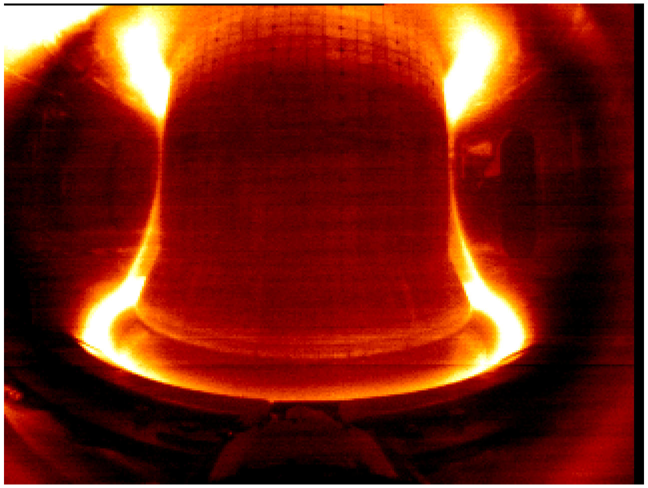
OVERVIEW OF THE ALCATOR C-MOD PROGRAM



IAEA-FEC November, 2004

Alcator Team

Presented by Martin Greenwald

MIT – Plasma Science & Fusion Center

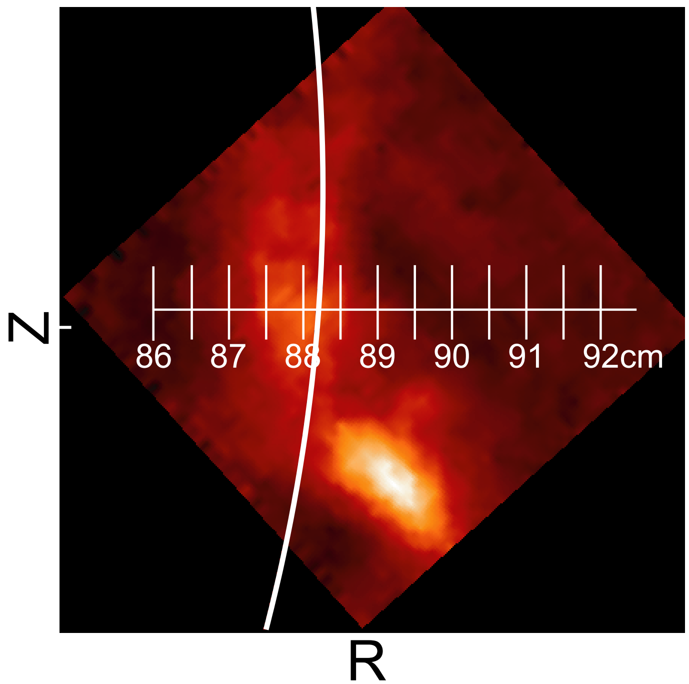
OUTLINE

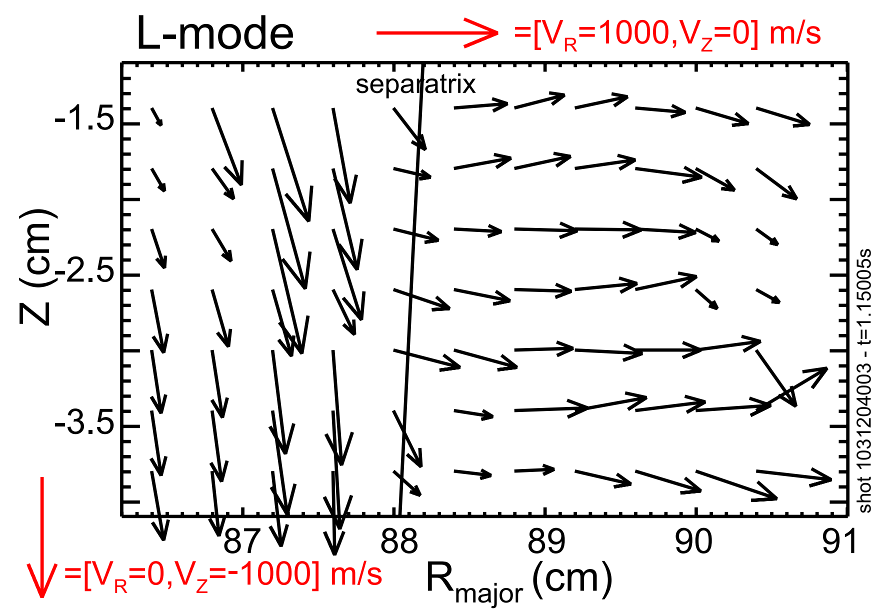
- C-Mod is compact, high field, high density, high power density
- B_T to 8 T, I_P to 2 MA
- P_{ICRH} to 6 MW
- Equilibrated ions, electrons
- No core momentum source
- No core particle source

- SOL Turbulence and Transport
- Self Generated Flows and Momentum Transport in the Core and Edge
- H-mode Threshold
- Control of ITBs
- ICRF – Mode Conversion
- Locked Modes Disruptions
- LHCD and Other Near-Term Plans

