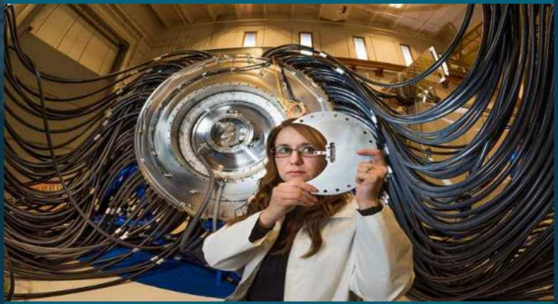
SAND2020-2761C

Magnetic Direct Drive – Research Challenges



PRESENTED BY

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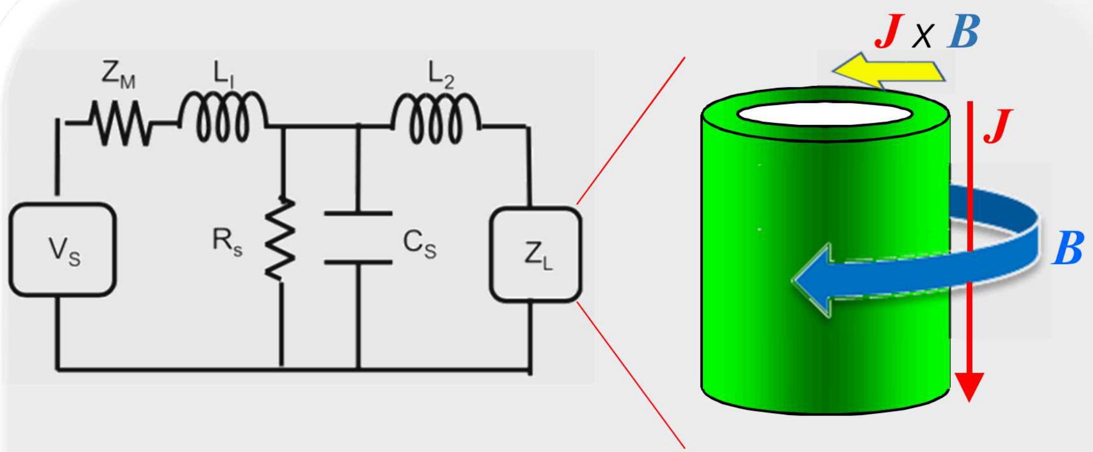
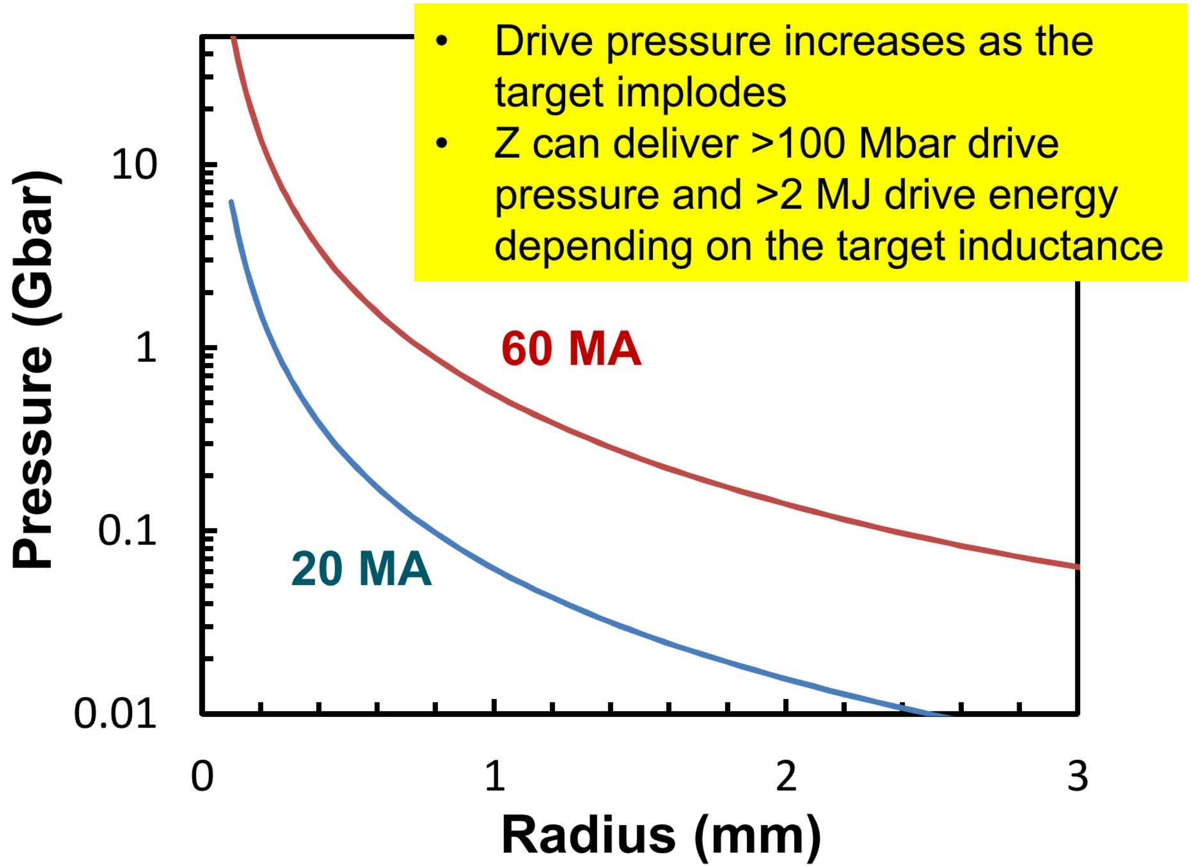
Magnetic Direct Drive (MDD) uses strong currents and magnetic fields to achieve high drive pressure.

