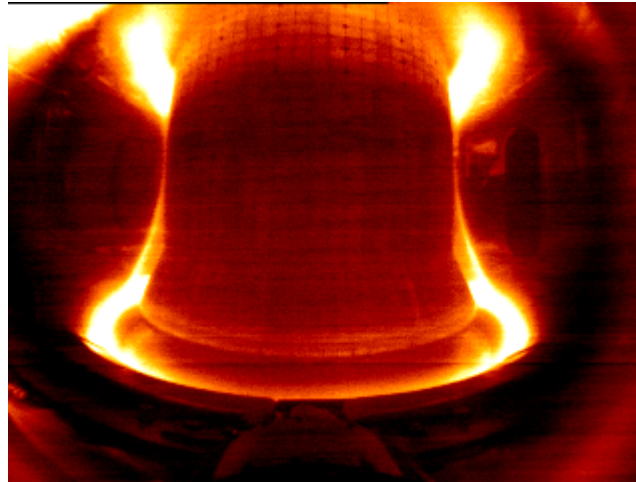

OVERVIEW OF THE ALCATOR C-MOD PROGRAM



IAEA-FEC November, 2004

Alcator Team

Presented by Martin Greenwald

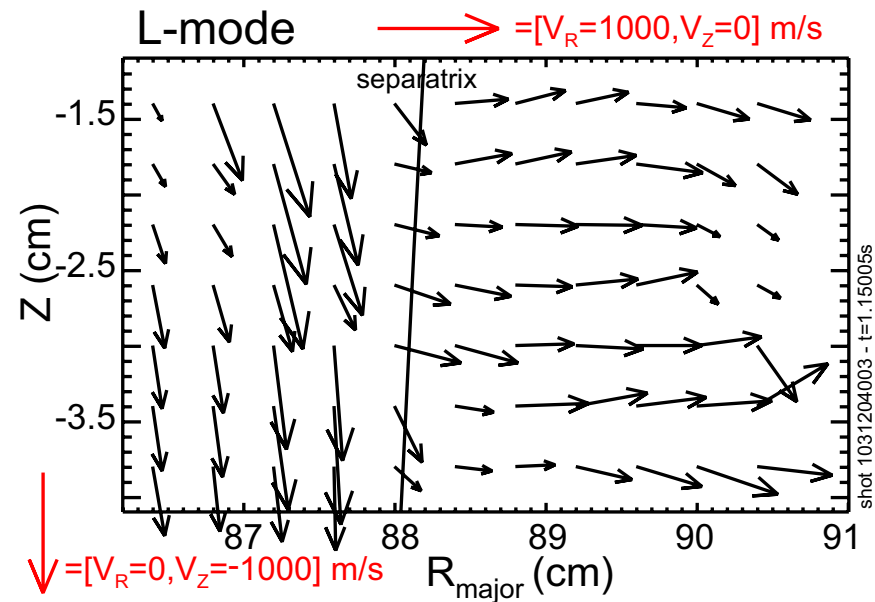
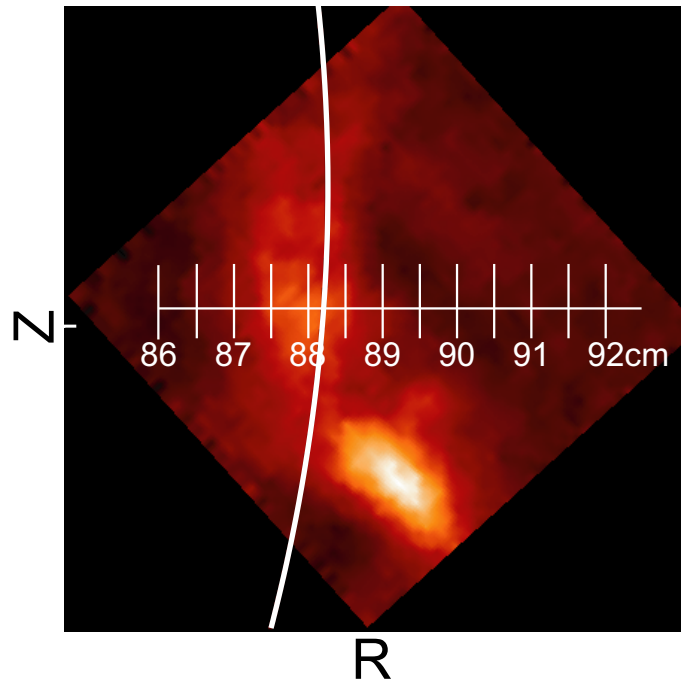
MIT – Plasma Science & Fusion Center

