SAND2021-11489PE

Overview of MagLIF program for TNB working group meeting

Adam Harvey-Thompson

TNB working group meeting

09/14/2021

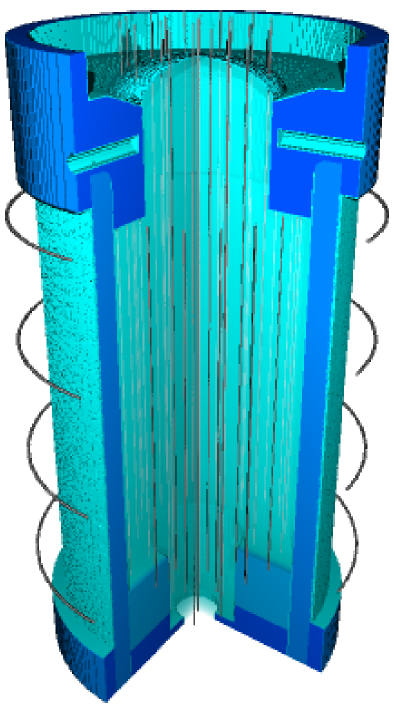
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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.

MagLIF relies on three components to produce fusion conditions at stagnation

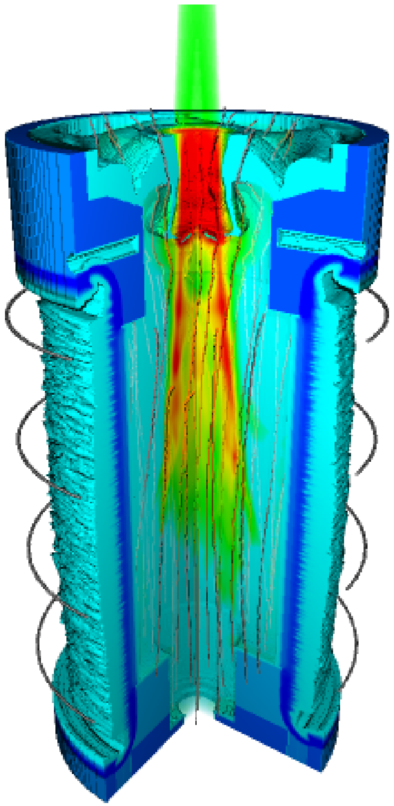
Magnetization

- Suppress radial thermal conduction losses
- Enable slow implosion with thick target walls



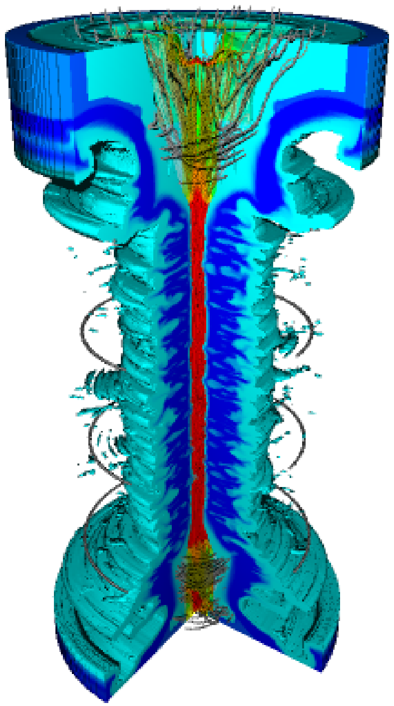
Preheat

- Increase fuel adiabat to limit required convergence



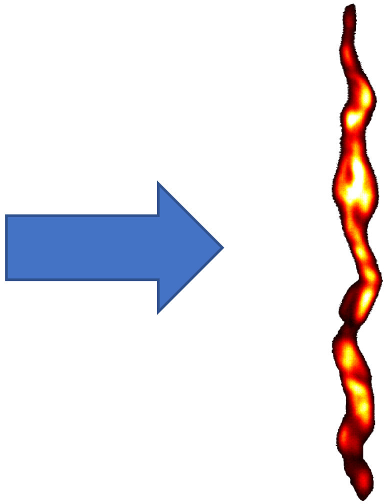
Implosion

- PdV work to heat fuel
- Amplify B-field through flux compression



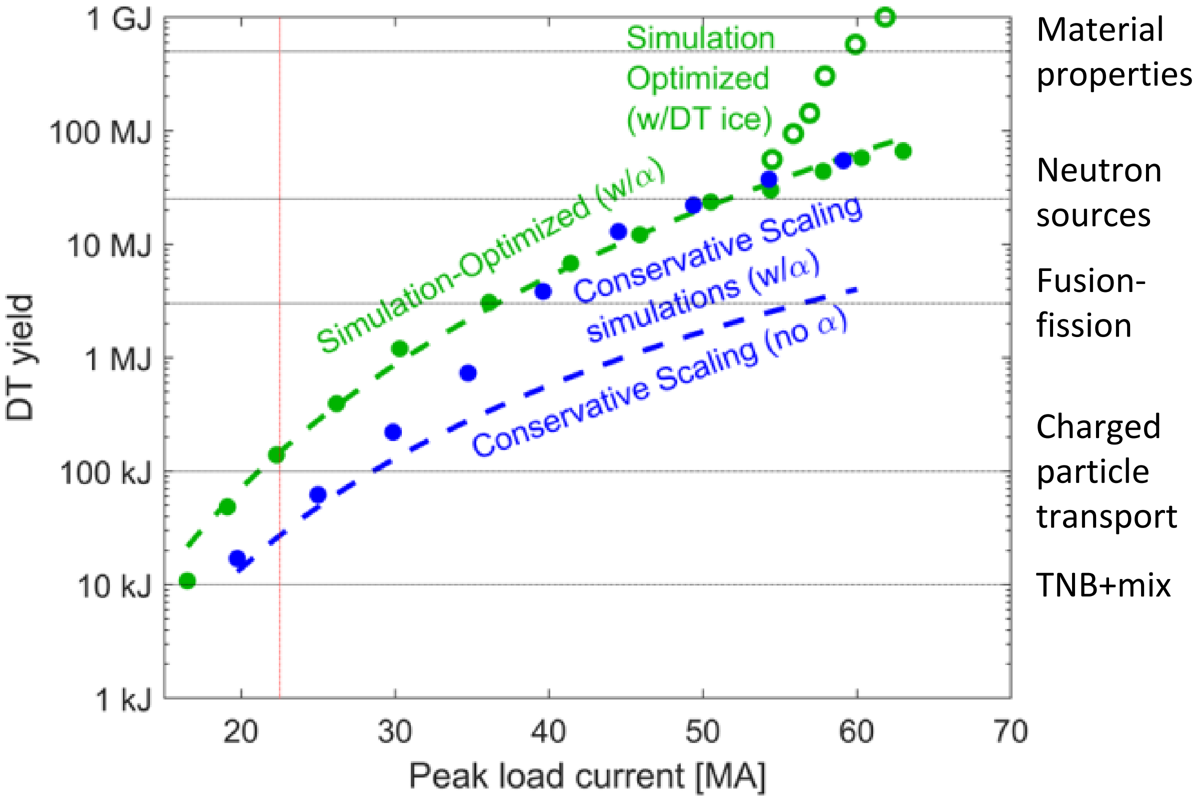
Stagnation

- Several keV temperature
- Several kT B-field to trap charged fusion products



Our MagLIF effort aims to increase confidence in its ability to scale to multi-MJ yields

- Simulations and analytic theory predict multi-MJ yields on possible future generators
- We are pursuing a multi-pronged strategy to pair down scaling risks
  - Explore scaling predictions over the currently-accessible parameter range
  - Increase our capabilities on Z to generate high performance anchor points
  - Explore aspects of the physics at scale where possible
  - Focused physics studies (mix etc.)

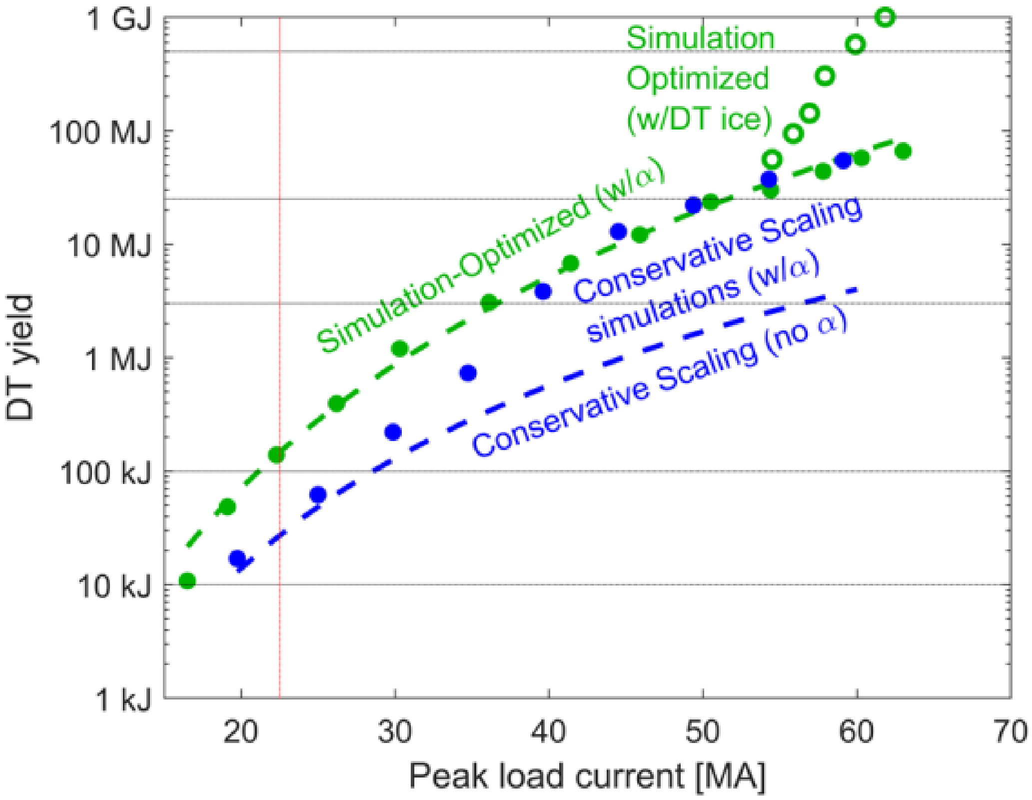


S.A. Slutz, et al., Phys. Plasmas **23**, 022702 (2016).
S.A. Slutz, et al., Phys. Plasmas **25**, 112706 (2018).
P.F. Schmit and D.E. Ruiz, Phys. Plasmas, **27**, 062707 (2020).
D.E. Ruiz, in preparation (2021).

