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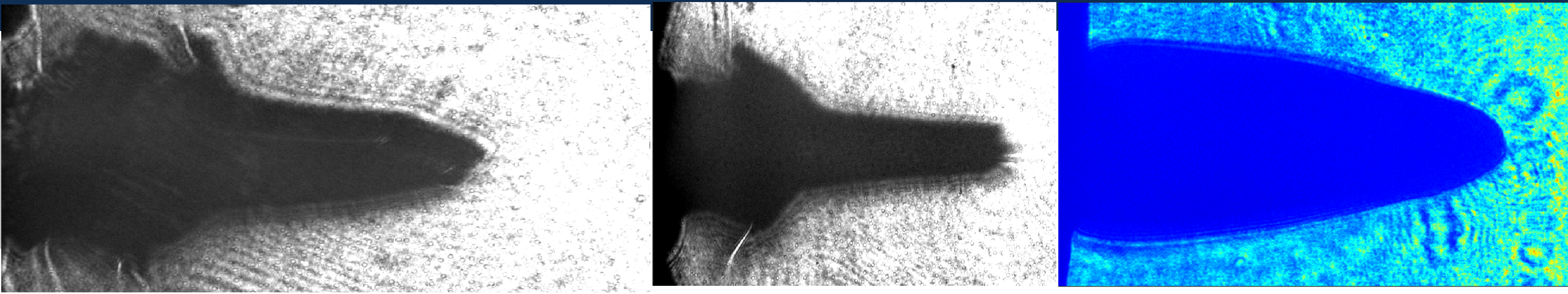

A New Laser Preheat Protocol for MagLIF

M. R. Weis, Sandia National Laboratories

for MagLIF Preheat 17 Team

APS-DPP 2017

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- J. Koning and M. Marinak (LLNL) for HYDRA code support
- MagLIF is a big (and yet not so big) team!

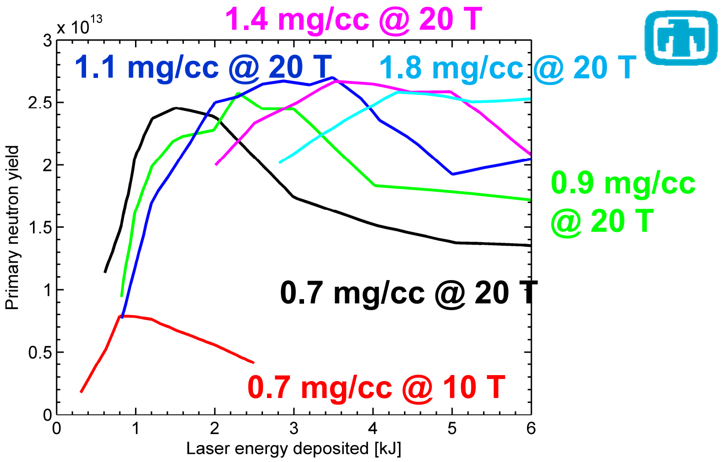
We have developed *two* phase plate smoothed laser preheat protocols that have been successfully integrated into MagLIF

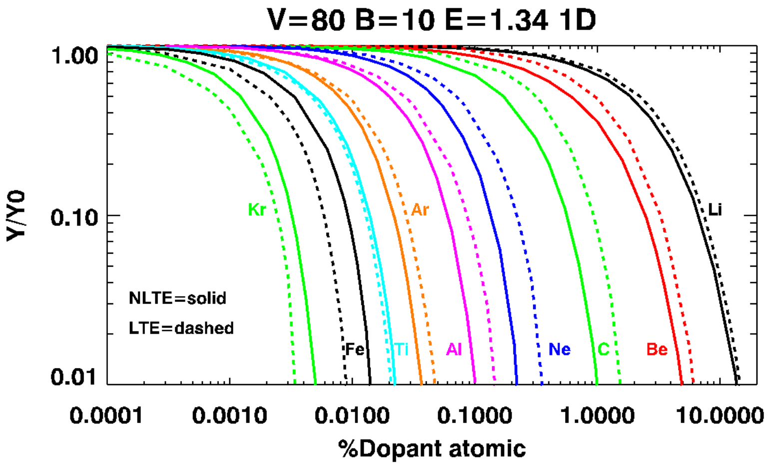
- Using only Z-Beamlet, moderate energies can be delivered to 60 psi (0.7 mg/cc D2) with negligible backscatter
  - Window absorbs large fraction of laser energy (> 40 %)
  - HYDRA predictions of window mix were observed in integrated MagLIF experiments
- Z-Petawatt co-injection capability allows for 90 psi operation with higher preheat energy and lower mix environment
  - Most feasible protocol to systematically increase the coupled laser energy
  - Less total energy is absorbed by the window and negligible window mix introduced
  - 60 psi targets could also benefit from this configuration but not yet tested

Improvements to the preheat protocol allow simulations to better impact design choices

Motivation

- Improved performance from MagLIF requires
  - More Bz
  - More drive current (Btheta)
  - **More (optimized) preheat energy**
- Considerations for improved preheat
  - Minimizing mix
  - Maximizing laser coupling efficiency (limiting LPI, losses to plastic window)
- Recent upgrades to the laser and facility have opened a new design space to achieve improved preheat





