Sandia National Laboratories

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

PRESENTED BY

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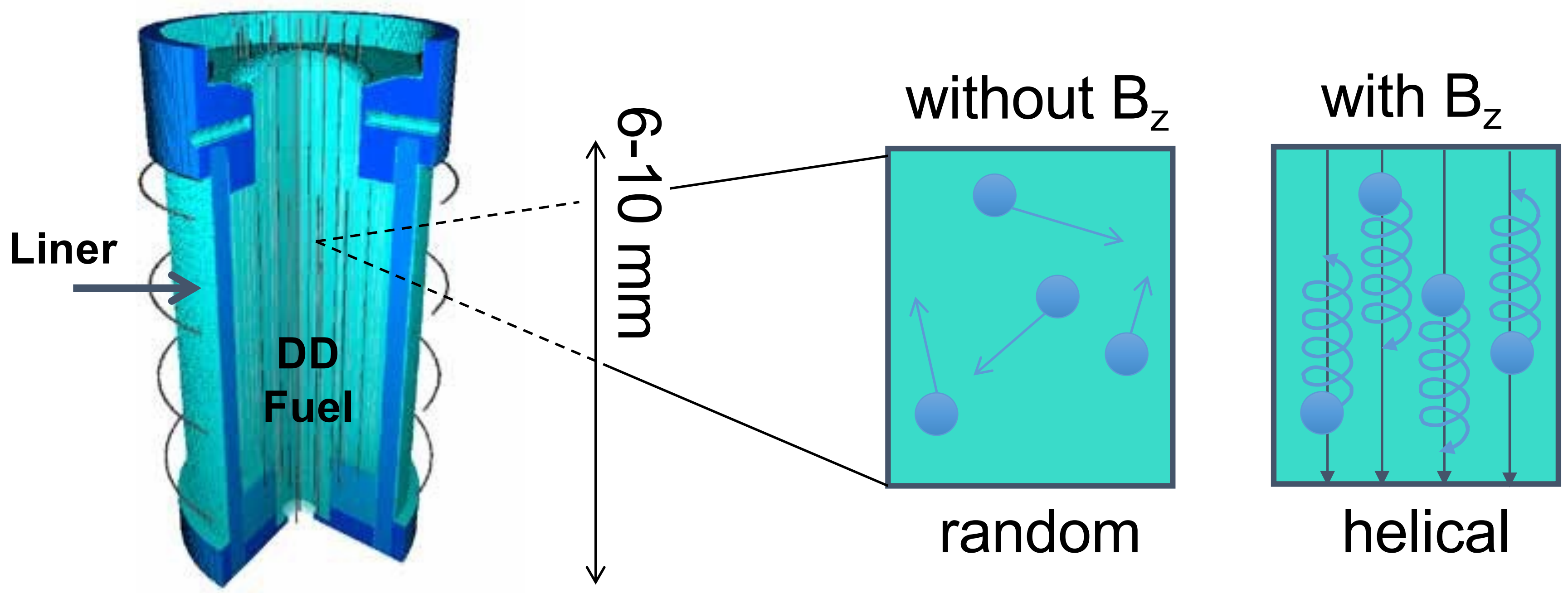
Fusion Power Associates | December 15-16, 2021

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).

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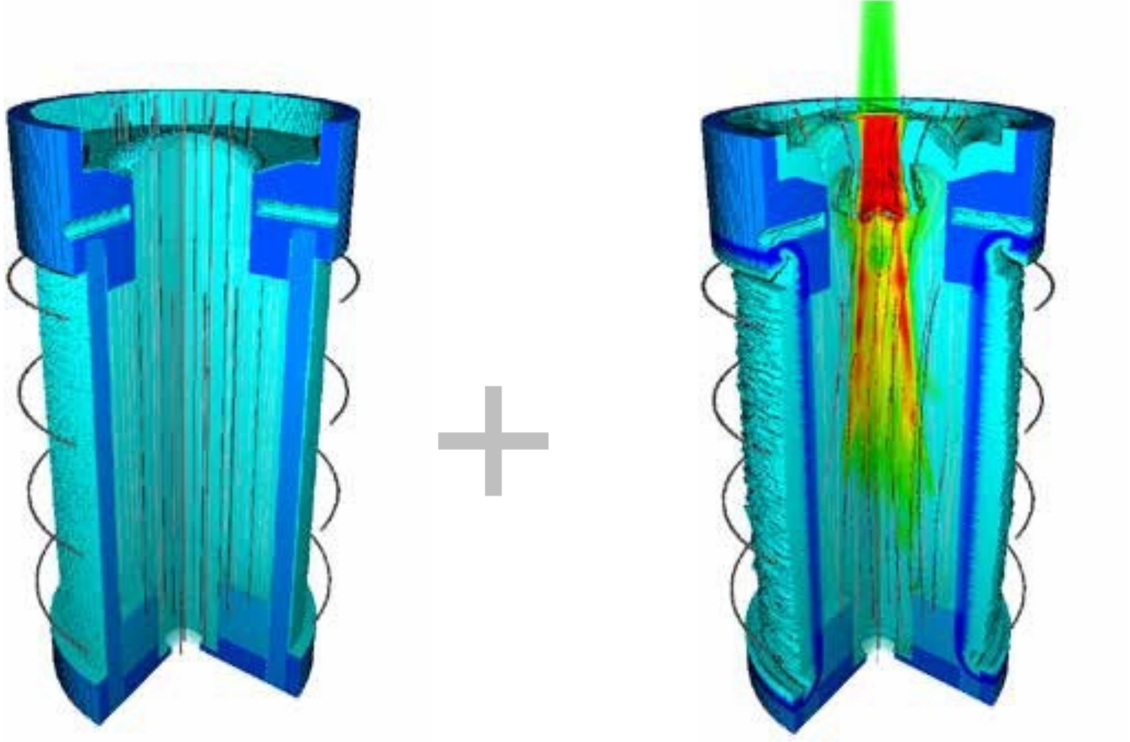
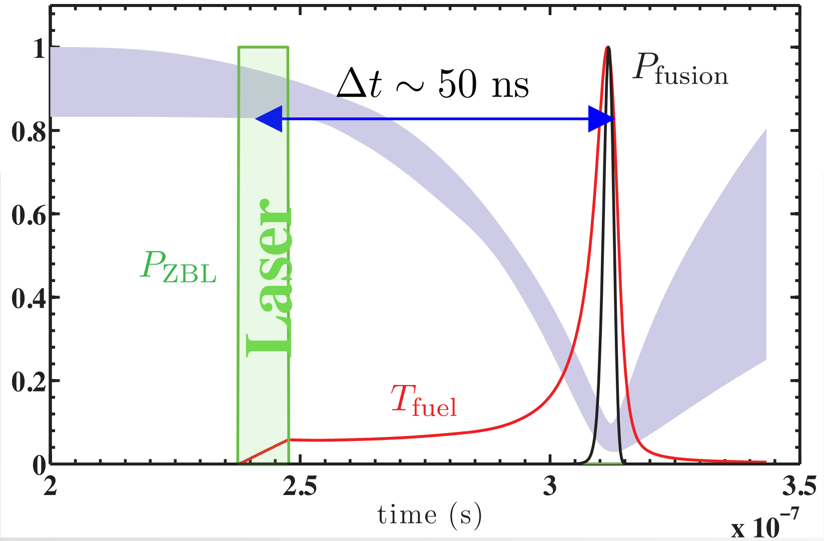


