Profile Scan Studies on the Levitated Dipole Experiment

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Abstract

A dipole-confined plasma is expected to be stable to interchange modes or convective cells wherever the following relation is satisfied:

$$\frac{P_{edge}}{P_{core}} \leq \left(\frac{V_{core}}{V_{edge}}\right)^{\gamma}$$

where P is the pressure, $V \equiv \oint \frac{dl}{B}$, and $\gamma = 5/3$. One of the missions of the Levitated Dipole Experiment is to attempt to exceed the marginal stability condition and drive instabilities. We have two "knobs" with which to explore the parameter space: we can can change the pressure by varying the heating profile, by adjusting the total RF input power as well as the relative power in multiple frequencies; and we can change the magnetic geometry. Initial results of scans of the RF power in two frequencies and scans of the magnetic field are presented.

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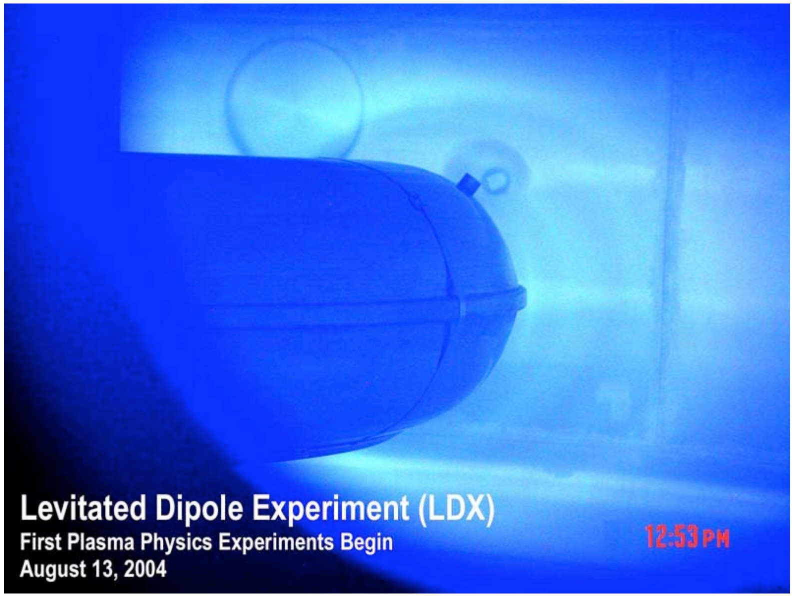
What's New

