Magnetized Target Fusion At General Fusion: An Overview

P. O'Shea, M. Laberge, M. Donaldson, M. Delage

General Fusion Inc., Burnaby, British Columbia, Canada

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GF Original ACOUSTIC MTF Concept

General Fusion's original Magnetized Target Fusion (MTF) concept involves compressing an initial magnetically confined plasma (t_E >100 msec) with a 1000x volume compression in ~100 microseconds. If near adiabatic compression is achieved, the final plasma would produce reactor relevant fusion energy gain. (see initial and final plasma parameters below)

- Pistons kinetic energy: 120 MJ
- Initial plasma density: 1.25E23 m^{-3}
- Initial plasma temperature: 100 eV
- Initial magnetic field: 7 Tesla
- Initial plasma radius: 20 cm

- Radial compression: 9.76
- Energy transfer to plasma: 14 MJ
- Maximum fluid-plasma velocity: -2609 m/s

- Peak plasma density: 1.16E26 m^{-3}
- Peak plasma temperature: 24.6 keV
- Peak plasma pressure: 4.7 Mbar
- Peak magnetic field: 665 Tesla
- Confinement time
- (FWHM of plasma density): 6.93 μs

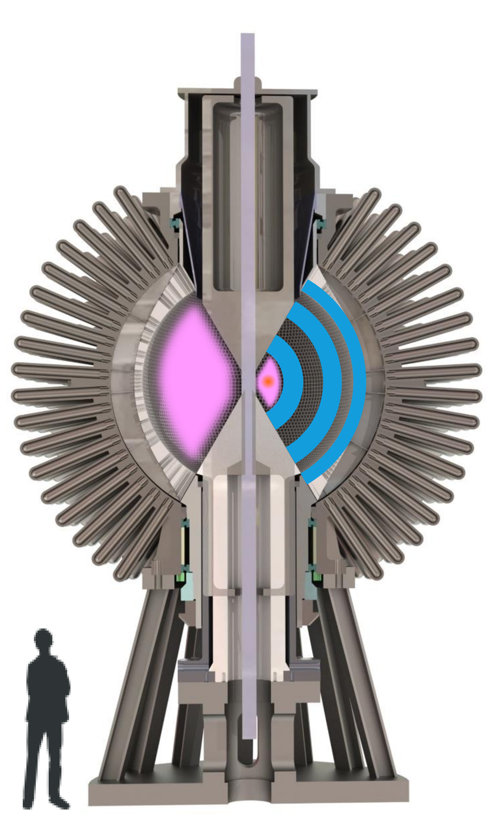
- Fusion energy produced: 704 MJ
- Energy gain: 5.9

Magnetic fields above 100 T will vaporize the liquid metal surface. This vaporized material presents two risks: first, the vapor has low electrical conductivity, allowing the magnetic flux to diffuse through vapor and escape the flux conserver; and secondly, depending how far it penetrates into the plasma, the vapor may cause instabilities or high radiative losses. These effects limit the maximum operating magnetic field when compressing on > 1 μs timescales.

GF Upgraded to Spherical Cavity, Slower Liner

General Fusion has updated its concept with a larger plasma target, slower compression, and lower peak energy density. No impact or shock wave. The cylinders are filled with liquid metal and the pistons push this liquid smoothly into the chamber, compressing the plasma. With a slower compression time better energy confinement is required, and General Fusion has therefore moved to a spherical tokamak plasma target.

The non-acoustic / direct drive system also allows General Fusion to implement technology that creates a quasi-spherical (non-cylindrical) cavity in the liquid metal. Combined with the driver array, this geometry provides for a nominally self-similar compression of the plasma. Rotation of the fluid establishes the cavity, and the preservation of angular momentum of the fluid during compression helps stabilize the wall against Rayleigh Taylor instabilities.



