Atlas for magneto-inertial fusion

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Synopsis

- Magnetized Target Fusion (MTF) is the approach to fusion energy that is intermediate in parameters between conventional magnetic and conventional inertial fusion. Typical parameters are microsecond time scales, megabar pressures, megagauss magnetic field, and megajoules of energy. The essential ingredients are formation of a plasma target containing the fusion fuel embedded in a magnetic field to improve energy confinement, followed by pulsed compression of the fuel to achieve fusion reactions during the inertial dwell time of the compression system. A variety of detailed approaches are being considered for this purpose.[1-4] Theoretical analysis shows that the intermediate regime of parameters has better prospects for economical development of practical fusion energy than either extreme represented by conventional approaches.[5]
- This year the Atlas pulsed power facility, designed and developed at Los Alamos National Laboratory, is beginning to operate at the Nevada Test Site. It is the world's largest microsecond pulsed power system. Given that the primary purpose of Atlas is high-energy-density science for stockpile stewardship, it is serendipitous that Atlas is also extremely well suited for critical tests of the magneto-inertial fusion concept.
- The design of an initial experiment on Atlas will be described that investigates magnetic flux compression without plasma, and generation of magnetic field in the megagauss regime.[6] An new and interesting aspect of the experiment is a unique method of providing seed flux for compression by diverting a small amount of current from the main Atlas power system while it drives a liner implosion.
- Progress on formation of an MTF plasma target has been recently reported by Los Alamos researchers,[7] and other possibilities are being investigated.[8] Plans for a campaign of Atlas experiments based on this progress are being developed. This campaign is one part of a roadmap for developing the MTF concept, which was recently prepared by the international community of scientists interested in MTF. The roadmap shows how Atlas in combination with other existing pulsed power facilities can provide a faster pathway to fusion than possible with conventional approaches.

References

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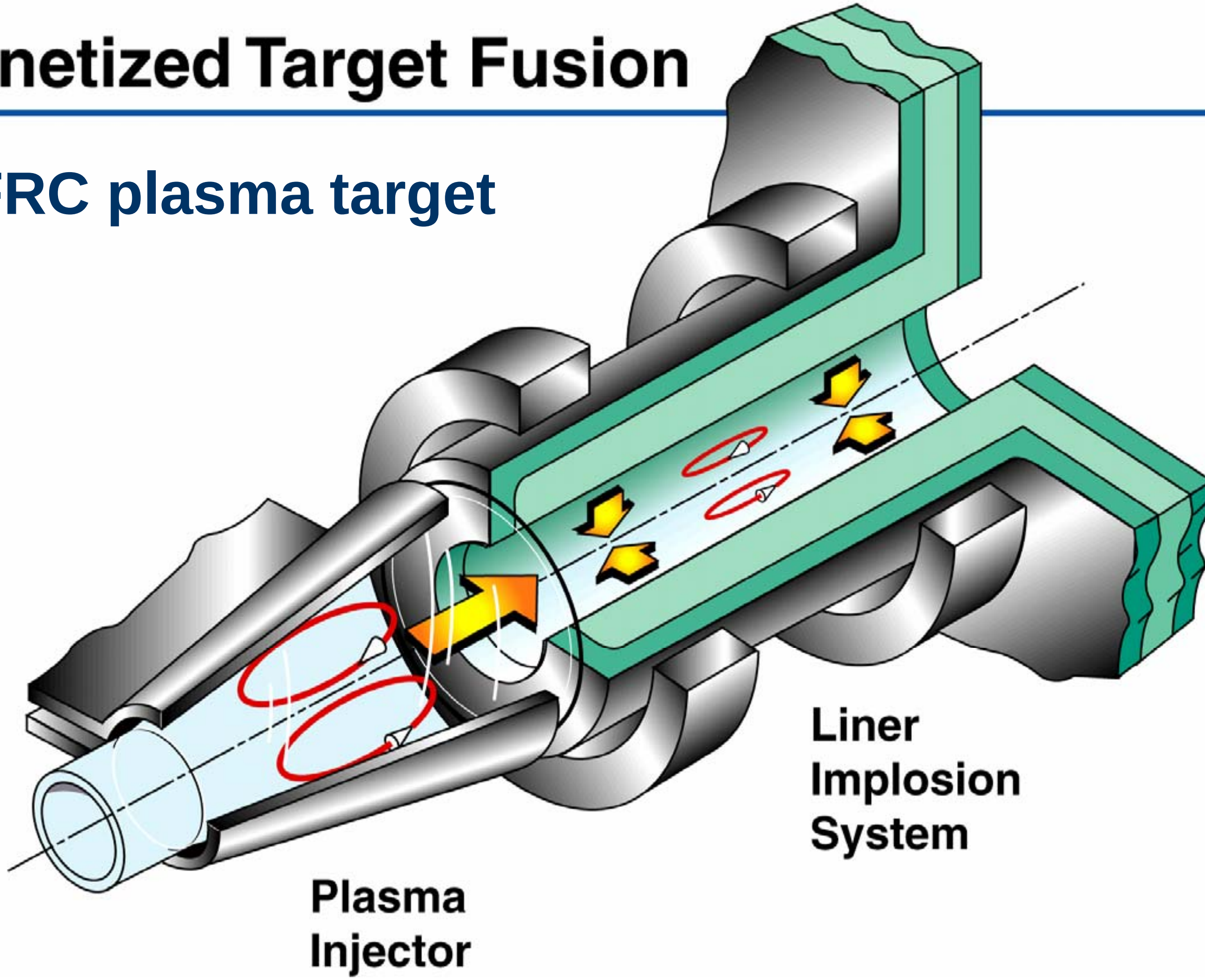
Terminology

•Magneto-inertial fusion (MIF) is the general idea of achieving fusion with a high-density pulsed system that incorporates magnetic field
--magnetic field to improve energy confinement during burn
--high-energy-density achieved with high-power pulsed technology
--time scale governed by inertia of material surrounding the heated fuel

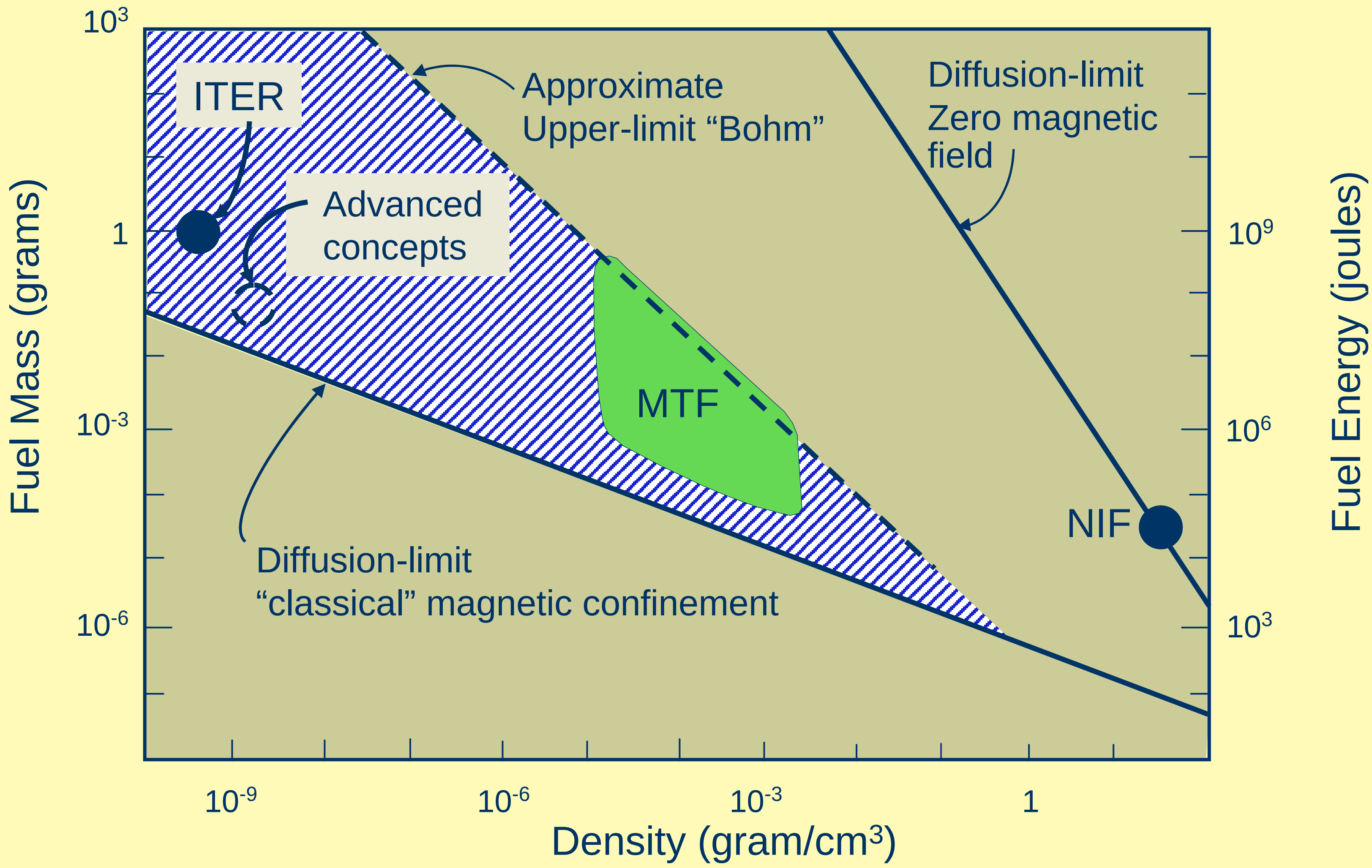
•Magnetized Target Fusion (MTF) is the subset of MIF approaches that seeks to work at a density intermediate between conventional inertial and magnetic systems.
--preheat the fuel and compress to thermonuclear temperature with one of several possible pushers.
--metal liners and pulsed systems like Atlas are available now to test basic concept

