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Understanding the Impact of Applied Magnetic Fields on Z-Machine Power Flow

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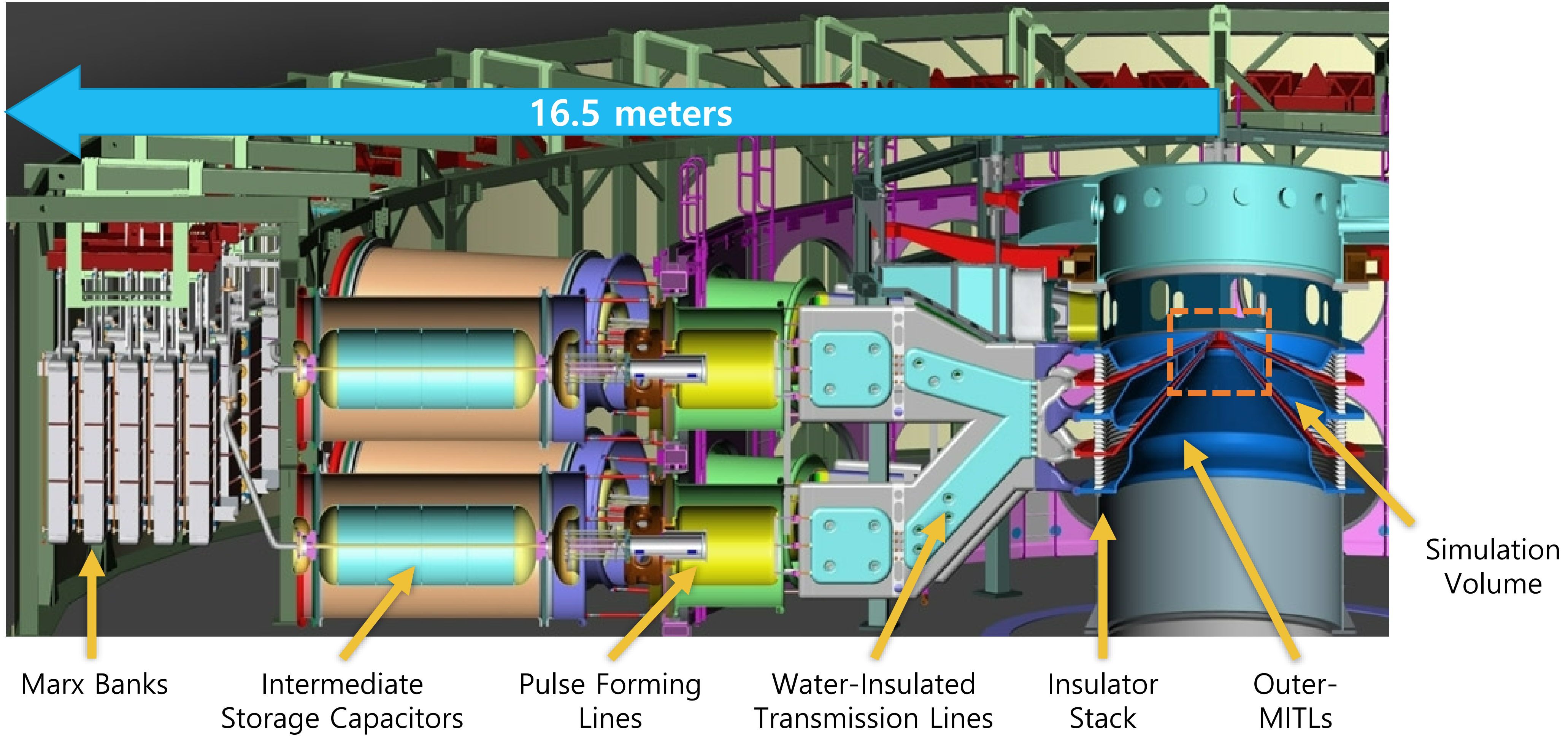
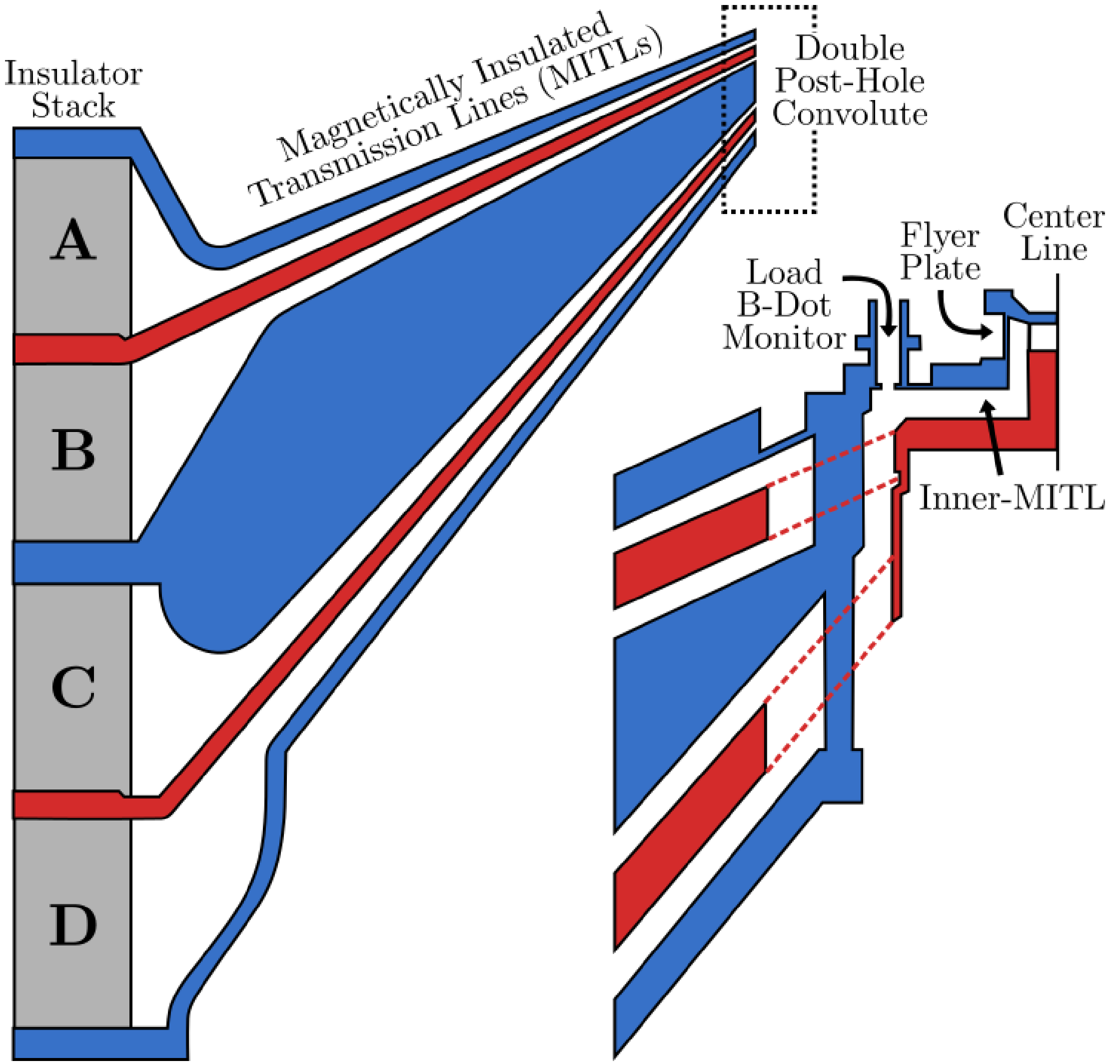
Abstract

