

# Modeling Progress for MagLIF Laser Preheat

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International Conference on Dense Z-Pinches

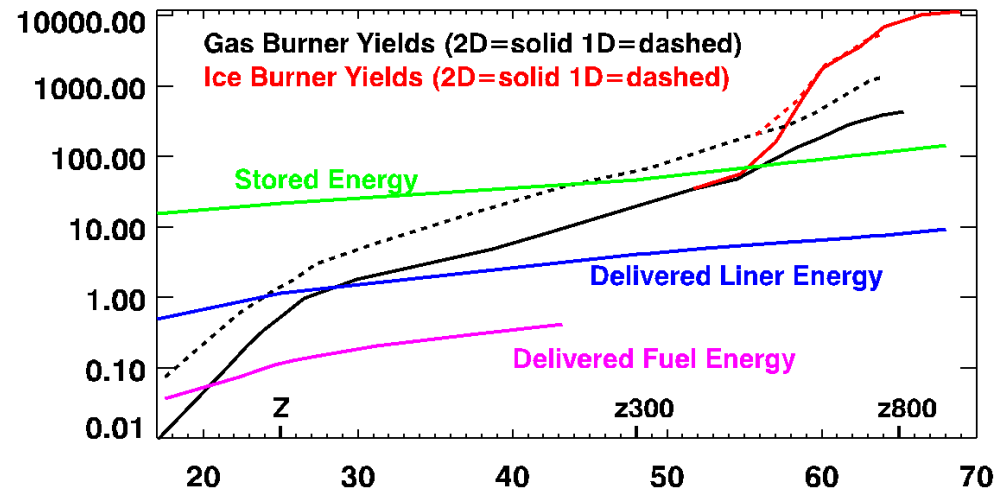
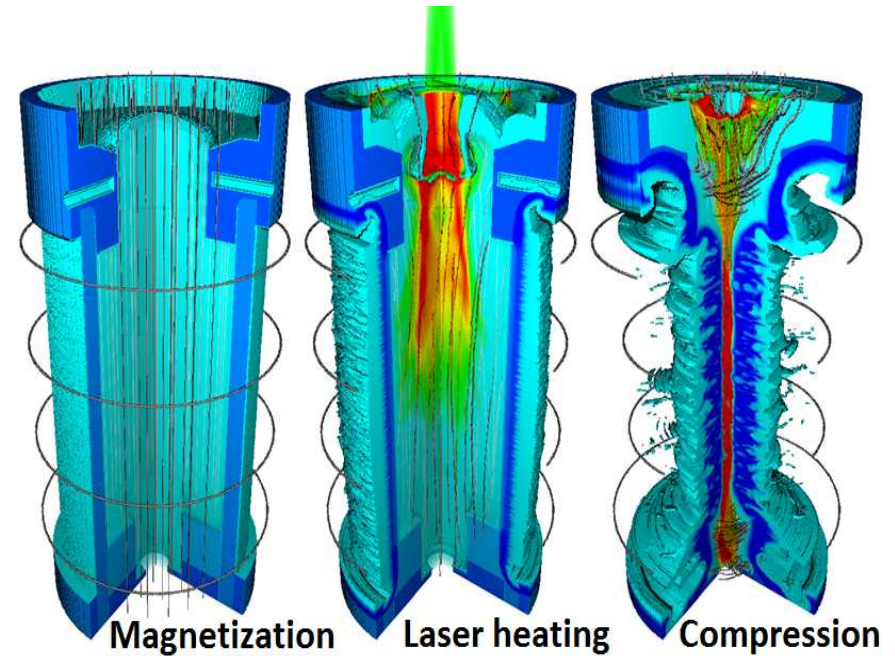
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# Acknowledgements

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

# Motivation

- Laser pre-heat is a key feature of MagLIF
  - Without it, no yield!
- For many years the preheat protocol was hardly changed
  - This was in part due to the limitations of the laser
- Recent upgrades to the laser and facility have allowed for rapid progress and opened new design space
  - There still remains much to learn about our models' predictability



# Outline

- Select Omega EP experiments and modeling results
  - One campaign out of many
- Pecos refresher and modeling results
  - Upgrades to Pecos and analysis of recent experiments
- Integrated performance

# Omega EP has been relied on for detailed laser preheat experiments since 2014

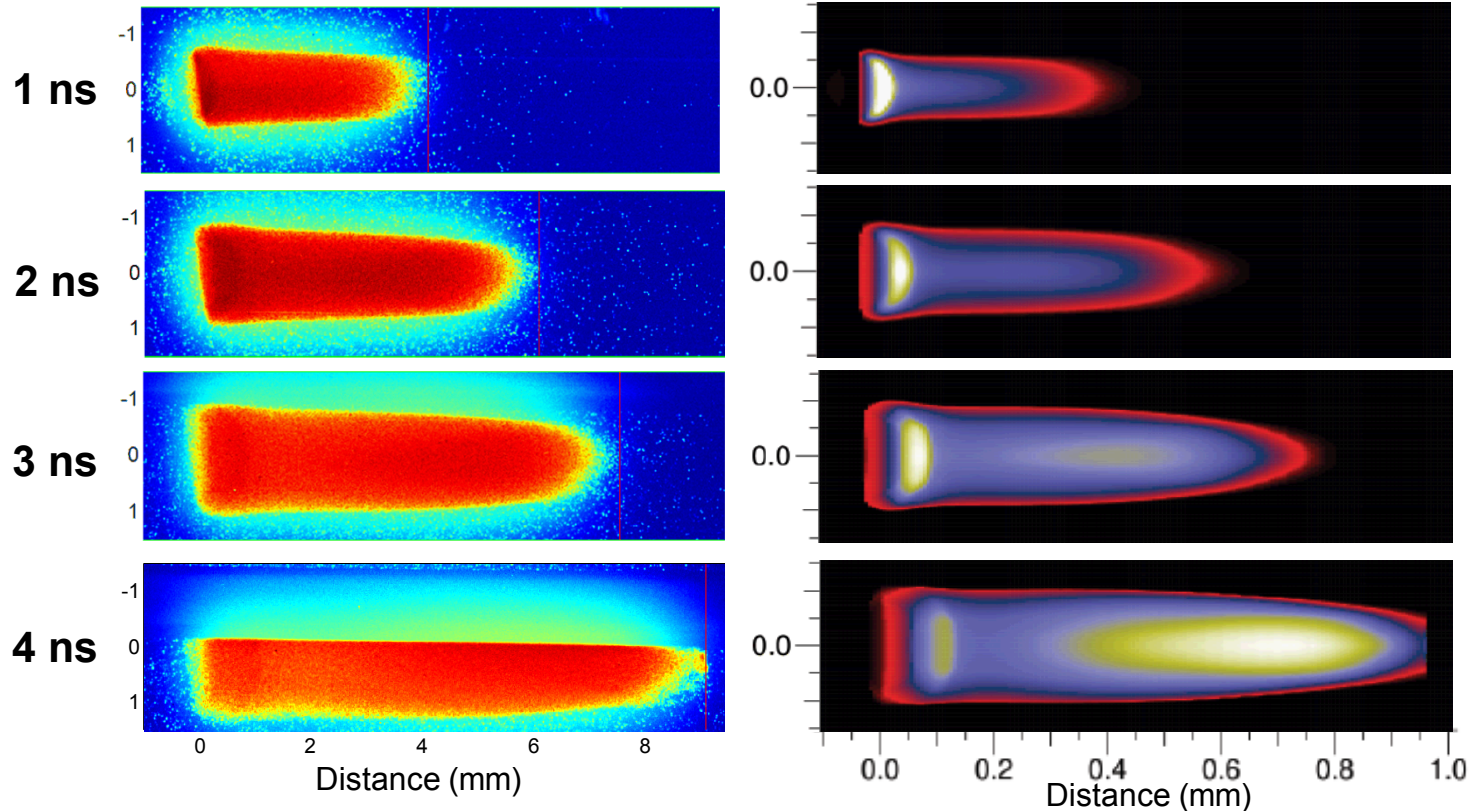
- Time gated X-ray images
- X-ray spectroscopy
- Most recently, time resolved SRS and SBS measurements
- Until this summer, only facility that could perform deuterium experiments
  - Laser only experiments in Z with D2 have been performed but are very infrequent
- $3\omega$  provides natural reduction in LPI
  - Largest difference between an experiment at EP and a MagLIF experiment on Z

# Modeling of pure Ar with thin windows was very successful\*

Experiments in pure Ar:  $n_e=0.047n_c$ , 1  $\mu\text{m}$  thick LEH,  $I\sim 2.5\times 10^{14}$  W/cm<sup>2</sup>

