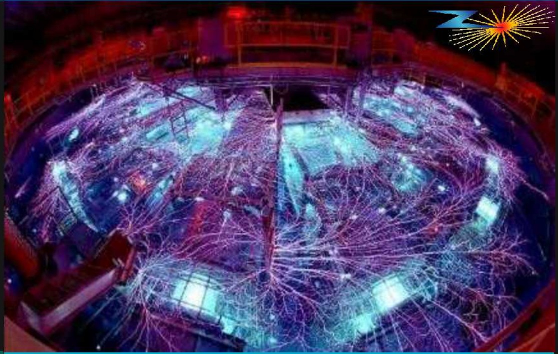
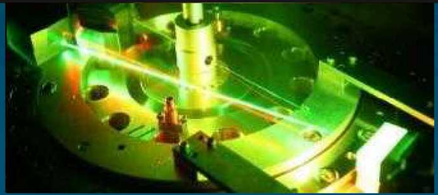
SAND2018-7378C

Pushing Laser Pre-Heat in MagLIF
(3-Phase Pulse Trains are the Charm)





PRESENTED BY

Matthias Geissel

July 10, 2018

48TH ANOMALOUS ABSORPTION CONFERENCE

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

The Makers of Pre-Heat

PECOS-EXPERIMENT-TEAM

- Matthias Geissel
- Adam Harvey-Thomson
- Jeff Fein
- Daniel Woodbury (intern)
- Daniel Davis (intern)
- David Bliss
- Daniel Scoglietti

Z-TEAM

- **Adam Harvey-Thomson**
- Matthew Gomez
- David Ampleford
- Thomas Awe
- Tony Colombo

DESIGN-TEAM

- **Matthew Weis** (first talk tomorrow)
- **Chris Jennings**
- Michael Glinsky
- Stephen Slutz
- Daniel Ruiz
- Kyle Peterson

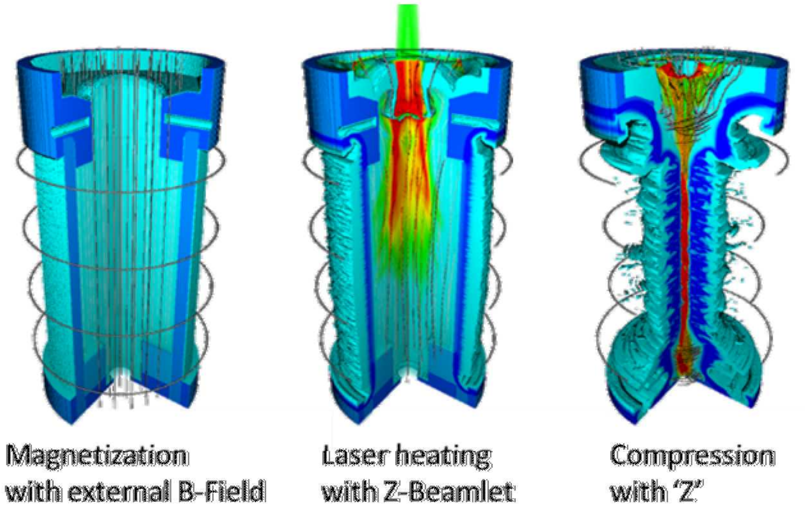
LASER-TEAM

- Ian Smith
- Jonathon Shores
- Mark Kimmel
- Patrick Rambo
- Jens Schwarz
- Ben Galloway
- Shane Speas
- John Porter

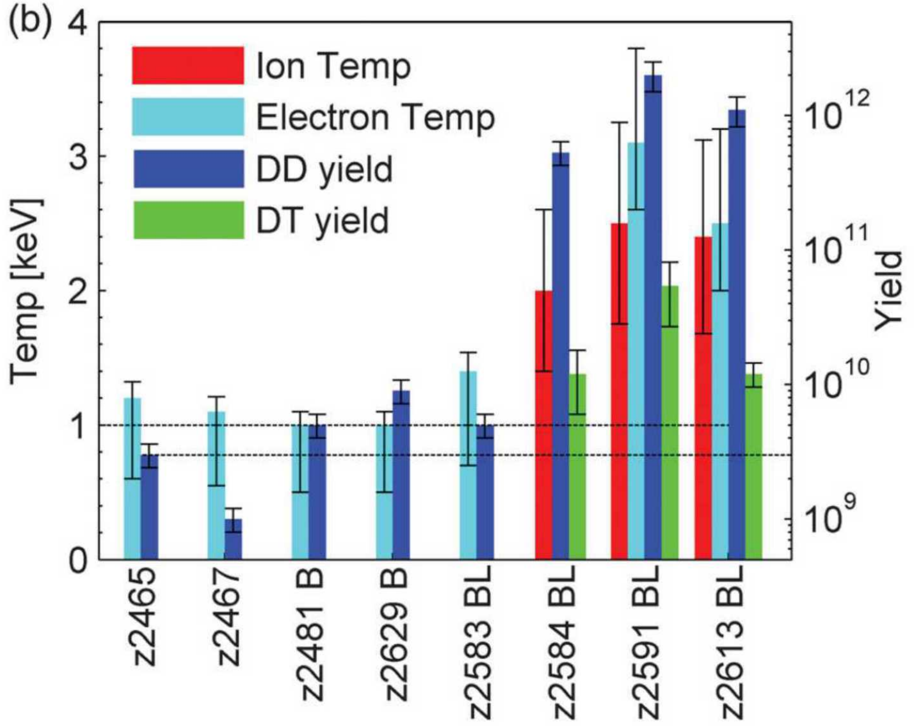
Outline

- Quick Review of MagLIF *(and what's special about its challenges)*
- Limitations and Capabilities at Sandia
- The LPI Beast – *and why its defeat didn't help right away*
- Upping the Pressure and the Arrival of a 3-Phase Pulse Train
- Solving Pre-Heat with Multiple Parallel Efforts (Institutions, Codes)
  - Pre-heat at Omega EP
  - Pre-heat with the NIF
- Where Do We Go From Here?

Magnetized Liner Inertial Fusion (MagLIF)



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



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

- 2E12 neutrons in 2014 were short of modeling predictions, but highly encouraging.
- Suspicion of poor laser coupling.

Wer einst fliegen lernen will, der muss erst stehen und gehen und laufen und klettern und tanzen lernen:

- man erfliegt das Fliegen nicht.

He who would learn to fly one day must first learn to stand and walk and run and climb and dance:

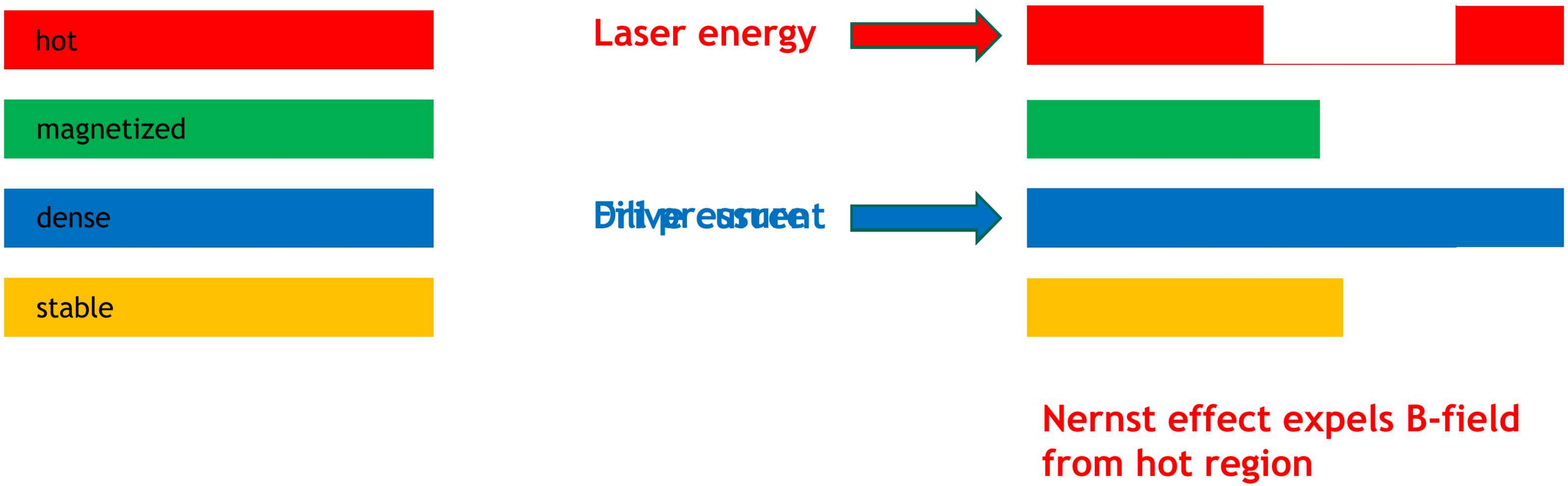
- one cannot fly into flying.

Friedrich Nietzsche

Interdependencies I

MagLIF requires sufficient temperature, magnetization, and stagnation density for high yield. But they need to be matched!

Z's discharge current drives the implosion and maximum stagnation density, but it may also lead to excessive convergence ratios and instability issues. As of today, the convergence ratio is higher than predicted (too high?) and helical features (instabilities?) are observed.



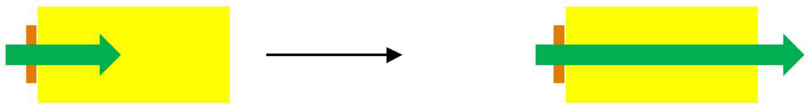
Laser coupling needs to be optimized stepwise while density is increased to match the other parameter improvements!!

Interdependencies II

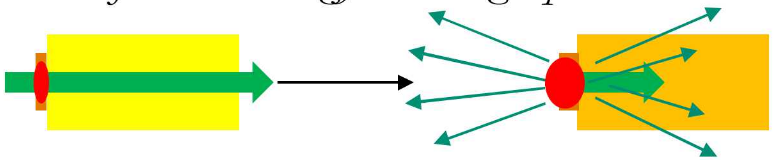
We found out early that LPI is the largest contributor to poor laser coupling next to having a thick LEH window. But increasing laser pre-heat is not a one-parameter game.

Always good: Keep the Laser Entrance Hole window as thin as possible. But … :

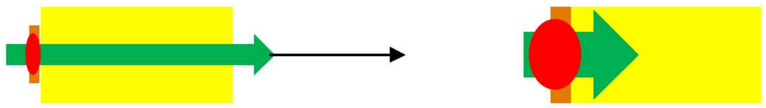
If you merely increase the laser energy, you may not couple all of it in the relevant depth range: "overshooting".



If you merely increase the density, you risk higher LPI losses and more losses to a thicker LEH: Need for more energy in a longer pulse.



