Experimental design of a magnetic flux compression experiment

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Innovative Confinement Concepts Workshop
February 13-16, 2006
Austin, Texas

Abstract

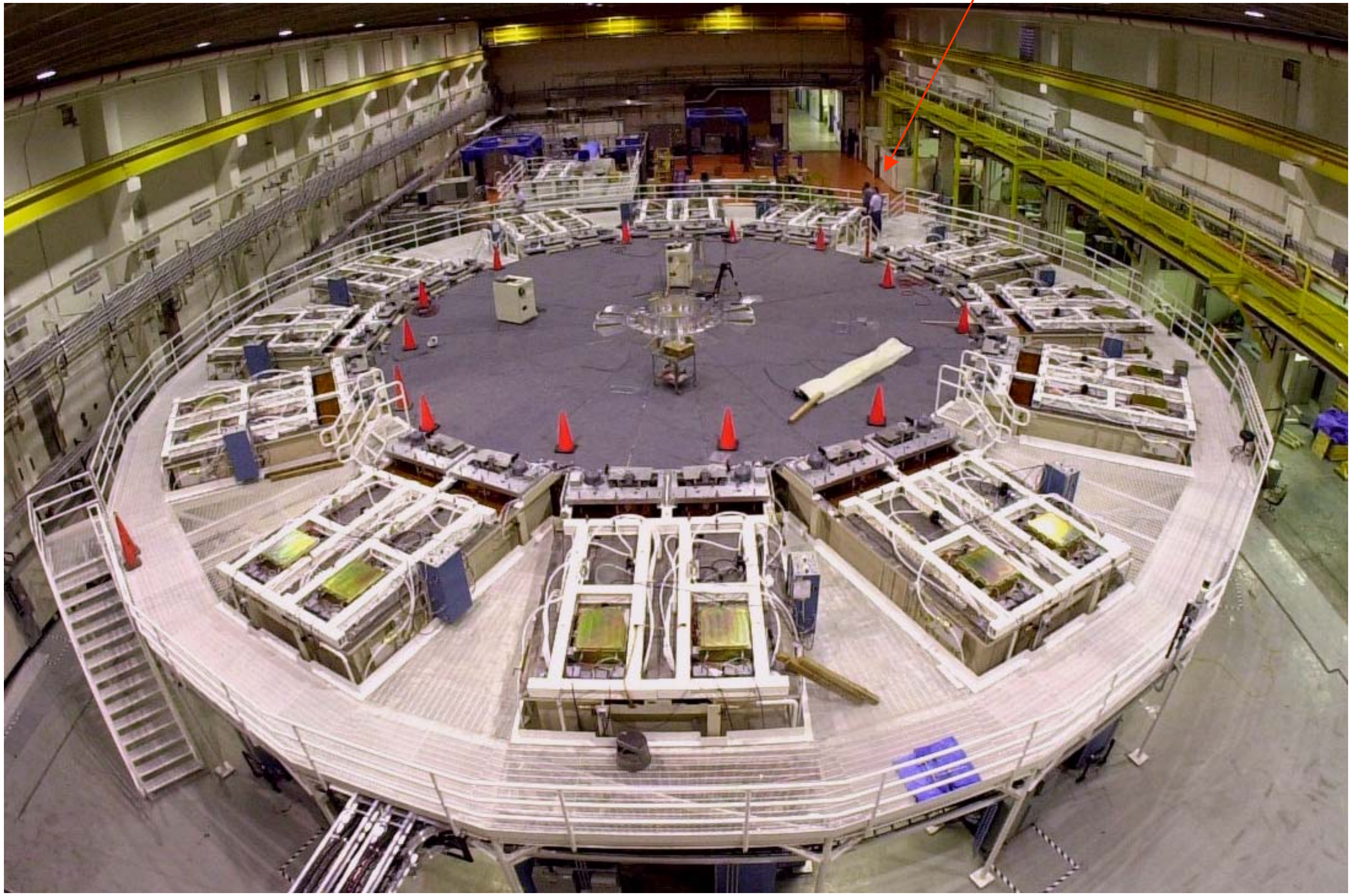
Generation of large magnetic fields is an interesting topic of high-energy-density physics, and an essential aspect of Magnetized Target Fusion. An experiment is planned on the Atlas facility at the Nevada Test Site, which will generate magnetic fields in the range of 1-5 MG. An initial toroidal bias magnetic field is provided from current on a hard-core center conductor. Current on the hard core is generated by diverting a fraction of the liner current using an innovative inductive current divider, thus avoiding the need for an auxiliary power supply. A 50-mm-radius cylindrical aluminum liner implodes along glide planes with velocity of about 5 km/s. Liner motion causes electrical closure of the toroidal chamber, after which flux in the chamber is conserved. For a typical choice of parameters, conservation of flux and realistic energy efficiency imply peak compression and liner dwell should occur with 3-mm spacing between the liner and the hard core, and 2-3 MG field depending upon efficiency. The mechanical design is performed in collaboration with Los Alamos National Laboratory using the solid modeling software 'Inventor' (AutoDesk). Diagnostics include B-dot probes, Faraday rotation, radiography, filtered photodiodes, and VUV spectroscopy. Optical access to the chamber is provided through small holes in the walls. In the MG regime, blackbody radiation is expected from plasma generated on the liner and hard core surfaces because of Ohmic heating (see adjacent poster on numerical modeling). The experimental plan includes initial tests at the AFRL using Shiva Star and then full-energy tests on Atlas.

