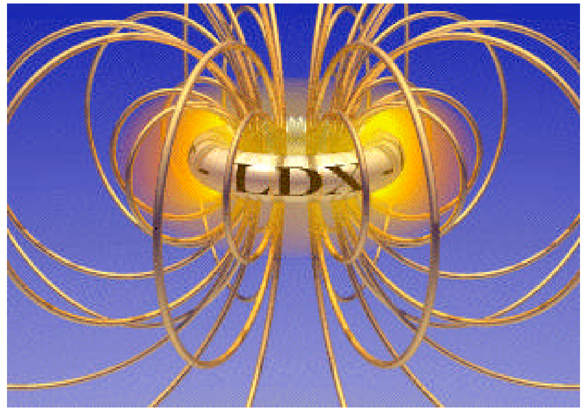


Plans for initial operation of the Levitated Dipole Experiment

A.K. Hansen, D.T. Garnier, M.E. Mauel, E.E. Ortiz – *Columbia University*

Columbia University

J. Kesner, A. Boxer, S. Dagen, J. Ellsworth, I. Karim– *MIT PSFC*

S. Zweben – *PPPL*

PPPL

PSFC

Poster KP1.115 Presented at the 44th Meeting of the American Physical Society, Division of Plasma Physics

Orlando, FL, November 13, 2002

Abstract

The goals of initial experiments of the Levitated Dipole Experiment (LDX) are to establish reliable operation of the superconducting coils during plasma experiments and to provide a physics baseline for following experiments. As appropriate for a first-of-a-kind experiment, LDX will be operated in a staged manner, with systems added progressively. To insure safety during initial experiments, the dipole coil will be mechanically supported rather than levitated. The initial RF heating will be 3 kW at 6 GHz, and the second, 10 kW at 10.5 GHz, source to be added soon afterwards. In order to remove impurities before first plasma, as well as between experimental operations, a glow discharge cleaning system is being constructed. The base-case diagnostic set includes external equilibrium magnetics and internal Mirnov coils, an emissive electrostatic probe, an X-ray pulse-height analyzer, and a microwave interferometer. In addition, an X-ray imaging camera will be provided through a collaboration with PPPL.

This work was supported by USDOE OFES.

What's New

- The systems required for initial operation of LDX are being made ready.
- Construction of the initial set of diagnostics is underway.
  - Varying stages of readiness.

Outline

- Operations Systems
  - Lifting fixture
  - ECRH
  - Helmholz coils
- Diagnostics
  - Magnetics
  - Electric probes
  - X-ray camera
  - Interferometer

Operations Systems

Lifting Fixture

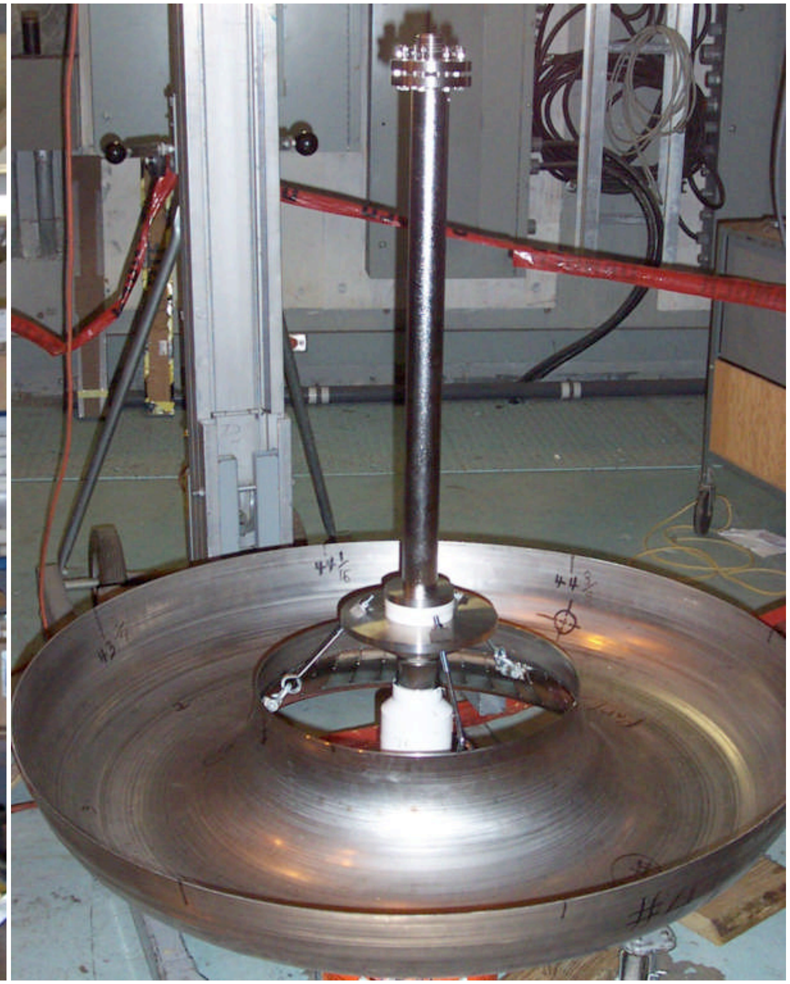
LDX will first operate with a supported internal coil.

- Allows for plasma operation while levitation and feedback systems are made ready.
- There will be enhanced losses on field lines that intersect the supports.
  - The support is designed to minimize interactions, however.
- The supported mode provides a benchmark with which confinement by a levitated coil may be directly compared.
  - Note: there is an X-point when the coil is levitated, which is absent in supported operation.
    - This is only the case when the coil is levitated from the top.

The supported dipole campaign will provide the physics baseline for LDX.

- Low density, quasi steady-state plasmas formed by multi-frequency ECRH with mirror losses.
- Areas of investigation:
  - Plasma formation
  - Density control
  - Pressure profile control
  - Characterization of equilibrium
  - Supercritical profiles & instability
  - Compressibility scaling
  - ECRH and diagnostics development

The support is designed to make a minimal perturbation to the plasma.



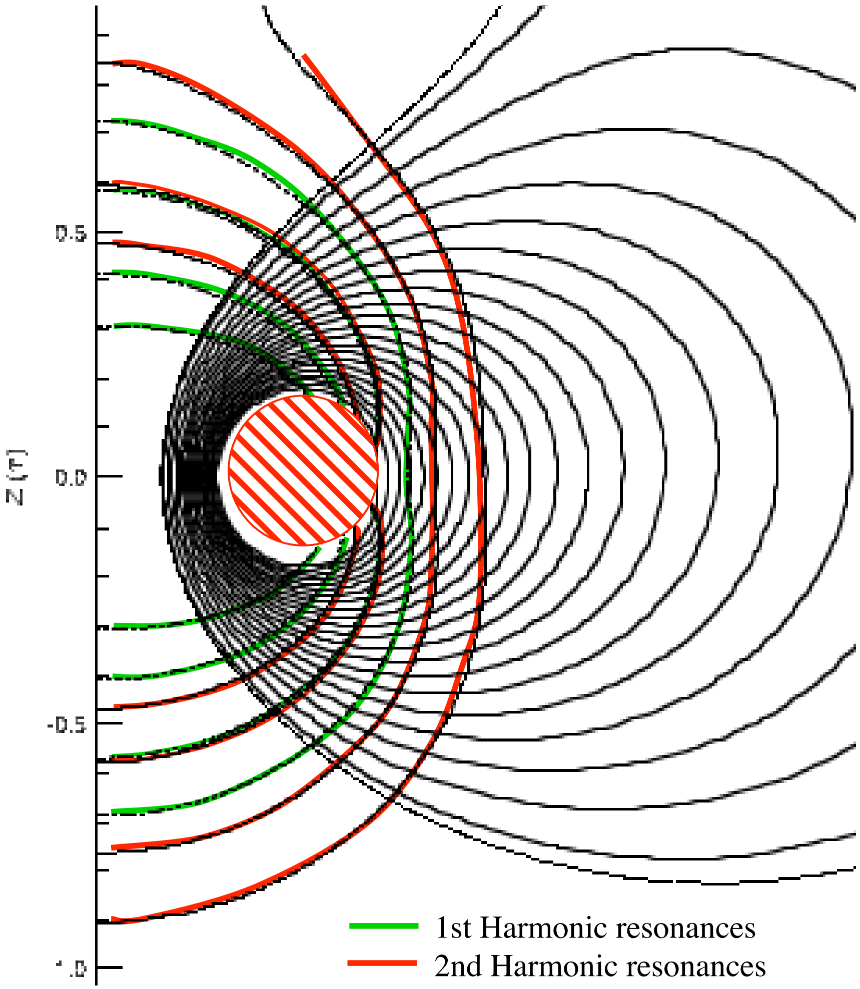
- The floating coil rests on a conformal ring.
- Field lines close to the coil intercept the lifting fixture at the struts.
- Shown:
  - Support loaded with shell of same minor radius as the floating coil
  - Struts shown are not the real ones that will be used.
    - 1” wide shields

