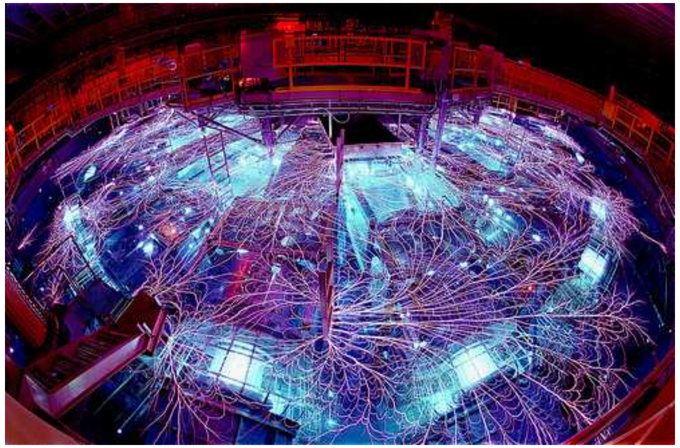
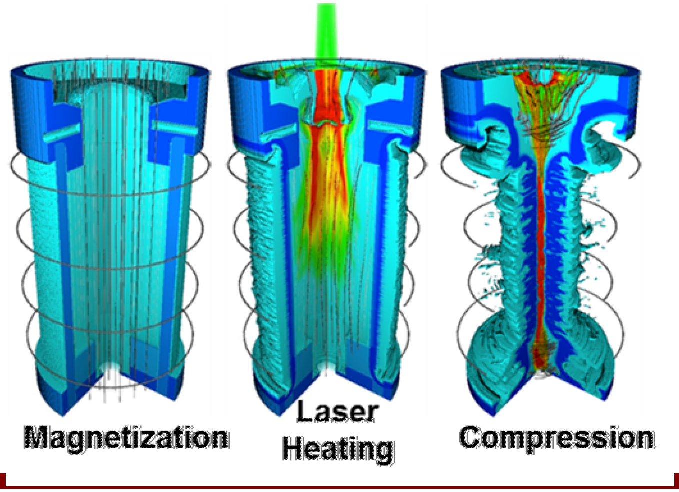
SAND2017-5746C





Increased Load Current In Magnetized Liner Inertial Fusion Experiments

M. R. Gomez, B. T. Hutsel, C. A. Jennings, M. R. Martin, M. E. Cuneo, M. H. Hess, G. Laity, D. C. Lamppa, K. J. Peterson, G. A. Rochau, D. C. Rovang, D. B. Sinars, S. A. Slutz, W. A. Stygar

Sandia National Laboratories

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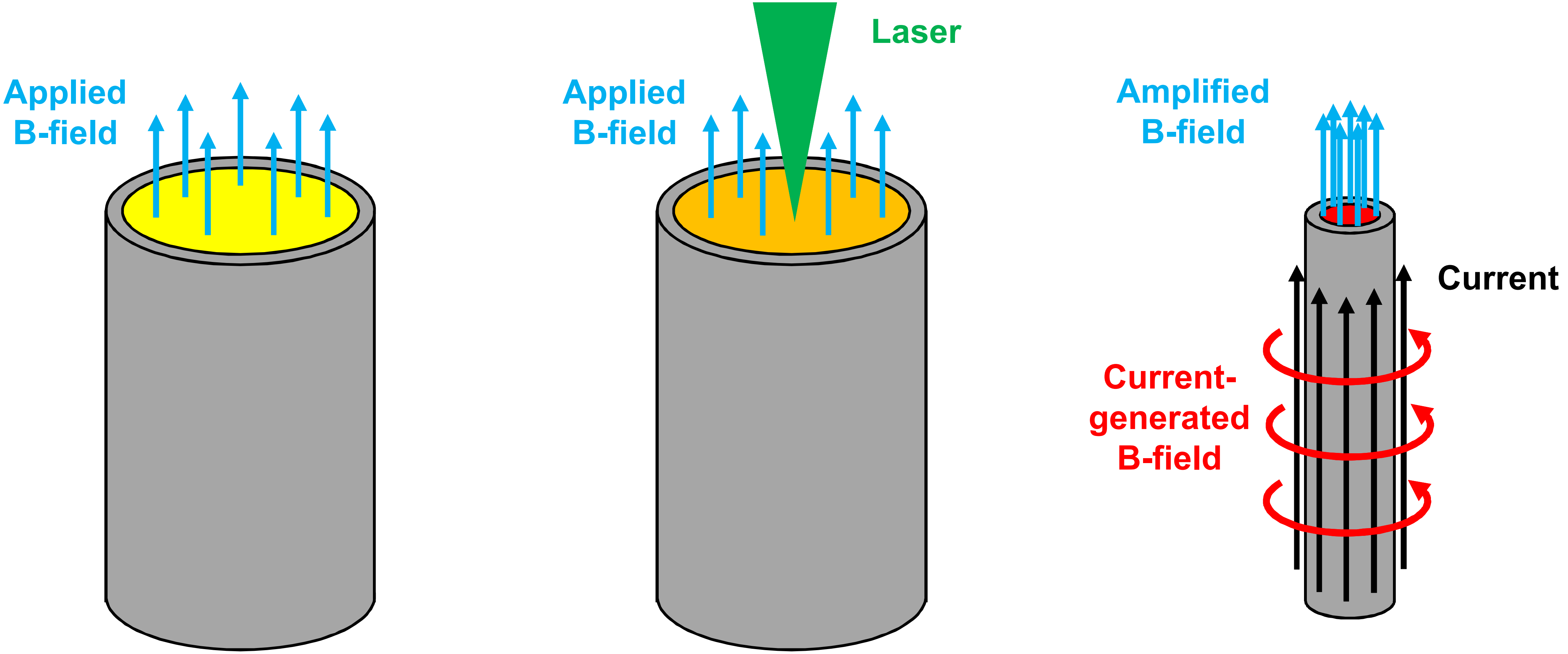
Magnetized Liner Inertial Fusion relies on three stages to produce fusion relevant conditions



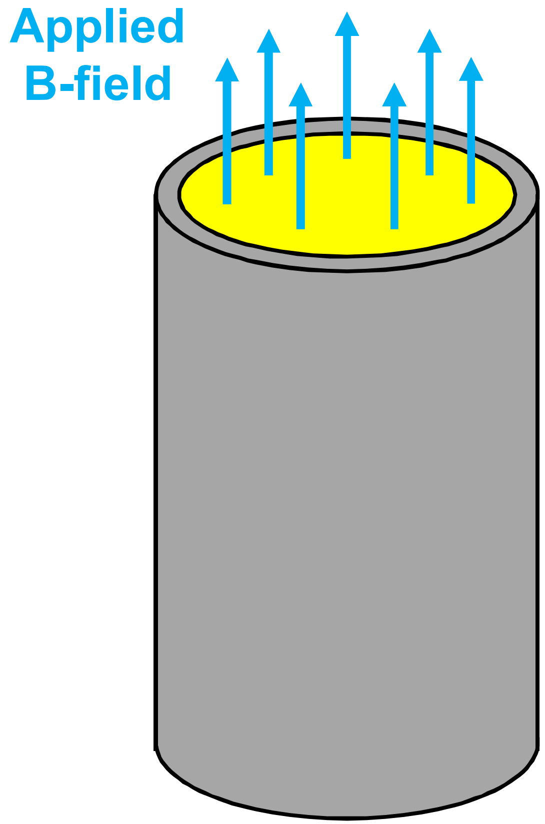
Apply axial magnetic field

Laser-heat the magnetized fuel

Compress the heated and magnetized fuel

S. A. Slutz, et al., Phys. Plasmas 17, 056303 (2010).

An axial magnetic field is applied to limit radial charged particle transport

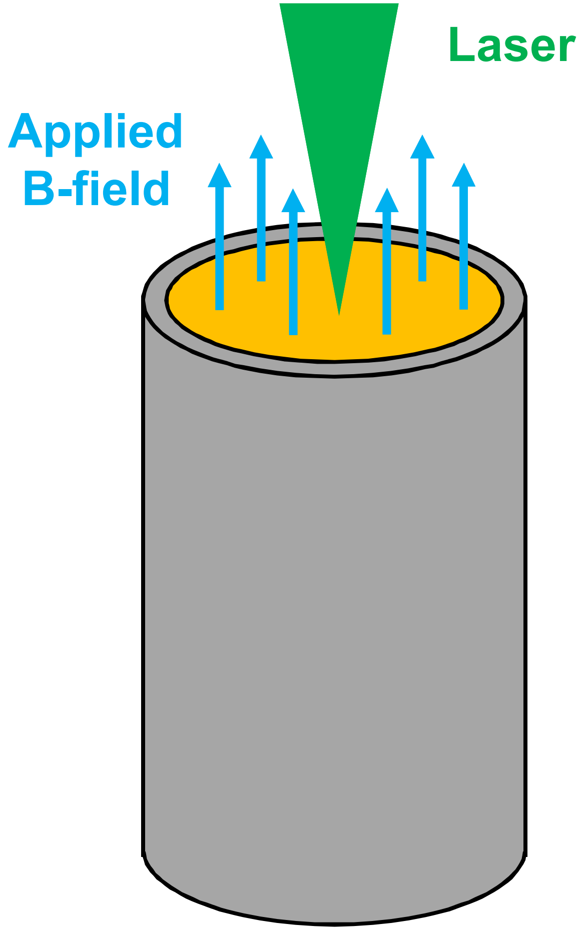


Apply axial magnetic field

- Metal cylinder contains ~1 mg/cm^3 of deuterium gas
  - 10 mm tall, 5 mm diameter, 0.5 mm thick
- Helmholtz-like coils apply 10-30 T
  - 3 ms risetime to allow field to diffuse through conductors