EDGE TURBULENCE DOMINATED BY LARGE STRUCTURES

Alcator C-Mod





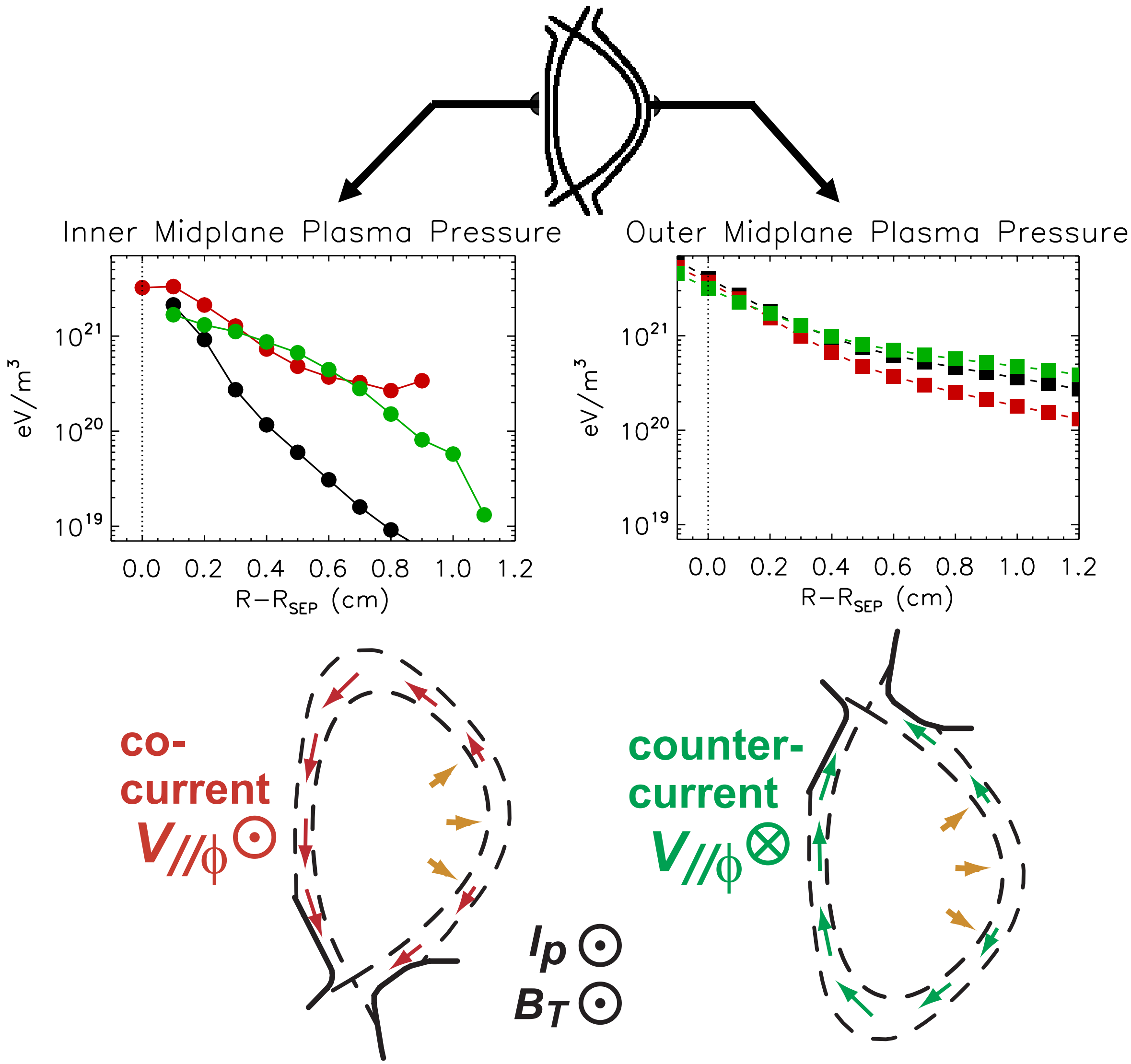
Terry EX/P4-12

- Edge turbulence visualized with high-speed camera (250,000 fps).
- Large, field aligned structures, “blobs”, account for most turbulence and transport.
- Analysis shows these structures move poloidally inside separatrix and accelerate radially outside.

Poloidal Asymmetries in SOL Profiles and Fluctuations Suggest that High-Field Side is Populated via Flows from Low-Field Side

Alcator C-Mod

- SN plasmas have the same pressure on both sides.
- Fluctuations are always much lower on the high-field side (ballooning).
- DN plasmas have very low pressure on the high-field side.
- The self-generated "symmetrizing" flows are observed (M ~ 1)

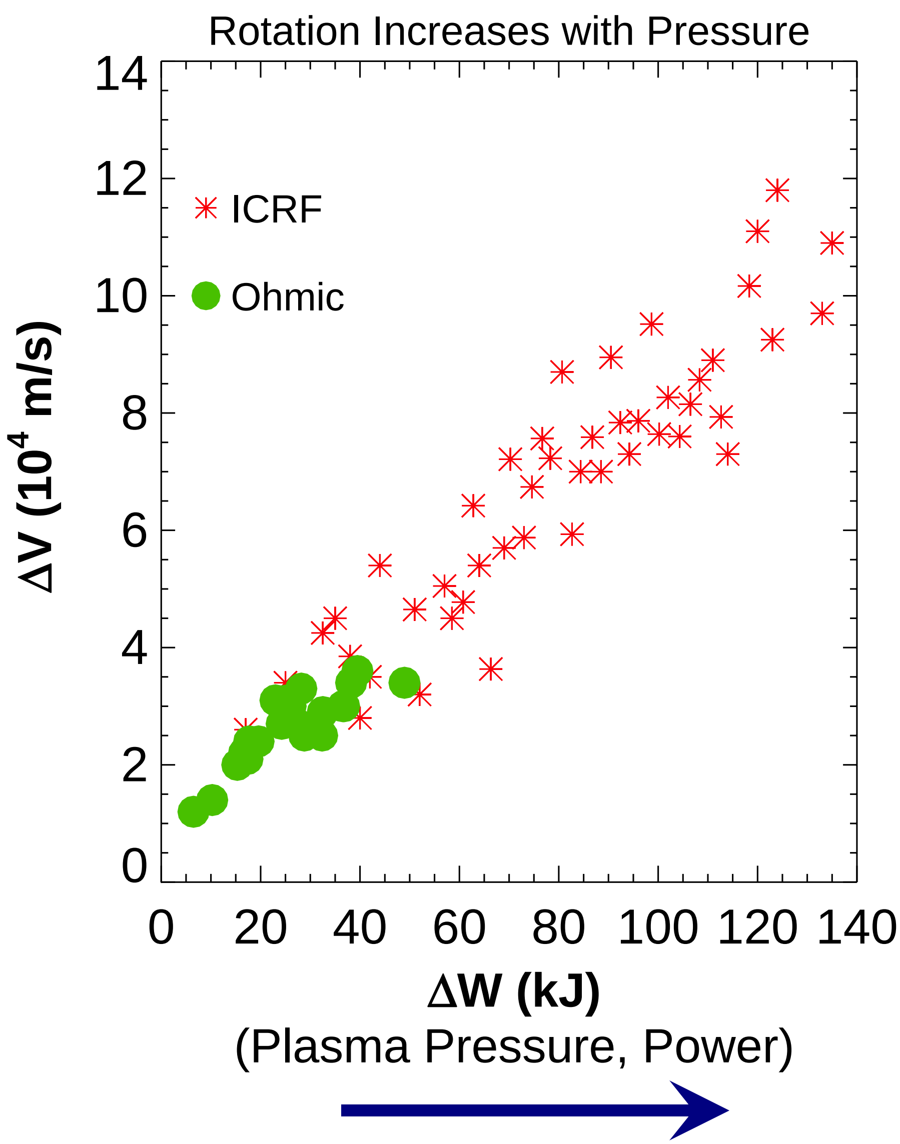


Strong Toroidal Rotation in Absence of External Torque

Is There a Connection to Boundary Physics?