If you merely increase the laser focus, you heat up a larger cross section of the LEH window, and that will likely be thicker: Need for more energy!



To increase laser coupling you need to simultaneously address

- Fill density
- Laser energy
- Spot size on LEH
- Pulse length
- LEH losses (if possible)

What else might be special about MagLIF pre-heat? - The LPI parameter space!

Parameter	ICF Capsule	ICF Hohlraum	MagLIF
Size	Sub-mm (except NIF)	~mm (except NIF)	10 mm
Density	$>> 1\%\ n_{crit}$	$<< 1\%\ n_{crit}$	few % n_{crit}
Laser wavelength (typ.)	~ 350 nm	~ 350 nm	527 nm*
T_e	2-5 keV	2-5 keV	< 1 keV
LPI controls in laser driver	Native	Native	none
LEH window thickness	< 0.5 μm or N/A	<0.5 μm	1.5-3 μm
Laser intensities	$> 10^{15}$ W/cm^2	$> 10^{15}$ W/cm^2	$< 10^{14}$ W/cm^2

*to be explained later

MagLIF versus Literature

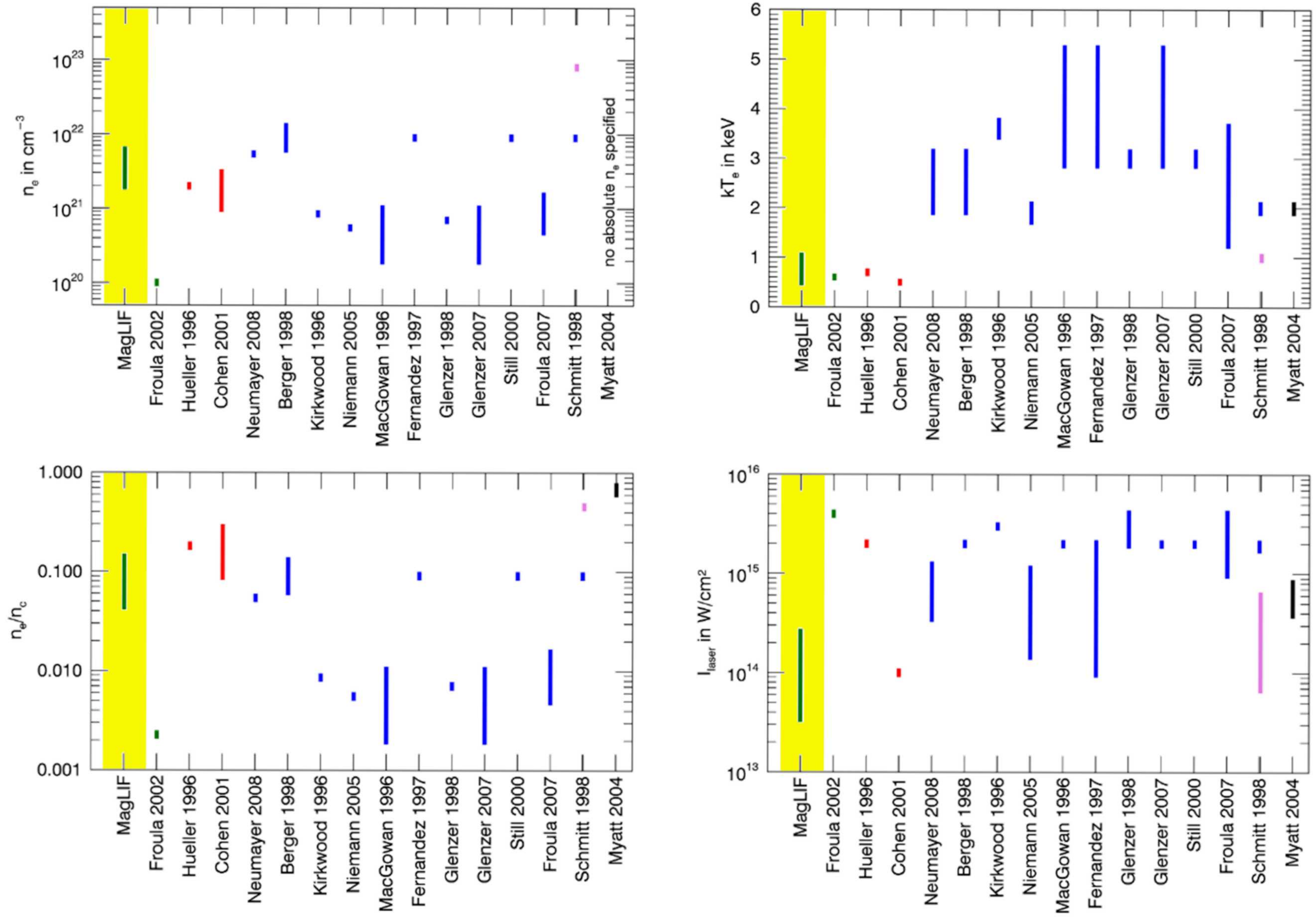
527 nm

1054 nm

351 nm

250 nm

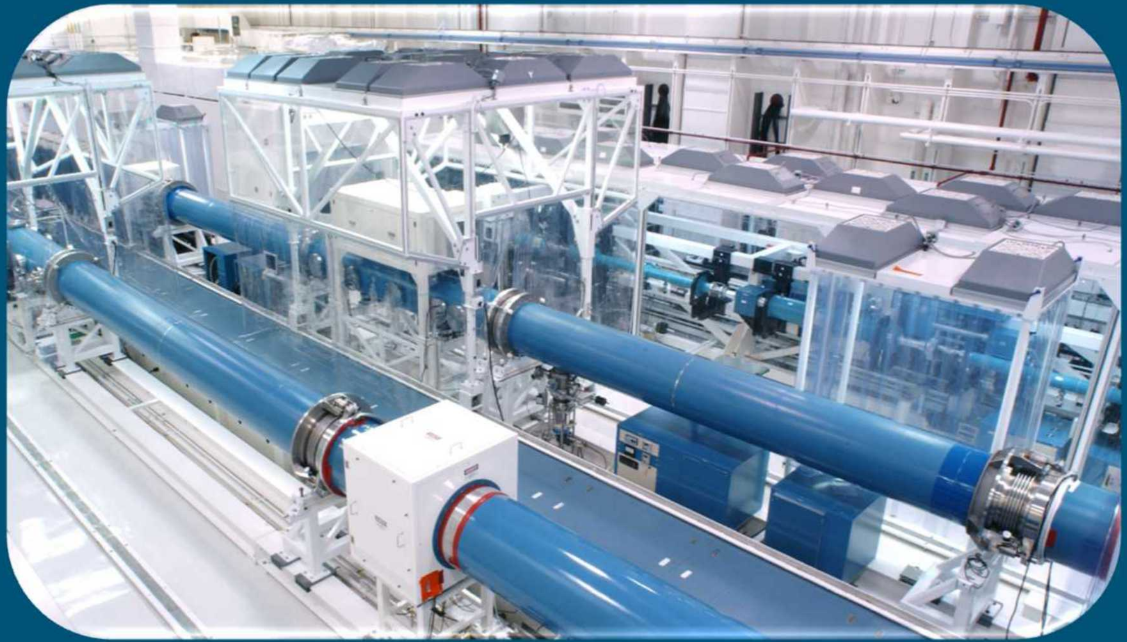
n_e/n_c scaled

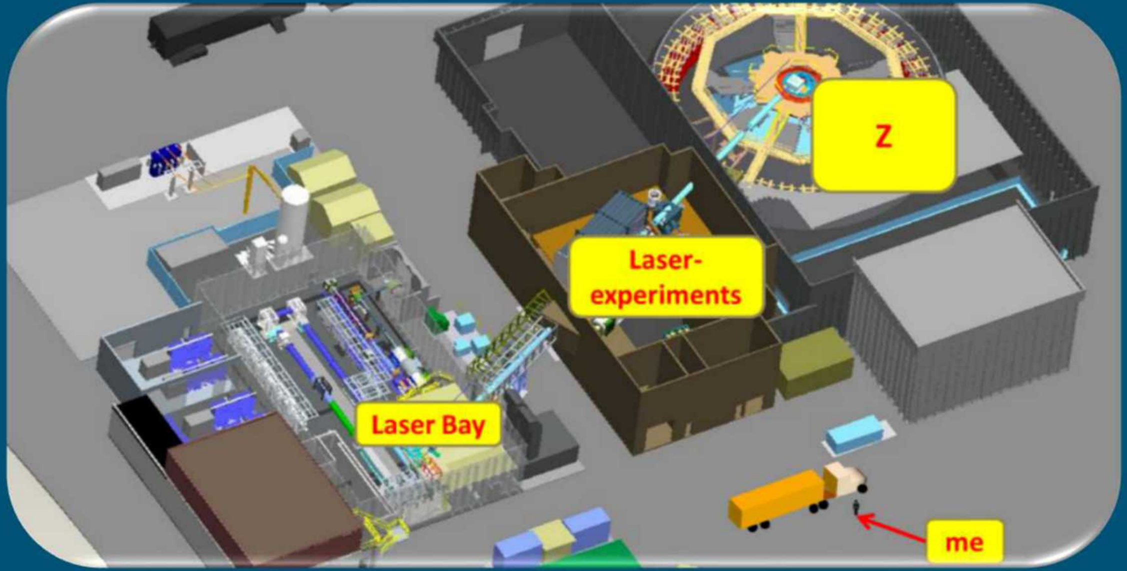


The Z-Beamlet Laser

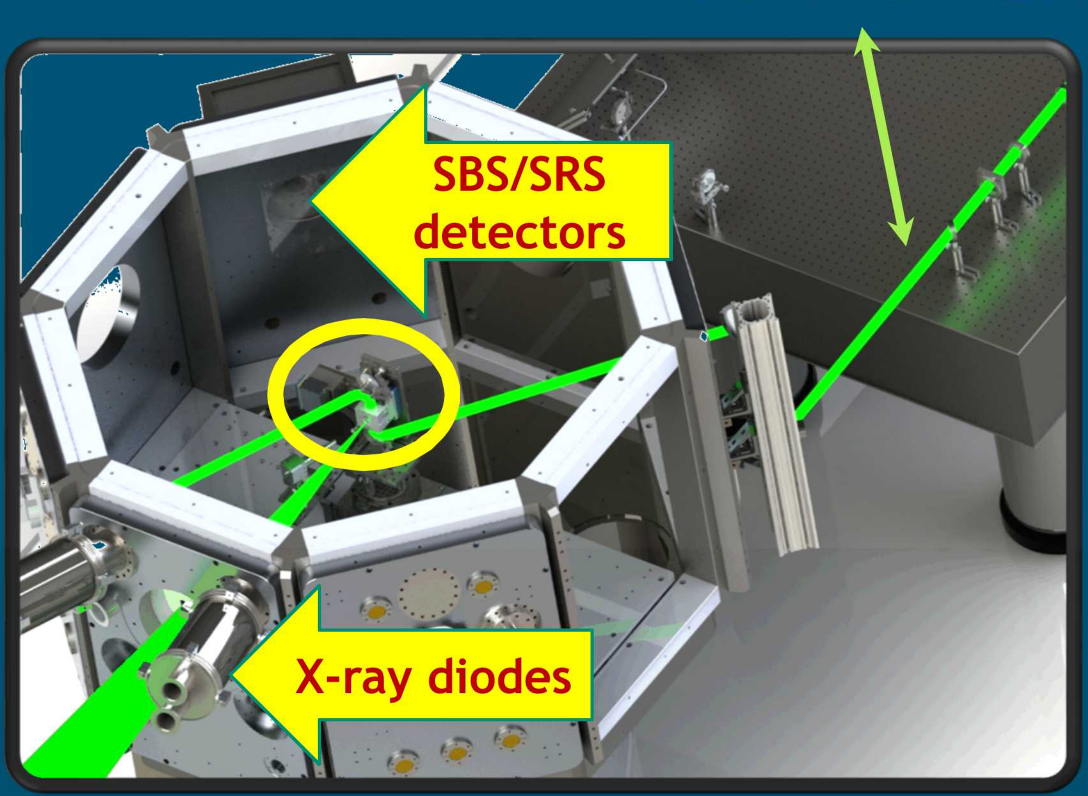
Capability as of:	July 2018
Max. Energy (to date)	3 kJ*
Pulse length	0.5 – 7 ns**
