Magnetized Target Fusion At General Fusion: An Overview

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GF MTF Concept

General Fusion is pursuing a concept for an MTF-based powerplant where a thick, flowing liquid metal liner serves as a flux conserver, first wall, and neutron blanket.

A quasi-spherical cavity is formed in liquid metal through a combination of fluid rotation and flow management features. A spherical tokamak "target" is injected into the cavity by a magnetized Marshall gun.

An array of piston "drivers" push on the back of the liner resulting in a smooth, nominally self-similar compression on a millisecond timescale. Preservation of angular momentum of the fluid during compression helps stabilize the wall against Rayleigh Taylor instabilities.

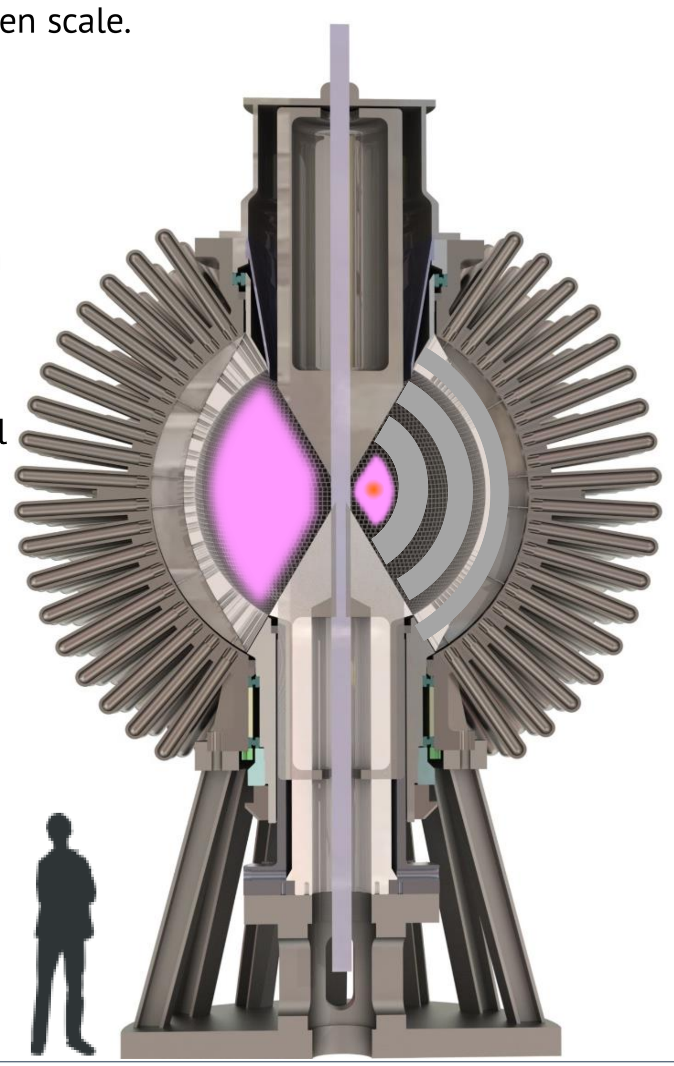
Current design efforts are focused on an integrated prototype that will demonstrate all aspects of the concept, resulting in adiabatic compressive heating driven by liquid metal.

Integrated Prototype Specifications

Initial plasma electron density:	4×10^{19} m^{-3}
Initial flux conserver radius:	1.5 m
Initial plasma temperature:	350 eV
Initial on axis B field:	0.6 T
Initial CT Poloidal flux	0.7 Wb
Initial β:	<7%
Initial shaft current:	2.5 MA
Initial plasma current:	1 MA
Volumetric Compression Ratio	1000:1
Compression time	3.5 ms
Final plasma density:	6.5×10^{22} m^{-3}
Final plasma temperature:	>10 KeV
Final β:	50%

