Measurements of radial profiles of rotational velocity on MCX and assessment of velocity shear stabilization

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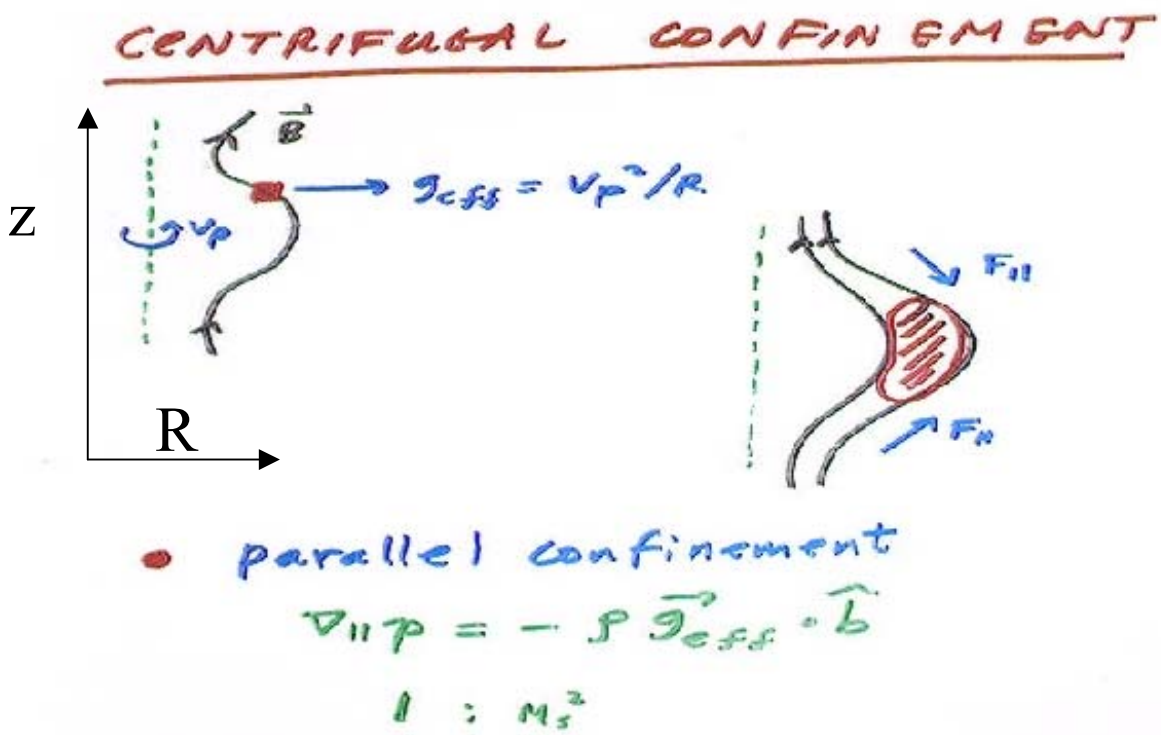
Maryland Centrifugal Experiment

- Innovative Confinement Concept experiment supported by DOE.

GOALS

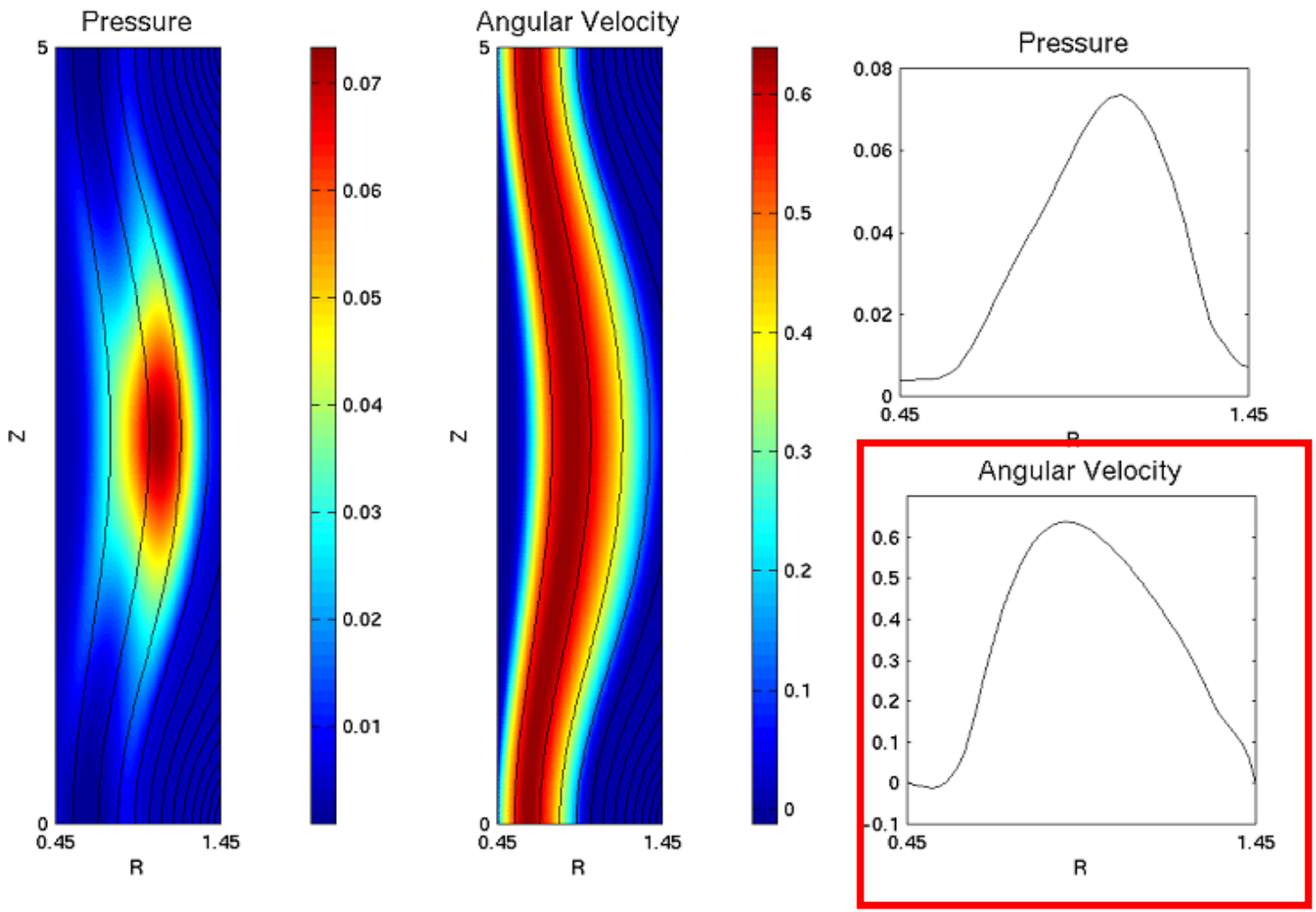
- Achievement of supersonic rotation:
  Done: Ellis et al., Phys. Plasmas, **12**, 055704 (2005).
- Demonstration of centrifugal confinement of magnetized plasma.
- Demonstration of velocity shear stabilization.

