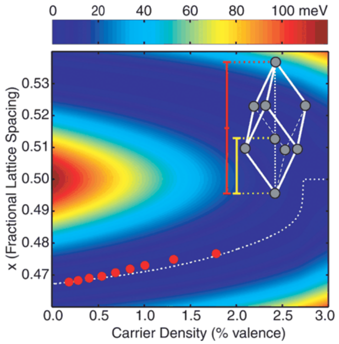
Courtesy of P. Heimann, et al

A Successful Pump-Probe Experiment

- Requiring accurate intensity and timing measurements
  - Measure relative intensity well to < 0.1% (LUSI hard X-ray IPM), upgrade is currently underway to increase dynamic range
  - Measure timing btw pump/probe < 10's fs or few fs, and post processing data



Courtesy of D. Zhu, L. H. Lemke, et al



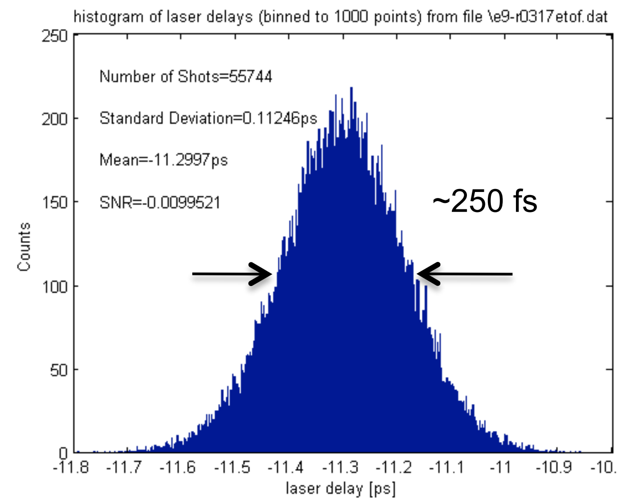
fs lattice dynamics in Bismuth photoexcited Peierls' distortion

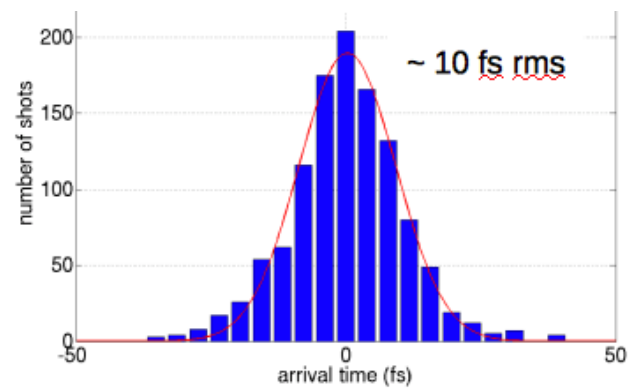
* D. M. Fritz *et al*, Sci. **315**, 5812 (2007).

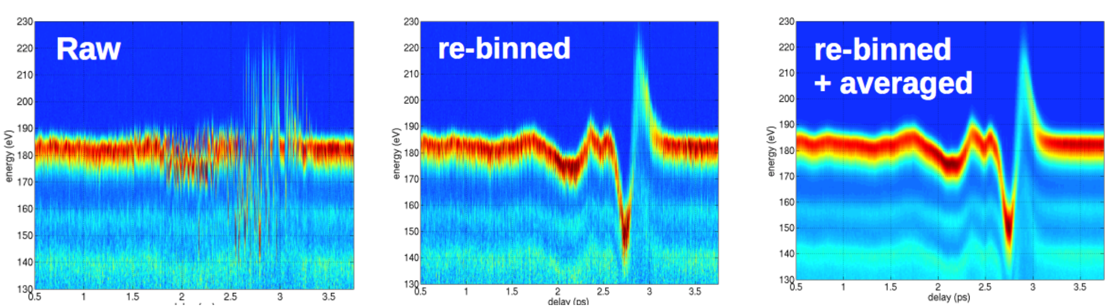
*but if not available, averaging is an option (inefficient S/N ~ 1/√#)

LCLS-I Enables Timing of Order 20 fs RMS

- LCLS-I convolves ~100 fs RMS timing jitter between RF and X-rays with ~50 -100 fs timing jitter between RF and optical lasers
- X-ray/optical cross-correlation measurements allow post-processing to ~10 fs RMS, and slow-feedback for drift



