Acoustically Driven Magnetized Target Fusion at General Fusion: An Overview

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INTRODUCTION

General Fusion's Magnetized Target Fusion (MTF) concept involves compressing an initial magnetically confined plasma (τ_E >100 μsec) 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)

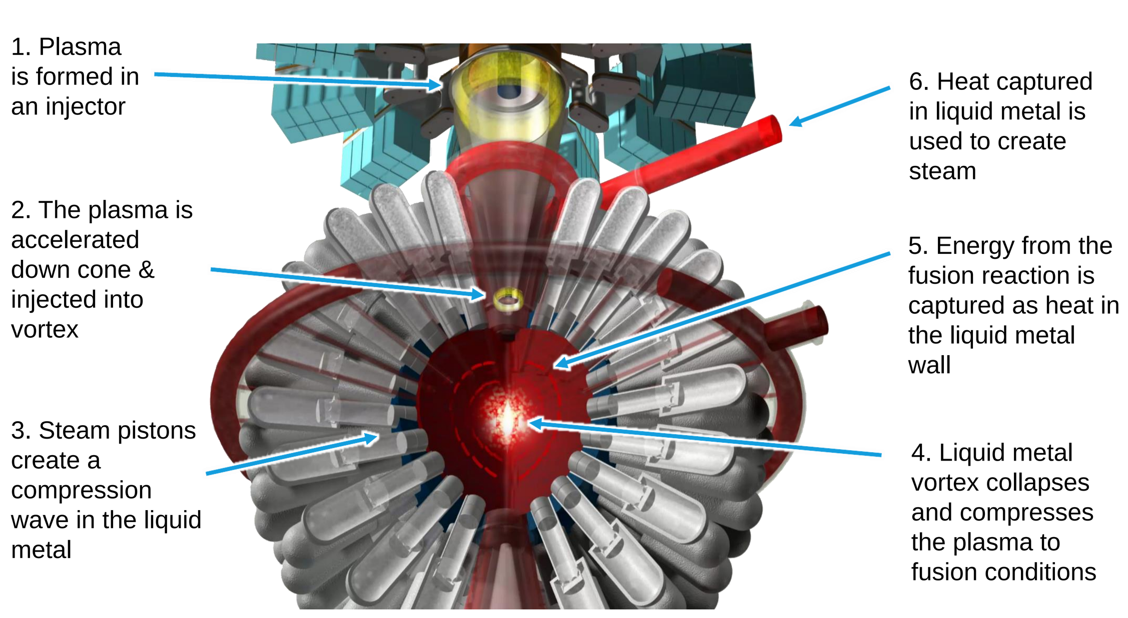
- Pistons kinetic energy: 120 MJ
- Initial plasma density: 1.25E17 cm^{-3}
- Initial plasma temperature: 100 eV
- Initial magnetic field: 7 Tesla
- Initial plasma radius: 20 cm

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

- Peak plasma density: 1.16E20 cm^{-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

General Fusion is developing an acoustic compression system (below) to drive the plasma compression. The CT plasma is injected into a vortex formed in the center of a 3 m diameter sphere filled with spinning liquid lead-lithium. Pneumatic pistons focus a pressure wave at the center, collapsing the vortex walls onto the CT on a timescale faster than the energy confinement time. A low cost driver, straightforward heat extraction, good tritium breeding ratio (~1.5x), and excellent neutron protection are very attractive features of this concept which seeks a path to a practical power plant.

