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Transport Barriers in NSTX Plasmas? – A Progress Report

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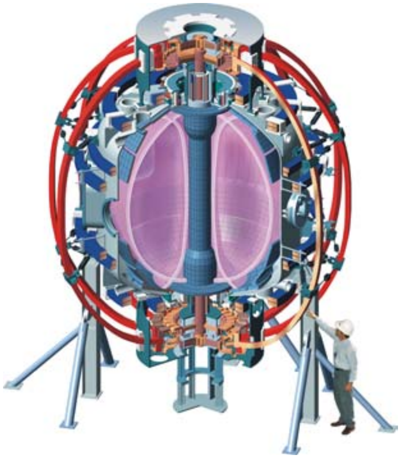
and the NSTX National Team



The Spherical Tokamak Workshop 2003
Culham Science Center, Abingdon, U.K.
September 15 – 17, 2003

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This Study Examines NSTX Data for the Near-Term Tasks Defined by ITPA Topical Group on ITB&T

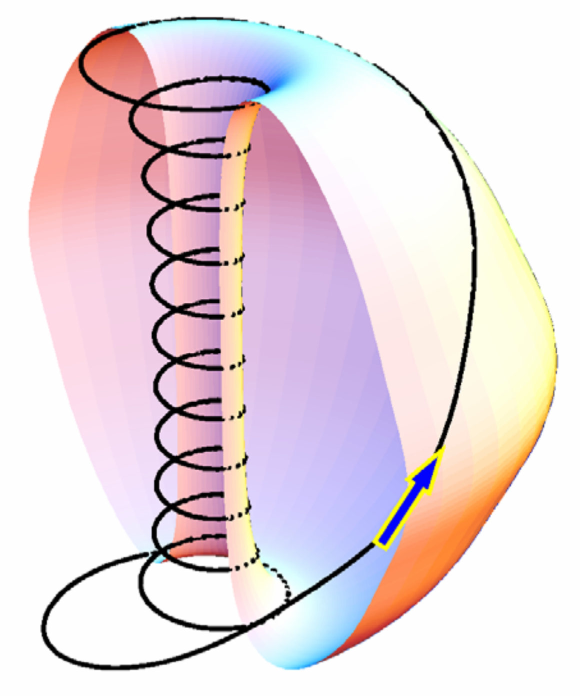
In 1-2 Years:

- Improve experimental understanding of critical issues of burning plasmas with ITB: $T_i \sim T_e$, low V_ϕ, flat density profile, $Z_{eff} < 2$
  - ***ITB formation, evolution, and sustainment conditions***
  - ***Impurity accumulation***
  - *Compatibility with divertor requirements*
- Develop, manage, and analyze new experimental ITB database
- Test simulation and modeling of ion transport
  - *e.g., JT-60U "box-like" ITB T_i profiles, JET $(r/a)_{ITB\text{-}foot}$ evolution, etc.*

Similarities and differences in TB behavior and plasma regimes of differing A provide levers for improved understanding.

Spherical Torus Challenges Transport Barrier Physics in Extended Parameter Regimes

Spherical Torus Magnetic Configuration



Extended Physics parameter Regimes Affecting Transport:

- High β_T ($\leq$ 40%) & central β_0 (~100%)
- Strong plasma shaping & self fields ($A \geq 1.27$, $\kappa \leq 2.5$, $B_p/B_t \sim 1$, $q_{edge} \sim 10$)
- Small plasma size relative to gyro-radius ($a/\rho_i \sim 30$–50)
- Large trapping fraction towards edge ($f_T \rightarrow 1$)
- Large plasma flow ($M_A = V_{rotation}/V_A \leq 0.3$)
- Large flow shearing rate ($\gamma_{ExB} \leq 10^6$/s)

NSTX Has Built up Basic and Modern Diagnostic Capabilities to Support Research

Core Plasma Diagnostics

- Thomson scattering (20 ch., 60Hz)
- Charge Exchange Recomb. Spect. (CHERS): T_i & v_ϕ (51 ch.)
- VB detector (single chord)
- Soft x-ray arrays (4) [JHU]
- Bolometer array (midplane tangential)
- X-ray crystal spectrometer (T_i (0), T_e(0))
- Edge rotation spectroscopy
- Electron Bernstein wave radiometer
- FIReTIP interf'r/polarim'r (4 ch) [UCD]
- PICXIS Fast 2D X-ray camera [Frascati, JHU]
- Tang. X-ray pin hole camera [U. Wisconsin]

Magnetics and MHD

- Magnetics for equilibrium reconstruction
- Diamagnetic flux measurement
- High-n and high-frequency Mirnov arrays
- Locked mode coils
- 1mm interferometer [UCLA]

Turbulence

- Edge reflectometer [UCLA]
- Edge fluctuation imaging [LANL, PSI]

Plasma Monitoring

- Fast visible camera [LANL]
- VIPS: Visible spectrometer
- SPRED: UV spectrometer
- Transmission grating spectrometer [JHU]
- EFIT (Columbia University)