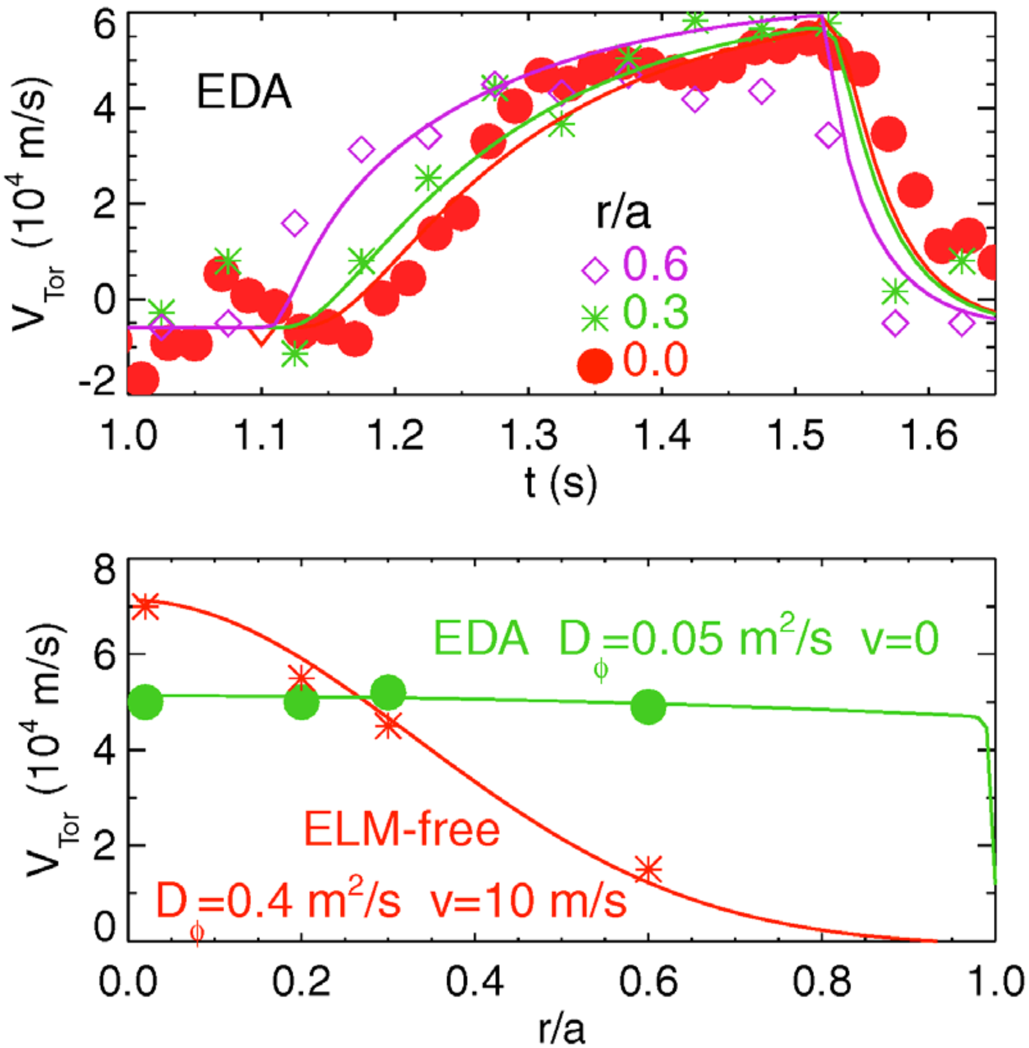
To Review

- Strong self-generated toroidal flows
- Rotation increases in co-current direction as plasma pressure increases
- Decreases with I_P
- Mach numbers up to 0.2-0.3
- Similar trends seen for RF and OH heated plasmas – not an RF or fast particle effect

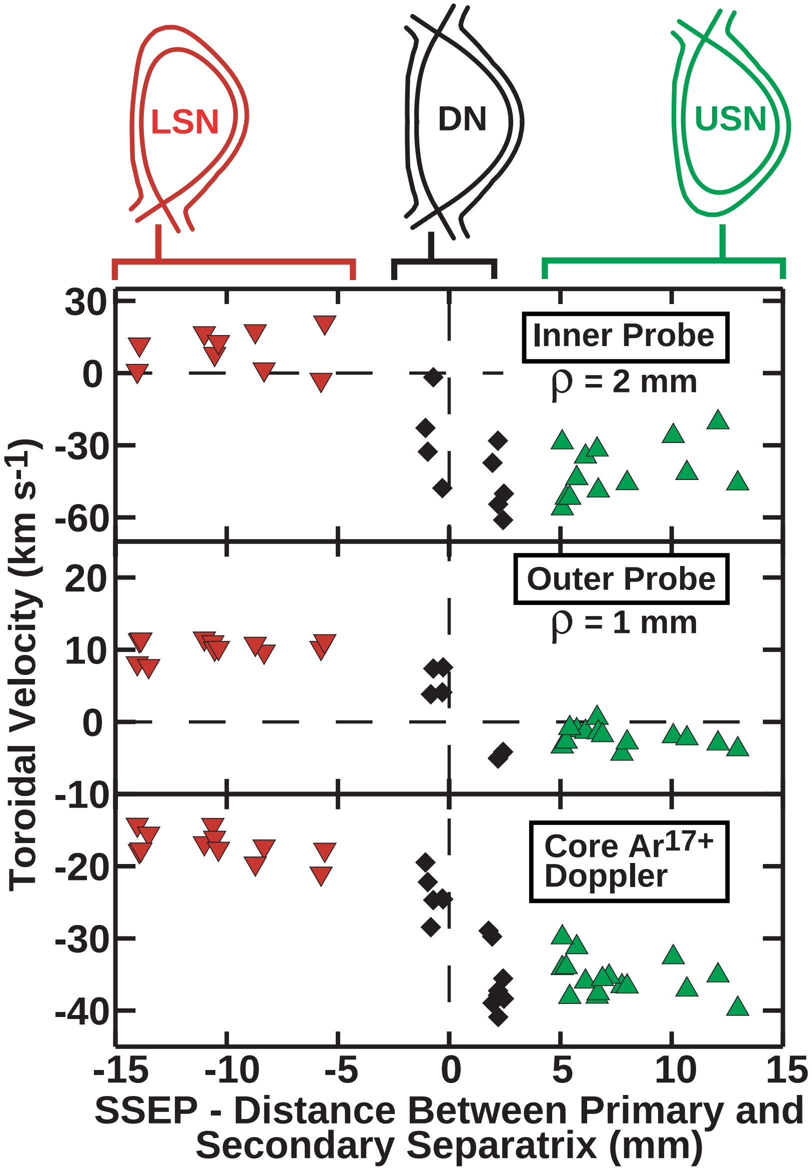


MOMENTUM IS TRANSPORTED INWARD FROM OUTER REGIONS

- Evolution of rotation profiles following transitions can be modeled to yield transport coefficients
  - EDA – diffusive
  - ELMfree – large **inward convection** as well
- Important role for boundary
- In all cases, transport is much faster than neo-classical



SELF-GENERATED CORE AND EDGE FLOWS EXTREMELY SENSITIVE TO MAGNETIC TOPOLOGY

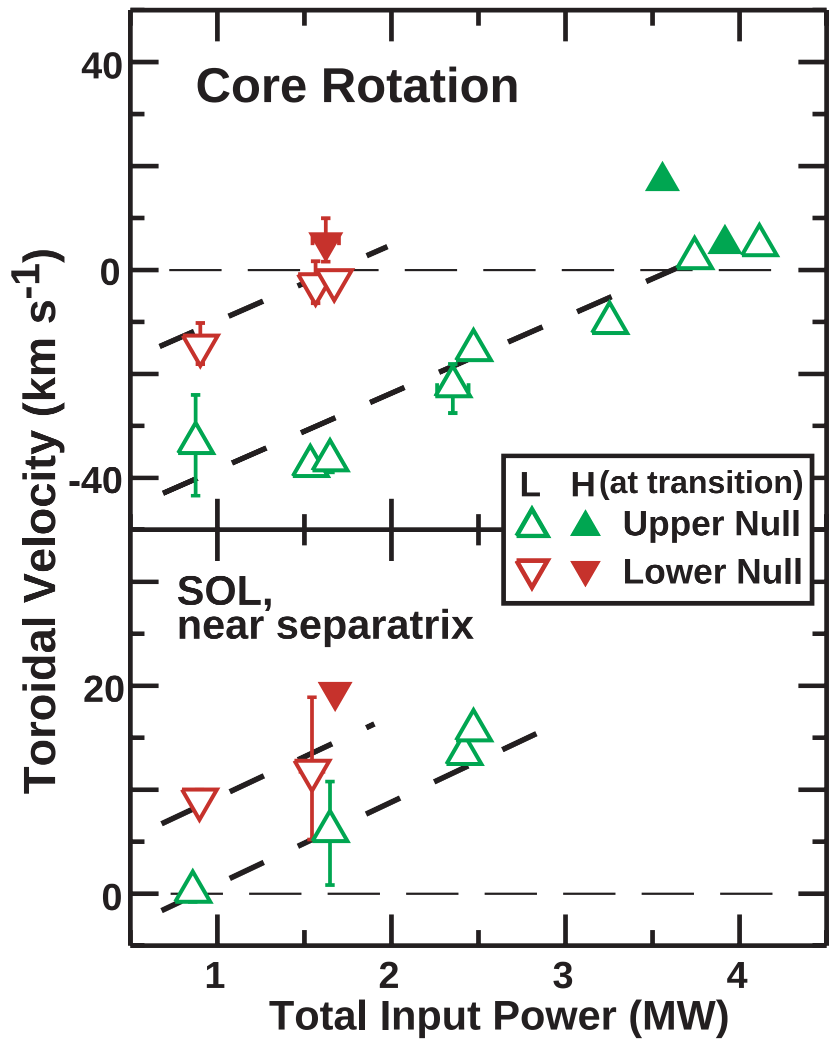


- Scan separation between primary and secondary separatrix (SSEP)
    - SSEP < 0 Lower null
    - SSEP > 0 Upper null
- Over a few mm, rotation shifts in counter direction by 20-30 km/s
- Scale comparable to SOL size.
- Links core and edge rotation
- Double null balance is critical

