Alcator C-Mod

The Dependence of Core Rotation on Magnetic Configuration and the Relation to the H-mode Power Threshold in Alcator C-Mod Plasmas with No Momentum Input

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Motivation:

Rotation and velocity shear play important roles in the H-mode transition and ITB formation.

Most measurements are in plasmas with strong momentum input from NBI, which masks spontaneous rotation.

Long-standing mystery of why there is a higher H-mode power threshold in plasmas with the X-point away from the ion ∇B drift direction.

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Outline

- Experimental Setup
- Toroidal Rotation in L-mode Plasmas and the Dependence on Magnetic Configuration
- Rotation in H-mode Plasmas and the Relation to the H-mode Power Threshold
- Summary and Conclusions

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$B_T < 8$ T, $I_P < 1.8$ MA, Mo PFC
R=0.67 m, strong shaping
$n_e < 1\text{x}10^{21}/m^3$, $T_e < 5$ keV
(no NBI)

ICRF

3 MW 80 MHz, 2 strap
3 MW 40-80 MHz, 4 strap
0-π phasing, no momentum input

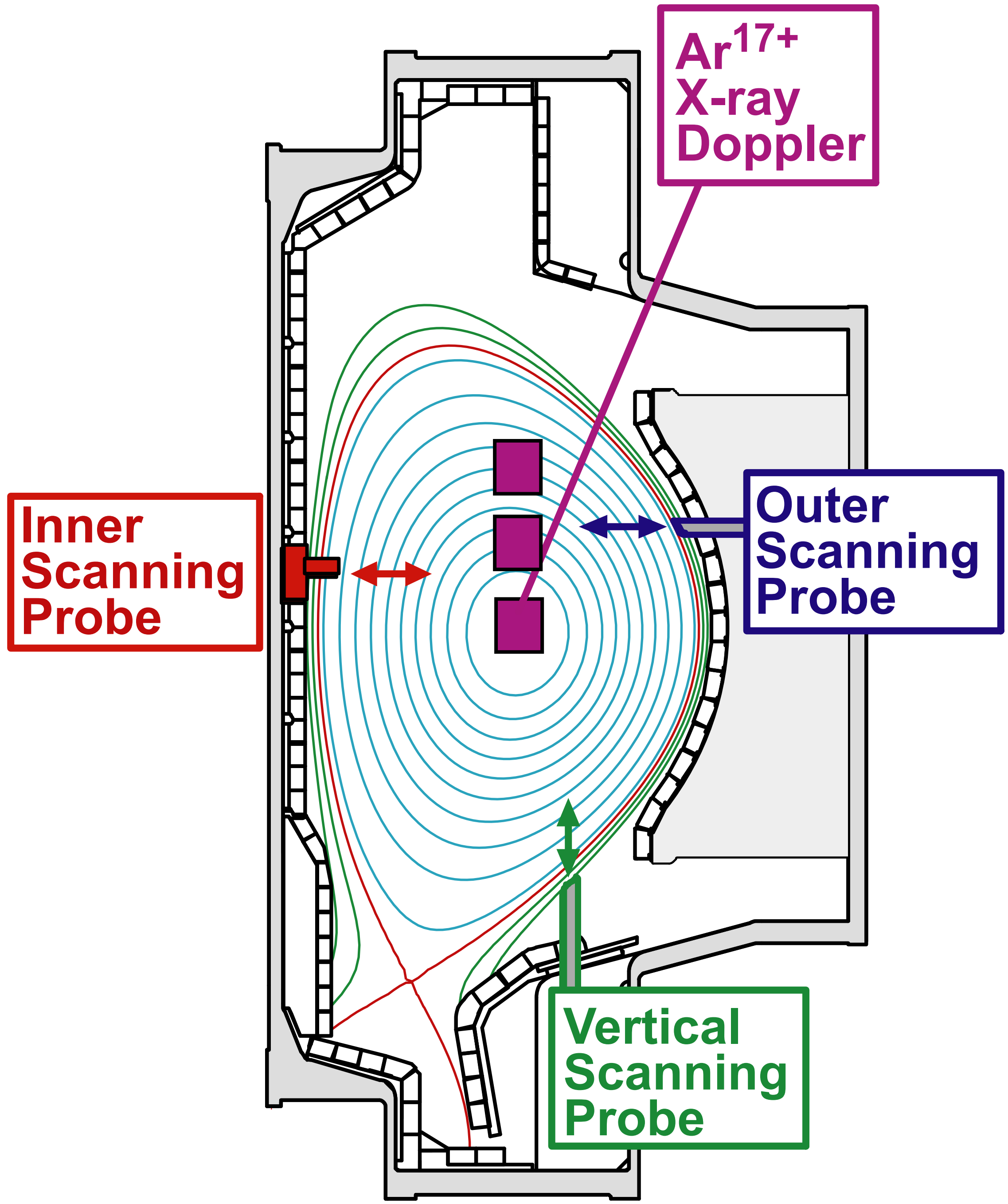
Rotation measurements:

X-ray Spectrometers

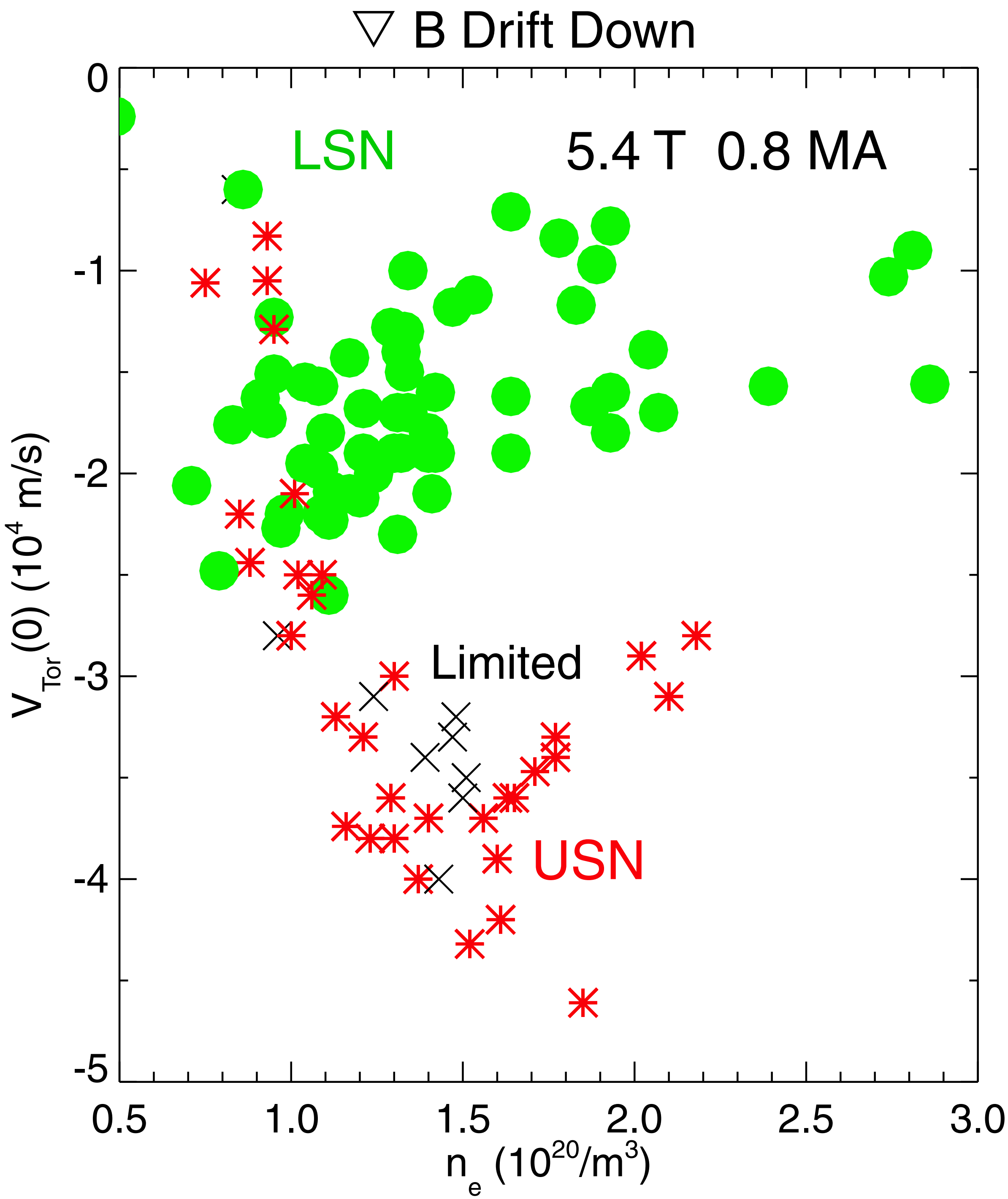
von Hamos type, H- and He-like Ar
3 tangential views, vertically offset
coverage at r/a = 0.0, 0.3 and 0.6