Impediments to optimizing preheat

- Laser pulse length / shape
  - Z-Beamlet has a finite window ~ 6 ns
- Backscattered light from LPI (Beamlet is 2ω)
  - Limits peak power
- Absorption of energy by LEH window

Facility upgrades

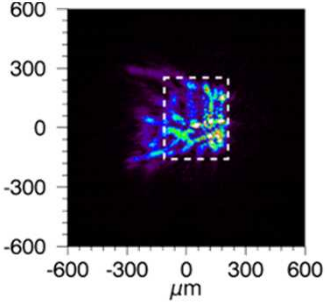
Design changes

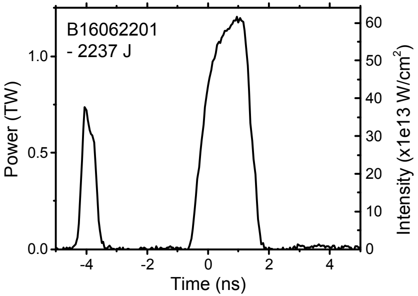
- Added ZPW as an independent laser source
  - Beamlet window is effectively longer
- Add phase plate
- Disassemble window as gently as possible
  - Limits shock formation
  - Also limits window mix
- Gently reheat low density window material to transparency

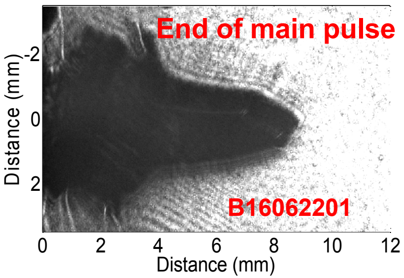
Increasing the spot size (including smoothing) and reducing peak power in the laser pulse substantially reduced Brillouin scatter but produced comparable propagation distance

Spot profile | Laser power | Shadowgraphy imaging | SBS backscatter

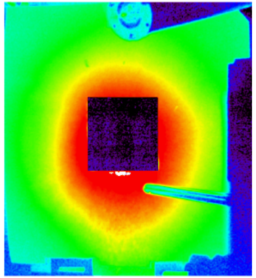
Old protocol
No DPP



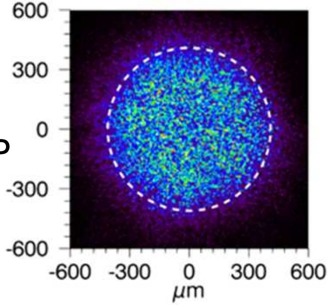


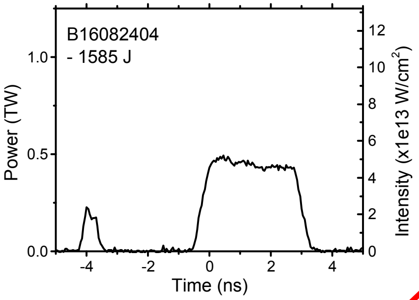


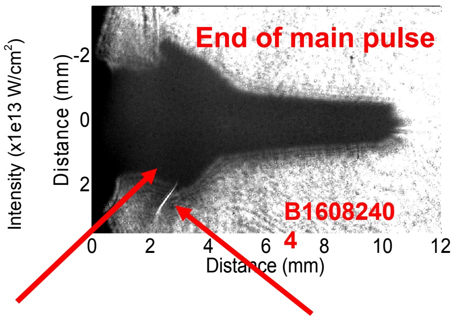
900 J



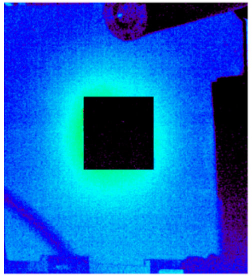
New protocol
1100 µm DPP







20 J



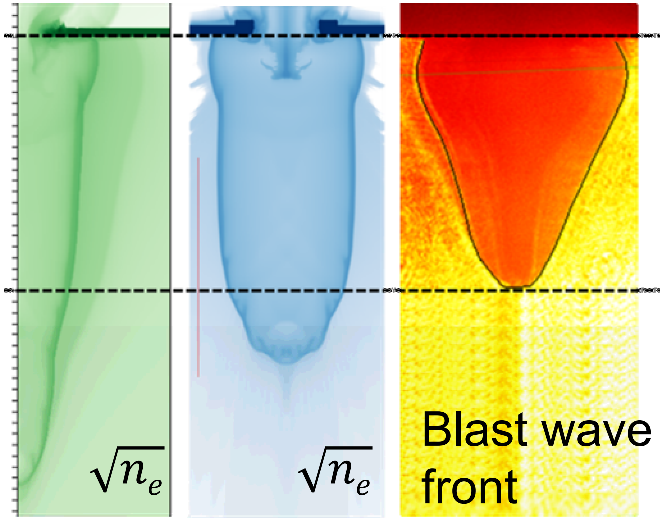
Bulbous features could be beam spray/filamentation or SRS side-scatter or ???

