SAND2021-15736C

Sandia National Laboratories

Magneto-Inertial Fusion: Scaling to multi-MJ yields in the laboratory

PRESENTED BY

Daniel Sinars

Director, Pulsed Power Sciences

Program Executive, Inertial Confinement Fusion & Assessment Science

Sandia National Laboratories

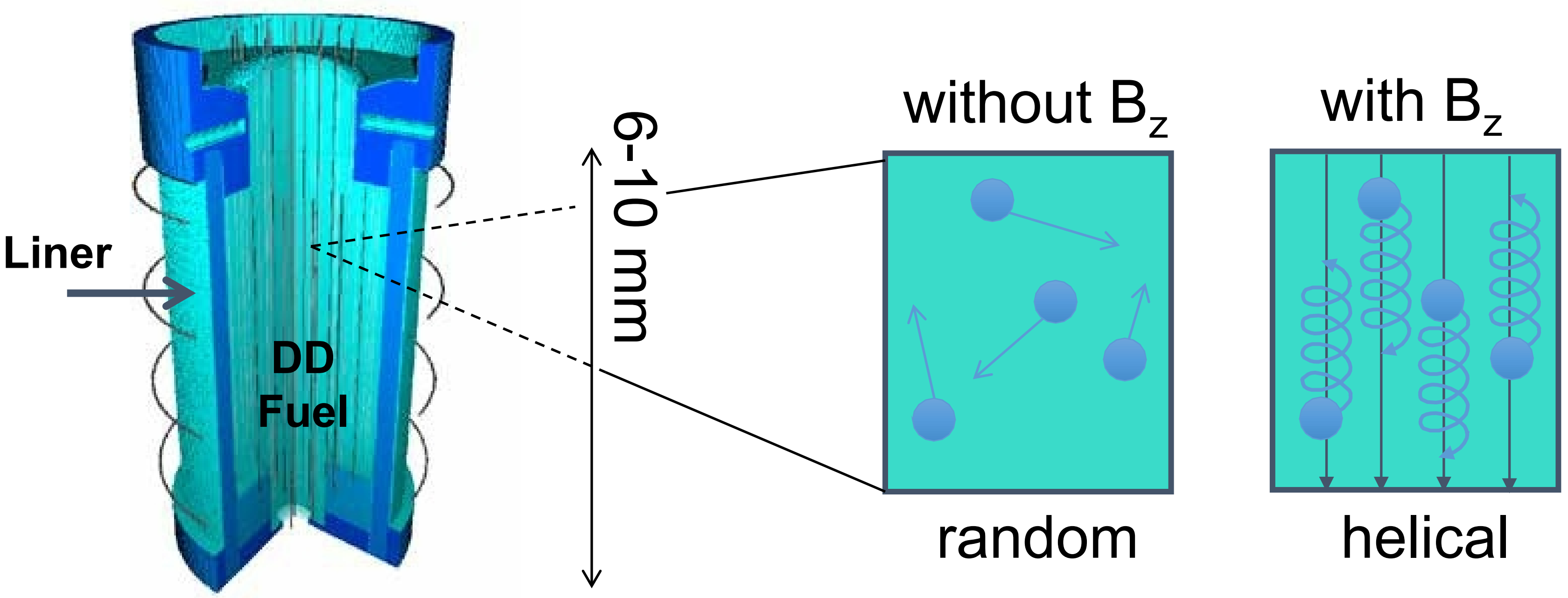
Fusion Power Associates | December 15-16, 2021

U.S. DEPARTMENT OF ENERGY NNSA

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 is a Magneto-Inertial Fusion (MIF) concept

Relies on three components to produce fusion conditions at stagnation



Magnetization: 10-30T at t=0

- **Reduces electron heat loss during implosion**
- **Traps charged particles at stagnation**

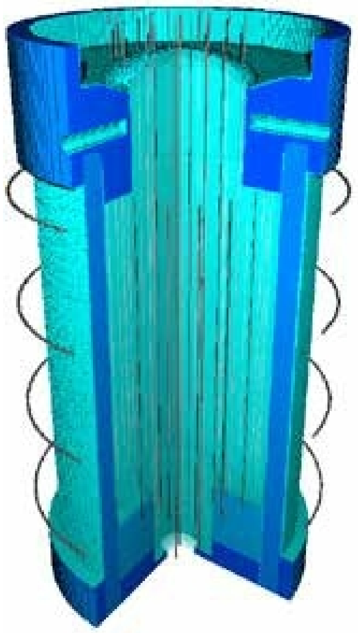
Magnetization

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

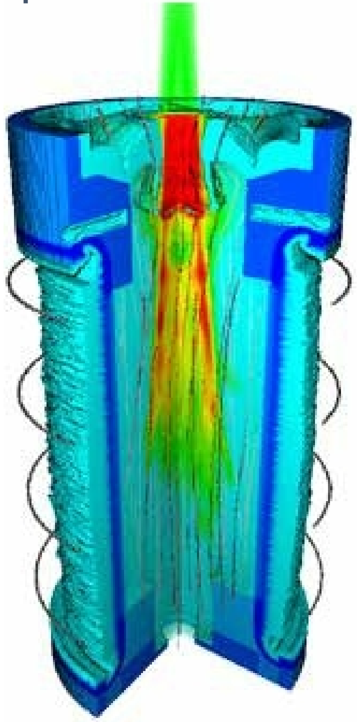
S.A. Slutz *et al.*, Phys. Plasmas (2010); A.B. Sefkow *et al.*, Phys. Plasmas (2014); S.A. Slutz *et al.*, Phys. Plasmas (2018).