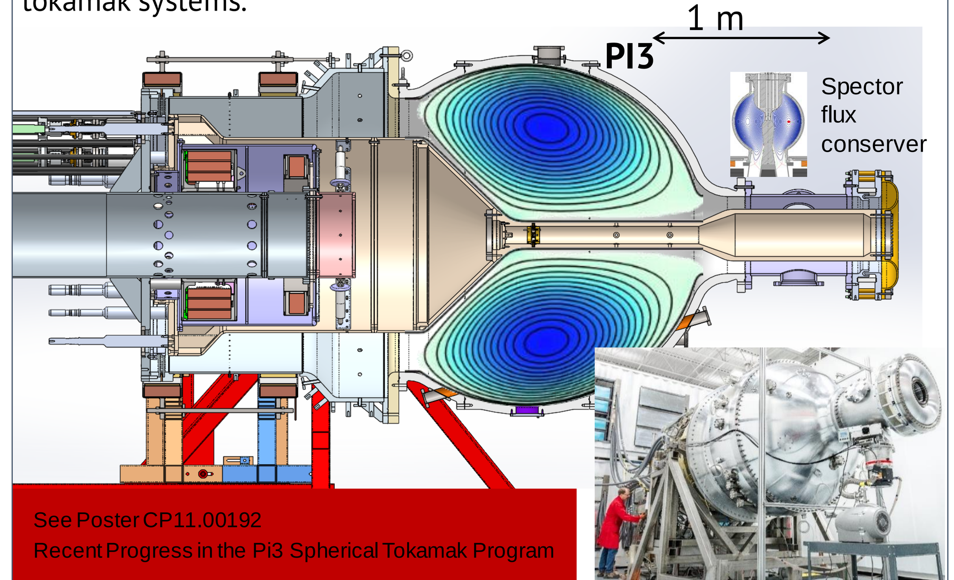
The image below shows General Fusion's proposed Prototype system, with the formation plasma shown at left, and compressed plasma on the right. This Prototype system is being designed to achieve fusion-relevant temperatures at low repetition rate (once per day), at below break-even scale.

The Prototype system will use a liquid lithium drive fluid and compress a ~1.5 m outer radius spherical tokamak plasma in ~3.5 ms. A solid center shaft and cones will provide access for system diagnostics.



Plasma Target Development: Large Injector

General Fusion's newest large injector, **Pi3**, is designed to demonstrate formation of a spherical tokamak target suitable for use in our large scale magnetized target fusion prototype. The technology may also have applications in solenoid-free startup in steady-state spherical tokamak systems.



See Poster CP11.00102 Recent Progress in the PI3 Spherical Tokamak Program

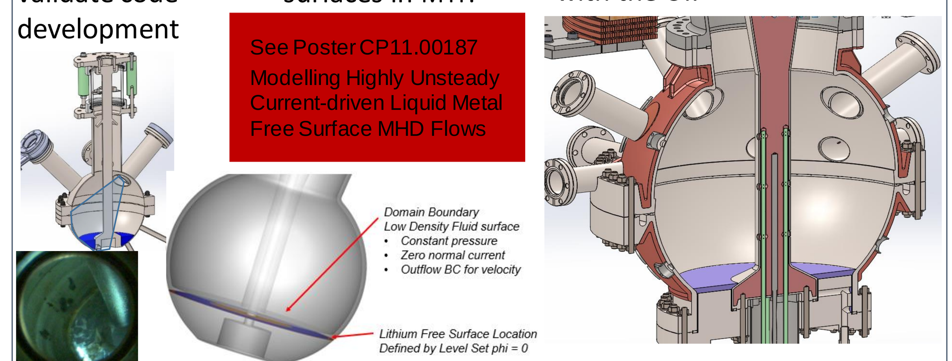
Plasma Experiments with Liquid Metal Free Surface (and corresponding simulation development)

General Fusion is pursuing using liquid metal as a flux conserver and first wall. Experimental and simulation paths are being pursued to explore the dynamics of liquid metal-plasma interactions.

MiniSLiC, a small-scale experiment in liquid metal dynamics used to validate code development

The HiMag code is being developed to simulate dynamics of liquid metal free surfaces in MTF.

SLiC, a version of our SPECTOR machine, will operate inverted, with an annular pool of liquid lithium in contact with the CT.