Filament

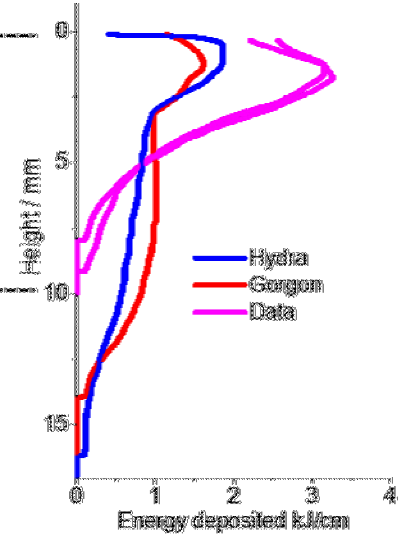
Benchmark experiment indicates different energy distribution

Laser Pulse 71 J + 1441 J; 54.3 psi He, t_{shadow}=22.7ns

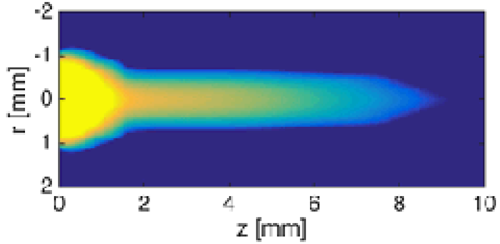
HYDRA GORGON Experiment



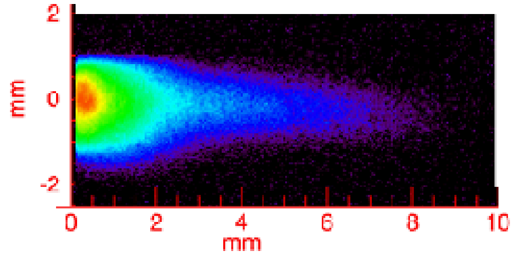
Energy vs. Depth



X-ray emission, $\log(I)$



SIM



EXP

<u>Inferred energy deposition:</u>

1159 J **1267 J** ***1213 J***

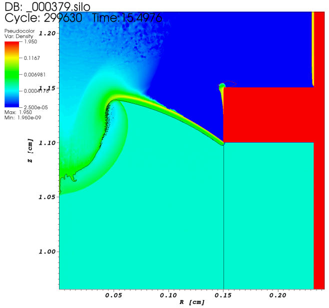
Window/gas region shows enhanced deposition in exp.

X-ray emission has good qualitative agreement.

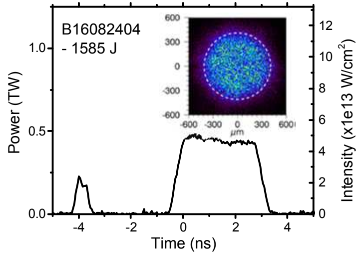
> 1 kJ in target, but much of it in LEH material (EXP+SIM) or outside MagLIF liner depth (SIM)!
HYDRA simulations calculate nearly 45 % of laser energy lost to window material – more in EXP, LPI?

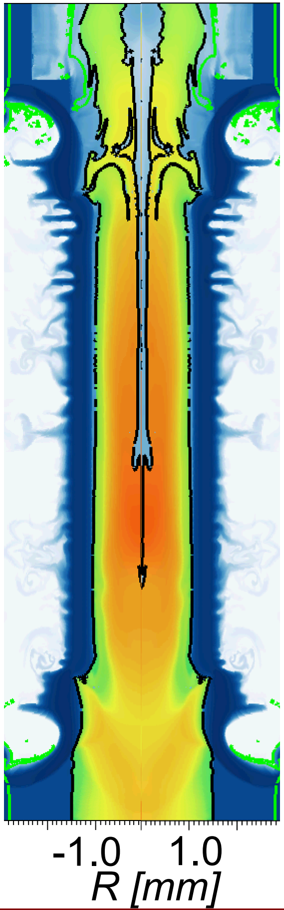
Initial HYDRA simulations predicted good performance (5e12 DD) but showed significant window mix in the fuel using the ZBL only configuration

- The window is accelerated downward by the combination of the large pre-pulse and short delay
  - Blast wave reflection off of the imploding liner squeezes the in-falling material down the axis until pressure equilibration
- The window material itself did not mix significantly with the fuel to degrade the yield substantially

