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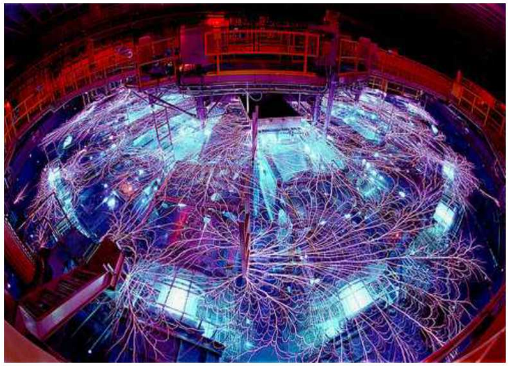

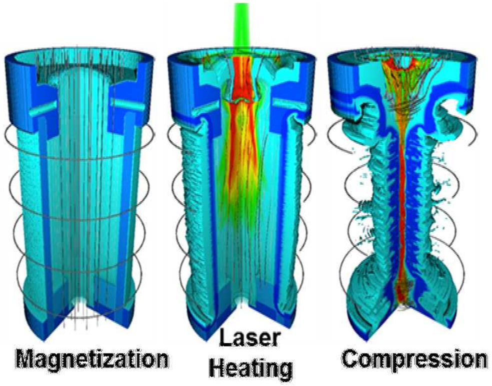


# Improving current coupling to the load in Magnetized Liner Inertial Fusion

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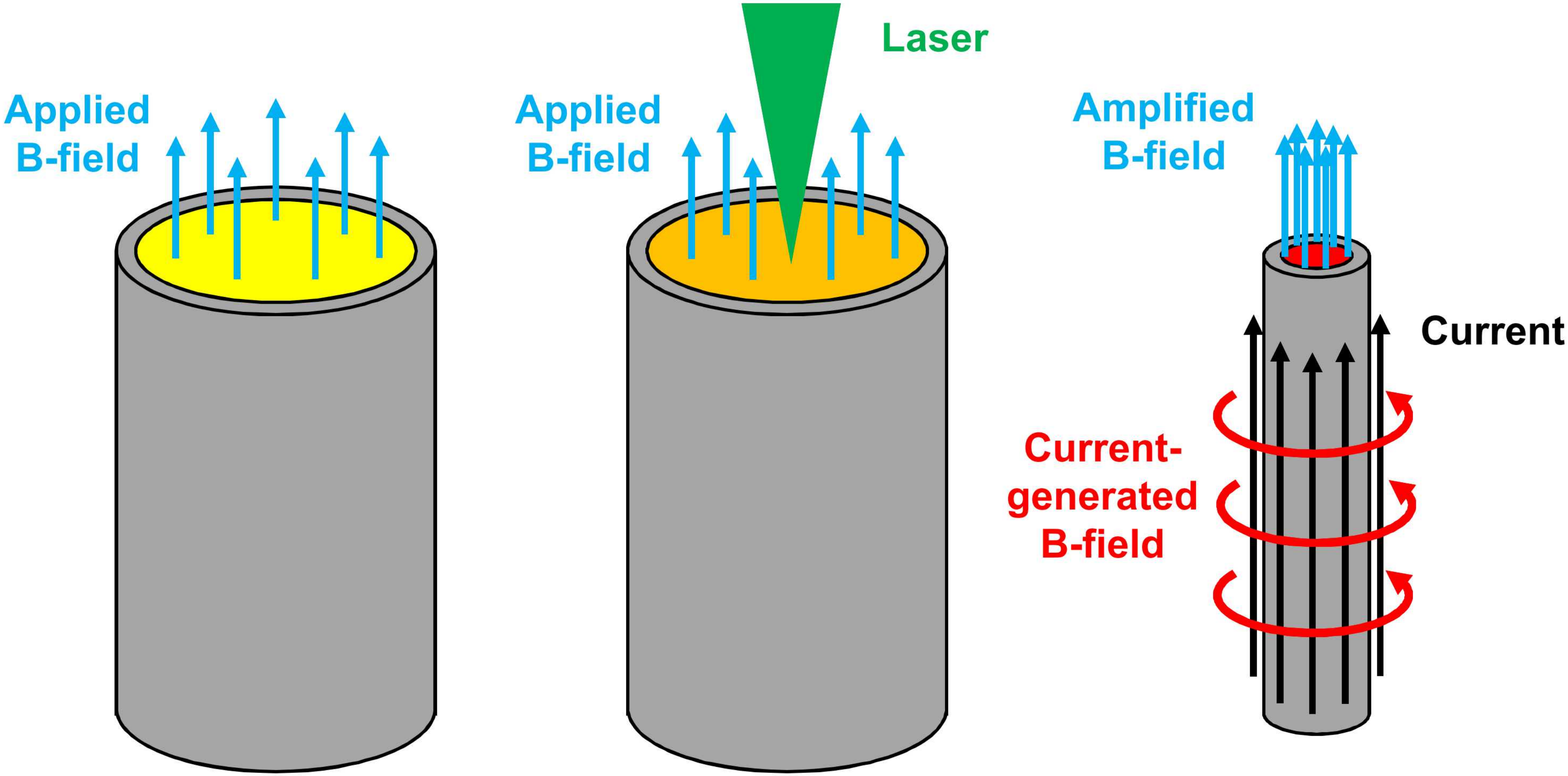
# MagLIF relies on three stages to produce fusion relevant conditions




