PROGRESS TOWARDS INCREASED UNDERSTANDING AND CONTROL OF INTERNAL TRANSPORT BARRIERS ON DIII-D

Presented by

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Presented at the
18th IAEA Fusion Energy Conference
October 4-10, 2000
Sorrento, Italy

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OVERVIEW

- Ultimate goal of work presented here is to establish control over Internal Transport Barriers (ITBs)
  - Need control of ITB location and profile gradients

- Substantial progress in creating, understanding and controlling ITBs

- Attractive new “Quiescent Double-Barrier” (QDB) operating regime

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PRINCIPAL RESULTS

- **Progress in creating and controlling ITBs:**
  - **Electron thermal ITBs created with ECH**
  - **Impurity injection expands ITB radius**
  - **Counter-NBI favorable for ITB expansion**

- **New "Quiescent Double-Barrier" (QDB) operating regime obtained in counter-NBI discharges:**
  - **Combination of core ITBs plus quiescent, ELM-free H-mode edge**
  - **ELM-induced pulsed divertor heat loads eliminated**
  - **Long pulse, high performance regime; $\beta_N H_{89} \sim 7$ obtained for $> 5\tau_E$**

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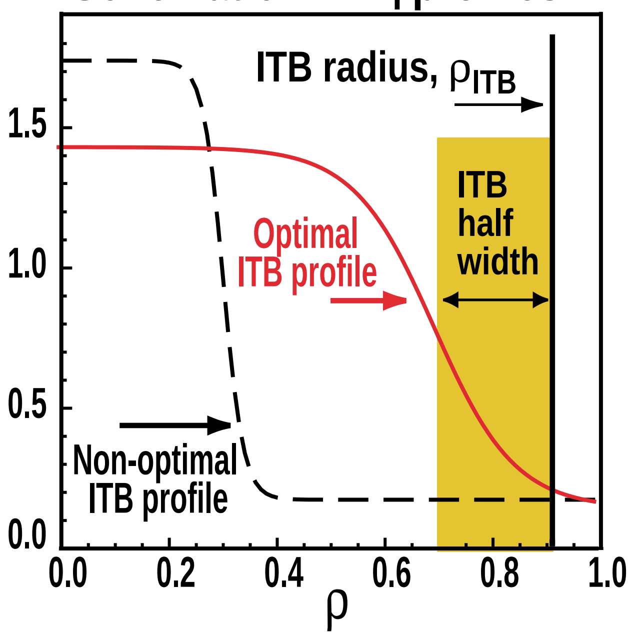
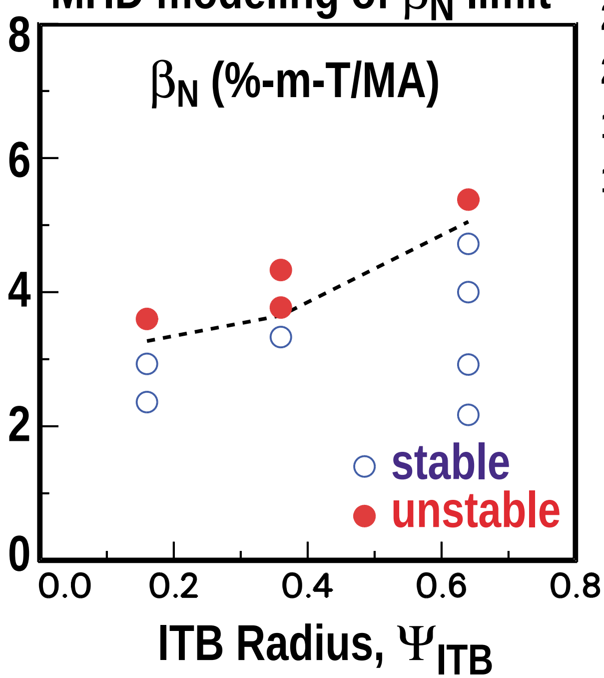
GOALS OF HIGH PERFORMANCE AND WELL ALIGNED BOOTSTRAP CURRENT REQUIRE ITB CONTROL CAPABILITIES

- Larger ITB radius and barrier width lead to:
  - Higher fusion performance (larger high confinement volume)
  - Improved MHD stability limits
  - Improved bootstrap current alignment

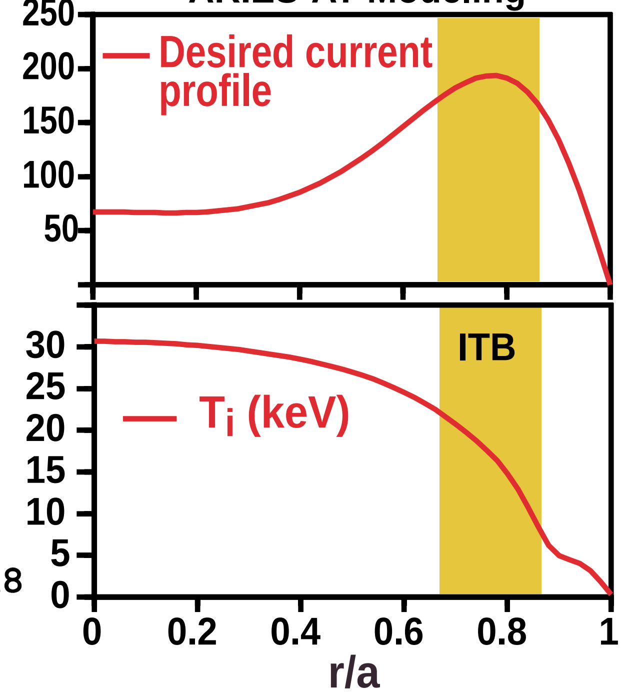
Schematic ITB T_i profiles



MHD modeling of β_N limit



ARIES-AT Modeling



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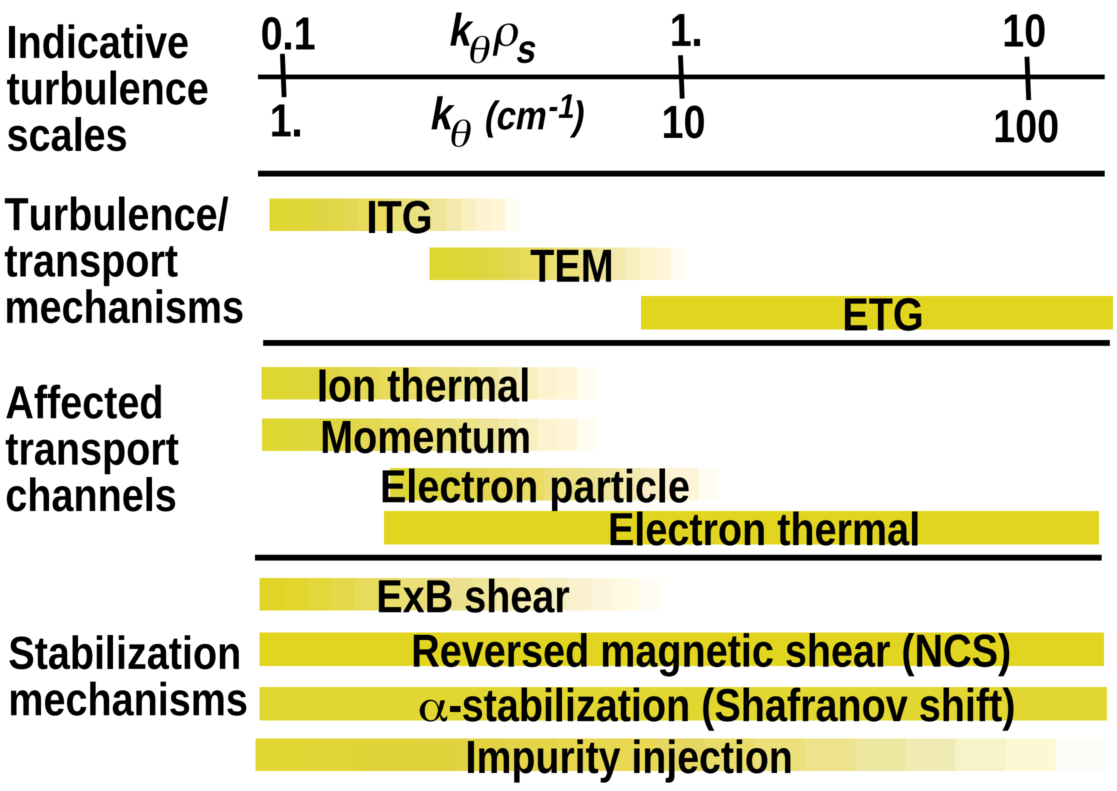
TURBULENCE SUPPRESSION MECHANISMS ARE KEY TO ITB FORMATION AND CONTROL