Pulse shape	Programmable in 100ps steps
Wavelength	527 nm***
Phase modulation	18 GHz
Active LPI measures (SSD/ISI, etc.)	No
Beam transport (laser bay to target)	~ 220 ft

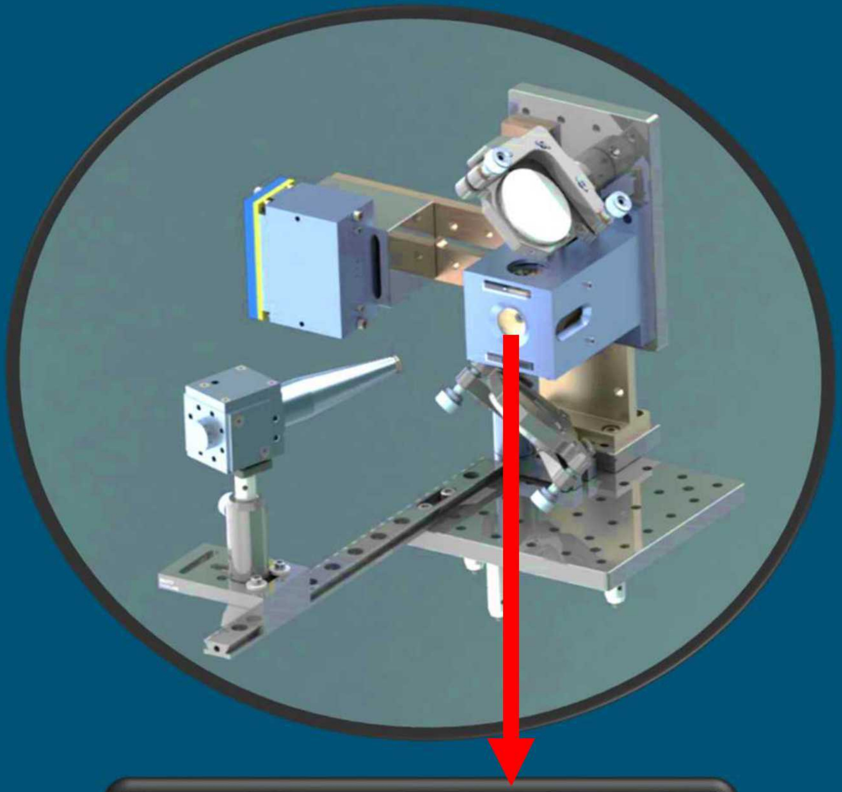
* Limited by a sensitive optical element
** Limited by regen length, spatial filters
*** 351 nm upgrade a complex challenge

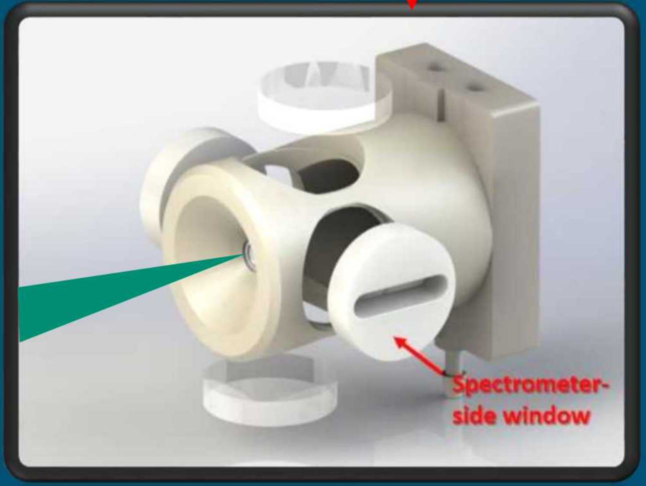




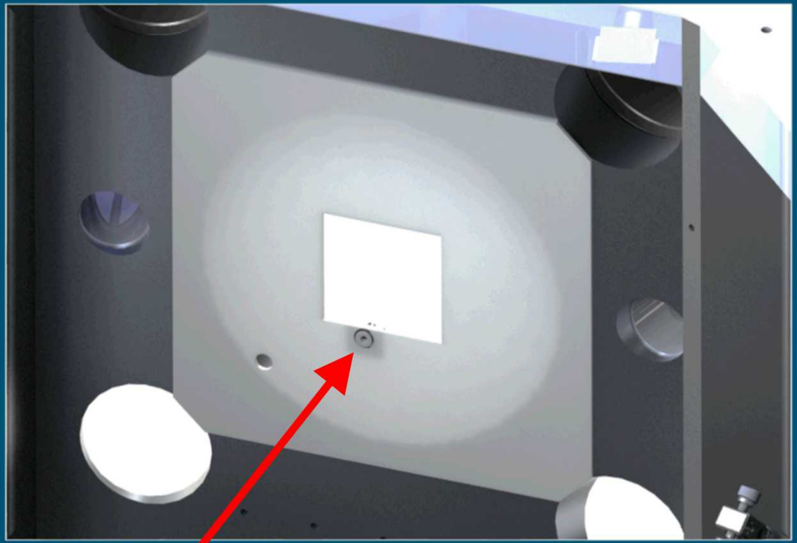
The Pecos Target Area







LPI Diagnostics



SBS and SRS NBI cameras

SBS diode

SRS diode > 610 nm

SRS diode > 715 nm

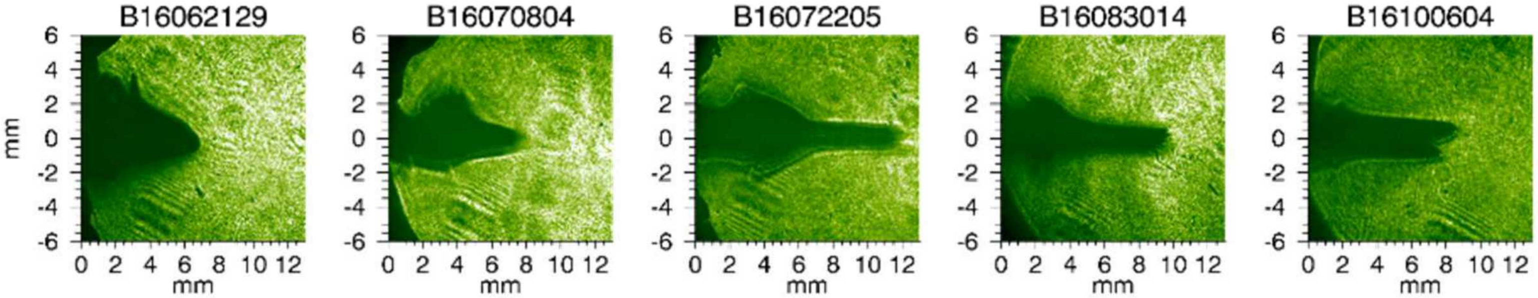
Backscatter screen

Fiber port for streaked visible spectrometer

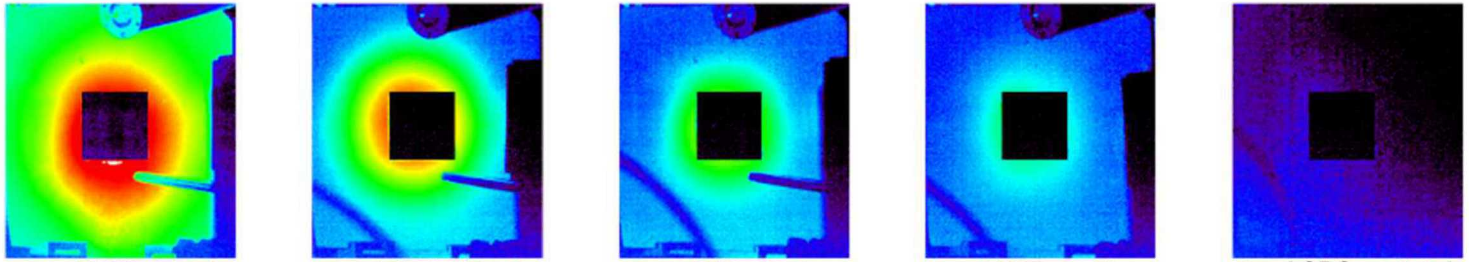
First Iteration of Improved Laser Coupling (AAC 2017)

	"Full Intensity"	"Full Intensity"	"Half-Intensity"	"Quarter-Intensity"	"1/8-Intensity"
Av. focal intensity:	(poorly defined)	190 TW/cm²	100 TW/cm²	50 TW/cm²	35 TW/cm²
Pre-pulse:	310 J	230 J	220 J	240 J	60 J
Main pulse:	1800 J	1300 J	1200 J	1300 J	850 J
Phase plate:	no DPP	750 μm DPP	750 μm DPP	1100 μm DPP	1100 μm DPP
Pulse duration:	2 ns	2 ns	3.5 ns	3.5 ns	3.5 ns

Shadowgraph immediately after the main pulse:



SBS data:

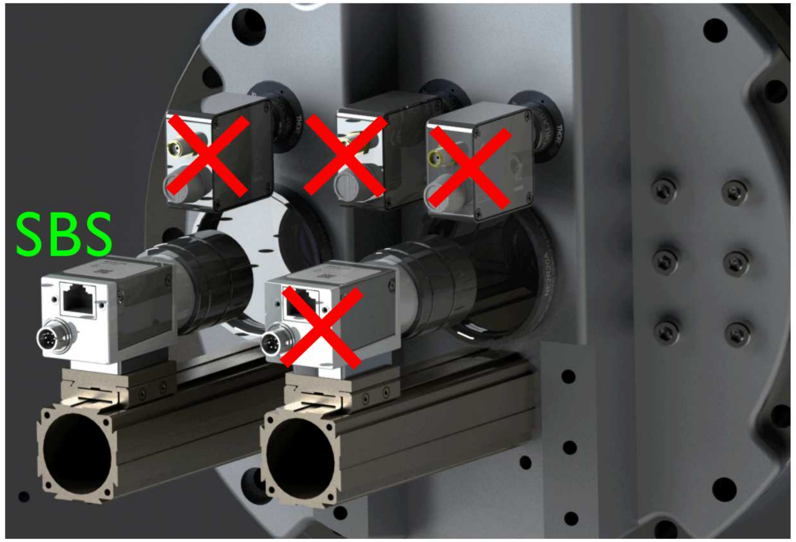


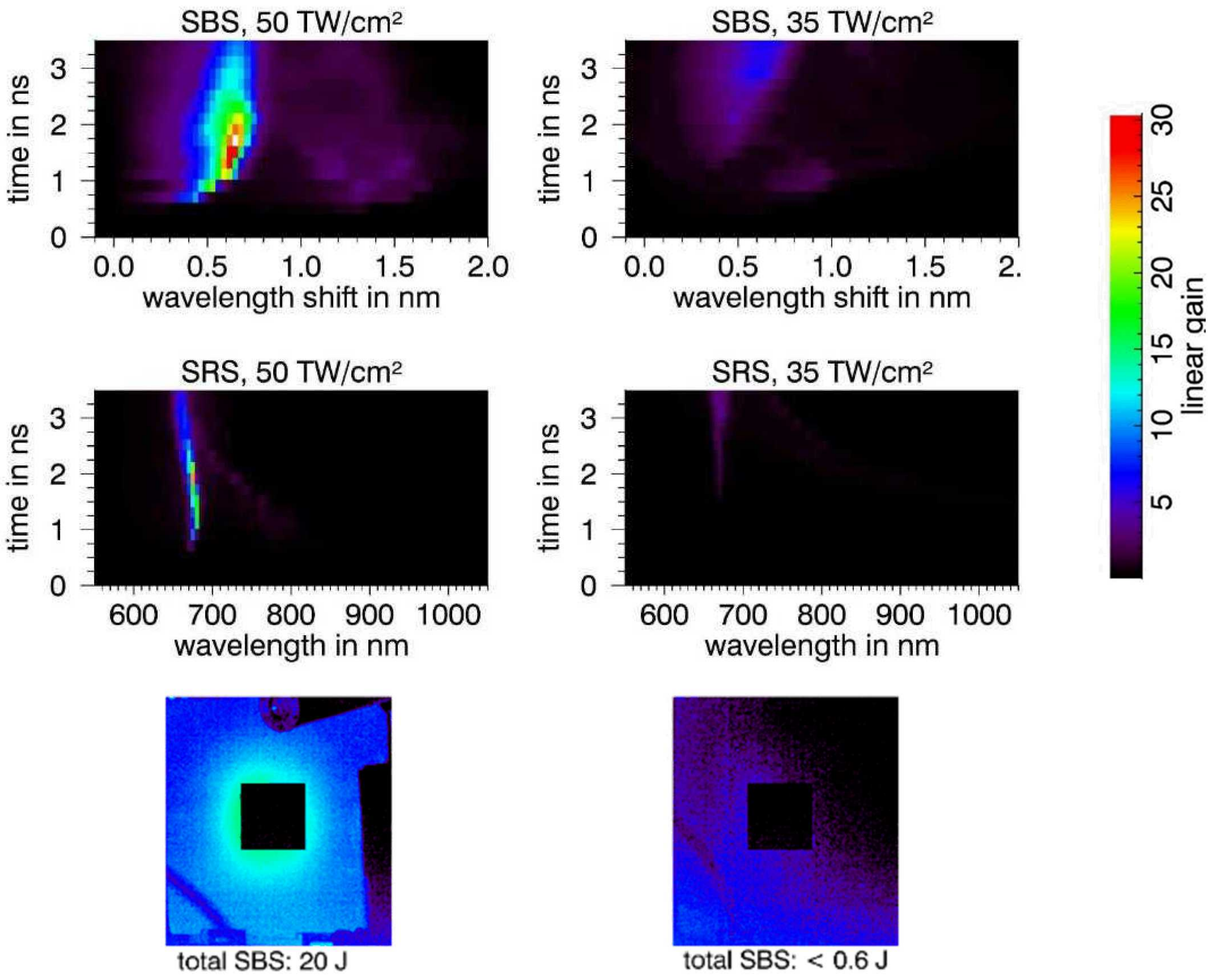
total SBS: 900 J | total SBS: 300 J | total SBS: 70 J | total SBS: 20 J | total SBS: < 0.6 J

LPI calculations

NewLIP gains calculations indicate that SRS should not be the dominating source of LPI.

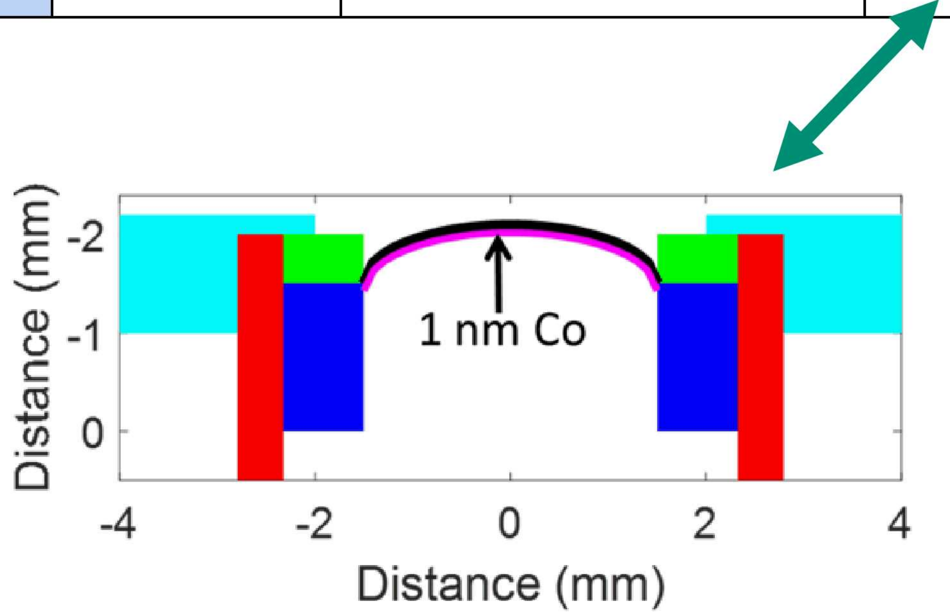
At the time of these experiments, no SRS diagnostics were online yet.





MagLIF Experiments with Minimized LPI (2017)

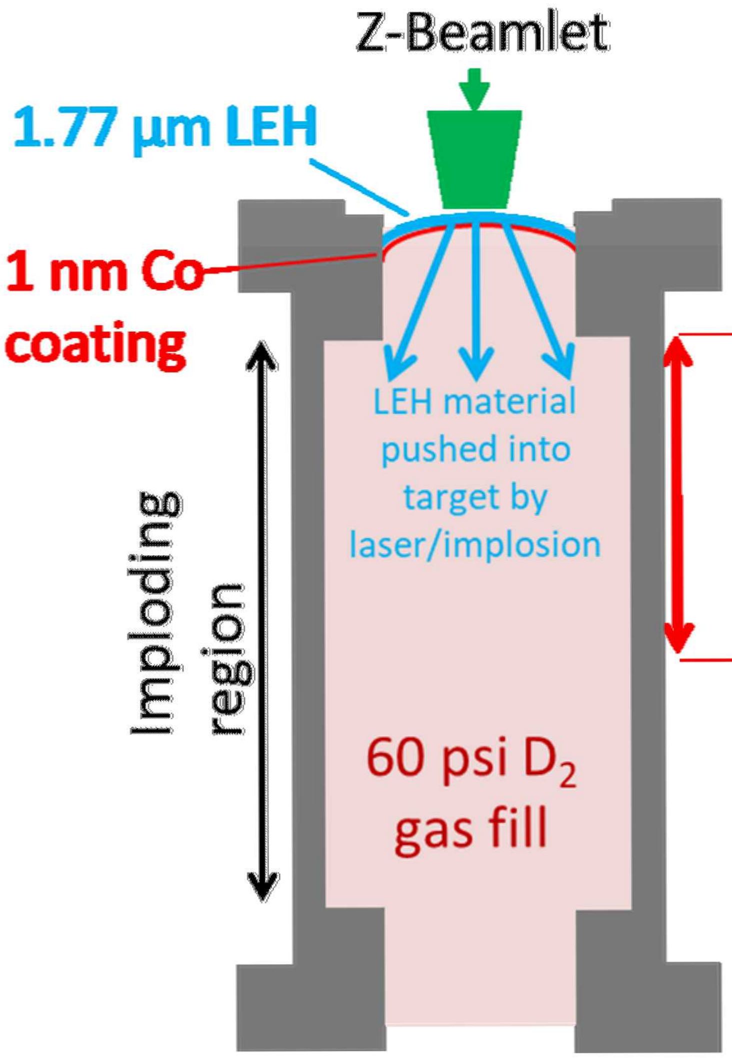
	Z3040	Z3041	Z3057
Laser energy	70 + 1460 J	73 + 1534 J	103 + 1283 J
Y_{DD}	4.1e12 ± 20%	3.2e11 ± 20%	2.0e12 ± 20%
Comments	Highest MagLIF yield at the time	Direct repeat of z3040. Factor 12 less yield. Suspicion of high mix.	Co coating on LEH used to investigate mix