S. A. Slutz, et al., Phys. Plasmas 17, 056303 (2010).

A laser is used to heat the fuel at the start of the implosion

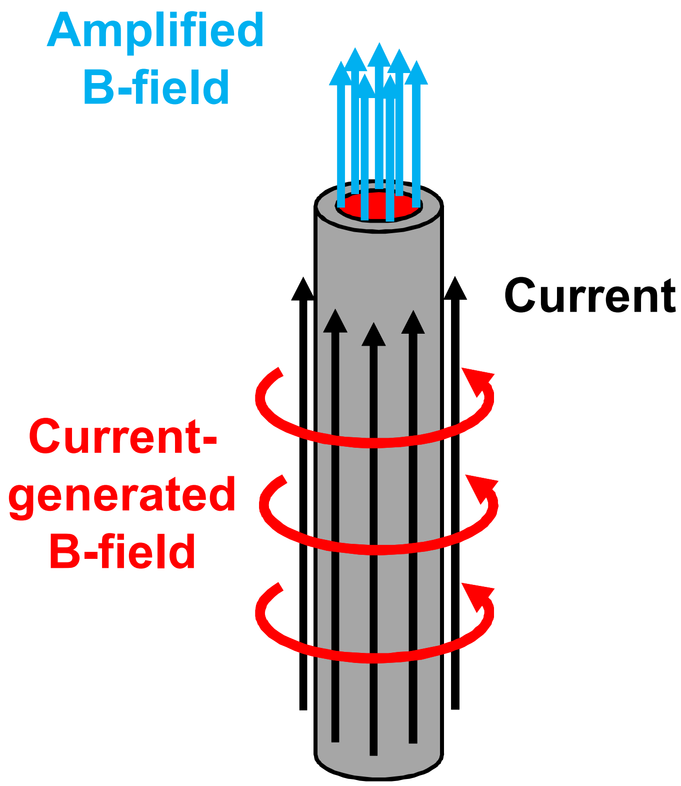


Laser-heat the magnetized fuel

- 527 nm, 2 ns, 2 kJ laser used to heat the fuel
- Laser must pass through ~1 µm thick plastic window
- Fuel is heated to ~100 eV
  - Recall the axial magnetic field limits thermal conduction in the radial direction

S. A. Slutz, et al., Phys. Plasmas 17, 056303 (2010).

The current from the Z machine is used to implode the target



Compress the heated and magnetized fuel

- Axial current is ~17 MA, risetime is 100 ns
  - Generates ~3 kT azimuthal B-field
  - Metal cylinder implodes at ~70 km/s
- Fuel is nearly adiabatically compressed, which further heats the fuel to keV temperatures
- Axial magnetic field is increased to 1-10 kT through flux compression

S. A. Slutz, et al., Phys. Plasmas 17, 056303 (2010).

We have demonstrated key aspects of magneto-inertial fusion on Sandia's Z facility

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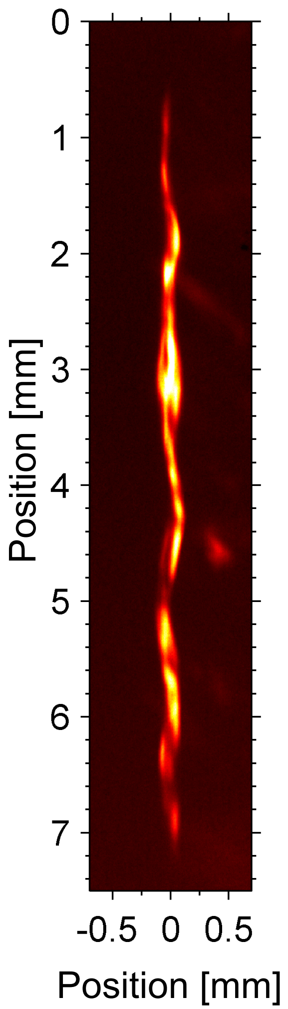
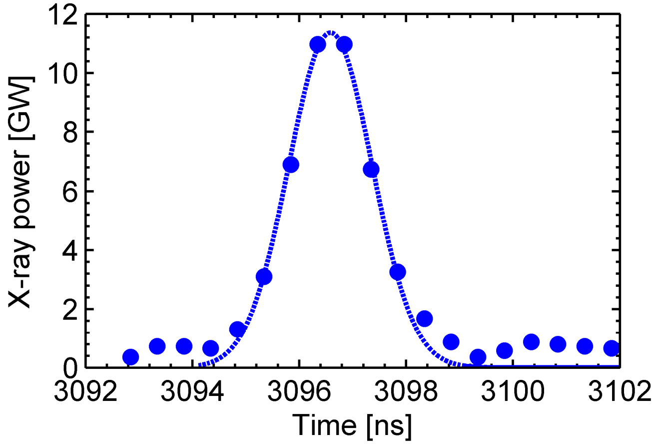
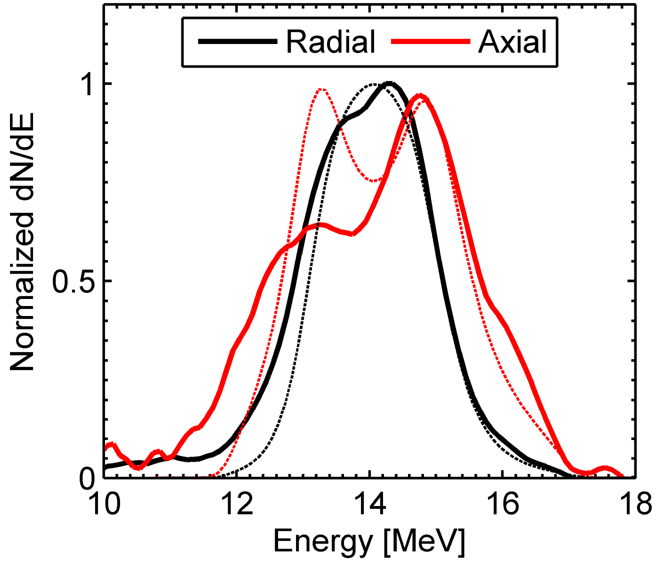
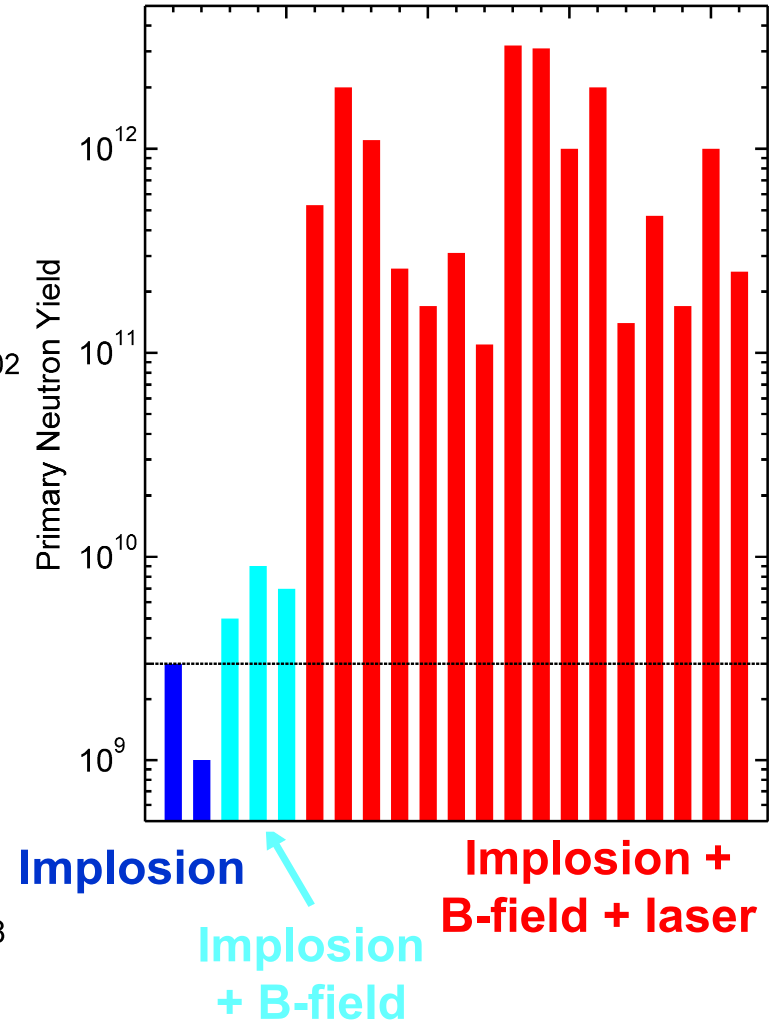