- **Laser preheat: 100-200 eV**
  - **Uses Z-Beamlet Laser**
  - **Relax convergence requirement**
  - **CR=$R_{initial}/R_{final}$= 120 → 20-40**



Magnetization

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Preheat

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

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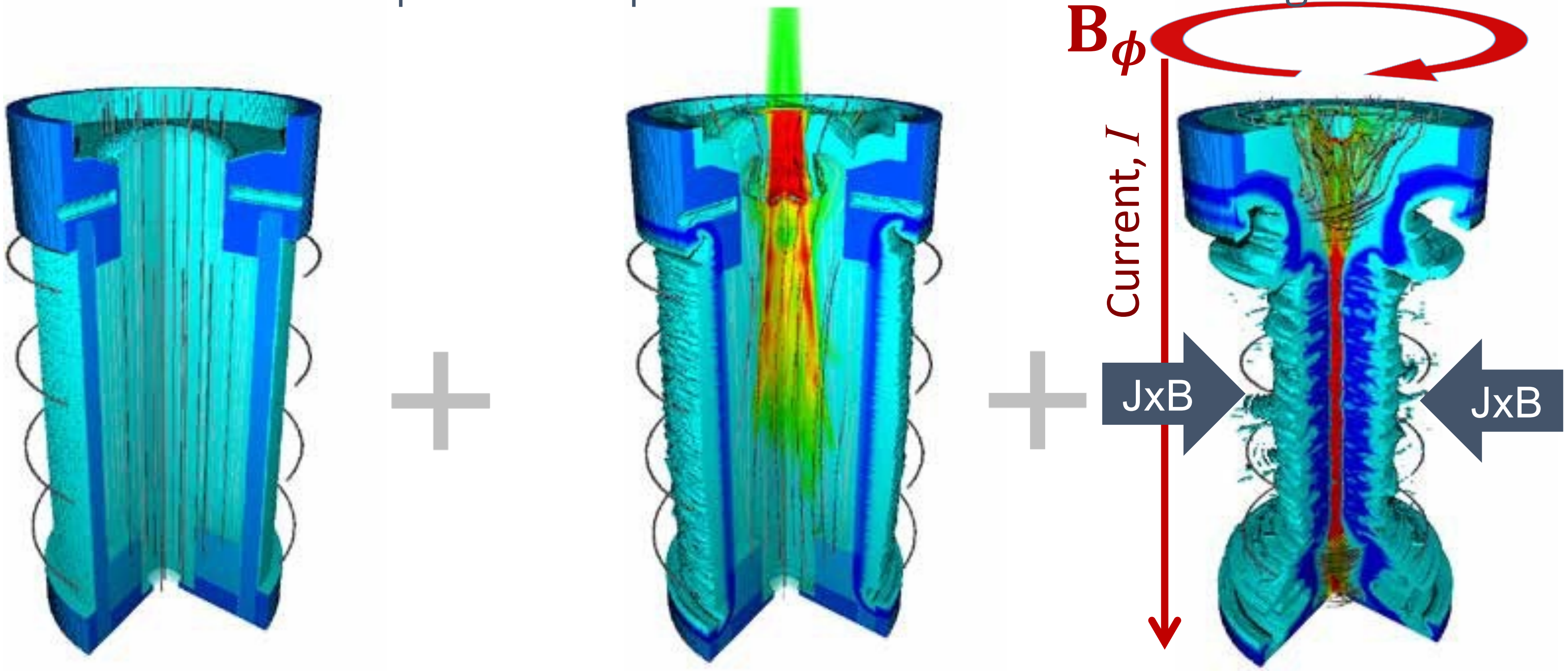