Centrifugal confinement of magnetized plasmas



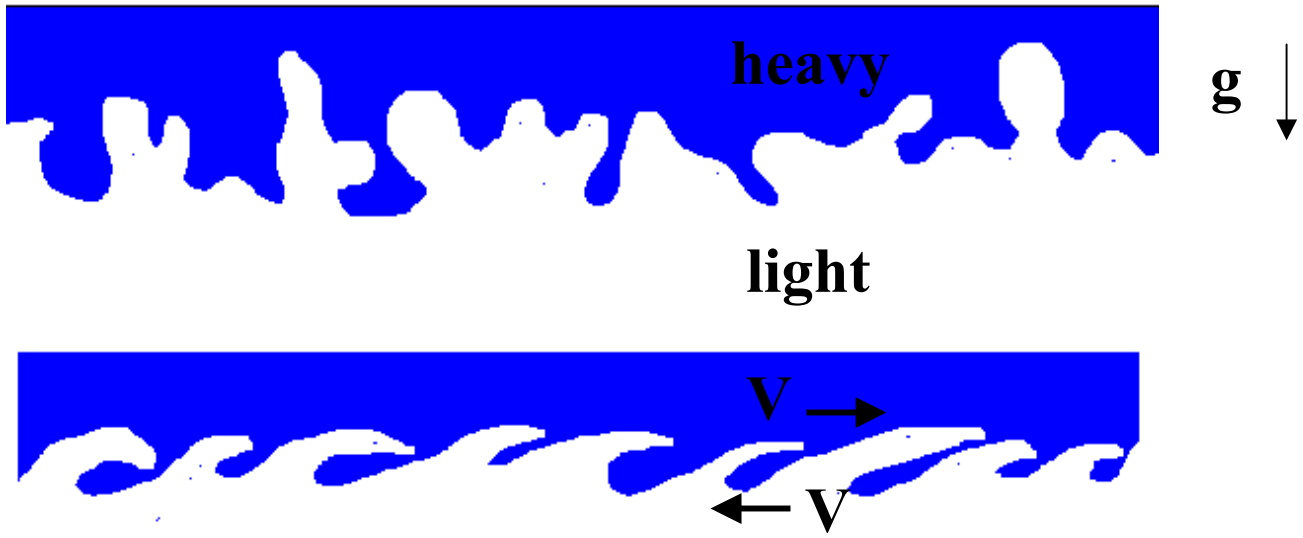
- Works in open magnetic field configurations.

