Experimental Evidence of the Effects of Pellet Injection on Barrier Physics

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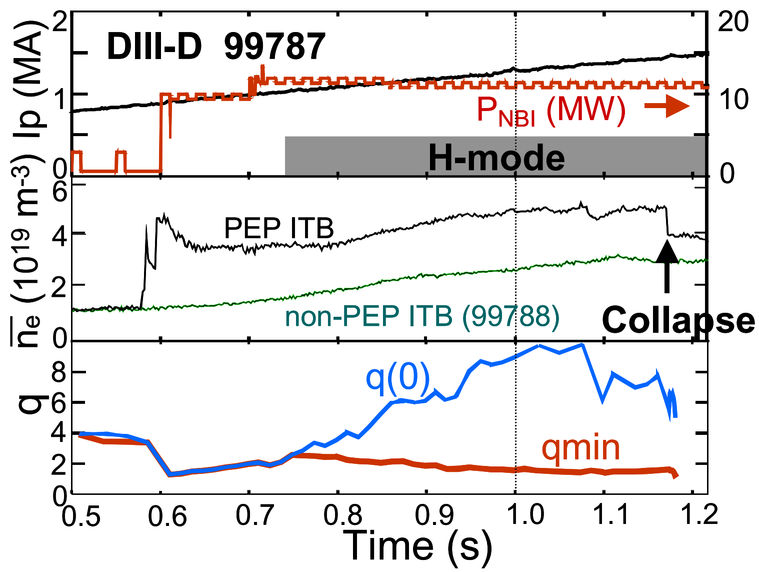
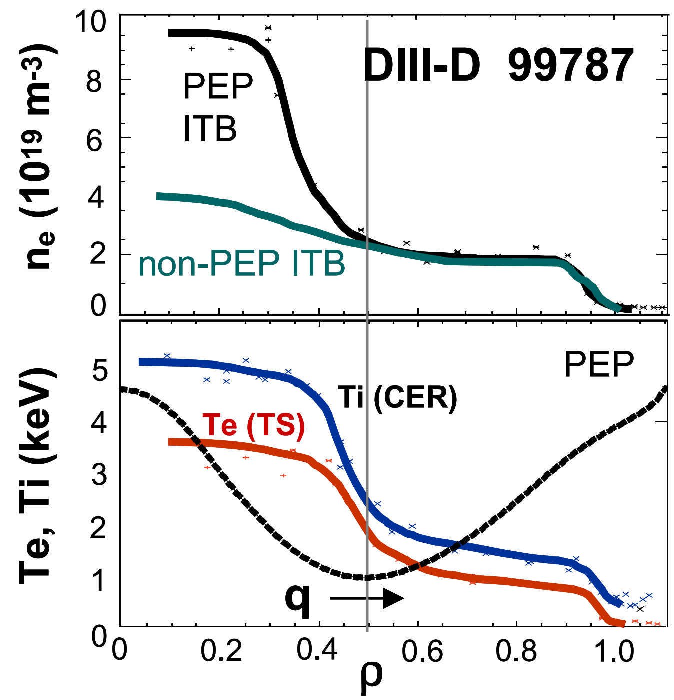
Overview

- Pellet enhanced performance internal transport barriers (PEP ITB) are formed with pellets injected from the high field side (HFS) followed by central heating:
  - $T_i \sim T_e$ and strong negative central shear
  - Reduced particle and both ion and electron energy transport is observed
  - The radial structures (e.g., profiles, radial electric field, transport properties) exhibit stronger variation than standard ITBs due to enhancement of the pressure gradients
- HFS (and sometimes LFS) pellets can trigger L to H-mode transitions:
  - Reduced power threshold
  - Plasma parameters are well below the standard data