MagLIF is a Magneto-Inertial Fusion (MIF) concept

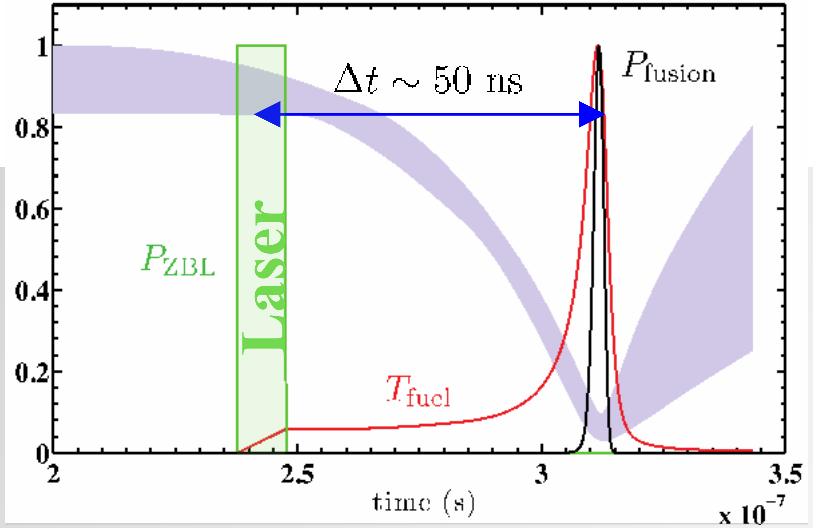
Relies on three components to produce fusion conditions at stagnation



+



- **Laser preheat: 100-200 eV**
  - **Uses Z-Beamlet Laser**
  - **Relax convergence requirement**
  - **CR=$R_{initial}/R_{final}$= 120 → 20-40**



Magnetization

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

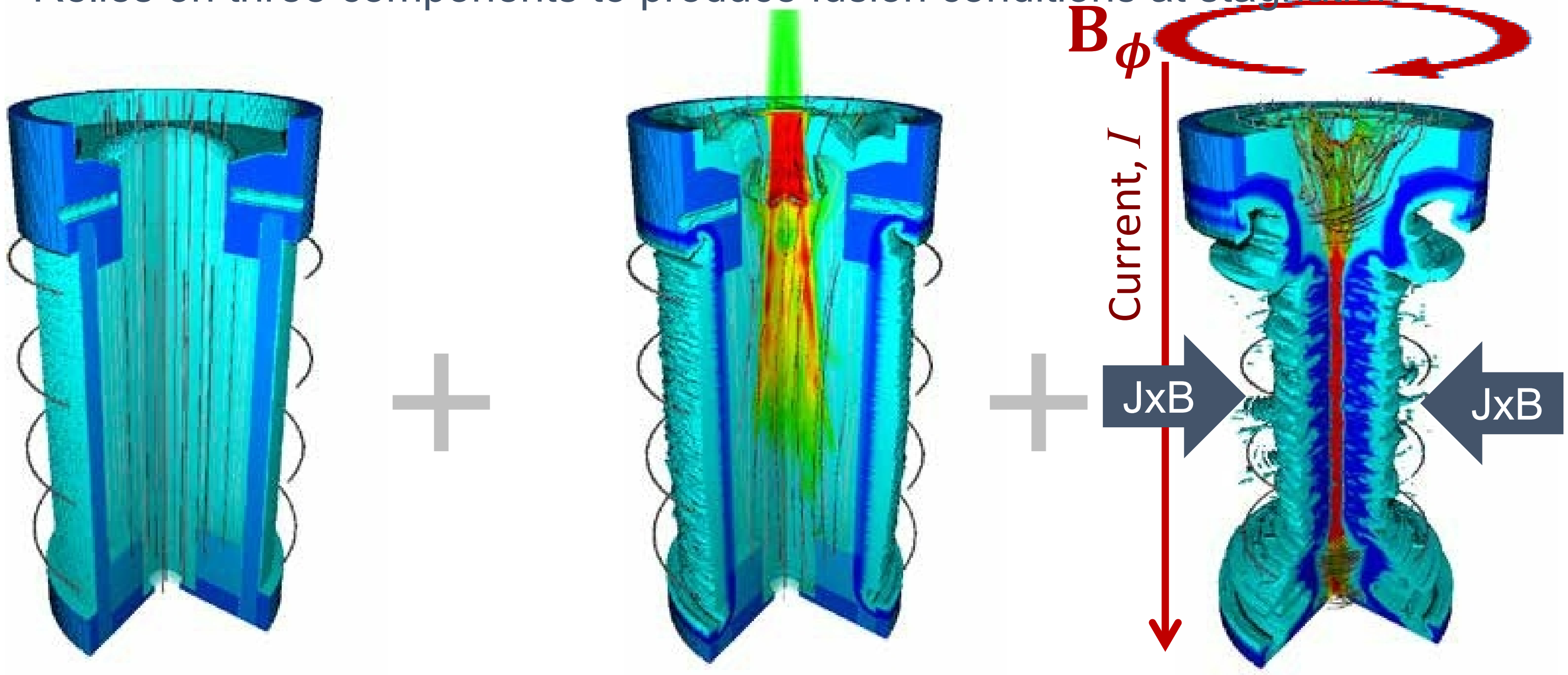
Preheat

- Ionize fuel to lock in B-field
- Increase adiabat to limit required convergence

S.A. Slutz *et al.*, Phys. Plasmas (2010); A.B. Sefkow *et al.*, Phys. Plasmas (2014); S.A. Slutz *et al.*, Phys. Plasmas (2018).