Our MagLIF effort aims to increase confidence in its ability to scale to multi-MJ yields

- Simulations and analytic theory predict multi-MJ yields on possible future generators
- We are pursuing a multi-pronged strategy to pair down scaling risks

Explore scaling predictions over the currently-accessible parameter range Increase our capabilities on Z to generate high performance anchor points **Sandia**
Explore aspects of the physics at scale where possible **NIF**
Focused physics studies (mix etc.) **Sandia/NIF/LLE**



Material properties

Neutron sources

Fusion-fission

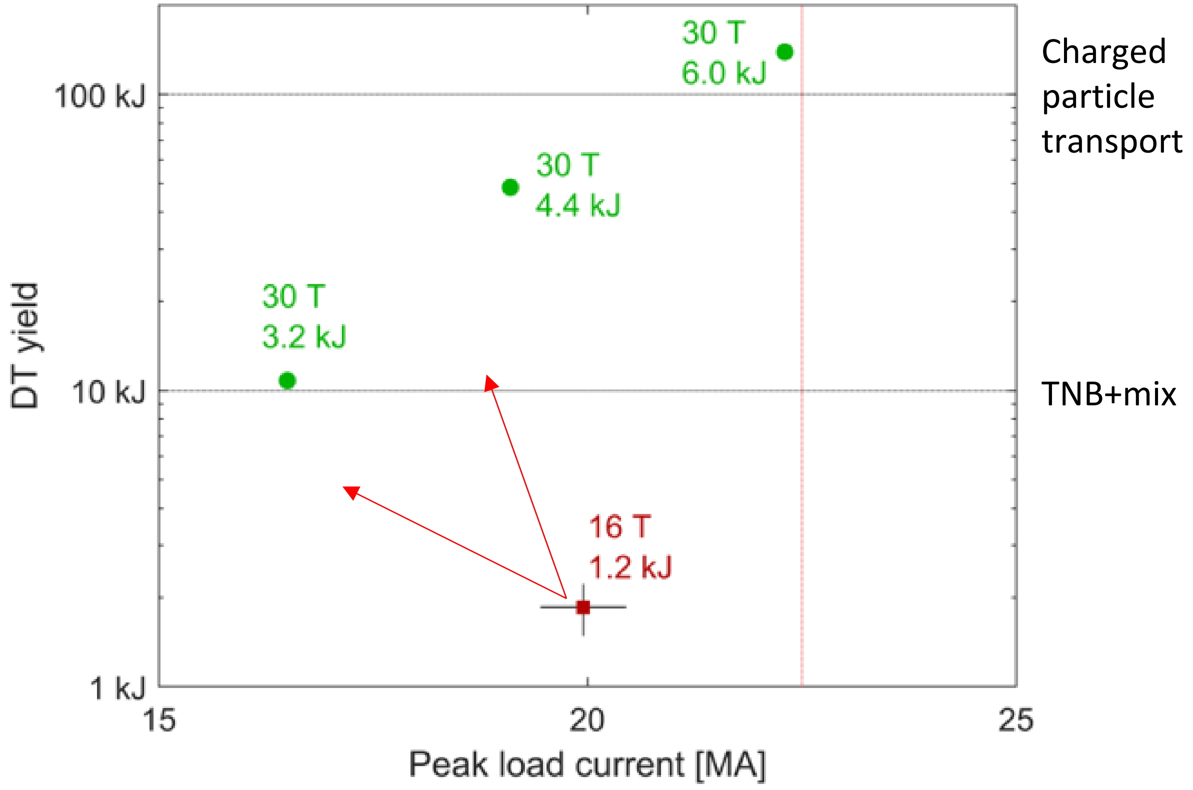
Charged particle transport

TNB+mix

S.A. Slutz, et al., Phys. Plasmas **23**, 022702 (2016).
S.A. Slutz, et al., Phys. Plasmas **25**, 112706 (2018).
P.F. Schmit and D.E. Ruiz, Phys. Plasmas, **27**, 062707 (2020).
D.E. Ruiz, in preparation (2021).

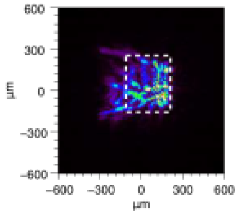
The past few years have focused on increasing our MagLIF input parameters on Z

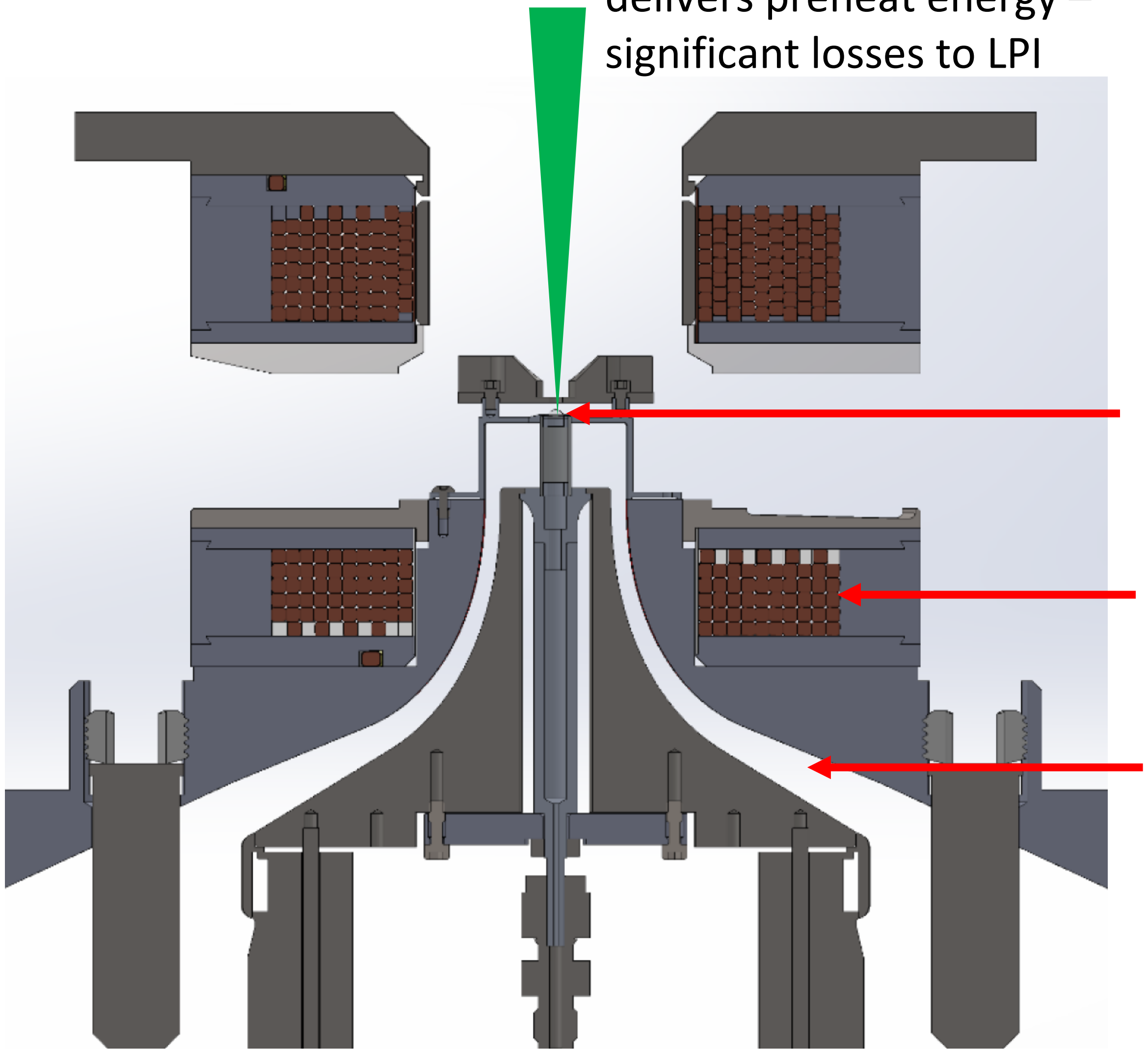
- Developing high yield anchor points and exploring scaling requires improving inputs
- We are increasing all three input parameters – current, B fields, preheat energy
  - Reduce current losses with lower inductances and more robust feeds
  - Increase B fields with advanced coil designs
  - Improve preheat efficiency by reducing losses to LEH foil and LPI through cryogenic cooling
- Developing and integrating each capability and integrating has been challenging!



We have changed almost every aspect of the MagLIF experimental setup

Un-smoothed Z-beamlet laser delivers preheat energy – significant losses to LPI





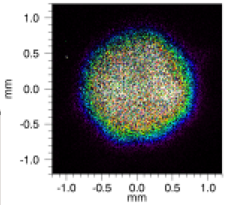
1.8-3.5 μm LEH foil contains the gas

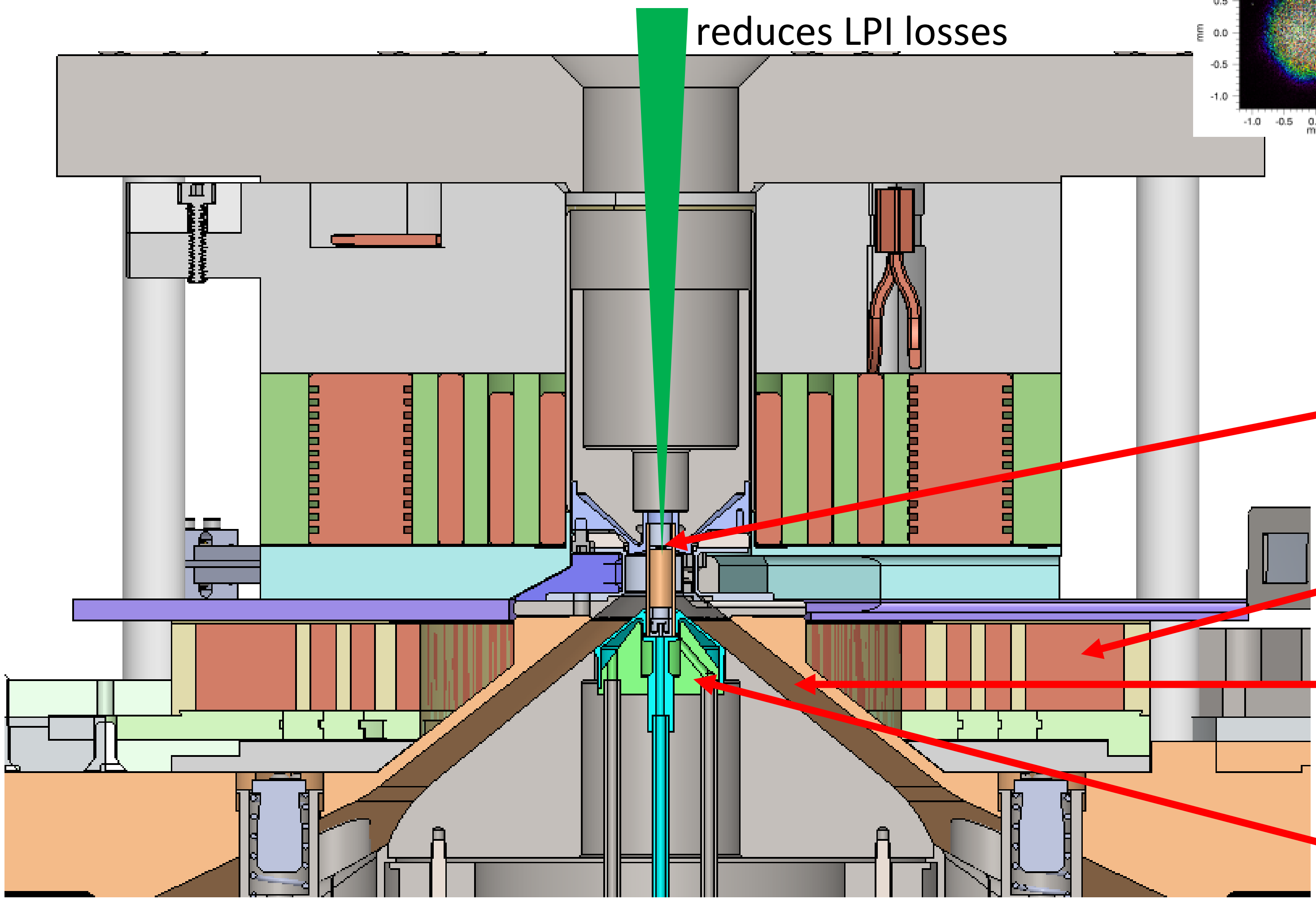
Magnetic field coils limited to 10 T
but with good diagnostic access

