Is fast ion MHD driving rapid electron transport in NSTX?

D. Stutman, L. Delgado, K. Tritz and M. Finkenthal

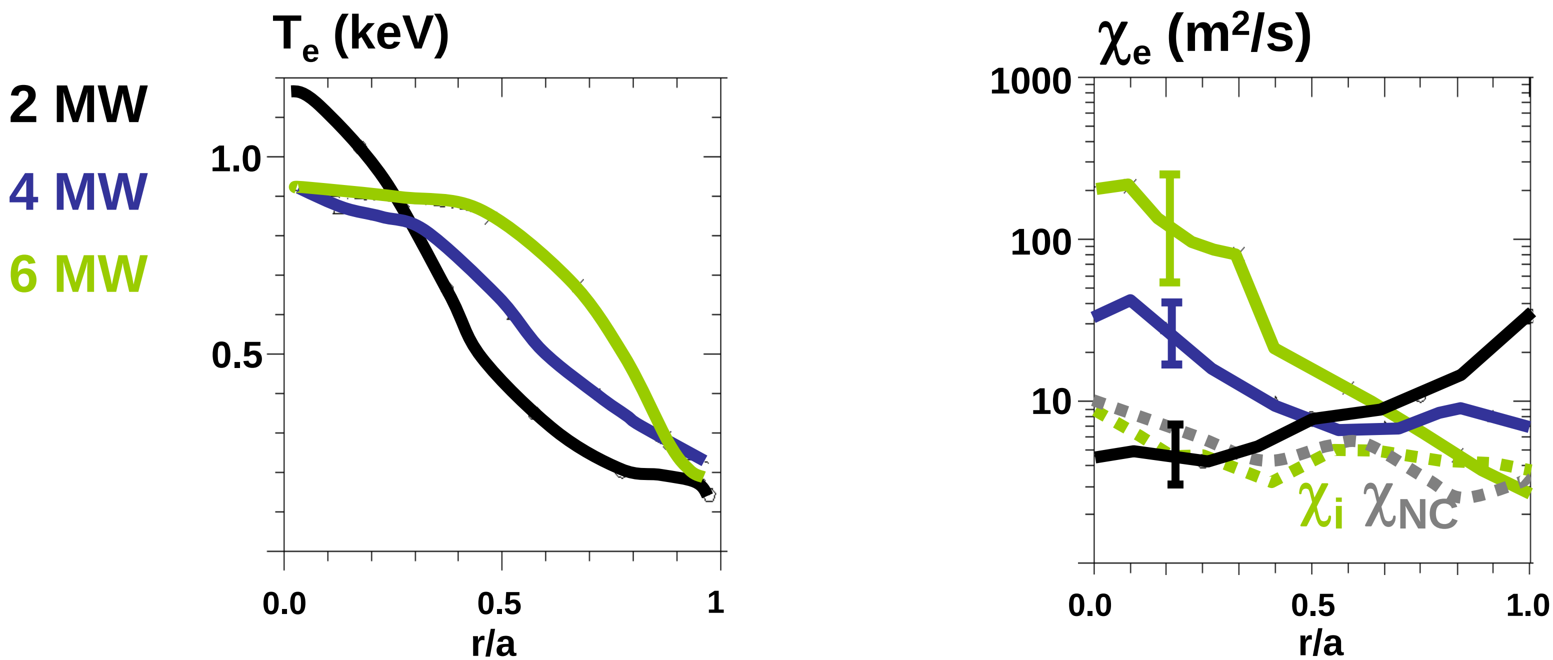
Johns Hopkins University

Outline

- Puzzle we try to solve: T_e flattening with P_{beam} in NSTX H-modes
- Is T_e flattening genuine electron transport effect ?
- Separating the role of P_{beam} in this effect
- The fast ion connection
- μ-tearing as possible link between fast ion MHD and electron transport
- ‘Direct drive’ hypothesis
- Implications and possible further work

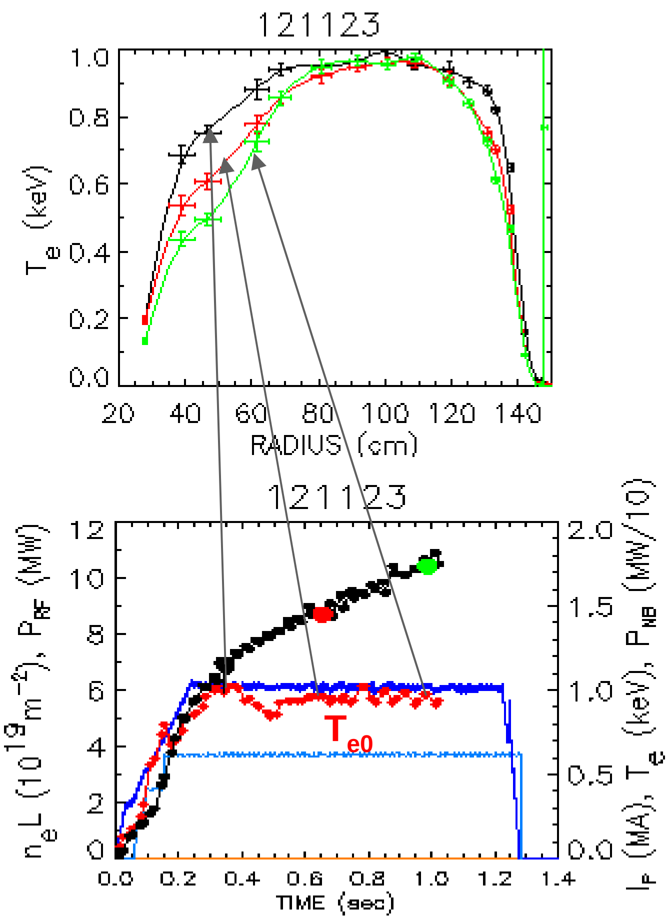
Unusual flattening of central T_e with P_{beam} in NSTX H-modes

1 MA / 4.5 kG, 'high performance' H-modes, t=0.42 s

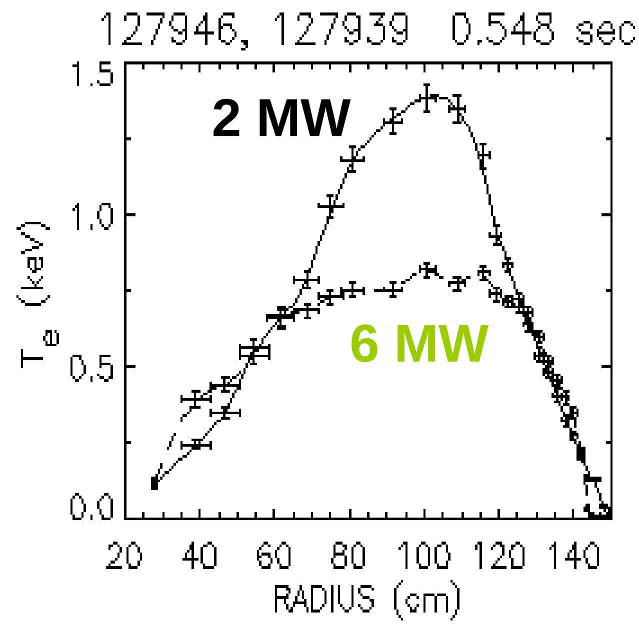


- TRANSP computes increasingly rapid electron transport inside r/a ≤0.4
- Ion transport consistently around neoclassical

Effect persists throughout discharge, as well as at higher B_t, I_p



1.1 MA, 5.5 kG



- Only slight rounding of T_e ‘shoulders’ with time
- Central T_e higher at 2 MW than at 6 MW, even at increased B_t and I_p

What other than electron transport could cause T_e flattening?

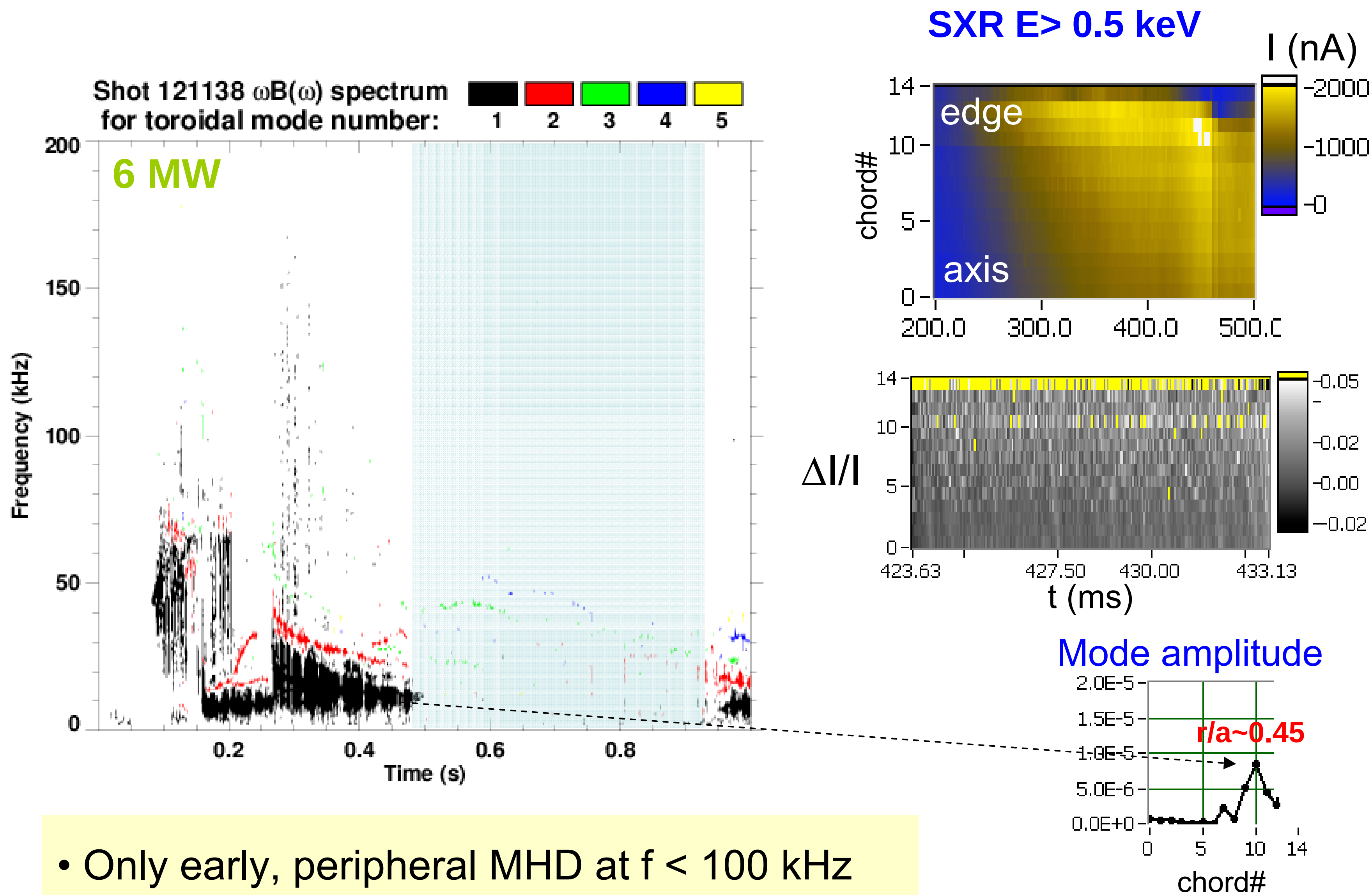
- Large islands in the central plasma

- Large Type-I ELMs affecting the center

- MHD flattening of fast ion density profile (main electron heating source)

