Status and Plans of the Flowing Magnetized Plasma (FMP) Experiment at LANL

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The Flowing Magnetized Plasma (FMP) Experiment

is a new laboratory plasma experiment at LANL

for studying fundamental aspects of flowing plasmas.

This poster focuses on plans to study the

magnetorotational instability (MRI), a candidate to

explain anomalous viscosity in astrophysical accretion.

First FMP plasma was achieved in September, 2003!

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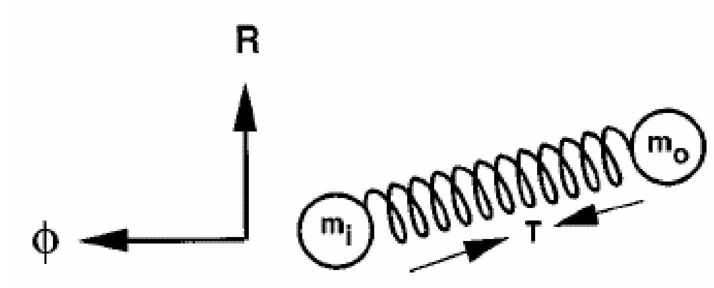
What is the Magnetorotational Instability (MRI)?

- Destabilization of MHD slow-mode wave in weakly magnetized, differentially rotating system

- Incompressible fluid displacement in Keplerian disk leads to same equations as two orbiting masses connected by spring with spring constant $(\mathbf{k}\cdot\mathbf{v}_A)^2$



- Due to tension, m_i loses ang. momentum to m_o; m_i drops down in radius, m_o radius increases; tension stronger → runaway process → magnetic turbulence

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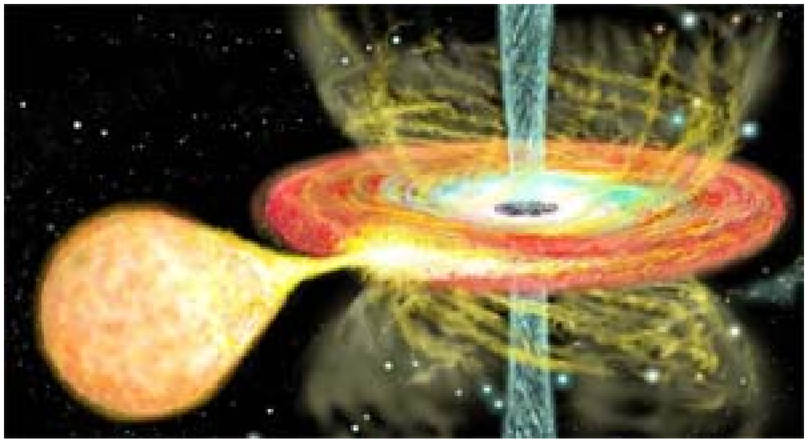
Why Study MRI? Why in Plasma Experiment?



Drawing of binary star system with accretion disk and jets.

- Angular momentum transport not understood in accretion disks
    - Not from classical molecular or plasma viscosity due to high Reynolds numbers
- MRI postulated to excite magnetic turbulence $\rightarrow$ enhanced viscosity
    - MRI has not been identified in observations nor realized in laboratory experiments
- Plasma experiment is flexible and complements liquid metal experiments
    - allows different choices of Prandtl number P_m
    - Couette flow profile achieved via $E_R \times B_Z$ rotation