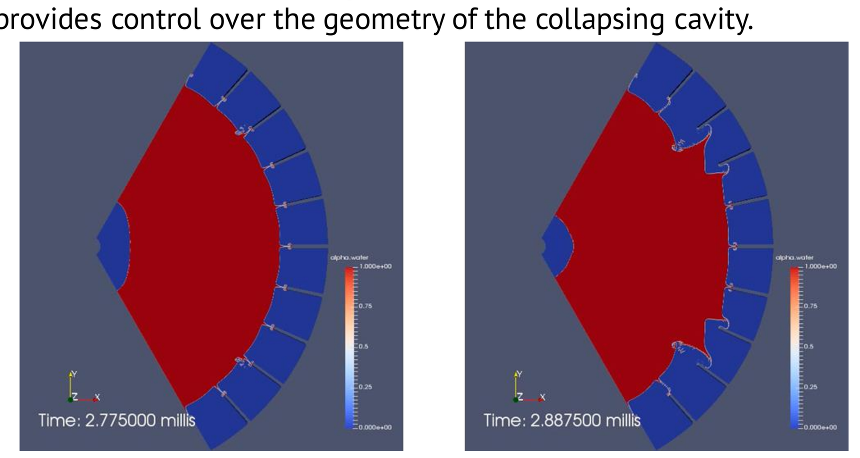


See Poster CP11.00187 Modelling Highly Unsteady Current-driven Liquid Metal Free Surface MHD Flows

Liquid Compression Technology

The SWC experiment is a test bed at General Fusion to explore the dynamics of rapid collapse of a spherical liquid cavity. Initial operation will be on water, and will progress to liquid metal operation with Galinstan.

CFD simulations in OpenFOAM demonstrate that varying the drive pressure and/or drive timing as a function of poloidal angle provides control over the geometry of the collapsing cavity.



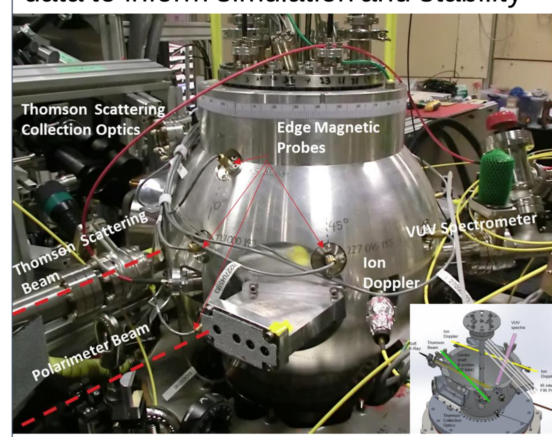
Above (left) cross-section shows a compressed, elongated cavity from equal pressure drive pressure, where above (right) shows a more self-similar compressed cavity geometry when the drive pressure is reduced towards the equator. By adhering to, or deviating from, a self-similar compression, the compression geometry can be optimized for plasma stability.

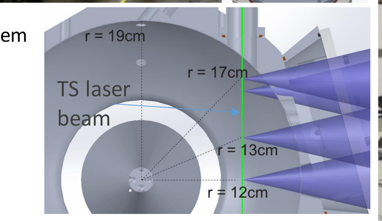
Plasma Target Development: Small Injectors

General Fusion has developed a complimentary set of small-scale CHI experiments forming spherical-tokamak compression targets.

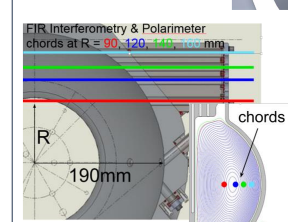
Spector, a well-diagnosed laboratory machine has explored a wide range of parameters, measuring detailed profile data to inform simulation and stability

Simplified machines with reduced diagnostics duplicate lab shots before destructive MTF tests