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



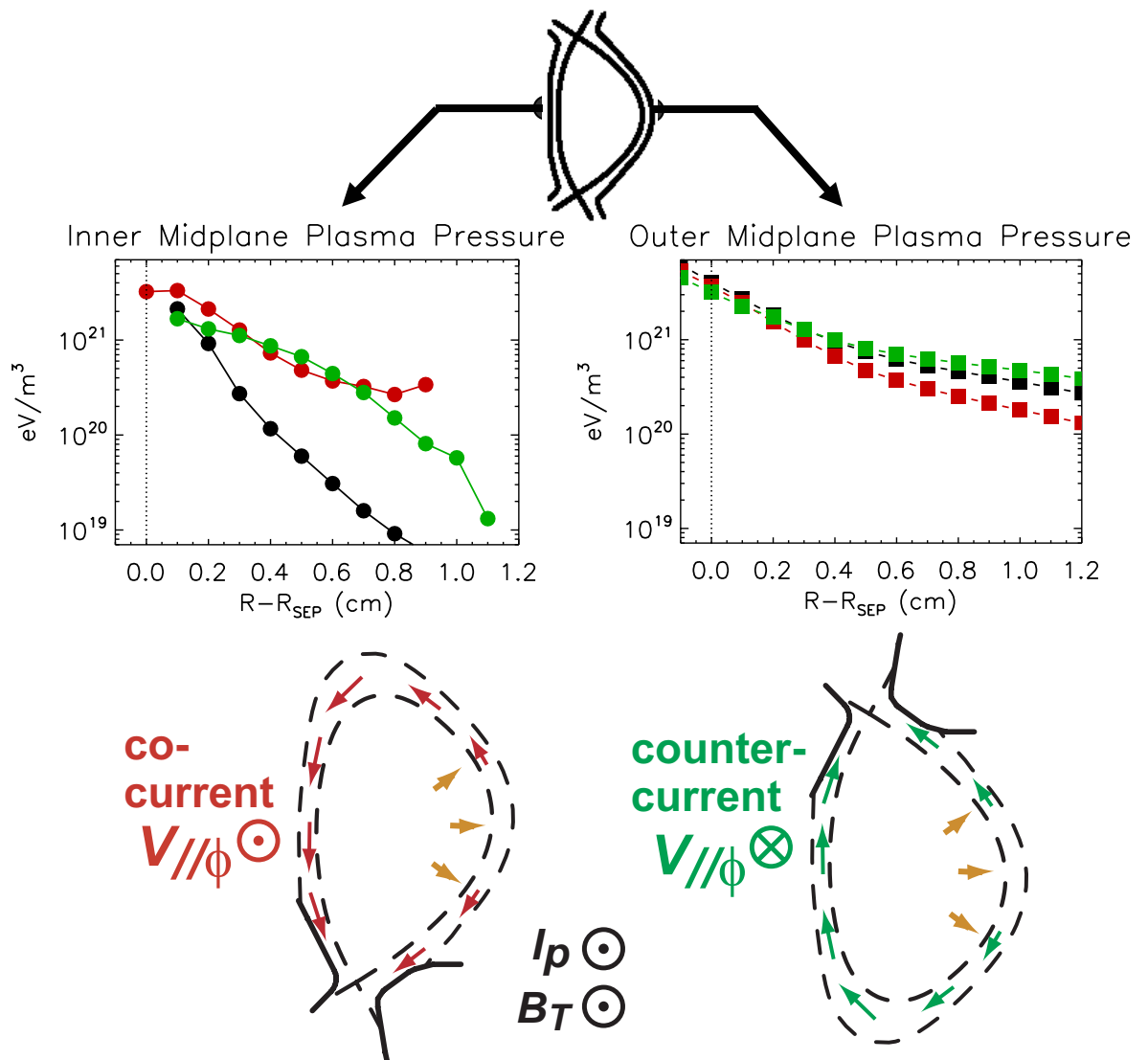
Terry EX/P4-12

- 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 ($M \sim 1$)



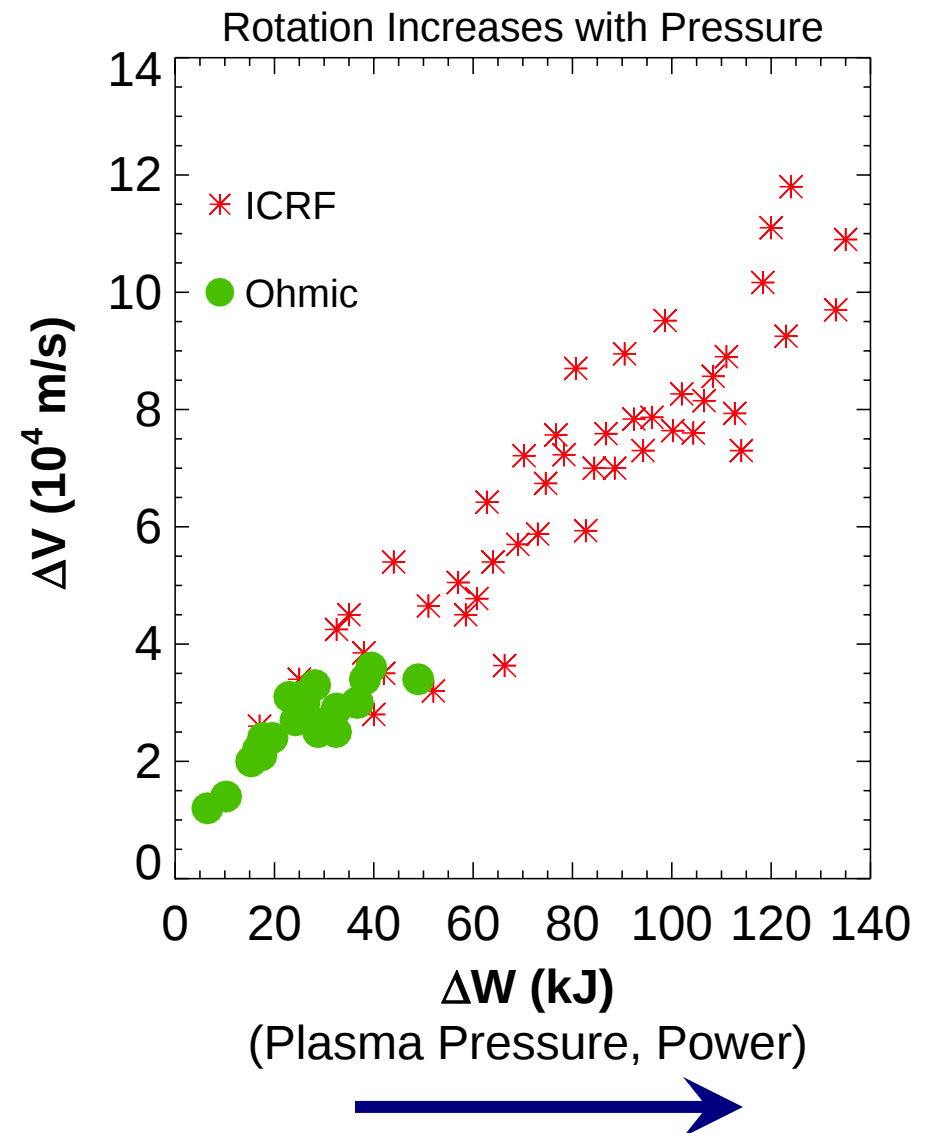
STRONG TOROIDAL ROTATION IN ABSENCE OF EXTERNAL TORQUE

IS THERE A CONNECTION TO BOUNDARY PHYSICS?



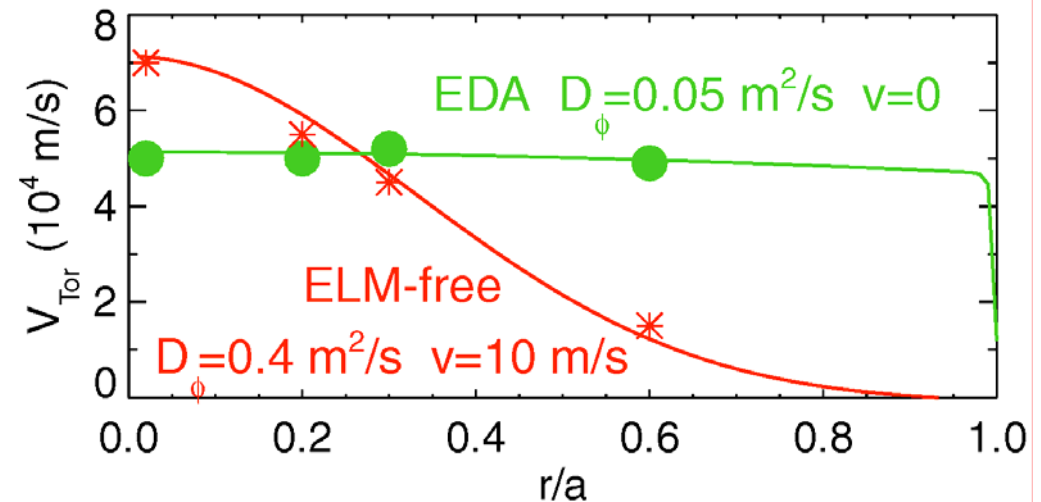
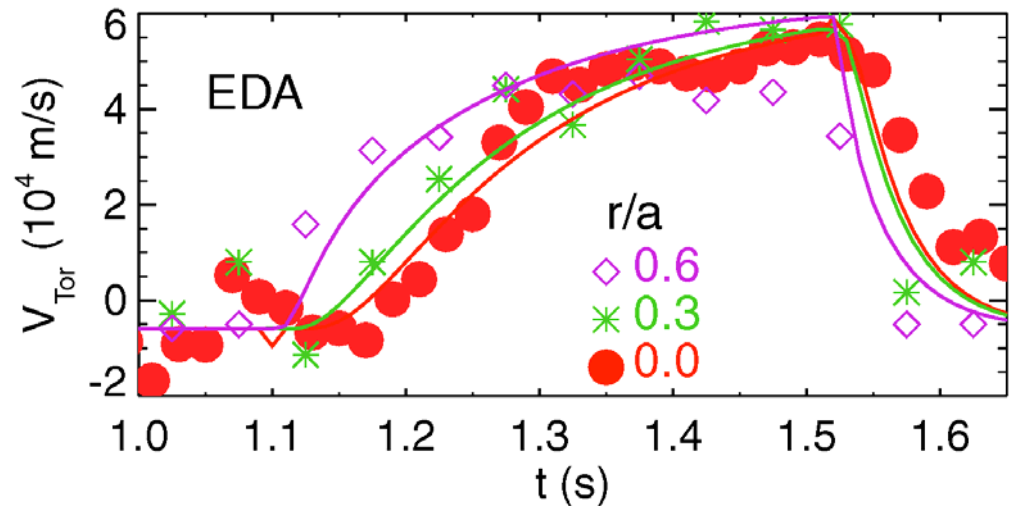
TO REVIEW