MagLIF is a Magneto-Inertial Fusion (MIF) concept

Relies on three components to produce fusion conditions at stagnation



Magnetically Driven Implosion
- **Relatively low implosion velocity ~100 km/s**
- **B-field amplified to >few kT**

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

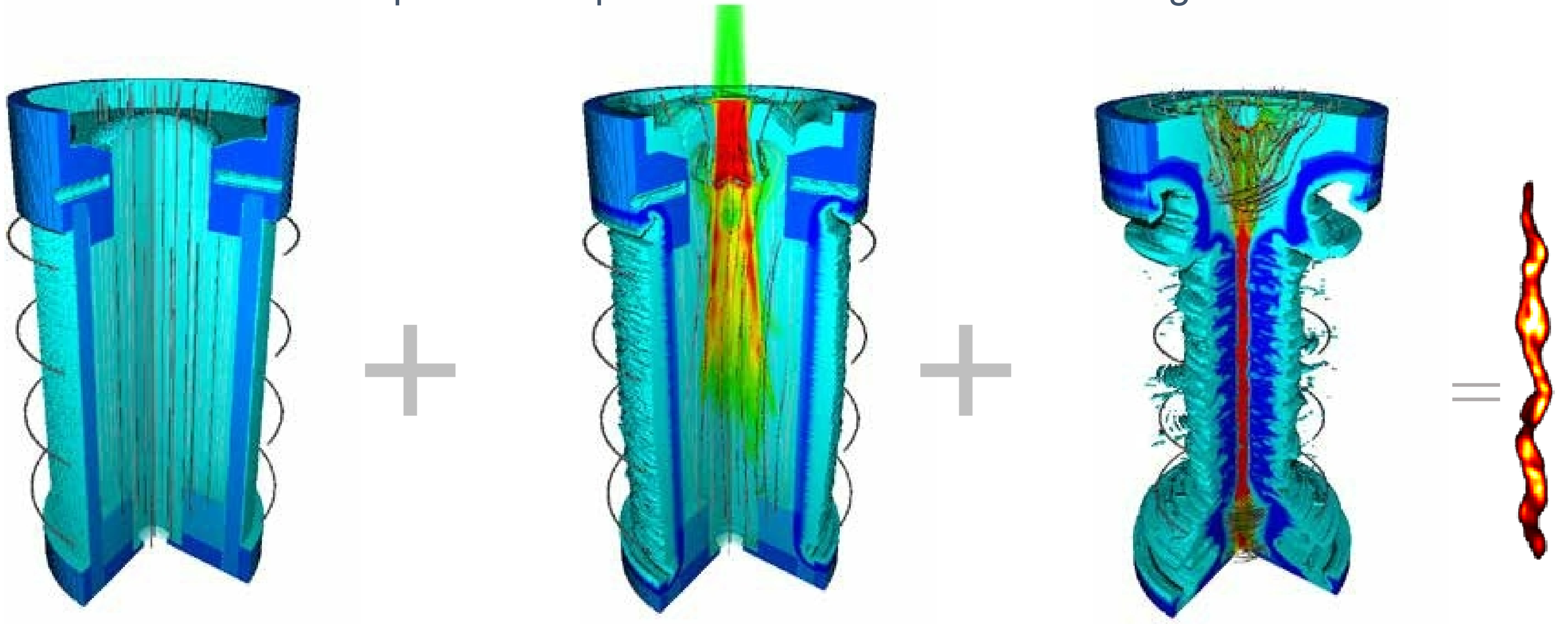
Preheat
- Ionize fuel to lock in B-field
- Increase adiabat to limit required convergence

Implosion
- PdV work to heat fuel
- Flux compression to amplify B-field

S.A. Slutz *et al.*, Phys. Plasmas (2010); A.B. Sefkow *et al.*, Phys. Plasmas (2014); S.A. Slutz *et al.*, Phys. Plasmas (2018).

MagLIF is a Magneto-Inertial Fusion (MIF) concept

Relies on three components to produce fusion conditions at stagnation



Stagnation

- Several keV temperature, ~1 g/cm^3 fuel density
- Several kT B-field traps charged fusion products

Magnetization

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

Preheat

- Ionize fuel to lock in B-field
- Increase adiabat to limit required convergence

