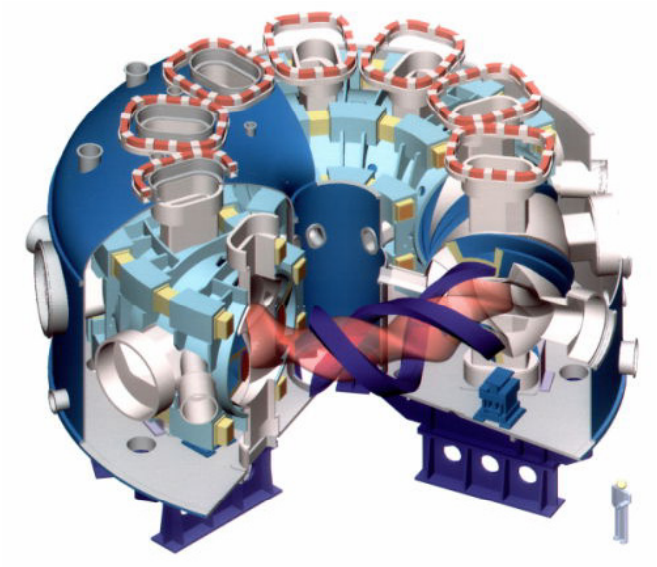
Experimental study on nonlocal electron heat transport in LHD

N. Tamura[1], S. Inagaki[2], K. Tanaka[1], C. Michael[1], T. Tokuzawa[1], K. Ida[1], M. Yoshinuma[1], T. Shimozuma[1], S. Kubo[1], R. Sakamoto[1], T. Fukuda[3], K. Itoh[1], Y. Nagayama[1], K. Kawahata[1], S. Sudo[1], A. Komori[1] and LHD team[1]



[1]National Institutes of Natural Sciences, Japan
[2]Kyushu University, Japan
[3]Osaka University, Japan

12th US-EU Transport Taskforce Workshop
San Diego, USA

17-20 April 2007

Outline

- ✓ Motivation
- ✓ Characteristics of nonlocal T_e rise in LHD
  - Observation regime
  - Time response of core T_e rise
  - T_i response to nonlocal T_e rise
- ✓ Results of transient response analysis for nonlocal T_e rise
- ✓ Summary

Motivation

- ✓ In order to obtain a good predictive capability for burning plasmas, full understanding of electron heat transport is highly necessary
- ✓ Recent experiments on toroidal plasmas shows non-locality in electron heat transport

$q_e(\rho_1) = f(\nabla T_e(\rho_1), \nabla T_e(\rho_1-\delta\rho), \nabla T_e(\rho_1+\delta\rho), \ldots)$