Concept image of proposed Prototype system

Preliminary Power Plant Concept

Initial plasma density:	2E20 m^{-3}
Initial flux conserver radius:	2 m
Initial plasma temperature:	400 eV
Initial on axis B field:	1.2 T
Initial β:	5%
Initial shaft current:	5 MA
Initial plasma current:	6 MA
Compression 7:1 linear in 40 ms	
Final plasma density:	7E22 m^{-3}
Final plasma temperature:	10 KeV
Final β:	20%
Time at peak compression:	2 ms
DT Yield:	1 GJ

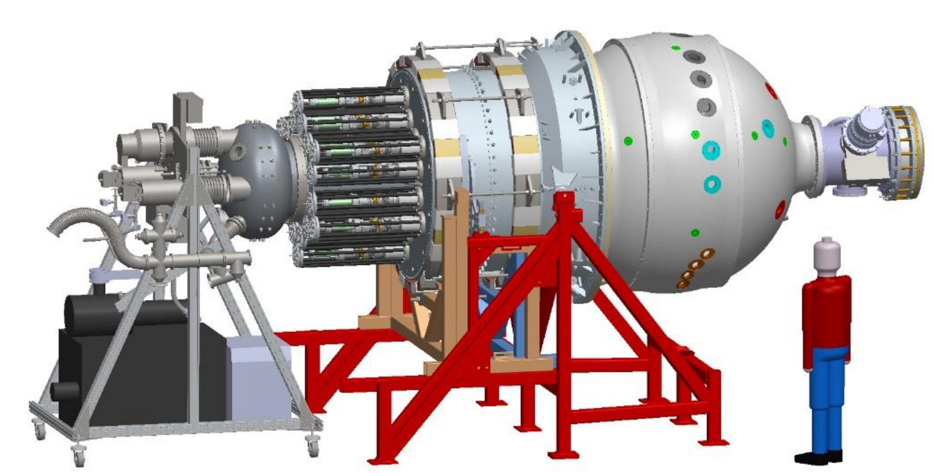
The image shows General Fusion's proposed Prototype system, with the formation plasma shown at left, and compressed plasma on the right. This Prototype system is being designed to achieve fusion-relevant temperatures at low repetition rate (once per day), at below break-even scale.

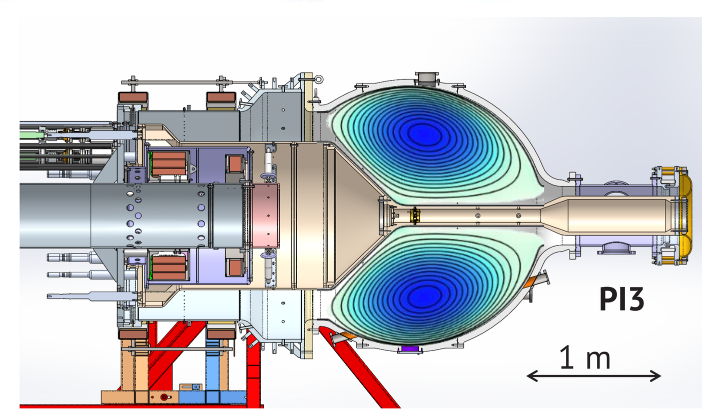
The Prototype system will use a liquid lithium drive fluid and compress a ~1.5 m outer radius spherical tokamak plasma in ~3 ms. A solid center shaft and cones will provide access for system diagnostics.

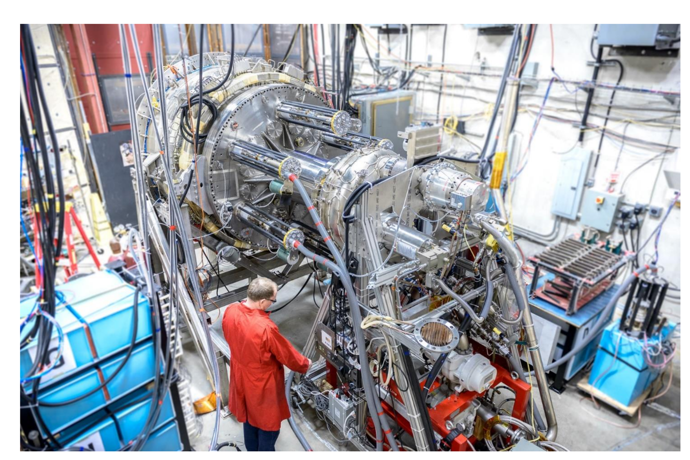
Plasma Target Development: Large Injector

General Fusion's **Pi1** and **Pi2** systems further demonstrated compression heating of a spheromak to over 300 eV and 3.2T magnetic fields. Unfortunately, energy confinement of the CT at the end of the acceleration section can be negatively impacted by high levels of residual pushing current.

