

OVERVIEW OF MAGNETO-INERTIAL FUSION

G. A. Wurden
Los Alamos National Laboratory

16th ANS TOFE Conference
Madison, Wisconsin
Sept. 15, 2004



Magneto-Inertial Fusion: An old idea....

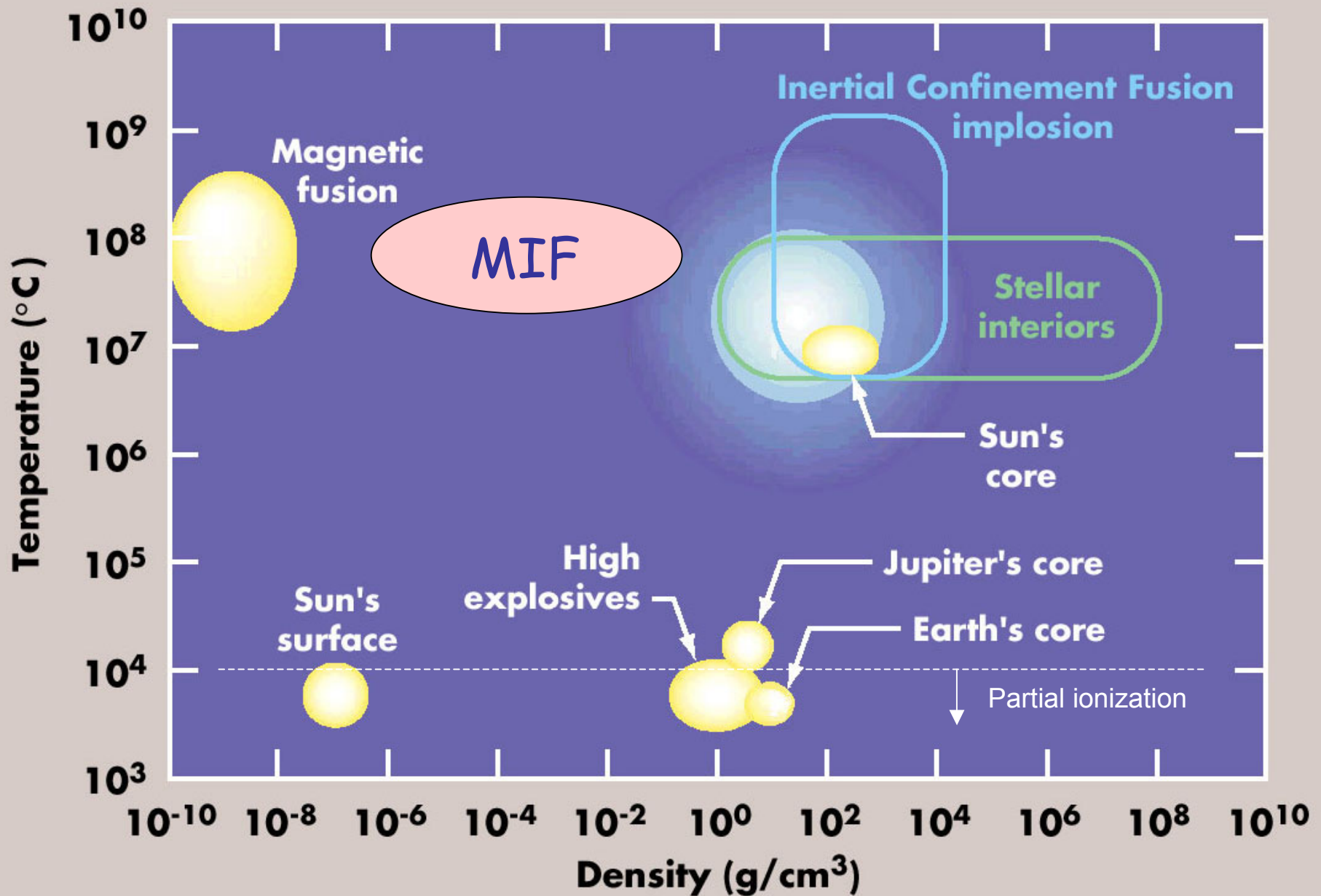
Involving the application of a magnetic field to inhibit heat flow in an inertially compressed (high pressure) target plasma, and thereby ease the driver requirements.

It can take on many possible implementations, both for targets and drivers.

At 1 Megabar pressure (or higher), it is in the regime of High Energy Density Physics (HEDP).

Early proponents of the topic include: R. K. Kurtmullaev, A. Velikovich, J. G. Linhart, T. Armstrong, F. L. Ribe, R. Gerwin, R. Bangerter, D. Ryutov, J. H. Hammer, R. D. Jones, M. J. Schaffer, W. C. Mead, R. C. Kirkpatrick, I. R. Lindemuth, R. W. Moses, T. Jarboe, R. Siemon, and probably others I didn't list.