The Z machine is a pulsed power generator capable of producing >20 MA current pulses, though multi-MA current losses are routinely observed. The Magnetized Liner Inertial Fusion (MagLIF) experiments are a subset of those conducted on the Z machine, with other campaigns ranging from x-ray production to dynamic materials science. Since the inner transmission lines are insulated by the self-magnetic field generated from the current pulse, interruptions to the magnetic field could significantly increase shunted current. Current loss attributed to plasma formation in the double post-hole convolute has been a previous focus of inquiry, though recent diagnostic developments beyond the B-dot probe have enabled current measurements closer to the load. This velocimetry-based diagnostic capability enables the study of loss mechanisms interior to the convolute, where MagLIF's axial magnetic field intersects with the final transmission line. We explore the hypothesis that this applied magnetic field interferes with magnetic insulation and drives current to shunt prior to the experimental load. Analytical calculations and experimental measurements will be presented.

Z machine generates ~20 MA current pulse



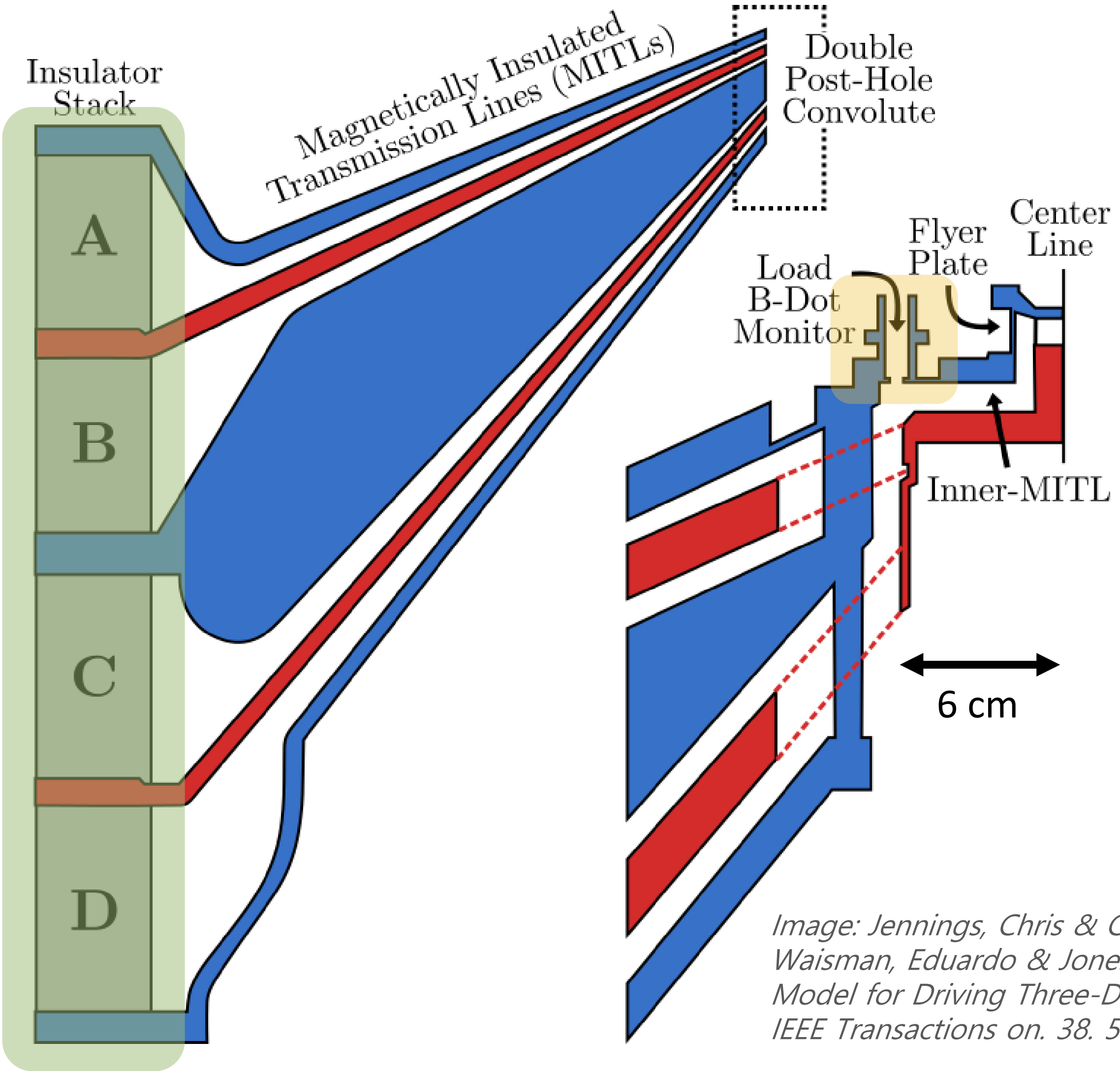
Multi-MA current losses occur near the load

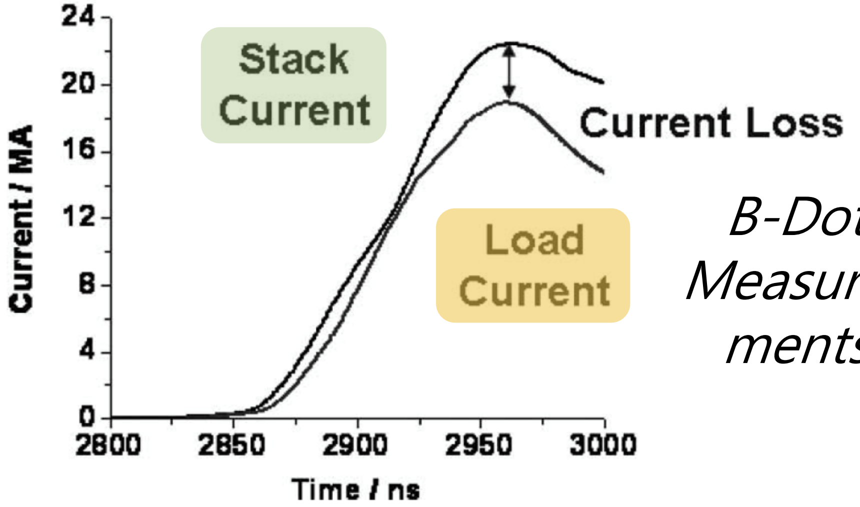


CURRENT

- **Magnetically Insulated Transmission Lines (MITLs)** — *Four transmission lines insulated by the J x B force*
  ↓
- **Convolute** — *Combines current from four into one transmission line*
  ↓
- **Inner-MITL** — *Final transmission line*
  ↓
- **Load** — *Wire array, MagLIF, etc.*

Multi-MA current losses occur near the load





B-Dot Measure-ments

Previous work focused on current loss due to plasma formation in the convolute.