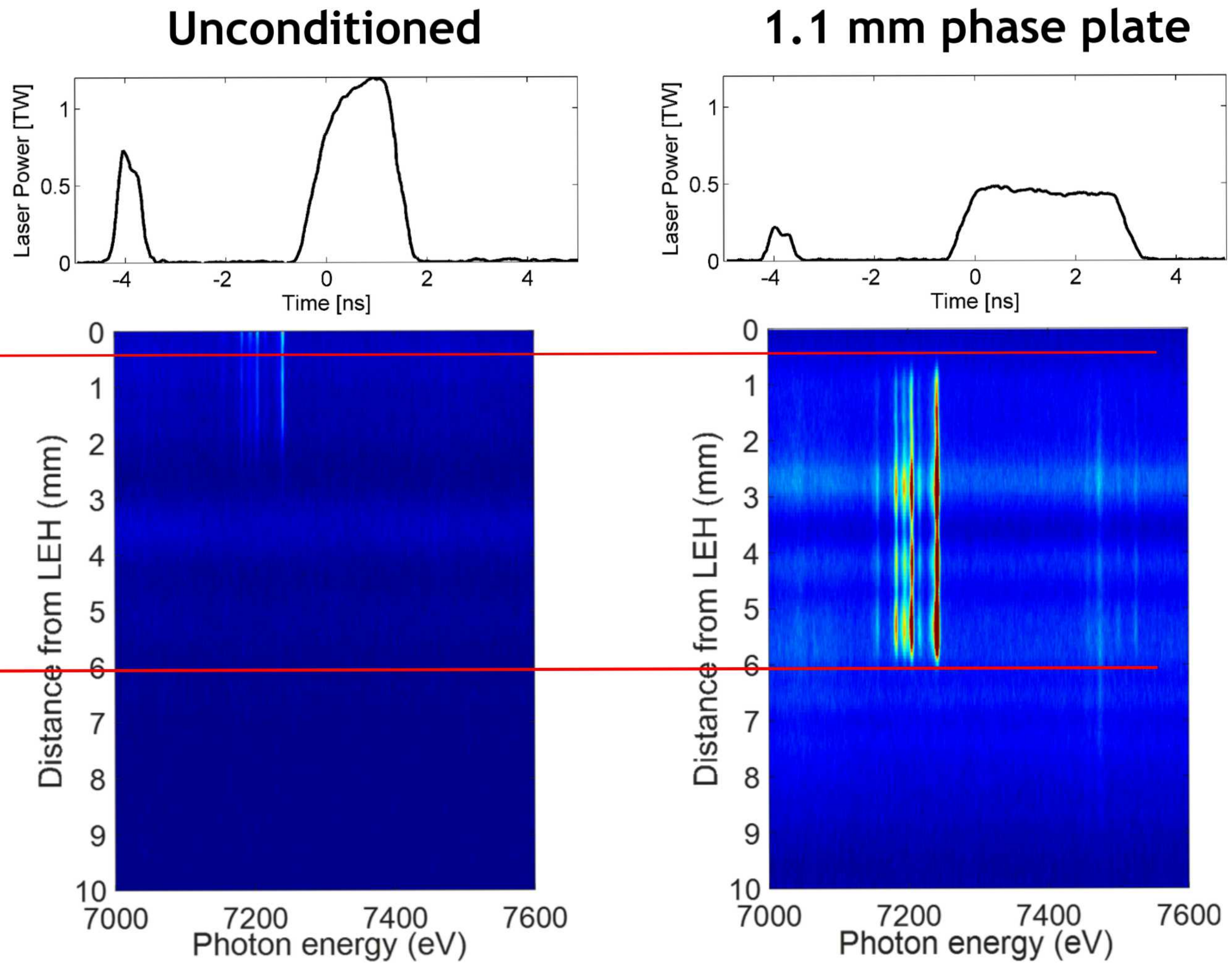


Z3057 was a MagLIF experiment with an inner coating on the LEH window to specifically look for mix.

Does the phase plate induce much more mix than an unconditioned beam ??

MagLIF Experiments with Minimized LPI (2017)

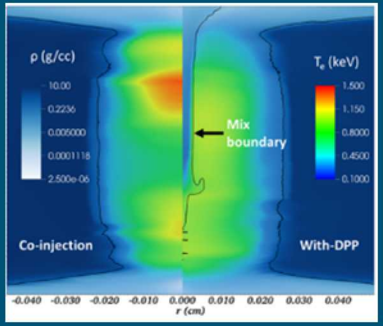


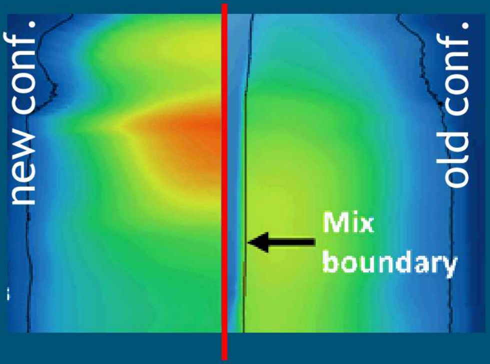


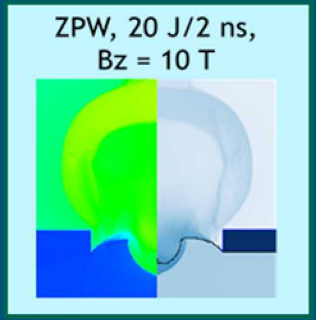
<u>Hypothesis</u>: Laser beam with phase plate acts like a piston for mix, unconditioned hot spots can pierce through LEH with less mix.

Designing a New Pulse Configuration

Dedicated *'a priori' HYDRA* simulations inspire several modifications





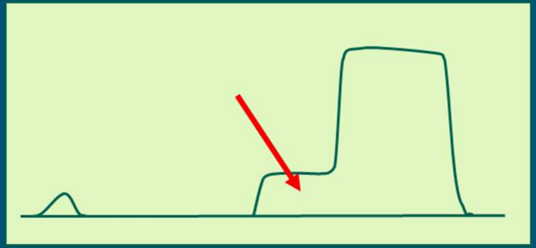


M.R. Weis, 2017:
LEH data
10-50 eV
~ 10^{20} cm^{-3}

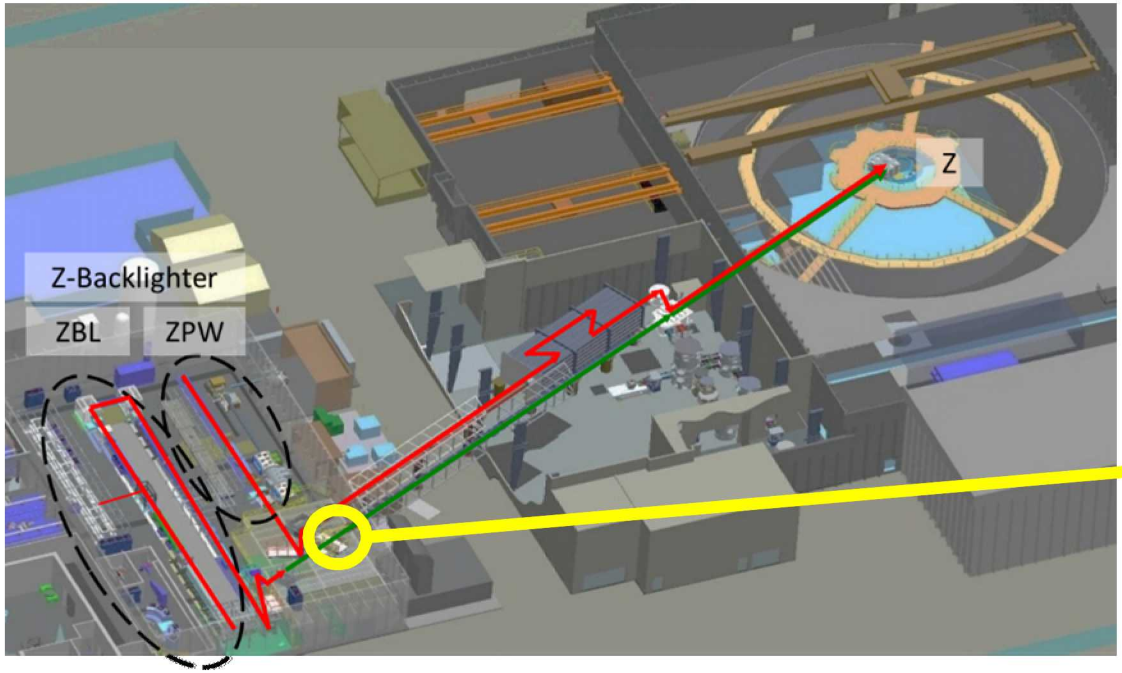
- The pre-pulse needs to be lower in energy and intensity
  - A method of early pre-pulse needed to be developed. The laser team created an option to 'co-inject' a separate laser into the Z-Beamlet beam path.

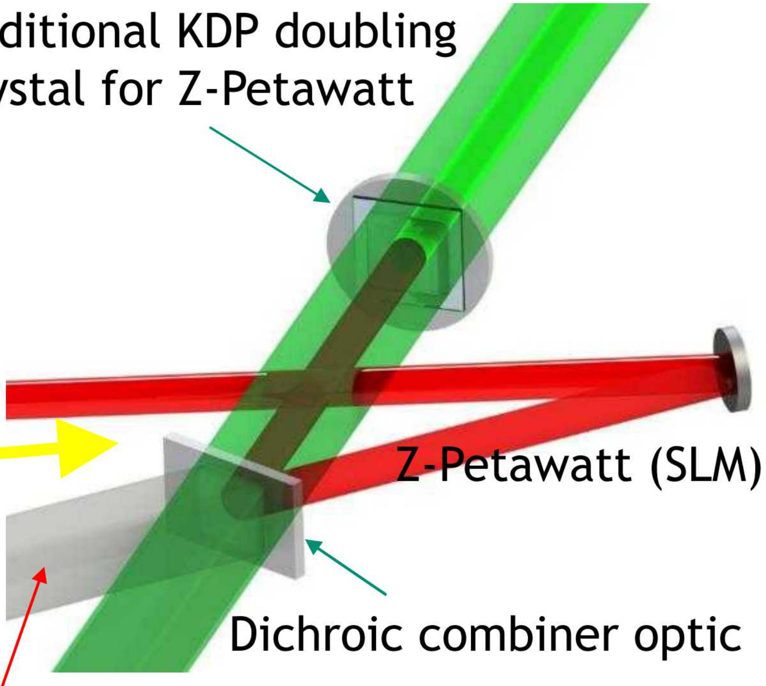
- 60 psi fill pressure (0.7 mg/cm^3) will likely not suffice to couple more than 1 kJ of laser energy to the target without "overshooting". Higher fill pressure will also benefit stability and mix mitigation.
  - The pressure was increased to 90 psi (1.05 mg/cm^3).
  - The LEH diameter shrunk from 3 mm to 2 mm to keep the same thickness.

- Since the expanding LEH window can cool down and become more absorbing again, the main laser pulse shall be preceded by a 'foot' that re-heats the window material.