Recently observed in LHD

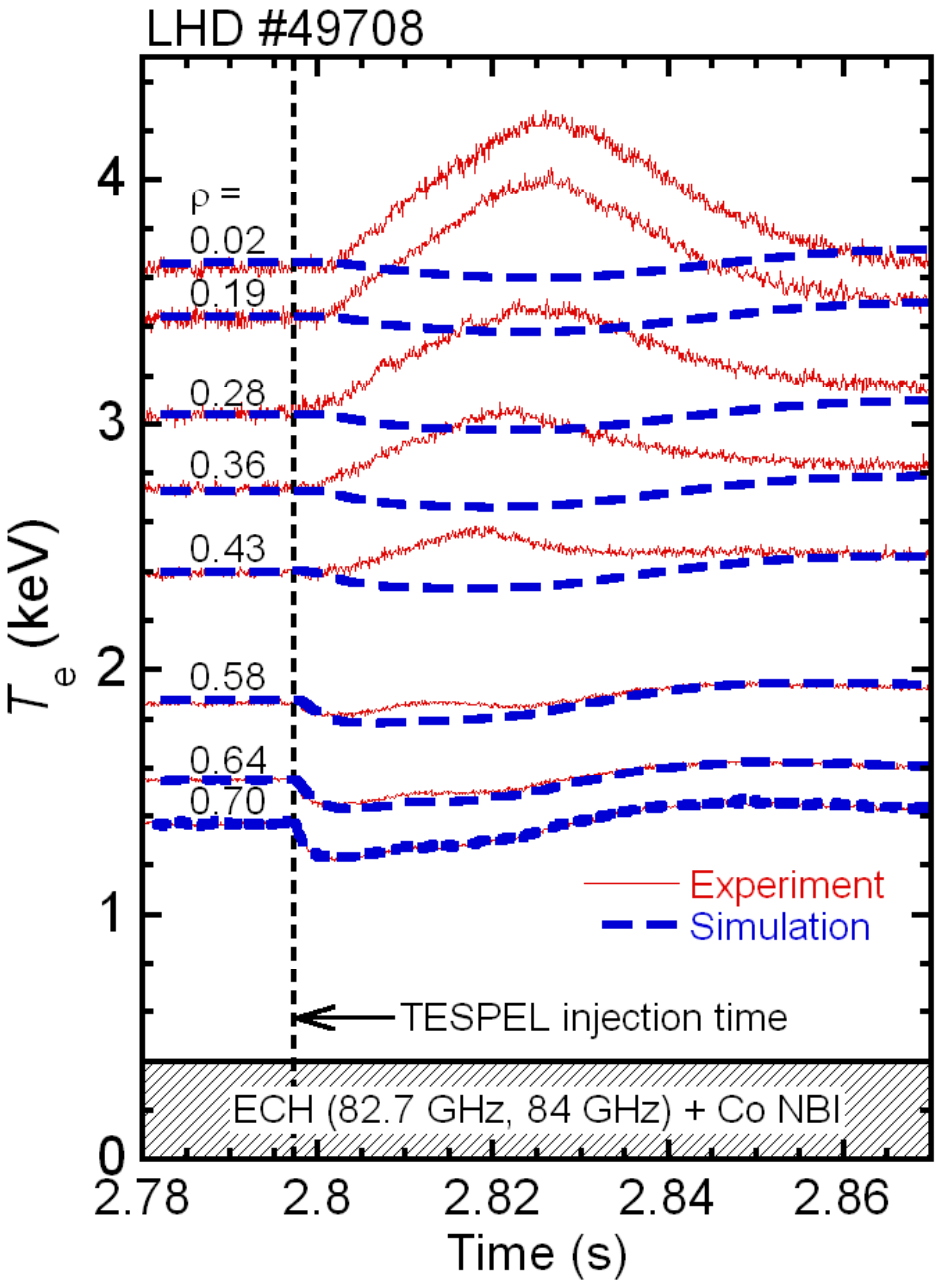
Profile resilience

Fast plasma response (non-diffusive, ballistic)

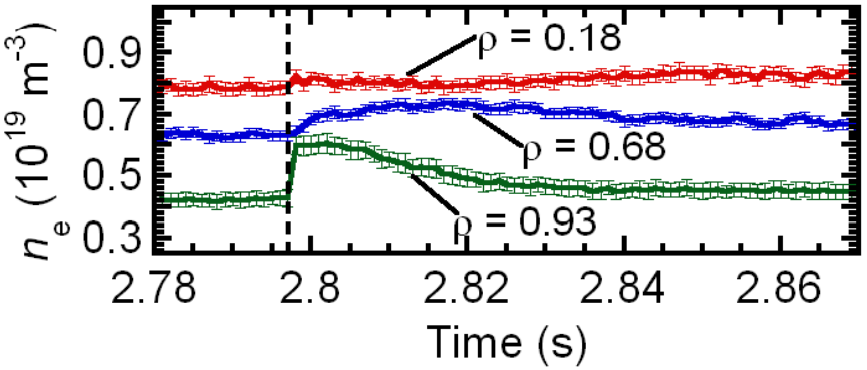
Phase inversion of cold pulse polarity

- ✓ Possible theoretical interpretation is "nonlocality" in turbulence (e.g. turbulence spreading)
- ✓ Observations in LHD heliotron give new insight into nonlocal transport
  - Because LHD has
    - different magnetic configuration (normally negative magnetic shear)
    - no tokamak-like stiffness in T_e profile

Significant rise of core T_e in response to edge cooling in LHD



- ✓ Edge cooling experiment of LHD shows a significant rise of core T_e
  - No change in low-*m* MHD modes
  - No density peaking like PEP, RI-mode