Image: Jennings, Chris & Chittenden, Jeremy & Cuneo, Michael & Stygar, W.A. & Ampleford, David & Waisman, Eduardo & Jones, Michael & Savage, M.E. & LeChien, K.R. & Wagoner, T.C.. (2010). Circuit Model for Driving Three-Dimensional Resistive MHD Wire Array Z-Pinch Calculations. Plasma Science, IEEE Transactions on. 38. 529 - 539. 10.1109/TPS.2010.2042971.

Magnetized Liner Inertial Fusion (MagLIF)

<u>MagLIF Load Region</u>

Experimental fusion concept:

- ➢ Load region magnetized up to 30 T
- ➢ Preionization via laser heating
- ➢ Cylindrical, fuel-filled metal liner imploded

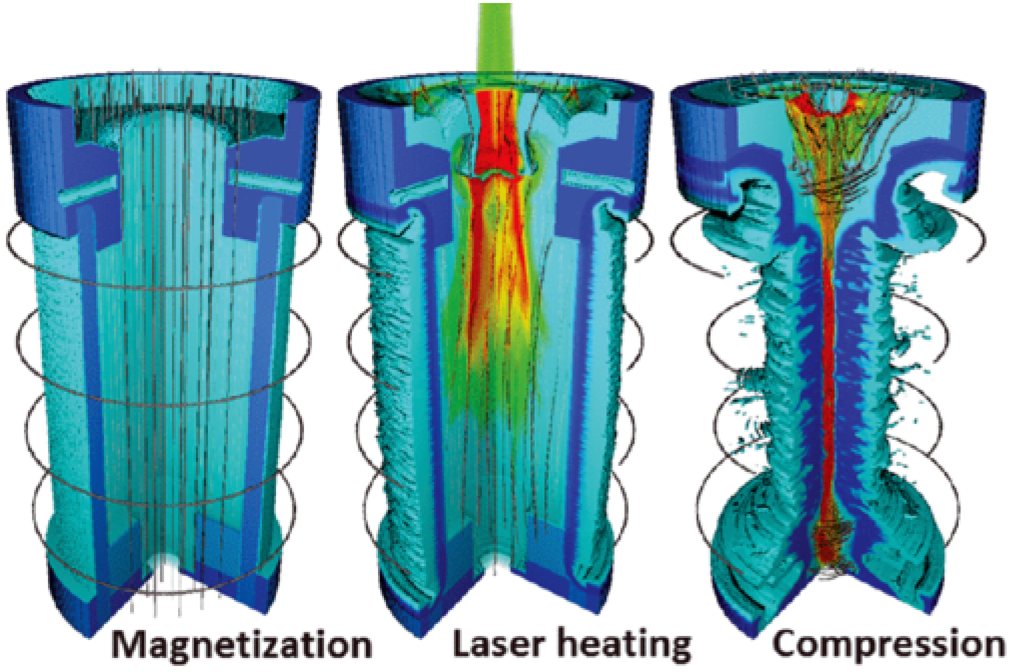
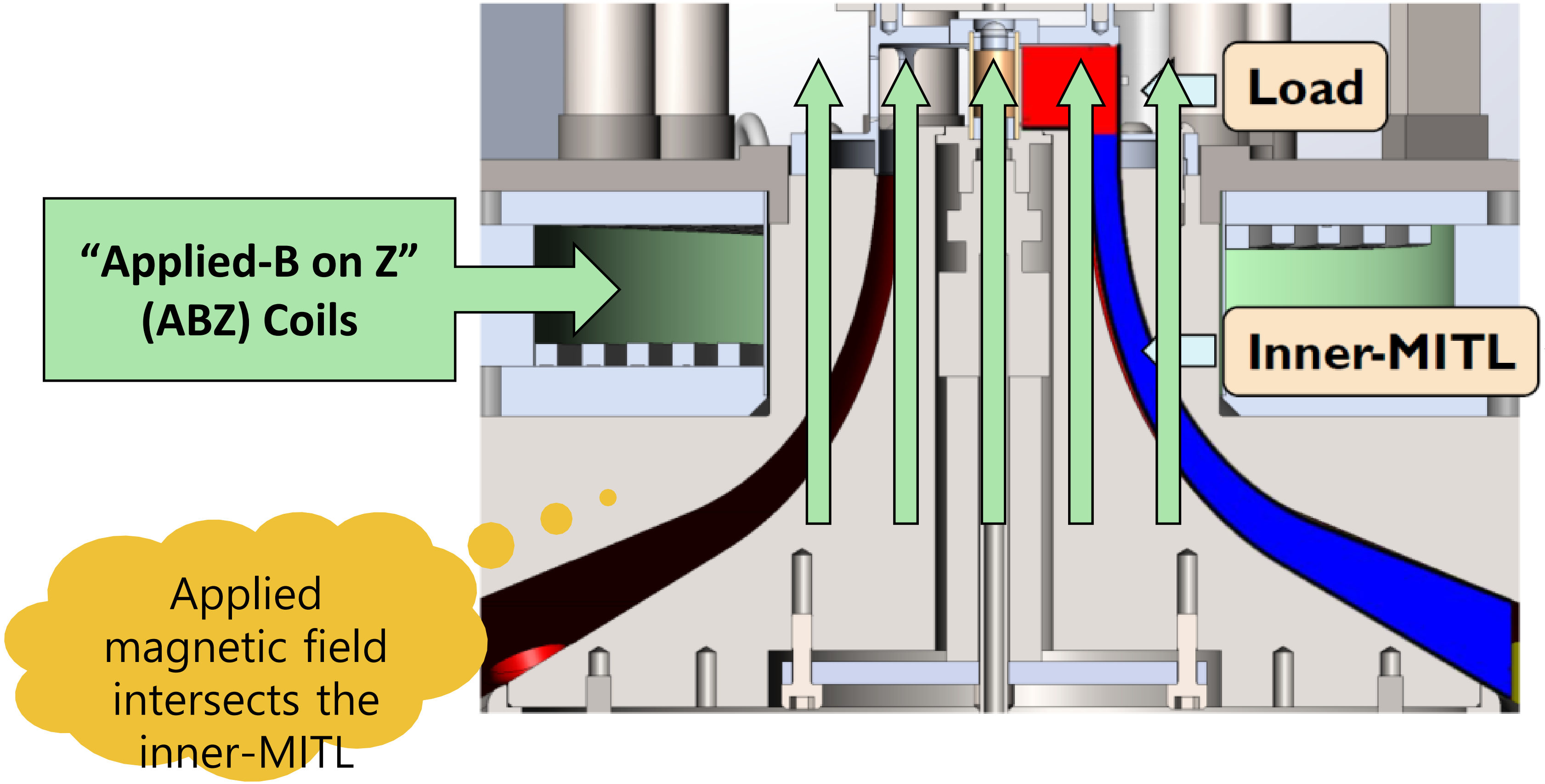
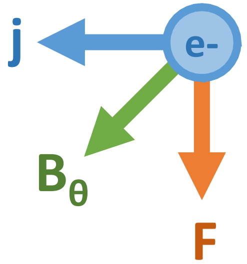


Image: M. R. Gomez, et al. (2014). Experimental Demonstration of Fusion-Relevant Conditions in Magnetized Liner Inertial Fusion. Phys. Rev. Lett. 113, 155003. 10.1103/PhysRevLett.113.155003.

