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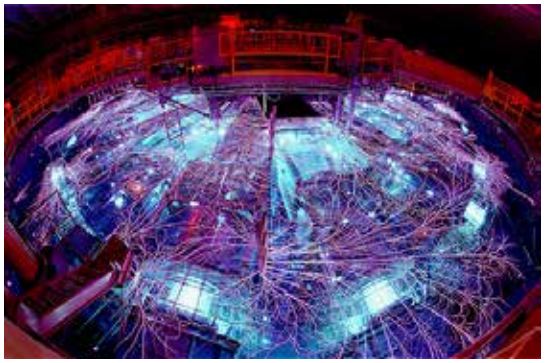


Progress in demonstrating magneto-inertial fusion science and scaling

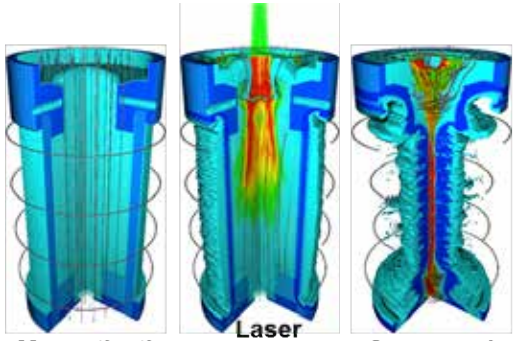
Dr. Daniel Sinars

for the MagLIF team

Sandia National Laboratories

ARPA-E Annual Meeting

August 29-31, 2017



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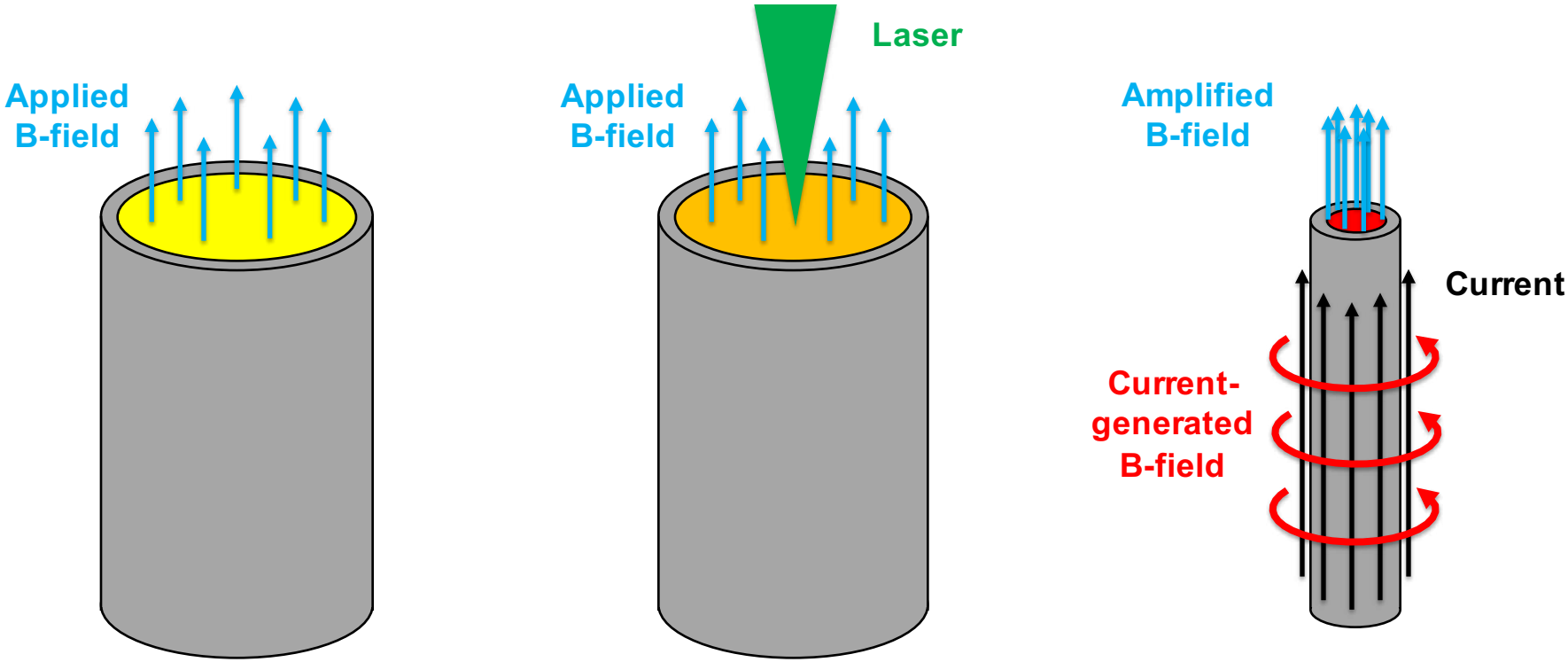
U.S. DEPARTMENT OF ENERGY

arpa·e CHANGING WHAT'S POSSIBLE

NNSA National Nuclear Security Administration

Magnetized Liner Inertial Fusion (MagLIF) relies on three stages to produce fusion relevant conditions



