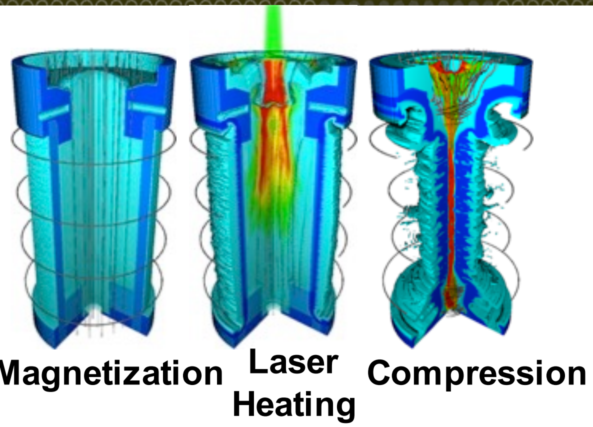
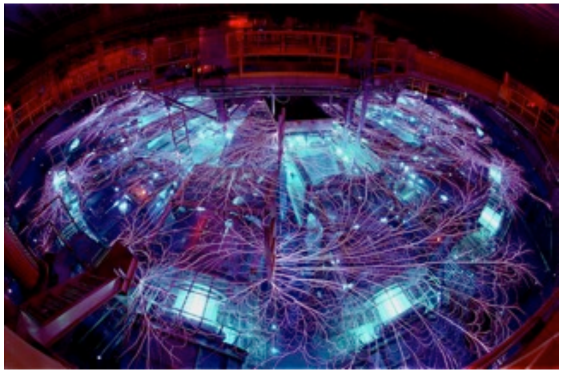
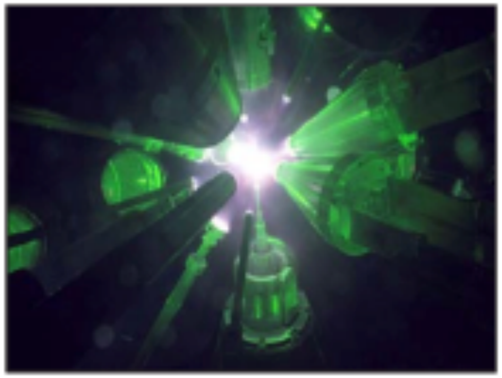
Exceptional service in the national interest





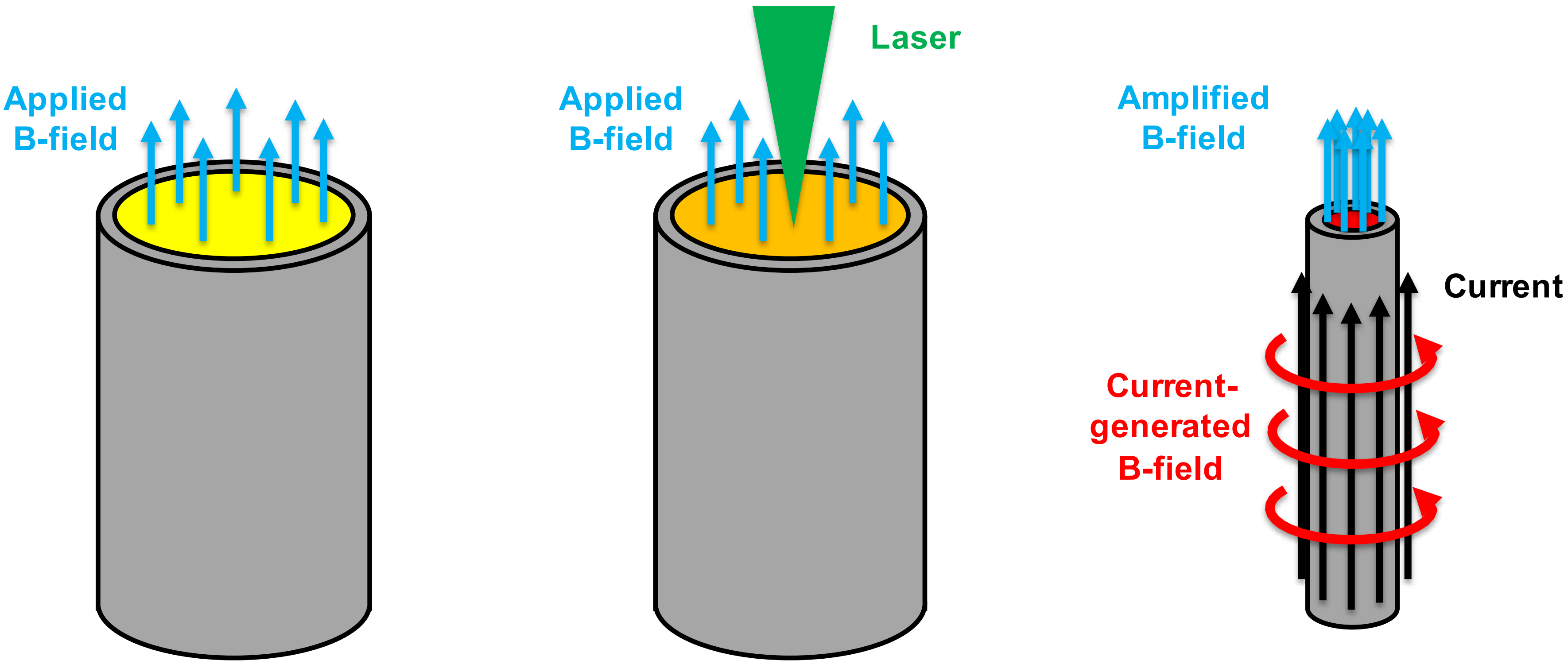


Status and Progress on Magnetized Liner Inertial Fusion

Daniel Sinars, Sandia National Laboratories

Fusion Power Associates Meeting Dec. 6-7, 2017 Washington, D.C.

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



Apply axial magnetic field

Laser-heat the magnetized fuel

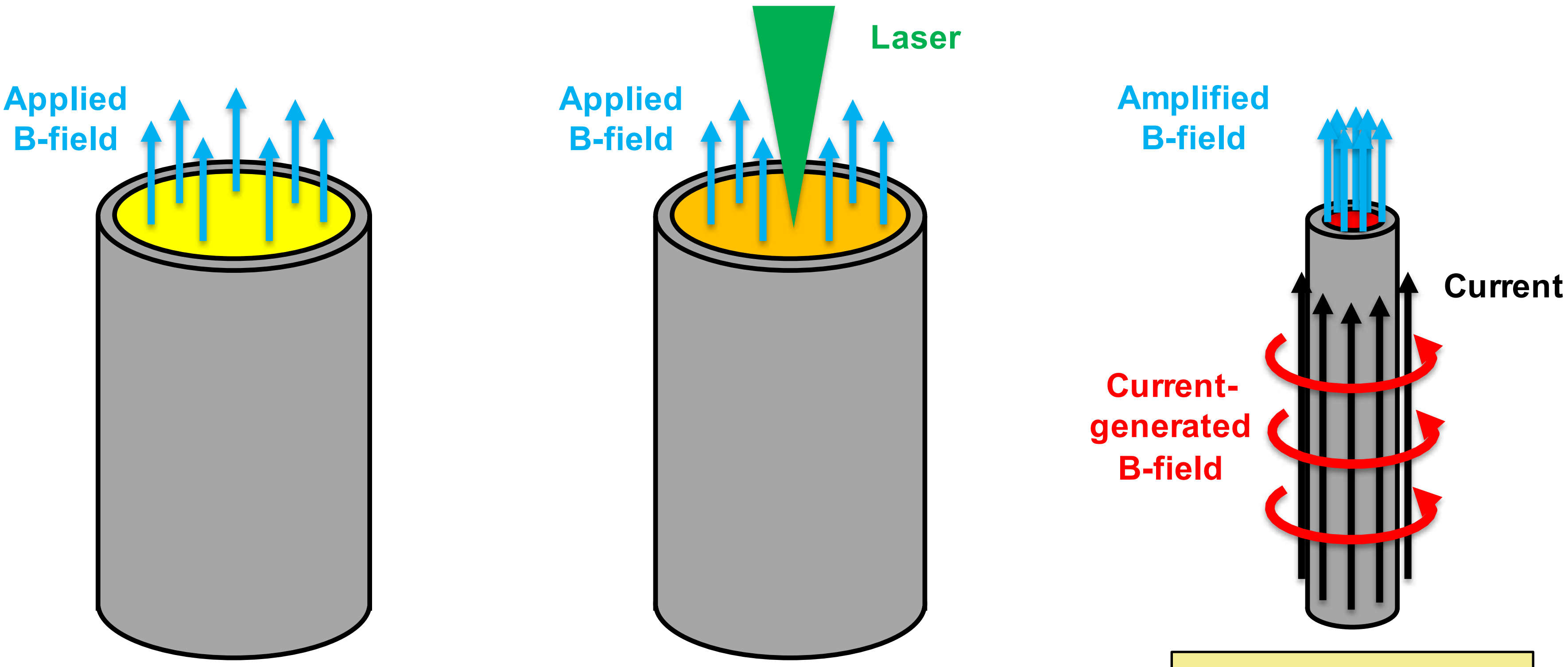
Compress the heated and magnetized fuel

S.A. Slutz *et. al.*, PoP (2010)
S.A. Slutz and R. A. Vesey, PRL (2012)
M.R. Gomez *et. al.*, PRL (2014)
P.F. Schmit *et. al.*, PRL (2014)
A.B. Sefkow, *et. al.* ,PoP (2014)

