Status of Fusion Energy Science Research at Los Alamos

G. A. Wurden

Fusion Power Associates Symposium
Fusion Energy: Status & Prospects
Washington DC

Dec. 1, 2010

LA-UR-10-07972

OUTLINE

• General information on Fusion Energy Sciences Program at LANL

•Contributions to ITER

•Fast Ion Generation experiments on Trident

•Magnetized Target Fusion (MTF) Experiments FRCHX at AFRL

•Plasma Liner Experiment (PLX) construction

•Contributions to NIF National Ignition Campaign

Fusion Energy Sciences (FES)

Priorities at LANL:

- Three legs: Theory & simulation, Experiment, and Engineering
- Fusion Simulation Program (FSP)
- High Energy Density Laboratory Physics (HEDLP)
- Basic plasma science, including joint fission fusion materials facility (FFMF)
- Supporting roles on FES machines around the nation and world, and at ITER

Changes for FES FY2011: ($5.1M FY11BA + $1.29M ITER)

- Two important off-site collaborations in MFE: Alcator C-Mod and W7X stellarator
- The ReNeW HEDLP report is available (Trident on its cover), magnetized HEDLP in Chapter 2
- Finishing an ITER intense neutron source design (with South Korea) for diagnostic calibrations
- Preparing proposals for HEDLP science call
- Submitted proposal 7/1/2010 for a US fusion materials irradiation facility preconceptual study
- Preparing inputs to the NAS IFE panel
- New ITER-IO contract proposals submitted, two early career FES science proposals submitted

Fusion Energy Science 2010 LANL Highlights

Research:

•ITER work is ongoing, but the pace has been reduced for FY11

•The first engineering test shot of the full FRC/Shiva Star magnetized target fusion experiment occurred on April 16, 2010. It was an engineering success (all subsystems worked correctly), but the captured plasma decayed too quickly. We have investigated why, and checkout testing prior to the next shot is in progress.

• The Plasma Liner Experiment construction is proceeding in its test bay. A large 9-ft diameter vacuum chamber and control systems are in place.

•A new ICC collaboration on the W7X stellarator, with PPPL and ORNL, starting FY11.
•Two of our ICC projects were terminated (Inertial Electrostatic Confinement (IEC) and U-Washington collaboration on FRC's). Three new proposals were not funded.
• A new HEDLP experiment with UC Davis to develop beat wave magnetic field generation.

•Theory work ongoing (you will hear about the Fusion Simulation Project later)

ITER fuel processing challenges

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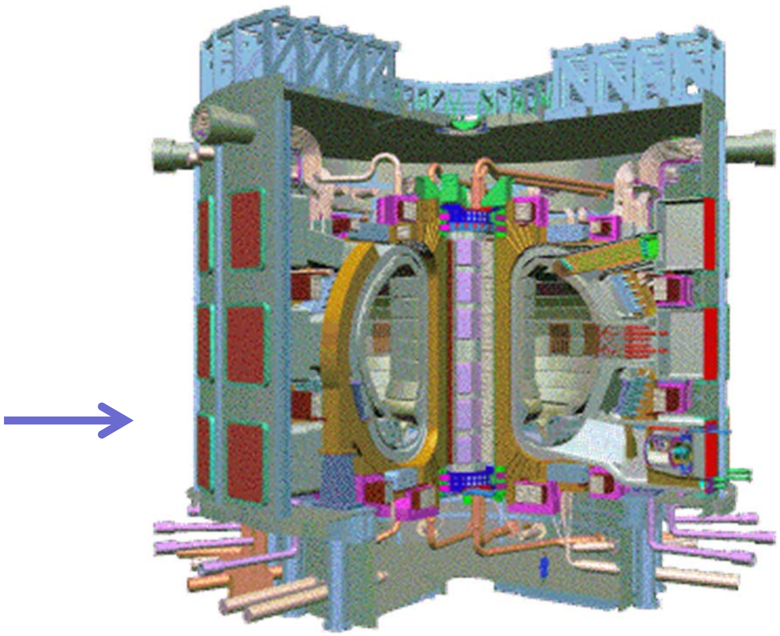
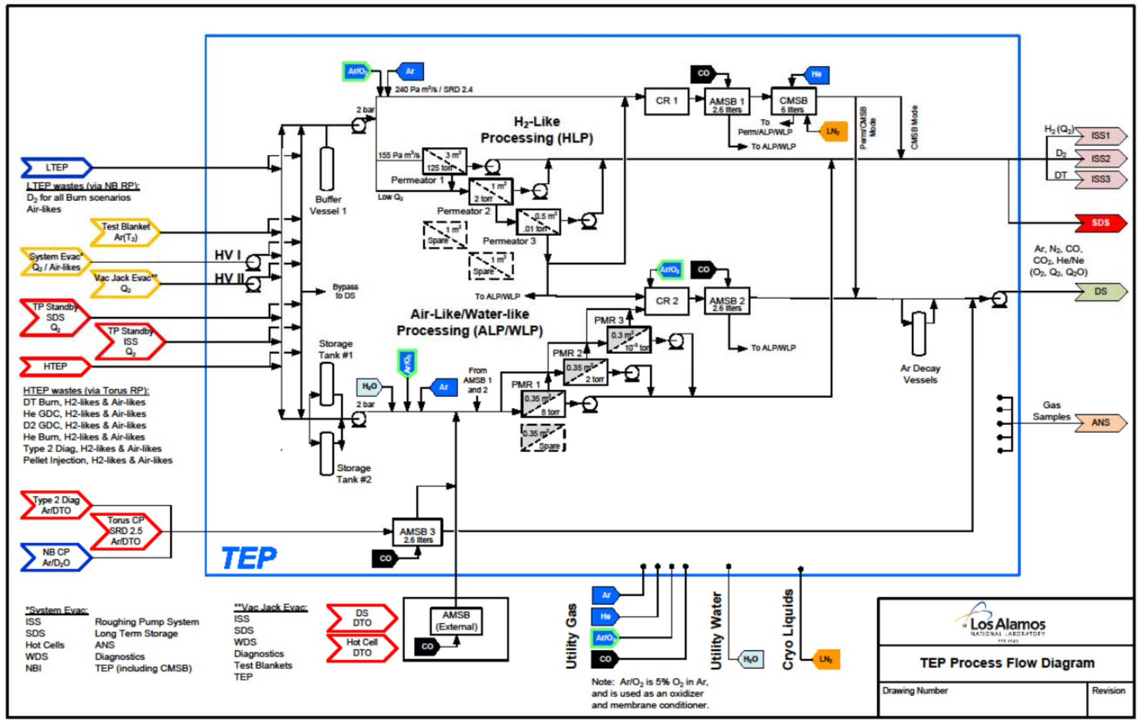
- Scale-up
  - 20x throughput
  - 20x inventory
  - 20x shorter processing time
- Melding tritium handling/safety approaches
- Requirements uncertainty
- Tritium is a limited resource



LANL ITER fuel cycle contributions

- Tokamak Exhaust Processing system - with SRNL
  - Design, R&D, Chemical flow sheet modeling
- Overall Fuel Cycle
  - Integration, commissioning plans, schedule
  - Tritium Plant, hazard analysis
- Test blanket module
  - Tritium extraction
  - processing