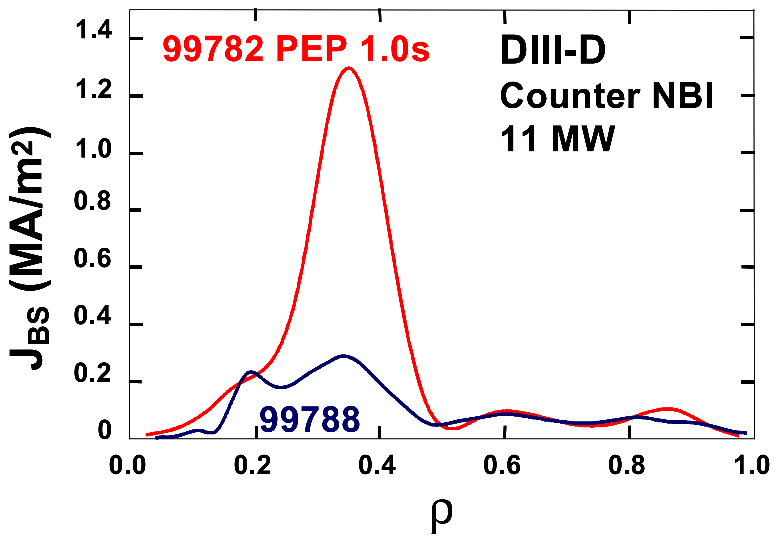
HFS Pellets During Current Rise Lead to Internal Transport Barrier - PEP ITB

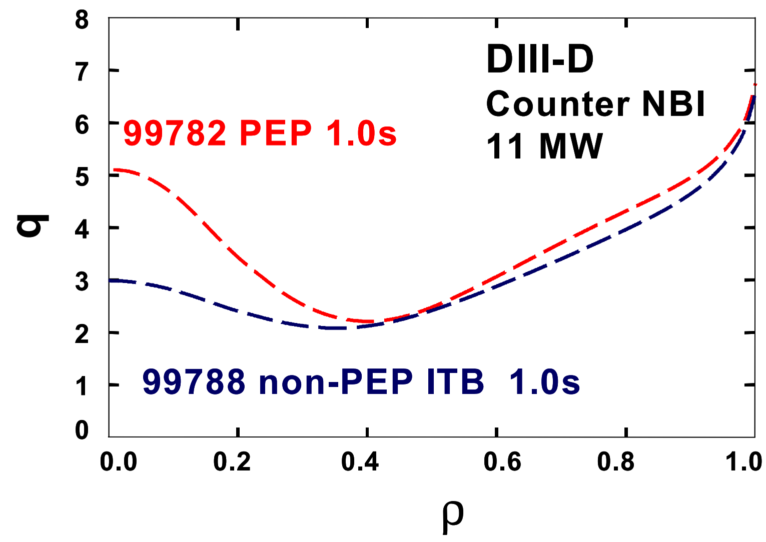




- **HFS 2.7mm pellets injected during the current rise produce highly peaked density profiles that develop a PEP ITB with $T_i \approx T_e$**
- **PEP ITB survives the L-H transition and can persist for > 1s**
- **Core collapse occurs as q_{min} reaches ~1.5**
- **Steepest n_e, T_e, T_i gradients occur inside q_{min}**

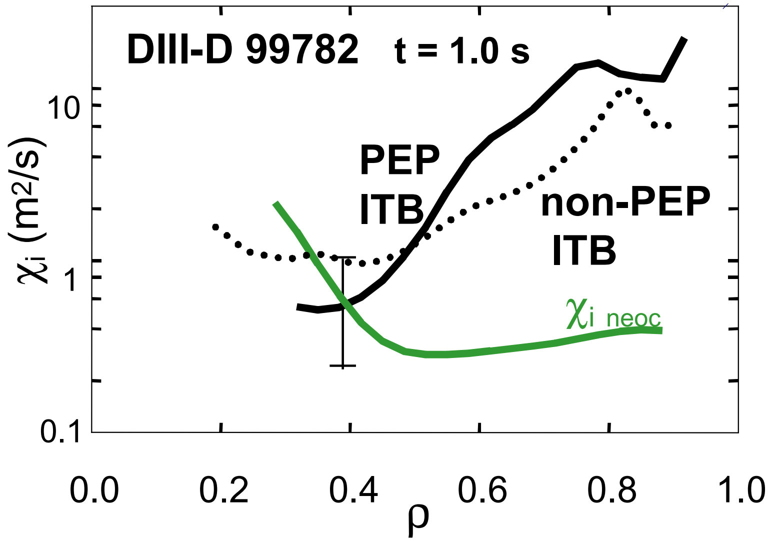
Strong Off-Axis Bootstrap Current Drives Negative Central Shear in PEP ITB