**Apply axial magnetic field**

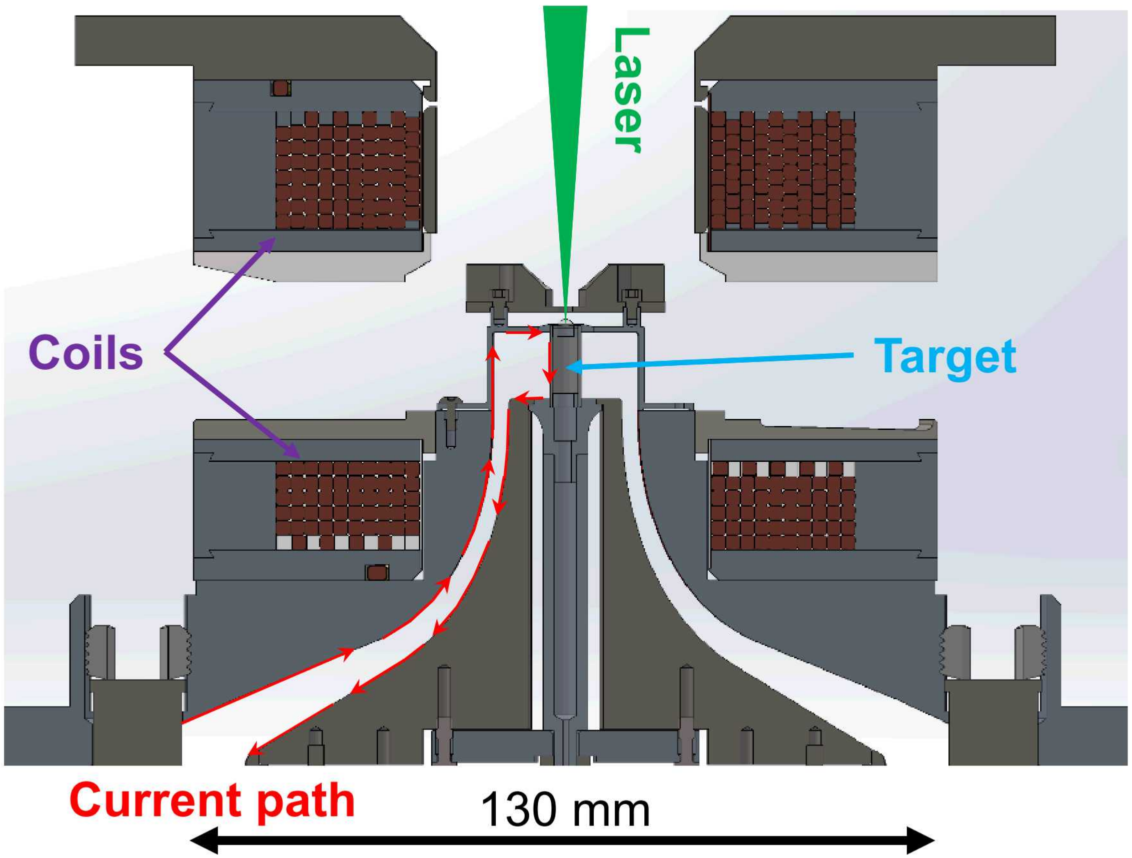
**Laser-heat the magnetized fuel**

**Compress the heated and magnetized fuel**



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

# In our initial experiments, we delivered 10 T, ~0.5 kJ of laser energy, and 18 MA peak current

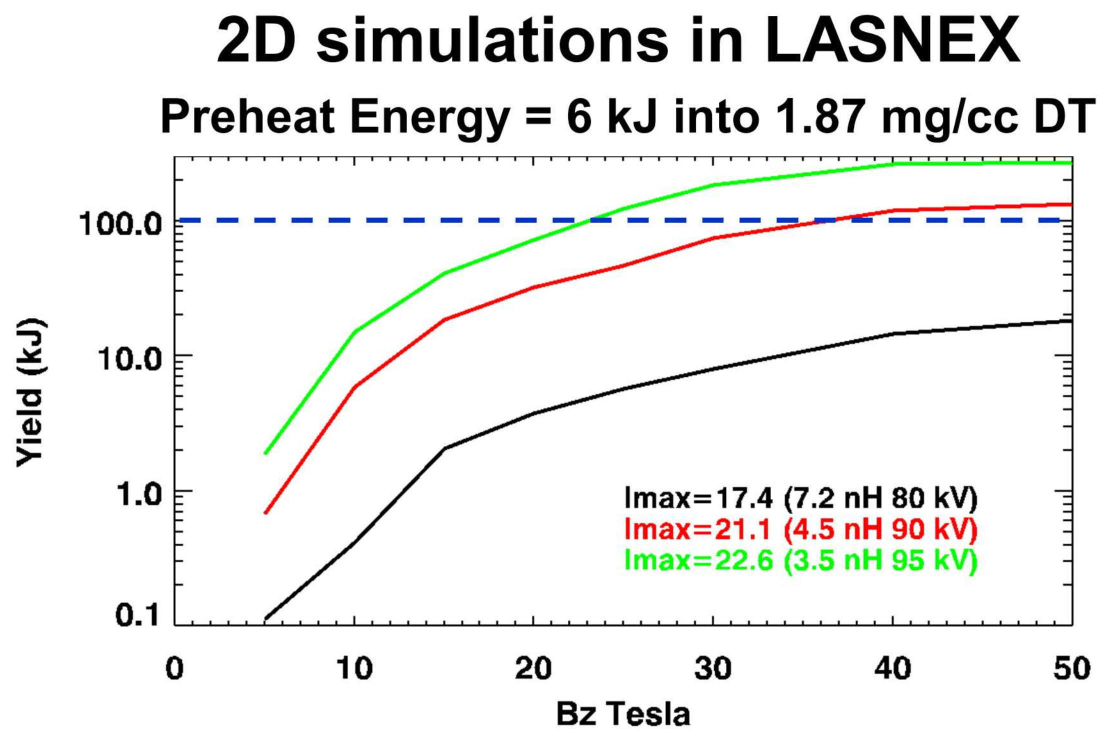



- Helmholtz-like coils provided 10 T B-field with less than 1% spatial variation
- 0.5 + 2 kJ laser pulse coupled ~0.5 kJ of energy to the 0.7 mg/cc $D_2$ fuel
- Initial inductance inside of the convolute was 6.34 nH
  - Peak load current was 18.2 MA
  - Significant losses were inferred in the convolute and inner-MITL regions