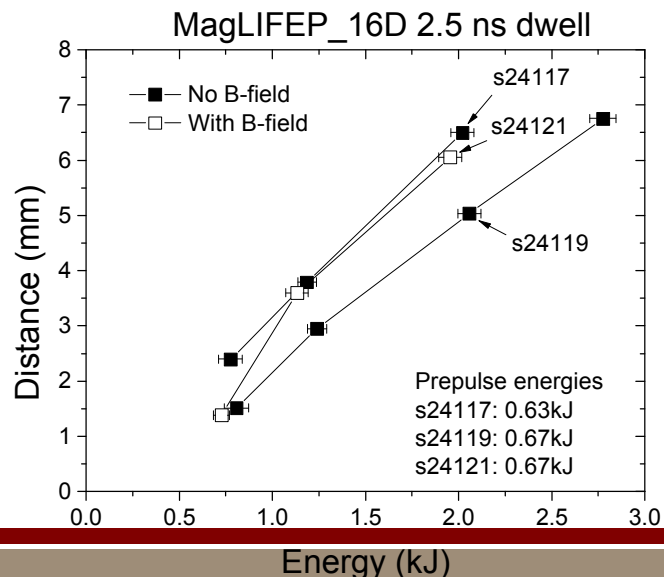
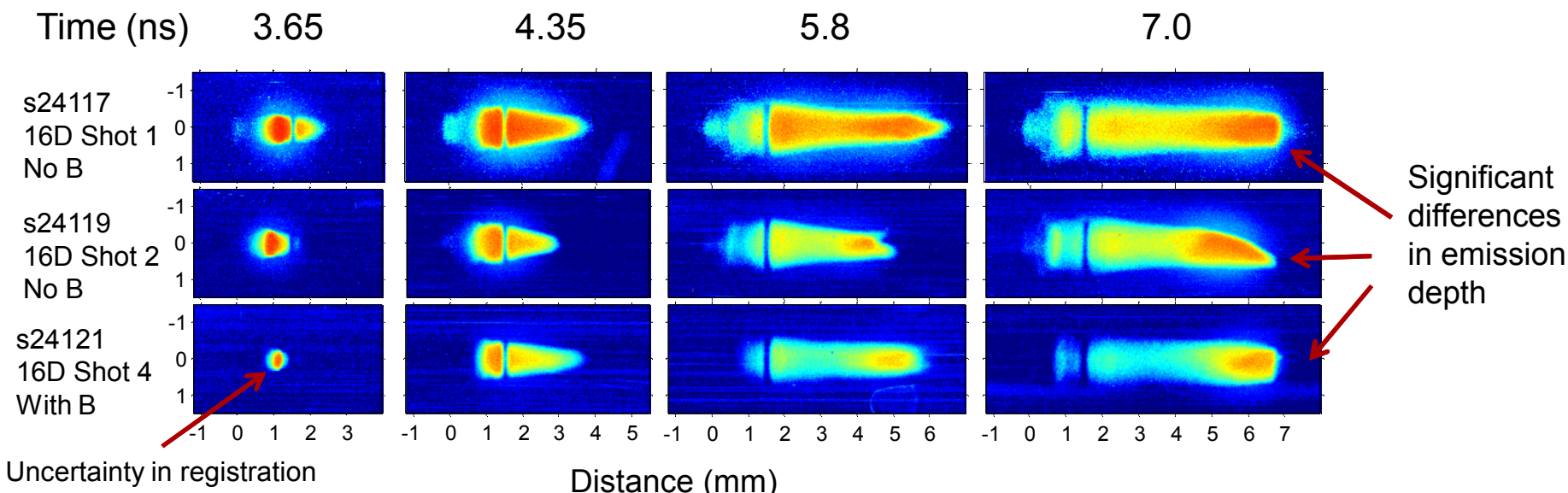
Experiments

2D HYDRA simulations

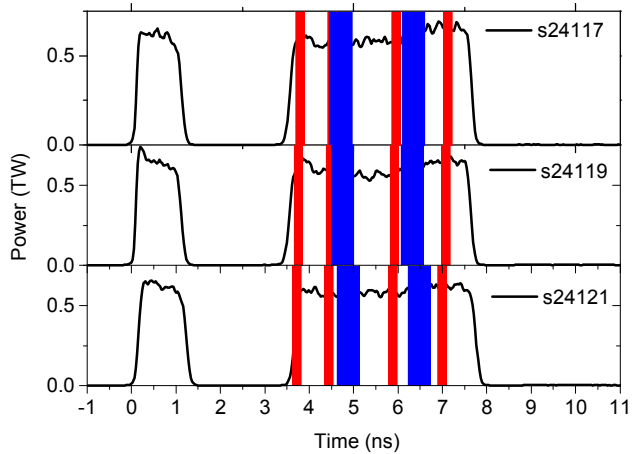


- HYDRA simulations match data well and can infer energy coupled into gas – results act as calorimeter
- No LPI detected or expected due to thin windows and high mass of ions

# Naturally, this success led to experiments with deuterium but required thicker windows and smaller apertures

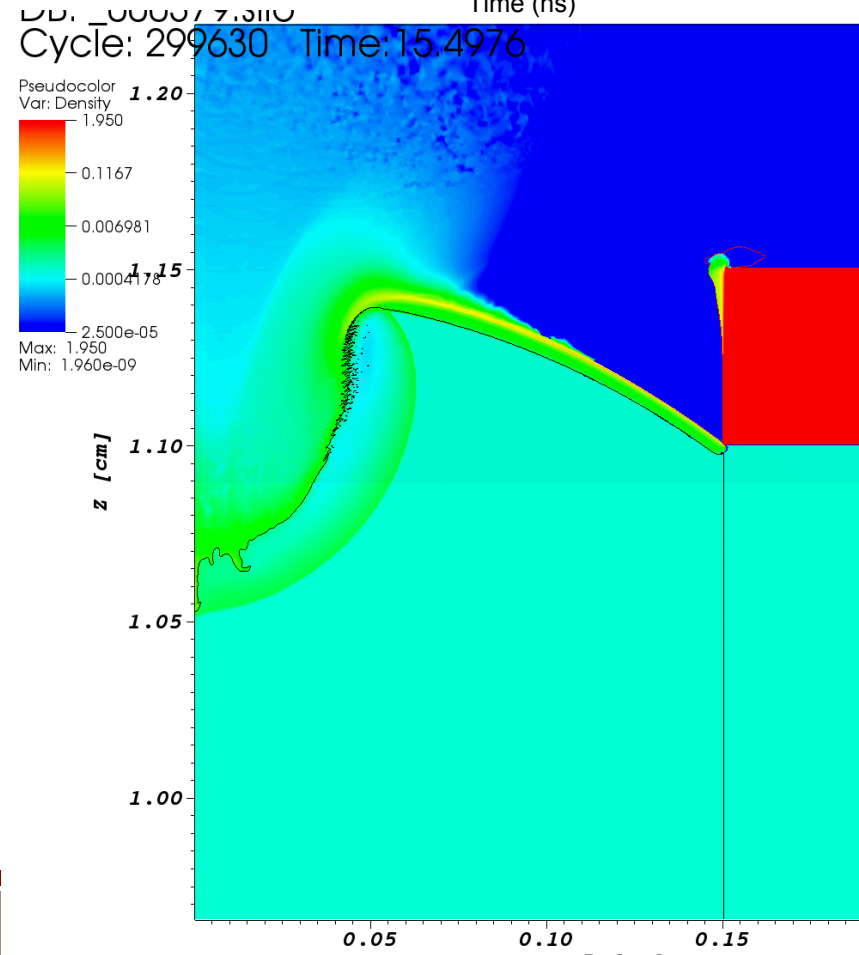
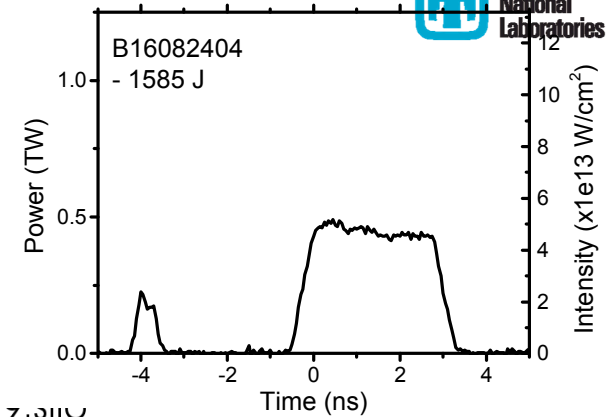