Drive Pressure Scales as $(I/R)^2$



$$P = \frac{B^2}{8\pi} = 105\left(\frac{I_{MA}/26}{R_{mm}}\right)^2 \text{ Mbar}$$

Drive Pressure vs. Radius

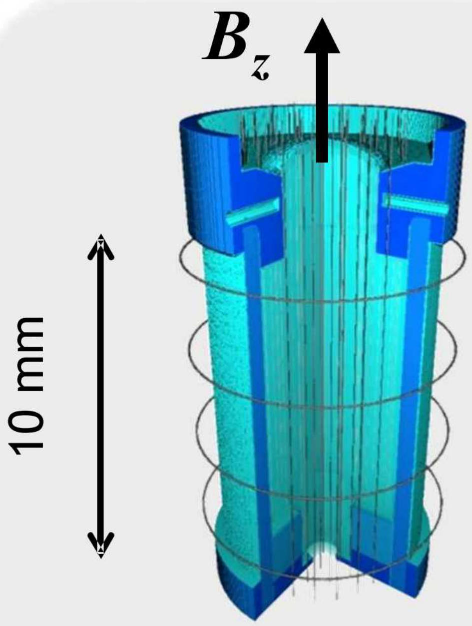


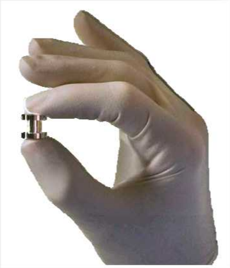
Key takeaways from the ICF Red Team review process:

- **MDD is an alternative approach to achieving multi-MJ yield and ignition with different risks.**
  - Compared to the other ICF approaches, MDD in its present form has been studied for the least amount of time and has the least amount of total investment
- **MDD target technologies have multiple scaling paths to achieve multi-MJ yield:**
  - Direct energy conversion (non-ignition, zero gain)
  - Volume ignition (moderate gain)
  - Hot-spot ignition and propagating burn (high gain)
- **Key scaling risks for MDD have been identified in the categories of target preheat, implosion stability, and current delivery and distribution.**
  - Improvements in modeling and measurement capabilities together with integrated scaling experiments are needed to answer questions about present performance and reduce scaling uncertainty.
- **Presently estimate it will require 2.5-3.5 times more current (6-12 times more energy) to achieve multi-MJ yield and ignition with magnetic direct drive**
  - Known pulsed-power technologies can generate the necessary drive energy and power
  - Need to get that energy to the target and safely handle tritium and yield

Magnetized Liner Inertial Fusion (MagLIF) is a magneto-inertial fusion approach that uses an axial applied B-field and laser preheat.

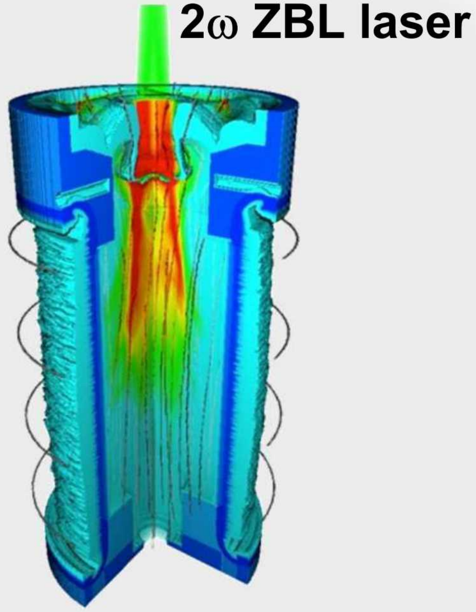
Pre-Magnetize





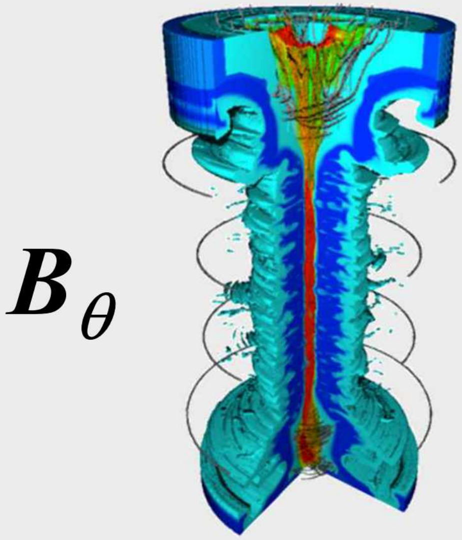
- B_z = 10-30 T
- Inhibit e^- conduction
- Confine α's