Sweeping feed provides room for coils
Losses limit current delivery to 17 MA

We have changed almost every aspect of the MagLIF experimental setup

Z-beamlet with 1.5 mm DPP reduces LPI losses





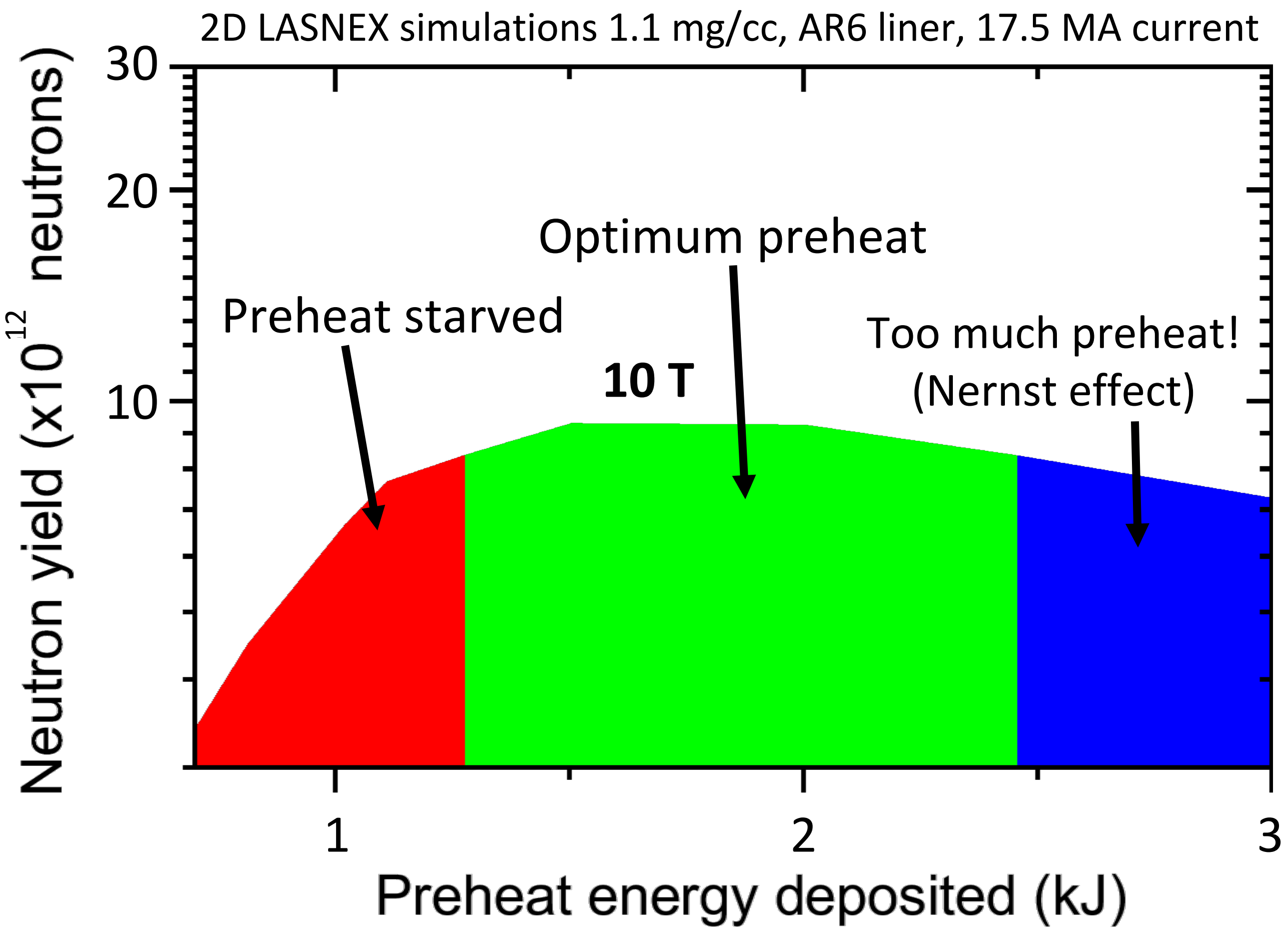
0.5 µm LEH foil contains the gas

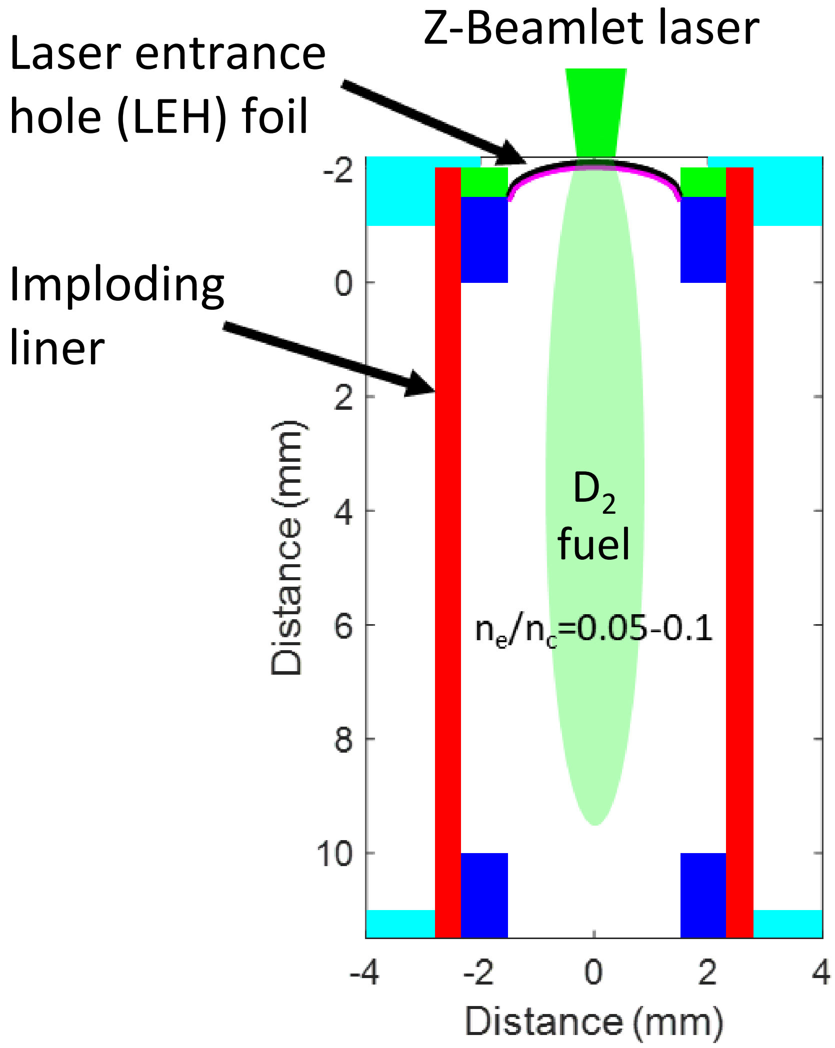
Advance magnetic field coil designs enable >20 T with a lower profile