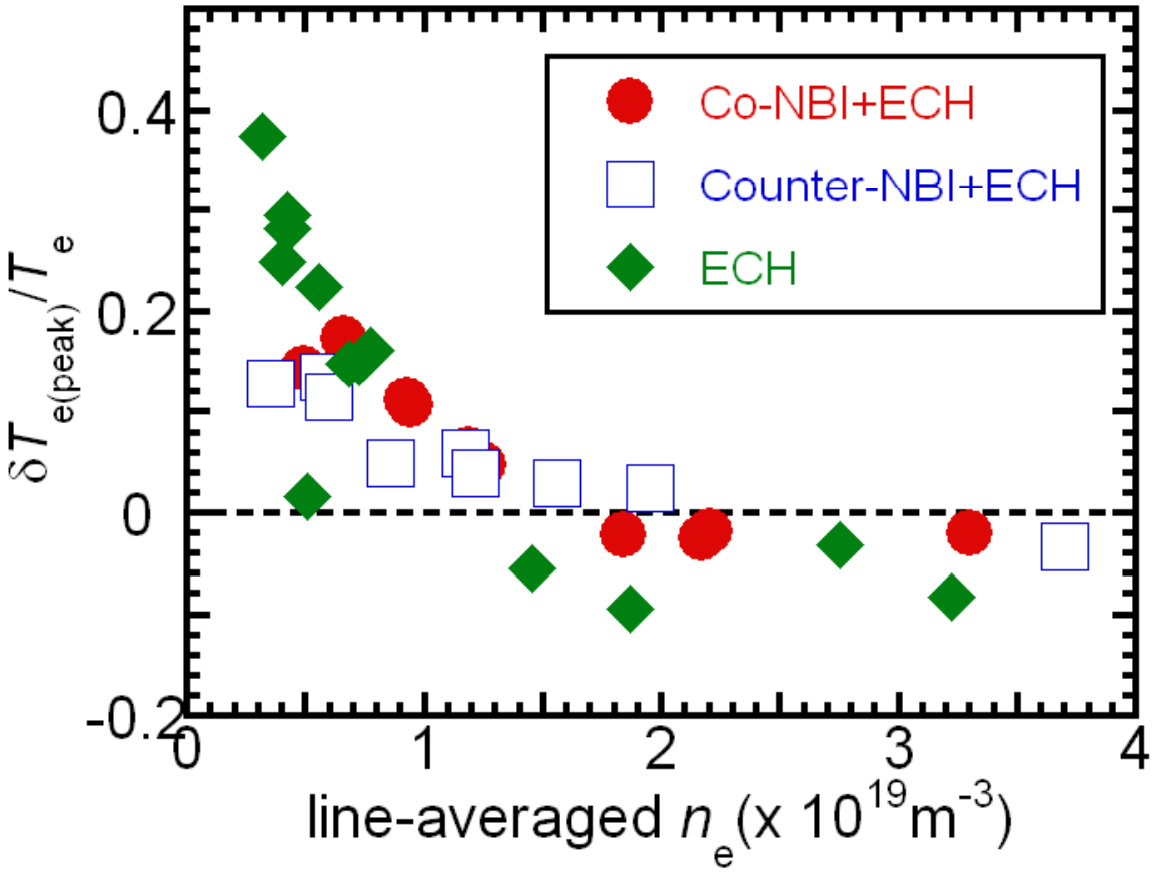


  - Electron heating dominates ($T_e/T_i > 1$)

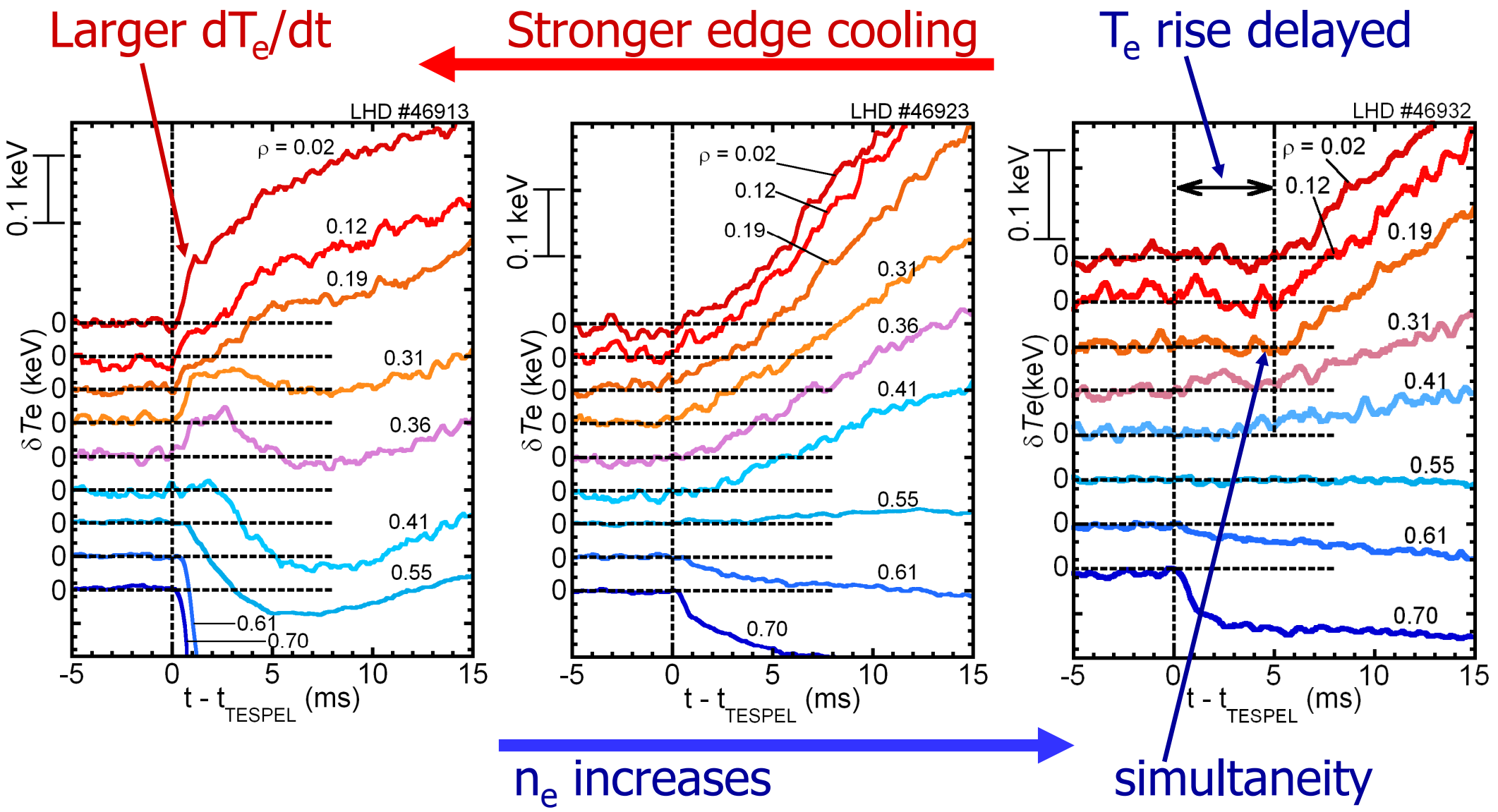
- ✓ Difference between T_e measured and that simulated based on simple diffusion model is
  - pronounced in the core ($\rho < 0.6$)
  - little at the edge ($\rho > 0.6$)