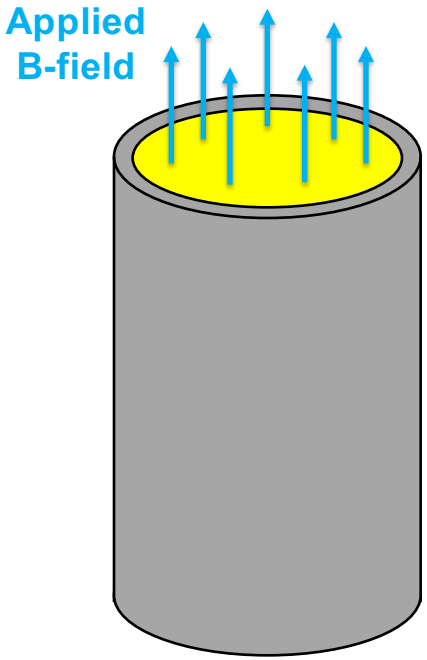
Apply axial magnetic field

Laser-heat the magnetized fuel

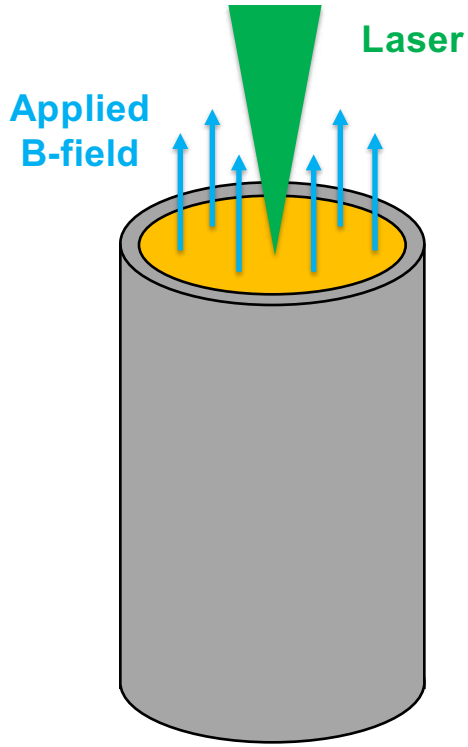
Compress the heated and magnetized fuel

S. A. Slutz, et al., Phys. Plasmas 17, 056303 (2010).

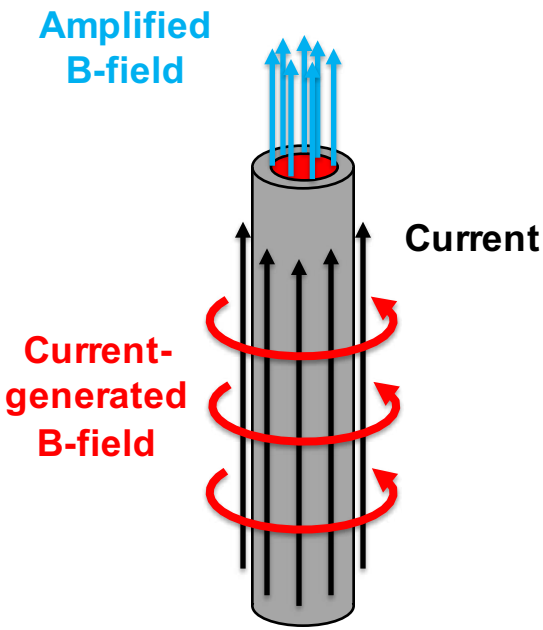
Magnetized Liner Inertial Fusion (MagLIF) relies on three stages to produce fusion relevant conditions



Apply axial magnetic field



Laser-heat the magnetized fuel



Can replace magnetic pressure with laser ablation pressure

S. A. Slutz, et al., Phys. Plasmas 17, 056303 (2010).

Our project utilizes existing capabilities* at two institutions to demonstrate magneto-inertial fusion science & scaling