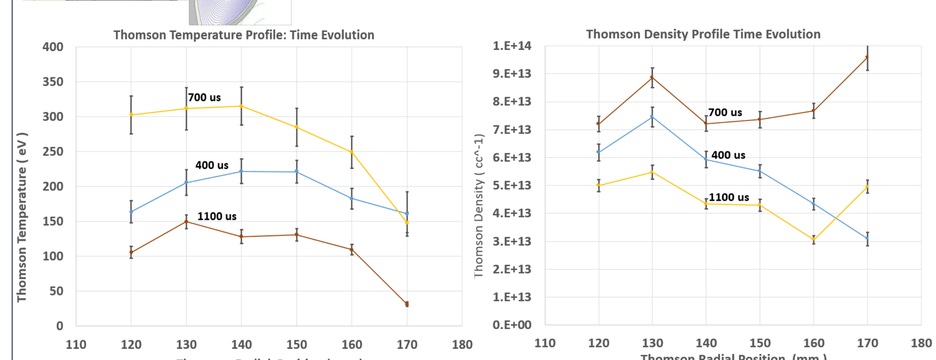




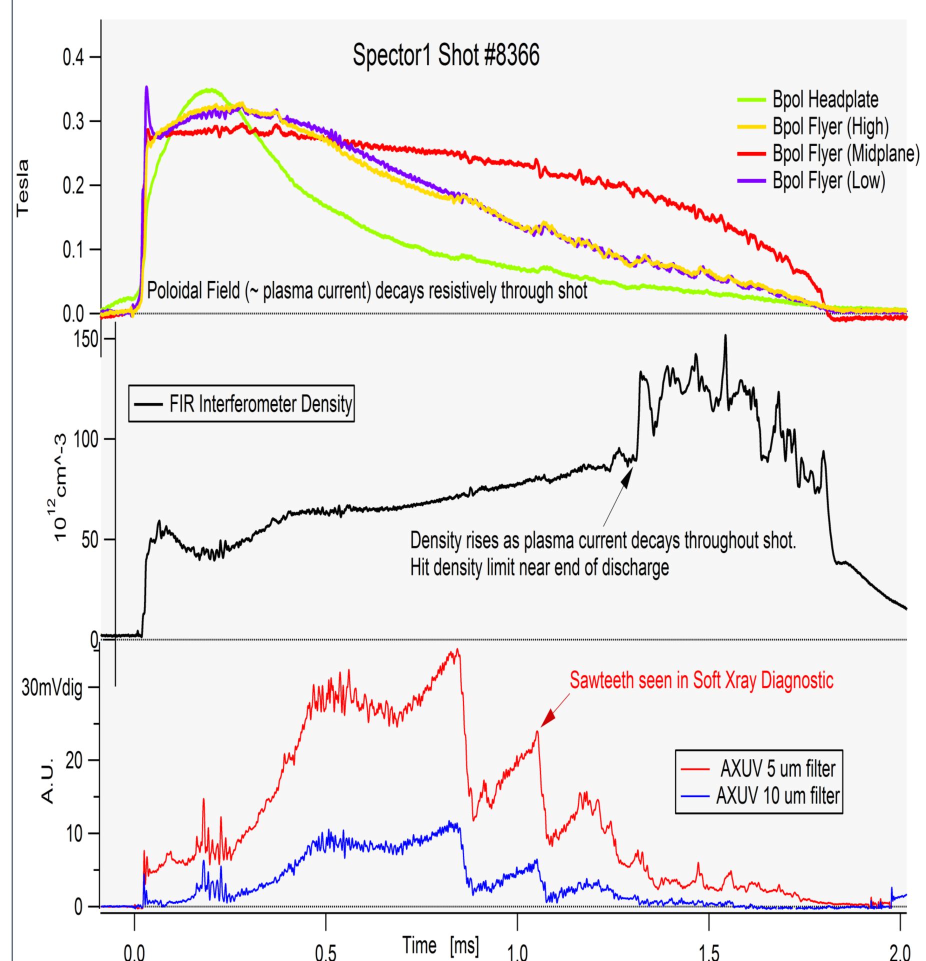
The Spector TS system measures six radial locations in the equatorial plane.



A FIR CO2 laser is used for polarimetry and interferometry, along four chords in the equatorial plane.



The temperatures and thermal confinement times of these plasmas are within the range needed to be considered as targets for adiabatic compression to fusion conditions. Our plasma development can now have increased focus on performance of our CTs under compression. We are addressing this issue through a combination of simulation and experiment.