Probes

scanning probes in the inner and outer SOL



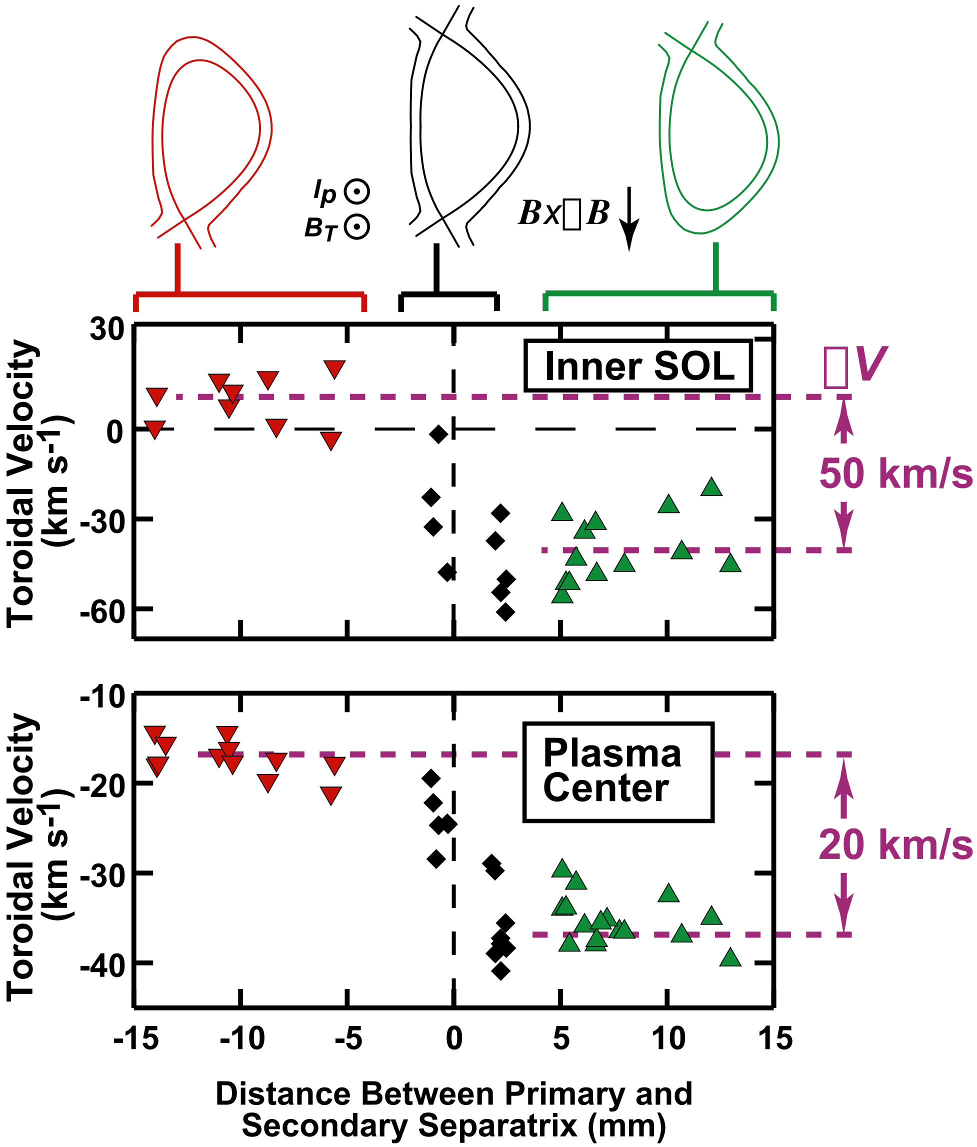
L-mode Rotation Velocity Depends Strongly on Magnetic Configuration



Core rotation is generally counter-current in L-mode (negative).

USN and limited discharges have very strong counter-current rotation in L-mode for electron densities above $1 \times 10^{20}/m^3$. Similar differences are seen in the inner and outer SOL.

X-point Topology Sets Magnitude and Direction of Transport-Driven SOL Flows => Core Plasma Rotation is Affected



- **Toroidal flows near separatrix shift toward counter-current in sequence: lower => double => upper-null**

- **Central plasma toroidal rotation correspondingly shifts more toward counter-current direction**

- **Toroidal velocity change is largest on inner SOL**
  => suggests inner SOL flow is responsible for change in rotation of confined plasma!

Transport-driven SOL flows impose boundary conditions on confined plasma

B. LaBombard, *et al.*, Nucl. Fusion **44** (2004) 1047.

If Transport-Driven SOL Flow/Rotation Paradigm is Correct, Radial Electric Fields in SOL Should Depend on X-point Topology

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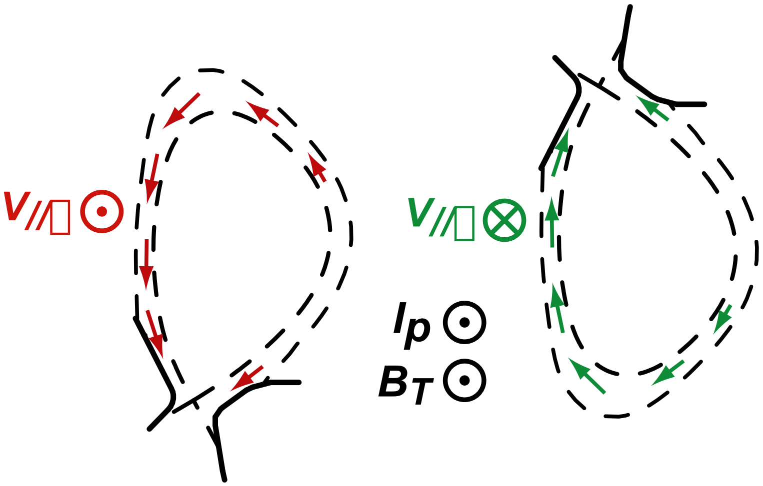
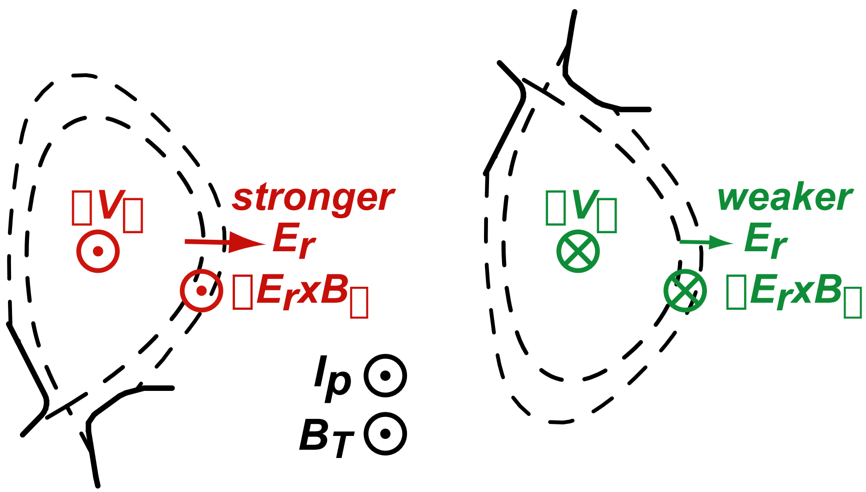
□ transport-driven parallel SOL flows



- **Ballooning-like transport leads to a helical flow component in the SOL with *net volume-averaged toroidal momentum*: co-current for lower null, counter-current for upper null**

- **Being free to rotate only in the toroidal direction, the confined plasma acquires a corresponding co-current or counter-current rotation increment**