- Non-classical beam slowing-down on thermal ions (e.g., Gates et al 2002) ‘diverts’ large portion of P_{beam} from heating the electrons

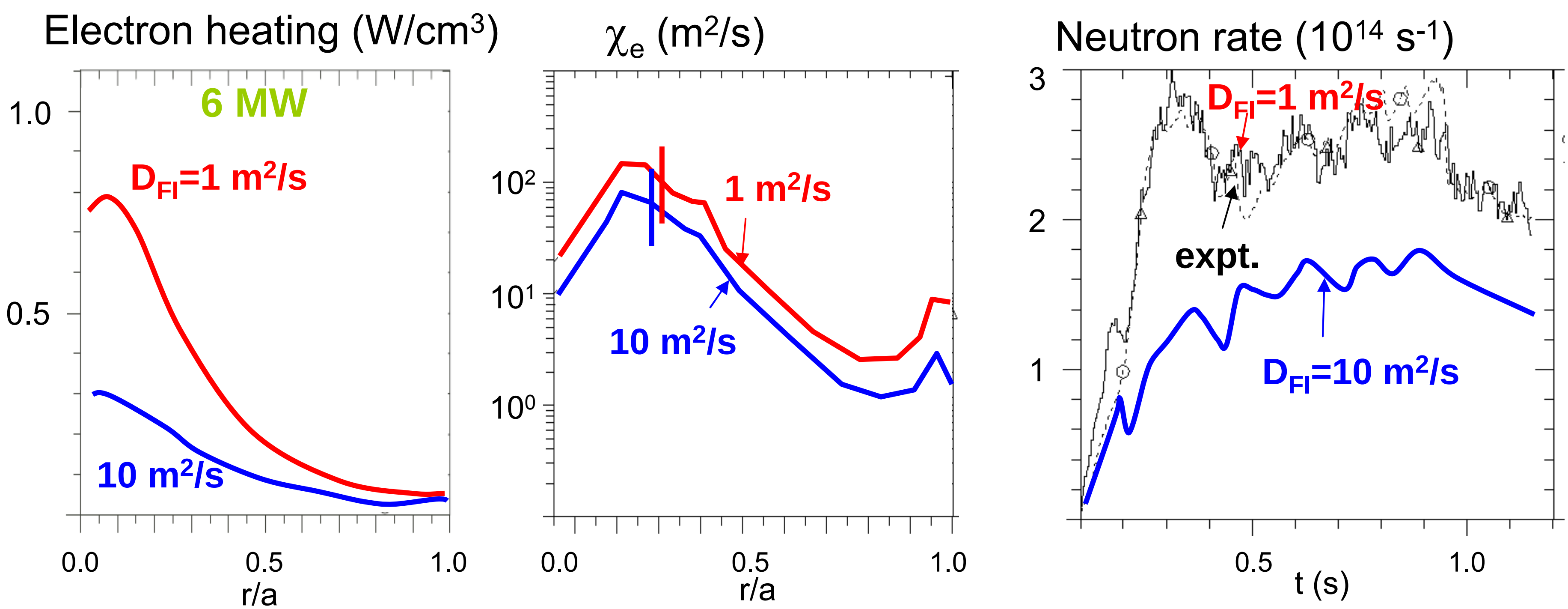
No large islands in central plasma or large ELMs



- Only early, peripheral MHD at f < 100 kHz
- T_e remains flat during MHD quiescent period

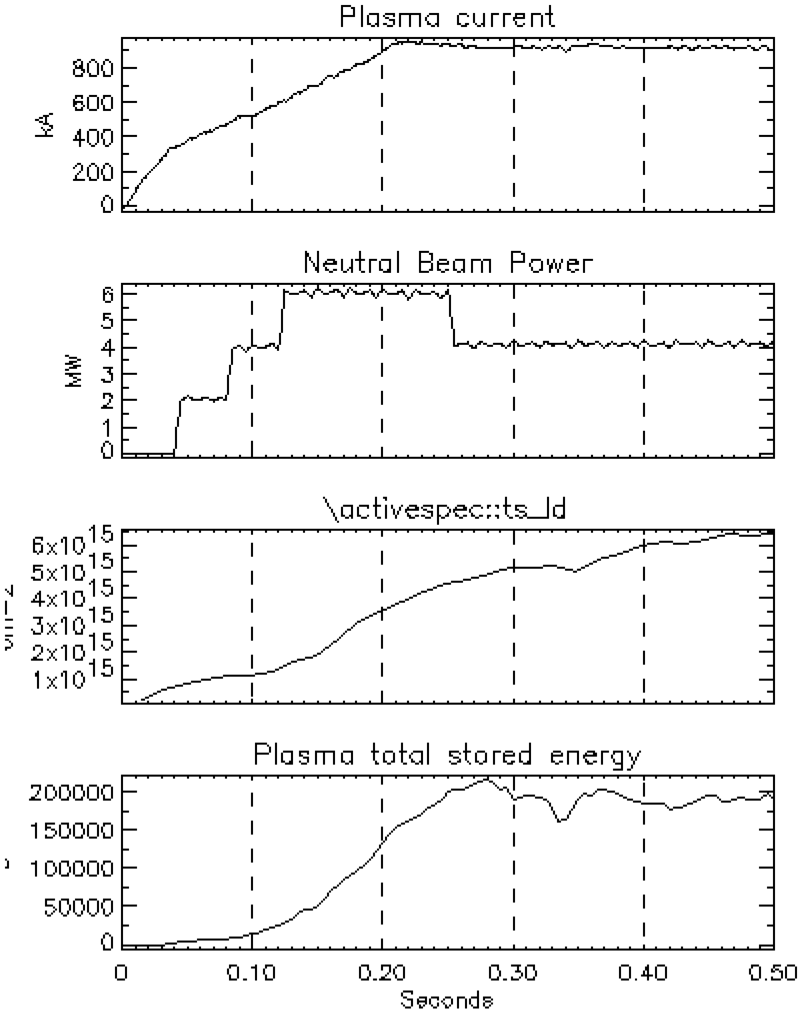
Sensitivity analysis indicates FI redistribution unlikely

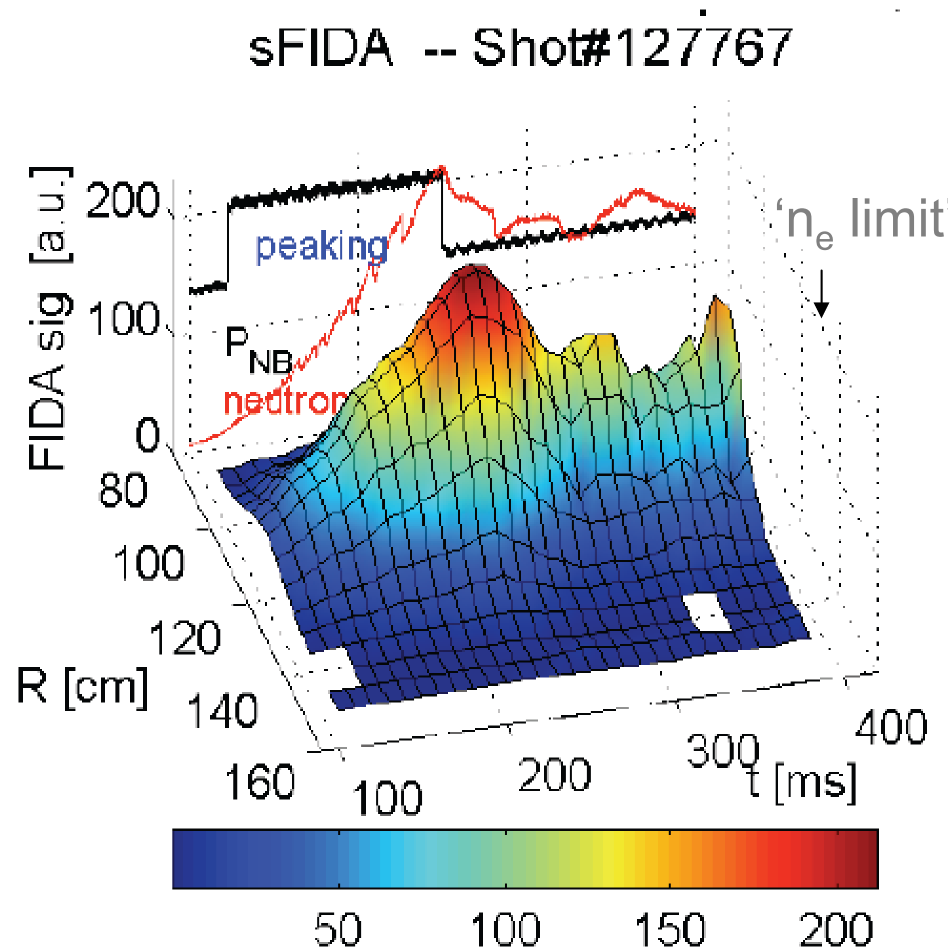
Stan Kaye



- FI diffusivity artificially increased in TRANSP to study redistribution effects
- While central χ_e would not significantly change, predicted neutron rate would decrease well below observation

