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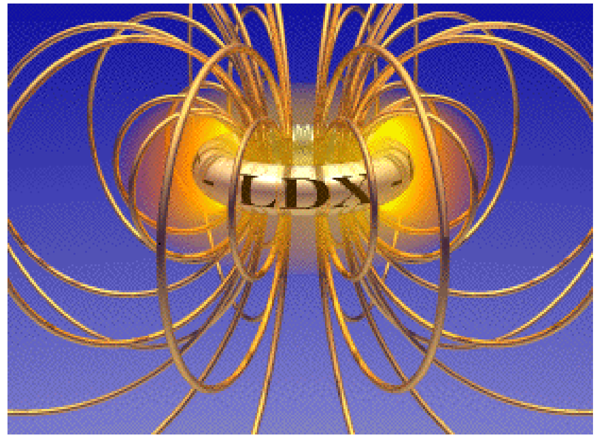

LDX Machine Design and Diagnostics

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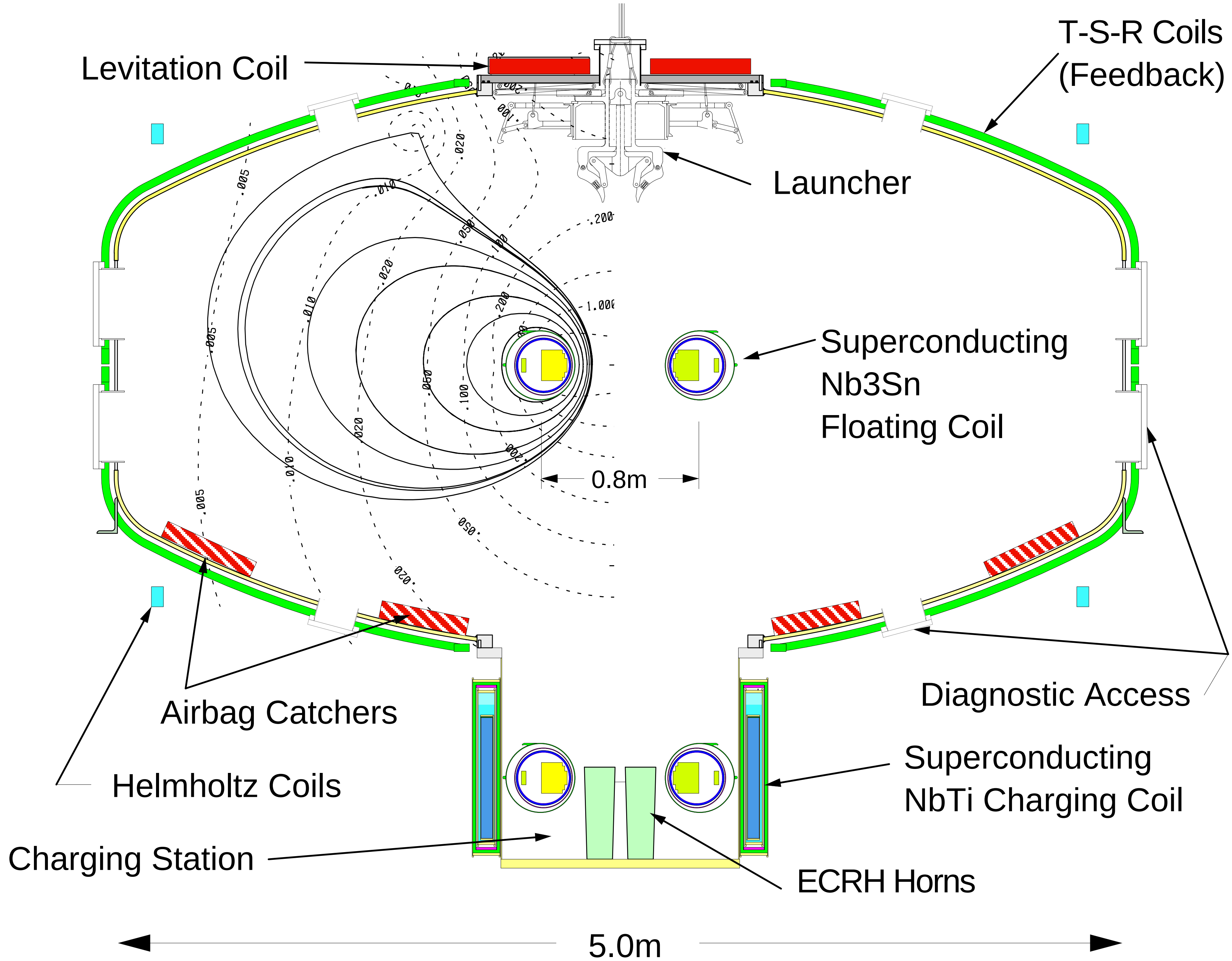
Abstract