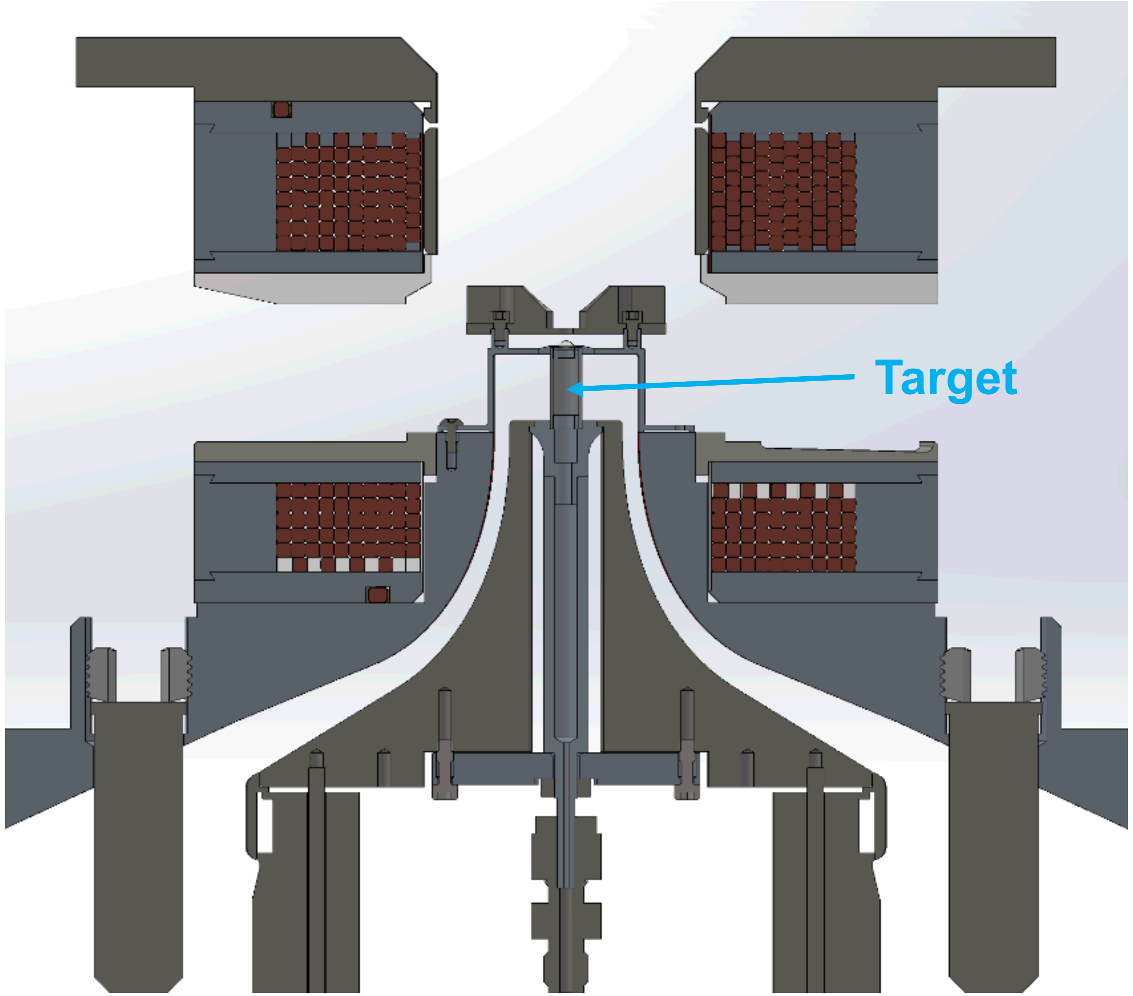




- Demonstrated 0.5-1 kJ DT-equivalent yields on Z
- Simulations indicate 10-100 kJ yields are possible
- We need to increase fuel density, B-field, laser energy, and current to get there

M. R. Gomez, et al., Phys. Rev. Lett. 113, 155003 (2014). P. F. Schmit, et al., Phys. Rev. Lett. 113, 155004 (2014).

We initially prioritized diagnostic access and B-field uniformity over minimizing inductance



D. C. Rovang, et al., Rev. Sci. Instrum. 85, 124701 (2014).

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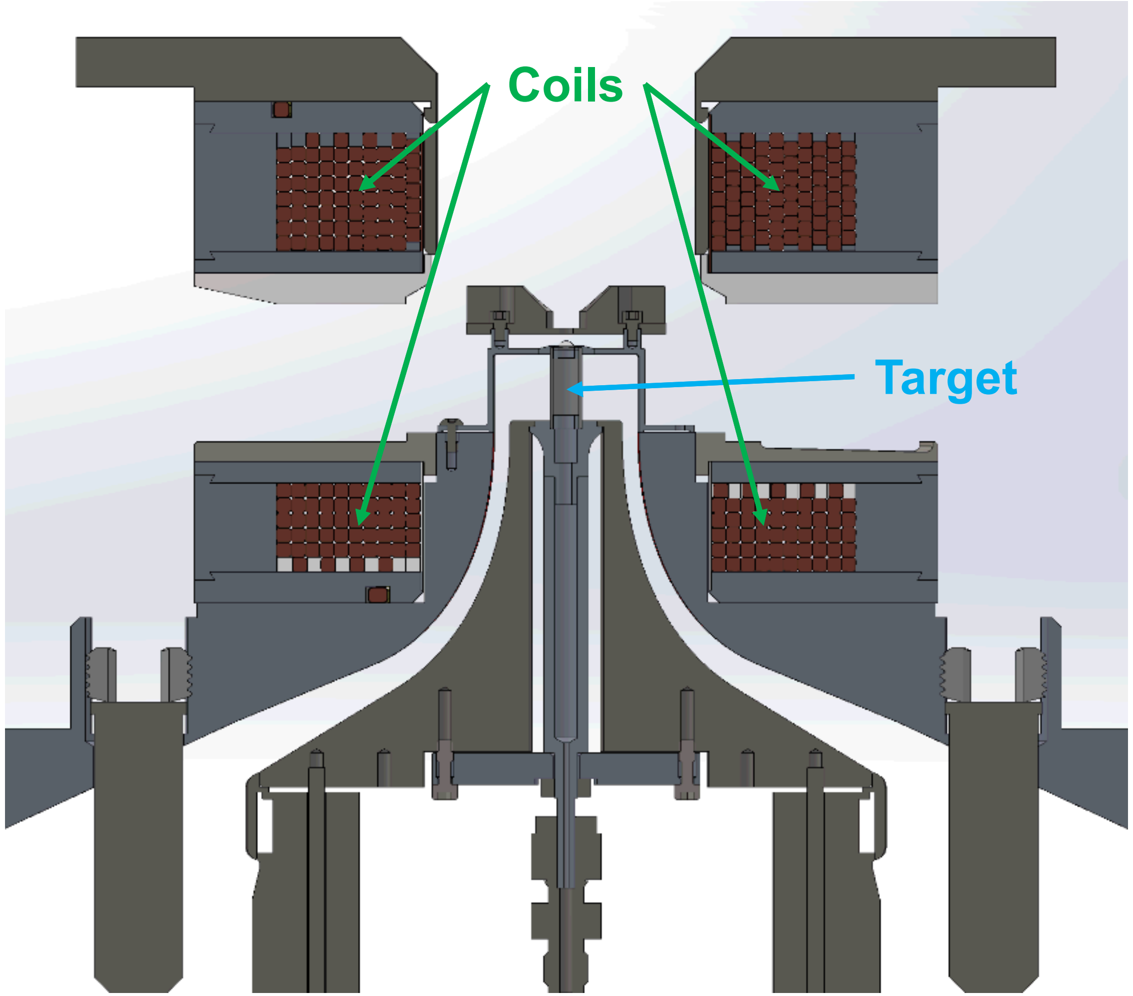