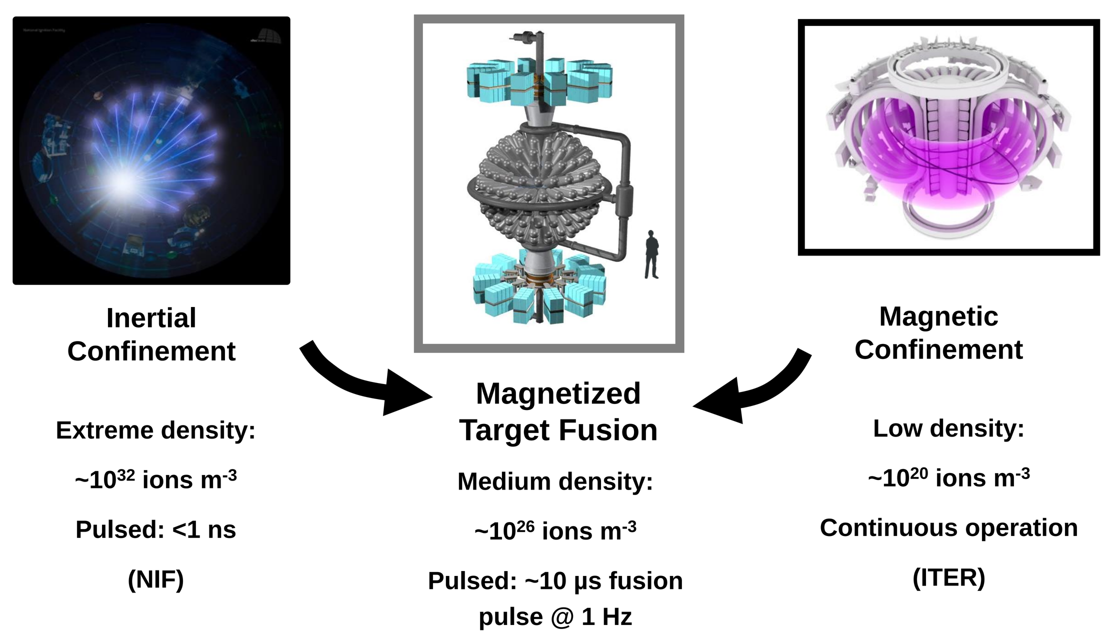


*The sphere is filled with liquid **Lead-Lithium** metal. The liquid metal is pumped tangentially at the equator so that it spins and creates a vortex.*

General Fusion (65 employees, 11 Ph.D's) has an active plasma R&D program including both full scale and reduced scale plasma experiments and simulation of both. Although acoustic driven compression of full scale plasmas is the end goal, present compression studies use reduced scale plasmas and chemically accelerated Aluminum liners. We review results from our plasma target development, motivate and review the results of dynamic compression field tests and briefly describe the work to date on the acoustic driver front.

THE CASE FOR MAGNETIZED TARGET FUSION (MTF)

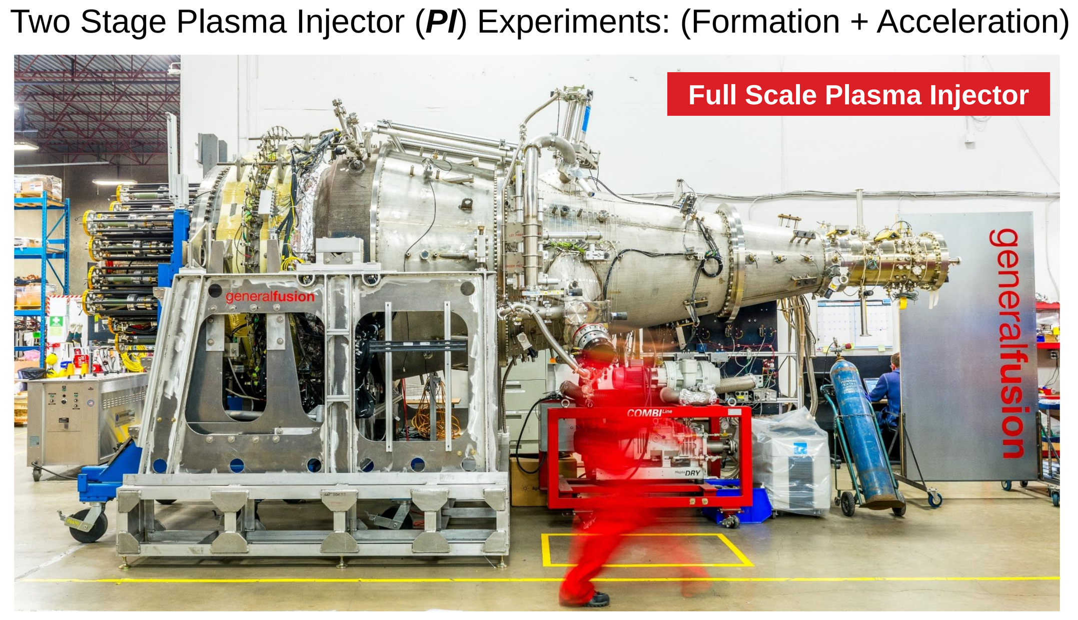
Magnetized Target Fusion (MTF) seeks to operate at densities and time scales intermediate to those of ICF and Magnetized Fusion Energy (MFE) [Turchi]. MTF has much lower peak power than ICF and much lower stored energy than Magnetic confinement, allowing use of more economical technologies.