M.R. Gomez, *et. al.*, PoP (2015)
S.B. Hansen, *et. al.* , PoP (2015)
P.F. Knapp *et al.*, PoP (2015)
A.J. Harvey-Thompson *et al.*, PoP (2015)
R.D. McBride, *et. al.*, PoP (2016)

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

Magnetized Liner Inertial Fusion (MagLIF) can also be studied on laser facilities such as Omega



Apply axial magnetic field

Laser-heat the magnetized fuel

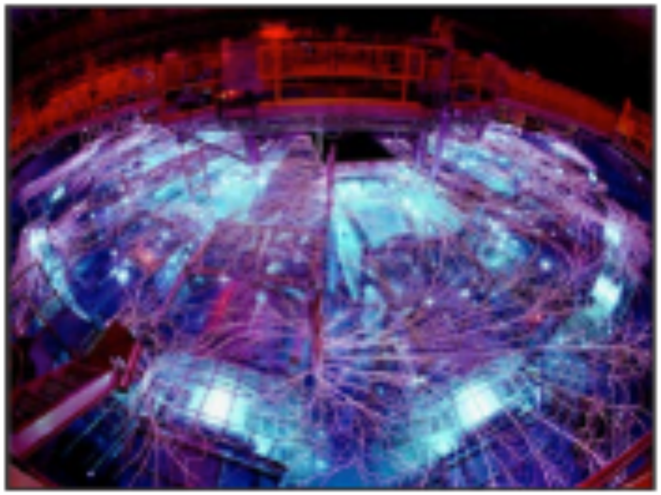
Can replace magnetic pressure with laser ablation pressure

J.R. Davies *et. al.*, PoP (2017)
D.H. Barnak *et. al.* ,PoP (2017)

A joint collaboration between Sandia and Rochester is exploring magneto-inertial fusion science & scaling

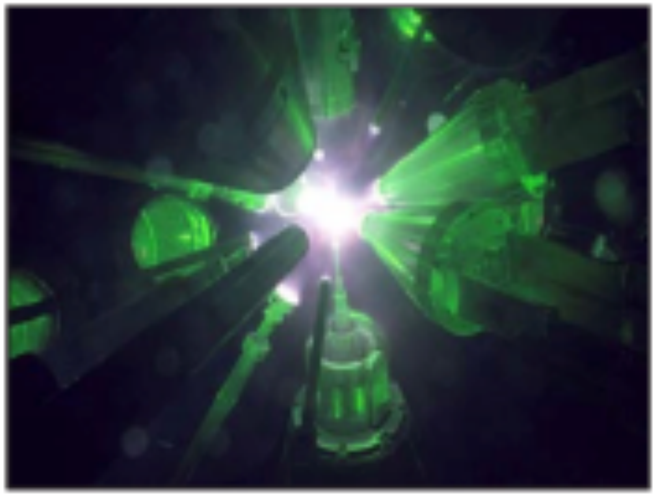
Sandia National Laboratories

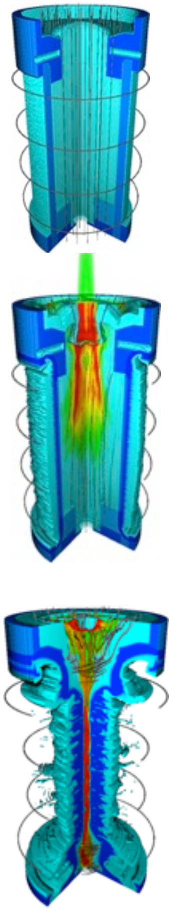
- 80-TW, 20 MJ Z pulsed power facility
- 1-TW, multi-kJ Z-Backlighter laser
- 30 T B-field system (900 kJ stored energy)



Laboratory for Laser Energetics

- 60-beam, 30-TW, 30 kJ, OMEGA laser facility
- 4-beam, TW to PW, multi-kJ OMEGA-EP laser
- 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)

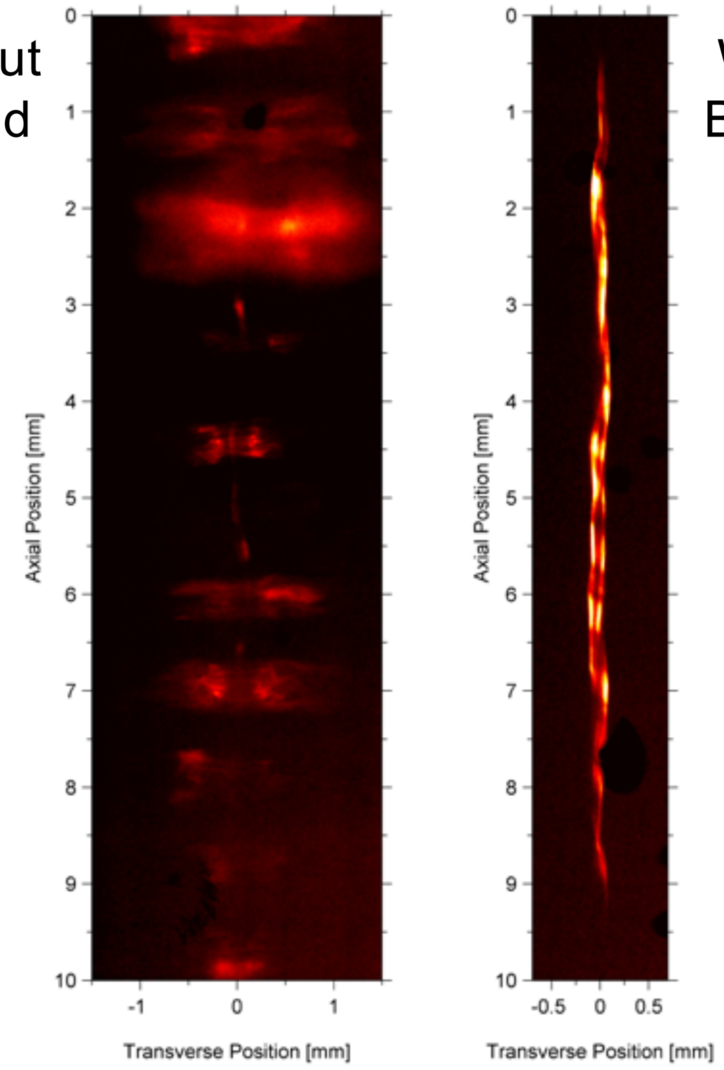
Laser Heating
- E_{laser} ~ 2-6 kJ @.53µm
- T_{DT} ~ 0.2 KeV
- $\omega\tau$ ~ 2-5
- Research on Z, ZBL, Omega, Omega-EP

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

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 Pre-heat	$0.3x10^{10}$	$1x10^{10}$
Pre-heat	$4x10^{10}$	$300x10^{10}$