Conical feed reduces losses enabling ~20 MA

Cryostats above and below the liner control the temperature at 70 K

MagLIF performance is sensitive to the preheat energy coupled

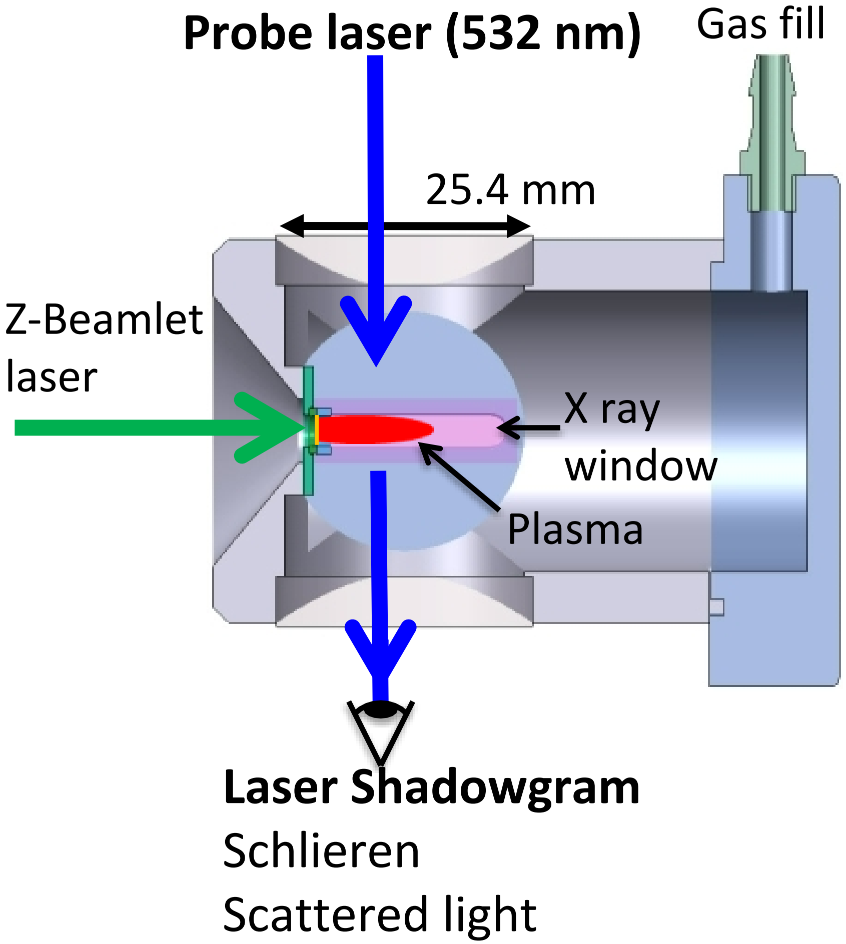




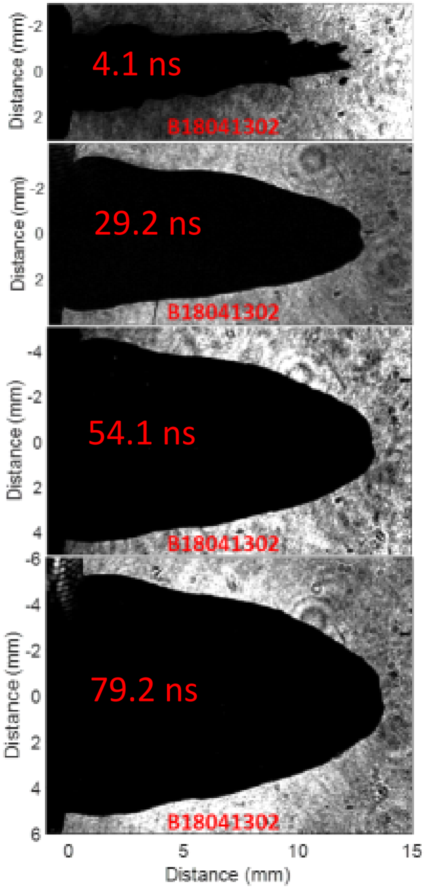
- There is an optimum preheat energy – too much energy impacts B field by Nernst

S. Slutz et al., Physics of Plasmas **25**, 112706 (2018)

Preheat configurations are designed in offline "Pecos" experiments

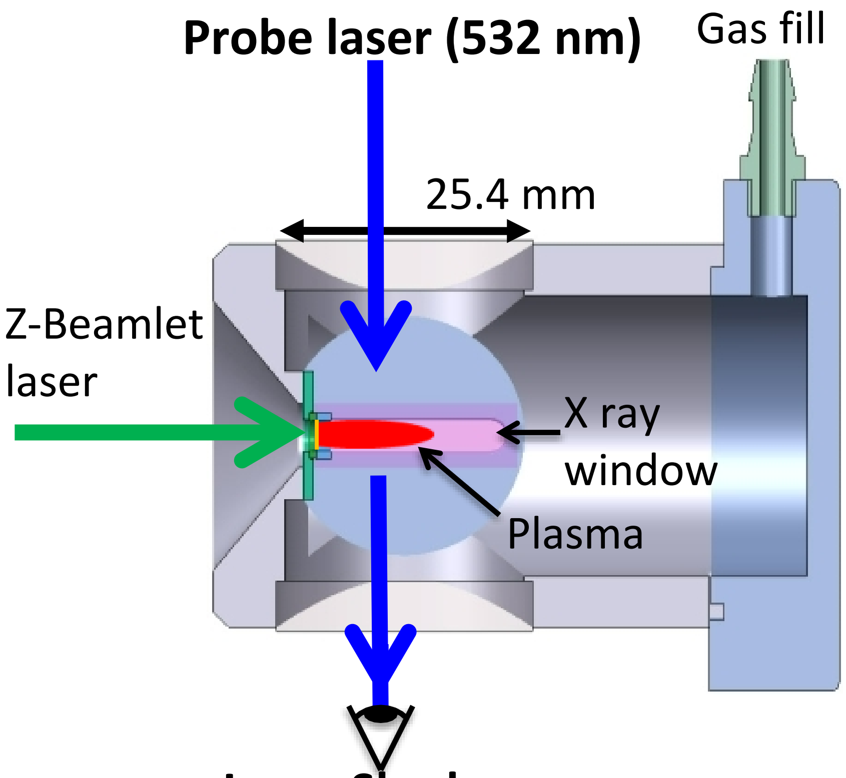


Blast wave expansion – energy deposited



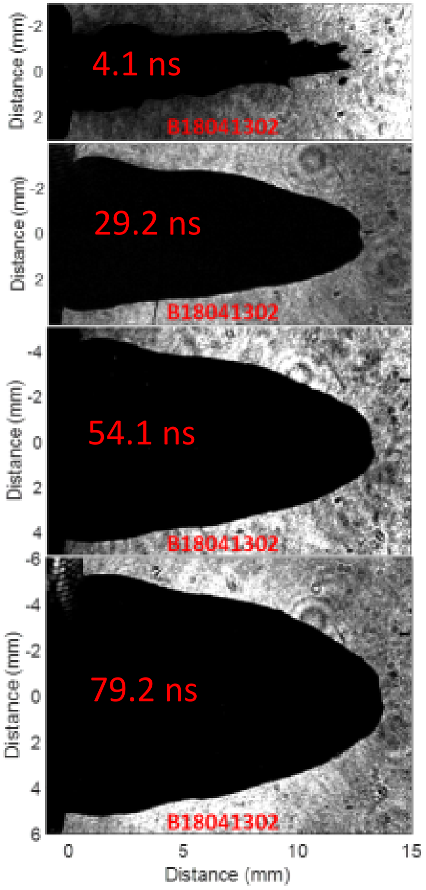
M. Geissel et al., Physics of Plasmas **25**, 022706 (2018)
A. Harvey-Thompson et al., Physics of Plasmas **26**, 032707 (2019)