Implementation of "Co-Injection"



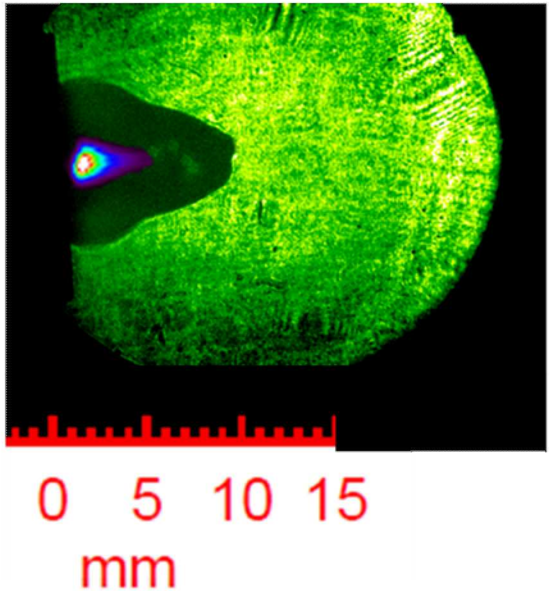


A single-longitudinal-mode, long pulse (2.5 ns) capability was implemented to the Z-Petawatt laser. Both beams can be combined before they are transported to the target areas.

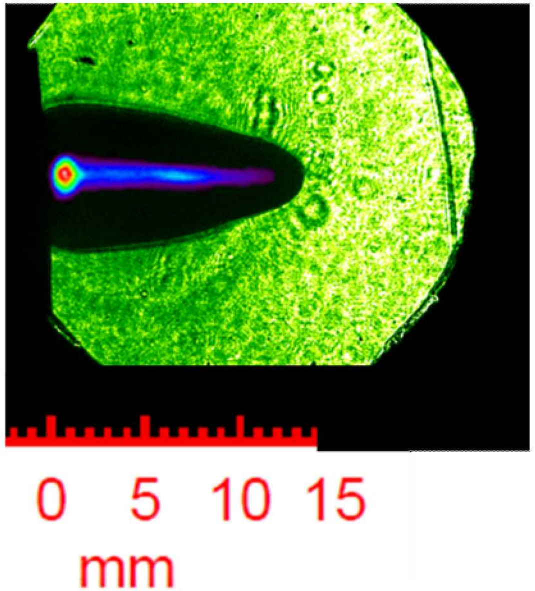
The required combiner optic requires a highly challenging, state-of-the-art coating (in-house capability). The damage threshold of this optic is limiting the energy of ZBL as of today. A new optic has been developed and is going to be available soon.

Experiments with Co-Injection in Pecos

1100µm Phase Plate
90 psi D_2
Pre-pulse 80 J
Main pulse 1270 J
(X-ray image: 60psi, 60/1060 J)



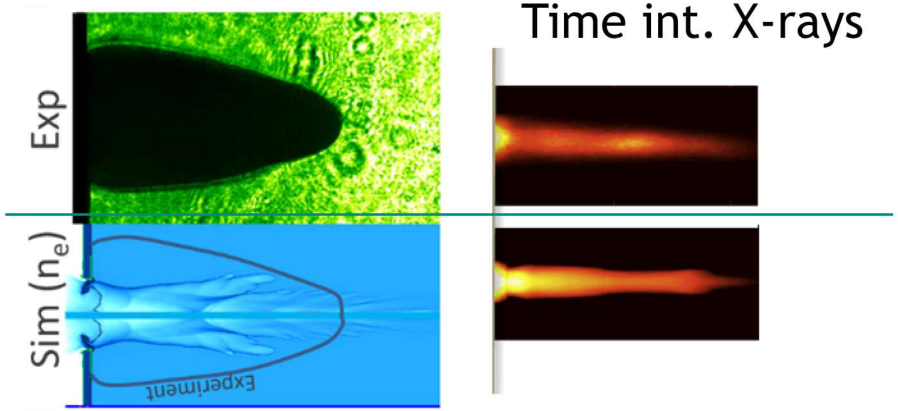
1100µm Phase Plate
90 psi D_2
"Foot": 190 J
Main pulse 1230 J
Co-Injection 24 J



Design vs. Experiment

Suggested: 10 J + 300/1800 J;
Experiment: 20 J + 200/1200 J;
Gas fill 90 psi D_2

Time int. X-rays



Energy in gas

numerical: 1200 J ('suggested' parameters)

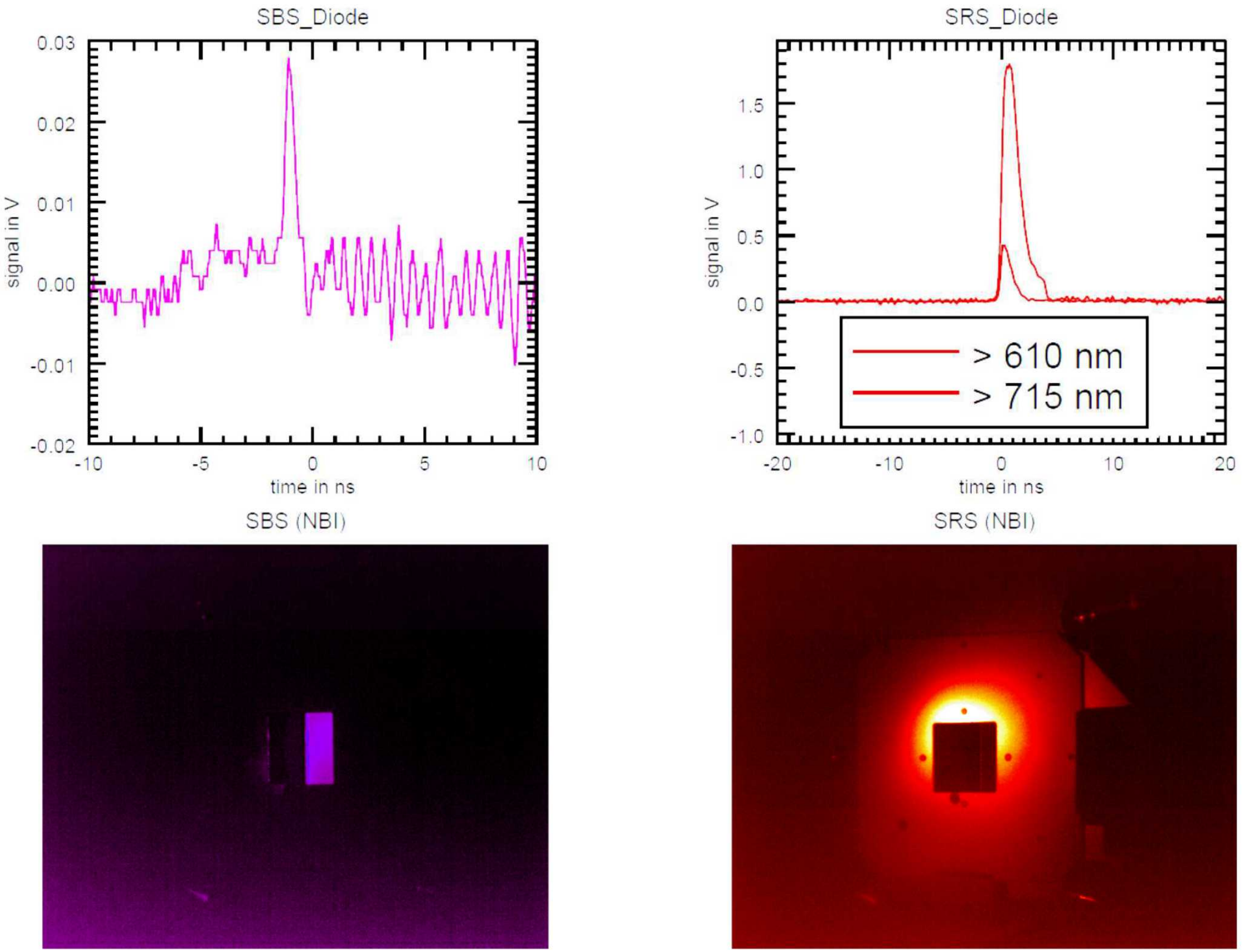
blastwave: 1100 J

Experiments with Co-Injection in Pecos: A look at Backscatter

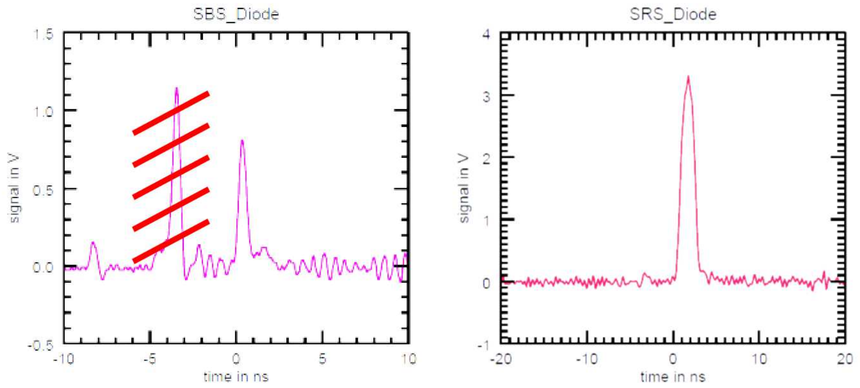
SRS instruments are not yet calibrated and have yet to be analyzed. It is higher than in the previous scenarios, though.
NewLIP simulations are pending

SBS is essentially eliminated (the recorded signal is stray light from focusing optics) or very low for the most energetic shots.