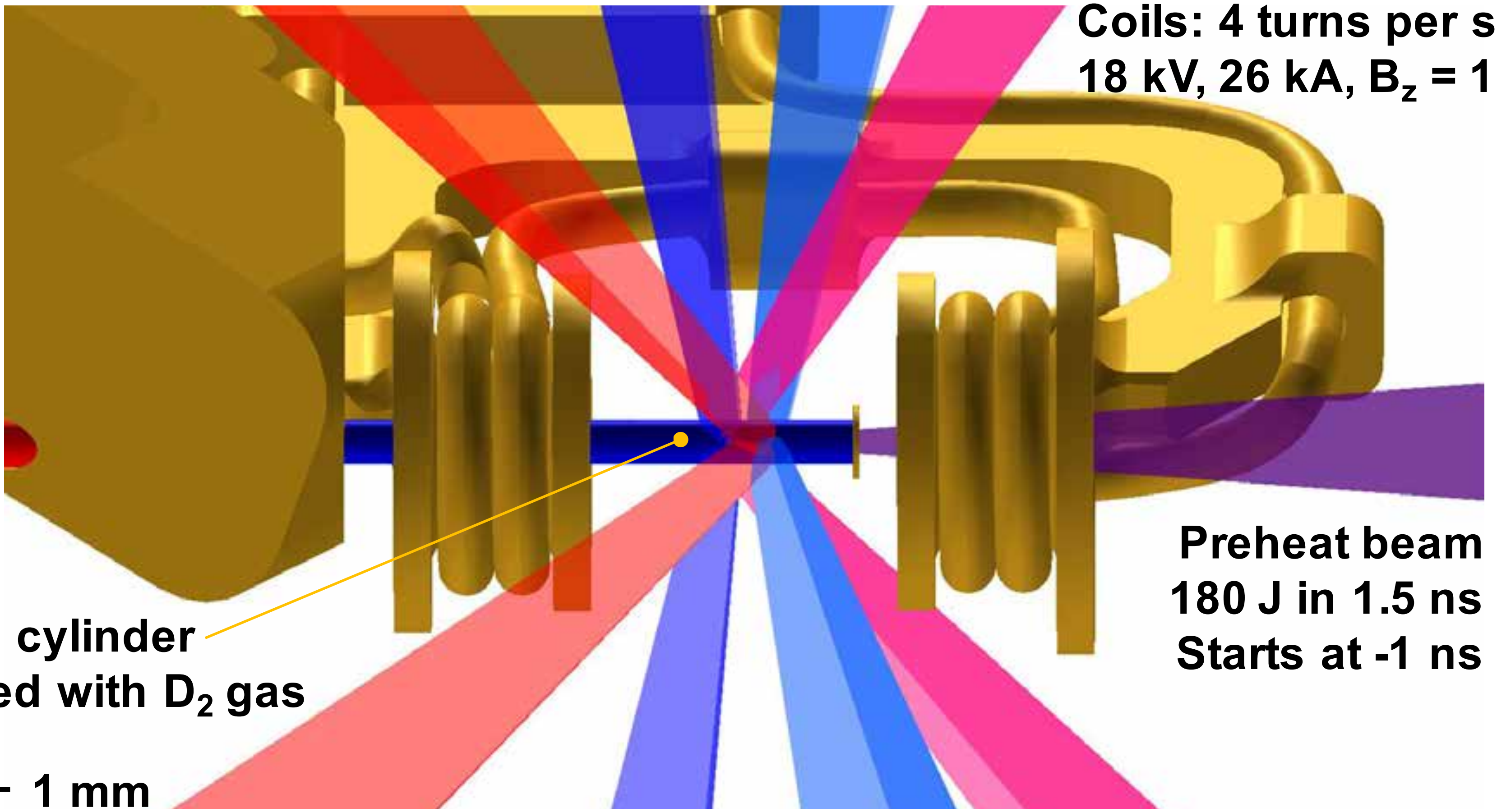
DD neutron yield



Without B-field

With B-field

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



40 compression beams
14 kJ in 1.5 ns

Coils: 4 turns per side
18 kV, 26 kA, B_z = 10 T

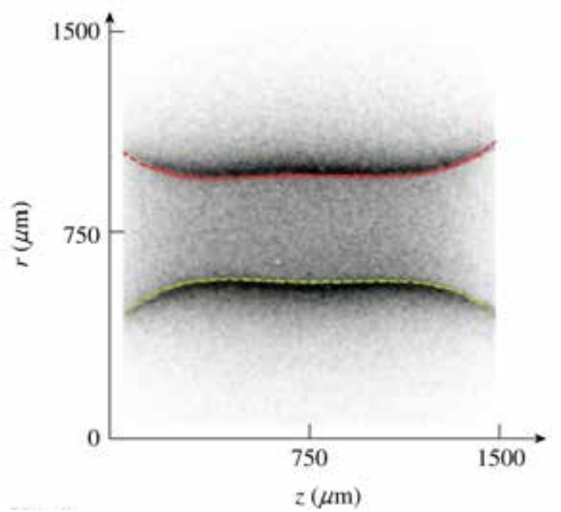
Preheat beam
180 J in 1.5 ns
Starts at -1 ns

CH cylinder
filled with D_2 gas

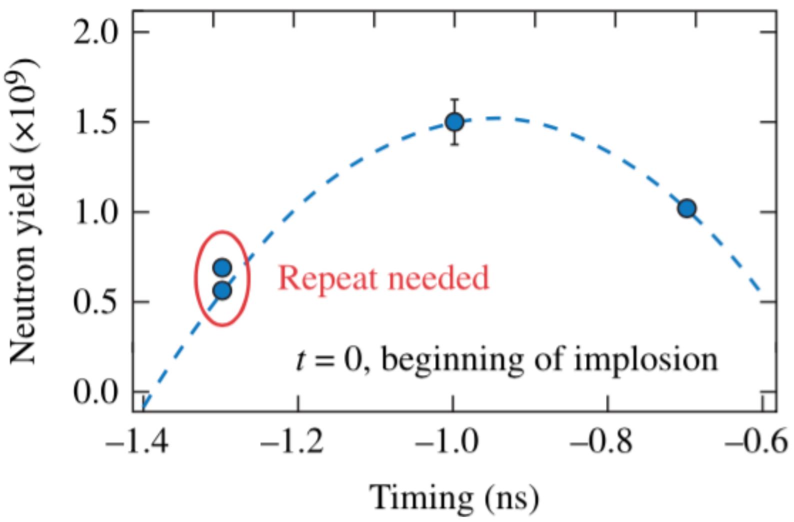
1 mm

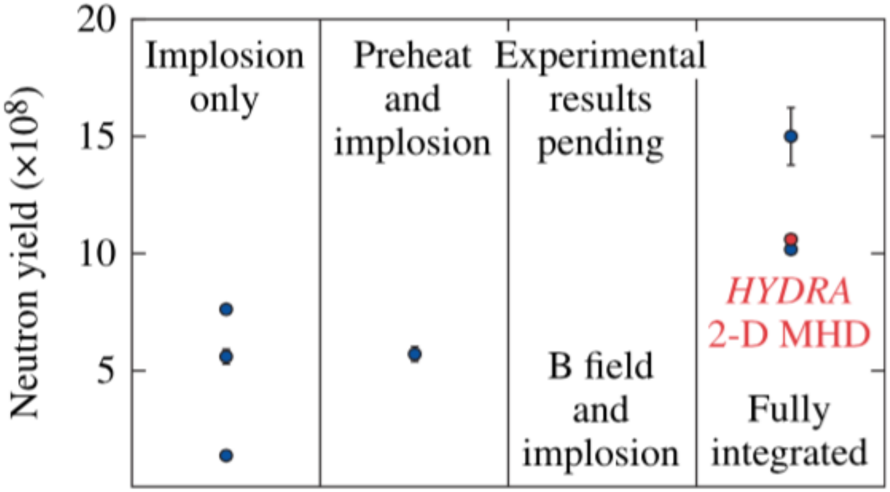
Rochester's laser-driven MagLIF uses targets 10x smaller than Z to study scaling and basic physics with a high shot rate and good diagnostic access

Optimized beam configuration to drive cylindrical compression



Optimized preheating timing





Integrated experiments appear to show effect of preheating & magnetization

J.R. Davies *et. al.*, PoP (2017)
D.H. Barnak *et. al.* ,PoP (2017)

Last year we reported on progress using a new laser protocol based on phase plates and lower laser intensity

