ION ITB CHARACTERIZATION USING T_e PERTURBATIONS

by

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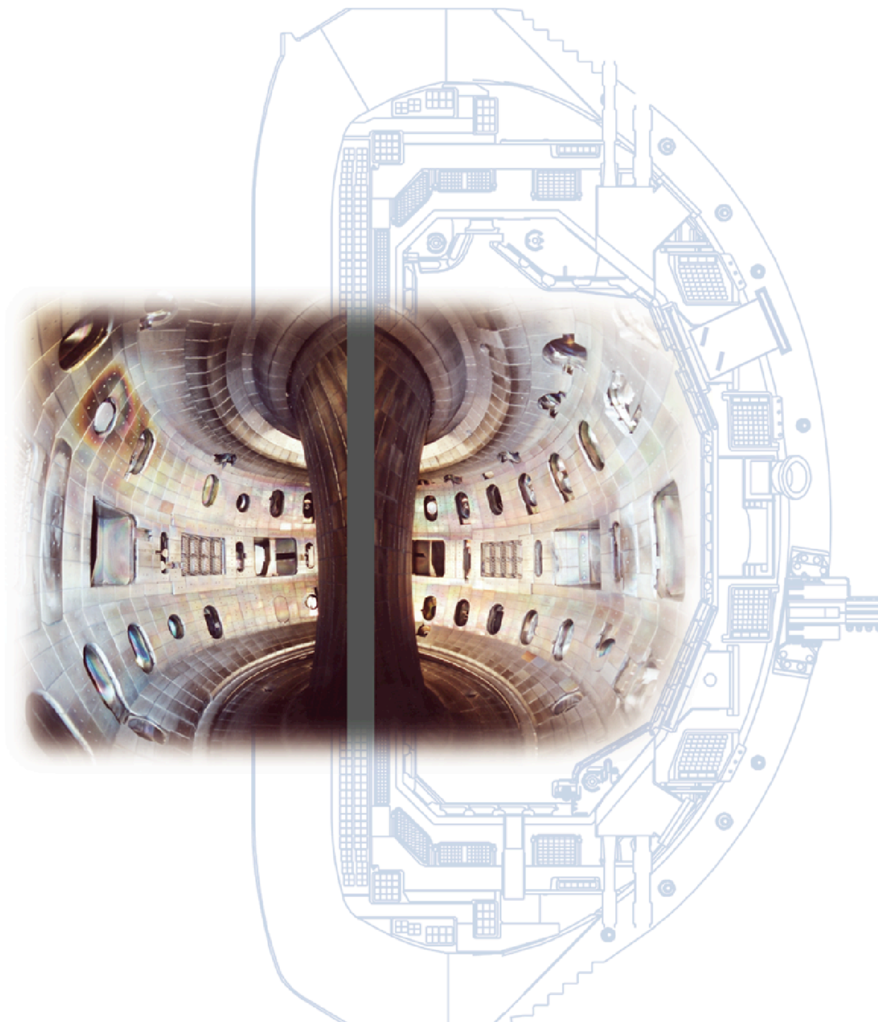

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DIII-D NATIONAL FUSION FACILITY

GENERAL ATOMICS

MOTIVATION and APPROACH

- **Motivation: Study the characteristics of an ion Internal Transport Barrier (ITB)**
  - Is the barrier of finite width or does it extend in to the plasma center?
  - How wide is the barrier if of finite width?
- **Approach: Use modulated ECH to create localized heat pulses**
  - have observed in the past that electron heat pulses produce a response in the ion channel
  - apply modulated ECH resonant outside the ITB
  - study ion heat pulses as they propagate through the ITB

TARGET DISCHARGE: QH-MODE WITH A STEADY ION ITB (QDB)