NMCX shows non-uniform angular velocity



- $\Omega(R) \neq$ constant

Sheared velocity stabilizes interchanges



$$V' > \gamma_{int} [ln\ R_\mu^{1/3}]^{1/2}$$

Hassam, *Phys. Plasmas 1992*

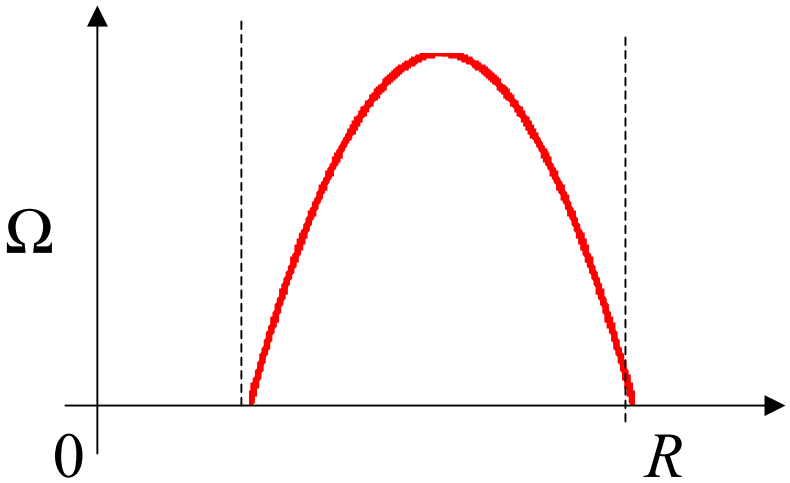
for smooth profiles, sonic interchanges

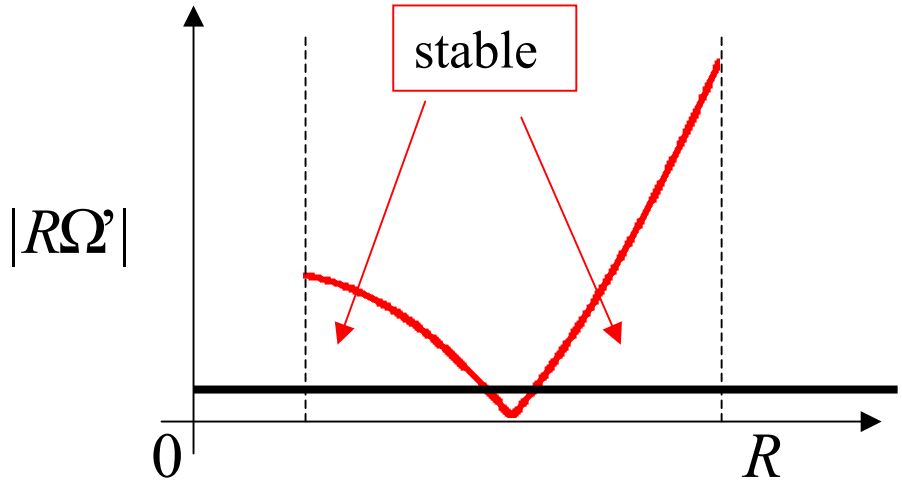
$$\Rightarrow \quad M_s > [ln\ R_\mu^{1/3}]^{1/2}$$

- Cylindrical coordinates R, Ω, z: $V' \equiv R(d\Omega/dR) = R\Omega'$
- Rigid-rotor rotation does not stabilize instabilities.

Shear is effective over almost the entire radial profile

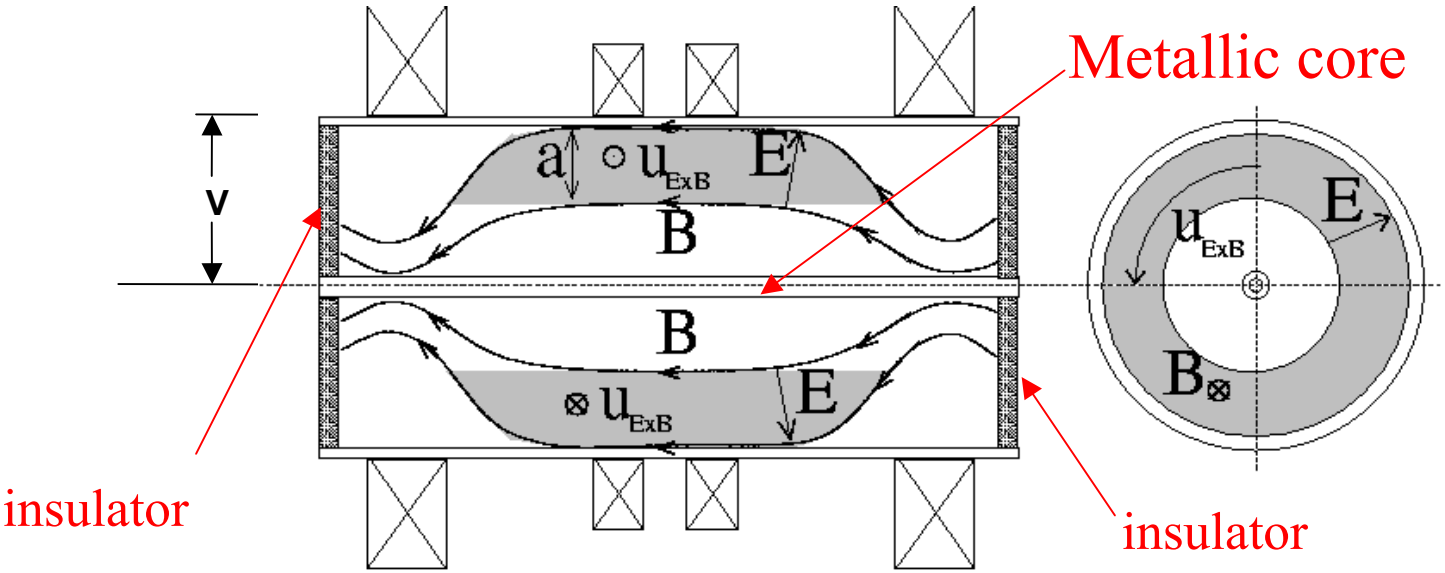
- Local stability condition: $R\Omega' > \gamma_{\text{int}} \left[ln(\mathbf{R}_{\mu}^{1/3}) \right]^{1/2}$





