DEPENDENCE OF ELECTRON TRANSPORT ON HEATING POWER AND Q-PROFILE IN NSTX H-MODES

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Abstract

The T_e profile is observed to broaden with increasing beam power P_{NB}, in the standard NSTX H-mode. The power balance indicates this is due to a large increase in electron transport, while perturbative experiments support this conclusion.

To separate the roles of P_{NB} and q(r) in this effect, we performed experiments in which the plasma is preheated throughout a current diffusion time and P_{NB} varied to change the electron heating. The equilibrium and perturbed electron transport are then assessed at about one beam slowing time after the P_{NB} variation.

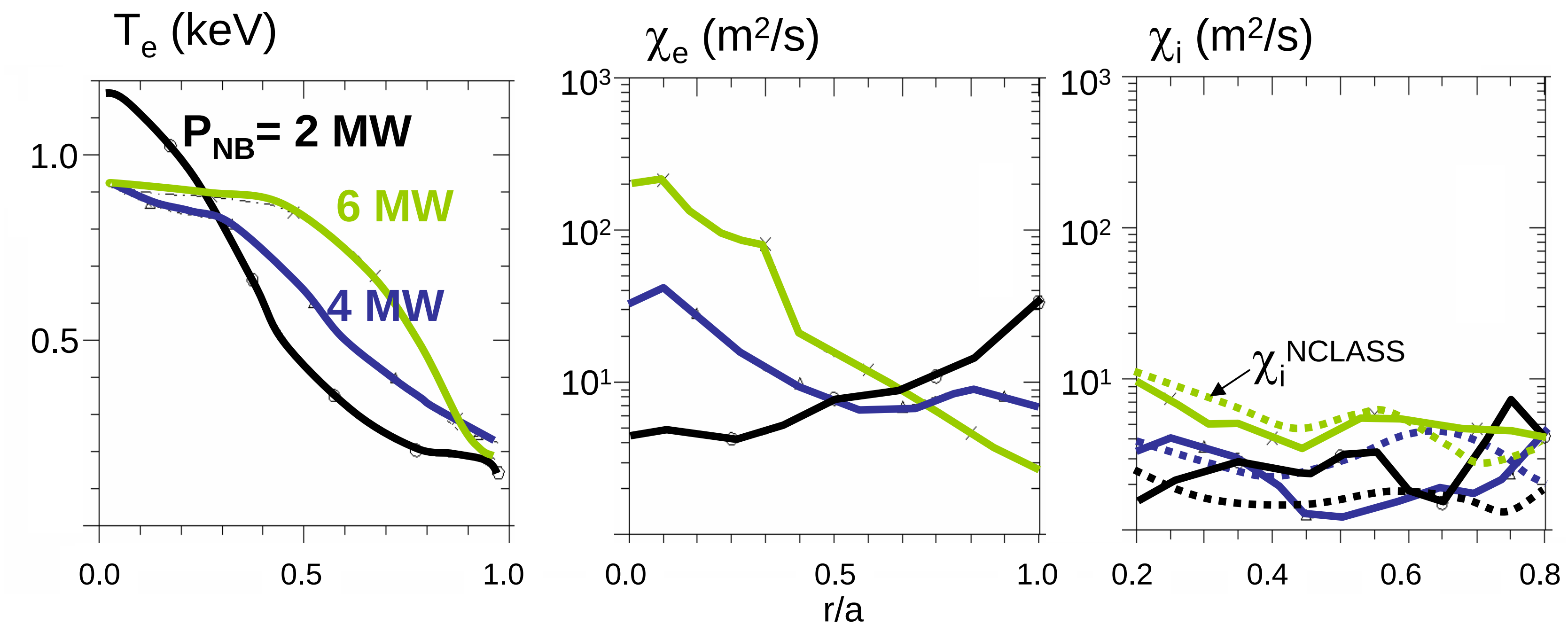
The results at fixed-q show that at high power the central χ_e reaches very large values, while at reduced power it decreases. The trends are confirmed by perturbative experiments, suggesting a low critical T_e gradient in the central NSTX plasma.
In addition, the electron transport correlates rather with heating power than with T_e gradient, suggesting the heat flux itself may be a driving factor.