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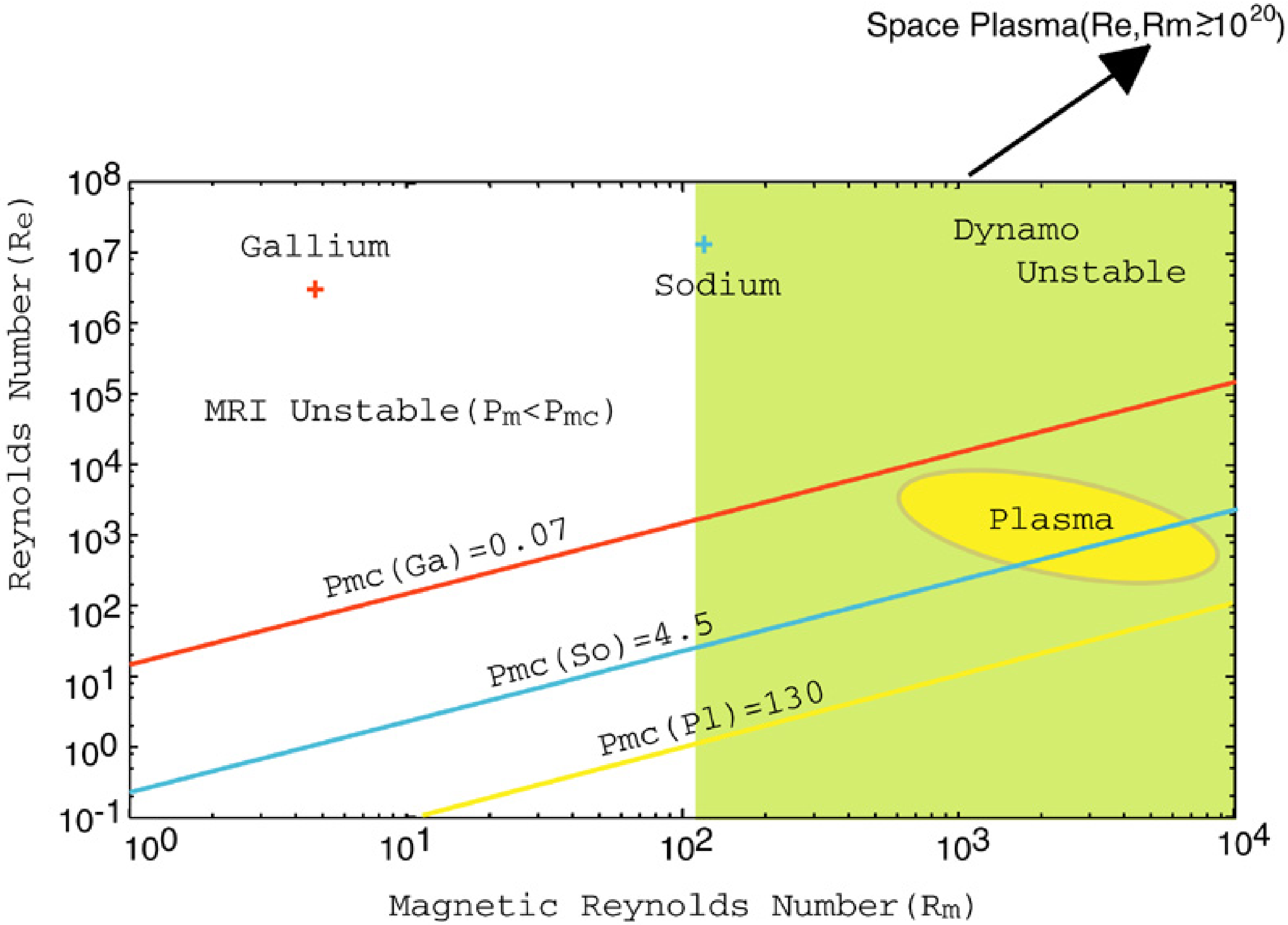
MRI Predicted in Achievable Plasmas



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MRI Linear Stability Analysis

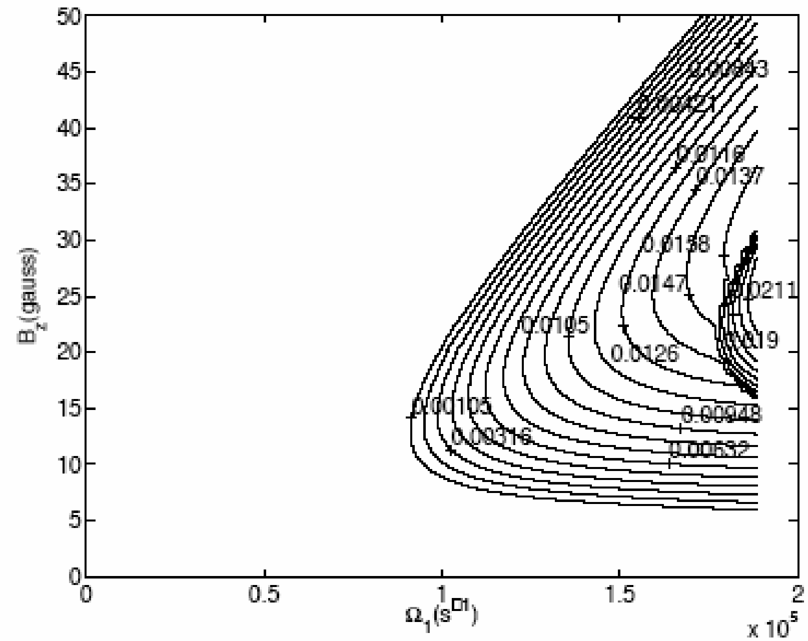
$$[(\gamma + \nu k^2)(\gamma + \eta k^2) + \omega_A^2]^2 + \frac{\partial \Omega^2}{\partial \ln r} \frac{k_z^2}{k^2} \omega_A^2 = 0.$$

Instability Condition

$$\omega_\nu \omega_\eta + \omega_A^2 < \sqrt{2r\Omega\Omega'} \frac{k_z}{k} \omega_A$$

shear Ω' destabilizing; ν,η stabilizing

Axisymmetric m=0 growth rates



P_m=10, n =10^{14} cm^{-3}, T_e=10 eV
R_1=15 cm, R_2=52 cm

Experimentally difficult to keep B_Z < 30 G $\rightarrow$
places constraint on Ω_1 and inner radius R_1 > 15 cm