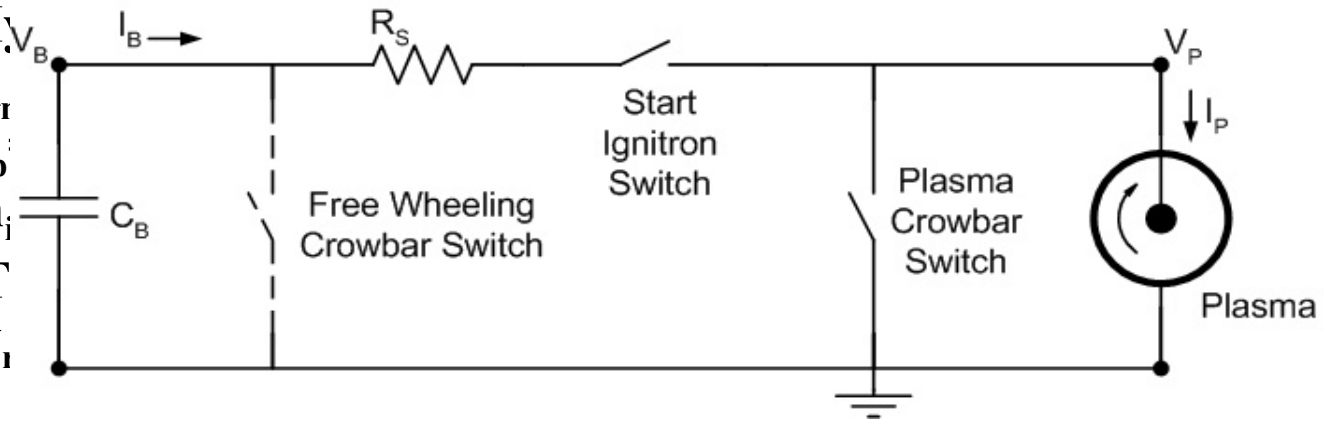
- $\gamma_{\text{int}} \propto c_s (a_p L_p)^{-1/2}$
- $\mathbf{R}_{\mu} \sim 150$

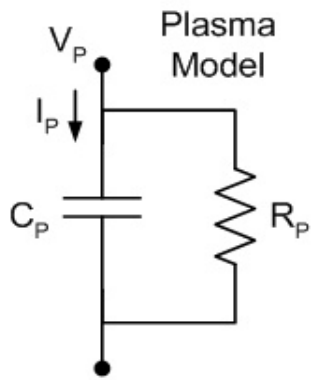
MCX: a shaped magnetic-field machine



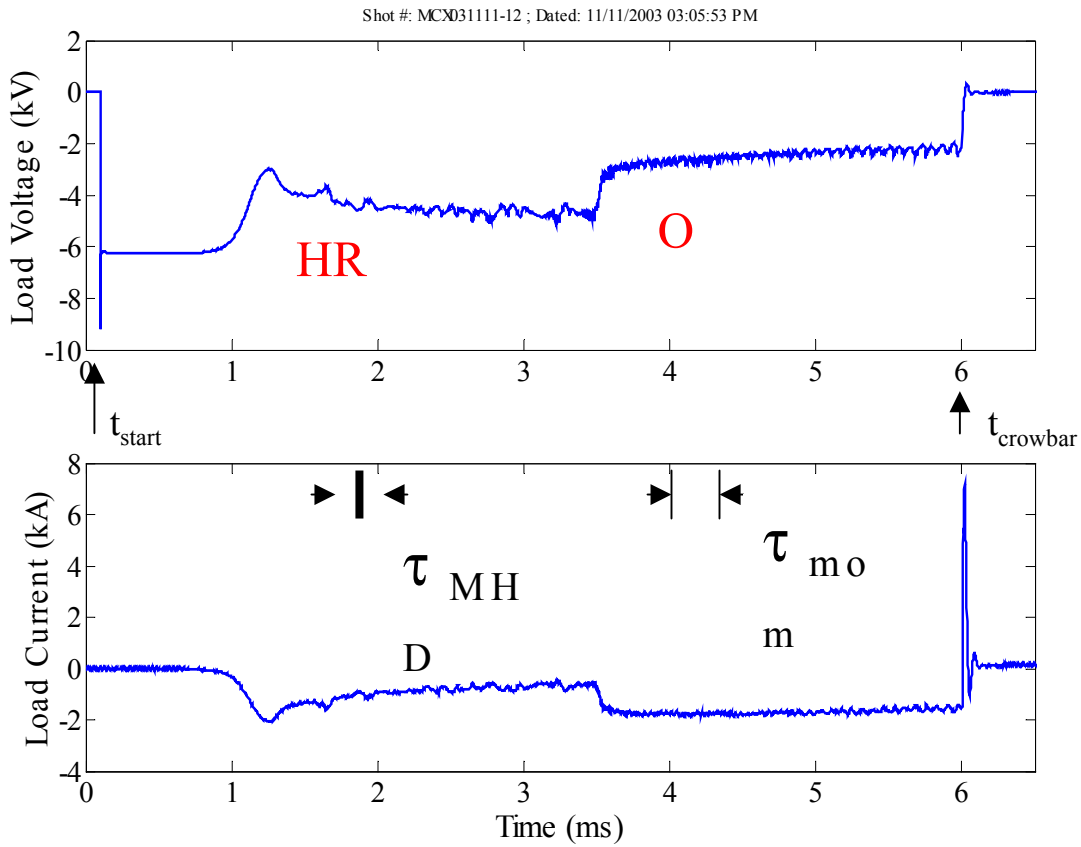
- initial vacuum **E·B** => breakdown, **V~ 10 kV**