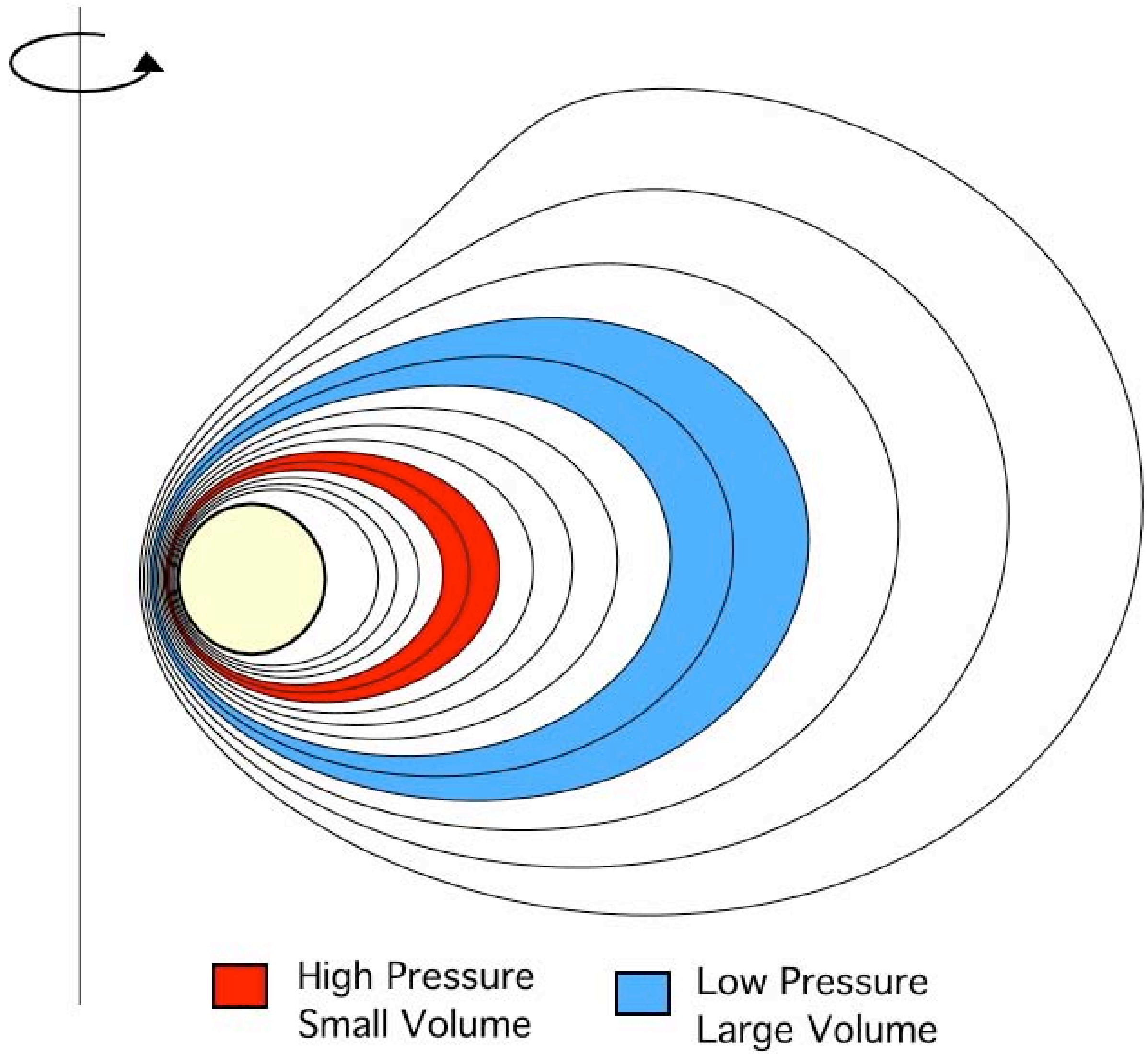


- First plasma operation in LDX!
  - The dipole coil was mechanically supported.
- We have had several runs and have varied the operational parameters.
  - Magnetic field
    - ◊ Two values
  - ECRH input power
    - ◊ Modulation proved to be a most interesting technique

Outline

- Background
  - Dipole confinement
  - ECRH
    - ◊ Multiple frequencies
- Parameter scans
  - Magnetic field
  - ECRH power modulation
- Future work
  - Shaping coils

Plasma Confinement in a Dipole Field Depends on Compressibility



Dipole Confinement Continued...

- Toroidal confinement without toroidal field
  - Stabilized by plasma compressibility
    - ◊ Not average well
    - ◊ No magnetic shear
  - No neoclassical effects
  - No TF or interlocking coils
- Poloidal field provided by internal coil
  - Steady-state without current drive
  - $J_{||} = 0$ -> no kink instability drive

Dipole Confinement Continued...

- Marginally stable profiles satisfy adiabaticity condition.
  - M.N. Rosenbluth and Longmire, *Ann. Phys.* **1** (1957) 120.

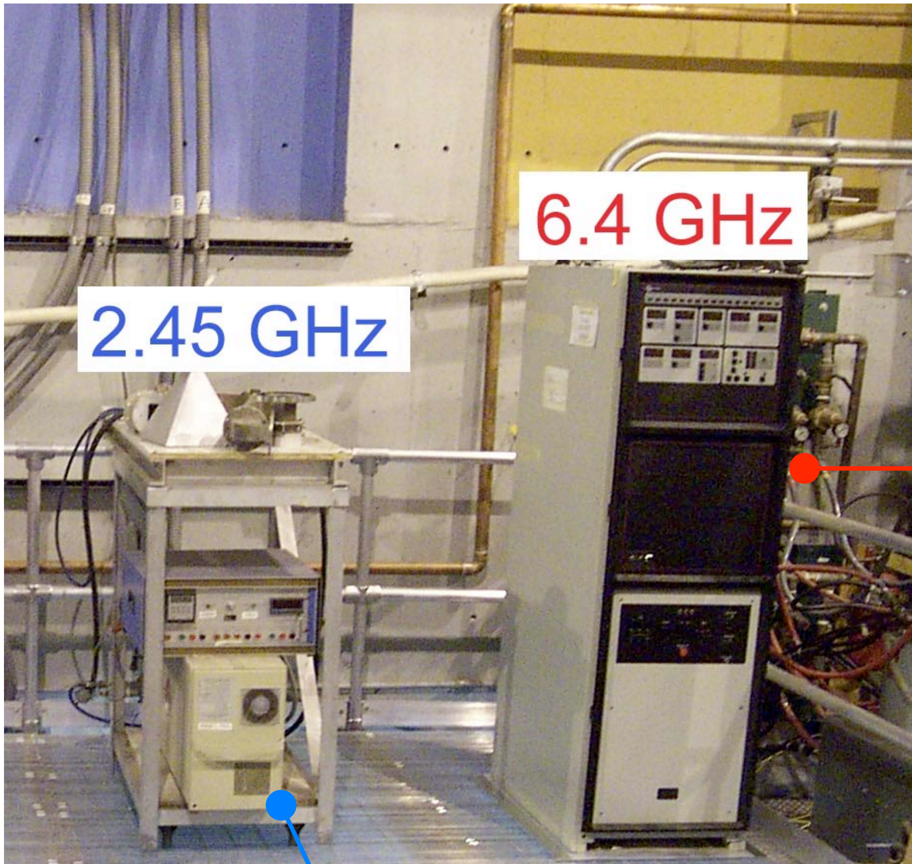
    $\delta\left(pV^{\gamma}\right) = 0$, where $V = \oint \frac{dl}{B}$, $\gamma = \frac{5}{3}$
  - Equilibria exist at high-β that are interchange and ideal MHD ballooning stable.
- For marginal profiles with $\eta = \frac{d \ln T}{d \ln n} = \frac{2}{3}$, dipoles are also drift wave stable.
  - Near-classical confinement ?
  - Drift waves exist at other values of η , but with with reduced growth rates.
- No Magnetic Shear -> Convective cells are possible.
  - For marginal profiles, convective cells convect particles but not energy.
    - ◊ Possible to have low τ_p with high τ_E .
  - Convective cells are non-linear solution to plasmas linearly unstable to interchange.
- We have two "knobs" to adjust the compressibility.
  - Magnetic geometry
    - ◊ We have run at different values of magnetic field
  - Heating power.