Influence on plasma rotation

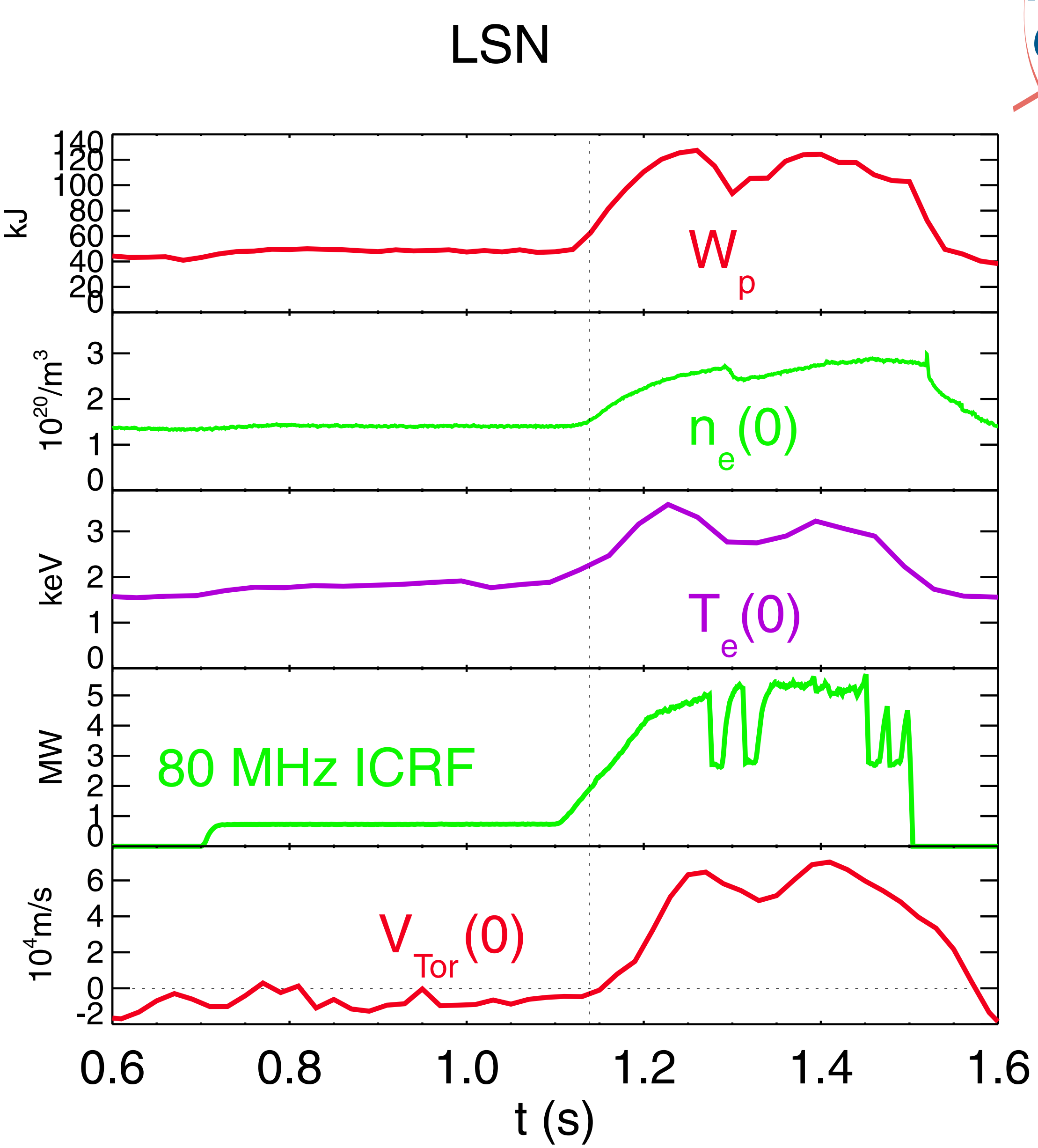


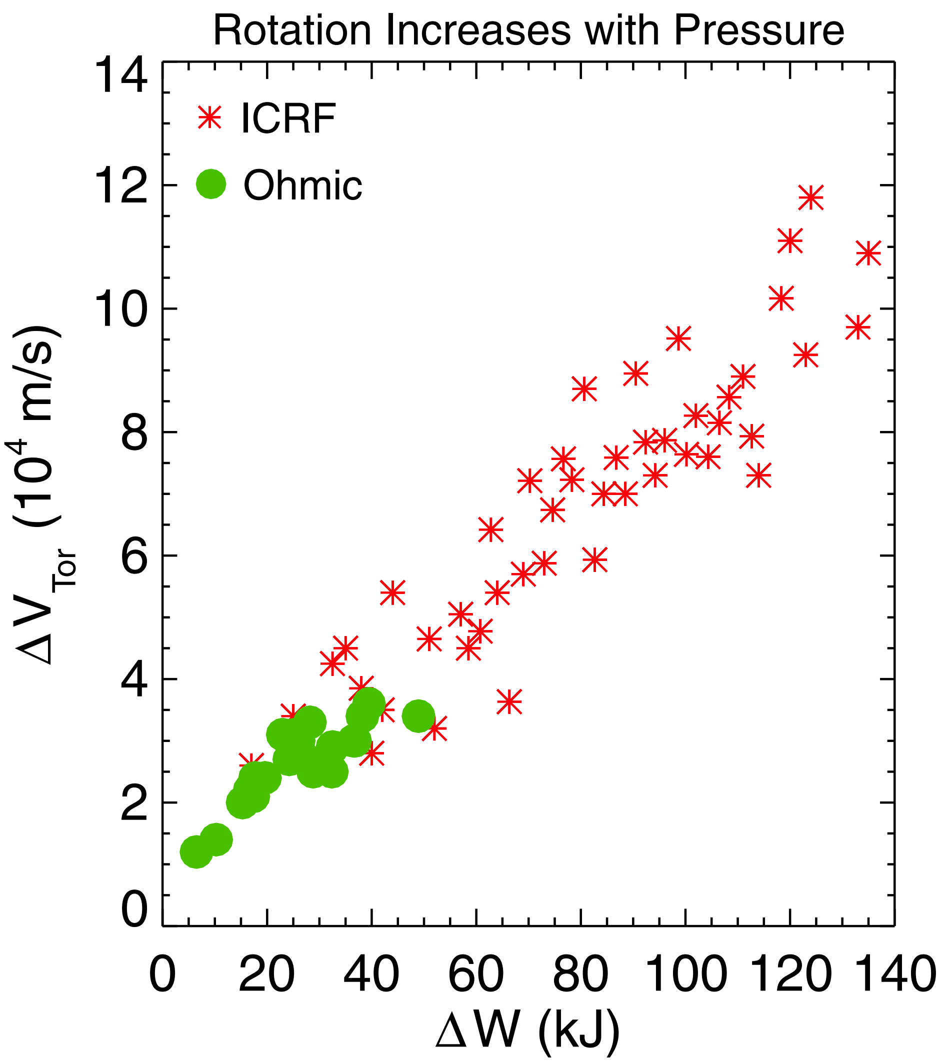
- **Via momentum coupling across separatrix, a topology-dependent toroidal rotation component, $E_r/B_□$, should appear in the SOL**