- 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

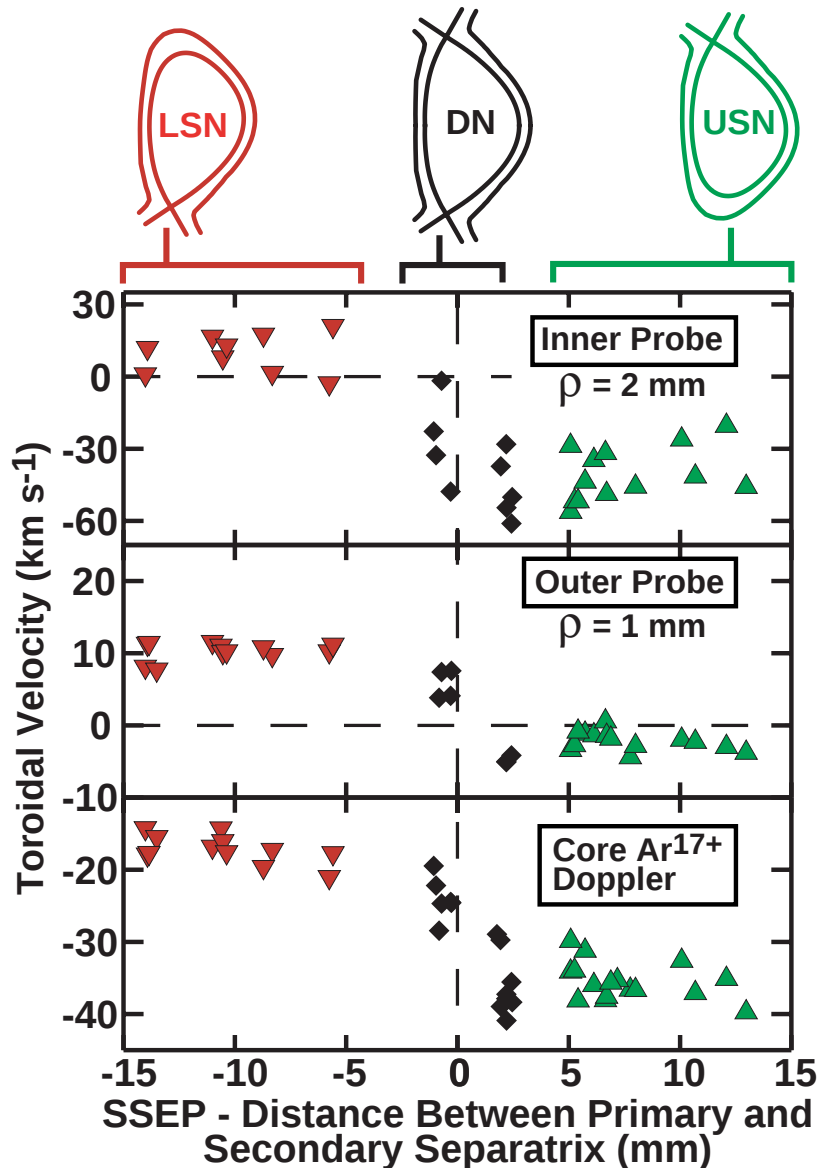


MOMENTUM IS TRANSPORTED INWARD FROM OUTER REGIONS

- 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

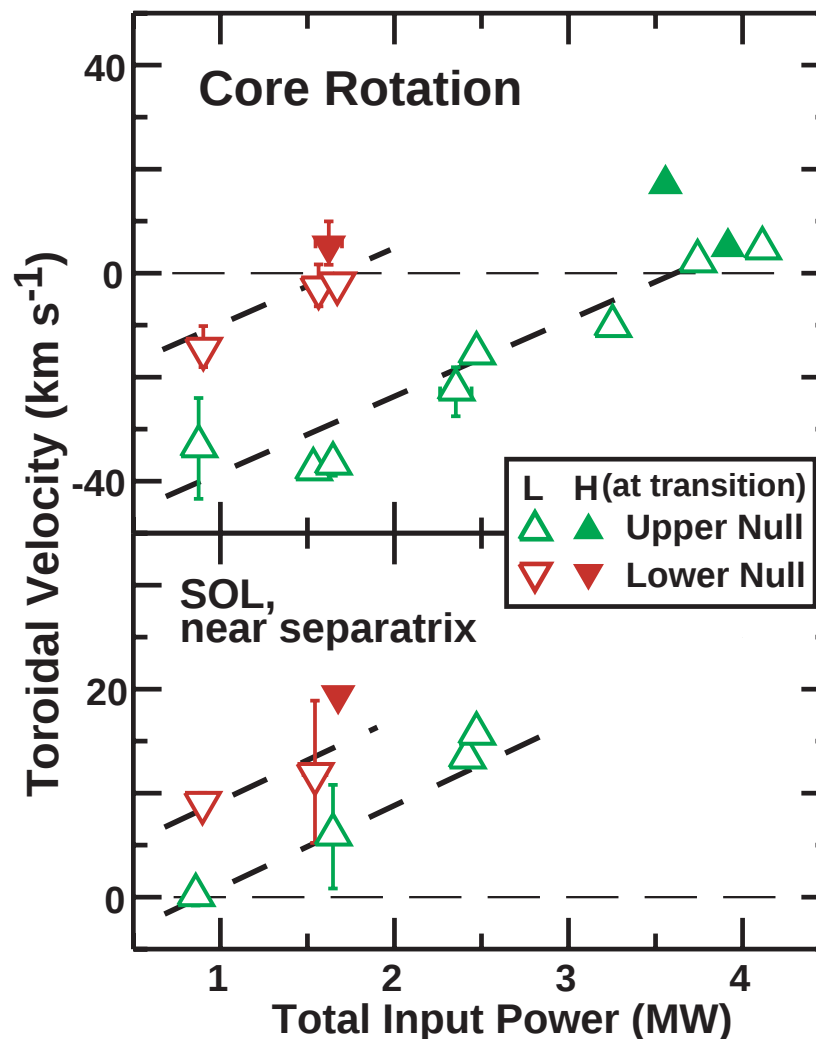


- Scan separation between primary and secondary separatrix (SSEP)
 - SSEP < 0 Lower null
 - SSEP > 0 Upper null
- Over a few mm, rotation shifts in counter direction by 20-30 km/s
- Scale comparable to SOL size.
- Links core and edge rotation
- Double null balance is critical