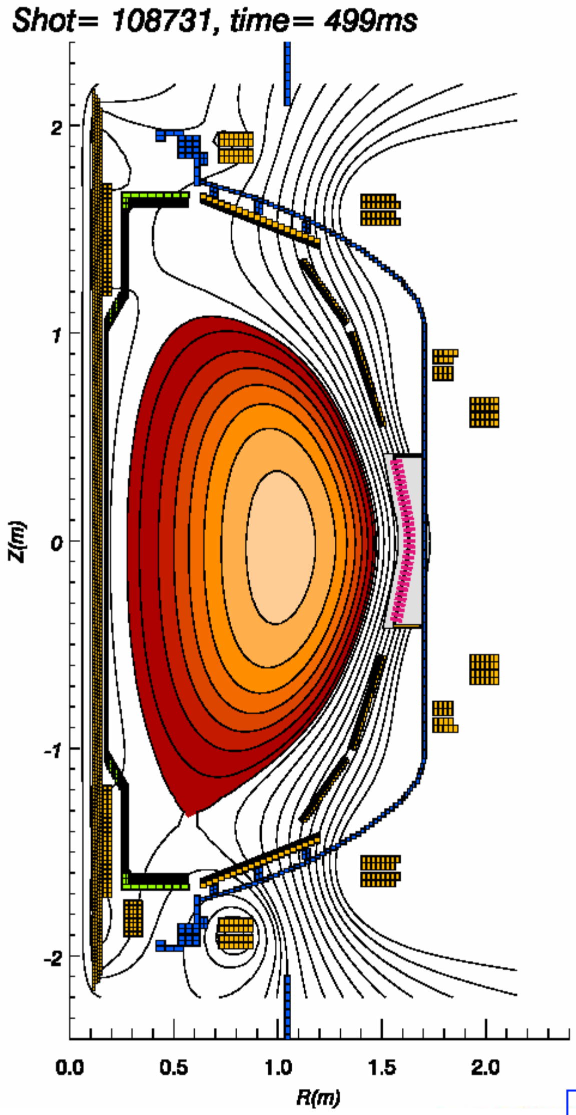
Boundary Physics

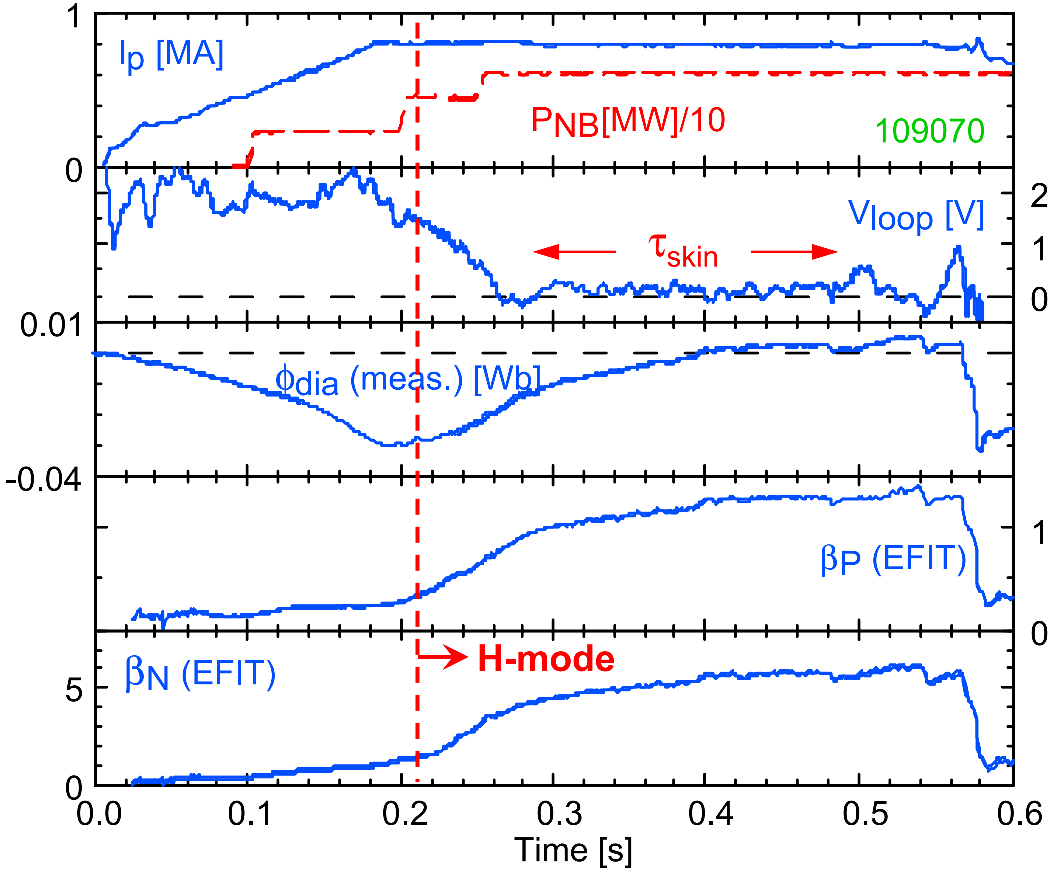
- Divertor Bolometer
- Fast probe [UCSD]
- Infrared Camera (2) [ORNL]
- Fast Ion Gauge [University of Wash]
- Divertor fast camera [Hiroshima Univ.]
- Divertor tile Langmuire probe array
- 1-D CCD H_α camera (2) [ORNL]
- Visible filterscopes (H_α, OII, CII) [ORNL]
- Scrape-off layer reflectometer [ORNL]
- Fast camera (PSI)

Energetic Particles

- Fission chamber neutron measurement
- Fast neutron measurement
- Neutral particle analyzer (scanning)
- Fast ion loss probe

NBI-Heated, High-β_p(~1), Nearly Sustained H-Mode Plasmas Provide Good Examples for ITB Studies