- The magnetic field uniformity is better than 1% in this configuration

D. C. Rovang, et al., Rev. Sci. Instrum. 85, 124701 (2014).

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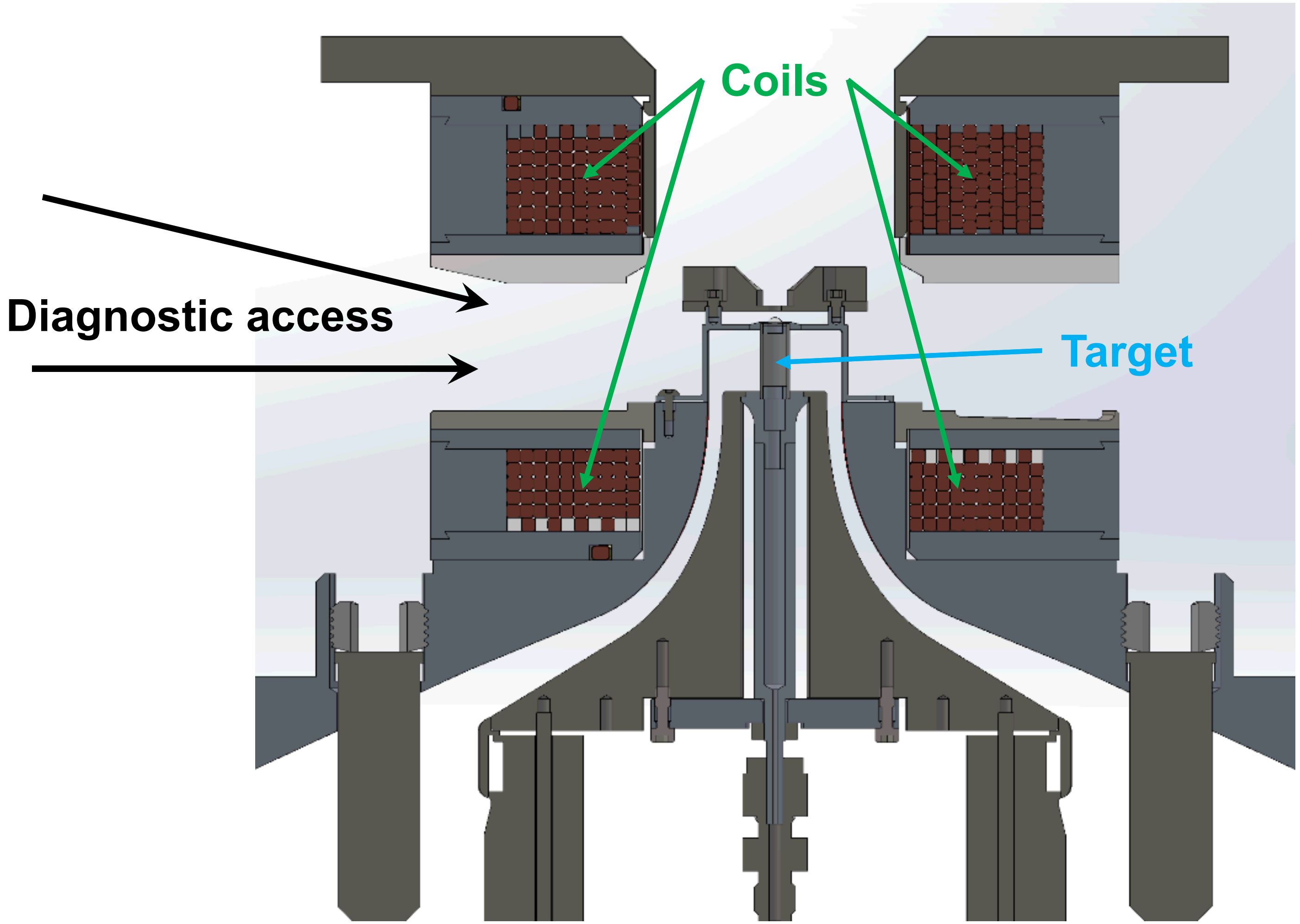

- The magnetic field uniformity is better than 1% in this configuration
- We have diagnostic access for 0 and 12 degree lines of sight

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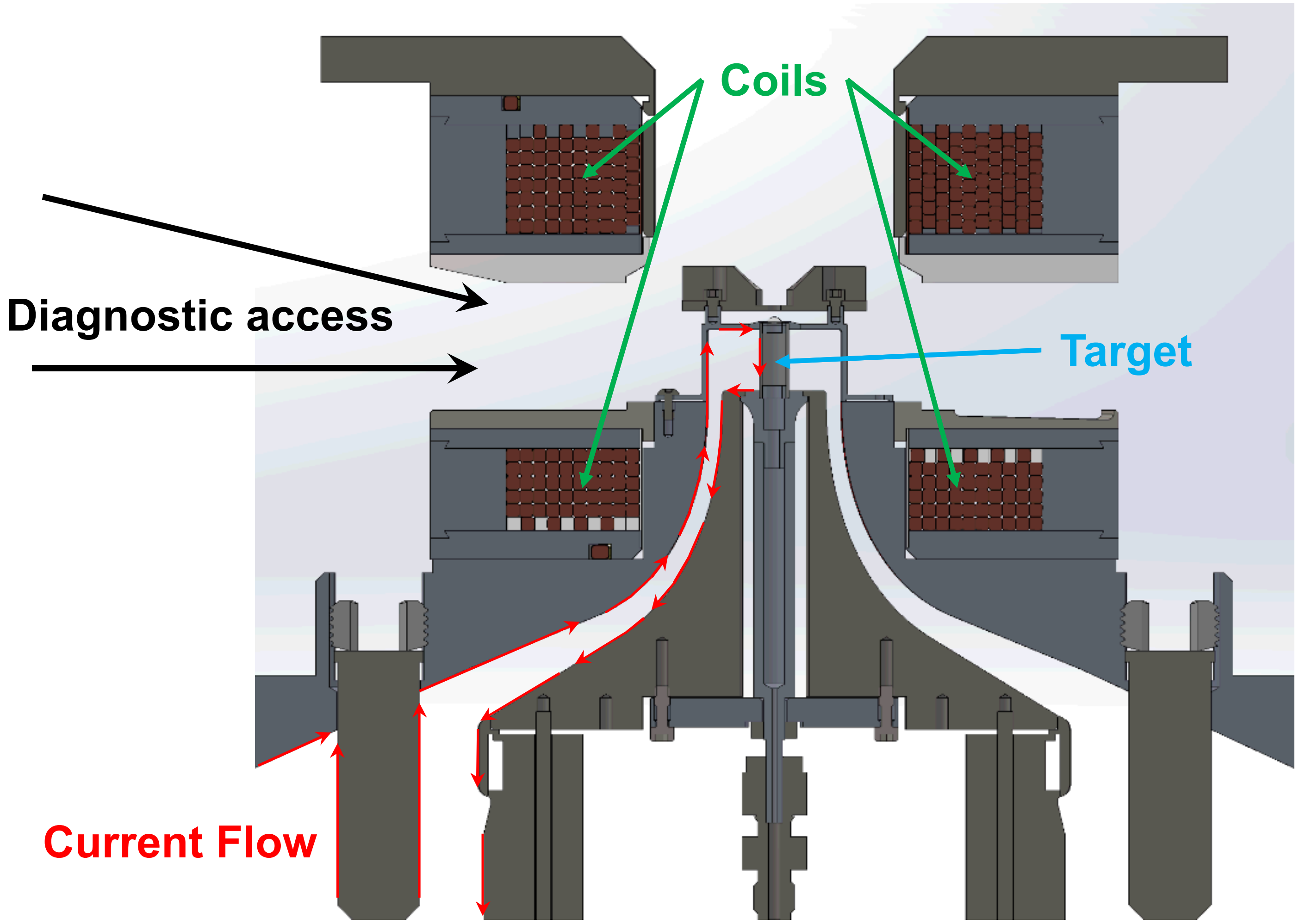
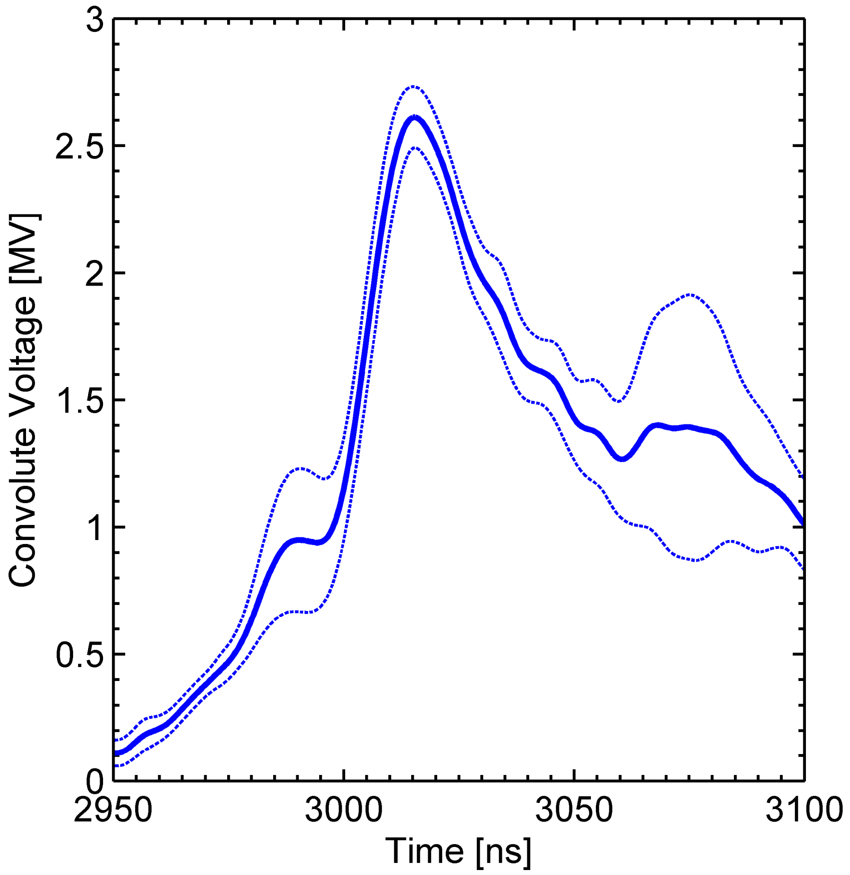
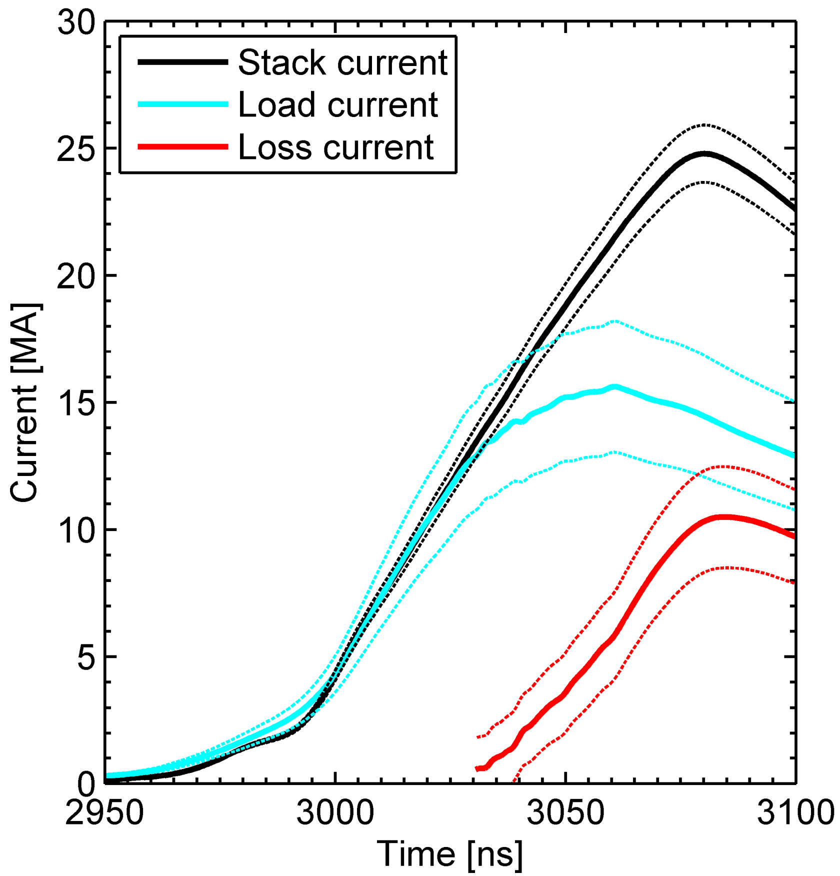