What effect does the applied axial magnetic field have on current coupling?

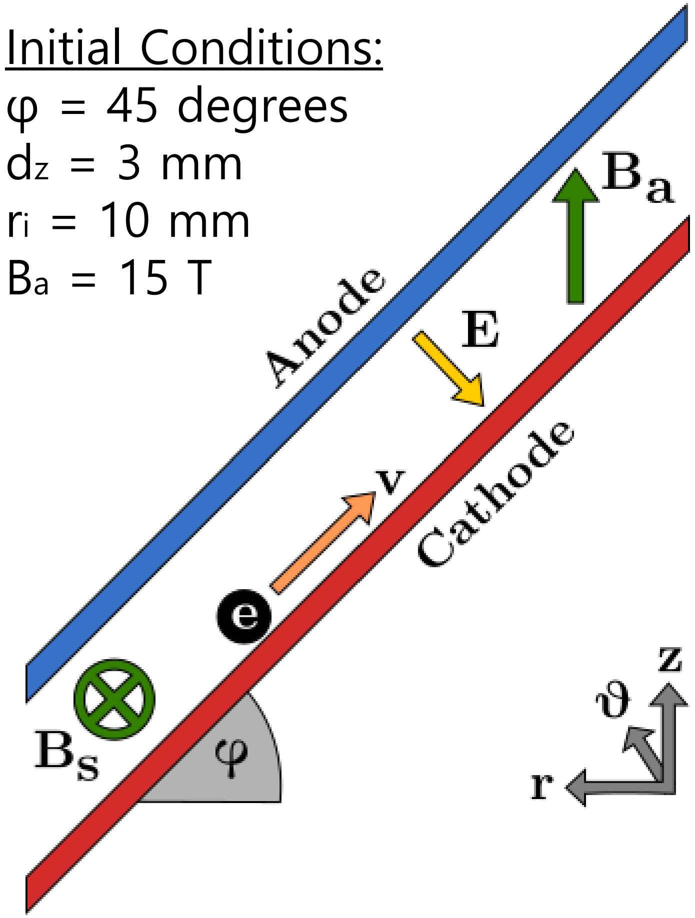


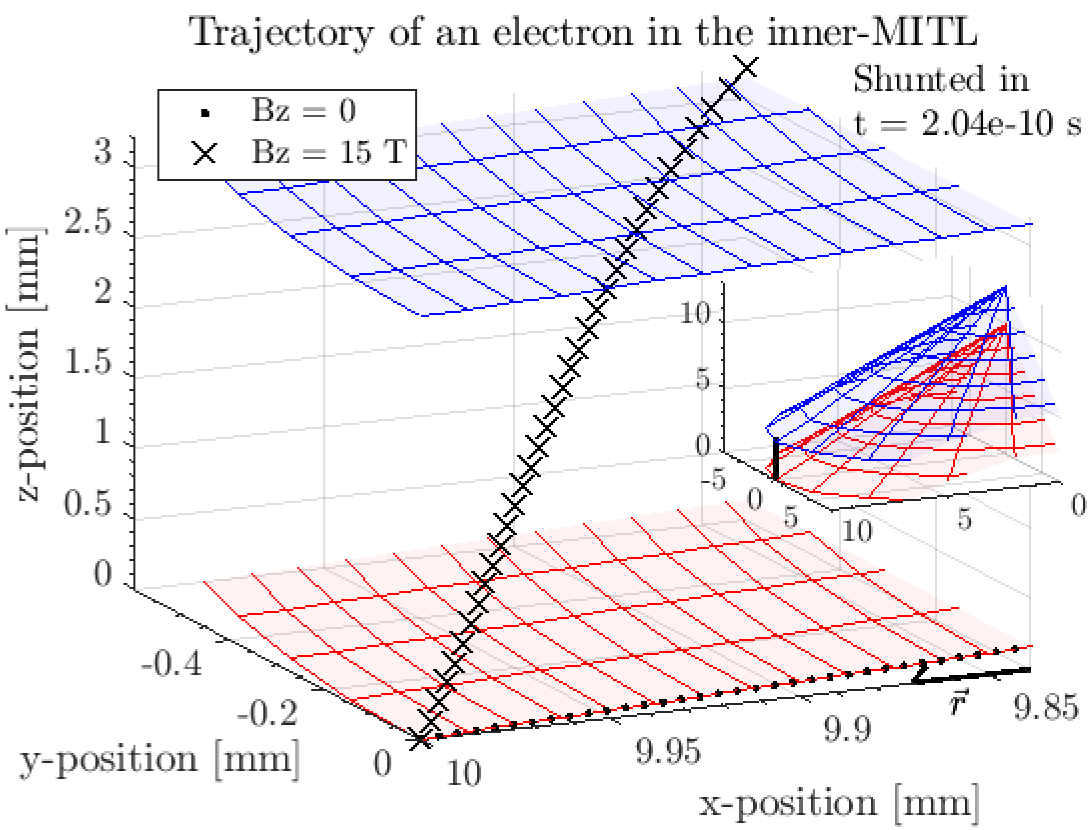
Magnetically Insulated by **J** x **B** Force



Simplified model of the trajectory of a free electron in the inner-MITL shows shunting in ~200 ps

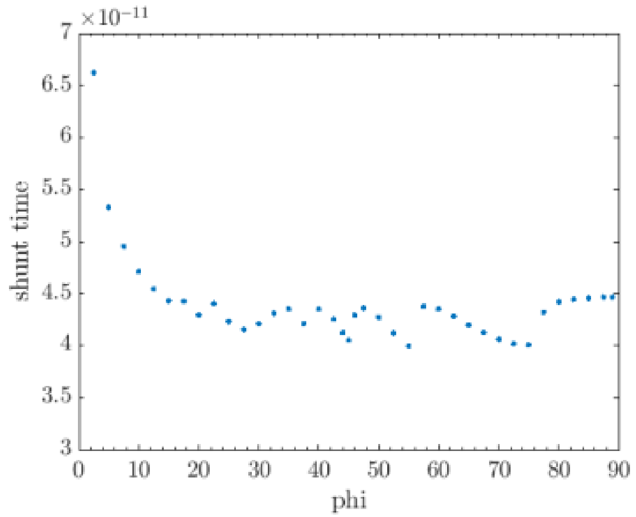
Initial Conditions:
φ = 45 degrees
d_z = 3 mm
r_i = 10 mm
B_a = 15 T