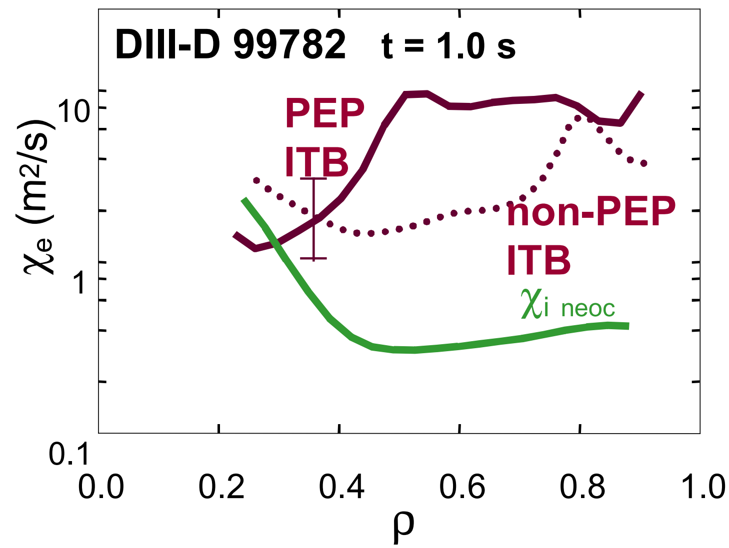




- The bootstrap current shows a stronger off-axis contribution in the PEP ITB case
- The safety factor (q) profile determined from MSE data has stronger negative central shear in the PEP ITB case
- The larger bootstrap current is a consequence of the stronger density and pressure gradients from pellet injection

Core Thermal Diffusivity Approaches Neoclassical in PEP ITB

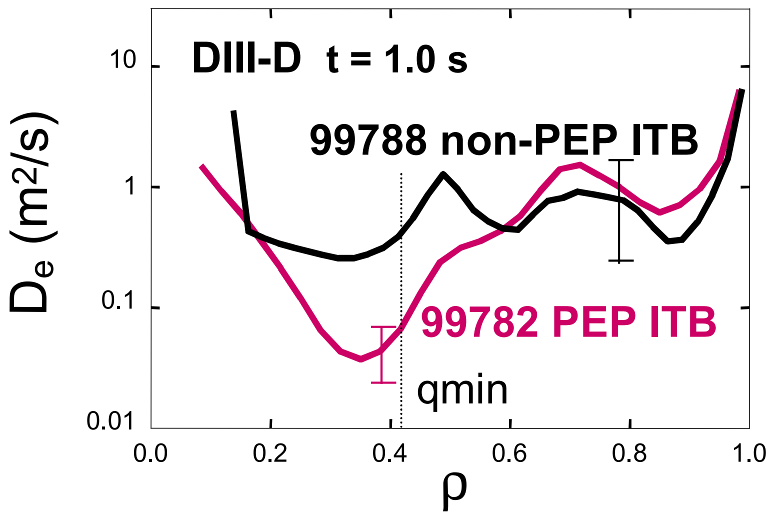




- **TRANSP calculations of χ_i and χ_e show stronger suppression of transport inside the ITB of the PEP case (0 < ρ < 0.4)**
- **Neoclassical χ_i is approached inside the ITB of both PEP and non-PEP cases**
- **ω_{EXB} is large enough to suppress ITG turbulence in both PEP ITB and non-PEP ITB plasmas**