Where in the universe is MIF?



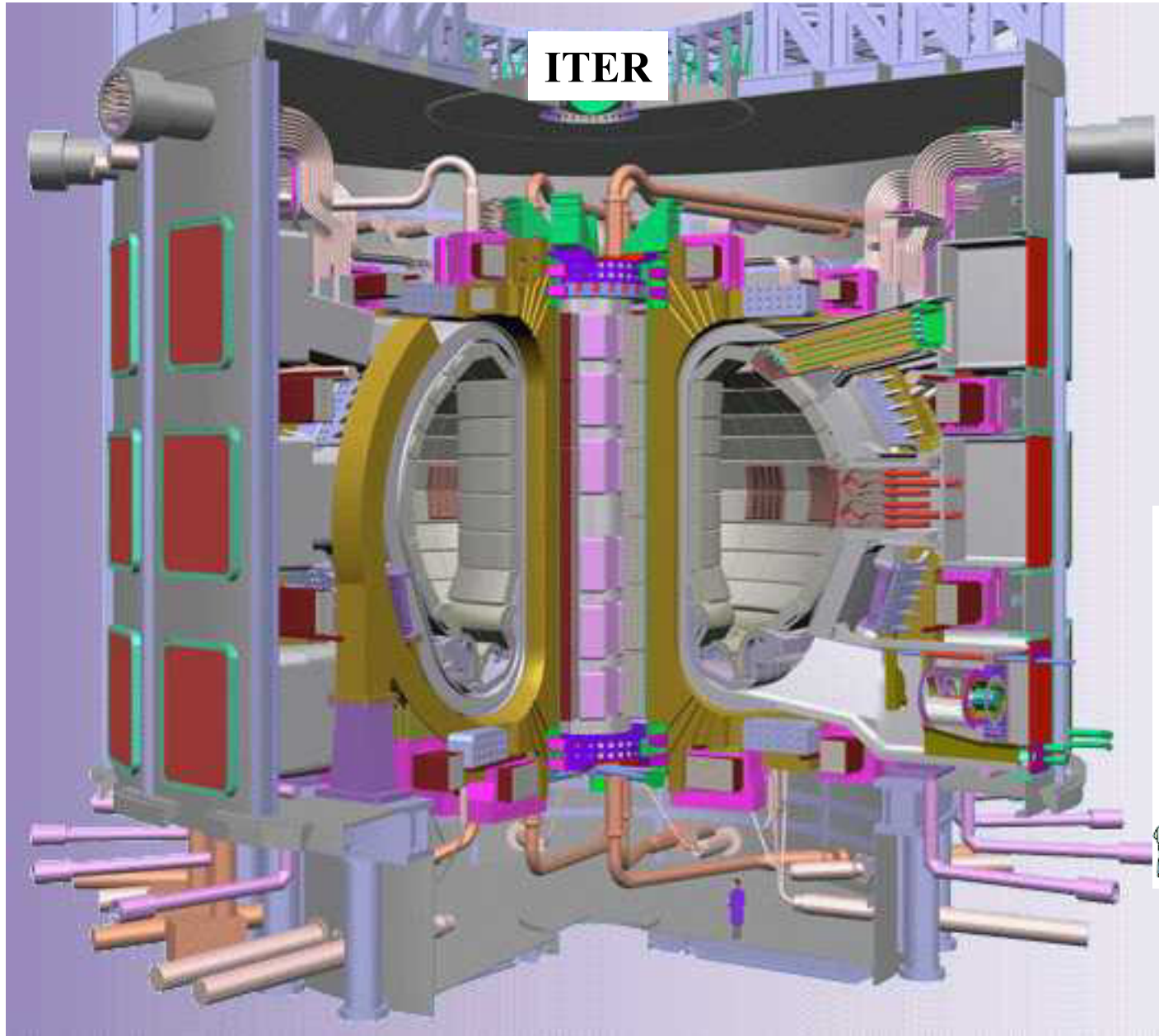
Special issues associated with MIF

- Required ρR of target is lower than with ICF (because the B-field helps)
- Compare slowing down time of alphas relative to configuration lifetime. If $BR > 0.3$ MGauss-cm, then thermonuclear self-heating can occur.
- Target symmetry is strongly affected by presence of a magnetic field
- The lower density burn regimes of MIF are in “batch burn mode”, with fractional burn-up of only a few %, and gains are less than ~ 20 .
- High-end density regimes for MIF should be able to burn cold fuel at the boundary.
- There may be more materials near the center of the chamber (due to liner and leads), and therefore there are associated issues with (non-plasma, non-radiation) blast debris.
- Cost of replacement parts relative to value of energy produced.
- Standoff from the location of fusion burn.
- Rep-rating a bigger absolute yield, but at a lower frequency (~ 0.1 Hertz). Lifetime of the pulsed-power driver elements.

