THE QUIESCENT DOUBLE BARRIER REGIME IN DIII-D

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General Atomics
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GENERAL ATOMICS

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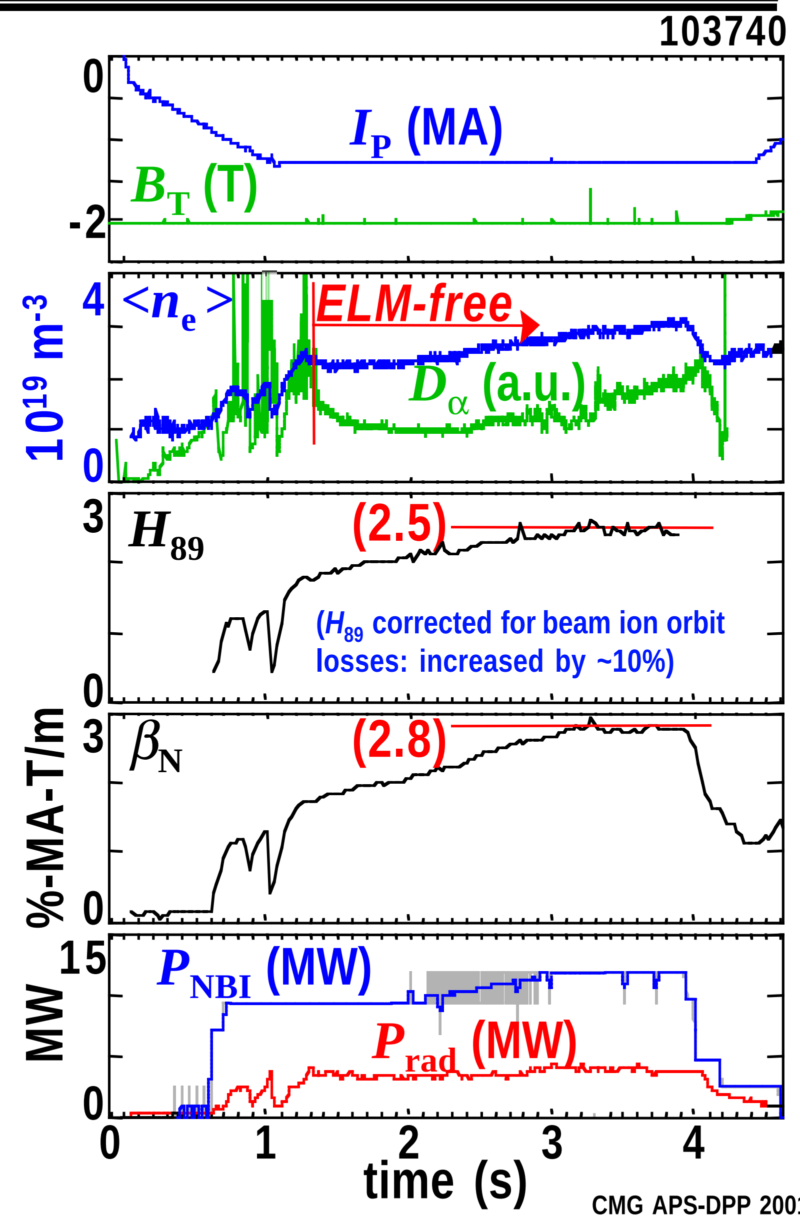
SUSTAINED HIGH PERFORMANCE IN THE QUIESCENT DOUBLE-BARRIER REGIME

- Quiescent double-barrier (QDB) regime combines:
  - ELM-free Quiescent H-mode edge barrier:
    - ELMs replaced by steady MHD activity.
    - Density control achieved through divertor cryopumping.
  - Core barrier:
    - Characteristics similar to L-mode edge ITB plus a pedestal.
    - Turbulence not completely suppressed.
      - Short turbulence correlation lengths may be responsible for reduced transport.

- Parameters obtained to date (with I_P=1.0-1.6 MA, B_T=1.8-2.1T):
  - $\beta_N \leq 2.9$, $H_{89} \leq 2.5$, $\beta_N H_{89} \leq 7$.
  - Sustained for length of beam pulse.