OBSERVATIONS OF SELF-GENERATED FLOWS AND INWARD MOMENTUM TRANSPORT LEAD TO A NOVEL HYPOTHESIS FOR ∇B DRIFT INFLUENCE ON L-H THRESHOLD

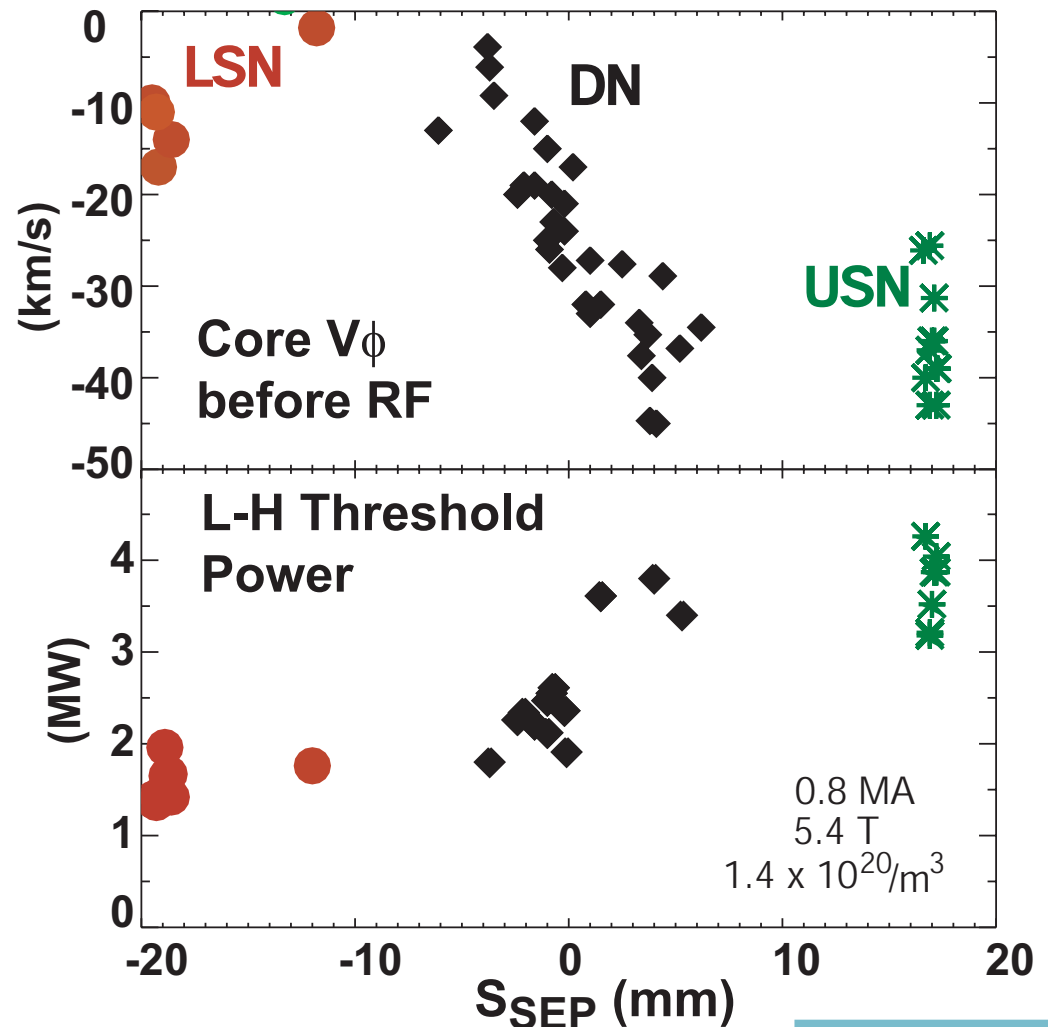


- Power/temperature threshold is 2x higher for unfavorable topology - ∇B ion drift away from SN.
- Edge rotation is sum of the two terms just described.
 - Topology dependent (from symmetrizing of ballooning transport) – more counter for unfavorable geometry.
 - Pressure (power) dependent – increases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