Observations of Self-Generated Flows and Inward Momentum Transport Lead to a Novel Hypothesis for ∇B Drift Influence on L-H Threshold

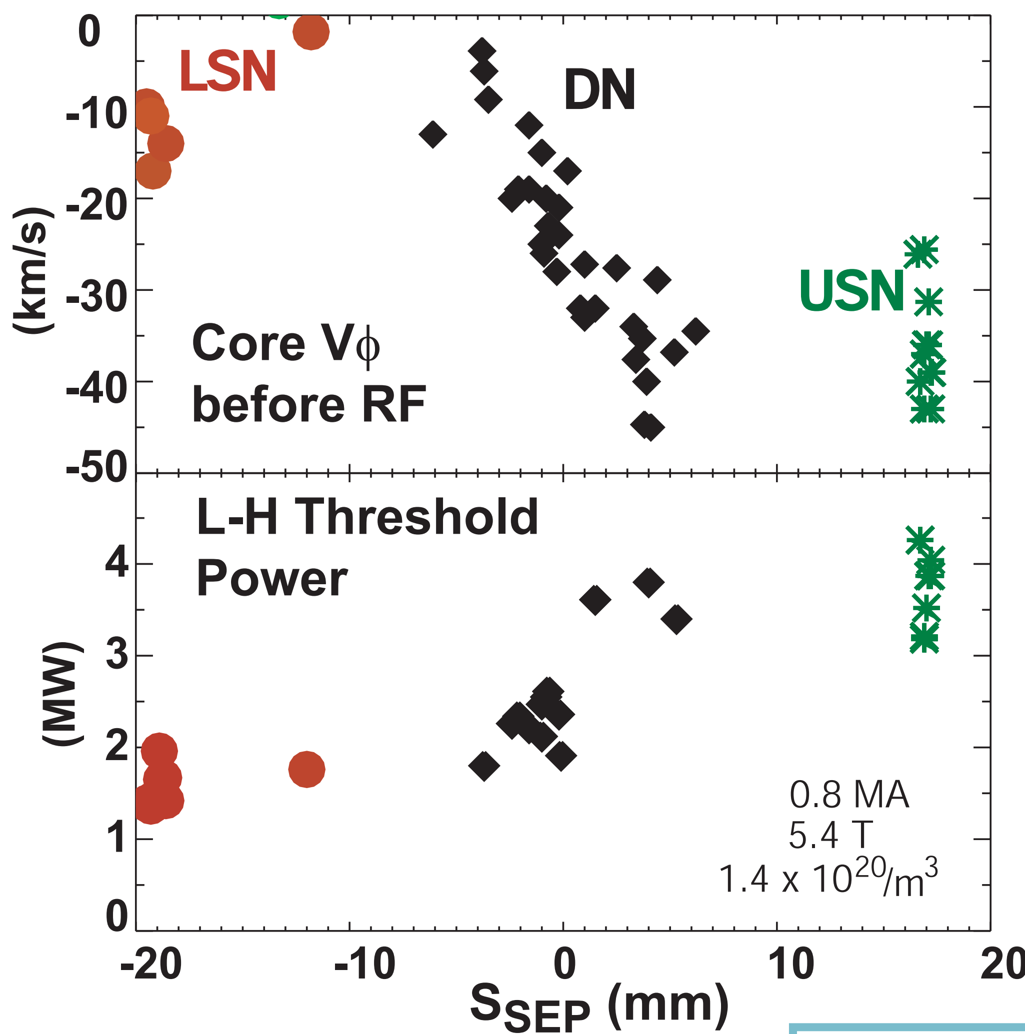
Alcator C-Mod

- Power/temperature threshold is 2x higher for unfavorable topology - ∇B ion drift away from SN.
- Edge rotation is sum of the two terms just described.
  - Topology dependent (from symmetrizing of ballooning transport) – more counter for unfavorable geometry.
  - Pressure (power) dependent – increases in co-current direction
- For unfavorable topology, discharge begins "farther" from threshold state.

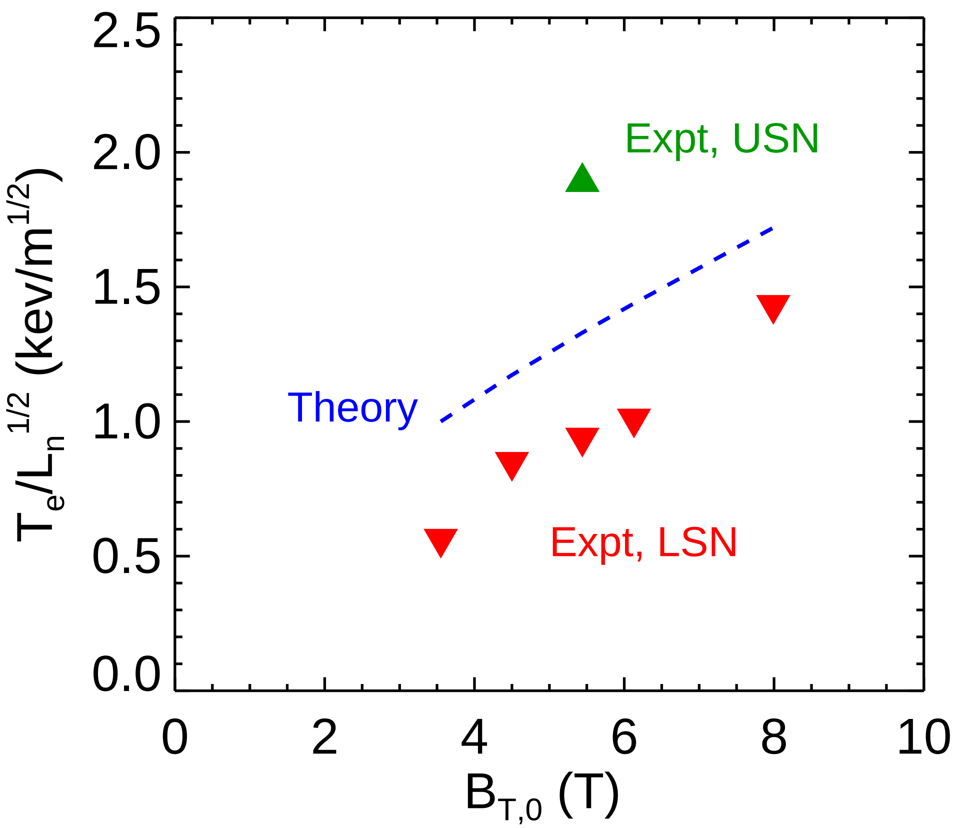


Correlation Between Topology, Rotation and Threshold is Strong

- A few mm change in SSEP result in 0th order changes in rotation and threshold.
- Comparable in distance to SOL width!!
- SOL apparently provides crucial boundary condition for core rotation.
- Large variation for shots labeled “DN” by EFIT.