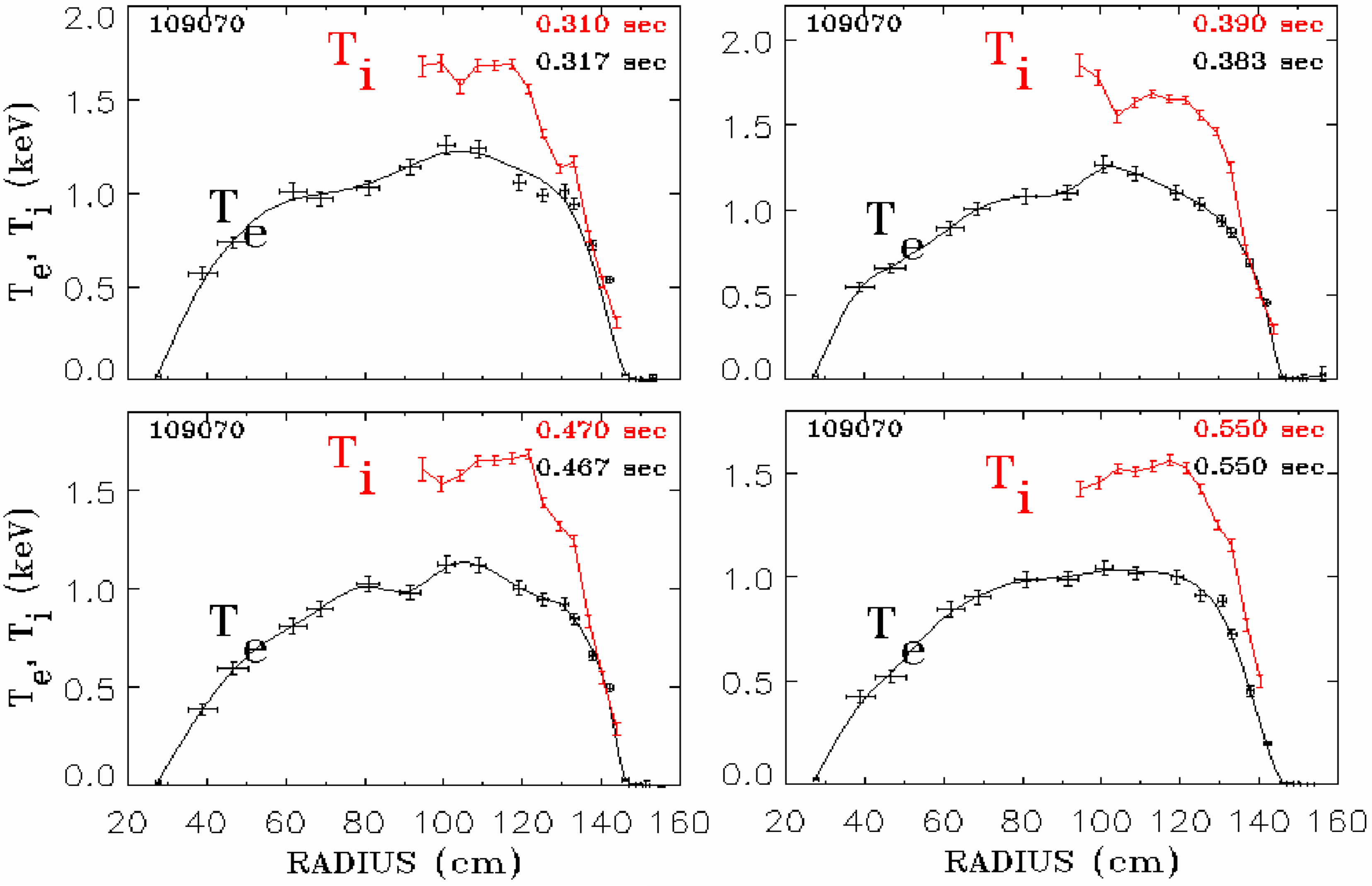




f_{BS} ~ 0.5; f_{NBI} ~ 0.1; V_L ~ 0.1 V for ≥ τ_{Skin}

Gates, Menard, Sabbagh

T_i Substantial Higher Than T_e in Plasma Core for the “Flattop” Duration



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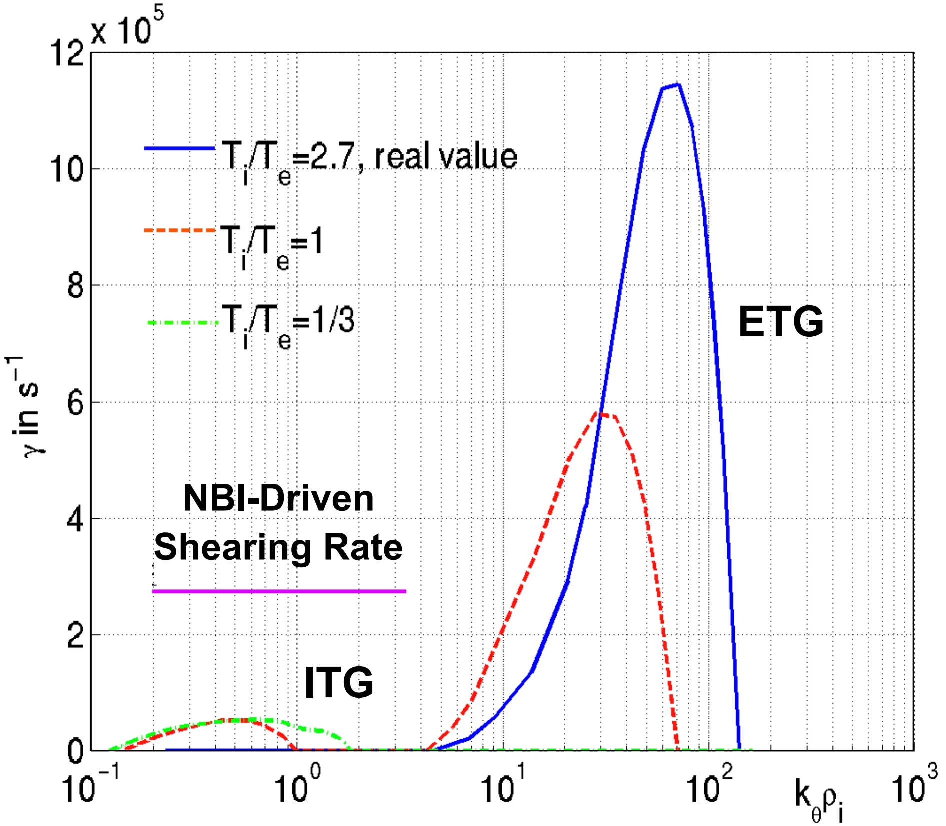
Gyrokinetic Microinstability Calculations Indicate Suppression of Weak ITG by Flow Shear