- The magnetic field uniformity is better than 1% in this configuration
- We have diagnostic access for 0 and 12 degree lines of sight
- Required a long axial extension of the inner-MITL
  - Inductance is 7.3 nH
  - Prefer less than 5 nH

D. C. Rovang, et al., Rev. Sci. Instrum. 85, 124701 (2014).

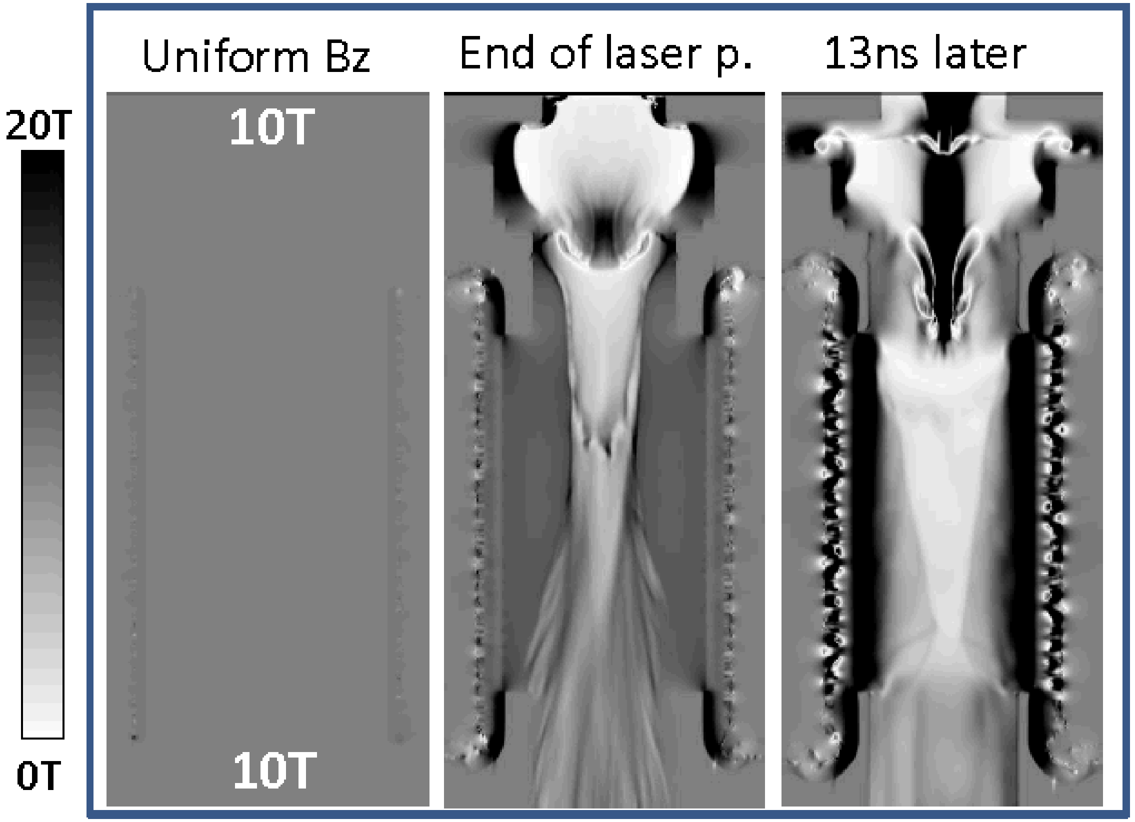
We observed high convolute voltage and high shunt current in this configuration





- The convolute voltage is >2.5 MV early in time
- Current loss begins shortly afterward
- The shunt current approaches 10 MA near stagnation

Simulations indicate B-field non-uniformity of ~50% has similar performance to uniform case