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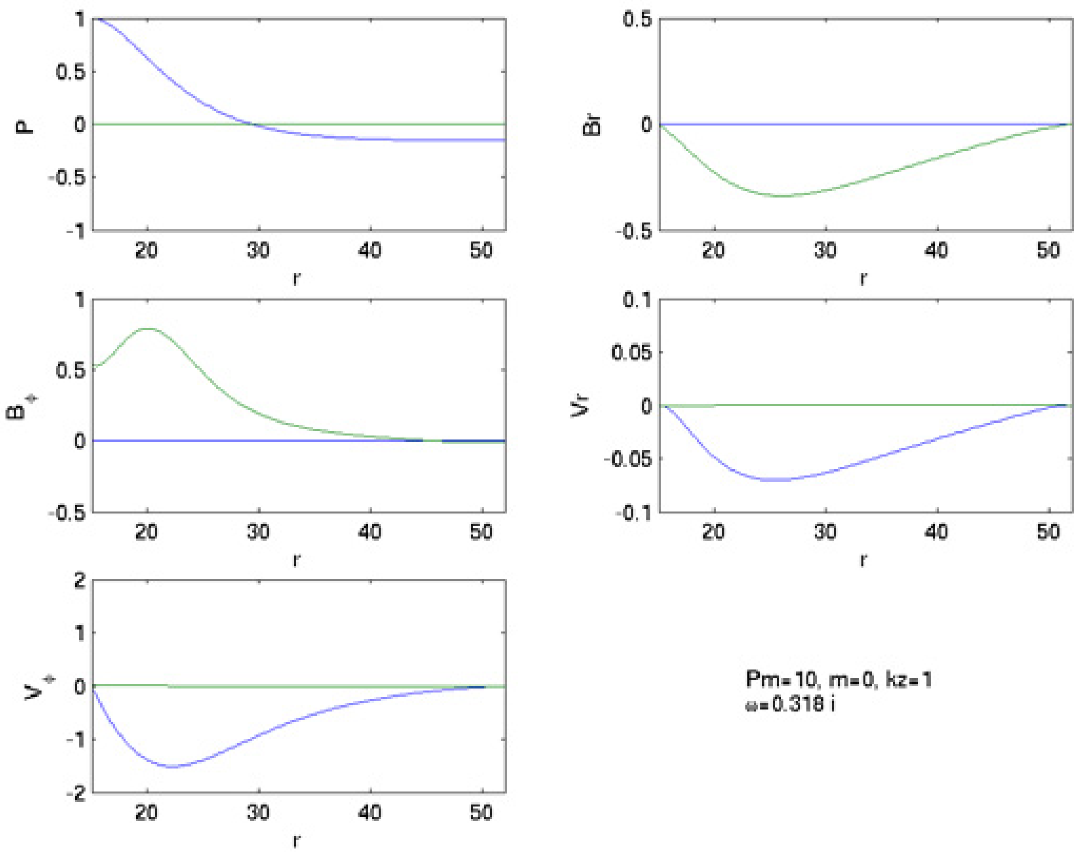
Global Eigenmode Analysis

Axisymmetric m=0 perturbed eigenfunctions



Close collaboration with theory will guide experimental measurements

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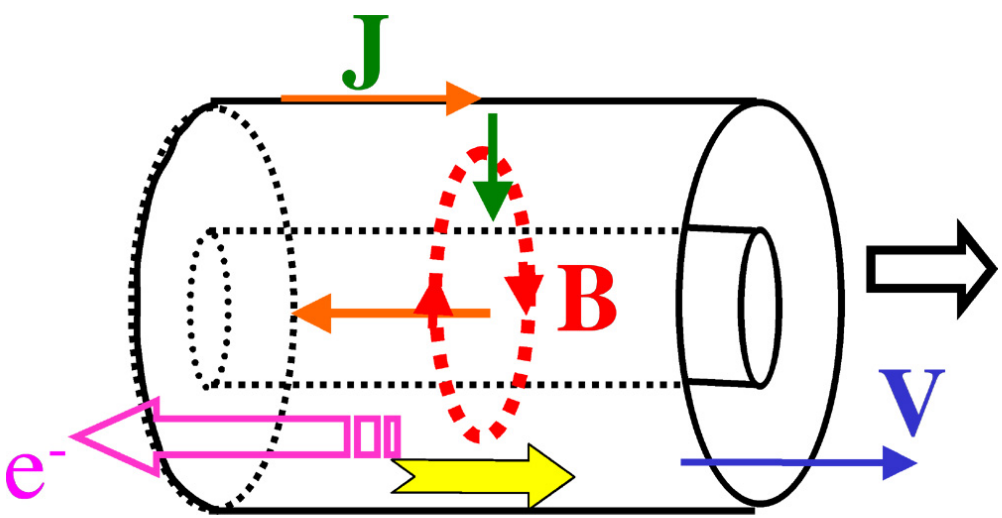
FMP Source Requirements