- **NBI-driven flow shearing rate >> ITG growth rate (T_i ~ $2T_e$)**
- **Virulence of ETG depends strongly on T_i/T_e**
  - not likely stabilized by flow shearing for $T_e \leq T_i$
- **Other physics under exploration**
  - effects of β'
  - stabilization by negative magnetic shear

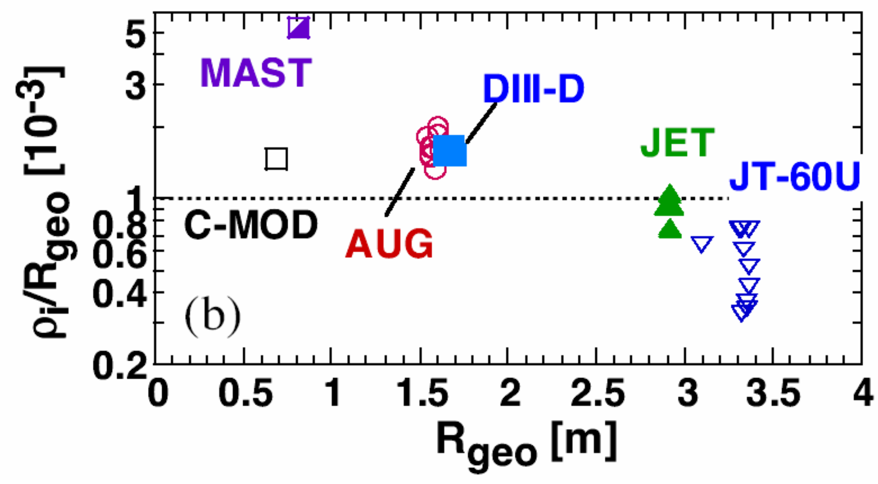
Gyrokinetic Microinstability Growth Rates

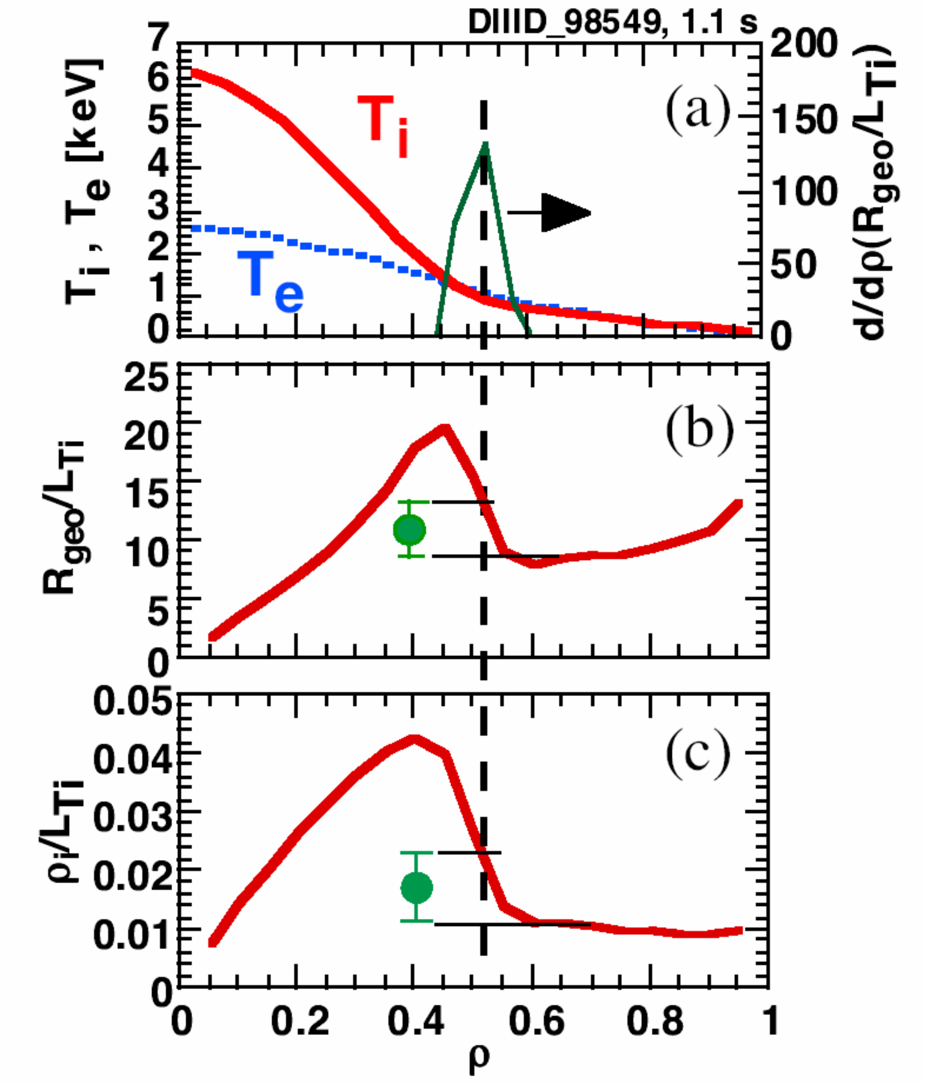


Bourdelle

Recent EPS Poster on ITB Provided Improved Definition of the ITB Behavior During Formation