Magnetically Driven Implosion

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

Magnetization

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Implosion

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

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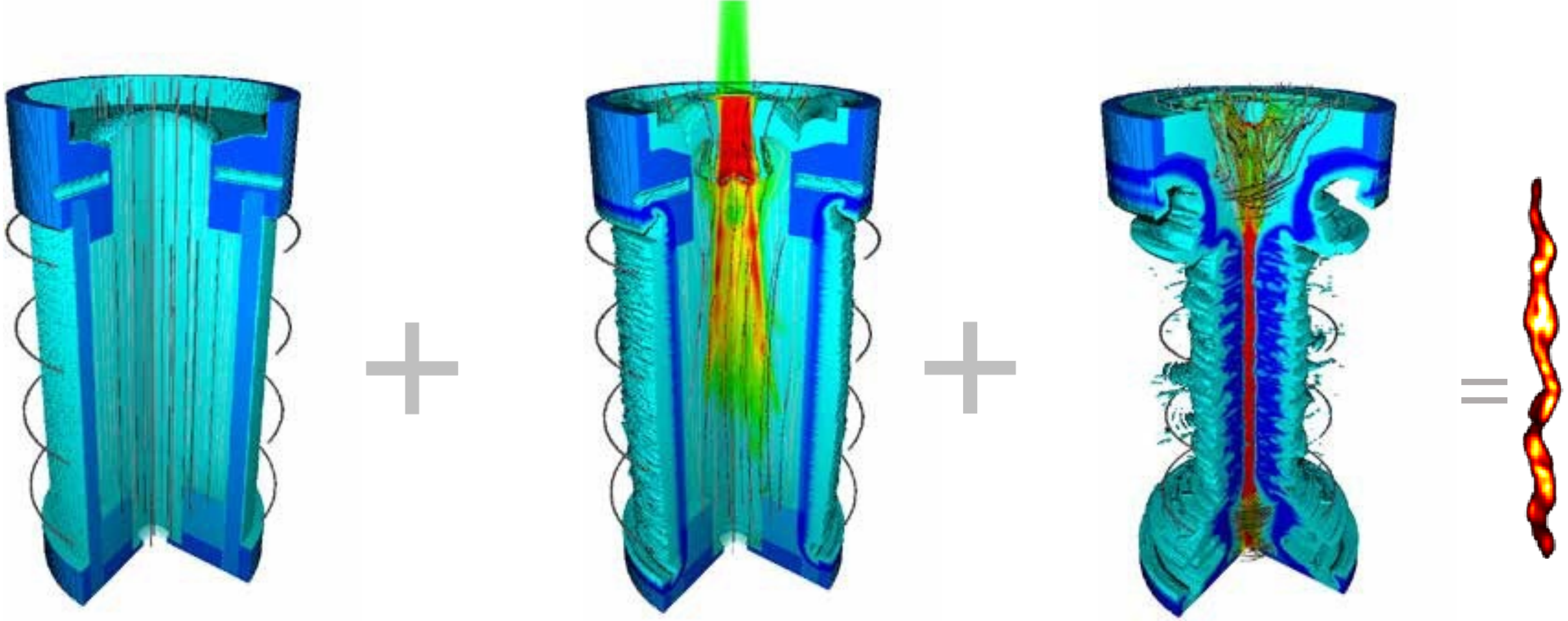

Stagnation

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

Magnetization

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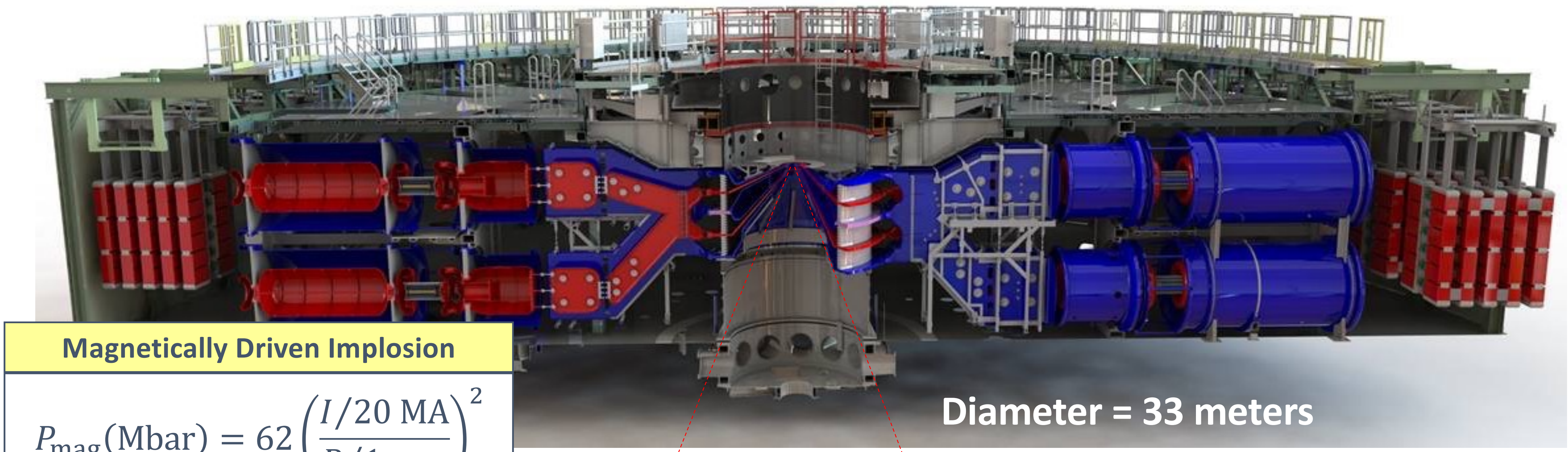
We have been using the multi-MJ Z pulsed power facility and the adjacent multi-kJ Z-Beamlet laser to perform integrated tests of the MagLIF concept since 2015