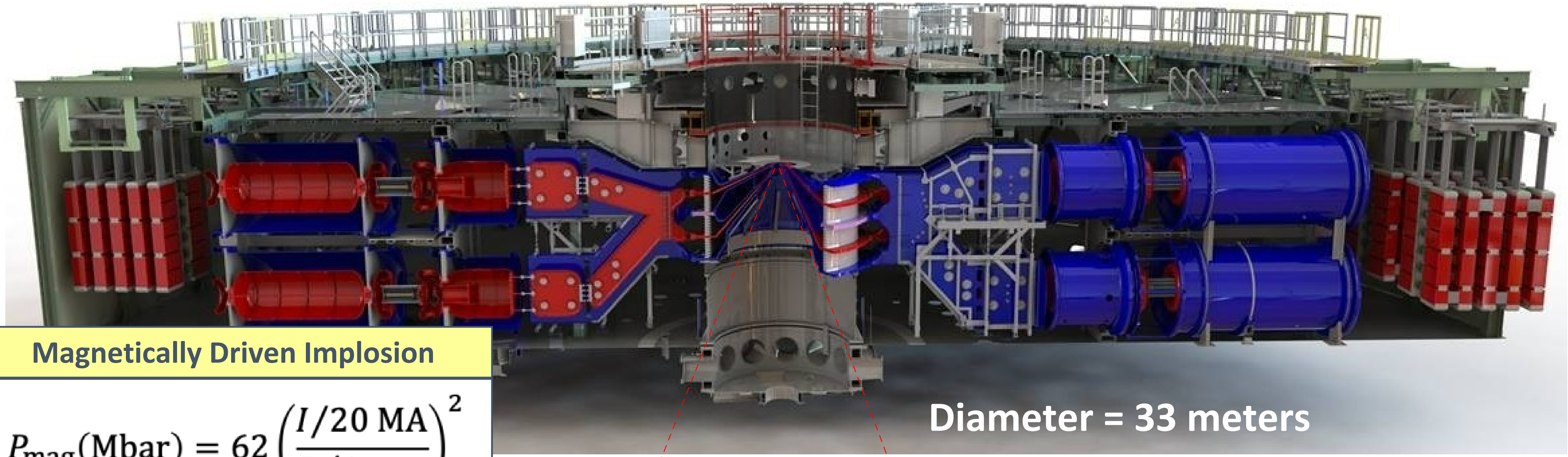
Implosion

- PdV work to heat fuel
- Flux compression to amplify B-field

S.A. Slutz *et al.*, Phys. Plasmas (2010); A.B. Sefkow *et al.*, Phys. Plasmas (2014); S.A. Slutz *et al.*, Phys. Plasmas (2018).

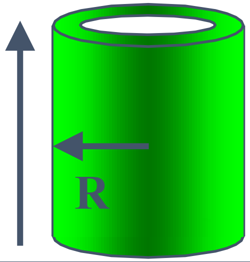
We have been using the multi-MJ Z pulsed power facility and the adjacent multi-kJ Z-Beamlet laser to perform integrated tests of the MagLIF concept since 2015

Z Pulsed Power Facility

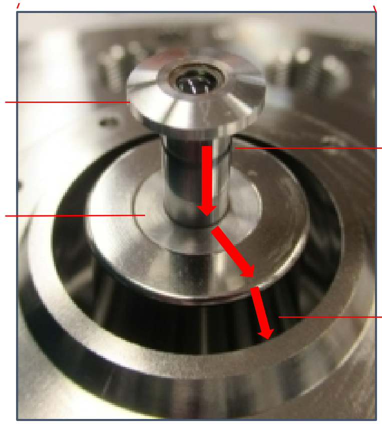


Magnetically Driven Implosion

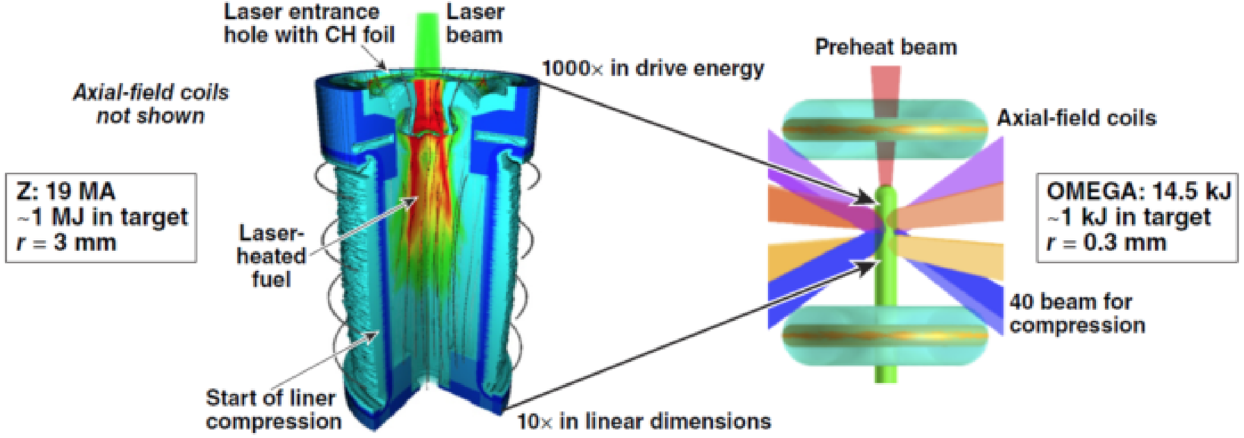
$$P_{mag}(\mathrm{Mbar}) = 62\left(\frac{I/20\ \mathrm{MA}}{R/1\ \mathrm{mm}}\right)^2$$

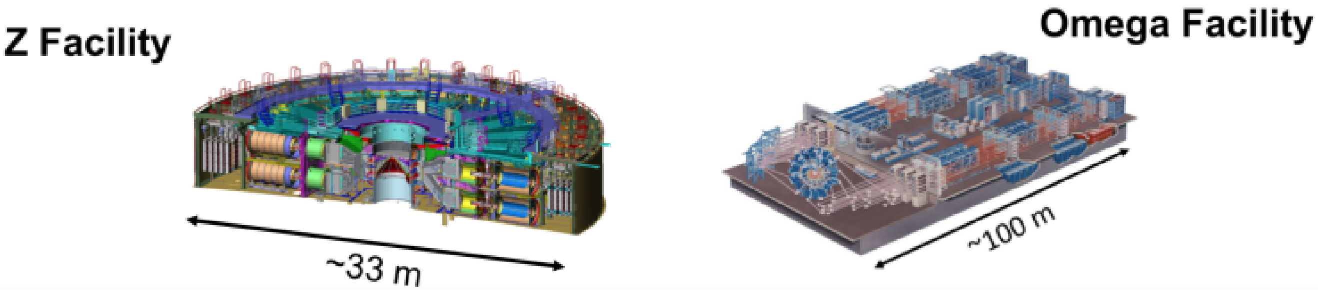


~7 Mbar → >100 Mbar during expt.