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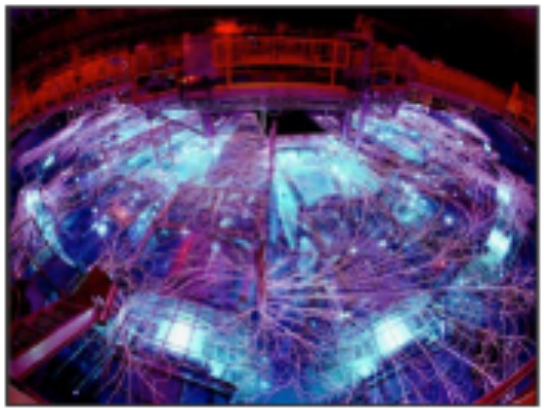
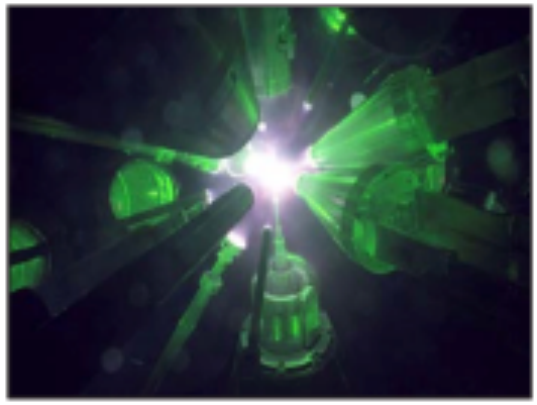
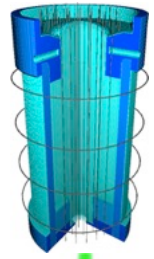
- 80-TW, **20 MJ** Z pulsed power facility
- 1-TW, multi-kJ Z-Backlighter laser facility
- 30 T B-field system (900 kJ stored energy)



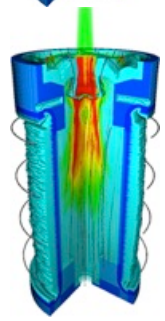
Laboratory for Laser Energetics

- 60-beam, 30-TW, **30 kJ**, OMEGA laser facility
- 4-beam, TW to PW, multi-kJ OMEGA-EP laser facility
- 20 T B-field systems (200 J stored energy)

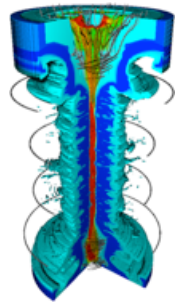




Initial Conditions
- Be liner
- ρ_{DT}~ 1-4 mg/cc
- B_{z0}~ 10-30 T (~0.1 MG)



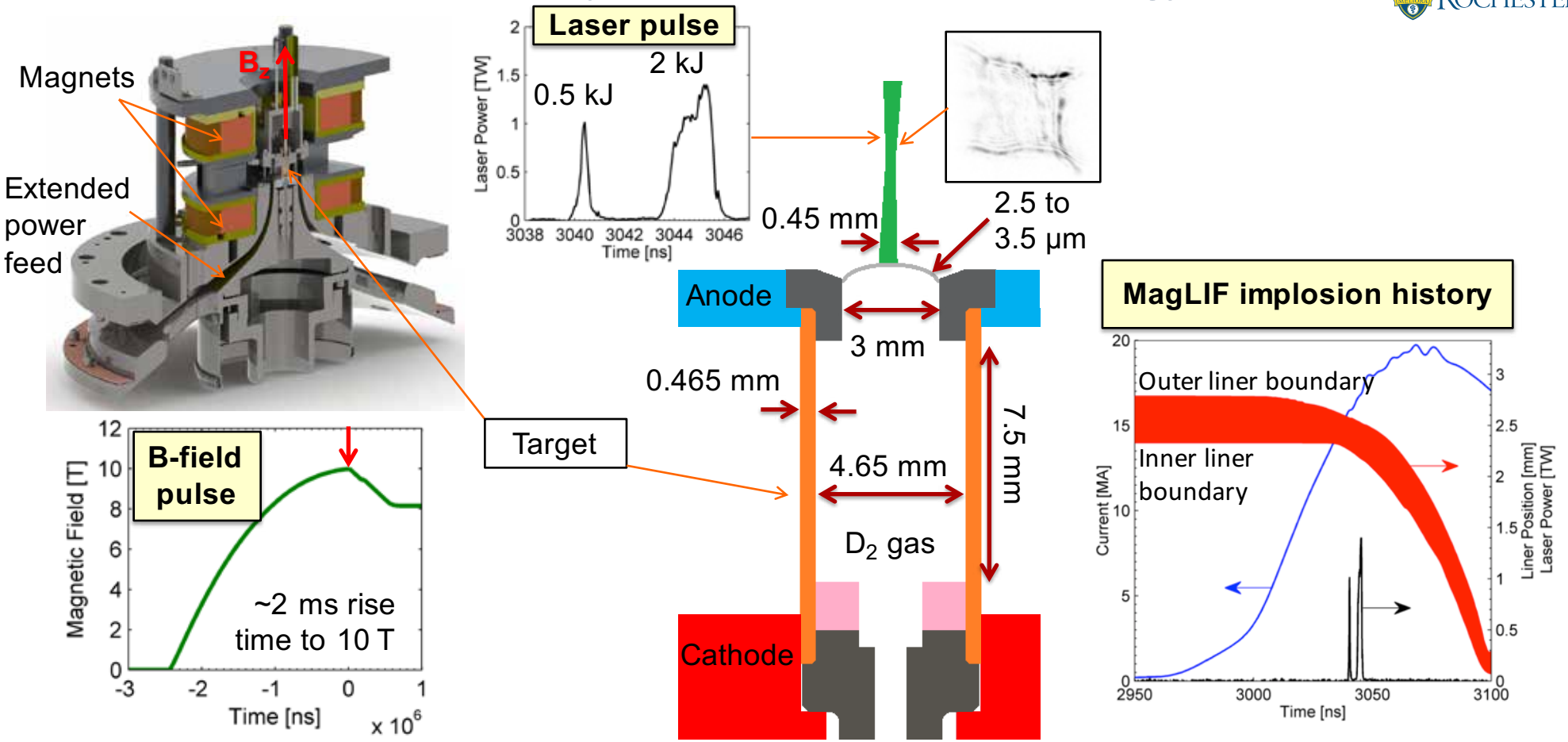
Laser Heating
- E_{laser} ~ 2-6 kJ @.53µm
- T_{DT} ~ 0.2 KeV
- $\omega\tau$ ~ 2-5
- Research on Z, ZBL, Omega, Omega-EP