  => Stronger E_r in SOL for lower null

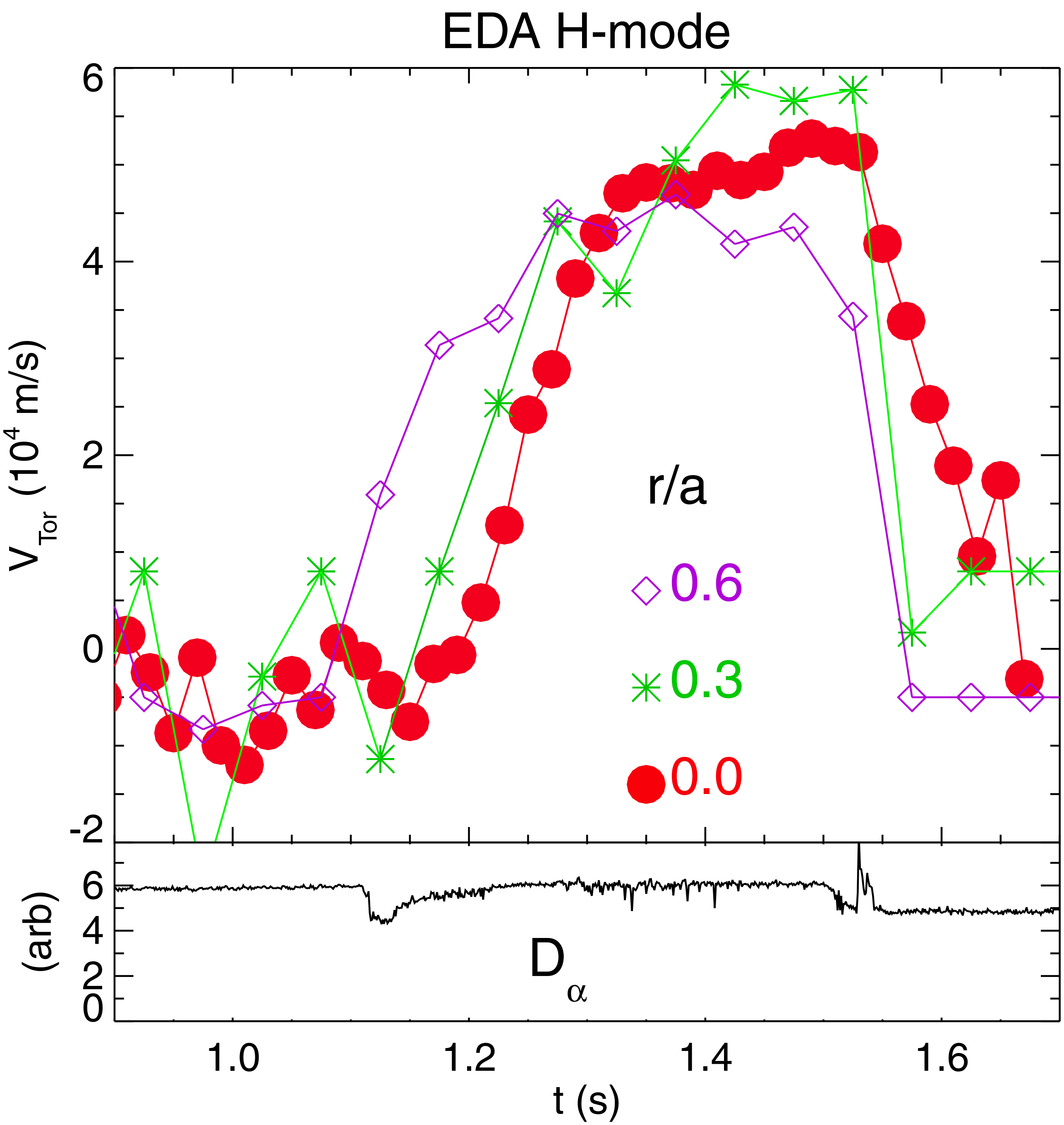
  => Weaker E_r in SOL for upper null

With application of ICRF power, there is an increment of the toroidal rotation velocity in the co-current direction, which is proportional to the plasma stored energy increase. NF **38** (1998) 75, NF **39** (1999) 1175.





Toroidal Rotation Propagates in from the Edge after the L-H Transition



The toroidal rotation, which is generated without an external momentum source, originates at the plasma edge.

The flat steady state profile suggests that momentum transport is diffusive.
$\chi_\phi \sim 0.05\ m^2/s$.

NF **44** (2004) 379.

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Comparison of LSN, DN and USN Discharges with Minimum ICRF Power Required to Induce the H-mode Transition

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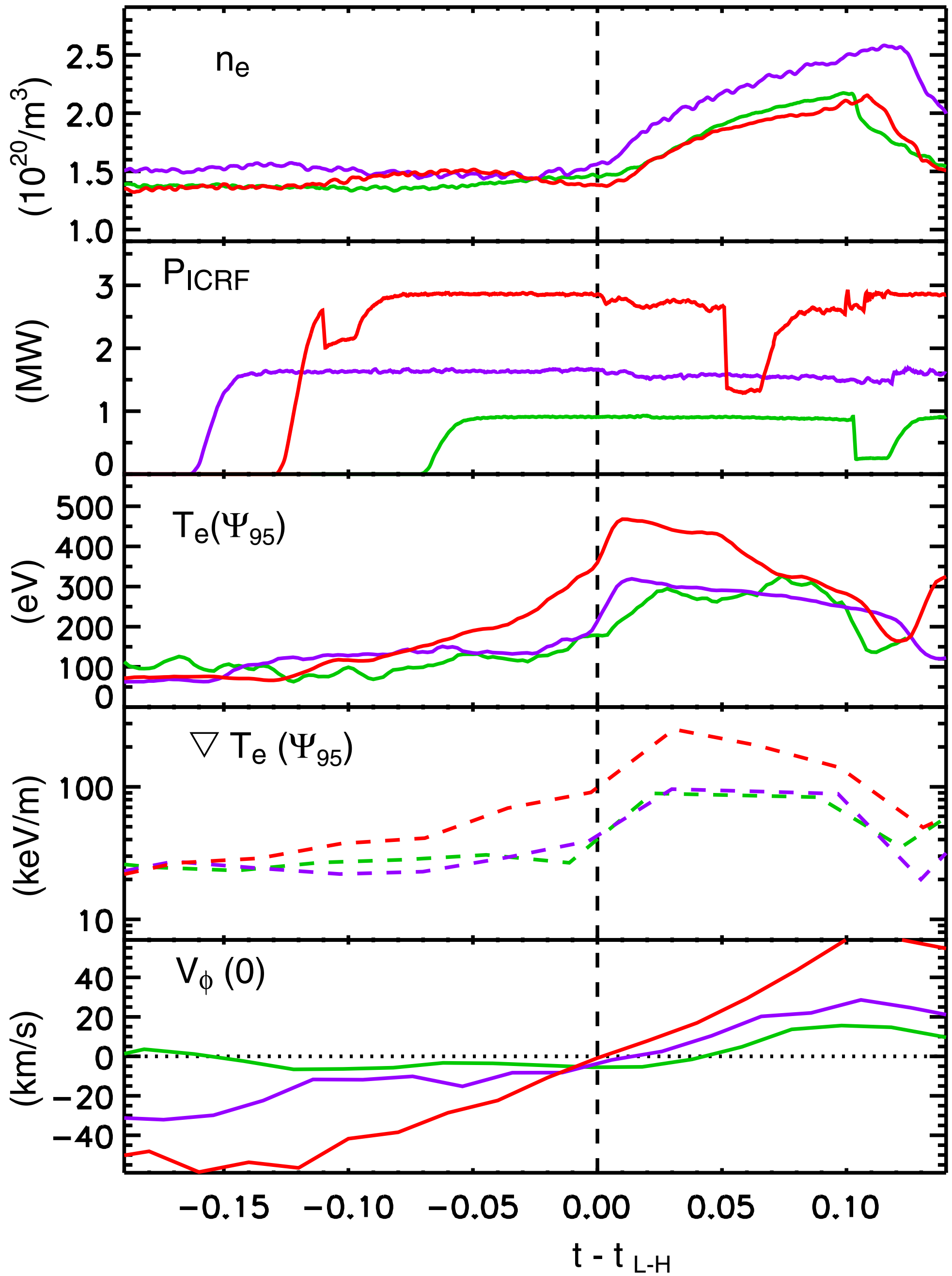
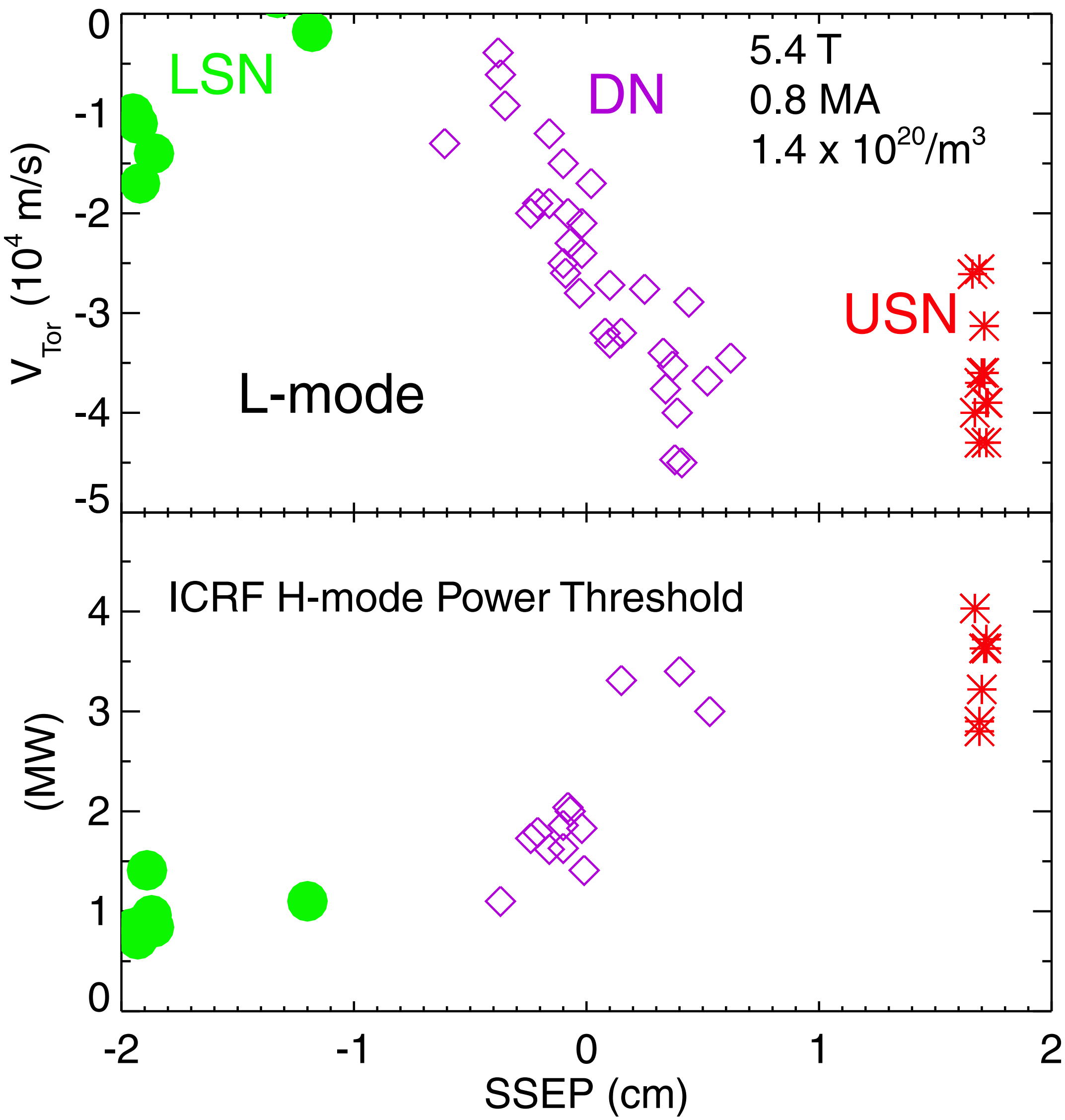