- Theory-based understanding of ITB formation has improved
  - — G. Staebler TH4/1, this morning
- More difficult to form electron thermal transport barriers (E-ITBs)
- Will discuss three aspects of turbulence suppression:
  - — Role of α-stabilization (Shafranov shift) in e-ITB formation
  - — Impurity injection
  - — Counter-NBI favorable for ExB shear suppression

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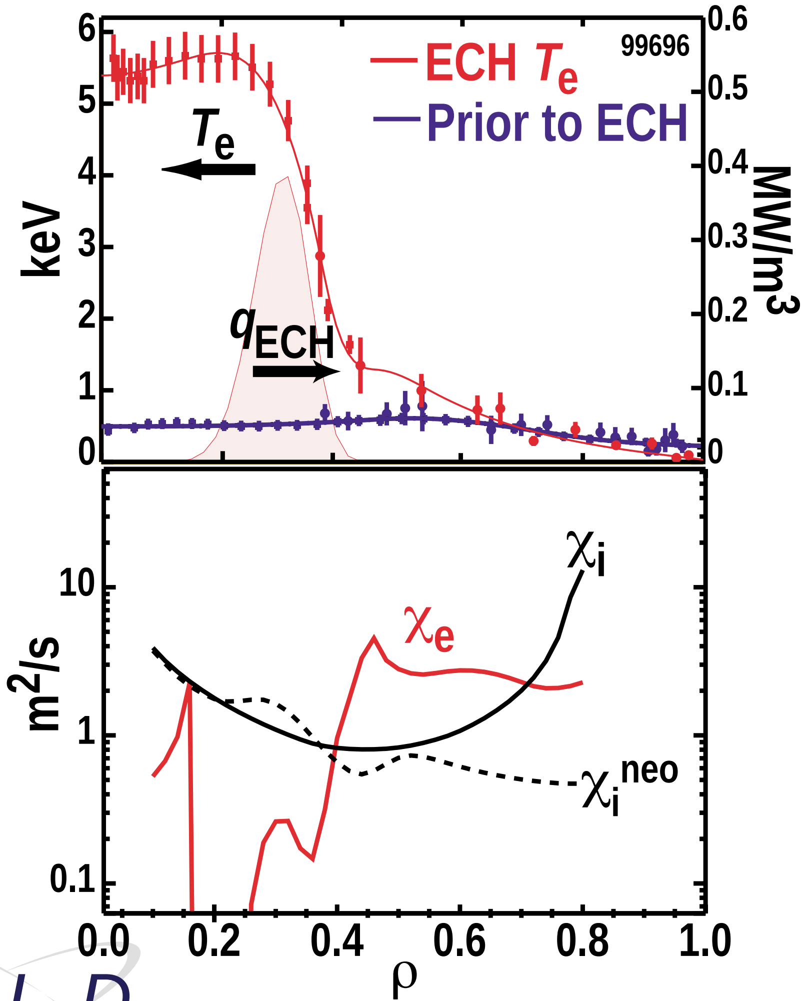
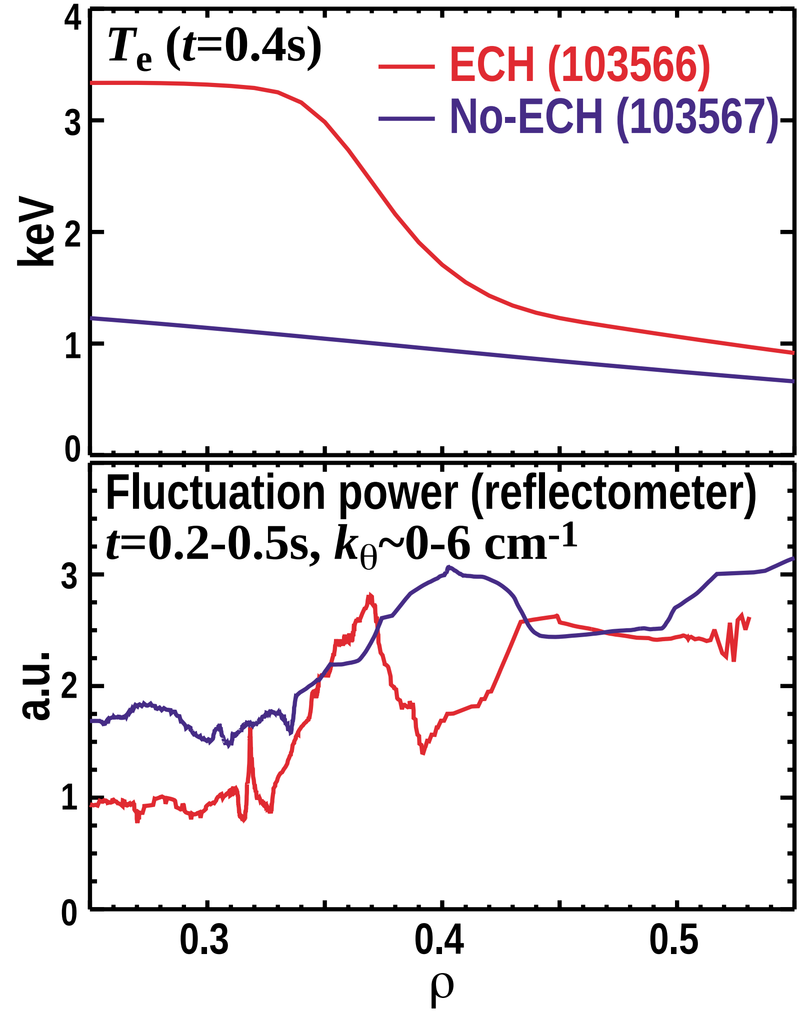
ELECTRON THERMAL ITB OBTAINED WITH LOCALIZED ECH

- E-ITB develops rapidly following ECH onset, electron thermal transport reduced



- Long wavelength turbulence reduced at and inside e-ITB location, but not outside