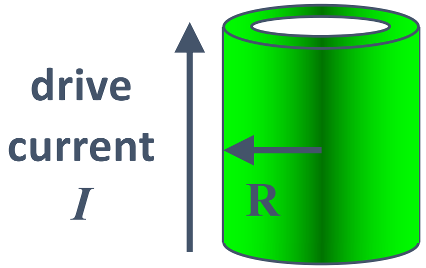
Z Pulsed Power Facility



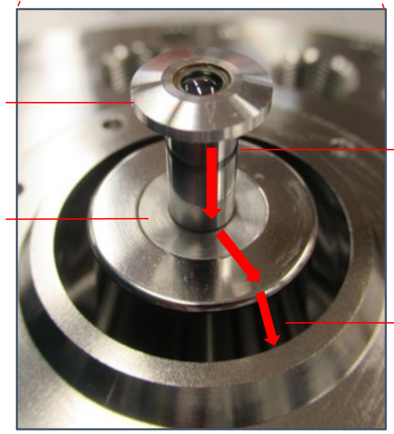
Diameter = 33 meters

Magnetically Driven Implosion

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



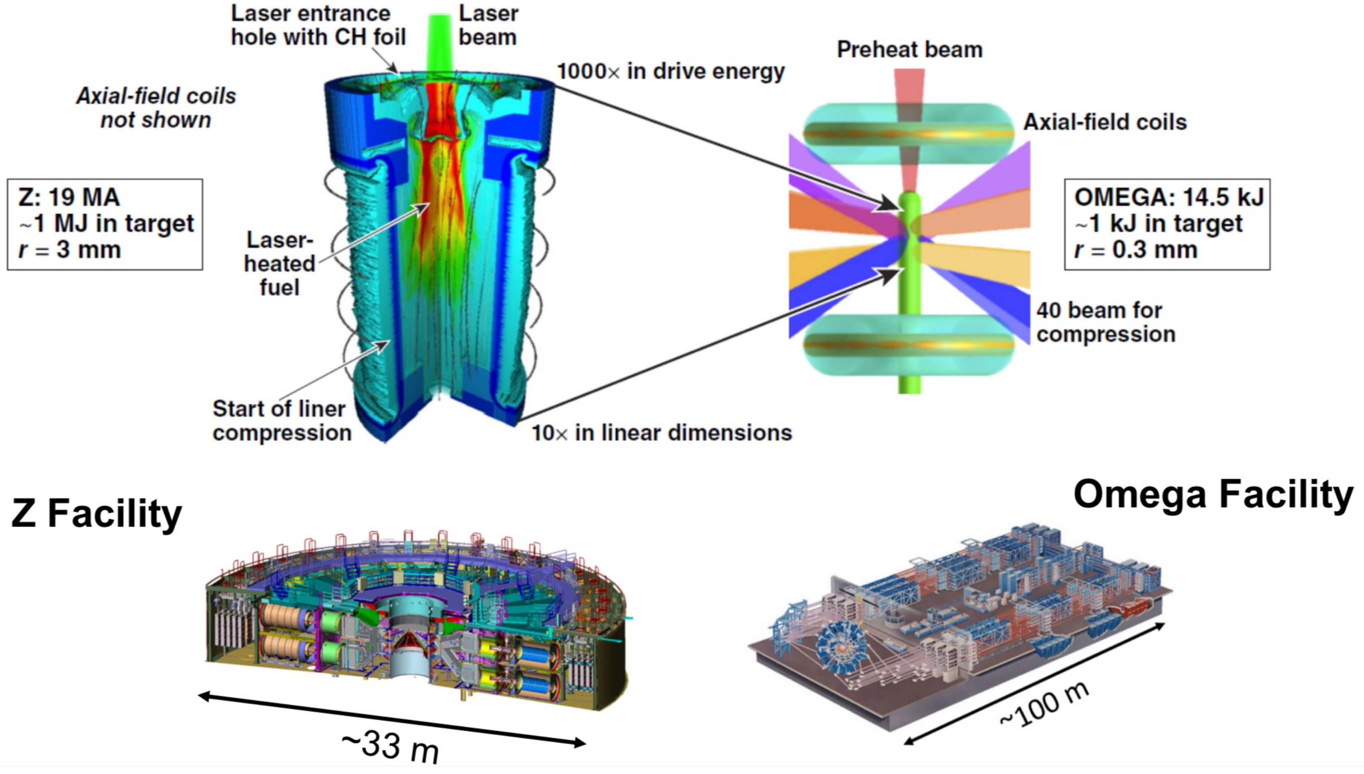
~7 Mbar → >100 Mbar during expt.