Implosion/stagnation
- V_{imp}~ 70-100 km/sec
- P_{DT} ~ 5 Gbar
- T_{ion} > 5 keV
- $\omega\tau$ ~ 200 (B~100 MG)
- Research on Z, Omega

* All facilities are multi-user, multi-program facilities funded by the NNSA

Work at Sandia is focused on improving the laser preheating over the parameters used in the initial 2013-2014 Z experiments (10 T, 2.5 kJ laser energy, and 17 MA)



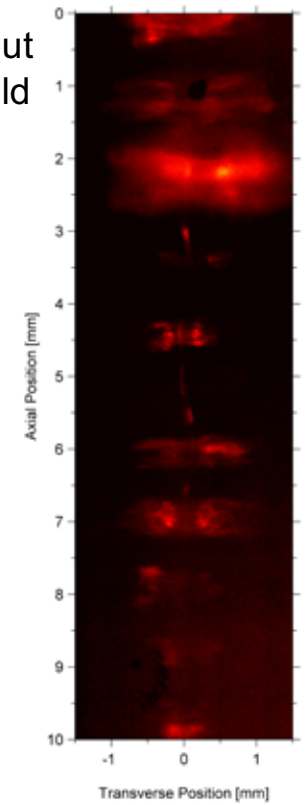
M.R. Gomez *et al.*, Phys. Rev. Lett. 113, 155003 (2014).

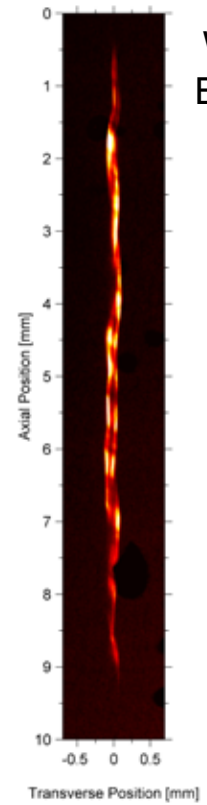
We have verified that good performance on Z, using our initial parameters, requires both applied B-field and laser heating

	No B-field	B-field
No Laser Heating	**$3x10^9$ (near-background)**	**$1x10^{10}$**
Laser Heating	**$4x10^{10}$**	**$3x10^{12}$**