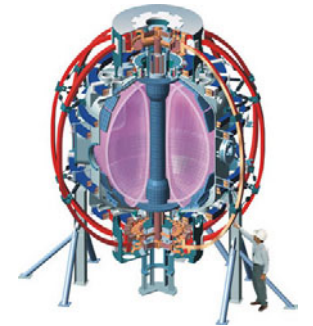
Definition of Magnetized Target Fusion

- MTF is a concept that covers a subset of MIF scenarios.
- For MTF, one must form an initial plasma “target” with an embedded magnetic field. It isn’t just a cold fuel capsule with an added magnetic field. The desired target plasma temperature is in the range of 50-300 eV.
- At Los Alamos National Lab and the Air Force Research Laboratory, the MTF approach that we have in mind, involves using electromagnetically driven solid liners to adiabatically compress not only a magnetically-insulated, but a magnetically-confined plasma (the $\delta\Omega \sim 1$ FRC). We chose this approach because it is the least restrictive, and in our view, the most likely path to succeed at demonstrating MTF principles.
- There are many other MTF scenarios, which use plasma liners, or assembly of plasma liners with converging plasma jets, or which use wall-confined ($\delta\Omega \gg 1$) plasmas. These other approaches offer their own particular advantages and disadvantages.

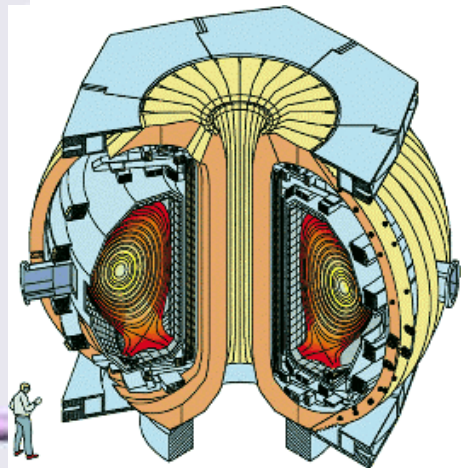
Some Fusion Experiments



MTF (Los Alamos)