∇B Effect is Only Part of the L-H Threshold Story



L-H Threshold Compared to Analytic Theory

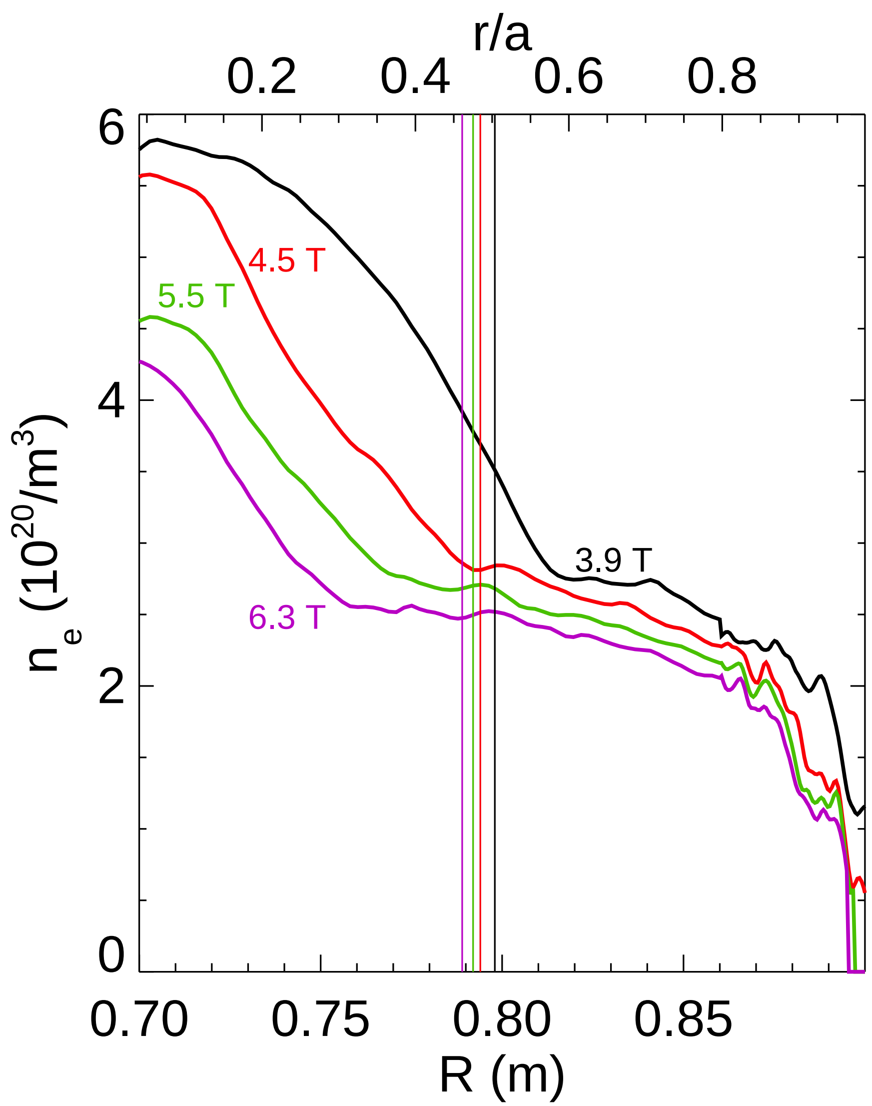
- Simulations: suppression of drift-Alfven turbulence via zonal flows. *(Rogers 1998)*
- Guzdar *(PRL 2002)* derives analytic formula.

$$\Theta \equiv \frac{T_e}{L_n^{1/2}} = 0.45\frac{B_T^{2/3} Z_{eff}^{1/3}}{(RA_i)^{1/6}}$$

- Splits difference between favorable and unfavorable topologies.

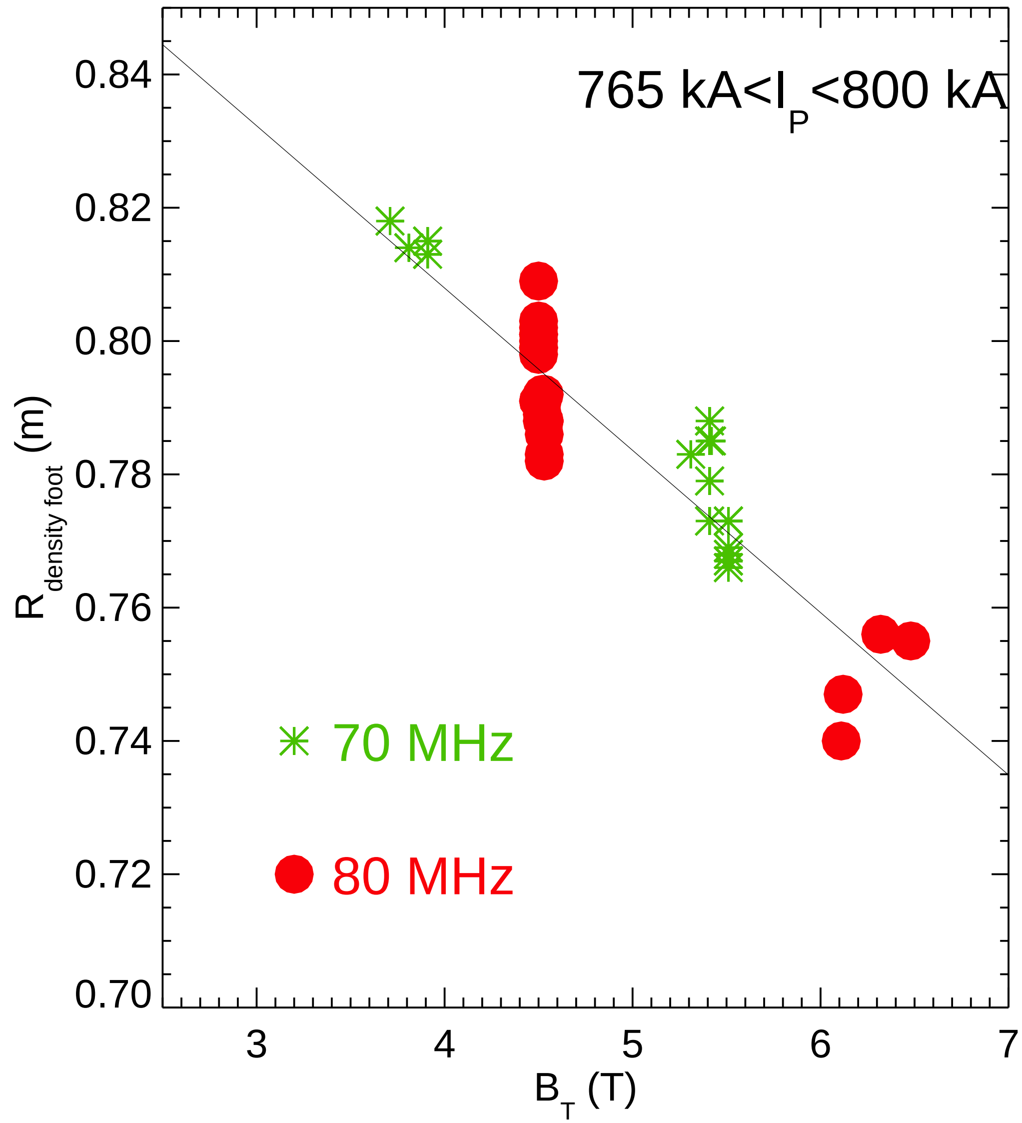
ITB Studies Have Focused on Barrier Control

- Barriers formed in C-Mod with off-axis ICRF heating.
- Steep density profiles, with χ_{EFF} reduced to ion neoclassical levels across entire core.
- Application of on-axis power arrests density peaking and allows control of particle transport (impurity accumulation).
- Barrier foot position is not linked to RF resonance location (or whether resonance is on low or high-field side).



