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An overview of magneto-inertial fusion on the Z Machine at Sandia National Laboratories

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ABSTRACT

- Magnetized Liner Inertial Fusion (MagLIF) is the first magneto-inertial fusion (MIF) concept to demonstrate fusion relevant temperatures, significant fusion production (>1e13 primary DD neutron yield) and magnetic trapping of charged fusion particles [1, 2]
- MagLIF is pursued on the Z Machine at Sandia National Laboratories, where an axially pre-magnetized, laser-preheated fusion fuel is imploded inside a cylindrical liner using ~20 MA to generate fusion conditions.
- MagLIF has the potential to achieve high gain and yield on a next generation pulsed power facility, and could provide an interesting path towards magneto-inertial fusion energy

BACKGROUND

- In MagLIF, a centimeter-scale beryllium tube or “liner” is filled with a fusion fuel, axially pre-magnetized, laser pre-heated and imploded using ~20 MA from the Z Machine in order to generate a thermonuclear column of plasma.
  - The laser preheat raises the initial adiabat of the fuel (100s eV)
  - The electrical current implodes the liner using ~20 MA and quasi-adiabatically compresses the fuel via the Lorentz force
  - The axial magnetic field (initially 10s T) limits thermal conduction losses from the fuel to the liner walls during the implosion, and is fluxed compressed to ~1000s T to increase trapping of charged fusion products

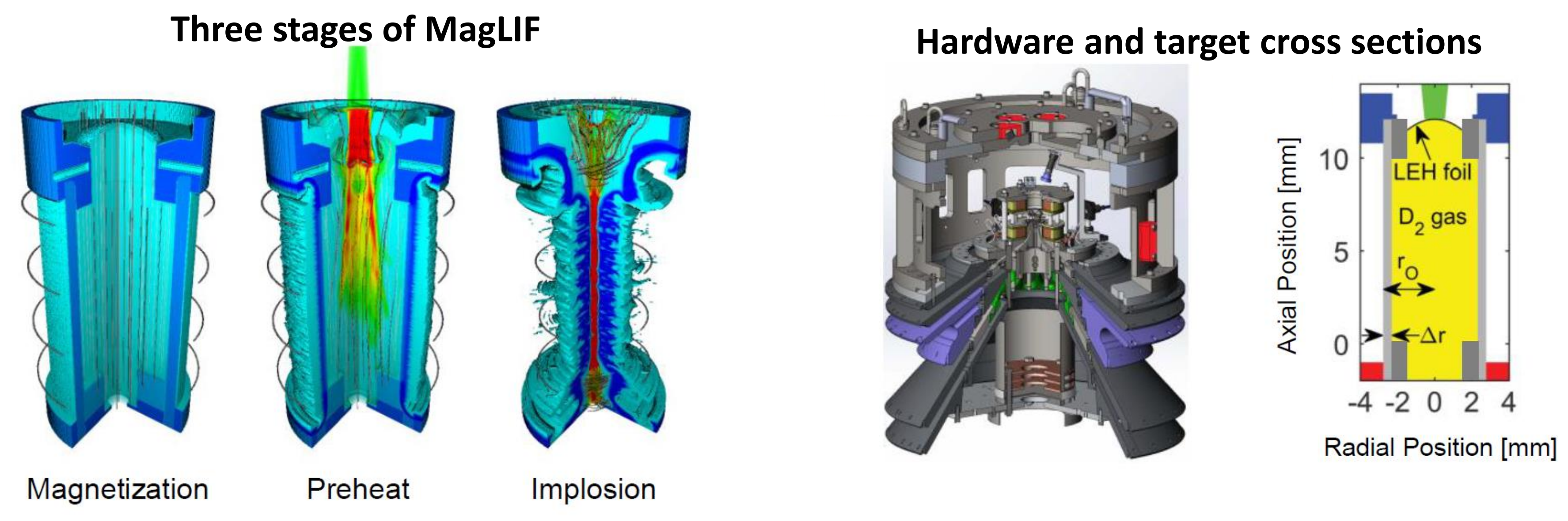


Fig 1. *Three-dimensional simulation demonstrating the three stages of MagLIF (left) and load hardware and target cross sections (right)*

- The magnetization relaxes the areal density requirements and opens a wide area of parameter space for self-heating. Present-day MagLIF has demonstrated relevant magnetization levels of BR = 0.3 - 0.5 MG-cm.