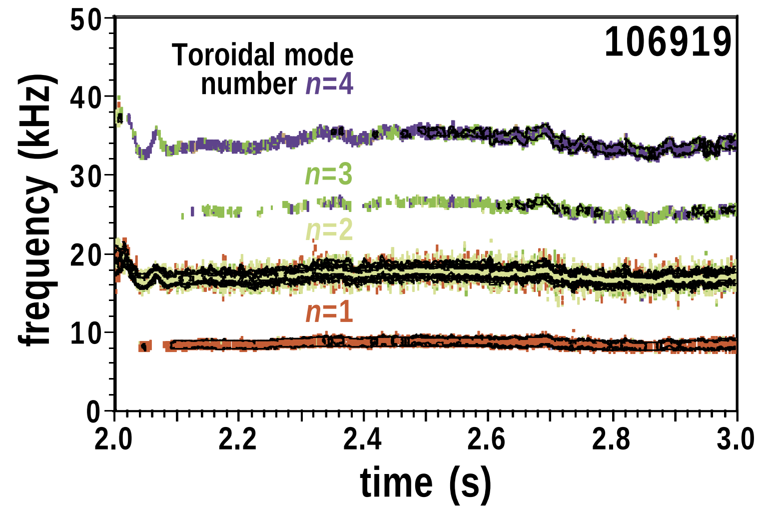


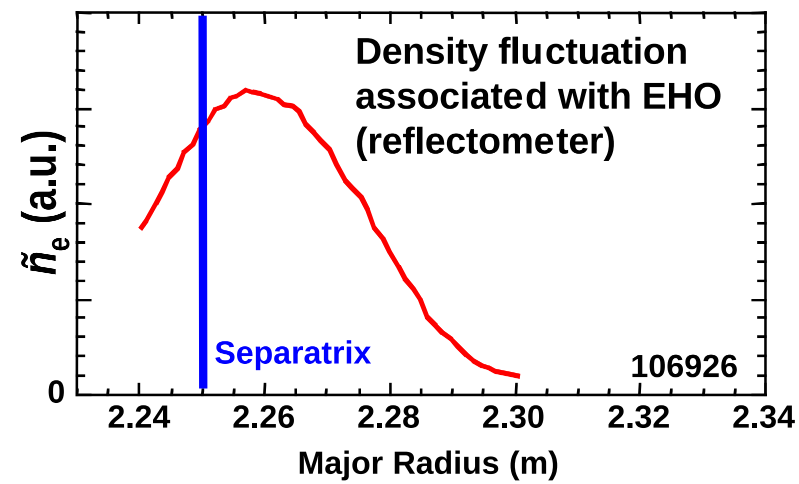
•West, invited talk KI1.004, Wed. AM
•Doyle, *et al.*, poster LP1.012 Wed. PM

ELMS ARE REPLACED BY COHERENT MHD ACTIVITY

- In most cases, the Edge Harmonic Oscillation (EHO) replaces ELMs in boundary region of the QDB.
  - Increases particle transport at the edge.
  - Eliminates undesirable effects of ELMs:
    - Highly localized: minimal interference with core barrier.
    - No pulsed heat load at the divertor.
  - Multiharmonic activity observed in magnetic and density fluctuation measurements.

- The EHO does not appear to be the ELM suppression mechanism.
  - It is not uniquely associated with ELM-free regimes.
    - Other MHD can fill the same role.
  - It has been observed in <u>both</u> ELMy and ELM-free discharges.
    - ELMs are only suppressed during the EHO in counter-NBI discharges.
    - EHO often observed *between* ELMs in both co- and counter-NBI discharges.
  - *The ELM suppression mechanism remains unidentified.*





- Zeng, *et al.*, poster LP1.016 Wed. PM
- Lasnier, *et al.*, poster LP1.036 Wed. PM
- Burrell, *et al.*, poster RP1.017 Thu. PM