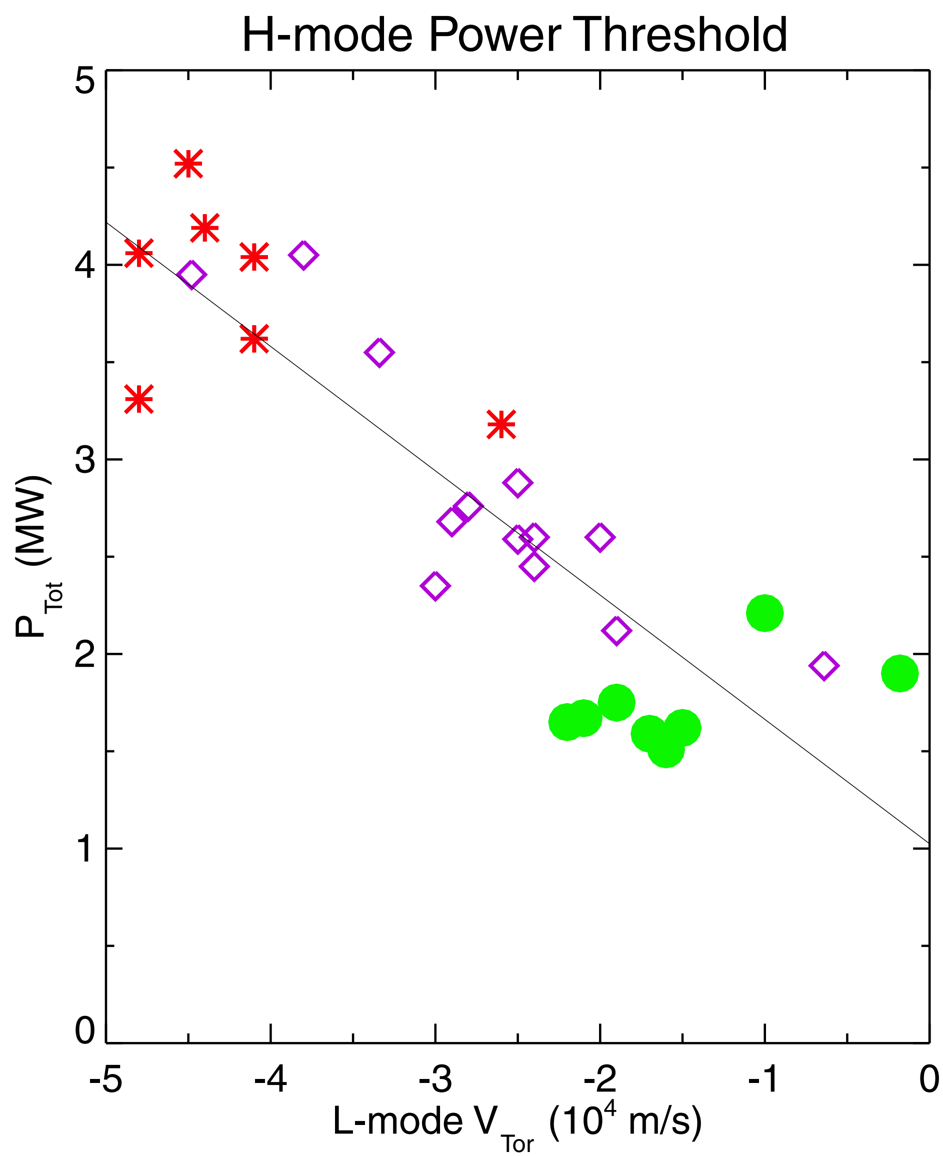
The ambient pre-ICRF L-mode rotation velocity is significantly more counter-current for upper single null (USN) and double null (DN) compared to lower single null (LSN). (ion Bx▽B drift down)

Addition of ICRF power increments the rotation towards co-current.

In all three configurations, the H-mode transition occurred as the core rotation velocity passed through 0 km/s for these discharges conditions.

The Ambient Core L-mode Rotation Velocity and H-mode ICRF Power Threshold Depend Sensitively on SSEP





Summary and Conclusions

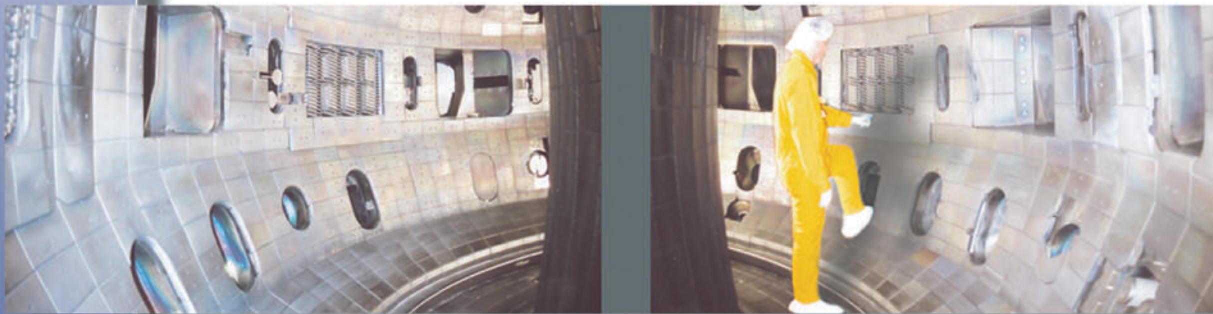
Alcator C-Mod

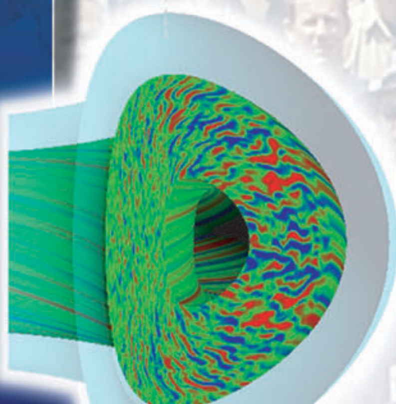
· Ambient L-mode rotation velocity depends strongly on magnetic configuration
· Core rotation responds to SOL boundary conditions
· Very sensitive to SSEP in near DN topology
· Strong counter-current rotation observed in USN and limited plasmas
· With increasing pressure, rotation velocity increments in the co-current direction
· H-mode transition occurs when core rotation goes co-current
· Presumably when edge E_r gradient reaches some critical value
· Higher power required to raise V_{Tor} to co-current in USN
· Higher power threshold for H-mode in USN

General remarks:

New light shed on higher H-mode power threshold with X-point away from ∇B drift direction.

