A Laser Backscatter Diagnostic (Time and Frequency) for Preheat Studies of MagLIF Targets on Z

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Sandia National Laboratories

National ICF Diagnostics Working Group
Los Alamos, October 6-8, 2015

U.S. DEPARTMENT OF ENERGY · NNSA National Nuclear Security Administration · Z Backlighter

Exceptional service in the national interest

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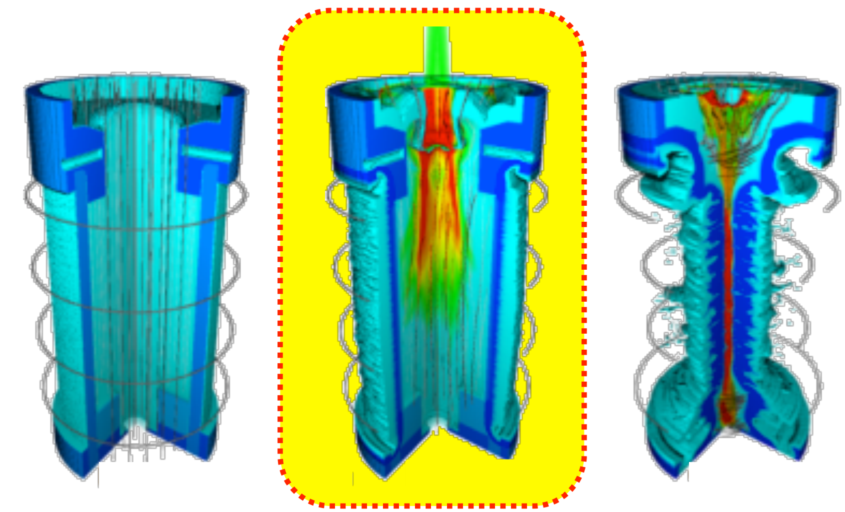

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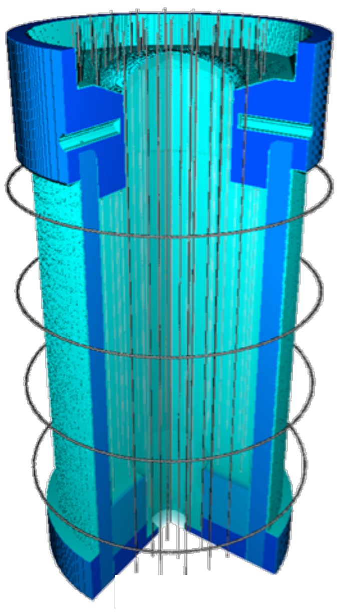
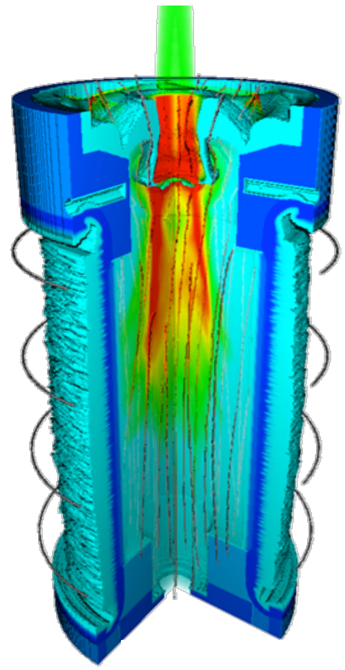
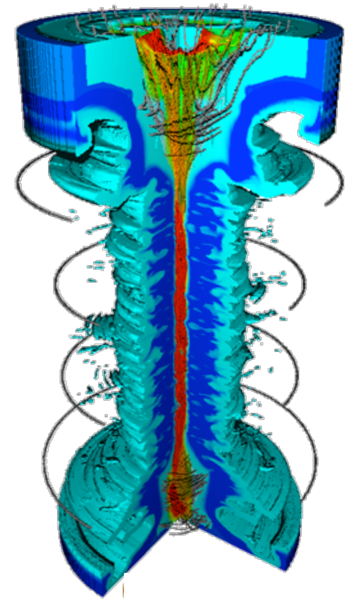
Magnetized Liner Inertial Fusion: MagLIF



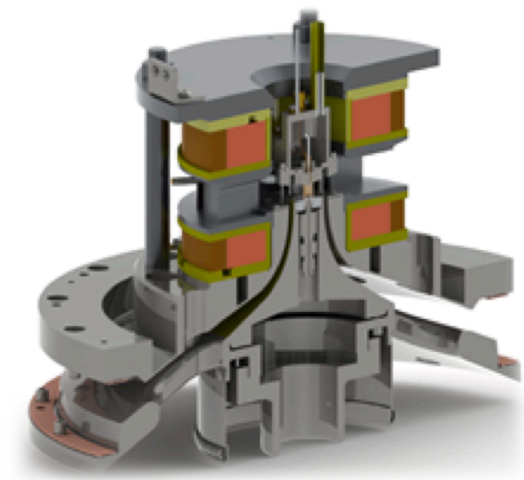
Magnetization with external B-Field (10-30T)

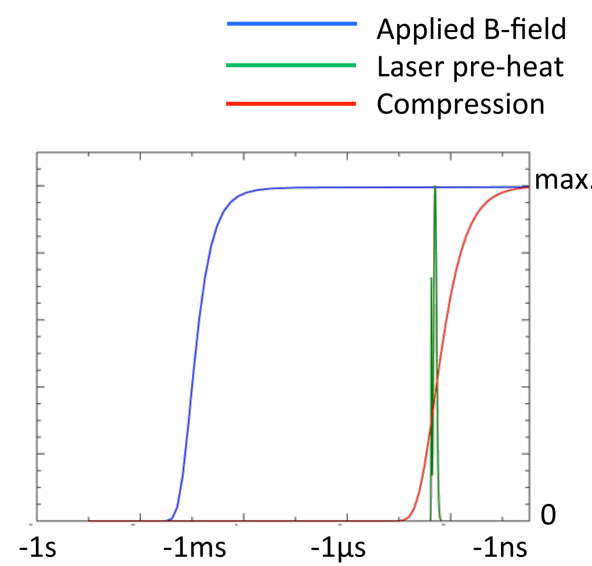


Laser heating with Z-Beamlet (2-6kJ @ 2-6ns)



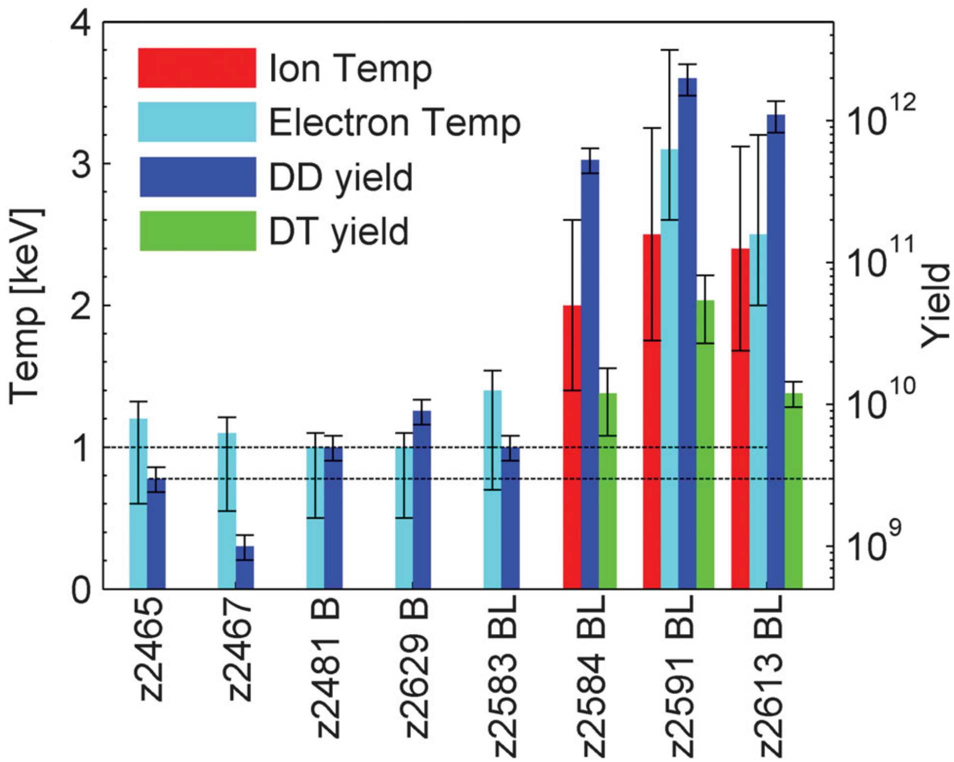
Compression with 'Z'





S. Slutz et al.: Physics of Plasmas **17**, 056303 (2010)

MagLIF (continued)



- 2E12 neutrons in 2014 were short of modeling predictions but still encouraging.
- We suspected poor laser coupling and possible fuel contamination.
- Later modifications that improve laser coupling lead to LOWER neutron yields on integrated shots!
- A pre-conditioning task group now investigates laser pre-heat and its impact on the target.

M.R. Gomez et al.: PRL **113**, 155003 (2014)

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Pre-Heat Challenges

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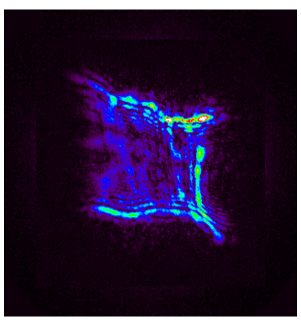
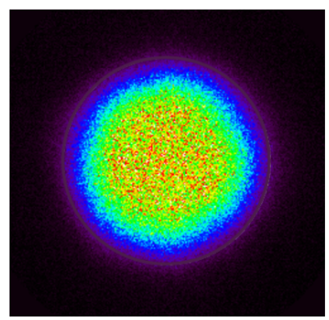
- ***High energy density requires high initial gas density***
  - *High pressure at room temperature*
  - *Thick window: 180 psi D_2 requires 3.5μm kapton across 3mm*
  - *Very high laser absorption and back-scatter in the window*

- ***Laser spot size is always a compromise***
  - *Small spots burn easily through Laser-Entrance-Hole (**LEH**)*
  - *Large spots are more efficient in fuel heating*

- ***Laser Plasma Instabilities (LPI): SBS, SRS, TPD, …***
  - *Hard to correctly predict or simulate*
  - *Lead to redirection and loss of energy*
  - *Caused by high intensity, inhomogeneity (laser spot!!), high density.*