Spot profile

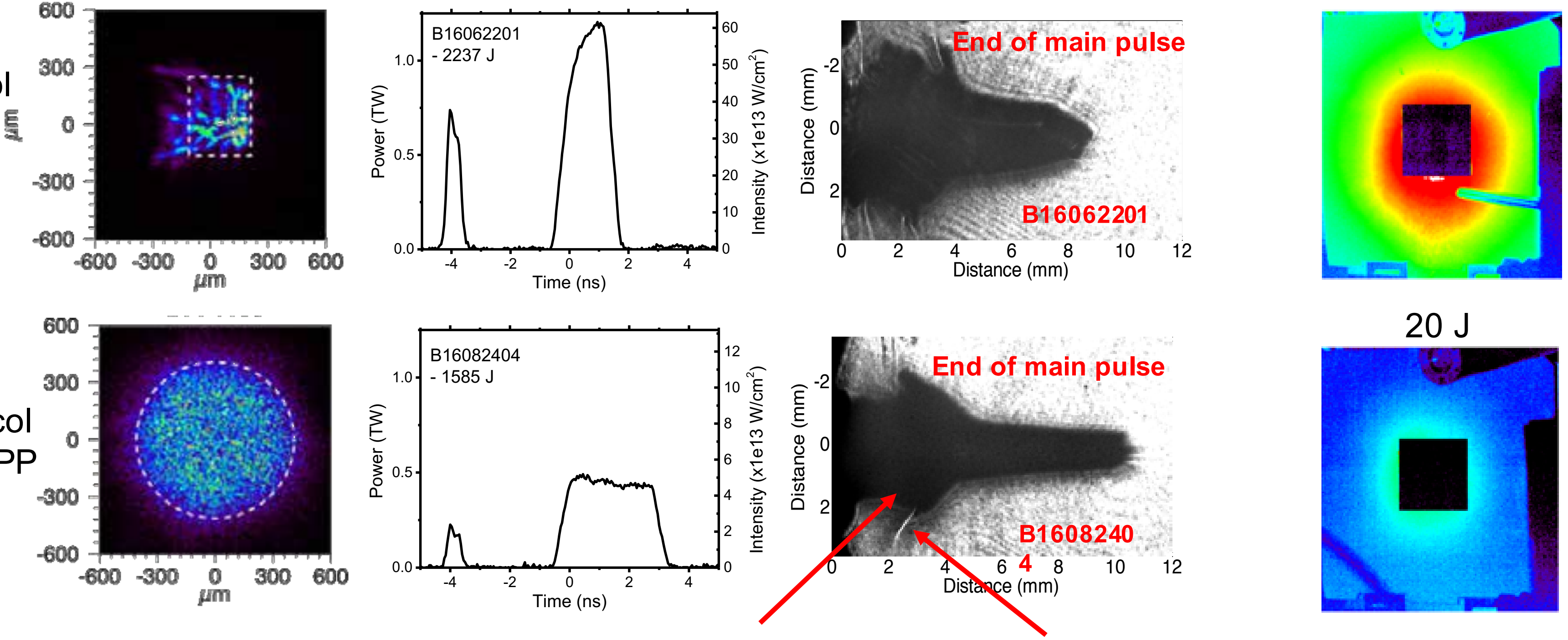
Laser power

Shadowgraphy imaging

SBS backscatter

Old protocol
No DPP

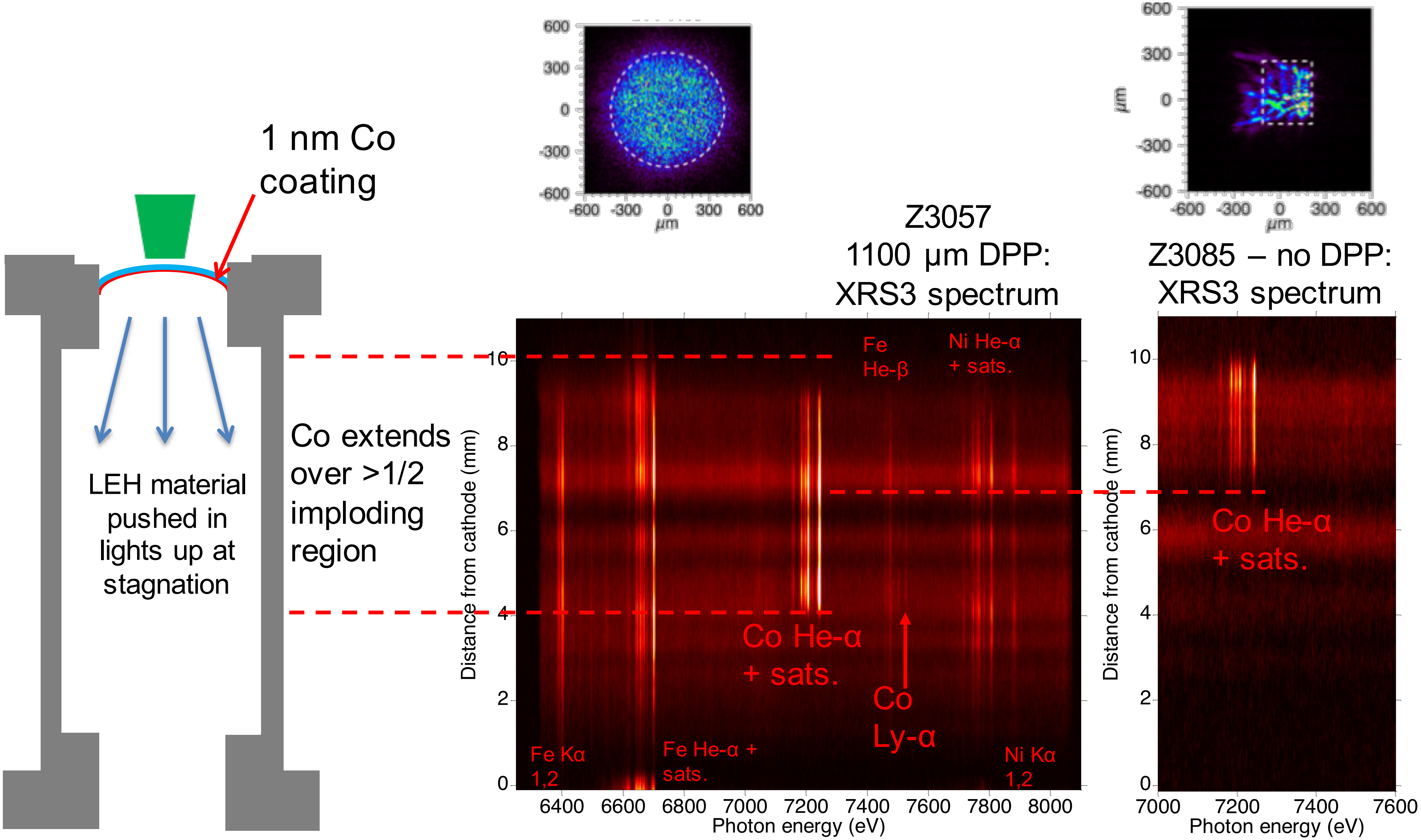
New protocol
1100 μm DPP



Bulbous features could be beam spray/filamentation or SRS sidescatter or ???

Filament

We have clarified that while more energy is coupled, this protocol also injects window material deeper into the fuel



1 nm Co coating

LEH material pushed in lights up at stagnation

Co extends over >1/2 imploding region

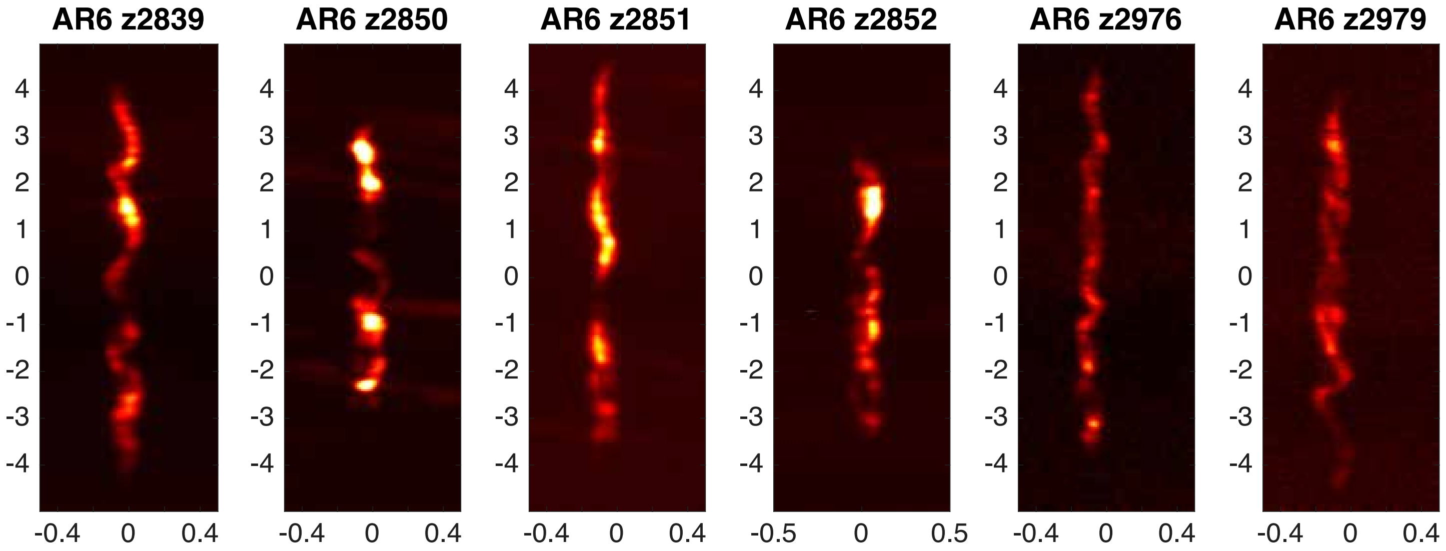
Z3057
1100 μm DPP:
XRS3 spectrum

Z3085 – no DPP:
XRS3 spectrum

We have also shown that while the new protocol has produced higher yields, its reproducibility is a concern