ECRH

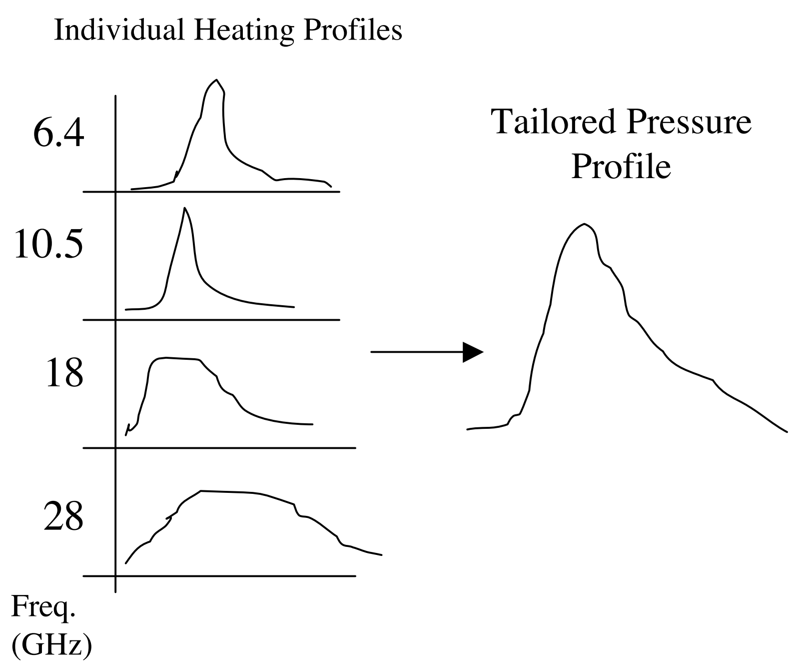
Using multiple frequencies of electron cyclotron heating provides a mechanism for pressure profile control.

- Use multiple sources with different resonant zones to tailor the pressure profile to marginal stability.
- Results from the SM-1 symmetric mirror:
  - Multiple frequency electron cyclotron heating with large frequency separation.
  - Elimination of low frequency fluctuations in cold electron population with multiple sources.
  - Order of magnitude increase in stored energy in hot electrons.
    - B. H. Quon, R.A. Dandl, W. DiVergilio, G. E. Guest, L.L. Lao, N.H. Lazar, T.K. Samec and R.F. Wuerker, *Physics of Fluids* **28**, 1503 (1985).
- Results from CTX supported dipole:
  - Hot electron interchange mode “bursts” with only one source.
    - D. Maslovsky, invited talk QI2.004 (Thursday morning).

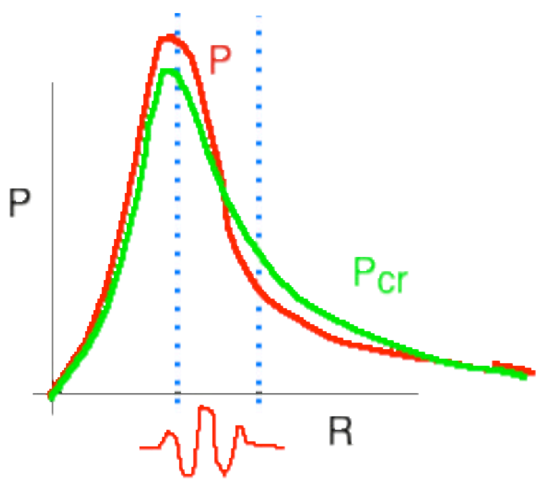
The pressure profile can be controlled via the multiple resonances.

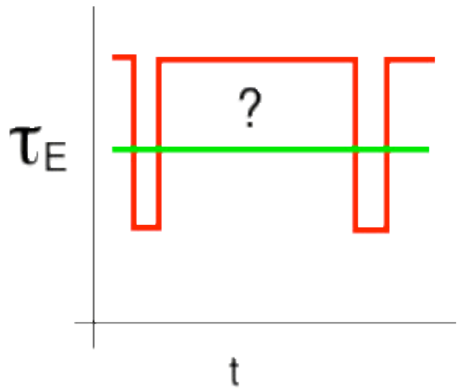


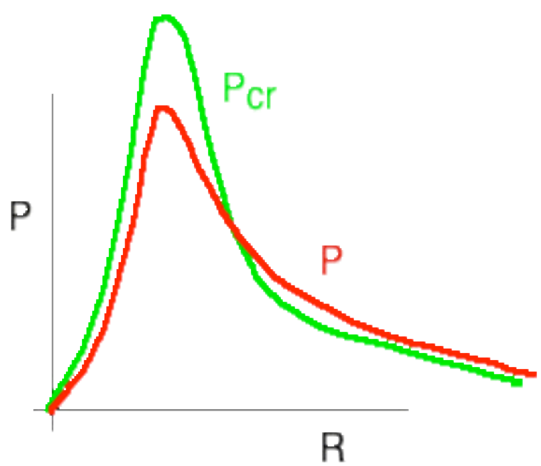
- Effective way to create high-□ hot electron population.
- Measure single frequency response.
  - X-ray pulse-height analyzer
  - X-ray camera (collaboration with S. Zweben, PPPL)
- Tailor multi-frequency heating power to produce ideal (stable) pressure profile with maximum peak □.

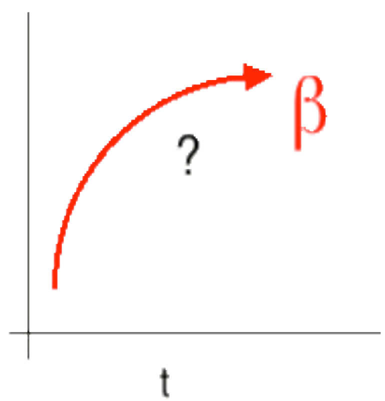


Instabilities and confinement can be investigated with ECH.