Preheat



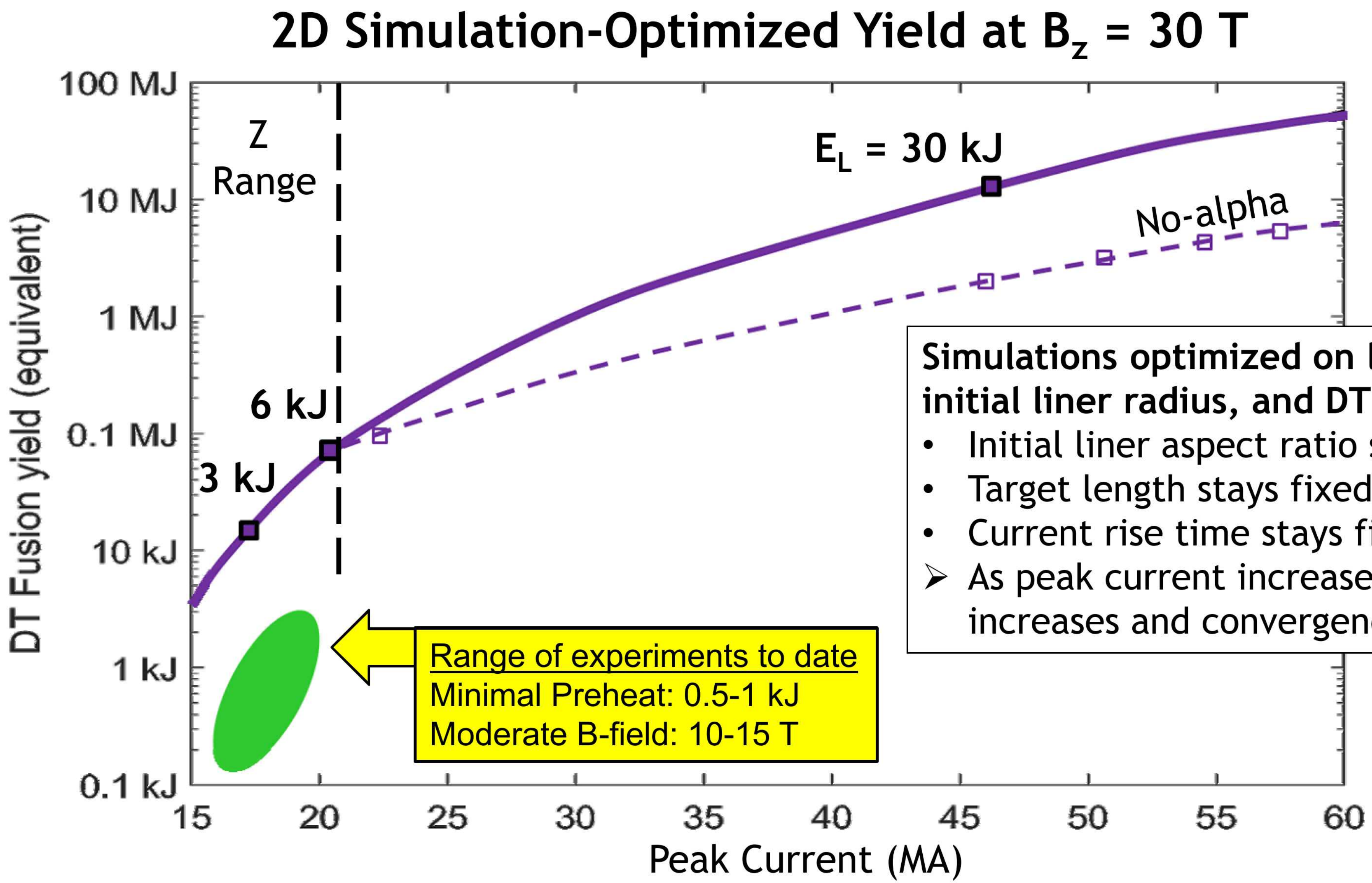
- Laser Energy = 1-4 kJ
- T_0 ~ 100's eV
- Reduce required implosion velocity

Compress



- CR ~ 35-45
- ρR ~ 0.003 g/cm^2
- P ~ 1-5 Gbar
- BR ~ 0.4 MG-cm

The simulated MagLIF scaling path requires enhanced preheat and current drive to achieve multi-MJ yield.

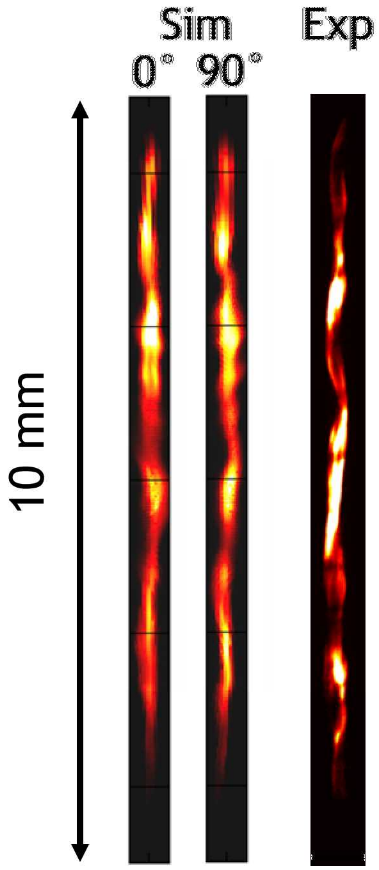


Simulations optimized on laser preheat energy, initial liner radius, and DT fill pressure:

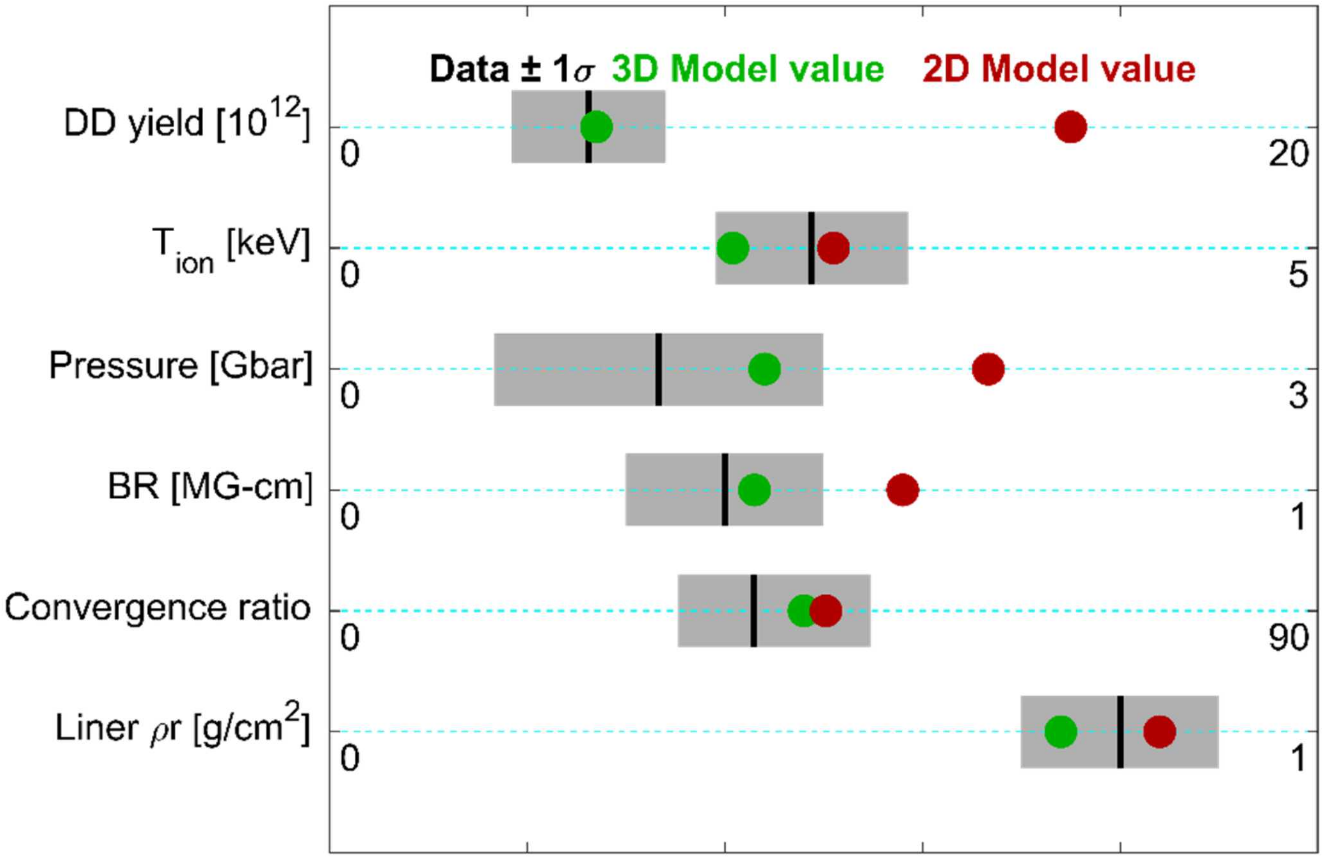
- Initial liner aspect ratio stays fixed
- Target length stays fixed
- Current rise time stays fixed
- ➢ As peak current increases, initial radius increases and convergence ratio decreases

3D effects impact the MagLIF performance, and the bulk parameters are approximately captured by 3D Hydra models.