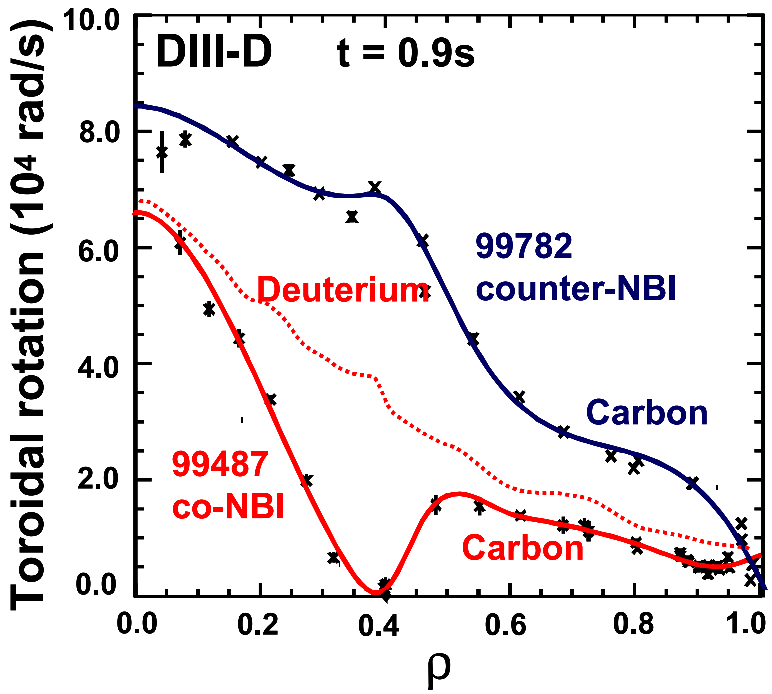
PEP ITB has Lower Electron Particle Diffusivity in the Core than non-PEP ITB

- TRANSP calculation of the electron particle diffusivity shows reduced particle transport in PEP ITB just inside the barrier region ($\rho < 0.4$) relative to a non-PEP ITB
- Both PEP and non-PEP ITBs show a strong increase in particle diffusivity toward the axis as inferred from the flat density profiles