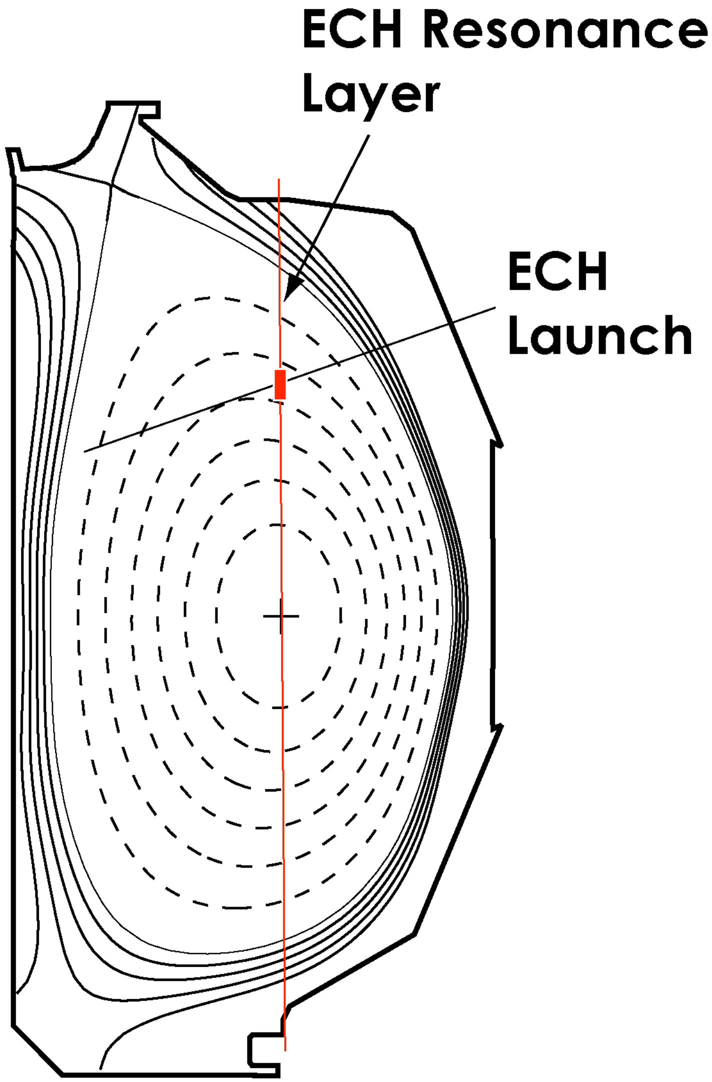
- **QDB has an ion ITB with characteristics most desirable for employing heat pulse propagation techniques**

- **QDB characteristics**
  - steady state ITB allows FFT analysis of heat pulses over many modulation periods
  - no ELMs or other transient events permits small perturbations to be employed ($\delta T_e/T_e$ ~ 3 - 5 % produces $\delta T_i/T_i$ ~ 2 - 3 %)