$3x10^{12}$ is a DT-equivalent yield of ~0.6 kJ

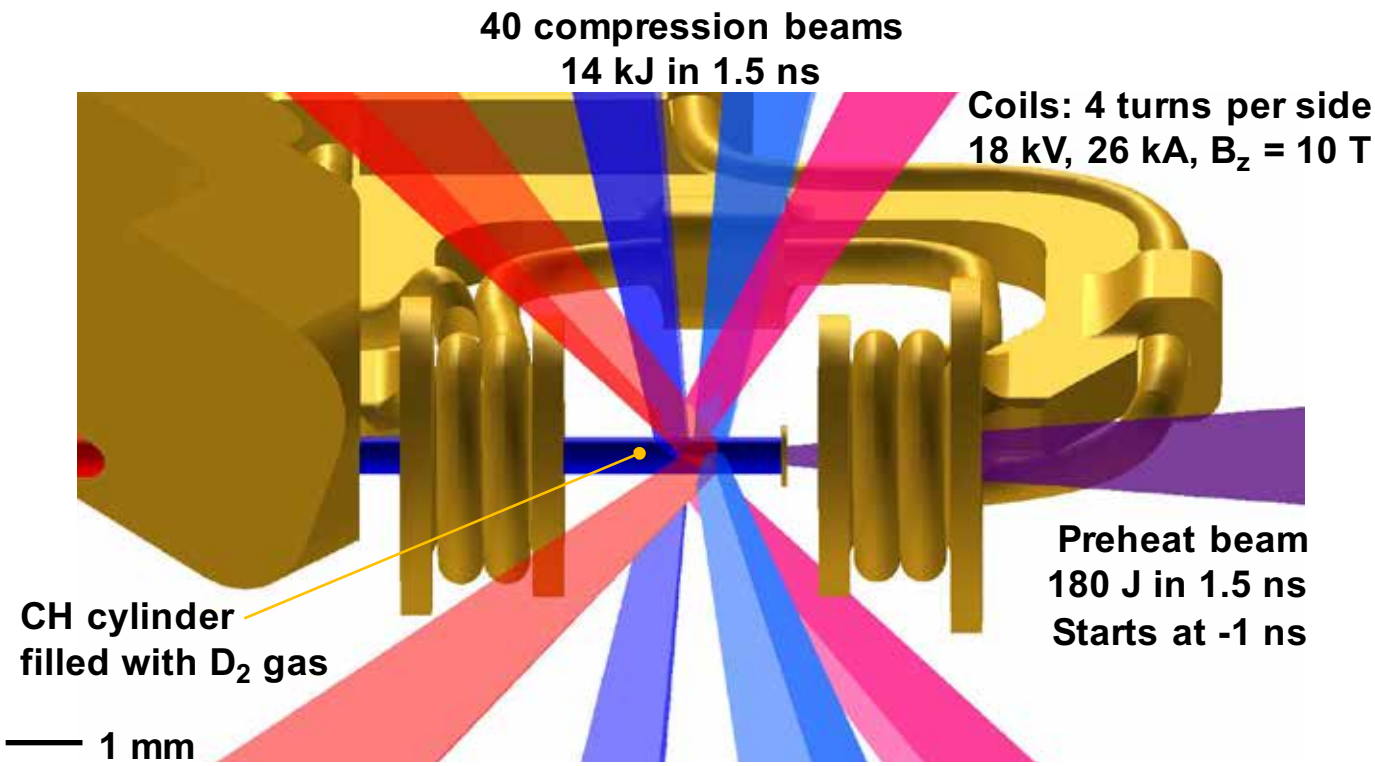
Without B-field





With B-field

Rochester's laser-driven MagLIF uses targets 10× smaller than Z to study scaling and basic physics with a higher shot rate and better diagnostic access