We Have Run at Two Different Coil Currents

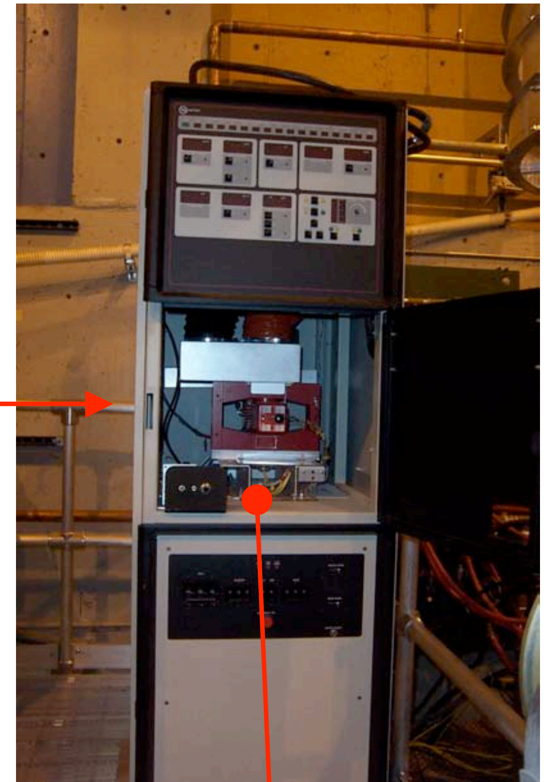
- 1080 kA-turns
- 1296 kA-turns
- This, of course, translates into different magnetic field profiles.
  - Magnitude, not shaping.
- Unlike most other magnetic confinement configurations, our field cannot be varied during an experimental run.
  - Here “run” means a charge-lift-plasmas-lower-discharge cycle.
  - No leads connected to the coil.
- With our existing hardware this can only be done with the floating coil supported mechanically.
  - This limit is set by the amount of current we can get from the levitation coil.

We Have Used Two Frequencies of ECRH to Form/Heat our Plasmas

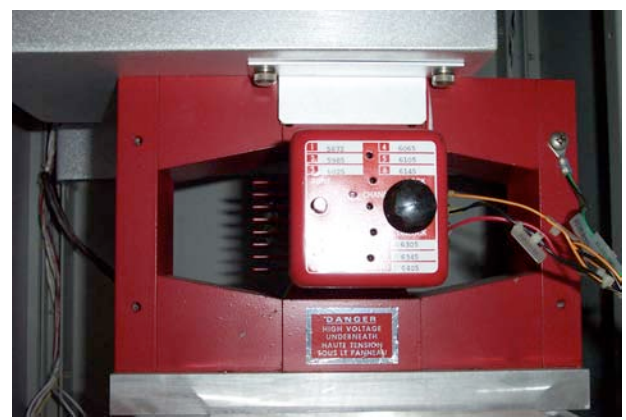
- ECRH is an effective way to create a high β hot electron population.
- We have the following sources online currently:
  - 3 kW CW at 6 GHz
    - ◊ Klystron
    - ◊ Operated for both runs
  - 3 kW CW at 2.45 GHz
    - ◊ Magnetron
    - ◊ Operated for second run
  - Poster BP1.109, Mahar *et al.*, this session, has details about the systems.



Showing Klystron Tube



Tube Detail



Side View of Controller (Top) and Magnetron (Bottom)

For Comparable Neutral Pressure, a Higher-field Discharge has a Higher Diamagnetic Flux.