Magnetized Target Fusion

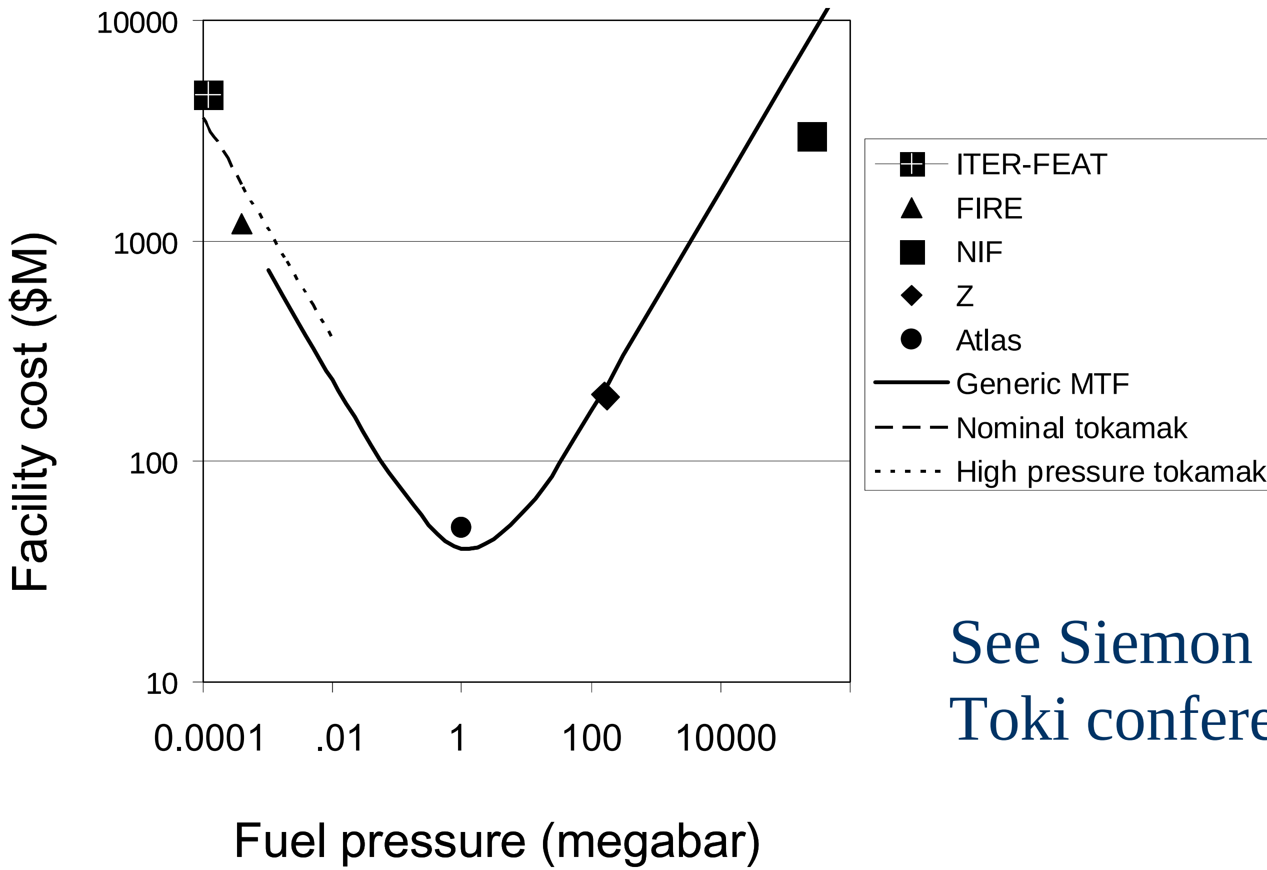
FRC plasma target



MTF regime is intermediate between MFE and ICF



Intrinsic fusion cost considering size and power is minimized around 1 Mbar

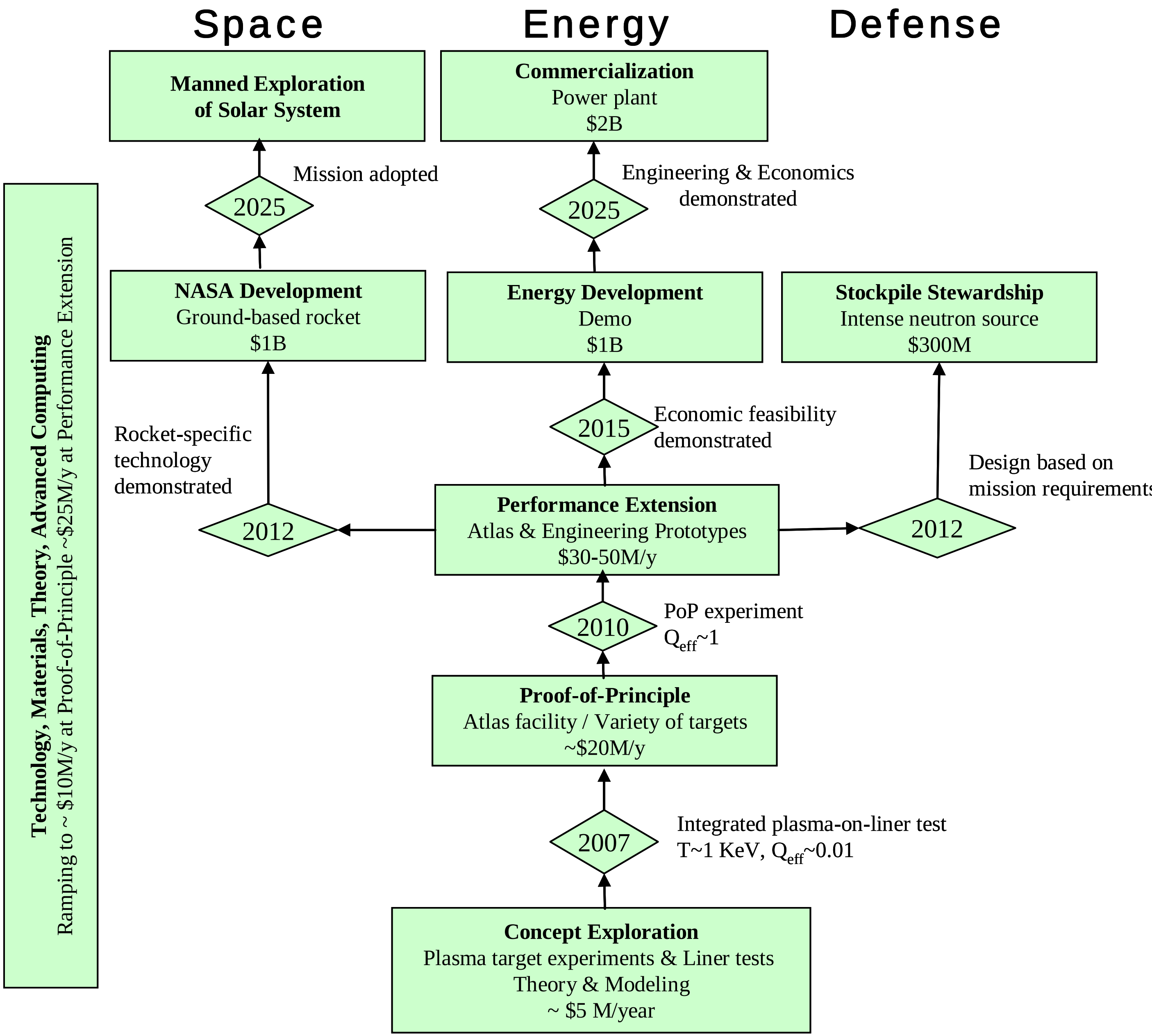


See Siemon *et al.*,
Toki conference (2001).