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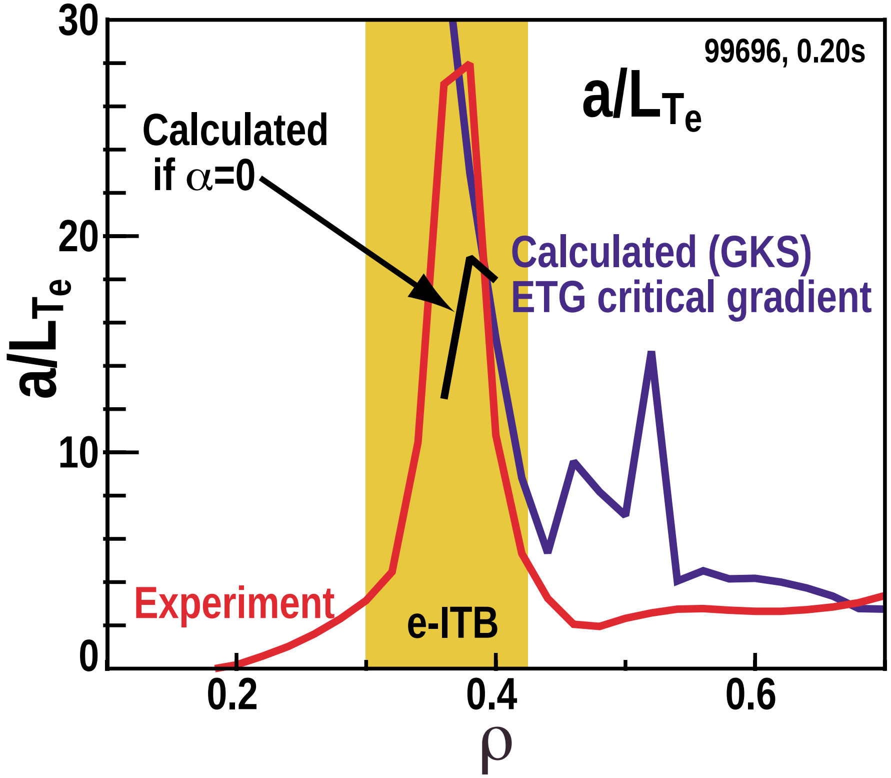
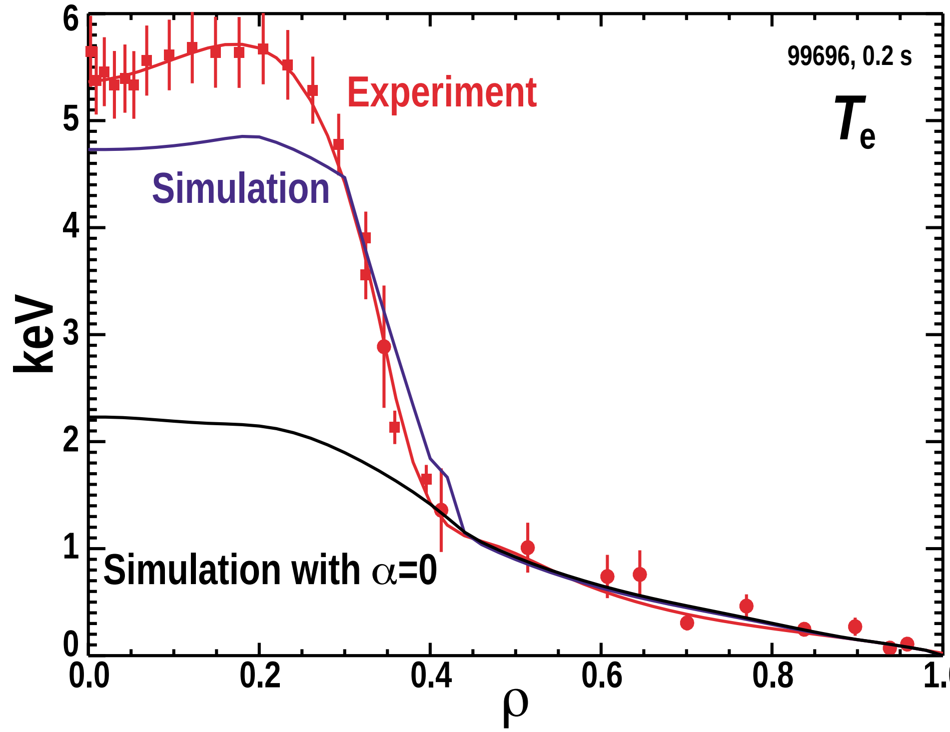
T_e GRADIENT IN BARRIER IS AT MARGINAL STABILITY FOR ETG MODES, SIMULATIONS INDICATE α-STABILIZATION IS CRITICAL

- T_e gradient at location of E-ITBs consistently observed to be at marginal stability to ETG mode



- Dynamical simulations using GLF23 model maintain E-ITB only if α is sufficiently large
  - GLF23 also reproduces dynamics of barrier evolution



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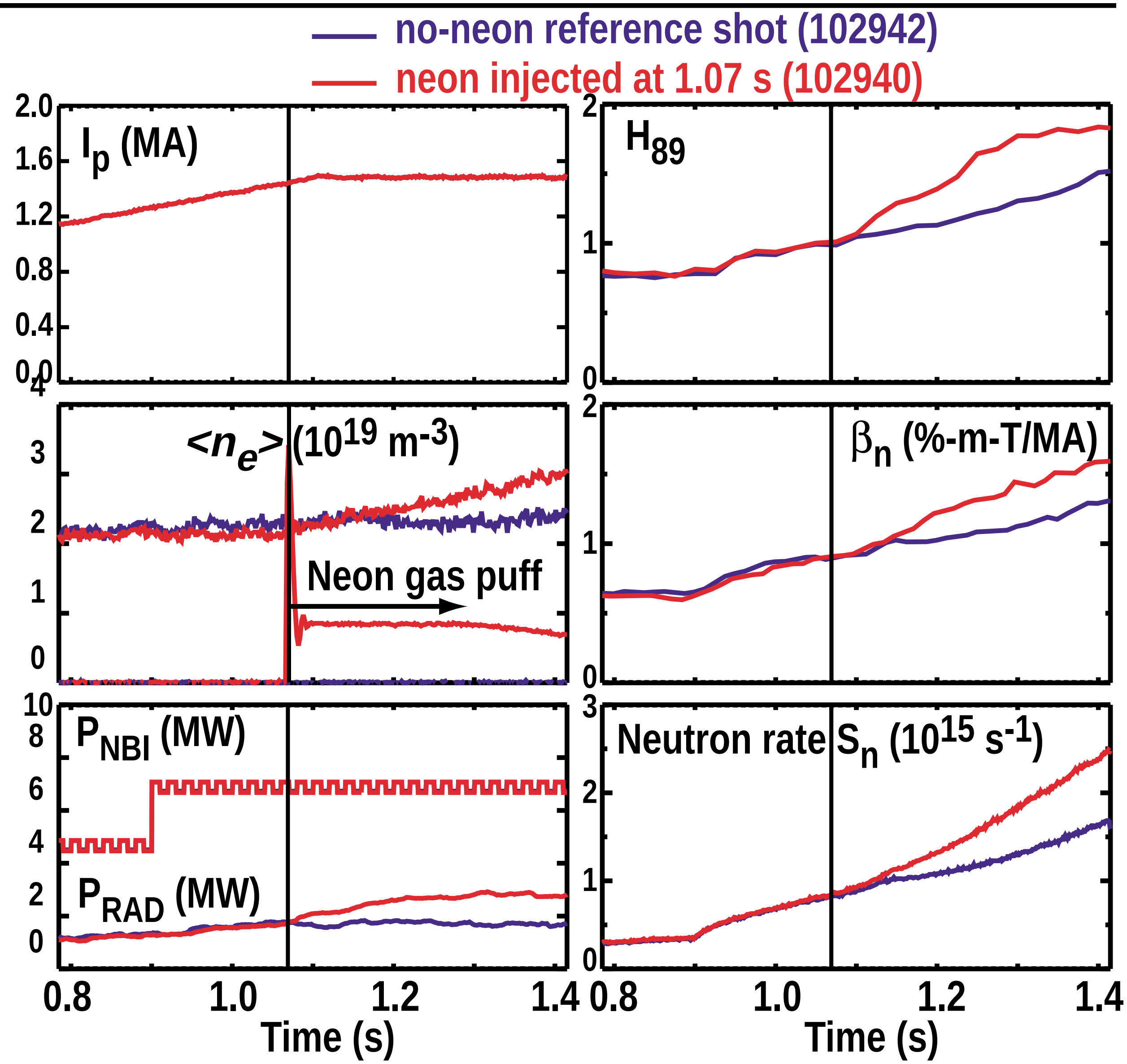
NEON INJECTION INTO PRE-EXISTING ITB IMPROVES PERFORMANCE

- Co-NBI, L-mode edge
- Physics of transport improvement mechanism described by M. Murakami EX5/1, Saturday
  - Improvement due to combination of reduced turbulence growth rates and increased ExB shear