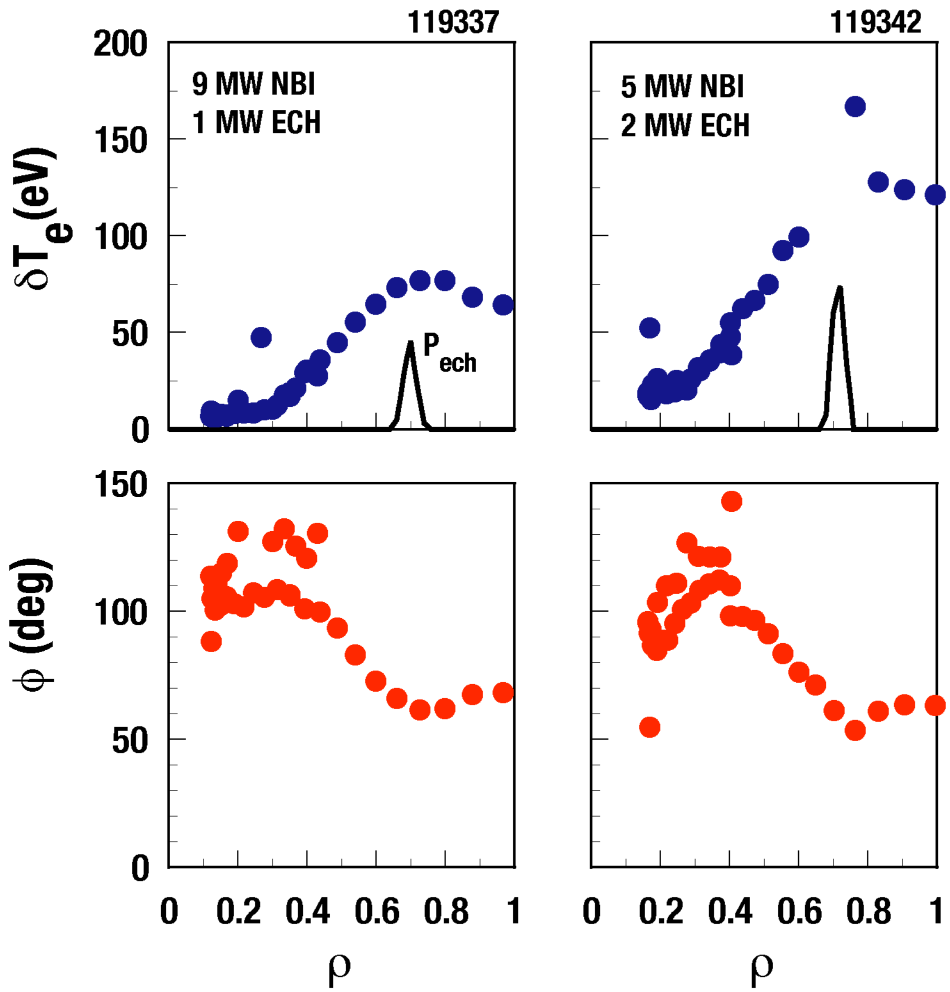
- **Focus on two cases**
  - Standard QDB with 4 sources of NBI, P_{NBI} ~ 9 MW
  - Reduce P_{NBI} ~ 5 MW to try and move the location of the ITB

QDB Discharge Shape Studied Is An Upper Single Null Divertor

- 1.3 MA, 2.0 T, 2×10^{19} m^{-3}
- P_{NBI}= 5.0 and 9.2 MW
  - counter injection
- Sawtooth and ELM free
  - q_0 = 1.1-1.2 with monotonic profile
- ECH Resonance at ρ_{ECH}= 0.7
  - f_{mod}= 25 Hz
  - P_{ECH}= 1-2 MW