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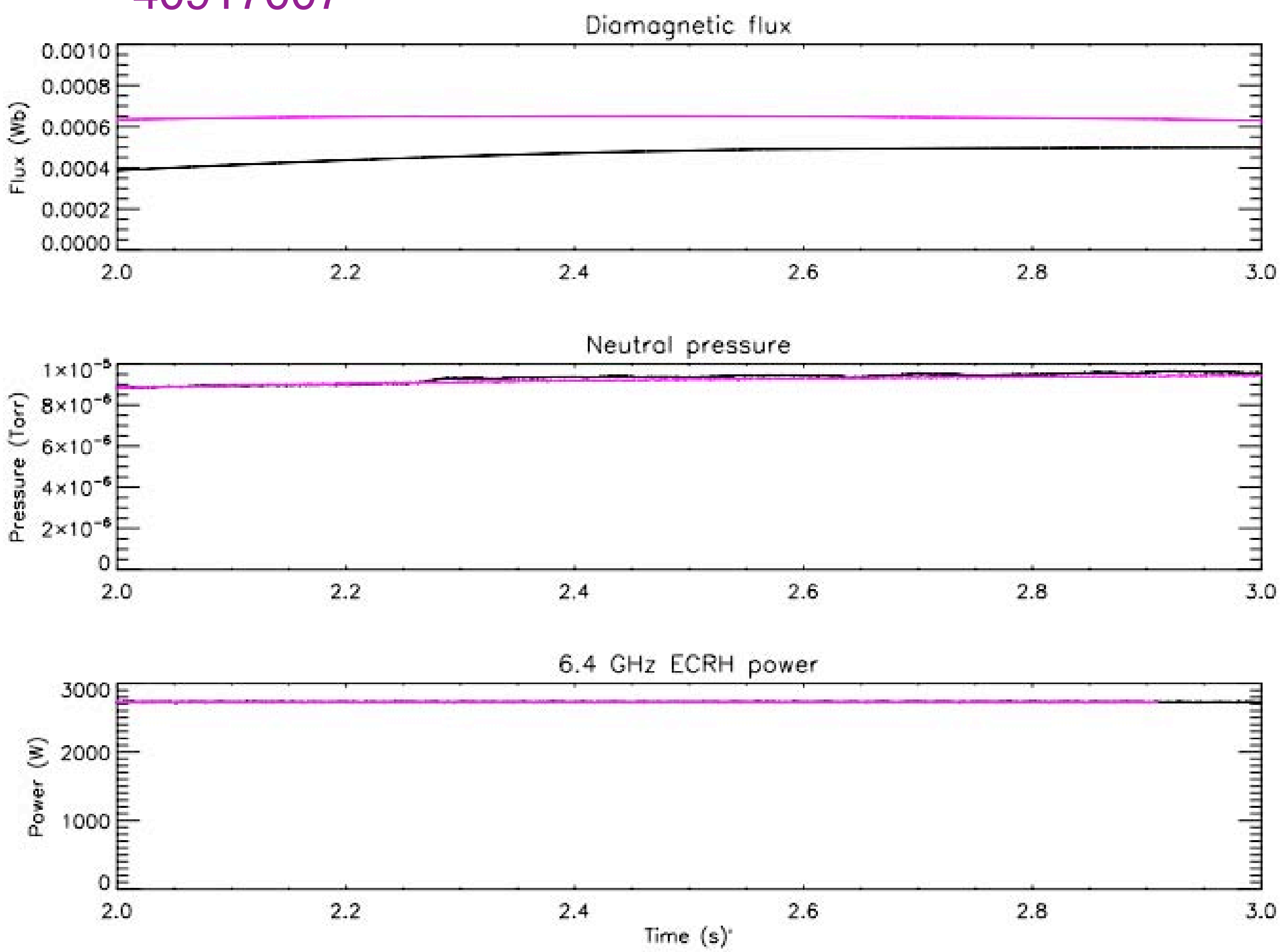
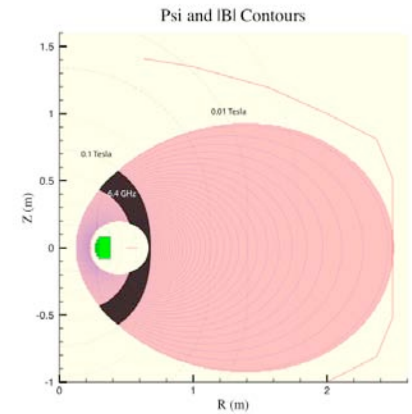
40917007