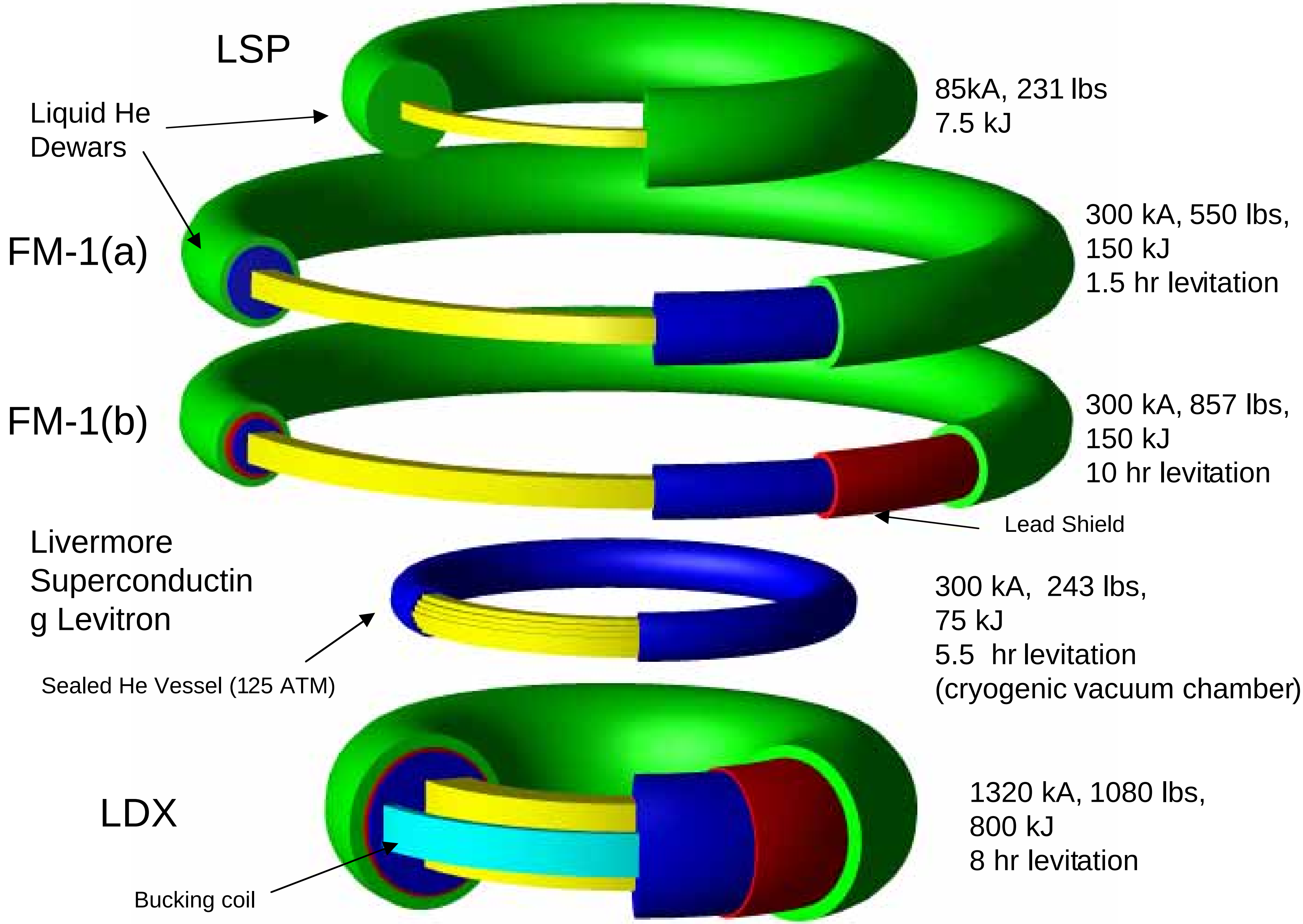
The LDX Experiment, presently being designed and built at MIT, requires a superconducting coil that can be floated within a large vacuum chamber. The 90 cm diameter, 1.2 MA, Nb_3Sn floating coil utilizes a novel cryostat design. The > 400 kg coil will float for up to 8 hours, centered within a 5 m diameter, 3 m tall vacuum chamber. When levitated from above, the coil is unstable only to vertical motion. A digital control system will be used for feedback control of the vertical position and damping of horizontal, tilt and rotational motions.

A simple diagnostic set is being developed to measure plasma equilibria, profiles, and instabilities. Equilibrium reconstruction from flux loops and hall probes will yield information on hot electron β and stored energy. A x-ray energy analyzer, xuv array, and reflectometer will measure hot electron profile parameters. Edge probes, magnetics and the xuv array will diagnose hot electron interchange instabilities driven by supercritical gradients. During thermal plasma operation, ion profiles will be measured using a charge exchange analyzer and secondary electron detector array.

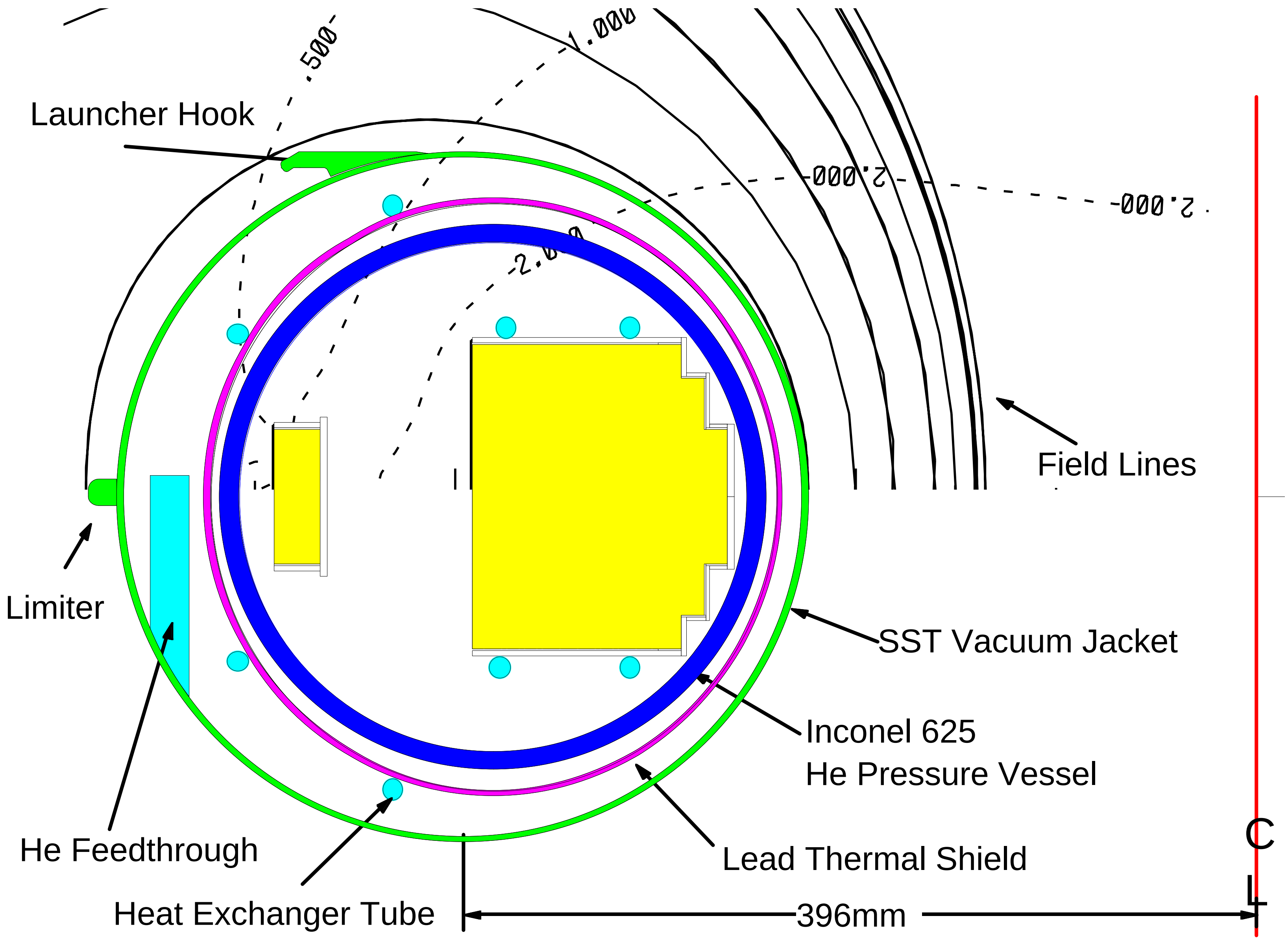
Levitated Dipole Experiment (LDX) Cross-section