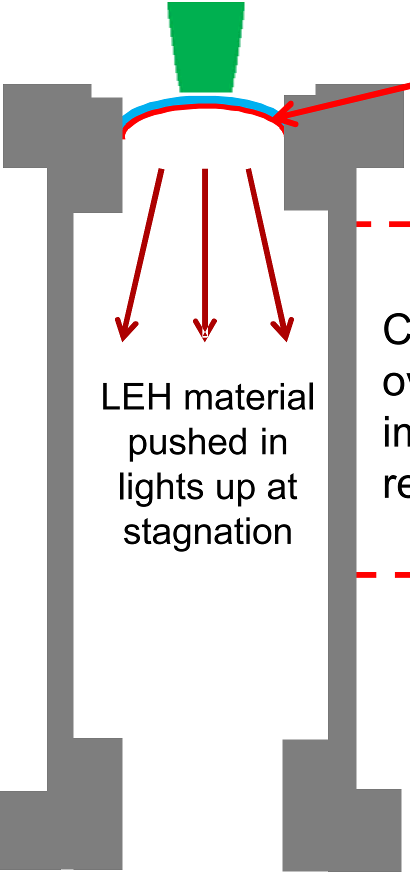


ZBL only, 60 psi,
~ 650 J coupled



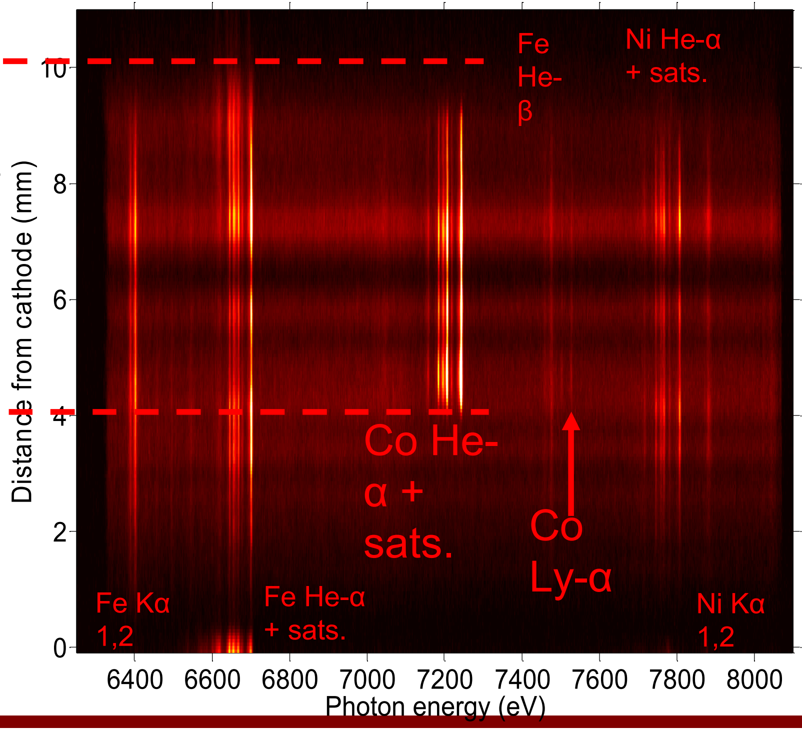


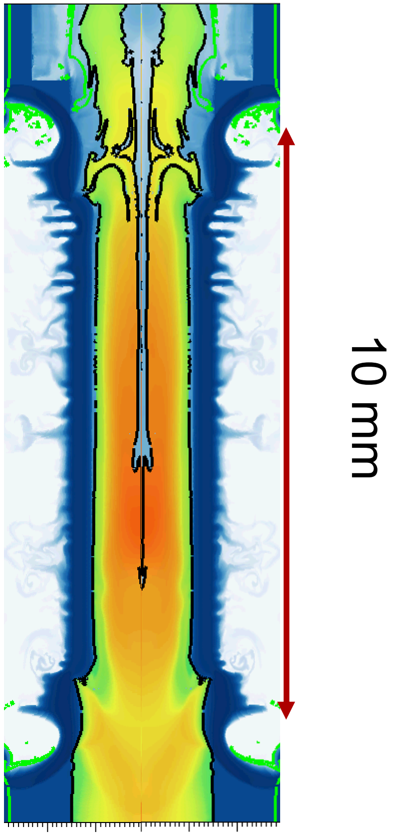
Integrated experiments performed as expected with ~ 4e12 DD yield despite the inference of high window mix