MHD Simulation

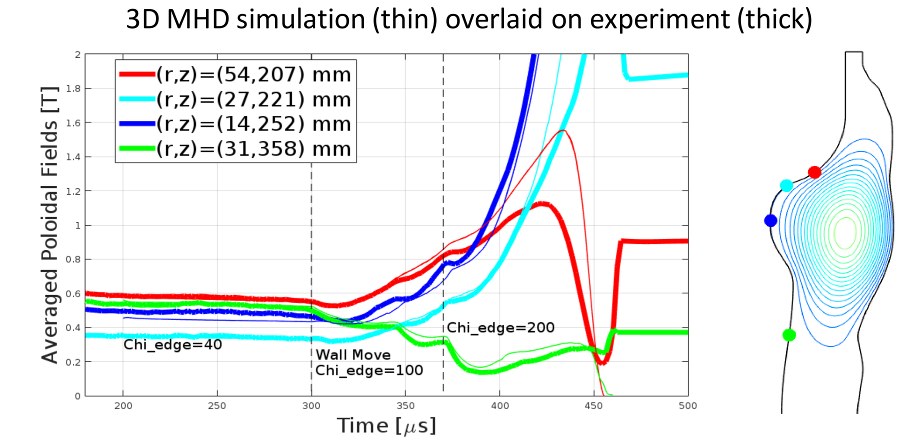
MHD simulation is primarily done using a modified version of VAC*, due to the ability to model the moving boundary required for MTF compression, and the advection effects involved in the CHI formation process.

* Originally developed by Gábor Tóth et al. at Michigan University.

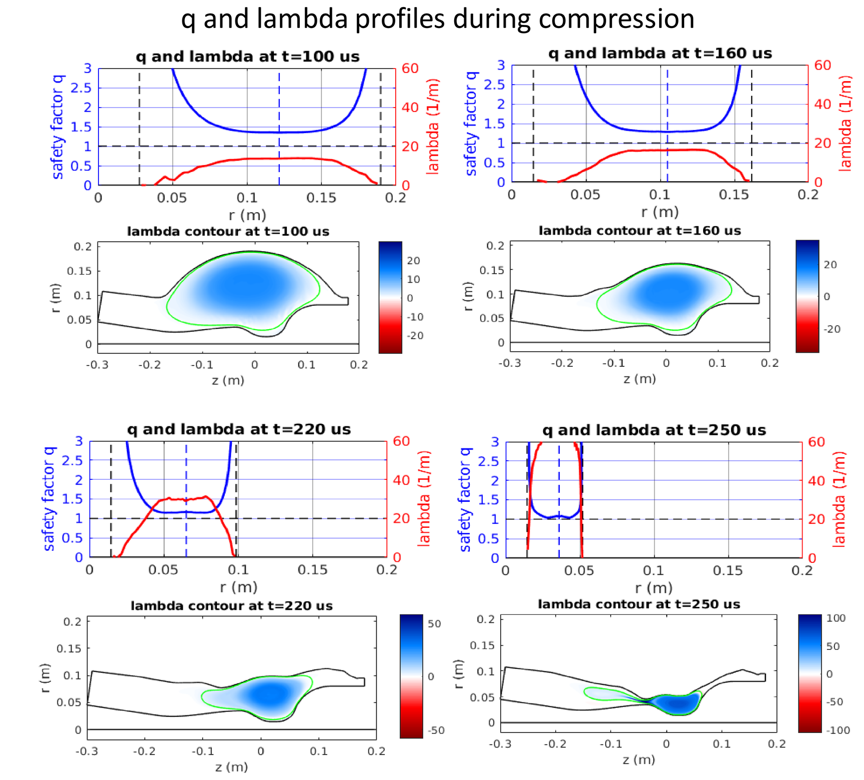
Compression Simulations

PCS16 Compression

3D MHD simulation (thin) overlaid on experiment (thick)