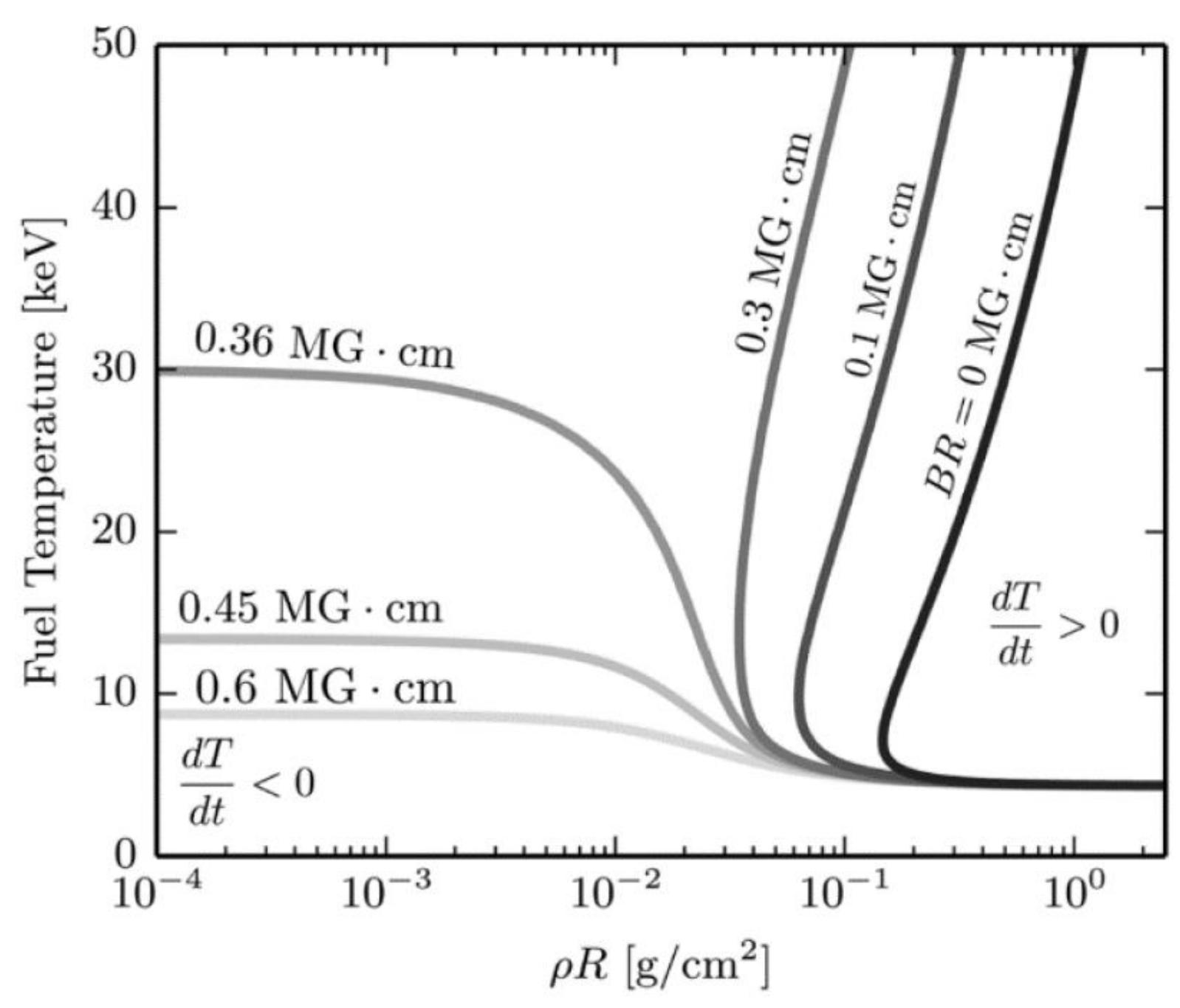
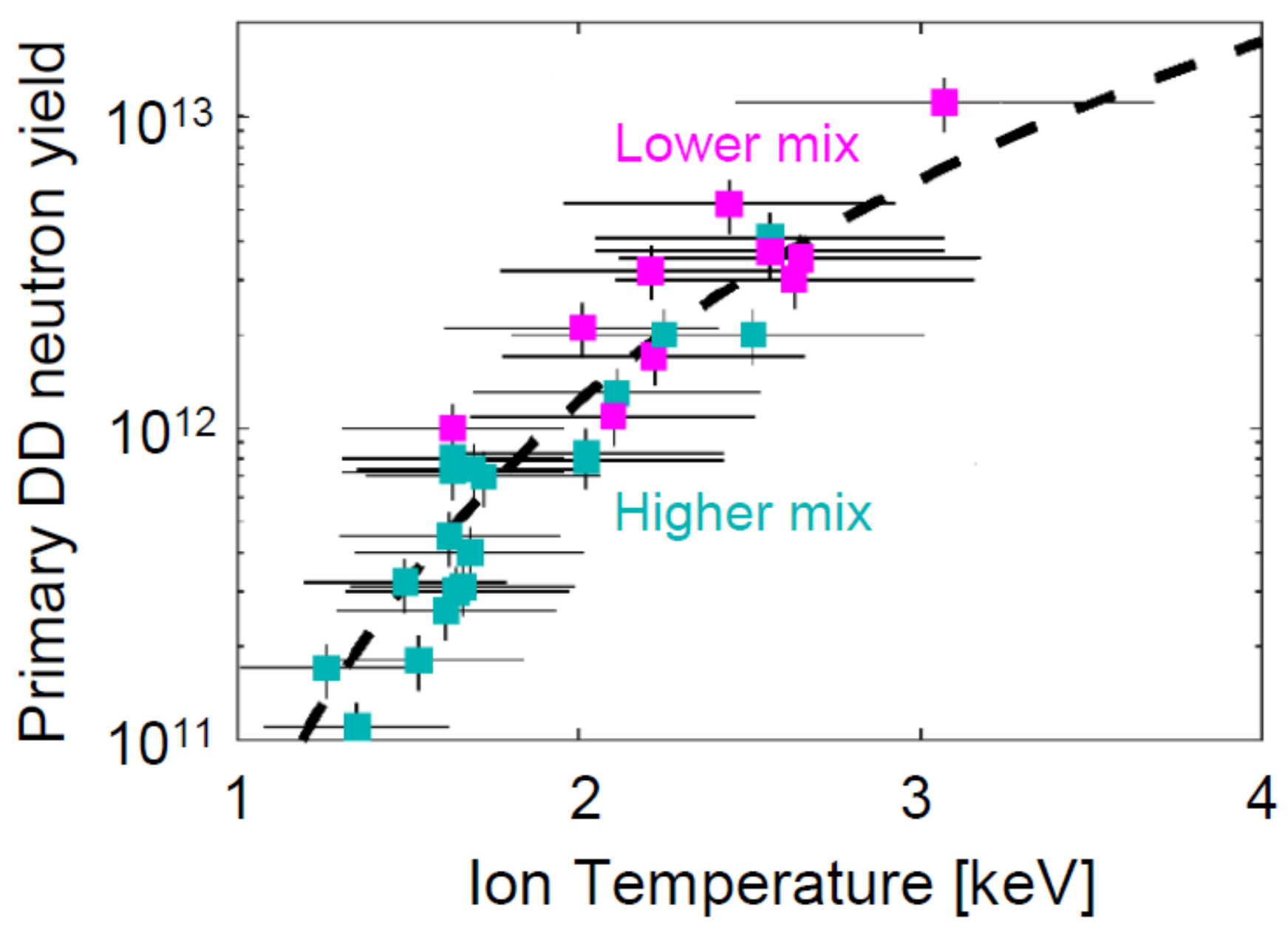