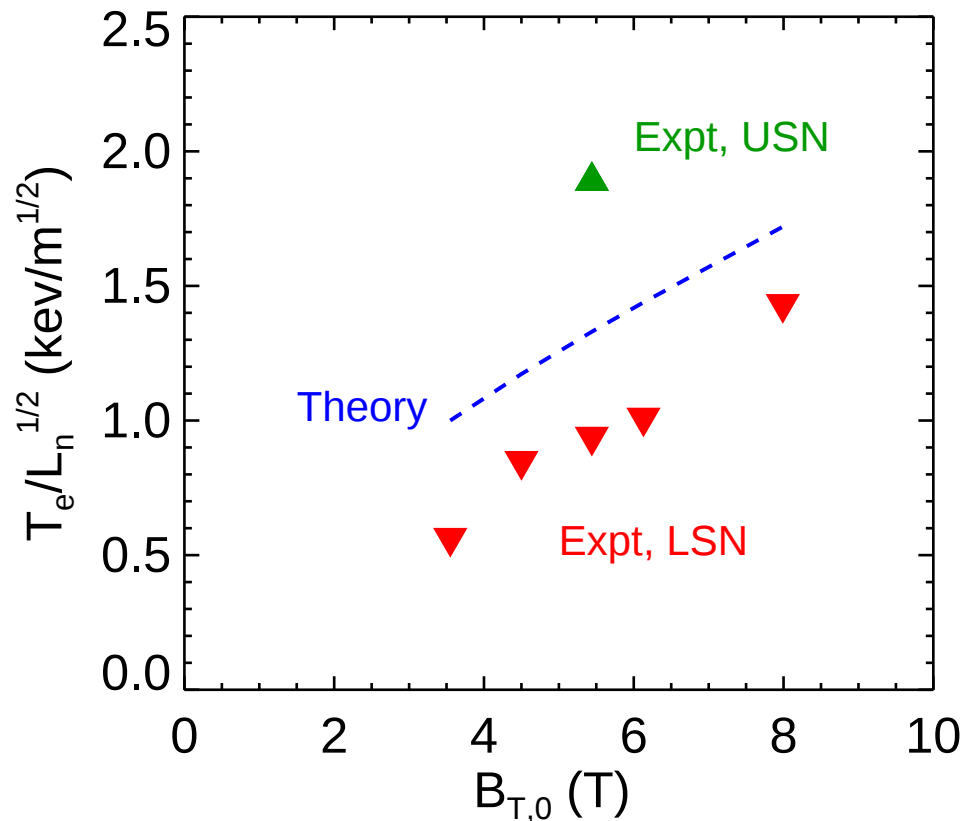


CORRELATION BETWEEN TOPOLOGY, ROTATION AND THRESHOLD IS STRONG

- 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

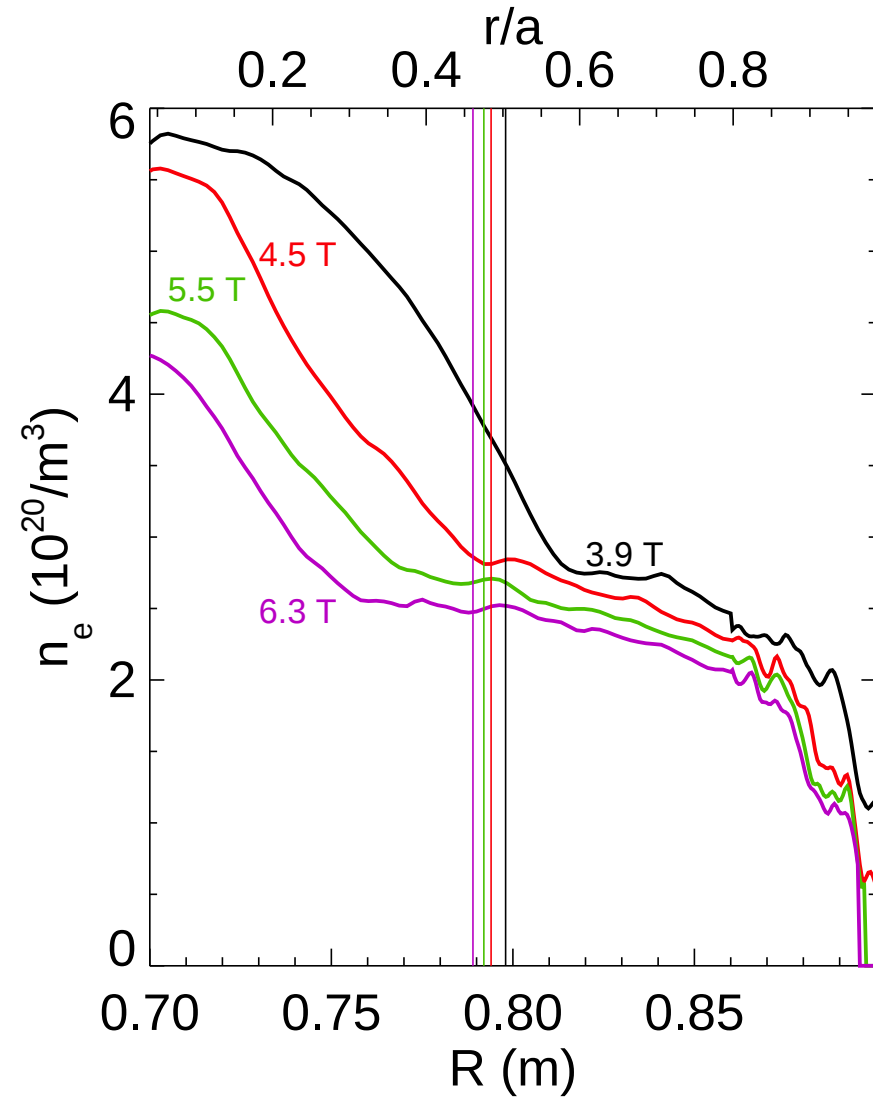
- Simulations: suppression of drift-Alfven turbulence via zonal flows. (*Rogers 1998*)
- Guzdar (*PRL 2002*) derives analytic formula.

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

- Splits difference between favorable and unfavorable topologies.

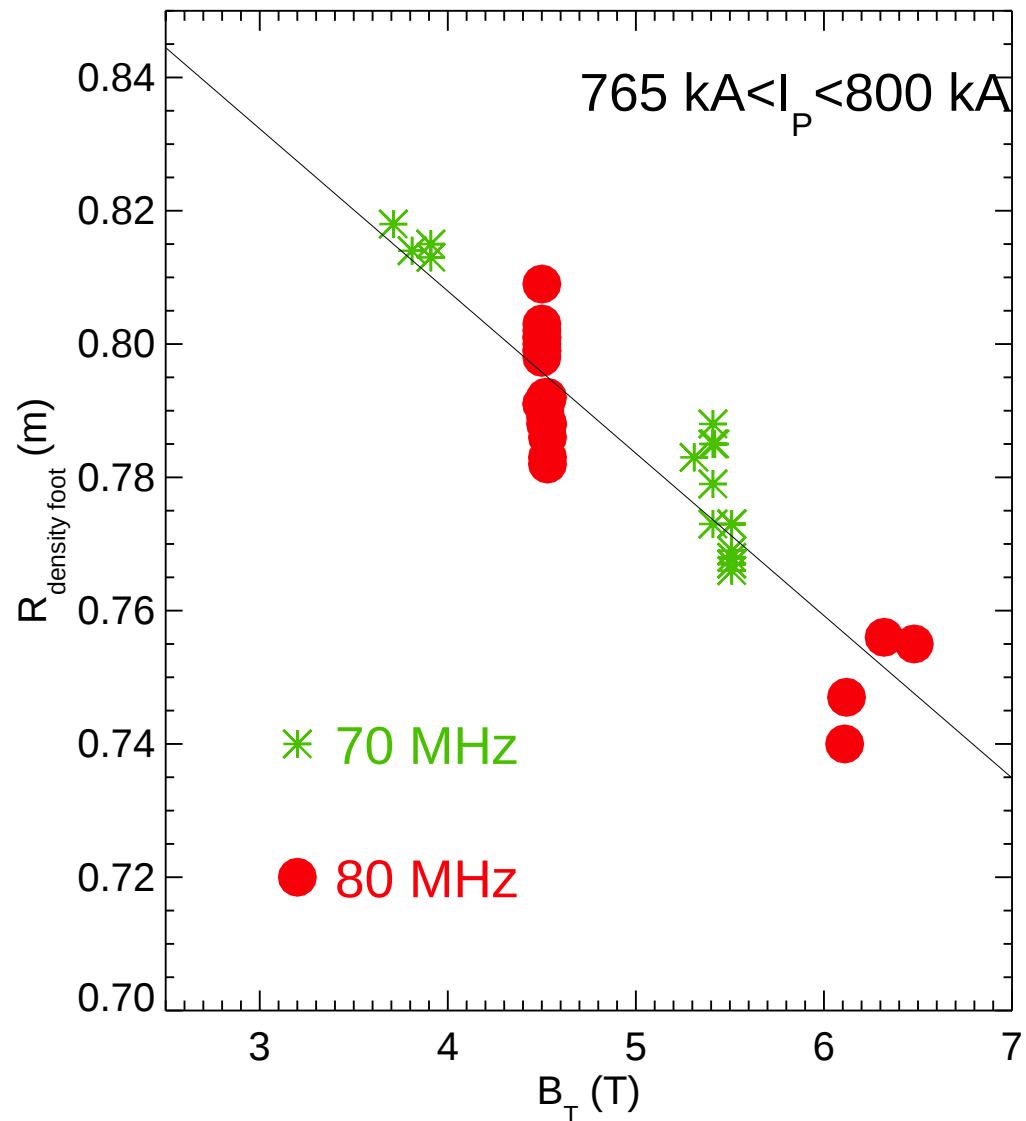
ITB STUDIES HAVE FOCUSED ON BARRIER CONTROL

- 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).