**This configuration produced up to $2 \times 10^{12}$ primary DD neutrons or ~0.4 kJ DT-equivalent**

# Our goal on Z is to produce a fusion yield of ~100 kJ DT-equivalent

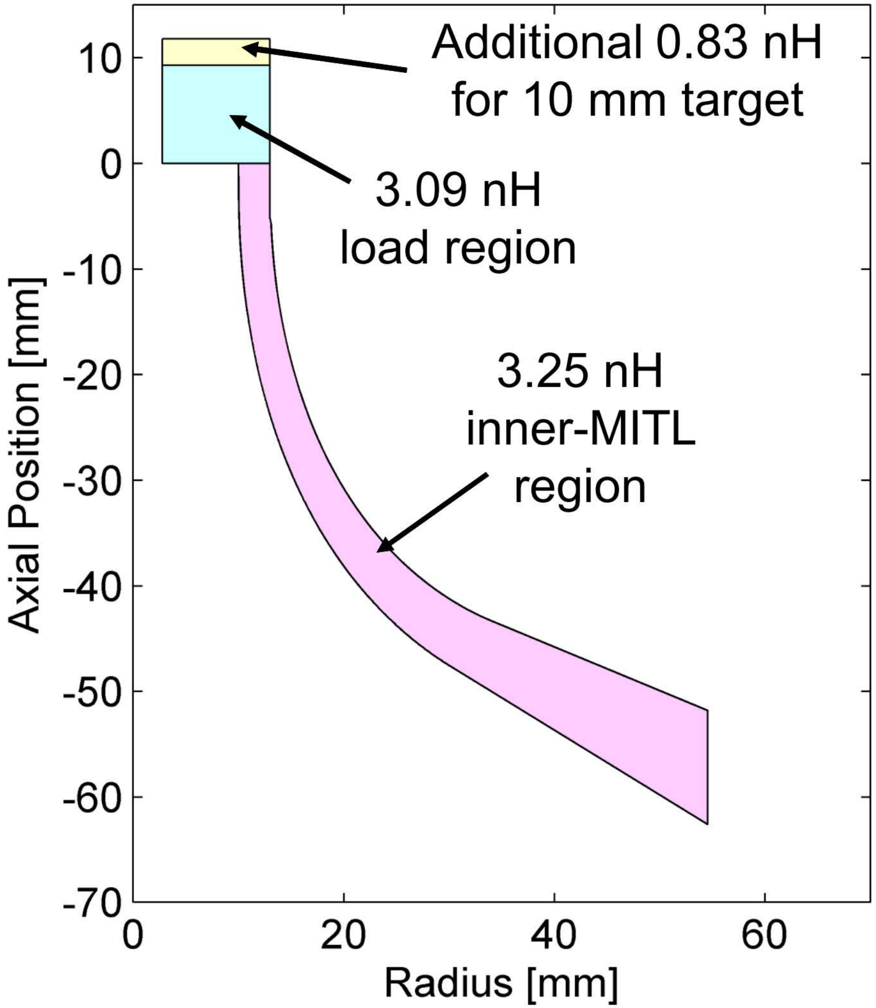
- Simulations indicate an experiment with 25-30 T, 6 kJ of laser heating, and 22 MA could produce >100 kJ
- We have preliminary designs for coils capable of applying up to 30 T
- Simulations indicate 6 kJ of laser energy can be coupled to the fuel with a large spot size (1.5 mm), thin window (<μm), and 10 mm tall target
- We are developing an inner-MITL configuration that is capable of delivering 22 MA to the load