Preheat configurations are designed in offline "Pecos" experiments

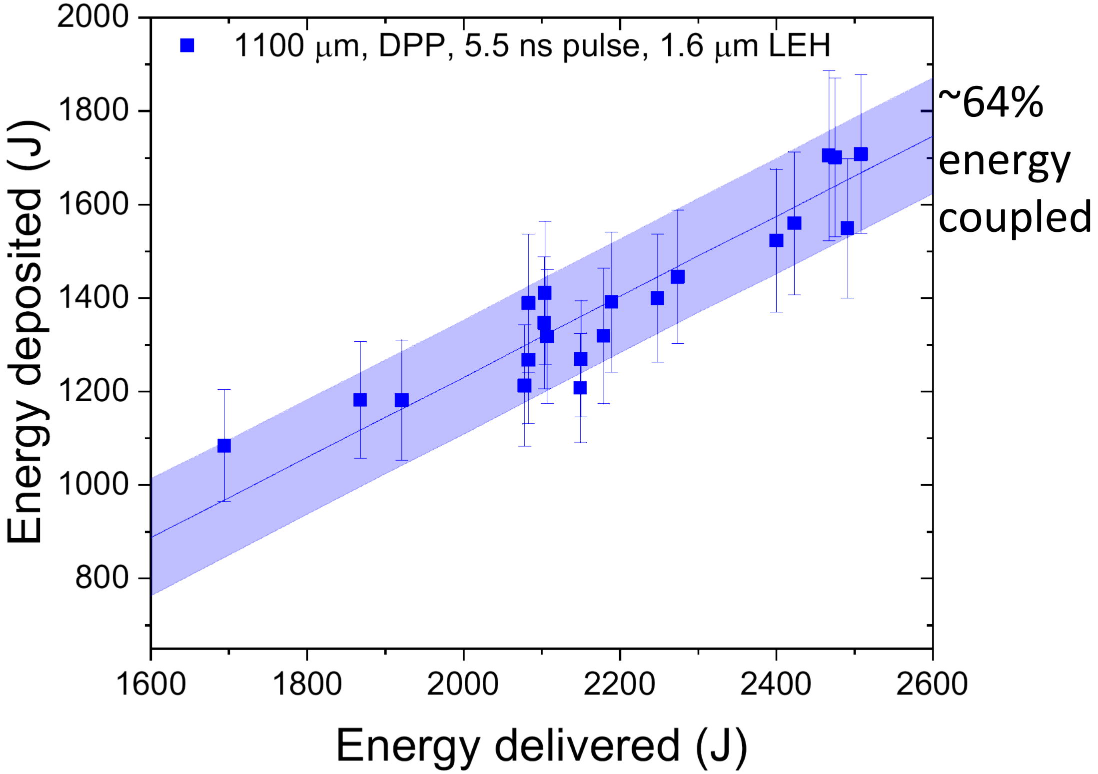


Laser Shadowgram
Schlieren
Scattered light

Blast wave expansion – energy deposited

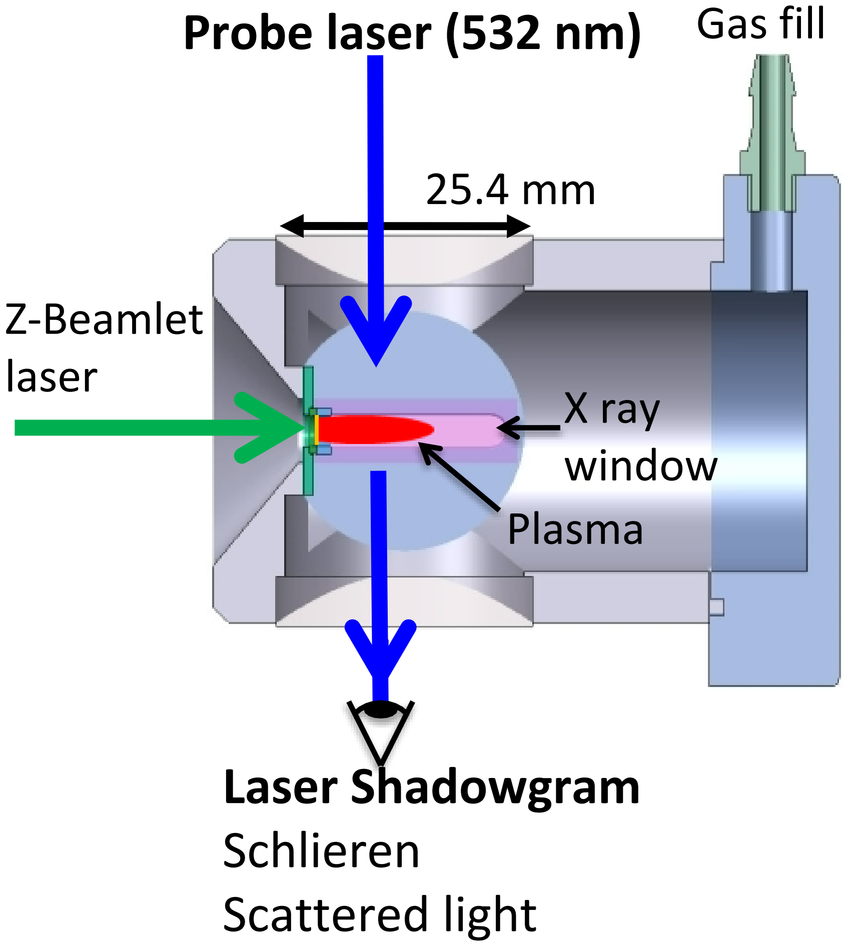


Best performing "warm" preheat configuration

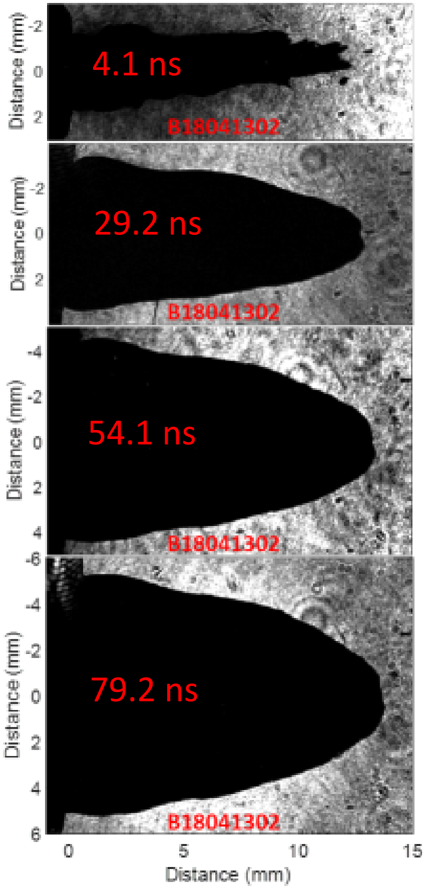


M. Geissel et al., Physics of Plasmas **25**, 022706 (2018)
A. Harvey-Thompson et al., Physics of Plasmas **26**, 032707 (2019)

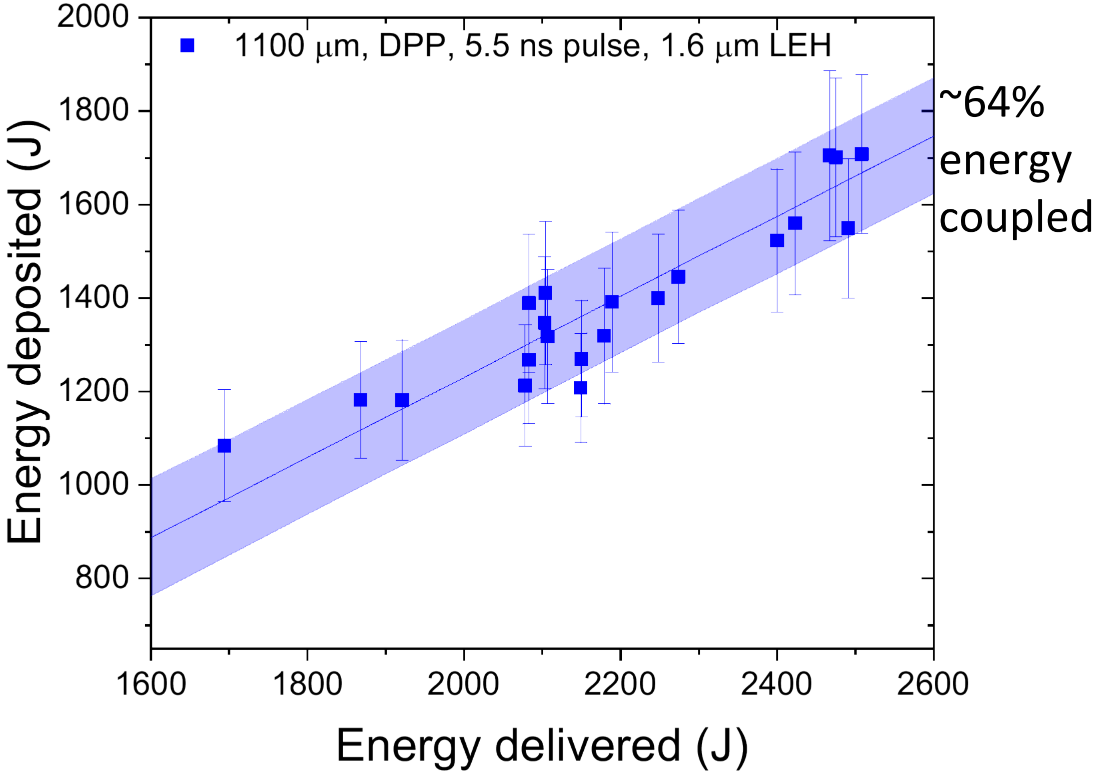
Preheat configurations are designed in offline "Pecos" experiments



Blast wave expansion – energy deposited



Best performing "warm" preheat configuration

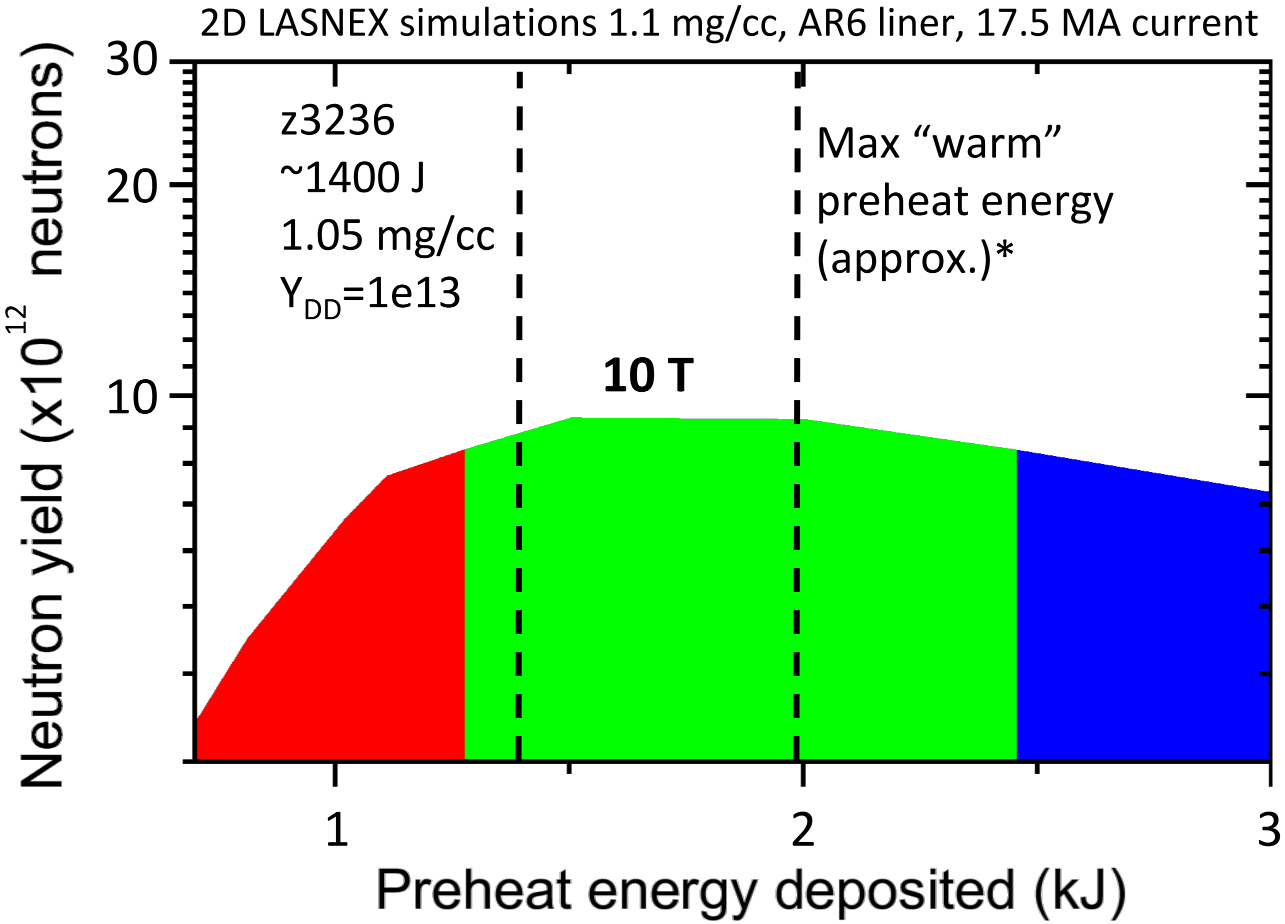


Primary sources of losses:

- Energy invested in heating LEH foil
- LPI backscatter losses from LEH foil and gas
- Laser overshooting the imploding region

M. Geissel et al., Physics of Plasmas **25**, 022706 (2018)
A. Harvey-Thompson et al., Physics of Plasmas **26**, 032707 (2019)