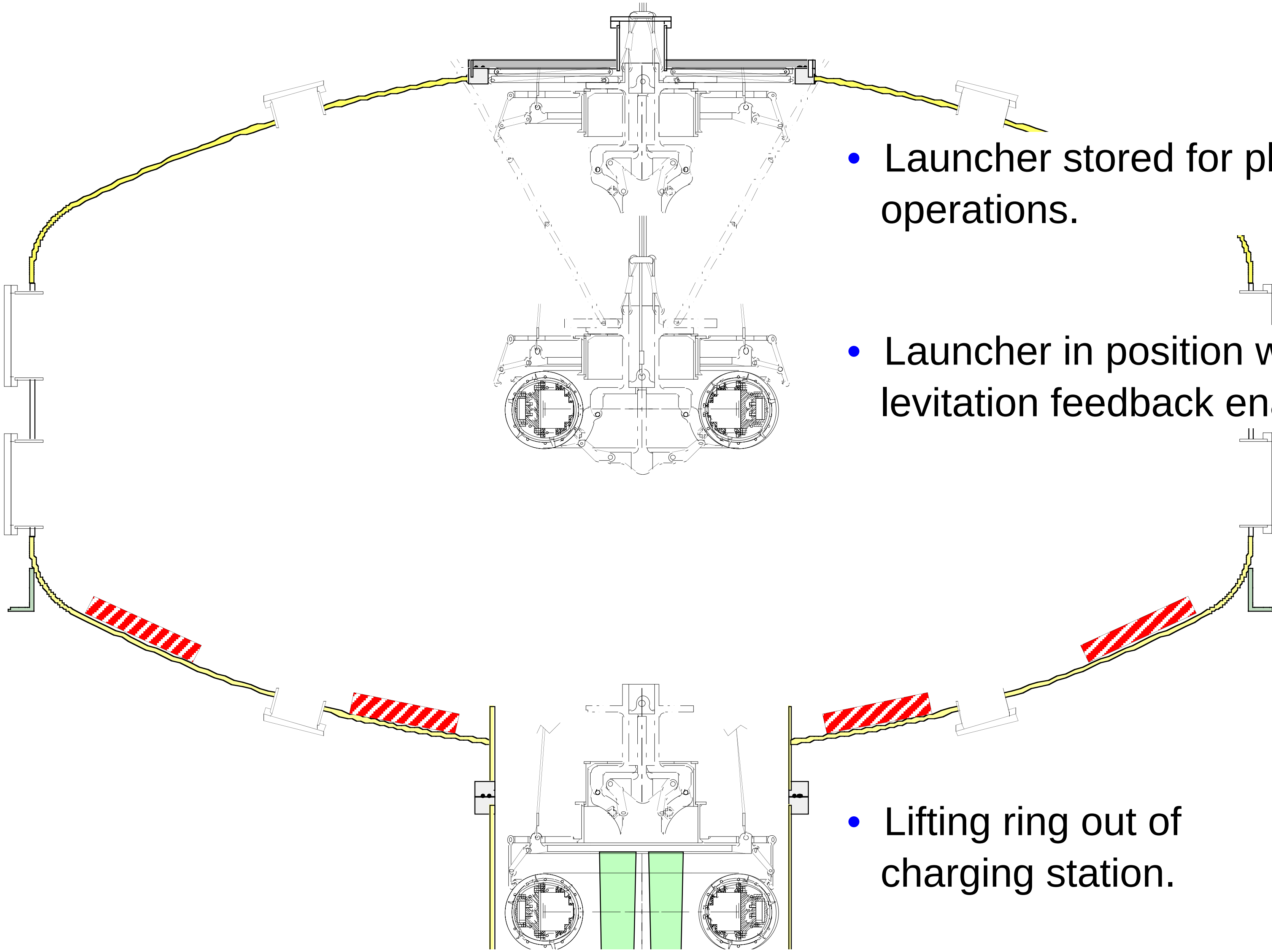
Nb_3Sn Floating Ring Experience Contributed to LDX Design