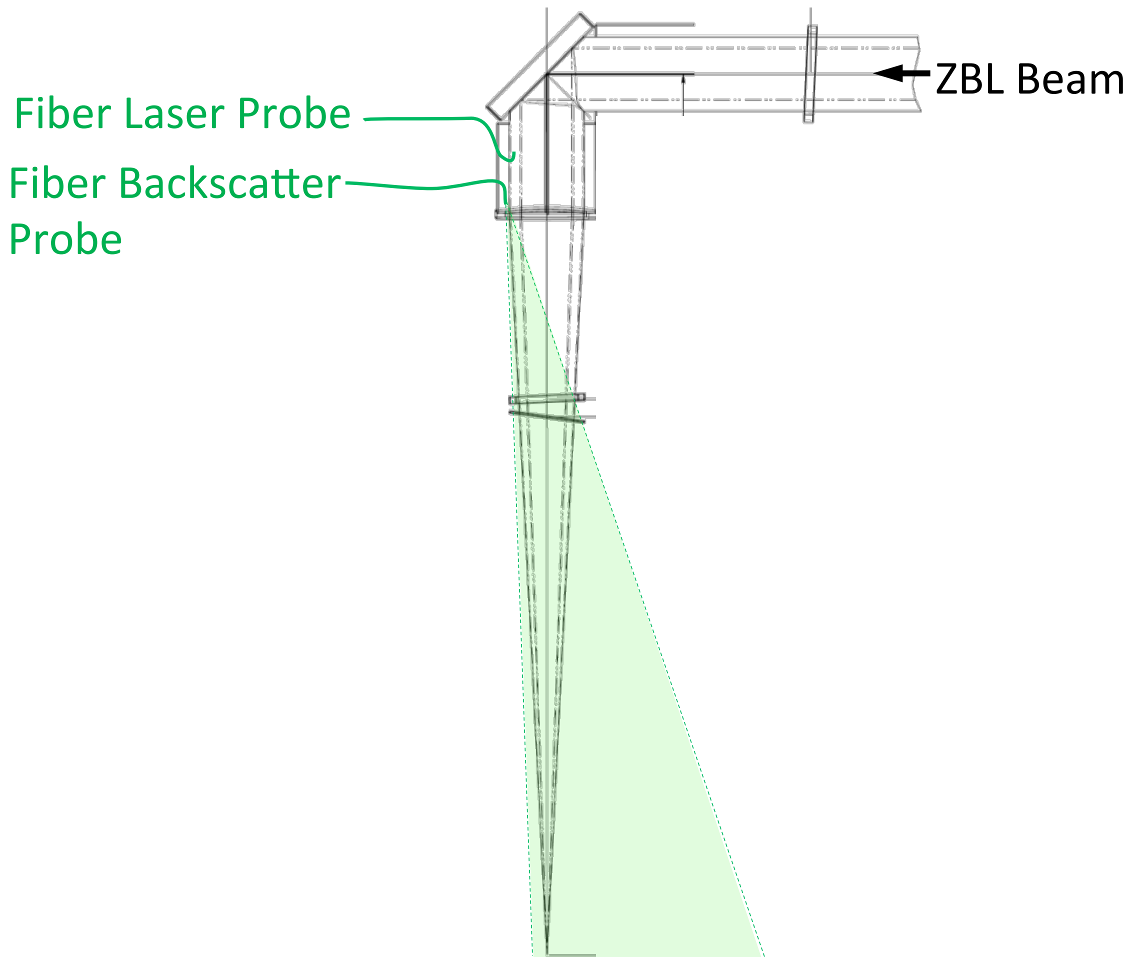


The current ZBL-spot is defocused and creates a non-uniform, spatially modulated illumination on the LEH.



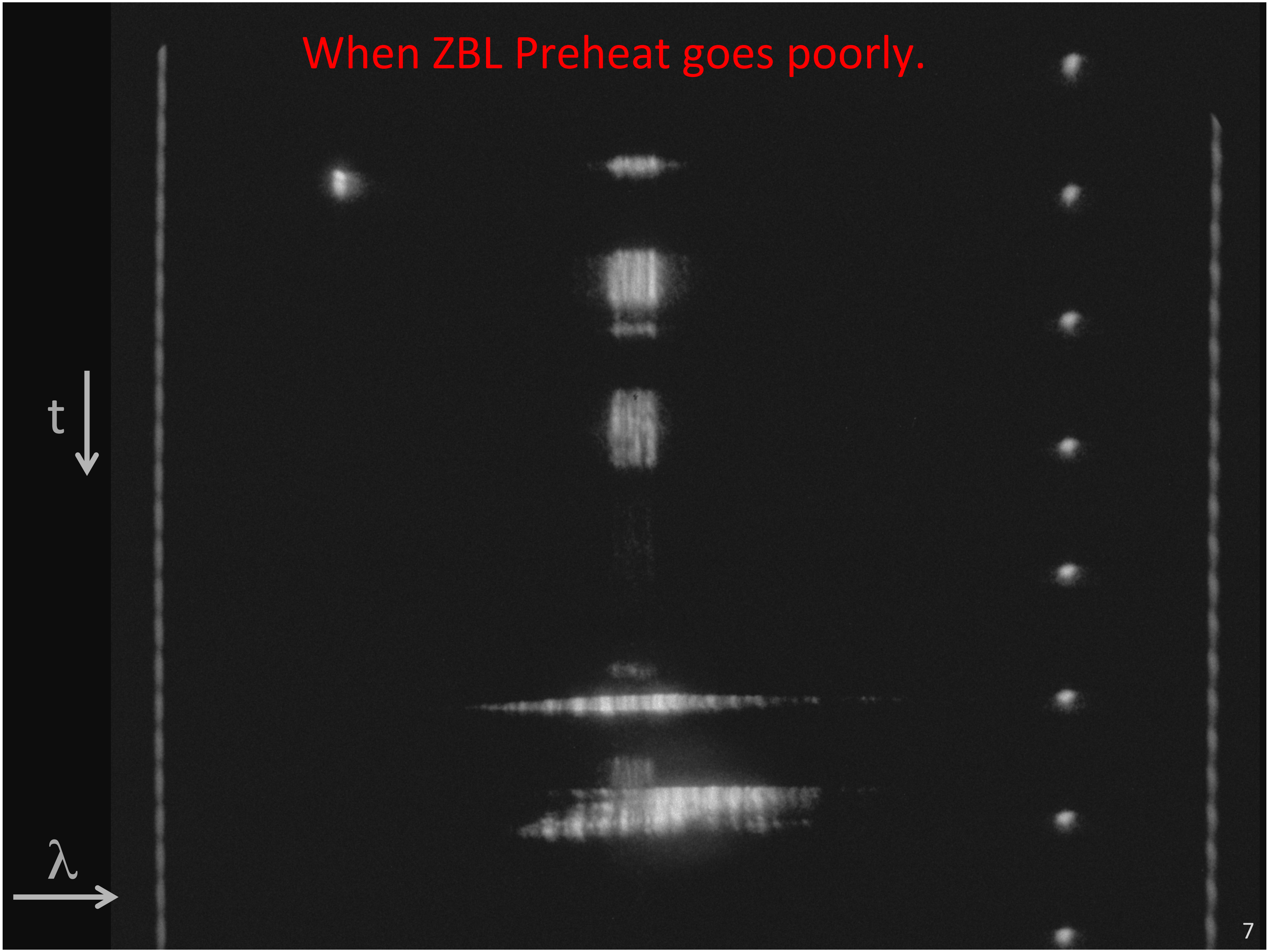
A phase plate creates a more uniform spot. Ideally the best spot could be created with polarization and temporal smoothing.

The fiber based ZBL backscatter diagnostic is coupled to the Streaked Visible Spectroscopy (SVS) system and views the laser/target interaction through the final lens.