MIF can be developed faster than conventional fusion

- Road map analysis suggests a time scale of 20 years instead of 50 years
- Cost of development is reduced because facilities are intrinsically less expensive.

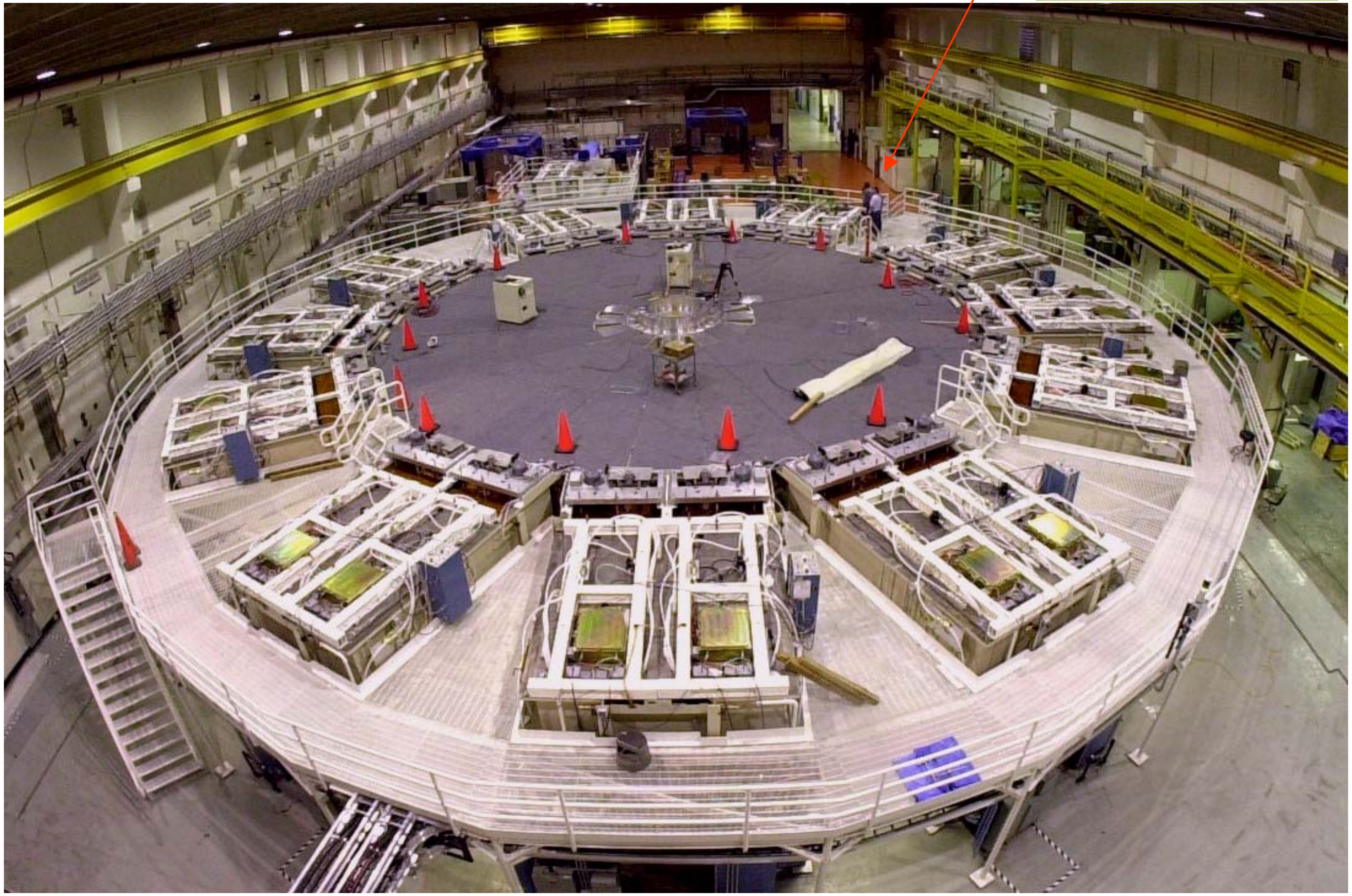
Magneto-inertial Fusion Roadmap



Standard person

Atlas power supply

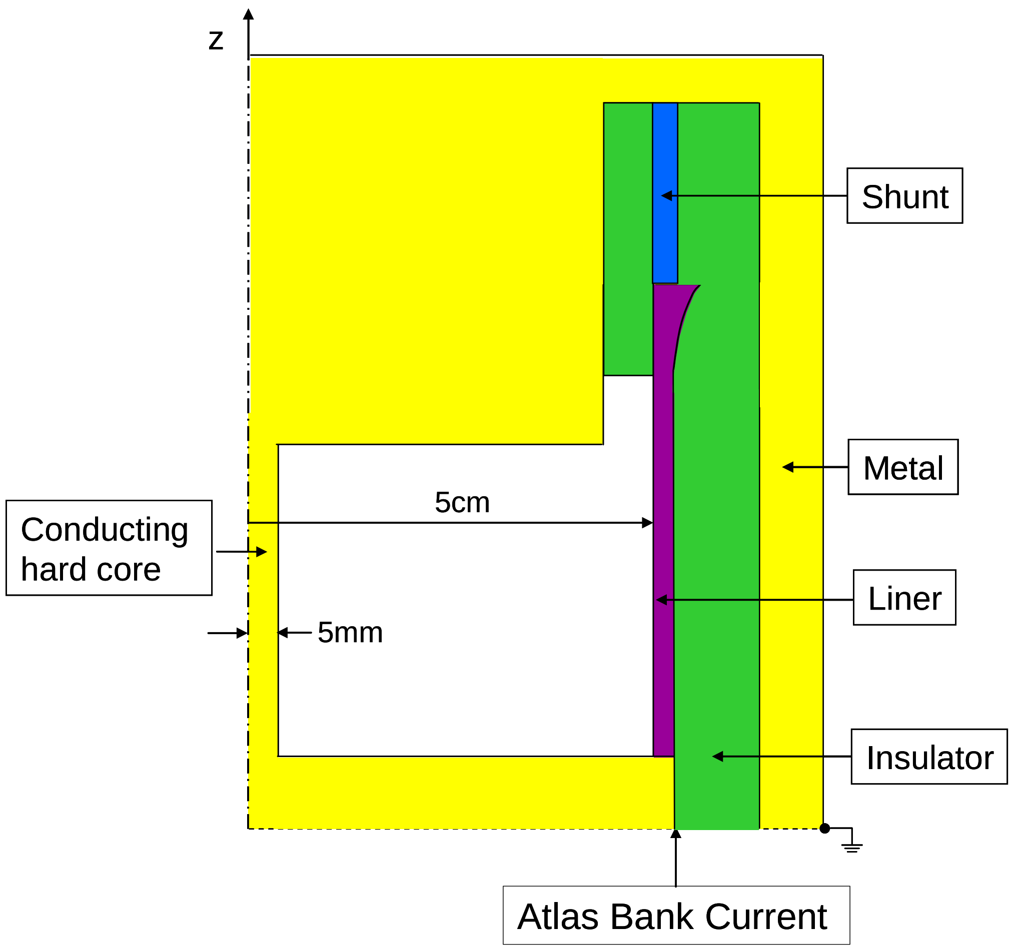
240 kV
24 MJ
~ 25 nH
30 MA



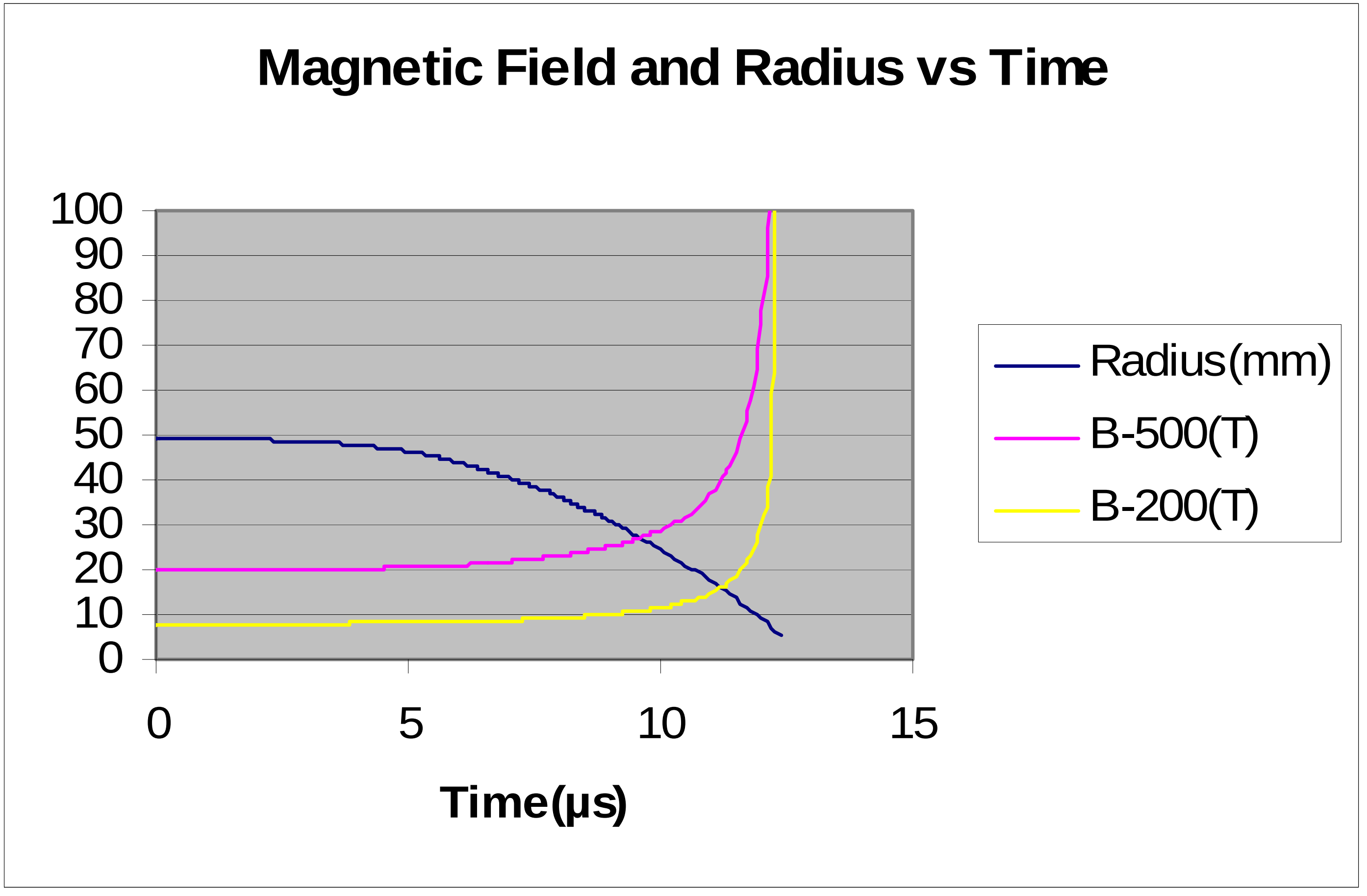
Atlas is ideal for doing important MTF experiments