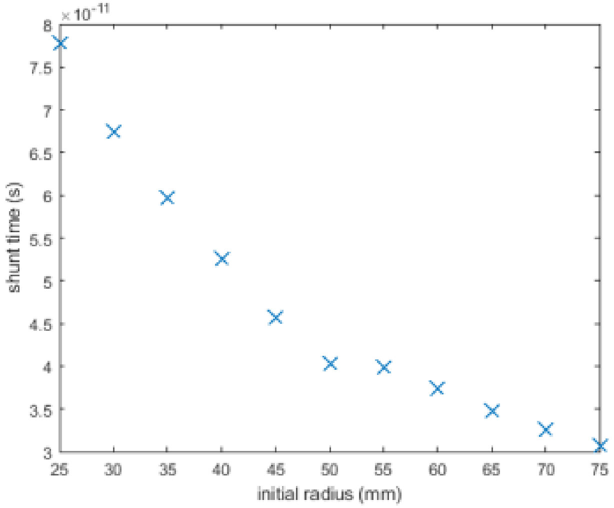




Shunt time trends by varying initial conditions

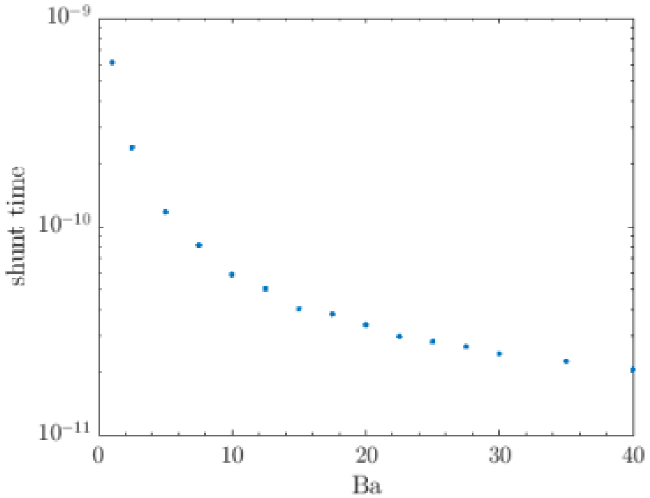
Angle between electron's initial velocity and applied magnetic field