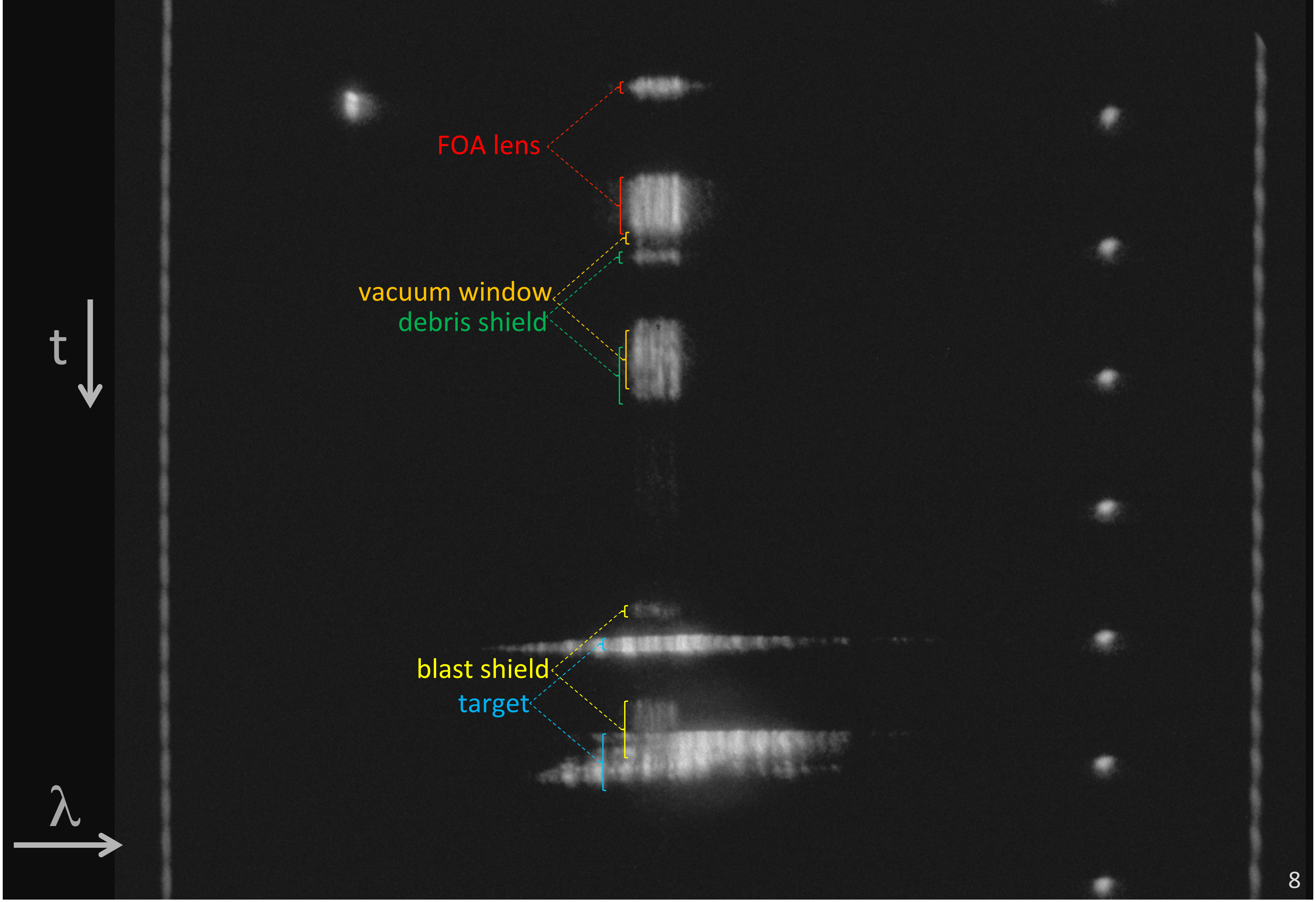


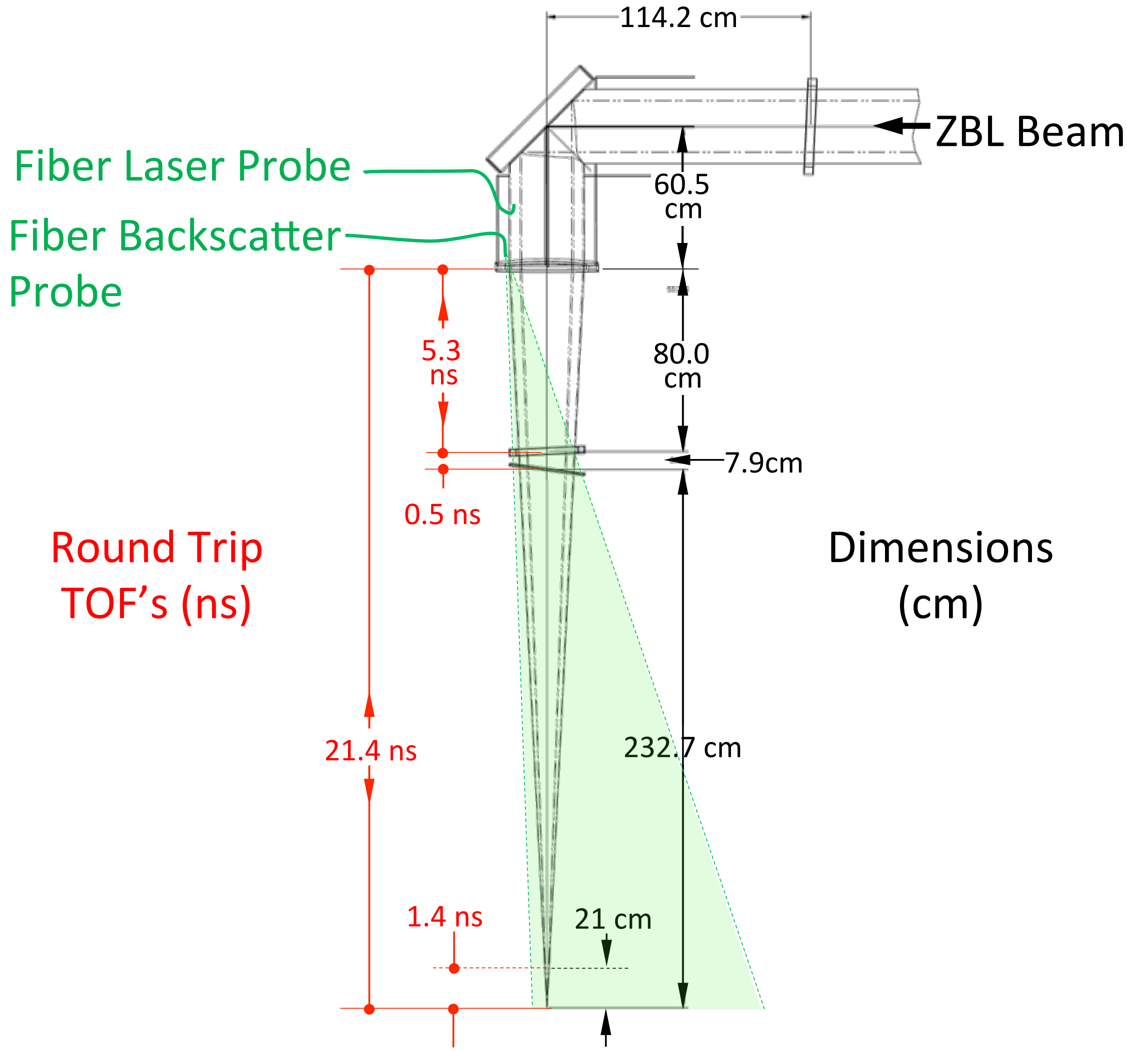
When ZBL Preheat goes well.

When ZBL Preheat goes poorly.

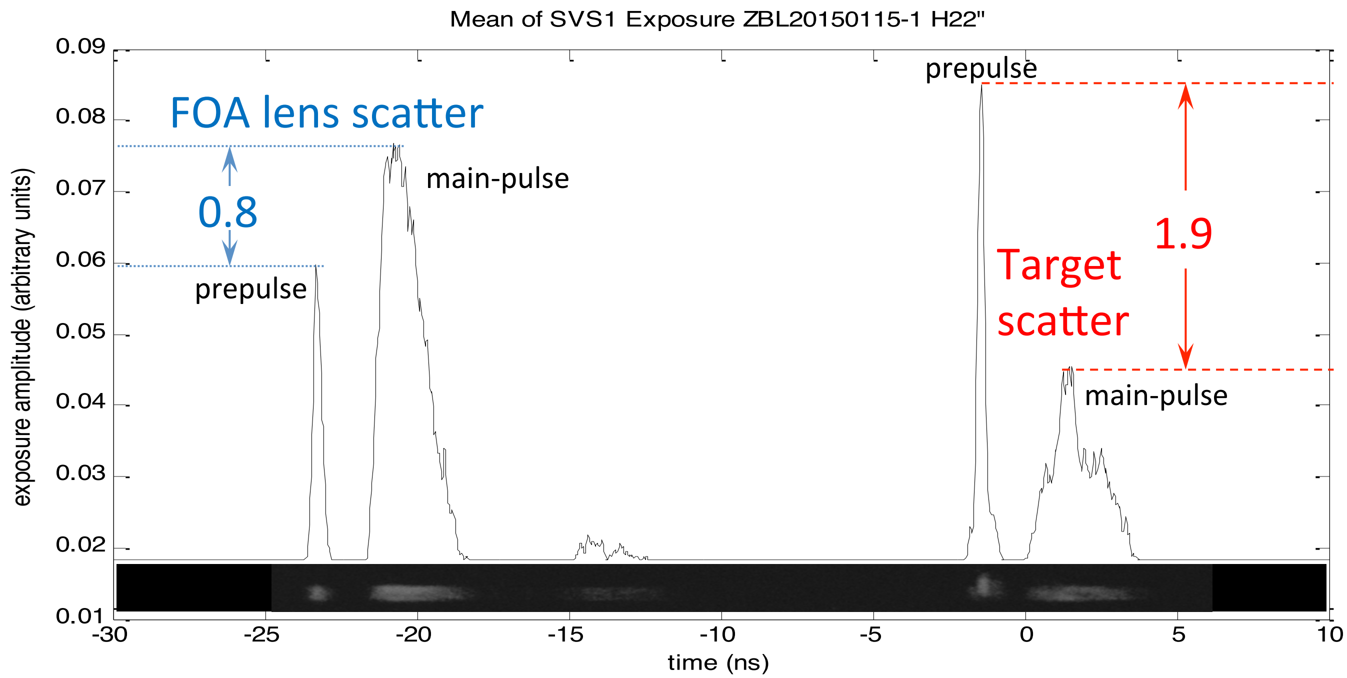


Origins of ZBL Backscatter

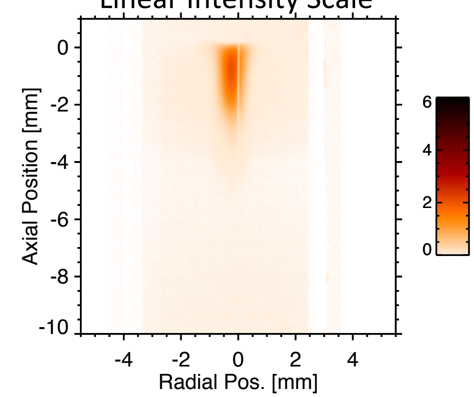



114.2 cm
ZBL Beam
Fiber Laser Probe
Fiber Backscatter Probe
60.5 cm
80.0 cm
7.9cm
5.3 ns
0.5 ns
Round Trip TOF's (ns)
Dimensions (cm)
21.4 ns
232.7 cm
1.4 ns
21 cm

Laser light at the target is preferentially scattered from the prepulse over the main-pulse. H22



Side-on View by Argon Imager
Linear Intensity Scale



- The laser entry window is blasted out of the way by the prepulse, thereby reducing the scatter of the main-pulse by the window.
- This was a successful laser-only preheat as indicated by side on x-ray diagnostics.

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LEH Laser transmission depends strongly on the pre-pulse and window thickness. (PECOS chamber studies)

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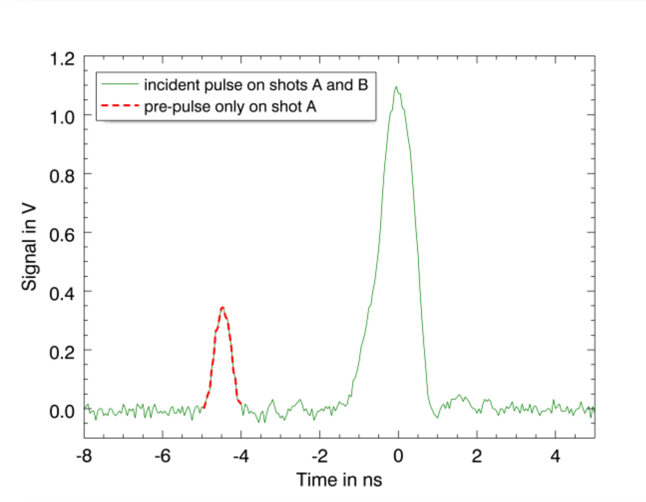
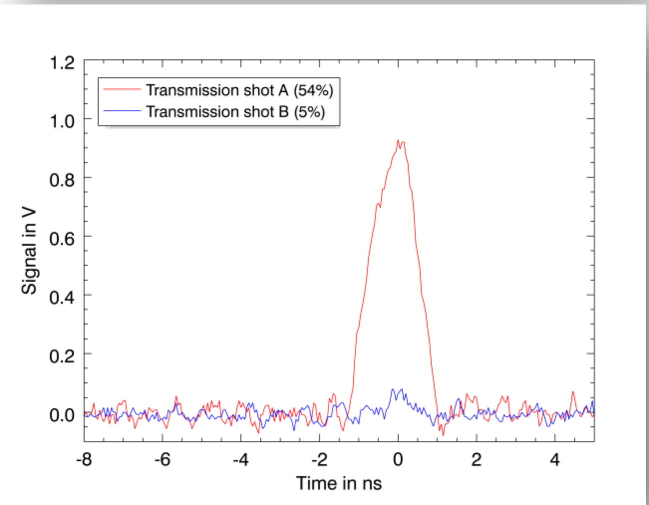
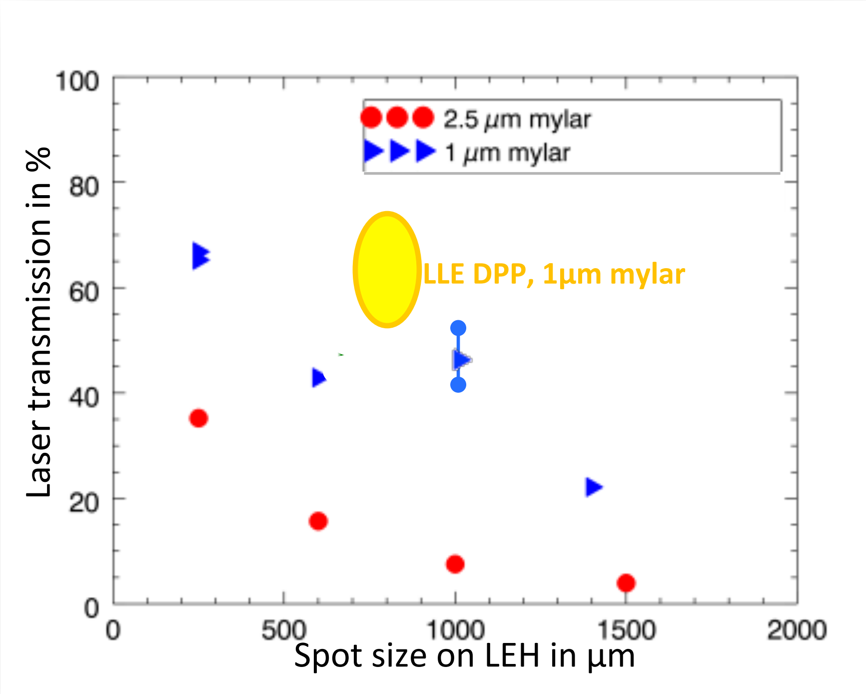
Importance of pre-pulse