- "ITB foot" is located by peak of $(d/dR)(R_0/L_{Ti})$, ~ peak of dL_{Ti}/dR
- Critical values are defined for the "ITB foot"
  - R_0/L_{Ti} & $\rho_i^* = \rho_i/L_{Ti}$
- Also value of ρ_i/R_0 at "ITB foot"

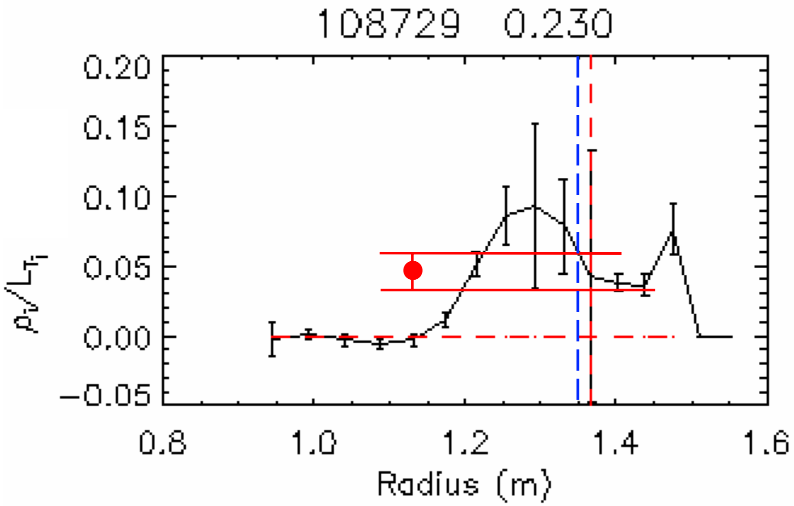


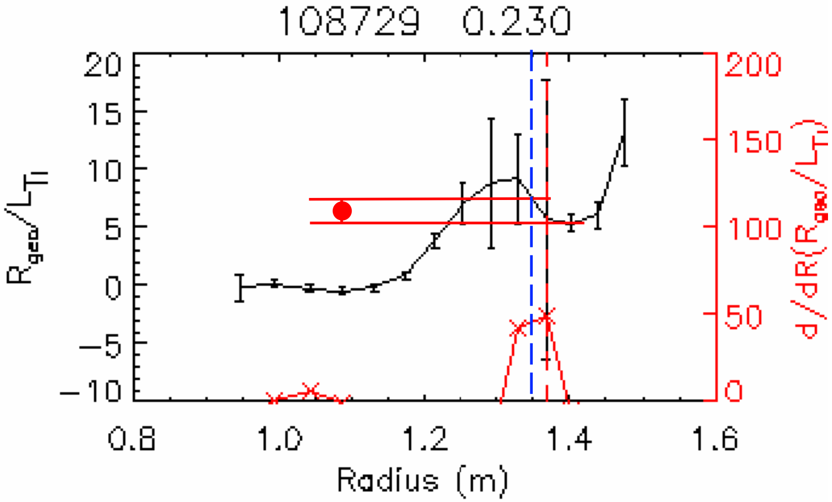


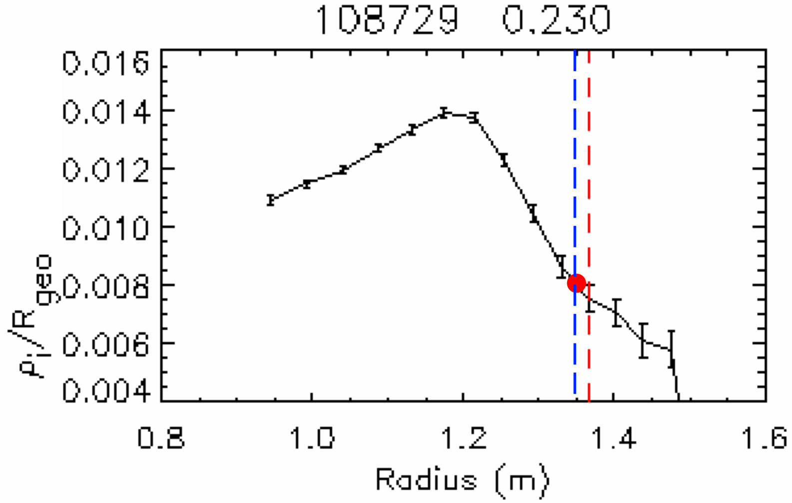
Fujita, EPS P.2-131, plot from DIII-D weak shear ELMy H-mode plasma

NSTX Routinely Exhibit Similar Behavior Under NBI Just Before H-Mode Transition

- >20 ms before H-mode transition after 2 NBI source power
- Peak (dL_{Ti}/dR) is clearly located
- Critical values measured
  - R_0/L_{Ti} & $\rho_i^* = \rho_i/L_{Ti}$
- And value of ρ_i/R_0