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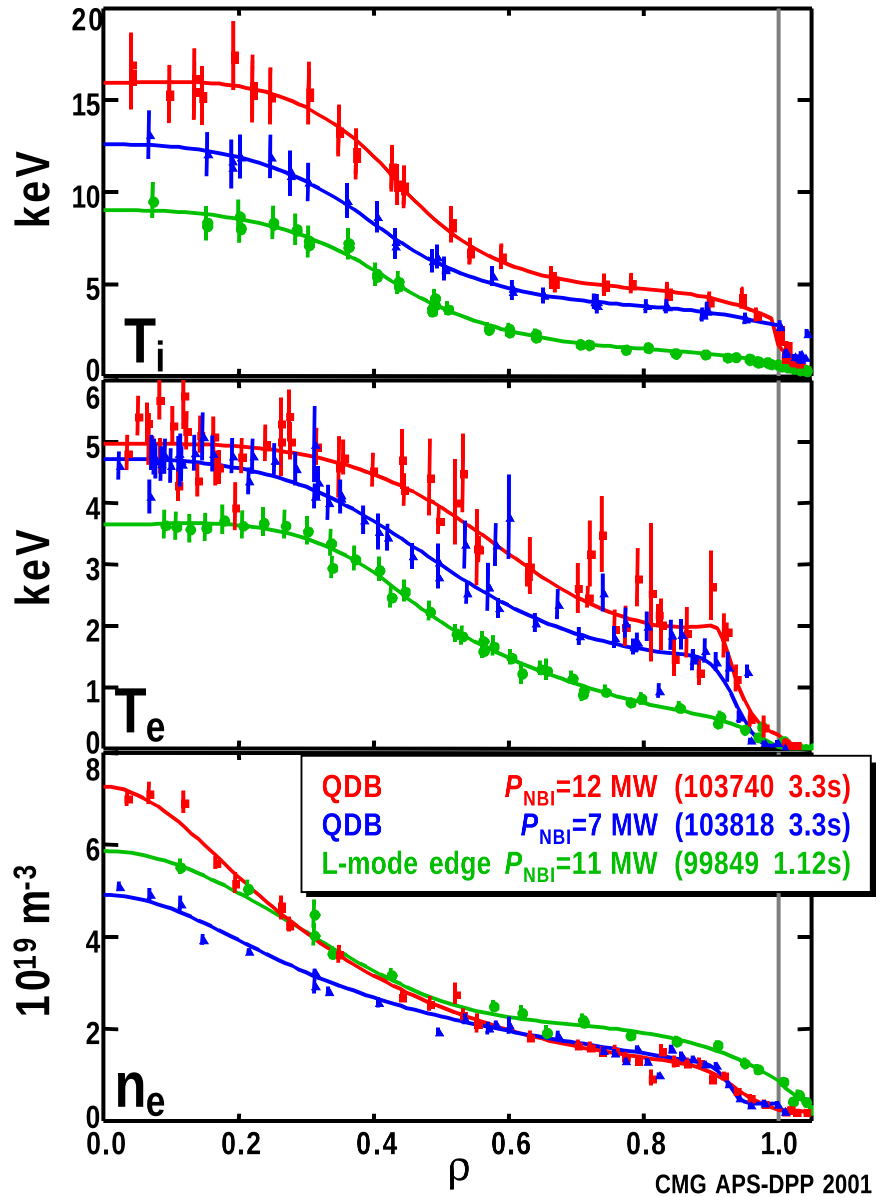
QDB ELEVATES TEMPERATURE PROFILES OF L-MODE EDGE ITB BY THE AMOUNT OF THE H-MODE PEDESTAL

- Core profiles similar to L-mode edge ITB with additional edge pedestal.
  - Ion temperature pedestals of up to 6 keV have been obtained.
- Edge density is *lower* than in L-mode due to strong pumping.
  - Core densities can become very peaked.
- Additional power tends to primarily impact the core barrier.
- *Discharges shown all have counter-NBI.*
  - *Core and edge barriers merge with co-NBI.*