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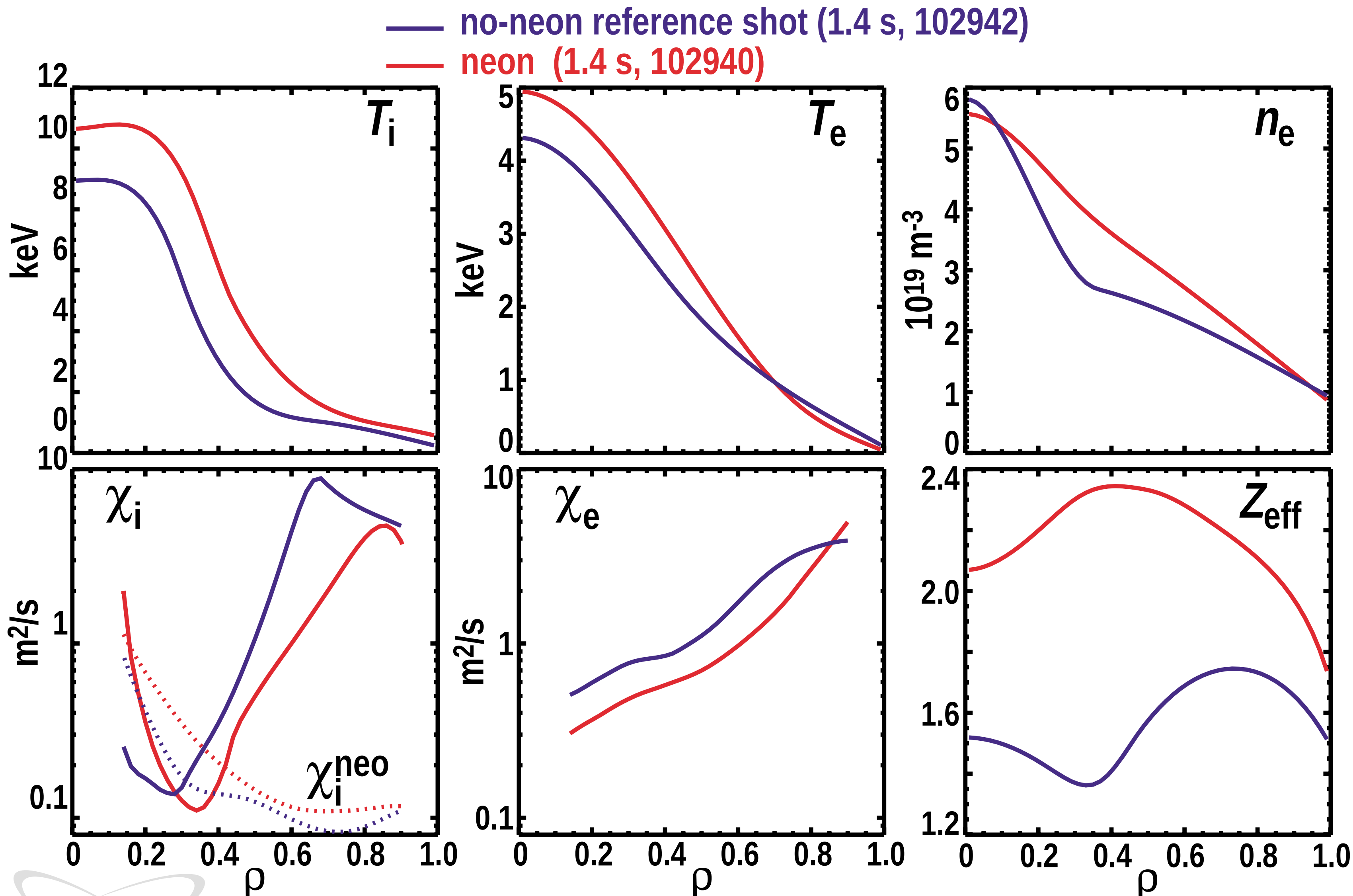
NEON INJECTION INTO PRE-EXISTING ITB BROADENS PROFILES AND EXPANDS REGION OF REDUCED TRANSPORT



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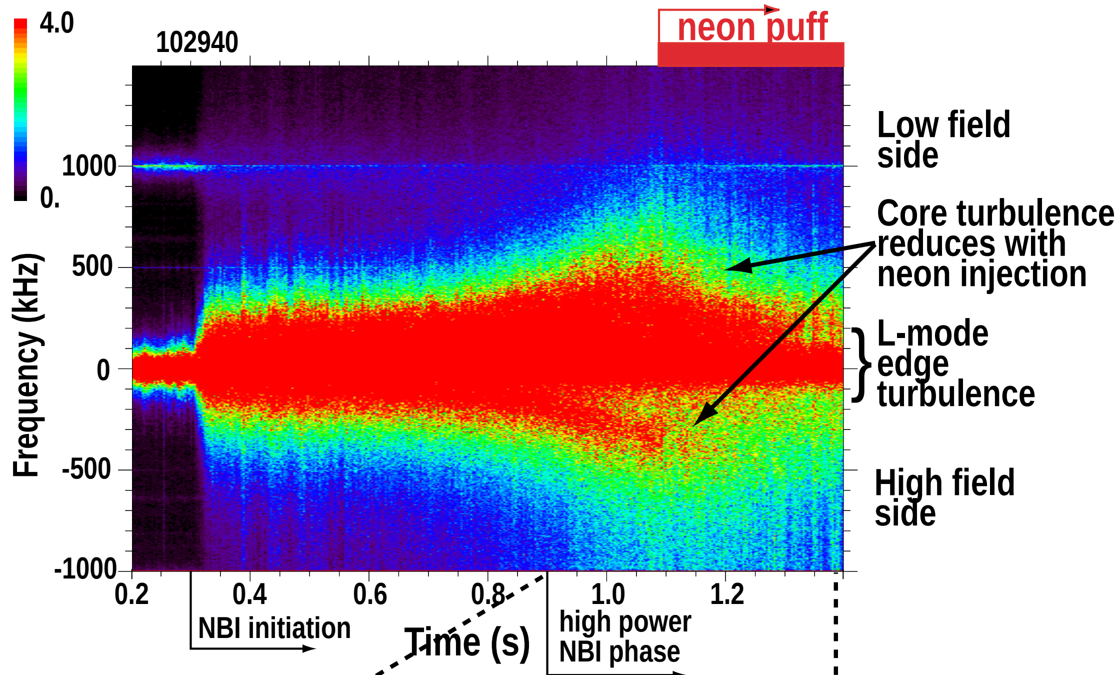
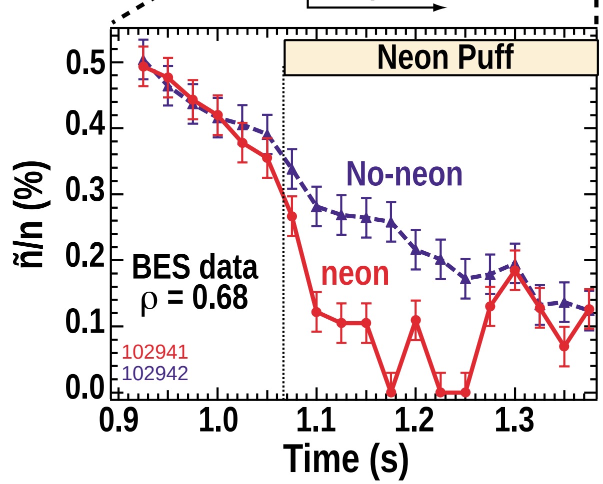
NEON INJECTION INTO PRE-EXISTING ITB FURTHER REDUCES TURBULENCE AMPLITUDES

- FIR scattering system monitors turbulence across plasma radius
  - Color contour plot of FIR signal amplitude (∝ñ) as function of frequency and time



- BES system provides local measurement of turbulence amplitudes
  - Clear turbulence reduction with neon injection