Characteristics of Nonlocal T_e rise in LHD plasmas
1) Condition for nonlocal T_e rise

- ✓ Inverse relationship between increment of core T_e due to nonlocal effect and n_e observed
  - Same as in tokamaks
  - In LHD, no differences among heating methods (however, electron heating is almost always dominant)



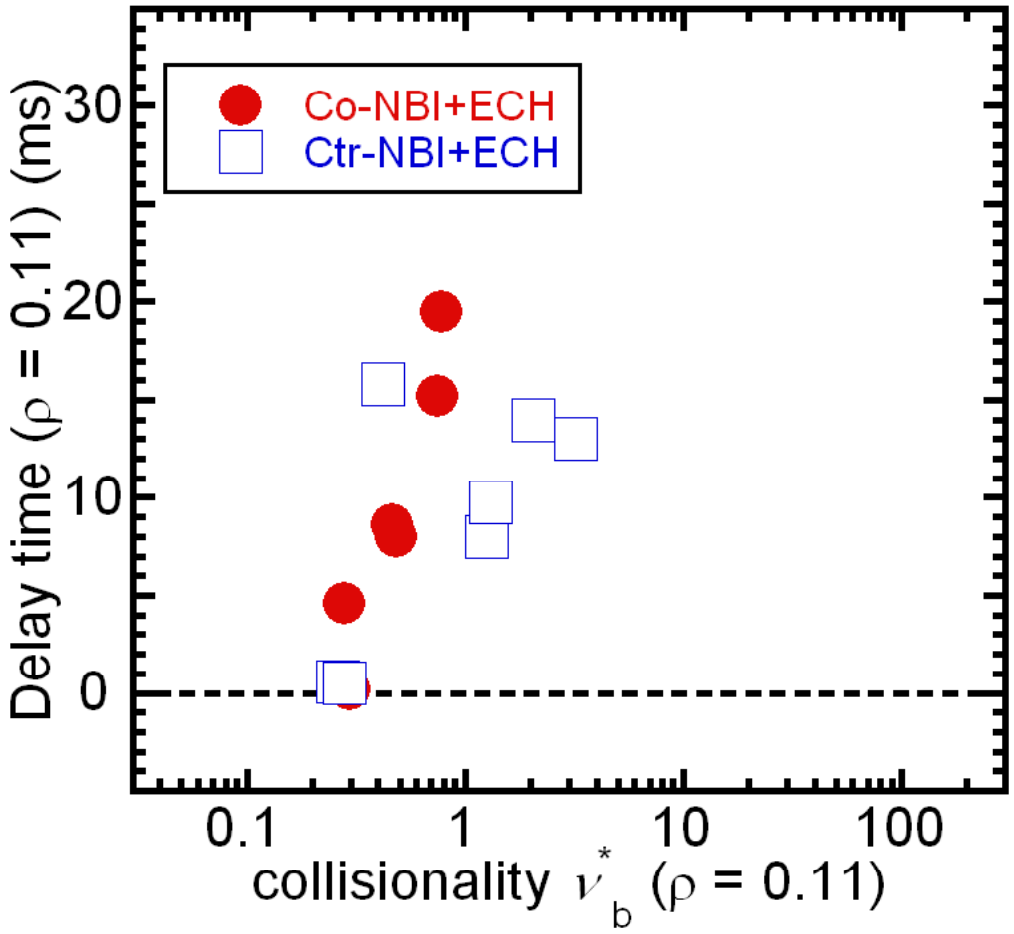
Characteristics of Nonlocal T_e rise in LHD plasmas
2) Variety of time response