HEDLP Fast Ignition with laser-driven ion beams

Juan C. Fernández

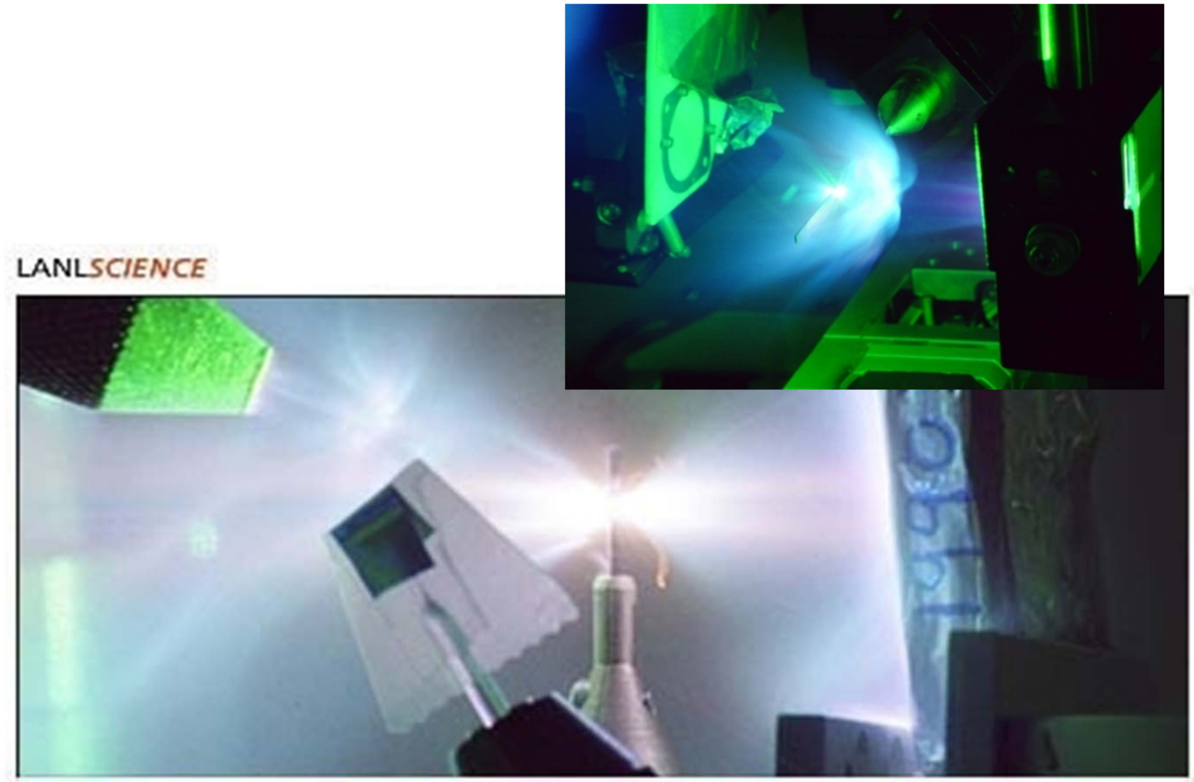
LA-UR-10-07520

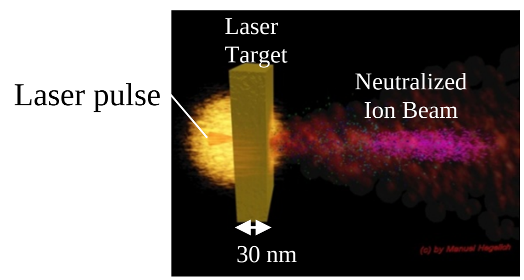
presented @:

APS DPP Conference

Chicago, Illinois

November 8 -- 12, 2010

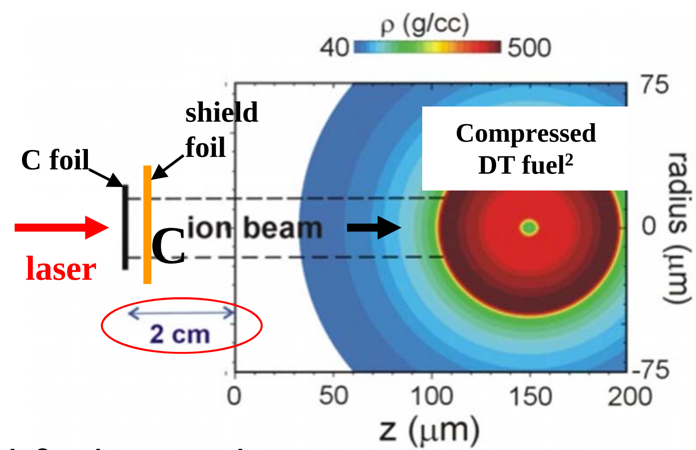




Quasi-monoenergetic low-Z ions (e.g., C) have potential advantages as a fusion ignitor beam.

CFI

- Potential advantages over electron* or proton-based[1] FI:
  - Quasi-monoenergetic-ion source may be placed far from the fuel
  - Sharper deposition (higher efficiency)
  - Most robust particle-beam transport
  - Many fewer ions than protons required



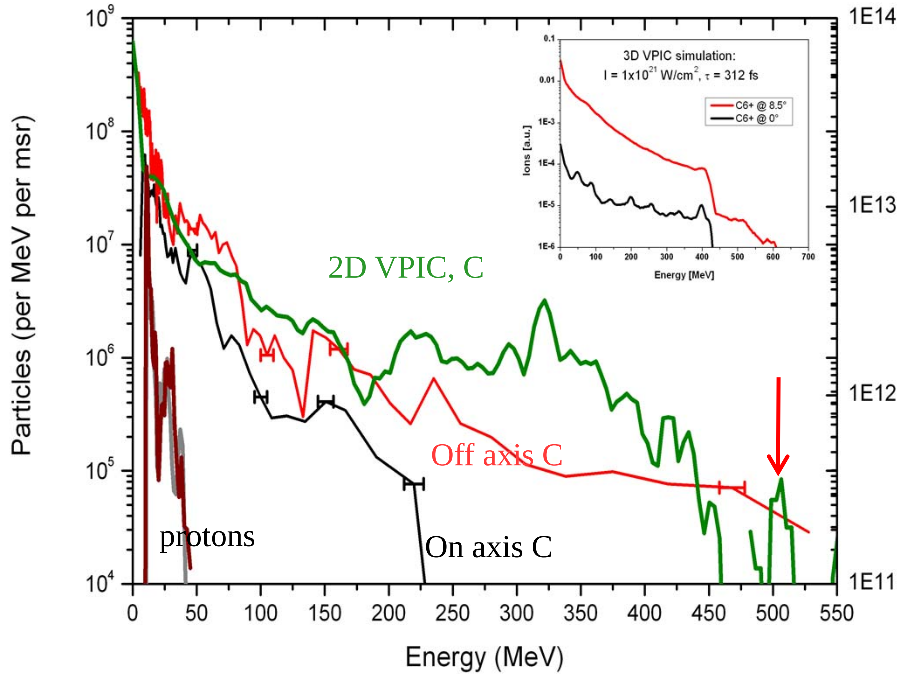
- Potential issues:
  - Demo ~ 400 MeV ± 10% C beam
  - Laser – ion conversion efficiency: ~ 10% desired & observed
  - Focusing C ion beam: only proton focusing demonstrated

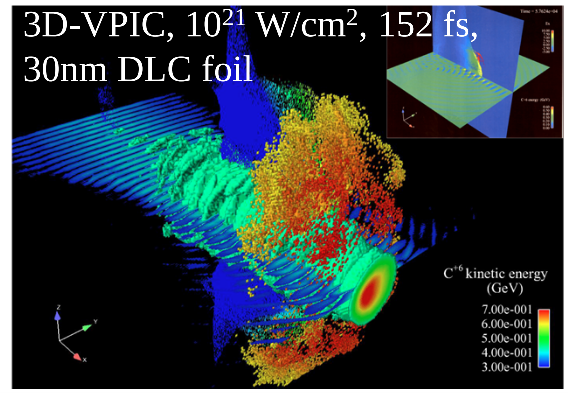
Beam Ion	Energy (MeV)	Number of Ions	Laser Intensity (W/cm²)	Minimum areal densities, layer thickness @ 0.1 mm²
Protons	7 – 19	~10^{16}	~ 10^{20} (TNSA)	10^{18} cm^{-2}, ~ 2 μm (CH)
C^{6+}	**400-480**	~10^{14}	~ 10^{21-22} (BOA, RPA)	10^{16} cm^{-2} , **~ 10 nm**

* Tabak *et al.*, PoP **1,** 1626 (1994); [1] Roth *et al.*, PRL **86,** 436 (2001);
[2] D. Clark & M. Tabak, Nucl. Fus. **24,** 1147 (2007)