FIDA data confirms peaked FI profiles as TRANSP predicts

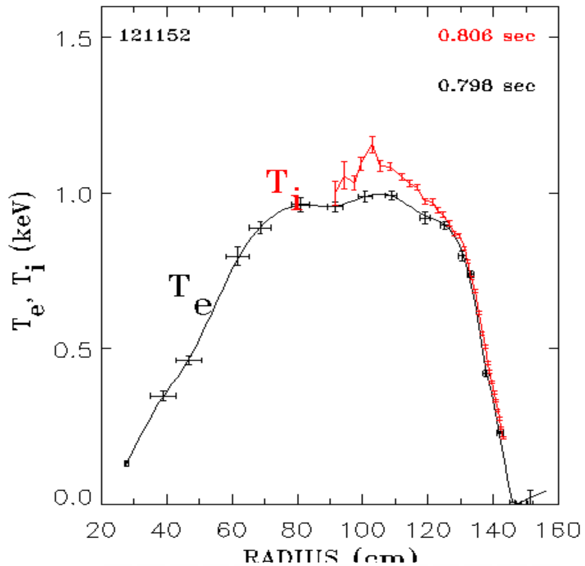




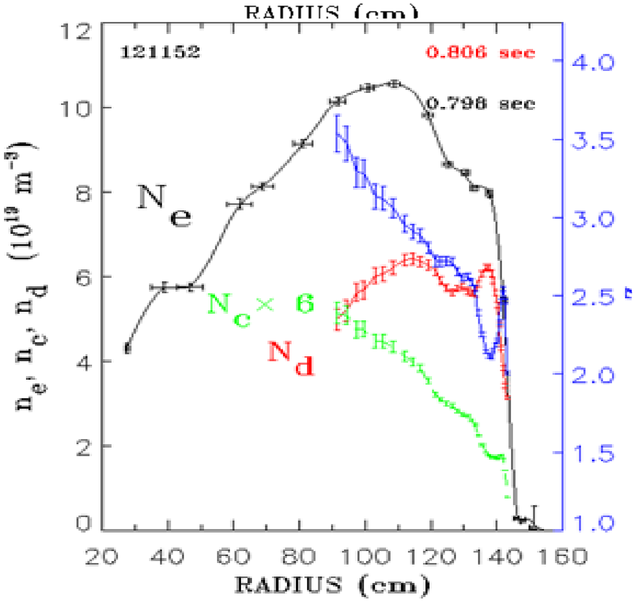
Mario Podesta

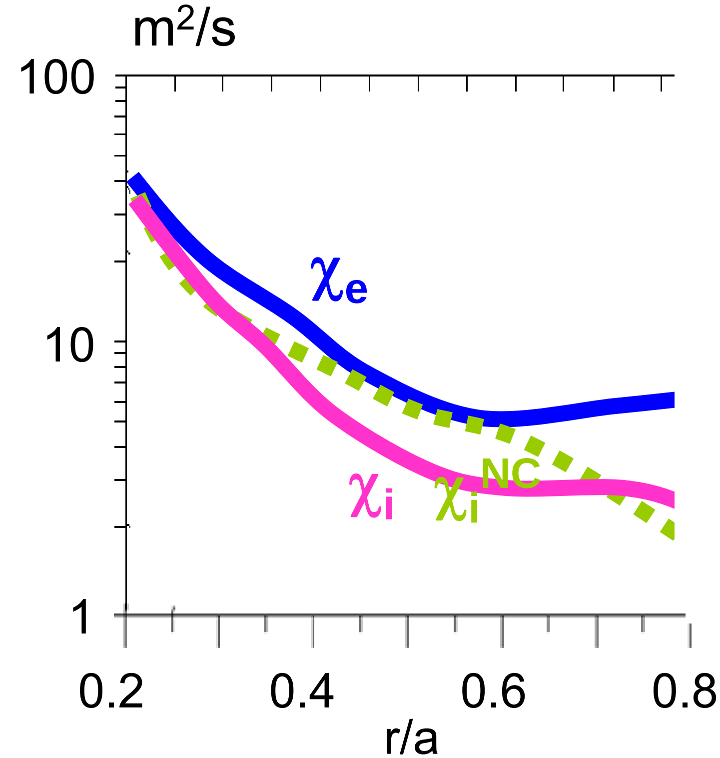
- FI density drops at MHD events but maintains peaked character
- Redistribution of fast ion density not cause for T_e flattening

Power balance at high n_e consistent with classical slowing



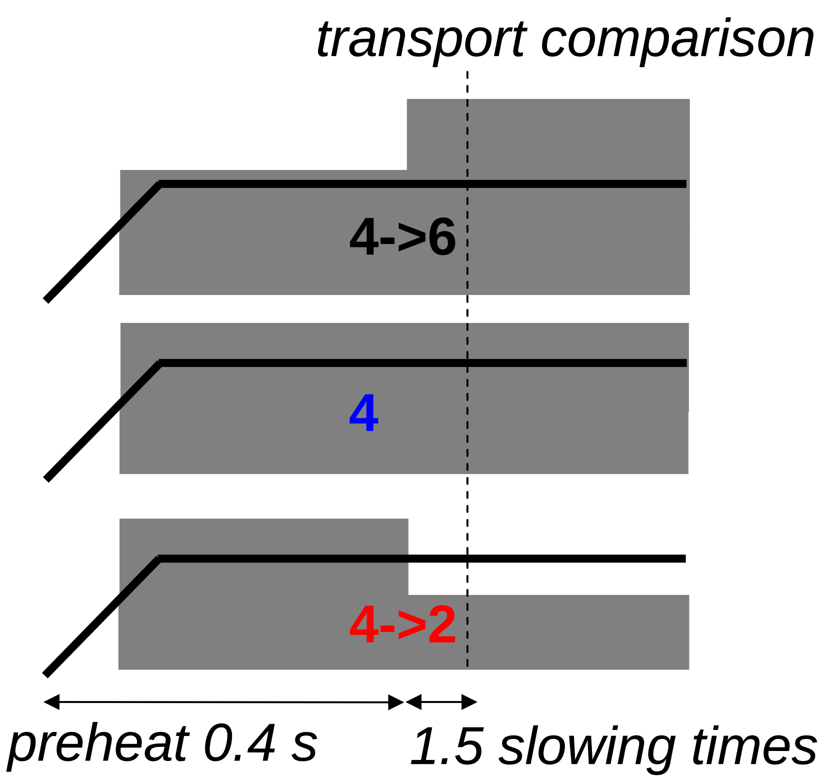
5.4 MW
1 MA
0.45 T

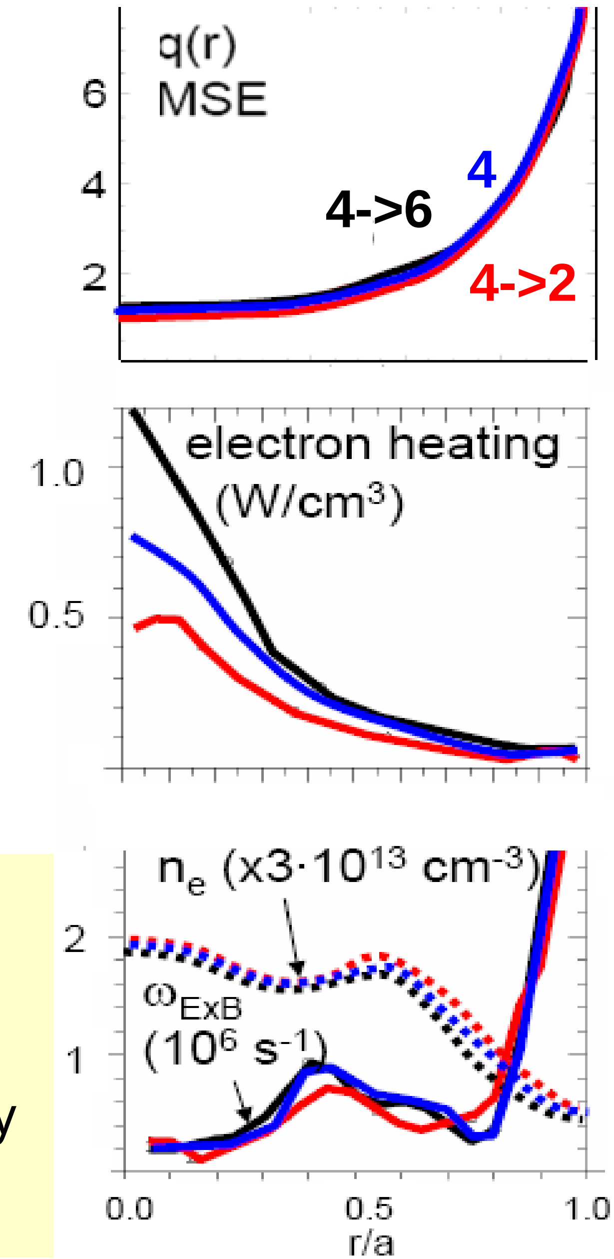




- Any PB anomaly enhanced at high n_e (Q_{ie}~P_b)
- Central T_i only marginally higher than T_e
- Within uncertainties $\chi^i \sim \chi^{NC}$ (note χ_e~χ^{NC} too)
- Impurity transport also at neoclassical levels
- T_e flattening genuine electron transport effect