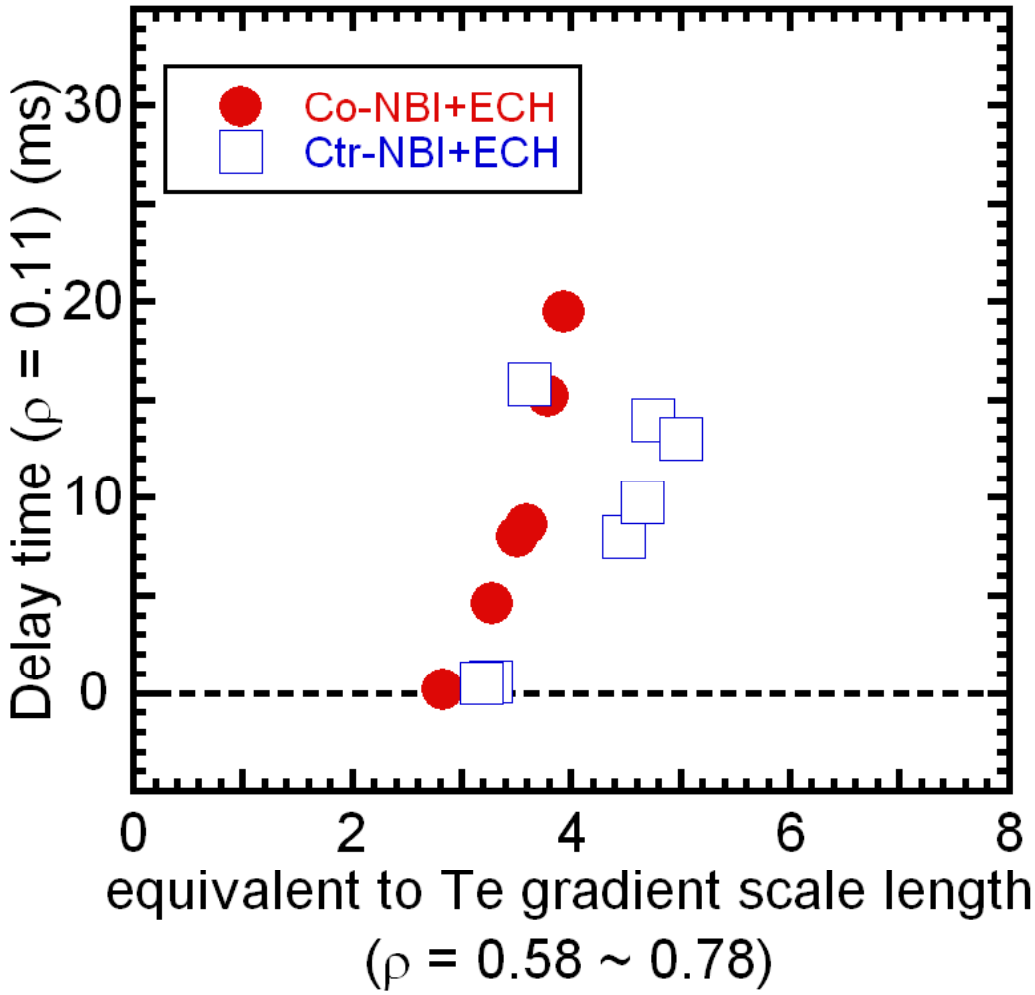


Characteristics of Nonlocal T_e rise in LHD plasmas
3) Dependence of delay time

✓ Favorable condition for delay of nonlocal T_e rise

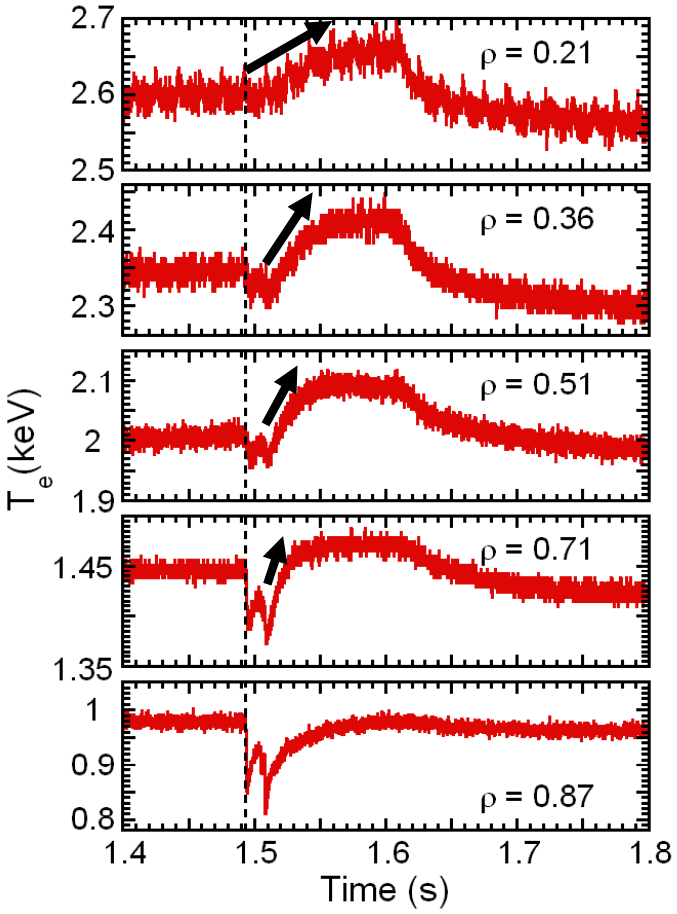
- Higher collisionality ν_b* in the core
- Longer T_e gradient scale length at the edge