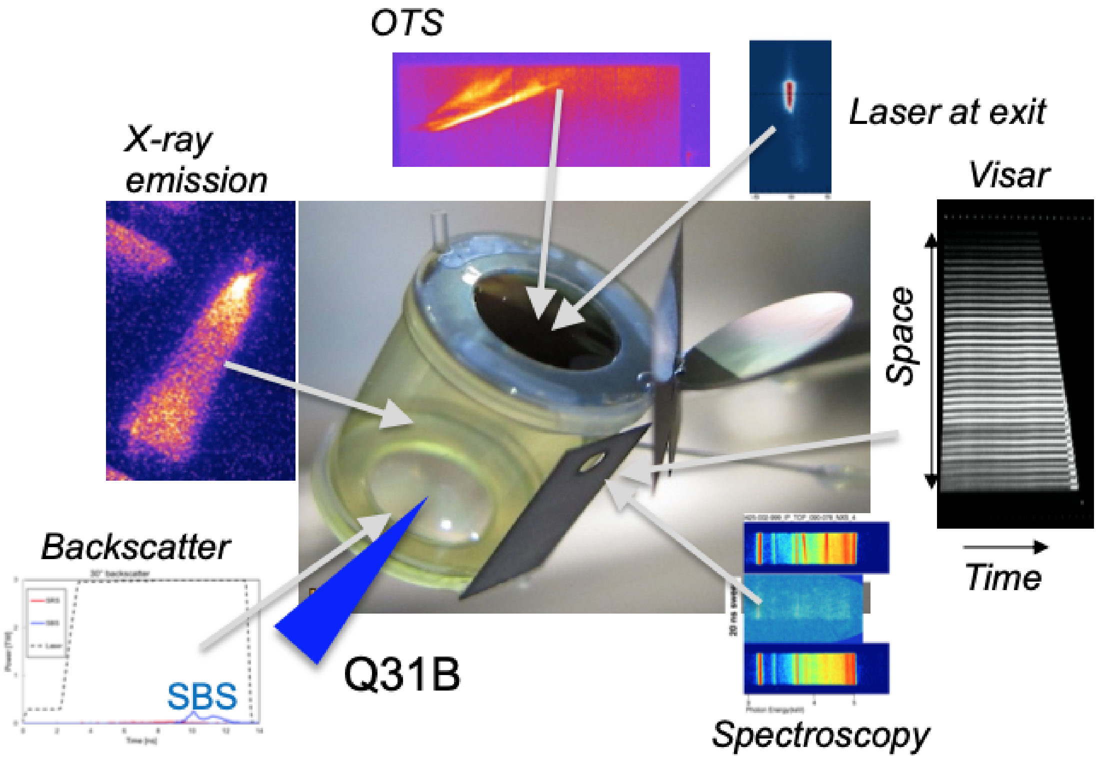


Both Omega and NIF are being used to study key aspects of the physics





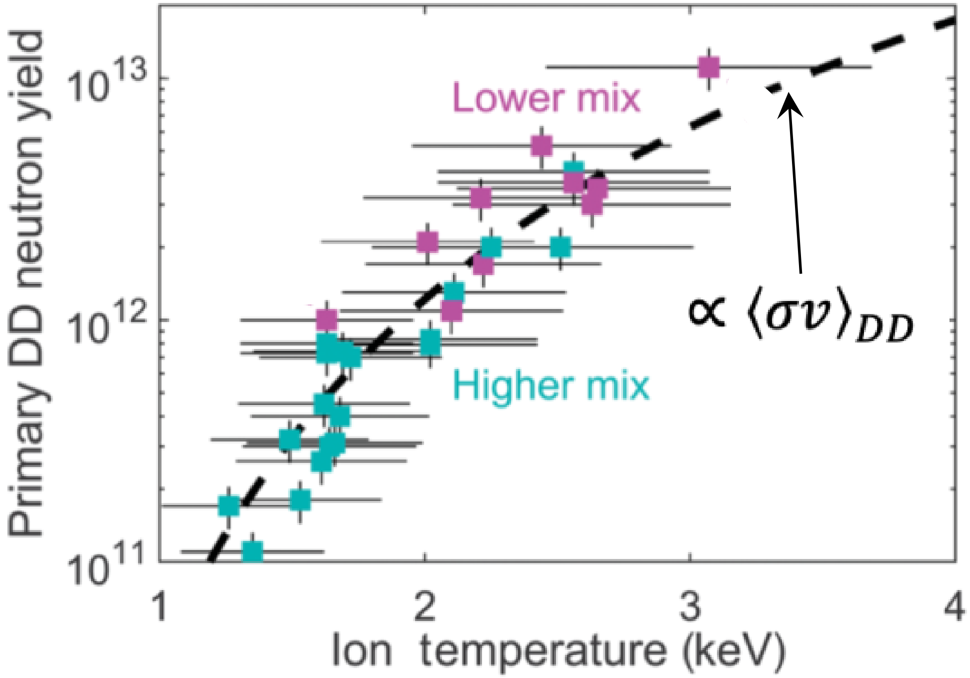
J.R. Davies *et al.*, Phys. Plasmas (2017).
D.H. Barnak *et al.*, Phys. Plasmas (2017).
E.C. Hansen *et al.*, Phys. Plasmas (2018).
J.R. Davies *et al.*, Phys. Plasmas (2019).
E.C. Hansen *et al.*, Phys. Plasmas (2020).
D.H. Barnak *et al.*, Phys. Plasmas (2020).