Co-injection Scenario

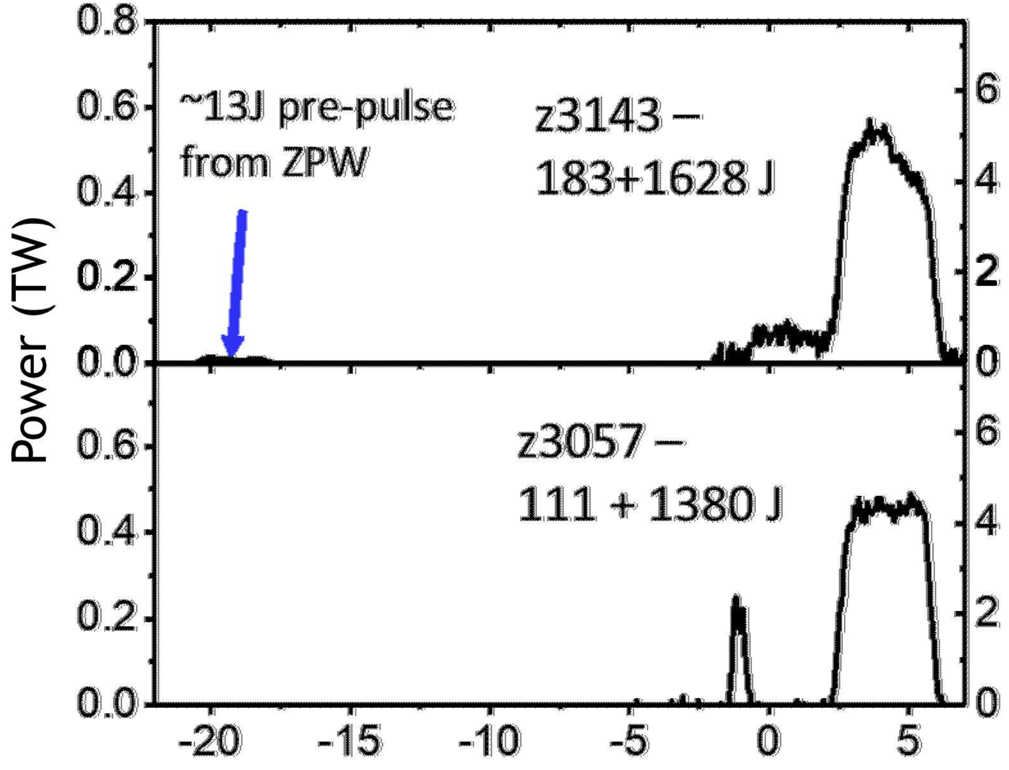


Original no-DPP Scenario

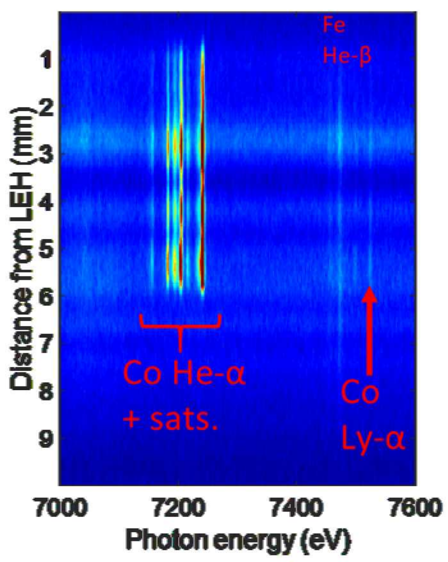


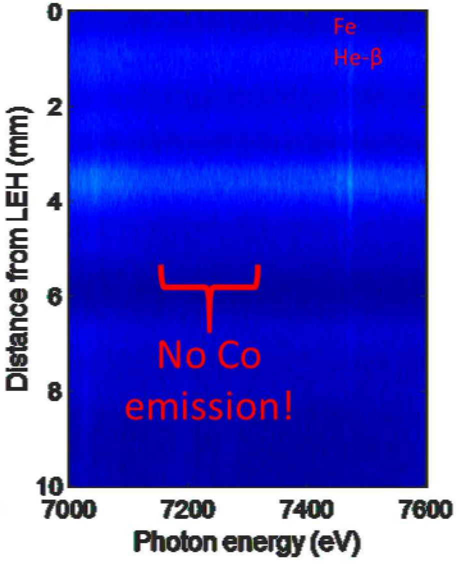
Relatively strong SRS !!

Co-injection Experiments in Z



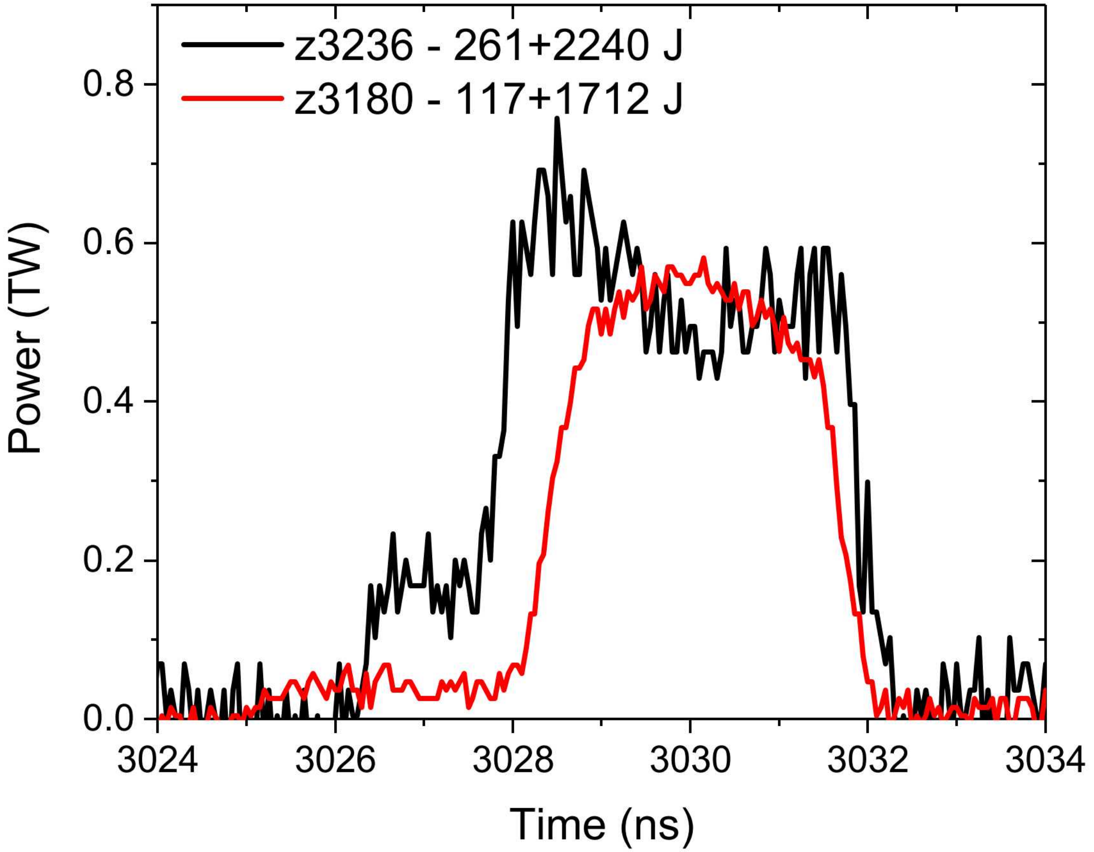
	z3057 ZBL only	z3143 Co-injection
Energy	111 + 1380 J	24 + 183 + 1626 J
Gas fill	60 psi (0.7 mg/cc)	90 psi (1 mg/cc)
LEH window	3 mm diam.; 1.77 μm thick	2 mm diam.; 1.77 μm thick
DD *(HYDRA)*	2.0e12 ± 20%	2.2e12 ± 20% *(2.4e12)*
T_{ion} (Ntof)	2.4 keV ± 20%	2.1 keV ± 20%





Co-injection Experiments in Z, Gen. II

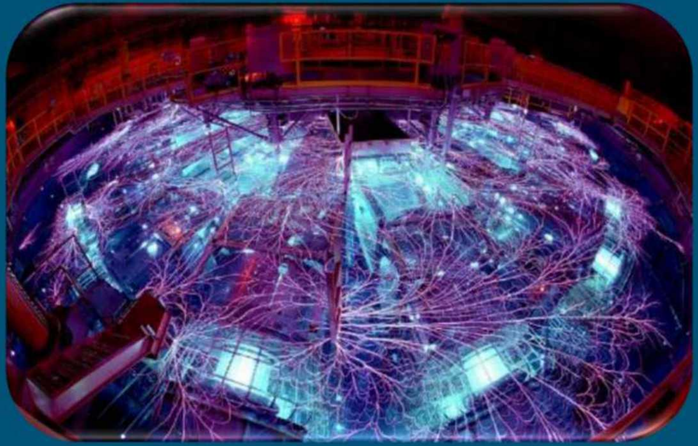
Energy is in foot + main pulse assuming 85% transmission
Both shots had 20-30 J co-injection at -20 ns



	z3180 ("Gen. I")	z3236 ("Gen. II")
Main pulse laser energy	117 + 1712 J	261 + 2240 J
Gas pressure	90 psi (1 mg/cc)	90 psi (1 mg/cc)
LEH window	2 mm diam. 1.77 um	2 mm diam. 1.77 um
Dopant	1 nm Co on LEH	1 nm Co on LEH
DD	~3.3e12	1.1e13 ± 20%
DD/DT	~82.5	100 +/- 28%
Tion (Ntof)	~2.3 keV	3.1 keV +/- 20%

Multi-Campaign, Multi-Platform Efforts

Sandia: Z, Z-Beamlet



- Integrated MagLIF experiments
- Pre-Heat Studies (527 nm)

LLE: Omega, Omega-EP

- "Mini-MagLIF" experiments
- Pre-Heat Studies (351 nm)

LLNL: NIF

- Next generation Pre-Heat Studies
  - 30 kJ laser energy (351 nm)
  - 4.8 mg/cc
  - 15% n_{crit} (351 nm)

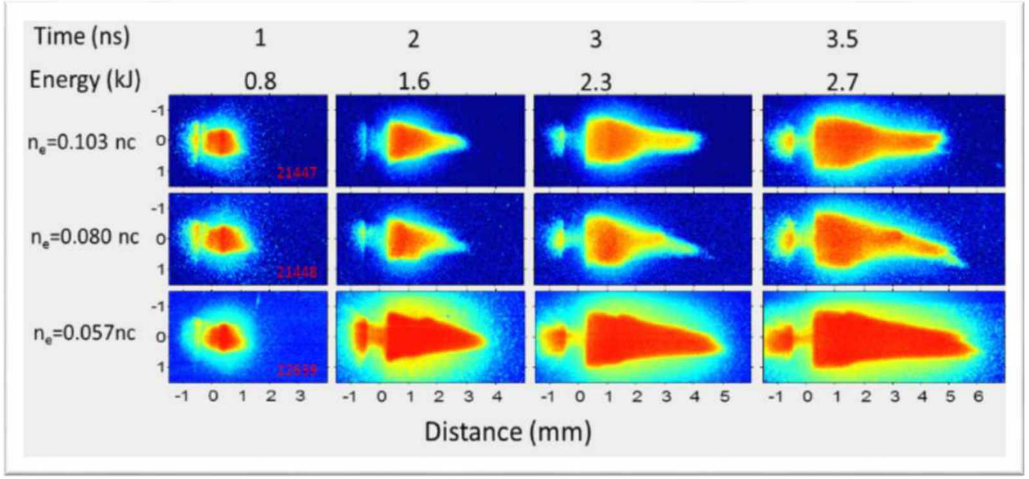
Simulation Tools

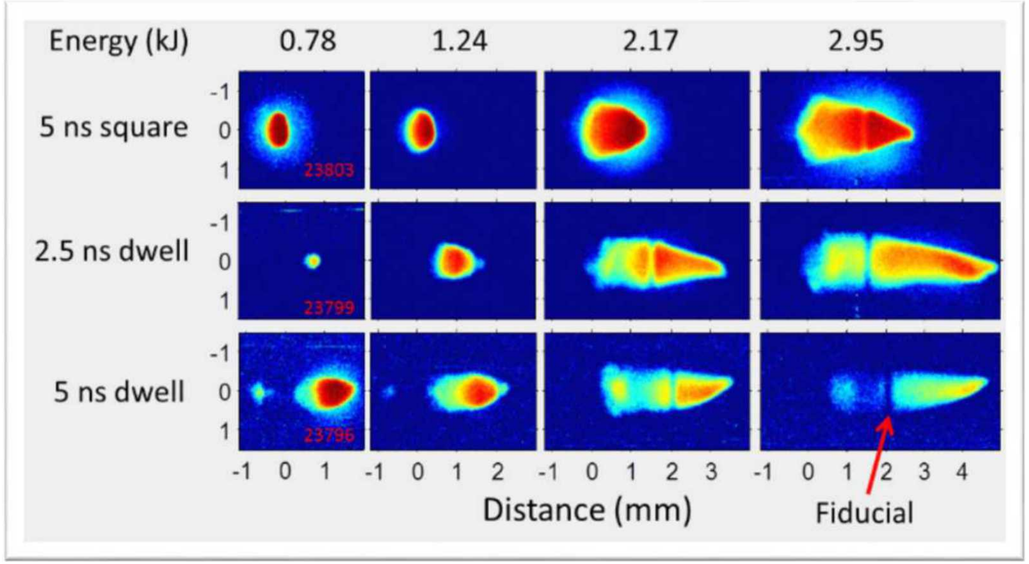
- Hydra
- Gorgon
- Lasnex
- NewLIP

Pre-Heat Studies at Omega-EP

A number of campaigns were performed at LLE in Rochester, addressing:

- 2w versus 3w scaling
- importance of the DPP
- "safe" regime of n_{crit} fraction
- influence of pre-pulse separation gap
- influence of B-Field (MIFEDS)



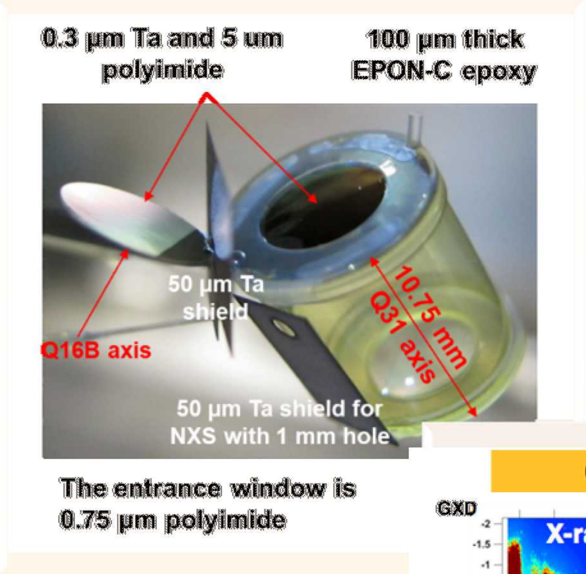


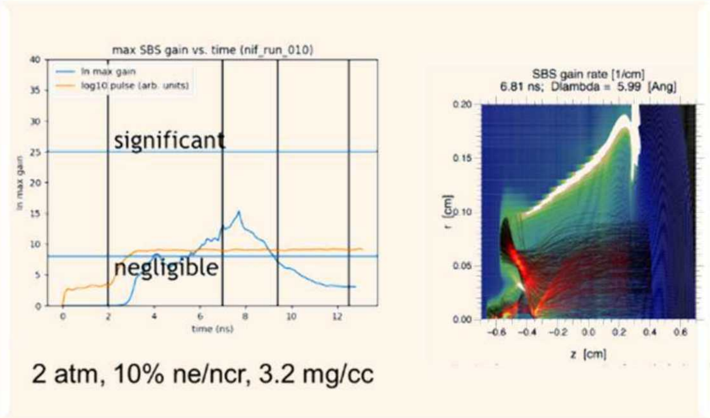
Pre-Heat Studies on the NIF

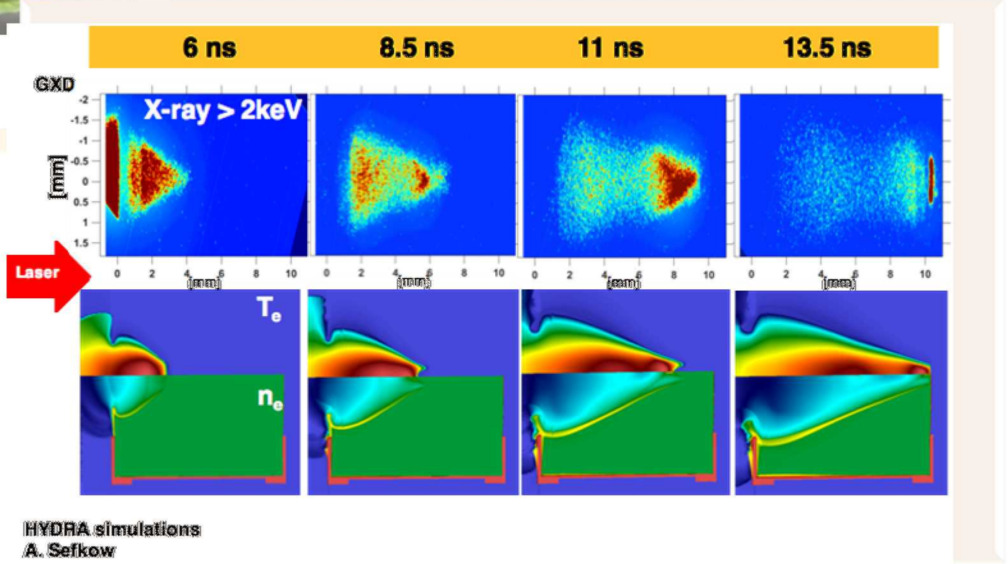
A high-yield MagLIF scenario would require several 10kJ of pre-heat.
Dedicated experiments with a Quad of the NIF were performed to study the feasibility.

Sandia National Laboratories
- **Michael Glinsky**
- Matt Weis
- Taisuke Nagayama
- Kyle Peterson
- Adam Sefkow (now LLE)

Lawrence Livermore National Laboratory
- **Brad Pollock**
- John Moody
- Dave Strozzi
- C. Goyon



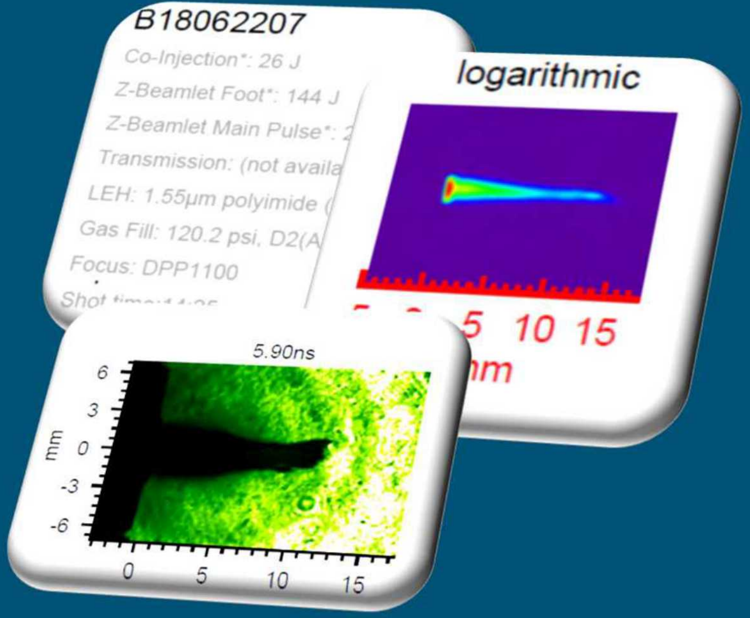




So far it is looking good!
Low LPI
Good agreement with codes

What comes next?

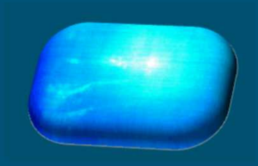
- ❖ Analysis of new(er) data: X-ray spectrometer, SRS, SVS, etc.



- ❖ Establishing a reliable 120 psi target platform with ~ 2 kJ laser deposition.
  - ❖ Z-Beamlet energy upgrade.
  - ❖ 1.5 mm DPP, already coated and conditioned.
  - ❖ New Dichroic beam combiner for co-injection, design done, not yet coated.
  - ❖ Experiments already in progress.

- ❖ Implement Optical Thomson Scattering for T_e measurements (in progress).

- ❖ Implement Schlieren Diagnostics (in progress).



- ❖ Add temporal resolution to X-ray spectrometer (challenging) and pinholes.

Advanced Pre-Heat Designs in Preparation

New concepts are emerging to minimize the losses from the LEH window:

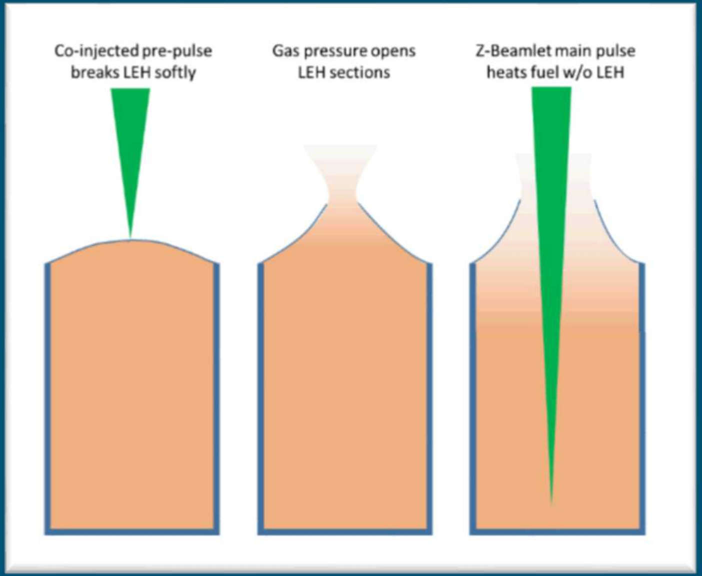
1. Get rid of the window altogether ("Lasergate")

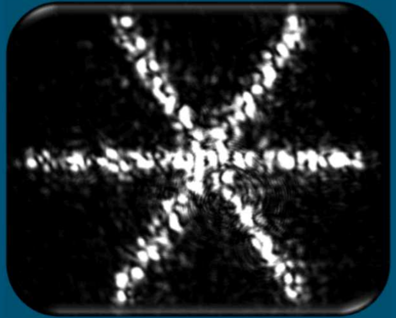
2. Reduce the pressure by cooling the deuterium ("Cryo")

A design for cryogenically cooling MagLIF targets has been developed and will be implemented in the Pecos target area within the next 6-8 months.

Lasergate is being studied at the "Conchas" target are of the Z-Beamlet Facility.

Rendering of the Pecos Cryo target





Focus with the laser gate optic (SNL design: Jens Schwarz)

Segmented "gate" after lasergate shot