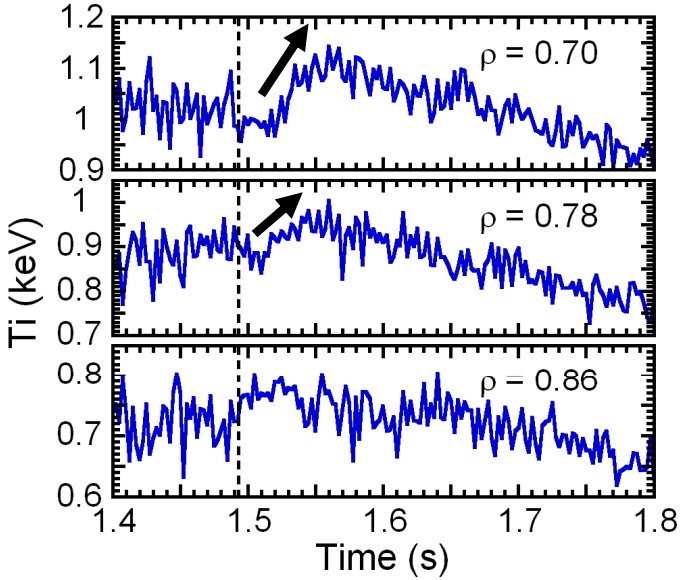


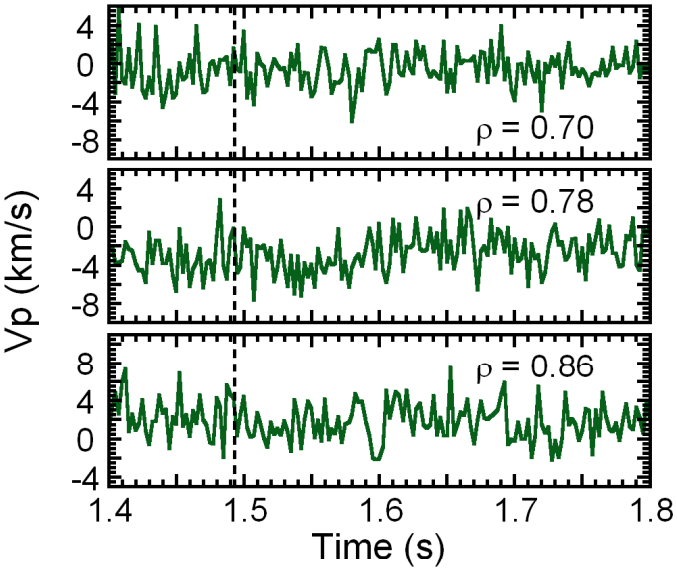


Characteristics of Nonlocal T_e rise in LHD plasmas
4) How about T_i response?

- ✓ High time-resolved (2.5ms) charge exchange spectroscopy system allows us to measure a Ti response to nonlocal T_e rise