- Time scale > few predicted growth times of MRI → ~1 ms
- Density ~ 10^{13} – 10^{14} cm^{-3}
- Temperature ~ 10 eV

Issues:

- End losses require average power input ~30 MW to sustain required *n* and *T*
- Several ms duration requires ~100 kJ total stored energy



Pulsed coaxial gun discharge best candidate to satisfy all the above

FMP Plasma Rotation Requirements

- Need Couette flow profile $U_\phi \sim 1/R \rightarrow E_R \sim 1/R$ if $B_Z(R)$ constant (for $E \times B$ driven rotation)
- For $U_\phi = U_{E\times B} = C_s \rightarrow E_R = C_s B_Z \approx$ 150 V/m for B=50 G and T_e=10 eV
- For negative bias center electrode $I_{sat} \approx (1/2) neAC_s \approx 200$ A (5 cm diameter, 1 m long rod, T_e=10 eV) $\rightarrow$ 20 kW required

Issues:

- Will U_ϕ arise from $E_R B_Z$?
- Understand $E_R(R)$ penetration into plasma
- How to get desired $E_R(R)$ profile (concentric end electrodes?)
- Achieve desired biasing without drawing too much electrode current (worry about intolerably high B-field)

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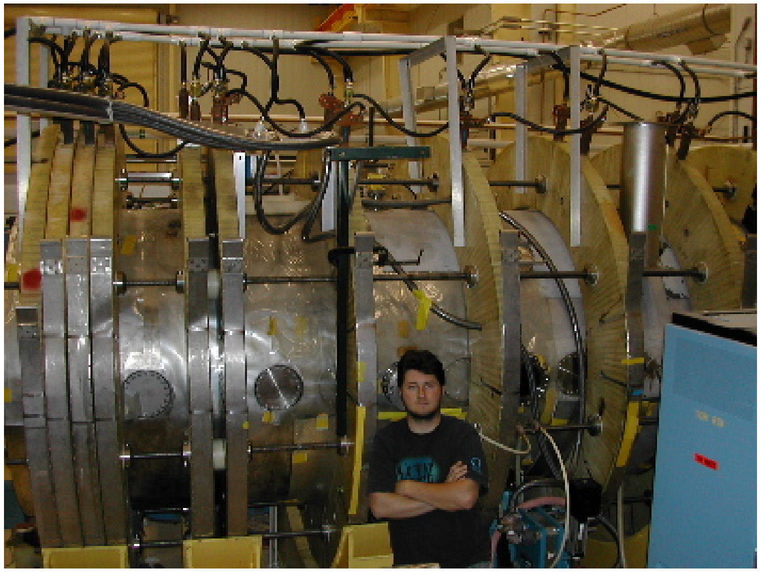
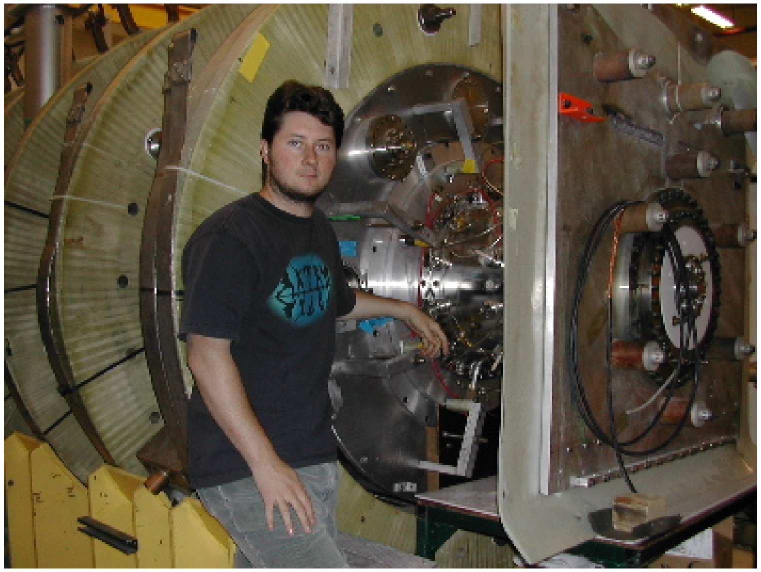
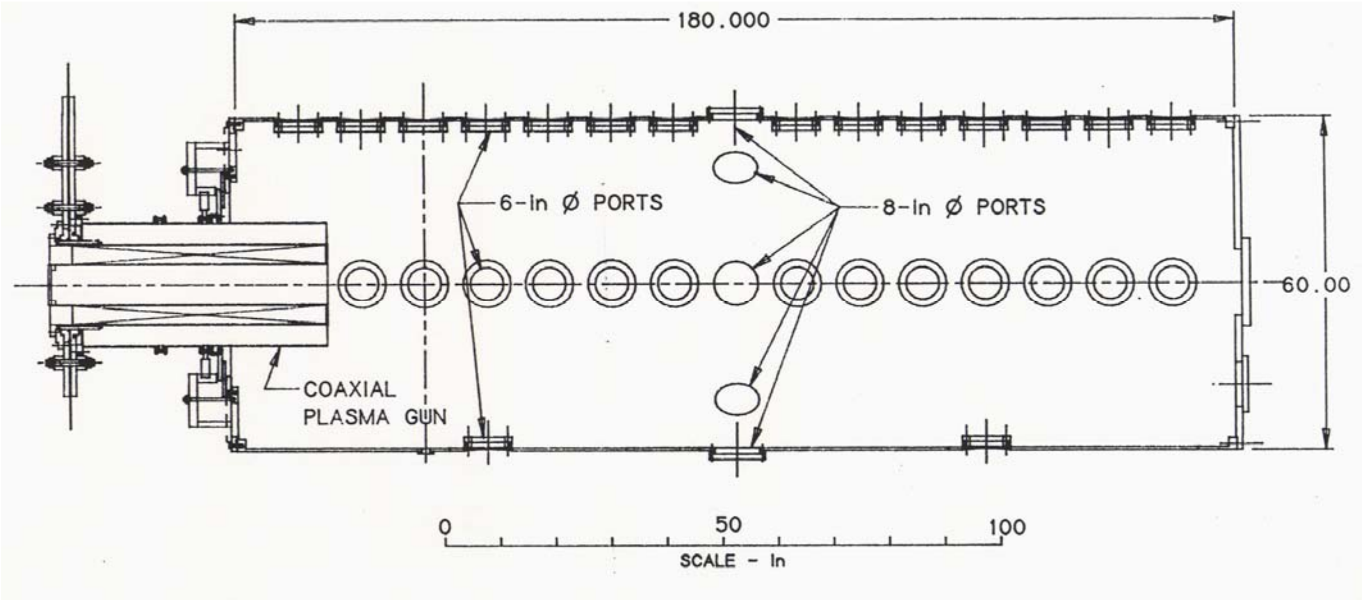
Old CTX Spheromak Facility Resurrected as FMP