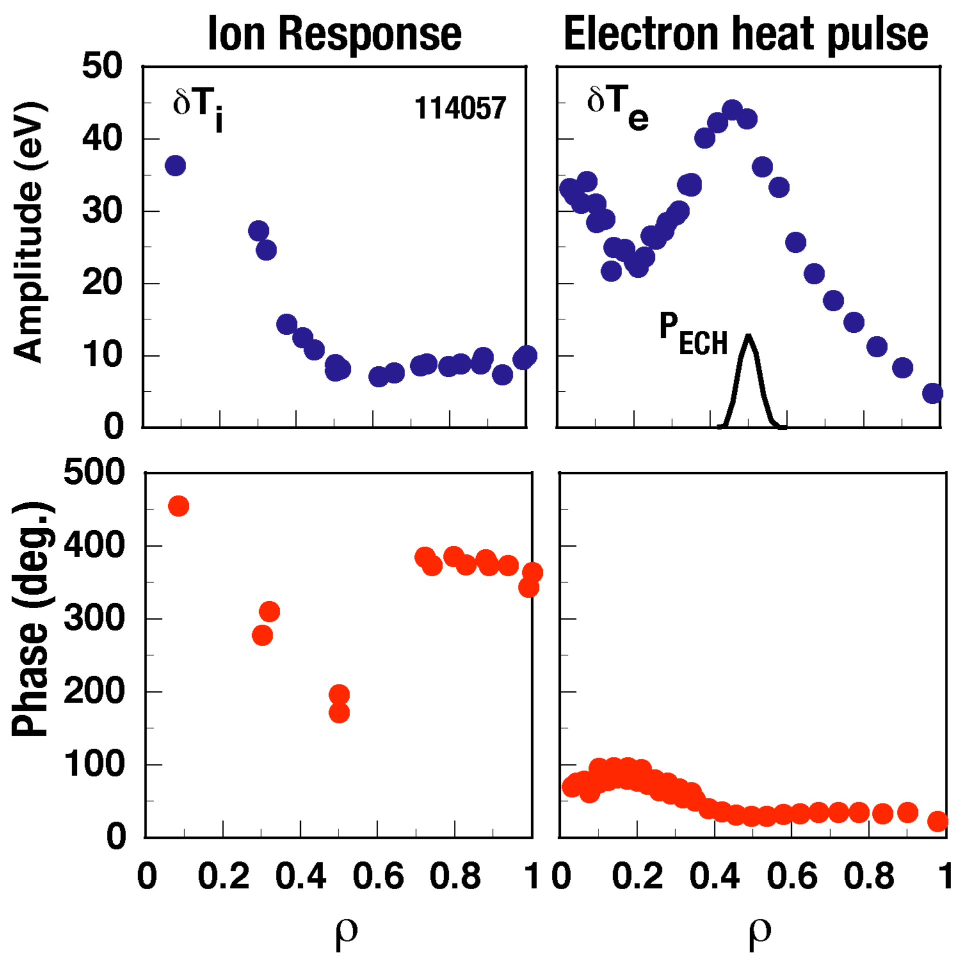


ELECTRON TEMPERATURE HEAT PULSES PRODUCED BY ECH



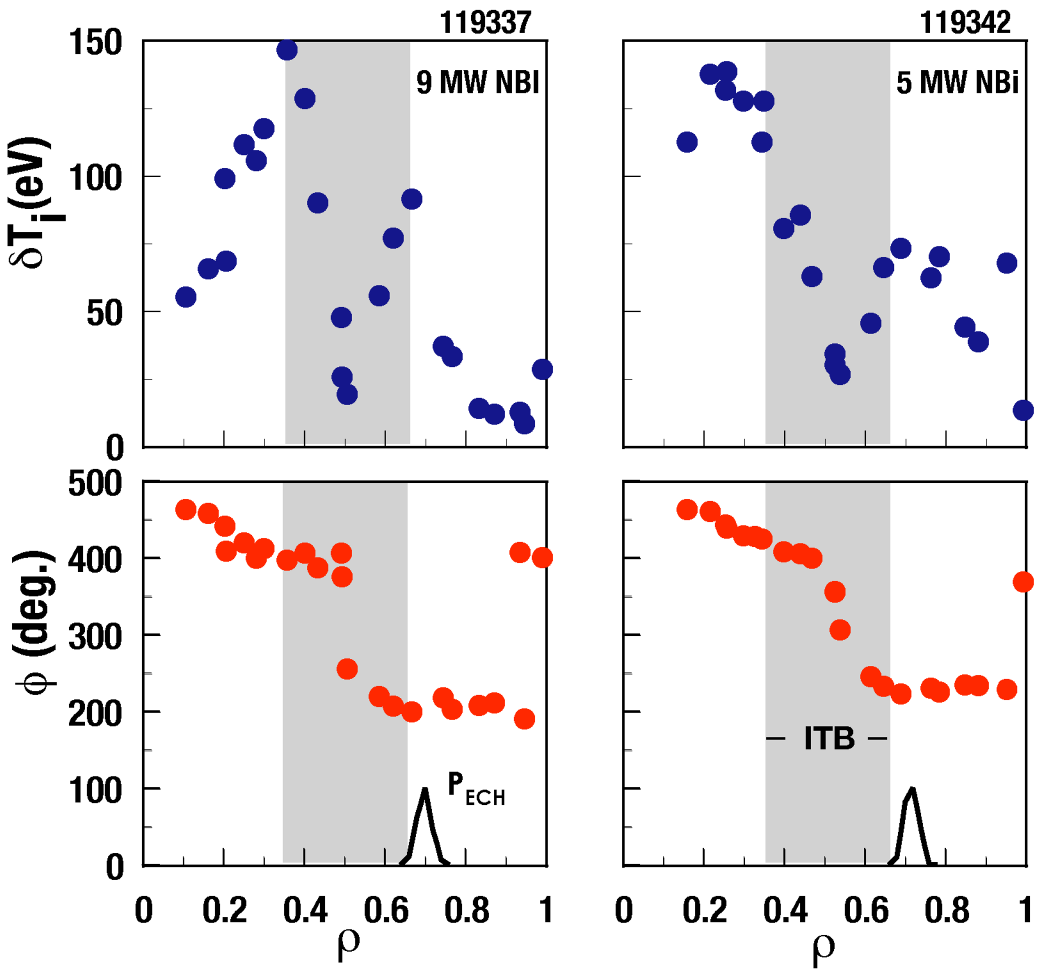
- T_e heat pulses are characterized by their amplitude and phase
- Produced with ECH power modulated at 25 Hz and deposited at ρ = 0.7
- Small perturbations, $\delta T_e/T_e$ ~ 2 - 3 %
- Amplitude peak and phase minimum occur at ρ_{ECH}
- T_e heat pulses produced a response in T_i