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



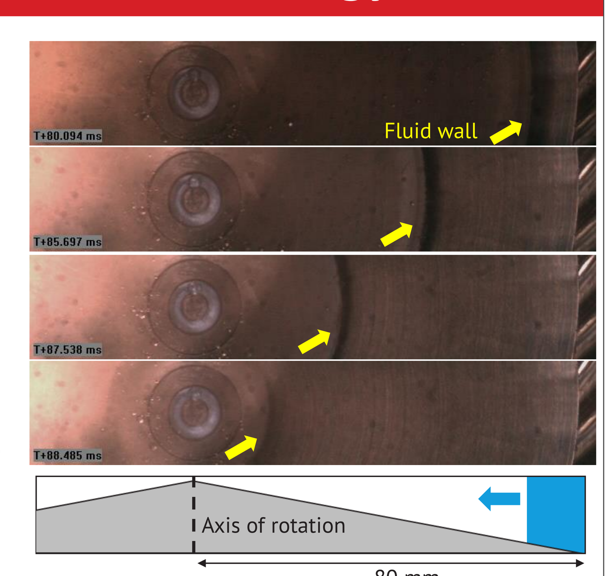




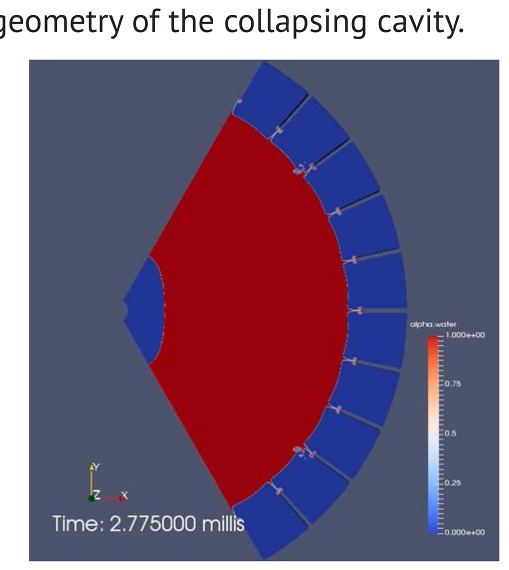
Liquid Compression Technology

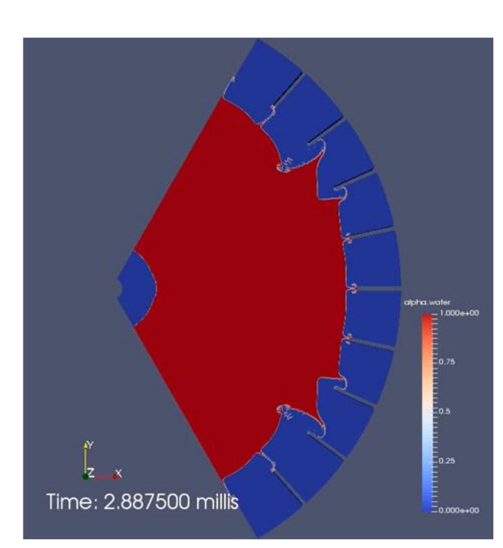
Stabilization of the liquid cavity wall against instabilities (as first demonstrated in the LINUS program at NRL) is a core element of the slow liner design.

Compression experiments at General Fusion, with multi-channel drivers and a fast rotating (1000 RPM) liquid liners in 2D and pseudo 3D (bowtie) compression geometries show good stability of the fluid wall over 10X radial compression ratio.



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.