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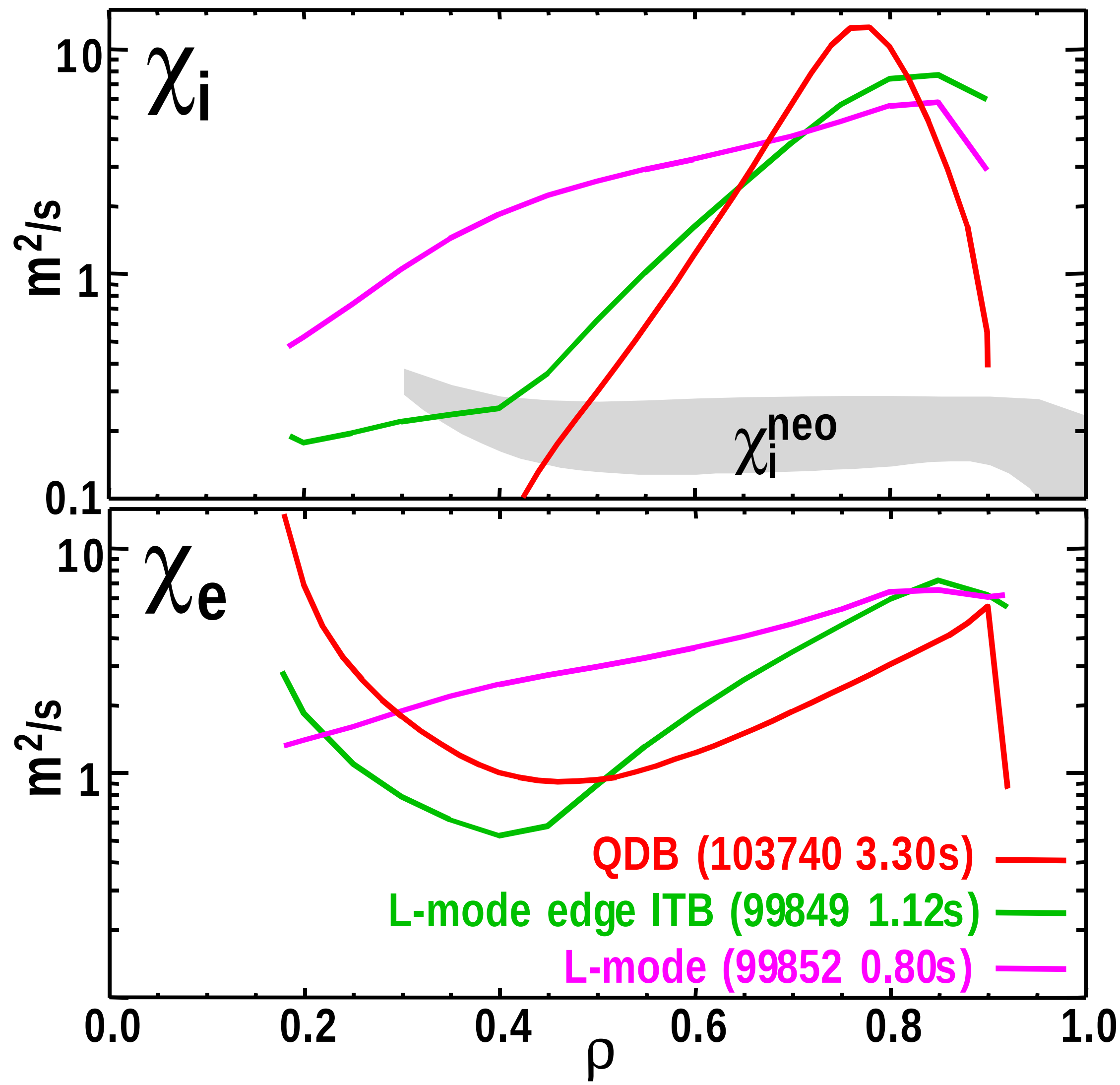
CORE AND EDGE BARRIERS COEXIST IN THE QDB REGIME