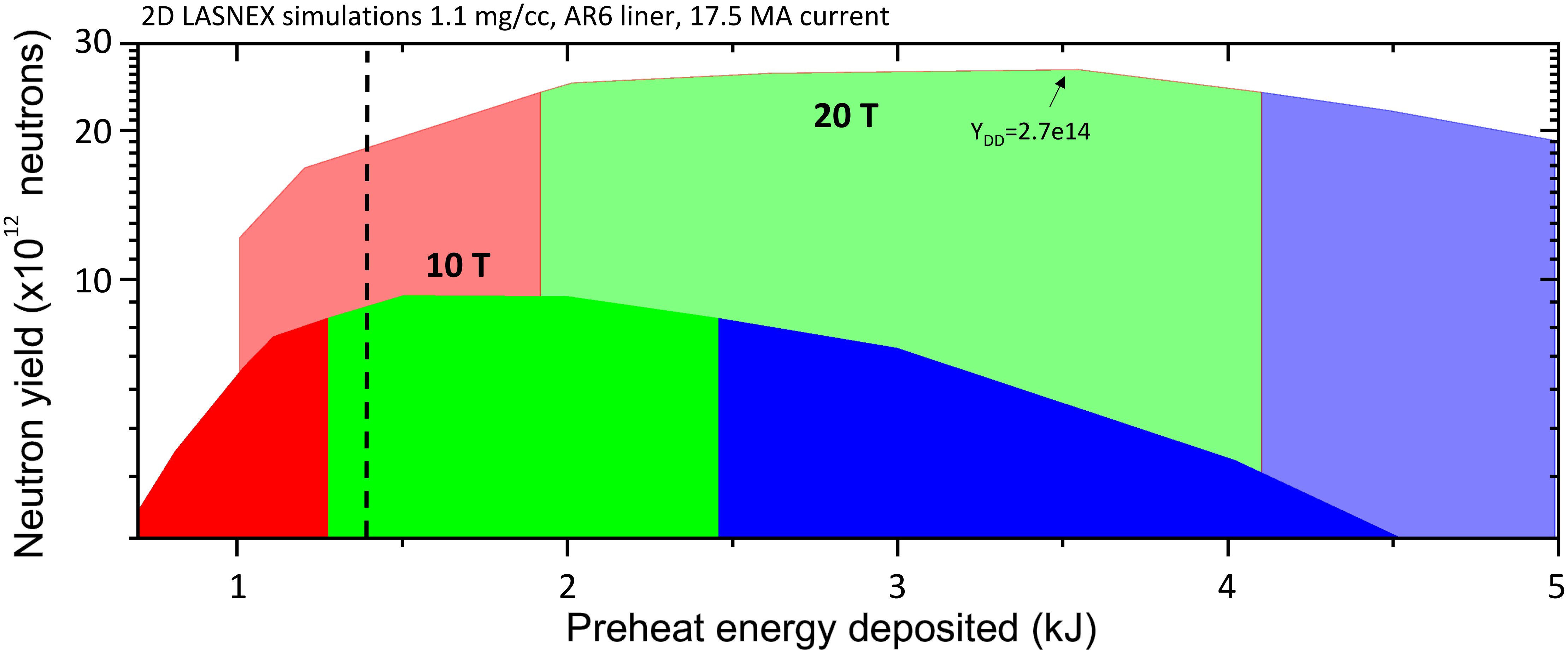
“Warm” preheat configurations are sufficient for experiments at 10 T



* Assumes 75% transmission, 4 kJ max ZBL energy

S. Slutz et al., Physics of Plasmas **25**, 112706 (2018)

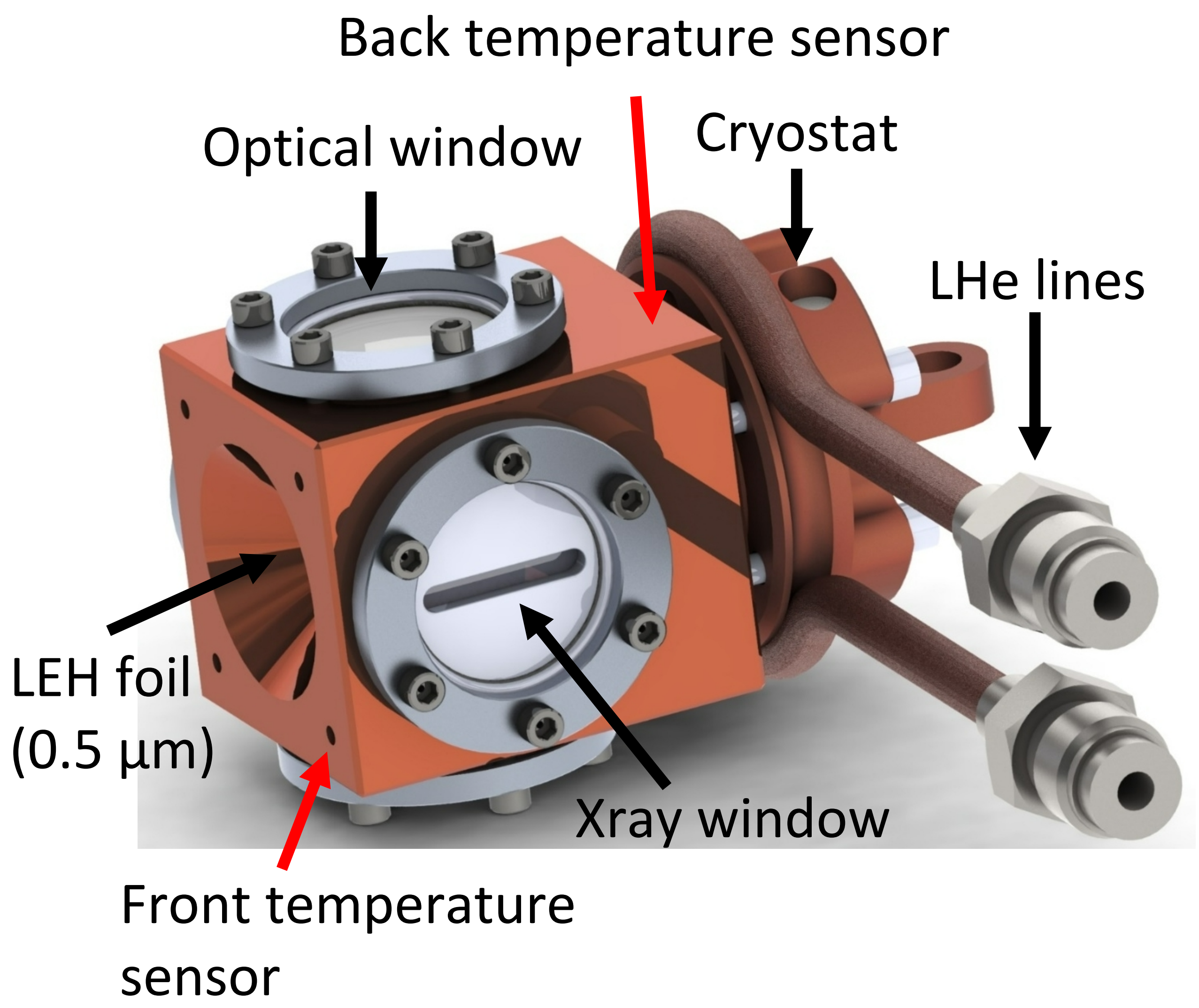
More preheat is required to optimize at higher fields – we are preheat starved

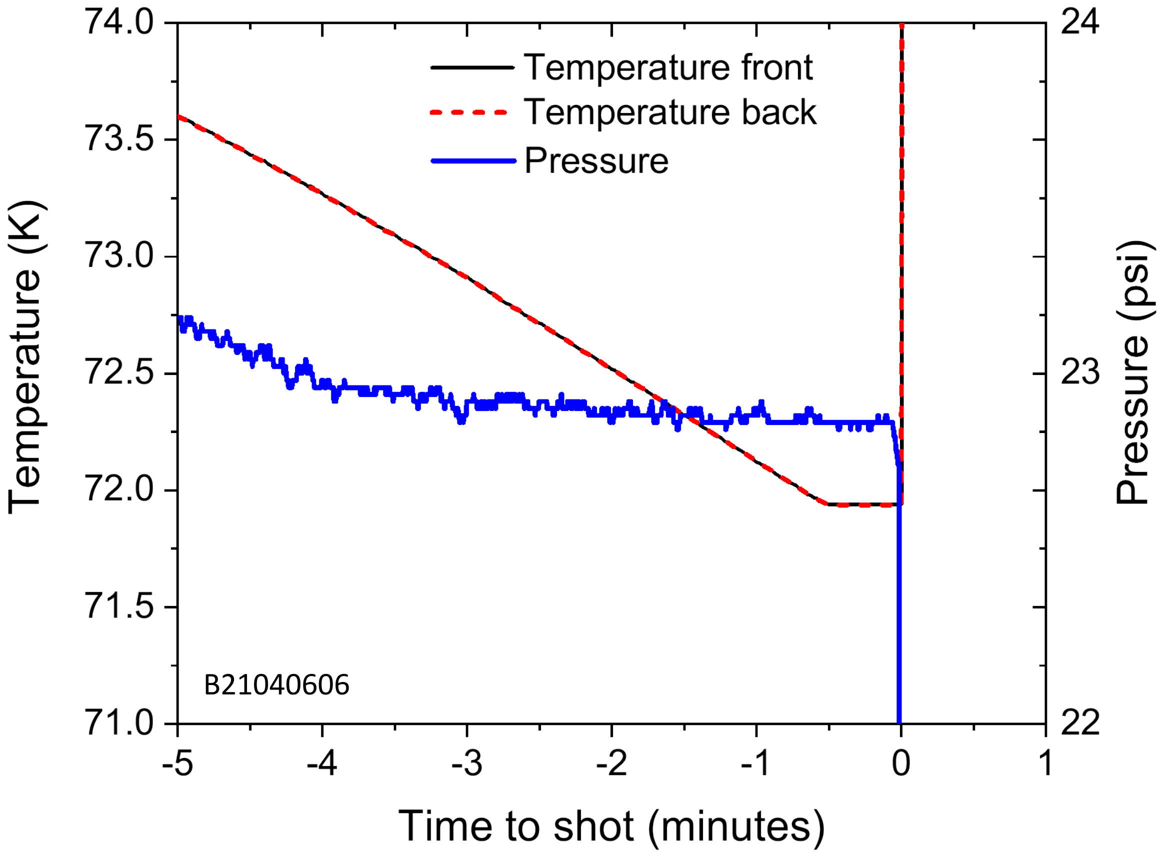


- Solution: Increase coupling efficiency through Cryogenic cooling
- Lower fuel temperature and pressure, reduce LEH thickness, increase spot diameter