Atlas power supply

Standard person

Summer 2005 -- began operation at Nevada Test Site

240 kV
24 MJ
~ 25 nH
30 MA



MTF experiments planned on Atlas

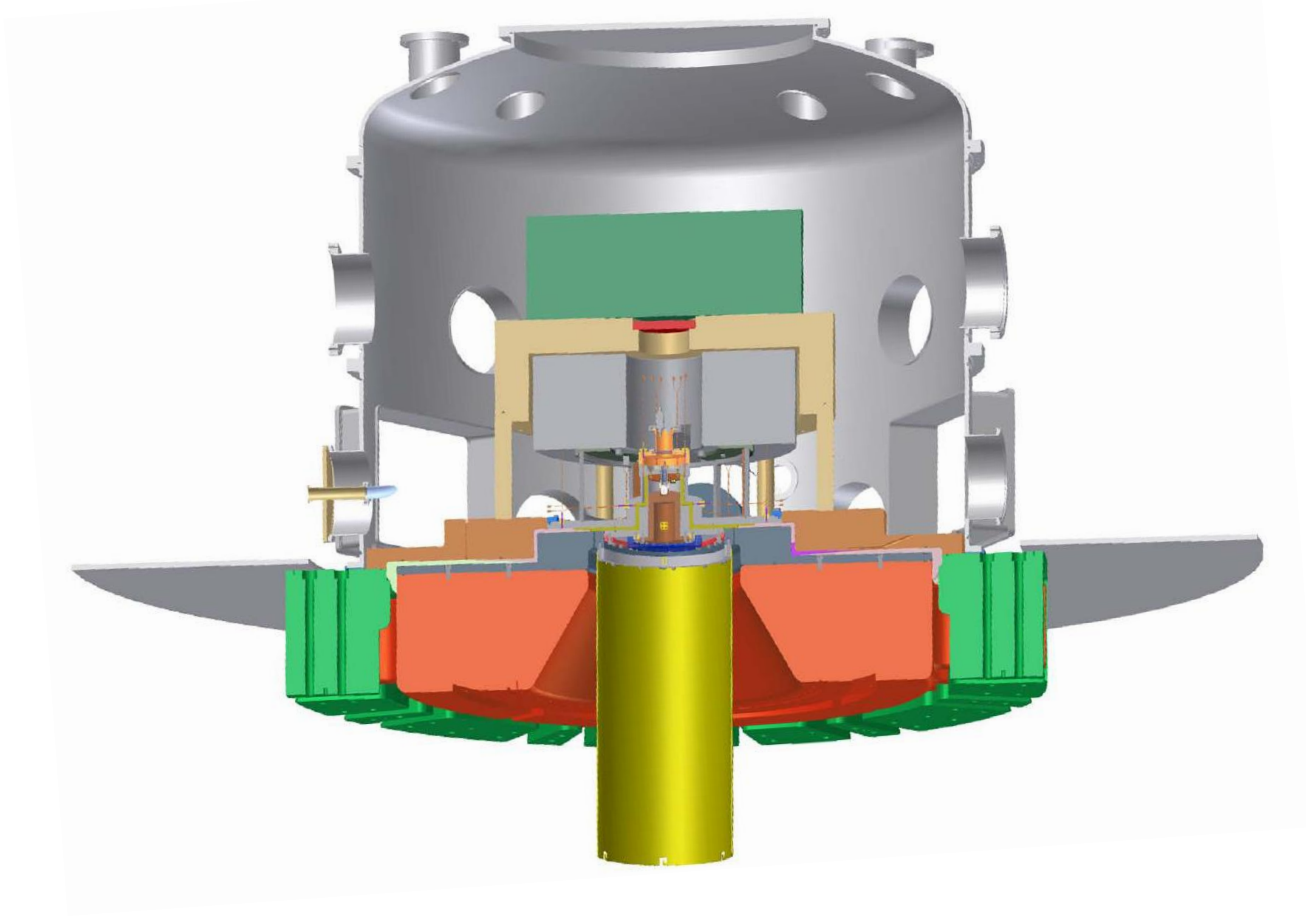
Goal:

Study compression of magnetic flux using MTF relevant pressure (MG magnetic field) in the geometry of a stabilized hard-core z pinch (MAGO-like geometry)

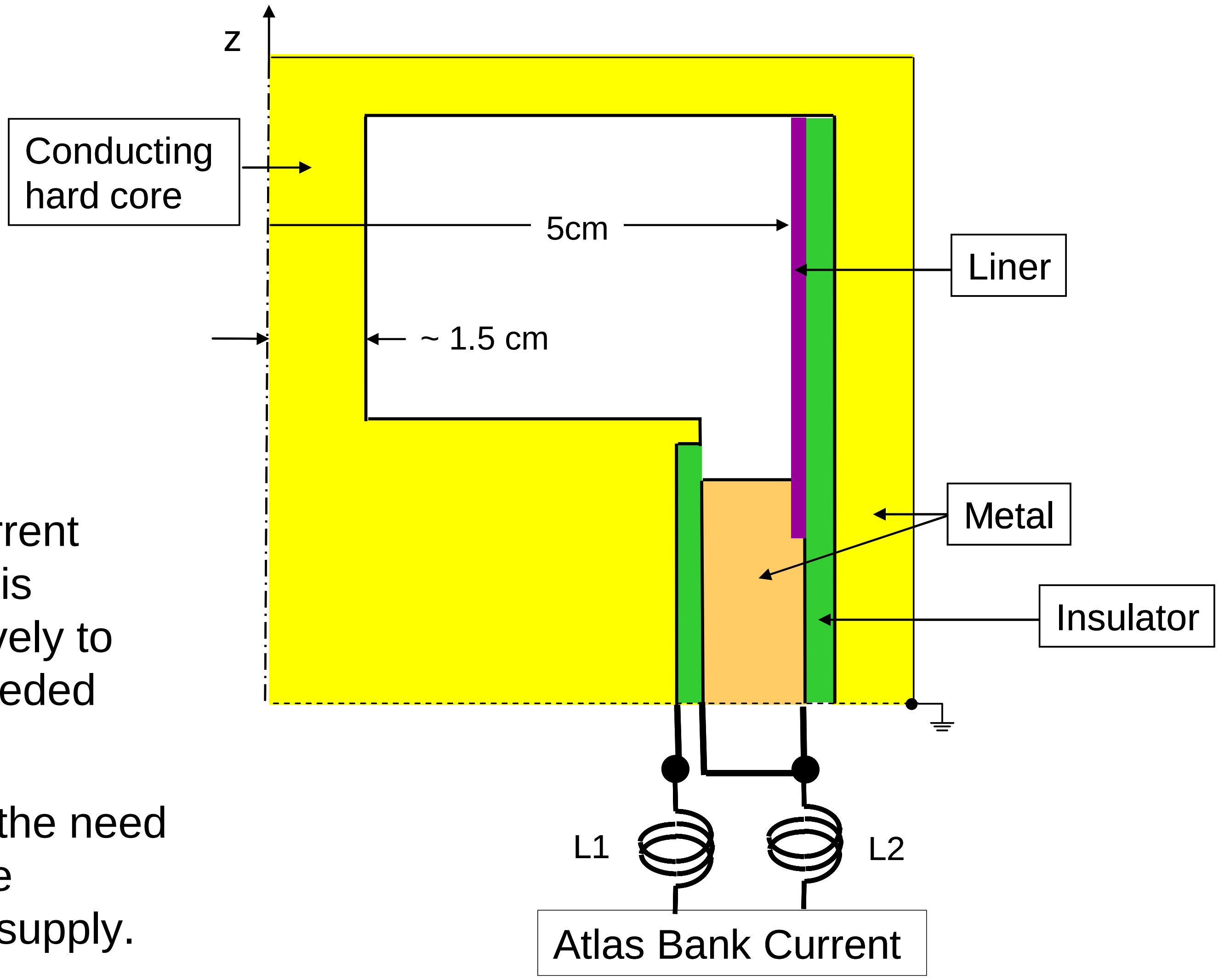
Specific objectives:

1. **Observe magnetic compression inside a glide-plane liner system (Does sliding joint have low resistivity?)**
2. **Determine efficiency limitations that result from resistivity and finite compressibility of aluminum material (Is ~ 50% efficiency realistic?)**
3. **Study effect of Raleigh-Taylor instability on flux compression (Is magnetic field compressed to high values inside RT "bubbles" ?)**

Atlas confinement chamber with typical liner experiment



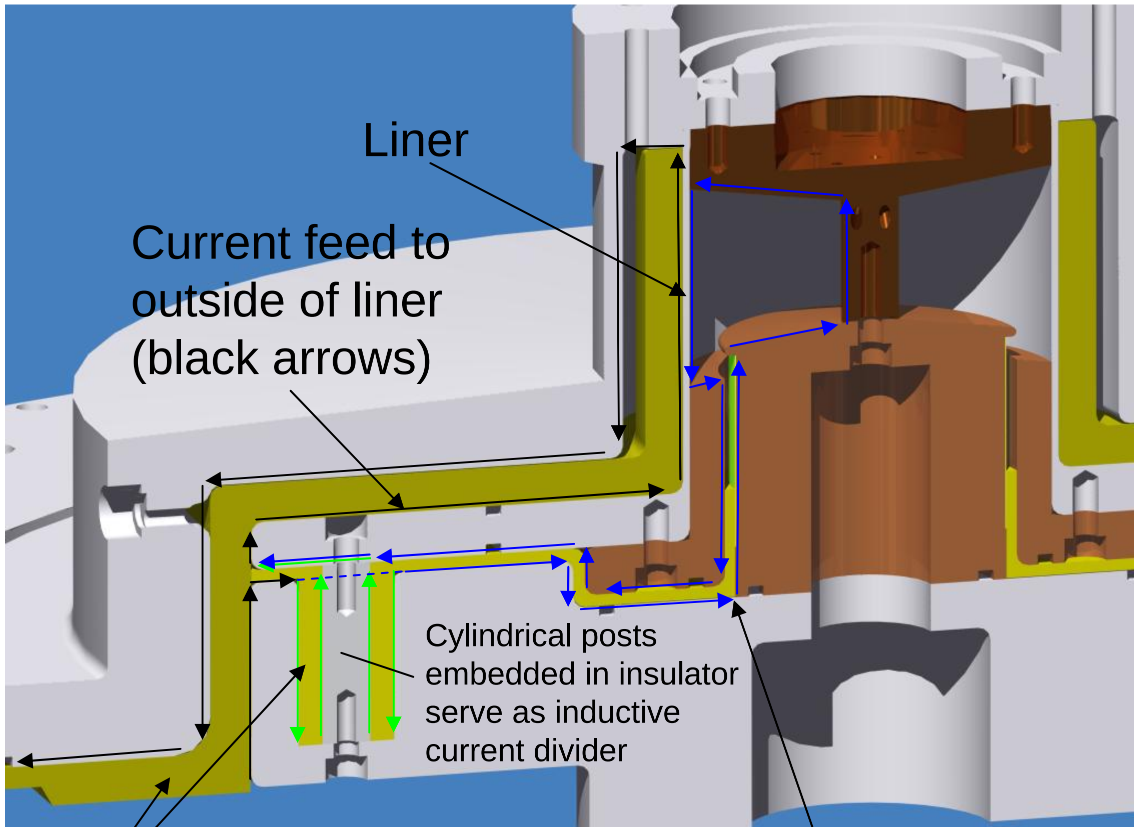
Concept – Inductive current divider



Part of Atlas current driving the liner is diverted inductively to generate the needed initial flux

This eliminates the need for an expensive auxiliary power supply.

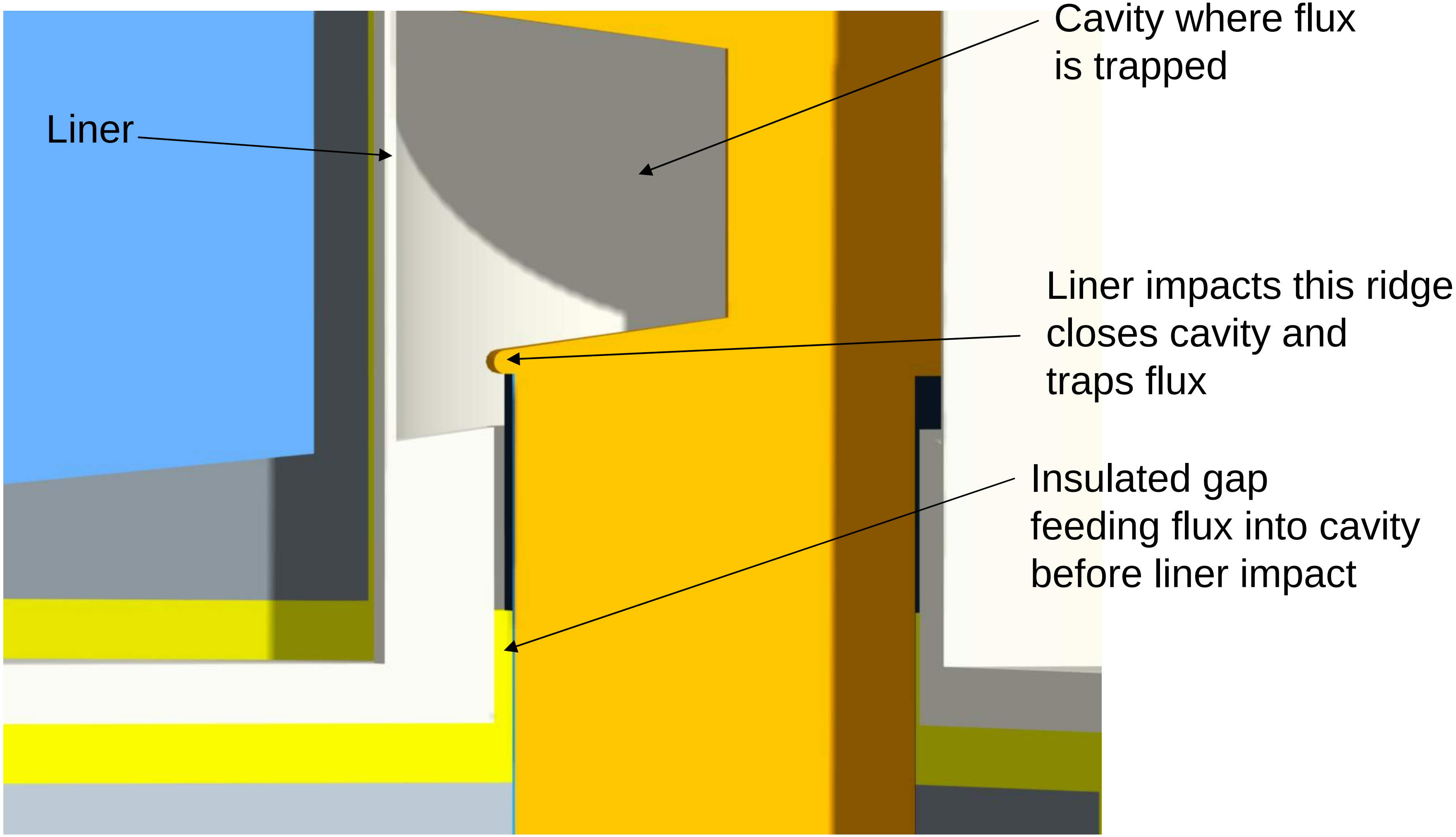
Inductive divider directs about 1/10 of Atlas current to inner cavity to create trapped flux