Co extends over >1/2 imploding region

Z3057 – 1100 µm DPP: XRS3 spectrum

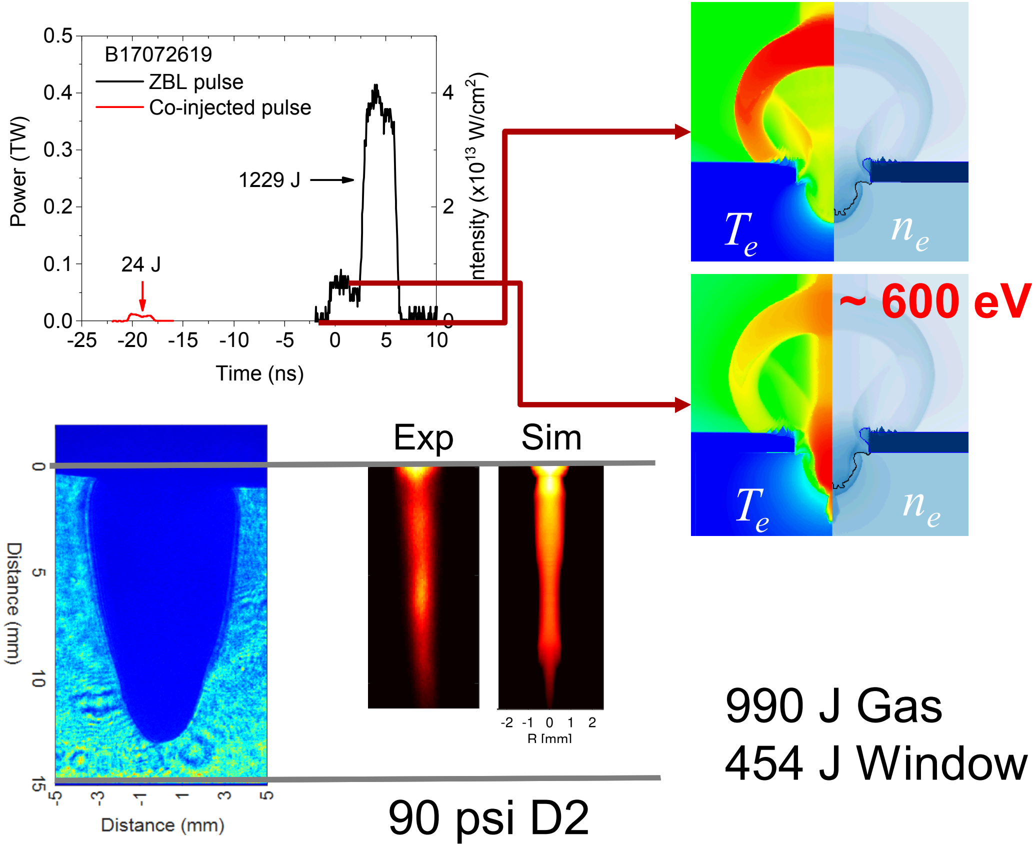




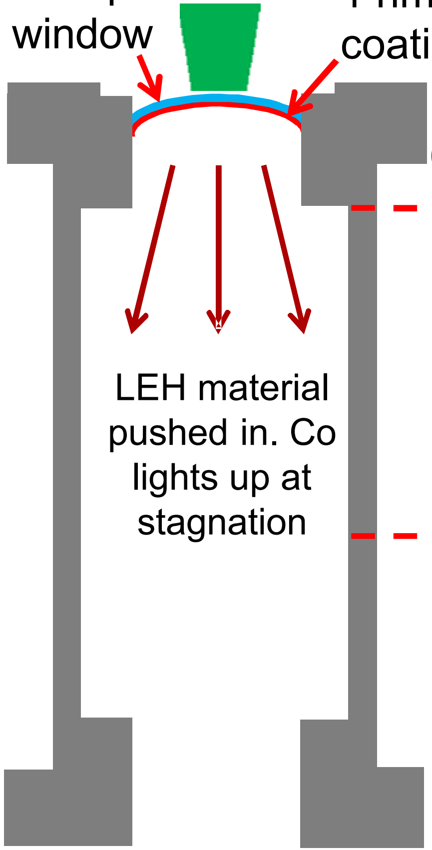
XRS3 – axially resolved spherical crystal spectrometer

Loss to the window and injected mix were addressed with the addition of ZPW as a co-injected laser pulse

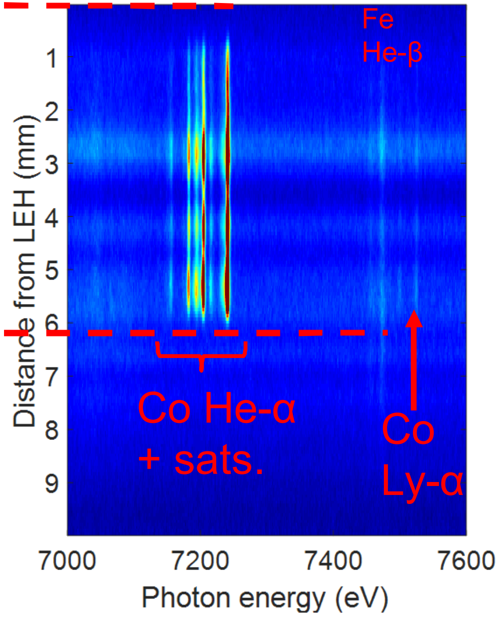
- Z-Petawatt supplies 10-20 J over 2 ns to disassemble window
  - Factor of 10 density reduction
- 200 J Pedestal reheats window material to support better propagation of main heating pulse
  - Roughly 20 % more energy coupled to the gas
- Experiments show more uniform heating in better agreement with simulations

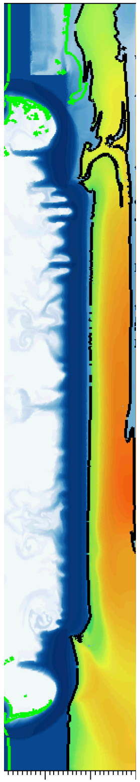


Simulation predictions of mix were again confirmed fielding co-injection

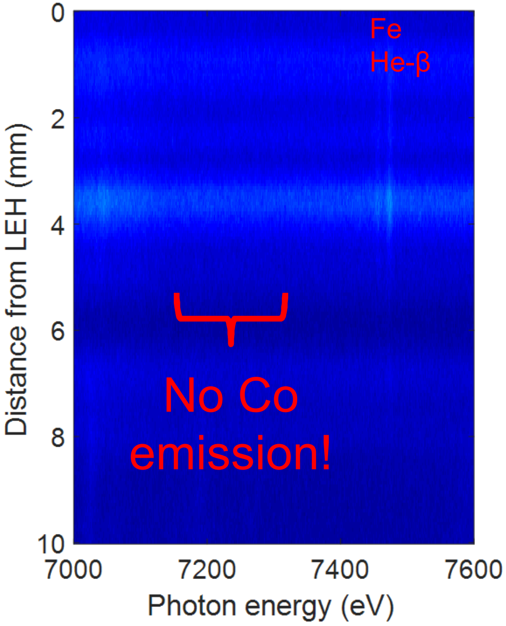


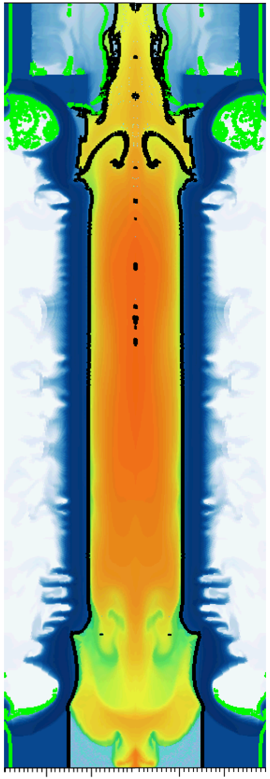
Z3057 – ZBL-only (significant window mix)