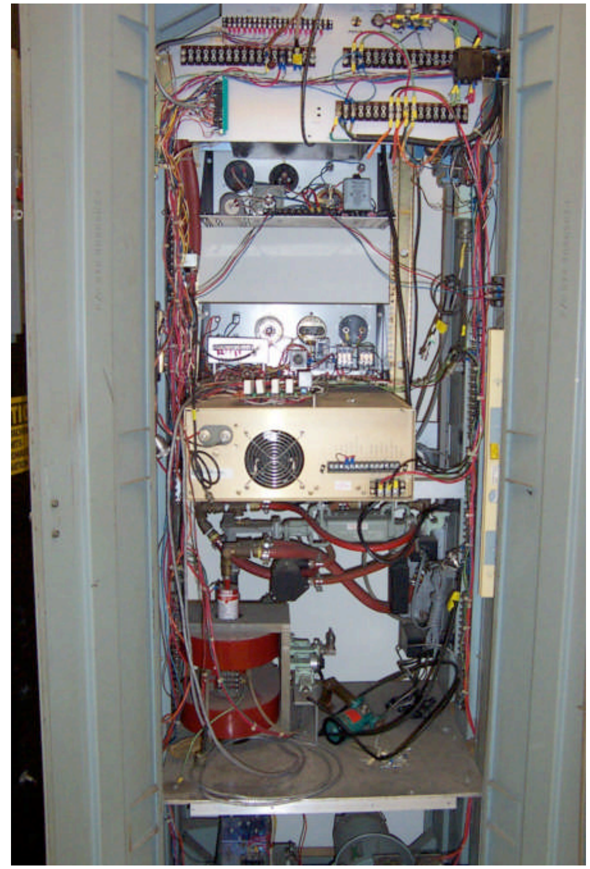




- Instability should exist when: $p' > p'_{critical}$.
- Investigate nature of instability.
  - How does it saturate?
  - How much transport is driven?
- Maximize β when: $p' < p'_{critical}$ everywhere
- What is maximum attainable β and what is limit?

The initial ECRH sources will be at 6.4 and 10.5 GHZ

6.4 GHz
(3.3 kW)



10.5 GHz
(10 kW)

- The 6.4 GHz supply is currently operable.
- The 10.5 GHz system requires a few additional components and testing.

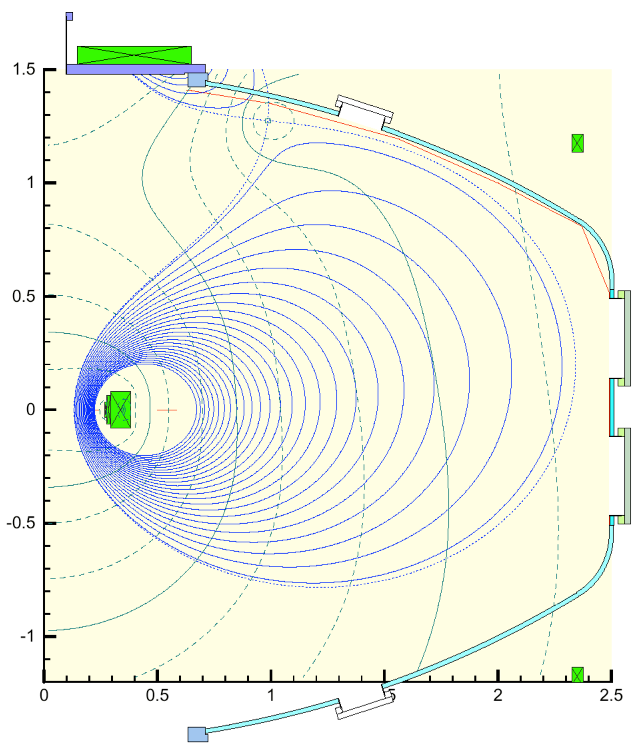
Helmholz Coils

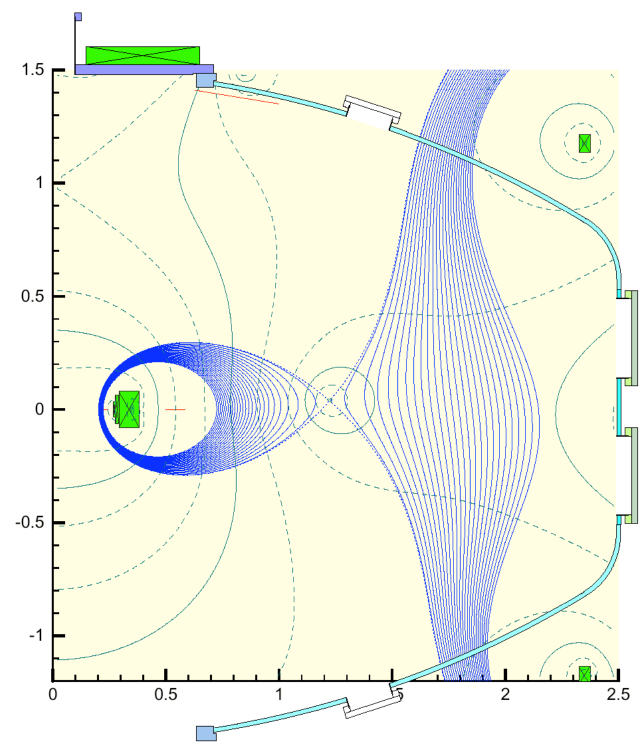
A Helmholz coil pair will be used to change the plasma volume.

$$\frac{P_{core}}{P_{edge}} \approx \left(\frac{V_{edge}}{V_{core}}\right)^{\gamma} \text{ where } V \equiv \oint \frac{d\ell}{B}, \text{ and } \gamma = 5/3$$

Helmholtz Coil Current:	0 kA
Vedge/Vcore:	228
Pcore/Pedge:	8500

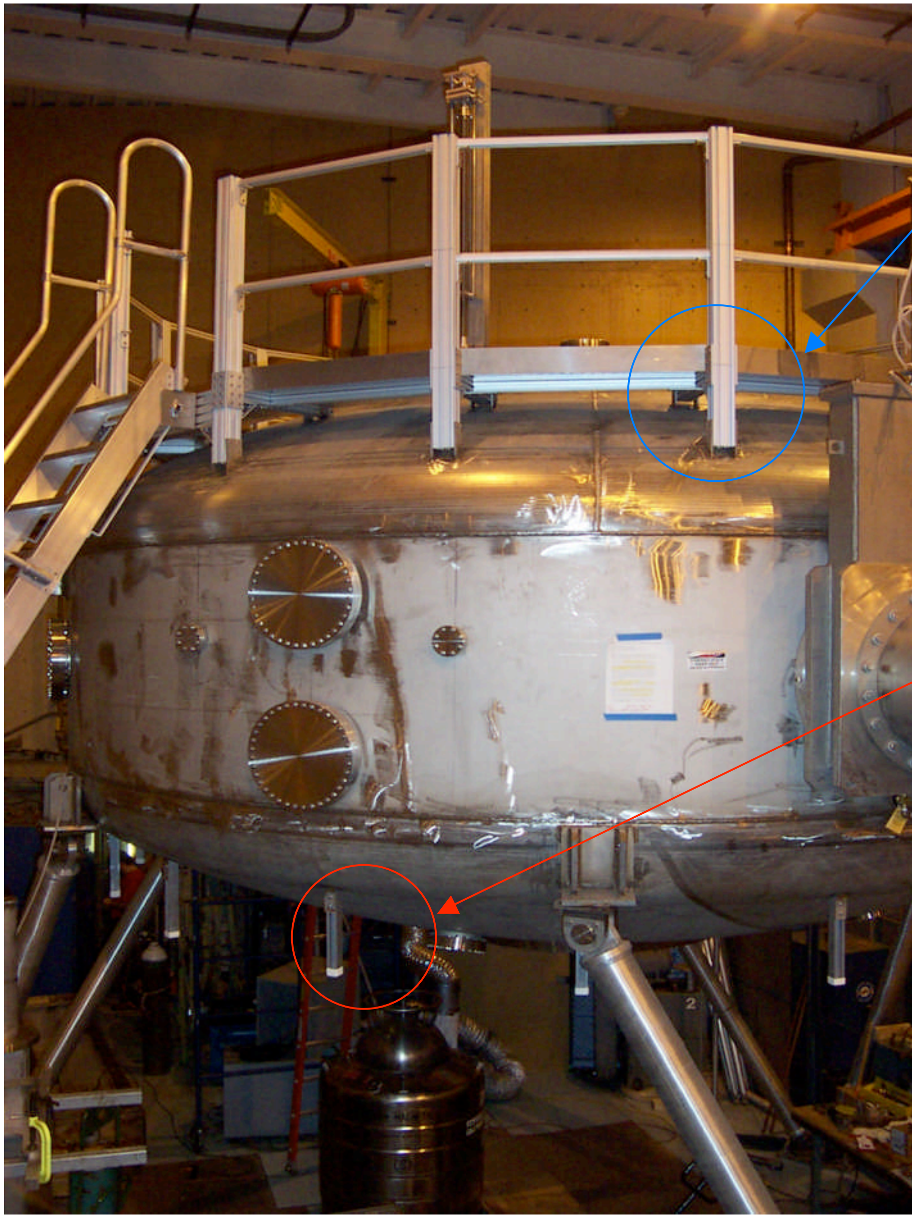
Helmholtz Coil Current:	80 kA
Vedge/Vcore:	14
Pcore/Pedge:	85