	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

Other MagLIF configurations can also have variability

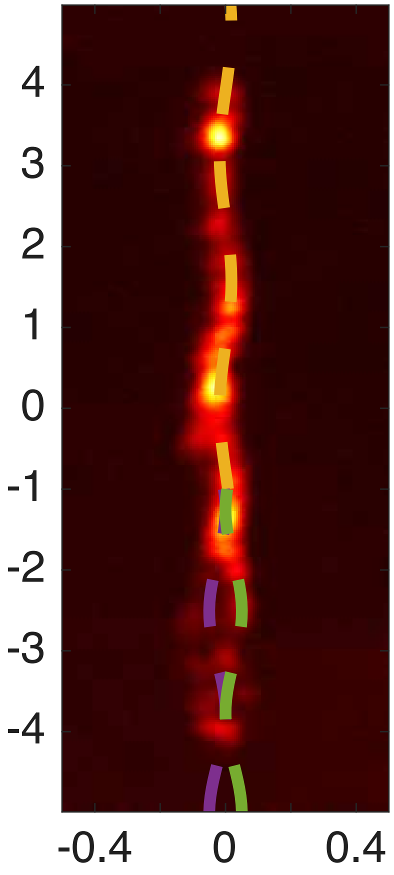


- Stagnations structures vary between experiments
  - Helices, bright spots
- Yield can vary an order of magnitude
- The source of the variations is poorly understood
  - Laser heating variations (non-uniform mix, dust?)
  - Implosion variations (too high convergence, 3D effects)

Data indicate a trend in wavelength and amplitude with aspect ratio (liner thickness); consistent with feedthrough