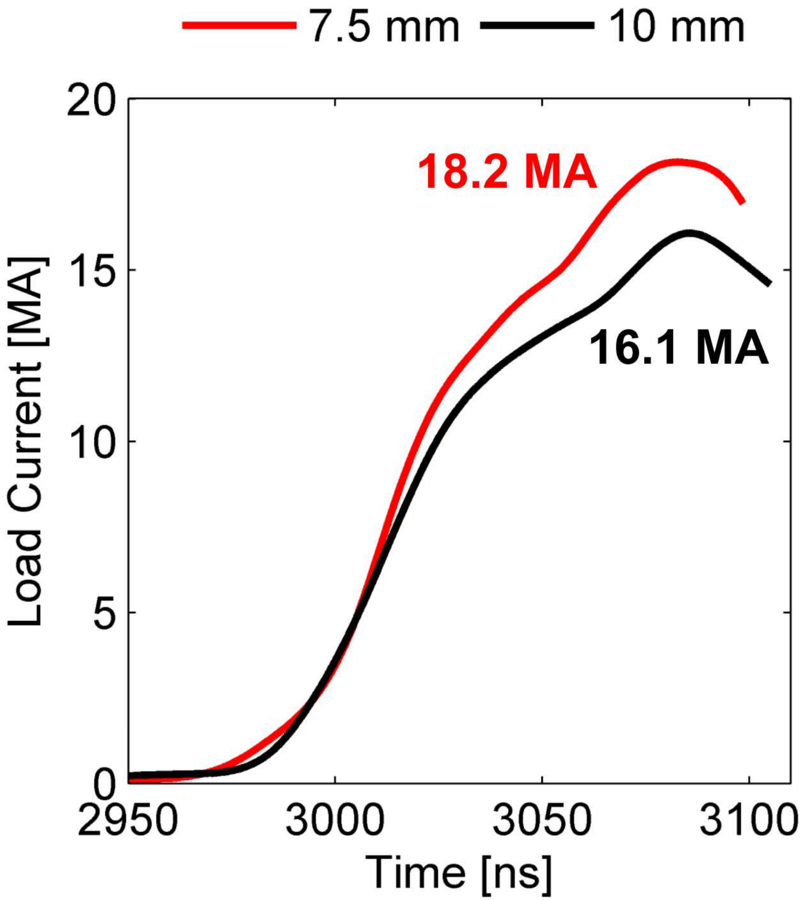


# Original inner-MITL and load design was not optimized for load current

- Relatively high initial inductance (6.34 nH)
  - Inner-MITL with long axial translation (3.25 nH)
  - Large load volume (2.86 nH)
  - Slotted return can for diagnostic access (0.23 nH)
- Relatively small A-K gaps (3 mm)
  - Plasma shorting
    - Plasma expansion at 2 cm/μs from both electrodes would short the gap
  - Ion diode losses
    - High voltage and small gaps allow significant emission of ions, which are generally not magnetically insulated
- Target height needs to be increased to improve laser coupling and reduce fuel end losses
  - 10 mm target (7.17 nH)