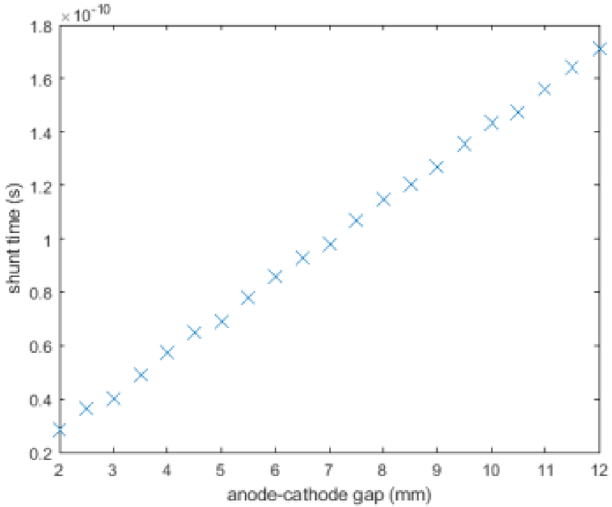




Free electron's initial radius

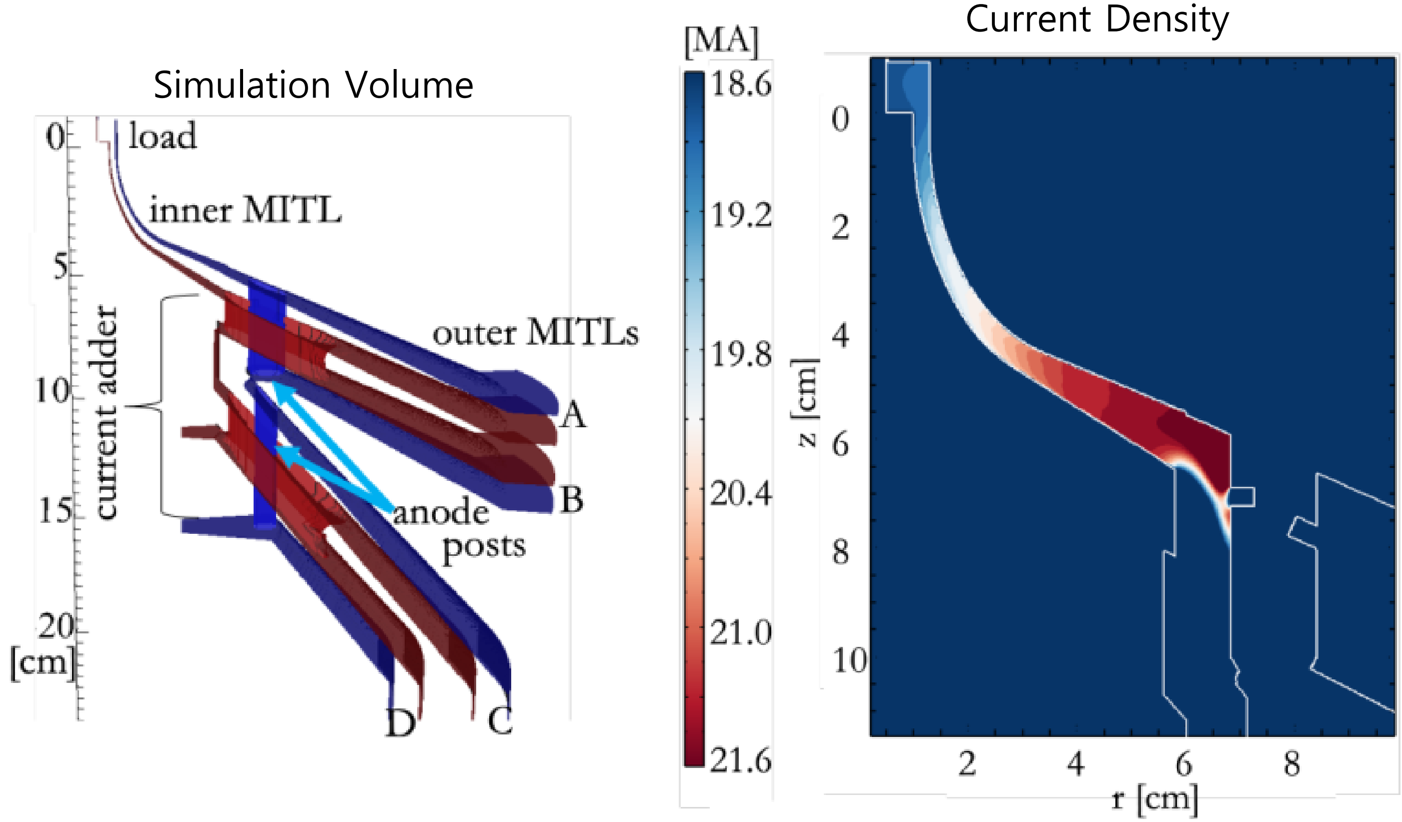
Applied axial magnetic field

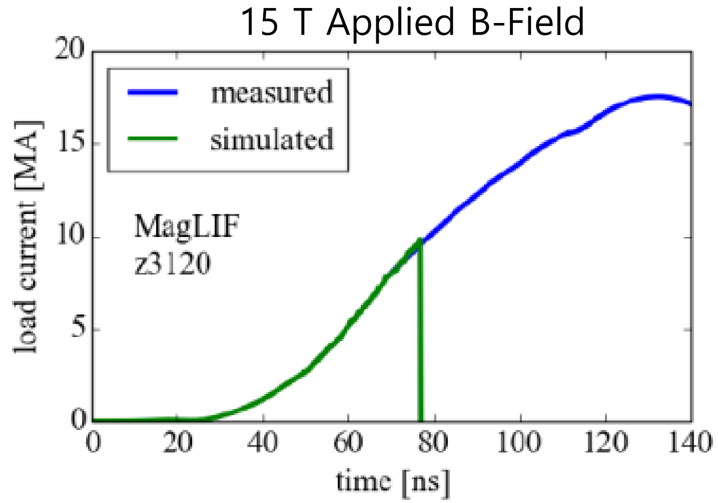


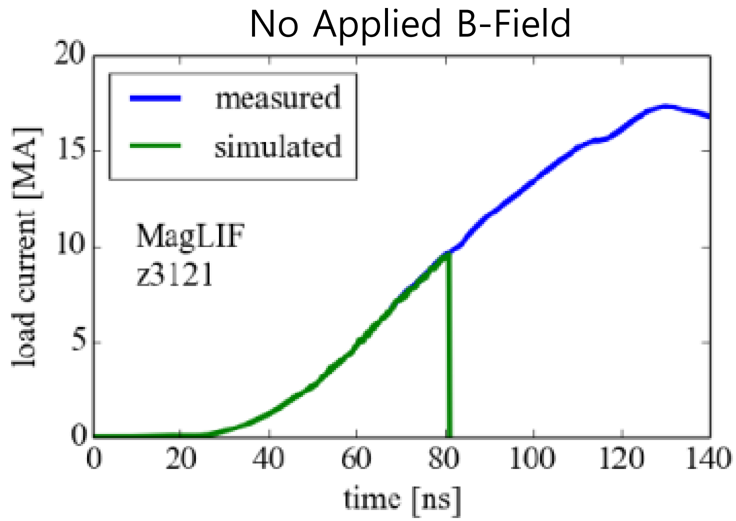


Vertical gap between anode and cathode

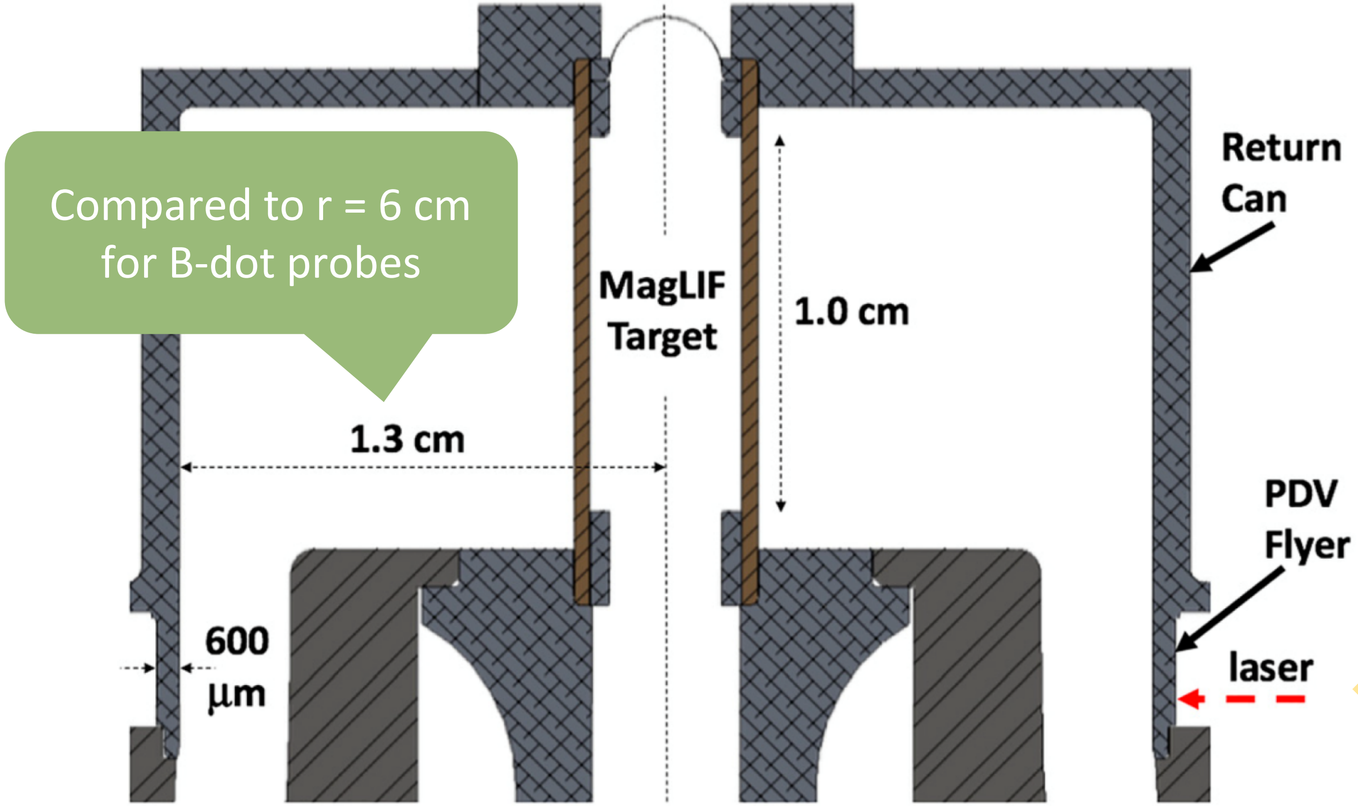
PIC simulations are ongoing







More accurate load current measurement with velocimetry



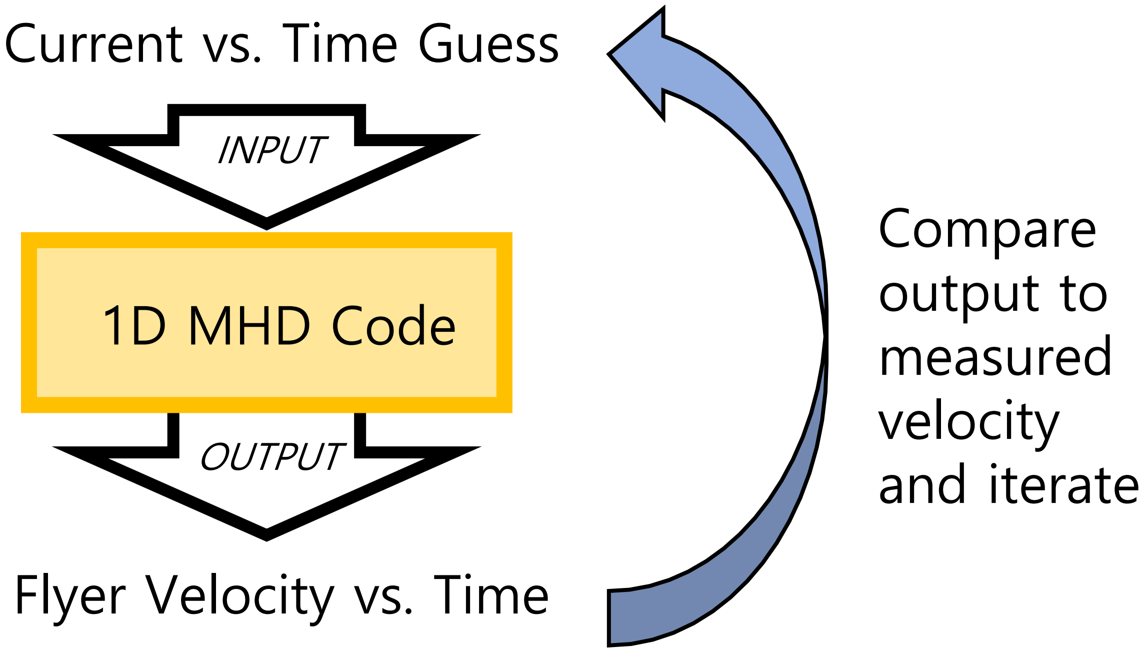
Two velocimetry diagnostics:

1. **PDV**: Photonic Displacement Velocimetry