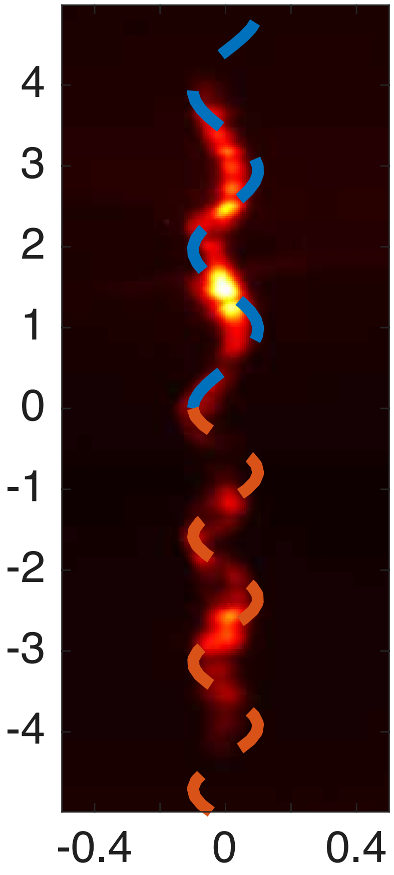
Aspect Ratio 4.5

AR4.5 z3017



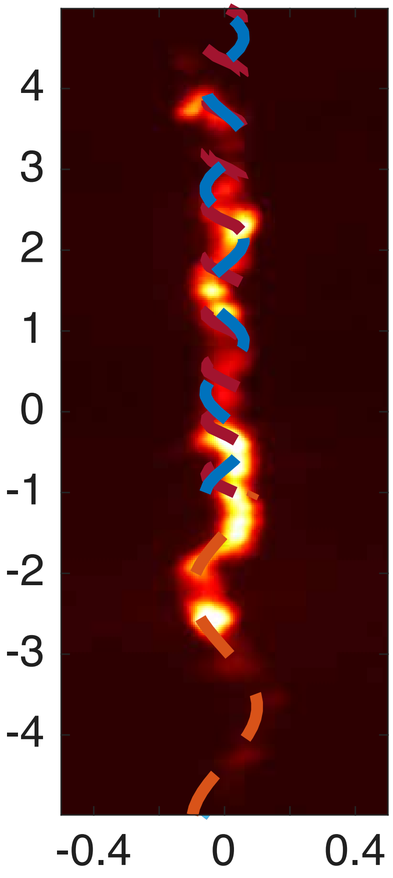
Aspect Ratio 6

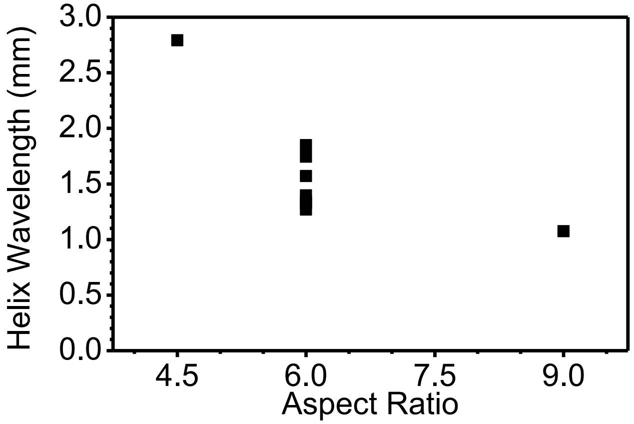
AR6 z2839



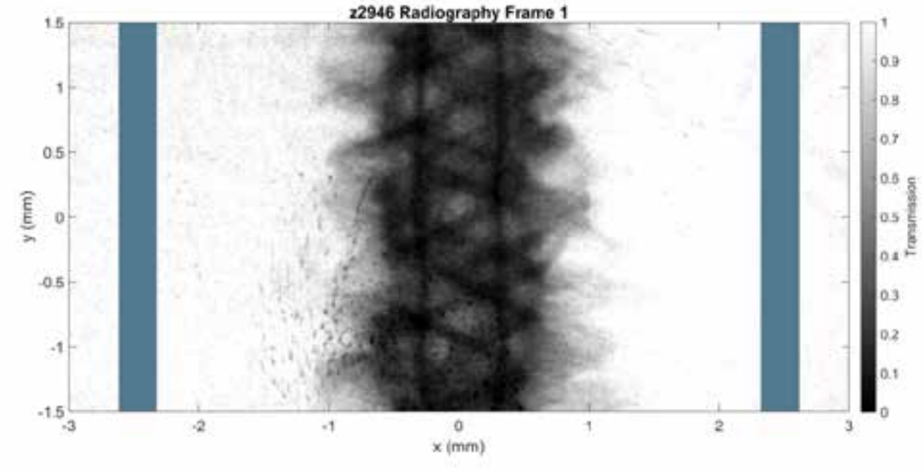
Aspect Ratio 9

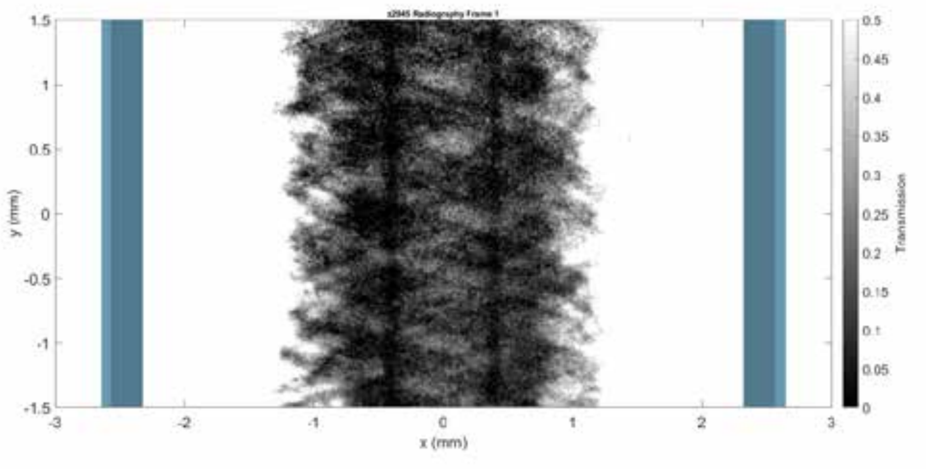
AR9 z3018

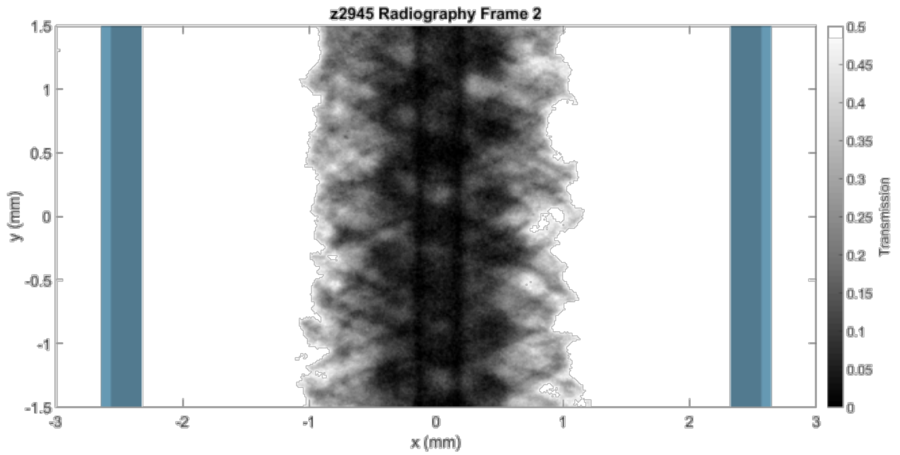




Applying a dielectric coating to the outside of liners appears to enhance implosion stability and affects the in-flight mass distribution

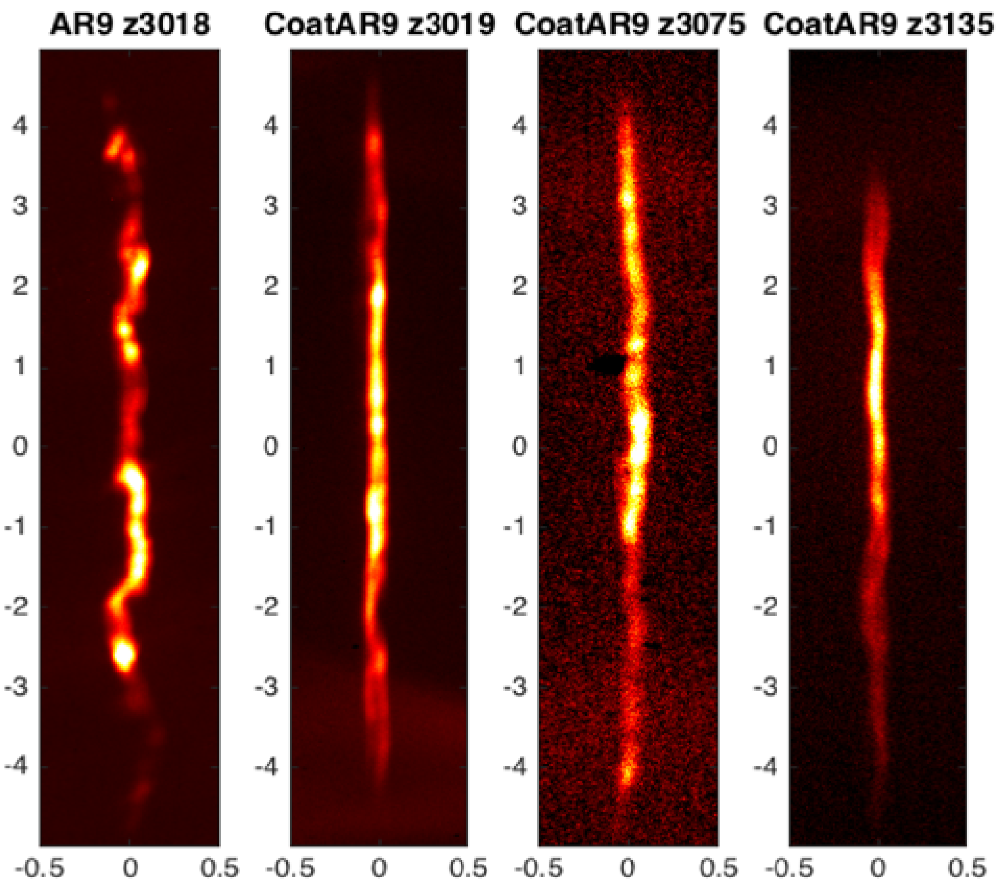


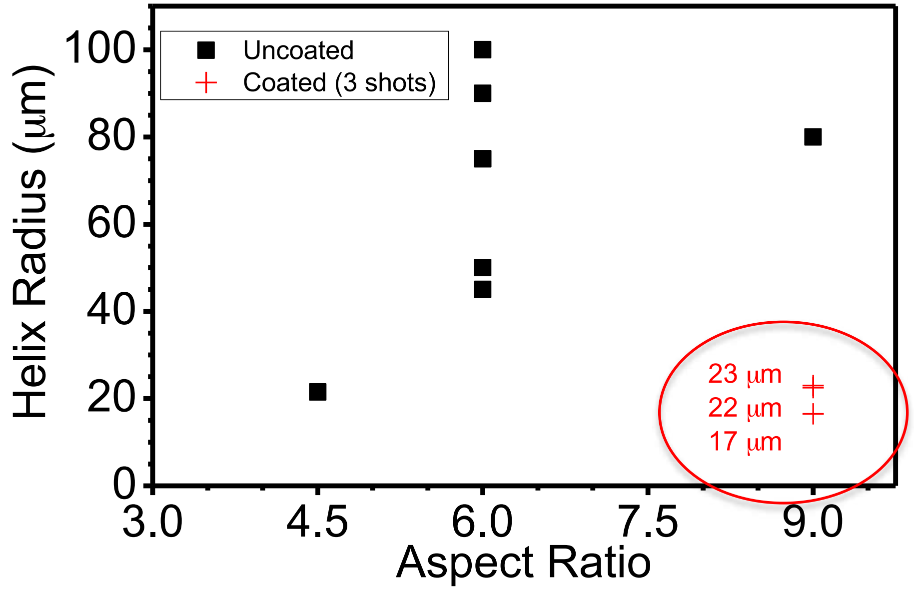


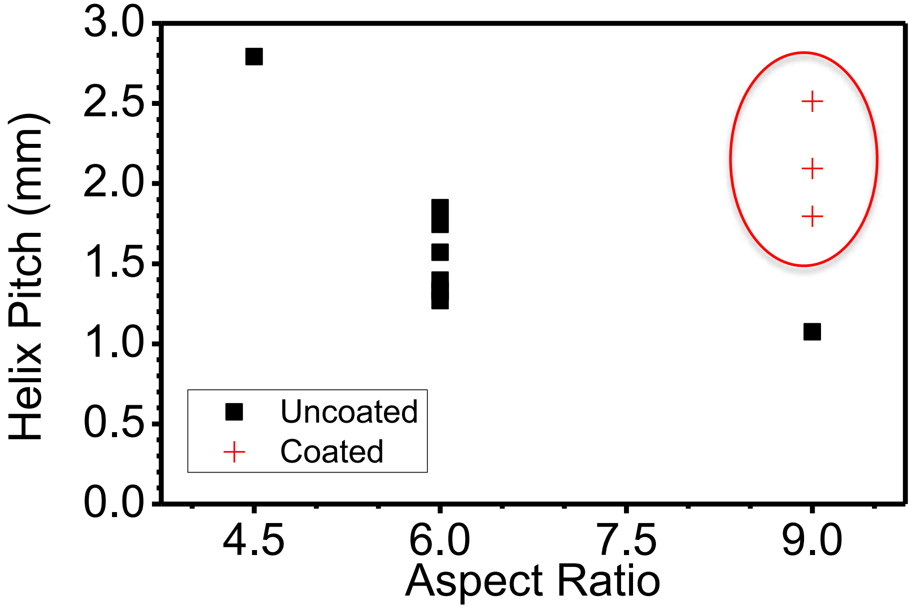


K.J. Peterson *et al.*, PoP (2012)
K.J. Peterson *et al.*, PoP (2013)
T.J. Awe *et al.*, PRL (2013)
K.J. Peterson *et al.*, PRL (2014)
T.J. Awe *et al.*, PoP (2014)
T.J. Awe *et al.*, PRL (2016)