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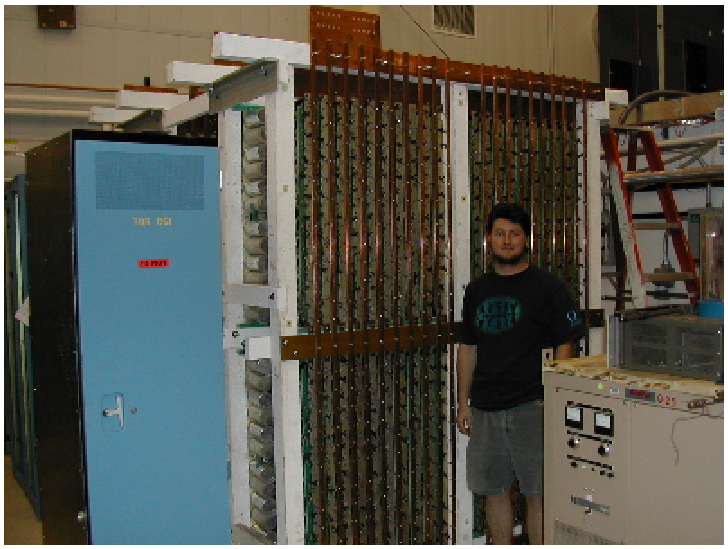
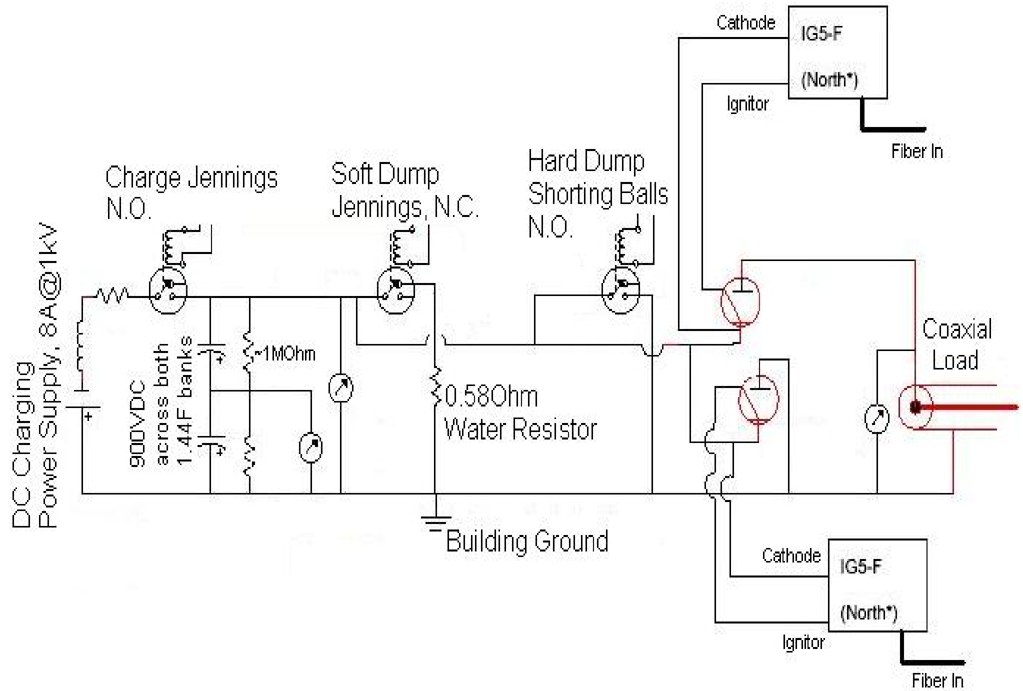
FMP Bank Constructed With Recycled Capacitors