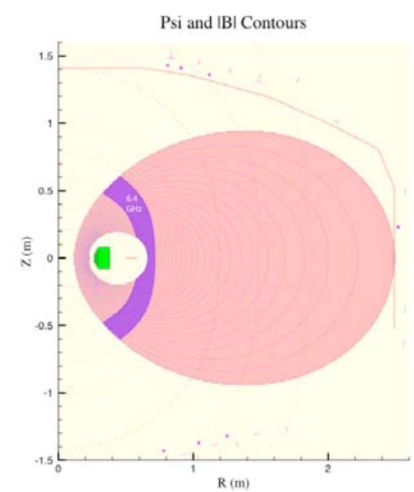


Modeled Equilibria

1080 kA-turns



1296 kA-turns

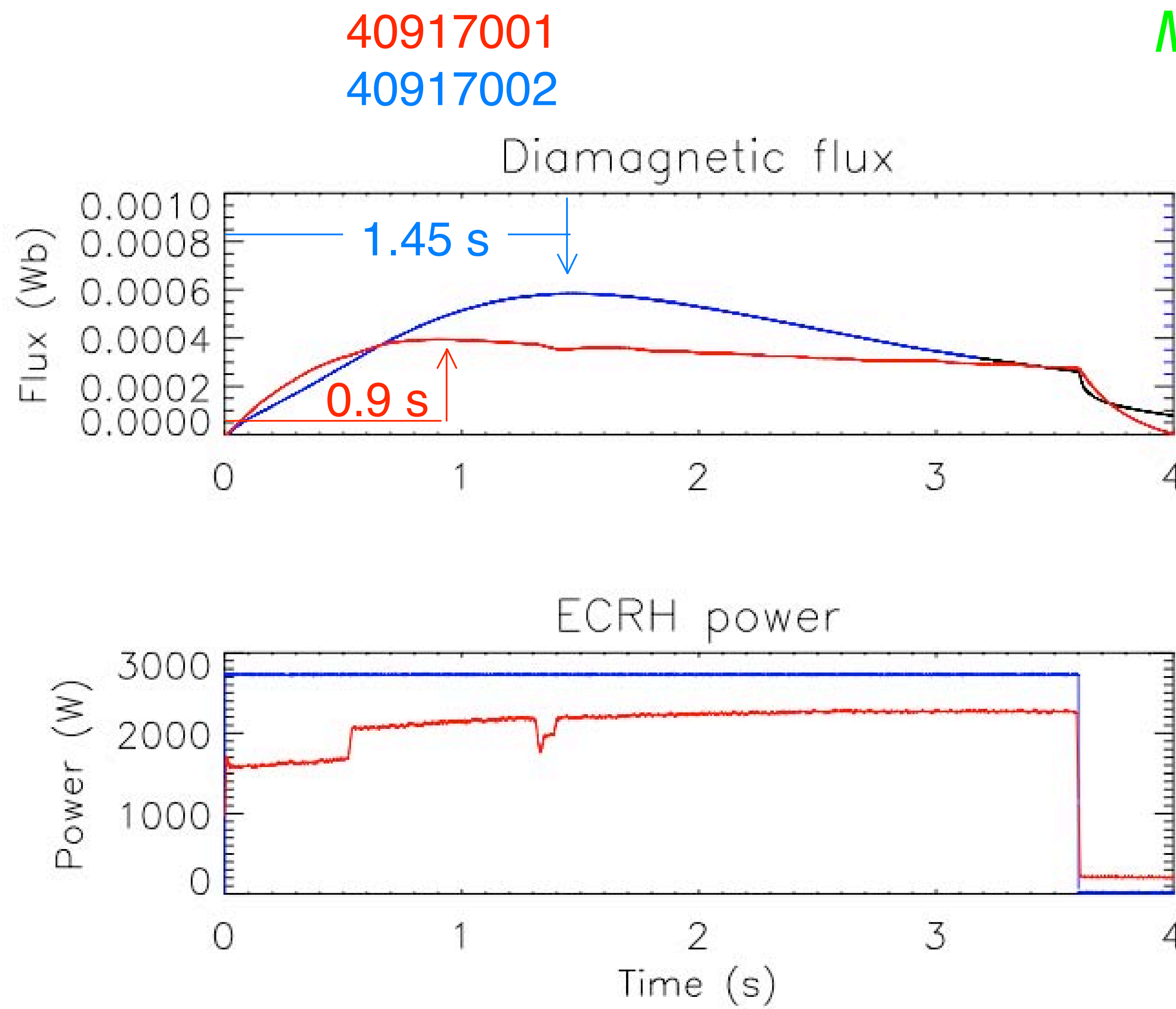


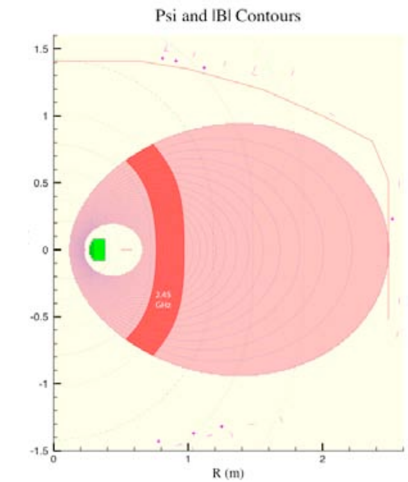
- Only the 6.4 GHz source was operational during the 1080 kA-turn run, so we will compare:
  - A discharge at 1080 kA-turns.
  - A discharge at 1296 kA-turns where only the 6.4 GHz source was employed.
- The hot electron energy inferred from the X-ray diagnostics was generally higher during the 1080 kA-turn run than the 1296 kA-turn run.
  - This is probably due to poorer vacuum conditions in the latter case.
- Comparing two discharges during a period of comparable neutral pressure (as measured by an ion gauge) and the same heating power:
  - The diamagnetic flux is ~25% higher for the 1296 kA-turn discharge.
  - This may be due simply to the change in the magnetic field:
    - ◊ At the higher field the 6.4 GHz resonance zone intercepts more closed field lines.
    - ◊ The volume of the 6.4 GHz resonance zone is larger.

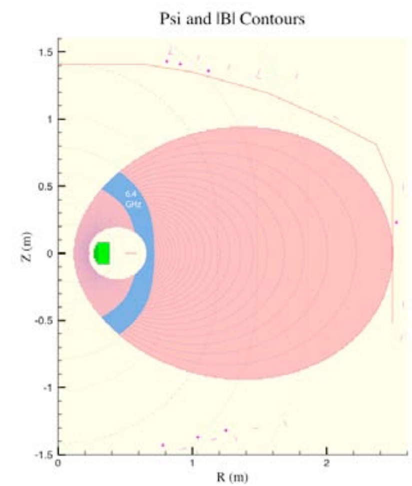
The Plasma Responds Differently to the Two Sources.