Fig 2. *Lindl diagram showing self-heating contours for various magnetization values* [3]

- MagLIF performance since the first 2013 experiments can be captured in a plot of primary DD yield vs ion temperature, which scales with the DD fusion reactivity. Early improvements to performance were accomplished by replacing fuel-facing components with beryllium to reduce mix.

Fig 3. *DD neutron yield as a function of ion temperature* [4]



MAJOR RESEARCH AREAS IN MagLIF

IMPLOSION STABILITY

- MagLIF is susceptible to the magneto Rayleigh-Taylor (MRT) instability, which may significantly affect the quality of the implosion, compression, and inertial confinement of the fusion fuel.
  - Experimentally benchmarked MRT simulations in pre-seeded liner implosions [5]
  - Demonstrated enhanced stabilization with dielectric coated liners to mitigate the electrothermal instability that seeds MRT [6, 7]

LASER PREHEAT

- The laser preheat protocol has been continuously upgraded to better reduce LEH window mix, increase the energy coupled to fuel, and optimize the propagation length of the laser
  - Beam profile smoothed using a distributed phase-plate [8]
  - Mix from the laser entrance hole foil reduced using a 24 J, 2 ns-long pre-pulse 20 ns prior to main preheat pulse [9]
  - 3d simulations suggest additional energy can be coupled using cryogenically cooled targets to allow thinner foils by reducing initial fuel pressure [10]