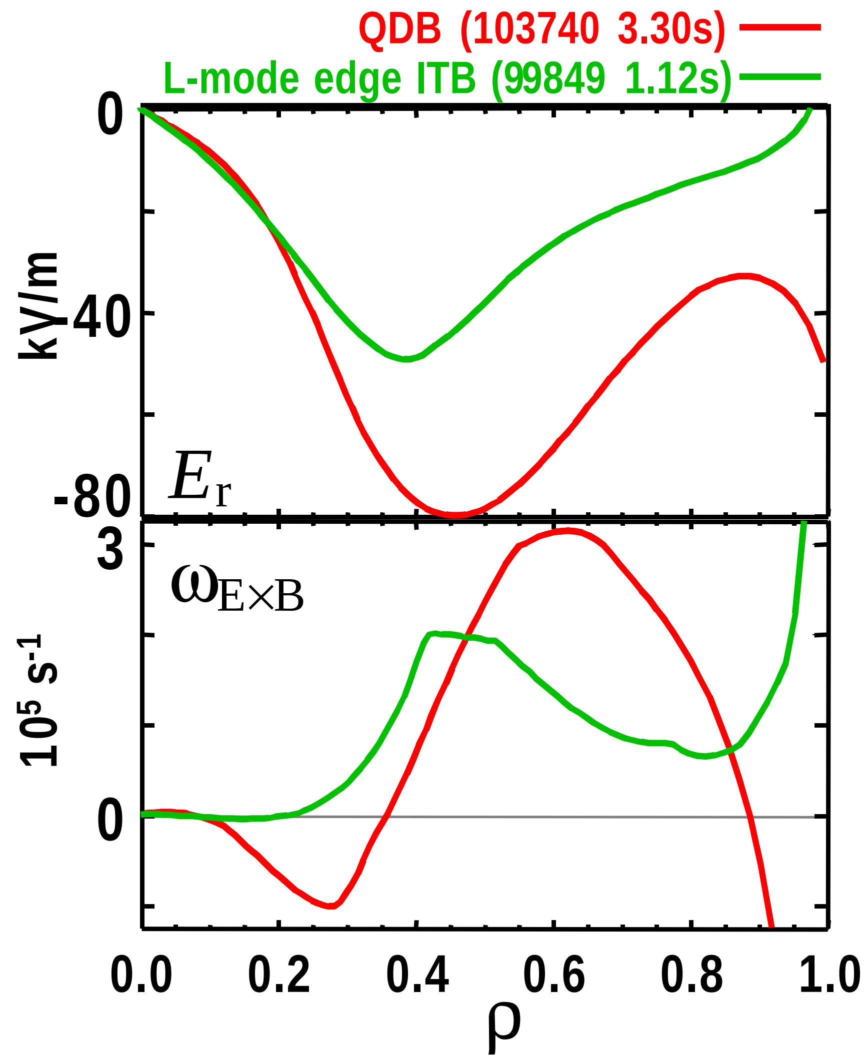
- **Diffusivities reduced near edge due to H-mode.**
- **Core thermal transport similar with L-mode edge ITB and QDB regimes.**
  - **Reduced significantly below standard L-mode.**



SEPARATION BETWEEN CORE AND EDGE BARRIERS RELATED TO ZERO CROSSING IN E×B SHEARING RATE

- Calculated directly from measured carbon impurity density, temperature and velocity (Charge Exchange Recombination spectroscopy).
  - E_r calculated using force balance.
  - E×B shearing rate calculated with Hahm-Burrell formula.