TYPICAL T_i RESPONSE TO δT_e IN AN L-MODE DISCHARGE



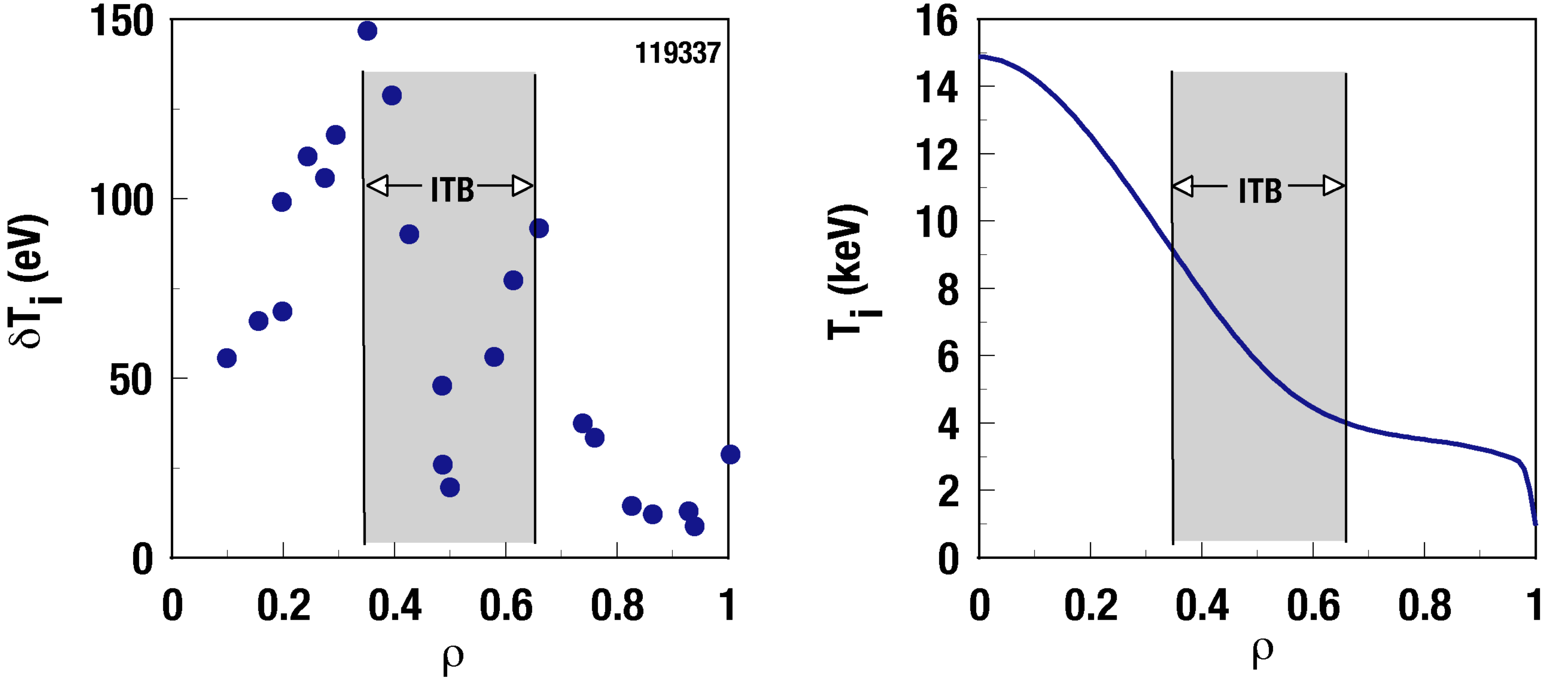
- T_i amplitude is minimum at ρ_{ECH} and increases toward the plasma core even though δT_e decreases as the pulse propagates to the plasma core
  $\Rightarrow$ not just e-i collisional coupling
- At ρ_{ECH} the ion response is typically about 180° out of phase with the electron response ($\phi_i \sim \phi_e$ +180), when T_e increases locally, T_i decreases
- This behavior is consistent with the impact of changes in T_e/T_i on ITG mode activity

