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# High–field FRC development on a 1-MA LTD, suitable for liner compression on the Z facility

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## Introduction

In the last few decades, field-reversed configurations (FRCs) have been identified as a promising plasma target in magneto-inertial a.k.a. magnetized target fusion (MIF/MTF), an approach which may offer a more economical route to fusion gain >1. FRCs are a compact plasma toroid characterized by a strong poloidal magnetic field and zero/weak toroidal magnetic field, thus enabling high values of $\beta \rightarrow 1$. Recently, Slutz et al [1] has used LASNEX to simulate magnetically-driven liner compression of high-field (~30 Tesla) FRCs on the Z-machine (20+ MA, 100 ns) at Sandia National Laboratories, with substantial fusion yield. FRC formation and general theta pinch behavior at such high energy density and short time-scale has not been sufficiently studied, so we are looking to explore this regime experimentally using the 1 MA, 200 ns MAIZE LTD at the University of Michigan.

## Experimental Plan

We plan to create an FRC using the traditional reversed-field theta pinch method inside a 12mm ID quartz tube. Strong axial magnetic field can be provided throughout the tube on a fast time-scale by a helical current path load in the LTD, as shown in Fig 1. Initial bias fields up to 2 Tesla could be provided by MAIZE's external Bz coils, but a more attractive option may be to use the natural LC-circuit behavior of the LTD to provide both a strong bias field and fast field-reversal. Fast pre-ionization (if desired) could be provided by an array of spark-gaps made of semi-rigid coax, pulsed with the output of a PT55 module (50 kV, 2 ns rise, ~3 J).