- Near term -- magnetic flux compression to megaguass field level in an MTF-relevant geometry
- Longer term – using various plasma targets, test plasma compression inside a liner

Flux compression experiment is being designed



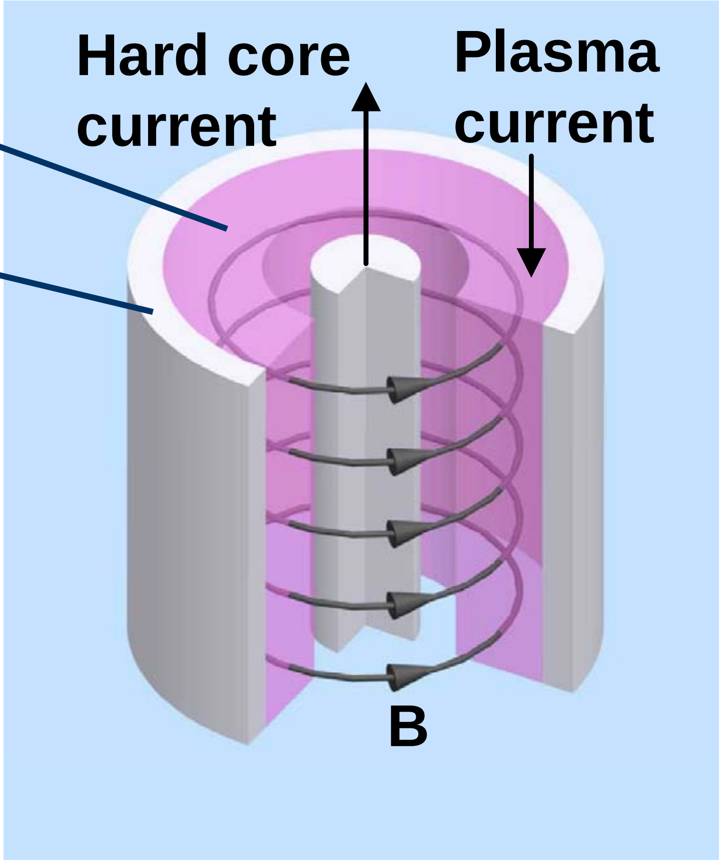
Liner implosion with trapped flux results in megagauss magnetic field



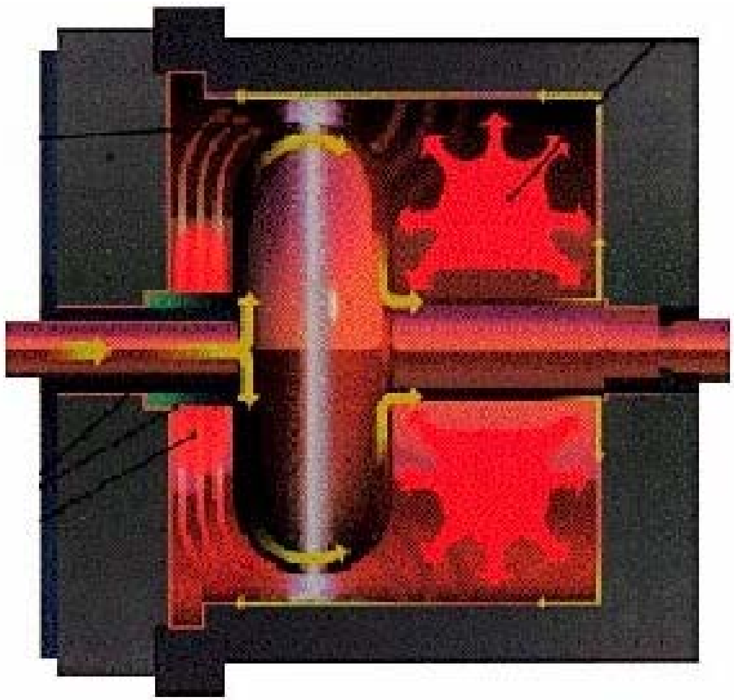
Hard-core stabilized z pinch is potential MTF target plasma