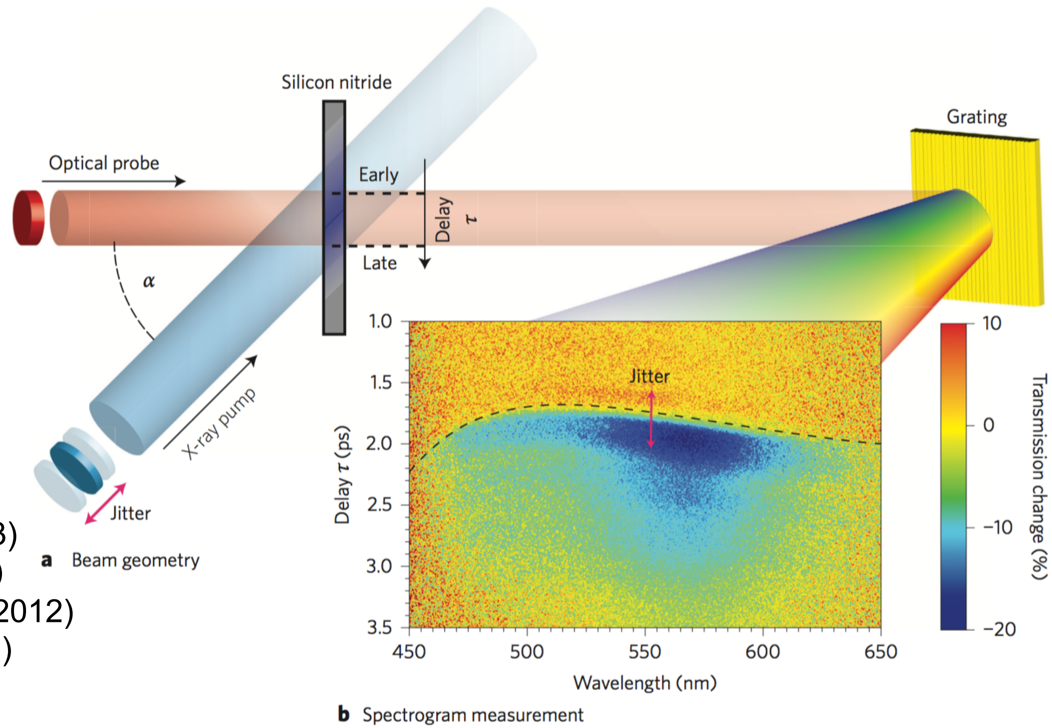




Courtesy of A. Fry, et al

LCLS High Resolution Time Tool

- Latest resolution ~ 1 fs rms using spectral encoding
  - Contract is based on transmission, requires strong FEL



Bionta *et al*, Opt. Express, **19**, 21855 (2011)
Lemke *et al*, Proc. SPIE **8778,** 87780S (2013)
Harmand *et al*, Nat. Photonics, **7**, 215 (2013)
Schorb *et al*, Appl. Phys. Lett. **100,** 121107 (2012)
Hartmann *et al*, Nat. Photonics, **8**, 706 (2014)

Figure 1 | Schematic of the single-shot geometry for measurement of the spectrogram. a, The X-ray and optical beams are crossed in a silicon nitride membrane and their relative delay is encoded in the spatial beam profile of the optical probe. The crossing angle α and beam diameters define the time window in which the X-ray-induced absorption is probed. **b**, Measured spectrogram using an unpumped normalization spectrogram to calculate the change in transmission. The result of the two-step edge-finding algorithm to determine the X-ray arrival time is overlaid as a black dashed line.