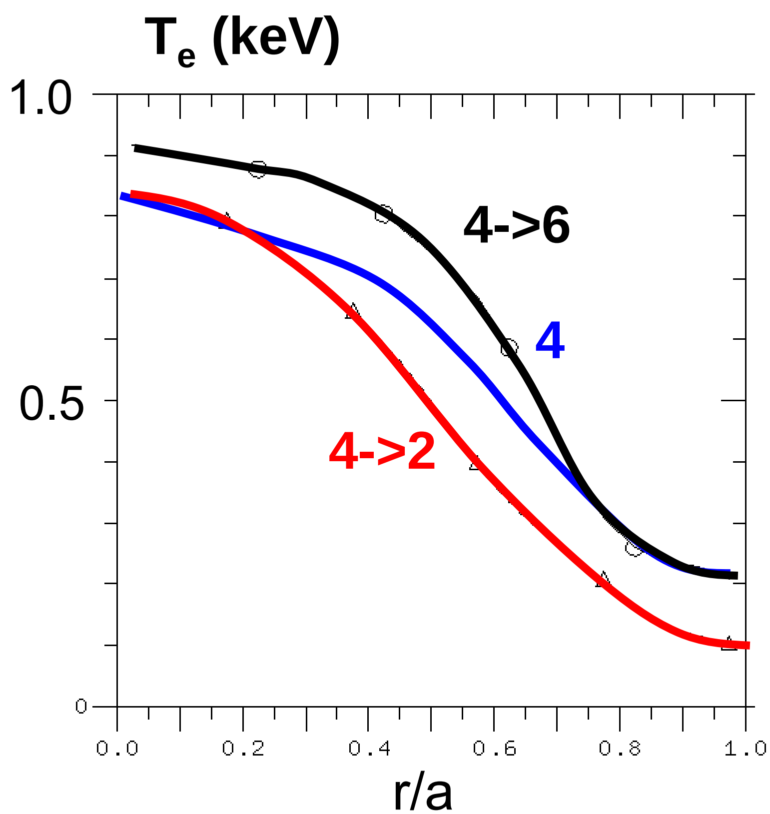
Experiment designed to isolate role of P_{beam} in χ_e change

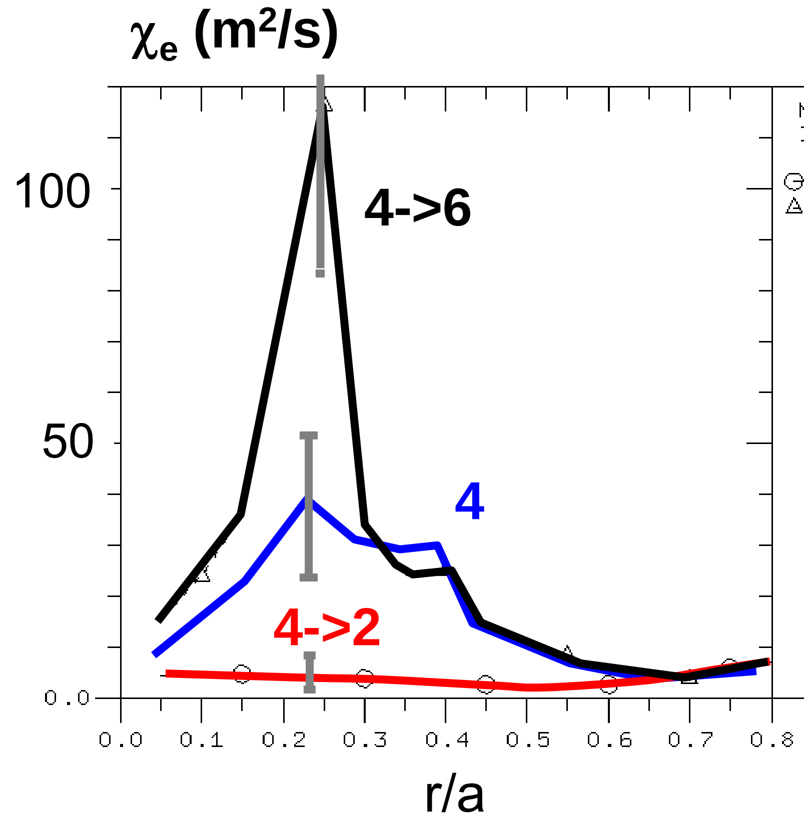




- Strong role of q, n_e in NSTX electron transport
- Both vary in the above
- Preheat/stepping technique developed to study effect of P_{beam} change at fixed q, n_e, ω_{ExB}

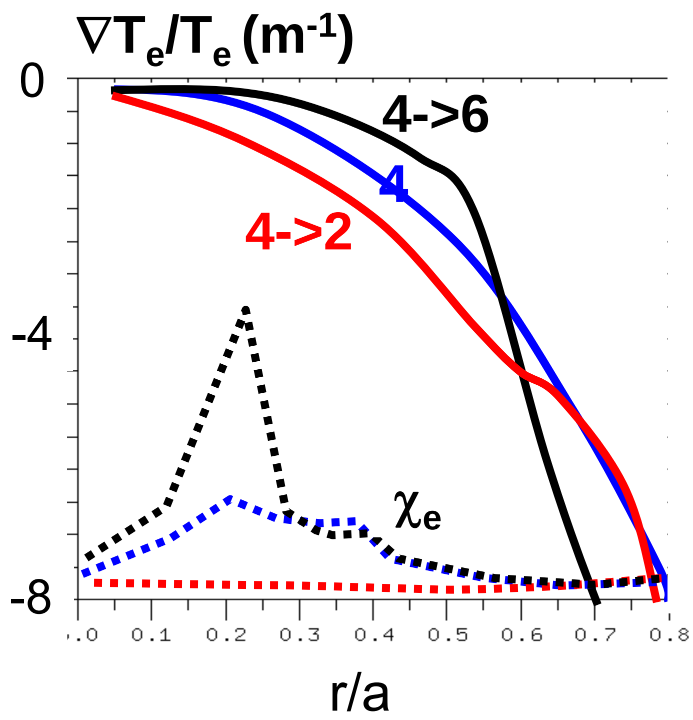
χ_e strongly changes with P_b also when q, $n_{e,}$ ω_{ExB} fixed



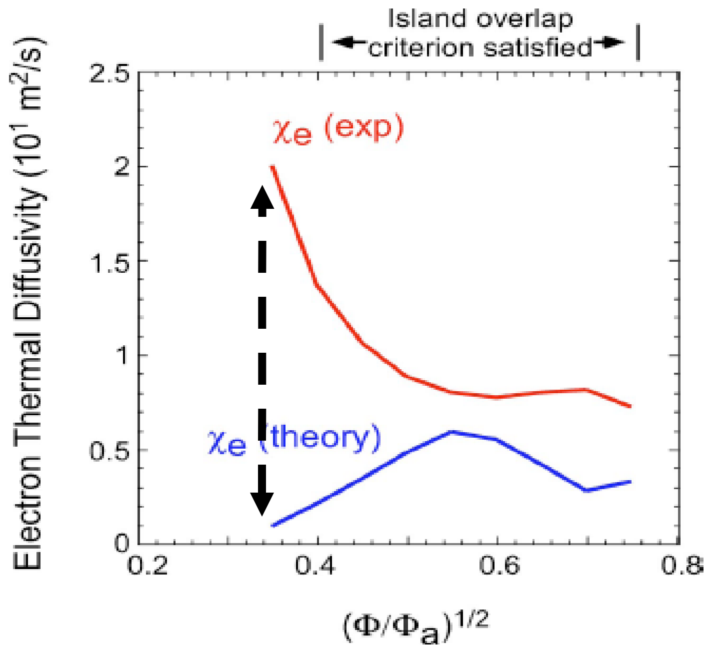


- Flatter T_e at higher P_b, consistent with unconstrained observations
- Largest χ_e change at 4->2 transition suggests change in *nature* of electron transport mechanism when P_{beam} > 2 MW

Paradigm of ∇T_e driven turbulence breaks inside r/a < 0.4

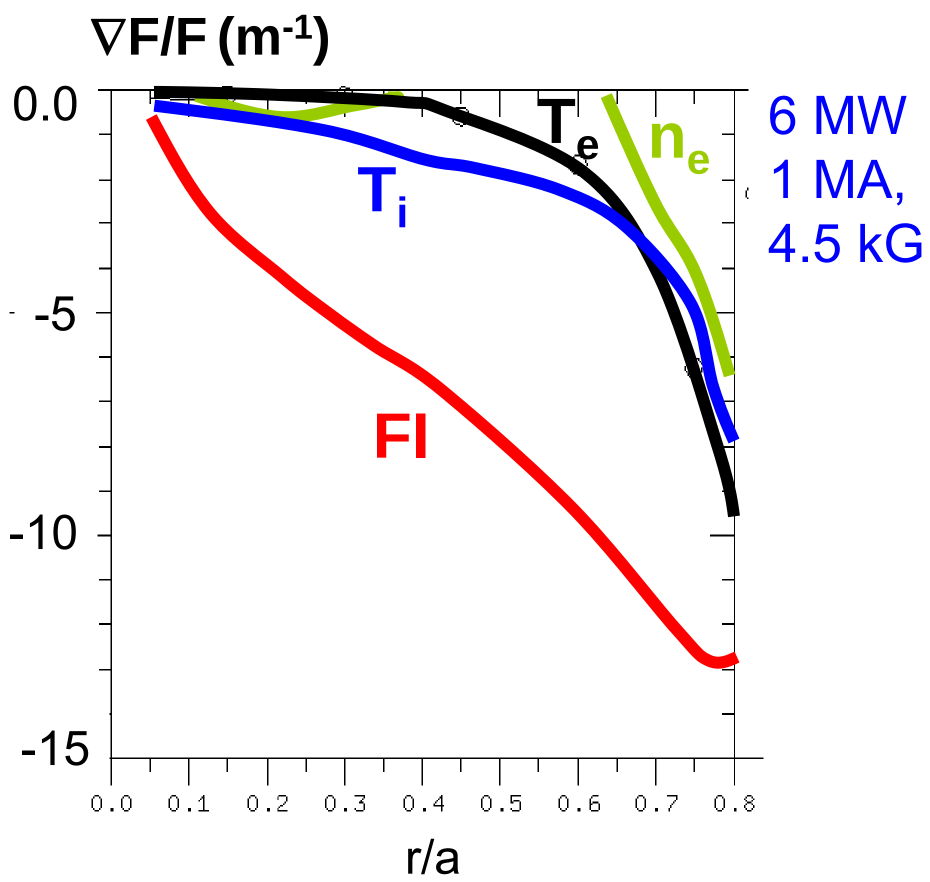


∇Te driven μ-tearing
(Wong et al., 2008)



- Plasma with smallest ∇T_e has worst turbulence
- Central ∇T_e in high P_{beam} H-modes insufficient to drive any instability
- What is driving rapid electron transport in region of low ∇T_e?