Z3143 – co-injection (no window mix)





Window mix does not seem to be an obvious culprit for yield degradation

	z3057 17a (ZBL only)	z3085 17b (unsmoothed)	z3143 17c (co-injection)
Laser energy	103 + 1283 J	300 + 2000 J	20 + 1626 J (co-injection)
Dopant	1 nm Co on LEH	1 nm Co on LEH	1 nm Co on LEH + 3ppm Kr in gas
DD	2.0e12 ± 20%	4.2e11 ± 20%	2.2e12 ± 20%
DD/DT	222 ± 28%	140 ± 20%	169 ± 20%
Tion (Ntof)	2.4 keV ± 20%	1.8 keV ± 20%	2.1 keV ± 20%

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Backups

3 ppm Kr dopant also provides evidence for much lower carbon mix with co-injection

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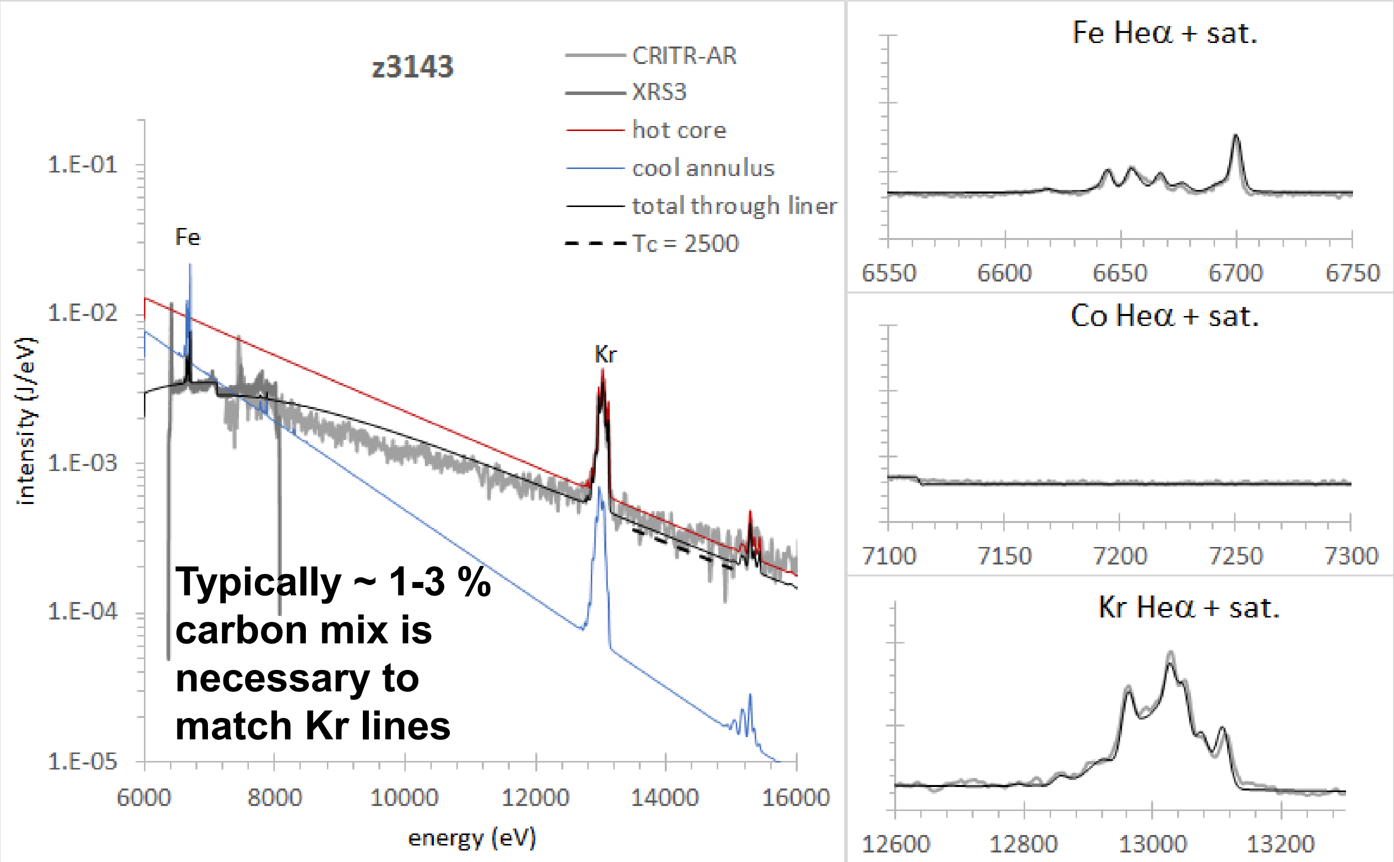


Good fit to data with:

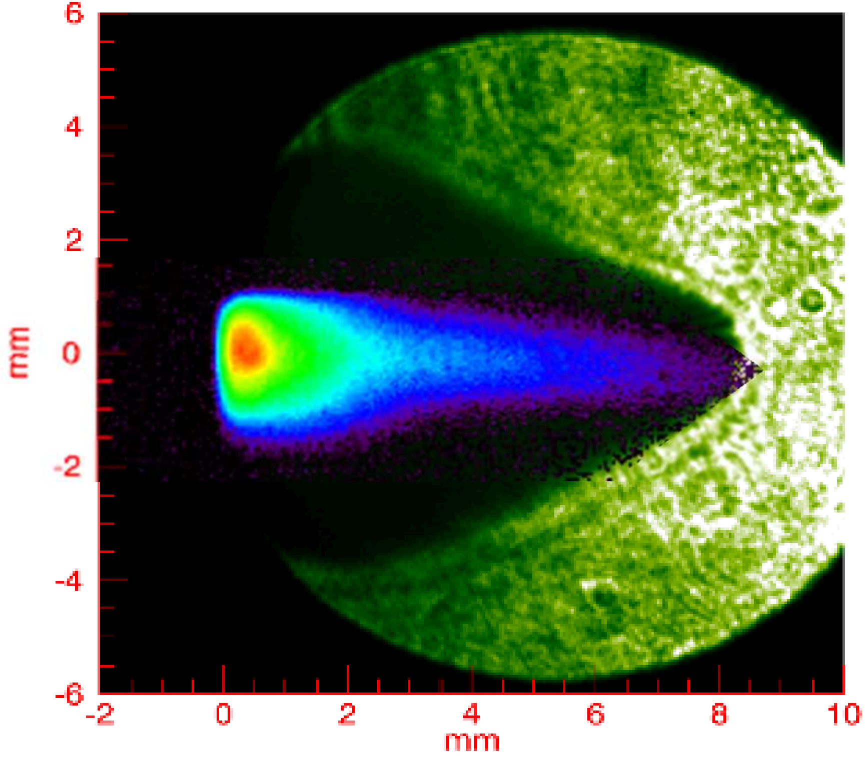
R_h = 48 um
0% C
(Kr & continuum intensity)

0 ppm Co from LEH
(Co intensity)

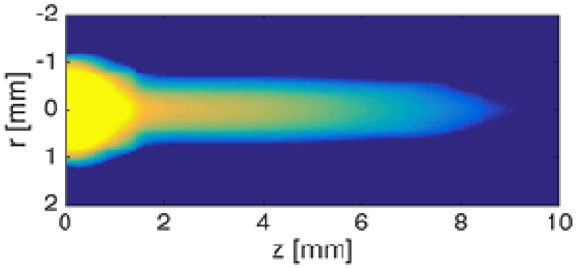
0.5% Be
(Fe intensity)

Note: ~2x increased absolute intensity (axially local) and Fe IC/resonance are both consistent with 1.5x higher densities

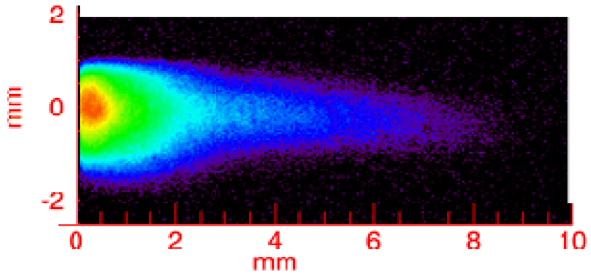
Combination of shadowgram and X-ray emission show more energy entrained in window region



X-ray emission, $\log(I)$



SIM



EXP

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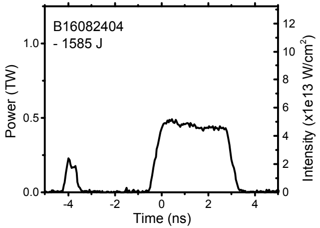
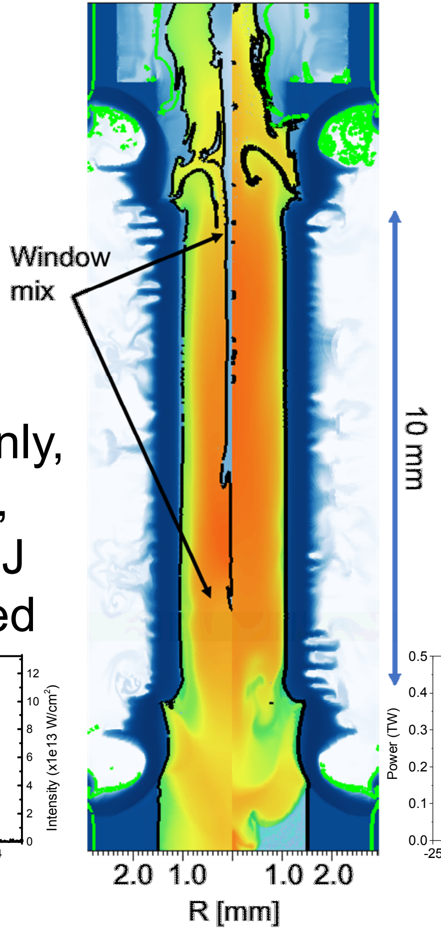
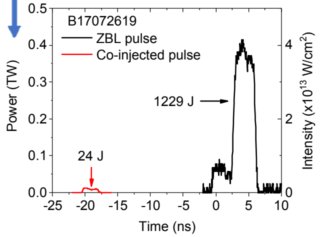
ZBL only, 60 psi, ~ 650 J coupled