Compressibility can be adjusted to change marginal stable pressure by factor of 100!

Vertical support elements for the Helmholz coils have been attached to the vacuum vessel.



- The upper supports are also supports for a guardrail for the walkway on top of the vacuum vessel.
  - This walkway provides access to ports on top of the vacuum chamber as well as to the levitation coil.
- The lower supports are independent.
- The coil will be 16 turns of copper wire.
  - Not technologically challenging!
- In addition, the coil will provide a vacuum magnetic field to use in recalibrating the sensor coils in situ after they are installed.

Glow discharge cleaning

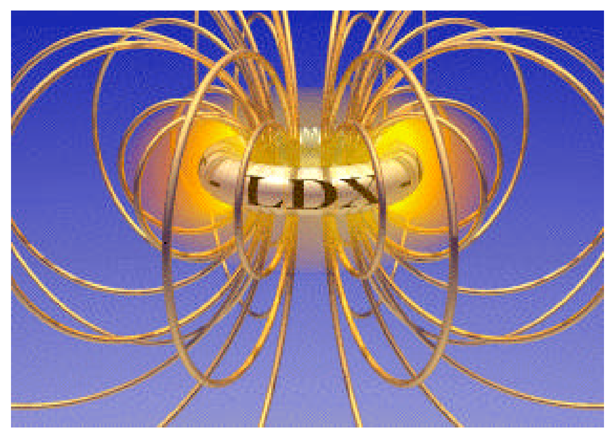
- **See poster GP1.029, S. Dagen *et al.*, Tuesday afternoon**

Importance of GDC for LDX

- LDX requires pure hydrogenic plasma--> experimental objective is to examine limits of stability in high pressure (high β) plasmas

  Large volume of plasma and limited power availability both limit the pressure obtainable in LDX
- Impurities on the interior of LDX vessel wall (such as oxygen, nitrogen, etc.) ejected into confined plasma by plasma and neutral bombardment

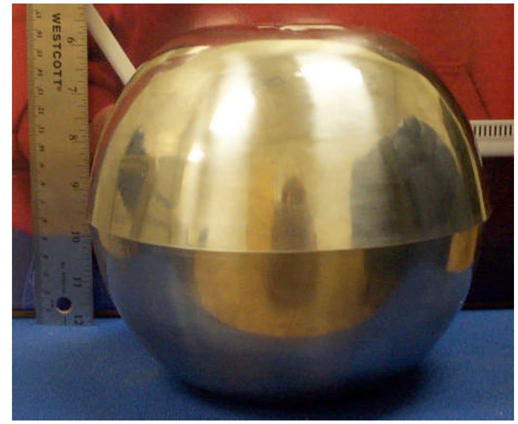
- Ejected atoms radiate power, causing the plasma to cool
- Impurities can dissipate power enough to severely lower confined plasma pressure
- Thus, LDX vessel must be free of impurities to obtain experimental objective!



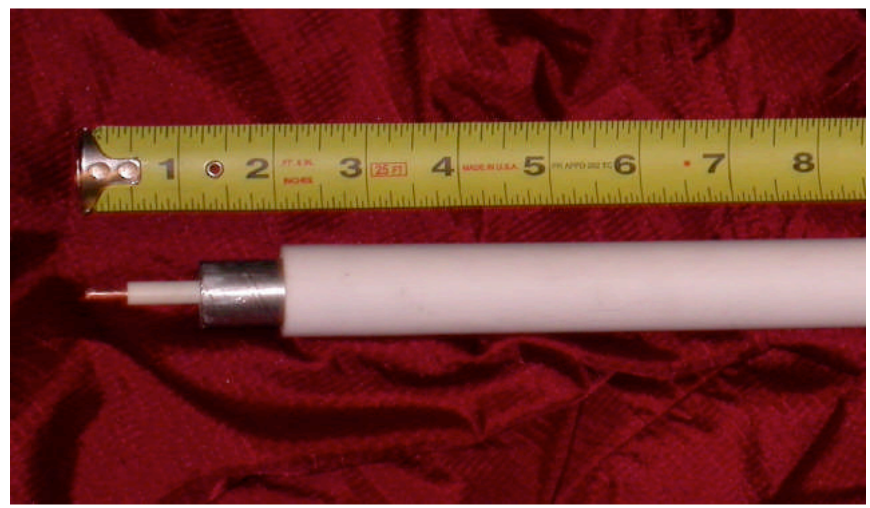
GDC Anode Probe

Anode Support Shaft

- **Biggest concern in design: arcing!**
- **Shaft design takes into careful account possibility of arcing**
- **1/8” copper conductor shielded with 1/4” OD alumina tube**
- **3/4” OD stainless steel main support rod shielded with 1”OD, 40” long alumina tube**
- **Steel rod is welded to a blank flange at lower end**
- **Shaft housed in bellows mechanism for insertion and retraction of GDC probe**