LDX Floating Ring Cross-Section

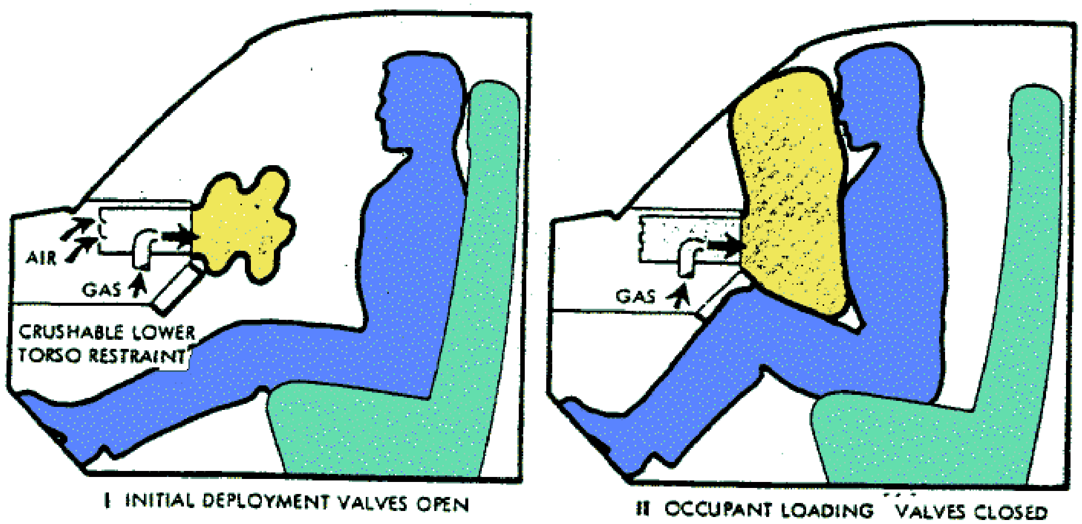


Launching/Retrieving the Floating Ring



- Launcher stored for plasma operations.
- Launcher in position with levitation feedback enabled.
- Lifting ring out of charging station.

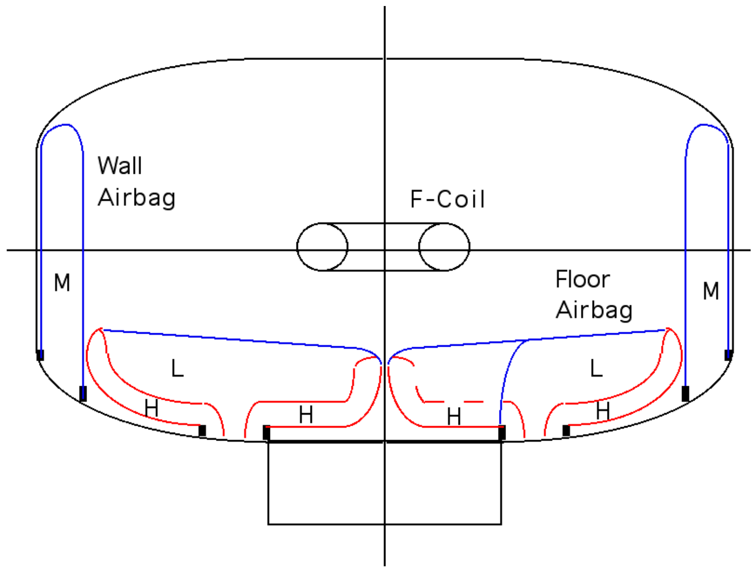
High Tech (in 1972) Catcher Solution



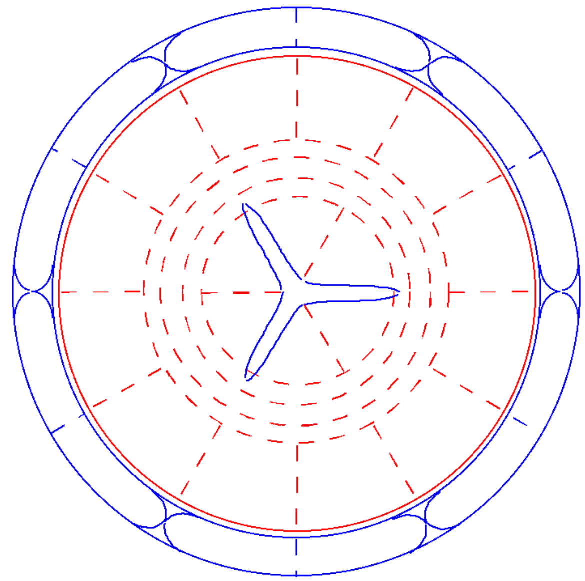
W.R. Carey et al, *Society of Automotive Engineers, 2nd International Conference on Passive Restraints*, Detroit, MI, 1972

- Dual pressure airbags proposed in 1972.
  - Can tailor deceleration profile
- LDX problem simpler than automotive airbags
  - Slower deployment requirement
    - ~ 1/2 sec compared to 20-60 msec for automotive
  - Inherently faster deployment
    - In vacuum, no air mass to resist inflation

LDX Airbag Emergency Catcher



Airbag Catcher (Side View)