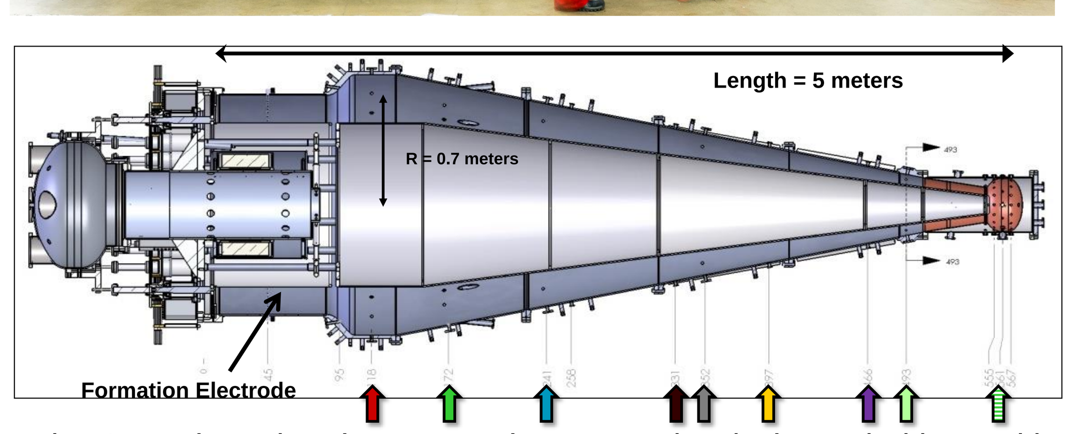


The molten lead-lithium metal that compresses the plasma to fusion conditions also moderates the neutrons [neutron flux >1 MeV is reduced 10,000x at first wall in MCNP simulations]. This essentially solves the 'first wall' problem that is a major issue with MFE and ICF approaches. The liquid metal can also serve as the primary fluid for the power plant heat exchanger.

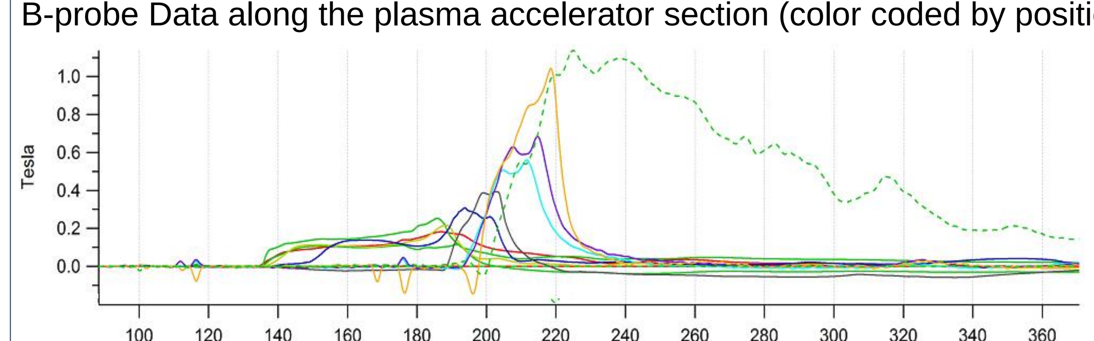
PLASMA TARGET DEVELOPMENT: LARGE INJECTOR

Two Stage Plasma Injector (*PI*) Experiments: (Formation + Acceleration)





B-probe Data along the plasma accelerator section (color coded by position)

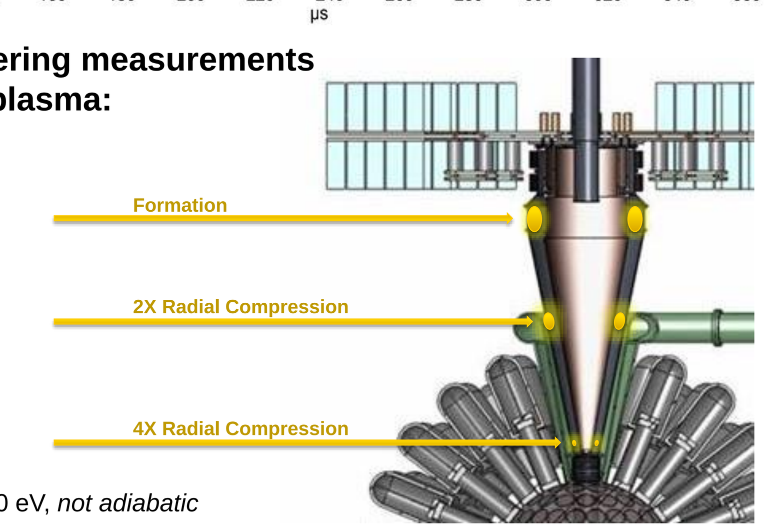


Thomson scattering measurements of accelerated plasma:

- 10^{20} m^{-3}
- 40 eV
- 0.2 T

- $8x10^{20}$ m^{-3}
- 160 eV
- 0.8 T
- **Adiabatic!**

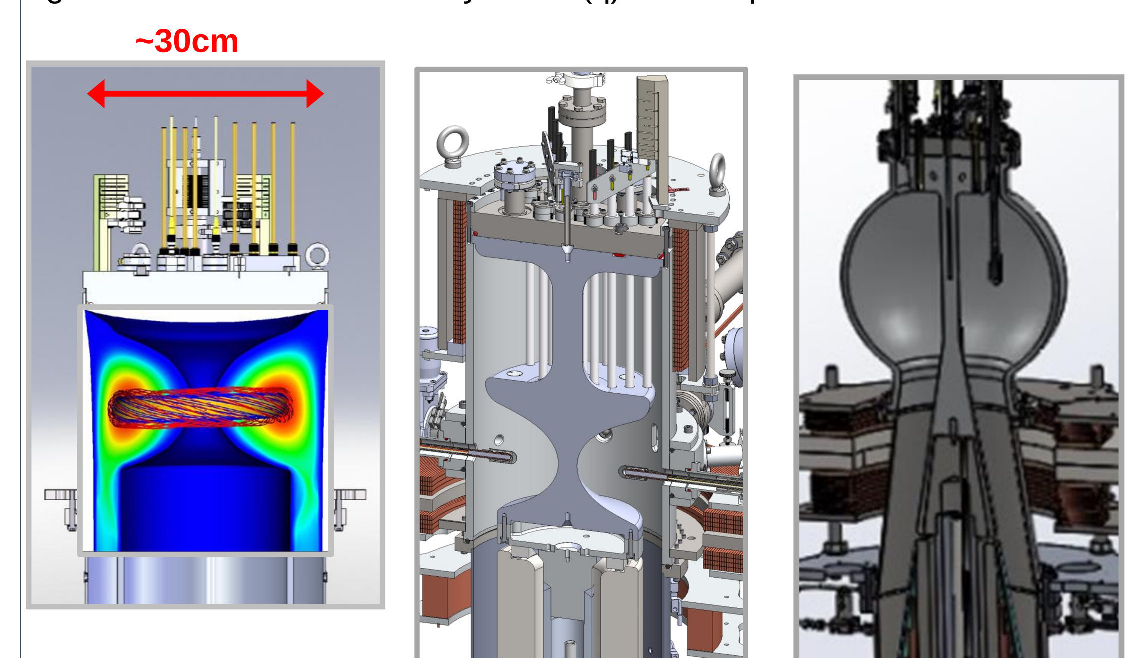
- $6x10^{21}$ cm^{-3}
- 3.2 T
- 300 eV
- Expect >600 eV, *not adiabatic*



Energy confinement of the CT at the end of the acceleration section can be negatively impacted by high levels of residual pushing current.

PLASMA TARGET DEVELOPMENT: SMALL INJECTORS

Several single-stage (formation only) 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.