- **H**
- **R**
- **a**
- **n**
- **T**
- **v**





Plasma voltage remains steady for 1000's of MHD instability times



V_P

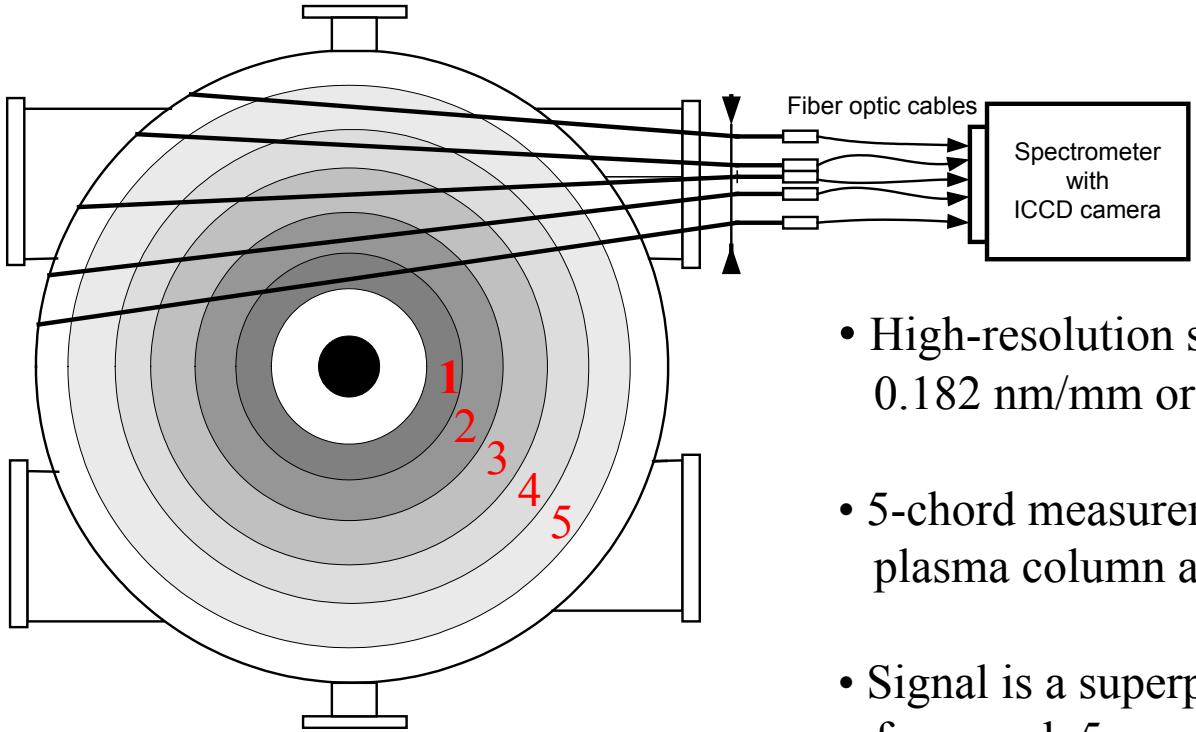
I_P

- HR mode: $M_S \sim 3$
- O mode: $1 < M_S < 2$

$M_S = v_{rot} / c_S$

- MHD instability growth time $\tau_{MHD} \sim 2$ - 20μs.
- Measured momentum confinement time $\tau_{mom} \sim 200$μs.
- **MHD stable due to velocity shear?**