Time-Integrated X-ray Images

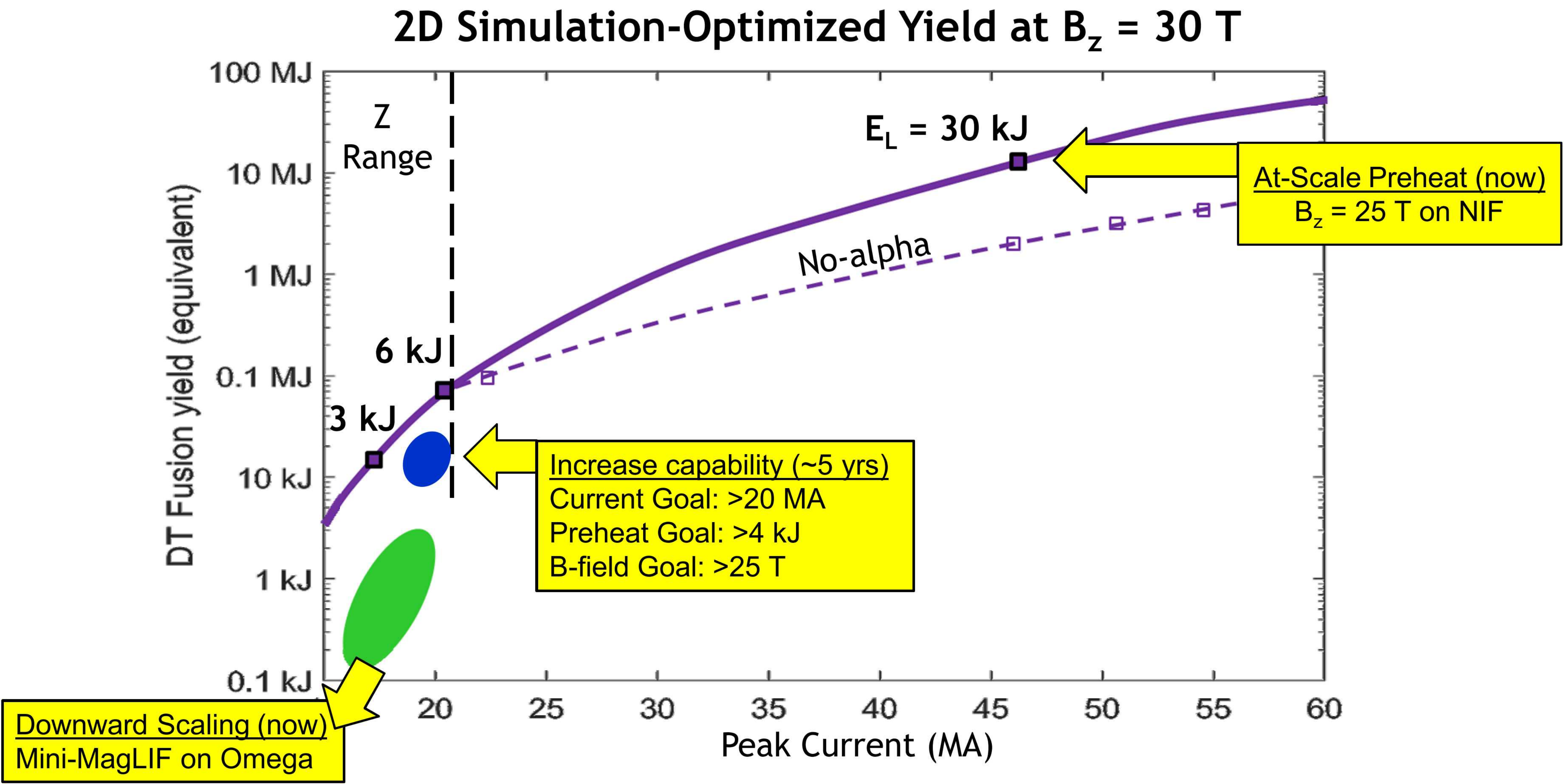


Time-Integrated Bulk-Parameter Estimates



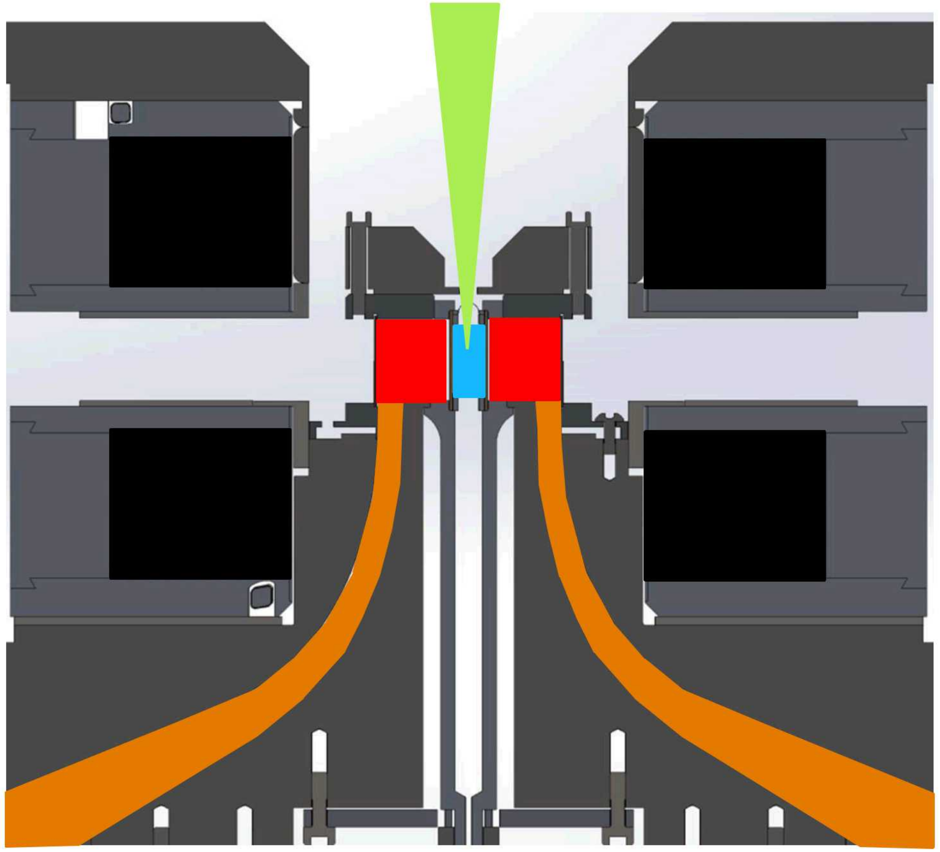
We need to dig deeper than time-integrated bulk parameter estimates to understand the true nature of the plasma conditions and dynamics

Efforts over the next 5 years will include increasing applied field and preheat on Z and testing preheat ‘at scale’ on NIF.