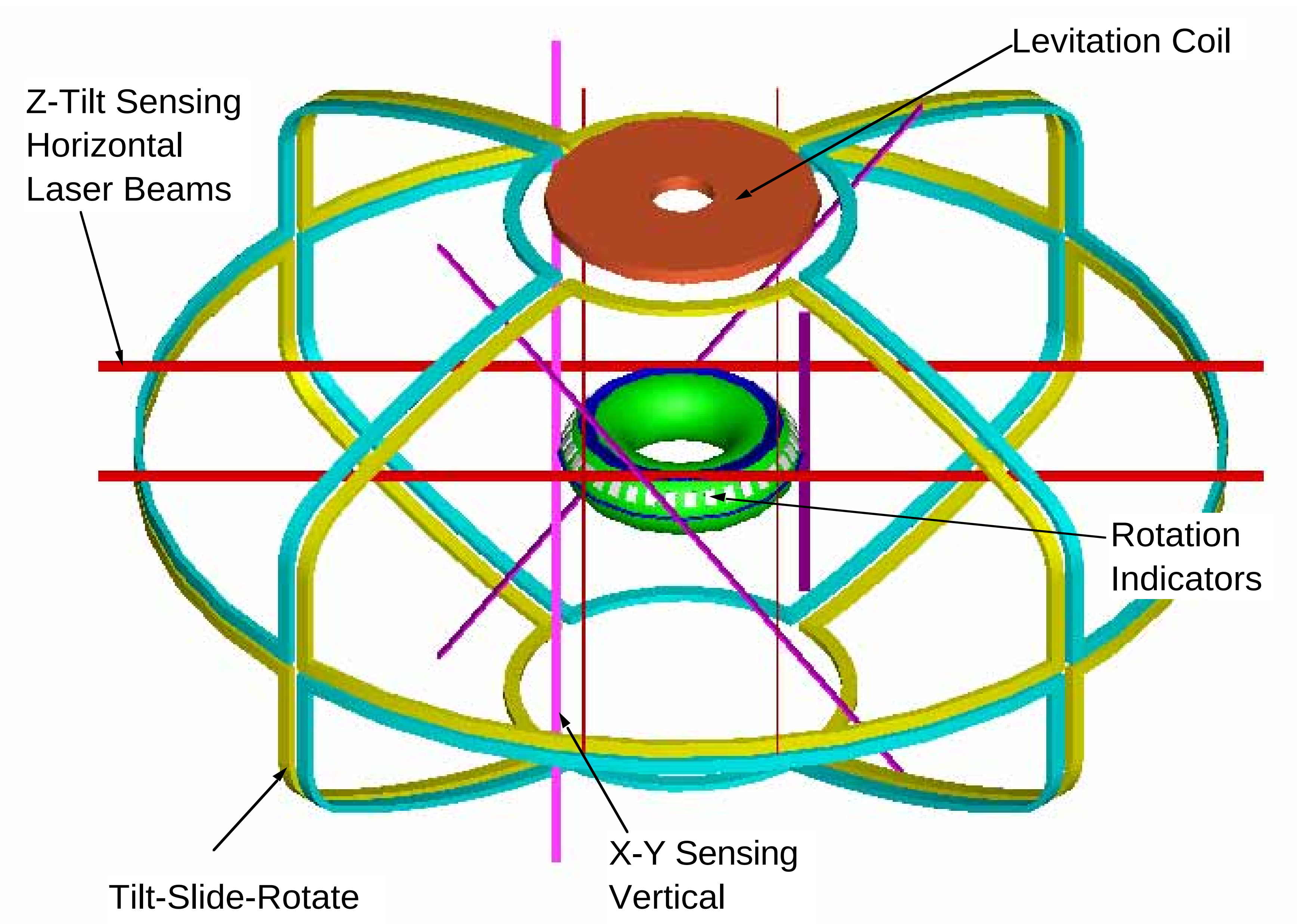
Airbag Catcher (Top View)

- Teflon-coated Kevlar fabric
- Vacuum compatiblity
  - Stored in troughs with separate rough vacuum sealed by metal foil
- Decelerations < 10g for all collision modes
  - Tailored for with lips to protect charging station
  - Bi-layered floor airbag to handle “swan dive” or “belly flop”

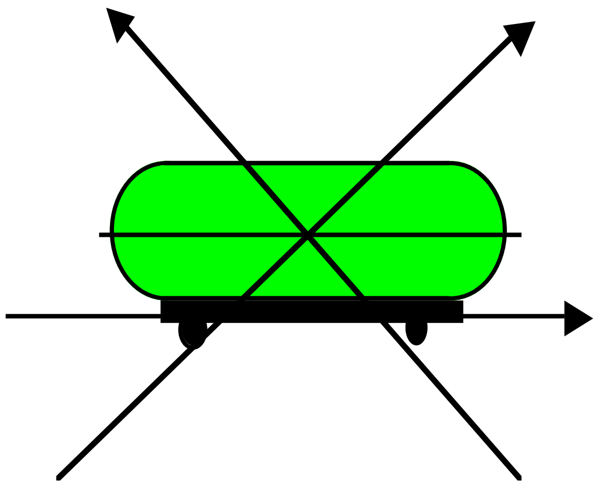
LDX Feedback Control System Overview

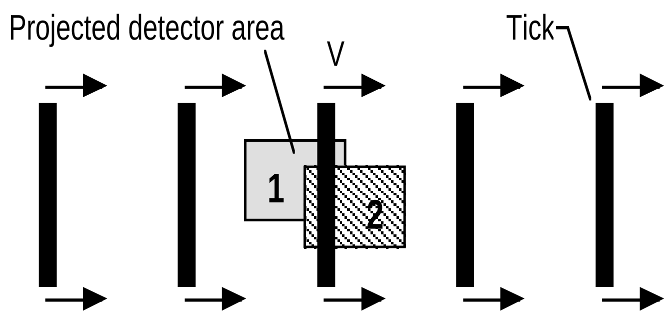
- Requirements
  - High Reliability, Low Noise, Modular
  - Resolution, Range, Response
    - 0.1 mm detection resolution within ± 1.0 cm range
    - ± 1.0 mm control of position
    - 1 kHz response for phase lag < 1° for fastest modes
- Optical Position Sensing System
  - Determine 6 degrees of freedom of floating ring
- Digital Control System
  - Inputs from position sensing system, plasma magnetic diagnostics, and power supply diagnostics
  - Implements process control algorithms
- Auxiliary Magnet Systems
  - Controls floating ring position - T-S-R Coils
  - Plasma equilibrium shaping - Helmholtz, S Coils