X-ray FEL Pulses Interaction w/ Liquid

- Proof-of-concept results w/ ISE are encouraging

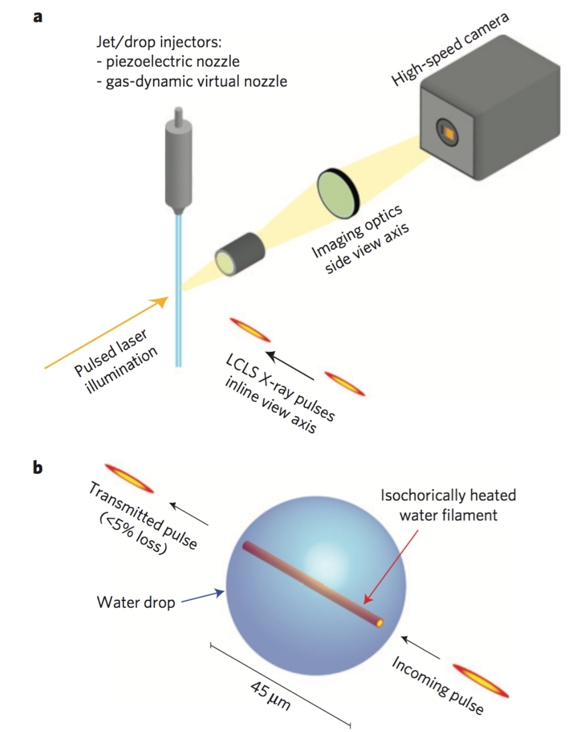
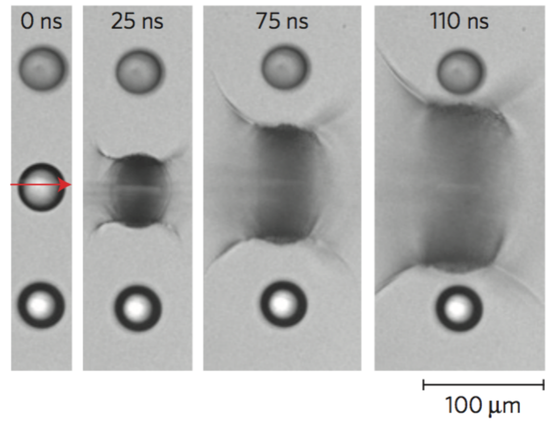
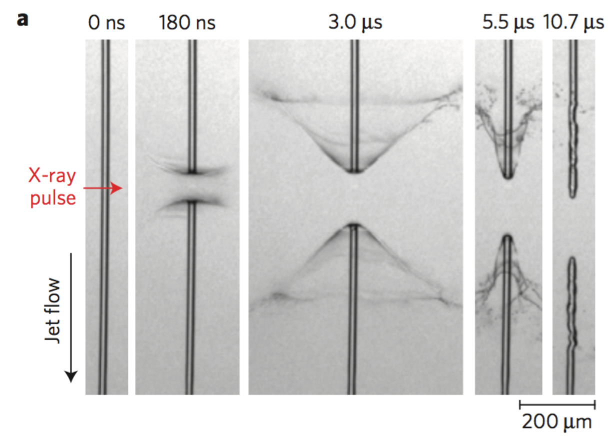


Figure 1 | Inducing liquid microexplosions with ultraintense X-ray pulses.





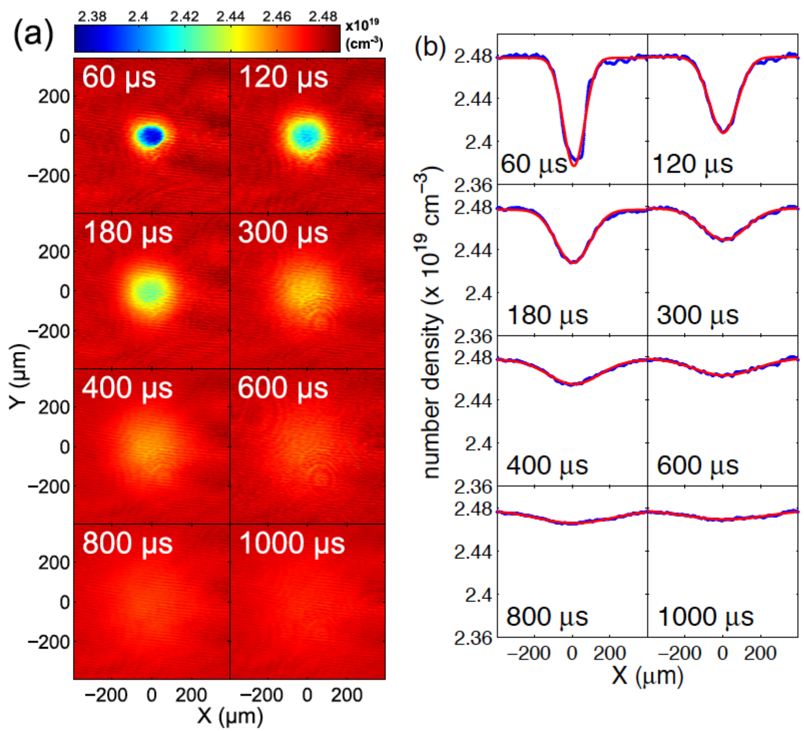
Liquid explosions induced by X-ray laser pulses

Claudiu A. Stan[1*], Despina Milathianaki[2], Hartawan Laksmono[1], Raymond G. Sierra[1], Trevor A. McQueen[3], Marc Messerschmidt[2†], Garth J. Williams[2†], Jason E. Koglin[2], Thomas J. Lane[2], Matt J. Hayes[2], Serge A. H. Guillet[2], Mengning Liang[2], Andrew L. Aquila[2], Philip R. Willmott[2,4], Joseph S. Robinson[2], Karl L. Gumerlock[2], Sabine Botha[5†], Karol Nass[5], Ilme Schlichting[5], Robert L. Shoeman[5], Howard A. Stone[6] and Sébastien Boutet[2]

Explosions are spectacular and intriguing phenomena that expose the dynamics of matter under extreme conditions. We investigated, using time-resolved imaging, explosions induced by ultraintense X-ray laser pulses in water drops and jets. Our observations revealed an explosive vaporization followed by high-velocity interacting flows of liquid and vapour, and by the generation of shock trains in the liquid jets. These flows are different from those previously observed in laser ablation, owing to a simpler spatial pattern of X-ray absorption. We show that the explosion dynamics in our experiments is consistent with a redistribution of absorbed energy, mediated by a pressure or shock wave in the liquid, and we model the effects of explosions, including their adverse impact on X-ray laser experiments. X-ray laser explosions have predictable dynamics that may prove useful for controlling the state of pure liquids over broad energy scales and timescales, and for triggering pressure-sensitive molecular dynamics in solutions.