•Stainless steel anode inserted into vacuum vessel for GDC



•View of shaft upper end-- will go inside probe

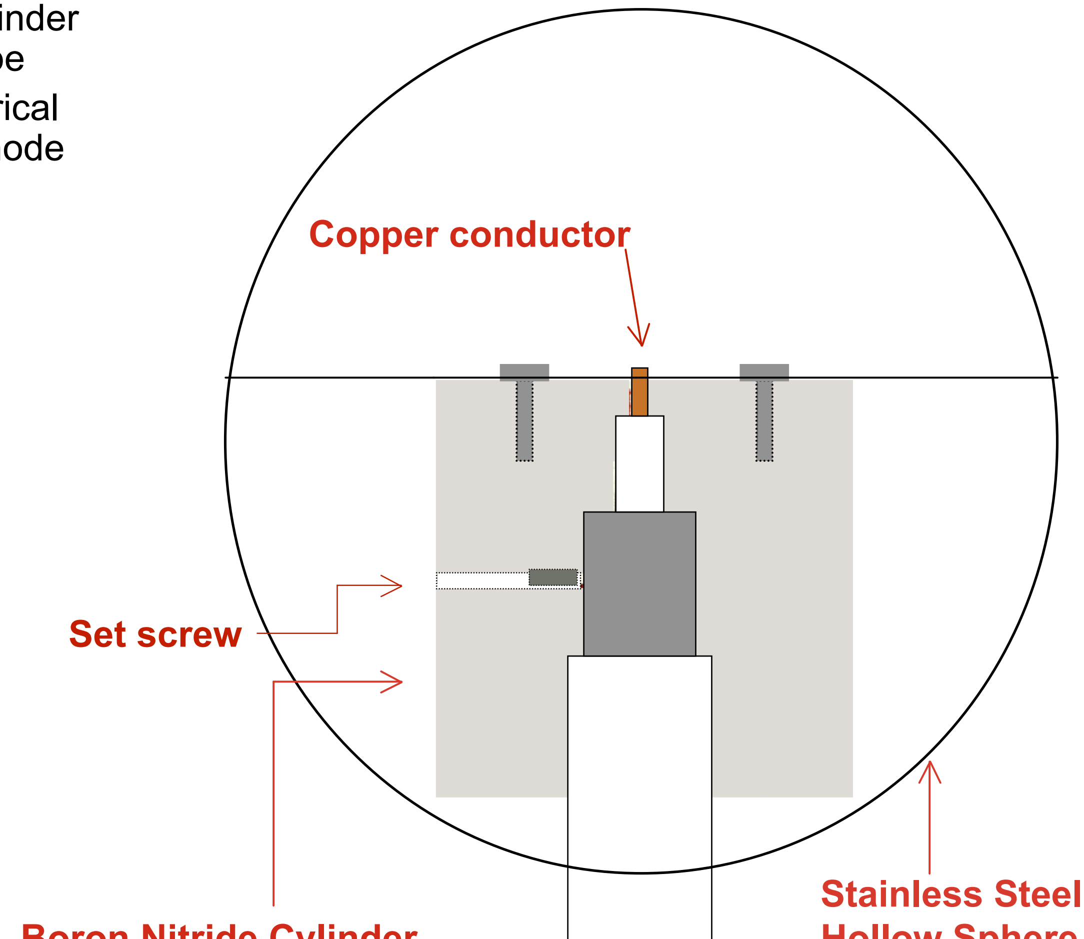
•Provides power to anode via copper wire- copper wire is attached to the inside of anode

Inside Anode Probe

- Key to inside of probe is boron nitride cylinder
- Cylinder provides insulated termination points for all shaft components
- 1/8" copper conductor exits top of cylinder and is attached to inside of steel probe
- BN cylinder is supported inside spherical anode via steel disk welded inside anode

Half of steel anode

Cross-section of anode probe



Diagnostics

We have a small diagnostic set planned for hot electron plasmas.

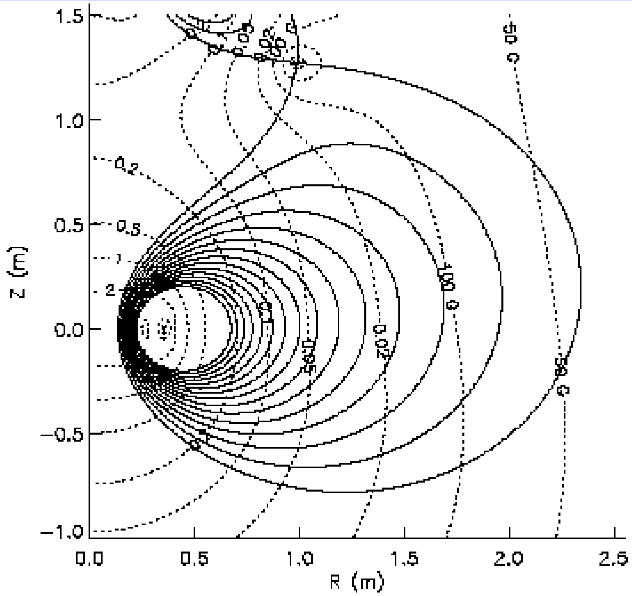
- Magnetics (flux loops, hall probes)
  - Plasma equilibrium shape, magnetic □ & stored energy
- Edge electrostatic probes
  - Potential; electron density, temperature, and pressure
- Microwave interferometer
  - Line-average density (for a single chord)
  - Density profile (multiple chords)
- X-ray camera
  - 2D imaging of x-rays from hot electrons
- X-ray pulse height energy analyzer
  - Hot electron energy distribution / profile
- Visible camera

Magnetics

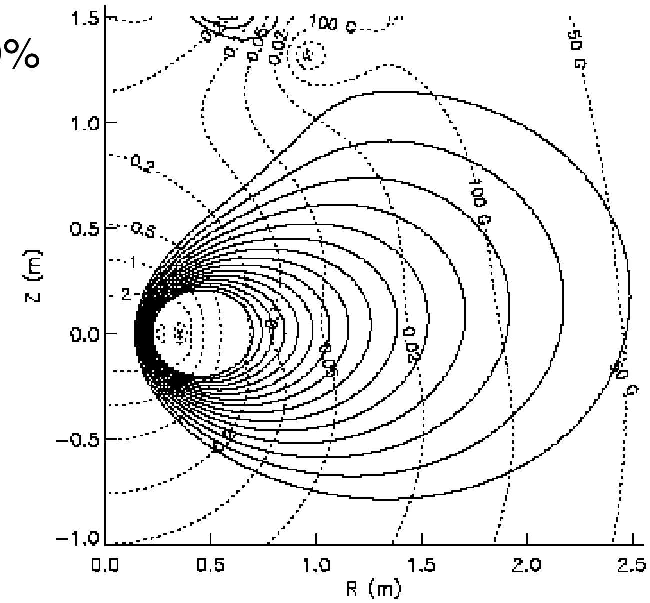
- See poster KP1.116, I. Karim *et al*., this session.

Magnetics measurements on LDX will be used to compute equilibria.