**146 psi  
(1.5 mg/cc) D2**

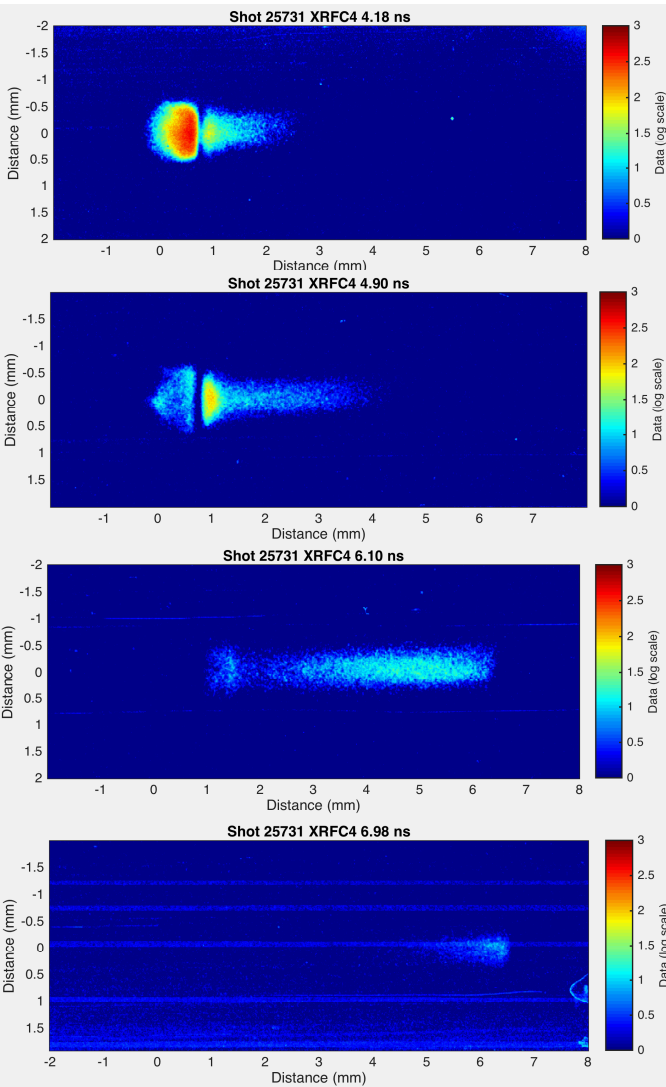


# What is so problematic about deuterium: LPI origins

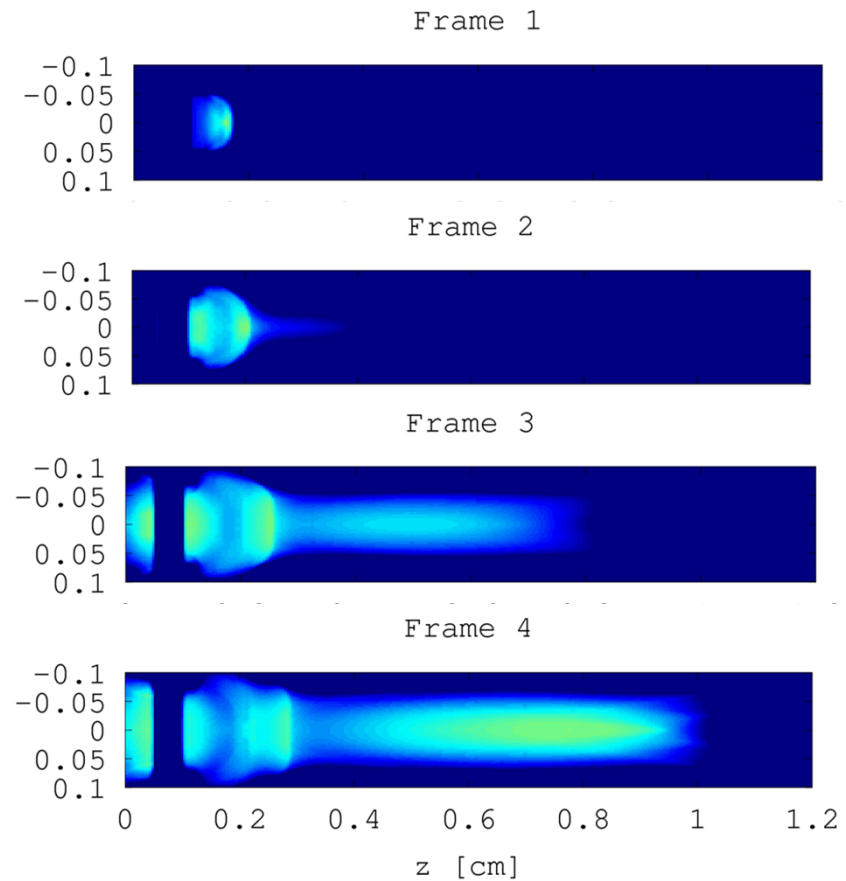
- LPI is expected to originate from a few possible scenarios
  - Initial pre-pulse interaction with solid window
  - Density jump in the fuel due to window ablation (particularly at the start of the main pulse)
  - Self-focusing by density channel
  - General interaction with high density gas
    - Low mass can better support ion waves



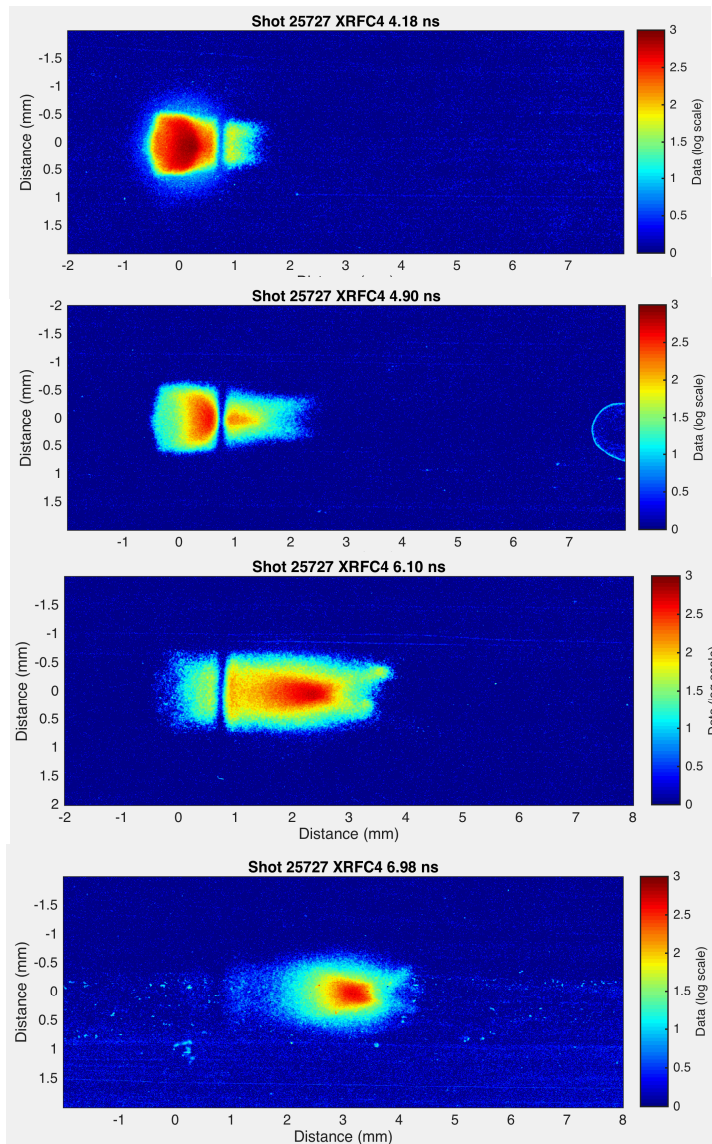
# Low LPI regime leads to better agreement between simulations and experiments



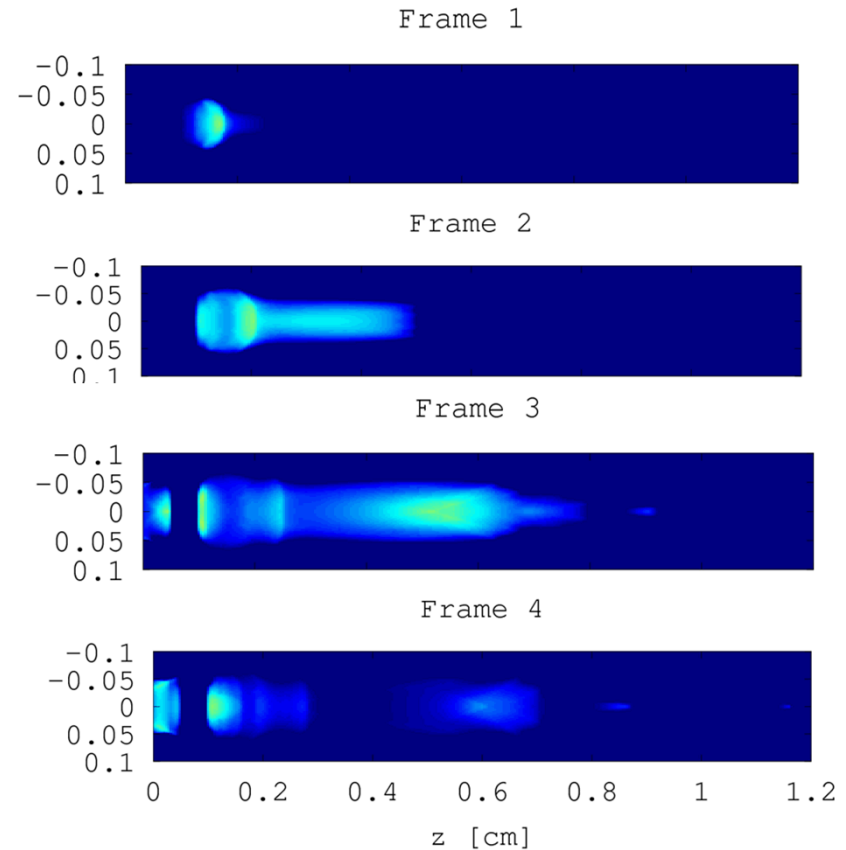
Shot 31, 1.6 kJ,  
60 psi, 1.7  $\mu\text{m}$  window, 2.0 mm diameter  
750  $\mu\text{m}$  DPP