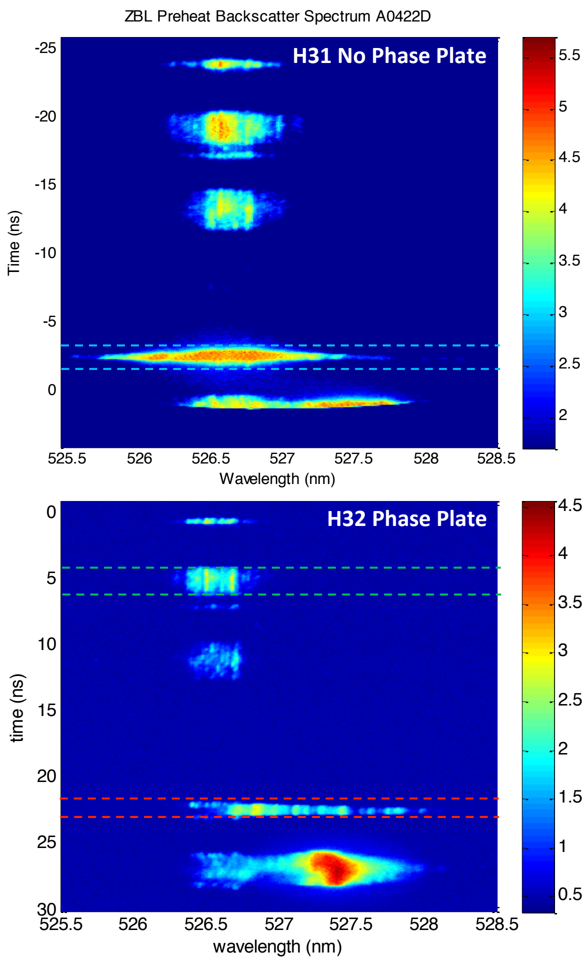


Importance of LEH Thickness

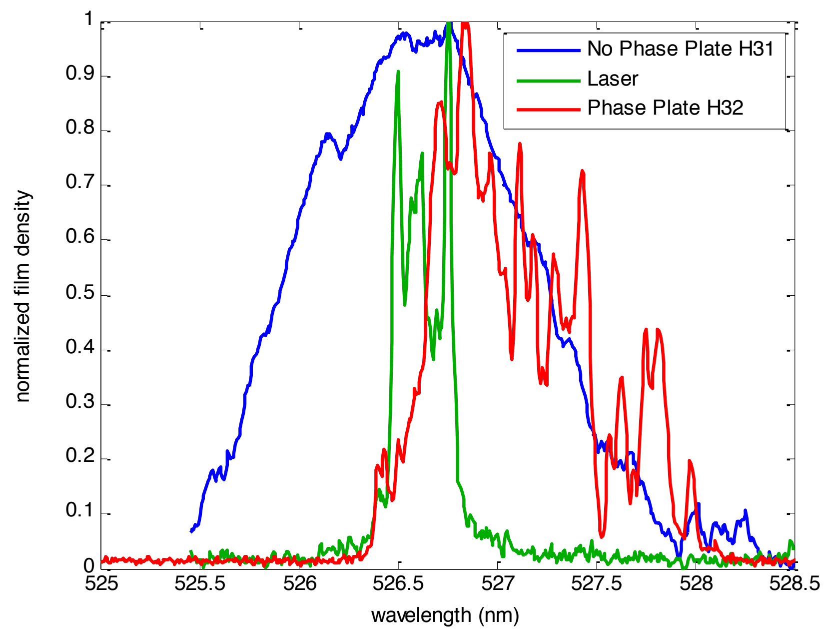


(0.5 + 2) kJ pulse energies,
1µm mylar window,
No phase plate.

The backscatter of the laser prepulse without a phase plate is blue shifted compared to with a phase plate.

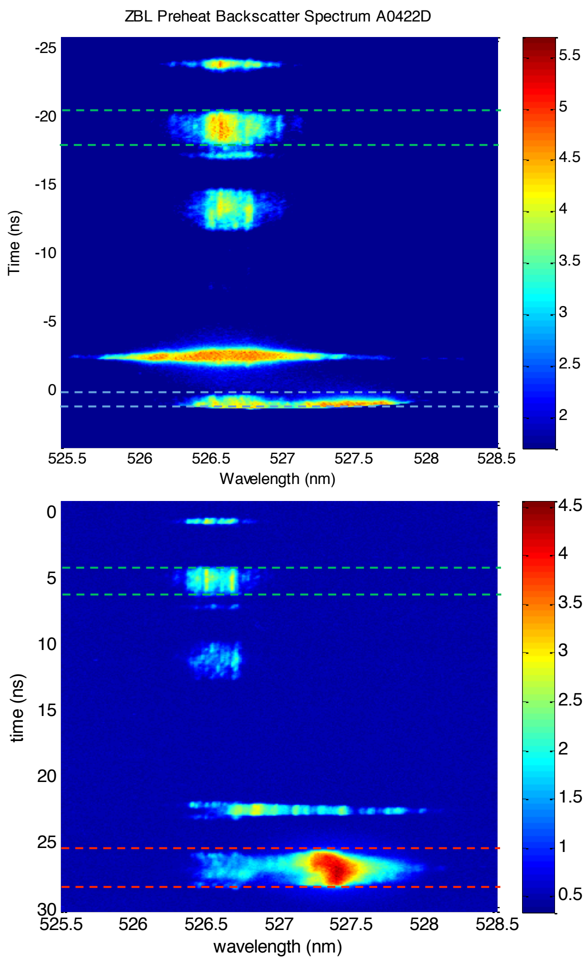


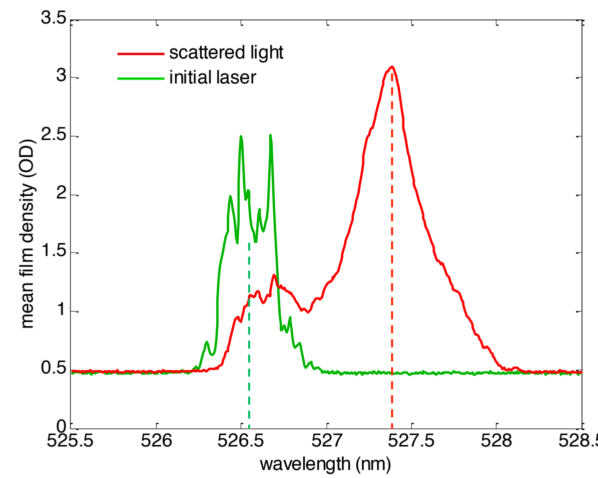
Liner filled with 15 psi Ne.



The blue shifted light is indicative of self-phase-modulation during self-focusing of the inhomogeneous laser spot.

The backscatter of the main laser pulse show a strong redshifted peak indicative of SBS. A simple analysis indicates T = 1keV heating of a Ne plasma.





$$v_{ia} = \omega_{ia}/k_{ia} = \Delta\omega_l/2k_l = \sqrt{k_B(\gamma_i T_i + Z\gamma_e T_e)/m_i}$$

$\Delta\lambda$ = 0.86 nm which corresponds to $\Delta\omega$ = 930 GHz

$\gamma_i = 3 \quad \gamma_e = 1$ (Laser convention)

Z_{Ne} = 10 fully ionized by the laser

$T_e = 1.0 \pm 0.2$ keV

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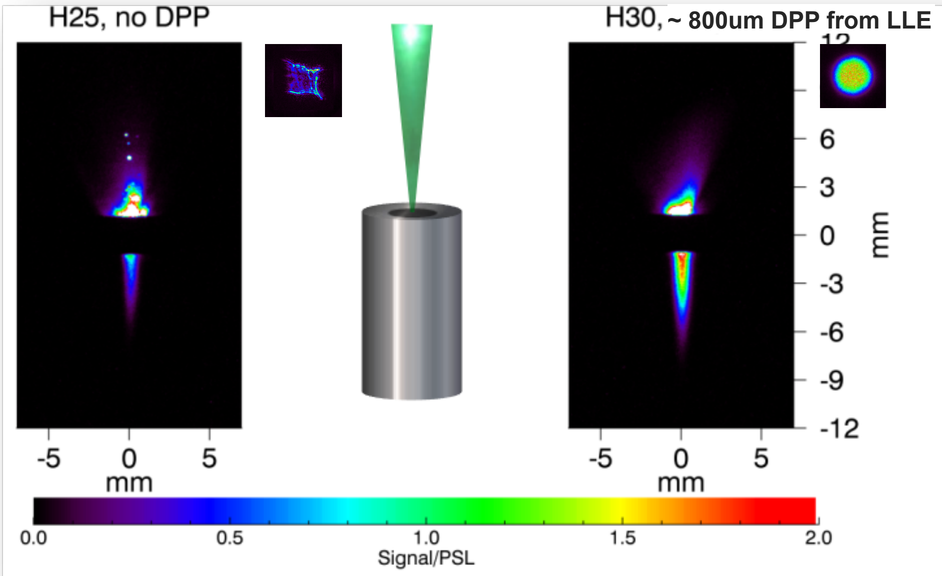
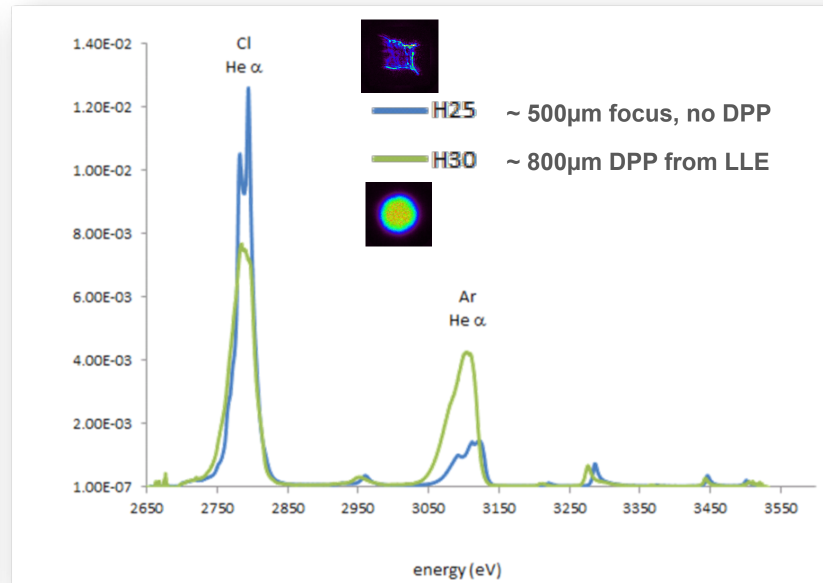
Phase Plate / No Phase Plate

60 psi D_2 with 0.1% Ar-dopant, Cl-doped LEH





Data analysis: Stephanie Hansen

- 1.6 mm depth increase
- 2x emission from gas for argon K-shell radiation

- Phase plate reduces window contamination
- Increases gas emission

Studies of the Ne-Emission through LEH in the PECOS chamber indicate that the Ne lights up after the main laser pulse.

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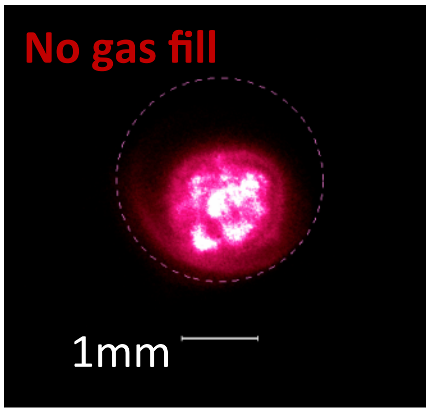
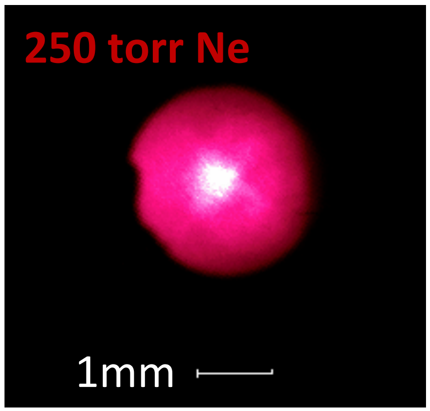
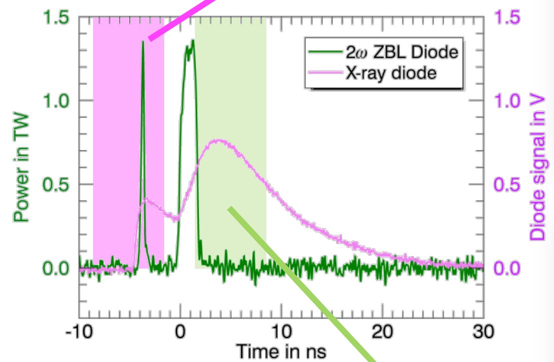
Time Integrated Images



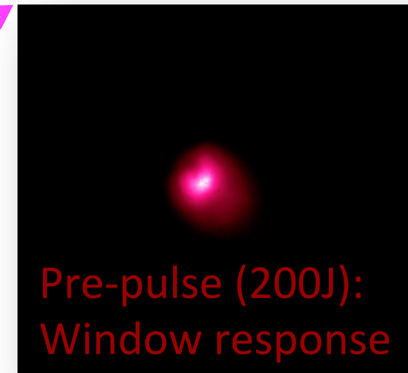


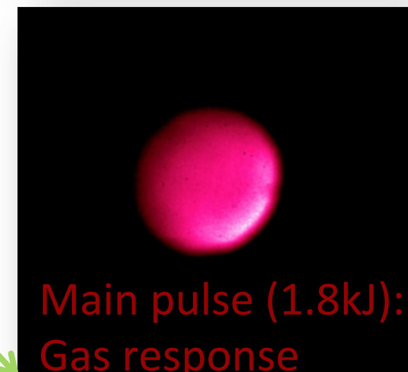
Only area irradiated by the laser lights up.