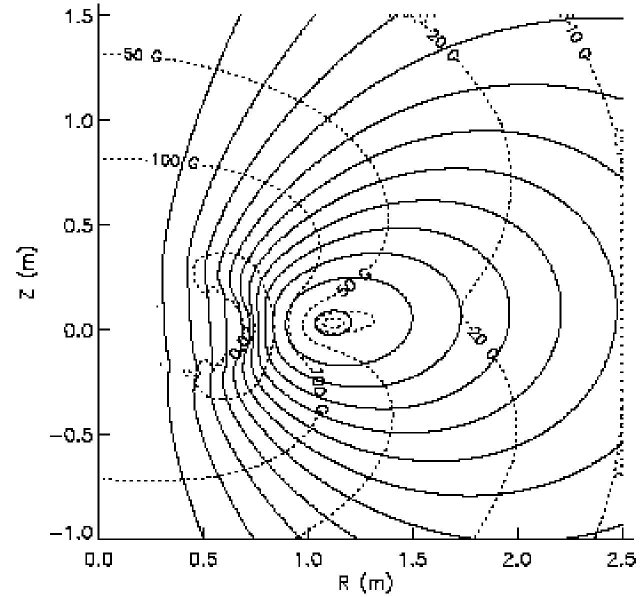
Vacuum



β_{max} = 50%

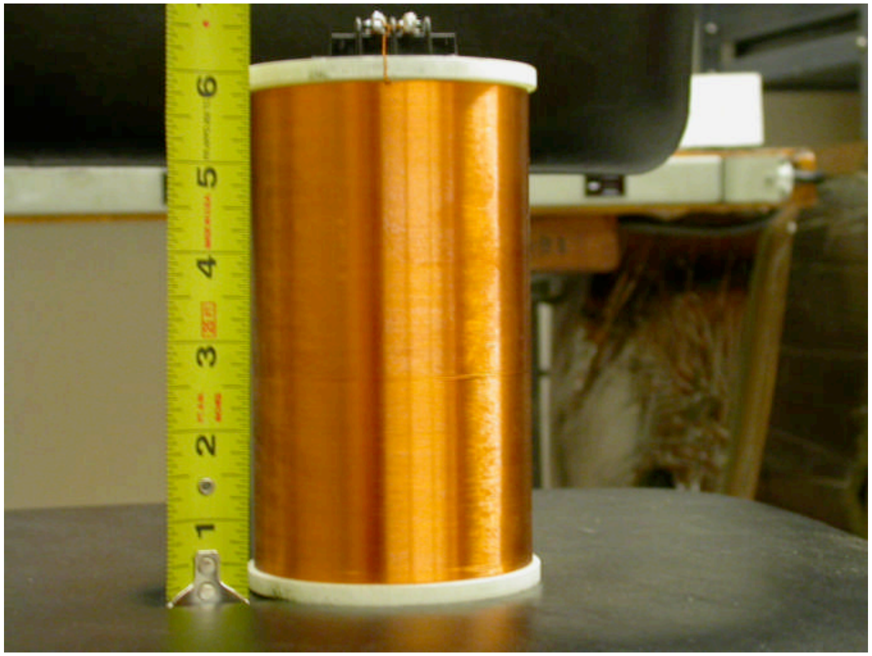


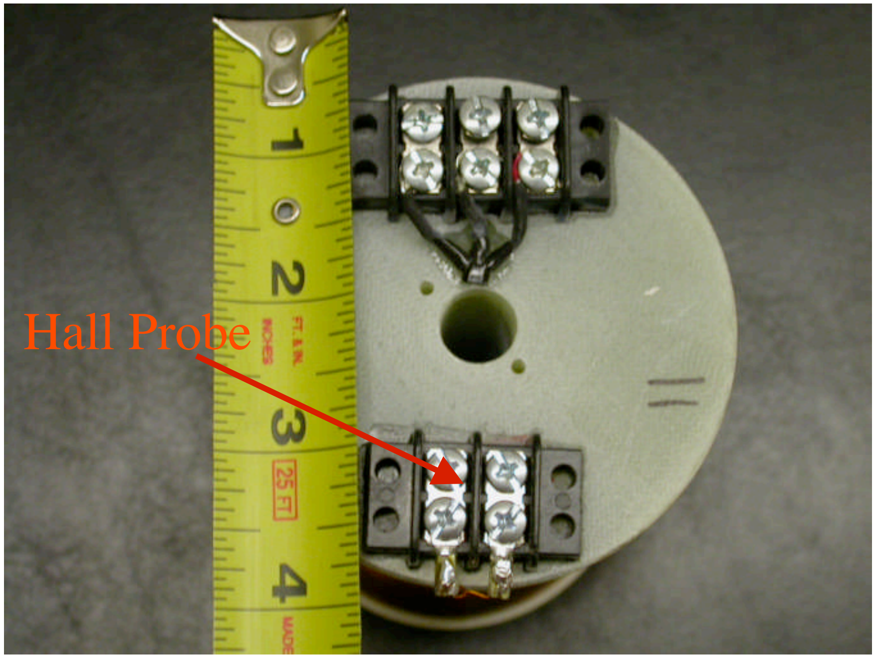
Difference



- DC dipole field means standard integrator diagnostics can be used.
- Superconductor dipole “freezes-in” flux giving an internal boundary condition for GS solver.
- Diagnostics include flux loops, Mirnov coils, and Hall probes.

A number of pickup coils with Hall sensors have been constructed for external magnetic measurements.





- **Pickup Coil Specs:**
  - Effective area ≡ NA ~ 5 m^2
  - Sensitivity: 5 V/(mT) (connected to a 1 ms RC integrator)
- **Hall Sensor Specs:**
  - Field Range: +/- 50 mT
  - Sensitivity: 50 (mV)/(mT)

Mirnov coils will also be used on LDX.

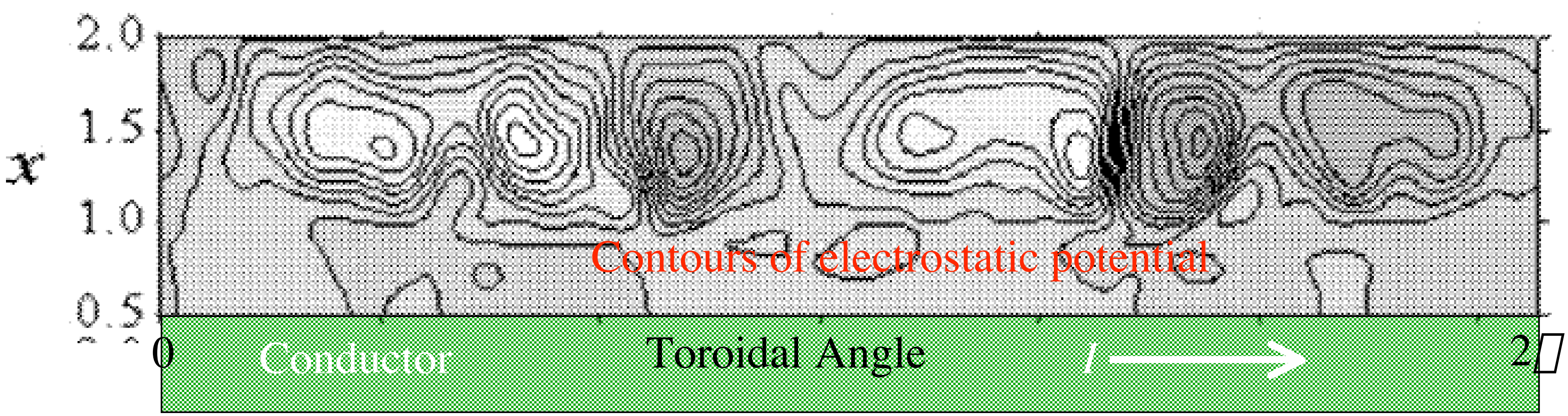
- Specs
  - Effective area ≡ NA: ~ 0.06 m^2
  - L/R_0: ~ 50 ps
  - f_0: ~20 GHz
- Directly measures dB/dt
- Placed inside the vessel
  - Shielded with boron nitride
- Measures fluctuations in the microsecond range