# Original inner-MITL and load design was not optimized for load current

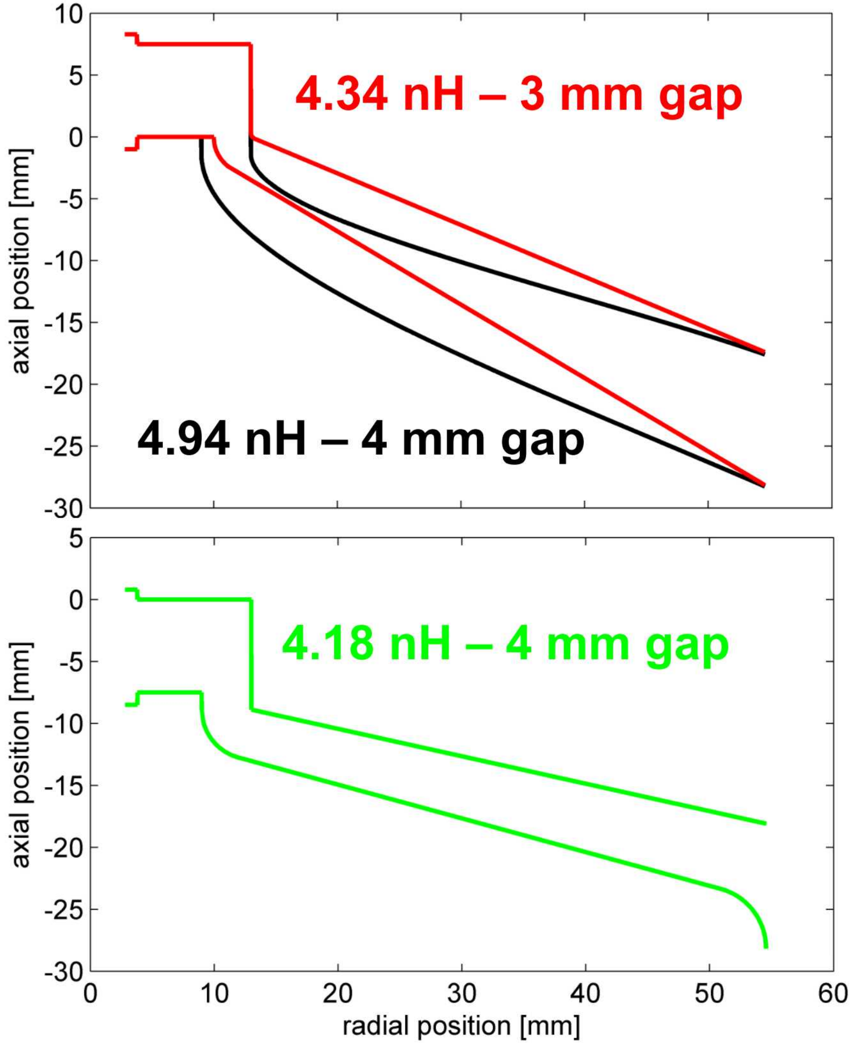


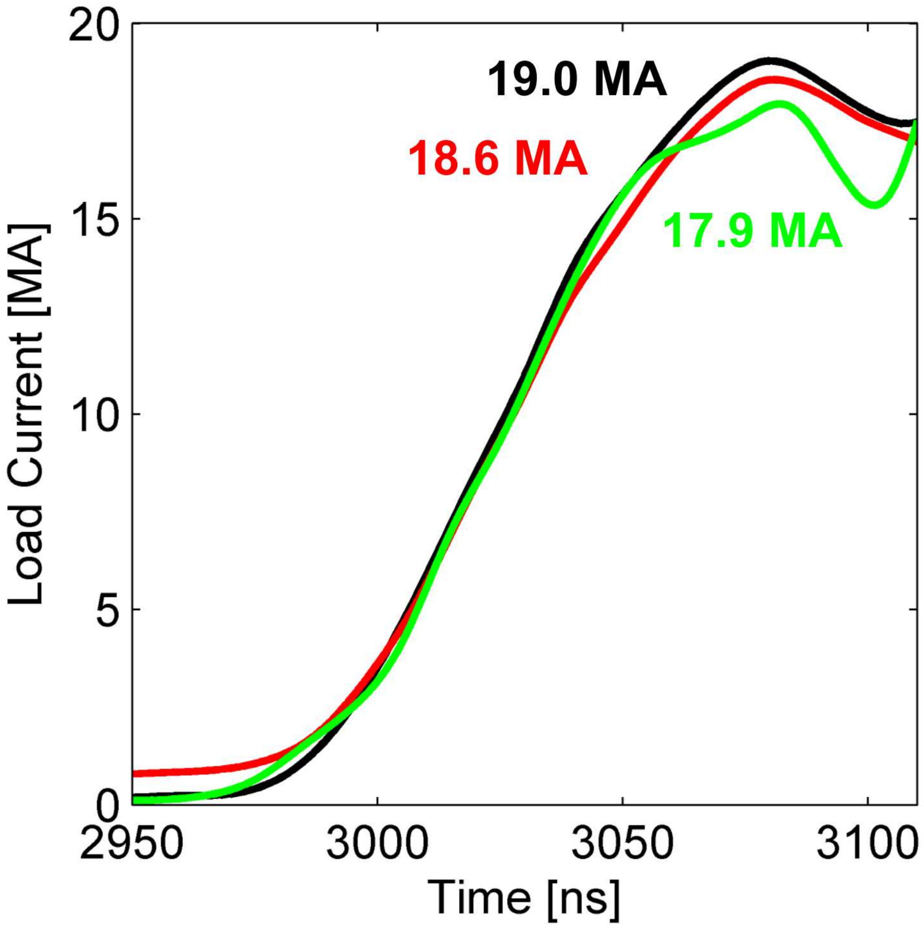



# The inner-MITL inductance was reduced to improve current coupling

- Eliminated the axial extension by removing the bottom B-field coil
  - Required a ~25% axial variation in B-field
- Tested three cases (all with 7.5 mm target):
  - **4 mm minimum gap with a smooth transition to the load: 4.94 nH**
    - **Peak load current increased to 19.0 MA (from 18.2 MA)**
  - **3 mm minimum gap with a sharp bend near the load: 4.34 nH**
    - **Peak load current increased to 18.6 MA (from 18.2 MA)**
    - **Note there was a Marx bank prefire on this experiment**
  - **4 mm minimum gap with a sharp bend near the load: 4.18 nH**
    - **Peak load current stayed nearly the same at 17.9 MA (compared to 18.2 MA)**
    - **Inner-MITL B-dots indicated minimal loss in the convolute**
    - **Suspect that sharp bend near load caused the increase in loss in the inner-MITL**