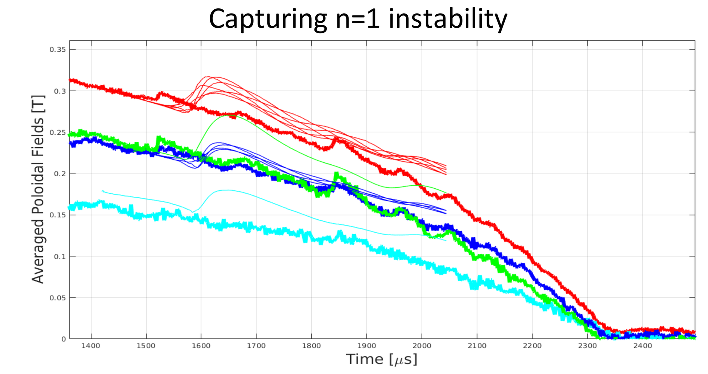
q and lambda profiles during compression



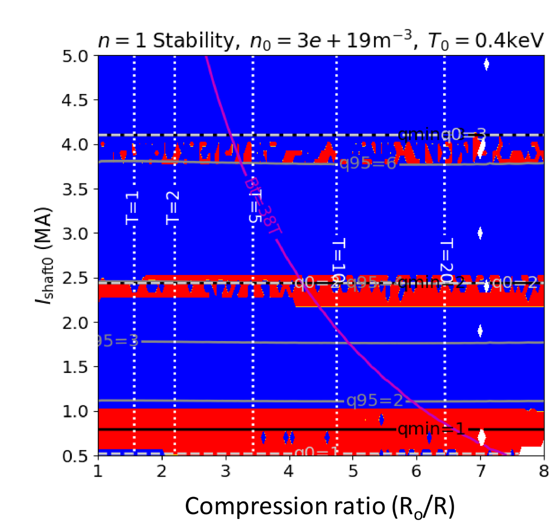
Non-compression Simulations

3D MHD simulation (thin) overlaid on experiment (thick)

Capturing n=1 instability



Prototype System Plasma Stability

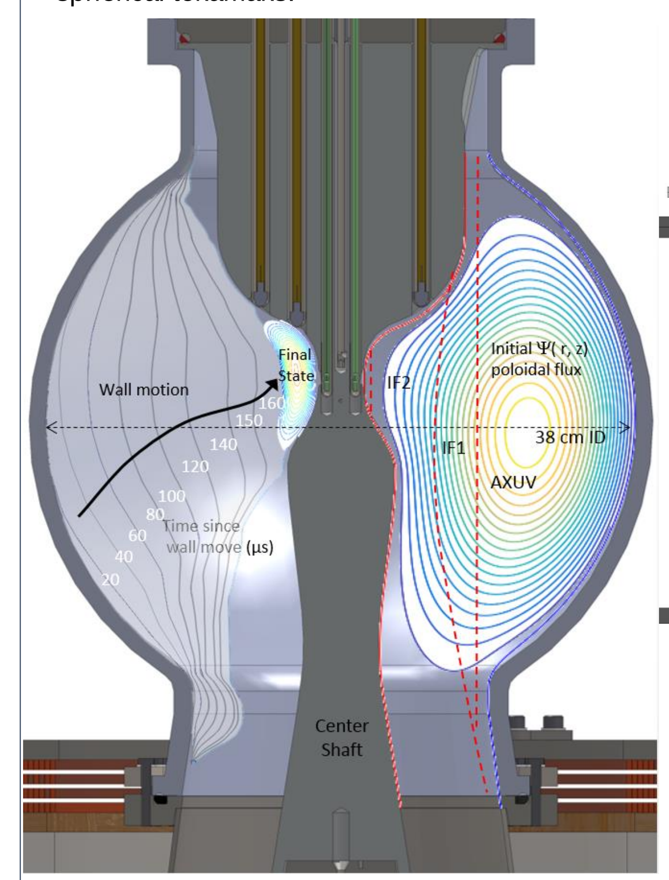


- Map of ideal compression trajectories (adiabatic, ideal MHD)
- Horizontal lines are trajectories (entropy and q constant)
- Ideal MHD stability analyzed using DCON
- Unstable regions are red
- Vertical white dashed contours are temperature in keV