Plasma

Outer conductor is the imploding liner



MAGO generates hard-core stabilized z pinch

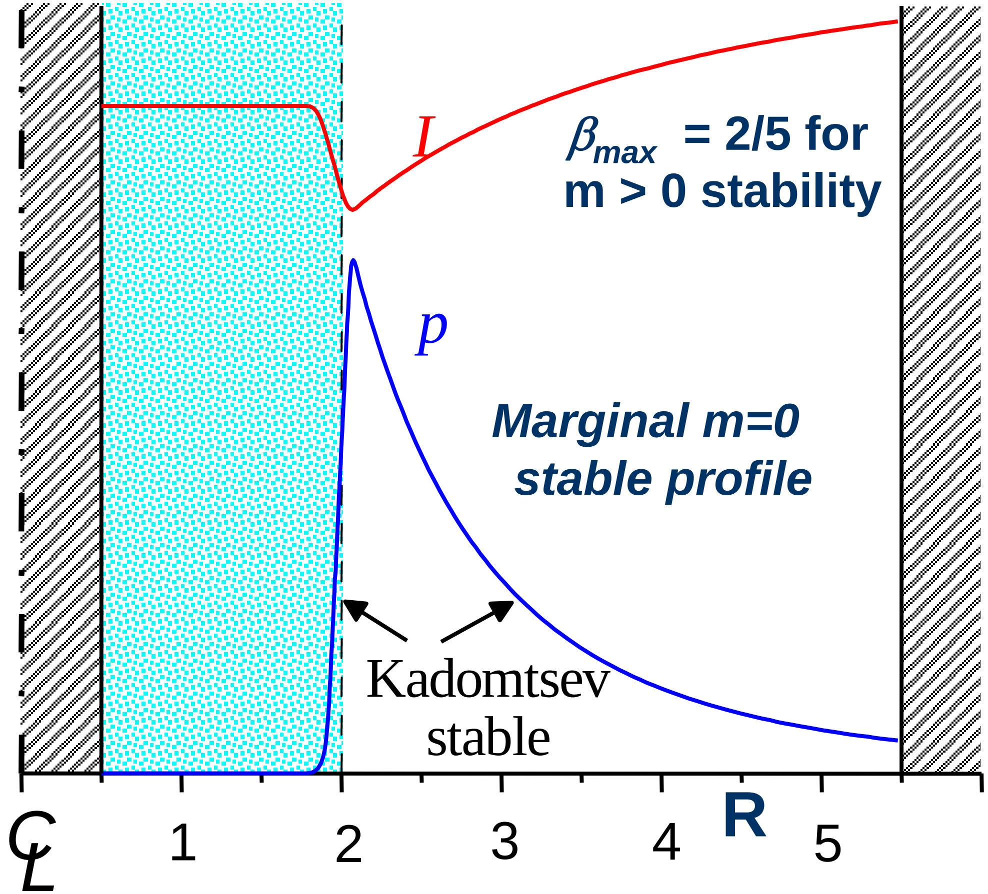


MAGO at VNIIEF

I. R. Lindemuth, *et al.*, *"Magnetic Compression / Magnetized Target Fusion (MAGO/MTF): A Marriage of Inertial and Magnetic Confinement*, 16th IAEA Fusion Energy Conference, Montreal, Canada, October 7-11, 1996.

Hard-core pinch can be stable to all MHD modes

Arbitrary width vacuum region



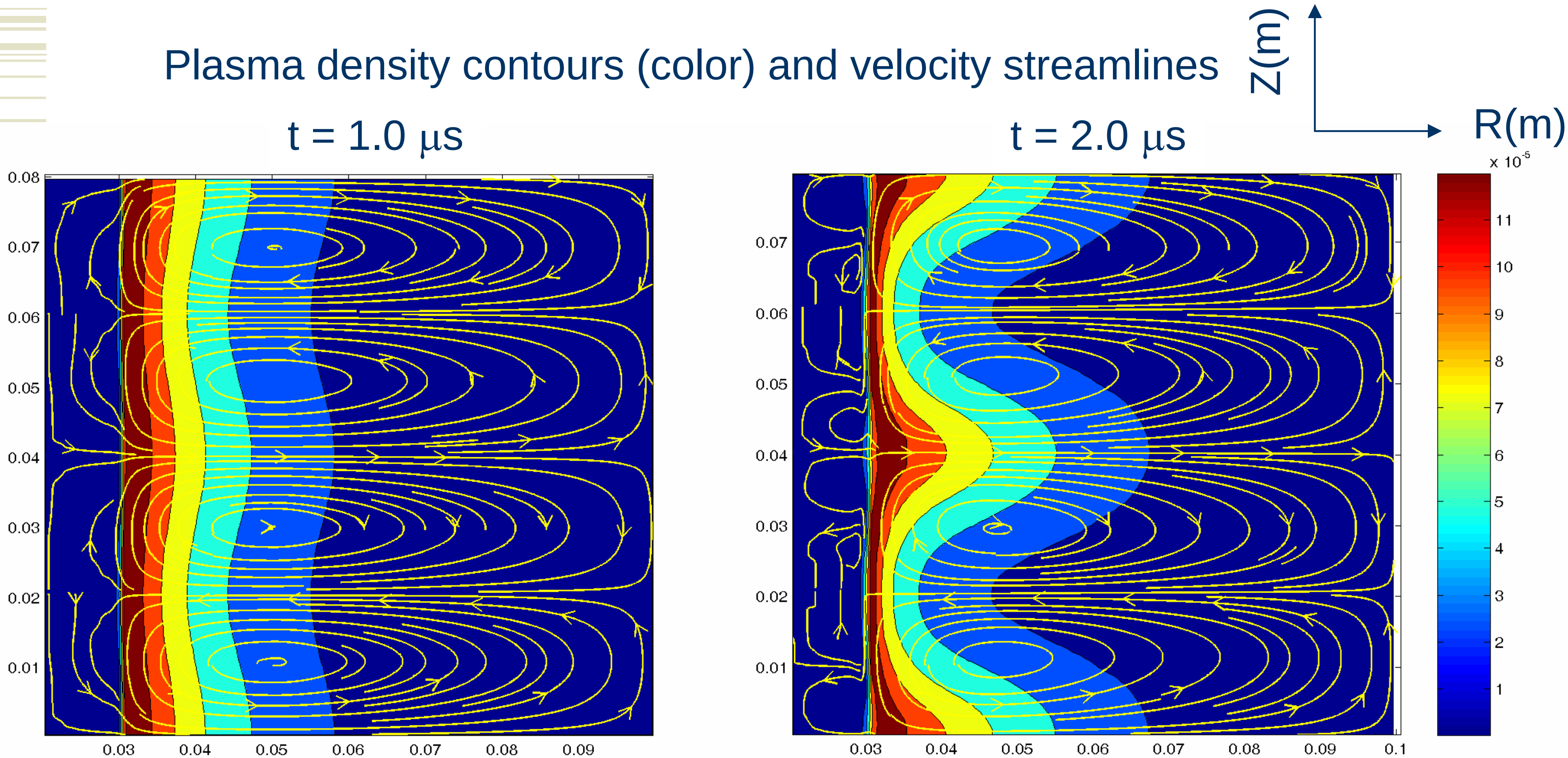
Self-organization in diffuse z pinch

- Plasma is unstable if pressure gradient violates Kadomtsev criterion
- Result is turbulent interchange motions of flux tubes in the rz plane ($B=B_\phi$).
- Plasma fluctuates in space and time around the marginal Kadomtsev-stable pressure profile.
- Process observed in numerical simulations of many different initial conditions; consistent with MAGO experimental data.
- Process illustrated by simulation using idealized initial conditions with *eg*. pressure gradient 10% too large