- Caveat: There were some electronics issues with the 2.45 GHz, so the power level isn't well established.
- The diamagnetic flux reaches a higher saturated value when only the 6.4 GHz source is employed than for the 2.45 GHz:
  - 0.004 Weber for 2.45 GHz
  - 0.006 Weber for 6.4 GHZ
- The flux reaches its saturated value earlier for the 2.45 GHz source:
  - 0.9 sec for 2.45 GHz
  - 1.4 sec for 6.4 GHz

Modeled Equilibria



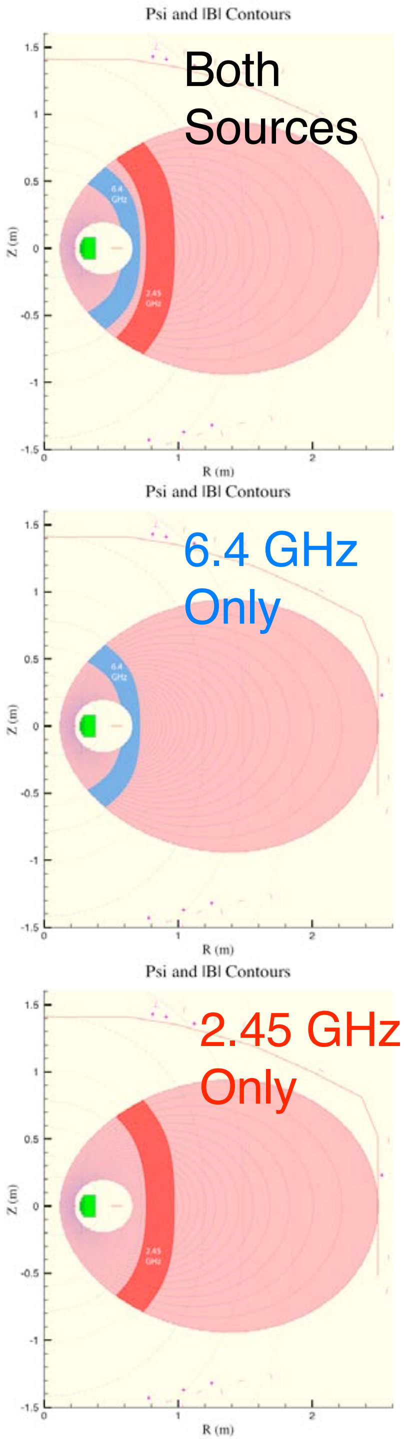


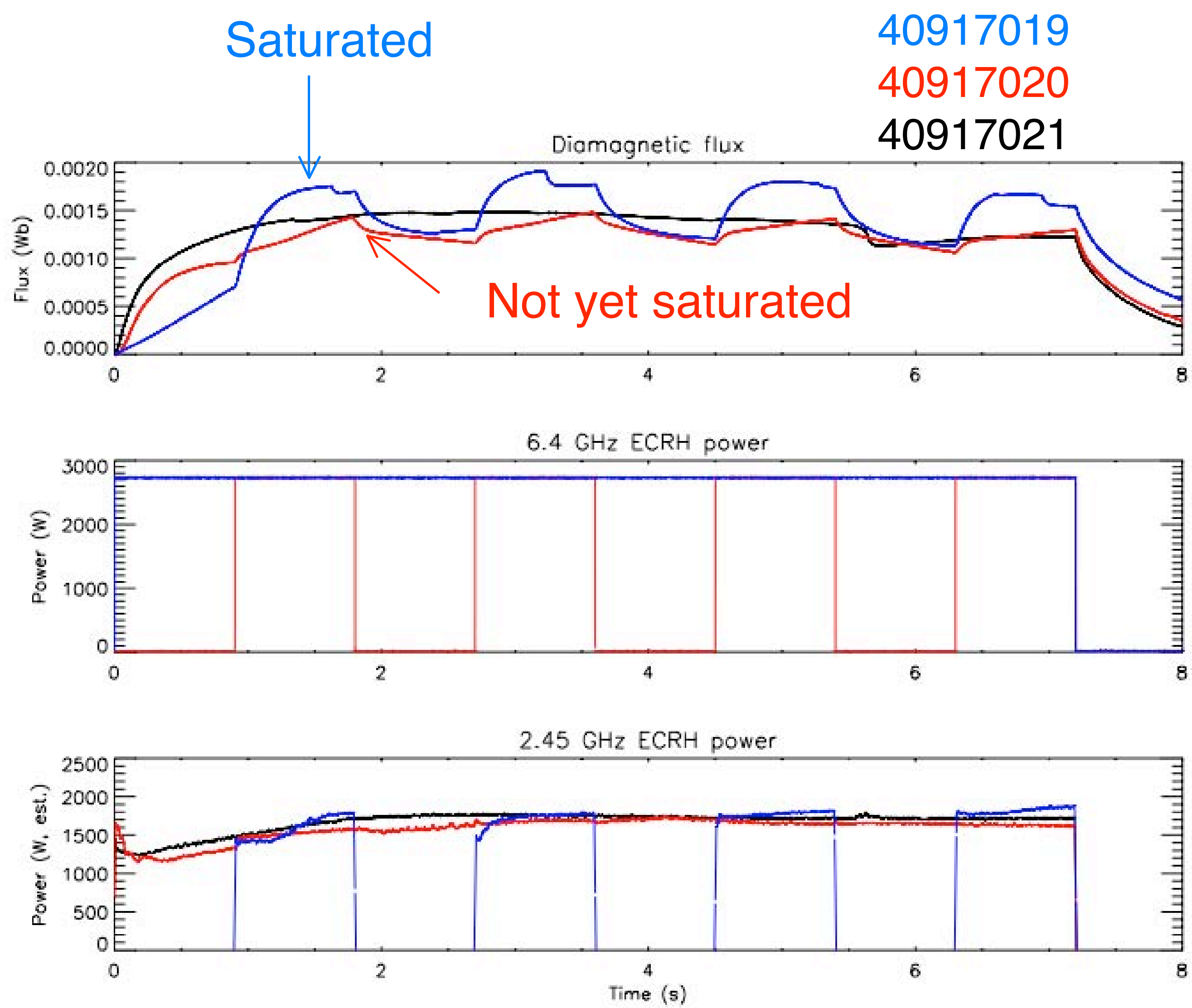


The Effect of Modulating the ECRH Power Depends on Which Source Is Modulated

- Unmodulated case
  - The injected power is the same as the total injected power when both sources were on in the discharges where modulation was applied.
- 2.45 GHz source modulation
  - The diamagnetic flux appears to saturate fully near the middle of the period when the 2.45 GHz source is on.
  - 46% change in flux from trough to peak.
  - The peak flux (2.45 GHz source on) is 27% higher than in the unmodulated case.
  - The minimum flux when 2.45 GHz is off is 20% lower than in the unmodulated case.
- 6.4 GHz source modulation
  - Unlike the 2.45 GHz modulation, this case appears not to achieve a saturated state at the time that the 6.4 GHz source shuts off.
    - ◊ The rise time to saturation in the flux for this source when used alone is 1.4 s
    - ◊ This is longer than the 1 s modulation cycle time that we've tried to date.