ION RESPONSE IN QDB



- Local minimum in δT_i may indicate localized ion transport barrier (shaded region)
- Location of ITB is not too sensitive to ∇T_i or V_ϕ since location does not vary for 9 MW NBI compared to 5 MW NBI case

ITB CENTERED AT ρ = 0.5 AND IS ~ 15 cm WIDE



- Decrease in δT_i is expected in region of decreased transport. As pulse enters ITB region, propagating from ρ_{ECH}=0.7, amplitude of pulse δT_i decreases and trend reverses as leave ITB region

WORK HAS BEGUN ON COUPLING ION TRANSPORT TO ELECTRONS THROUGH A DEPENDENCE OF ION TRANSPORT COEFFICIENTS ON T_e AND ∇T_e

- **Equation for ion energy conservation**
  - $3/2\ \partial n_i T_i/\partial t + \nabla q_i = S_i$

    where heat flux $q_i = -n_i \chi_i \nabla T_i + n_i T_i U_i$
  - χ_i diffusion, U_i convection coefficients

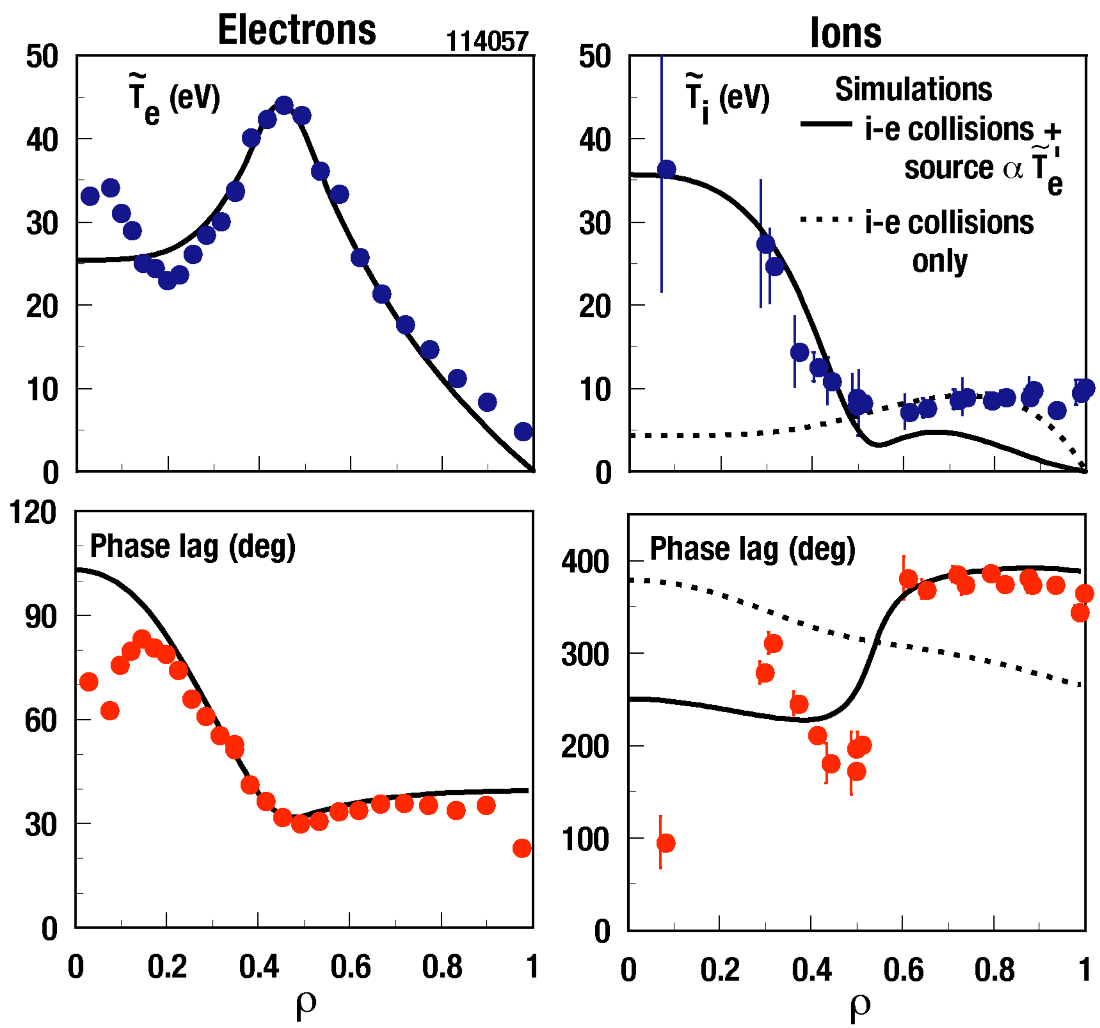
- **Two sources of coupling to electrons**
  - source term, $S_i = Q_{NBI} - Q_{ie}$ and collisional coupling $Q_{ie} = n^2(T_i - T_e)/T_e^{3/2}$
  - ion transport coefficients may depend on T_e and/or ∇T_e,

    $\chi_i(\rho, T_i, \nabla T_i, T_e, \nabla T_e)$ and $U_i(\rho, T_i, T_e)$

- **Fourier transformed, linearized equation for $\tilde{T}_i$ with effective diffusion, convection and damping terms, D, V, $1/\tau$. Note there is a spatially distributed source.**