We are actively working to understand key uncertainties that may affect scaling to multi-MJ yield.

MagLIF Assembly



Liner Implosion Stability and Mix

Optimize stagnation conditions and confinement

Preheat Efficacy

Optimize preheat and minimize associated mix

Current distribution within the target volume

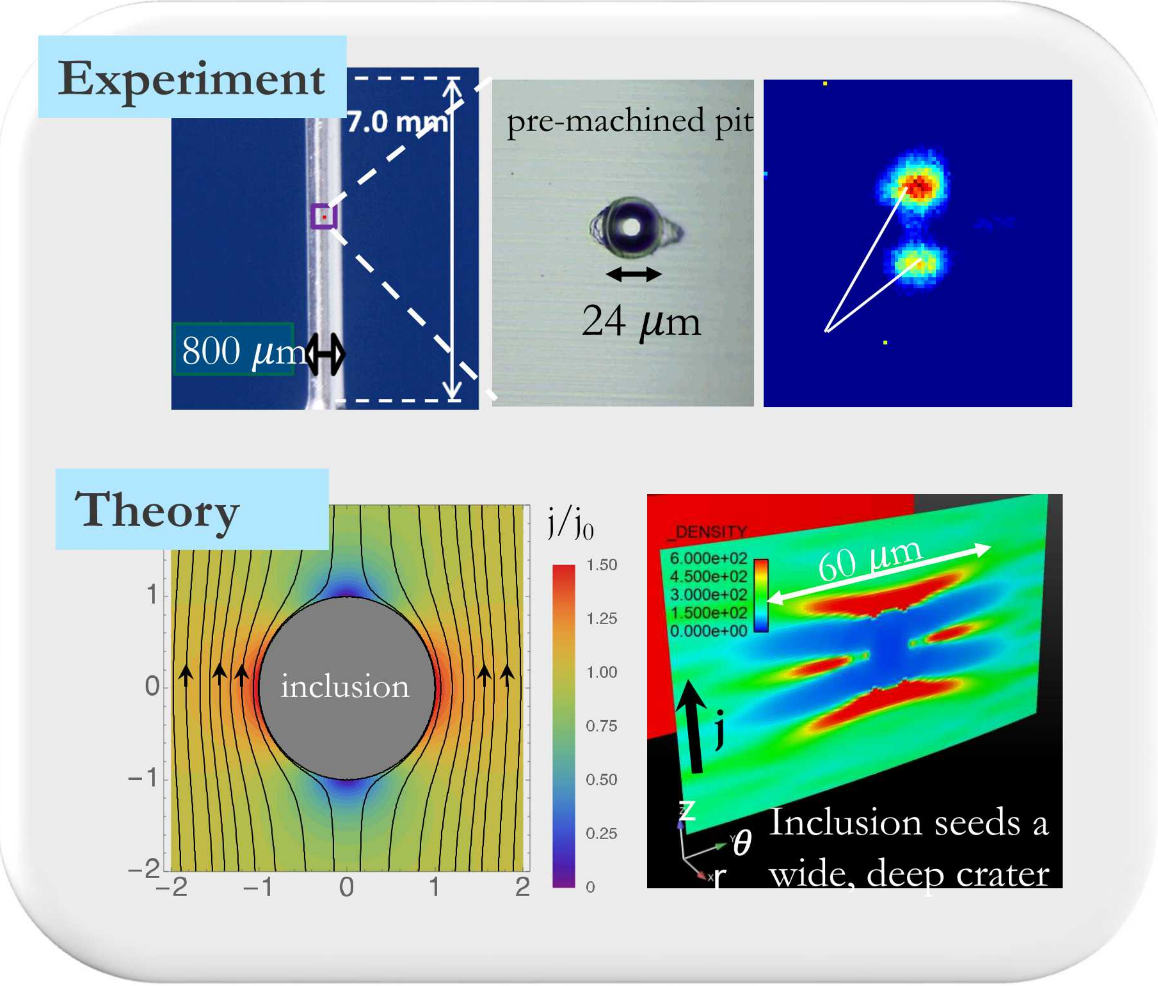
Optimize current to small radius (and drive pressure)

Power flow to the target

Optimize current to the target region

Instabilities are a key concern with scaling – we need to improve measurements and test understanding of the seeds and evolution.