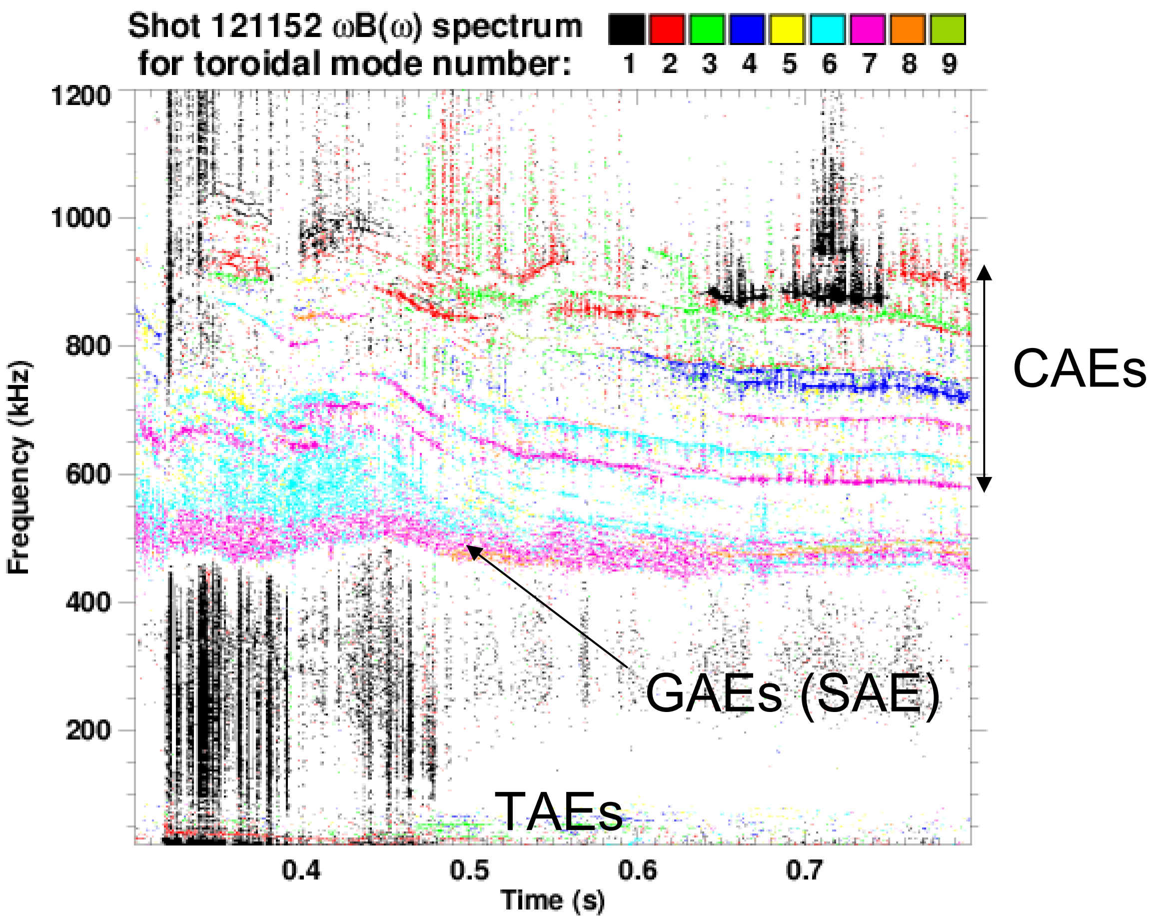
Only fast ion density has significant gradient inside r/a < 0.4



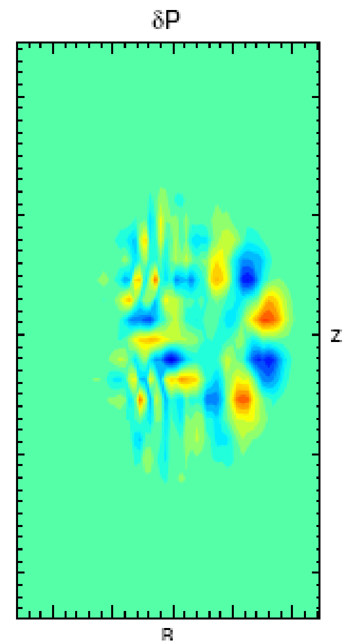
- Fast ions have also gradient in phase space
- Fast ion MHD (e.g., SAEs) likely mediating agent for electron transport

Persistent SAEs in high P_{beam} H-modes as GAE component

6 MW
1MA
4.5 kG

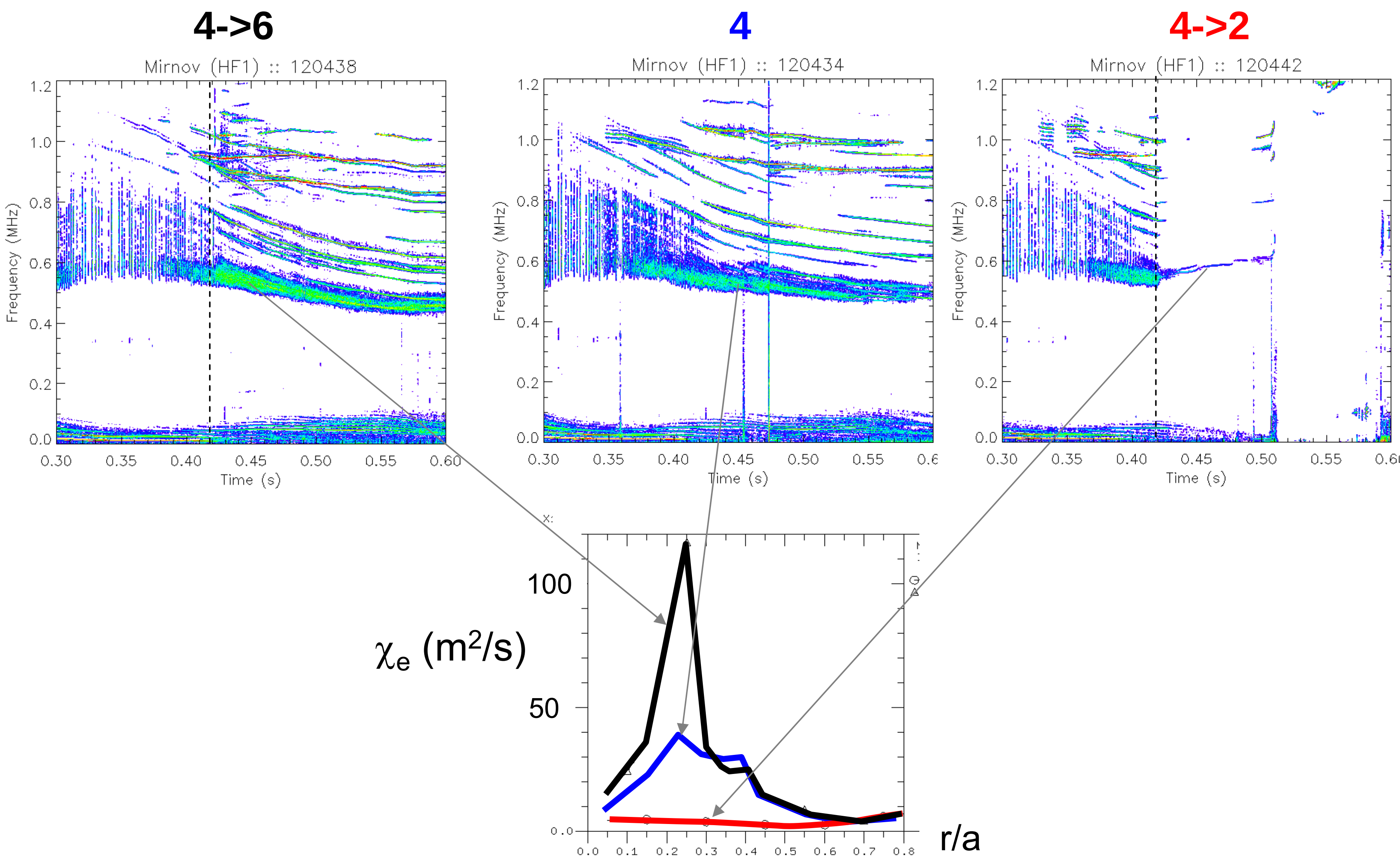


Predicted GAE structure, n=8 (Belova)