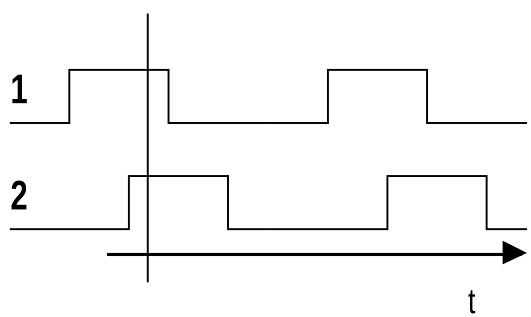
LDX Control System Geometry



Optical Position Sensing System



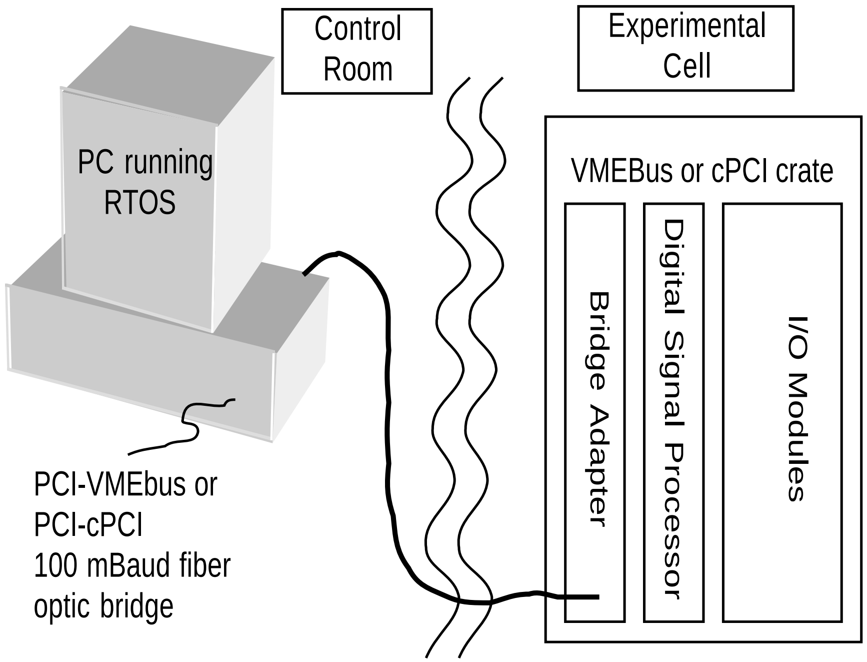




- Position/Attitude Sensing
  - Occulting system of 8 beams
    - Simple, proven
  - Position Sensitive Diode
    - PSD sensor allows non-absolute measurement of position
- Rotation Sensing
  - Rotation control
  - Nonaxisymmetry noise correction
  - Implementation
    - Set of reflective tick marks on floating ring
    - Illumination laser and three photodiode detectors
    - Digital TTL logic circuit

Digital Control System

Digital Control Schematic



- Design Choices
  - All digital process control
  - Real-time operating system embedded platform
- Digital Signal Processor
  - Process controller
- Embedded PC
  - Data logging
  - Operator control / Status Display
  - DSP Watchdog

Experimental Goals

- Study of high beta plasma stabilized by compressibility.
- Explore relationship between drift-stationary profiles having absolute interchange stability and the elimination of drift-wave turbulence.
- Examine coupling between the scrape-off-layer and the confinement and stability of a high-temperature core plasma.
- The stability and dynamics of high-beta, energetic particles in dipolar magnetic fields.
- The long-time (near steady-state) evolution of high-temperature magnetically-confined plasma.
- Demonstrate reliable levitation of a persistent superconducting ring using distant control coils.

LDX Experimental Plan

- Supported Dipole Hot Electron Plasmas
  - May 2000
- Levitation / Control System Testing
  - July 2001
- Levitated Dipole Physics
  - High-β Hot Electron Plasmas - August 2001
  - Thermal Plasmas
  - Concept Optimization / Evaluation