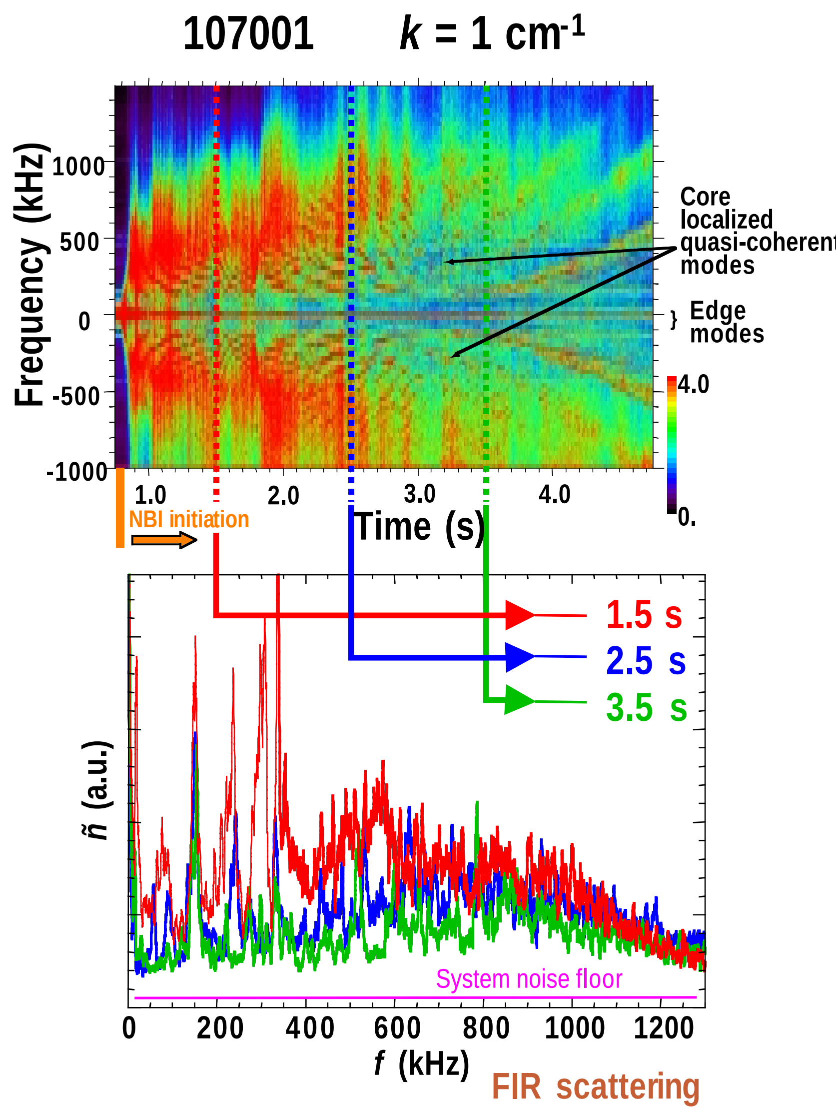
- Low shearing rate region consistent with core-edge separation.
  - E_r always negative with counter-NBI.
  - E_r also negative with H-mode edge.
  - Turnover point between barriers results in zero crossing of shearing rate.



QDB CORE BARRIER EXISTS WITHOUT COMPLETE SUPPRESSION OF TURBULENCE

- Internal broadband turbulence is reduced as the QDB core barrier evolves.
  - Residual turbulence still significantly above instrument detection limit.
  - Contrasts with typical ITB in DIII–D, where core turbulence is suppressed to the noise floor.

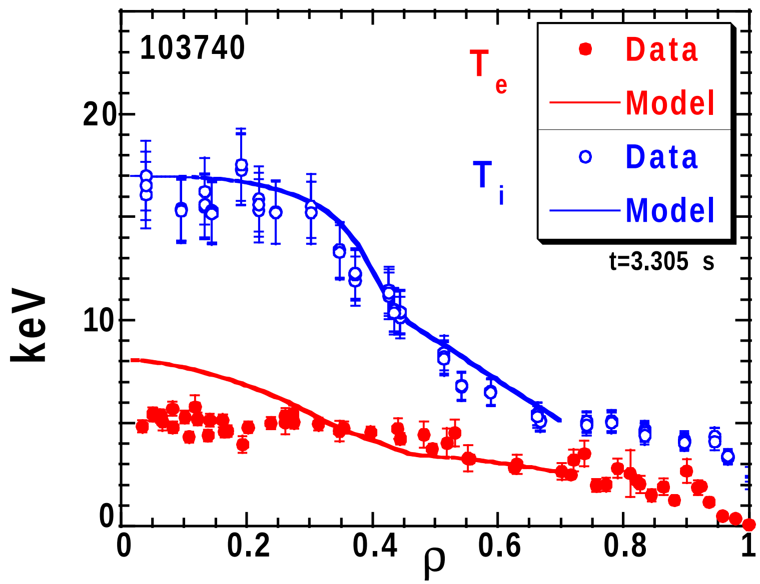
- High frequency coherent core modes are often detected.
  - Reflectometer data indicate these modes are localized to ρ~0-0.4.