Gas Filamentation by Ultrashort Optical Pulses

- 1st reported in ultra-short intensity optical laser
  - "Hole burning" effect induced by fs lasers in gas, leading to density depression with slow recovery time of ms



Ti:Sapphire 800 nm 40 fs
0.72 mJ/pulse at 20 Hz
100 μm FWHM

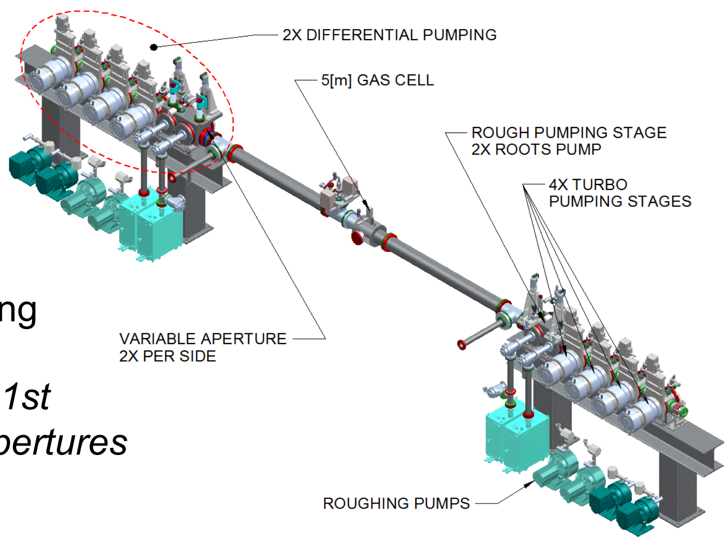
N_2 at 1 atm pressure
Up to 10-20% density depression
recovery time ~ 1 ms

Interferometer technique
after one pulse

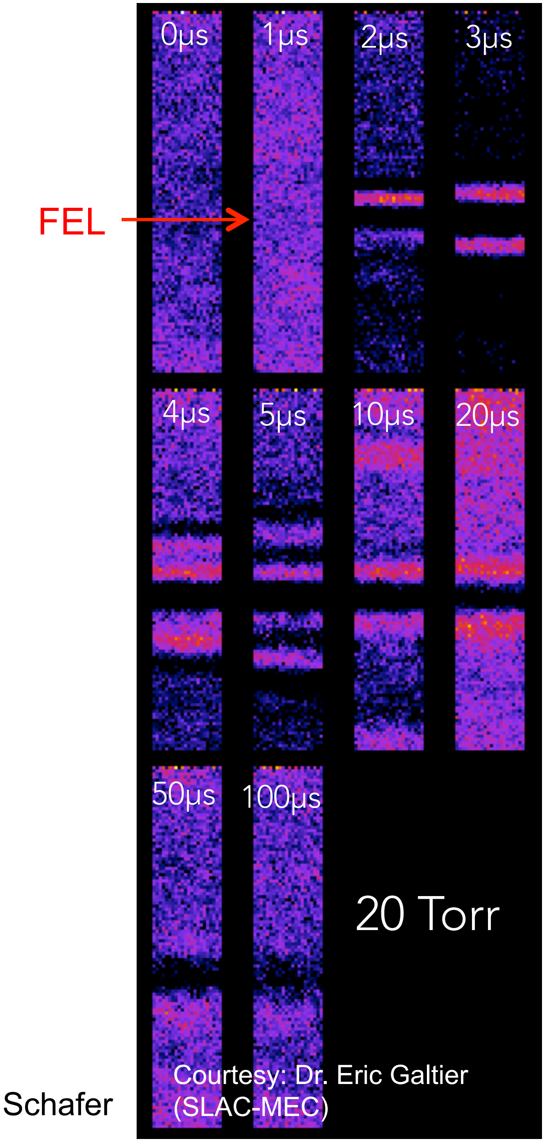
Y-H. Cheng, et al, *Opt. Express* **4**, 4740 (2013)

Gas Filamentation by X-ray FEL Pulses
(concern for LCLS-II high rep rate)

- Confirmed by similar ultra-short optical laser experiment
  - Optical-pump and optical probe (done, Don and Eric, table-top setup)
  - X-ray-pump and optical probe, installed in the LCLS FEE, test on 10/25/2106