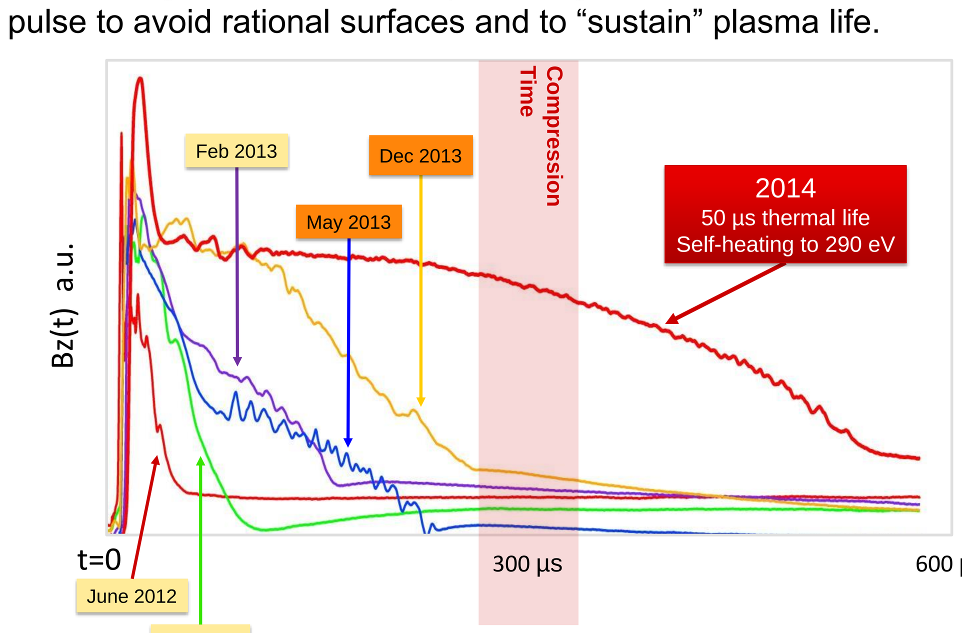


MRT **: Magnetic Ring Test**

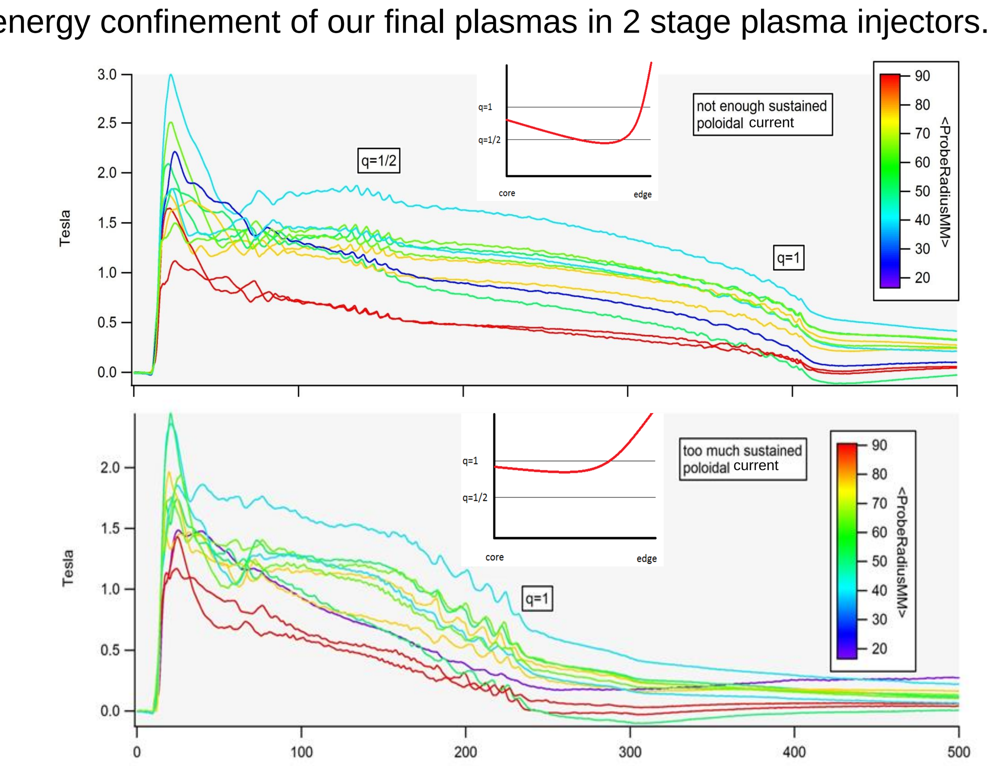
PROSPECTOR

SPECTOR**: Spherical Compact Toroid**

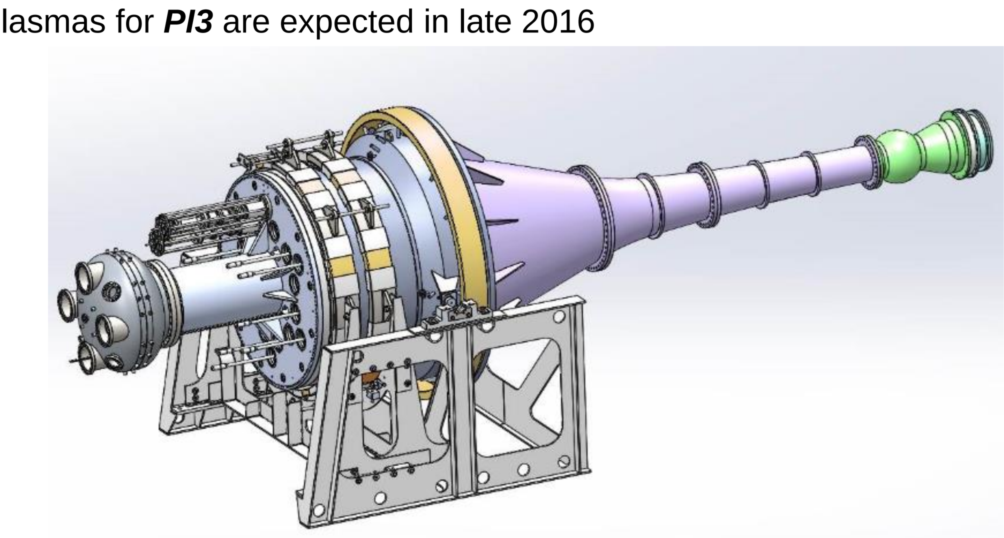
Spheromak Plasmas (q<1): Large improvements in magnetic and thermal lifetime were made on the ***MRT*** style single-stage injectors. The greatest improvement came by modifying the global ***q*** profile by maintaining small amounts of poloidal gun current after the main formation pulse to avoid rational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