- Zeng, *et al.*, poster LP1.016 Wed. PM

SIMULATIONS USING THE GLF23 MODEL REPRODUCE CORE ION BARRIER IN THE QDB

- Steady-state simulation preserves core ion barrier.
  - Boundary condition is QH-mode edge inwards to ρ≈0.7.
- E×B shear primarily responsible for core barrier formation.
  - Turbulence not completely suppressed.
- Electron behavior is not reproduced by simulation.



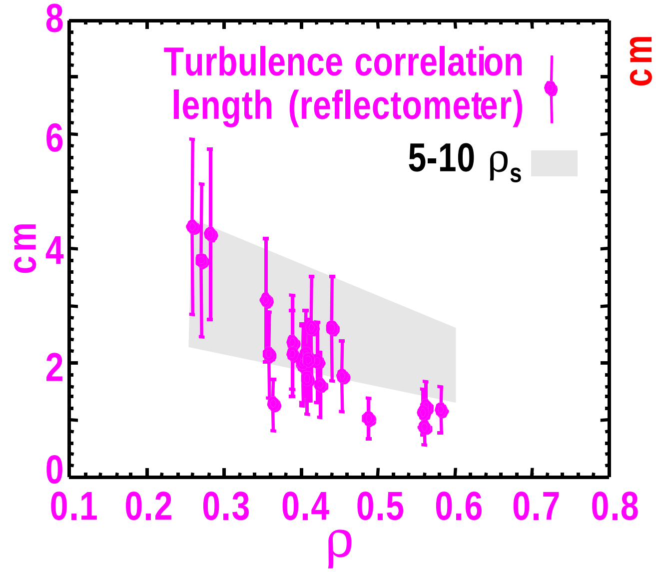
• Kinsey, *et al.*, oral QO1.012 Thu. AM

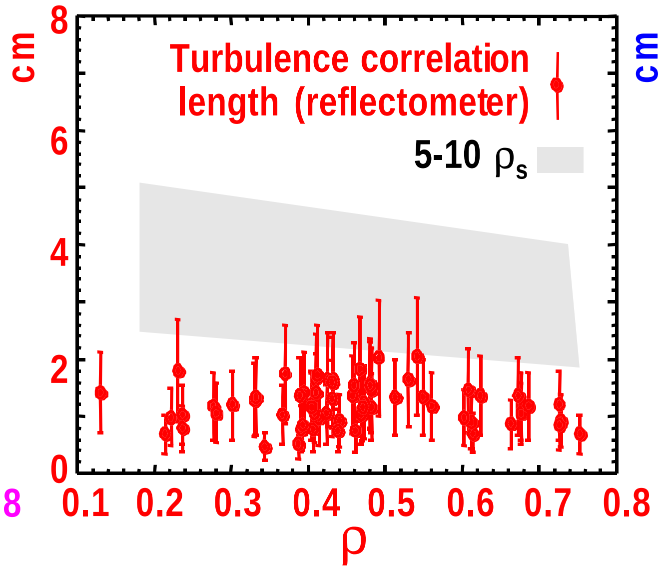
CORE TURBULENCE CORRELATION LENGTHS DECREASE IN QDB REGIME - REDUCED STEP SIZE FOR TURBULENT TRANSPORT

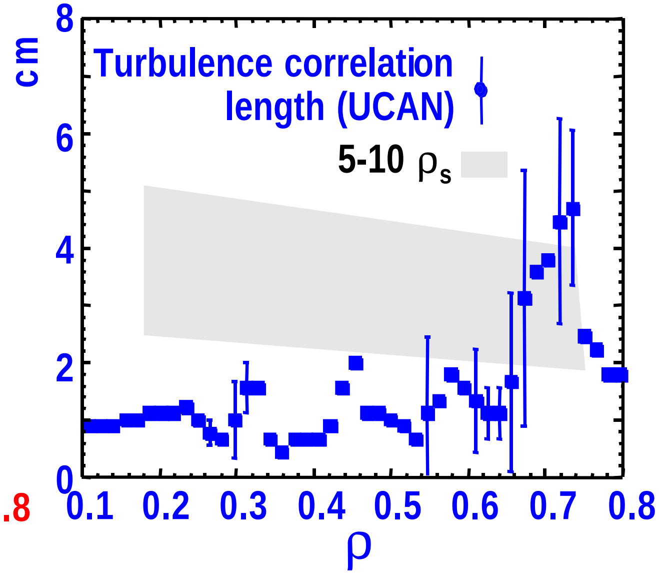
L-mode:
Correlation lengths scale approximately with the ion gyroradius.