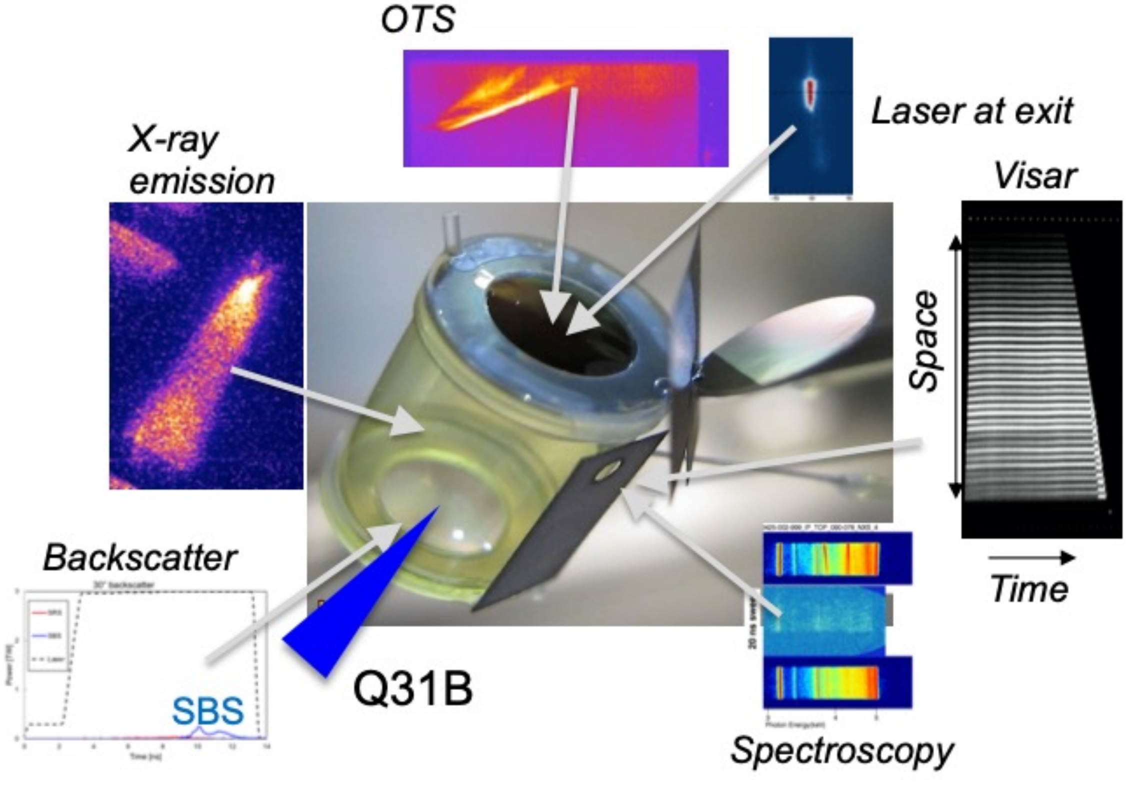


Beryllium liner (MagLIF)
Diameter = 6 mm

Peak electrical current ~ 20 MA
Rise time ~ 100 nanoseconds

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).
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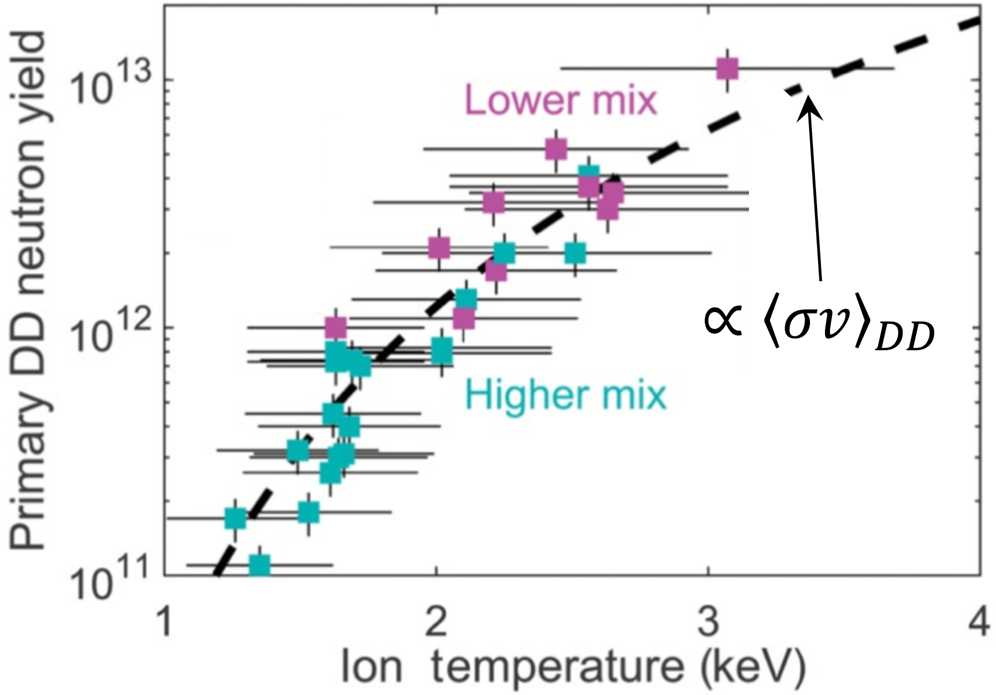
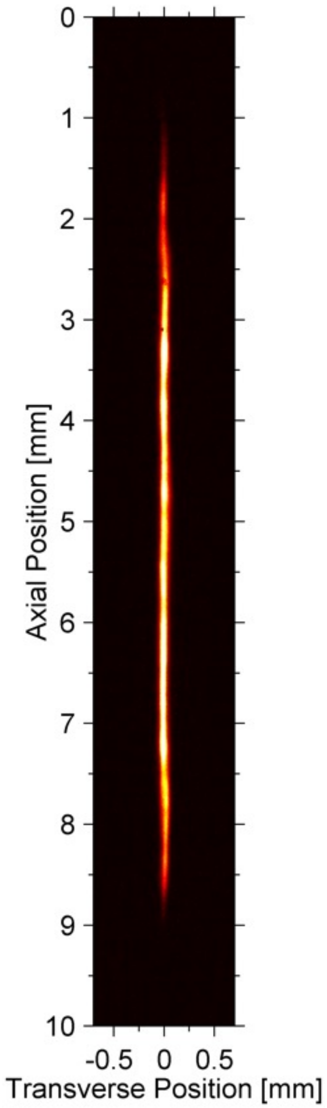
D.H. Barnak *et al.*, Phys. Plasmas (2020).