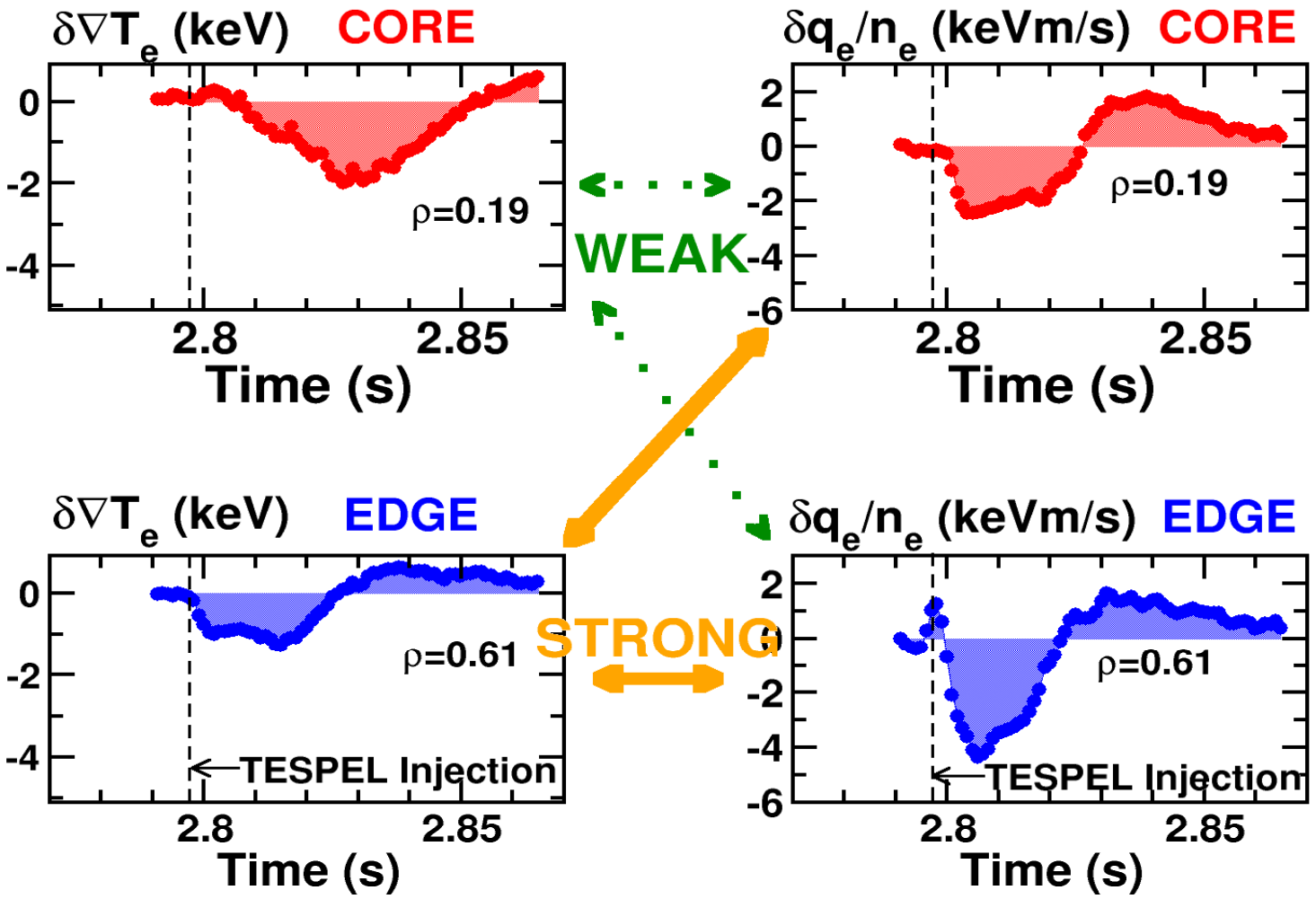


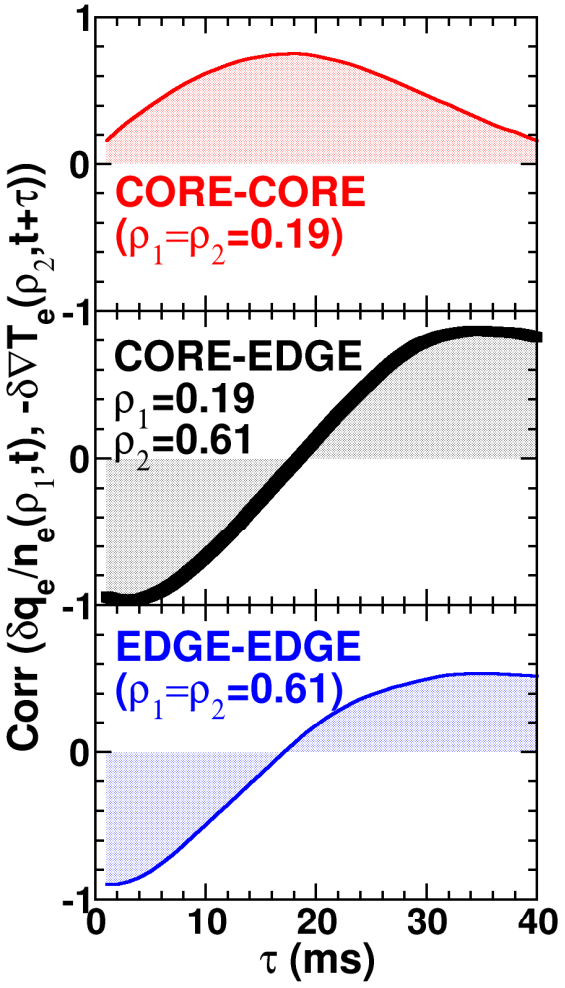


- ✓ TESPEL (doubled accidentally) is deposited outside ρ ~ 0.9
- ✓ T_i is increased nonlocally as well as T_e after rapid edge cooling
  - At ρ ~ 0.7, increment of T_i is slightly larger than that of T_e
  - not just e-i collisional coupling
- ✓ No change in V_p is seen

Transient response analysis suggests strong coupling between the core and the edge

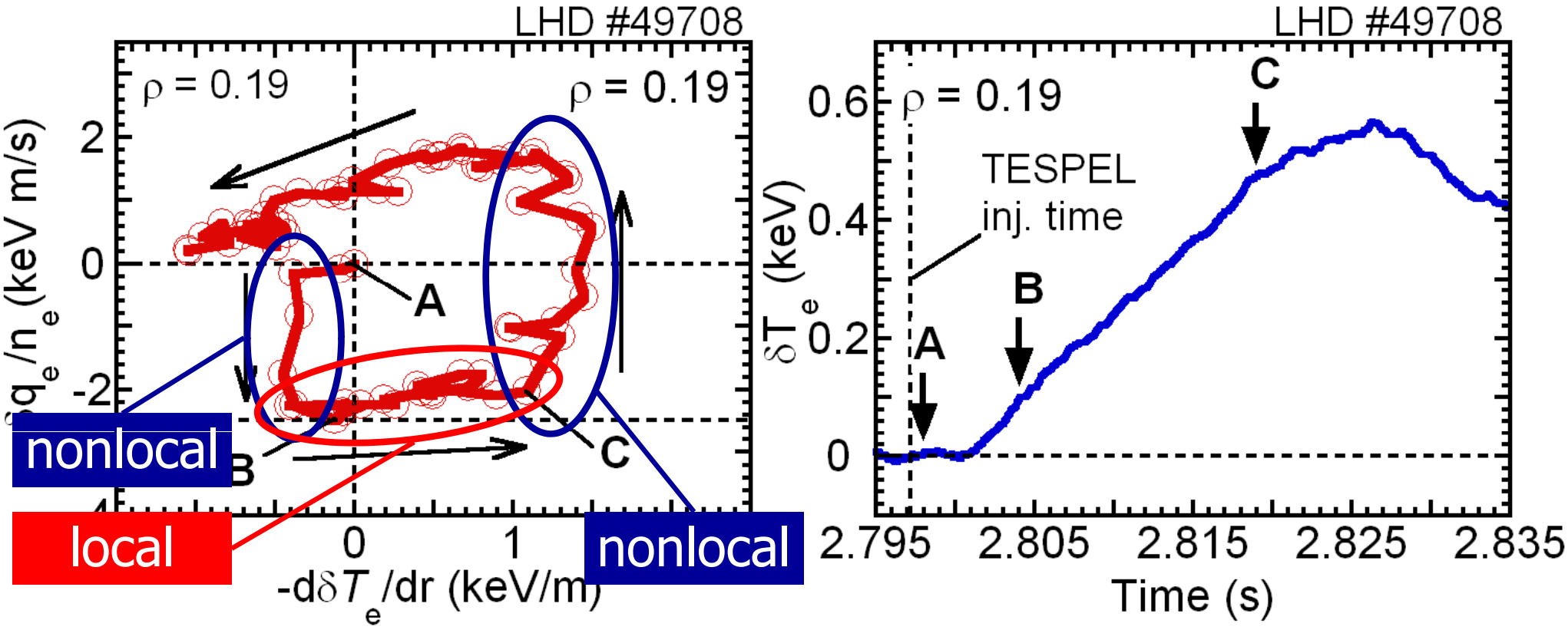
✓Heat flux perturbation $$\delta q_e(r,t) = -\frac{1}{r}\int_0^r \frac{3}{2} n_e \frac{\partial \delta T_e(r,t)}{\partial t} \rho d\rho$$