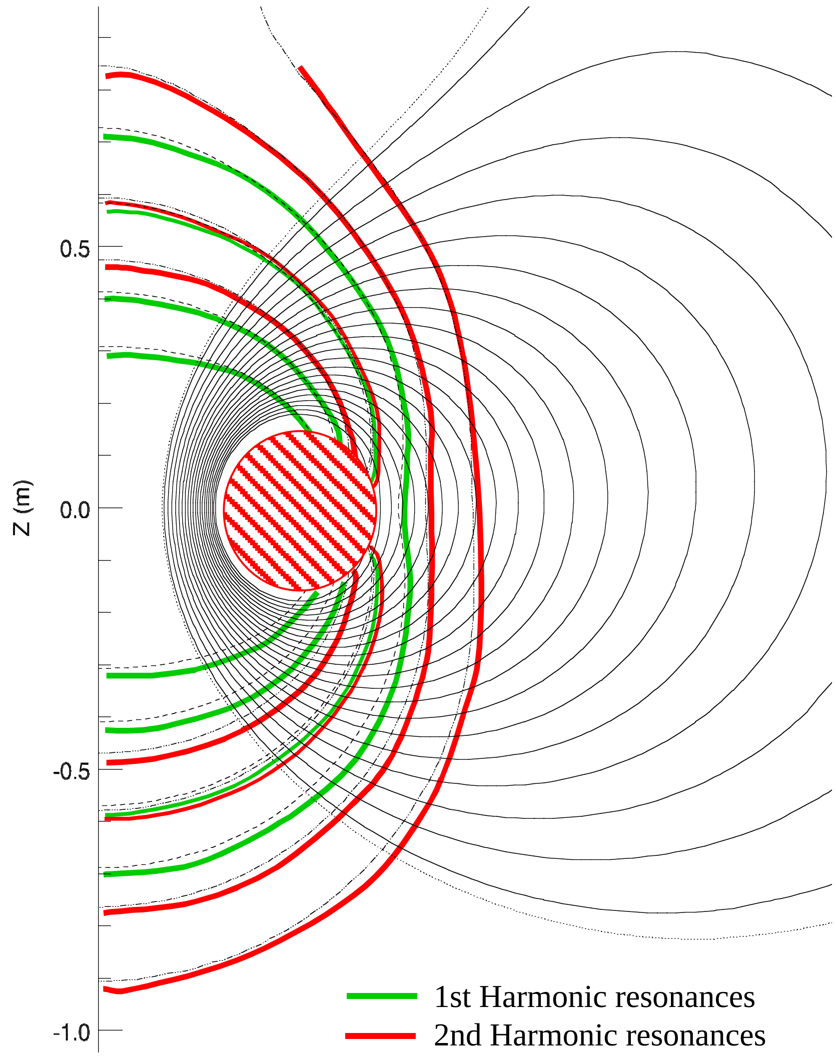
Supported Dipole Operations

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

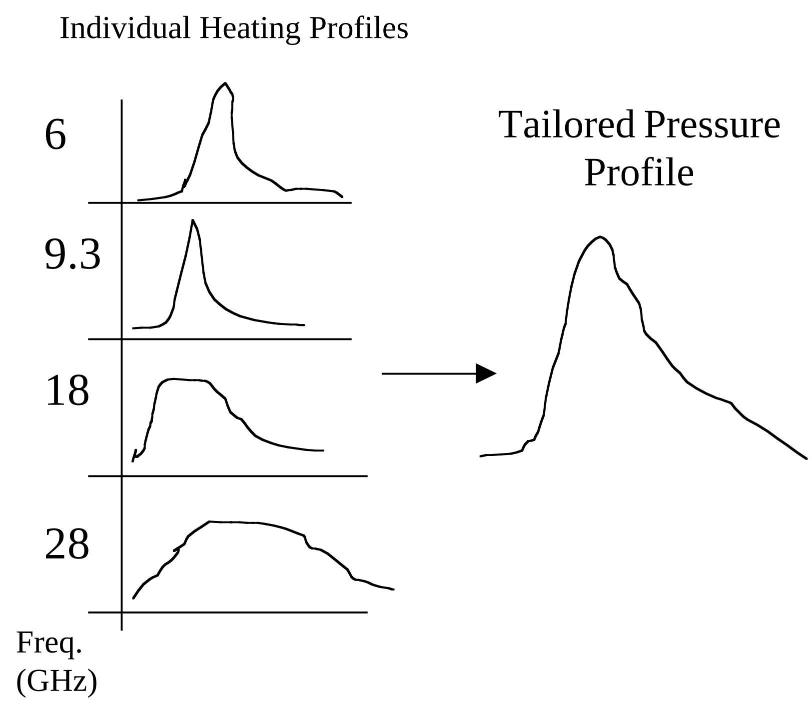
Hot Electron Plasma Diagnostics

- Magnetics (flux loops, hall probes)
  - Plasma equilibrium shape, magnetic β & stored energy
- Reflectometer
  - Density profile
- X-ray pulse height energy analyzer
  - Hot electron energy distribution / profile
- XUV arrays
  - Instabilities and 2-D profiles
- D_α camera
- Edge probes

Profile Control



- Multi-frequency ECRH
  - Measure single frequency response
  - Tailor multi-frequency heating to ideal profile.



Levitation / Control Test Plan

- Initial Levitation
  - No vacuum, safety straps, catcher disabled
  - Final alignment/calibration of optical system to magnet
  - Test control system step & impulse response
- Levitation optimization for plasma operations
  - Reduce proportional gain of T-S response -> 0
    - Shim levitation coil
  - Minimize T-S derivative response
- Test Rotation Control Methods

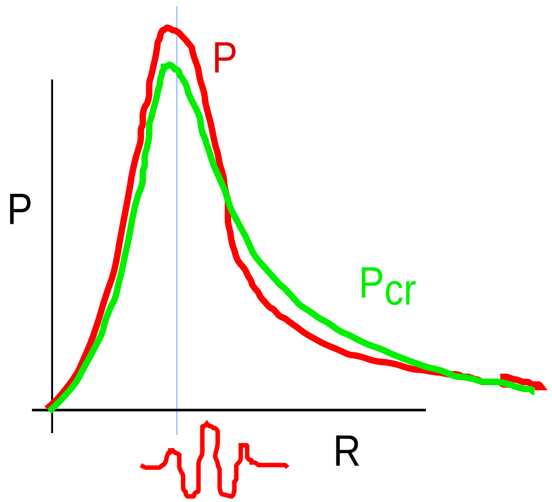
Levitated Dipole Physics

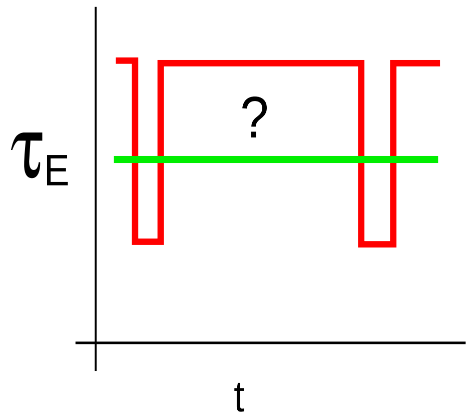
- High-β Hot Electron Plasmas
  - Global Confinement
  - β scaling
- Thermal Plasmas
  - Transient thermal plasmas produced by gas puff or lithium pellet injection into hot-electron plasma
  - Areas of Investigation
    - Thermalization of hot-electron β
    - Transient Transport
      - Instability driven transport during profile relaxation
    - Convective Cells
      - Investigate possibility of $\tau_p << \tau_E$

Thermal Plasmas Campaign

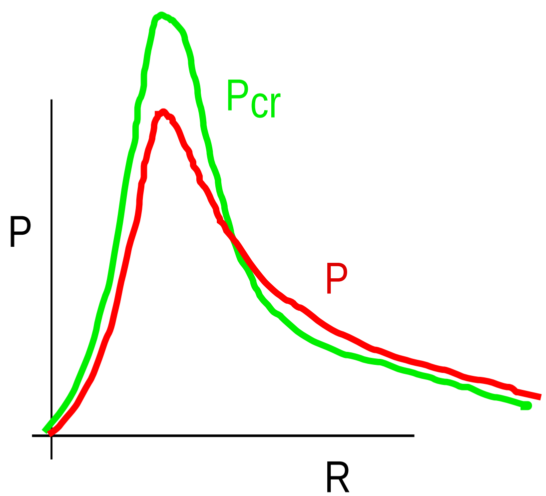
- Upgrades for campaign
  - Lithium pellet injector
  - Fast-gas puffing (axisymmetric)
  - Diagnostics
    - Charge exchange analyzer
      - Ion energy distribution
    - Secondary Electron Detector Array
      - Hot ion profile
    - Edge probes
      - Measure density, temp, flow near plasma edge
    - Others (Collaborators?)