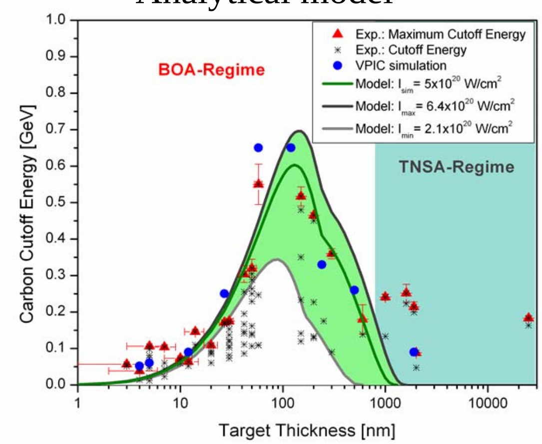
C acceleration: achieved *separately* high energy[1], low energy spread, high efficiency.*

- **Demonstrated ~ 500 MeV energies (Trident)**



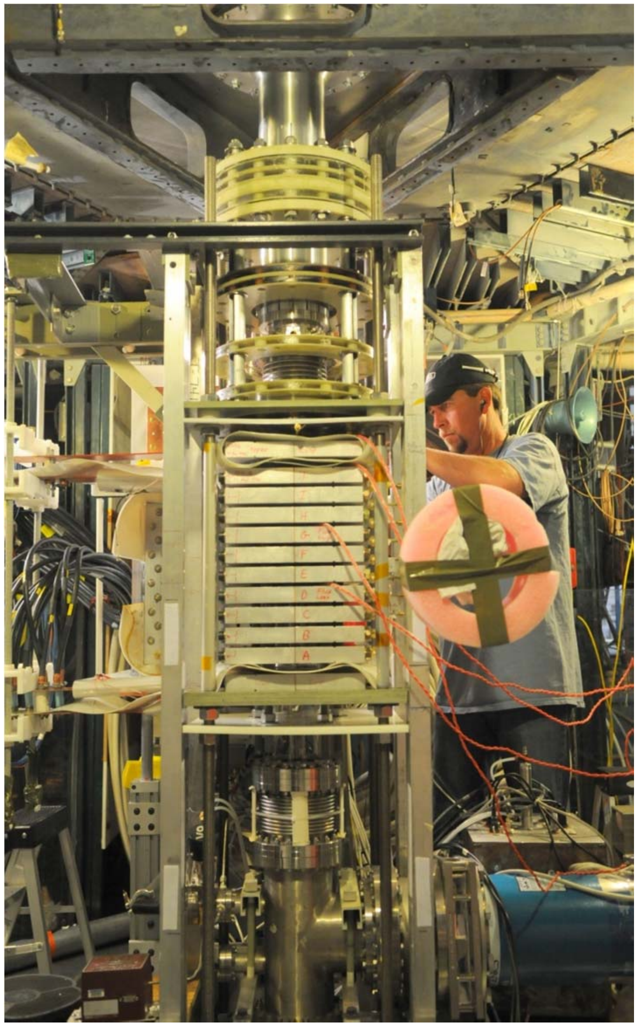


Analytical model



[1] B. M. Hegelich, *et al.*, Subm. Nature Physics, (2010)

HEDLP Magnetized Target Fusion, LANL/AFRL FRCHX



Our first full-up systems test was April 16, 2010. An engineering success, with interesting physics, but a failed compression. The second shot in this series is being readied & tested now.

FRCHX Team (April 2010)

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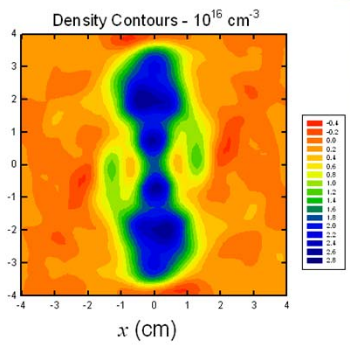
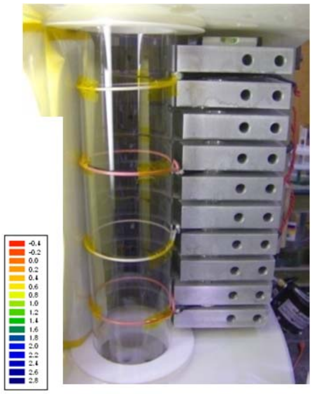
Overview of FRCHX

* Grabowski, Degnan, et al., APS-DPP 2010 posters





Integrated Technologies

- FRC formation, translation, and capture
- Solid liner implosions
- MHD modeling in concert with electromagnetics modeling yields end-to-end simulation with high correlation to experimental hardware
- Pulsed power, plasma, and neutron generation diagnostics

Description

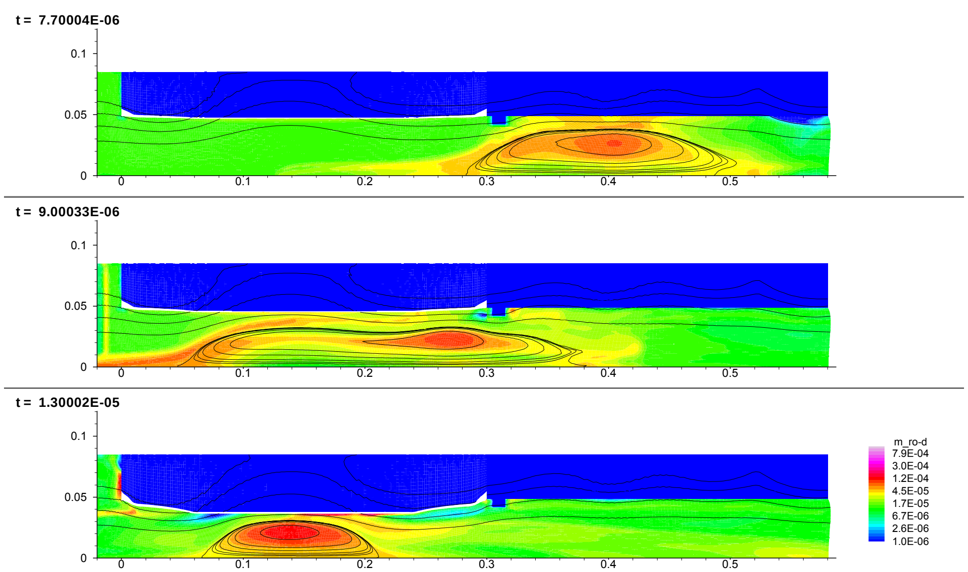
- Magnetized plasma compression provides an intermediate and low cost approach to HED plasmas
- One application: magneto-inertial fusion pathway between ICF and MFE
- Compact toroid (CT) insulates dense hot plasma from low temperature impurity species
- Field reversed configuration is an attractive CT
- Liner implosion to drive compression and heating of the FRC

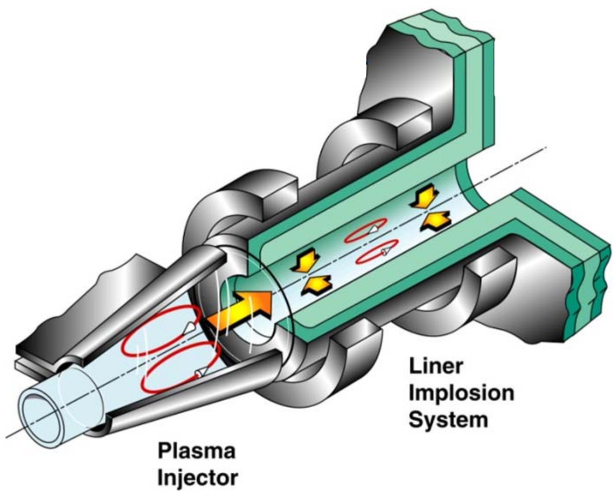
Research Areas

- In-depth study of the fundamentals of physics of HED laboratory plasmas in the presence of high magnetic fields
  - ◊ Magneto-inertial fusion
  - ◊ Studies of particle transport in highly magnetized, dense plasmas
  - ◊ FRC Plasma instabilities