Using Ar gas, 14.7 m long volume, up to 10 torr
Differential pumping *w/ 1st variable (impedance) apertures to reduce conductance*



Courtesy of E. Galtier, D. Schafer

Thermodynamic Steady-State & Transient Simulations

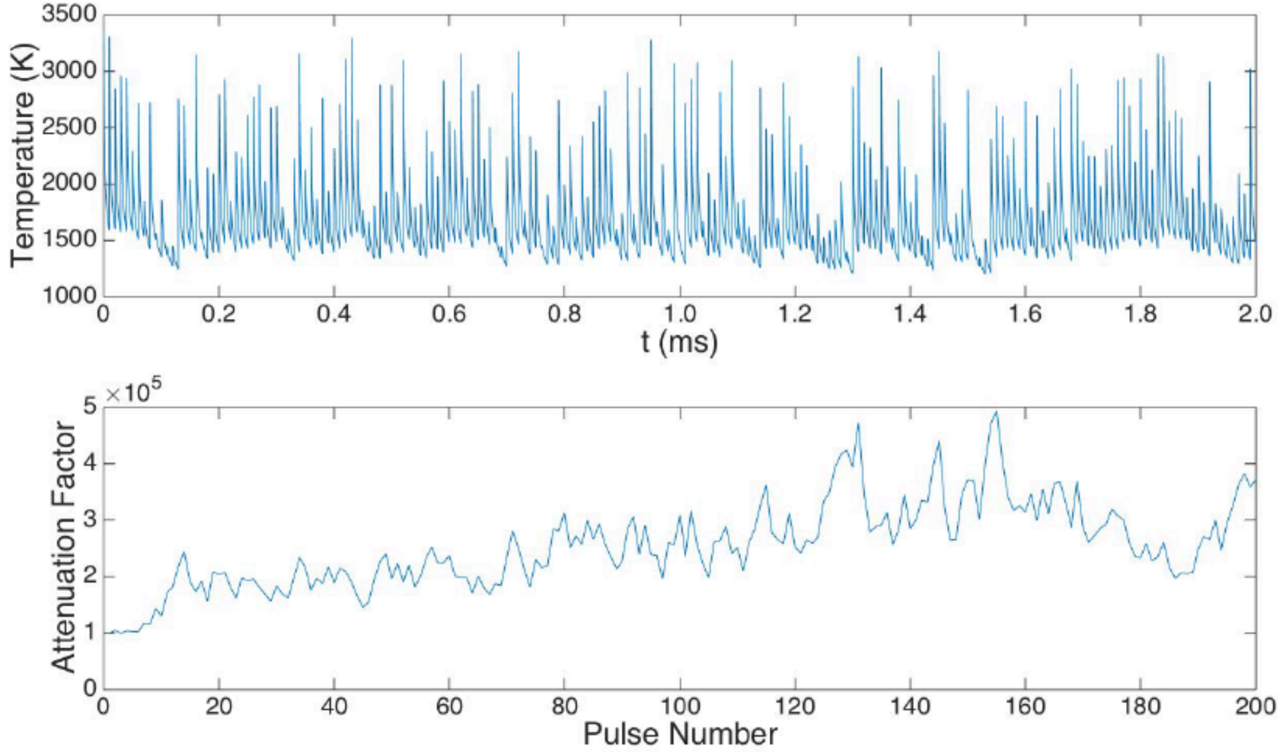
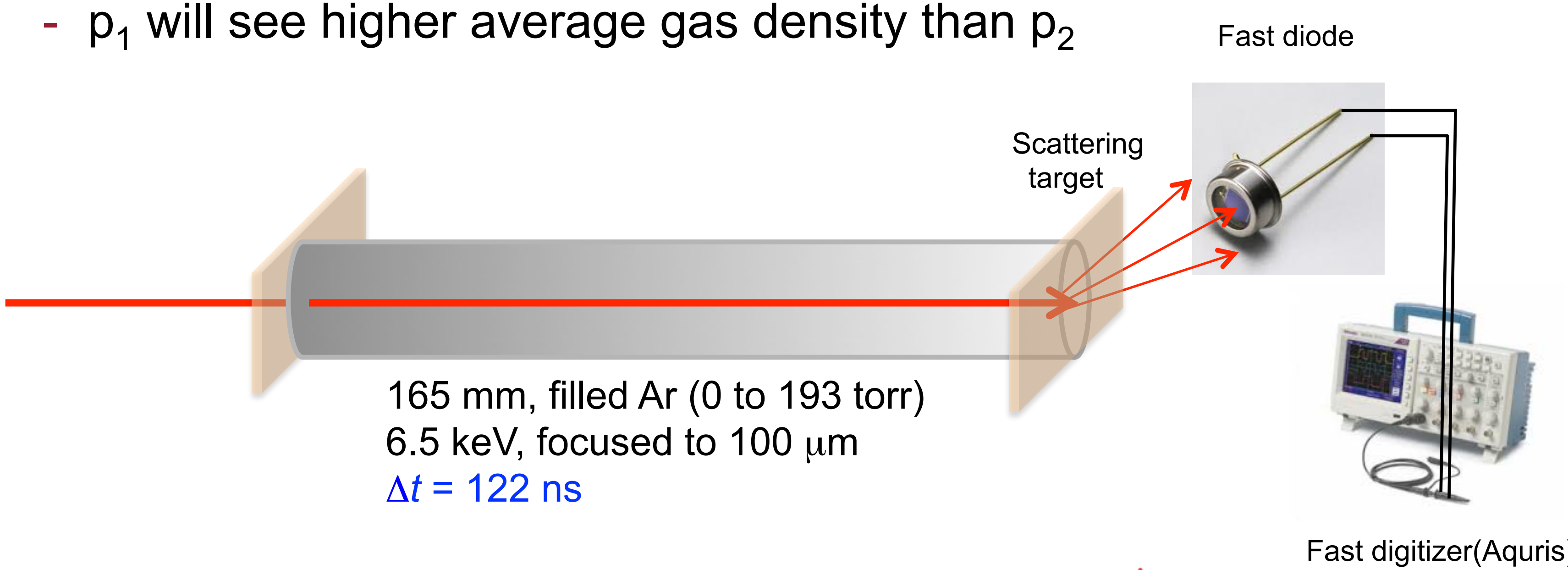