# Simulations show strong self-focusing with the combination of thick windows and high density



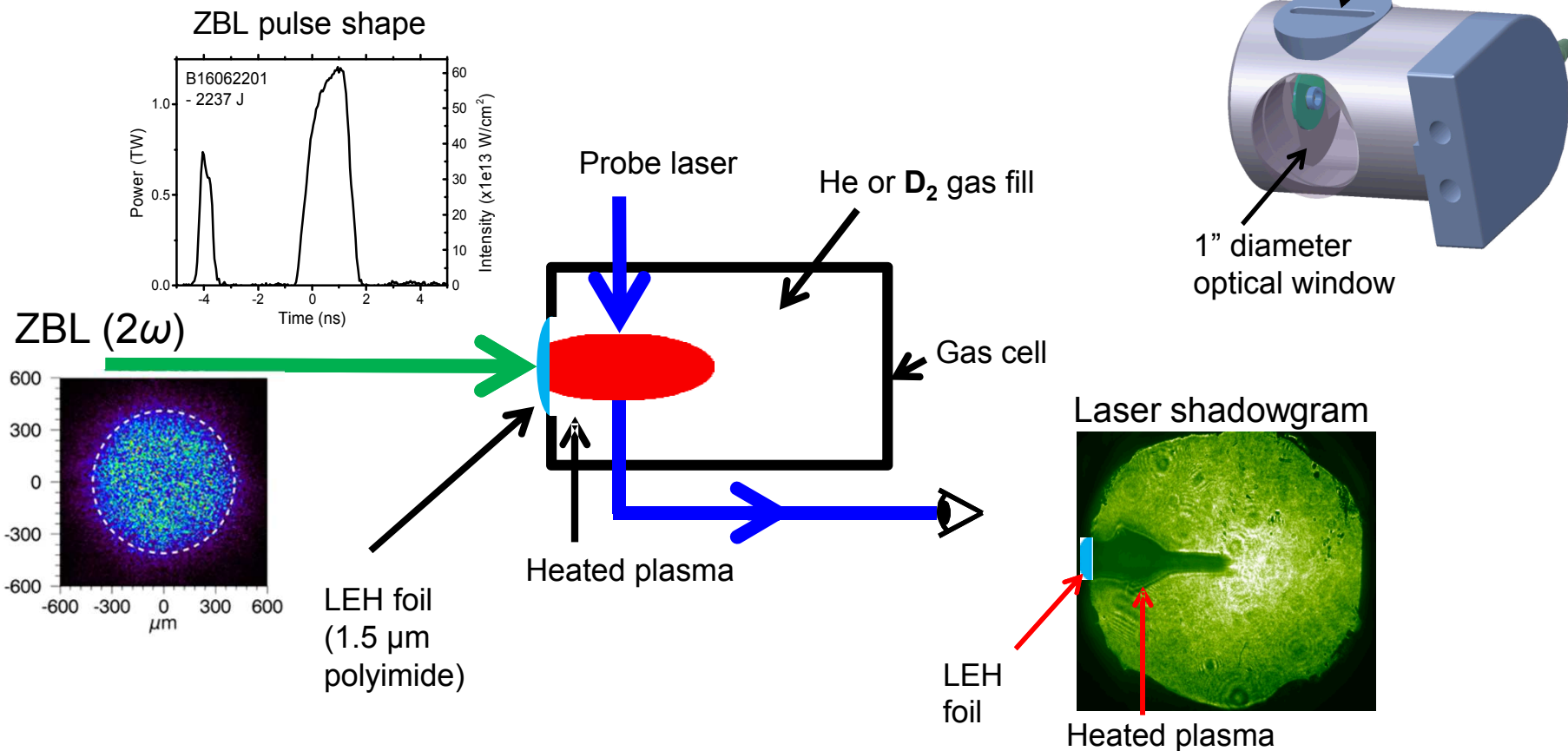
Shot 31, 1.6 kJ,  
135 psi, 2  $\mu\text{m}$  window, 1.6 mm diameter  
750  $\mu\text{m}$  DPP



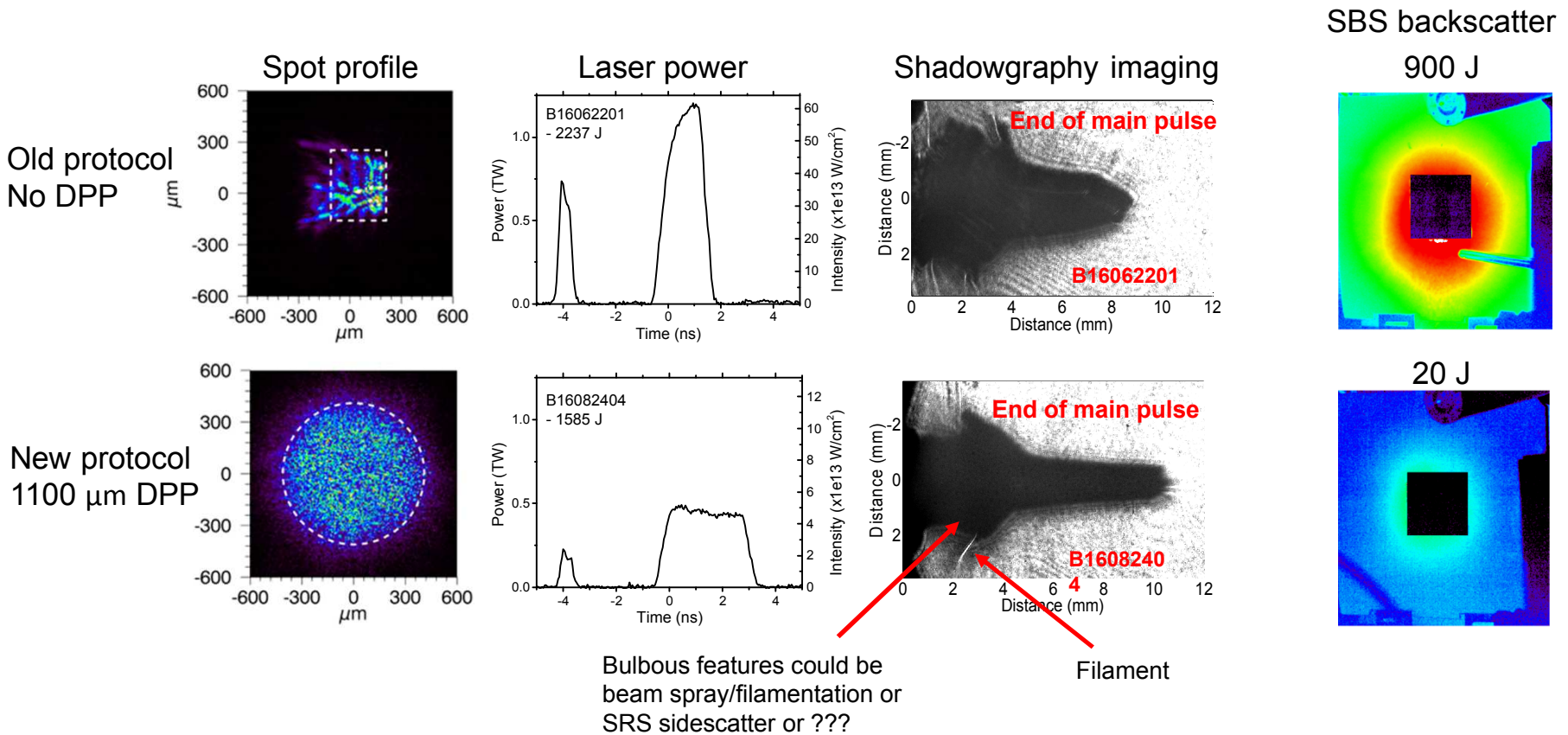
# Omega EP summary

- Experiments at Omega EP have shown  $3\omega$  is not a complete panacea, plenty of LPI still exists with D2
  - The effect of window thickness and aperture size were not able to be completely controlled for in the 60/135 psi comparison
    - Is the difficulty with the gas, the window, a combination?
    - Ideally 135 psi targets would use the same window thickness as 60 psi, but would require too small an aperture
  - 60 psi results agree fairly well
    - more detailed analysis is necessary but difficult to get absolute comparisons
- Shocked up gas due to window ablation could exacerbate LPI in high density case
  - While thick windows seem detrimental to laser preheat it seems unlikely an extra 300 nm is responsible for the large discrepancies seen between experiments and simulations
  - Future cryo experiments at Sandia will look to address the impact of gas density using as thin a window as possible