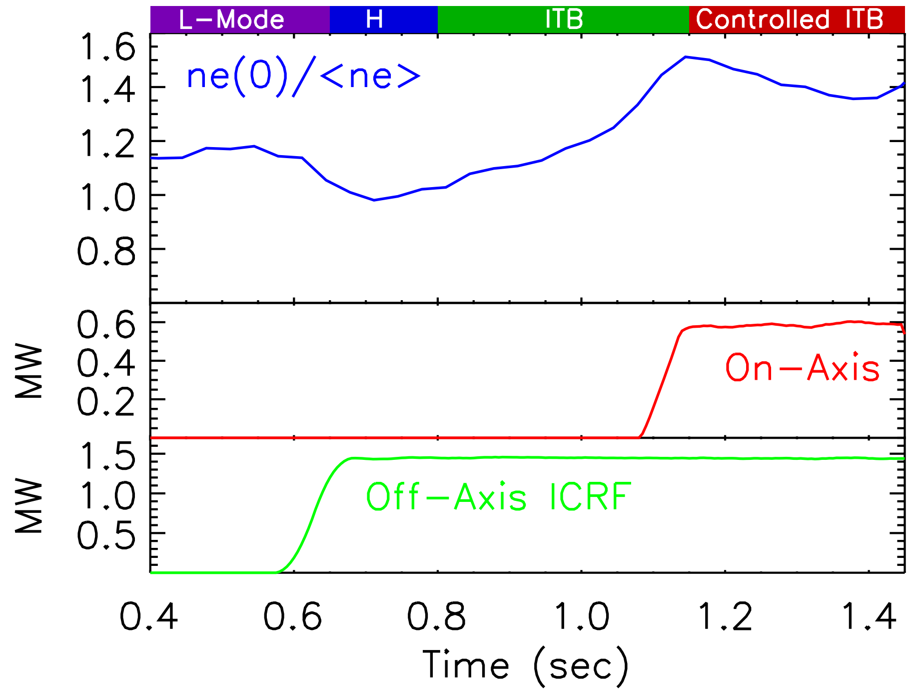
BARRIER FOOT LOCATION DEPENDS MAINLY ON B_T

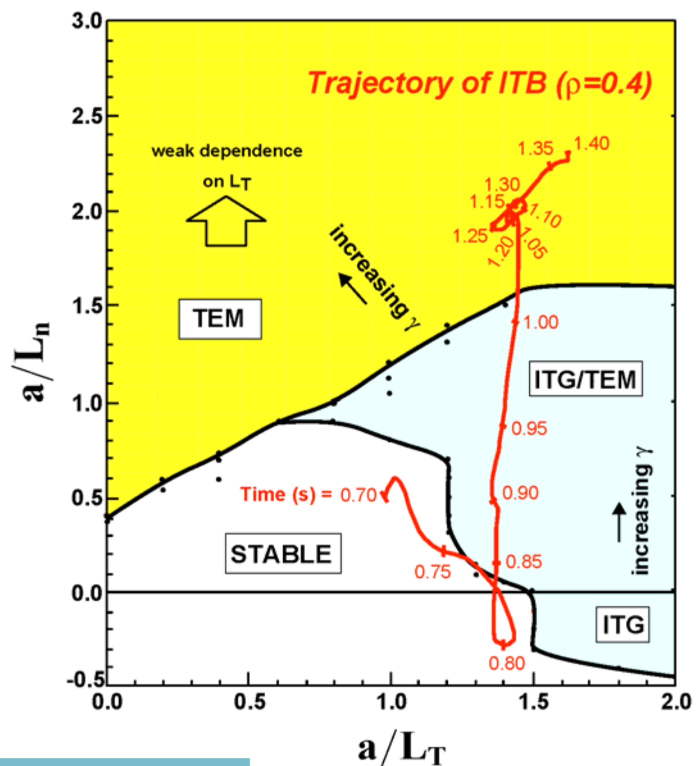
- Barrier position can be varied from r/a ~ 0.3-0.6
- Strongest scaling is with B_T.
- Weaker scaling seen with I_P.
- Barrier foot location at q_ψ ~ 1.1 – 1.35
- Magnetic shear may be the critical parameter?



PICTURE OF CONTROL MECHANISMS EMERGING FROM GYROKINETIC SIMULATIONS

- Off-axis heating flattens Te, begins to stabilize ITG.
- With reduced diffusivity, Ware pinch causes density to peak.



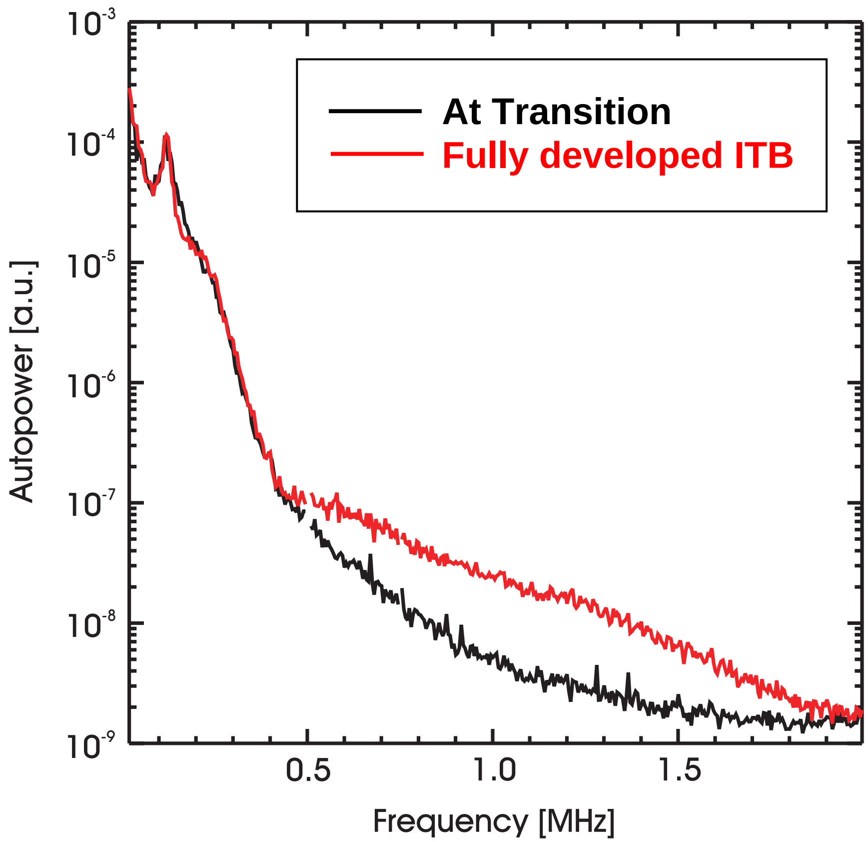


- TEMs are destabilized by ∇n.
- Discharge reaches steady state when TEM diffusivity balances Ware pinch.
- Barrier strength controlled by on-axis heating via $T^{3/2}$ dependence of turbulent diffusivity