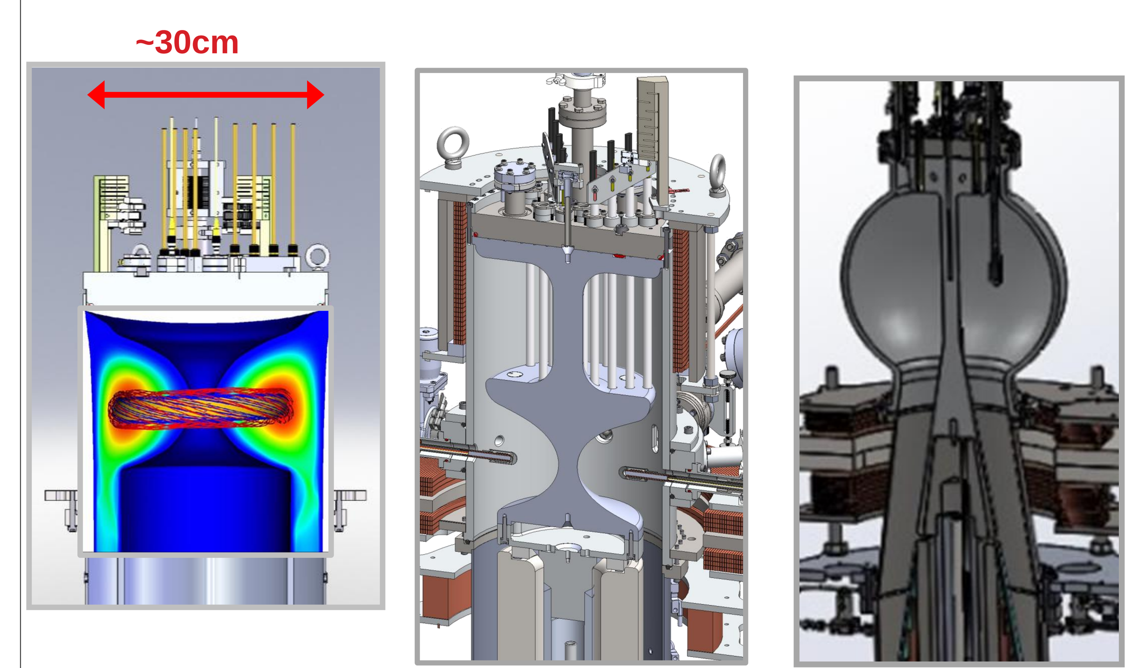




Above (left) cross-section shows a compressed, elongated cavity from equal pressure drive pressure, where above (right) shows a more self-similar compressed cavity geometry when the drive pressure is reduced towards the equator. By adhering to, or deviating from, a self-similar compression, the compression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