0.72 F bank at 900 V $\rightarrow$ 300 kJ

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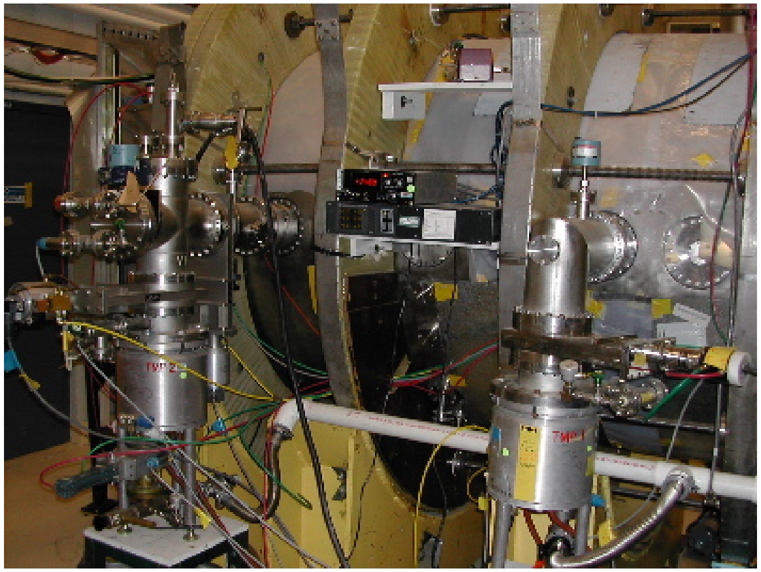
More Experimental Details

- Vacuum chamber at 10^{-5} Torr, expect low 10^{-6} Torr range
  - 3 turbo pumps (total 1500 liters/sec)
- Up to 100 G axial field produced by external magnets powered by 30 V, 1250 A DC supply



- Large control room
- LabView control and data acquisition
- Dozens of DAQ channels, 1-100 MHz, 8 & 10 bits

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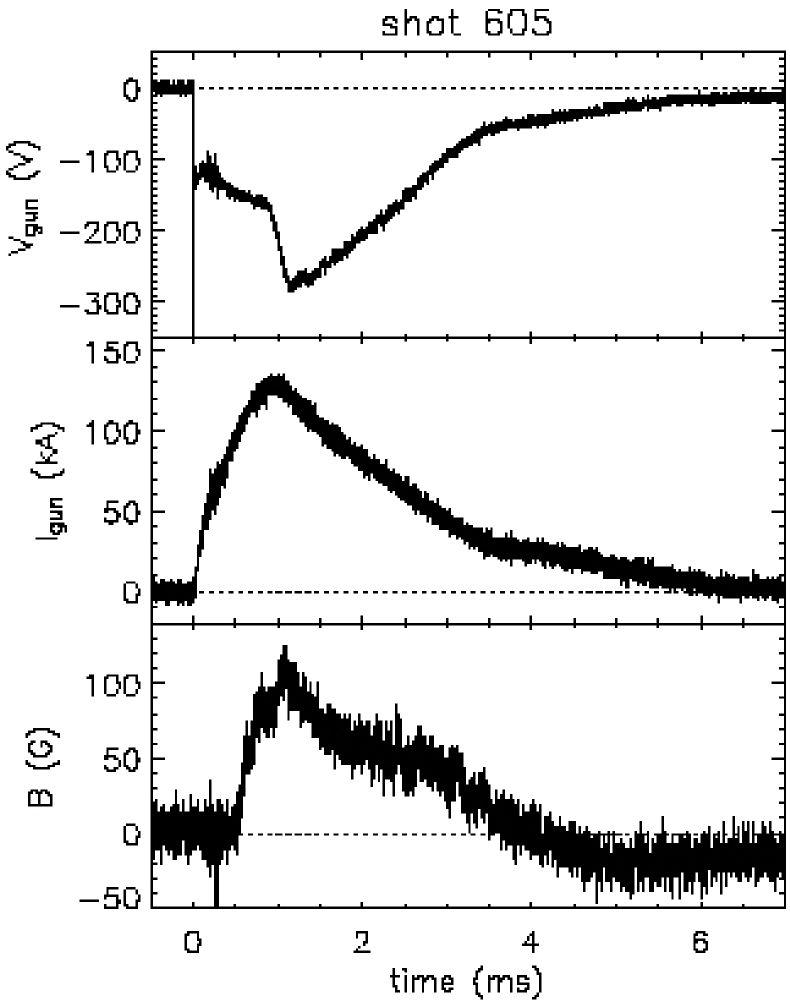
First Plasma Achieved September 2003!!