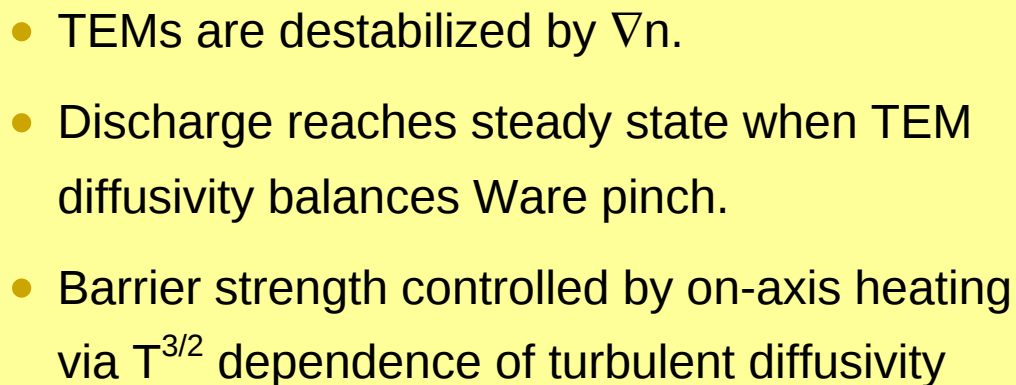
BARRIER FOOT LOCATION DEPENDS MAINLY ON B_T

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



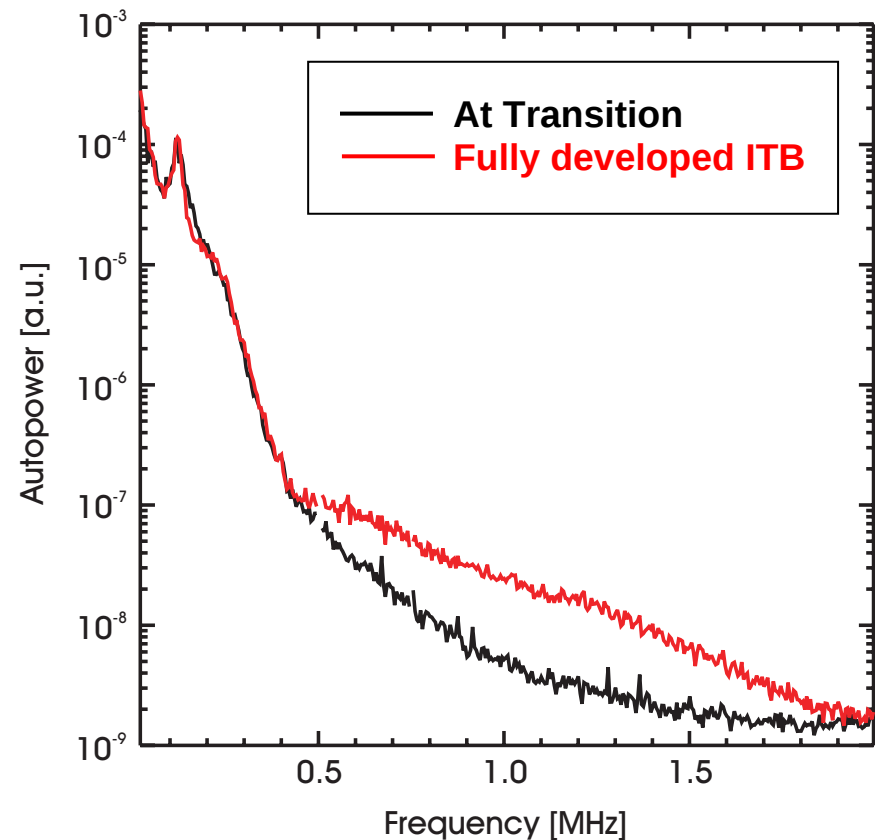
Alcator
C-Mod

-
- Figure 1 is a plot showing the relationship between the normalized vertical scale length a/L_n (Y-axis, ranging from -0.5 to 3.0) and the normalized horizontal scale length a/L_T (X-axis, ranging from 0.0 to 2.0). The plot is divided into three main regions: TEM (Top Left, yellow), ITG/TEM (Top Right, light blue), and ITG (Bottom Right, white). A black curve separates the TEM and ITG/TEM regions, and another black curve separates the ITG/TEM and ITG regions. A red trajectory, labeled "Trajectory of ITB ($\rho=0.4$)", is shown, starting in the TEM region and moving towards the ITG/TEM region. The trajectory is marked with time values (s): 0.70, 0.75, 0.80, 0.85, 0.90, 0.95, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25, 1.30, 1.35, and 1.40. The trajectory shows a loop in the ITG/TEM region. A black arrow labeled "increasing γ " points upwards in the ITG/TEM region. A black arrow labeled "weak dependence on L_T " points upwards in the TEM region. A black box labeled "STABLE" is located in the TEM region.