S. Slutz et al., Physics of Plasmas **25**, 112706 (2018)

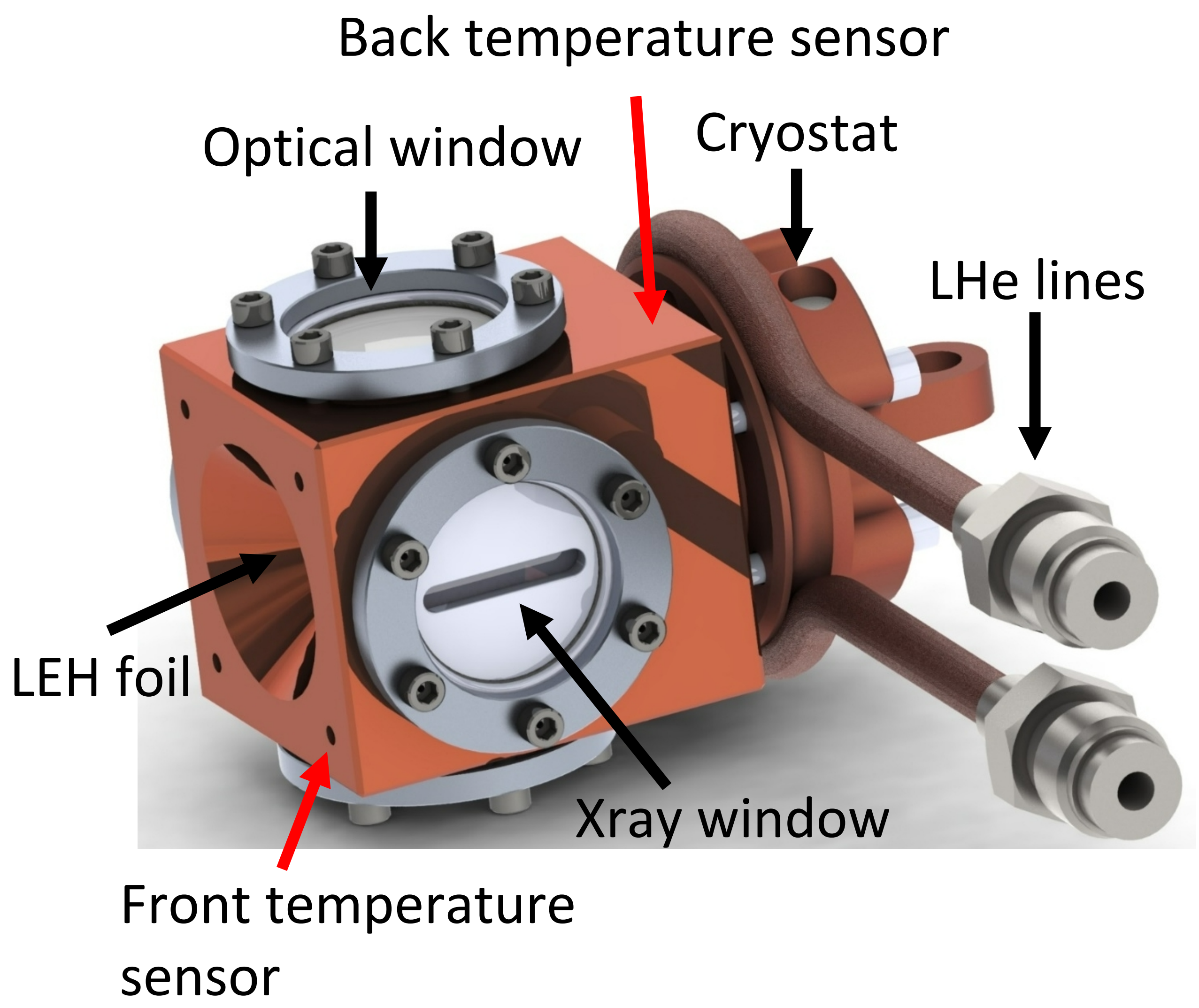
Cryogenic cooling enables lower pressures, thinner LEH foils