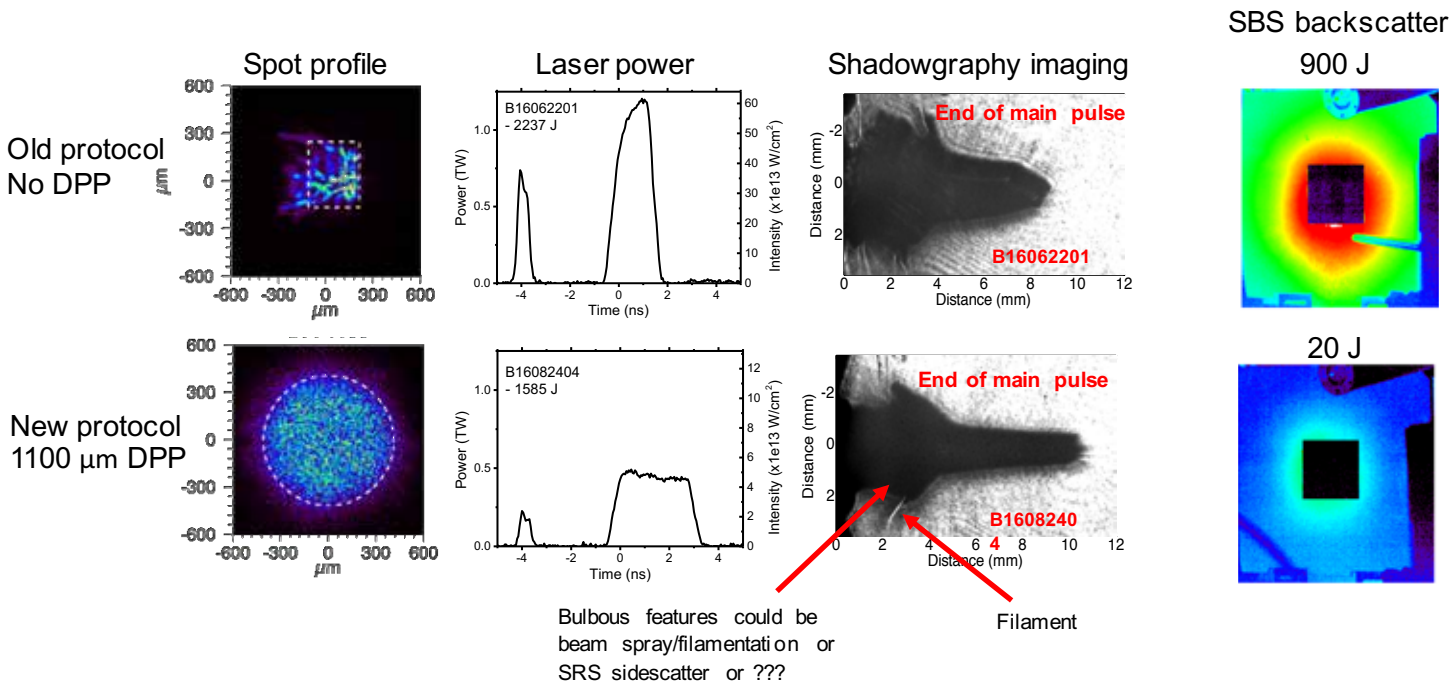


Laser-driven MagLIF data indicate that magnetization and preheating increase yield and ion temperature and reduce convergence

Type	Y_{DD} (10^8)	T_i (keV)	ρR (mg/cm²)	$\rho R/\rho R_0$
Compression-only 11 atm D_2 (3)	10.0±0.74	2.27±0.40 (2)	1.41±0.28 (2)	27.3±5.4
Compression+Preheat 11 atm D_2 (2)	14.4±2.7	2.49±0.34	0.71±0.21 (1)	14.1±4.2
Compression+Field 11 atm D_2 (2)	16.9±0.85	2.36±0.29	0.71±0.15	13.9±2.9
Integrated 11 atm D_2 (1)	15.7±0.16	2.67±0.5	-	-
Compression-only 7 atm D_2 (2)	3.93±0.28	2.14±0.17	-	-
Compression+Field 7 atm D_2 (2)	5.54±0.91	2.42±0.35	1.29±0.25	39.2±7.4

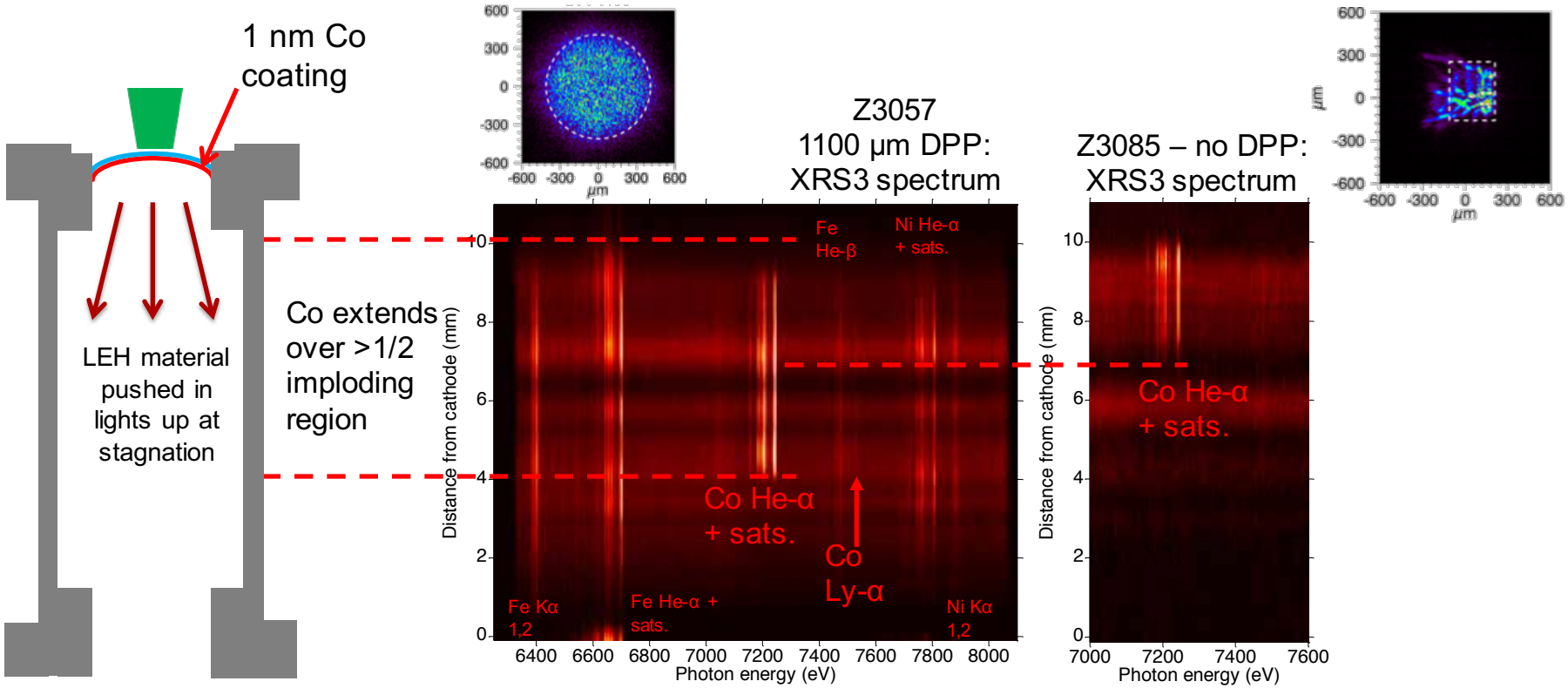
- Lower convergence leads to higher yields
- Confirmed that magnetization and preheat provide a practical route to low convergence inertial confinement fusion