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.





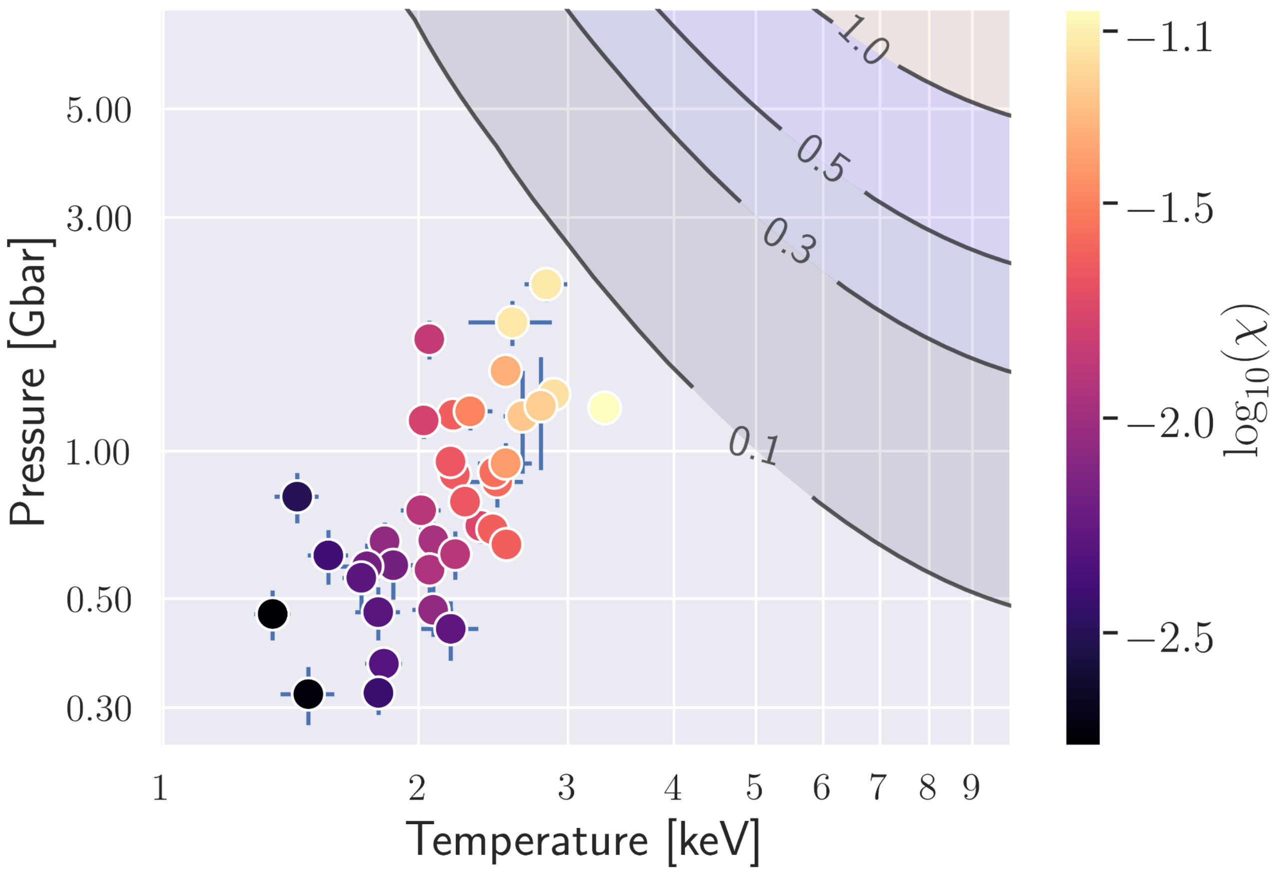
Hallmark of MIF: significant fusion only when both the **laser preheat** and **magnetization** stages are present.

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 criteria 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