Electric probes

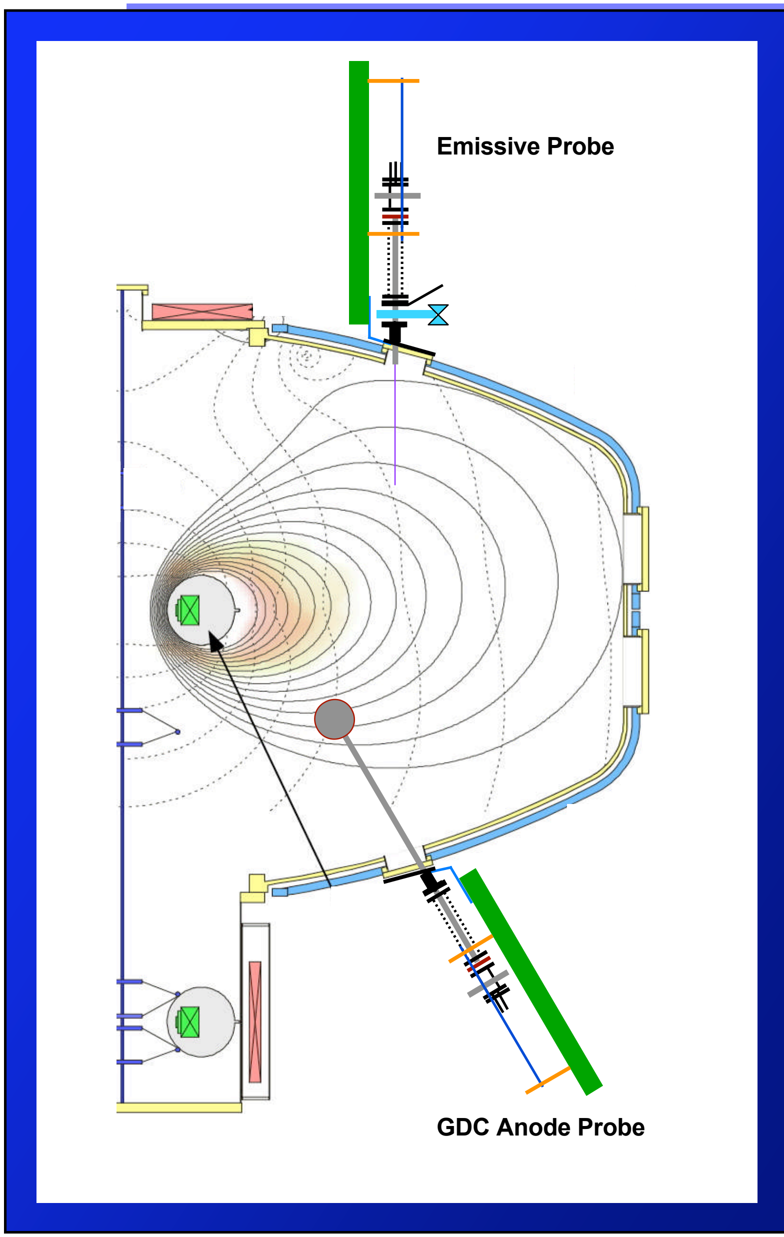
- See poster KP1.117, E.E. Ortiz *et al*., this session.

Electric probes will be used for measurements beyond "standard" edge studies.

- Equilibrium and fluctuating quantities of interest
  - Electron density
  - Electron temperature
  - Potential
- New feature: convective cells
  - Non-axisymmetric, nonlocal transport.
    - V.P Pastukov and N.V. Chudin, *Plasma Physics Reports* **27**, 907 (2001).



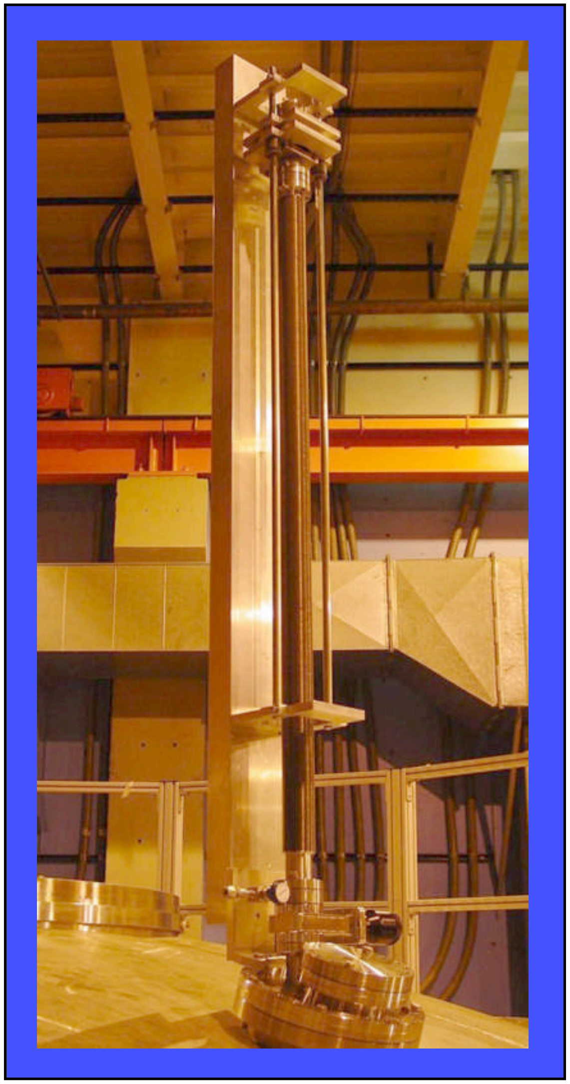
The electric probes will be installed on top of the vacuum vessel



* Drawing by Eugenio Ortiz, November 10, 2002

- **Linear motion vacuum interface**
  - Probe incursion depth of 60 cm
  - Allows for easy easy probe replacement without breaking vacuum.
  - Physics benefits
    - Measuring edge phenomena
    - Can bias single field lines with an emissive probe.