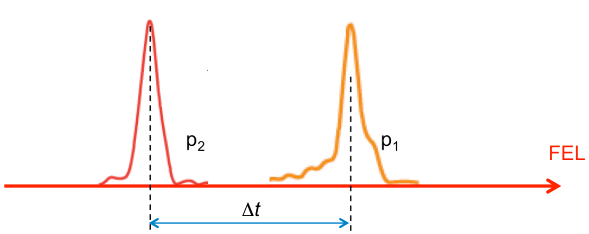
Figure 5. (Top) Time evolution of the temperature at the center of the entrance of the attenuator ($r = 0$, $z = 0$ mm) with randomized input pulse energies. The simulation was for an Argon gas attenuator for attenuating a 200 eV soft X-ray FEL beam of random pulse energies, which were uniformly distributed between 0 and 4 mJ with an average of 2 mJ, producing an average power of 200 W. The targeted attenuation was set for 10^5, for which the pressure was adjusted to 2.51 Torr as obtained by the CW calculation, 1.76 times higher than the low-power limit of 1.43 Torr. (Bottom) The actual achieved attenuation for each pulse, which also varies randomly in response to the fluctuating pulse energy.

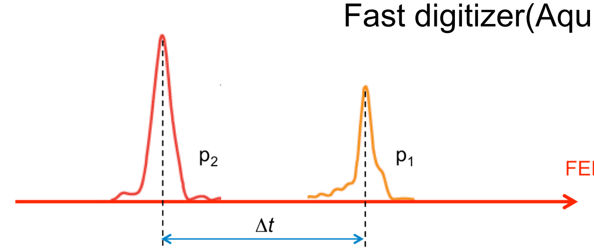
Courtesy of Y. Feng, J. Krzywinski, et al

Testing Using Fast Diodes and Digitizers

- On average the measured pulse energy of p_2 after gas will be higher
  - p_1 will see higher average gas density than p_2