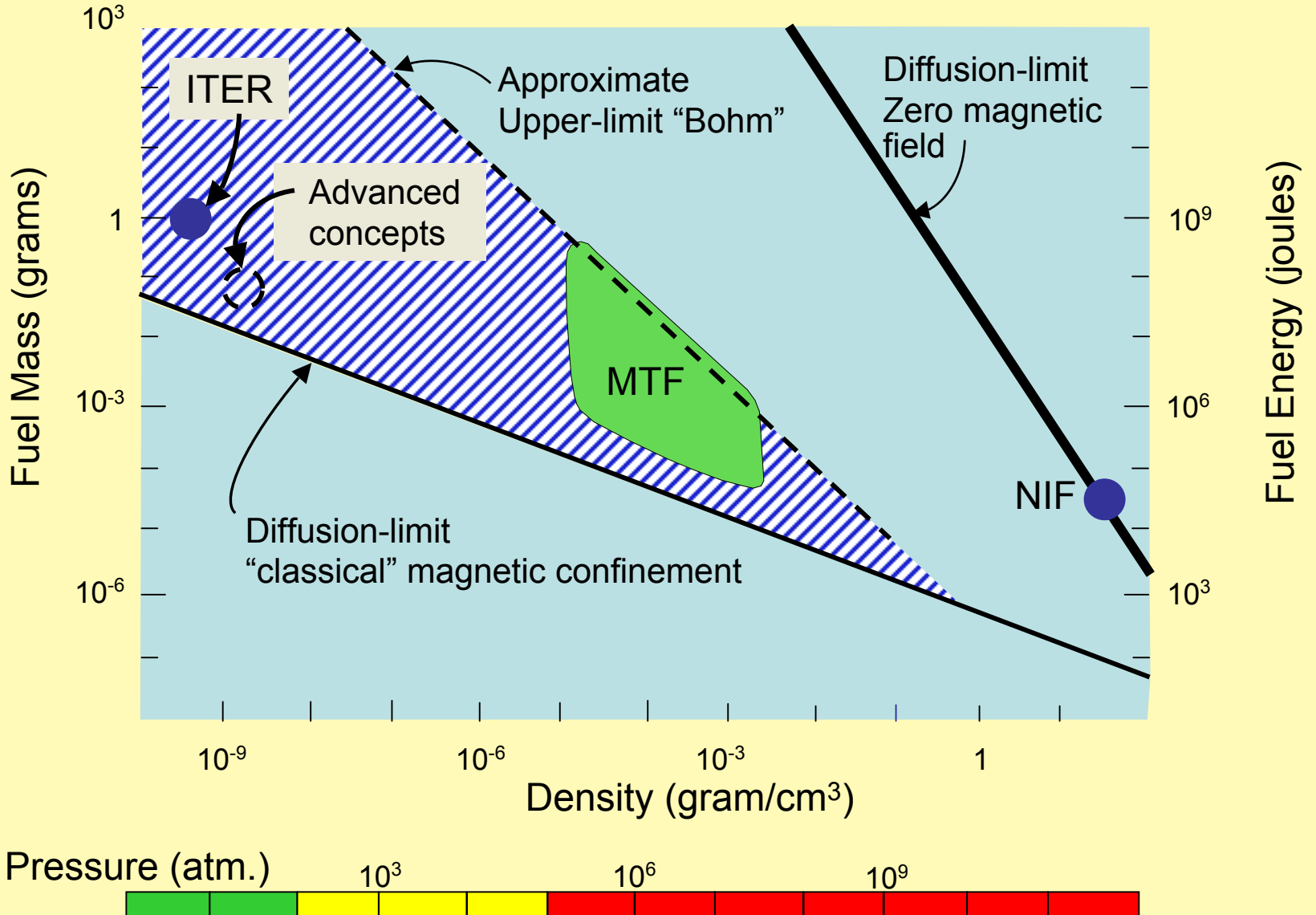


National Spherical
Torus Experiment
NSTX (Princeton)



DIII-D Tokamak
General Atomics
(San Diego)

Required DT Fuel Mass



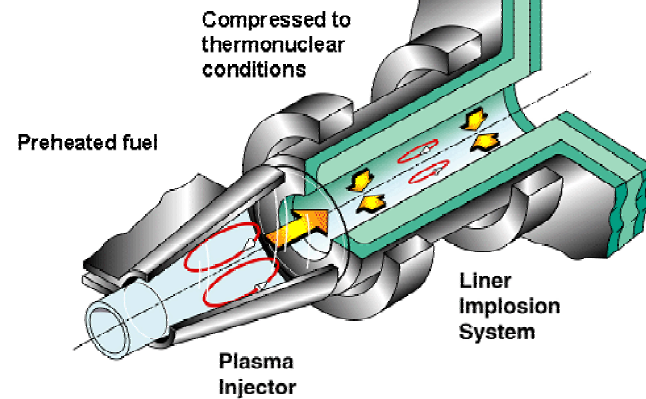
Low, Medium, and High Pressure MTF Regimes

- Low pressure (< 10 kbar), resembling LINUS or UC Berkeley compression of a spheromak, which allows for minimum damage to equipment on each pulse
- Medium pressure (0.01-10 Megabar) is appropriate for electromagnetically driven solid metal liners (the approach we chose for MTF). Batch burn.
- High pressure (> 10 Megabar) resembles conditions closer to inertial fusion conditions, in Z or heavy ion drivers. Advantage of the possibility of burning cold fuel, for higher yields.

Magnetized Target Fusion:



Magnetized Target Fusion

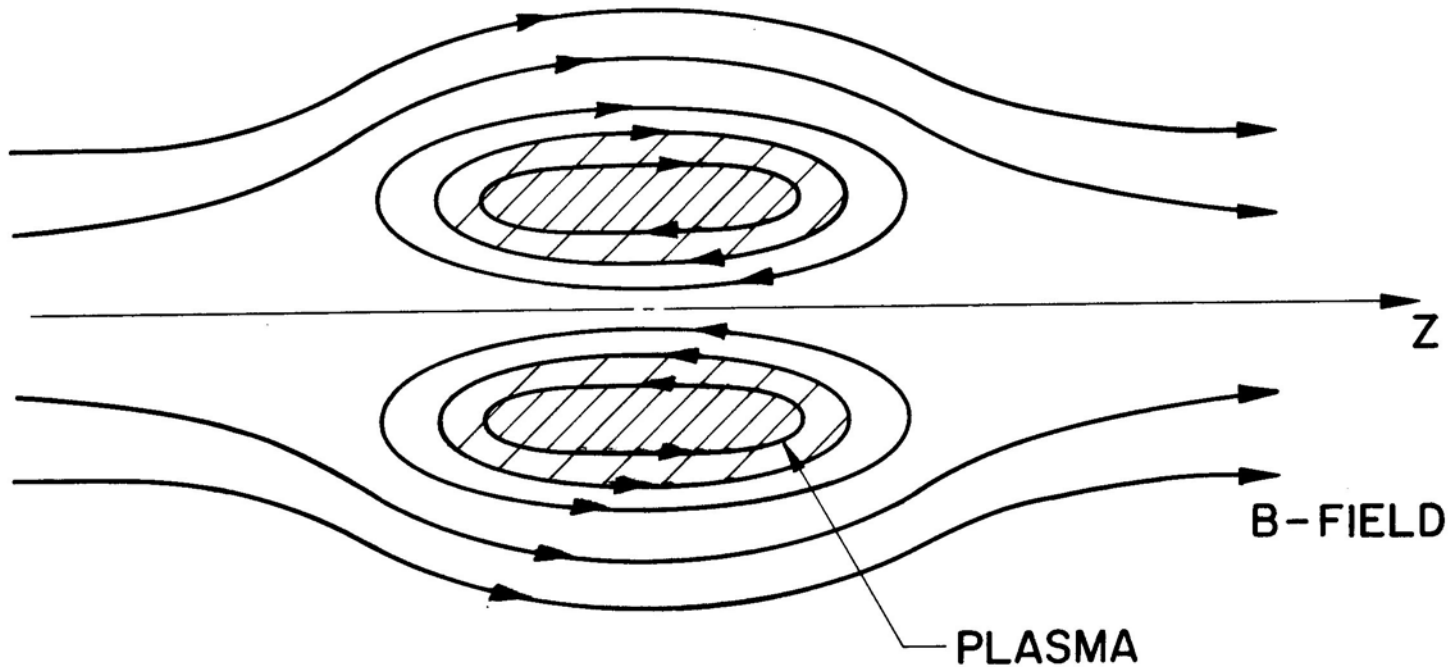


Our choice of parameter space

Imagine a fusion concept where:

- The plasma beta ranges from 0.8 to 1
- The heart of the device fits on a modest table-top
- The final plasma density is $\sim 10^{19} \text{ cm}^{-3}$
- The magnetic field confining the plasma is 500 Tesla !
- The auxiliary heating power level is ~ 1000 Gigawatts !
- The heating is “slow” adiabatic compression
- Most of the initial physics research can be conducted with existing facilities and technology
- In a reactor, on each pulse the liquid first wall would be fresh
- The repetition rate is ~ 0.1 Hertz, so that there is time to clear the chamber from the previous event

Smoke-ring-like Field Reversed Configuration



FRC is a high beta plasma object, and easy to translate

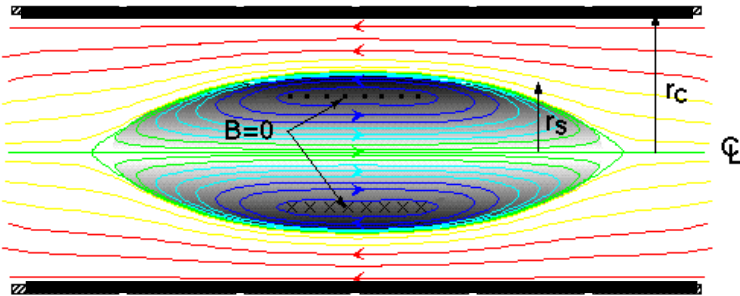
MTF using the FRC as target plasma

Magnetic field of ~ **3-5 T** in a closed-field line topology

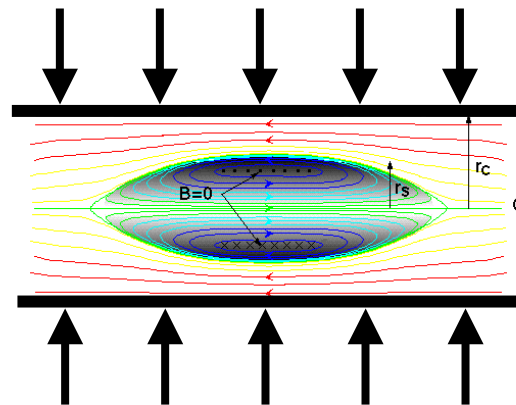
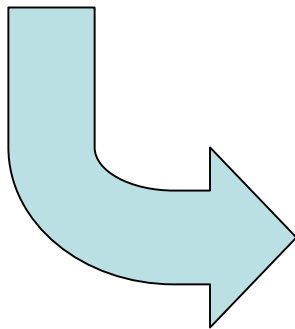
Density ~ **10^{17} - 10^{18} cm⁻³**

Free of impurities (reduce radiation losses)