We have learned from our 'sustained' CT experiments on ***MRT*** (below) what level of residual acceleration current can be used to improve the energy confinement of our final plasmas in 2 stage plasma injectors.

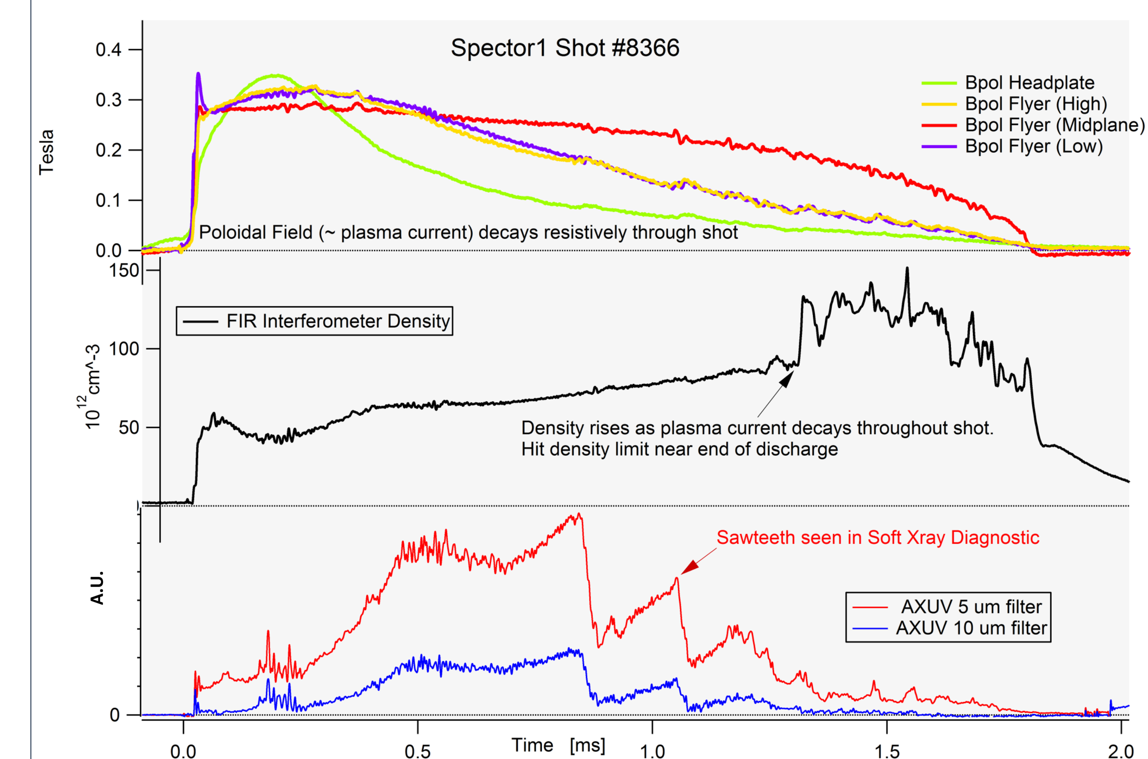


The geometry (inductance) of the acceleration stage of our next generation full scale plasma injector (***PI3***, below) has been designed to deliver optimal sustain current at the end of the acceleration section. First plasmas for ***PI3*** are expected in late 2016



SPHERICAL TOKAMAK DISCHARGES (Q>1)

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 General Fusion 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.