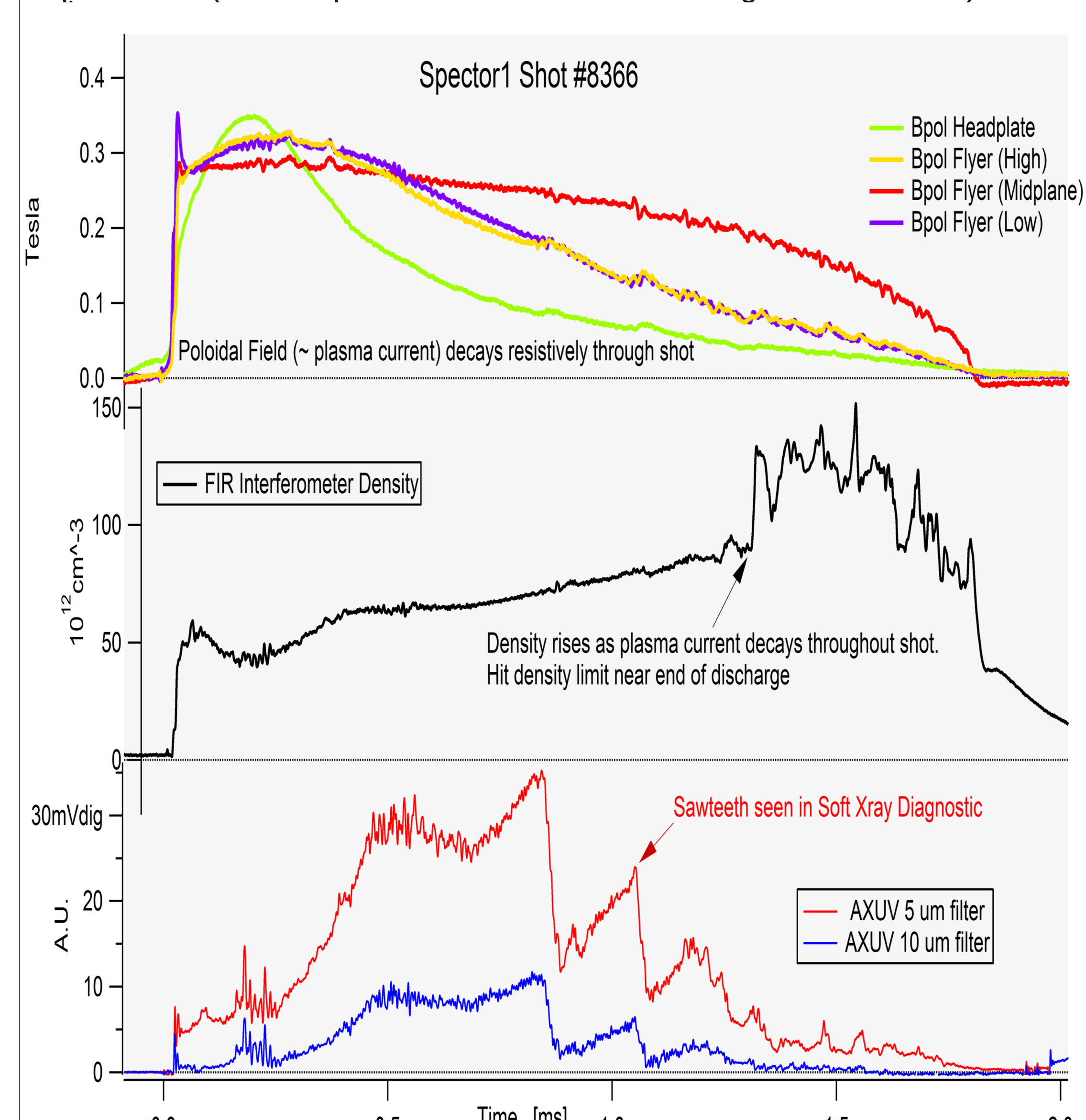
Plasma Target Development: Small Injectors

Multiple plasma injectors have been designed and tested at General Fusion. They have been built on a reduced scale to reduce iteration time and expense and allow a variety of geometries and overall safety factor (q) to be explored.

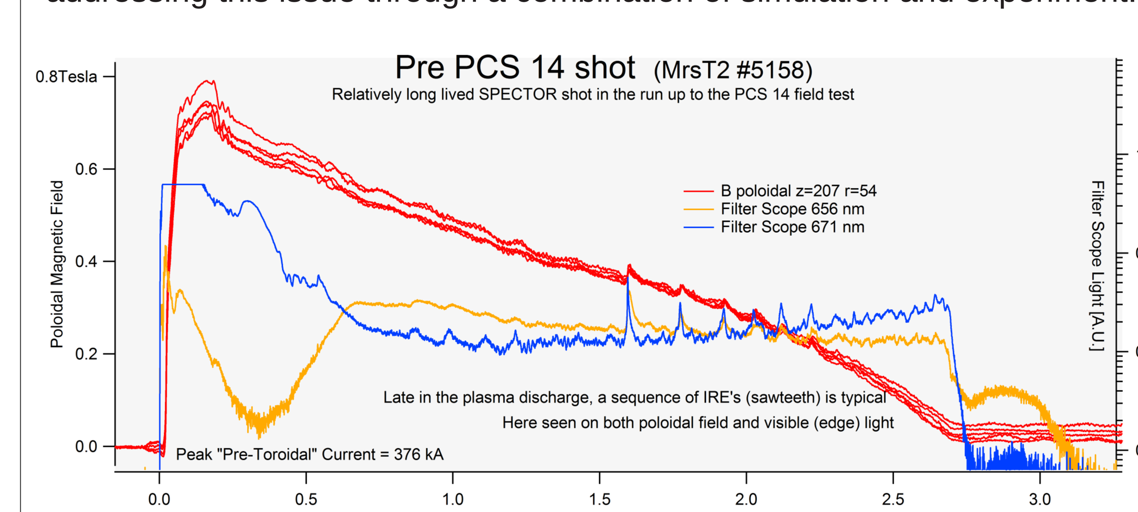


Spheromak Plasmas (q<1): Large improvements in magnetic and thermal lifetime were made on the ***MrT*** style single-stage injectors. The greatest improvement came by modifying the global ***q*** profile by maintaining small amounts of poloidal gun current after the main formation pulse to avoid rational surfaces and to "sustain" plasma life.