Multi-chord spectroscopic measurements of Doppler shifts at midplane

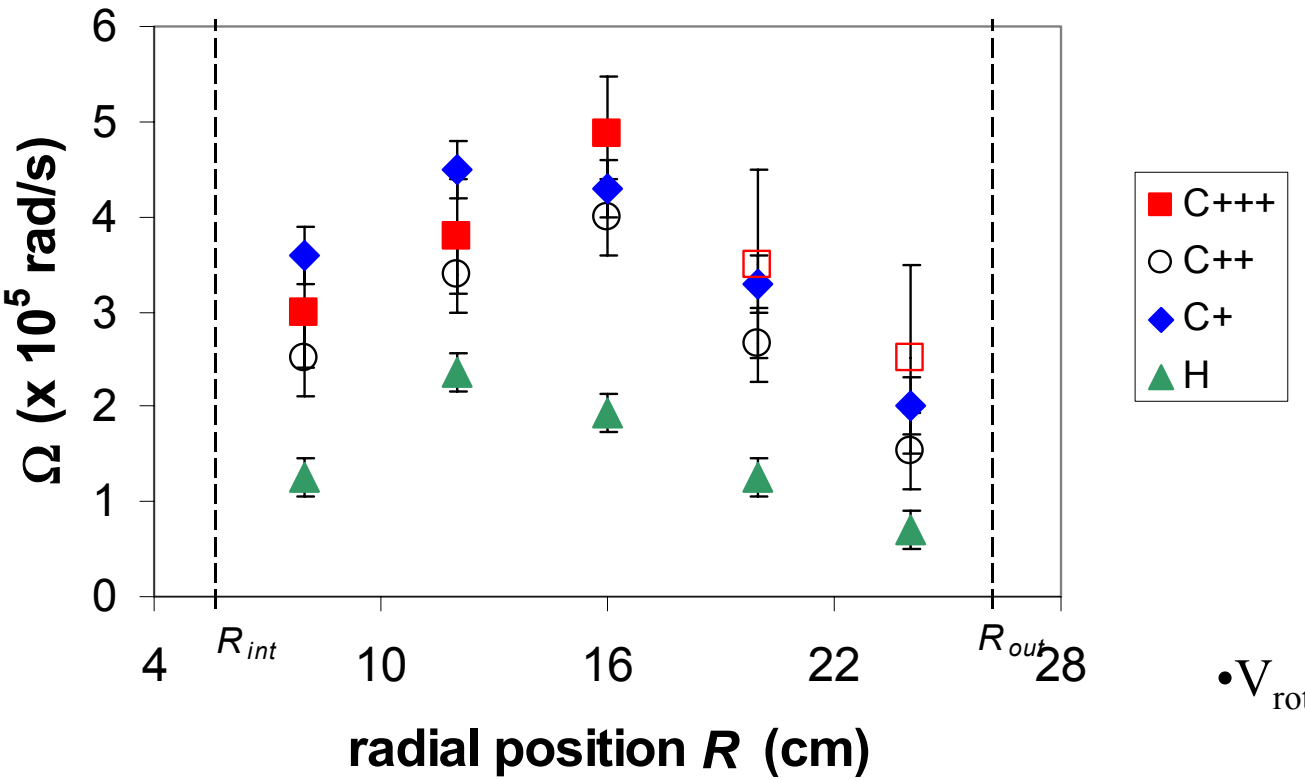


- High-resolution spectrometer: 0.182 nm/mm or 0.692 nm/mm.
- 5-chord measurements across plasma column at midplane.
- Signal is a superposition of signals from each 5 user-defined annular zones:

$$S_i(I_i, v_i) = S_{ii}(I_{ii}, v_{ii}) + \sum_{i<j} S_{ij}(I_{ij}, v_{ij}), \quad i, j = 1,\ldots,5$$

- Deconvolution yields intensity $I(R)$ and velocity $v(R)$ radial profiles.

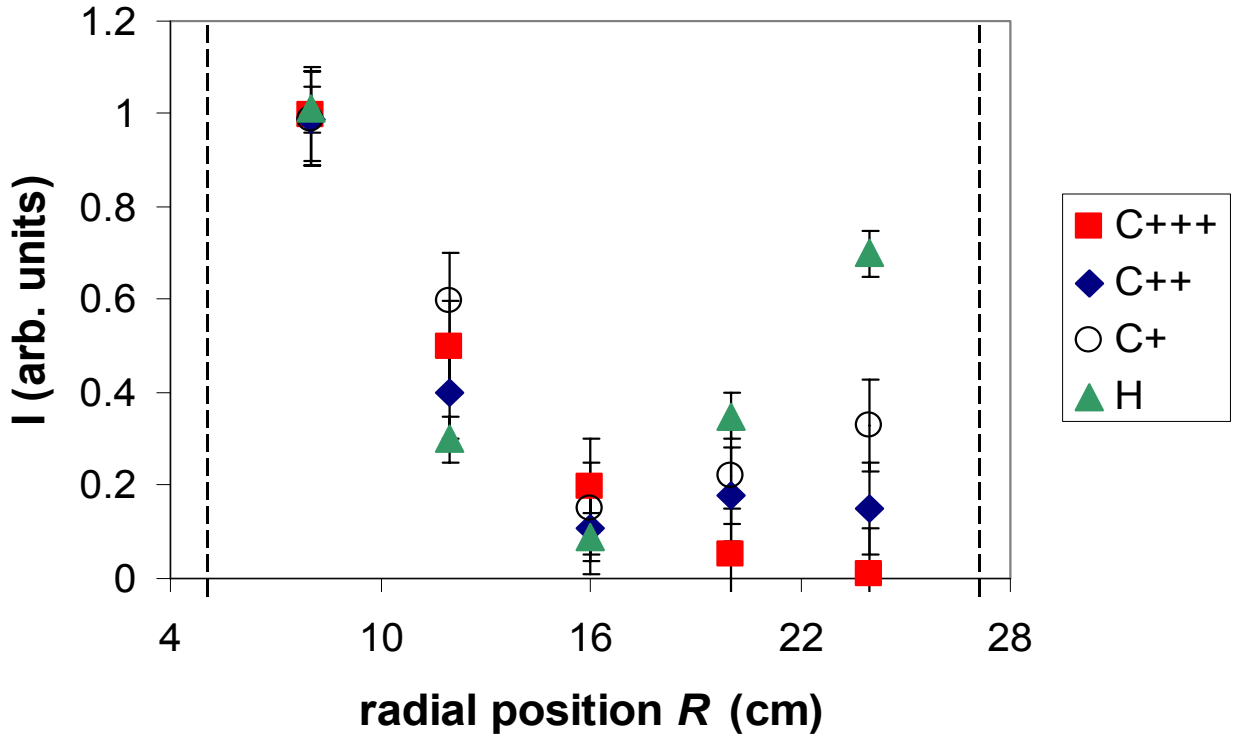
Plasma angular velocity peaks in the middle of the plasma column



•V_{rot} ~ 80 km/s

- MCX plasma does not show rigid-rotor rotation.
- **E** × **B** drift is the dominant motion ⇒profiles are species-independent.