# The inner-MITL inductance was reduced to improve current coupling

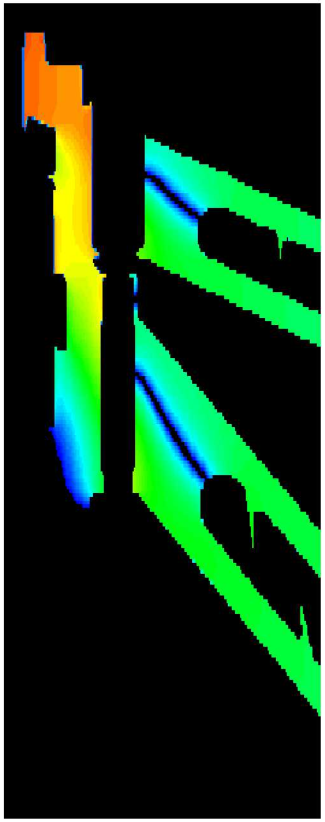


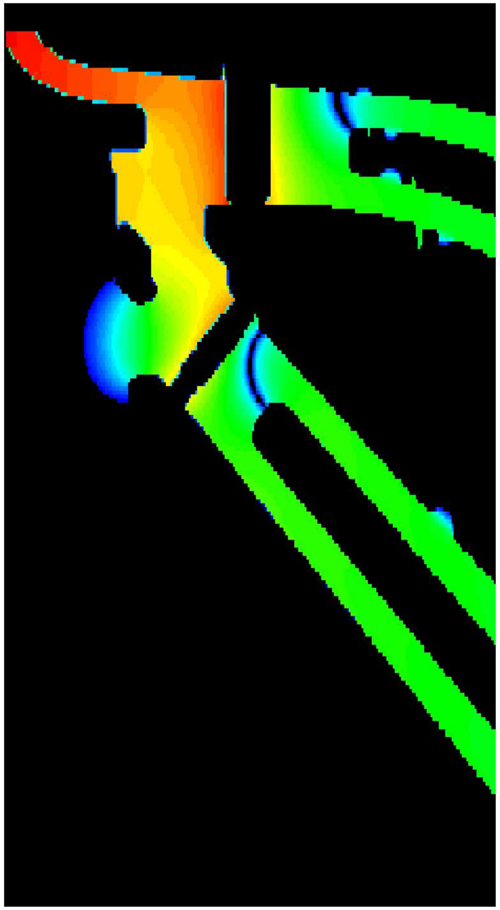



# A more robust convolute was used to improve current coupling

- Doubling the radius of the post-hole convolute current combination allowed for larger A-K gaps in the convolute and lower current densities on the components
  - Reduced losses have been observed for many load configurations
  - Increased inductance of the system can lower load current for configurations where convolute losses are already low
- No significant modifications were made to the inner-MITL or load
- Peak load current stayed nearly the same (17.9 MA compared to 18.2 MA)
  - The lack of improvement indicates that the dominant loss may be in the inner-MITL as opposed to in the convolute

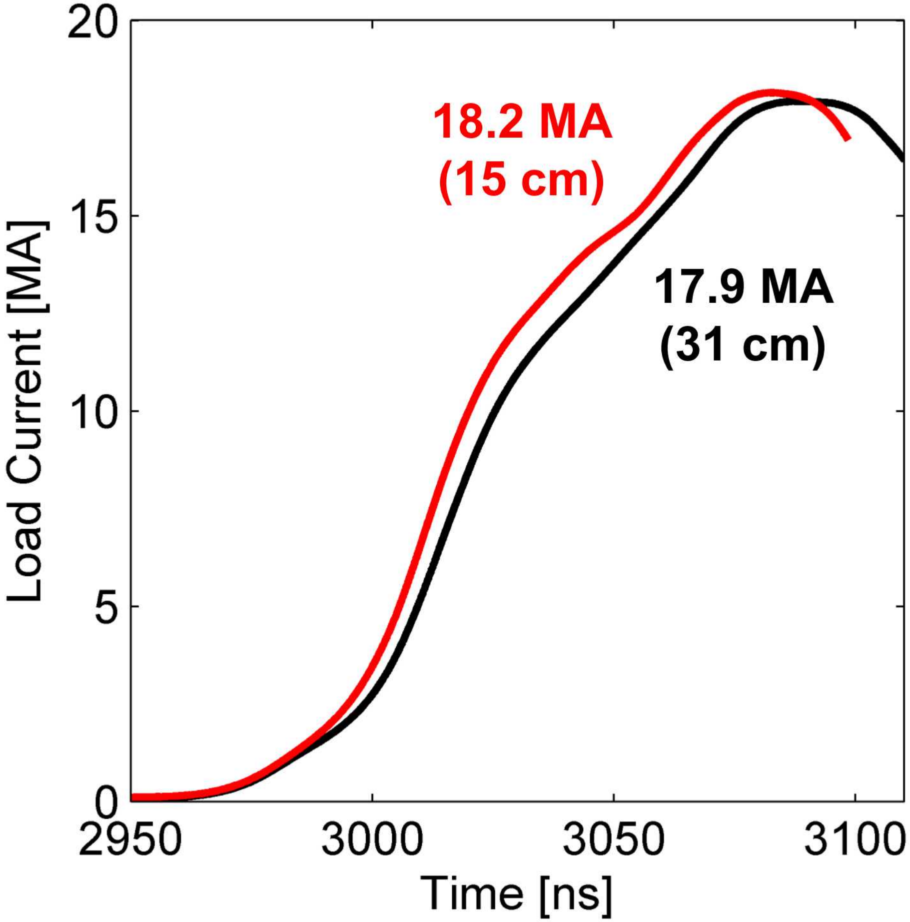
# A more robust convolute was used to improve current coupling