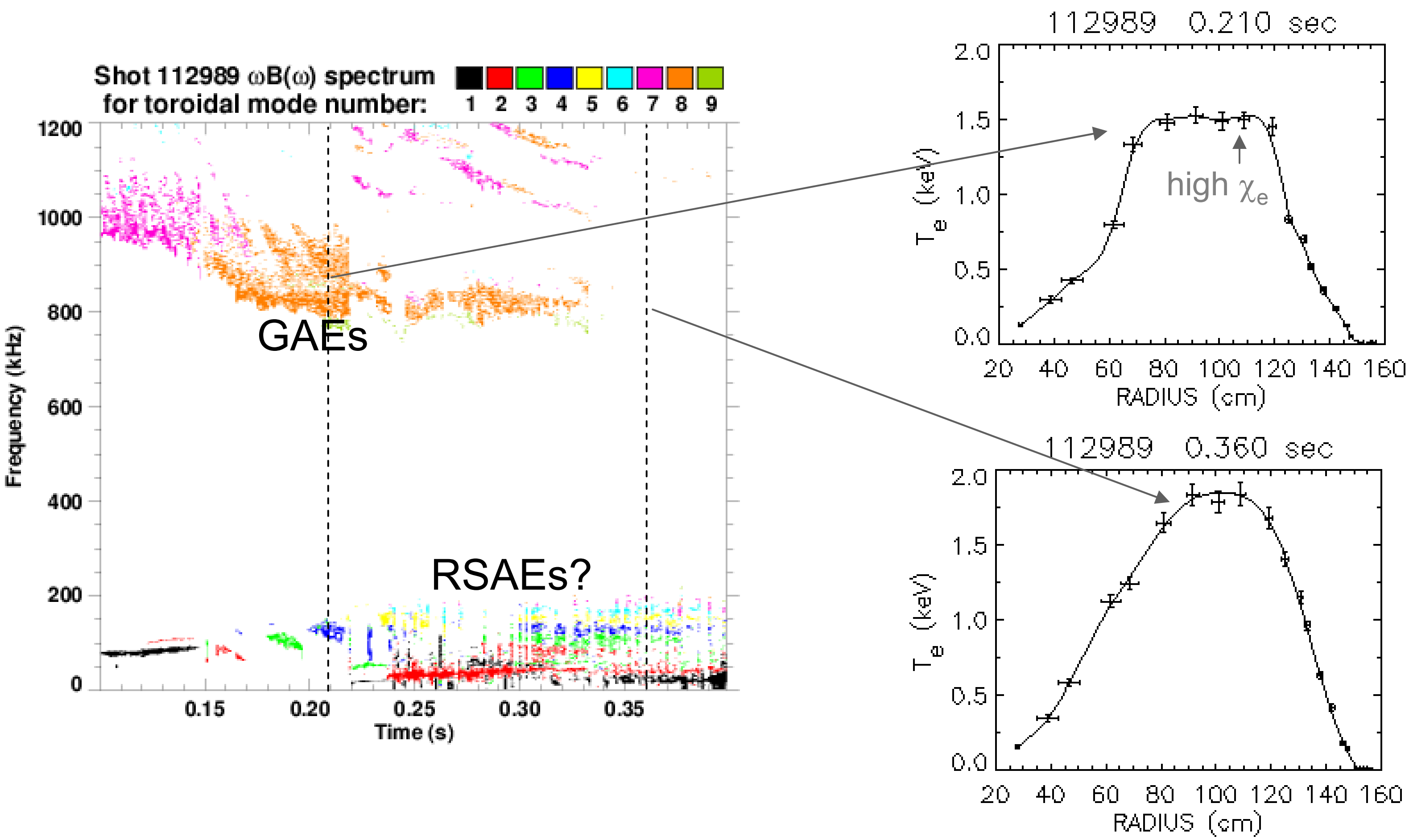


- High-n modes localized in central plasma, $\delta B/B \leq 10^{-3}$ amplitude
- Lower frequency TAEs less persistent

Strong/weak GAE activity correlates with high/low central χ_e

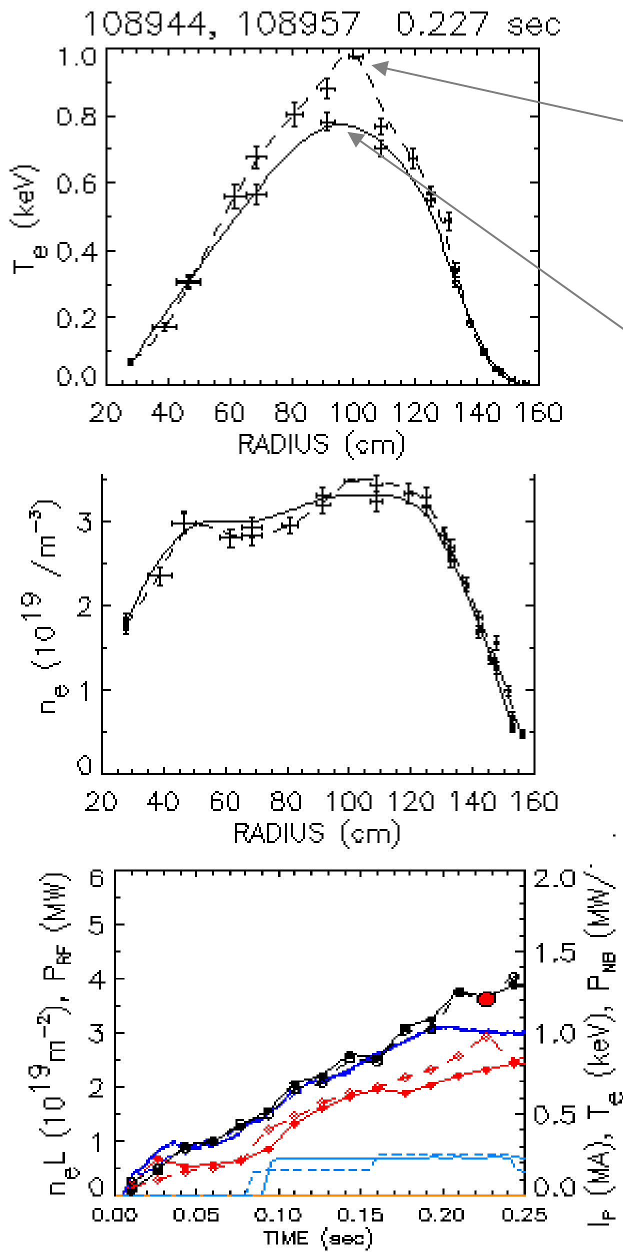


FI MHD and T_e flattening correlate also in L-modes



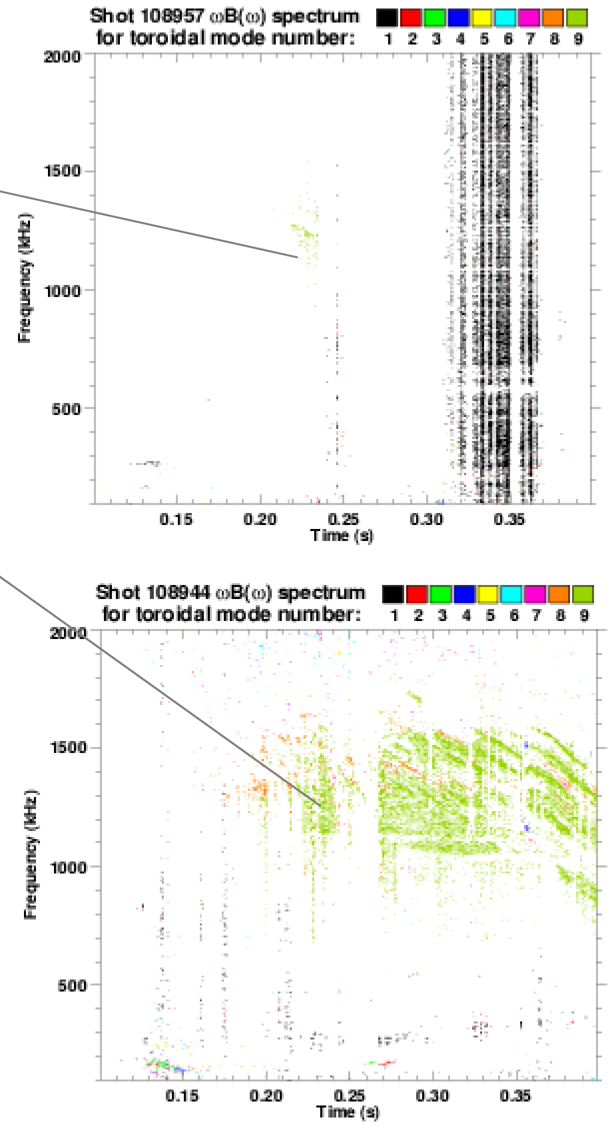
- Correlation with GAEs again most prominent
- q-profile reversed in these plasmas