2. **VISAR**: Velocity Interferometer System for Any Reflector

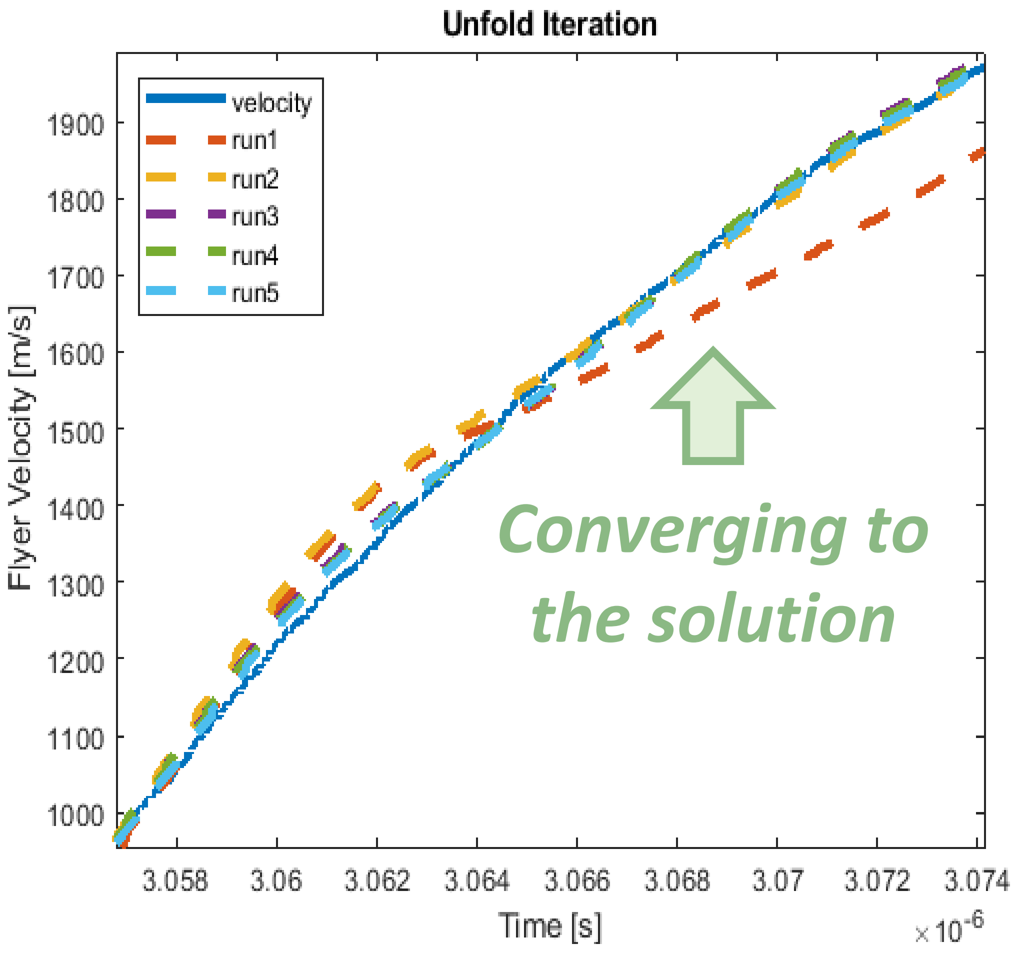
Measures Doppler-shifted light reflected from the flyer that is pushed outwards by magnetic pressure.

Image: M. H. Hess, K. J. Peterson, D. J. Ampleford, B. T. Hutsel, C. A. Jennings, M. R. Gomez, D. H. Dolan, G. K. Robertson, S. L. Payne, W. A. Stygar, M. R. Martin, and D. B. Sinars (2018). Design and testing of a magnetically driven implosion peak current diagnostic. Physics of Plasmas. 25. 042702.