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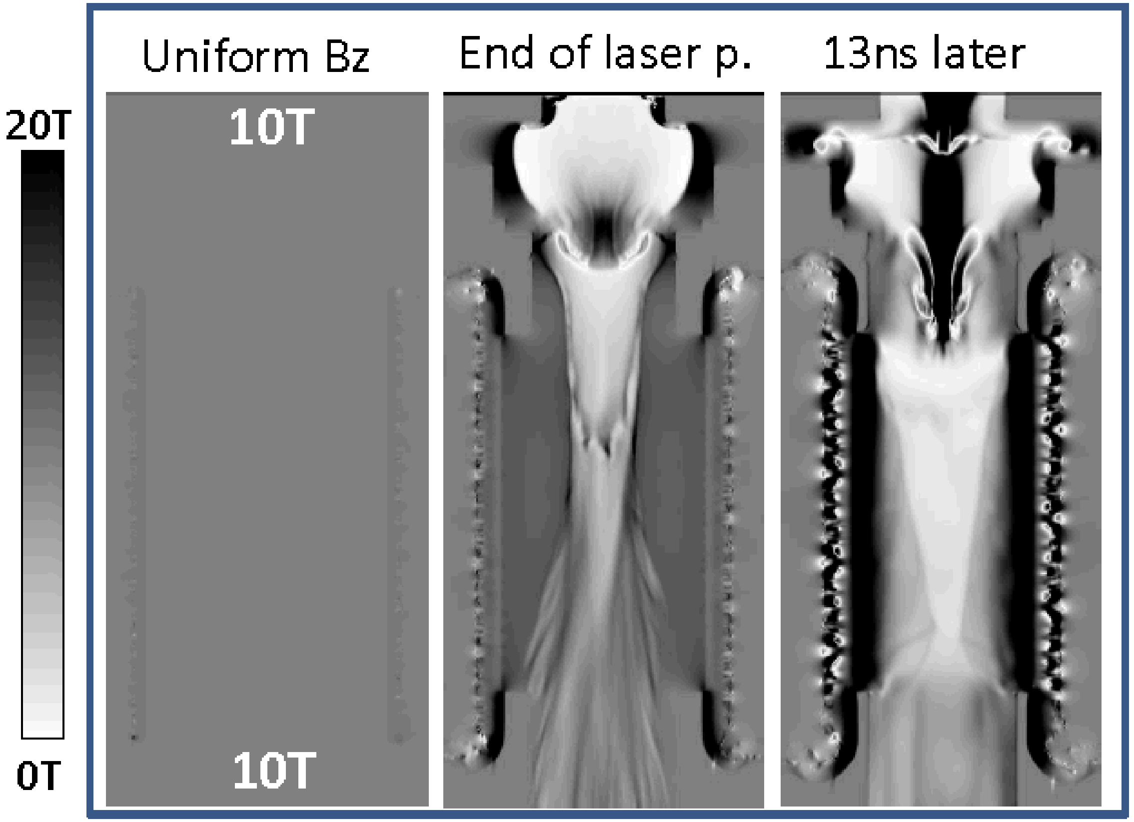
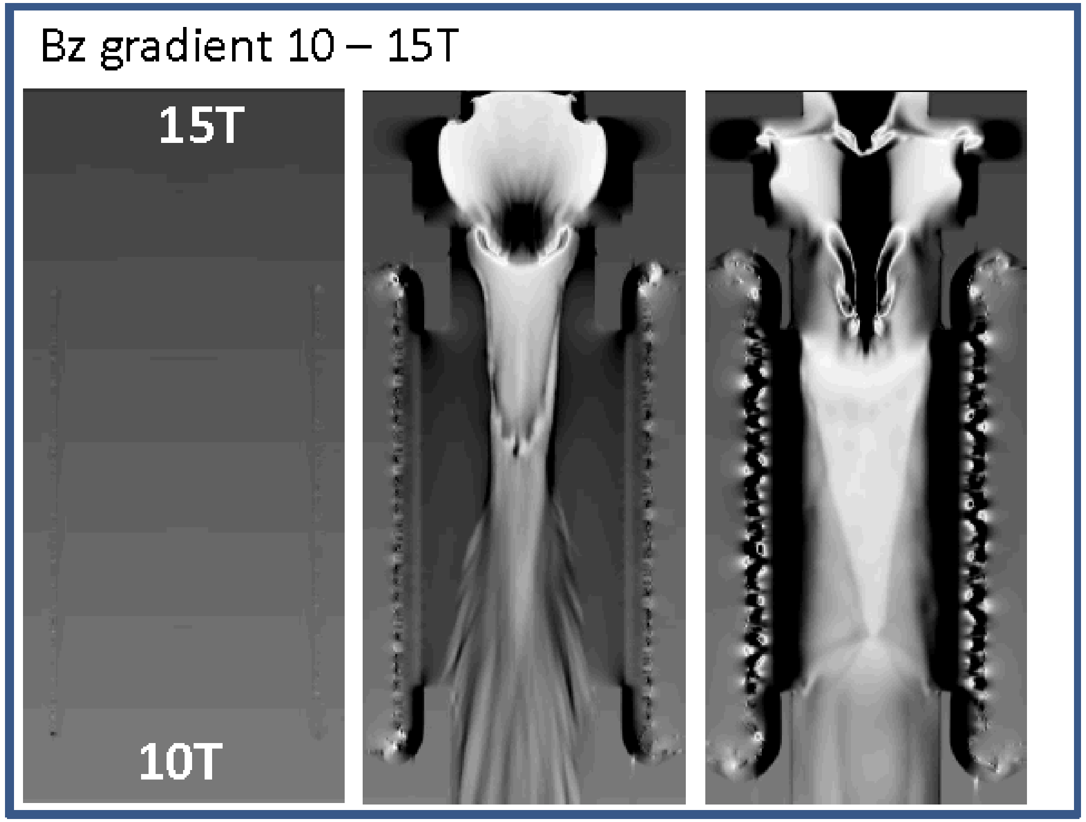
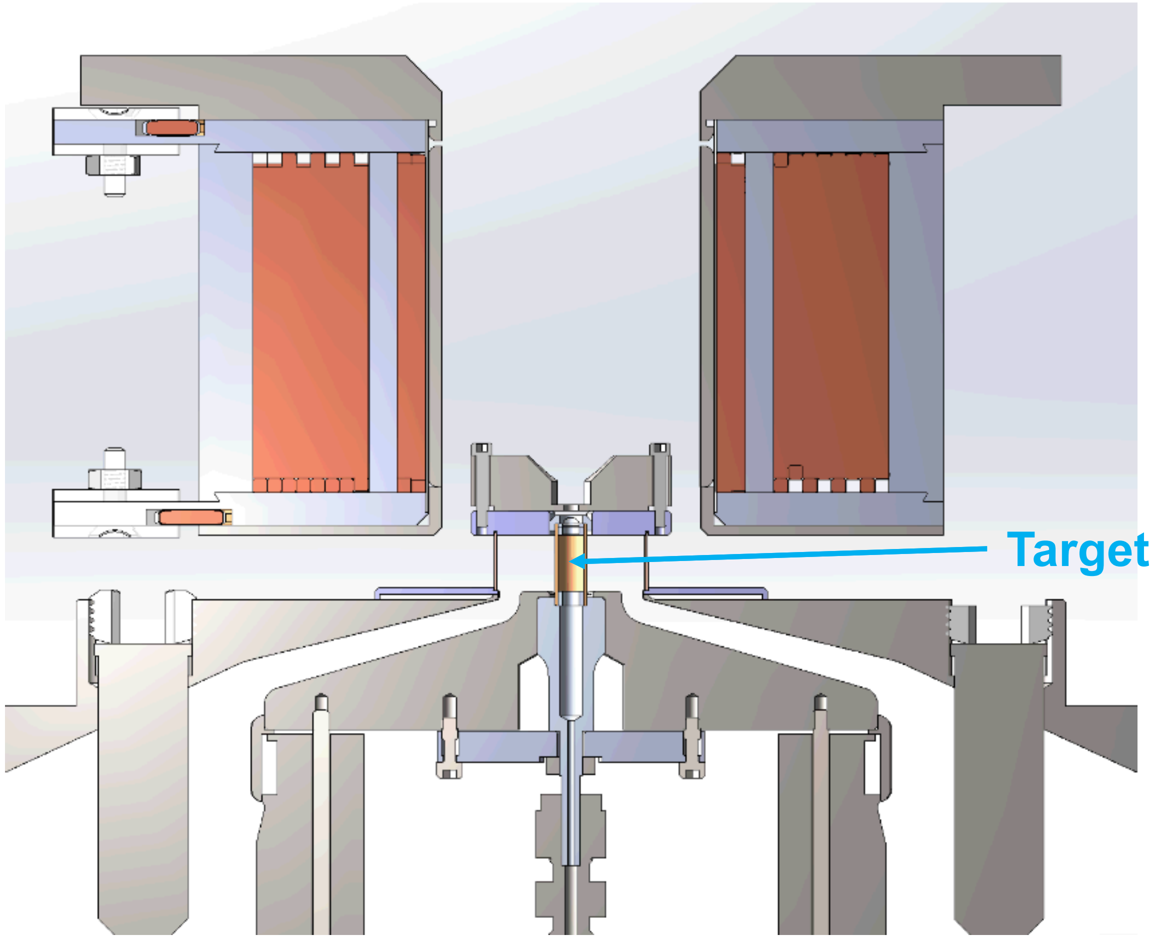




- Laser heating stage has larger impact on magnetic field uniformity
- Axial temperature profiles at stagnation are nearly identical between the two simulations

We redesigned the inner-MITL and coils to reduce inductance and maintain diagnostic access



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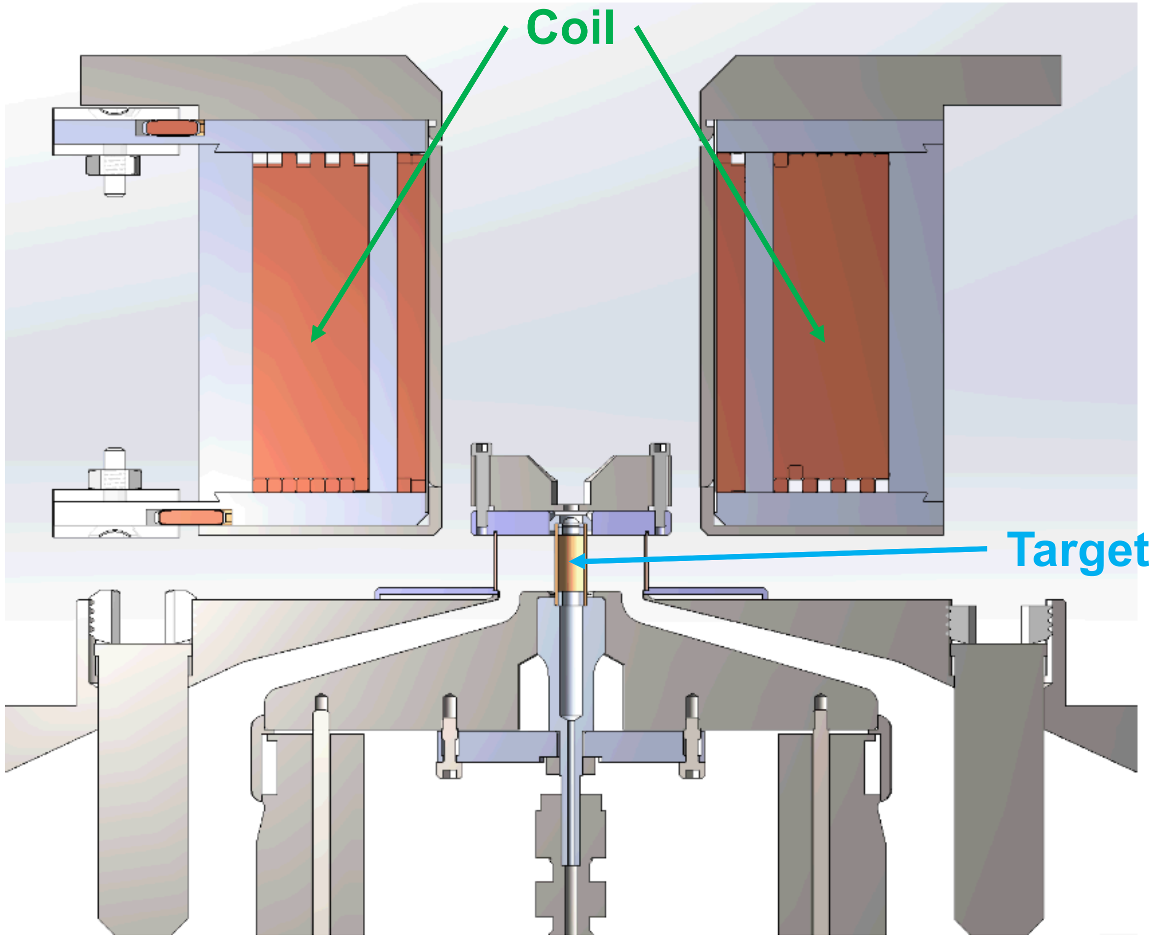