Explanation should address strong dependence of ambient L-mode rotation velocity on magnetic configuration.





"PLASMA ROTATION IN ELECTRON CYCLOTRON HEATED H-MODES IN DIII–D"

by
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DIII–D
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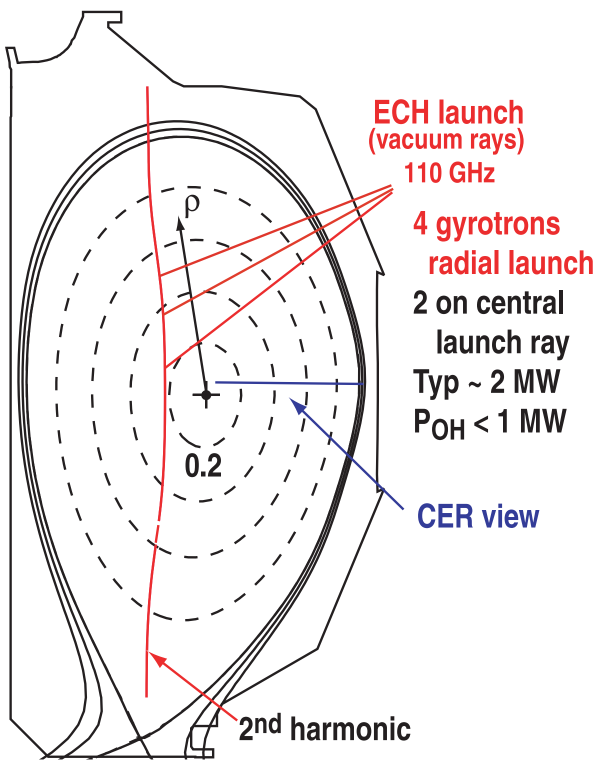
GENERAL ATOMICS

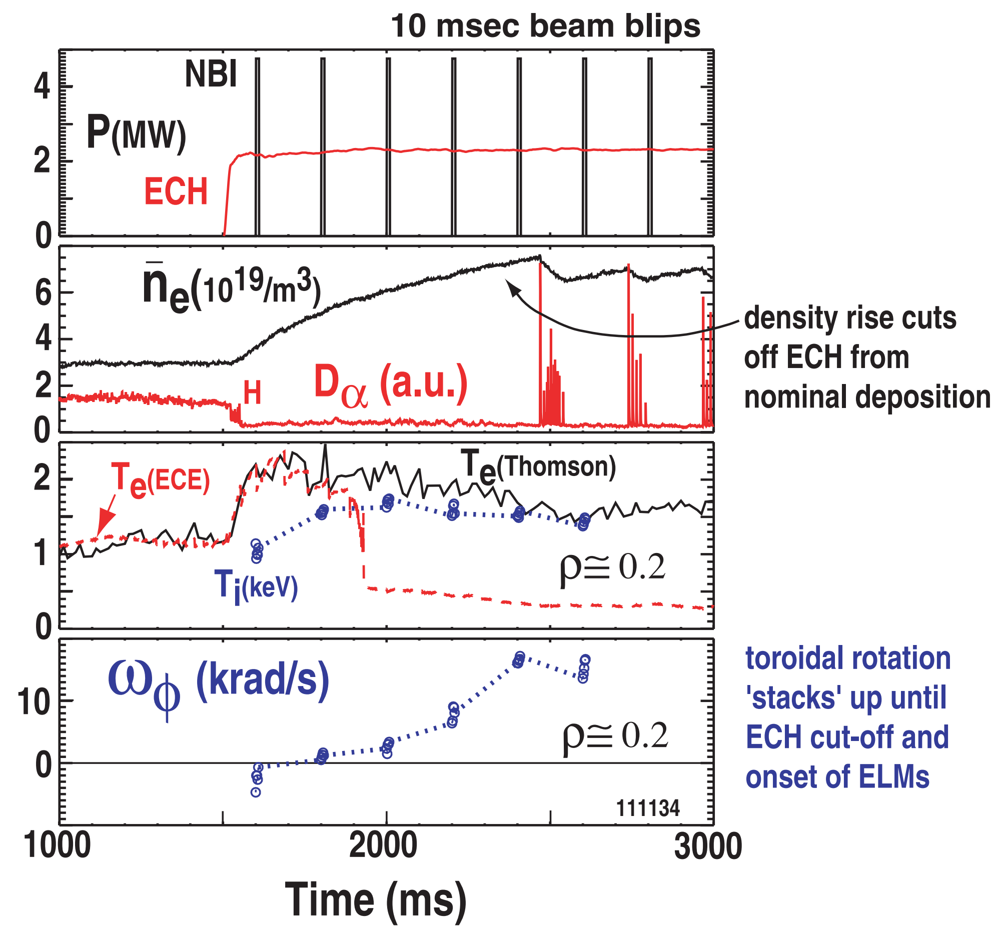
279-04/TST//jy

285-04/JSD/rs

TOROIDAL ROTATION MEASUREMENTS IN DIII–D IN ECH H-MODE DISCHARGES

- Charge Exchange Recombination Spectroscopy: C^{+6} Bulk ion D^{+}; (and CER of bulk He^{+2})
- Requires NBI. Beam torque limits measurement interval to < 4 ms to have an unperturbed state
- Toroidal momentum from short beam 'blip' injection is well confined, → typically one timeslice/shot
- Move the timing of the first beam blip shot-to-shot to obtain a time sequence
- Generally these ECH H-modes have long ELM-free periods, → evolving conditions





* deGrassie et al, PoP, **11** 4323 ('04)

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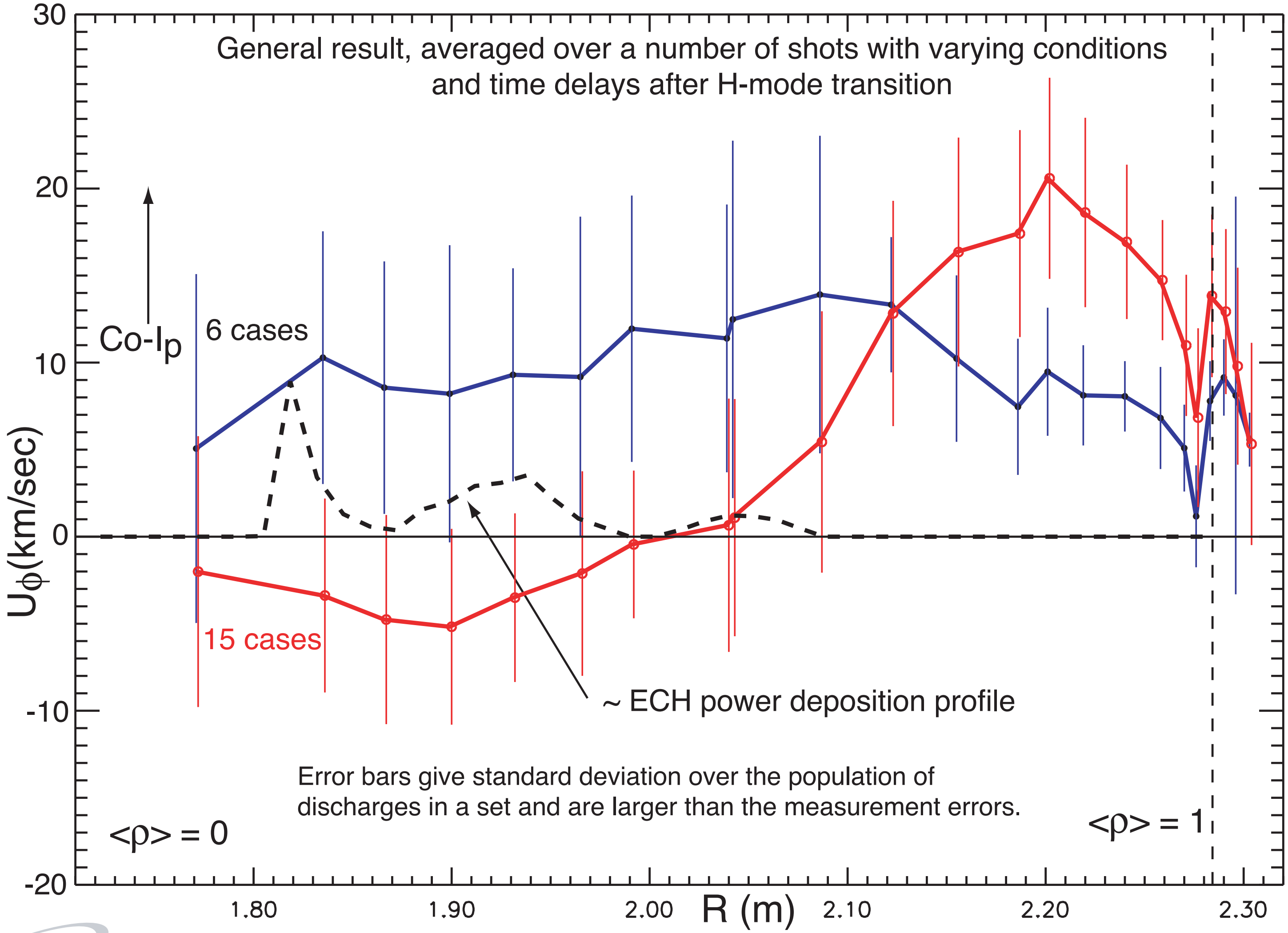
ECH H-MODES IN DIII–D SHOW A HOLLOW TOROIDAL ROTATION PROFILE IN CONTRAST TO OH-H MODES, WHICH HAVE A RELATIVELY FLAT PROFILE