Ernst TH/4-1

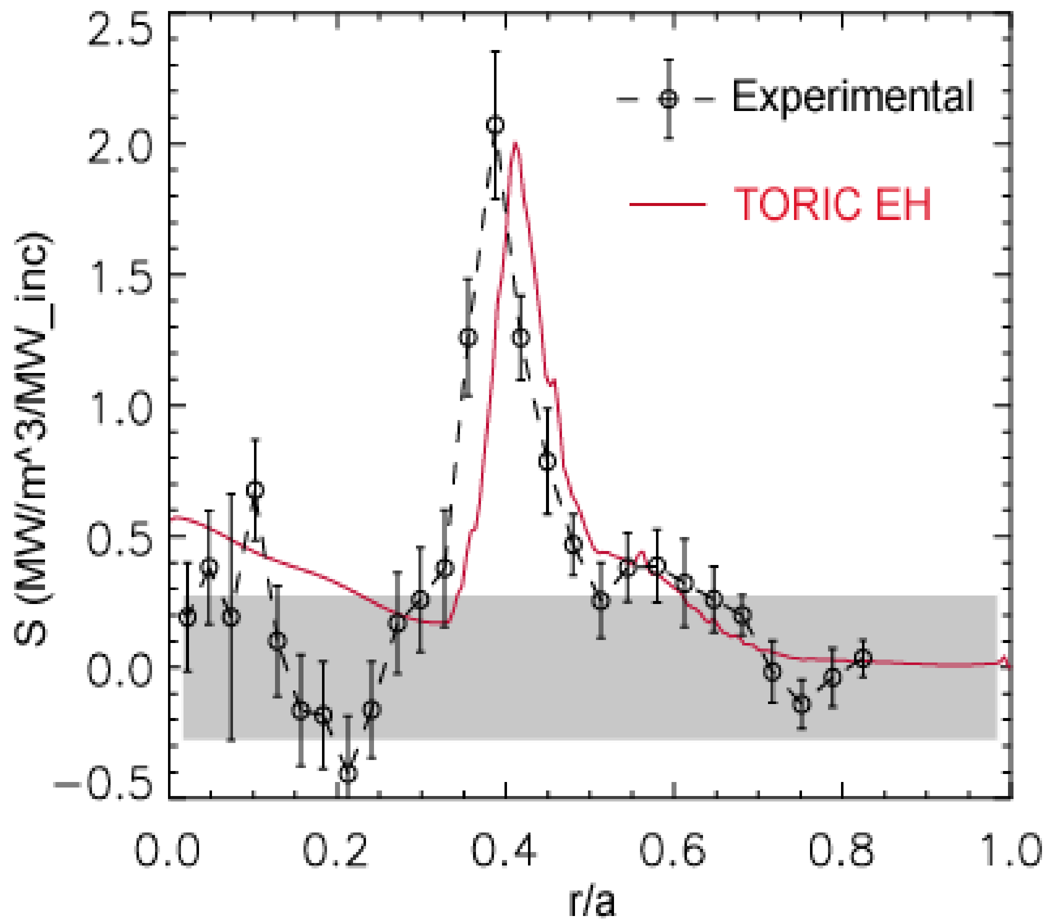
Fluctuations Seen with PCI May Support ITB Scenario

- PCI has very high S/N, dynamic range, wide bandwidth (to 5 MHz)
- Fluctuations at $k\rho_s \sim 0.3 – 1.0$ increase as barrier develops
- TEM?
- Future work will help localize fluctuations and extend k range.

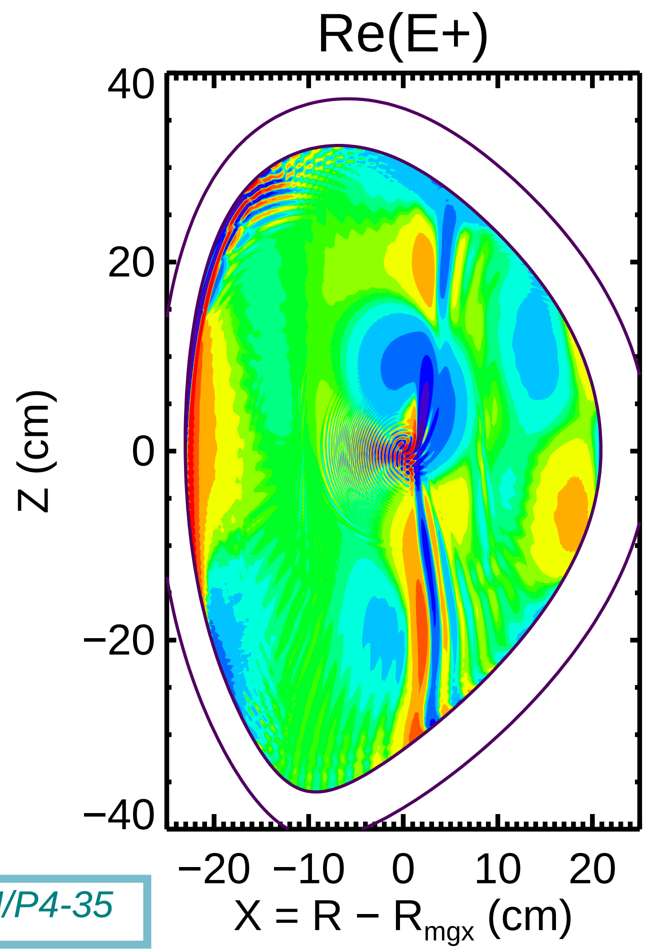


MODE CONVERSION ICRF – FOR LOCALIZED HEATING, CURRENT DRIVE, FLOW DRIVE

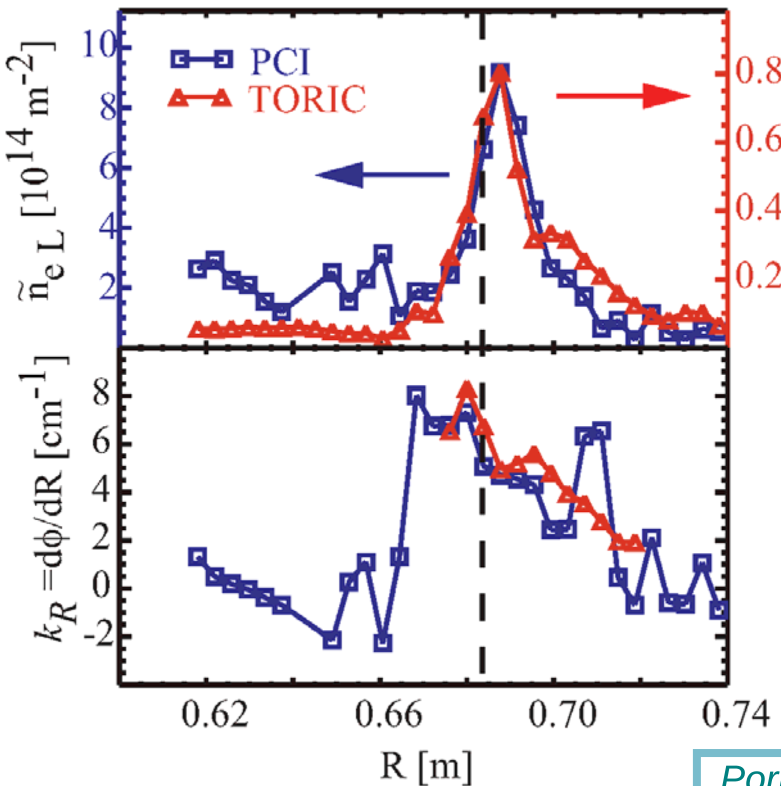
- Power Deposition Measurements Validate Simulations of Mode Conversion Process
- Off-axis deposition with 23% H, 77% D (measured) at 80 MHz
- Ion-ion hybrid layer at r/a = 0.35
- Total efficiency
  - Experiment 20%
  - TORIC 18%



ICRF Mode Conversion Process Studied in Detail with Fluctuation Diagnostic and Advanced Simulation