Standard
15 cm convolute

31 cm convolute



# Load inductance was reduced and A-K gap was increased to reduce inner-MITL loss

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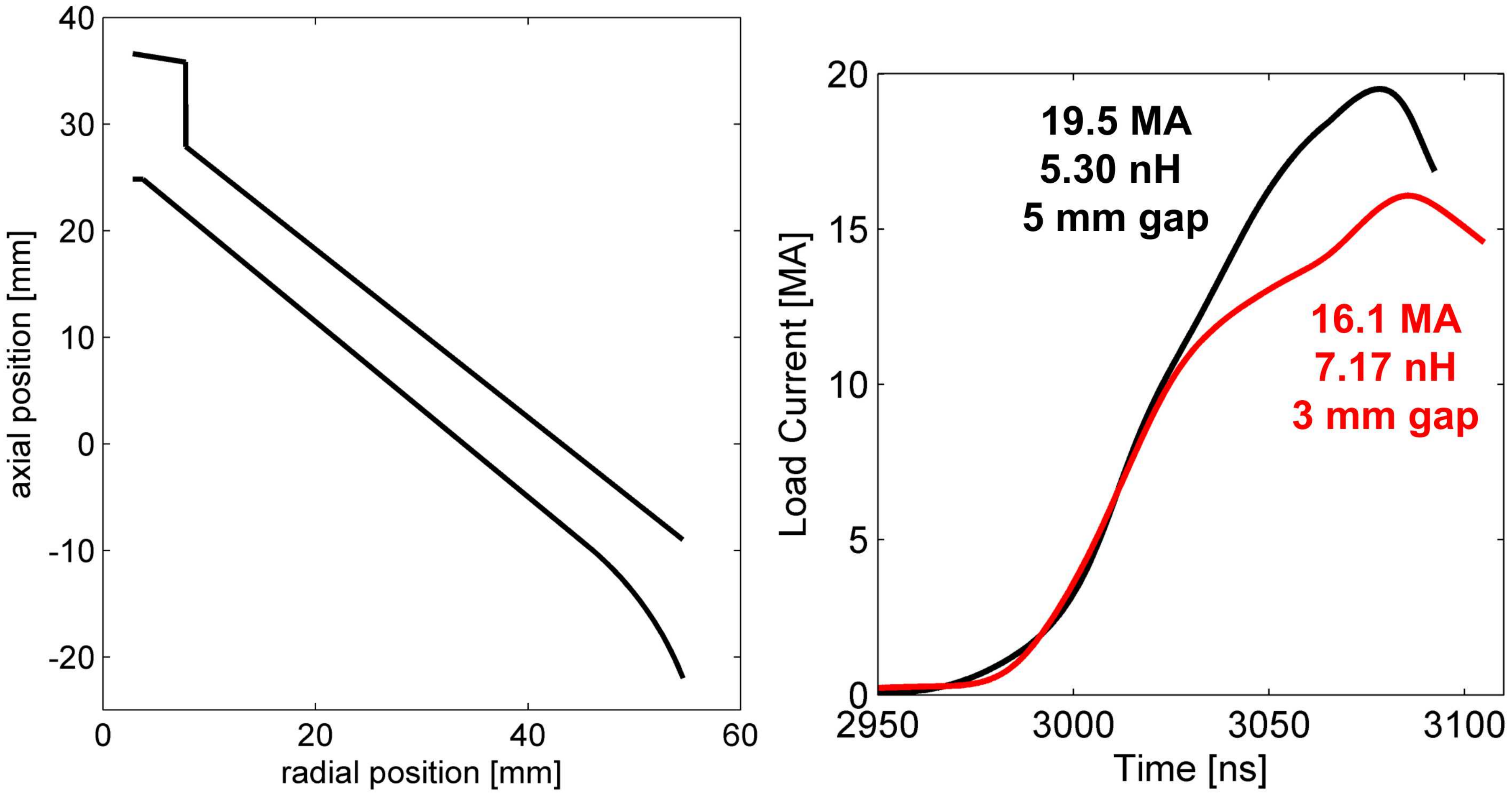
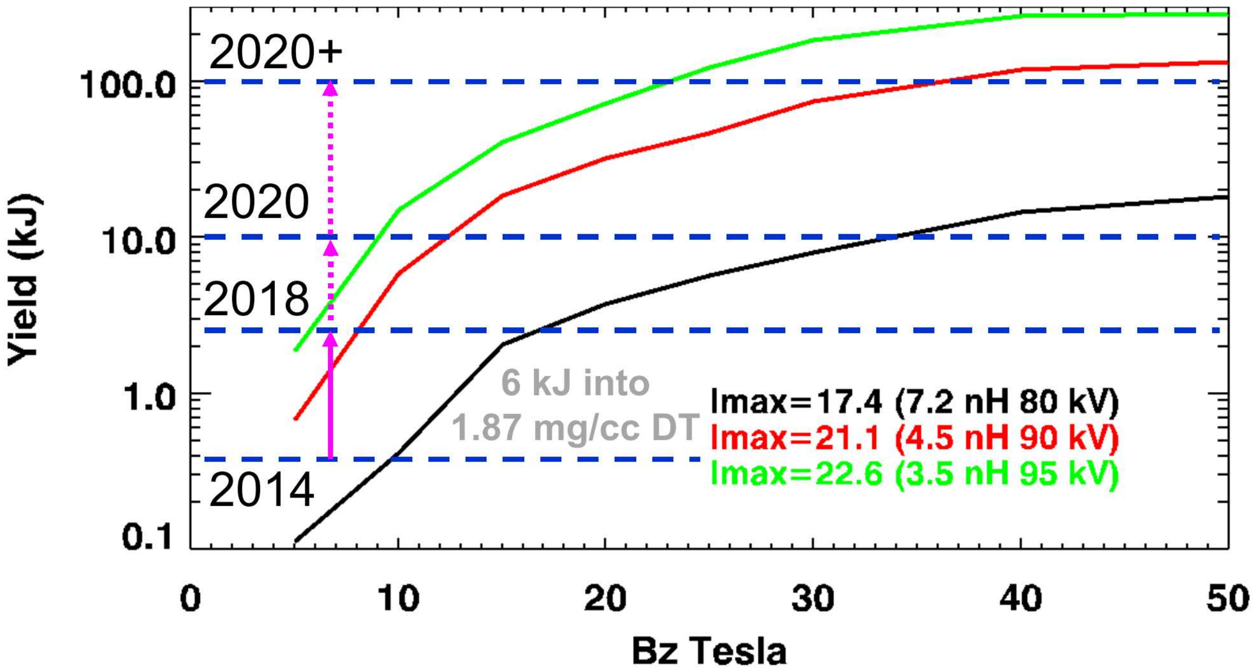
- Total inductance reduced to 5.30 nH (from 7.17 nH)
  - Load inductance reduced to 2.56 nH (from 3.92 nH)
    - Note: 10 mm target height
  - Inner-MITL inductance reduced to 2.74 nH (from 3.25 nH)
- Goal was to reduce losses in the inner-MITL without increasing losses in the convolute too much
- Peak load current increased to 19.5 MA (from 16.1 MA)
- Inner-MITL current was 20.0 MA
  - Indicates that losses in the convolute are dominant in this configuration
- Axial extension enables non-rectangular cross-section bottom coil
  - Up to 30 T average field with ~10% spatial variation appears possible in this configuration