Choosing the FRC

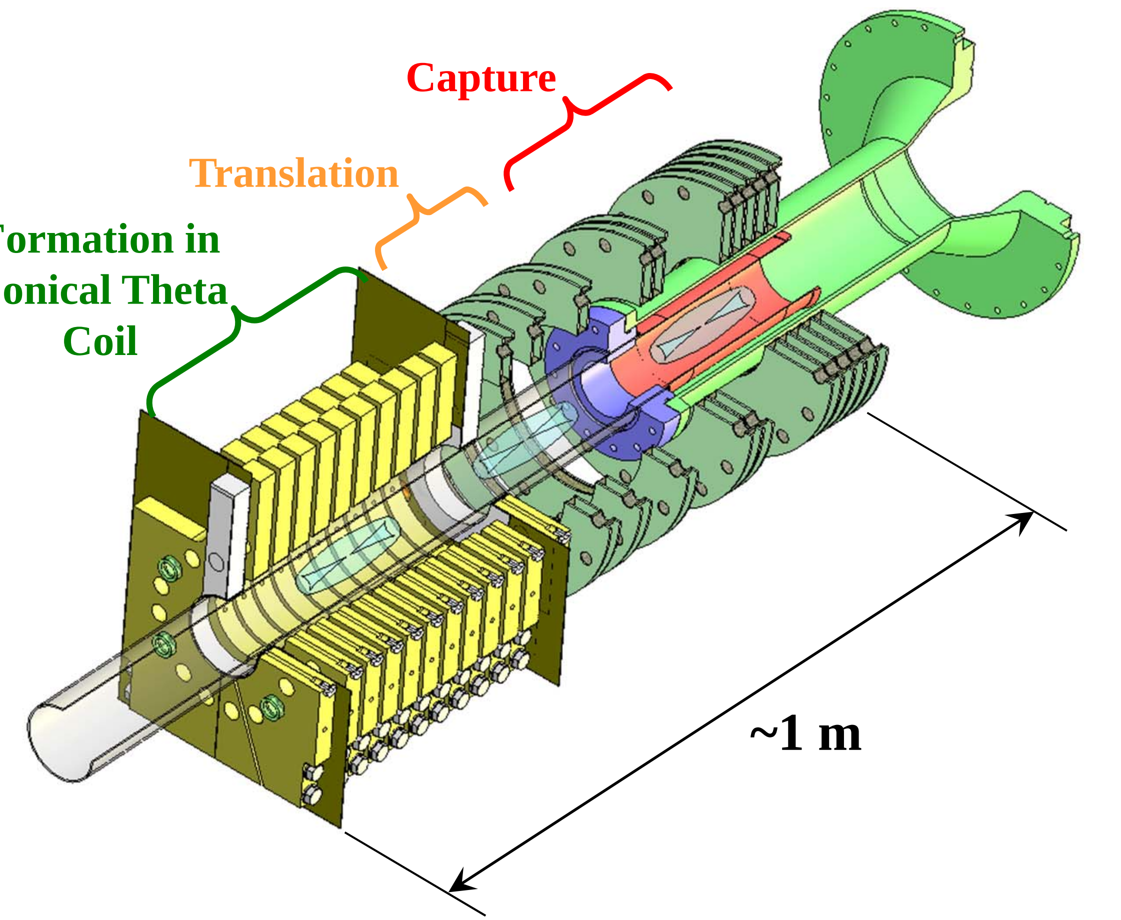
- Advantages of FRCs for HED plasmas:
  - Simple cylindrical geometry
  - High β (β ~ 1) and high power density → compact system
  - Translatable → formation and adiabatic heating regions can be separated
  - Natural separatrix diverter – isolation from walls, impurity barrier





FRC Translation

- The FRC is ejected from the formation region by J x B_r forces
- Fields along the short translation region keep the FRC from expanding
- Lower and Upper mirror fields form a capture region for the FRC that stops it within the center of the liner



Target Plasma Parameters

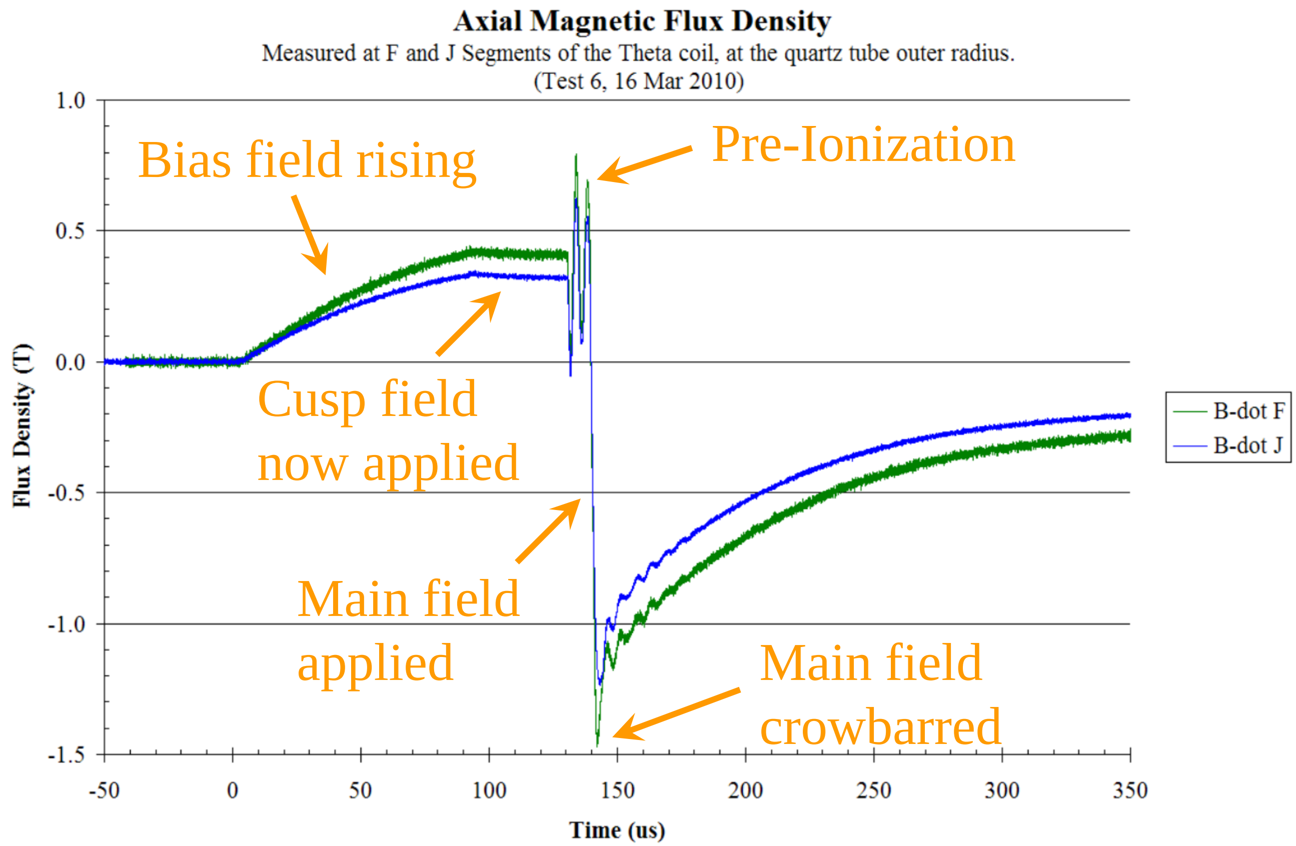
- Present and Projected FRC Parameters
  - In formation region of experiment
    - $n \sim 10^{17}$ cm^{-3}
    - T ~ 100 – 300 eV
    - Poloidal B ~ 2 - 5 T
  - After solid liner compression
    - $n > 10^{19}$ cm^{-3}
    - T $\rightarrow$ several keV
    - Poloidal B ~ 200 - 500 T
- Energy confinement time > 10 μs needed, 20 μs desired

FRCHX Test Milestones
Past 12 Months

Event	Date	Significance
Confirmed translation and capture of an FRC plasma in the extended quartz tube test setup	Feb 2010	This was the first confirmation of successful FRC translation and capture in the AFRL experiment. Densities and temperatures were appropriate for a compression-heating experiment, though lifetimes were short.
Confirmed translation and inferred capture of an FRC plasma in the compression-heating test setup	Apr 2010	Confirmation of FRC entry into the liner without observation of any plasma returning from the liner was a pre-requisite for performing the compression heating test.
Performed first FRC compression heating test	Apr 16, 2010	This was the first ever reported solid liner compression test of an FRC plasma in a laboratory environment.
Confirmed FRC capture with a mock-up of the compression heating test hardware	Sep 2010	B-dot probes inserted from above into the liner confirmed, for the parameters that were used in the April 16 test, that plasma was captured in the liner but that the trapped flux lifetime, as suspected, ended before compression would have been completed.