Both ***PROSPECTOR*** and ***SPECTOR*** devices can produce spherical tokamak targets by forming plasma into a pre-existing toroidal field, producing lifetimes up to **2 *msec***, and electron temperatures in excess of ***T_e ≥ 400eV*** (see GF poster on Thomson Scattering in this session).



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.

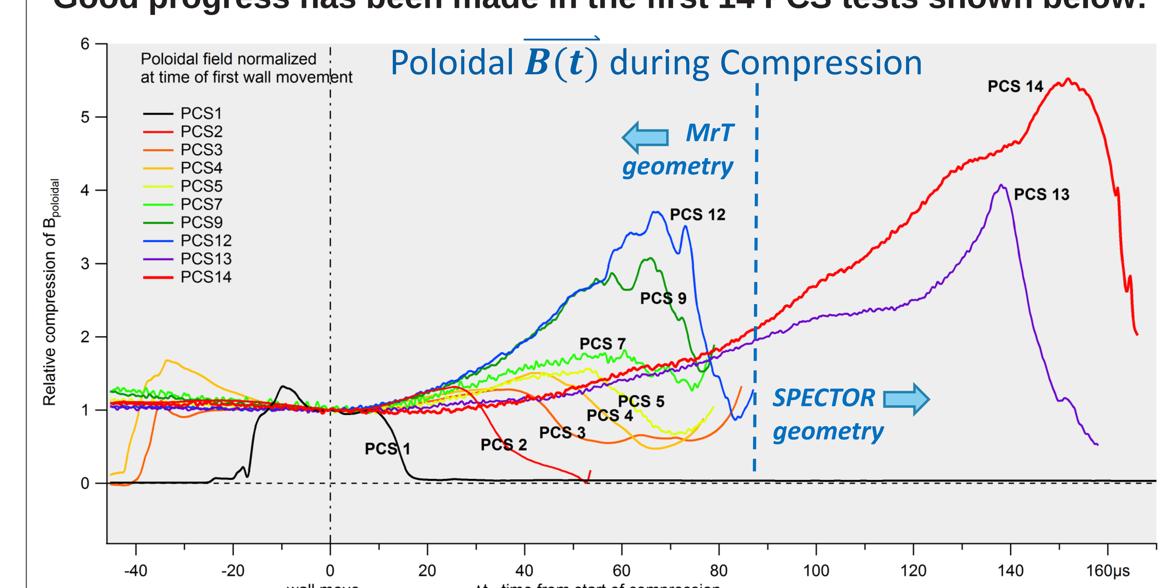


Plasma Compression Tests (*PCS* program)