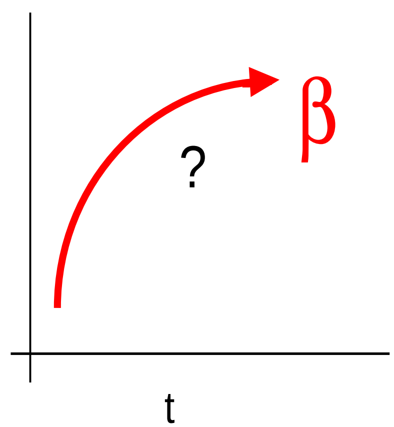
Instabilities & Confinement





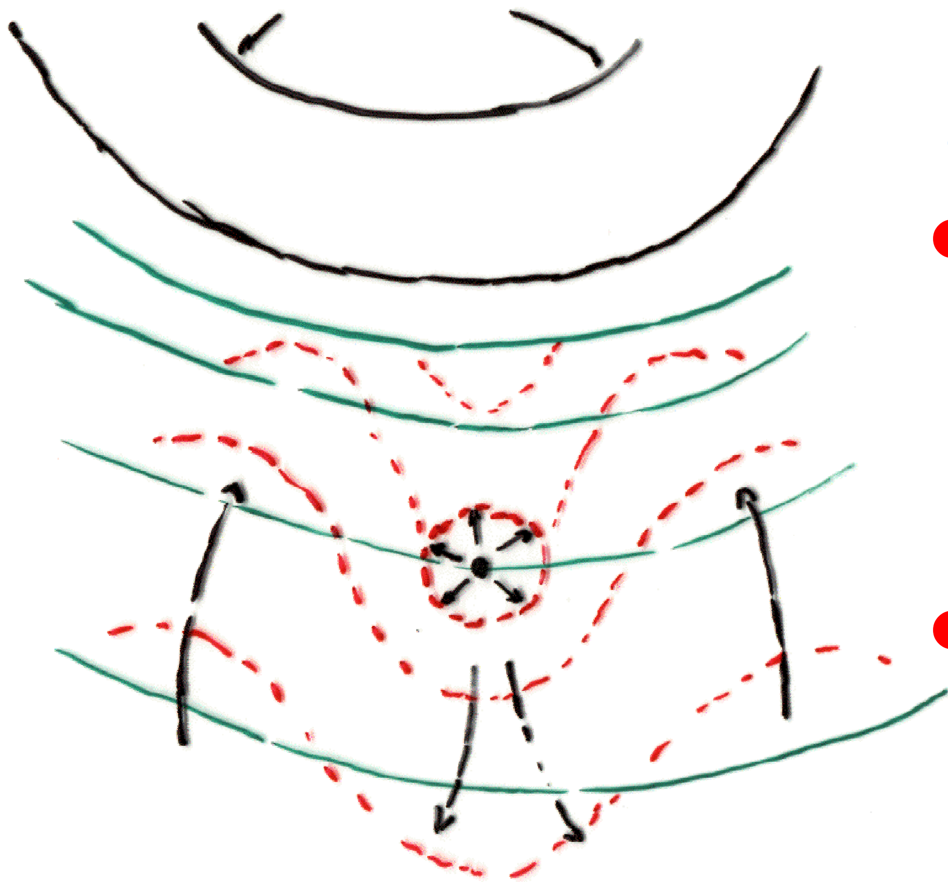
- Instability should exist when: $p' > p'_{critical}$
- Investigate nature of instability
  - How does it saturate?
  - How much transport is driven?





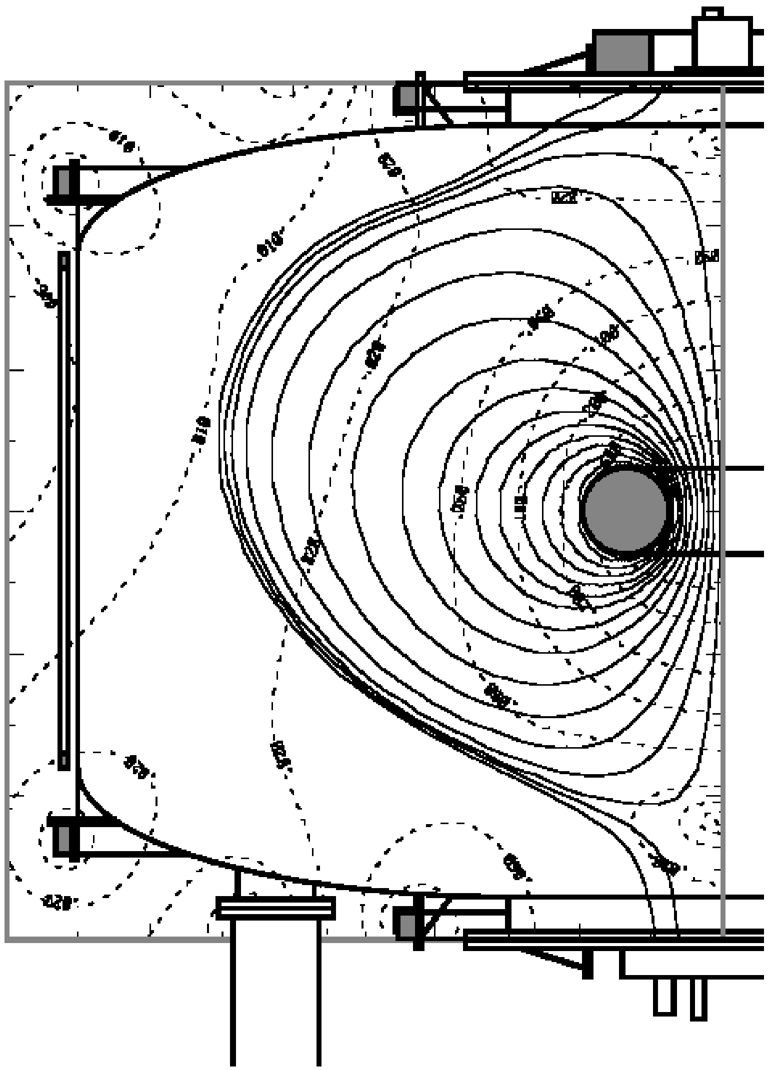
- Maximize β when: $p' < p'_{critical}$ everywhere
- What is maximum attainable β and what is limit?

Convective Cells



- Do they exist?
  - Are they the nonlinear saturation of interchange modes?
- Do they degrade energy confinement?
  - Can we have high energy confinement with low particle confinement?
- Explore methods for driving and limiting.

Bottom Levitation



Charging coil and additional shaping coils used for lower levitation

- Improved performance
  - Point Null
    - Reduced SOL volume
      - Less heat flux through LCFS
      - Higher edge pressure
      - Higher peak pressure
    - $$\oint \frac{dl}{B} \xrightarrow{\text{point null}} \infty$$
  - Private inner flux volume
    - No wall recycling neutrals
      - Reduced charge exchange losses
- Effect of ring stability fields ?
  - Higher non-axisymmetric error fields.