B-dot Probe Measurements

Formation Region

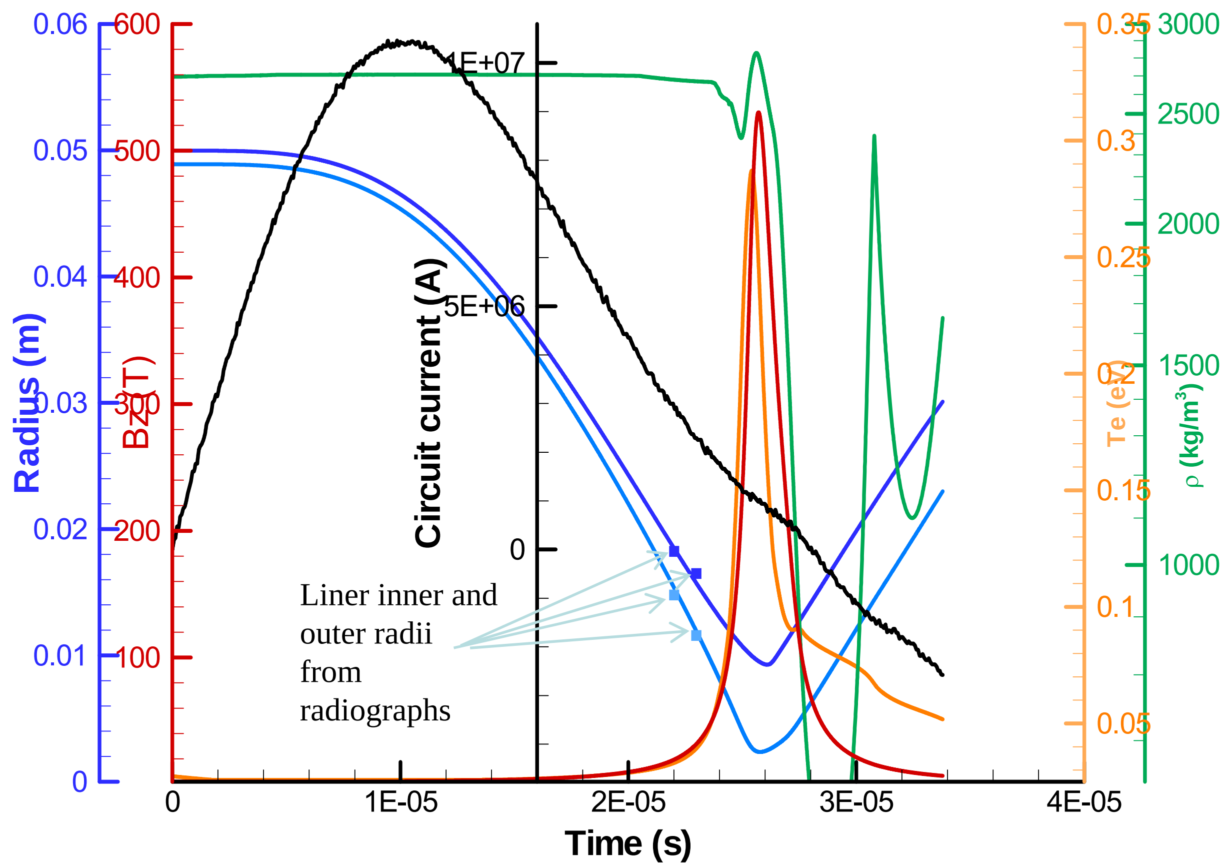


- Axial magnetic probe signal shows field vs. time from Bias, Cusp, Pre-Ionization, and Main Theta discharges.
- All discharges except that of the Cusp are through the 10-segment Theta coil.

Overview: Formation, Translation, Capture Results with Extended Quartz Tube

- Field exclusion lifetimes of captured FRCs were 6 to 10 μs
  - This is sufficient for injection and capture tests but considerably short for compression of closed field line configuration.
  - The lifetime was, however, deemed adequate for an engineering test of the overall formation, translation, capture, and compression system.
- Density path integral was ~ 2 x 10^{17} cm^{-2} in the capture region
- Lifetime of this density exceeded 20 μs
  - This was in range of interest for a compression experiment.
- Inferred temperature from exclusion radii, field pressure, and density was ~ 200 to 300 eV
  - This was also in the range of interest for compression experiment.

MHD simulation using experimental current agrees with radiography on liner radius vs time