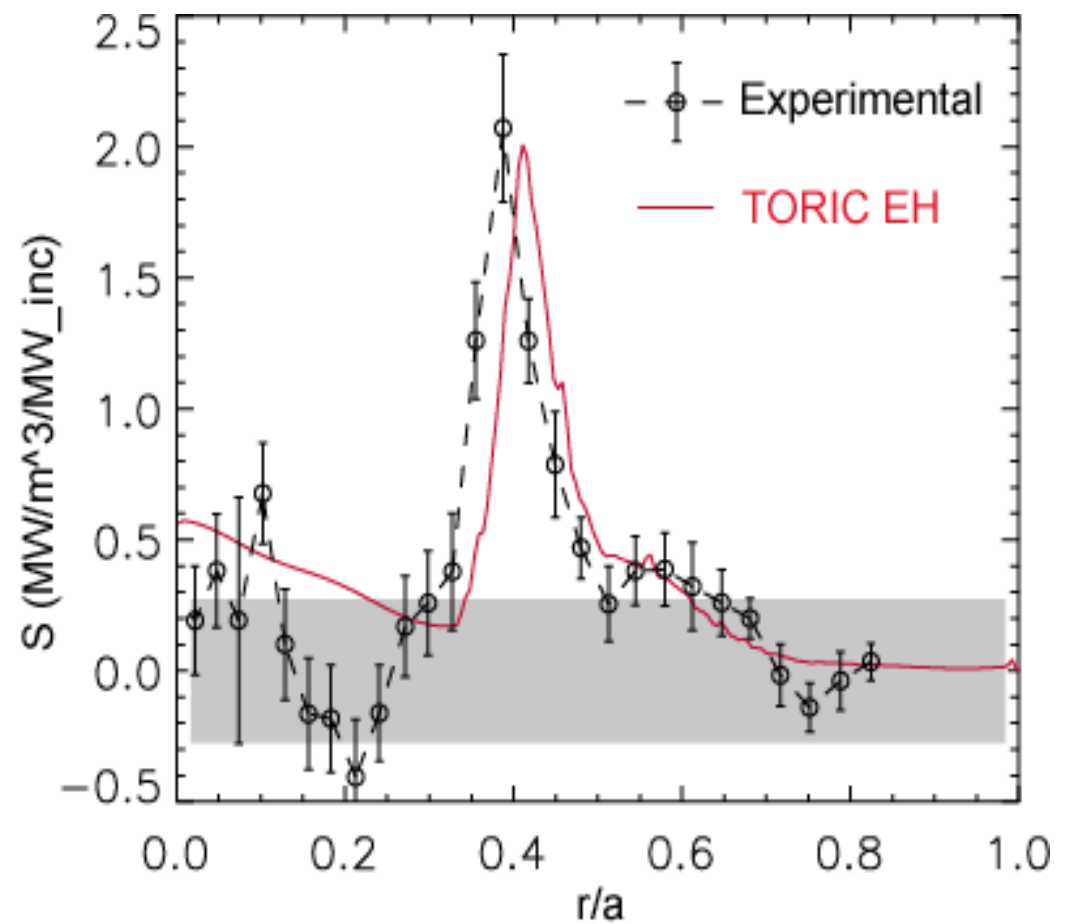
FLUCTUATIONS SEEN WITH PCI MAY SUPPORT ITB SCENARIO

- 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.