T_e ~ **50-300 eV**



Initial target: **preheated & magnetized**



Liner
Compression
~ **1 cm/ μ s**

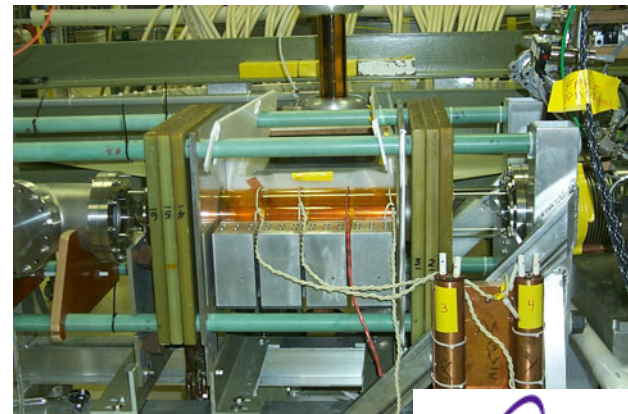
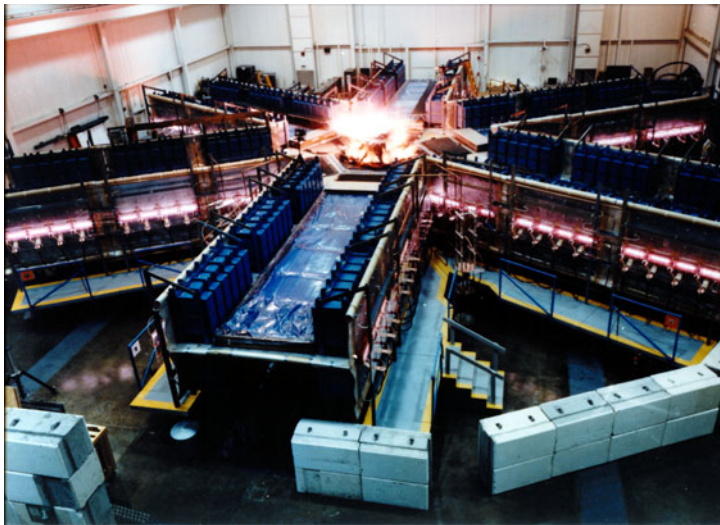
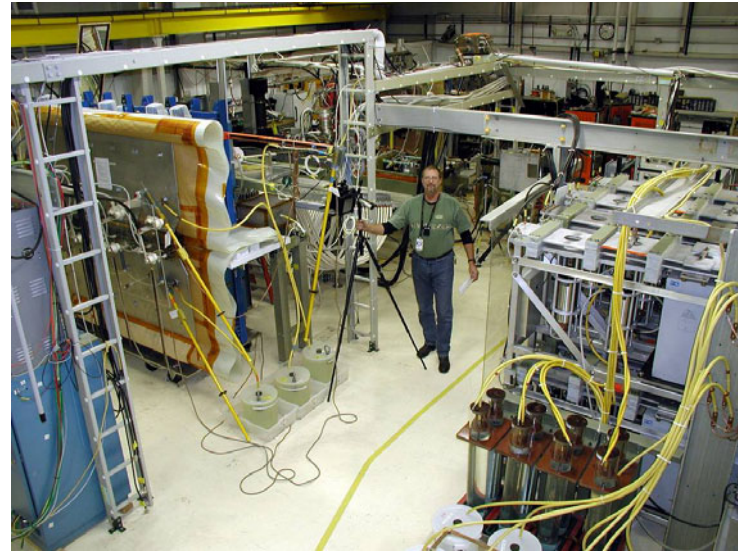
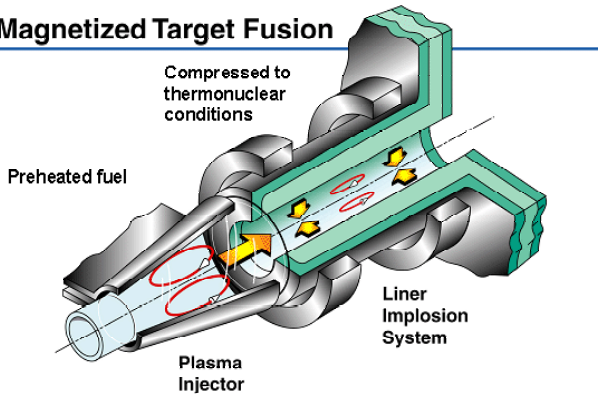
~ **factor of 10x**
in radius