# Load inductance was reduced and A-K gap was increased to reduce inner-MITL loss



# A significant improvement in performance was observed with the new configuration




We have made significant progress in improving load current while maintaining the ability to achieve high magnetic fields and laser preheat energy

| Date | Liner | Fill (D2) | Current | B-field | Preheat | Yield (DT-eq.) |
|---|---|---|---|---|---|---|
| 2014 | AR=6 | 0.7 mg/cc | 16-18 MA | 10 T | ~0.5 kJ | 0.2-0.4 kJ |
| Aug. 2018 | AR=6 | 1.1 mg/cc | 19.5 MA | 15 T | ~1.2 kJ | ~2.4 kJ |
| 2020 Goal | TBD | ~1.5 mg/cc | 20-21 MA | 20-25 T | 2-4 kJ | ~10 kJ |
| Beyond 2020 | TBD | 1.5 mg/cc | 22+ MA | 25-30 T | 6 kJ | 100 kJ |

# We are considering two paths to further increase load current in the near term

- The newest version of the inner-MITL could be coupled to the 31-cm diameter convolute
  - The inductance of the present design is a little high for the standard convolute, and convolute losses appear to dominate
  - Convolute losses could be reduced significantly using the large diameter convolute, resulting in a significant increase in load current
- The A-K gap in the newest version of the inner-MITL could be reduced slightly
  - The inductance of this design could be reduced to <5nH (down from 5.3 nH) by decreasing the A-K gap to 4 mm
  - Finding a balance between inner-MITL and convolute losses could lead to an increase in load current
- Combining these two solutions could result in further increases