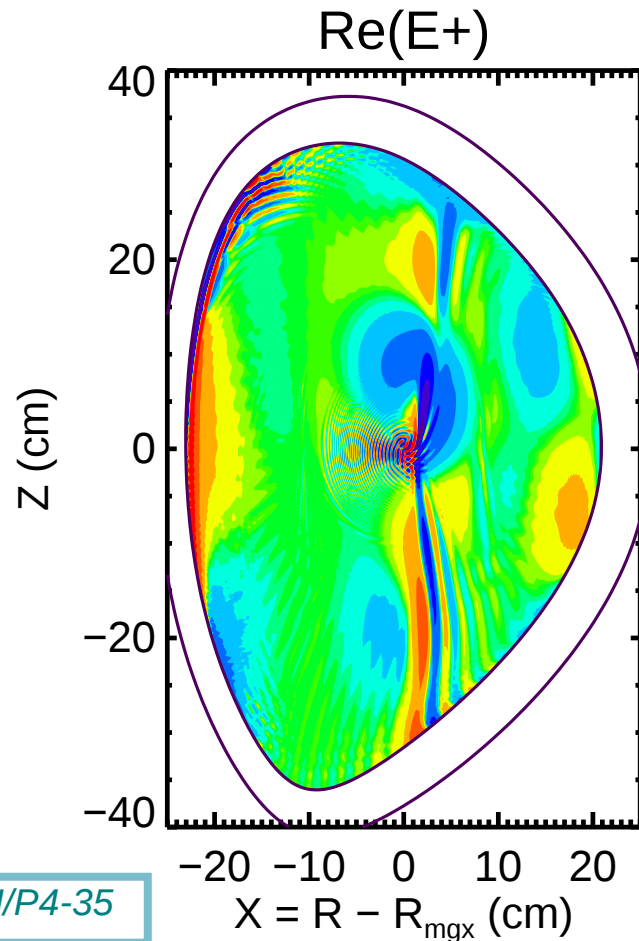


MODE CONVERSION ICRF – FOR LOCALIZED HEATING, CURRENT DRIVE, FLOW DRIVE

- 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%

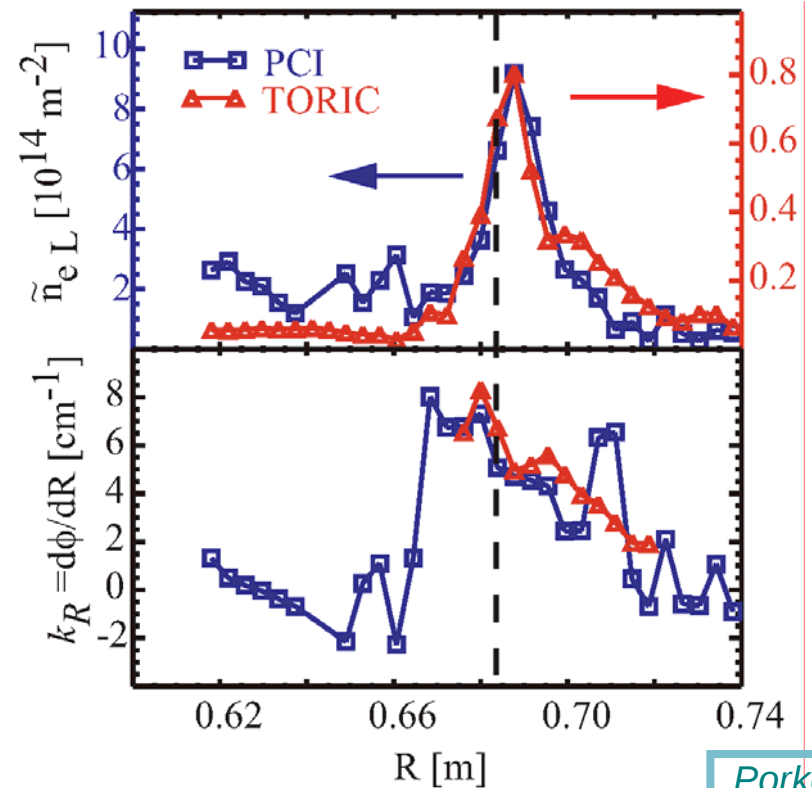


ICRF MODE CONVERSION PROCESS STUDIED IN DETAIL WITH FLUCTUATION DIAGNOSTIC AND ADVANCED SIMULATION



Wright TH/P4-35

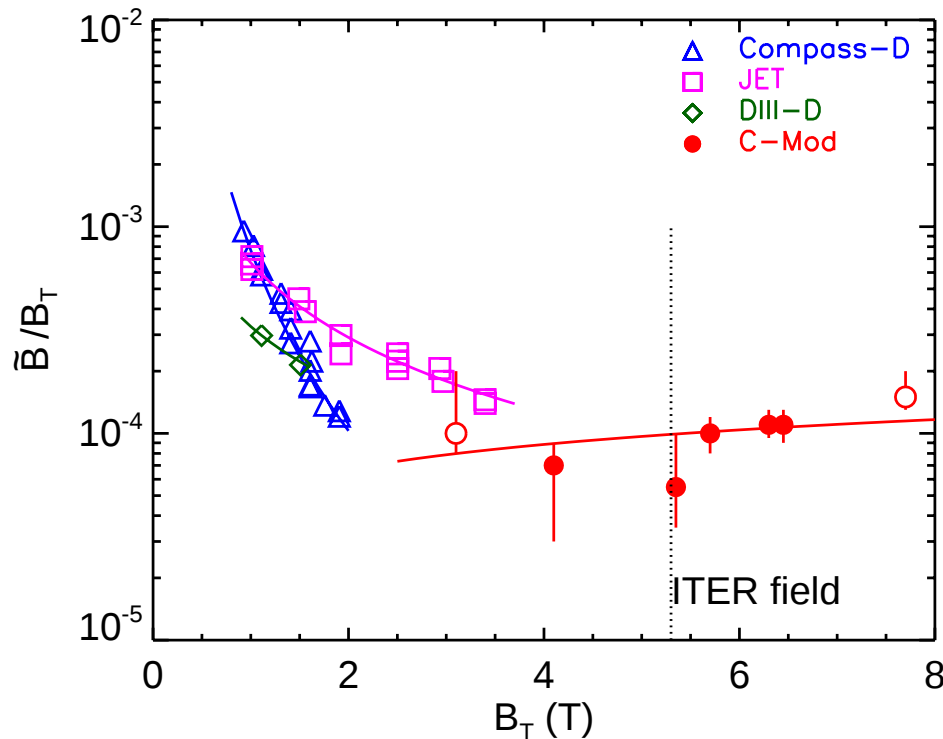
- Parallel version of TORIC with $n_r = 240$, $n_m = 255$.
- Resolves details of MC process.



Porkolab P4-32

- 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



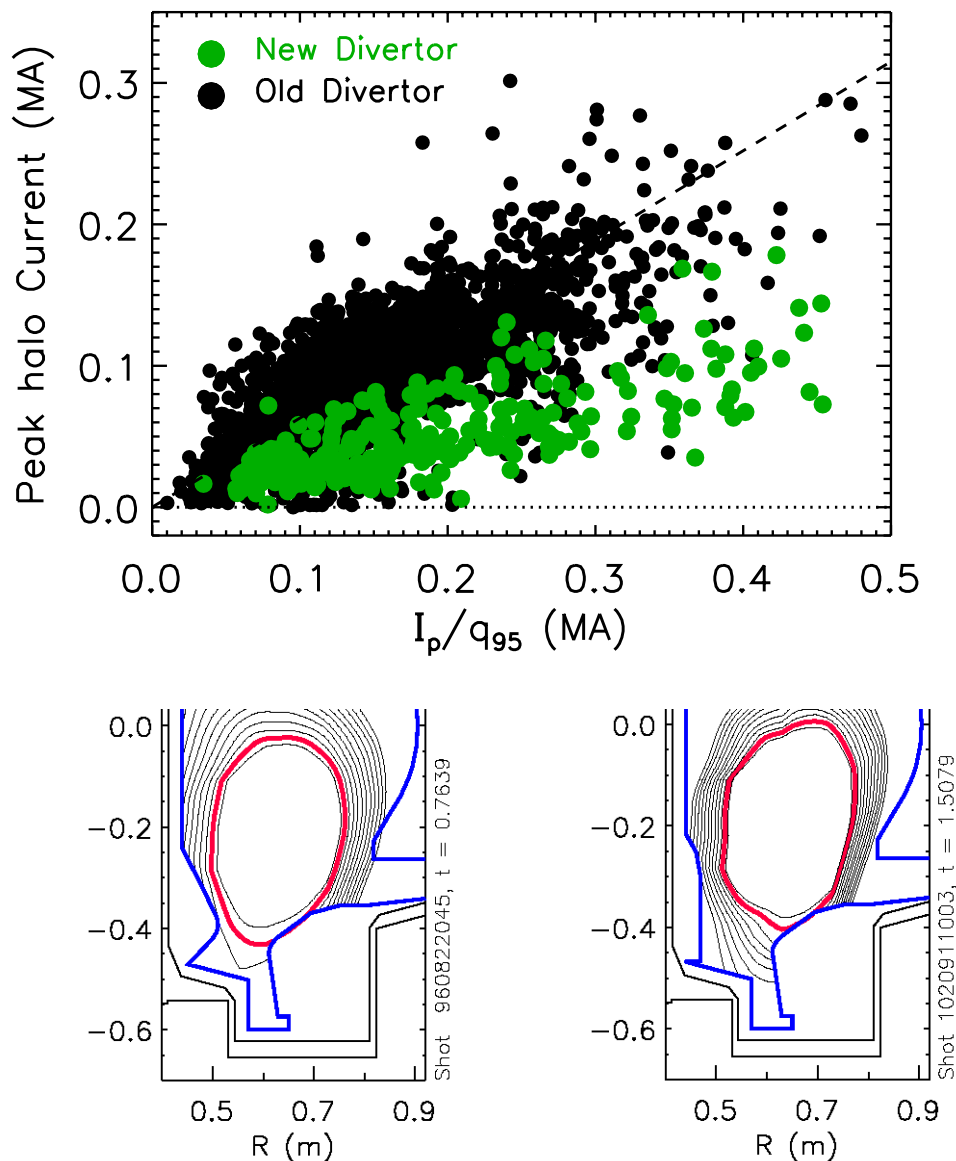
- C-Mod, DIII-D, JET data in same range for n/n_{LIMIT} .
- 5x range in machine size.

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

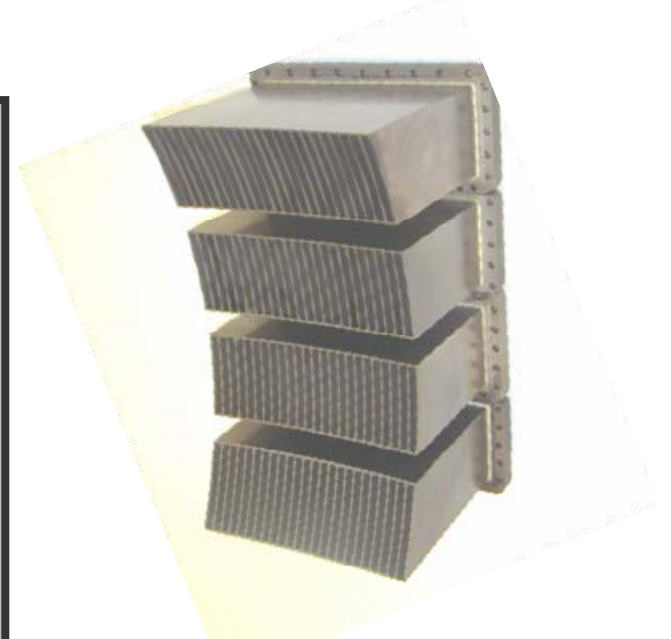
- Previous work found that halo currents scaled with I_P/q_{95} with strong poloidal asymmetry.
- After divertor modification, same scaling observed but with lower magnitude (1/2) and less asymmetry.
- Drop in halo current may be explained by change in plasma/divertor contact during VDE.
- *Nota bene* 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; $T_i \sim T_e$
 - $t_{\text{PULSE}} > \tau_{L/R}$
 - 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