Very similar L-modes without GAEs have higher central T_e



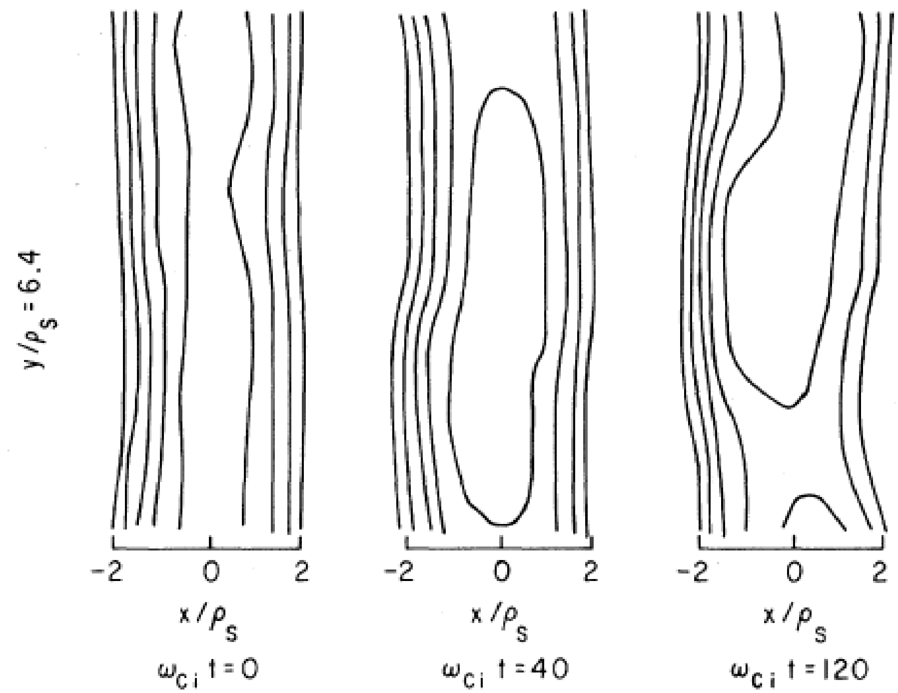
2.4 MW
A+B+C
60 kV

2.2 MW
A, 100 kV

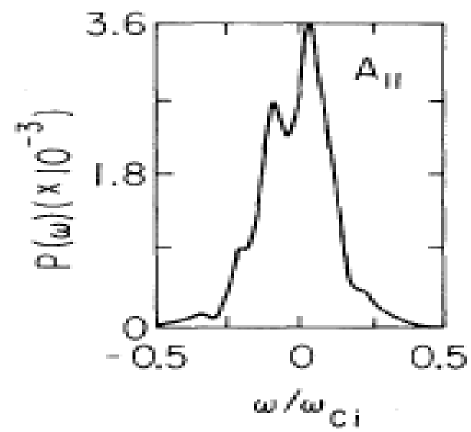


SAEs predicted to drive electron transport through μ-tearing

Lee, Chance and Okuda, 81



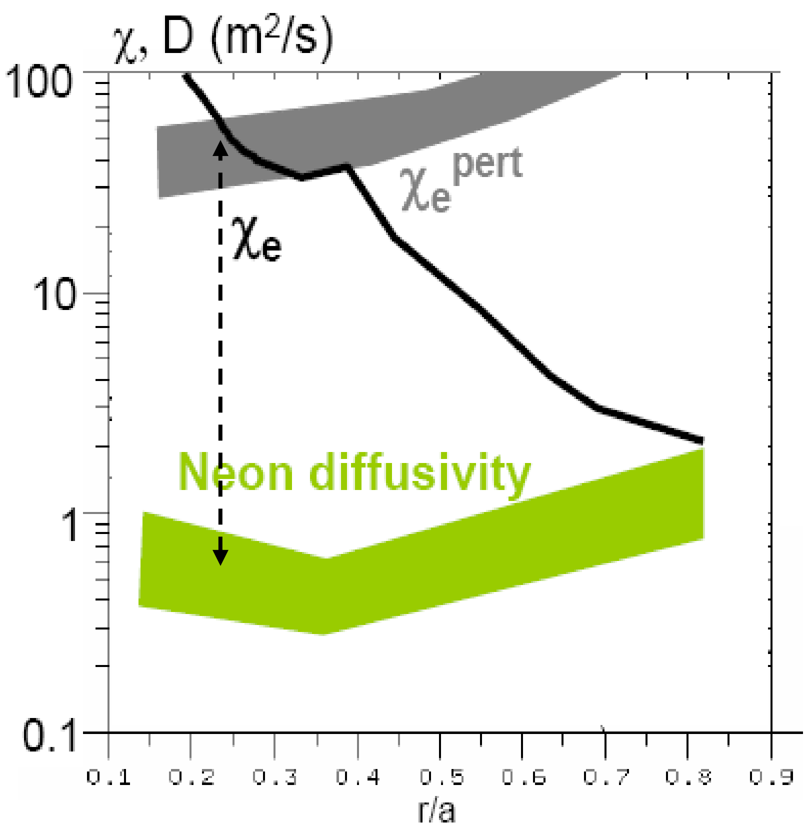
Frequency spectrum



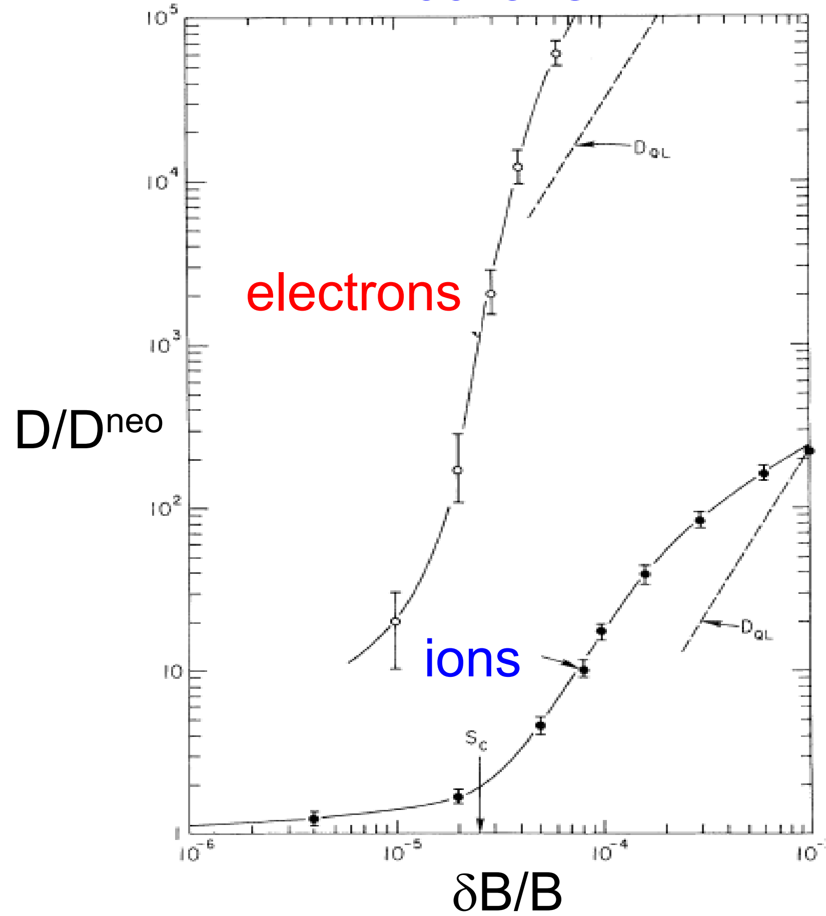
- ρ_i sized islands at rational surfaces (AE eddy current cancels shear)
- Rational surface spacing ~ ρ_i -> large volume could be affected
- RSAE μ-tearing recently proposed by N. Gorelenkov
- Lee et al mode frequency however well below that of GAEs in NSTX
- Nevertheless hints for magnetic (stochastic) transport in flat T_e region

Very large gap between χ_e and D_{imp}

Delgado 07, Tritz 08

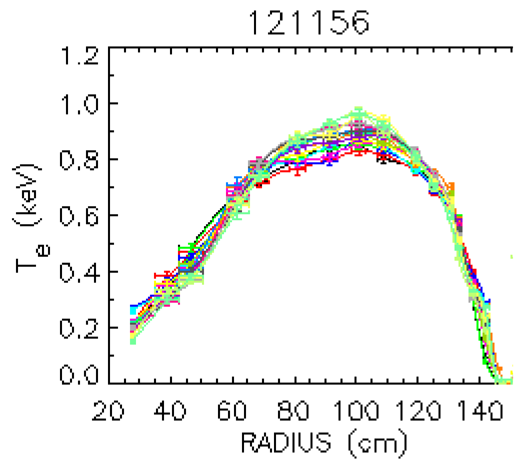


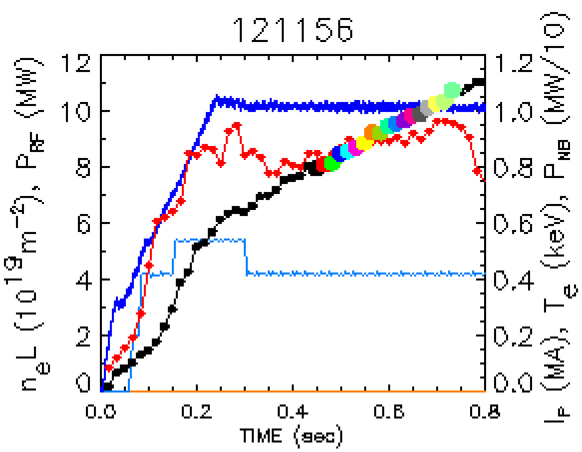
Boozer 82

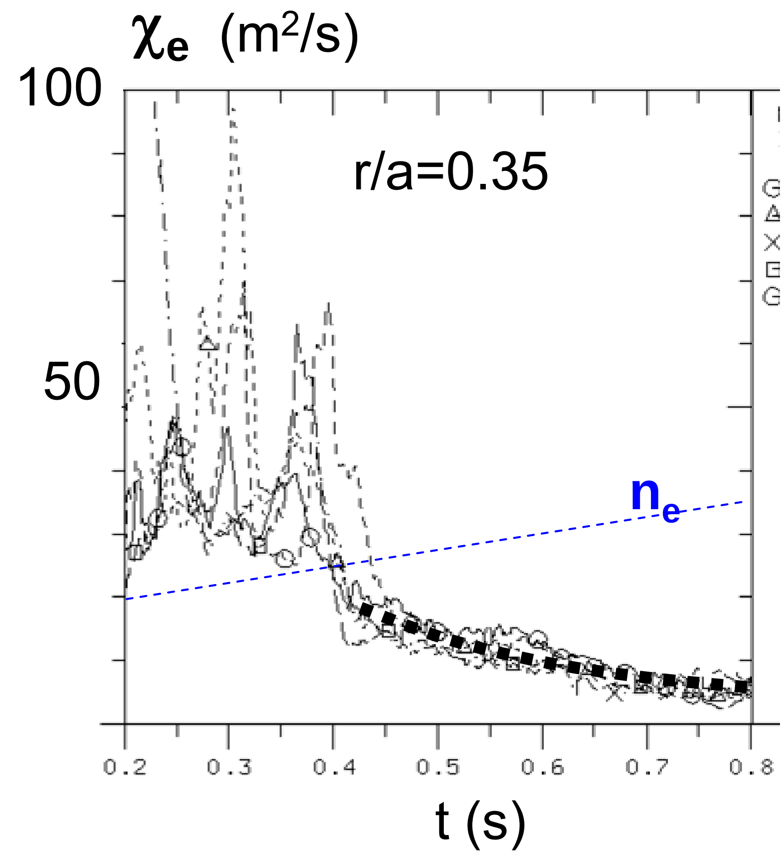


- Magnetic transport brings parallel velocity into play
- Electron thermal transport up to ~80 faster than Ne transport, as observed