No auxiliary momentum input

- Rotation profiles measured for bulk He+2 are also hollow and reversed



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ROTATION PROFILES FOR ALL ECH POWER DEPOSITION PROFILES ARE HOLLOW

The core (near central) rotation profile depends only weakly upon ECH deposition, while there is no discernable effect on the outer region profile

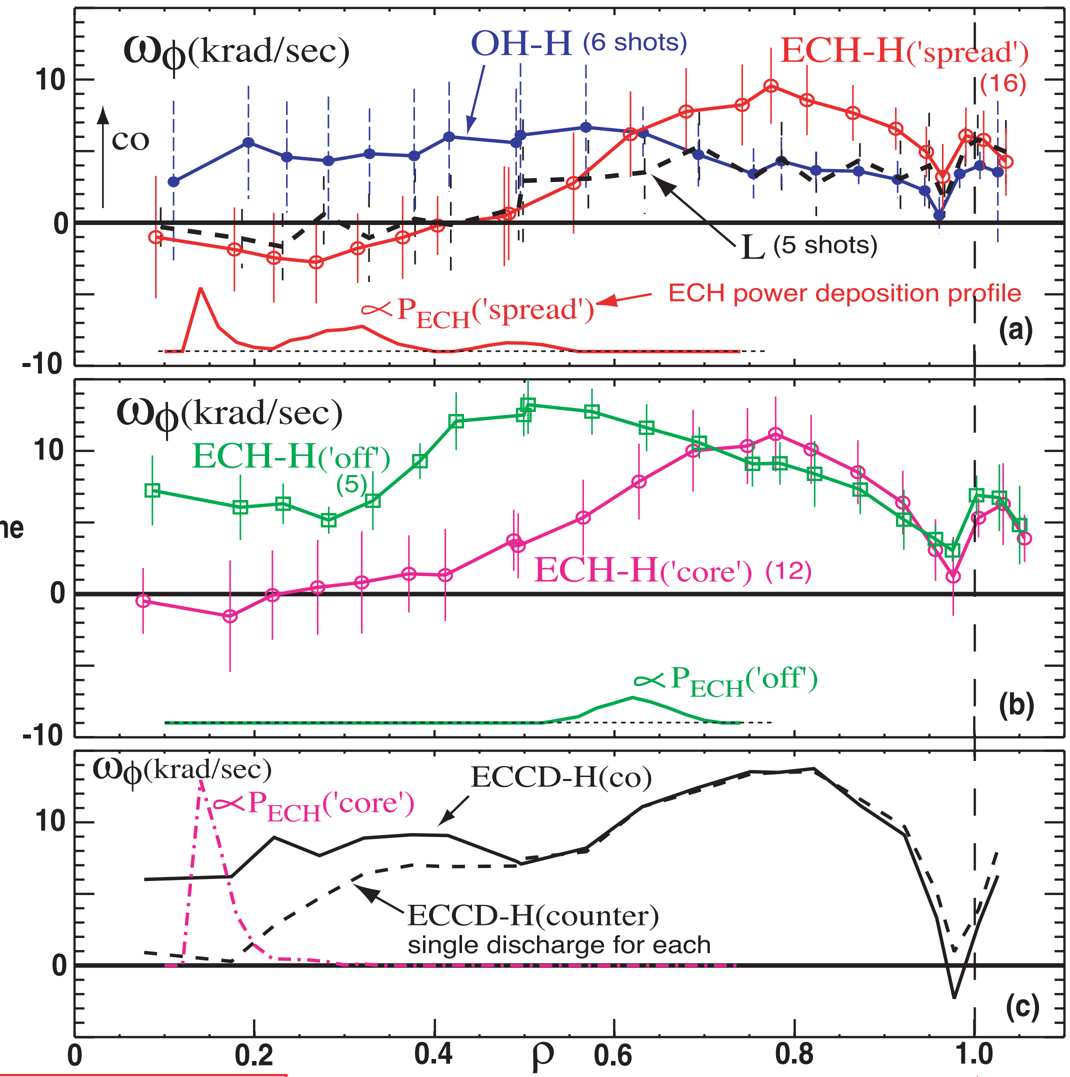
(a) Same data for ECH-H and OH-H, now plotting rotation frequency:

$\omega_\phi = U_\phi/R$ vs ρ

The pre H-mode slices (L) are hollow also, but to a lesser extent.

(b) ECH H-mode profiles are hollow for all power deposition profiles used. Off-axis heating is most unique; yet the rotation profile details are not highly sensitive to the P_{ECH} deposition.

(c) The ECCD database is limited. Here an example profile for a co- and a counter-ECCD H-mode with core deposition shows an interesting variation in the core.