Neon emission fills entire LEH.



Time Gated Images





PECOS Experiments by Matthias Geissel

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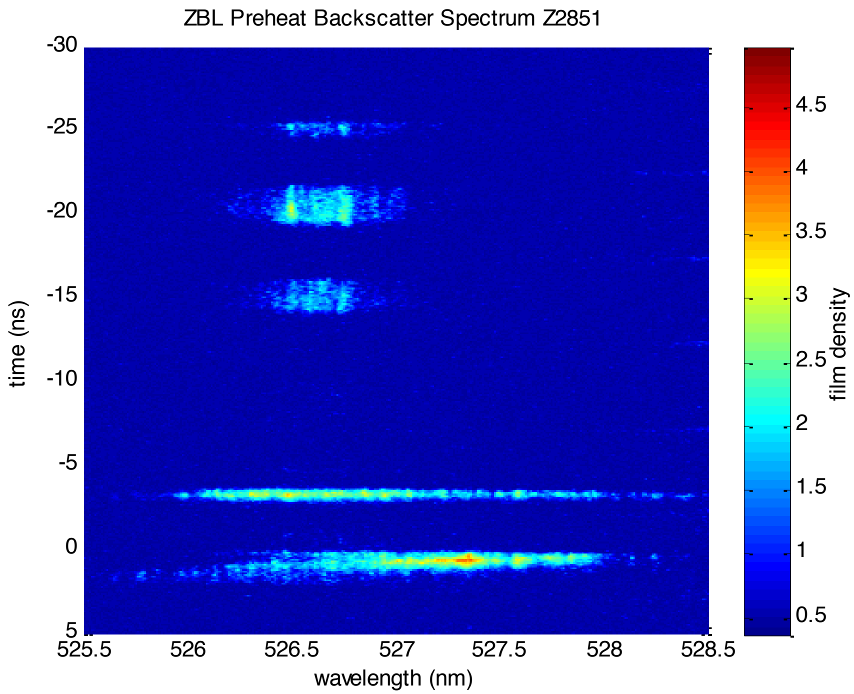
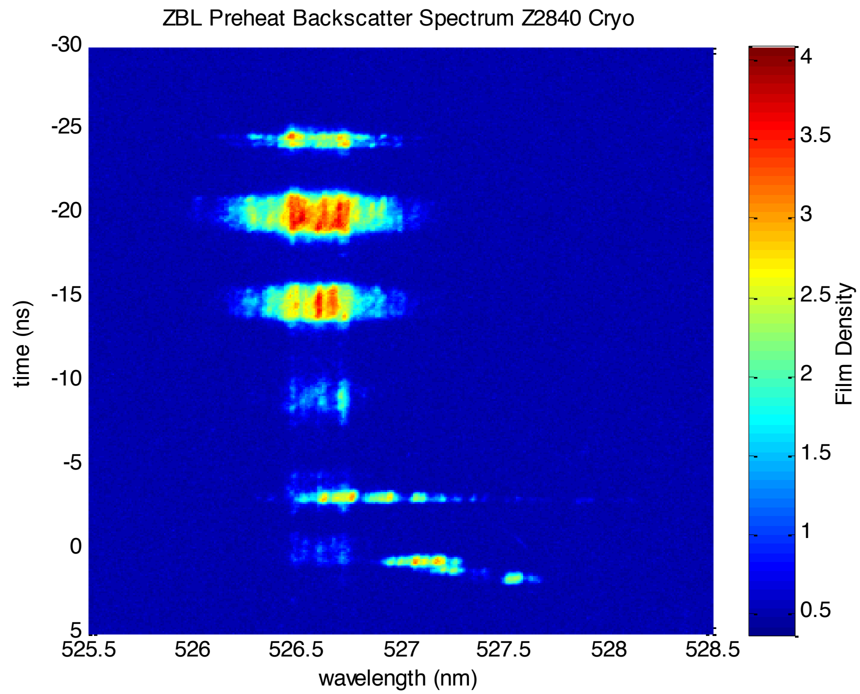
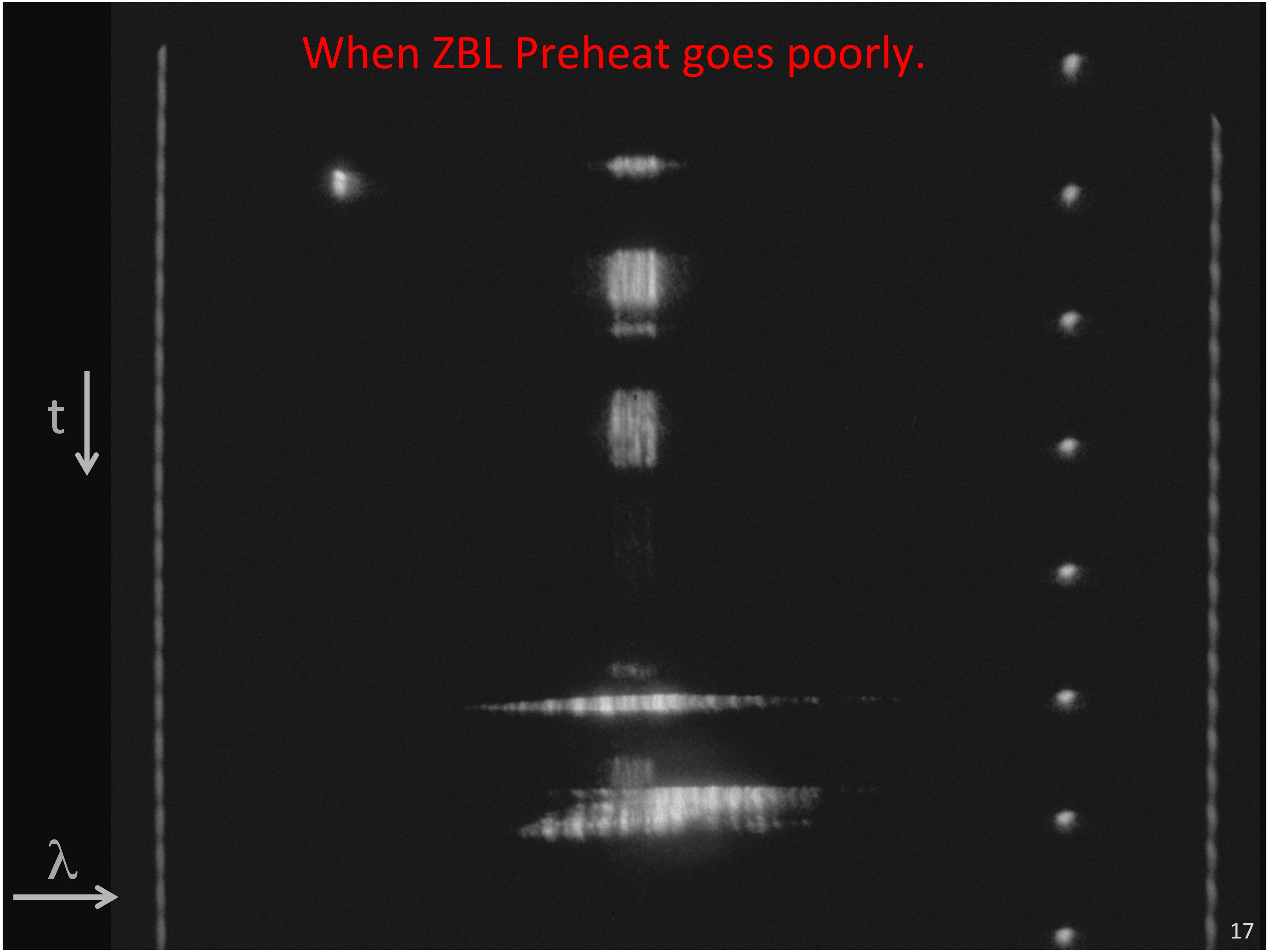
This is what neutron success and failure look like from the perspective of the laser backscatter diagnostic. Can you tell the difference?



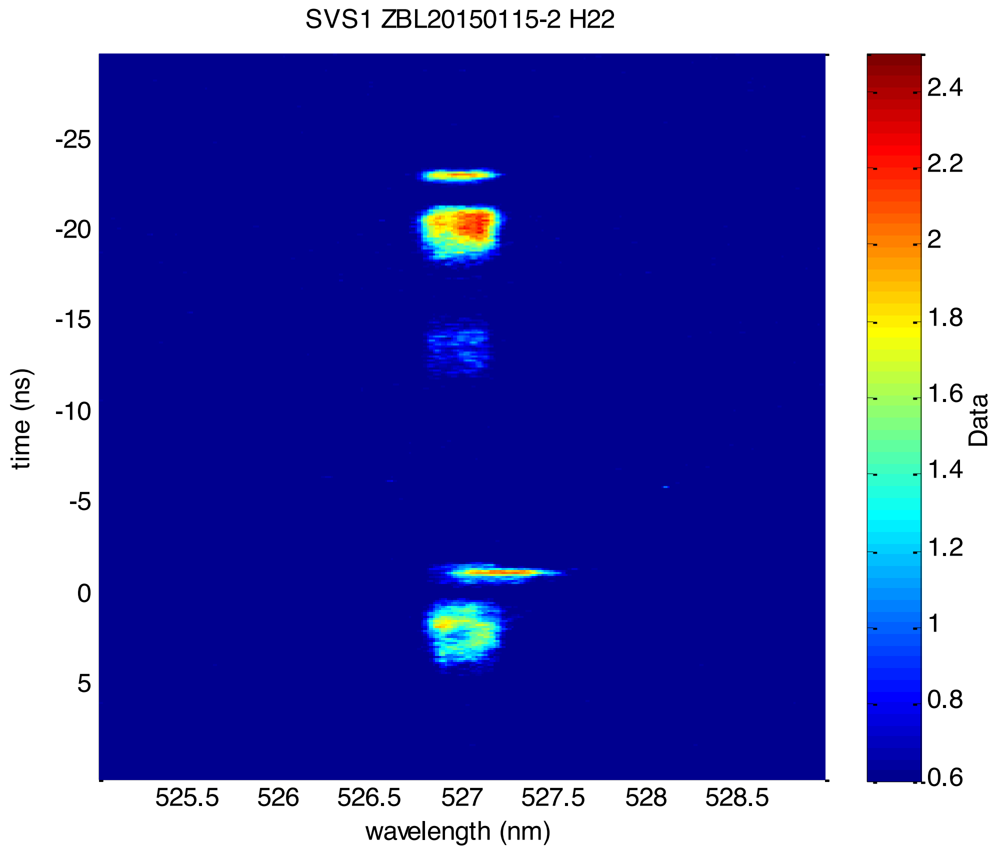


When ZBL Preheat goes poorly.