1/ν scaling of χ_e consistent with magnetic transport



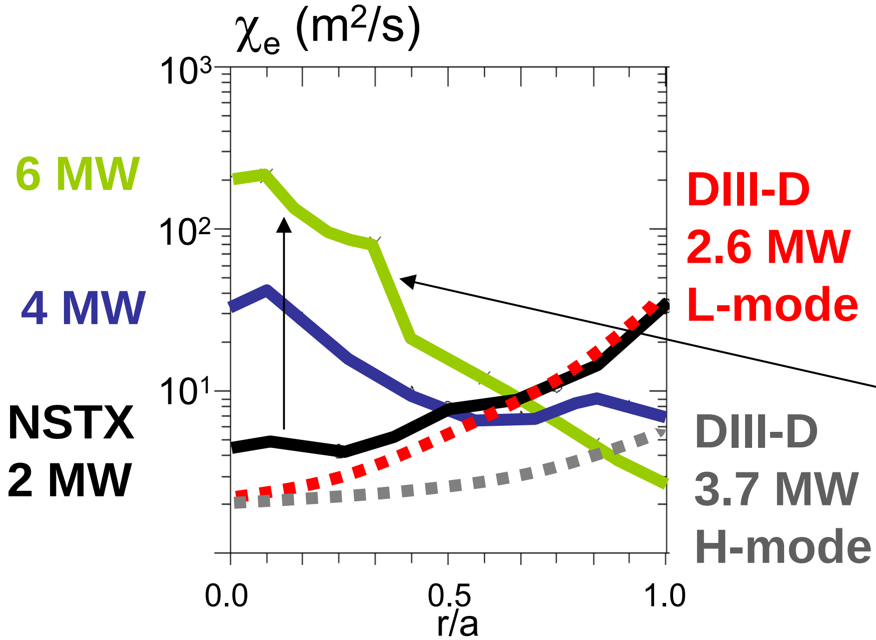




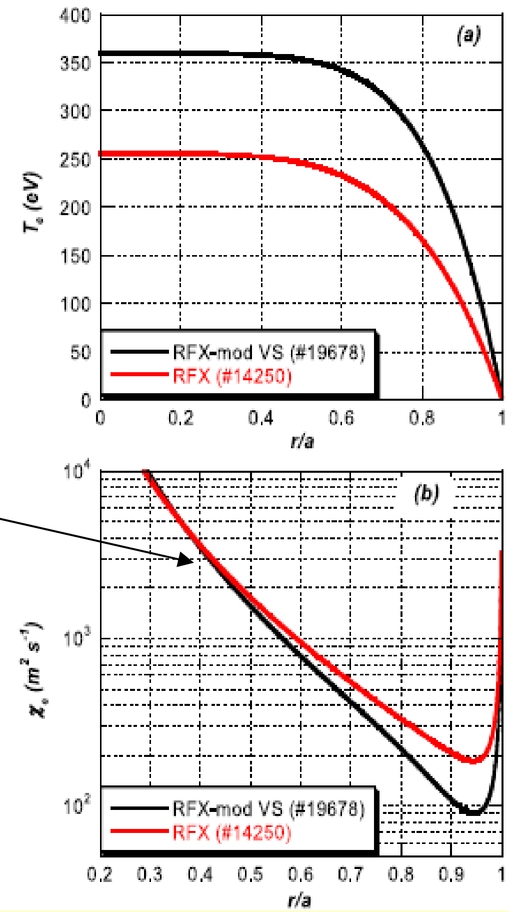
- T_e profile does not change, while n_e increases linearly -> $\chi_e \propto 1/n_e$
- 1/ν_{ei} expected for stochastic transport
- Not clear if early peaks in χ_e physical (correlation with integer-q in L-modes)

Tokamak-like χ_e at low P_{beam}, RFP-like at high P_{beam}

χ_e in NSTX and DIII-D (Peebles 08)



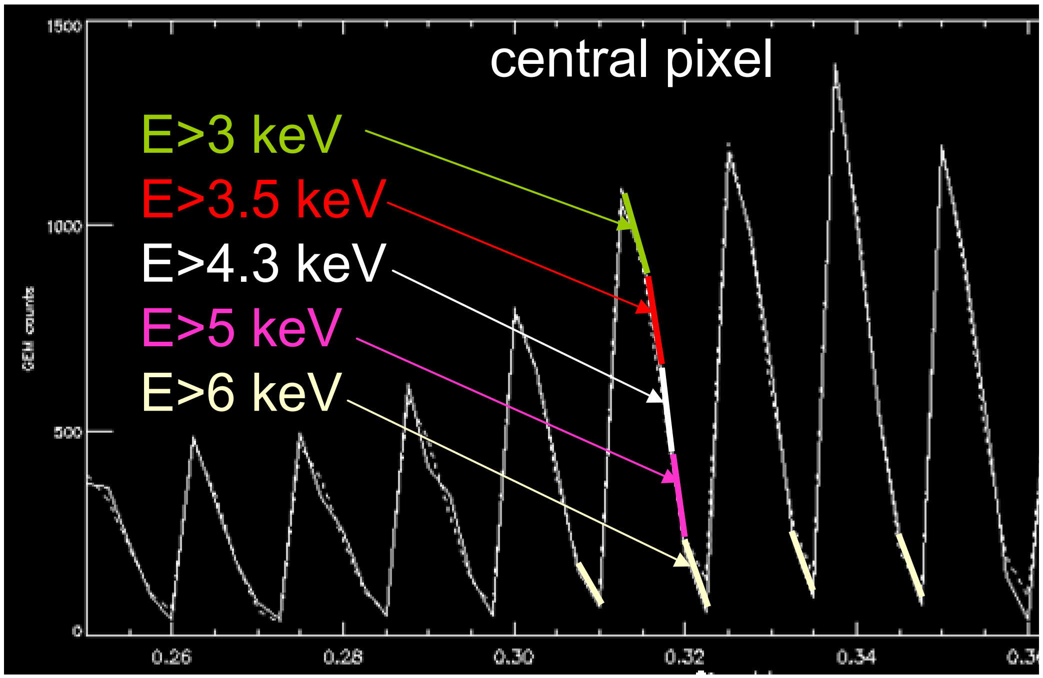
T_e and χ_e in RFX (Innocenti 07)



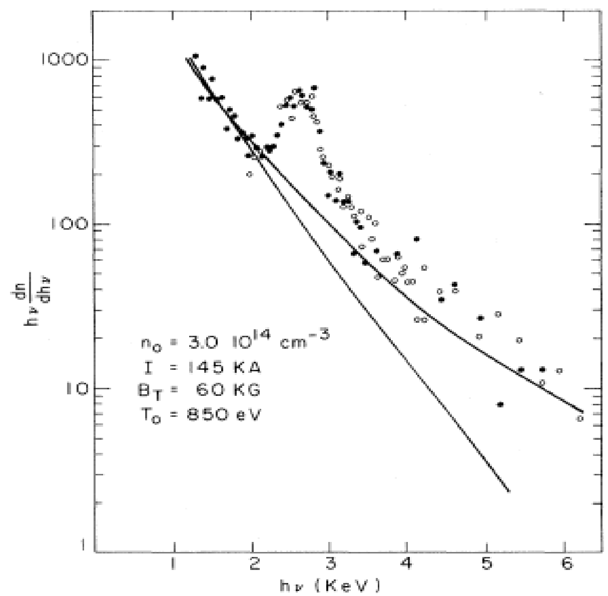
- Rapid magnetic transport without ∇T_e in RFP core, due to tearing modes
- Large χ_e increase beyond 2 MW in NSTX possibly explained by transition from electrostatic to magnetic turbulence

Possibly non-maxwellian electrons in the core

Gas Electron Multiplier (GEM) hard X-ray spectrum in 4 MW NSTX H-mode (Pacella 06)

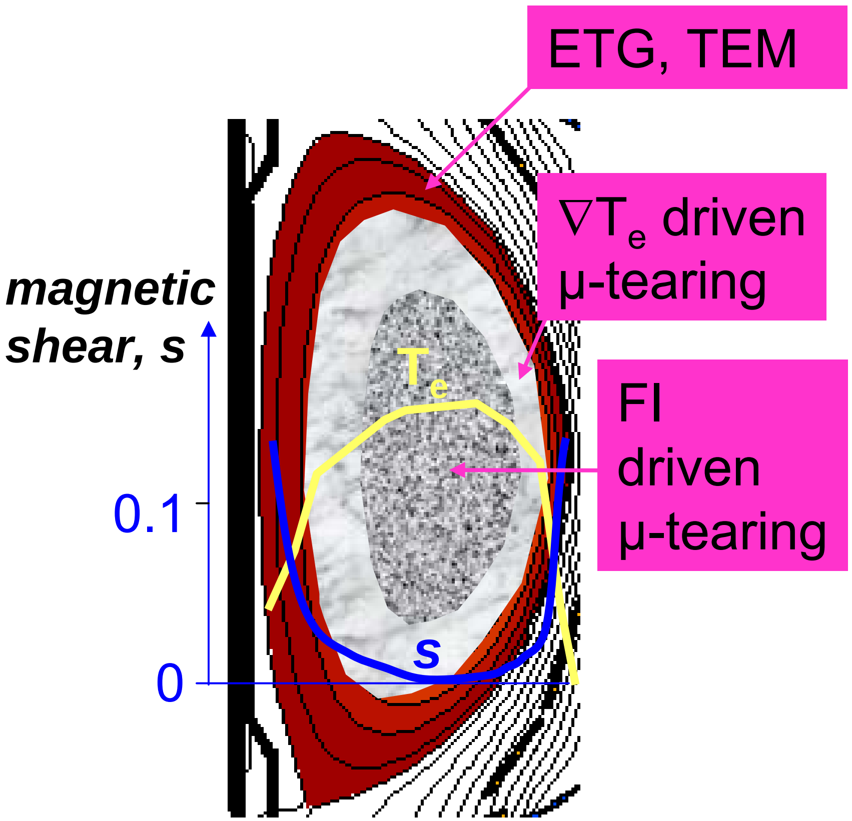


Early Alcator X-ray spectrum
Molvig 78



- Detector counting threshold scanned in time (10 ms)
- Apparent tail above 6 keV

Possible transport picture in high P_{beam} NSTX H-modes



<u>Conditions</u>

high P_{beam}
(FI drive)

moderate to high n_e
(resistive MHD)

elevated central q, q'>0
(density of rational surfaces, island overlap)

- 'Magnetic core', 'electrostatic edge'
- Strong influence of q-profile on electron transport
- Some stochastic ion heating, non-thermal T_e (T_i?) possible
- Alternate picture (AE 'direct-drive') being examined (Fredrickson, Gorelenkov)

Possible implications and further work

• If hypothesis correct, substantial implications for fusion in general and for beam-driven CTF in particular, possible

• We might have defined a new confinement regime
('random-walk' step of both ions and electrons ~ ρ_i)

• Rapid electron transport driven by AEs may also explain T_e flattening inside ITBs in tokamaks

• NSTX best suited device to study fast ion MHD/electron transport connection

• Joint Transport/Energetic Particle research program connecting measurements of electron and ion EDF, magnetic and density fluctuations, with theory and modeling

• Experiments this run comparing GAE/no GAE H-modes (high/low V_{beam})