to fusion relevant conditions

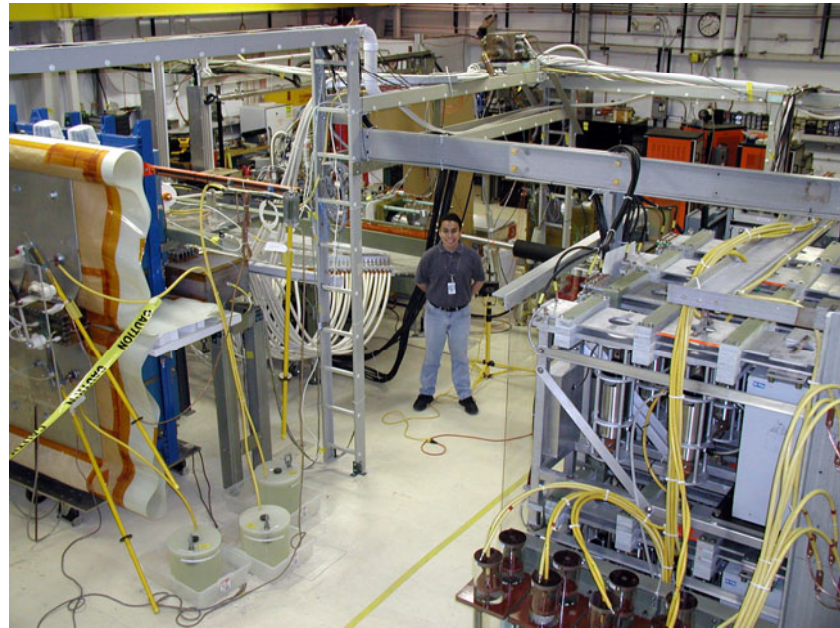
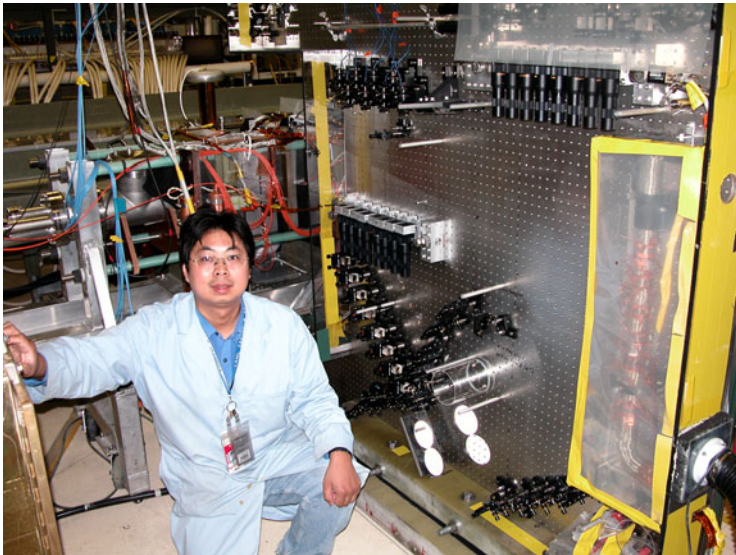
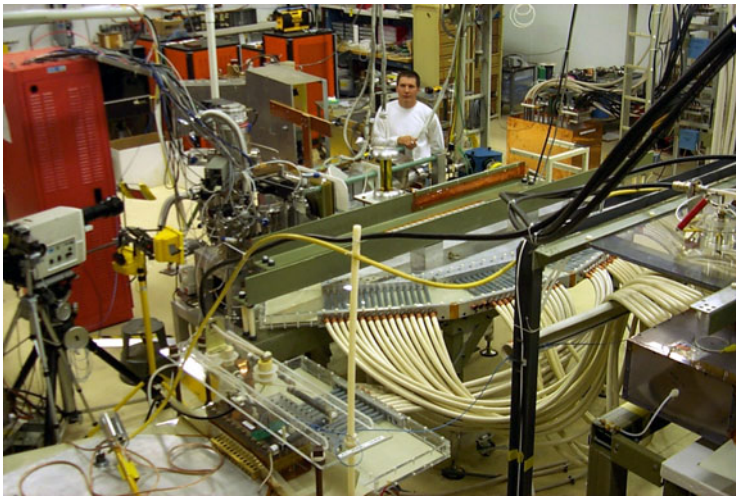
Goal: Near-term FRC Plasma/Liner implosion physics demonstration

CIC-100-0126 (11-99)