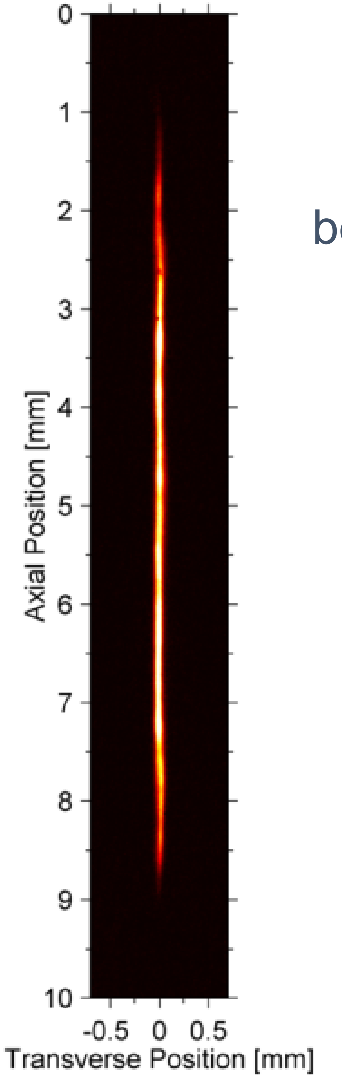


B. Pollock *et al.*, APS-DPP 2021

Integrated MagLIF experiments on both Z and Omega have demonstrated the fundamental principles of MIF

Thermonuclear neutrons, multi-keV temperatures from high aspect-ratio, cylindrical fuel assemblies.





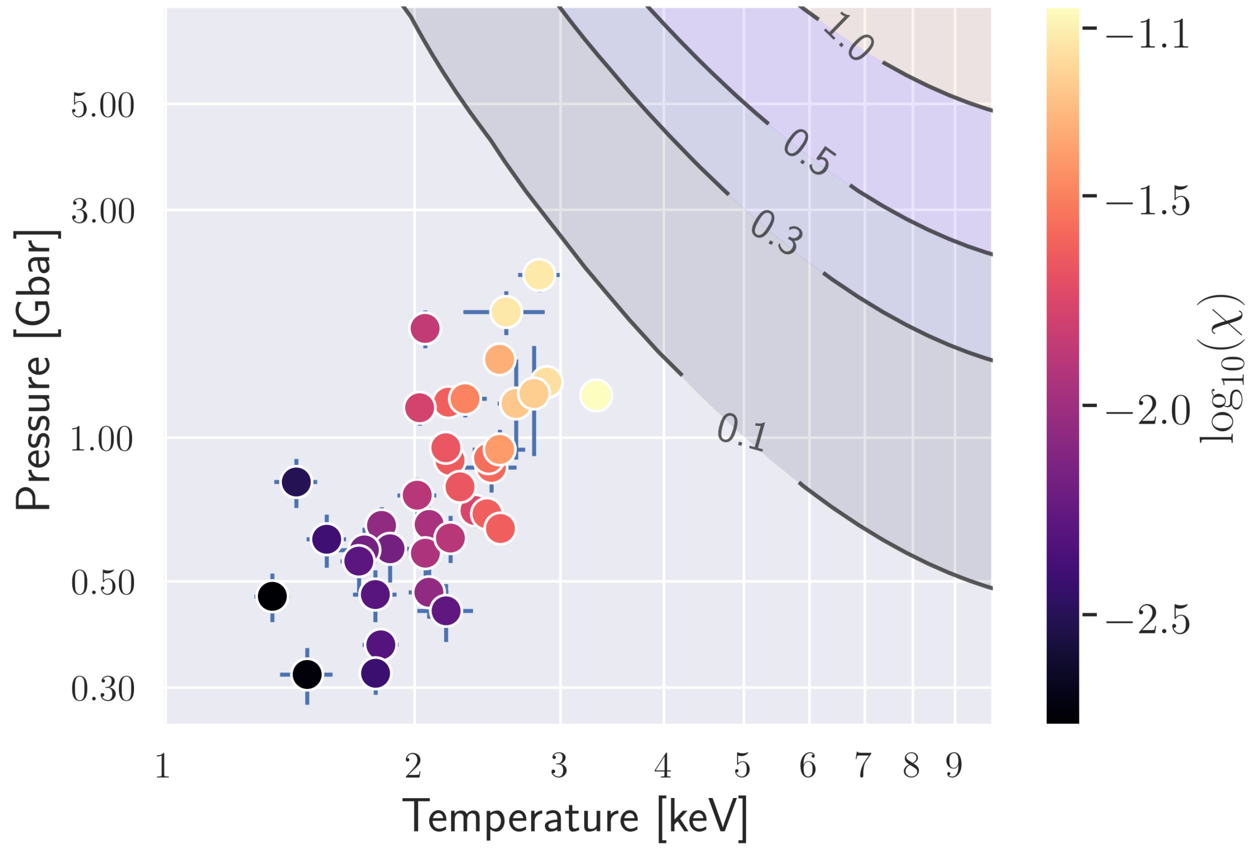
Hallmark of MIF: significant fusion only when both the **laser preheat** and **magnetization** stages are present.