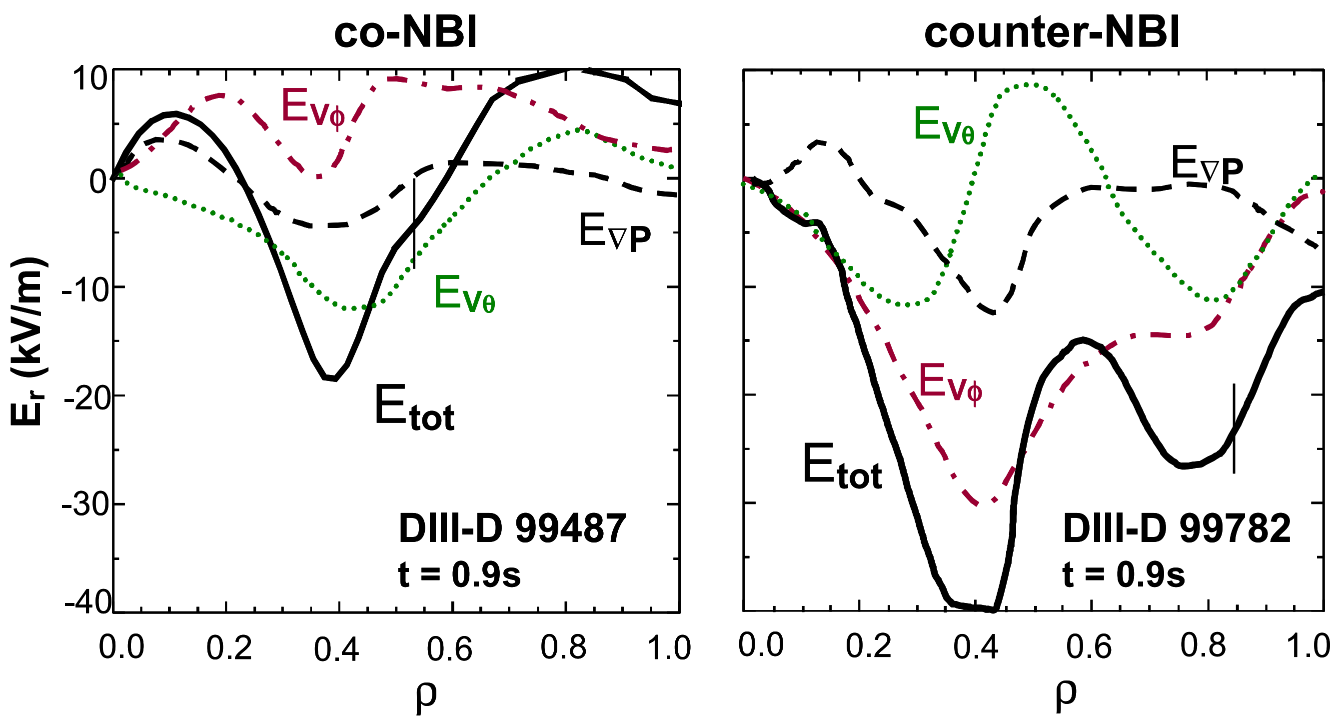


Co-NBI PEP ITB Exhibits the Neoclassical Toroidal Rotation Notch

- **Toroidal carbon rotation in PEP ITB shows a “notch” with co-NBI**
- **Similar to that seen on TFTR supershots due to neoclassical parallel momentum exchange** (see D.R. Ernst, et al. *Phys. Plasmas* **5** *(*1998) 665 for explanation of notch)
- **NCLASS calculated deuterium rotation profile is monotonic**
- **Experiments have been performed on D-IIID (but not yet analyzed) to directly validate the relative toroidal rotation velocity of ion species**



The Radial Electric Field has a Well at the PEP ITB Location that is Deeper for Counter-NBI



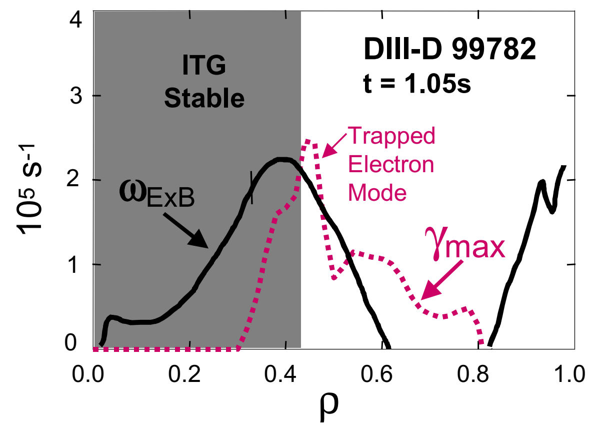
- **Radial force balance calculation for carbon shows E_r has well at the notch location**
- **Toroidal rotation is the dominant term: $E_r = (Zen)^{-1} \nabla P + v_\phi B_\theta - v_\theta B_\phi$**

ITG Modes are Stabilized inside the PEP ITB

- The **ExB shearing rate exceeds the ITG growth rate** inside the ITB

$$\omega_{ExB} = \frac{(RB_\theta)^2}{B} \frac{\partial}{\partial \psi} \left(\frac{E_r}{RB_\theta} \right)$$

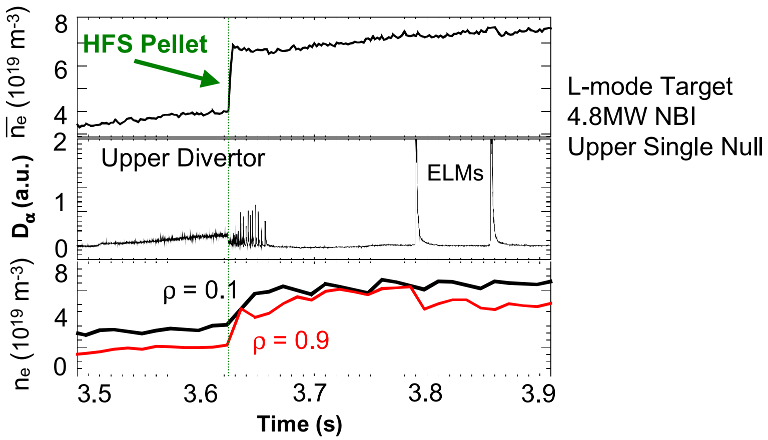
- The shearing rate is also strong in the H-mode barrier