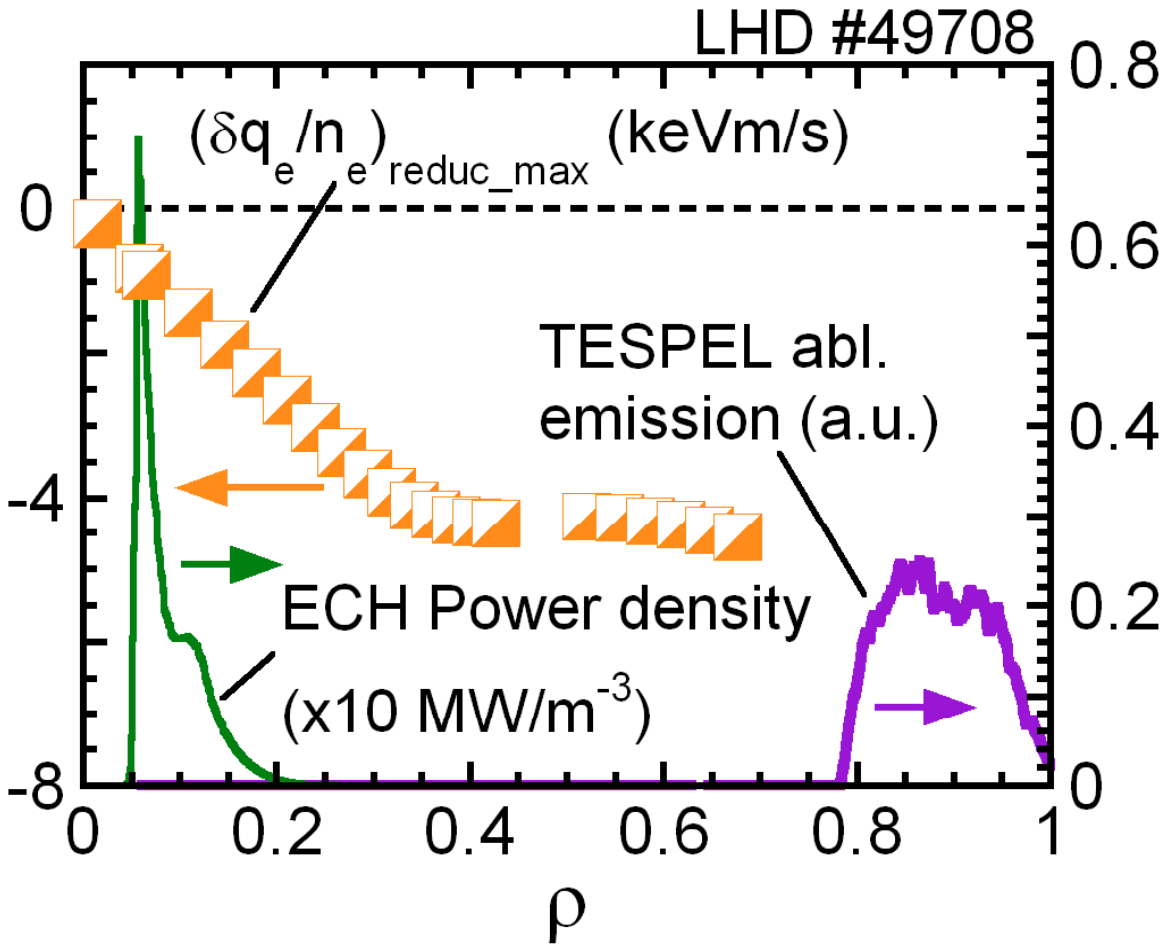
Transient response analysis reveals complex relationship between heat flux and T_e gradient

- ✓ Reduction of $\delta q_e/n_e$ is not accompanied by changes in local ∇T_e
  - Evidence against "standard transport theory" (local & diffusive)
- ✓ Turn-back of $\delta q_e/n_e$ is also independent of local ∇T_e



Reduction of normalized heat flux due to nonlocal effect takes place in a wider region

- ✓ Region where reduction of $\delta q_e/n_e$ prominently appear is far from rapidly cooled region and strongly heated region



Summary

- ✓ New aspects of nonlocal T_e rise from LHD
  - Observation in net-current free plasma
  - Time response of nonlocal T_e rise can take on a variety of forms
- ✓ Time response of core T_e rise is quicken by larger edge perturbation (shorter T_e gradient scale length?)
- ✓ Delay of nonlocal T_e rise increased with…
  - increase in collisionality in the core
  - increase in T_e gradient scale length at the edge
- ✓ Nonlocal rise of T_i as well as T_e has been observed after rapid edge cooling
- ✓ Transient response analysis for electron heat transport suggests
  - strong coupling between the edge and the core
  - complex relationship between flux and gradient
  - transitions between "nonlocal" and "local"