A representative early shot:

End view toward coaxial gun



- sub-kV breakdown
- 36 MW peak gun power w/half bank
- $B_\phi \approx 100$ G at vacuum wall

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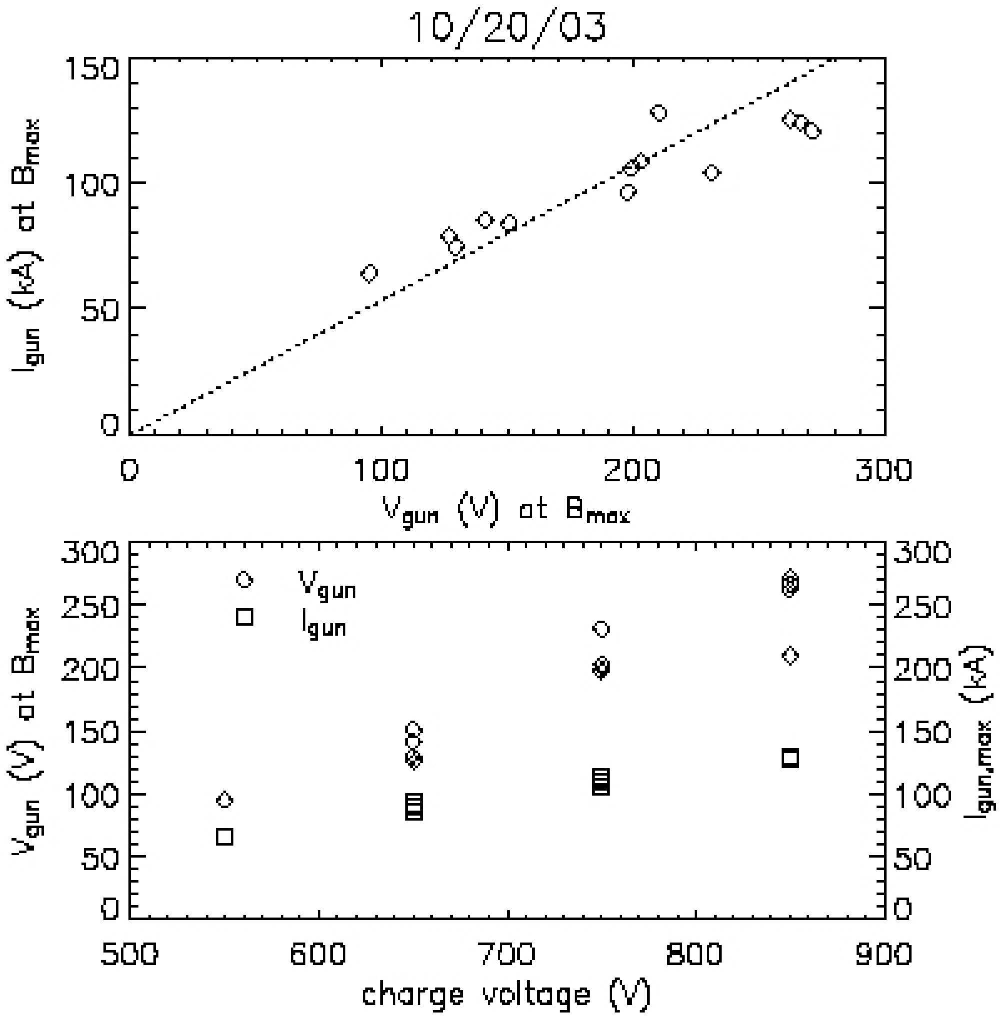
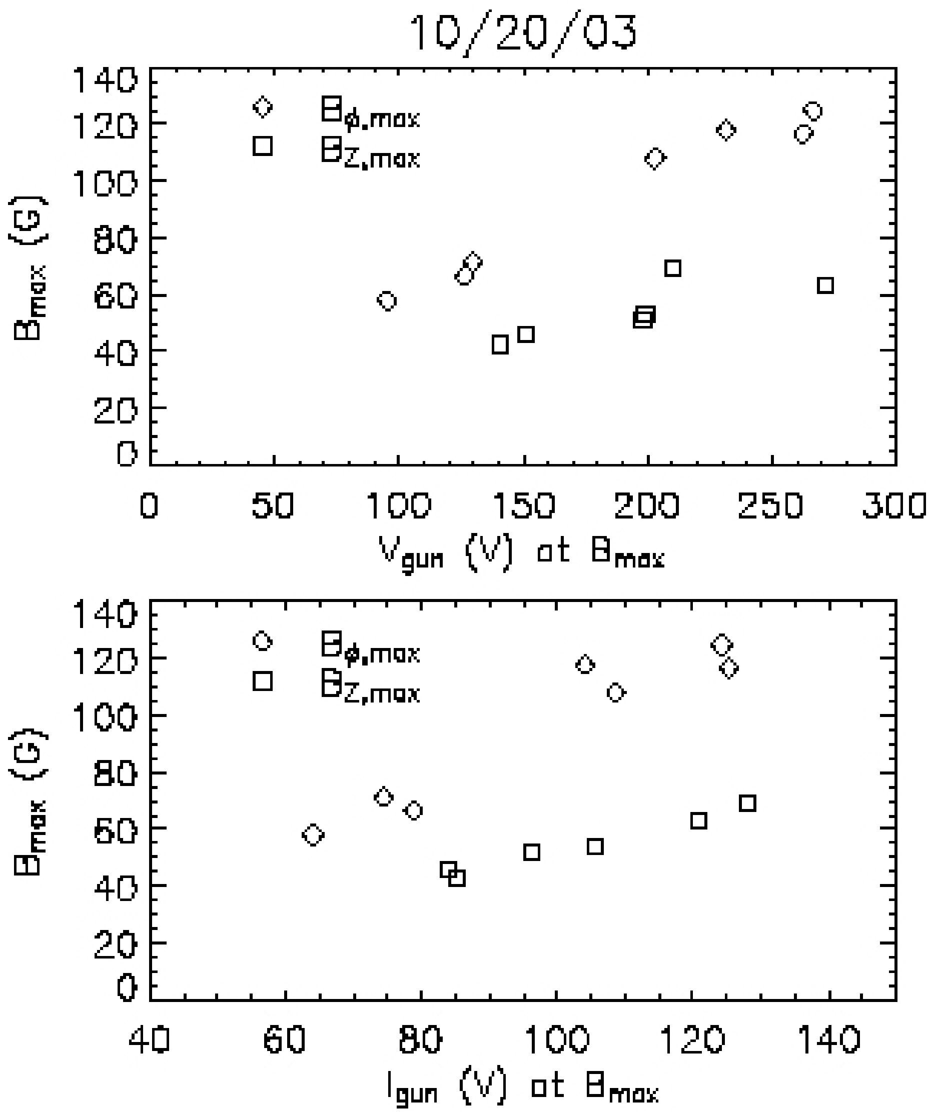
Early Data on Gun Characterization