# Upgrades to PECOS gas cell experiments have dramatically improved their utility and provide a direct link to MagLIF experiments



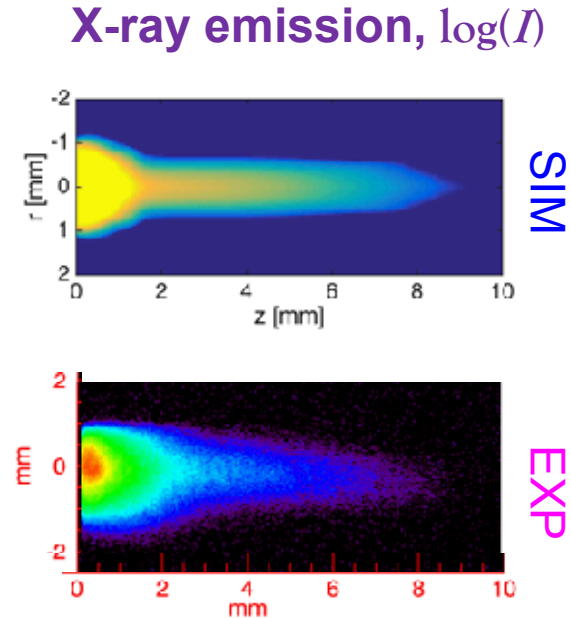
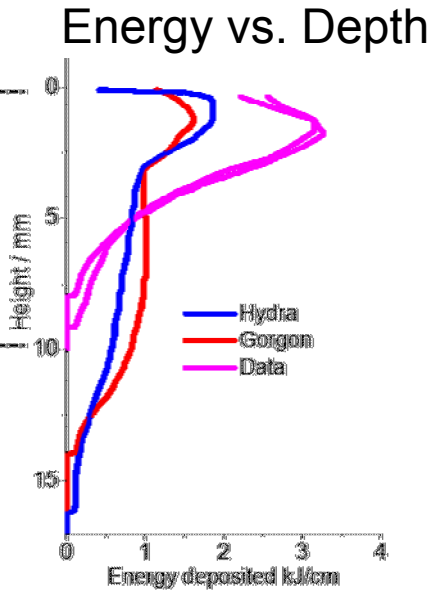
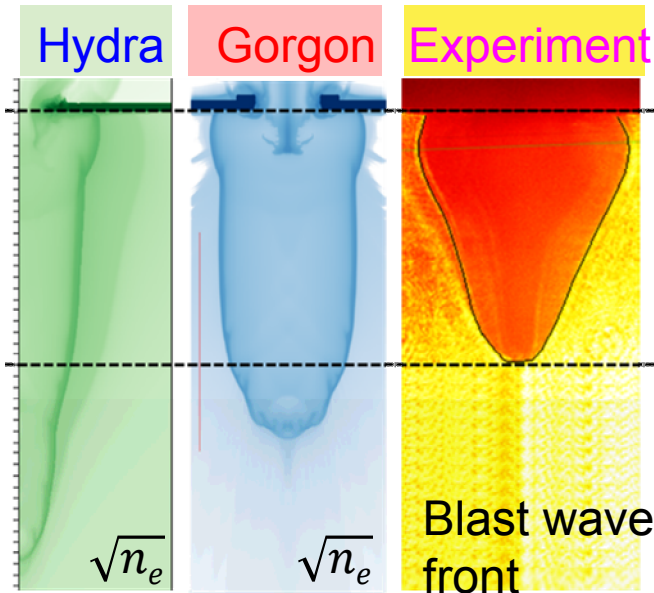
# A new laser protocol was developed that uses phase plate smoothing, reduced intensities to reduce LPI and modeling uncertainties



With such huge amounts of energy being diverted into LPI in old configuration, no hope for HYDRA to accurately model preheat consistently

# Comparisons with simulations have led to better understanding of limitations of calculations

**Benchmark Experiment: Laser Pulse 71 J + 1441 J; 54.3 psi He,  $t_{\text{shadow}} = 22.7\text{ns}$**



Energy deposition:

1159 J   1267 J   1213 J

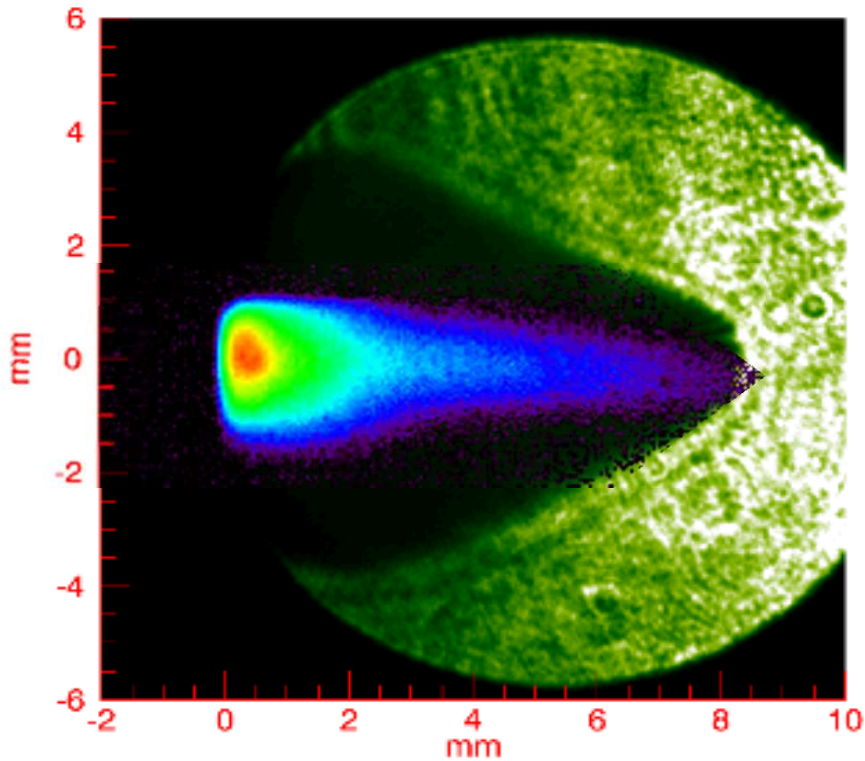
Total inferred energy matches well. Experiment seems more “top-heavy”.

X-ray emission has good qualitative agreement.

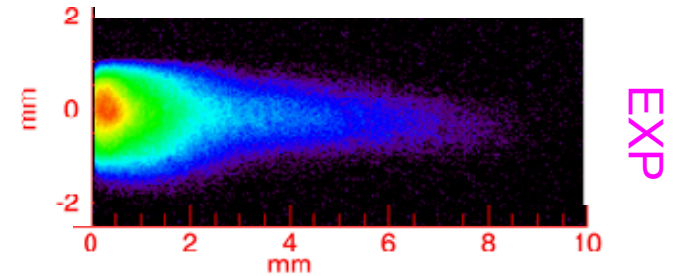
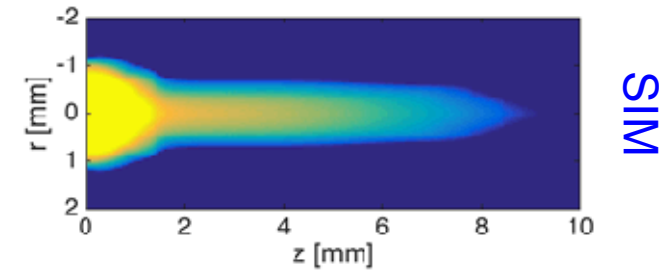
> 1 kJ in target, but much of it in LEH material (EXP+SIM) or outside MagLIF liner depth (SIM)!

More laser energy and higher gas density required for better coupling!