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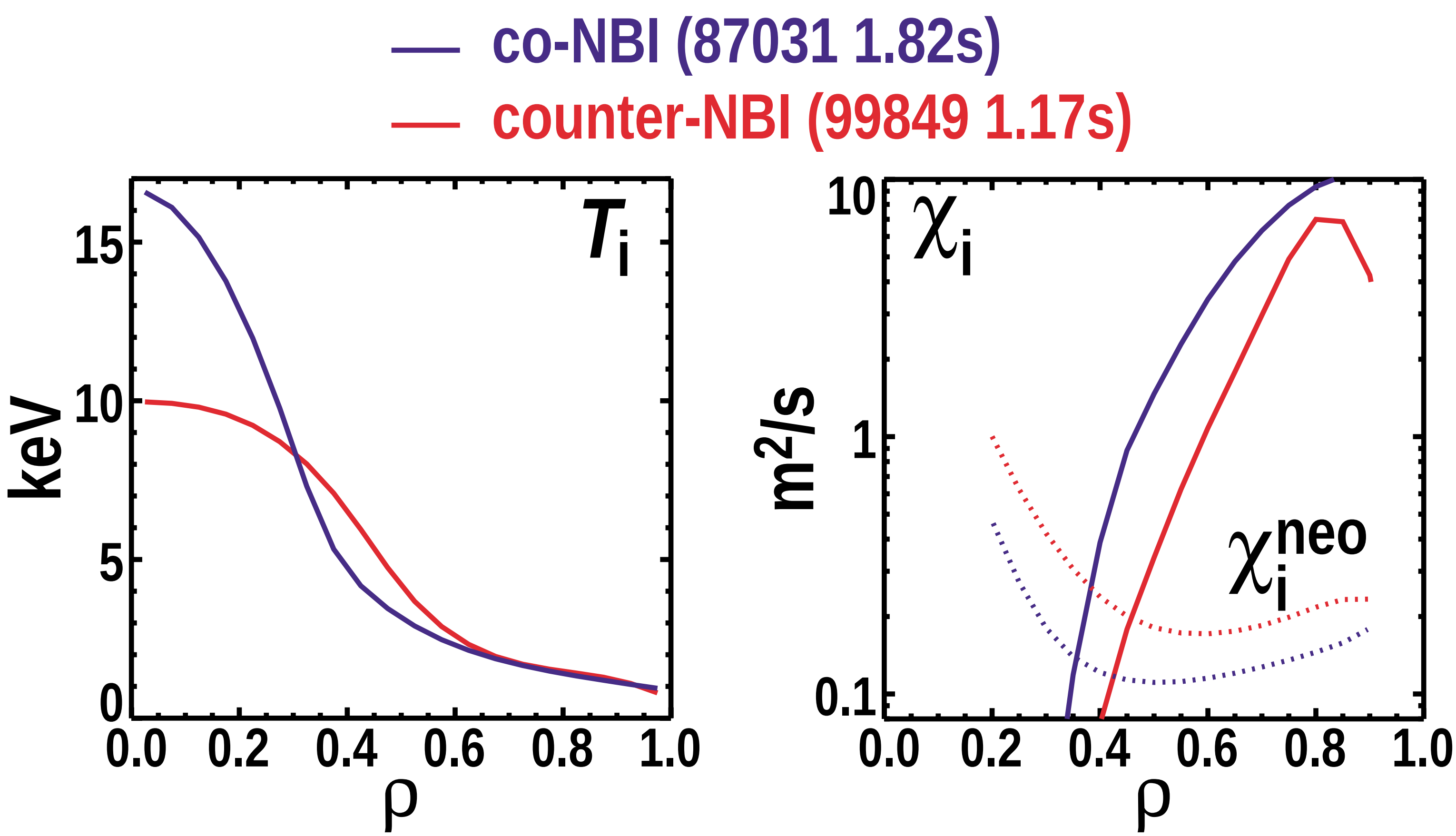
COUNTER-NBI RESULTS IN LARGER ITB RADIUS AS COMPARED WITH CO-NBI



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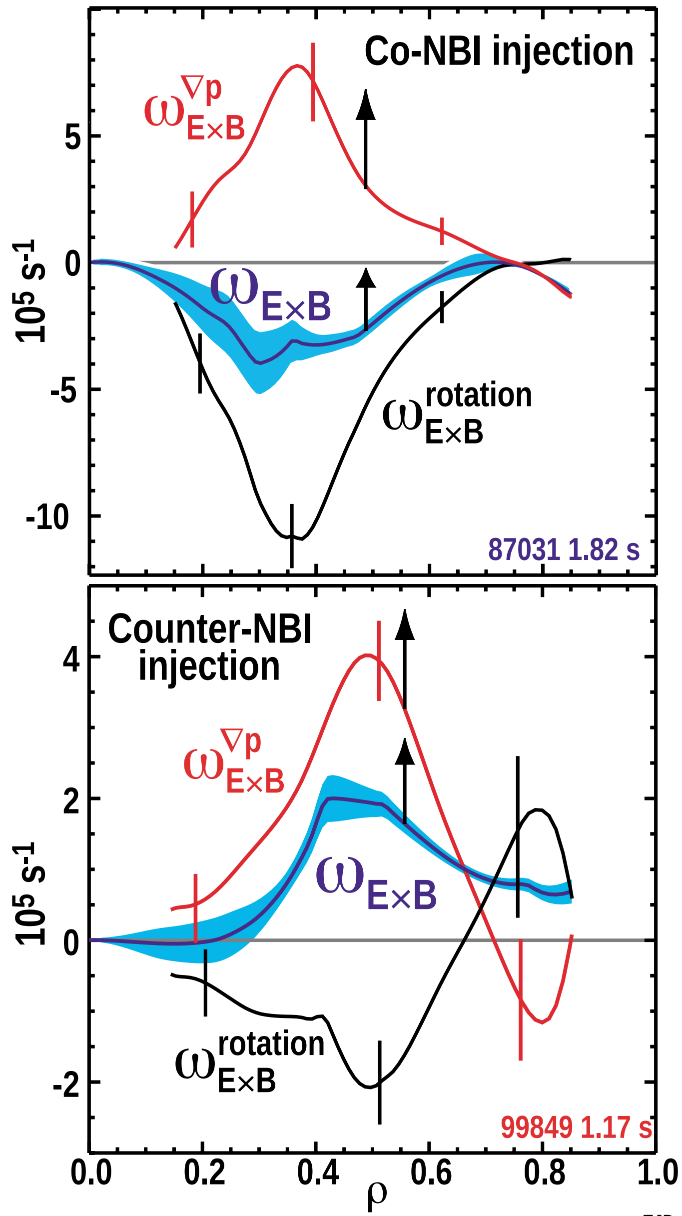
COUNTER-NBI INJECTION FAVORABLE FOR ITB EXPANSION DUE TO INTERPLAY OF TERMS IN ExB SHEARING RATE, $\omega_{E\times B}$

- Main ion shearing rate $\omega_{E\times B}$ can be separated into pressure and rotation terms

$$\omega_{E\times B} = \omega_{E\times B}^{\nabla p} + \omega_{E\times B}^{rotation}$$

  - Total $\omega_{E\times B}$ calculated from CER impurity measurements
  - Main ion pressure component determined from profile measurements
  - Rotation term obtained by subtraction

- With counter-NBI, increasing the pressure gradient component increases $\omega_{E\times B}$, rather than reducing it, as with co-injection
  - Counter-NBI favorable for ITB expansion