  - 12% trough-to peak change in flux.
  - The value when the 6.4 GHz source is off is about 20% lower than in the unmodulated case.
    - ◊ Similar value to when the 2.45 GHz source is off, above.
  - The maximum value when the 6.4 GHz source is on (at the modulation cycle we've studied) is approximately the same as for the unmodulated case.
- Suggests a pressure profile effect.

Modeled Equilibria


Psi and |B| Contours
Both Sources
Psi and |B| Contours
6.4 GHz Only
Psi and |B| Contours
2.45 GHz Only
Z (m)
R (m)
6.4 GHz
2.45 GHz


Saturated
40917019
40917020
40917021
Diamagnetic flux
Flux (Wb)
Not yet saturated
6.4 GHz ECRH power
Power (W)
2.45 GHz ECRH power
Power (W, est.)
Time (s)

We Will Employ our Shaping Coils in the Immediate Future.

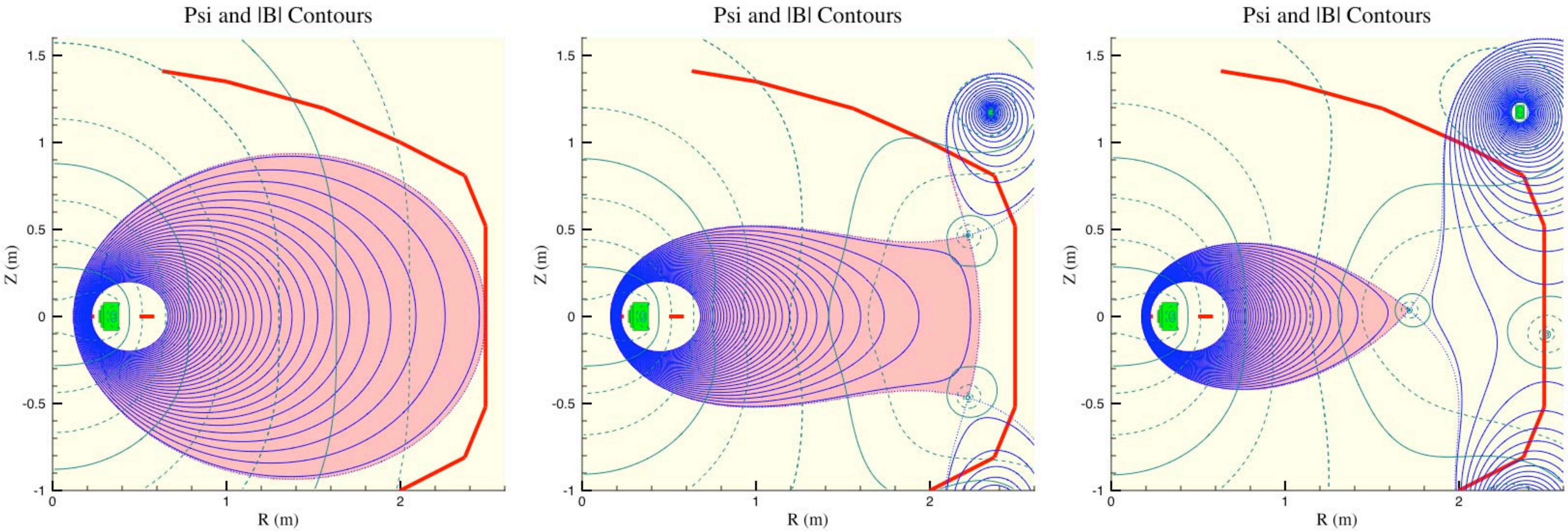
- By altering the magnetic geometry, the plasma volume -> the compressibility, can be reduced dramatically.
- When there is no field from the levitation coil (i.e. up-down symmetric equilibria) the coils can reduce the volume.
  - Supported operation only!
  - The plasma is limited by the vacuum chamber wall and the floating coil.
- When the levitation coil is turned on, the volume can be enhanced with respect to the base case.
  - Uses the coils in a non-Helmholtz configuration.
  - Really only brings the volume approximately to what it is in supported operation sans external field.