DD neutron yields

	No B-field	B-field
No Preheat	3×10^{9}	1×10^{10}
Preheat	4×10^{10}	**Up to 10^{13}**

Gomez et al., PRL 113, 155003 (2014)
Gomez et al., PRL 125, 155002 (2020)

We have used a combination of Bayesian data analysis techniques to determine the plasma conditions and Lawson parameter for our integrated experiments*

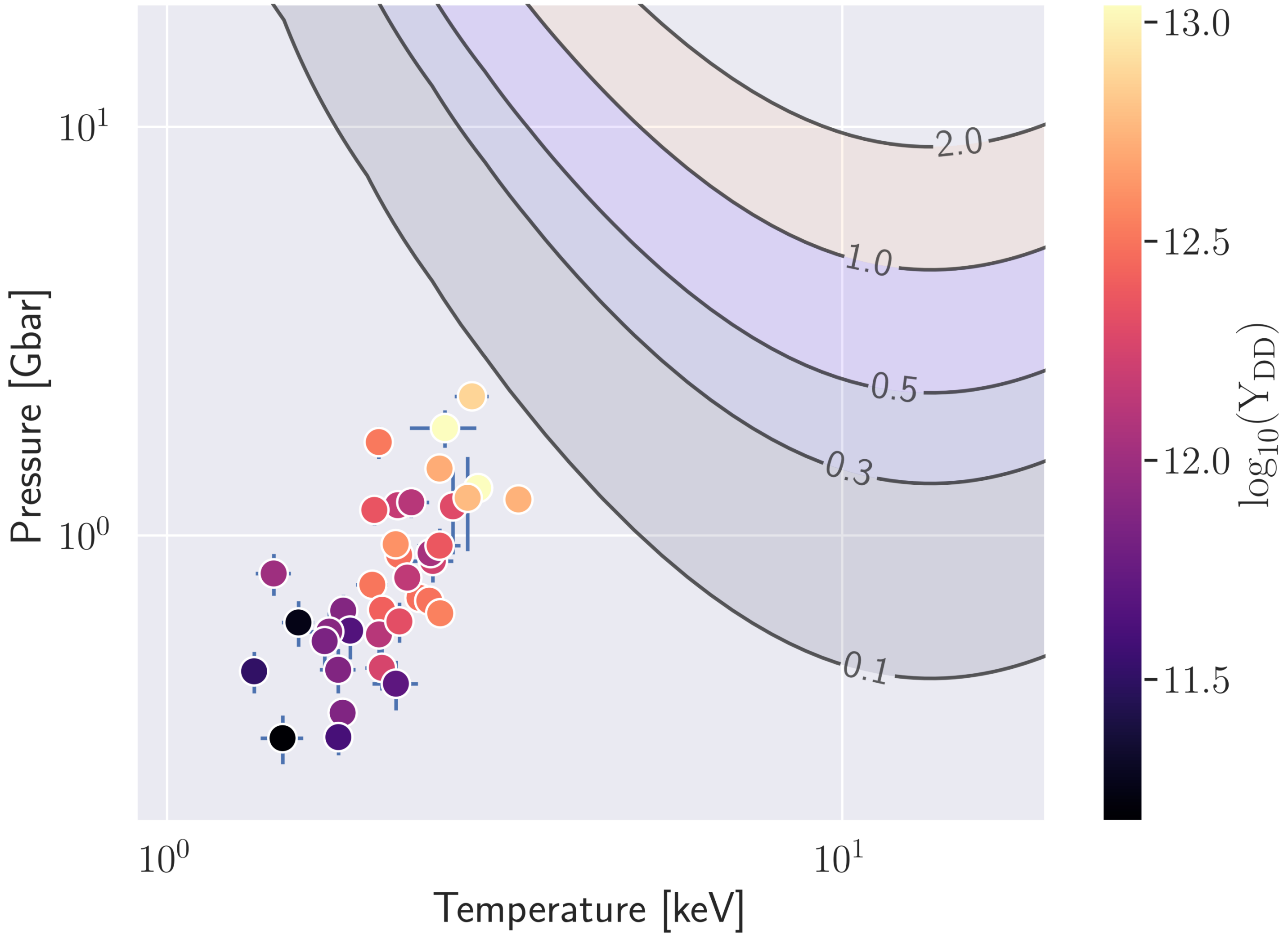


- We analyzed a database of 36 MagLIF experiments dating back to 2015
- Includes a wide range of neutron yields, preheat configurations, initial magnetic field strengths, fill densities, etc.
- Method finds plasma parameters consistent with the full ensemble of different data, not just a handful of instruments

$$\chi = \frac{\varepsilon_\alpha}{24} P_{\mathrm{HS}} \tau_{\mathrm{E}} \frac{\langle \sigma v \rangle_{\mathrm{DT}}}{T^2}$$

* P.F. Knapp *et al.*, manuscript in preparation.

Multiple *existing* data points show the ability to scale to self-heating at realizable drive current



- Using analytic scaling theory*, we can assess the performance of experimental data points at larger driver energy
- We choose a scaling path that preserves implosion time, radiation losses, ion-conduction losses, and end-losses