Summary

- ***The backscatter diagnostic is simple to field and is sensitive many changes in MagLIF experimental parameters: Phase plate, gas species, window thickness, etc.***
- ***When other diagnostics cannot be fielded the backscatter diagnostic can give important information about laser target interactions.***
- ***Significant difference between pre- and main pulse laser interaction!***
- ***Check for LPI such as SBS (possibly ~1kJ), SRS, TPD***
- ***Avoid LPI or maybe not!***



SVS1 ZBL20150115-2 H22
time (ns)
-25
-20
-15
-10
-5
0
5
525.5
526
526.5
527
527.5
528
528.5
wavelength (nm)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
Data

Pecos X-ray Diode Measurements

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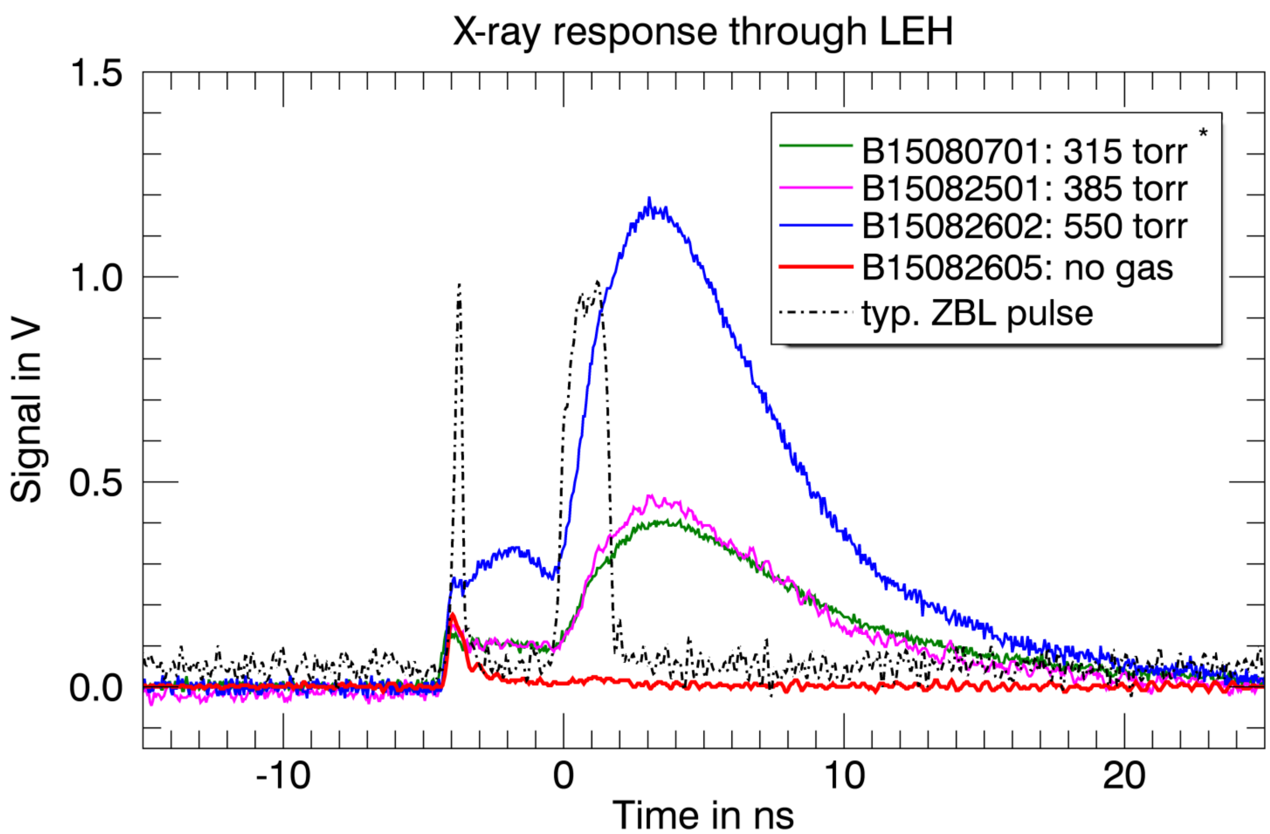
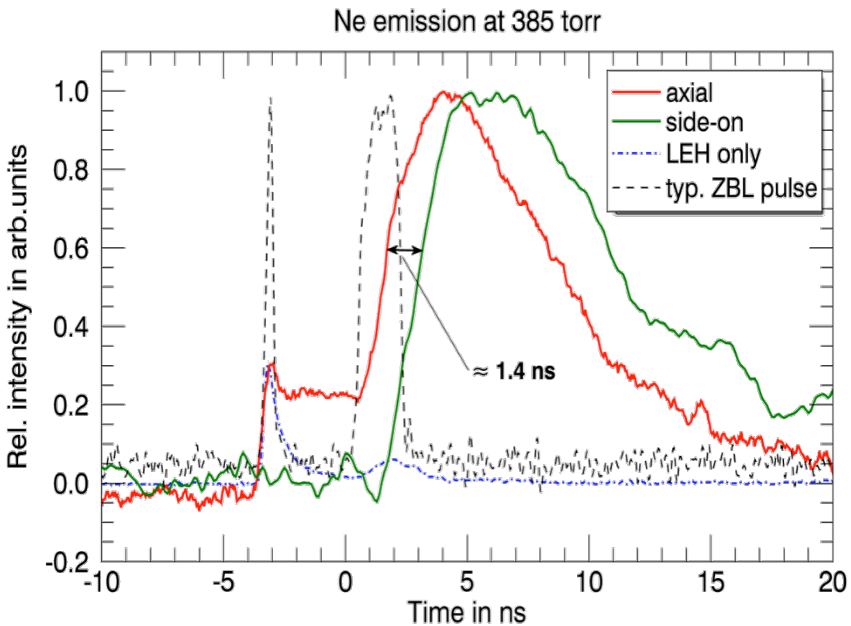
Ne X-ray output versus pressure with 1µm mylar LEH

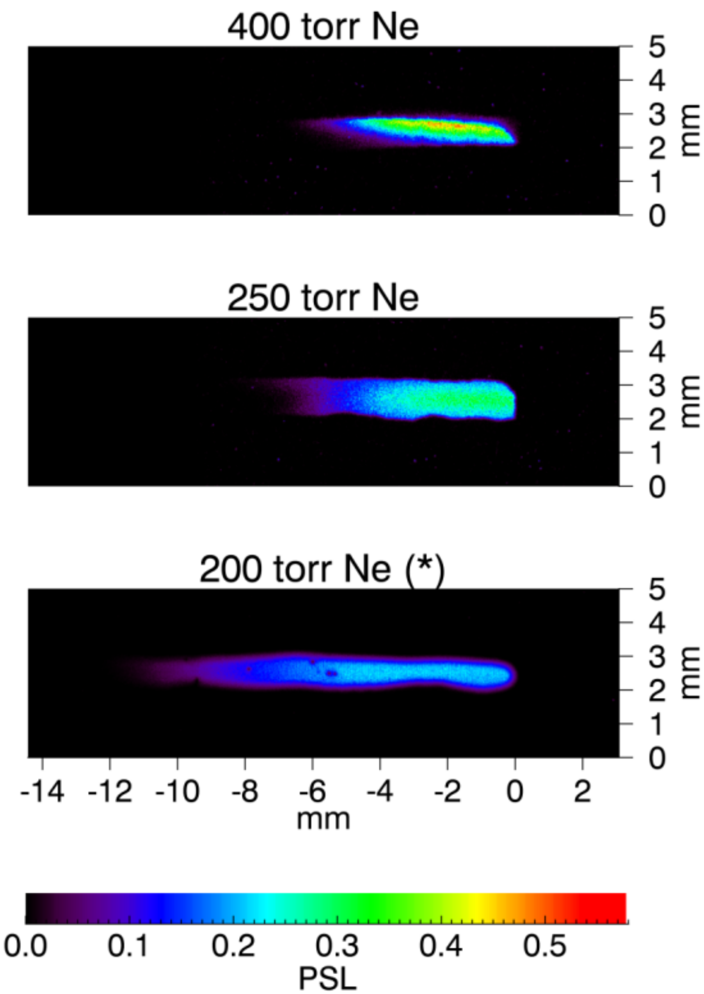


*: Shot with phase plate

Ne-Emission
Side-On



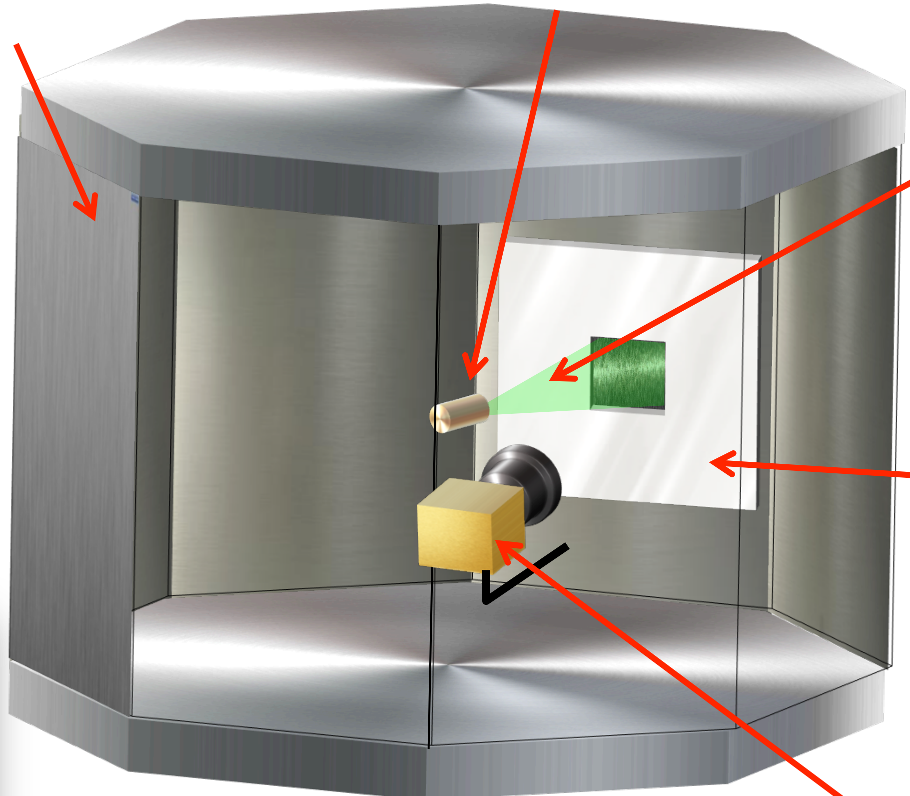
The side-on window's field-of-view starts 4-5 mm behind the LEH. Therefore the laser drills into gas at around 3000 km/s!