QDB regime:
Core correlation lengths 2-8 times smaller than in L-mode.

Preliminary nonlinear turbulence simulations with the UCAN code reproduce the QDB observation.







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•Rhodes, invited talk UI1.005 Fri. AM

SUMMARY

- The Quiescent Double Barrier regime: ELM-free steady H-mode with core barrier.
  - Edge barrier modulated by MHD activity, but specific mode is not required.
    - Outstanding scientific question: What suppresses the ELMs?
  - Core and edge barrier separation related to zero crossing of shearing rate.
  - Core barrier increases with increasing heating power.
    - Strongly peaked density and ion temperature profiles.

- Core transport reduction:
  - Appears without complete suppression of turbulence.
    - Consistent with GLF23 simulation.
  - Turbulence correlation lengths become very short $\Rightarrow$ transport step size is reduced.
    - Consistent with preliminary calculations with UCAN.

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FOR MORE INFORMATION RELATED TO THE QUIESCENT DOUBLE BARRIER REGIME…

- Invited talks
  - KI1.004: W.P. West, "*Energy, Impurity and Particle Transport in Quiescent Double Barrier Discharges in DIII–D.*"
  - UI1.005:T.L. Rhodes, "*Comparison of Turbulence Measurements From DIII-D L-mode and High Performance Plasmas to Turbulence Simulations and Models.*"

- Poster, Tuesday morning
  - FP1.048: T.A. Casper, "*Predictive Modeling of Tokamak Configurations.*"

- Posters, Wednesday afternoon
  - LP1.004: P. Gohil, *et al*., "*Development of Methods to Control Internal Transport Barriers in DIII-D Plasmas*."
  - LP1.012: E.J. Doyle, *et al*., "*Recent Results from the Quiescent Double Barrier Regime on DIII-D*."
  - LP1.016: L. Zeng, *et al*., "*Fluctuation Characteristics of the QDB Regime in DIII-D*."
  - LP1.036: C.J. Lasnier, *et al*., "*Scrape-off Layer Characteristics of QH and QDB Plasma Compared with ELMing H-mode and Advanced Tokamak Plasma*."

- Contributed oral, Thursday morning
  - QO1.012: J.E. Kinsey, *et al*., "*Progress in Modeling Internal Transport Barrier Formation Using the GLF23 Transport Model*."

- Poster, Thursday afternoon
  - RP1.017: K.H. Burrell, *et al*., "*Physics of the Edge Harmonic Oscillation in Quiescent H-Mode Discharges in DIII-D*."

ADVANCED TOKAMAK ISSUES FOR THE QDB REGIME

- "Advanced tokamak" (AT) research seeks to produce a steady-state high performance regime.
  - QDB appears to be an excellent target for sustainment using ECCD [Casper, *et al*., poster FP1.048, Tue. AM].

- Barriers to AT applications of the QDB regime:
  - Counter-NBI
    - Balanced NBI (no momentum input) should be similar to counter for formation of separate barriers (both have pressure dominated E_r).
    - Role of counter-NBI still unknown for EHO dominated edge.
    - Counter-NBCD is small but significant; needs to be overcome by current drive.
  - Peaked density profile:
    - Associated peaked pressure profile limits attainable plasma β.
    - Narrow bootstrap current profile not optimal for steady-state sustainment.
    - Neoclassical impurity transport leads to retention of high-*Z* impurities.
    - Near-term studies of the QDB will focus on methods of broadening the density profile.

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