- A single coil above the target magnetizes it to 12.5 T at the top and 10 T at the bottom

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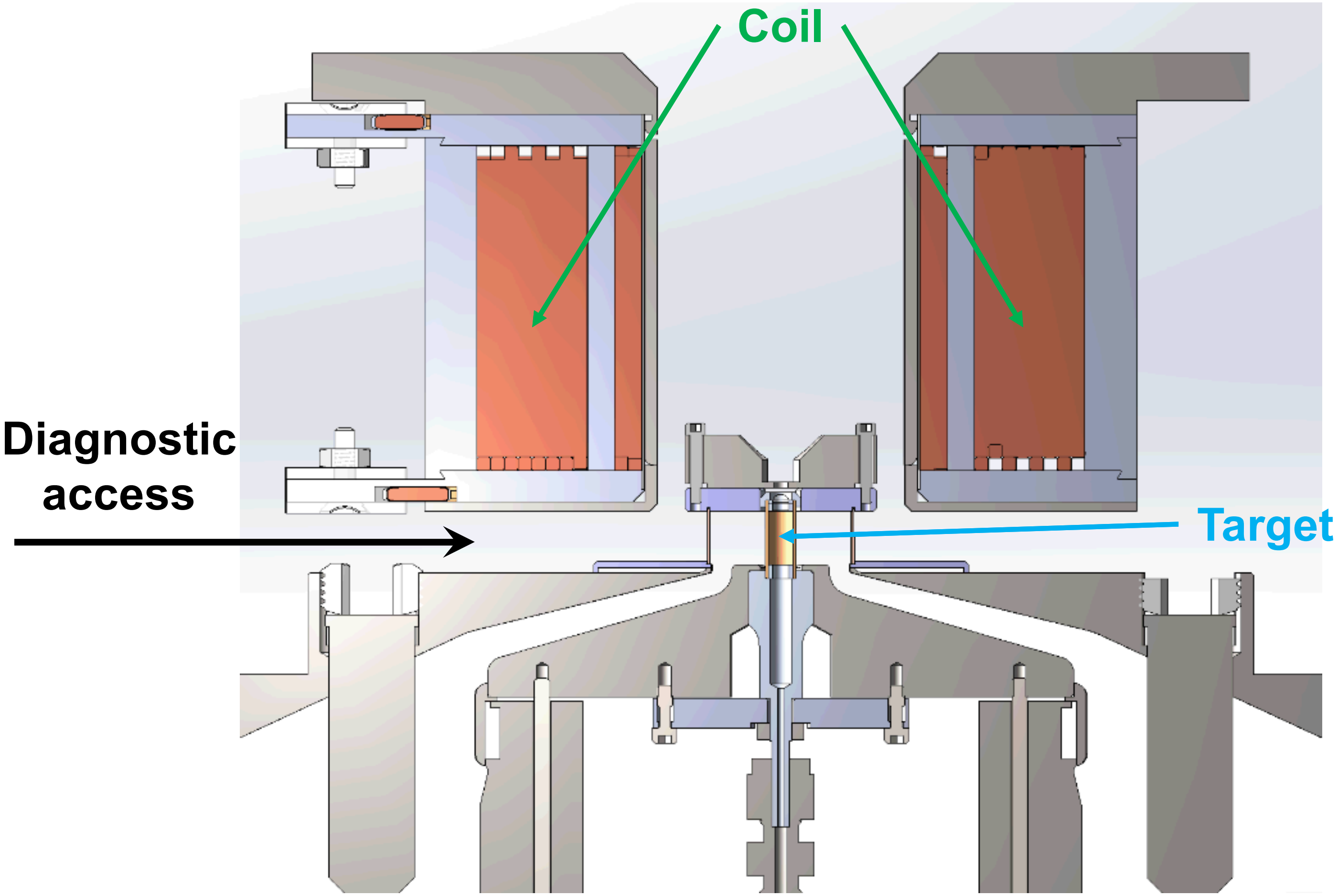

- A single coil above the target magnetizes it to 12.5 T at the top and 10 T at the bottom

- Diagnostic access is limited to 0 degree lines of sight

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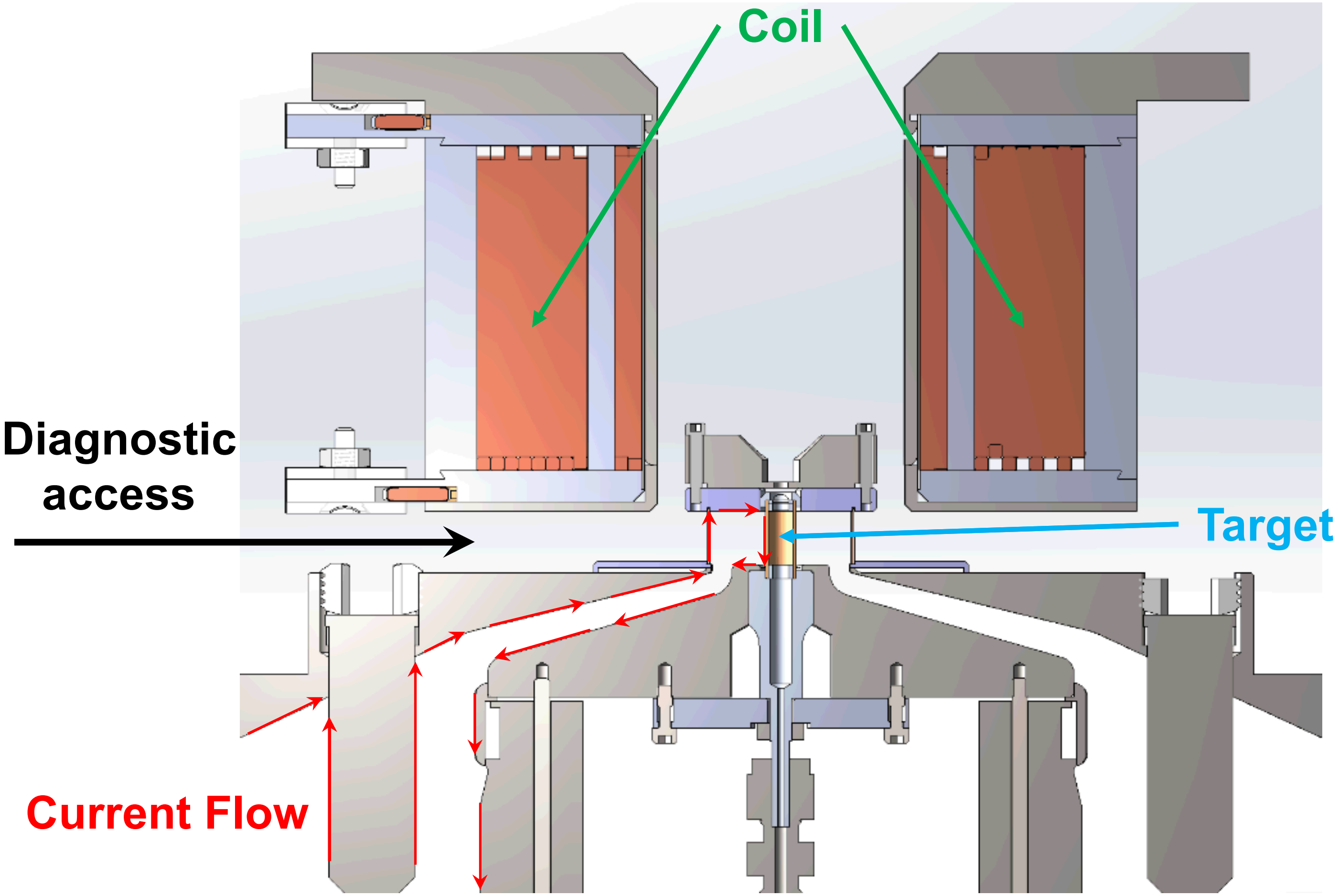
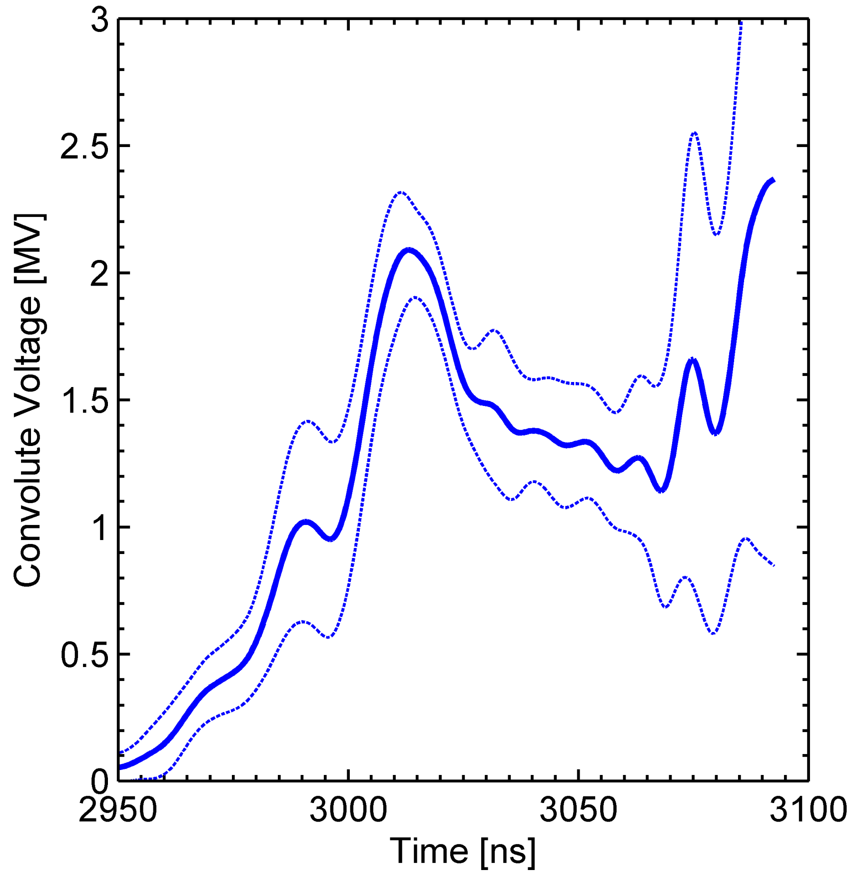
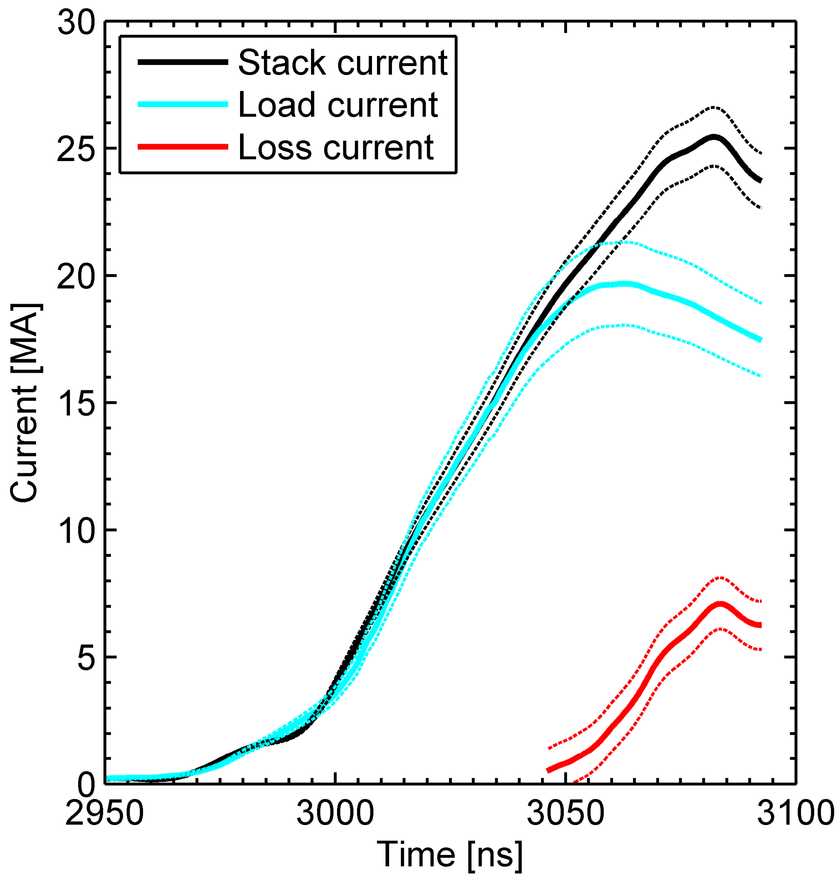