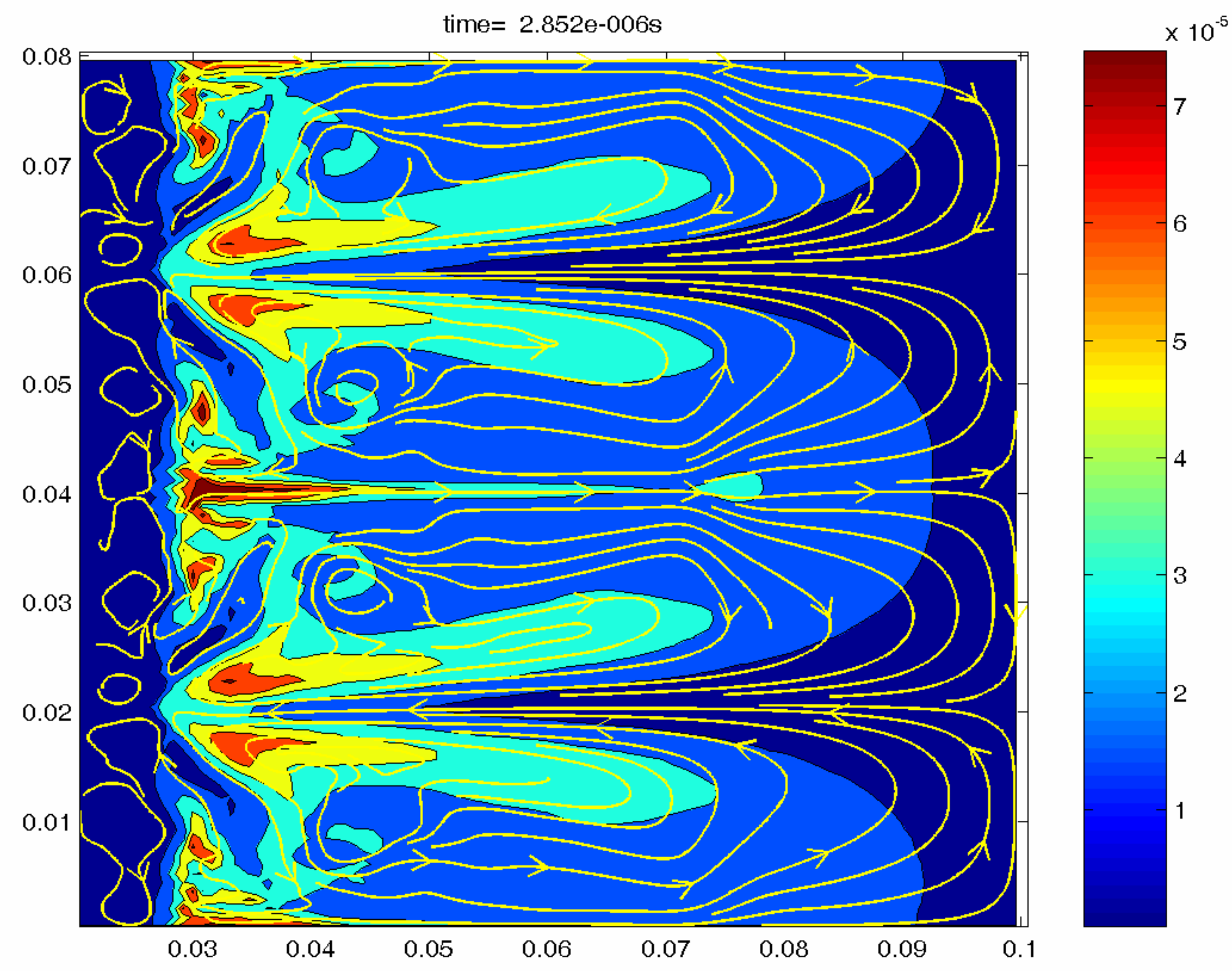
See Makhin *et al*., Physics of Plasmas, April 2005

Sequence of interchange motion following Q=1.1 initial profile

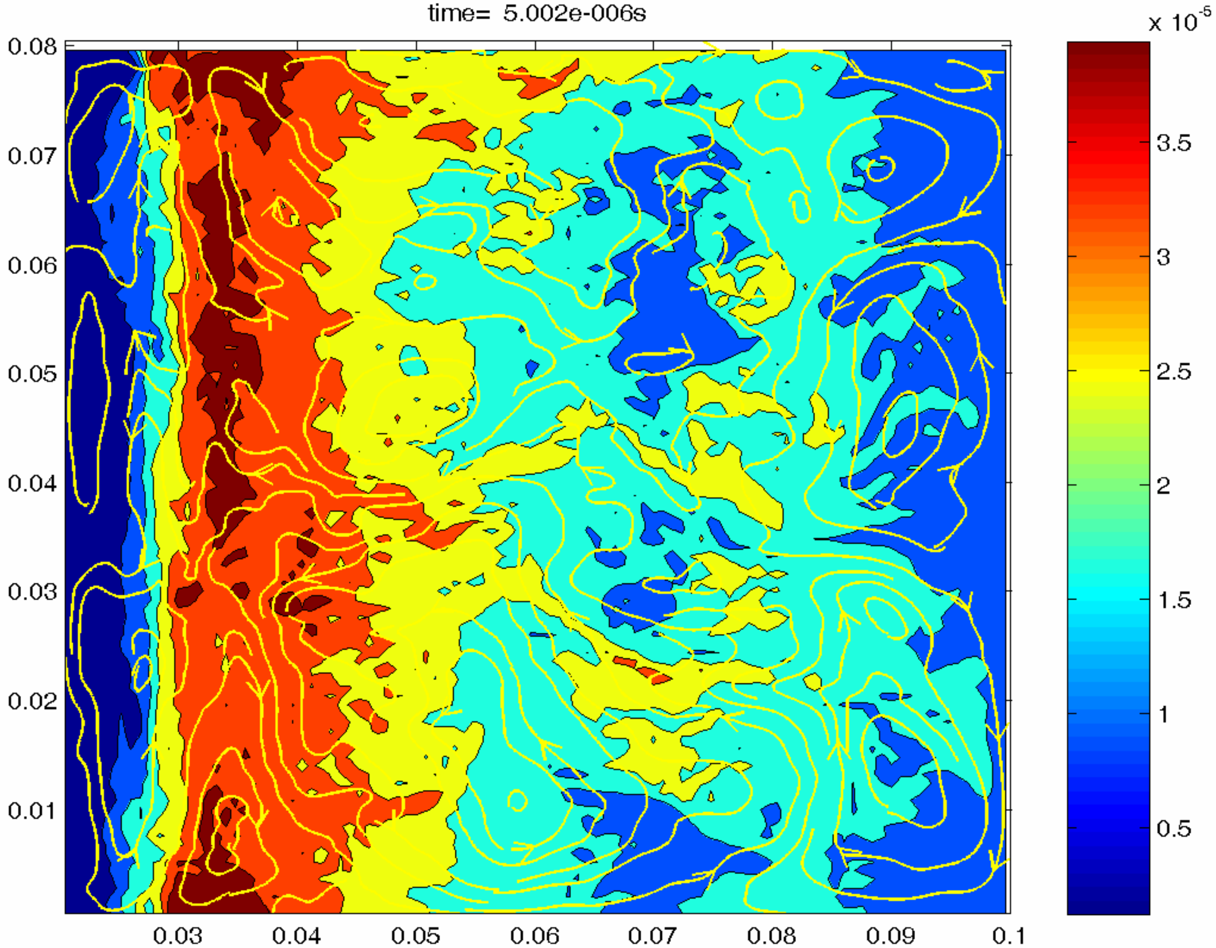
Plasma density contours (color) and velocity streamlines



Last moment of interchange before chaotic mixing; Mass contours and velocity stream lines