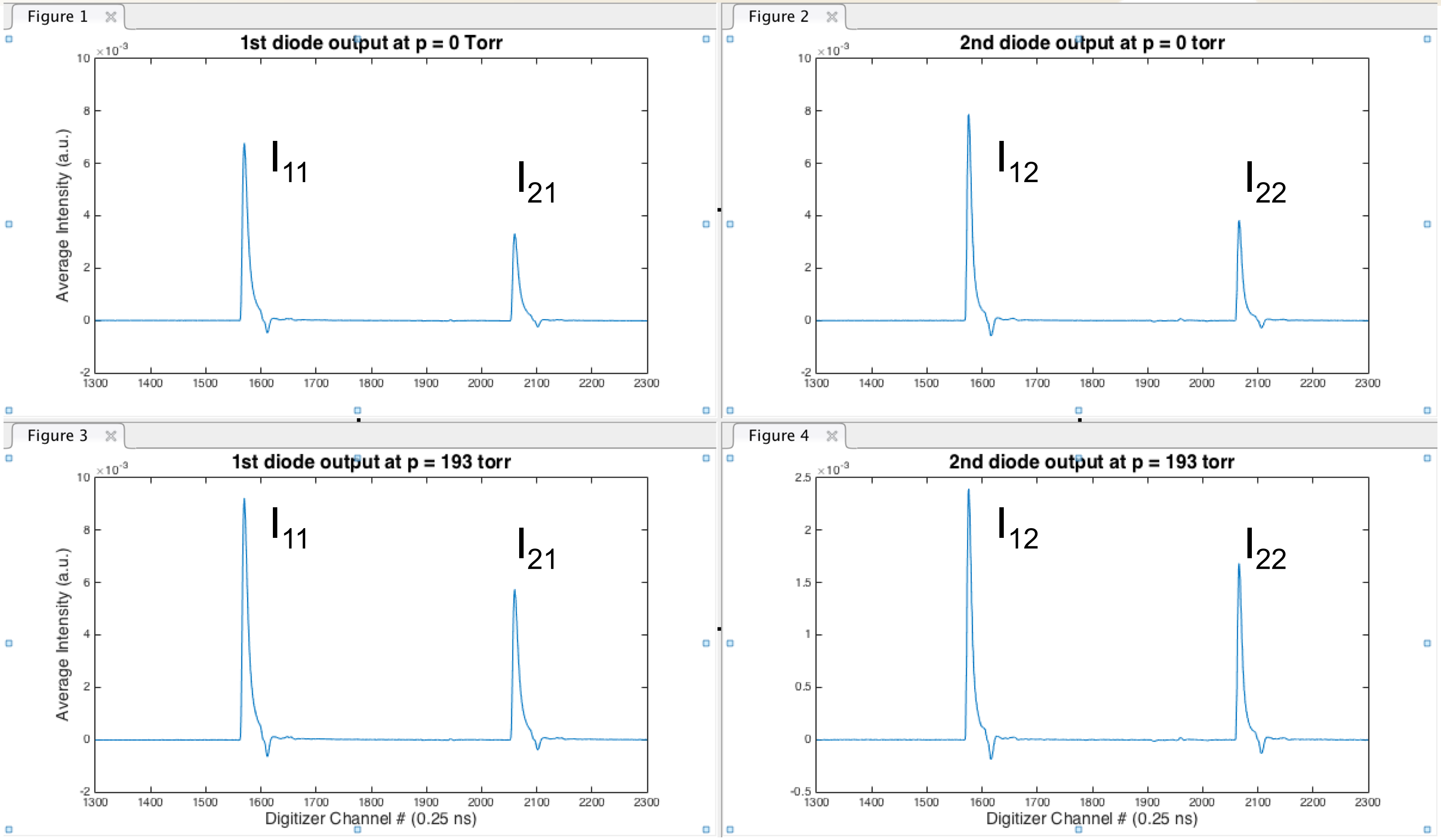






Courtesy of Y. Feng, D. Schafer, S. Song, D. Zhu, C. Weninger, et al

Preliminary Results (IH-X119, Oct. 3-4 2016)