Boundary rotation value is nonzero

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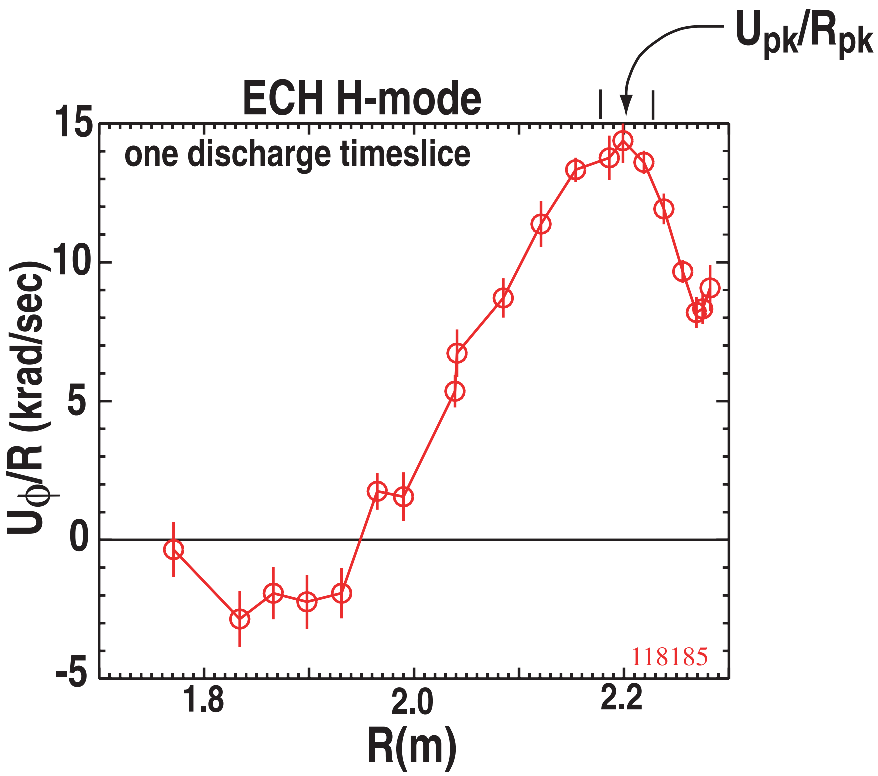
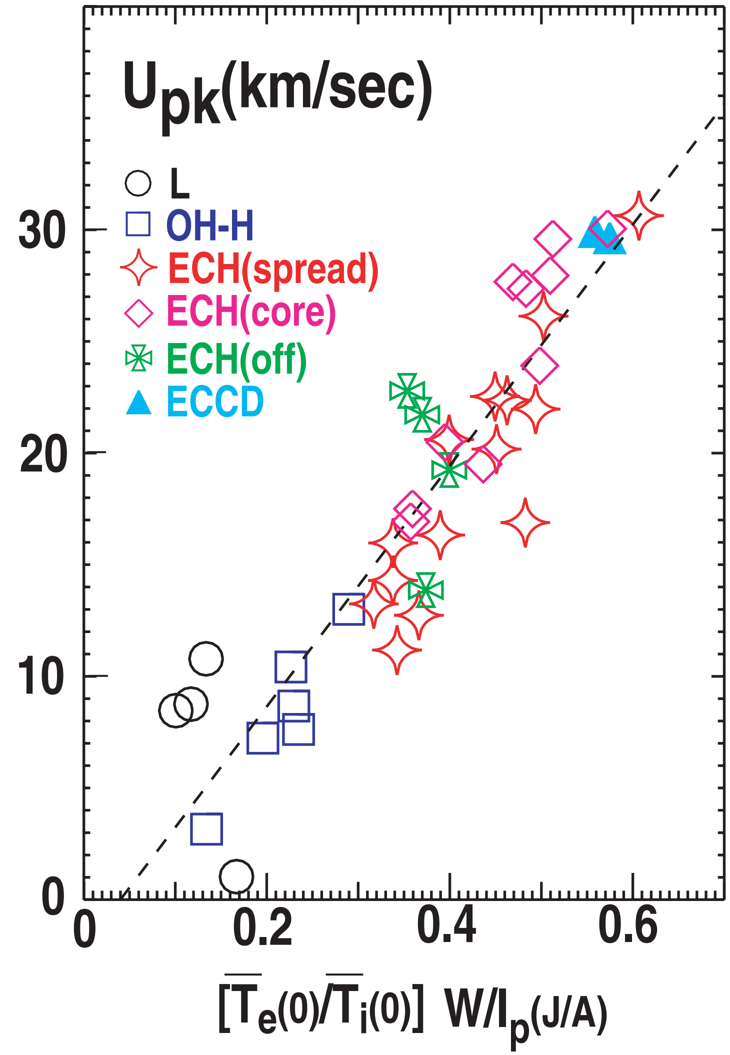
TOROIDAL ROTATION VELOCITY AT $\rho \sim 0.77$, U_{pk}, SCALES AS $[T_e(0)/T_i(0)][W/I_p]$

- Common to all 'non-driven' cases is co-Ip directed rotation near $R_{pk} \sim 2.2$ m





$\overline{T}_e(0)$ = near central, averaged electron temperature
$\overline{T}_i(0)$ = near central, averaged ion temperature
W = plasma thermal energy
I_p = plasma current

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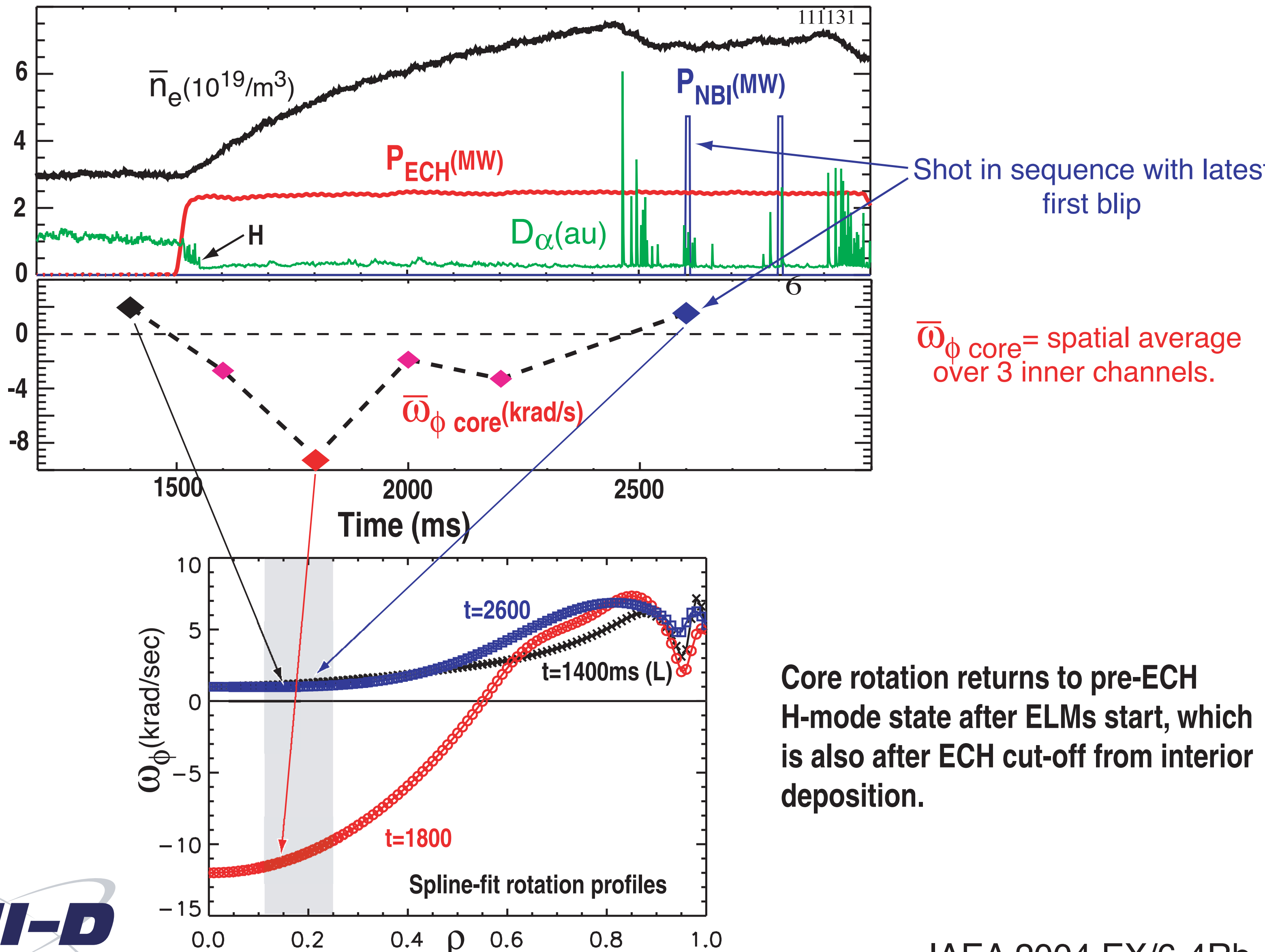
TEMPORAL HISTORY FOR CORE ROTATION SHOWS THAT COUNTER-ROTATION CAN DEVELOP IN TIME; IT IS NOT A RESIDUAL FROM THE L-MODE STATE (pre-ECH)



Core rotation returns to pre-ECH H-mode state after ELMs start, which is also after ECH cut-off from interior deposition.

PLASMA ROTATION IN ECH H-MODES IN DIII–D SUMMARY

- Rotation profiles in ECH H-mode are hollow; co-Ip outside, depressed or counter- Ip in the interior. OH H-modes by contrast have a relatively flat, co-rotation profile
- All ECH power deposition profiles used result in a hollow rotation profile the 'off-axis' deposition results in less depression of the core co-rotation
- The boundary rotation is nonzero. It is in the co-direction, $\langle \omega_\phi(\rho=1) \rangle \sim +5$ krad/s averaged over this set. The effect of an ion velocity loss cone is under investigation
- All discharges with non-driven toroidal rotation show a co-rotation peak near $\rho \sim 0.77$. The velocity here scales as $[T_e(0)/T_i(0)](W/I_p)$
- The temporal history of the core rotation shows that the counter-rotatoin can develop in time. It is not due to a remnant of the pre-ECH ('L') state
- Mechanism? (speculation!)
  (a) Outer region driven by an edge co-source with momentum diffusion and an inward pinch, as in the C-Mod model for the ELM-free H-mode rotation profile
  (b) Interior results from nonambipolar currents, but with an integrated net zero torque, analogous to models explaining nonzero toroidal rotation with ICRH