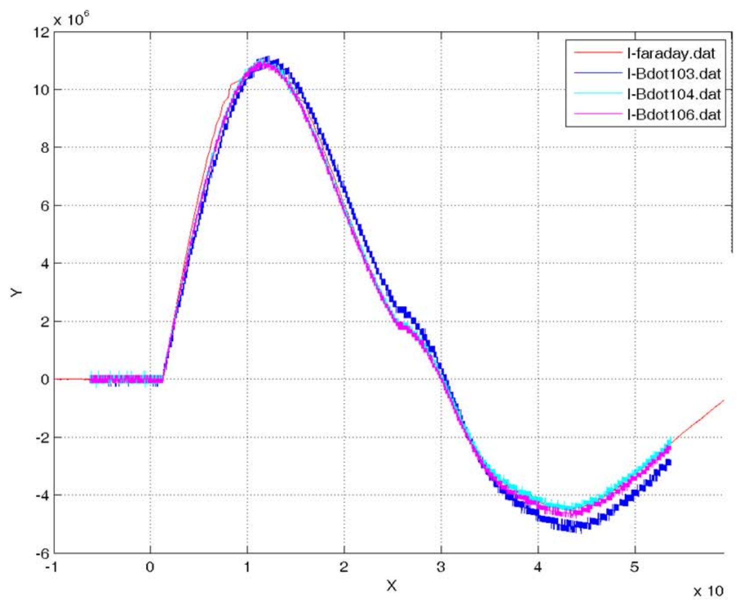


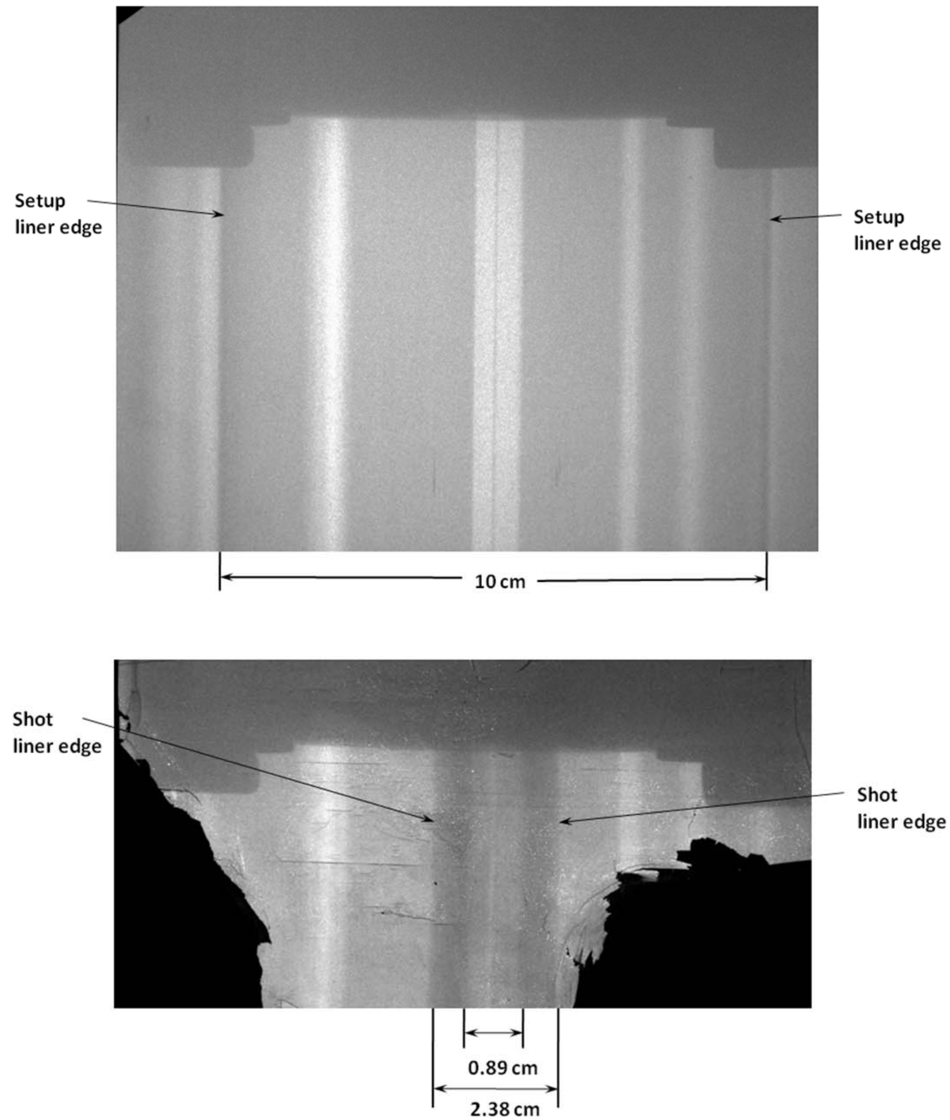
NumerX MACH2 results for Shiva Star liner compression for 2 Tesla initial axial magnetic field

Calculated peak field is 540 Tesla

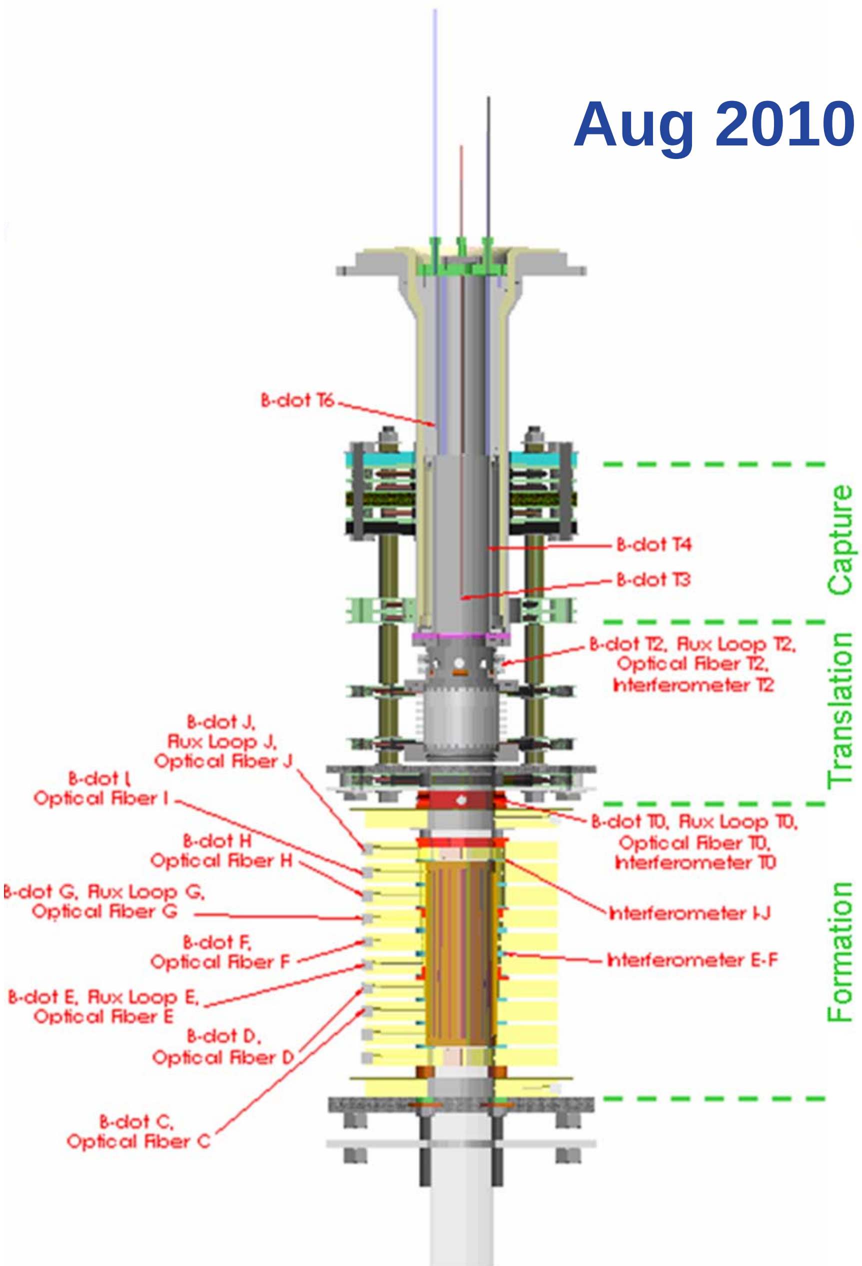
Despite heavy debris damage to digital film we obtained useful radiograph

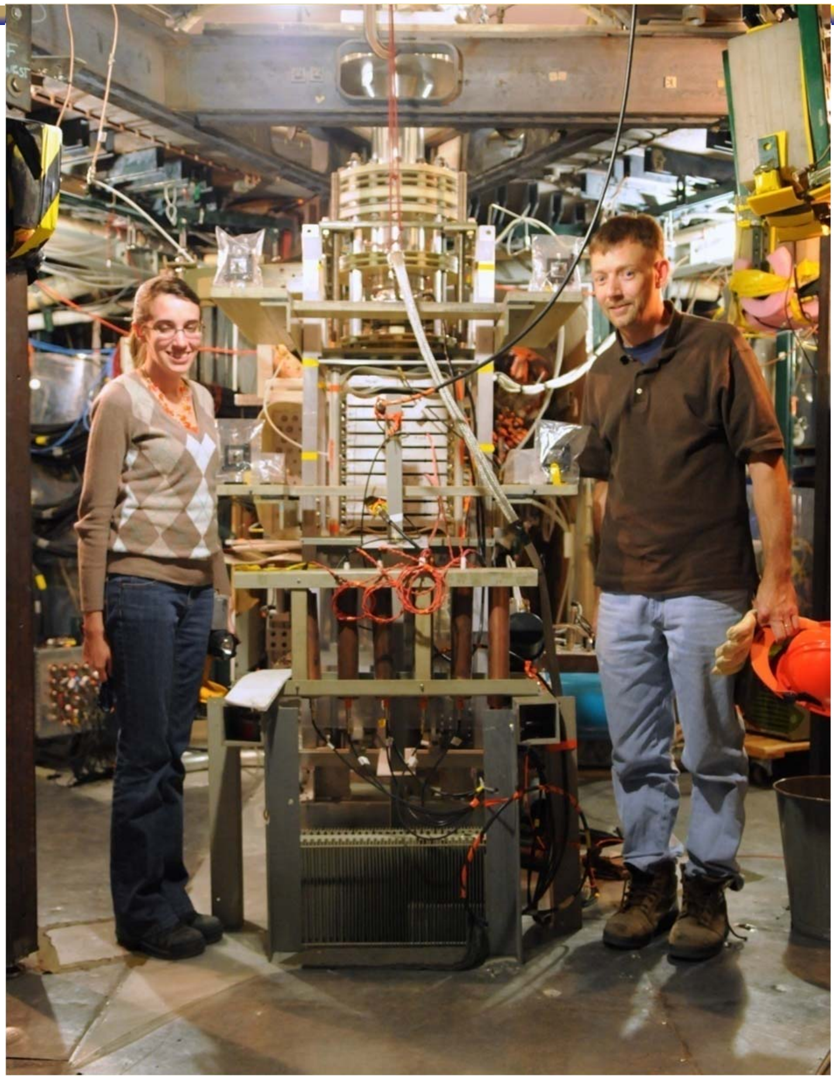
Implosion - compression experiment radiograph obtained at 22.985 μs after start of implosion discharge current indicates that liner imploded symmetrically, with little or no instability growth, and achieved 11 times radial compression of inner surface. Faraday rotation and inductive current probes indicated ~ 11 MA implosion current with 10 μs rise time.