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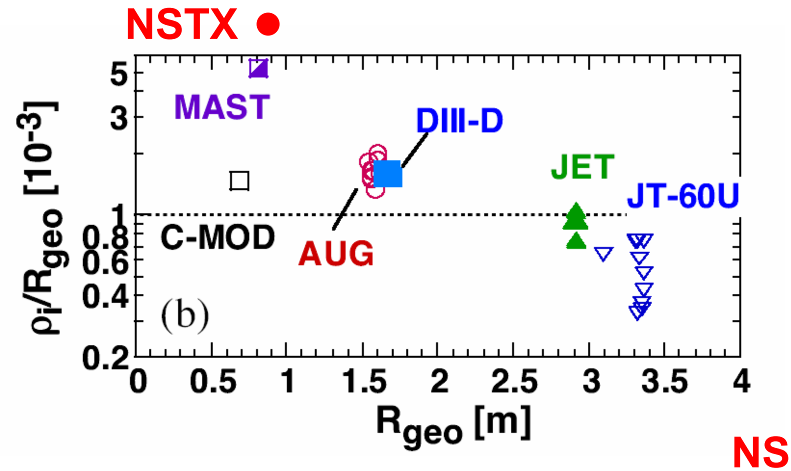
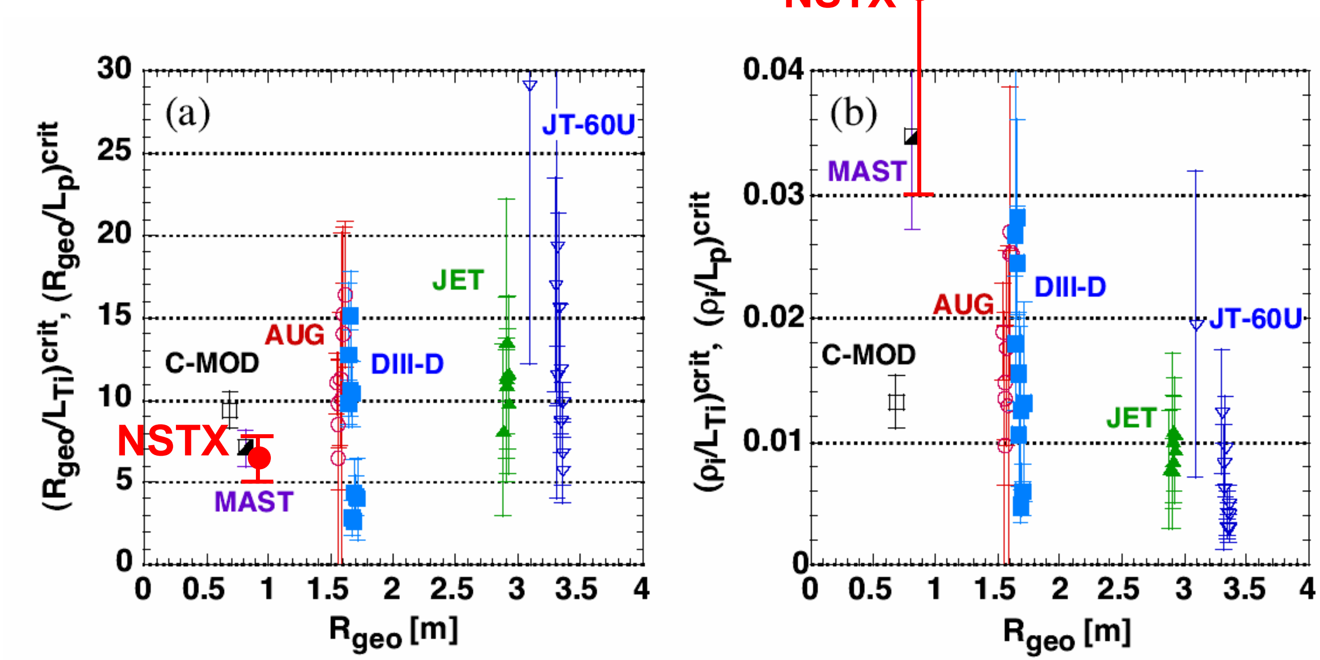
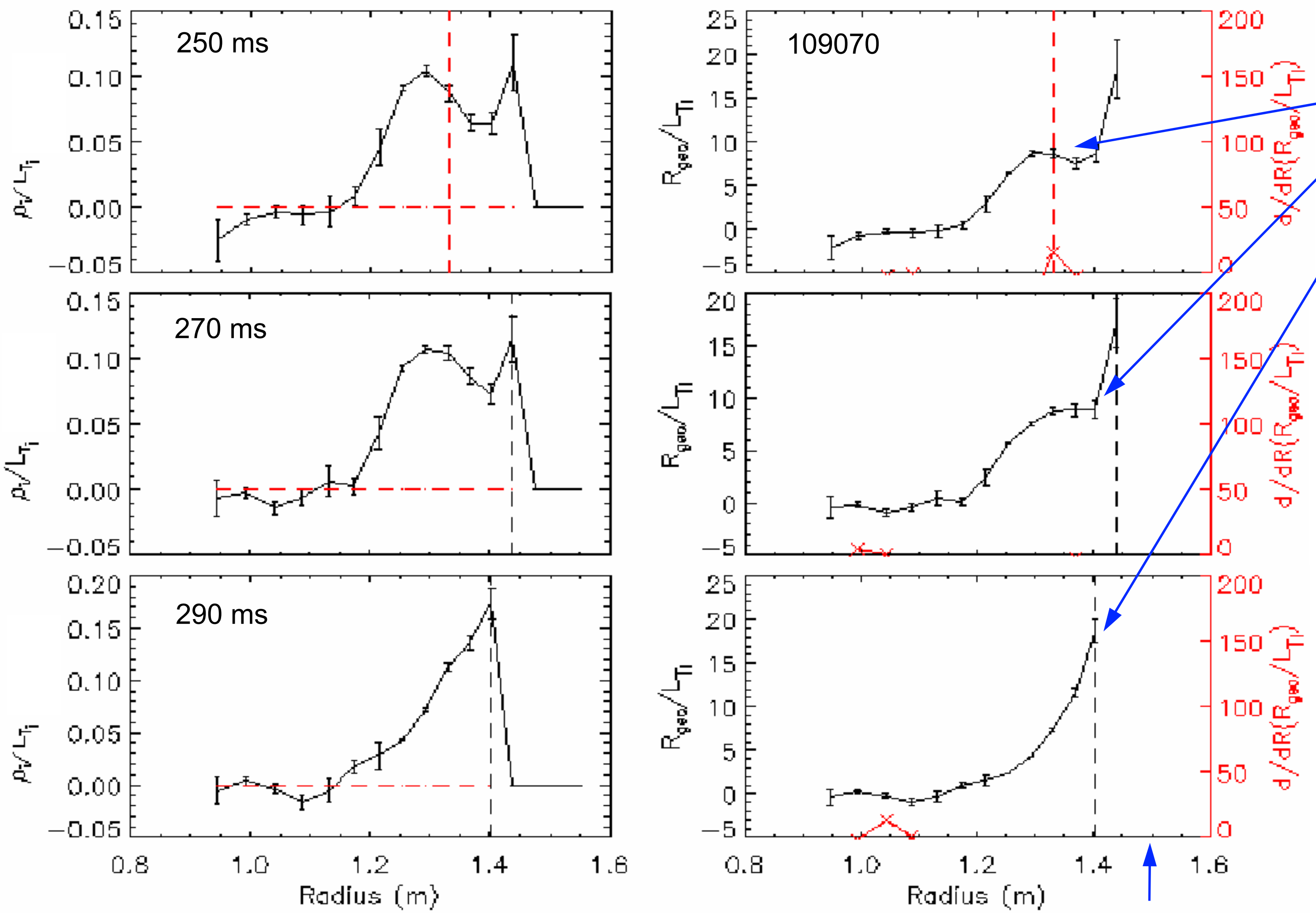
NSTX Data Generally Near or Beyond the Boundary of the Tokamak Range