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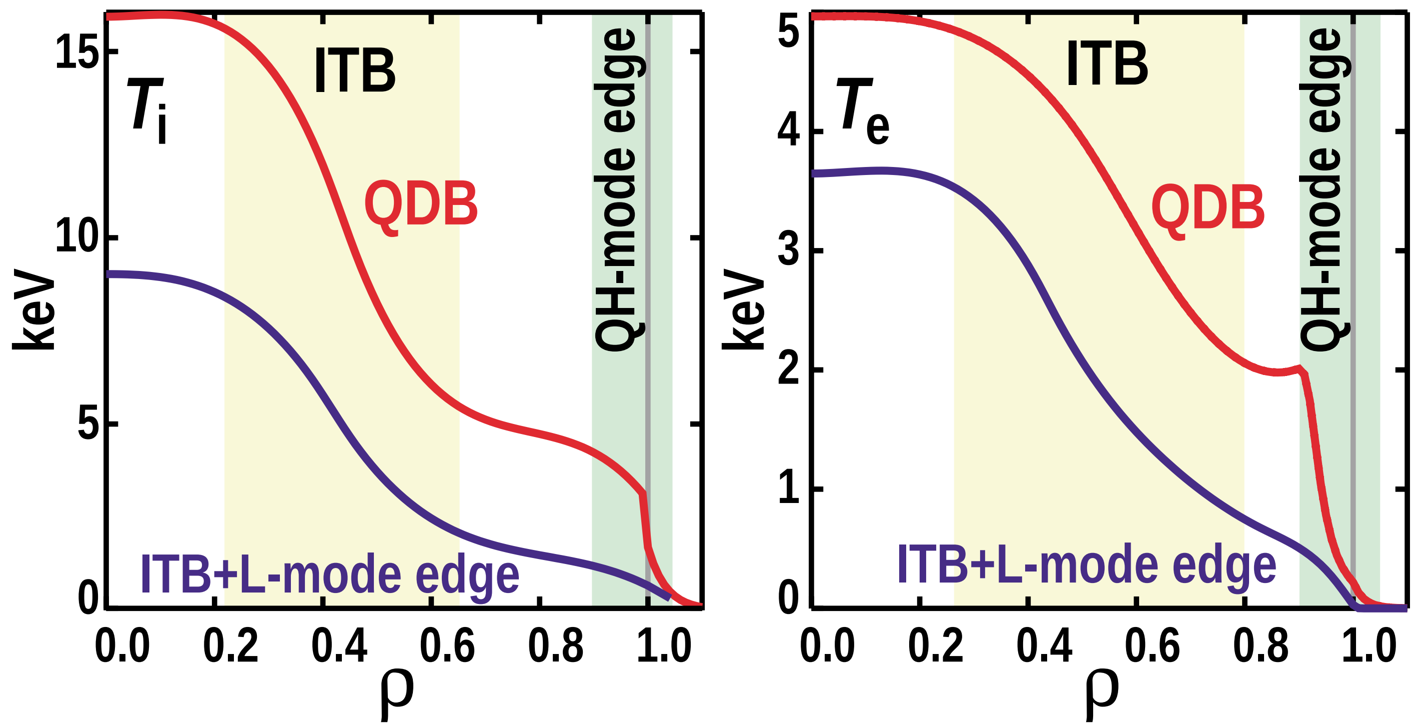
NEW OPERATING REGIME OBTAINED WITH COUNTER-NBI — QUIESCENT DOUBLE-BARRIER (QDB) REGIME

- QDB regime combines:
  - Core transport barriers, and
  - Quiescent H-mode (QH-mode) edge barrier



★ ELM-free edge, with similarities to C-MOD EDA H-mode regime (R. Groebner EXP5/21, tomorrow)

★ Only observed to date with counter-NBI and divertor pumping

★ Core and edge barriers are compatible

★ Name "QDB" derived from JET (ELMy) Double-Barrier (DB) mode

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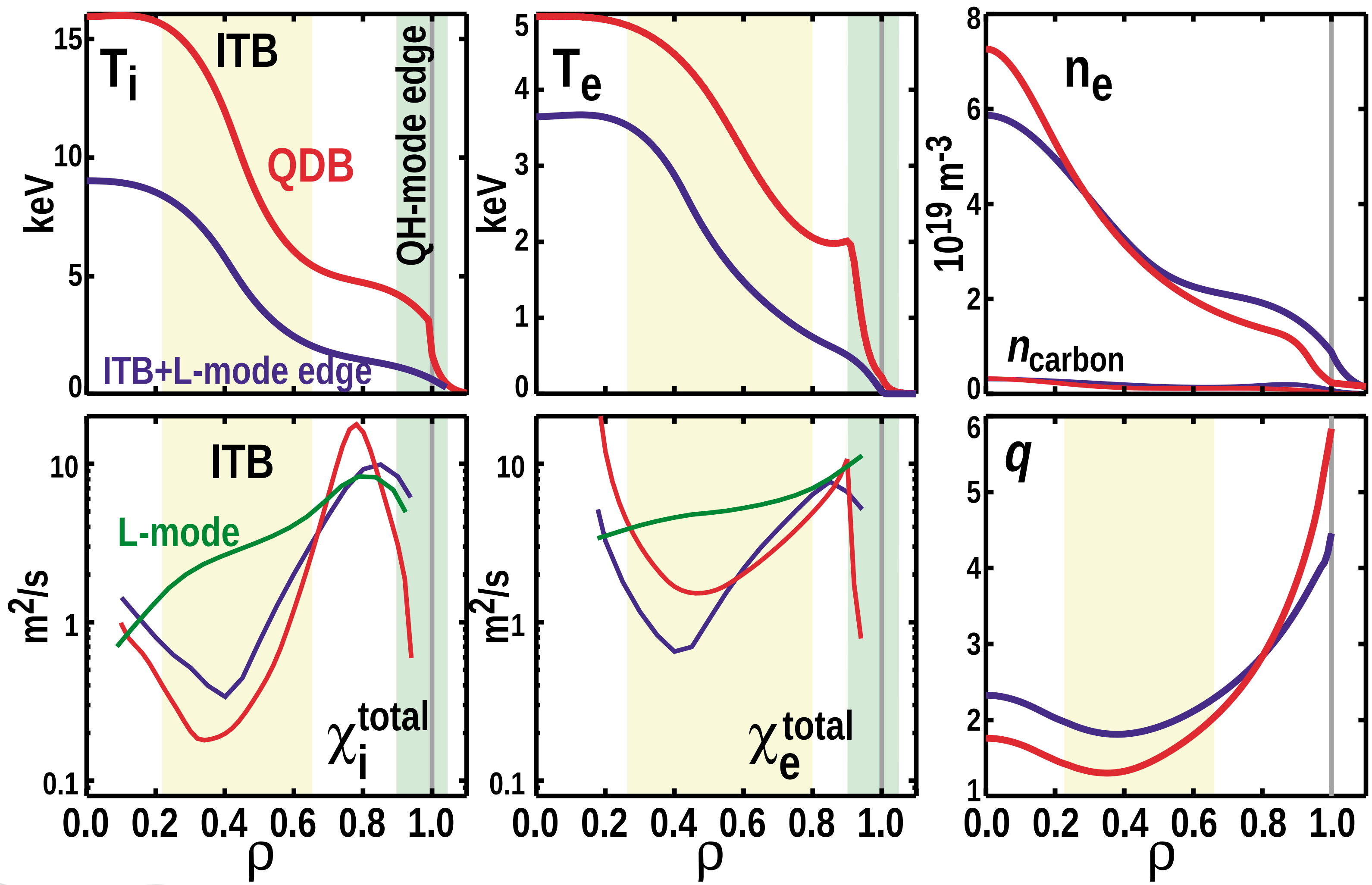
QDB REGIME FEATURES BROAD ITB PROFILES WITH EDGE TEMPERATURE PEDESTAL