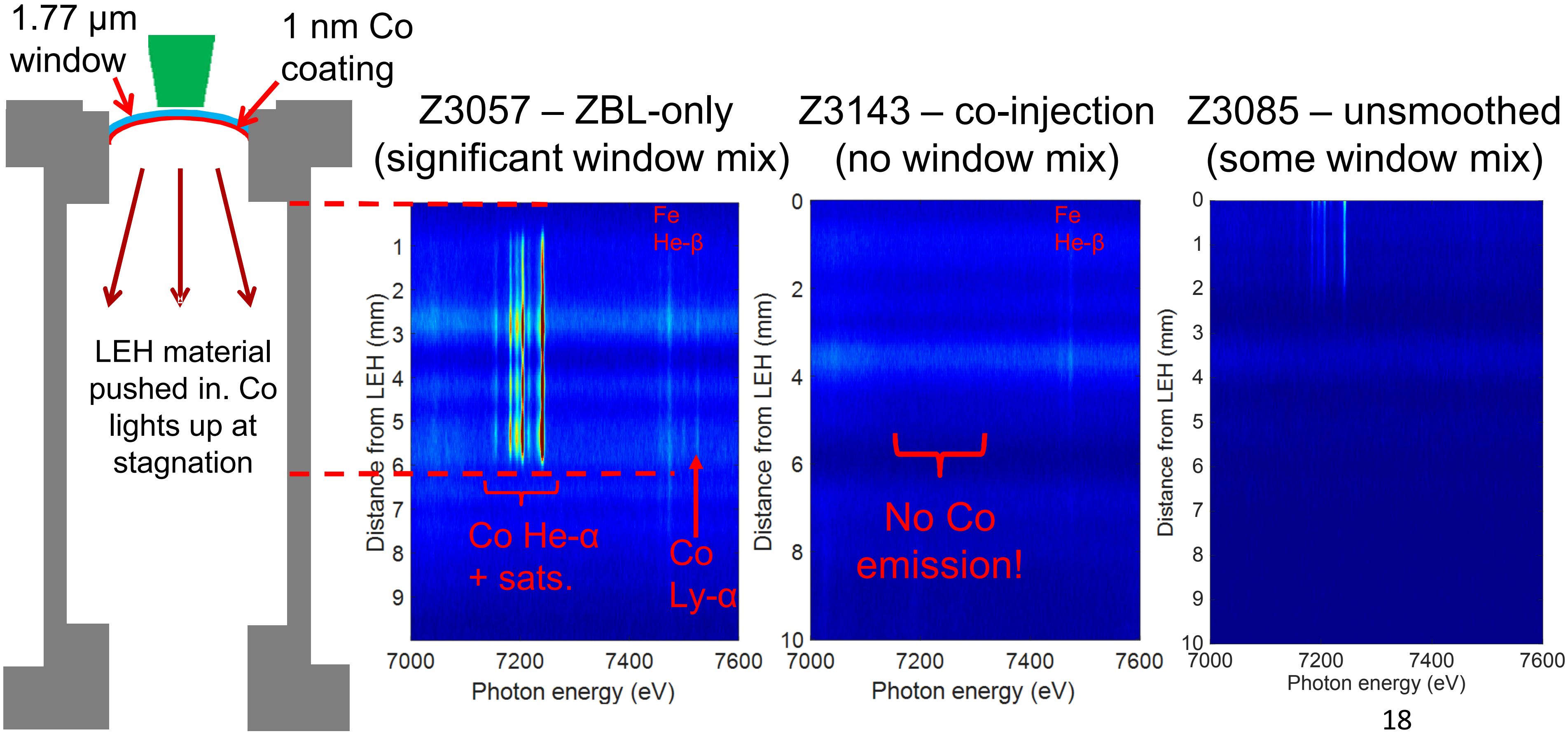




Co-injection, 90 psi, >1 kJ coupled



We now have some control over window mix



Config. A: 80/1500 J

- Preheat energy in the gas is roughly 625 J
  - Window absorbs roughly 650 J
- Yield ~ 1.0 – 1.8×10^{12}
- Ion temperature: ~2.4 keV
- Fuel density: 0.5 – 1.5 g/cc
- Hot core with radius 50 um
- Peak current is 16.5 MA
- Bz ~ 130 MG (10e4 T) => 0.5 MG*cm
  - Nernst can reduce this to 40 MG
- Less than 1 ug of window material in fuel region but dispersed axially over many mm (radially only 5 um)

Repeat shots in CY17 show high yields, variability

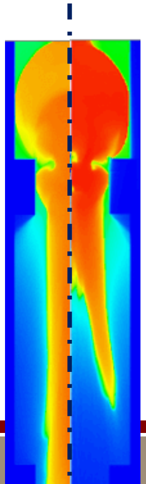
	Z3040	Z3041	Z3057
Laser energy	70 + 1460 J	73 + 1534 J	103 + 1283 J
Y_{DD}	4.1e12 ± 20%	3.2e11 ± 20%	2.0e12 ± 20%
Comments	Highest MagLIF yield to date	Direct repeat of z3040. Factor 12 less yield. Evidence of high mix.	Co coating on LEH used to investigate mix

(All shots use 1100 μm DPP)

Phase plate configuration with low intensity has potential for very high yield, but is less reproducible than unconditioned beam!!!

Why? Still unclear, but DUST on the LEH is a hypothesis (simulation by M. Weis):

Clean LEH



100 μm dust particle on axis