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

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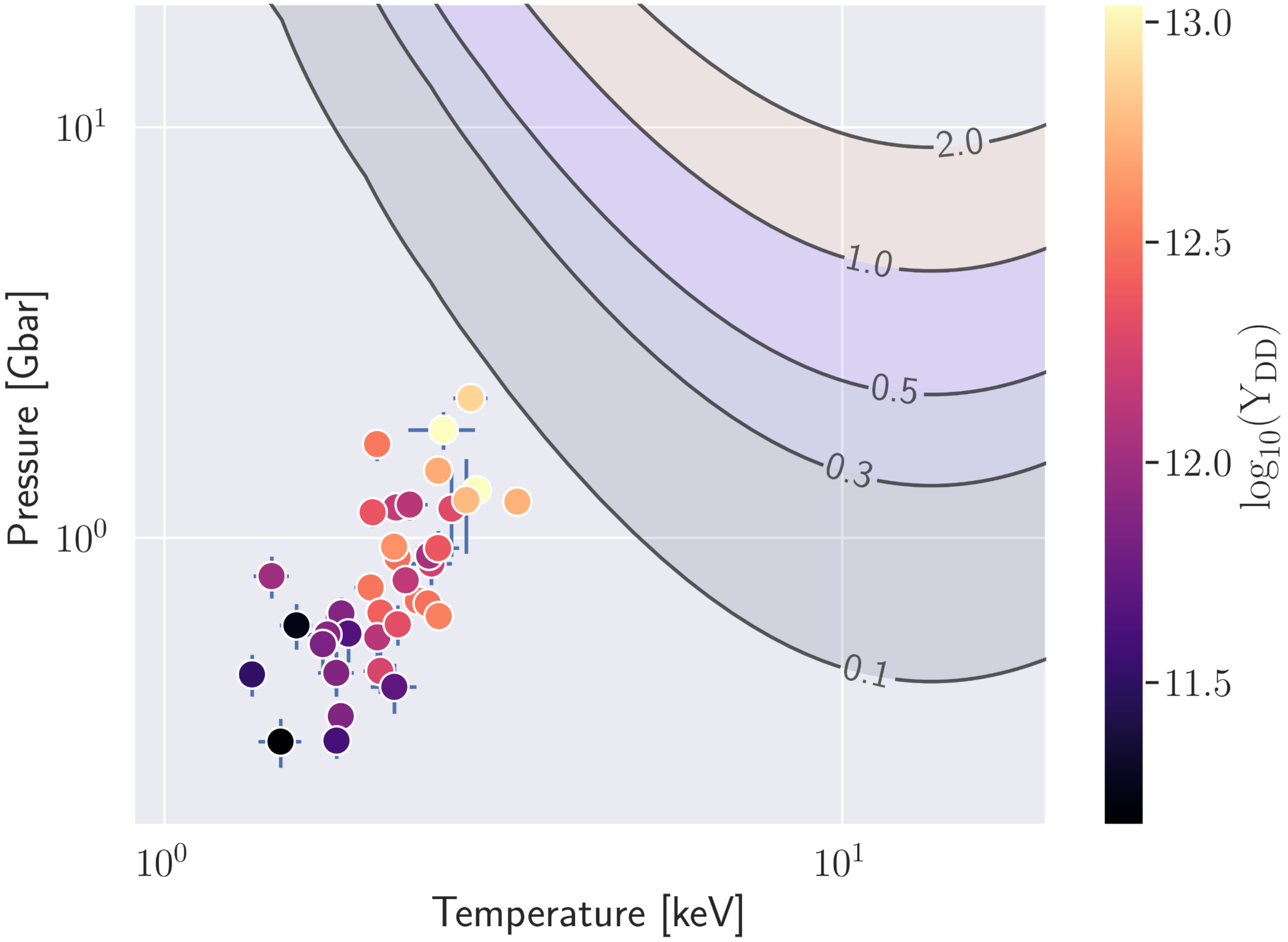
* P.F. Knapp *et al*., manuscript in preparation.

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

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

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

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

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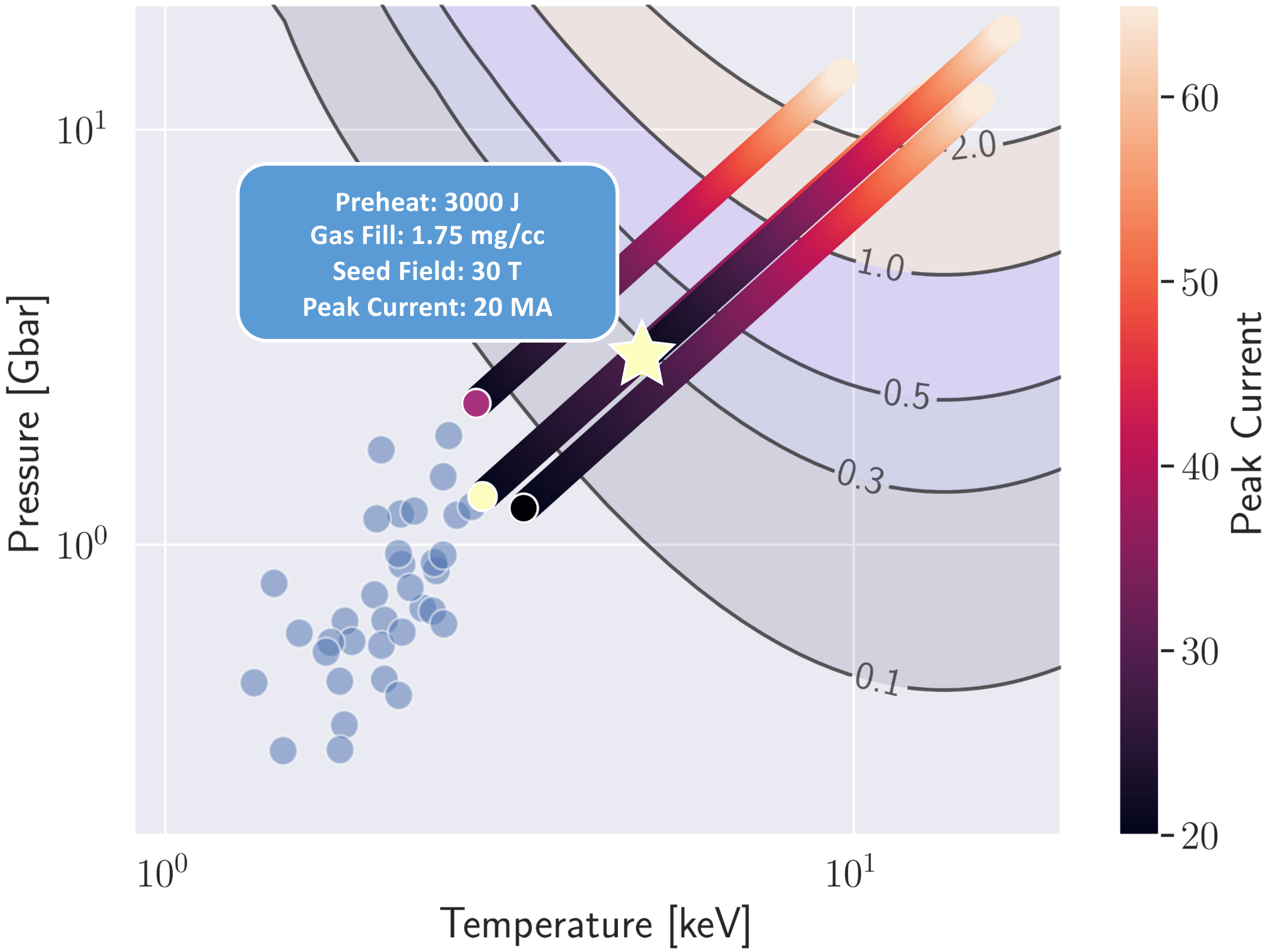
* P.F. Schmit and D.E. Ruiz., Phys. Plasmas **27**, 062707 (2020)