Shaping Coils

- The coils are arranged in a Helmholtz configuration.
- They are driven in parallel by two separate supplies, so they can have different currents.

An Applied Vertical Field Can Decrease the Plasma Volume

Equilibria (Supported Coil Configuration)



Increasing vertical field

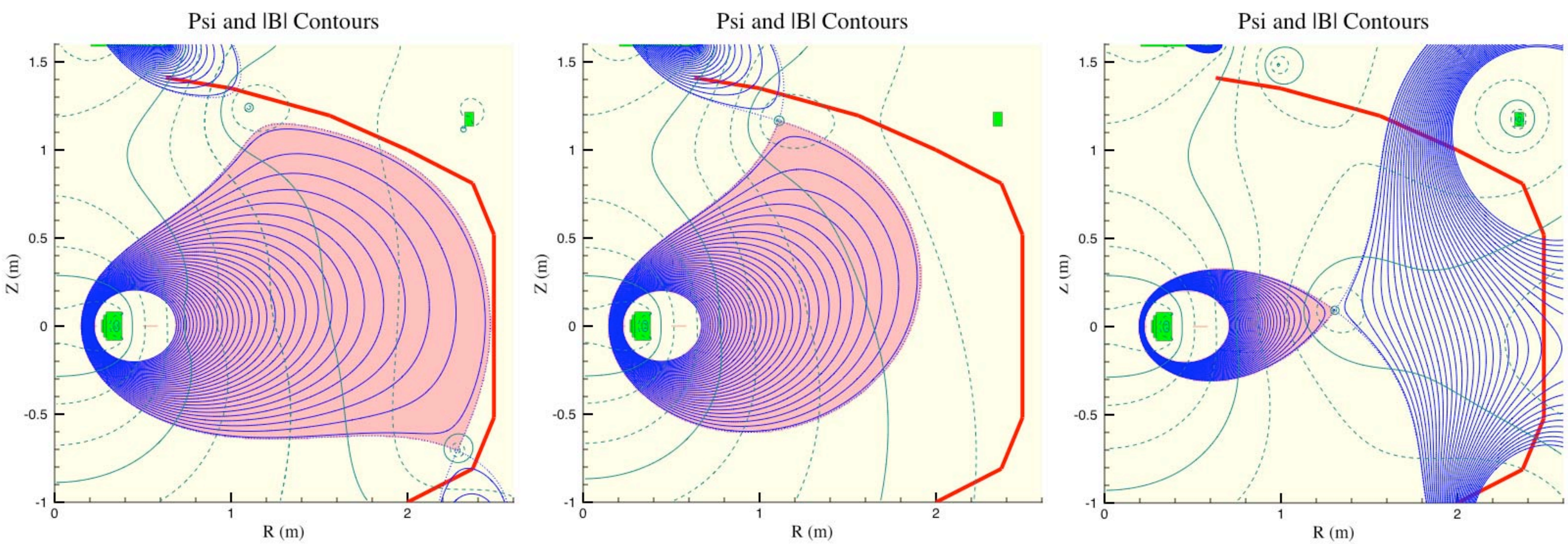
No shaping coil current:
Plasma fills vacuum chamber.

A separatrix is produced

50 kA-turns:
Plasma volume is dramatically reduced

With the Levitation Coil on, a Vertical Field can Expand the Plasma Volume

Equilibria (Levitated Coil Configuration)



Optimized (coil not run as Helmholtz pair)

No applied vertical field (base case)

Vertical field reduces volume

Further Future Work

- Supported campaign
  - Run the floating coil at full nominal current
    - ◊ Additional magnetic field profile point(s).
- Levitated campaign
  - Hot electron plasmas
    - ◊ Additional ECRH frequencies and power
      - More heating profile control than now.
    - ◊ Toroidal field
  - Thermal plasmas
    - ◊ Since the ECRH will be cut off at the relevant densities, this may require additional heating sources.
      - Further profile study will be required.

Summary

- First Plasma!
- We have done limited profile scans of
  - Magnetic field
    - ◊ Moves the 6.4 GHz resonance region such that more closed field lines are accessed.
    - ◊ Increases the overall volume of the absorption region.
    - ◊ Result: Increased diamagnetic flux
  - ECRH Power
    - ◊ Modulation of one source while the second was held constant
      - When outer source (2.45 GHz) is modulated the diamagnetic flux reaches a higher value than for an unmodulated case when the total input power is the same (i.e. both sources are on).
      - When the inner source (6.4 GHz) is modulated the diamagnetic flux is lower than in the unmodulated case.

Reprints of this and other LDX posters are available at our website:

http://www.psfc.mit.edu/LDX