- $Z_{plasma} \approx 2\ m\Omega$
- V_{gun} & I_{gun} linear with charge voltage
- 35–40% energy efficiency from bank to gun

Single Point Magnetic Measurements at Wall



- *B*-probe indicates $B_{\phi,max} \approx 2B_{Z,max}$ at wall
- Consistent with flux conversion, dynamic relaxation
- Magnitude of *B* may be too big for MRI → need to reduce *B*

Planned Diagnostics to Look for MRI Modes

- Magnetic probe arrays for $\mathbf{B}(R,Z,t)$
- Mach probes, Doppler spectroscopy for $U_{i\phi}(R,Z,t)$ and viscosity measurements
- Langmuir probe for $n_e(R,Z,t)$, $T_e(R,Z,t)$, $V_f(R,Z,t)$
- Emissive probe for $V_p(R,t) \rightarrow E_R(R,t) \rightarrow$ independent determination of $U_{i\phi}$ via $E_R \times B_Z$
- Fluctuation diagnostics to confirm frequency spectra of MRI mode activity

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Other Experimental Issues

- Gas injection (slow and fast gas puffing) to maintain plasma for several ms time-scale
- *B* field strength associated with coaxial gun operation probably stabilizes MRI
  - devise method to trap flux inside gun (*e.g.*, metal mesh at mouth of gun)
- Conducting or insulating boundary (guidance from numerical results)
- Center and (?) end concentric-ring bias electrodes

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Summary

- New Flowing Magnetized Plasma (FMP) experiment underway at LANL
- Will create Couette flow configurations to excite MRI
  - MRI postulated to generate magnetic turbulence and enhanced viscosity in accretion disks
- Obtained first plasma in September 2003
- Upcoming plans:
  - Further gun and plasma characterization
  - Bias electrode implementation
  - Diagnostic development
  - Find suitable rotational equilibrium for MRI excitation

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