Z: A new laser protocol was developed for Z-Beamlet that uses phase plate smoothing & lower laser intensity 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

While more energy is coupled using DPP smoothed laser configuration, it also appears to inject window material deeper into the stagnation column

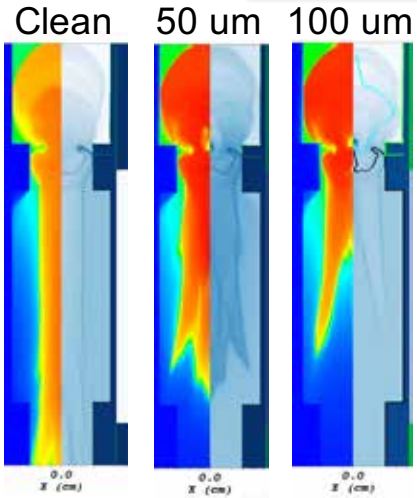


Z: The new laser preheat configuration has produced the highest MagLIF yields in integrated experiments, but questions remain about reproducibility

	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	**~50% of clean 2D**	Direct repeat of z3040.	Co coating on LEH

We are presently investigating hypotheses for the shot-to-shot variations

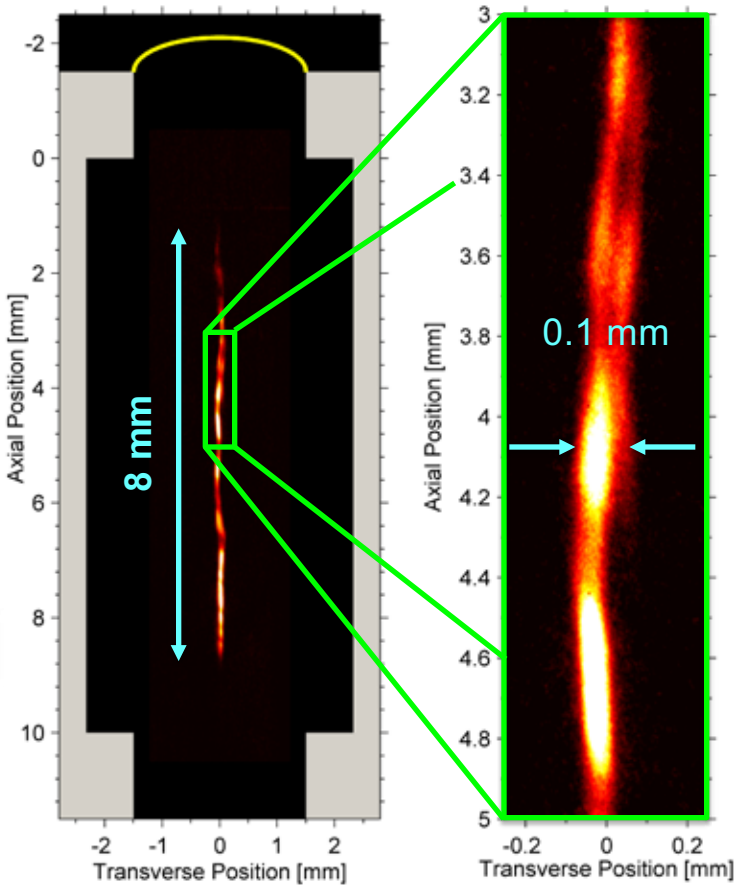
Dust on the laser windows



- Dust particles >50 microns can significantly change laser energy deposition in simulations
- Some evidence that dust of this size can occur under nominal conditions on Z
- However, laser-only tests appear reproducible