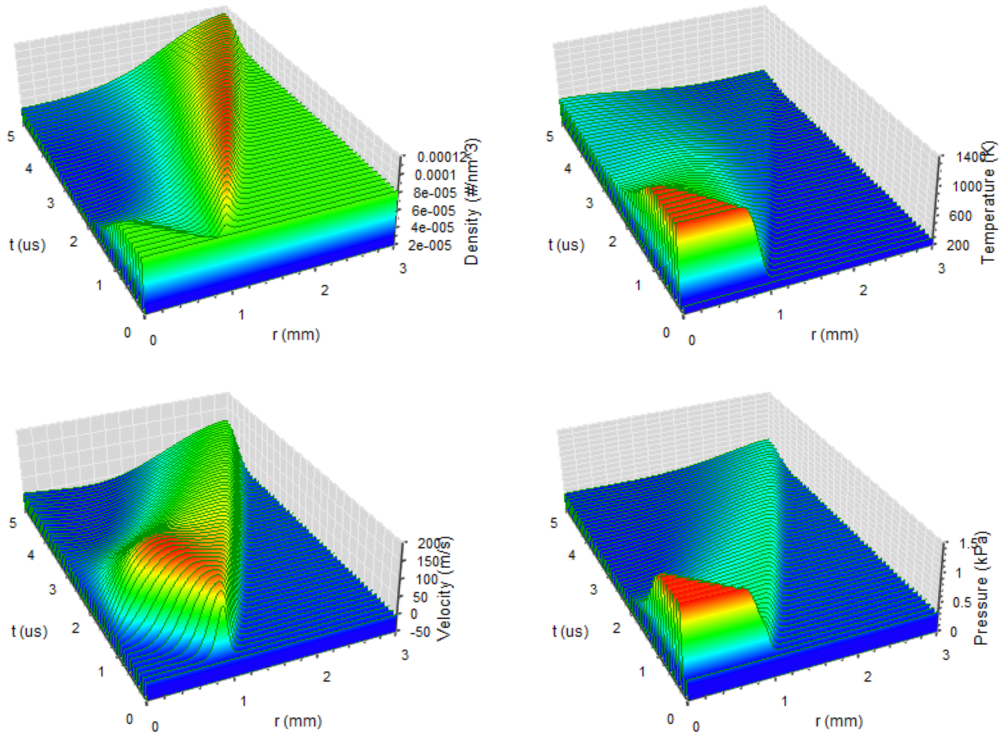


For p = 0 torr, $I_{12}/I_{11}\,/(I_{22}/I_{21}) = 1.00$

For p = 193 torr, $I_{12}/I_{11}\,/(I_{22}/I_{21}) = 1.11$ ➔ 11% effect

Hydrodynamic Simulations
(PI: B. Yang, Univ. of Taxes at Arlington)

- Including macroscopic motions (shock waves) and thermal diffusion
  - Development of filament ~ μs time scales

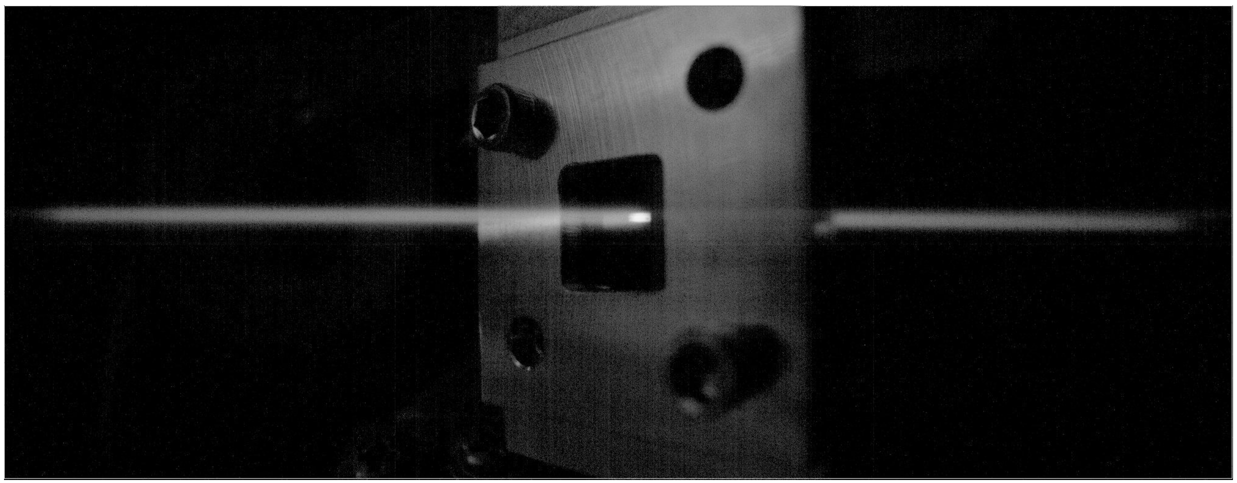


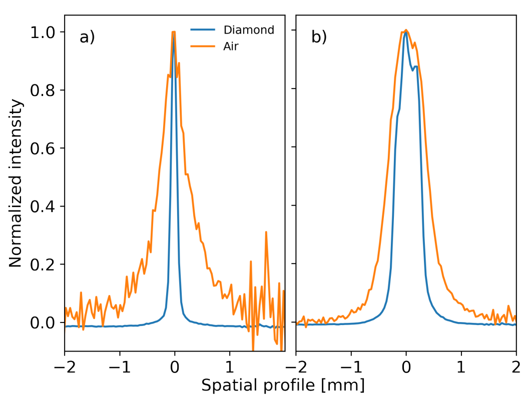
3D plots of density, velocity, temperature and pressure fields at z= 0 over r-t

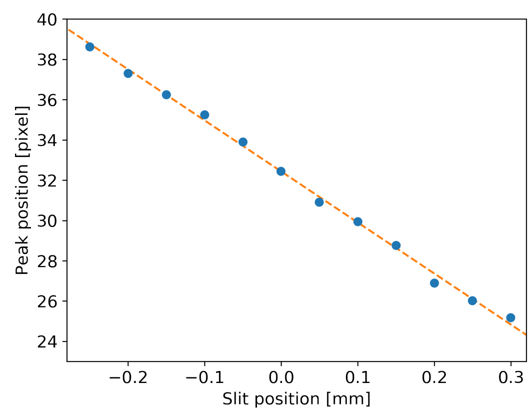
Courtesy of B. Yang, J. Wu, Y. Feng

Gas Fluorescence Imaging

- Optical imaging of ambient air irradiated by X-ray FEL
  - Non-invasive X-ray BPM and intensity monitor, especially for SXR







Courtesy of C. Weninger, D. Zhu, Y. Feng