Wright TH/P4-35

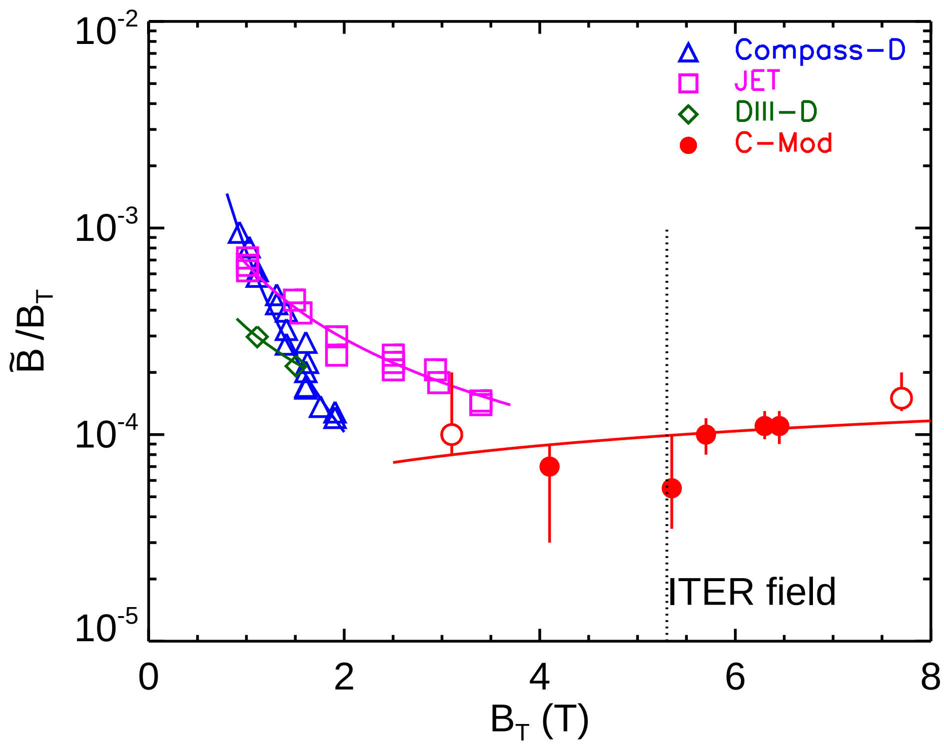


Porkolab P4-32

- Parallel version of TORIC with $n_r = 240$, $n_m = 255$.
- Resolves details of MC process.

- D/He3 at 50 MHz
- All three waves - FW, IBW, ICW – seen in experiment with phase contrast imaging diagnostic (PCI).

LOCKED MODE THRESHOLD HAS WEAK SIZE SCALING



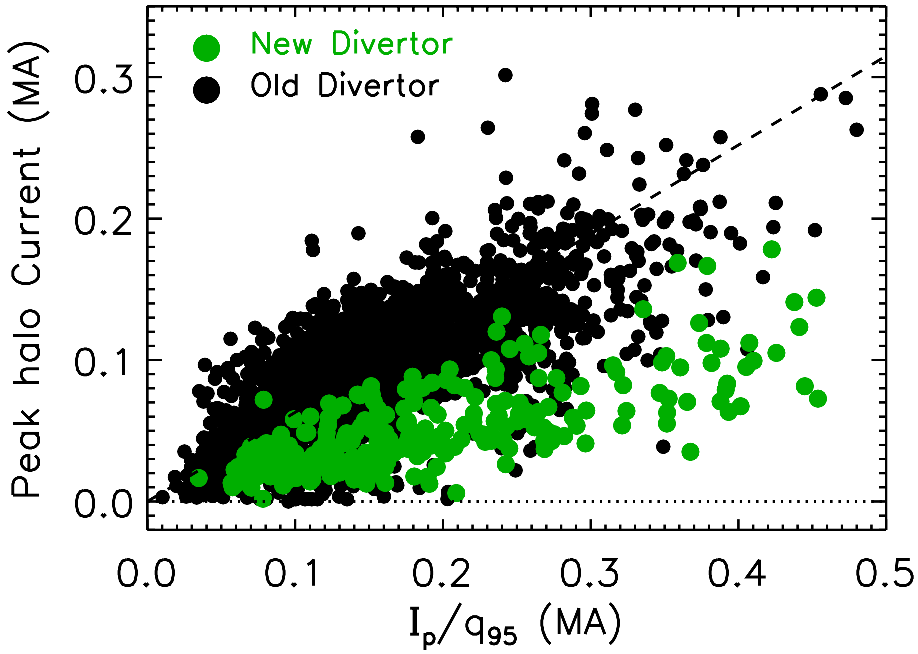
- C-Mod, DIII-D, JET data in same range for n/n_{LIMIT}.
- 5x range in machine size.

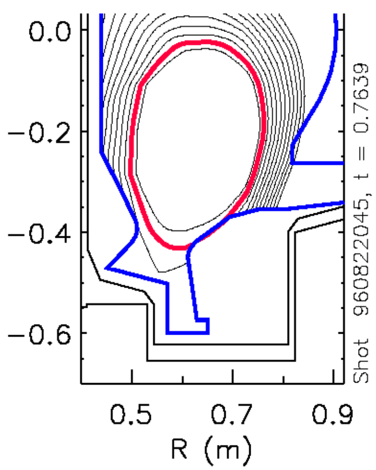
Hutchinson EX/P5-6

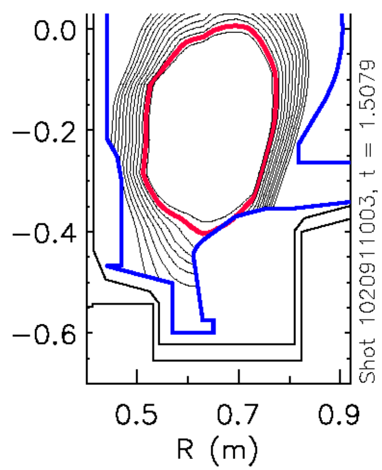
- Set of external non-axisymmetric control coils installed.
- Allow determination of intrinsic error field and mode locking threshold.
- Dimensionless identity experiments performed w/JET, DIII-D.
- Weak size scaling found.
- Locked modes should not be worse for ITER than for current machines
- Coils allowed suppression of locked modes, 2 MA operation.

Significant Drop in Halo Current Magnitude and Asymmetry with Modified Divertor Geometry

- Previous work found that halo currents scaled with I_P/q_{95} with strong poloidal asymmetry.
- After divertor modification, same scaling observed but with lower magnitude (1/2) and less asymmetry.
- Drop in halo current may be explained by change in plasma/divertor contact during VDE.
- *Nota bene* for future machines

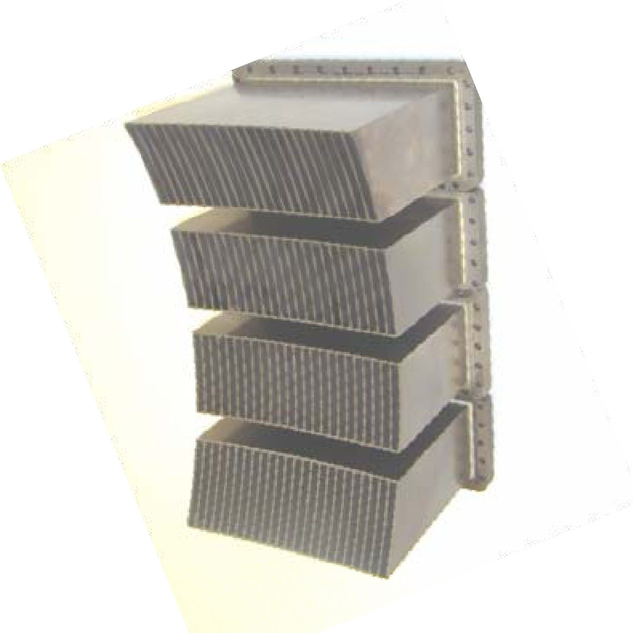






Future Work: Emphasizes AT research and Support for Burning Plasmas (ITER) in Reactor Relevant Regimes

- Reactor relevant conditions
  - Ions and electrons coupled; $T_i \sim T_e$
  - $t_{PULSE} > \tau_{L/R}$
  - No core momentum or particle sources.
- Enabled by LHCD
  - 3 MW source at 4.6 GHz.
  - 4 x 24 waveguide array – realtime phase control
- Cryopump for density control
- Prototype tungsten brush divertor tiles to help manage heat load.
- Long pulse DNB.



The End