(*) Brightness adjusted for increased pinhole size

Backscatter Measurements

SBS Near Beam Imaging Measurements



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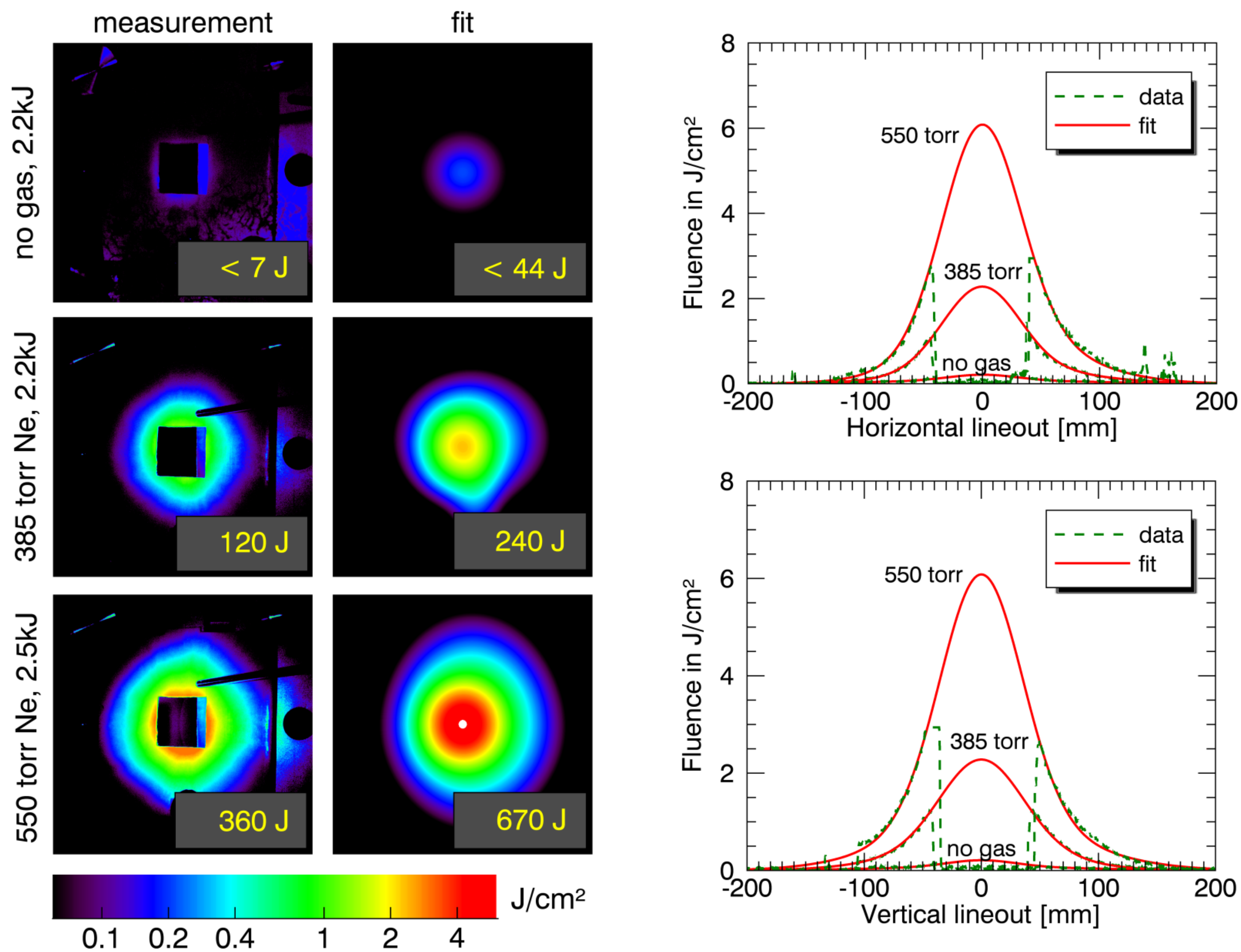
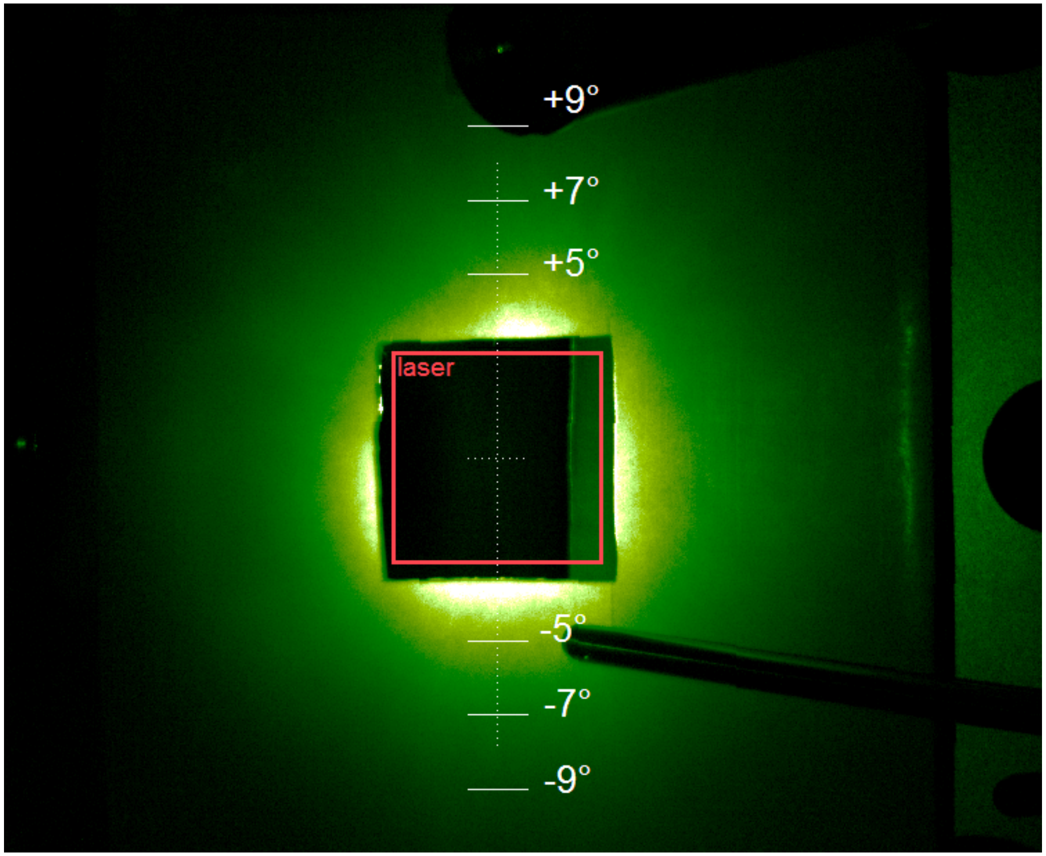
Backscatter Measurements

SBS Near Beam Imaging Measurements

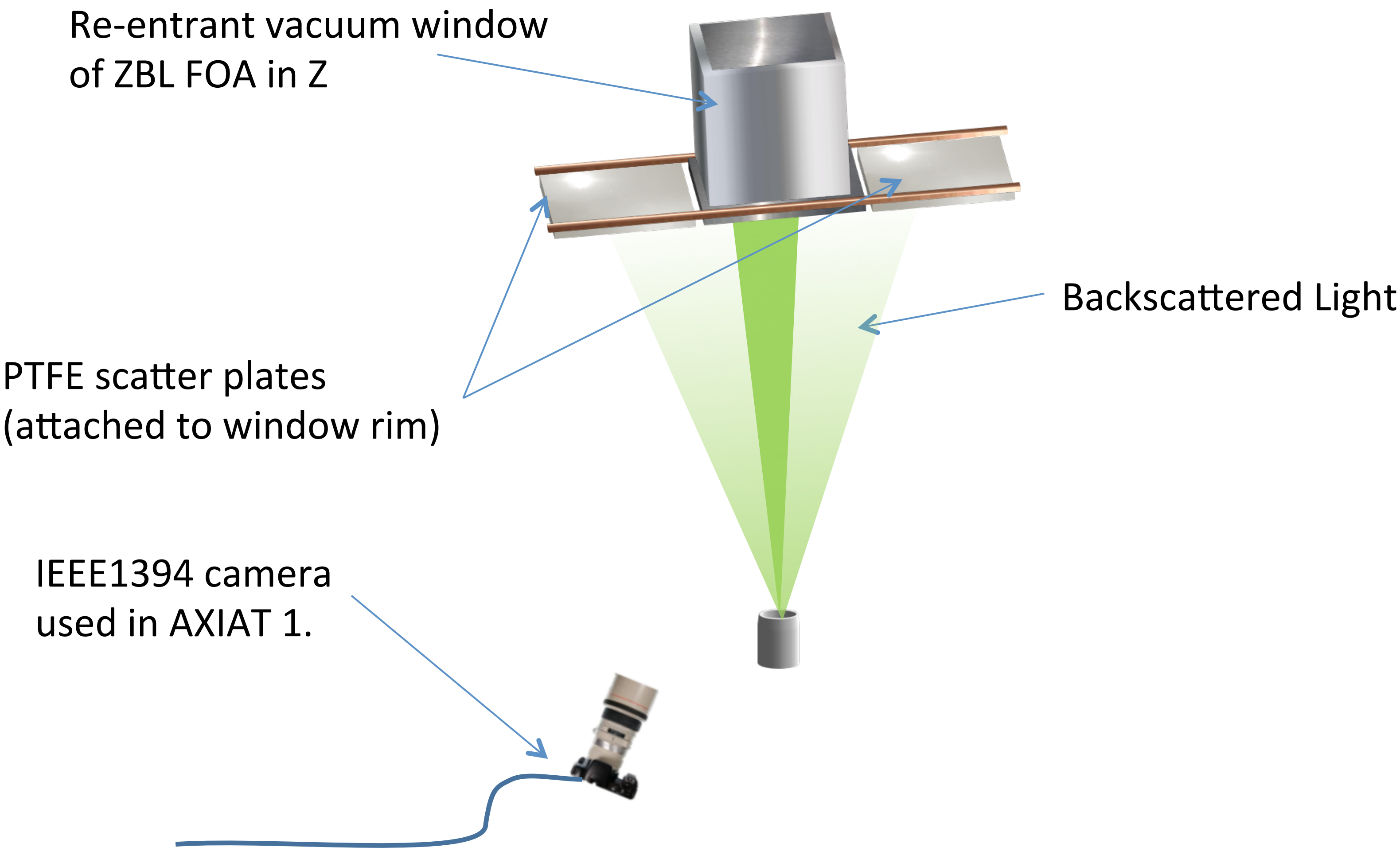


Pecos Backscatter Measurements



SBS measurements

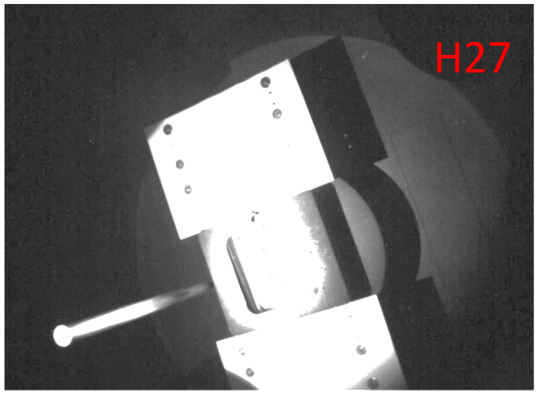
Near Angle Backscatter Measurements



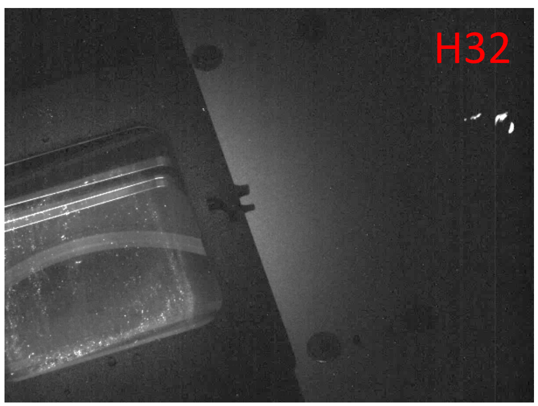
SBS Measurements

Camera: Evaluation pending

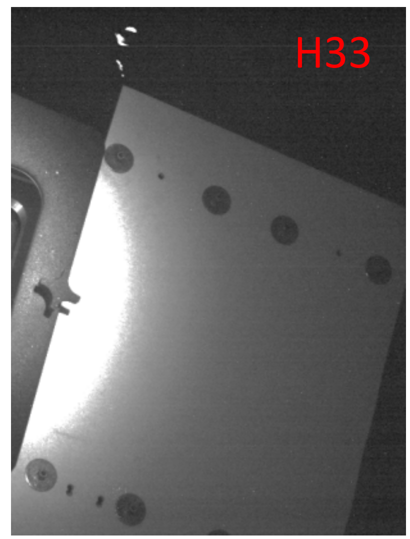
LASPE2 (no phase plate. ND4)



AXIAT2 (LLE phase plate, ND5)