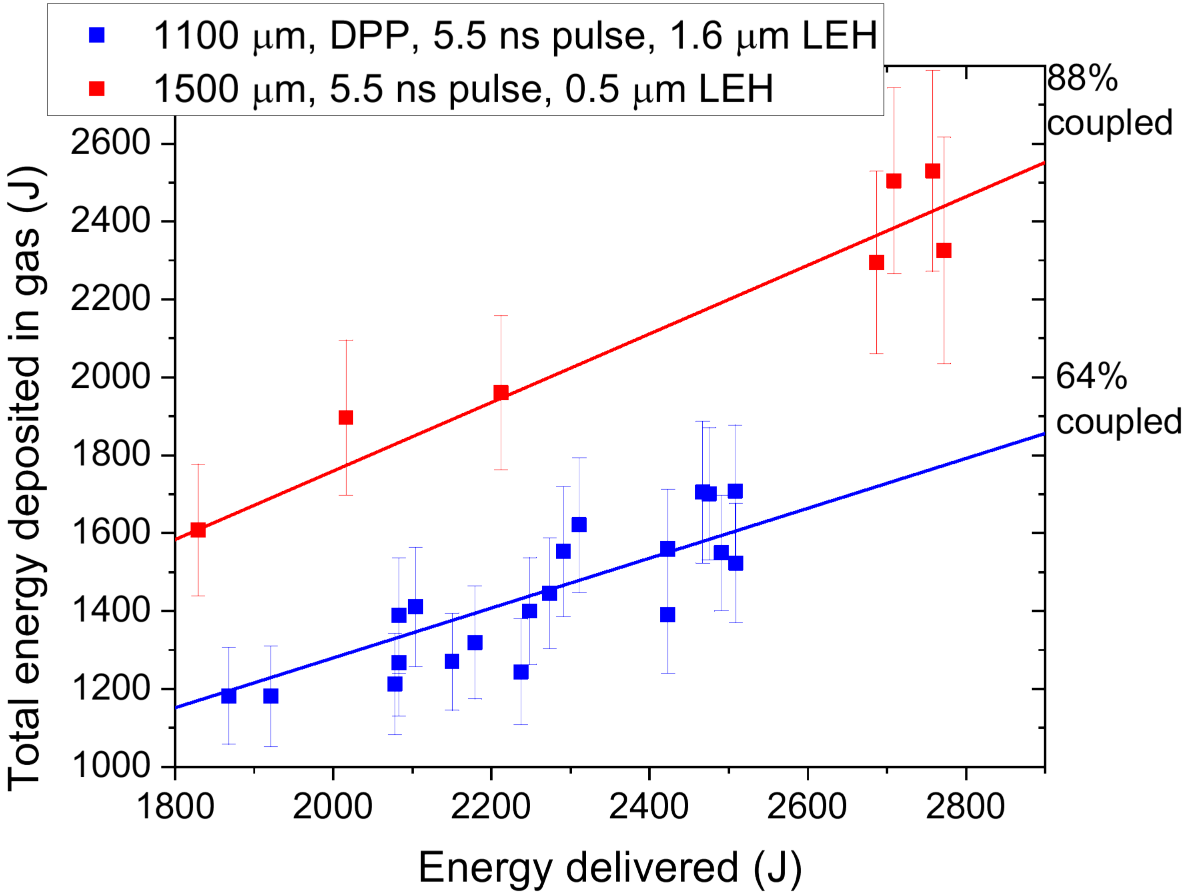




Conditions at shot: 22.83 psi, D2, 71.94 K, 1.06 mg/cc

Cryogenic cooling enables lower pressures, thinner LEH foils

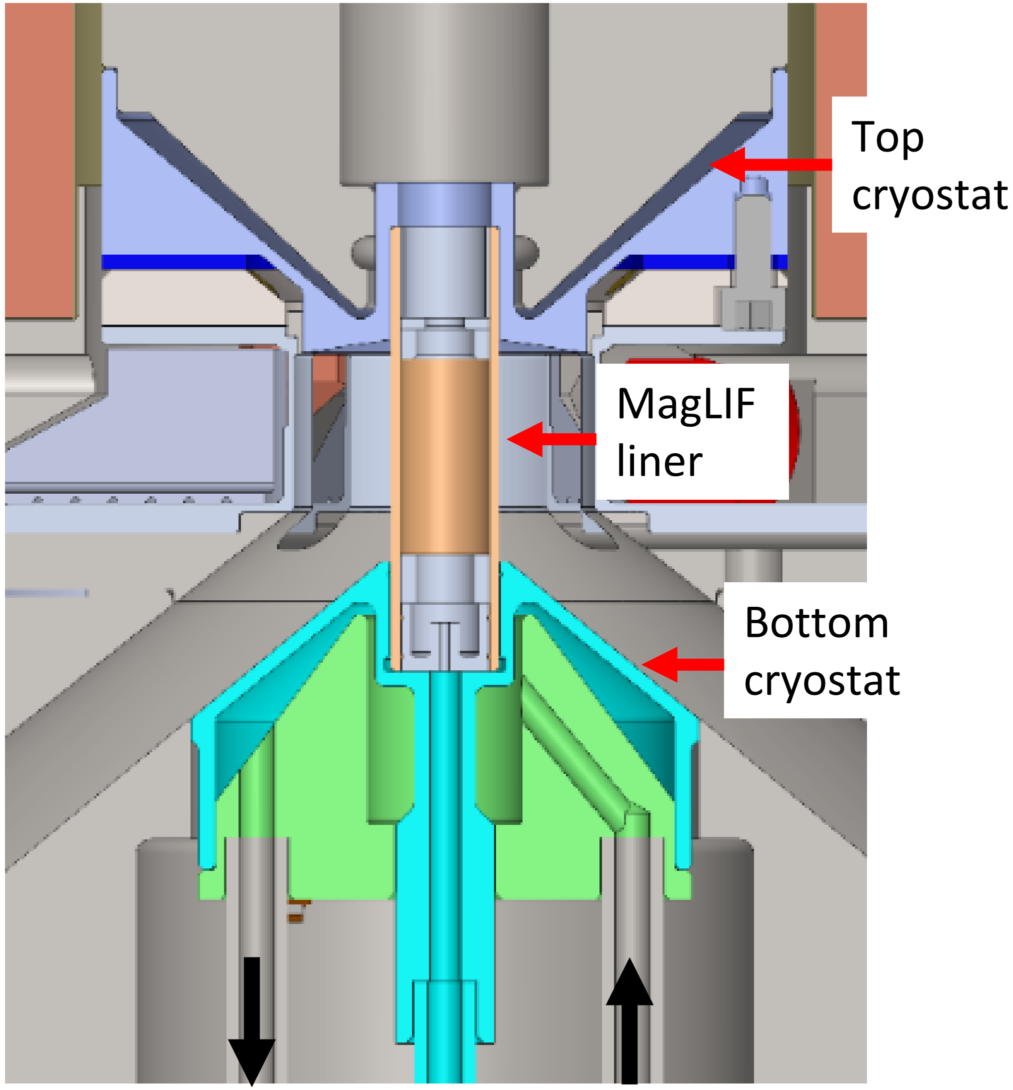


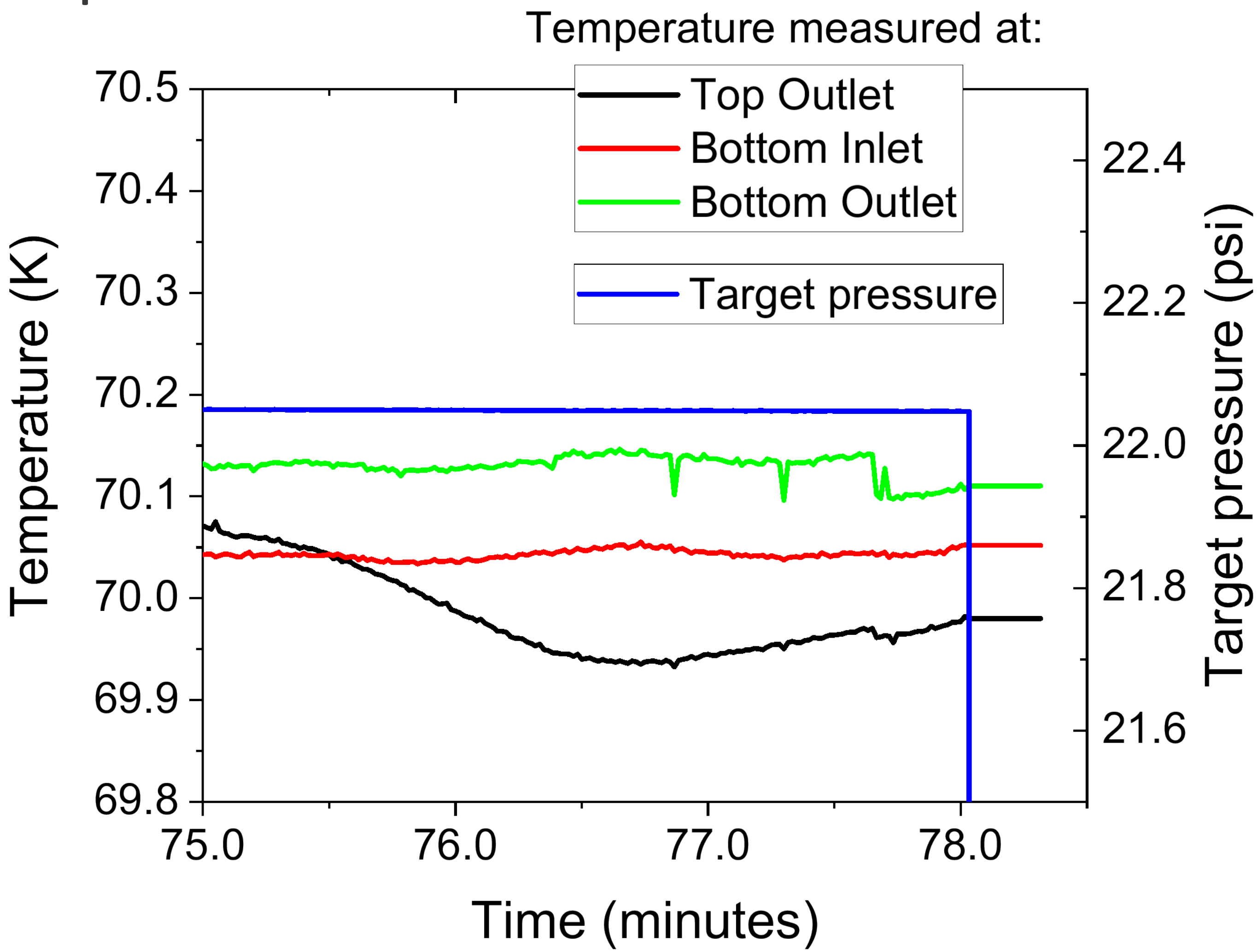


Principle changes from warm to cryo:

- Reduced LEH foil thickness from 1.6 to 0.5 μm
- Increased spot diameter from 1.1 to 1.5 mm

Advanced dual cryostat improves temperature control in integrated experiments

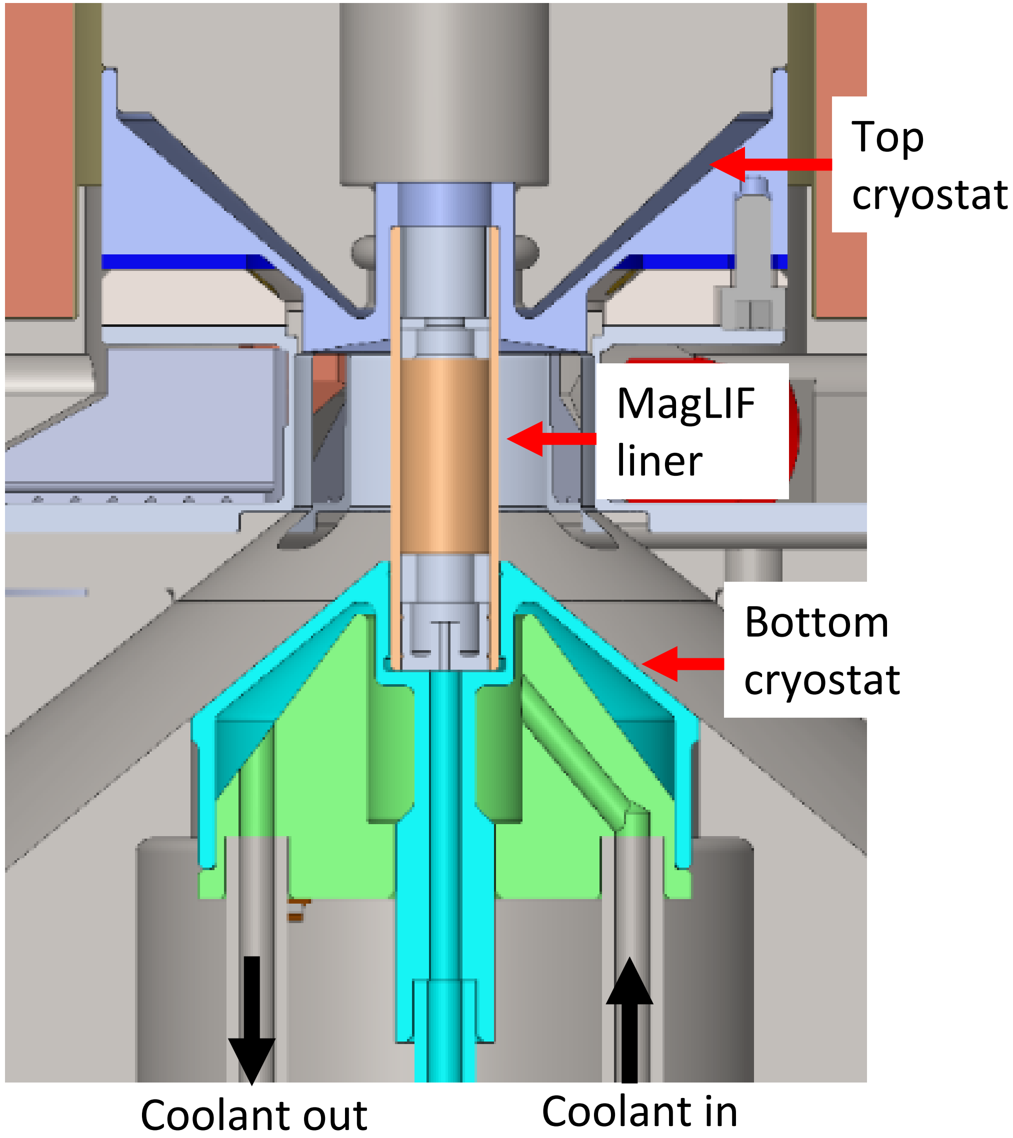




Final pressure: 22.05 psi. Final temperature: 70.05+/-0.07 K.
Final density: 1.045+/-0.001 mg/cc

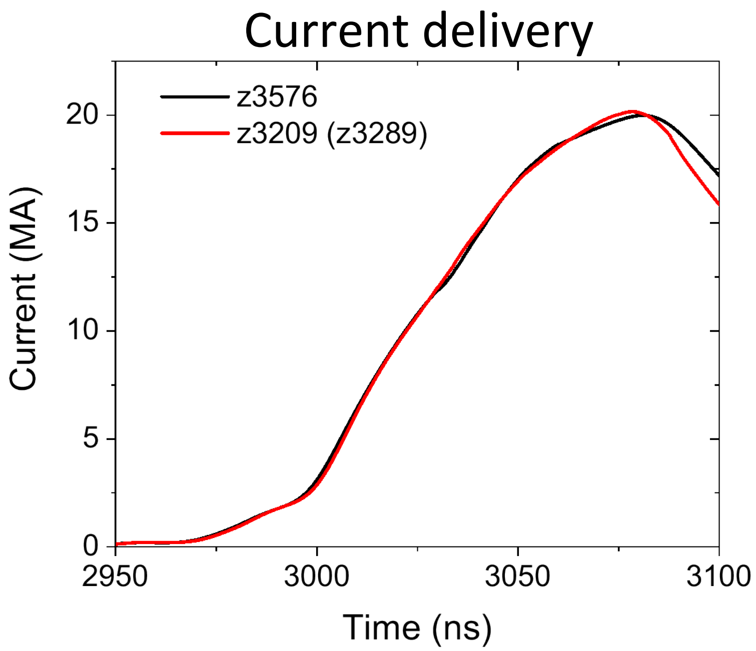
Previous cryo configuration: Awe et al., Rev. Sci. Instrum. 88, 093515 (2017)

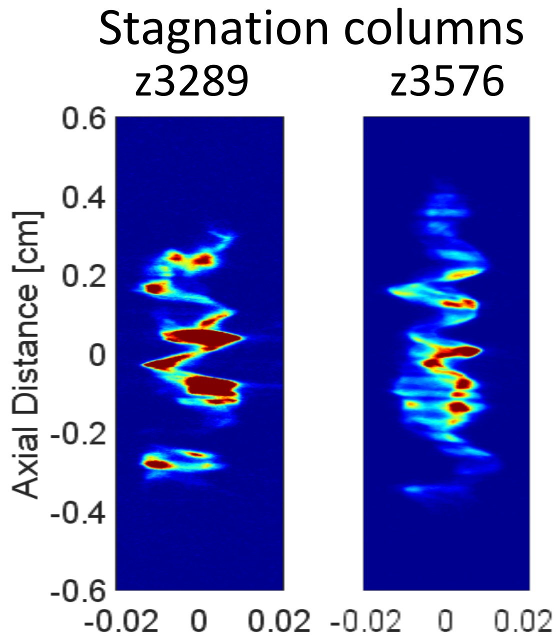
Z3576 coupled >2 kJ preheat energy, compare well to similar warm shots



Stagnation parameters for similar shots

Shot no.	Z3289 (warm)*	Z3576 (cryo)
B field (T)	15	15
Preheat energy (J)	1146+/-109	2250+/-250 J
Density (mg/cc)	1.03	1.045+/-0.001
DD yield ($x10^{12}$)	11.1+/-3.1	7.6+/-2.7
DT yield ($x10^{12}$)	0.22	0.10
DD/DT	55	74.8
T_{ion} (keV)	3.3 ± 0.6	2.7 ± 0.1





Summary

- Simulations and scaling theory suggest MagLIF may scale to high yields
- Our MagLIF effort aims to increase confidence in this scaling
- We have increased the performance of key aspects of MagLIF experiments – current delivery, applied magnetic field and preheat
- Cryogenic cooling enabled more efficient preheat allowing >2 kJ coupled for the first time
- Experiments on the NIF allow us to directly test preheat scaling at coupled energies >20 kJ