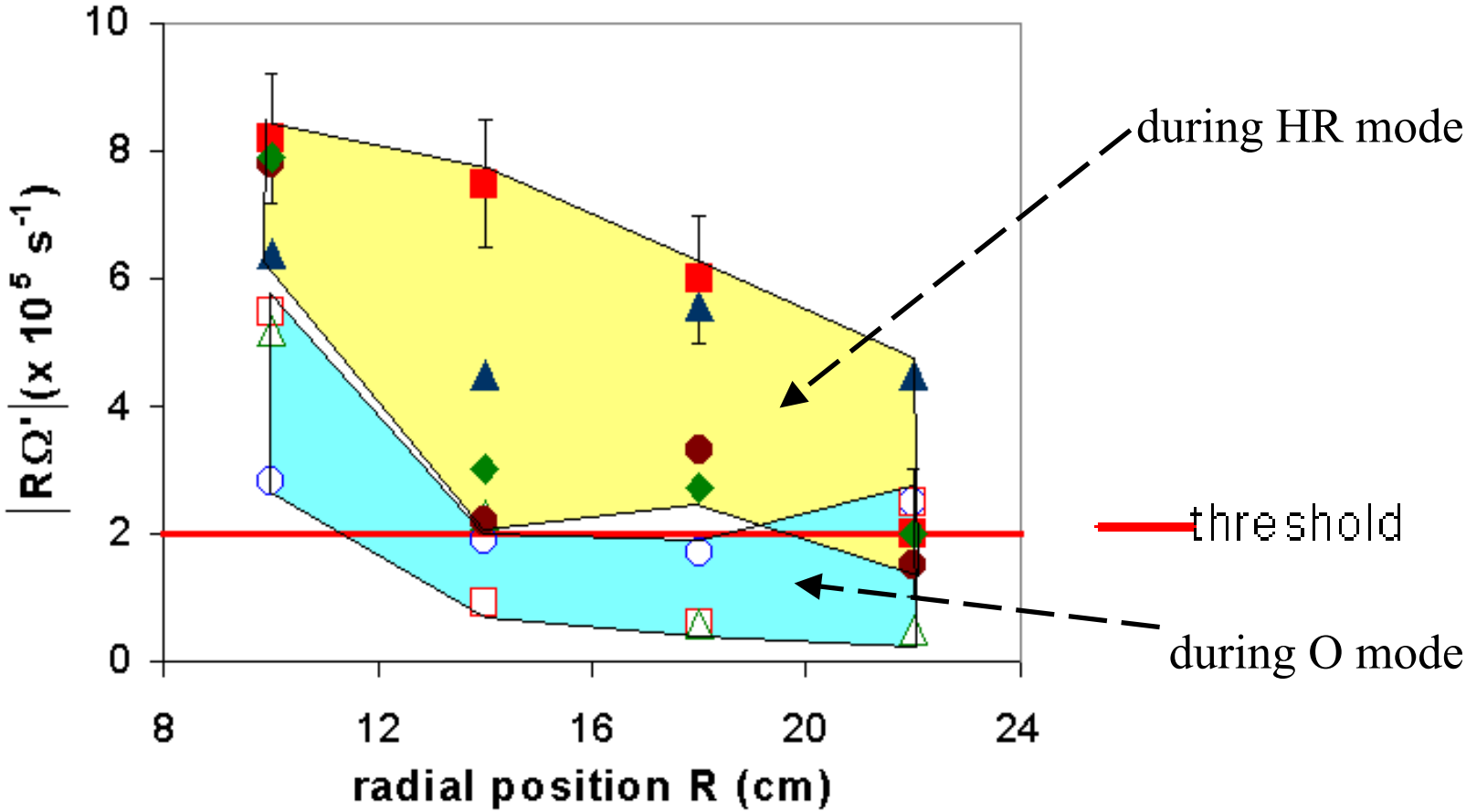
Neutrals and impurities are largely depleted in the middle of the plasma



• Neutrals at the plasma edges produce large velocity drag.

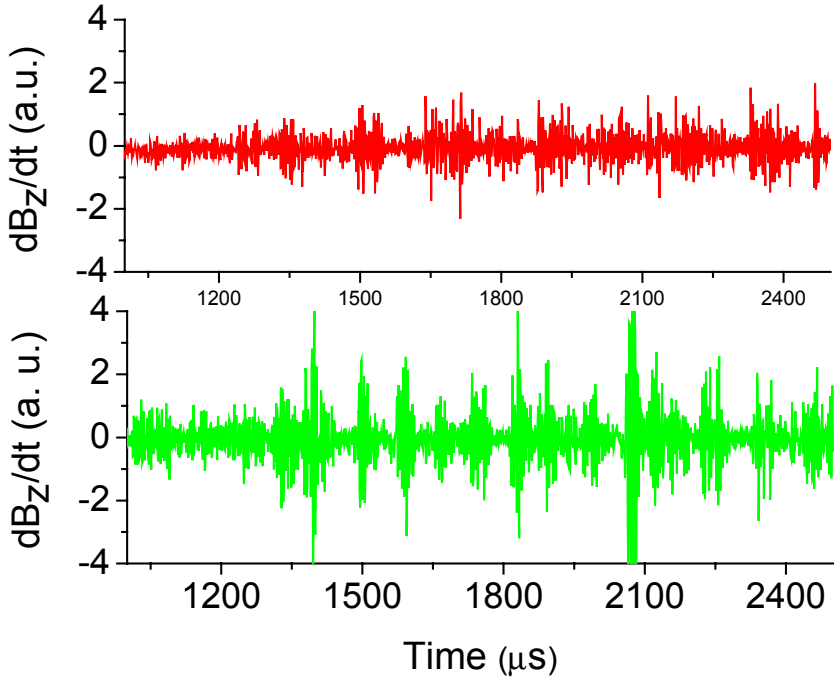
Shear is large enough for mode stabilization