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



Preheat: 3000 J
Gas Fill: 1.75 mg/cc
Seed Field: 30 T
Peak Current: 20 MA

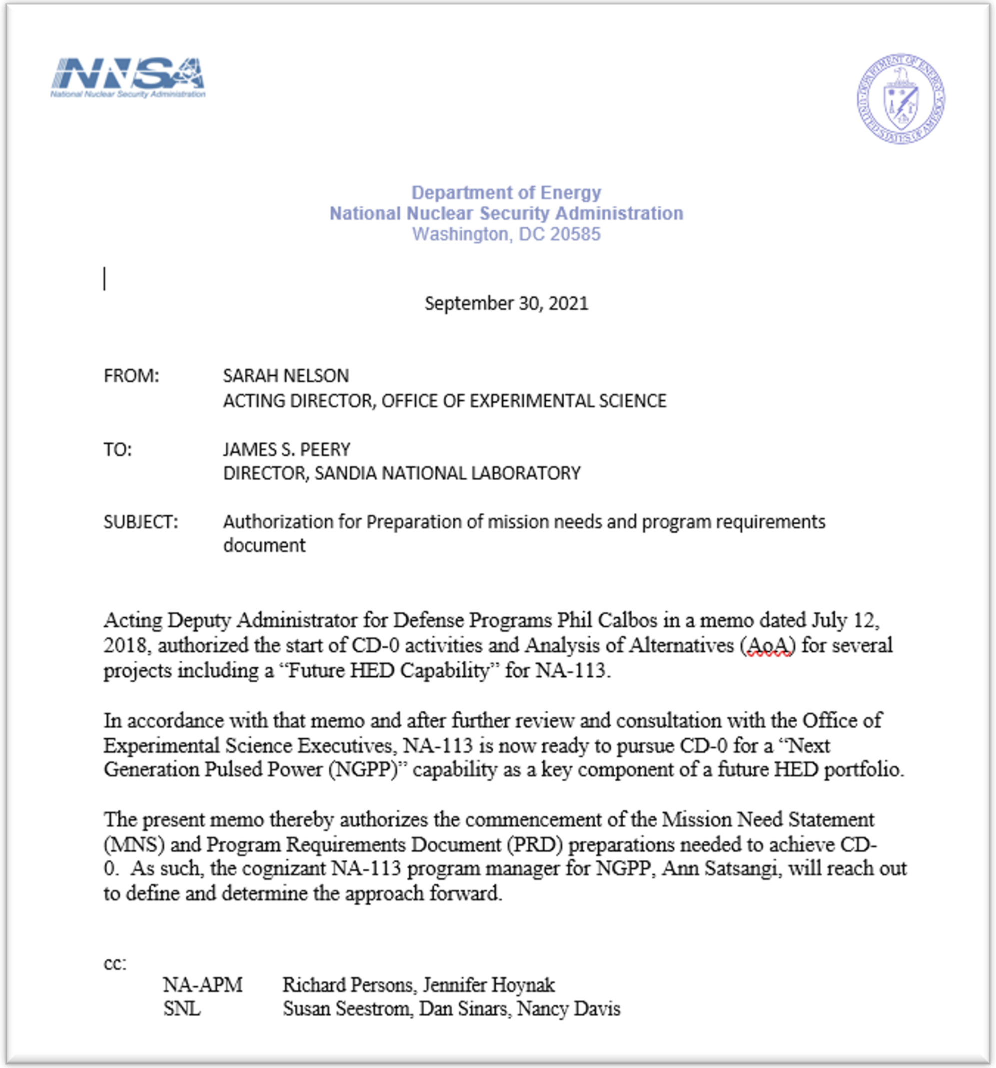
Shot	Y_{DD} [10^{13}]	$\chi_{no\text{-}\alpha}=1$	$Y_{no\text{-}\alpha}=1$ MJ	Y_{α} [MJ]
z3179	0.5	40 MA	49 MA	6-10
z3236	1.1	38 MA	44 MA	5-9
z3576	0.7	45 MA	62 MA	5-10
*Opt.	21	28 MA	41 MA	3-4.2

- 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

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