> "It is suggested that critical values of ρ_i/L_{Ti} depends on other quantities than ρ_i and L_{Ti}" – Fujita



The Peak (dL_{Ti}/dR) Location Moves to Plasma Edge in ~50 ms After H-Mode Transition



Need 51-ch. CHERS (ready), and MSE to estimate q(R).

Plasma Edge

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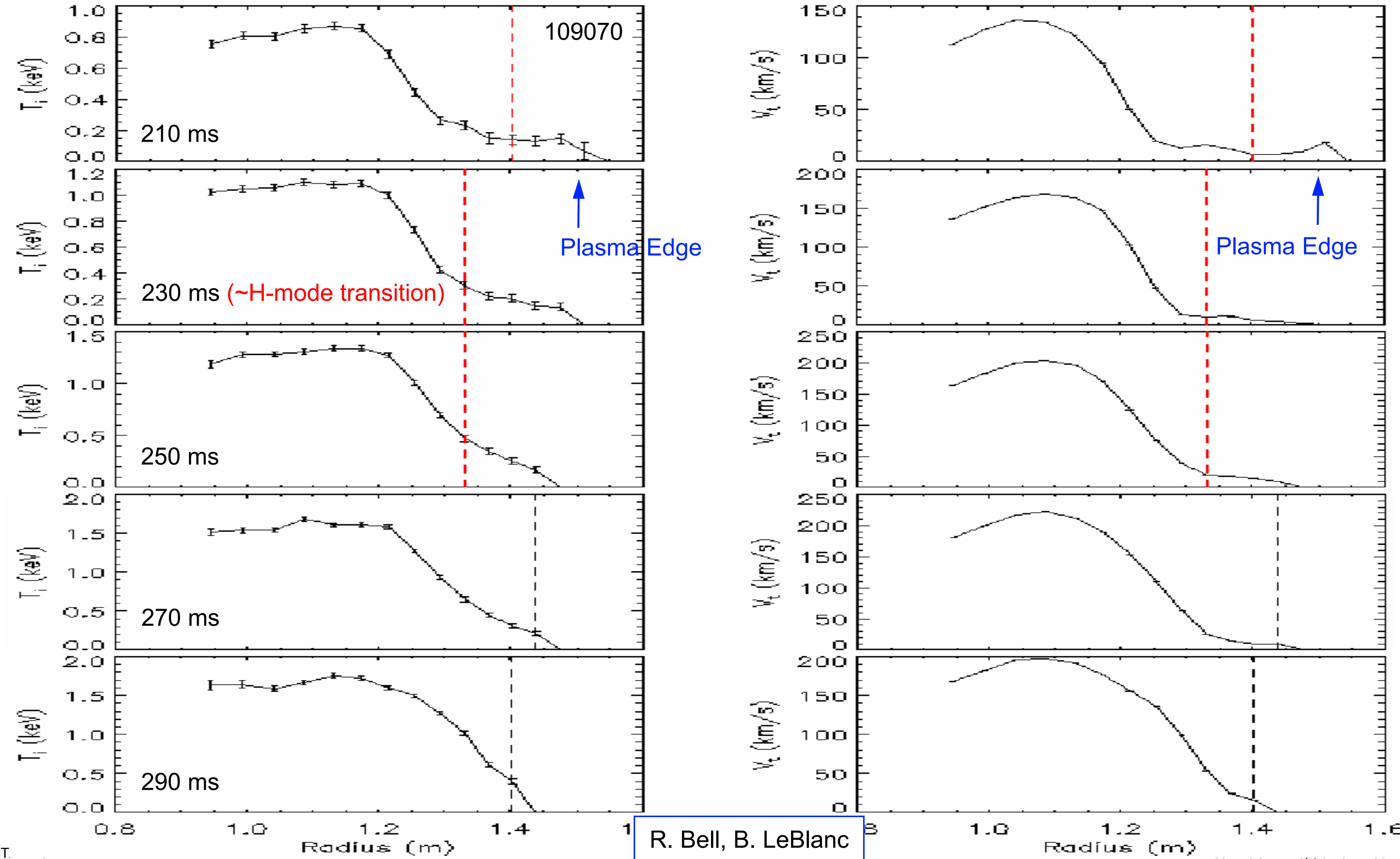
Location of Steep T_i & V_ϕ Gradients Broadens and Moves Outward Following H-Mode Transition