Magnetized Target Fusion

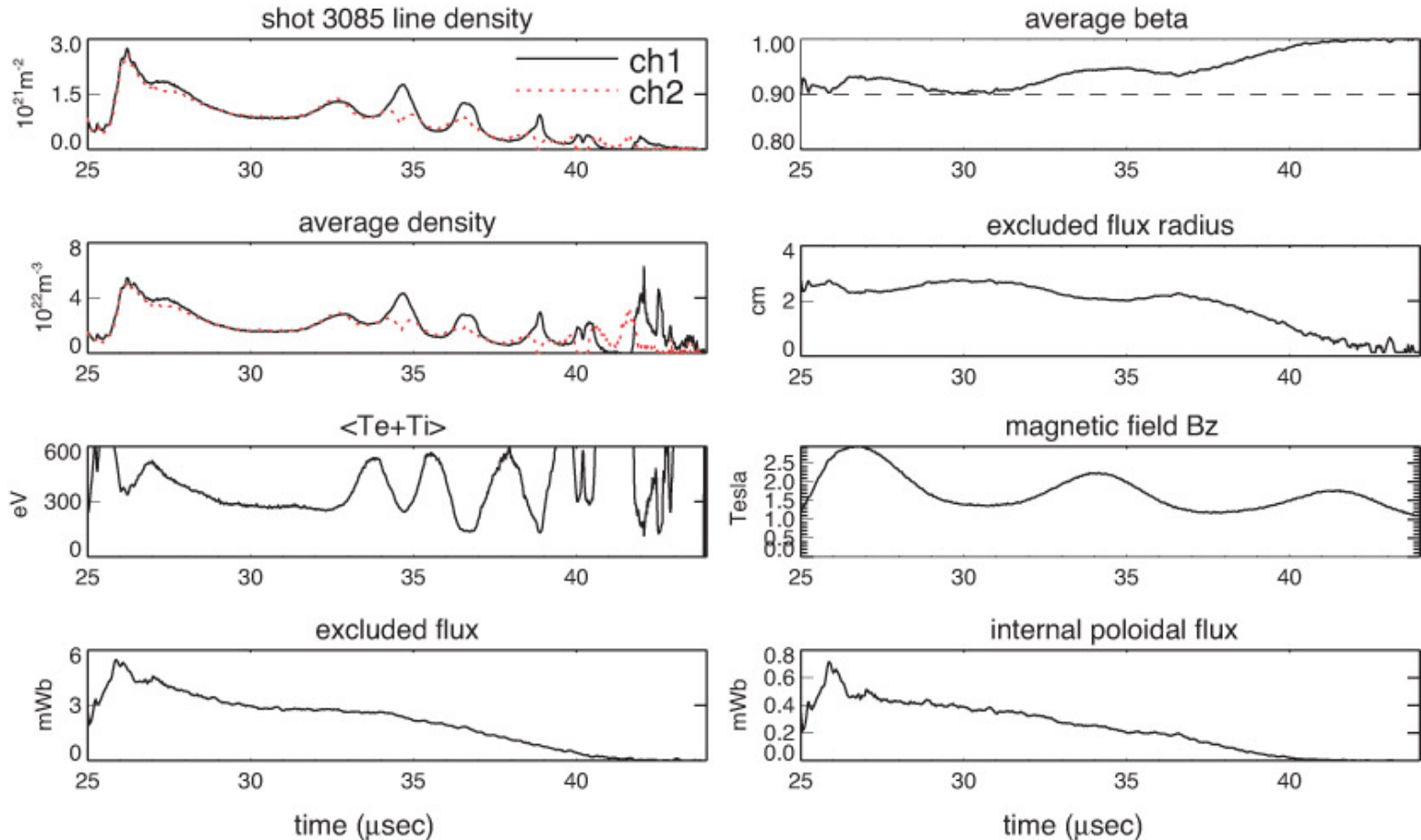


FRX-L: The Field Reversed Configuration (FRC) Plasma Injector for MTF



FRX-L Field Reversed Configuration Target Plasma Data

Plasma performance is adequate for initial integration to a plasma/liner experiment



Magnetized Target Fusion:

Reference Materials

- Our web pages: <http://fusionenergy.lanl.gov> and <http://wsx.lanl.gov>
- “Amplification of magnetic fields and heating of plasma by a collapsing metallic shell”, by Linhart, Knoepfel, and Gurlain, *Nuclear Fusion*, CN-10/11, suppl. Pt. 2, 733 (1962).
- “Why Magnetized Target Fusion Offers a Low-Cost Development Path for Fusion Energy”, by Siemon, Lindemuth, and Schoenberg, *Comments Plasma Phys. Controlled Fusion*, Vol 18, No. 6, pg 363-386 (1999).
- “Scaling Relations for High-Gain Magnetized Target Fusion Systems”, by D. C. Barnes, *Comments Plasma Phys. Controlled Fusion*, Vol 18, No. 2, pg 71-84 (1997).
- “Magnetized Target Fusion: An Overview”, by R. C. Kirkpatrick, I. R. Lindemuth, M. S. Ward, *Fusion Technology*, Vol 27, pg 201 (1995).