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

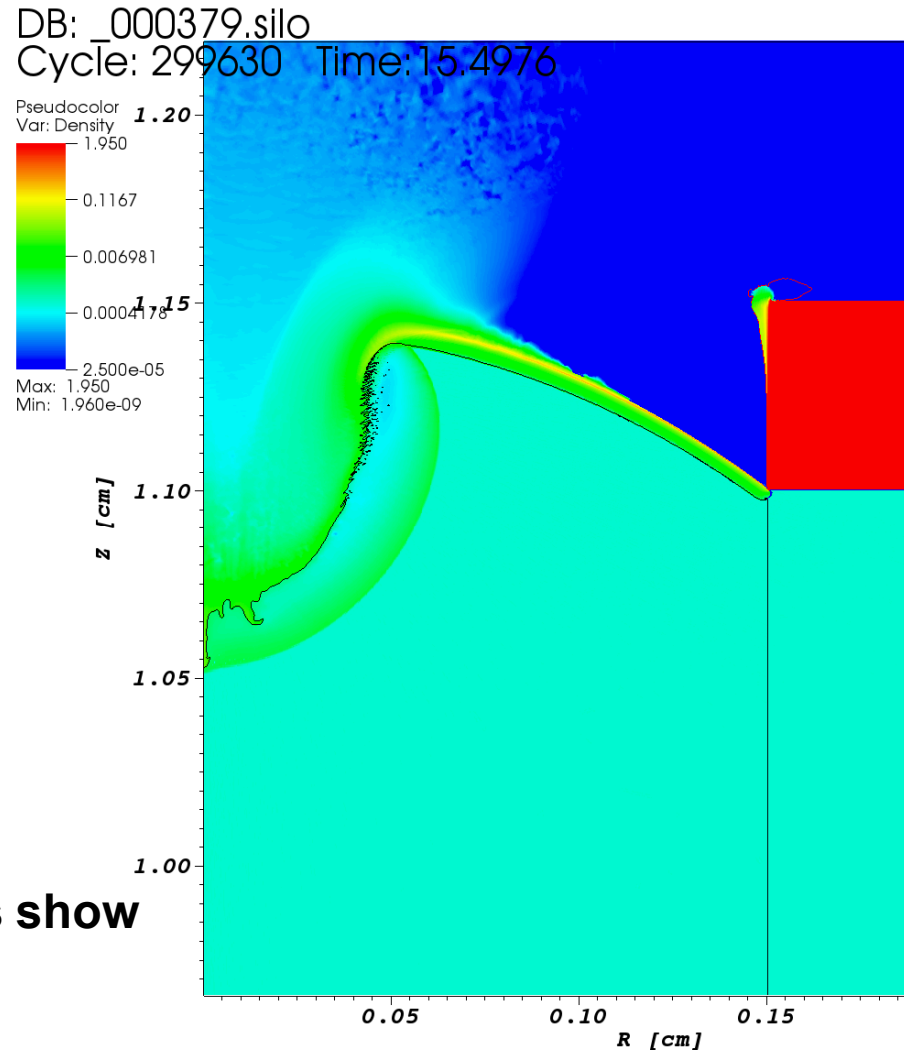


X-ray emission,  $\log(I)$



# Majority of disagreement is hypothesized to relate to interaction with the window

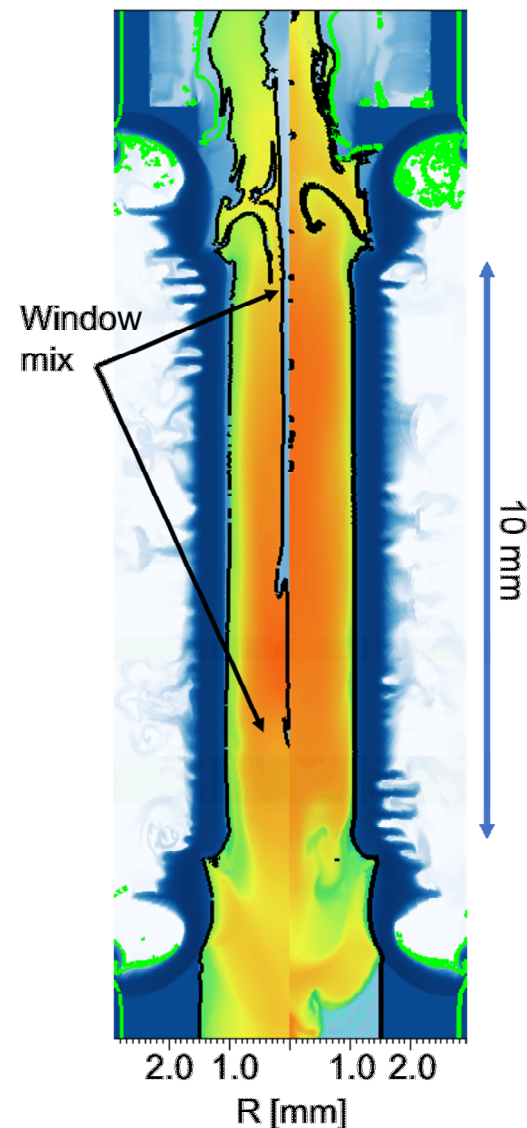
- 100 J (0.5 ns) pre-pulse interacts with solid density window (strong potential for LPI)
- Ablated window also drives a shock into the gas
  - High density region can lead to additional filamentation and LPI
  - Increasing flux limiters and reducing the f-number can lead to enhanced energy deposition near the top of the target



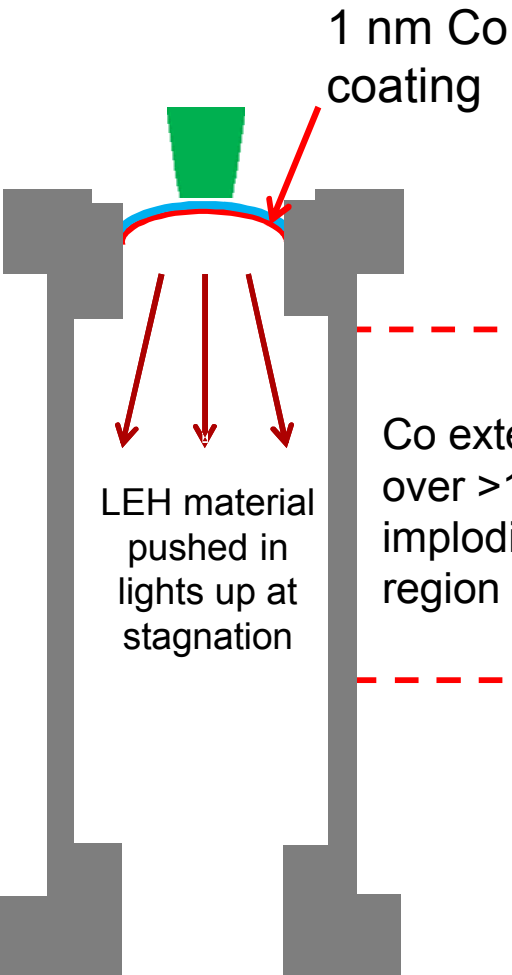
**In the absence of mix, HYDRA calculations show similar yield when varying these ‘knobs’**

# Integrated performance

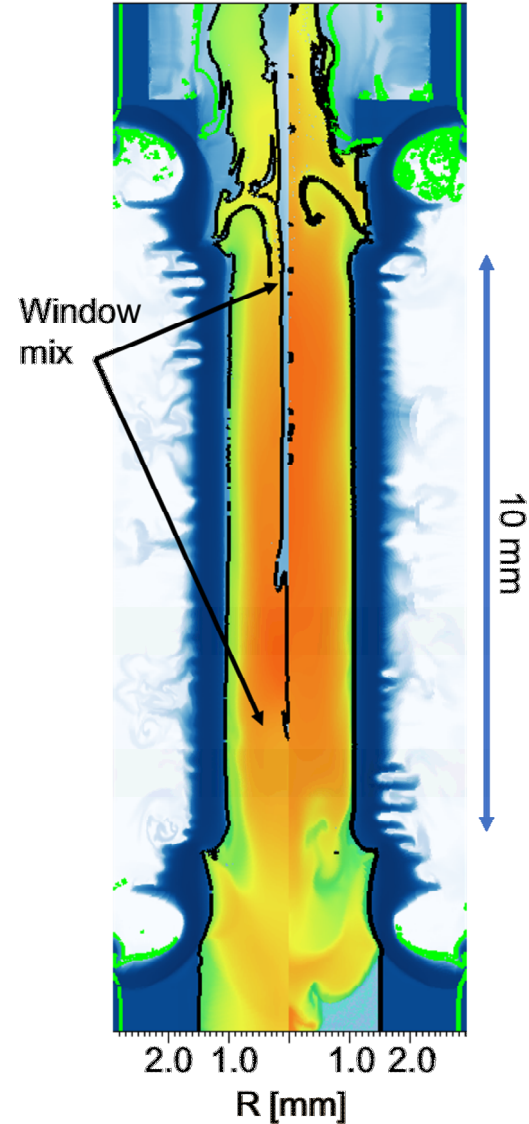
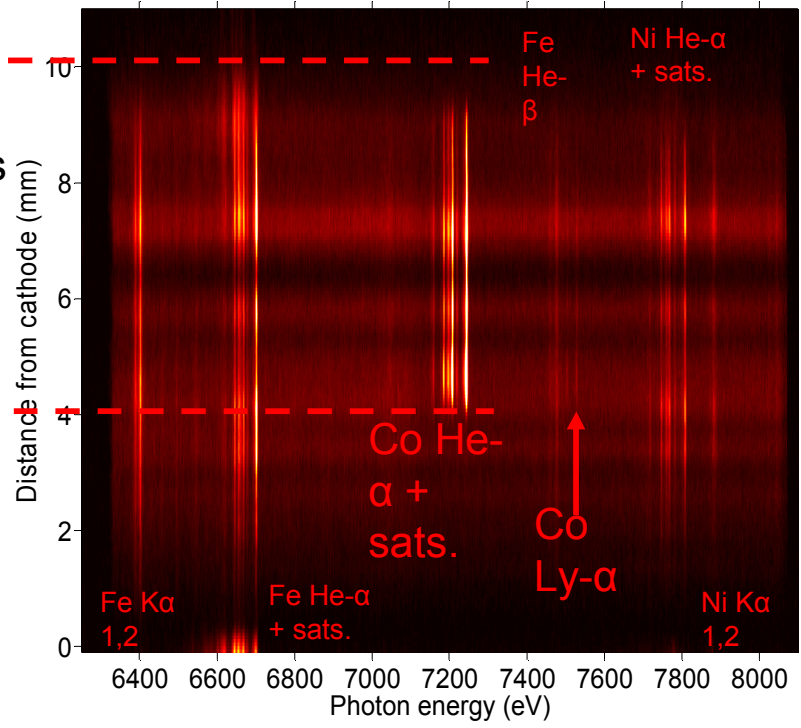
- The configuration A, 100 J + 1500 J laser pulse with 1100  $\mu\text{m}$  DPP was selected as the new baseline laser configuration
- Simulations indicate roughly 600 – 700 J coupled to the fuel
  - Majority of energy is lost to the window
- Combined with 16.5 MA current drive and 10 T magnetic field this target was expected to perform comparably to the unconditioned configuration
  - 400 J + 2000 J pulse
- Simulations predict the presence of window mix in the fuel