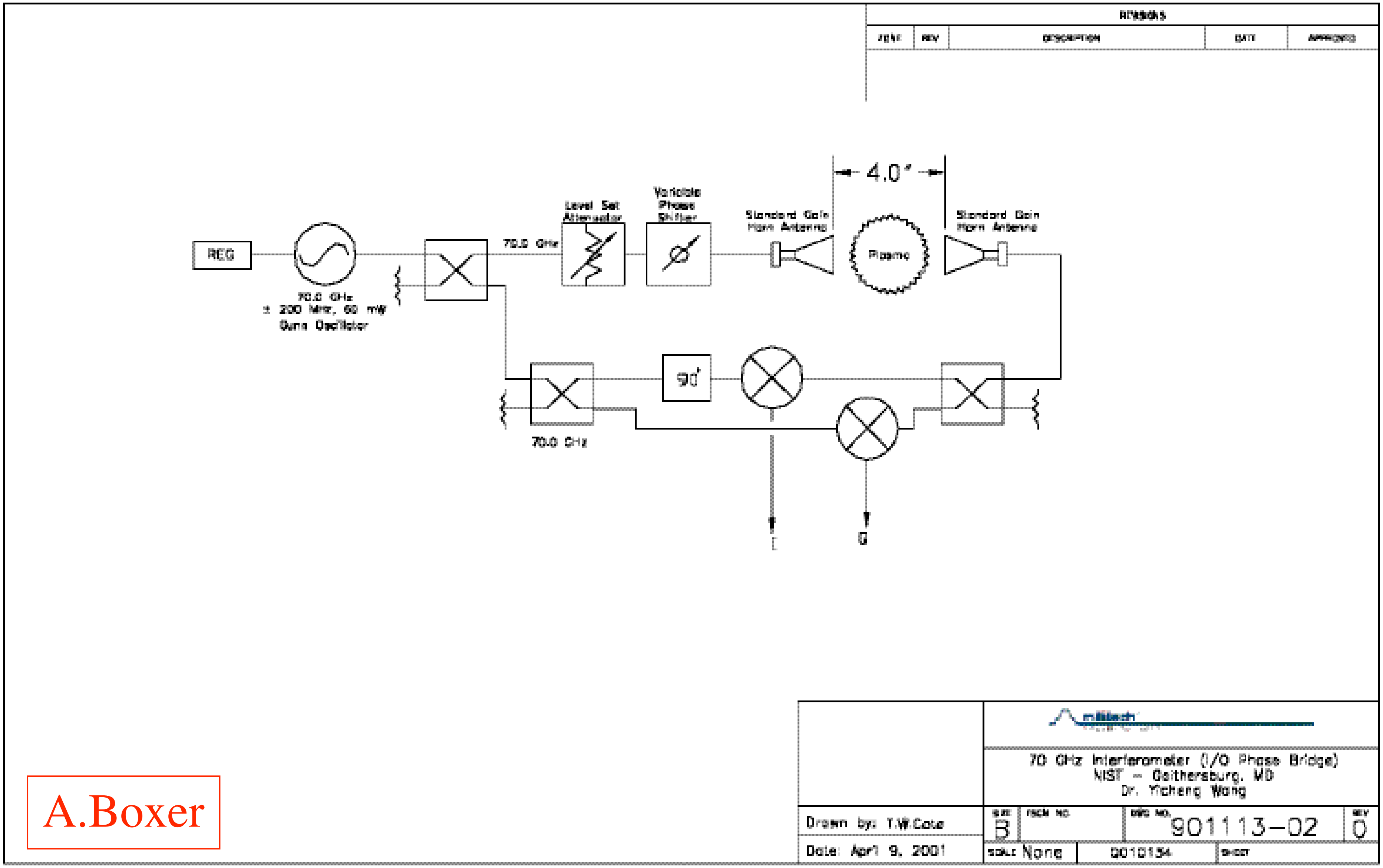
Electric Probe Mounting



- Easy access via platform
  - Actual height ~ 4.5 ft (137 cm) from base flange
- 32.5” (83 cm) stroke bellows.
  - Max length ~ 42.25” (108 cm)
  - Min length ~ 9.75” (25 cm)
- Standard 2.75” conflat vacuum components.
- Rotatable lower interface flange allows for 48 distinct probing angles.

Interferometer

We have investigated possible initial designs for an interferometer



A.Boxer

X-Ray Camera

We are using an intensified X-Ray camera that is on loan from PPPL

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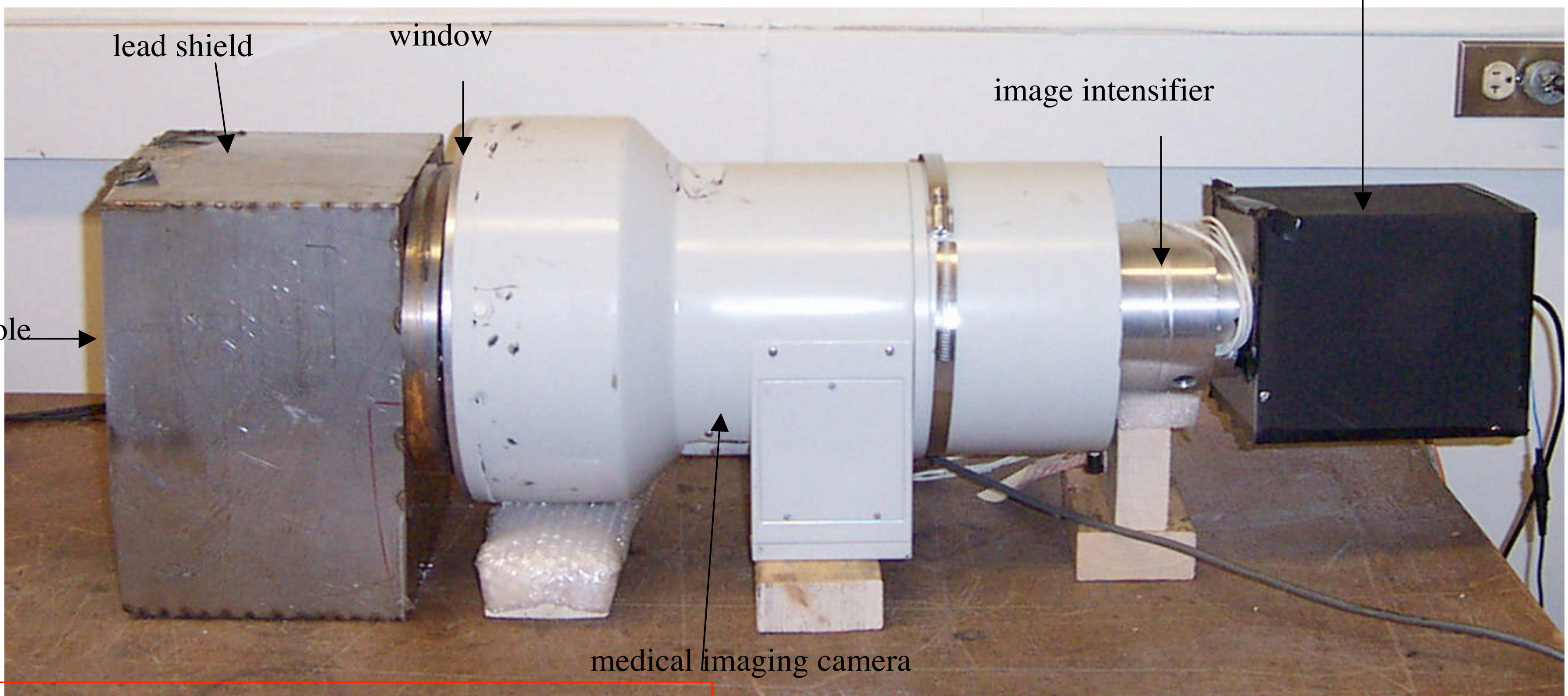
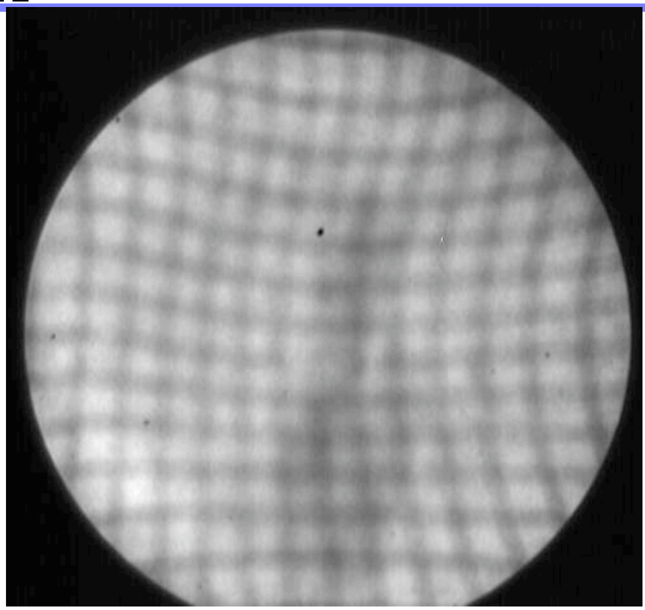


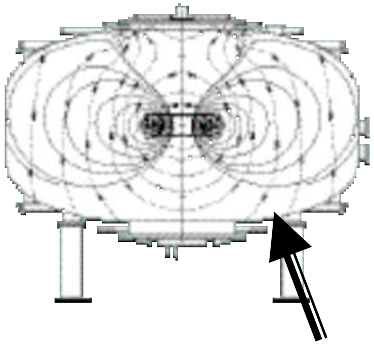
J. Ellsworth, S Zweben (PPPL)

The camera is in the process of being calibrated.

- Tangential viewing pinhole camera.
- Device is a standard medical imaging camera borrowed from PBX-M.
- CCD camera films phosphor display of image intensifier. Data from CCD camera is digitized using video capture card.
- Spatial resolution depends on pinhole size, desired value is 10cm.
- Temporal resolution is set by CCD camera which has standard video output of 30 frames per second.



X-ray camera picture of Am^{241} source viewed through 3"x3" pinhole. Because absorption of the detector in the camera is non-uniform, the Am^{241} source will be used to calibrate the camera. The grid in the picture is a lead grid placed over the window of the camera.



camera view of plasma

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Future work

- Finish building all operations systems and diagnostics
- First plasma!
- Begin supported campaign
- Beyond:
  - Levitated campaign
  - Thermal plasmas

Summary

- The operations systems for initial operation of LDX are nearing completion.
- The diagnostic set will provide valuable information for our initial runs.

LDX posters will be available at http://www.psfc.mit.edu/LDX/