Aug 2010 – Present Test Setup

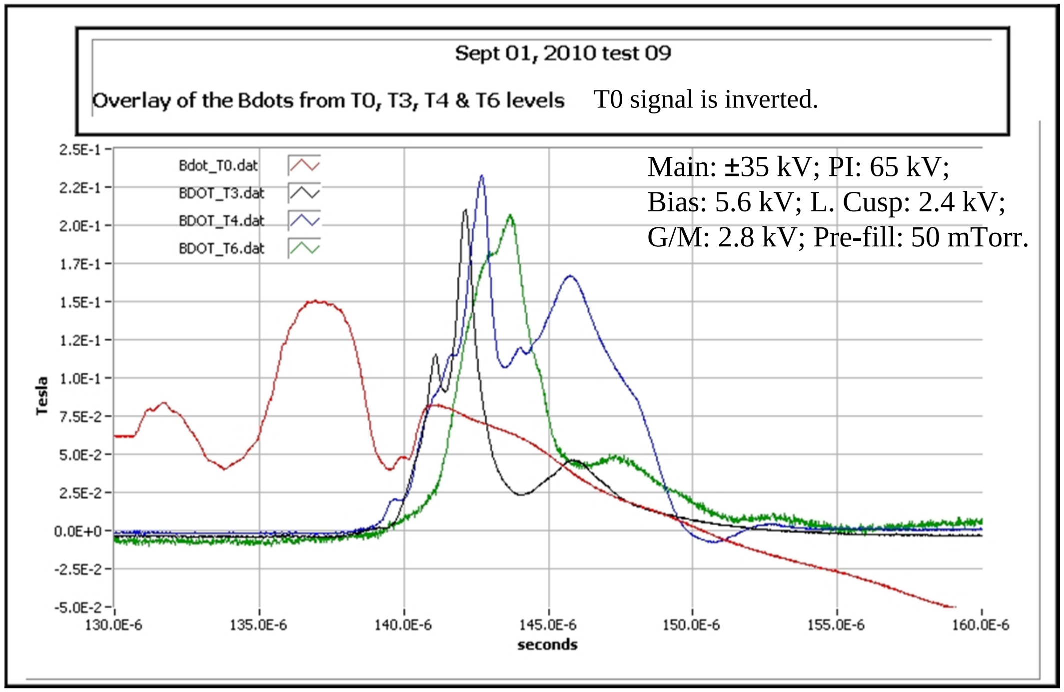




FRCHX under the Shiva bank (Nov. 2010).

B-dot Probe Measurements

Guide Field Matching Compression-Heating Test

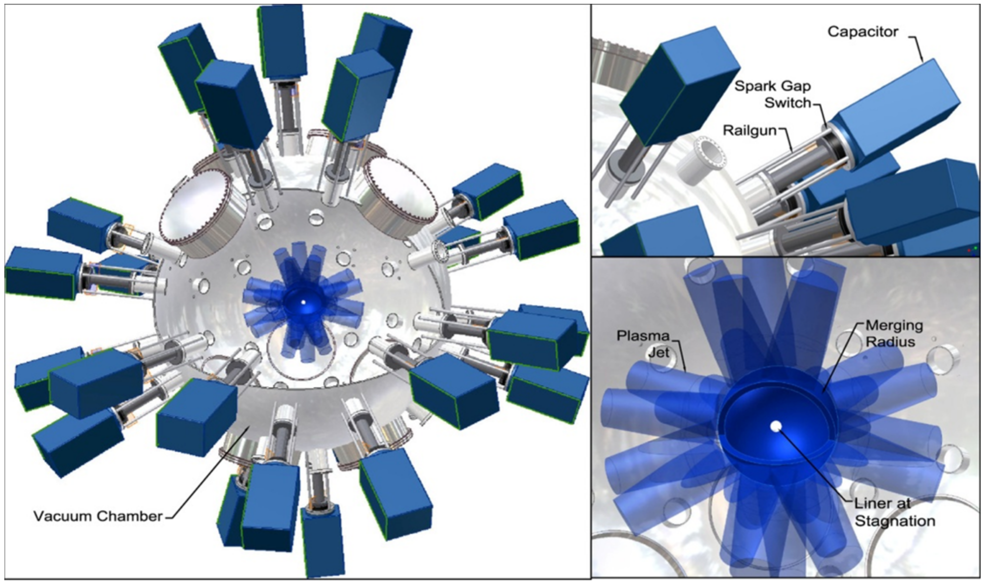


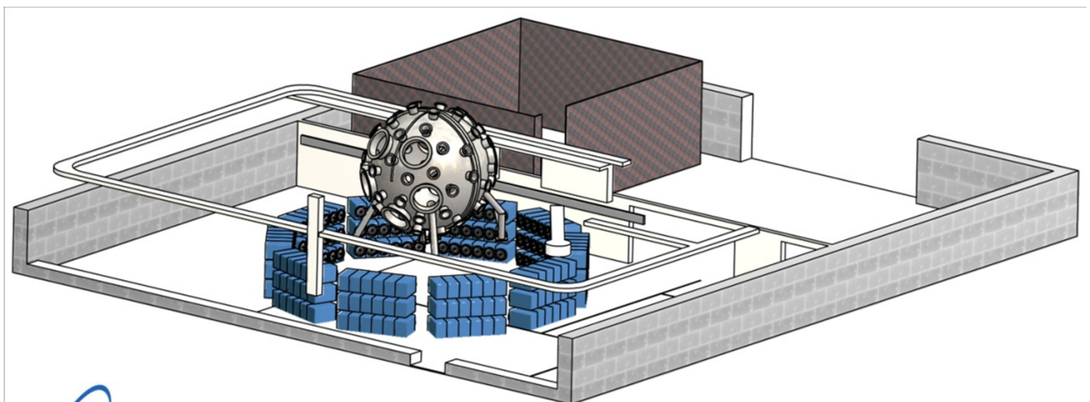
- Strong T6 signal observed.
- Secondary peaks on T4 and T3 signals after the first T6 peak; secondary peak on T6 signal, as well.
- At least some plasma captured; elasticity of the FRC allowing it to stretch beyond the upper mirror while a portion remains trapped between the mirrors.

FRCHX Test Summary

- Numerous FRC formation, translation, injection, and capture experiments have been conducted to characterize FRC T, n, and lifetime with FRCHX.
- Three capture region configurations have been implemented:
  - An extended quartz tube through the capture region to facilitate diagnostic access
  - The complete compression-heating hardware configuration
  - A mock up of the liner with modified upper electrode and top flange to allow B-dot probe insertion into the liner
- Plasma T and n have typically been 200~300 eV and 10^{16}~10^{17} cm^{-3}, respectively; trapped flux lifetimes have been only been 6~10 μs in duration.
- MHD simulations are being closely coupled to the experiment to aid in improvements.
- The first full-up implosion test (April 16, 2010) was an engineering success
- Second implosion experiment is ready, and is being statically tested now, to be dynamically imploded in Jan 2011.
- We are working on longer trapped FRC lifetimes, through higher bank settings, better trapping, more uniform preionizaiton. Further modifications will be implemented in subsequent tests in FY11.