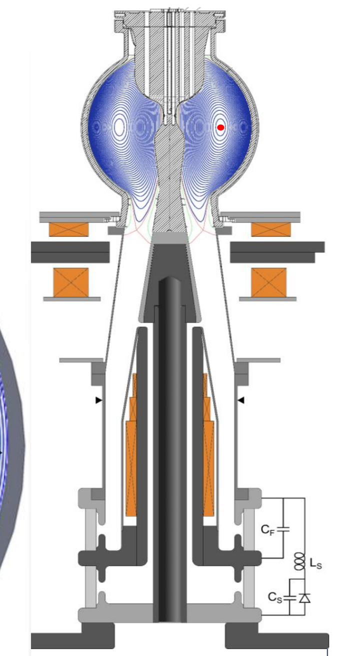
See Poster CP11.00190 MHD Stability of a Magnetized Target During Non-Self-Similar Compression

Plasma Compression Tests (PCS program)

General Fusion is conducting a sequence of subscale experiments of compact toroid (CT) plasmas compressed by chemically driven implosion of an aluminum liner, providing insight into plasma behavior needed to advance toward a reactor-scale demonstration. These experiments are referred to as "Plasma Compression Small" (PCS) and in total 16 experimental campaigns have been completed each with a final "field shot" where the CT is actually compressed by the aluminum liner at a remote location. In all PCS shots to date CT plasmas are formed by a coaxial Marshall gun, with magnetic fields supported by internal plasma currents and eddy currents in the wall. We are currently investigating the behavior of plasma configurations similar to spherical tokamaks.

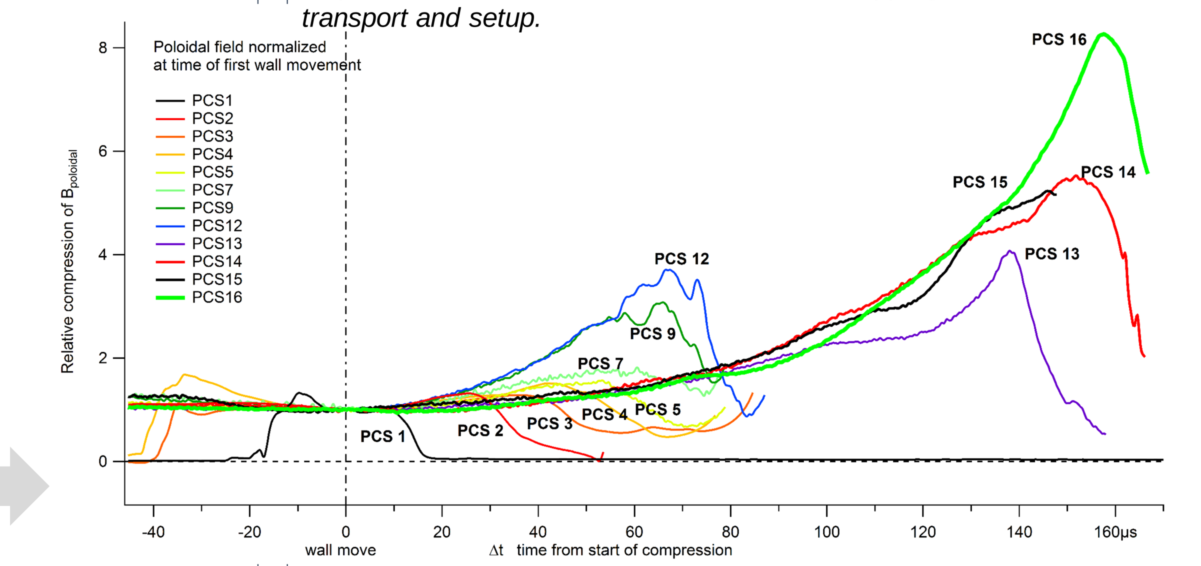


Wall trajectories during a PCS compression test, showing poloidal magnetic field in the initial and final states.