# Window mix has been inferred experimentally



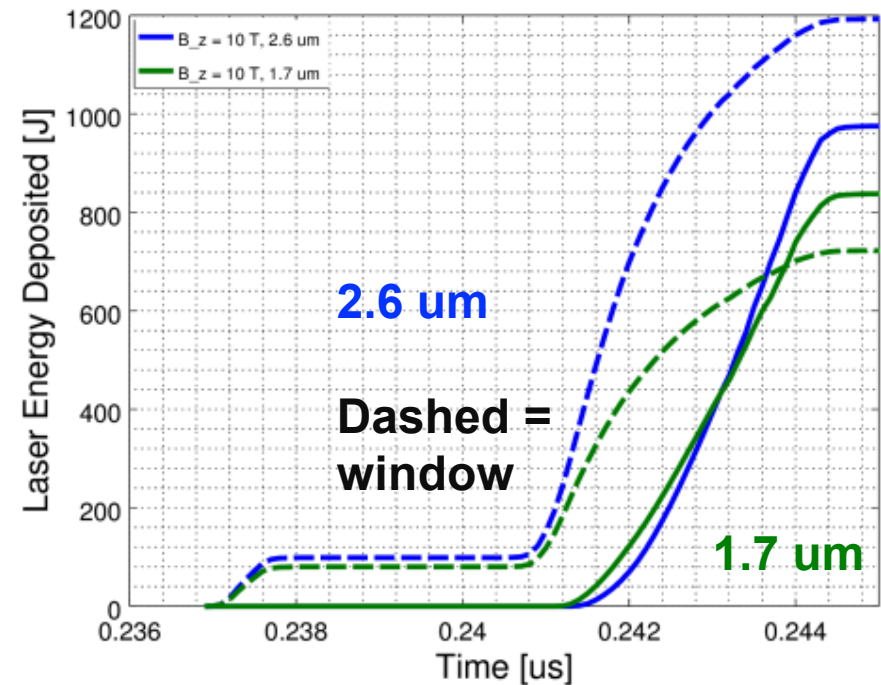
Z3057 – 1100  $\mu\text{m}$  DPP:  
XRS3 spectrum



# Optimizing preheat for MagLIF

- Optimized MagLIF experiments target higher fuel densities (1.5 mg/cc) and necessarily require higher preheat energy (2 kJ) to achieve comparable temperatures
- Higher densities require thicker windows
  - Losses to the window can make high energy preheat regimes inaccessible without changes to the laser
  - Thicker windows can also introduce more mix mass

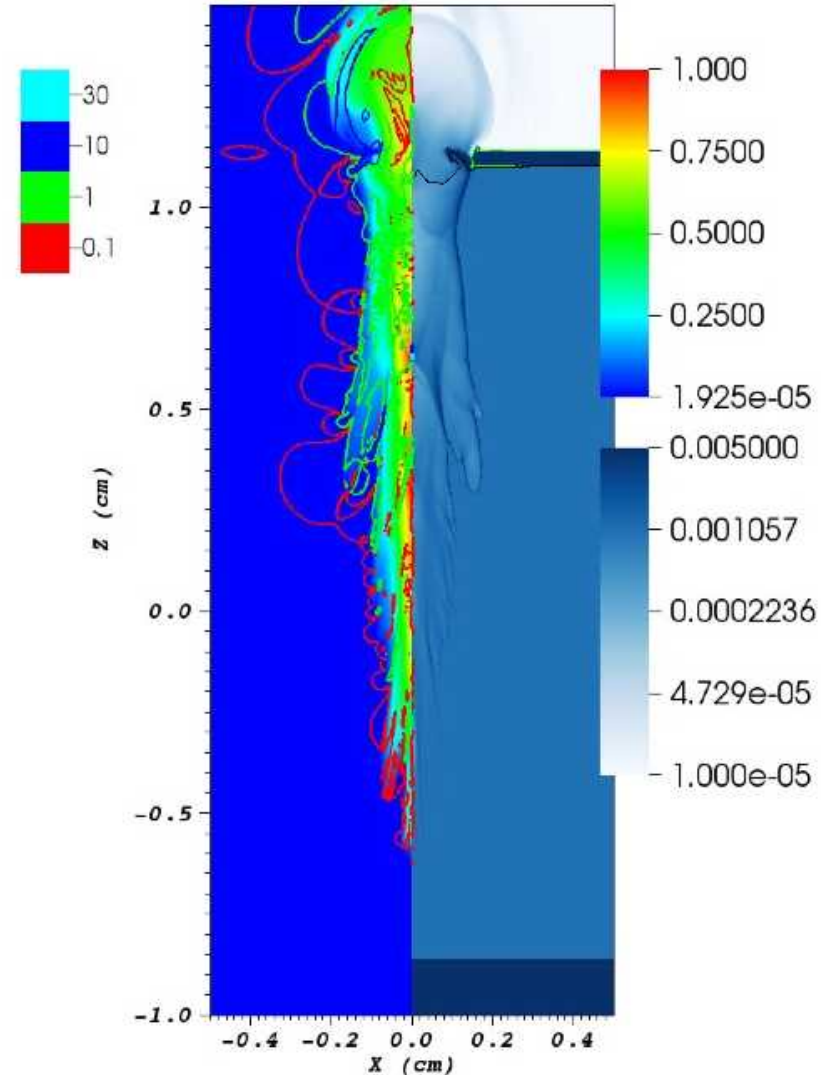
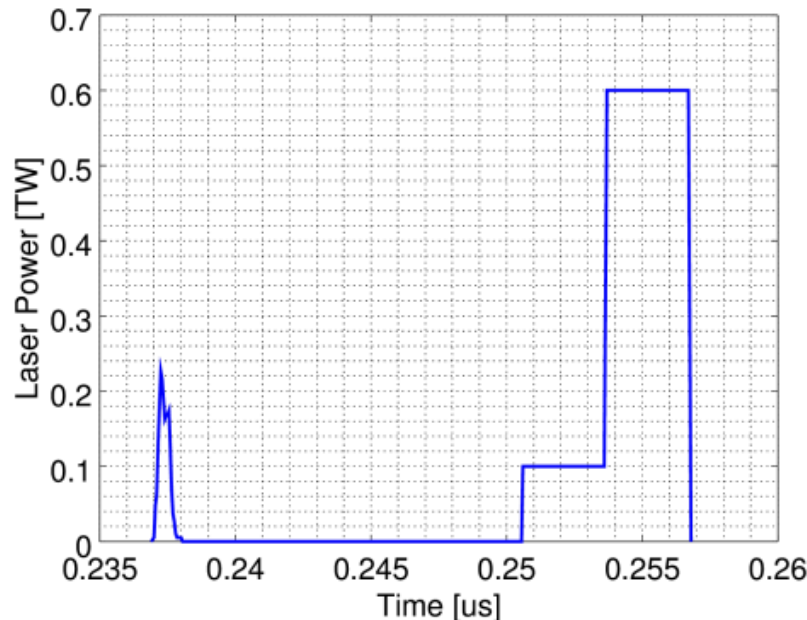
Window limits coupled energy to the fuel