CURRENT DELIVERY AND APPLIED MAGNETIC FIELD

- The transmission line leading up to the target was re-designed to improve current coupling from 16 to 20 MA while simultaneously enabling the possibility of 30 T pre-magnetization
  - Experiments with simultaneous improvements to laser preheat, current delivery and applied axial magnetic field increased performance by an order of magnitude (2 kJ DT equivalent yield) [4]

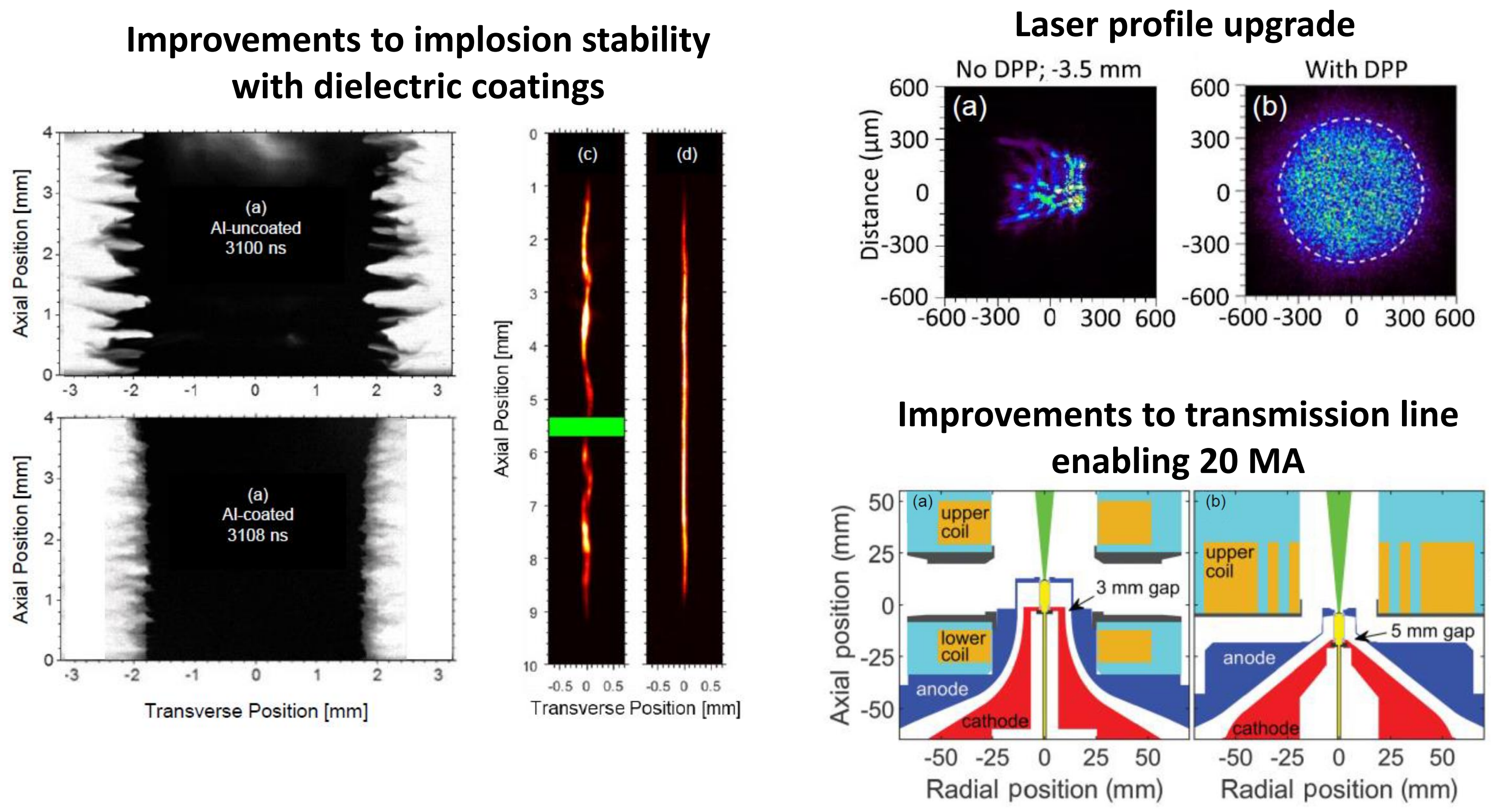


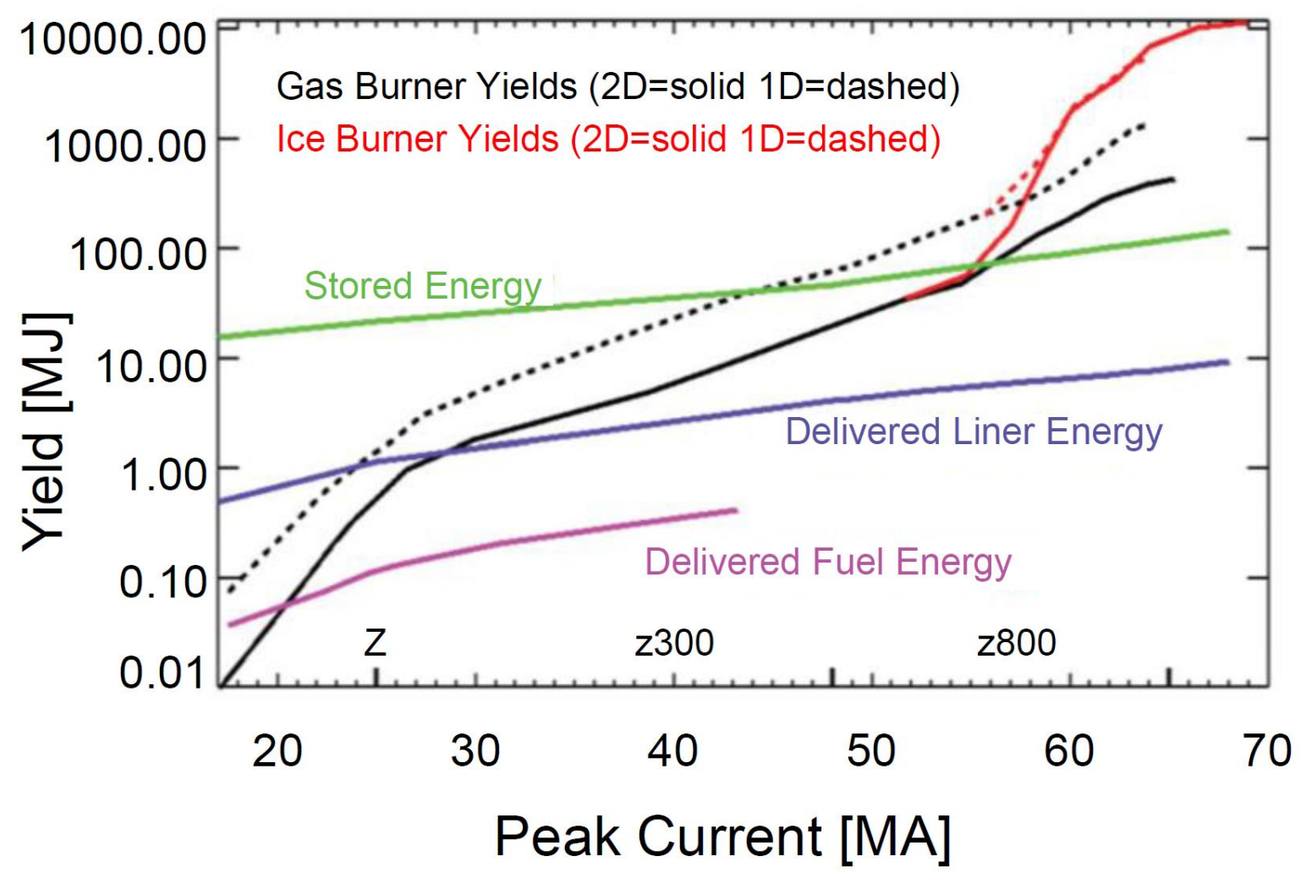
Fig 4. *Images showing improvements to implosion stability in liners and stagnation columns via dielectric coatings (left), improvements to laser profile using distributed phase-plate smoothing (right, top) and transmission line cross-sections enabling 20 MA of current coupling to the target (right, bottom)*

SCALING TO HIGH YIELD

2D simulations indicate MagLIF has the potential to scale to high yield at currents attainable on a next generation pulsed power machine (~60 MA)

- Performance can be drastically improved by propagating the fusion burn into an annulus of DT ice on the inside of the liner
- With simulated gains of ~70, MagLIF has the potential to be a viable source of fusion energy

Fig 5. *Fusion yield as a function of peak current. At 56 MA, the fusion yield exceeds the stored energy in the capacitor bank* [11]



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