$$-\mathbf{D}\tilde{T}_i'' + \mathbf{V}\tilde{T}_i' + \left(\frac{1}{\boldsymbol{\tau}} + i\frac{3}{2}\omega\right)\tilde{T}_i = C_o\tilde{T}_e + C_1\tilde{T}_e' + C_2\tilde{T}_e''$$

COLLISIONAL TERM ALONE CAN NOT EXPLAIN ION RESPONSE



- Collisional term alone can not account for ion perturbed response since $\tilde{T}_e$ decreases toward plasma core whereas $\tilde{T}_i$ amplitude increases.
- Not able to compute effective transport coefficients yet, but can model them with simple polynomials.
- Much better fit to ion response obtained by including a source term $\propto \tilde{T}_e'$.

SUMMARY

- **Evidence for an ion ITB has been observed in QH-mode discharges in DIII-D based on measurements of T_i perturbations driven by T_e heat pulses created with modulated ECH power.**

- **The ion ITB appears to be spatially localized at ρ ~ 0.5 with a width of ~ 15 cm.**

- **The location of the barrier and its width were insensitive to changes in ∇T_i (factor 2.6 increase) and toroidal rotation velocity V_ϕ (60% increase) obtained by doubling P_{NBI}.**

- **Work has begun to solve the full second order partial differential equation for transport of ion perturbations with ion transport coefficients that are dependent on T_e and ∇T_e .**
  - collisional coupling alone can not account for the ion perturbations observed
  - some coupling between ion transport coefficients and electrons is required