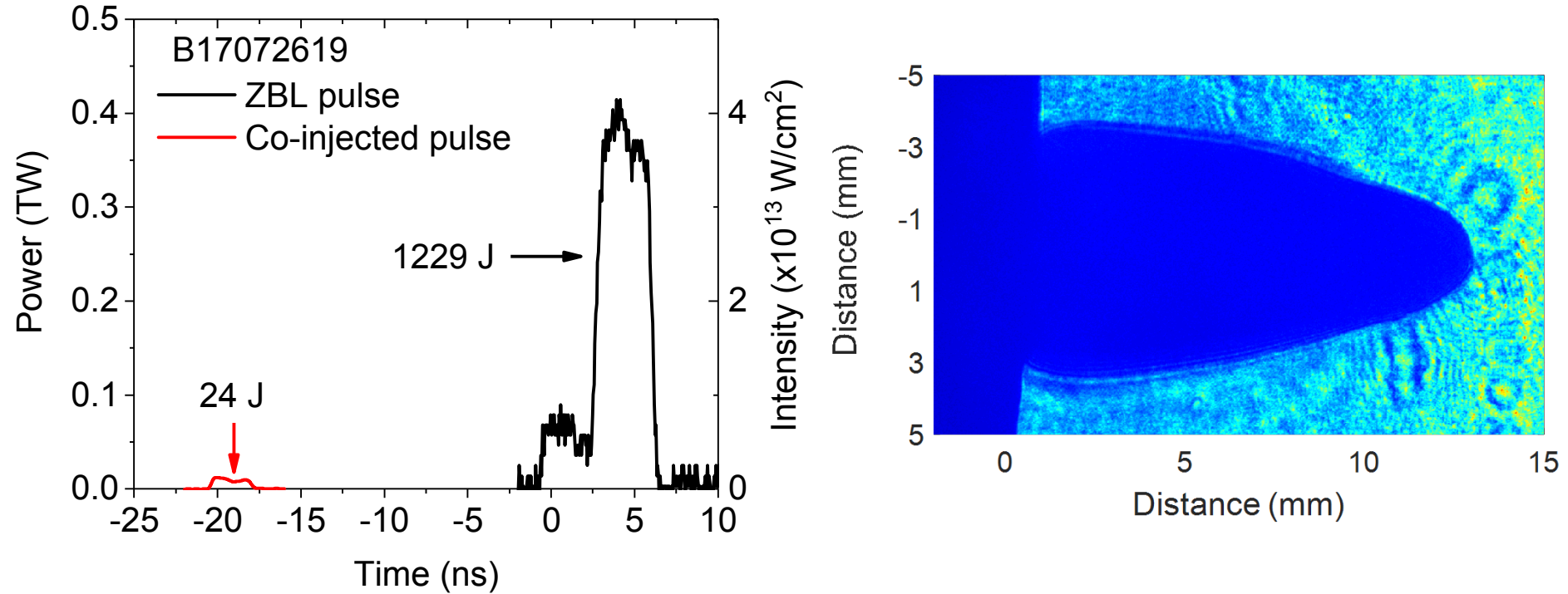
90 psi / 1.05 mg/cc

# Optimizing preheat for MagLIF

- Upcoming experiments will utilize a new laser pulse shape, incorporating the Z-Petawatt laser; simulations predict:
  - Reduced window mix
  - > 1 kJ coupled to 90 psi fuel (standard 1.7 um window)



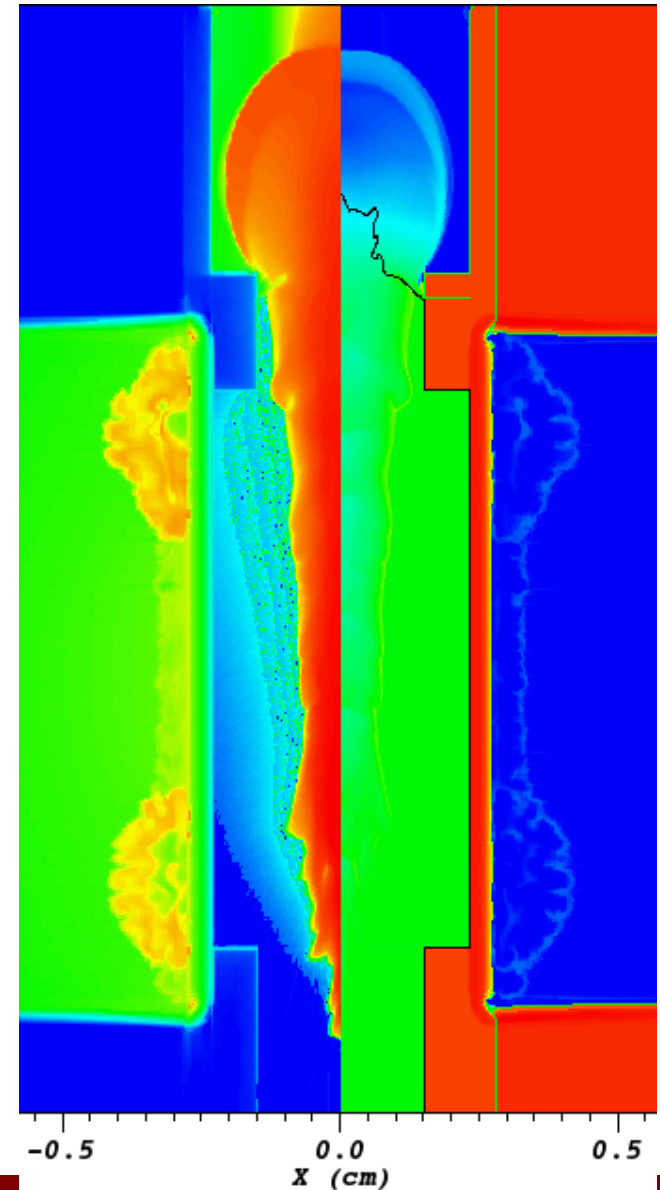
# The co-injection pulse gently disassembles the window and allows the density to drop for ~ 20 ns



- The foot on ZBL reheats the ablated window material allowing the main pulse to propagate through a more transparent plasma

# Longer term solutions for preheat

- Co-injection pulse shape still does not scale well as the window thickness is increased
  - Thinning the window for fixed density requires reducing the pressure (cryo cooling)
- 500 nm thick windows couple 10 % or less of the total laser energy
  - Largely a benefit of the lower total mass
  - Maintaining the low energy 'foot' pulse shape can also eject the window material



# Summary

- Omega EP experiments have shown that shorter wavelengths do not necessarily lead to improved modeling and predictability
  - Generally, just switching to  $3\omega$  does not improve laser preheat, improvements to the laser pulse shape and window mitigation strategies are necessary
- The MagLIF laser preheat platform has progressed significantly via dedicated Pecos experiments
  - Addition of phase plates and pulse shaping have led to promising preheat configurations that have dramatically reduced LPI and that are more tractable to model
  - Comparison of simulations and experiments indicate mitigating the influence of the window is a very high priority
- Addition of the Z-Petawatt laser for co-injection provides a more tractable path to higher fill density and preheat energies
  - ZBL can use full 6 ns window and ZPW can provide  $\sim 300 - 400$  J in addition (particularly useful for cryo)
  - ZPW can provide some window mitigation but doesn't do much about the total mass in the way of the laser
  - Simulations also show more favorable agreement with these experiments but only two experiments so far!

# Backups

# Config. A: 80/1500 J

- Preheat energy in the gas is roughly 625 J
  - Window absorbs roughly 650 J
- Yield  $\sim 1.0 - 1.8 \times 10^{12}$
- Ion temperature:  $\sim 2.4$  keV
- Fuel density: 0.5 – 1.5 g/cc
- Hot core with radius 50  $\mu\text{m}$
- Peak current is 16.5 MA
- $B_z \sim 130$  MG ( $10^4$  T)  $\Rightarrow 0.5$  MG\*cm
  - Nernst can reduce this to 40 MG
- Less than 1  $\mu\text{g}$  of window material in fuel region but dispersed axially over many mm (radially only 5  $\mu\text{m}$ )

# Integrated Experiments in Z

**Repeat shots in CY17 show high yields, variability**

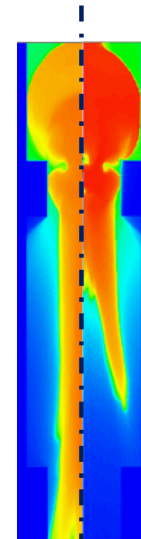
	Z3040	Z3041	Z3057
Laser energy	70 + 1460 J	73 + 1534 J	103 + 1283 J
$Y_{DD}$	$4.1e12 \pm 20\%$	$3.2e11 \pm 20\%$	$2.0e12 \pm 20\%$
Comments	Highest MagLIF yield to date	Direct repeat of z3040. Factor 12 less yield. Evidence of high mix.	Co coating on LEH used to investigate mix

(All shots use 1100  $\mu\text{m}$  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  $\mu\text{m}$  dust particle on axis

See also Adam Harvey-Thomson's Poster later today!!