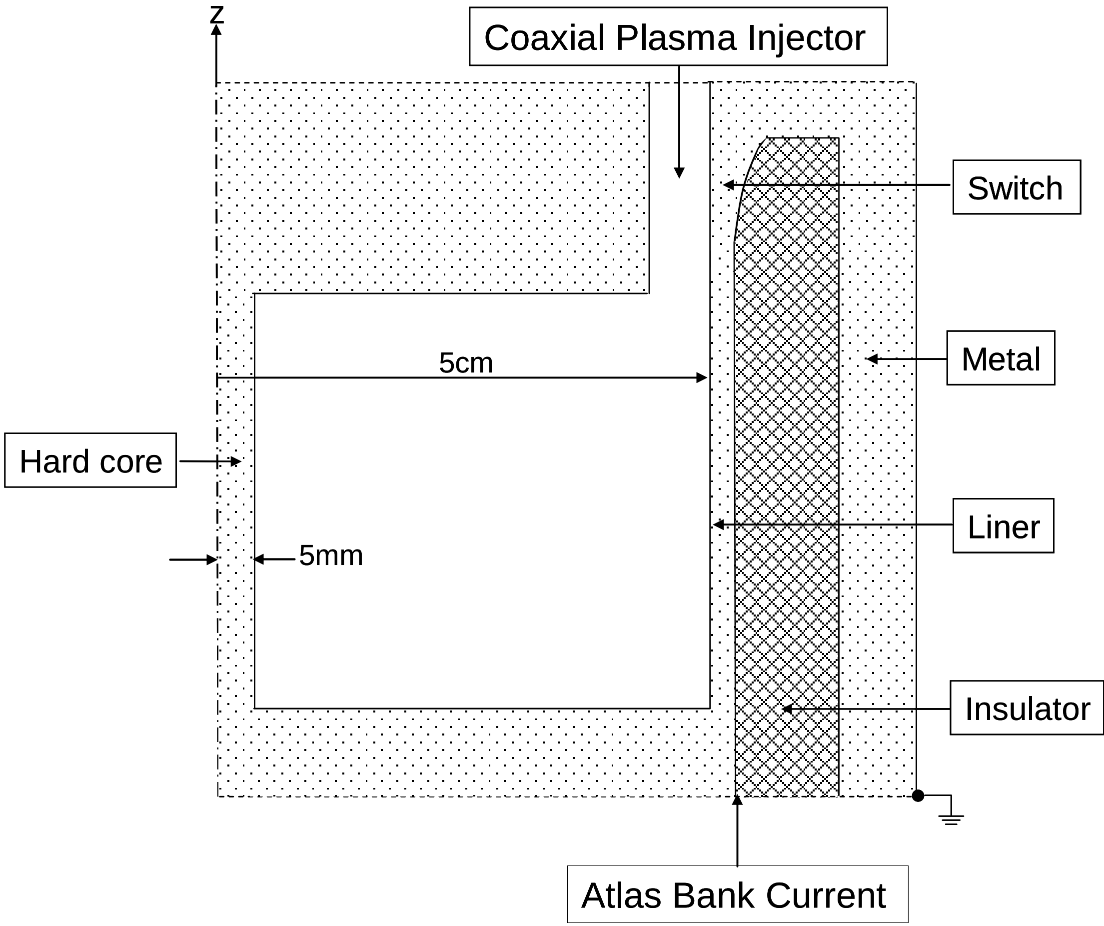


Chaotic mixture after interchange; mass contours and velocity stream lines

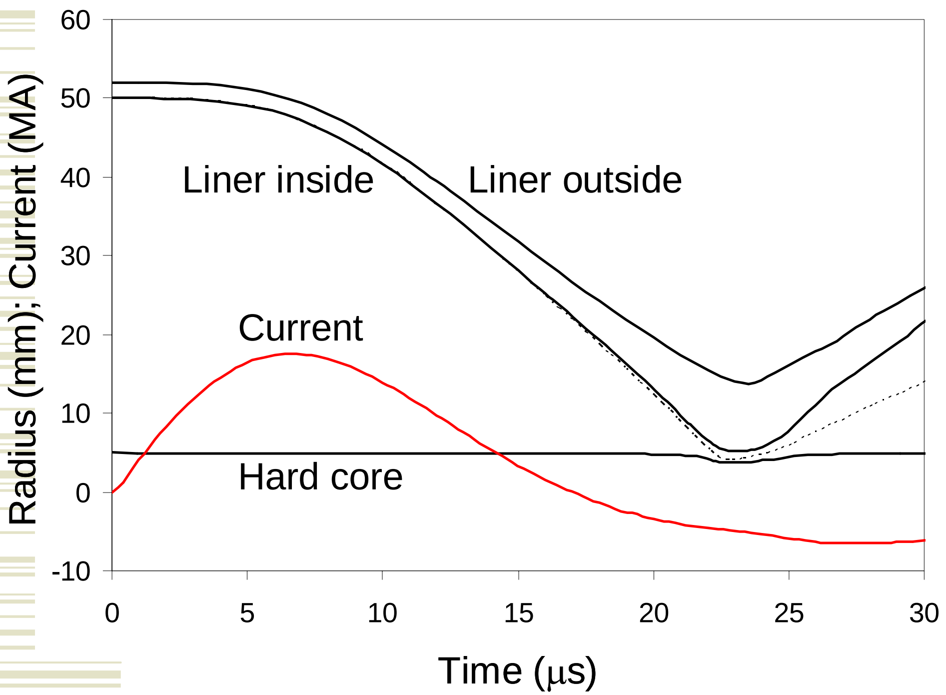


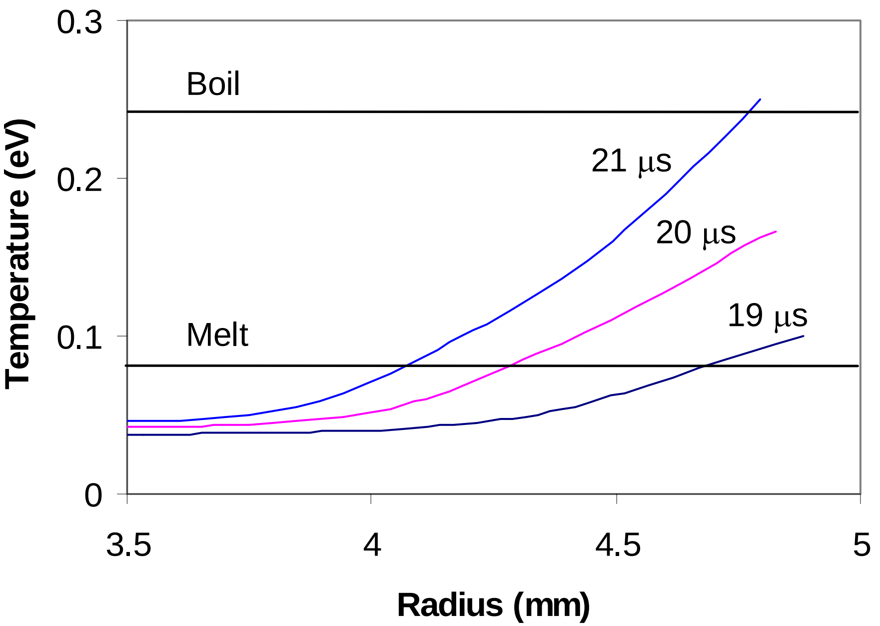
Diffuse z pinch target on Atlas

- **Plasma injector and Atlas Bank are separate electrical circuits**
- **Coaxial injector could be a MAGO device or a Marshall Gun type accelerator**
- **Liner region labeled "switch" causes the plasma injection gap to close at the beginning of liner compression**
- **After switching action plasma with flux is trapped in a toroidal chamber surrounding the hard core, and compressional heating occurs as the liner implodes.**



Liner driven by Atlas (Raven 1D code)





Initial liner 50-mm radius, 10-cm long, 2-mm thick

Surface of hard core reaches boiling temperature just before time of maximum compression

2D MHRDR simulation results

--compressible two-fluid model

--Braginskii coefficients of thermal conduction and electrical resistivity.

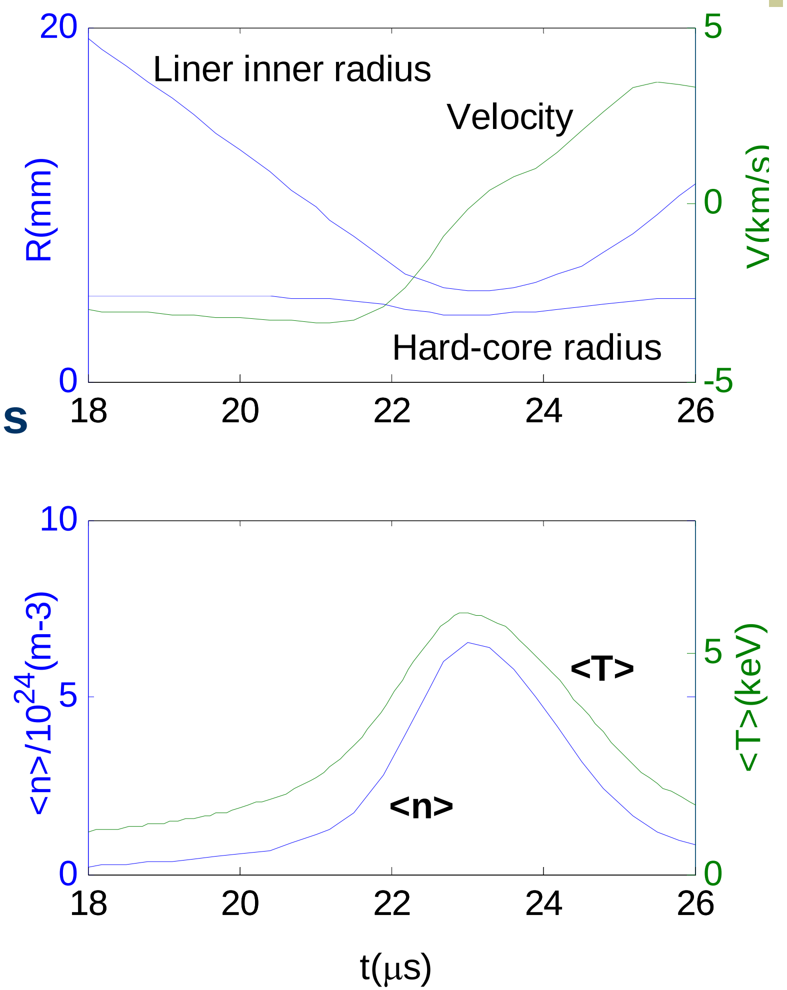
--Ohm's law is *E*+vx*B* = η*j*

-- No Hall terms or thermoelectric terms such as Nernst current included.