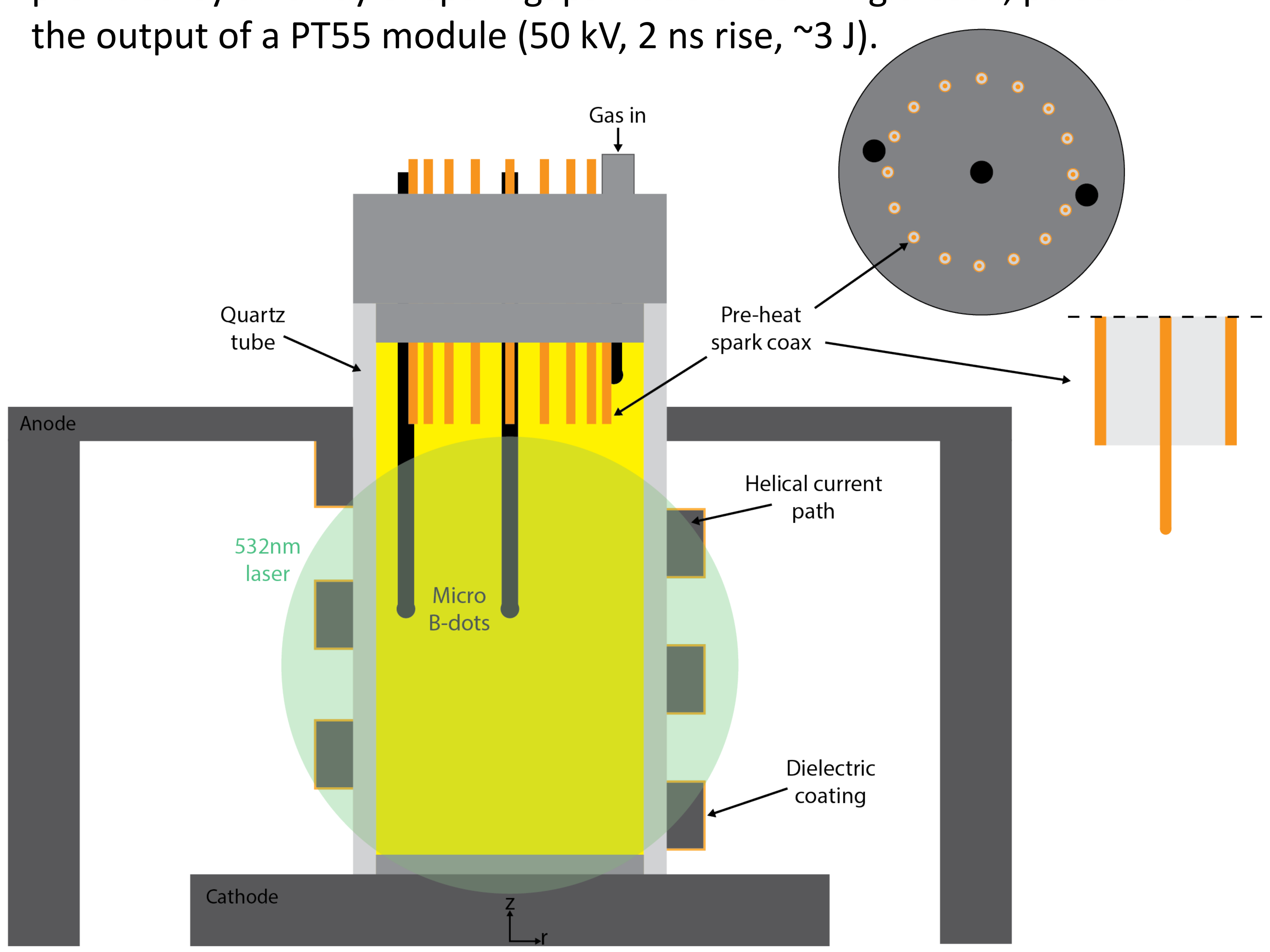


*Figure 1: Experimental plan for FRC experiment on MAIZE LTD*

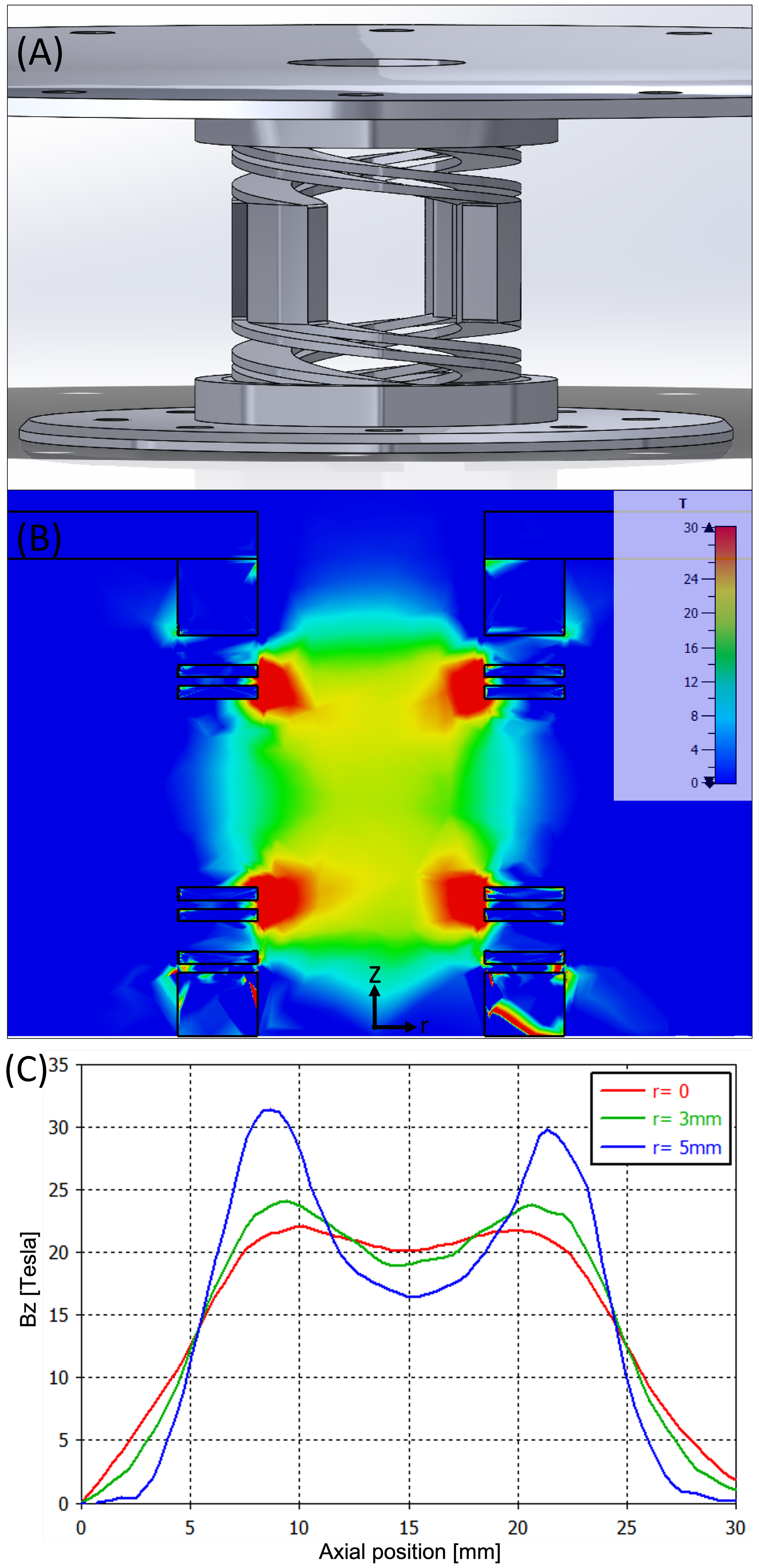


*Figure 2: (A) Design #2 mid-field helical hardware for MAIZE LTD*
*(B) 2D axial field strength in center-plane @ 700kA current*
*(C) 1D axial field strength, showing mirror effect at all radii*