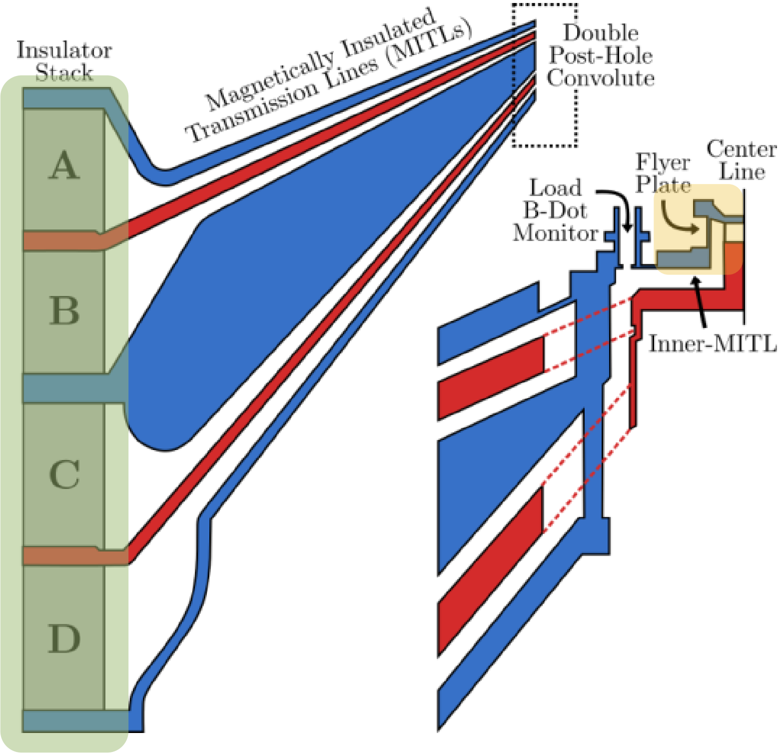
Unfold Process Overview

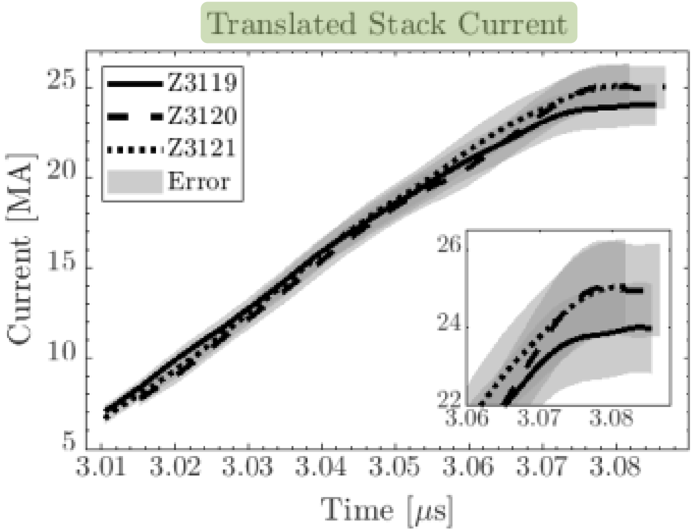


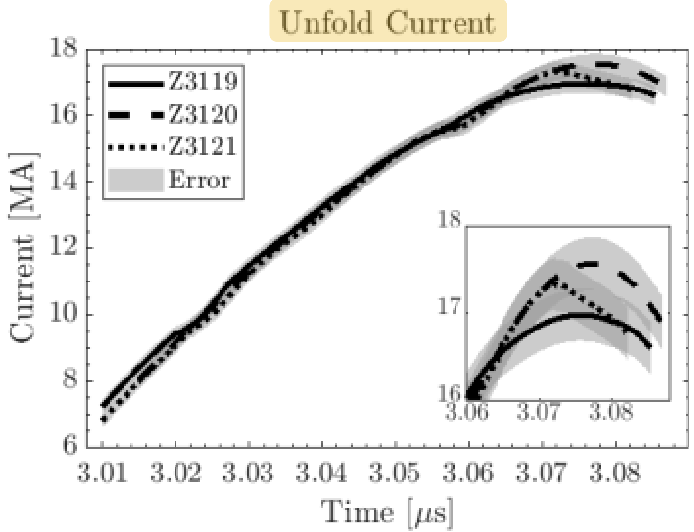
*Use **stack current** as the initial guess*



Measured Result Shows No Effect From Applied Field







$h = -$

via B-dot probe via unfold velocimetry

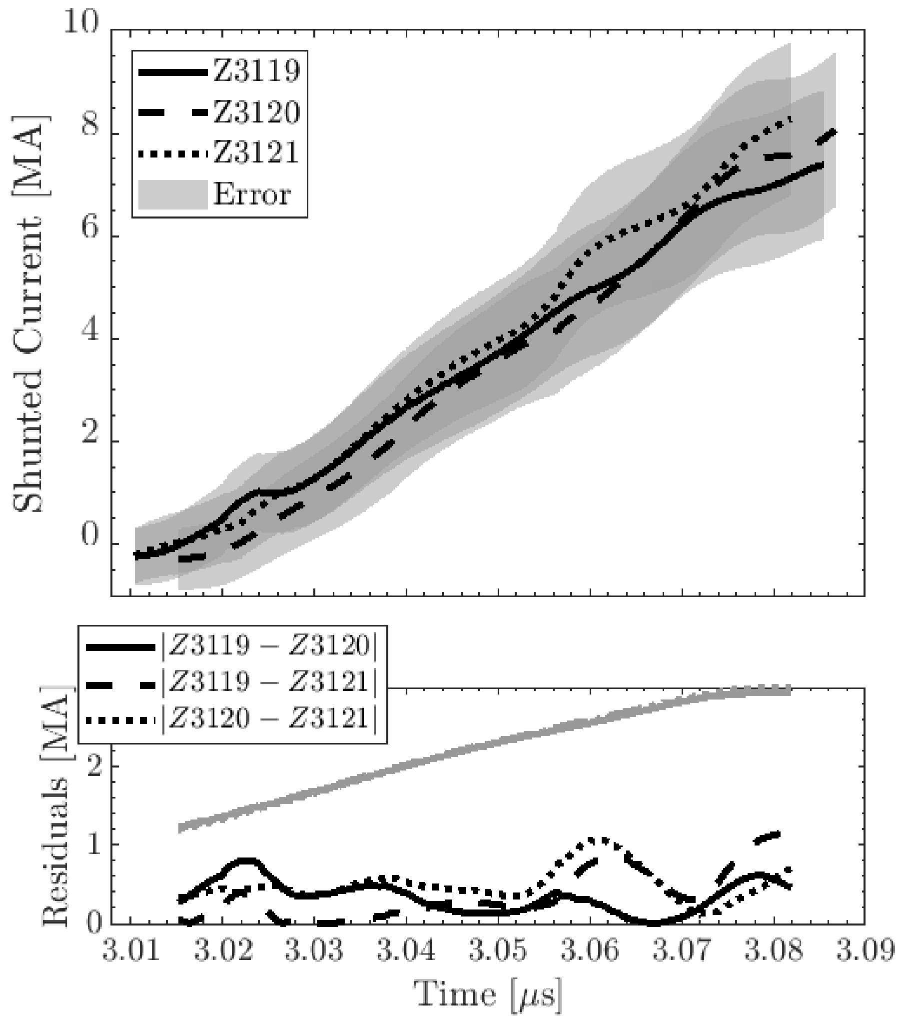
Measured Result Shows No Effect From Applied Field

h = −

Applied B-Field

Identical Set-up

Z3119	14 T
Z3120	15 T
Z3121	0 T



Conclusion

Unfold-velocimetry technique enables…

- **measurement** of current **closer to the load** than B-dot probes on Z-machine (radius 1.3 cm vs 6 cm), and…
- **analysis** of current loss in the **inner-MITL region.**

Upcoming paper on the **effect of axial magnetic fields** from MagLIF on current coupling.

- Experimental results show that **performance is not affected** by the applied field.
- Simulation results pending.

Thank you!

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