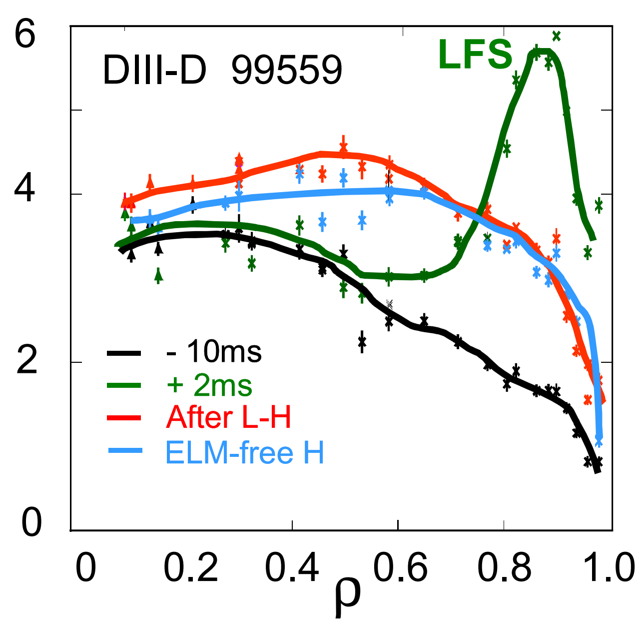
Gyrokinetic Stability Calculation

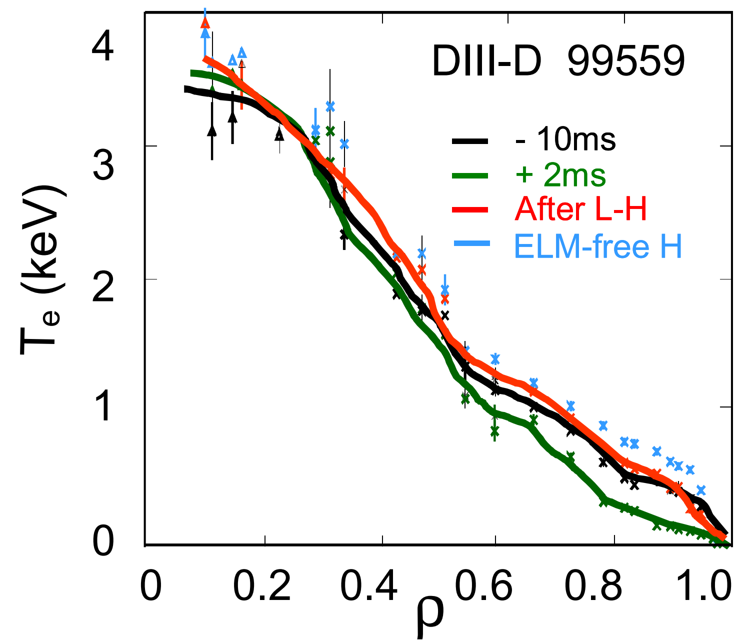
HFS Pellets Have Induced H-mode Transitions

- **HFS pellet induces an H-mode transition that is maintained**
- **The H-mode power threshold is reduced by 2.4MW (up to 33%) using pellet injection**



Pellet Induced H-mode Transition Occurs at Lower Edge Temperature





- **This LFS case was the consequence of a broken pellet**
- **The pellet induced H–mode transitions contradict critical edge temperature models (edge T_e and T_i are reduced following pellets)**
- **Pellet induced H–modes have L-H transitions at plasma parameters far below the standard data**

Summary

- Pellet injection modifies ITB physics:
  - Through modification of the density profile and as a consequence to the pressure, E_r, ω_{ExB}, and other profiles
  - Both the transition threshold and post transition characteristics are modified
  - HFS and vertical launch enhance the flexibility for modifying the ITB behavior
- These enhancements may have similar underlying physics to the enhancements seen in L-mode plasmas
- Any device examining burn dynamics can take advantage of this enhanced flexibility by allowing vertical or inside access for pellet injection