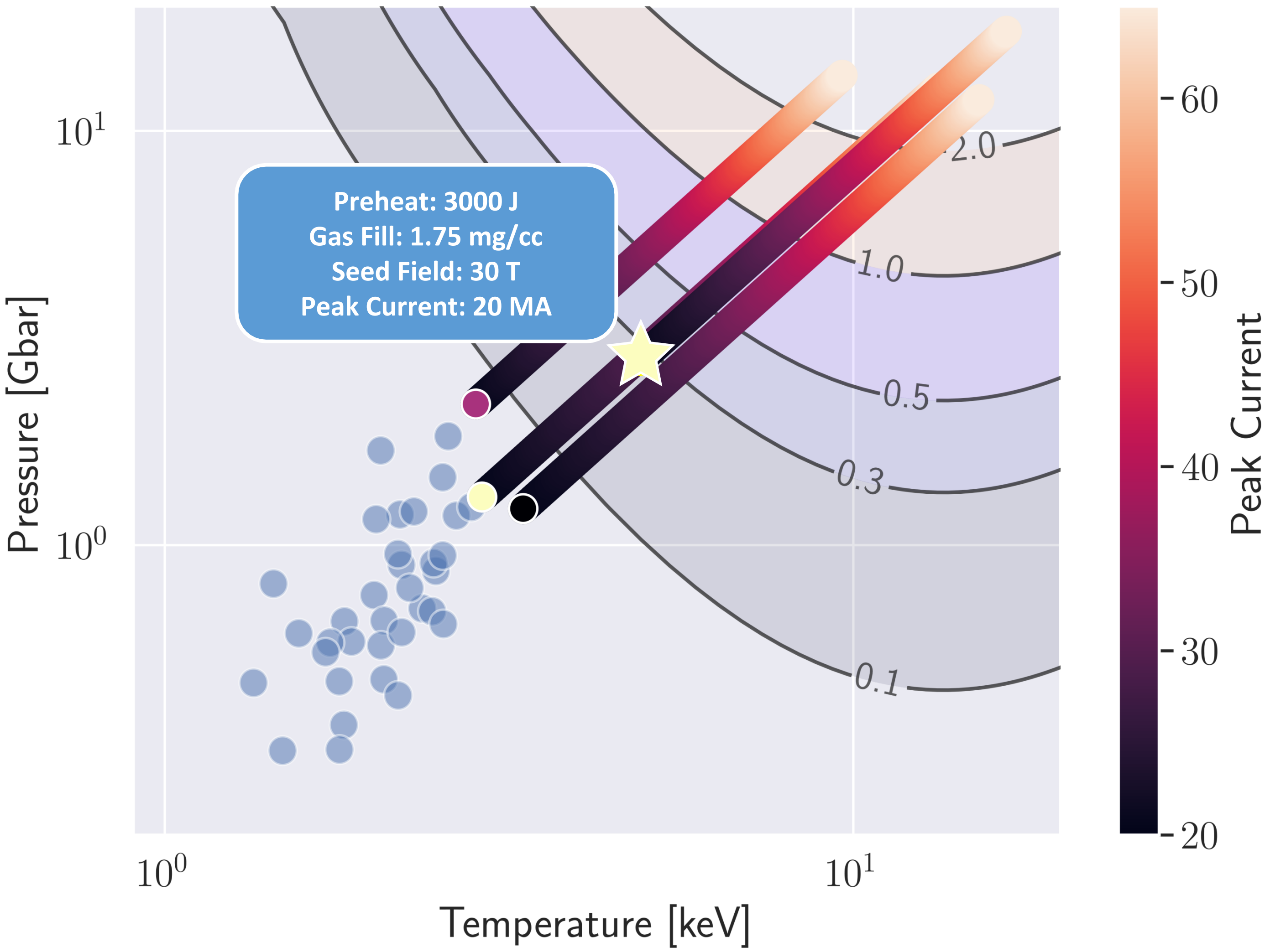
$$P_{no-\alpha} \propto I_{peak}^{1.5}$$

$$T_{no-\alpha} \propto I_{peak}$$

$$Y_{no-\alpha} \propto I_{peak}^{6.2}$$

* P.F. Schmit and D.E. Ruiz., Phys. Plasmas **27**, 062707 (2020)

A design utilizing optimized input parameters on Z scales to tens of MJ's at ~60 MA



Shot	Y_{DD} [10^{13}]	$\chi_{no\text{-}\alpha}$=1	$Y_{no\text{-}\alpha}$=1 MJ	Y_{α} [MJ]
z3179	0.5	40 MA	49 MA	6-10
z3236	1.1	38 MA	44 MA	5-9
z3576	0.7	45 MA	62 MA	5-10
*Opt.	21	28 MA	41 MA	3-4.2

- The optimized target exceeds $Y_{no\text{-}\alpha}$=1 MJ at the lowest drive current
- Yield amplification due to α-heating is 3-4x
- At 60 MA this target produces >40 MJ

*S.A. Slutz, et al., Physics of Plasmas **23**, 022702 (2016)

The NNSA has begun working toward a Next Generation Pulsed Power project that Sandia anticipates will be capable of tens of MJ yields

- We are presently working on defining the specific mission need and requirements with the NNSA and our nuclear security enterprise partners
- The nominal proposal is a facility that would be ~3x the size and ~9x the power of the existing Z facility at Sandia National Laboratories
- Like Z today, it would support the missions of all three NNSA laboratories and provide data on
  - Hostile radiation environments
  - Dynamic material properties
  - Complex weapons physics

Acting NA-113 director Sarah Nelson memo to James Peery on September 30, 2021

NNSA
National Nuclear Security Administration

Department of Energy
National Nuclear Security Administration
Washington, DC 20585

September 30, 2021

FROM: SARAH NELSON
ACTING DIRECTOR, OFFICE OF EXPERIMENTAL SCIENCE

TO: JAMES S. PEERY
DIRECTOR, SANDIA NATIONAL LABORATORY

SUBJECT: Authorization for Preparation of mission needs and program requirements document

Acting Deputy Administrator for Defense Programs Phil Calbos in a memo dated July 12, 2018, authorized the start of CD-0 activities and Analysis of Alternatives (AoA) for several projects including a "Future HED Capability" for NA-113.

In accordance with that memo and after further review and consultation with the Office of Experimental Science Executives, NA-113 is now ready to pursue CD-0 for a "Next Generation Pulsed Power (NGPP)" capability as a key component of a future HED portfolio.

The present memo thereby authorizes the commencement of the Mission Need Statement (MNS) and Program Requirements Document (PRD) preparations needed to achieve CD-0. As such, the cognizant NA-113 program manager for NGPP, Ann Satsangi, will reach out to define and determine the approach forward.

cc:
NA-APM Richard Persons, Jennifer Hoynak
SNL Susan Seestrom, Dan Sinars, Nancy Davis