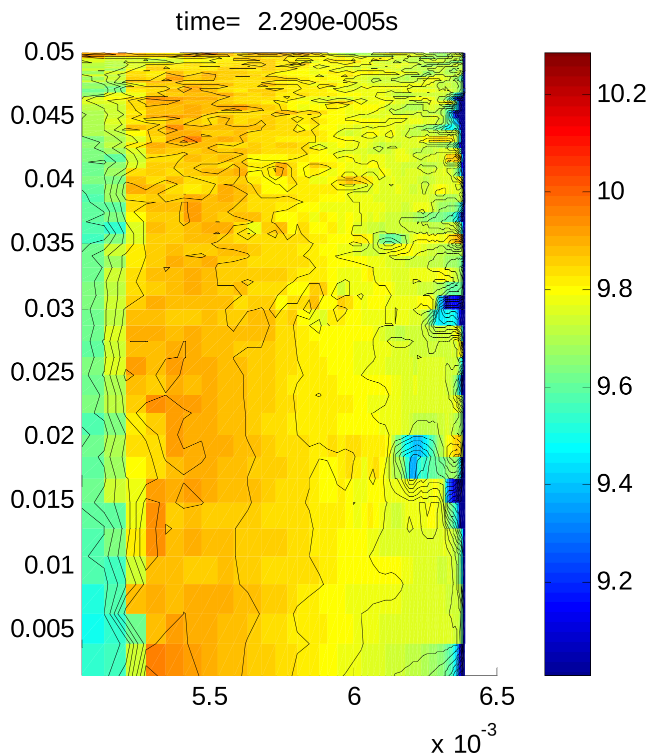
Neutrons ~ 4×10^{12}

Excellent diagnostic

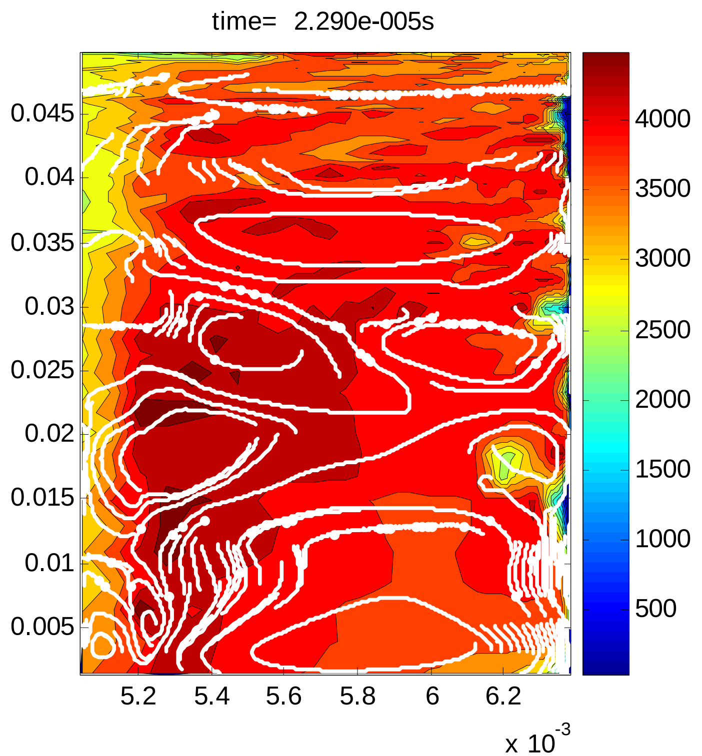
See Siemon *et al.*, Nuclear Fusion, to be published (2005).



Compressed plasma turbulent structure



Pressure contours

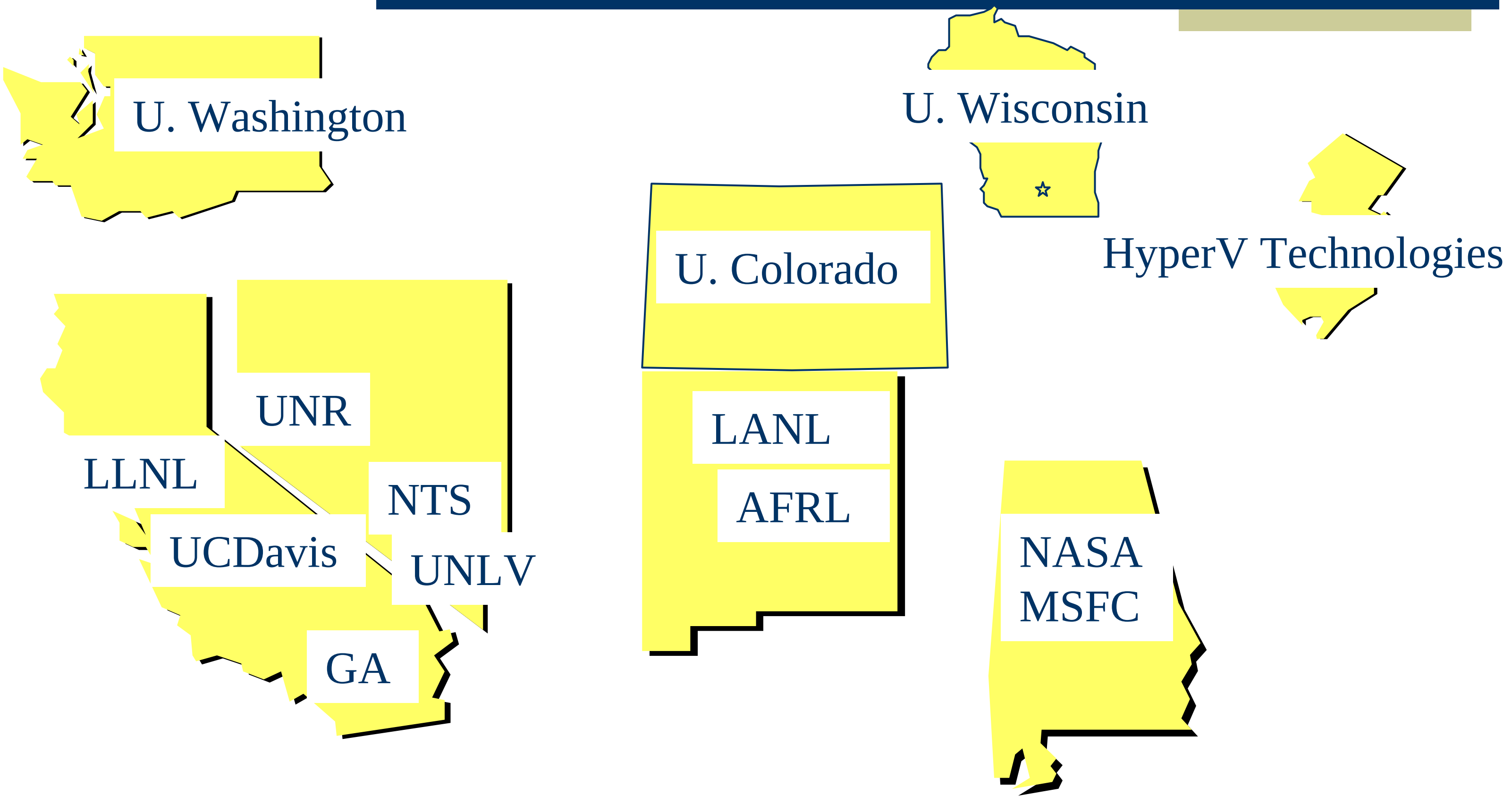


Temperature contours & white streamlines

Issues that need study

- Modeling of plasma formation process by MAGO or other coaxial generators is needed.
- Transport modeling should include estimates for Bohm microturbulence, wall-plasma interaction, sheath physics, and radiation from impurities.
- A coating of lithium on walls (optionally including dissolved hydrogen fuel) offers the possibility of low-Z contamination. Future simulations should examine radiation from a lithium-hydrogen plasma mixture.
- Hall terms and thermoelectric terms such as Nernst current (not in simulation) need further investigation.

MTF Team



Groups funded (often small) or proposing to work on MTF

Summary

- An exciting possibility to advance fusion with MTF on Atlas presents itself.
- Results from MTF exploratory experiments on Atlas and Shiva Star in the next two years will motivate a larger MTF Proof-of-Principle campaign on Atlas.
- International team is in place to do this work.
- Proposed plan has small impact upon other DP plans and resources; valuable method for recruiting DP manpower.
- The moment is right for a significant MTF initiative