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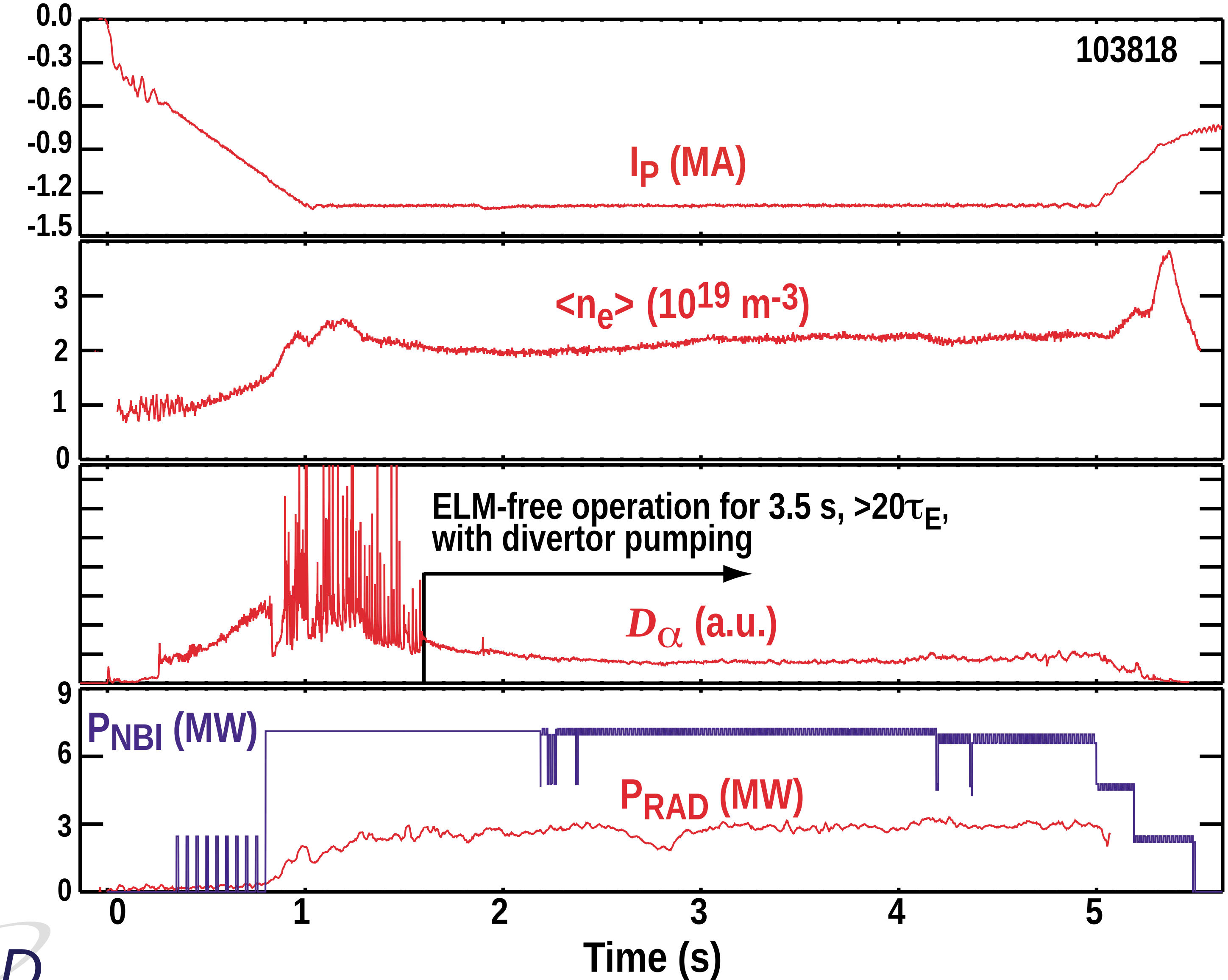
QDB REGIME EXHIBITS SUSTAINED ELM-FREE OPERATION WITH DENSITY AND IMPURITY CONTROL



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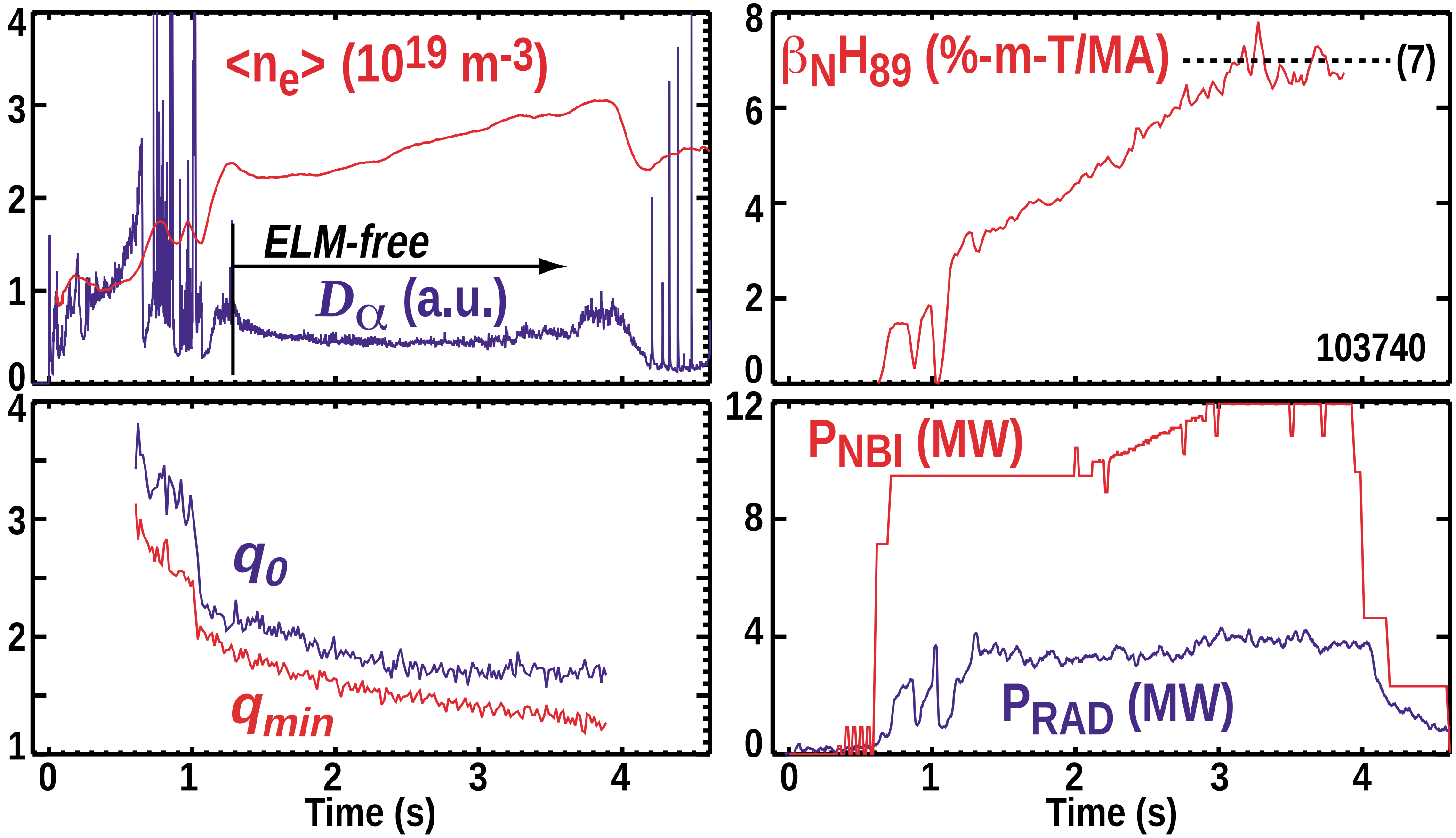
SUSTAINED HIGH PERFORMANCE HAS BEEN OBTAINED IN THE QDB REGIME



- **QDB regime is a long pulse, high performance candidate:**
  - β_T=3.3%, τ_E=150 ms, f_{BS}=0.45
  - Duration of high performance phase (>5τ_E) limited by duration of NBI injection
  - Not optimized, potential for higher performance