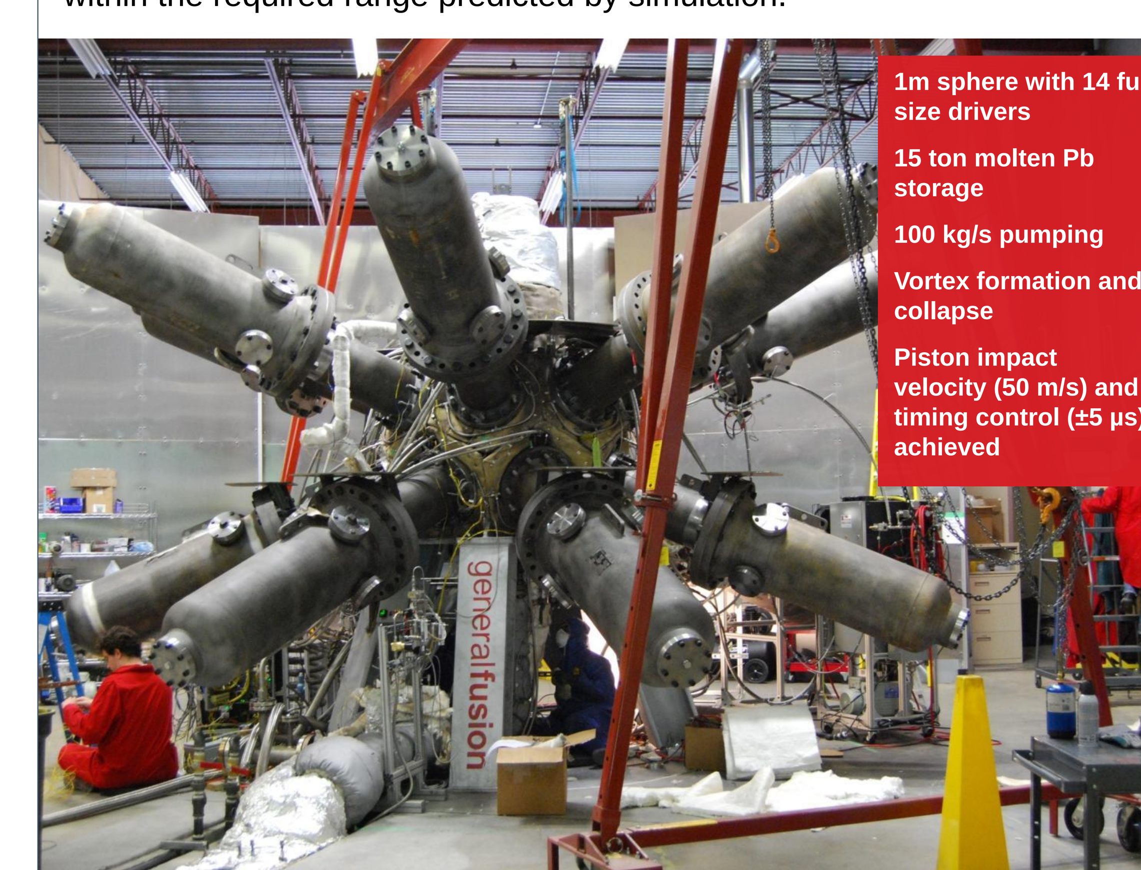
PLASMA COMPRESSION TESTS (*PCS* PROGRAM)

All of the plasma results shown above 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 thirteen 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.

ACOUSTIC DRIVER DEVELOPMENT

Engineering development of the molten lead-lithium system has been successfully completed. The servo controlled piston synchronization is within the required range predicted by simulation.



Requirements for and refinements of the vortex uniformity and surface smoothness are being developed through CFD simulation and reduced scale experiments

REFERENCES

P. Turchi, "A compact-toroid fusion reactor design…", *Proc. 3rd Inter. Conf. on MegaGauss Magnetic Field Generation and Related Topics*, Nauka Publ., 184 (1984)