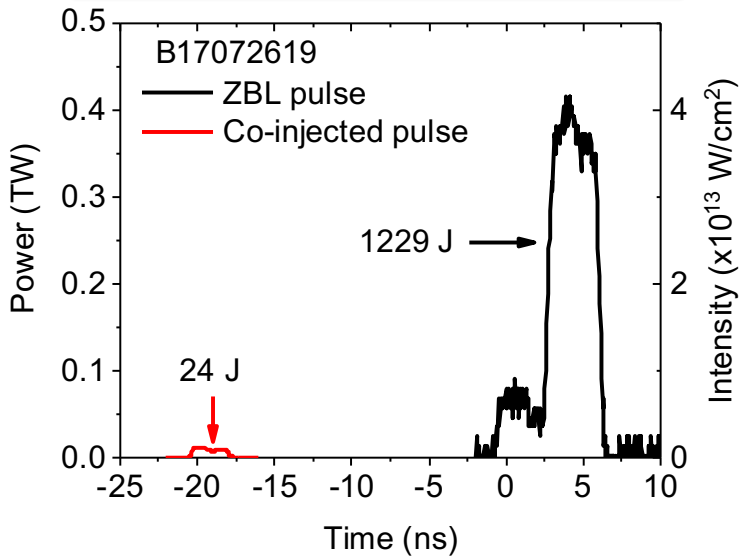
Variability in fuel convergence

- New high-resolution x-ray images show considerable sub-structure—will reducing the convergence ratio help?



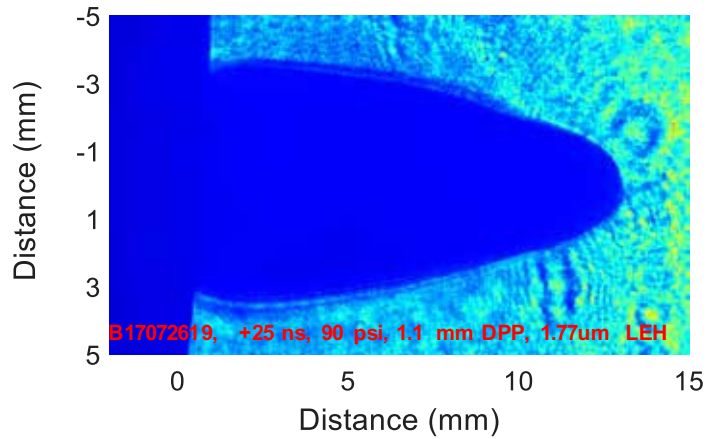
A new laser pulse shape more gently disassembles the window and allows the density to drop for ~ 20 ns, minimizing interaction with steep density gradients

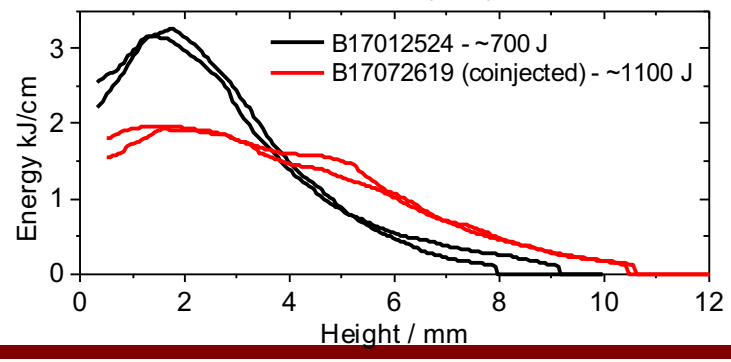
Independently timed prepulse



First integrated Z shot on August 31

More uniform and deeper penetration



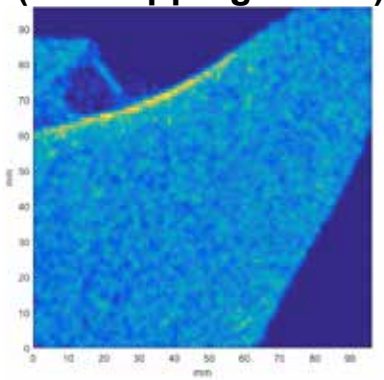


Over the next year, we expect to scale MagLIF on Z to higher drive conditions and to further improve our quantitative measurements on Omega

- Our main near term goal for Z is to **reduce the convergence** of the system to produce a more reliable and easily-diagnosable stagnation
  - Increase the energy density of the fuel through more effective laser coupling, higher initial fuel density, and increased inhibition of thermal transport
- We have been operating at 10 T, 0.2-1 kJ, and 17 MA
- We expect to be operating at 15-20 T, 1-2 kJ, and 19-20 MA within the next year

- Our main near term goal for Omega is to **improve our diagnosis of the stagnation conditions**, including measurements of the compressed magnetic field
  - Increase the level of magnetization by using two coils instead of one
  - Use protons to measure the BR increase

Proton Tracing 10 T (no stopping in coil)



Integrated Shot