Plasma Liner Experiment (PLX) will merge 30 plasma jets to create cm and μs scale plasmas approaching HED conditions (~0.1 Mbar)



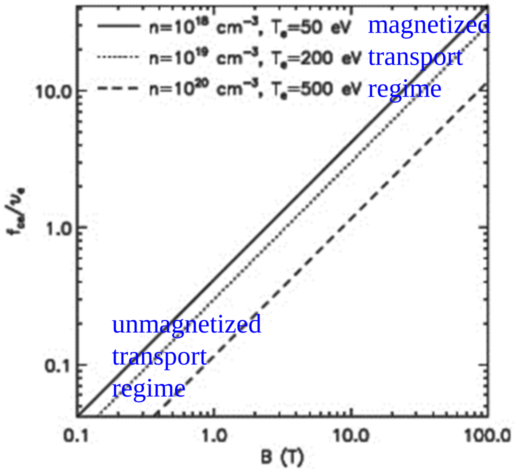


- Scientific goals: predictive understanding of jet propagation/merging, spherical plasma liner formation/convergence/stagnation, and “standoff” magnetization
- Motivations: enable platform for discovery-driven HEDLP science, especially magnetized HEDP, and standoff embodiment of magneto-inertial fusion
- Status: Phase 1 construction nearing completion with first experiments in 2011

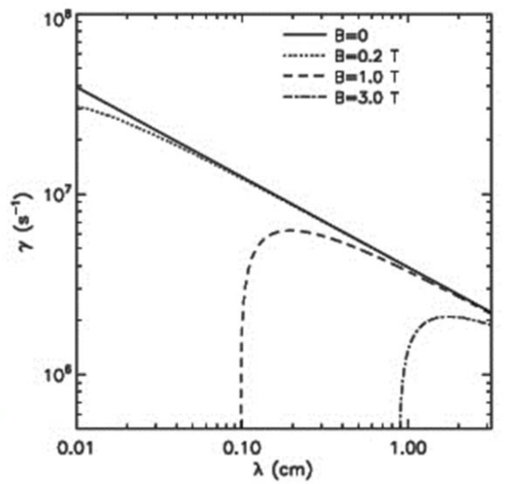
Drawing by David Van Doren, HyperV

Motivation: PLX can study transport/stability in magnetized HED plasmas and field unique laboratory plasma astrophysics experiments

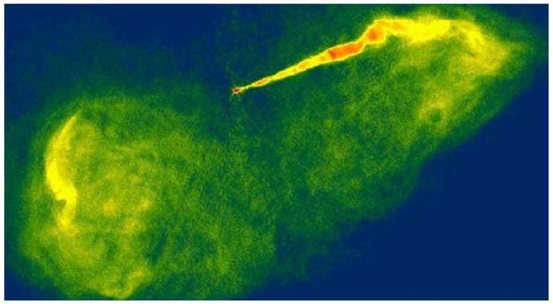
PLX can study transport in M-HED plasma:

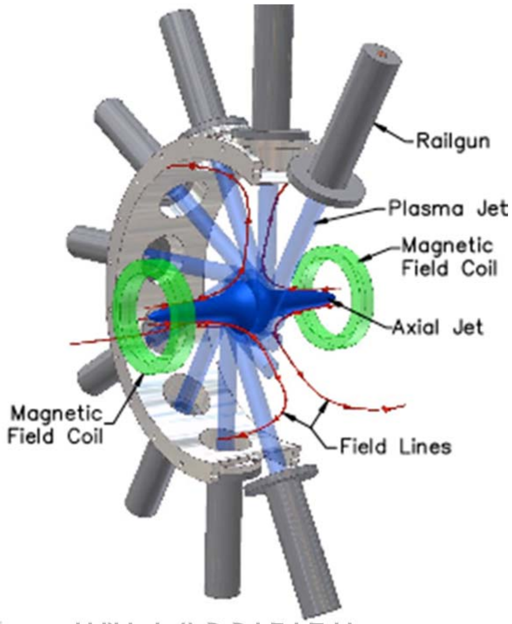


PLX can span linear stability thresholds for magnetic Rayleigh-Taylor instability:

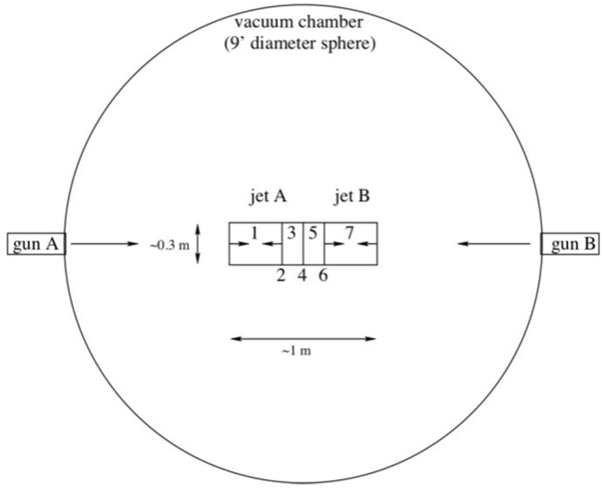


An experiment to generate a rotating plasma disk and (hopefully) emergent axial jets:





An experiment to generate both magnetized and unmagnetized collisionless shocks:



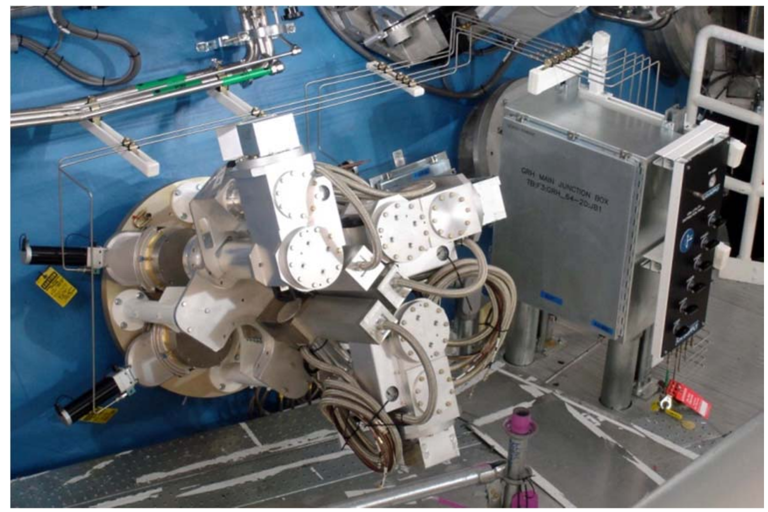
UNCLASSIFIED

CAD by David Van Doren, HyperV

LANL is engaged in National Ignition Campaign activities at the NIF

- LANL has ~35 people working in the Inertial Confinement fusion program
- LANL has four employees that spend > 75% of their time at LLNL working at the NIF with several more spending a significant amount of time at LLNL
  - Designing, leading, and participating in experiments, as well as installing diagnostics
  - *LANL personnel lead the fielding of the symmetry experiments this fall up to 1.3 MJ**
- LANL is building two key nuclear diagnostics for ignition
  - Gamma Reaction History to measure the burn history and bang time of the capsule implosion
  - Neutron imaging to measure the shape of the burning fuel

First three gas cells for GRH installed on the NIF chamber



*Invited talks at the APS-DPP by John Kline and George Kyrala

Conclusions

• It is an exciting time to be doing Fusion and HEDP research.

• We look forward to contributing to the NAS IFE Review, through all forms of our IFE-related work.

•We are on a good path for the next several years, and hope that the course can be maintained, and even accelerated.