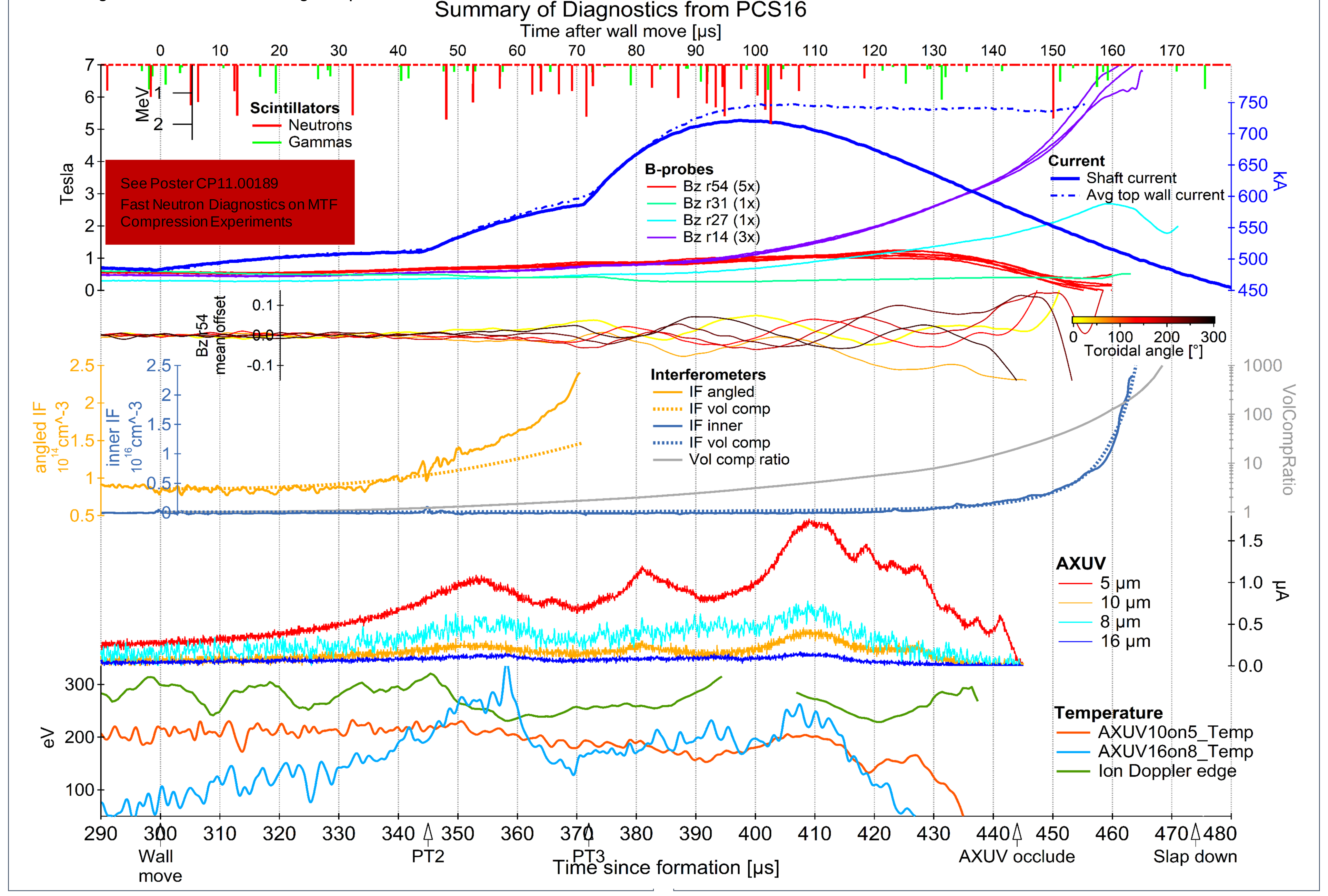


A PCS field test being commissioned at a licensed blast range. Pulsed power capacitor banks, vacuum system, control system, and data acquisition screenroom are all built into shipping containers for fast transport and setup.

Summary graph showing steady progress in magnetic compression over 16 MTF tests spanning multiple years. Many factors contribute to improved outcomes, including optimization of liner shape and reduced ejecta, Lithium coating of flux conserver, control of neutral gas, and magnetic configuration. Current efforts are focused on controlling MHD instabilities during compression.



Summary of Diagnostics from PCS16



See Poster CP11.00189 Fast Neutron Diagnostics on MTF Compression Experiments