Example: Electro-thermal instability



Liner Implosion Stability and Mix

Risk:

- Implosion and deceleration instabilities can introduce mix and degrade tamping

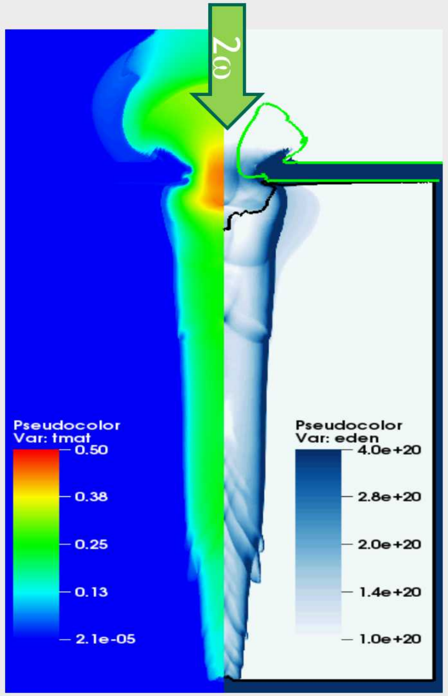
Research Approach and Opportunities:

- Solidify theories on origins of implosion instabilities:
  - Electro-thermal instability
  - Helical instability
- Develop advanced diagnostics to assess multi-dimensional temperature and density profiles
- Employ target design features to reduce instability seeds and/or growth factors

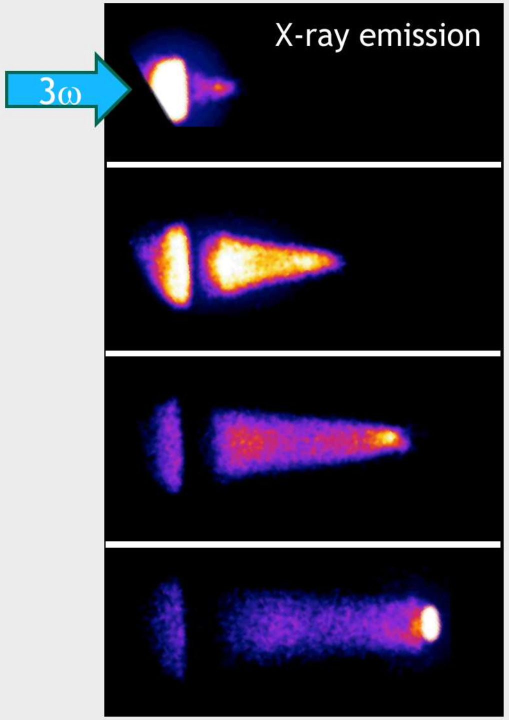
We are investigating preheat through simulations and experiments across a range of scales from Omega to NIF.

Example: Preheat studies on Omega and NIF

ZBL 1-2 kJ preheat simulations



NIF data at >20 kJ



Preheat Efficacy

Risk:

- If not avoided, laser plasma instabilities (LPI) can limit efficient energy coupling into MagLIF fuel.
- Mix and magnetized transport effects can cause energy loss between preheat and stagnation

Research Approach and Opportunities:

- Improve fundamental understanding of magnetized transport properties
- Study laser preheat, induced mix, and limits on LPI across a range of scales:
  - OMEGA (0.05-0.2 kJ) and OMEGA-EP
  - ZBL (1-4 kJ)
  - One quad of NIF (10-30 kJ)

Low density plasmas in the target volume are not well-represented in most MHD codes and can impact current coupling.

Example: Extend the physics in MHD codes

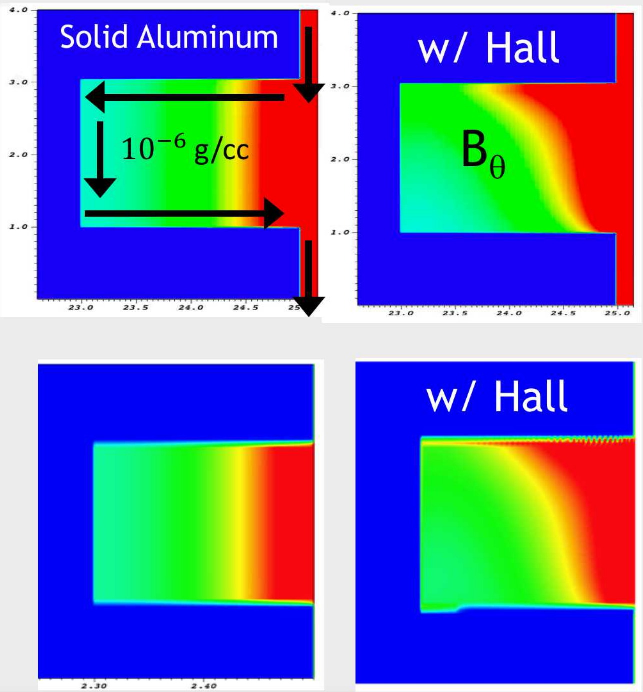
$$\frac{m_e}{n_e e^2}\frac{\partial \boldsymbol{J}}{\partial t} = \boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B} - \frac{\boldsymbol{J}}{n_e e} \times \boldsymbol{B} - \eta \boldsymbol{J}$$

electron inertial term

Hall term

PERSEUS

HYDRA



Current distribution within the target volume

Risk:

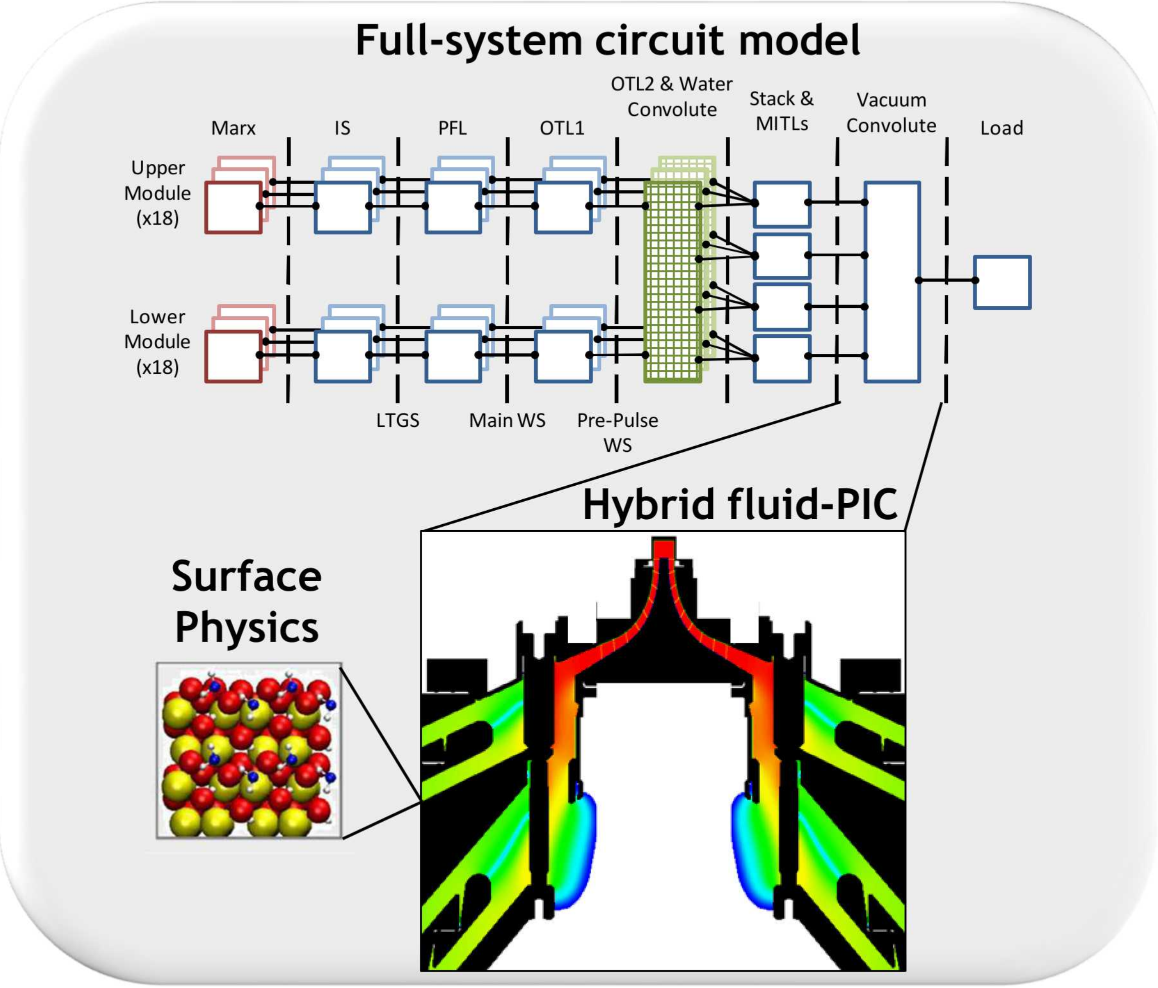
- Target performance can be affected by low density plasma formation that redistributes the current away from small radius and reduces the drive pressure.
- Many MHD models are not able to calculate the low density plasma formation on Z or at larger scale.

Research Approach and Opportunities:

- Extend the physics in our MHD models
- Develop new diagnostics to assess current delivery at small radius

We aim to capture power flow scaling through full-system circuit models coupled to validated 3D hybrid fluid-PIC models.

Example: Develop accurate circuit models and hybrid fluid-PIC codes



Power flow to the target

Risk:

- Efficiency and predictability of current delivery depends on the target inductance and implosion history.
- Current needs to be efficiently and predictably delivered as the energy density increases on larger-scale drivers

Research Approach and Opportunities:

- Advance understanding of surface physics, plasma formation, and loss mechanisms
  - New Diagnostics, Platforms, and Models
- Develop accurate 3D hybrid fluid-PIC models of the convolute and final power feed for both Z and a 60 MA-scale driver.

There are multiple ways to get involved:

- **ICF Community Workshop**
  - July 14-16, Lawrence Livermore National Laboratories
  - Details coming soon
- **11th Z Fundamental Science Workshop**
  - August 2-5, Albuquerque (location TBD)
  - Student sponsorships available for travel/hotel/registration
  - Contact: Marcus Knudson, mdknuds@sandia.gov
  - Call for proposals for Z fundamental science shots expected in June 2020
- **ZNetUS**: an association of HED research scientists who utilize pulsed-power machines in academia, national laboratories, and industry with the goals to:
  - Support and enable collaborative research on pulsed-power facilities across the country
  - Recommend improvements to the existing Z Fundamental-Science Program
  - Provide recommendation and follow-on requirements for the development of a new, mid-scale pulsed-power facility (5-10 MA) if appropriate