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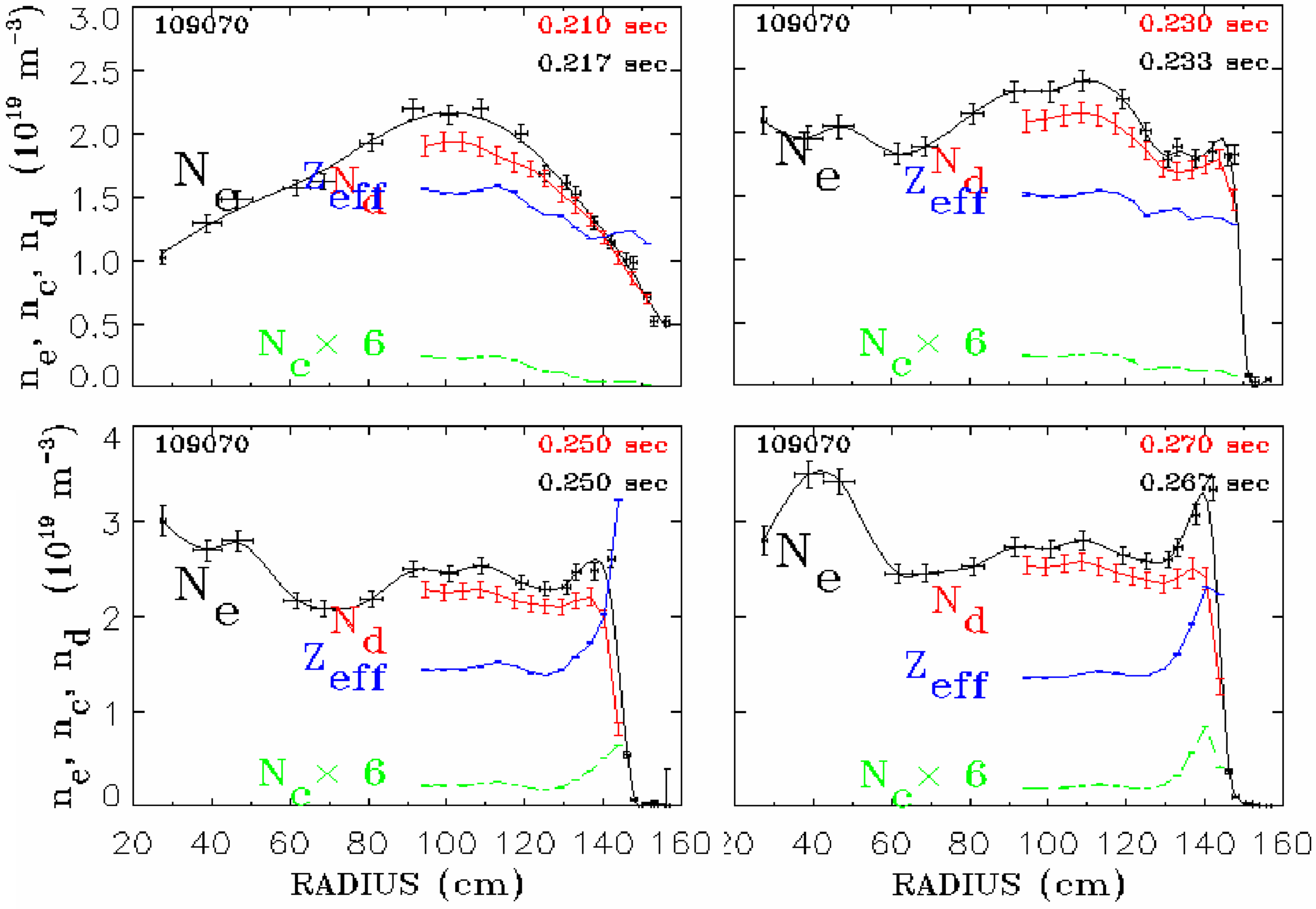
Impurity (Carbon) Peaks Toward the Outboard Region Following H-mode Formation and Stayed



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Observations and Key Questions to be Answered for the NSTX Plasmas with Steep T_i Profiles

- Strong evidence for $\chi_i \sim \chi_{iNC}$ over substantial regions; is this for the entire plasma during flattop?
- Evidence for small region of suppressed ion transport before H-mode transition; is this the ITB formation phase?
- The regions of peak barrier $(dL_{Ti}/dR)_{peak}$ and $(dV_\phi/dR)_{peak}$ move toward edge region within 50 ms of H-mode transition; what mechanisms drive this evolution?
- Impurity carbon ions peaks toward outboard region (r/a > 0.7); is this a result of large and persistent potential well there?
- Started neoclassical momentum balance calculations. Strong toroidal flow ($V_\phi/V_{Alfven} \leq 0.3$) affects?
- High resolution CHERS, edge flow spectroscopy, MSE in 2004.

What are the similarities and differences wrt standard A?