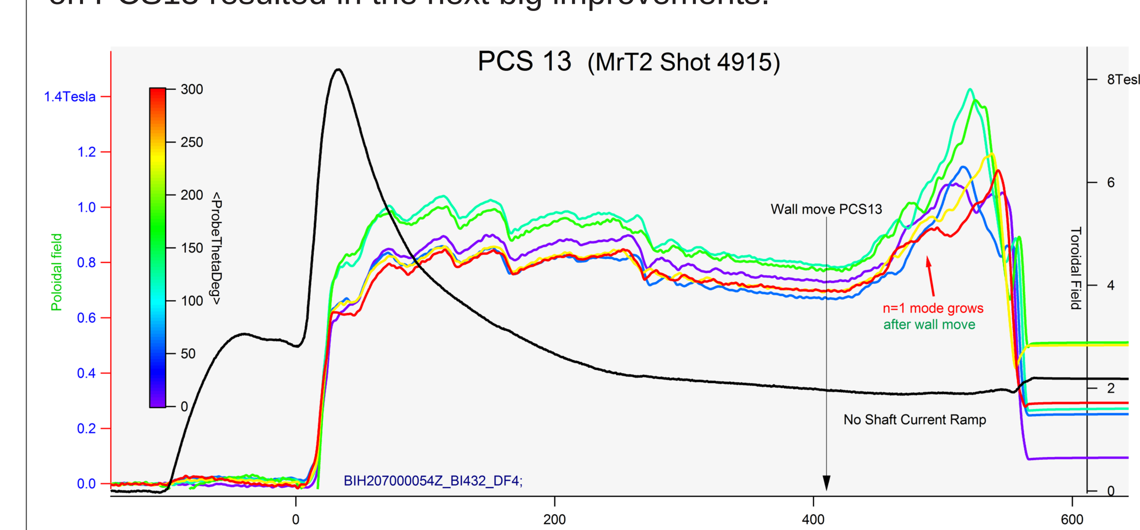
All of the plasma results shown previously should be interpreted in the context of General Fusion's goal of developing an MTF power plant. Our plasmas need to be appropriate targets for ~adiabatic compression by a collapsing metal wall.

In order to better diagnose the behavior of our magnetized plasma targets under compression, our initial compression tests are done in the field with chemically accelerated Aluminum walls. This testing program has generated fourteen successful tests to date (see posters in this session). The ***PCS*** program is an economical, diagnosable way of studying our plasmas under compression. The power plant plan uses compression by liquid metal walls.

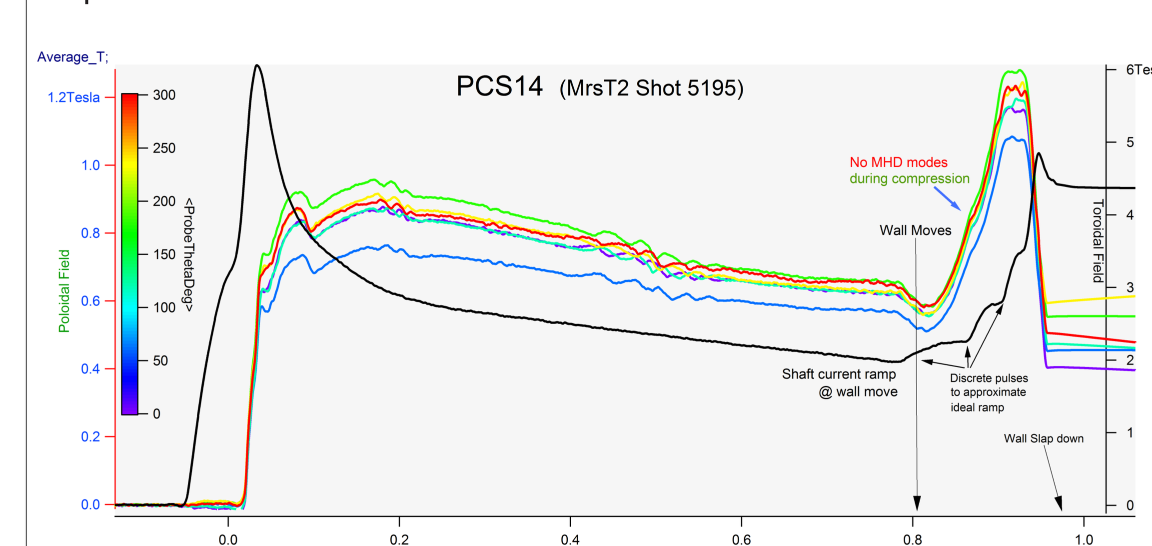
Good progress has been made in the first 14 PCS tests shown below:



Once radiation was eliminated as the dominant energy loss during compression after PCS7, MHD stability during compression was the limit. The addition of shaft current on PCS12 and better compression geometry on PCS13 resulted in the next big improvements.



Further improvement of MHD stability was achieved on PCS14 by ramping the shaft current during wall move such that it roughly balances the increase in plasma current.



Further improvements in stability are being pursued through management of the plasma current profile (and thus q- profile).