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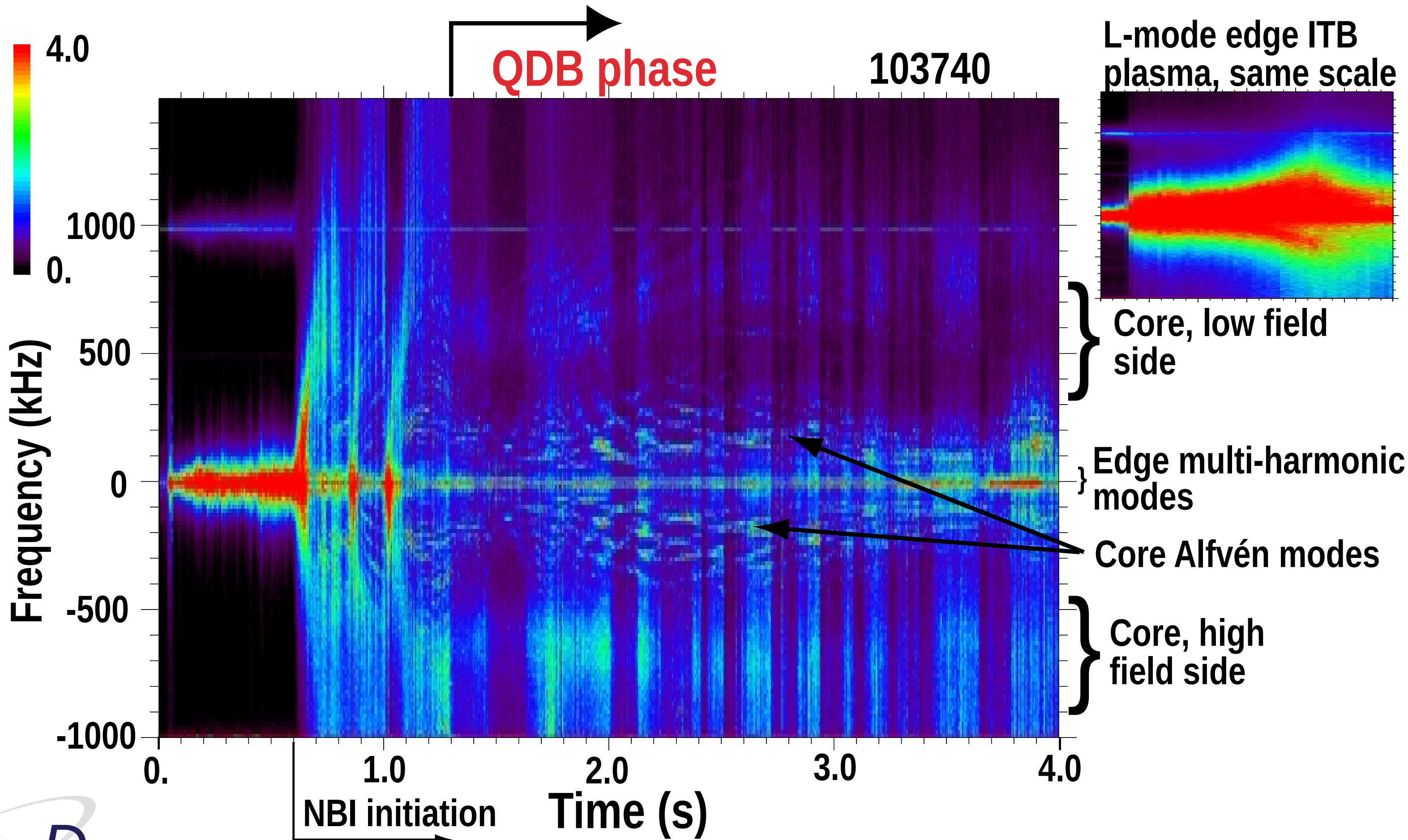
TURBULENCE IS REDUCED ACROSS MOST OF PLASMA DIAMETER IN QDB REGIME

- With reduced broadband turbulence, core Aflvén modes are clearly visible in FIR scattering data, as are low frequency edge multiharmonic modes associated with QH-mode operation



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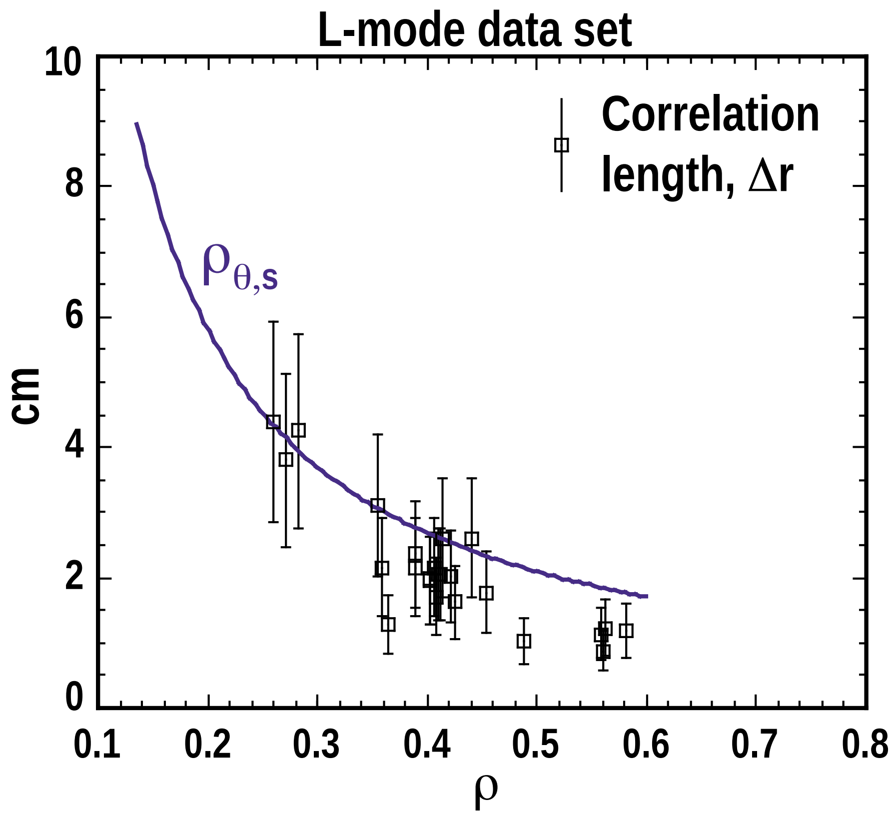
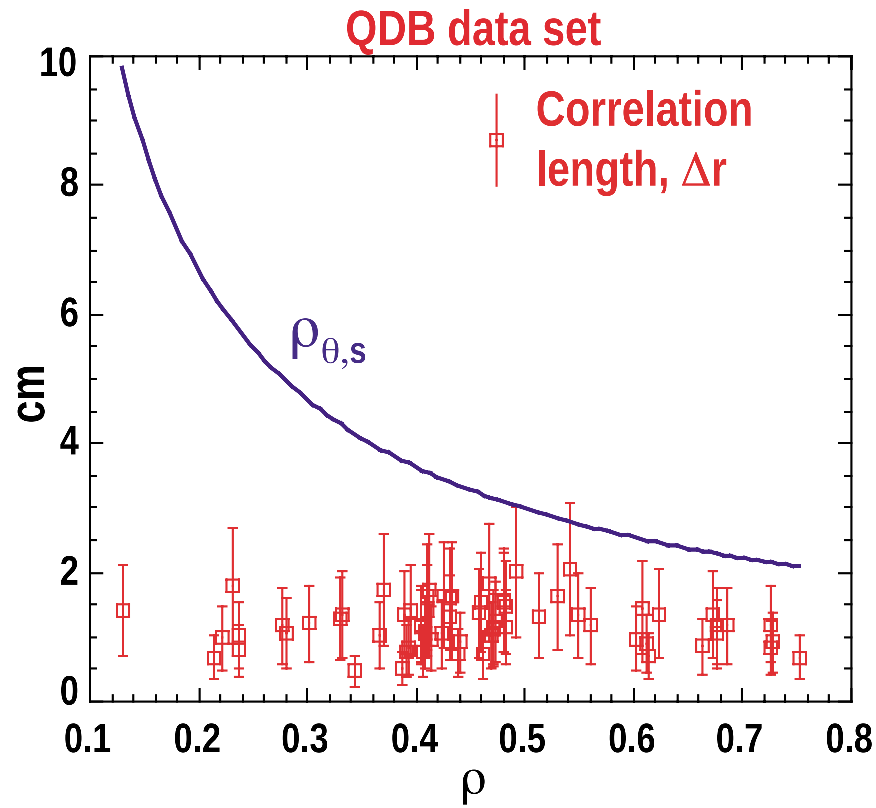
CORE TURBULENCE CORRELATION LENGTHS ARE DECREASED IN QDB REGIME - REDUCED STEP SIZE FOR TURBULENT TRANSPORT

- In L-mode, correlation lengths are observed to scale approximately with the poloidal ion gyroradius $\rho_{\theta,s}$ (or $5\text{-}8\rho_s$)

- In QDB plasmas, core correlation lengths are significantly different. Factor of 2-8 smaller than the L-mode scaling





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SUMMARY AND FUTURE DIRECTIONS

- Attractive new “Quiescent Double-Barrier” (QDB) operating regime obtained in counter-NBI discharges:
  - Combination of core ITBs plus steady-state, ELM-free QH-mode edge
  - Transient divertor heat loads eliminated
  - Long pulse, high performance regime; $\beta_N H_{89} \sim 7$ obtained for > $5\tau_E$

- Substantial progress in creating, understanding and controlling ITBs
  - Electron thermal ITBs created with ECH
  - Impurity injection expands ITB radius
  - Counter-NBI favorable for ITB expansion

- Priority for future is to investigate scaling and robustness of the QDB regime

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