Stagnation data appears to confirm the impact of dielectric coatings improving the stagnation uniformity and structure

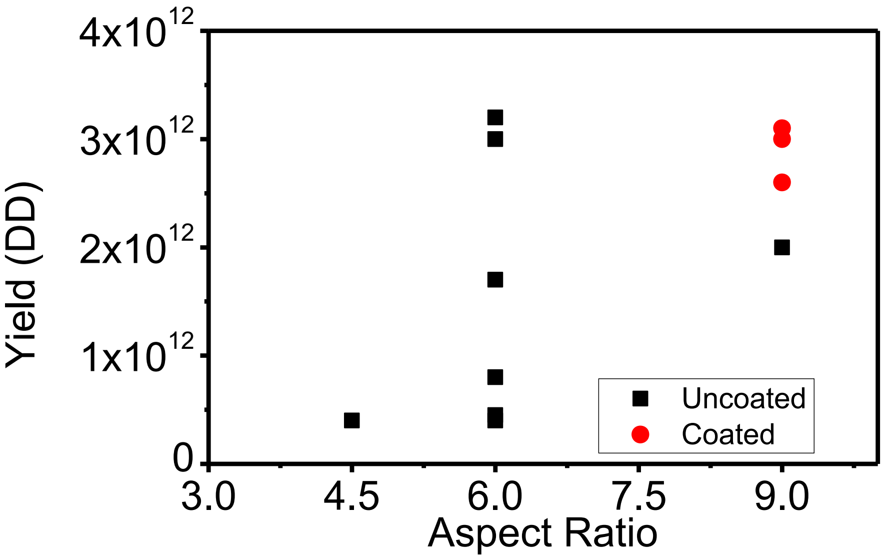


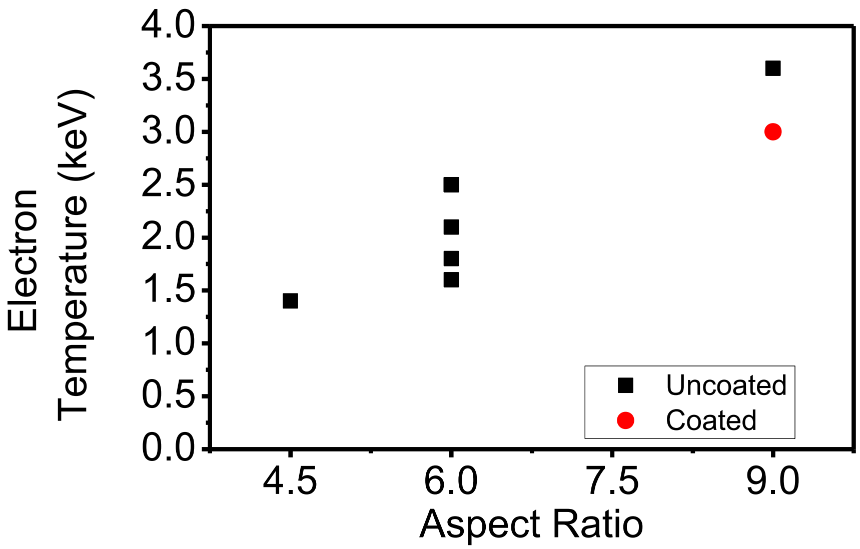




While coatings don’t appear to improve our average stagnation conditions, they do appear to improve our reproducibility

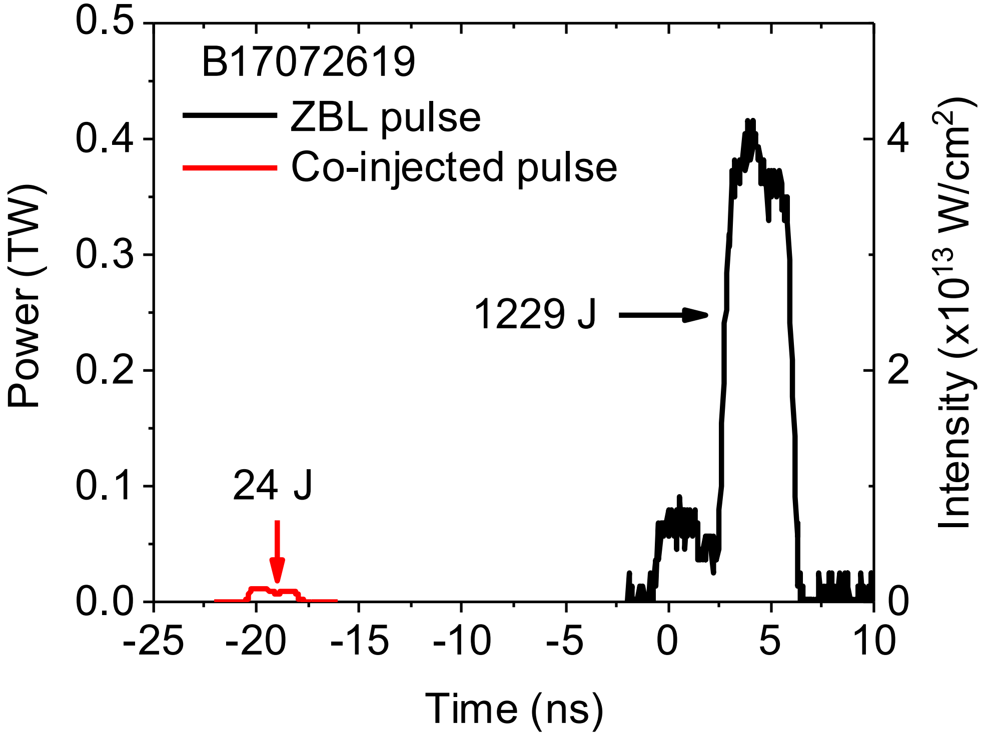
	3019	3075	3135	Mean	Variation
DD	3.0e12	2.6e12	3.1e12	2.9e12	9%
DT	4.8e10	4.1e10	5.5e10	4.8e10	15%
DD/DT	62.5	63.4	56.4	60.8	6%
T_{ion} (nTOF)	2.5 keV	2.2 keV	2.2 keV	2.3 keV	8%
T_e (continuum)	3.0 keV	3.3 keV	No data	3.15	7%