## Helical Hardware Field Simulations

The electromagnetic solver CST Studio is used to model the fields of helical load hardware on the MAIZE LTD at 1.25 MHz. A wide survey of designs has produced some interesting possibilities. For instance, we can change the pitch of helices to produce a magnetic mirror effect, which should keep the plasma centered in the helix. We are presently having three helical designs 3D-printed in steel using the direct metal laser sintering (DMLS) technique; their qualities are summarized in Table 1 below. The details of the mid-field Design #2 are shown in Fig 2.

*Table 1: Properties of three helical load designs for MAIZE LTD*

| Design | Center Bz @ 700kA [T] | Mirror Ratio (r=0) | Inductance [nH] |
|---|---|---|---|
| #1 | 12.6 | 1.06 | 14 |
| #2 | 19.7 | 1.09 | 19 |
| #3 | 39.0 | 1.04 | 30 |

## Axial B-dot Development

Initial experiments will use small magnetic induction probes known as "B-dots" to measure the expected axial field within the helical hardware, for comparison to simulation. Once the expected axial field behavior is verified, the quartz tube can be sealed and filled with low-pressure gas. Micro B-dot fabrication methods have been explored by John Greenly at Cornell [2] and by Gabriel Shipley at Sandia (for helical 'AutoMag' liners [3]). We are considering their methods, and other methods involving acid-etch. An example of an acid-etched axial B-dot is shown in Fig 3.

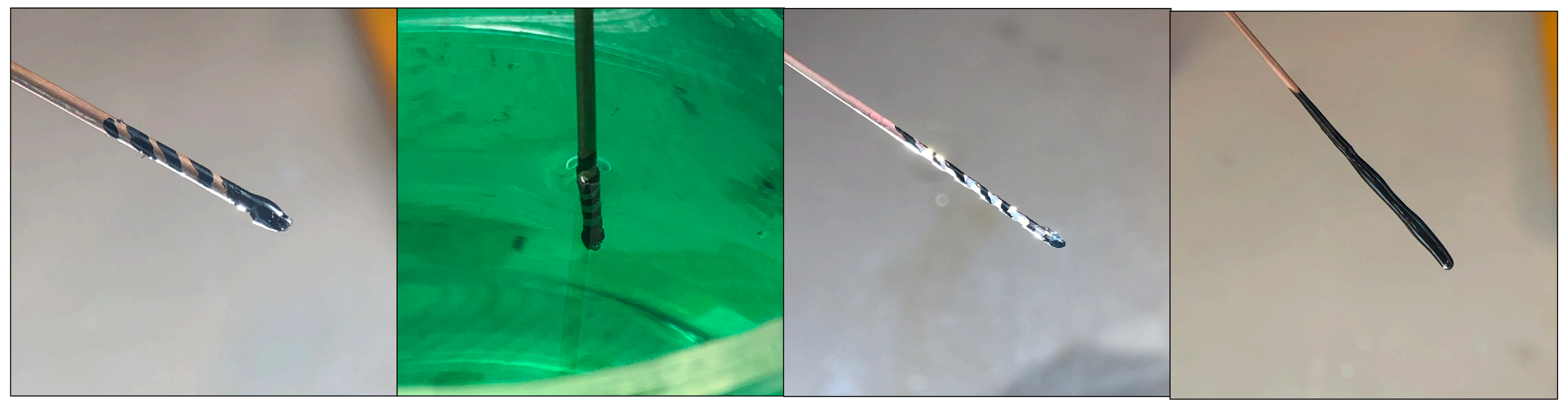

*Figure 3: Axial B-dot probe is produced by helical acid-etch of semi-rigid coax*

## References:

[1] Slutz, Stephen A, and Matthew R Gomez. "2020 Z Fundamental Science Workshop." Liner Driven FRC Implosions.

[2] Greenly, John, et al. "The Role of Flux Advection in the Development of the Ablation Streams and Precursors of Wire Array Z-pinches." AIP Conference Proceedings. Vol. 1088. No. 1. American Institute of Physics, 2009.

[3] G. A. Shipley et al., "Implosion of auto-magnetizing helical liners on the Z facility", Phys. Plasmas 26, 052705 (2019).

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