Insulator (yellow)

Current feed to inner cavity (blue arrows)

Detail view of cavity where flux is compressed



We calculate the maximum current that can be carried by a cylindrical post.

The yield strength of tungsten is about 1000 MPa. This corresponds to a maximum magnetic field $B_{max} = \sqrt{2\mu_0 p_{max}} = 50T$ for the current carrying post. Then the maximum surface current per cm carried by that post is:

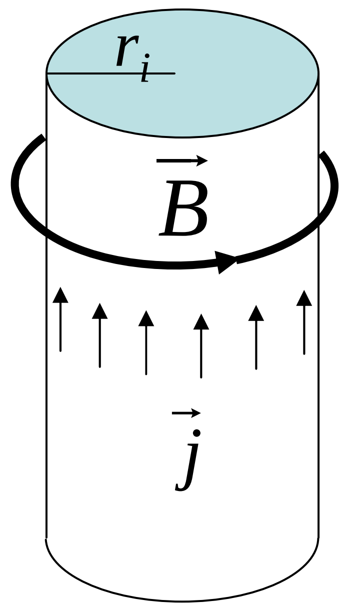
$$\oint \vec{B} d\vec{s} = \mu_0 \int \vec{j} d\vec{a}$$

$$B 2\pi r = \mu_0 I$$

$$\sigma_{max} = \frac{I}{2\pi r} = \frac{B_{max}}{\mu_0}$$

$$\sigma_{max} = 400 \frac{kA}{cm}$$

Maximum current per cm

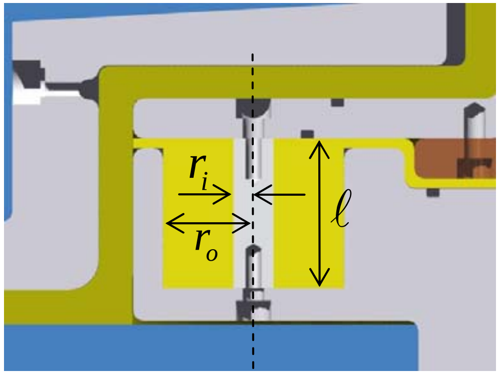


Post dimensions:

$$\ell = 47.5mm$$

$$r_o = 28.6mm$$

$$r_i = 6mm$$



We calculate the inductance for the liner cavity and the posts

The maximum Atlas current is 20MA, 90% of which will be carried by the inductive divider posts:

Required min. number of posts:

$$n_p = \frac{0.9*20MA}{2\pi r_i \sigma_{\max}}; \qquad n_p = 11$$

We choose 12 posts; then the total inductance of six posts is:

$$L_p = \frac{\mu_0 \ell}{2\pi n_p} \ln(\frac{r_o}{r_i})$$

$$L_p = 1.72nH$$

The inductances of the current paths are:

$$L_{cp1} = .83nH, \qquad L_{cp2} = .95nH$$

The inductance of the liner inner cavity is:

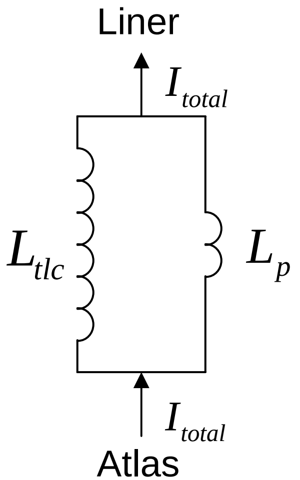
$$L_{lc} = \frac{\mu_0 \ell_{lc}}{2\pi} \ln(\frac{r_2}{r_1});$$

$$\ell_{lc} = 40mm, \; r_2 = 50mm, \; r_1 = 14mm$$

$$L_{lc} = 11.2nH$$

The current divider passes 10% of the Atlas current through the liner cavity

The inductances of the posts and the liner cavity are dividing the current.
The fraction of current passing though the liner cavity is given by:



$$L_{tlc} = L_{lc} + L_{cp1} + L_{cp2} = 12nH$$

$$Ratio = \frac{I_{lc}}{I_{total}} = \frac{L_p}{L_{tlc} + L_p} = 10\%$$

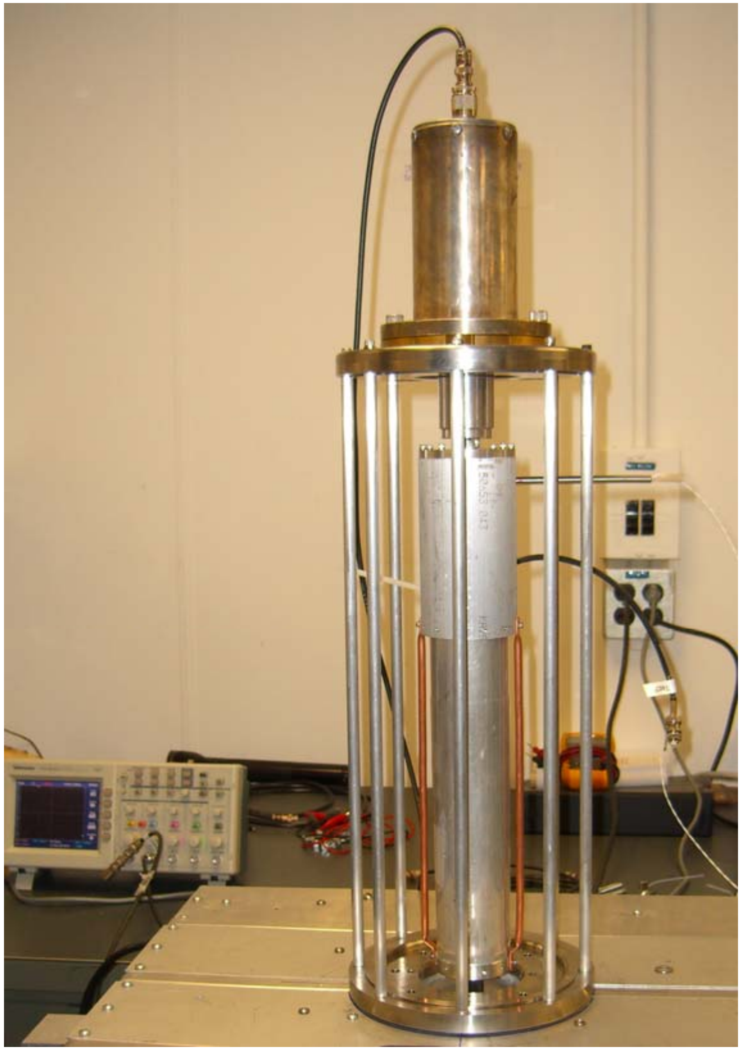
In this configuration about 10% of the Atlas current will be diverted to the inner cavity of the liner.