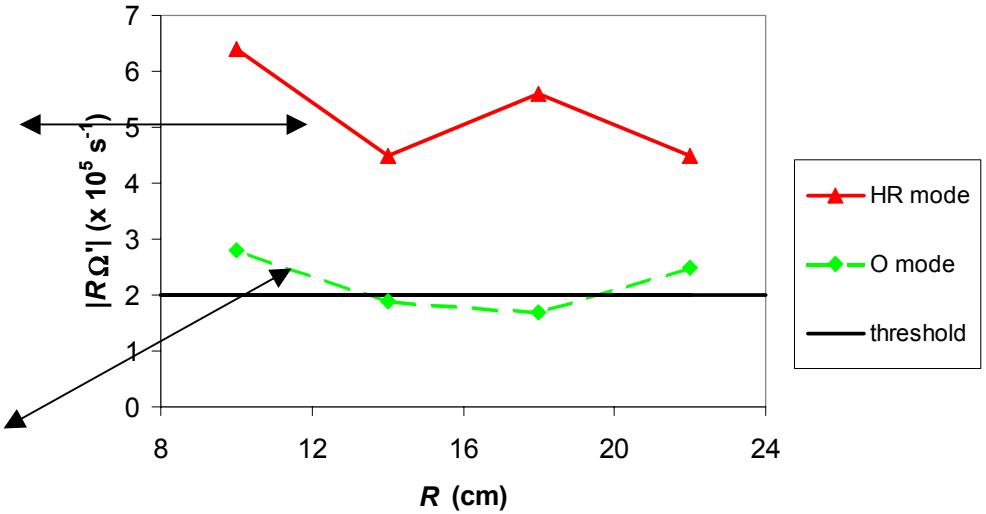
- Velocity shear from C^+ Doppler shifts shows stability threshold is exceeded



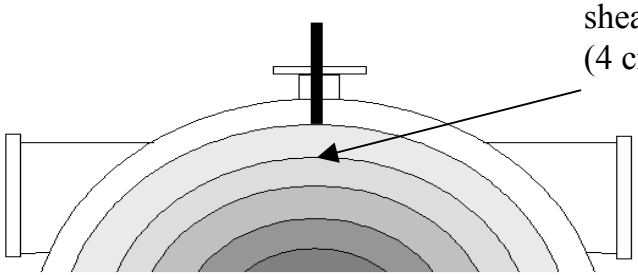
$$R\Omega' > \gamma_{\text{int}} \left[ln(\mathbf{R}_{\mu}^{1/3}) \right]^{1/2} \Leftrightarrow \text{stable} \quad (\gamma_{\text{int}} \propto T^{1/2}, T=30 \text{ eV})$$

Strong shear correlates with decreased magnetic activity amplitude on the outer edge of plasma

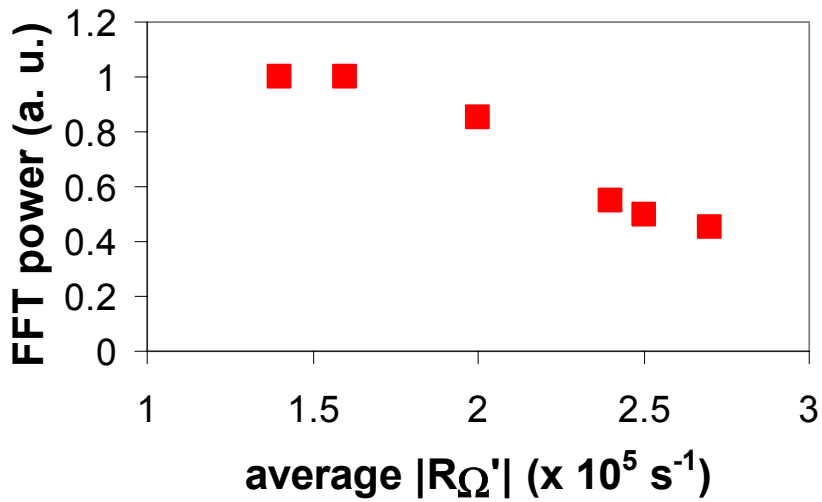




Off-midplane magnetic probe



Outermost point where shear is calculated (4 cm from probe tip)



Summary

- Multi-chord, Doppler shift measurements of impurity and neutral lines were performed on MCX.

- MCX plasma does not show rigid-rotor rotation: $\Omega(R) \neq$ constant.

- Rotation velocity shear $R\Omega'$ exceeds predicted threshold for stabilization of interchanges.

- Off-midplane, plasma-edge magnetic activity amplitude diminishes in the presence of strong shear.