- A single coil above the target magnetizes it to 12.5 T at the top and 10 T at the bottom
- Diagnostic access is limited to 0 degree lines of sight
- Load inductance reduced to 5.1 nH with a minimum gap of 4 mm

In the new configuration the convolute voltage dropped and so did the current loss



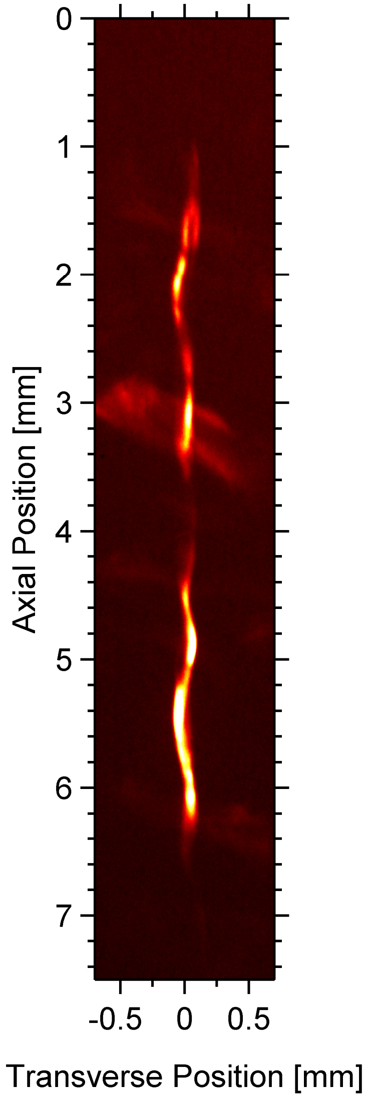


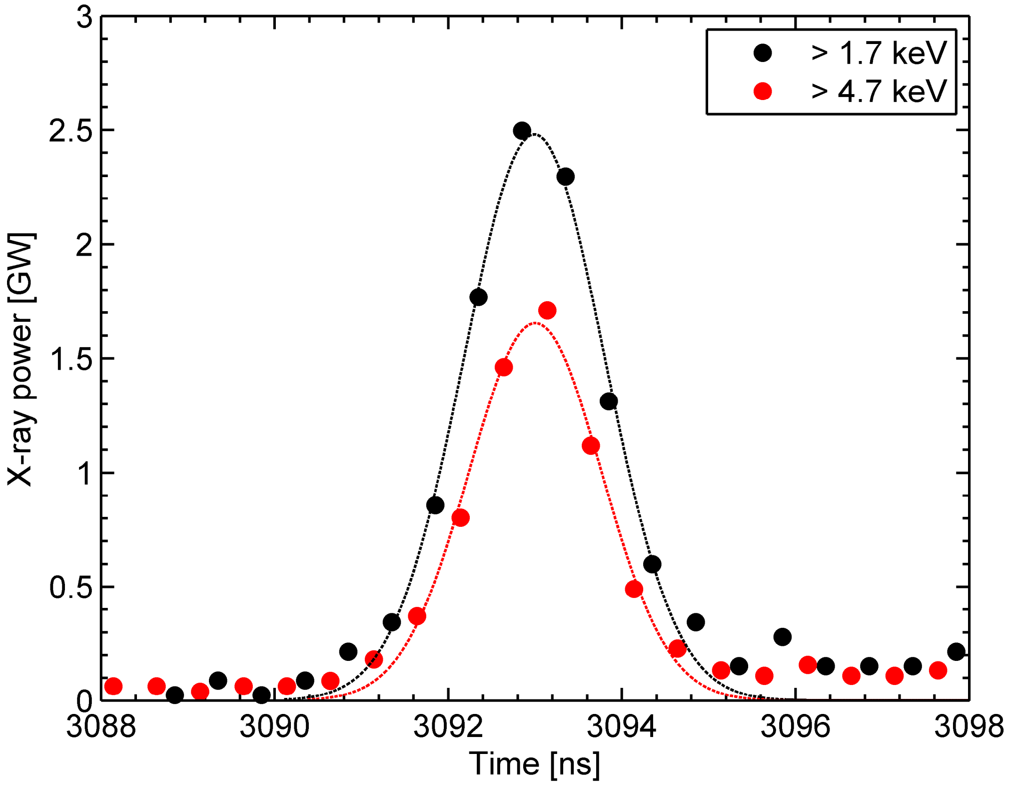
- The convolute voltage dropped to only ~2 MV early in time
- Current loss delayed by about 15 ns
- The shunt current reduced to 7 MA near stagnation

We believe that there is more room to further reduce the initial inductance

We also demonstrated nominal stagnation performance with a non-uniform B-field

- Primary DD neutron yield = 1.0e12
- Ion temperature = 2.0 keV
- Secondary DT neutron yield = 5.2e9
- Nominal stagnation image
- Nominal stagnation duration





We need increased fuel density, laser energy, and B-field to take advantage of higher current

- Our standard capability is 10 T, 0.5-1 kJ, and 16-18 MA
  - We are targeting 15-20 T, 1-2 kJ, and 19-20 MA in the near term
  - We would like to reach 20-30 T, 2-4 kJ, and 20-22 MA by 2020

- New coil designs should enable magnetic fields 18-26 T that are compatible with low inductance inner-MITL configurations

- New laser heating configurations with beam smoothing have demonstrated an increase in stagnation performance
  - New record MagLIF yield is ~4e12 with a lower-intensity, smoothed laser beam

- Experiments that combine increased magnetic field, laser energy, and current are planned for later this year