0.5μm kapton, 15 PSI Ne



1.6μm kapton, 60 psi D_2

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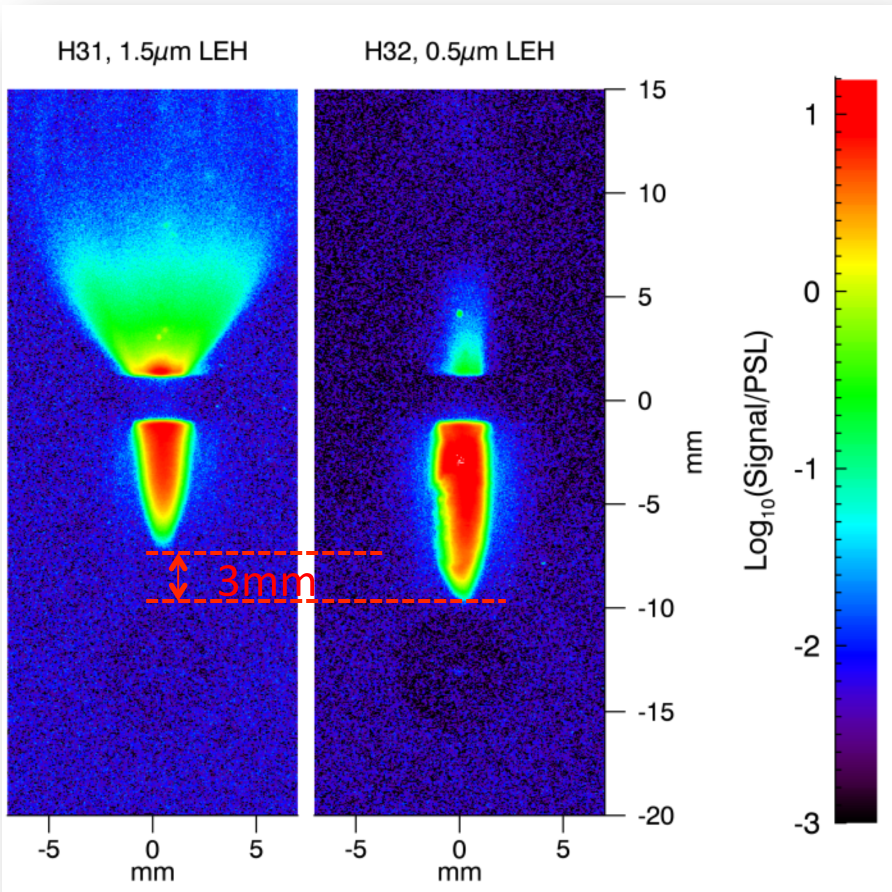
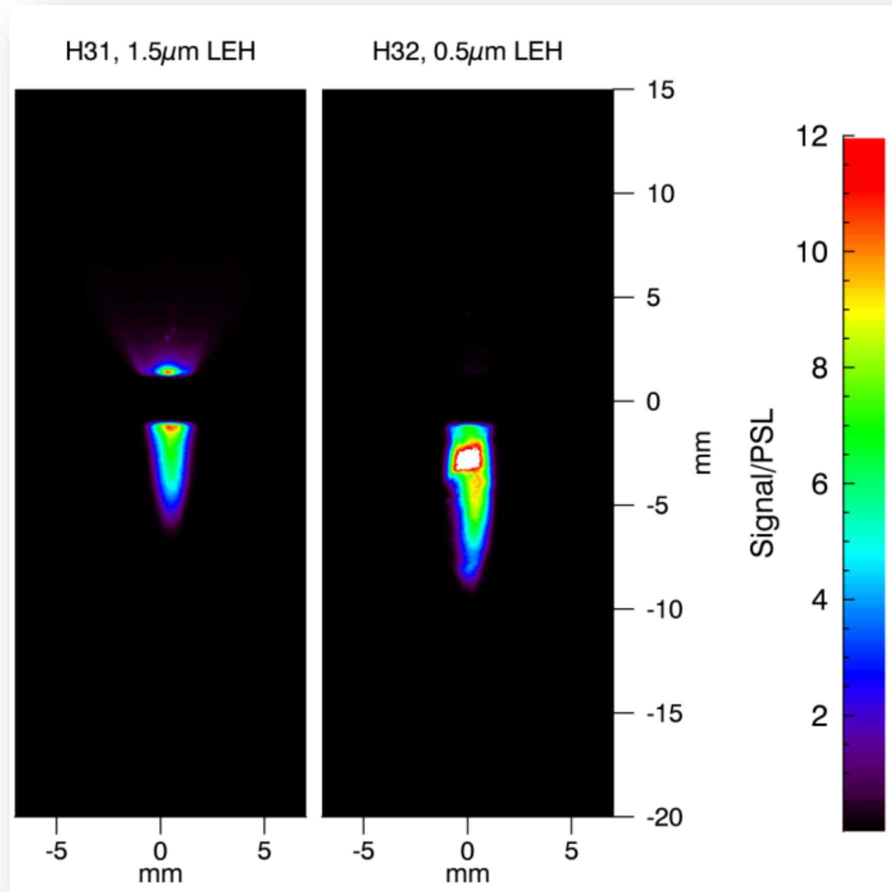
Why we like thin windows:

Aperture Ring Camera, 15 psi neon, LOS 90



Logarithmic scale

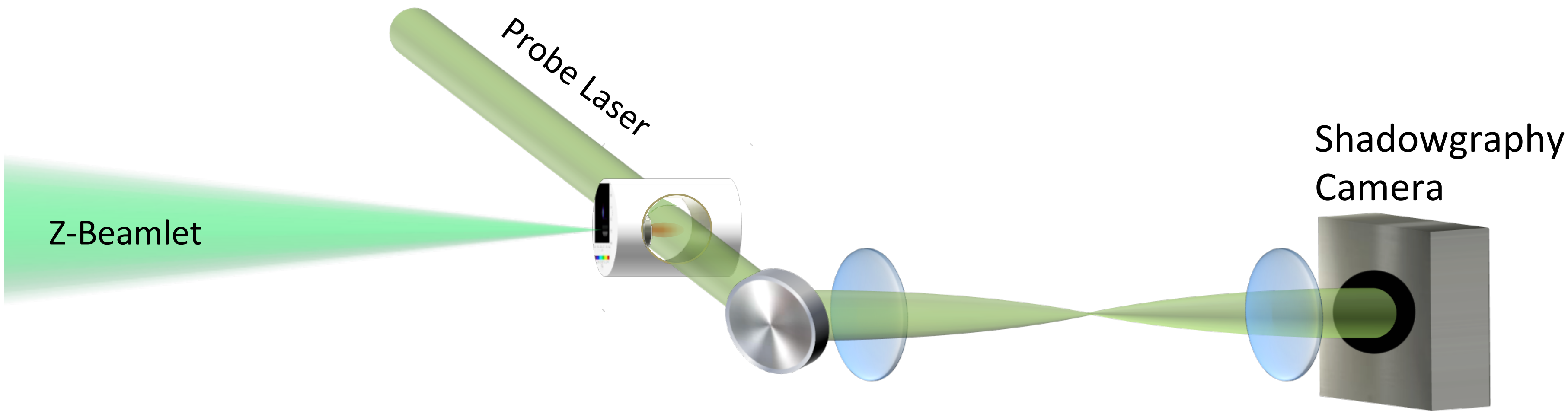


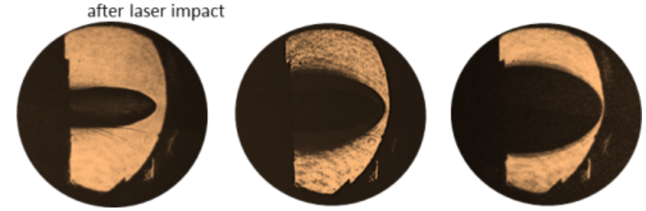
Linear scale

SAND2015-4867C

PECOS Chamber Gas Cell Experiments

“Hippogriff” Hybrid CMOS Camera (J. Porter)





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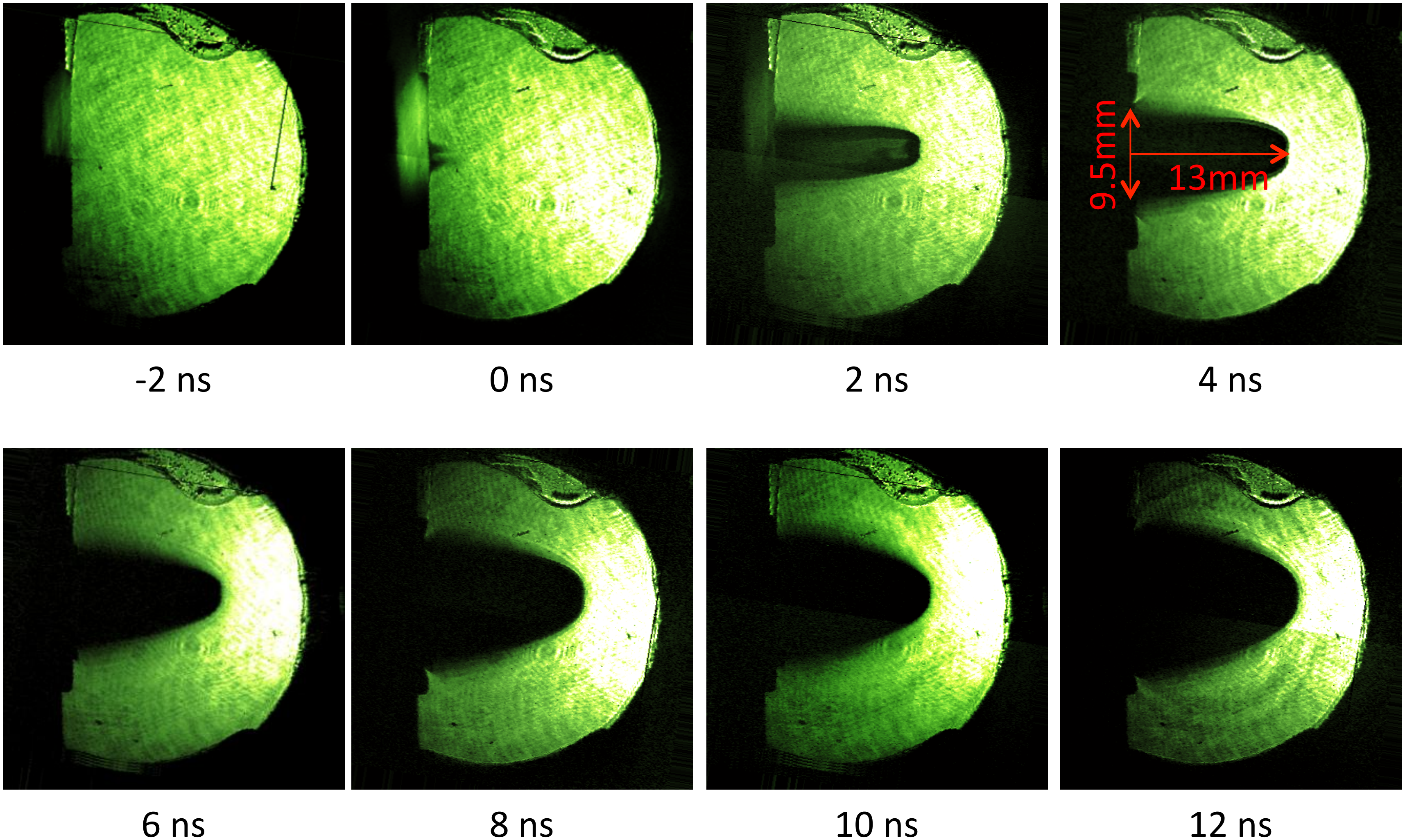
8-frame* probe beam B14121104

1μm LEH, ~2kJ

Pre-Pulse — **Duration of Main Pulse**



*: 2x interlaced Hippogriff with polarization multiplexing

Courtesy: John Porter, Mark Kimmel, Sean Lewis