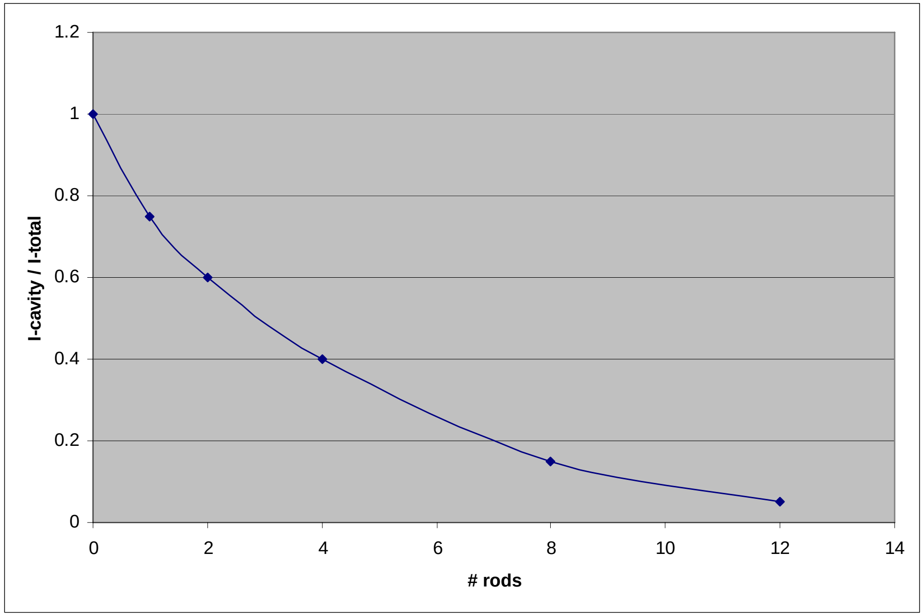
Experimental facility to test magnetic probes and inductive dividers

Constructed by graduate student Tom Awe

20 kV, 10 kA, $\tau_{1/4}$ ~ 700 ns

Inductive divider test





Data prove that inductive divider is readily constructed to give desired current of ~ 1/8 total.

Gap size for switching

Optimum switching is at peak Atlas current. Allows minimum diversion of Atlas current to generate maximum trapped flux. Initial current rise is almost linear in time, which results in displacement increasing as t^4 . During the quarter period rise time of a sinusoidal current we can estimate the liner displacement as follows:

$$dR = \frac{\mu_0}{4\pi} \frac{I_{\max}{}^2 \tau_{1/4}{}^2}{8R\mu}$$

Eg., when Imax = 20 MA, quarter period is 6 microseconds, mass per unit length is 1.7 kg/meter, and initial radius is 5 cm, we have dR of about 2 mm at time of peak current.

Summary

- Atlas offers an exciting possibility to advance the understanding of high-energy-density metal liners with application to MTF
- An inductive current divider has been modeled for passing 10% of Atlas current into the liner cavity.
- Experiments are a collaboration between Los Alamos National Laboratory, Air Force Research Lab, and the University of Nevada, Reno