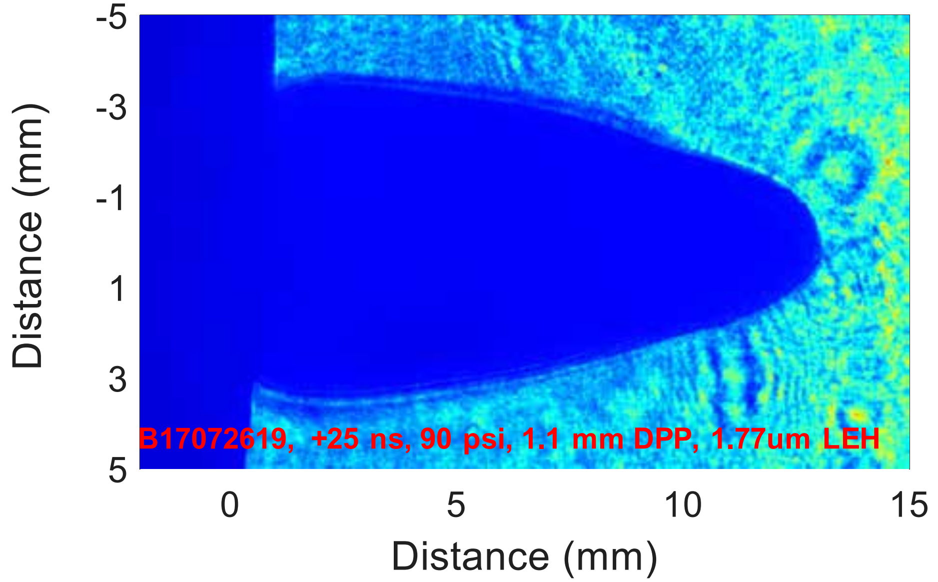


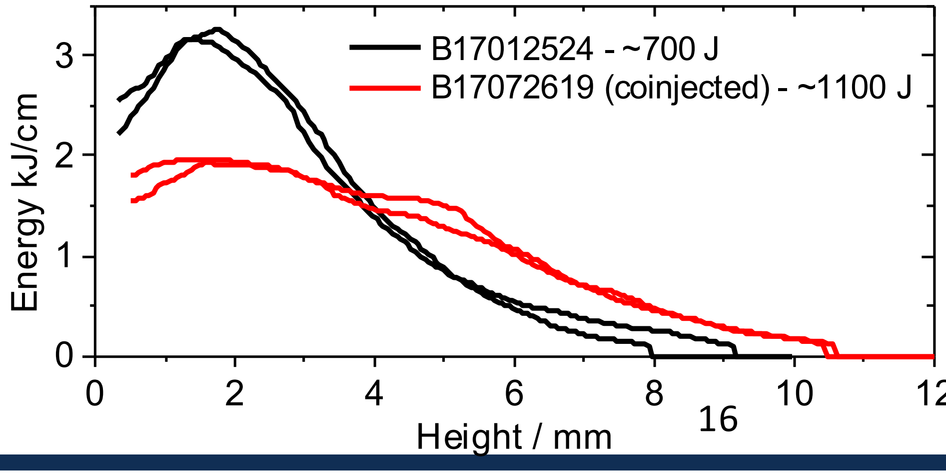
After ~1.5 years of work, we now have a new laser pulse shape that more gently disassembles the window and allows the density to drop for ~20 ns

Independently timed prepulse



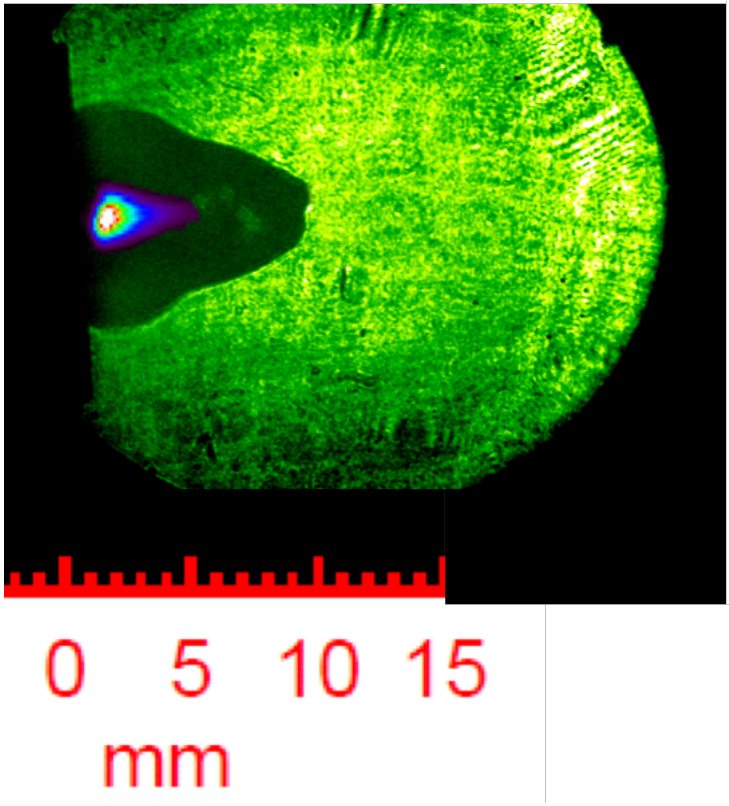
More uniform and deeper penetration



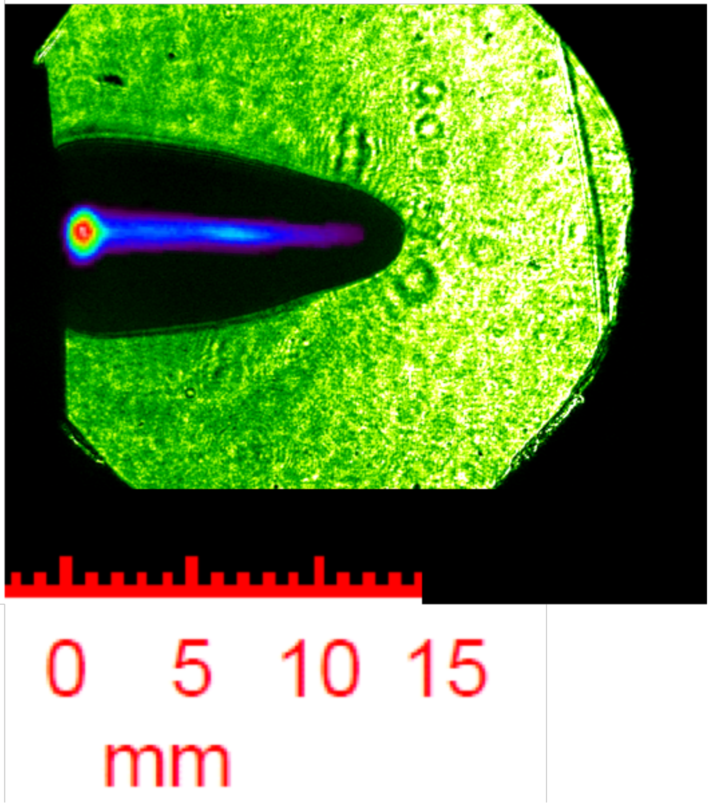


Overlay of x-ray and and optical blast wave images illustrates the difference in the laser configurations

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



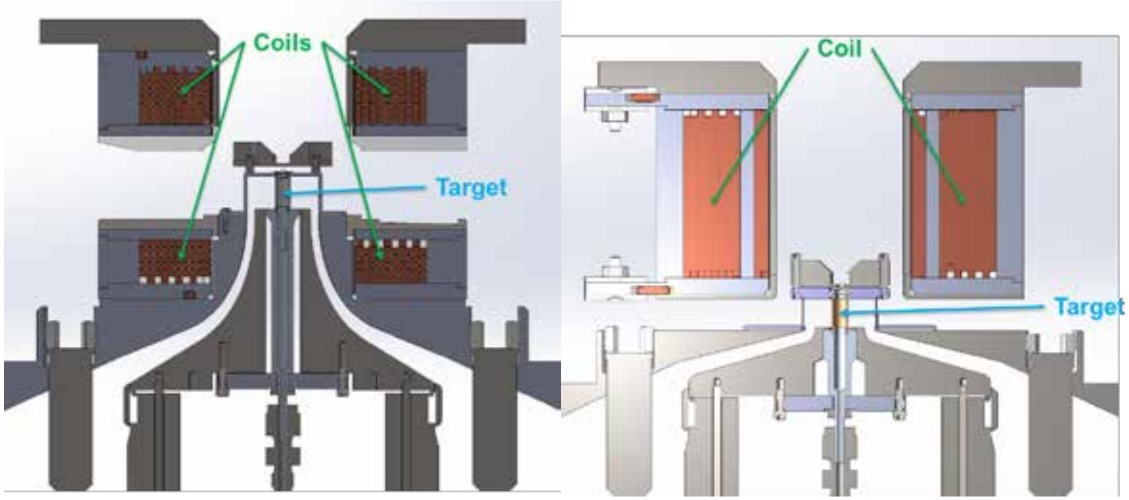
1100µm Phase Plate
90 psi **D_2**
“Foot”: 190 J
Main pulse 1230 J
Co-Injection 24 J



(D_2 capability recently added)

The MagLIF effort has a lot of moving parts proceeding in parallel, which are being integrated in 2018-2020

- We are advancing new hardware platforms on Z capable of delivering higher current to the targets to facilitate scaling studies
- These hardware platforms will allow higher magnetic fields, which are generally predicted to improve performance at our present scales



17 MA peak load current in standard geometry

- Our laser capabilities have been improved, which has already resulted in dramatically improved laser heating. Work will continue on these platforms with an emphasis on heating higher-density fills.
- We have made progress in improving the stability of our stagnation plasmas, which has so far produced more reproducible results.
- Implementing higher magnetic fields and higher preheat should *reduce* the convergence ratio of our implosions, which should further improve stability.
- Upcoming Omega MagLIF tests will look at the impact of increasing magnetization