The q(r) change at fixed P_{NB} has also profound effects on electron transport. Large central χ_e, together with global, fast T_e perturbations are observed with the narrow q(r) resulting at high power preheat. With the broad, slightly reversed q(r) obtained at low preheat power, the central χ_e strongly decreases and the cold pulse slows down or reverses inside q=2 and q=1, suggesting a role for rational surfaces in NSTX transport.

Work supported by US DoE grant DE-FG02-99ER5452 at JHU

T_e profile broadens with P_{NB} in NSTX

1 MA, 4.5 kG, ELM-free/small-ELM H-modes, t=0.4 s



- Results of TRANSP analysis with classical thermalization of NBI ions
- χ_i remains close to neoclassical level
- Negligible low frequency (<20 kHz) MHD, but high frequency CAE and EPM activity apparent on dB/dt signals
- Could affect profile of heating power be redistributing fast ions

Analysis suggests power balance correct

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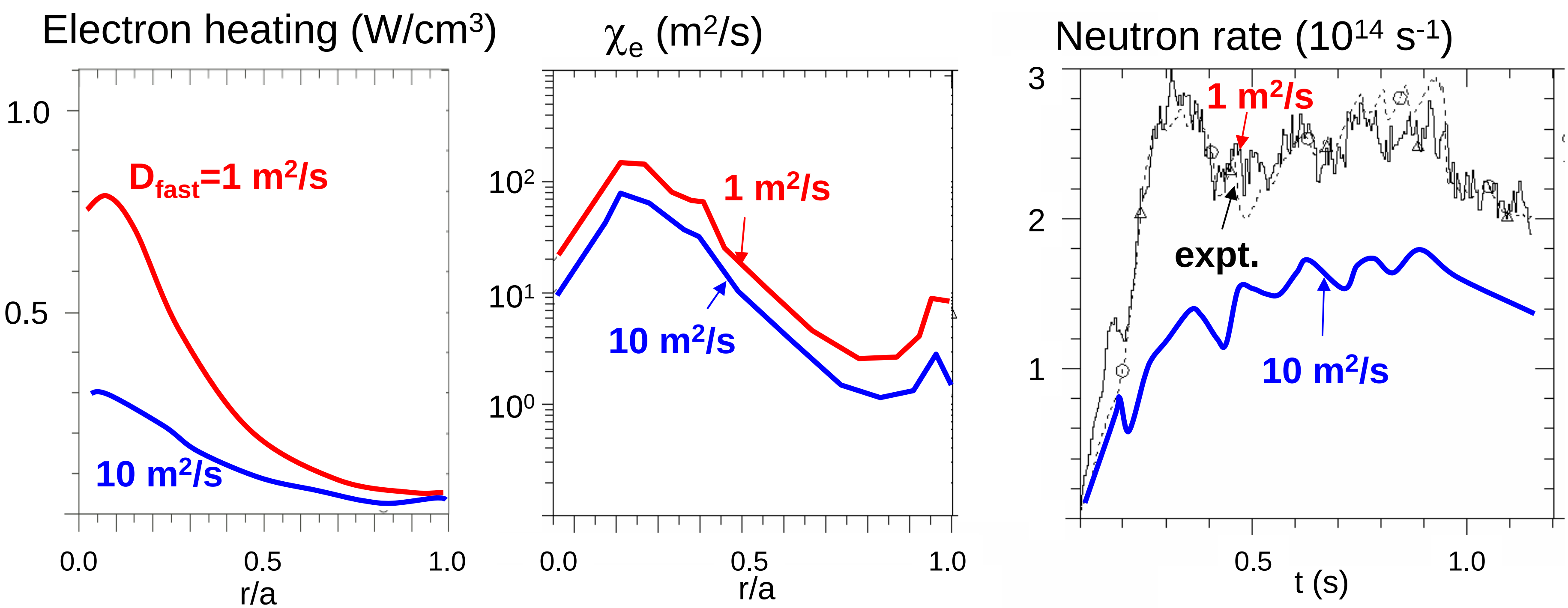
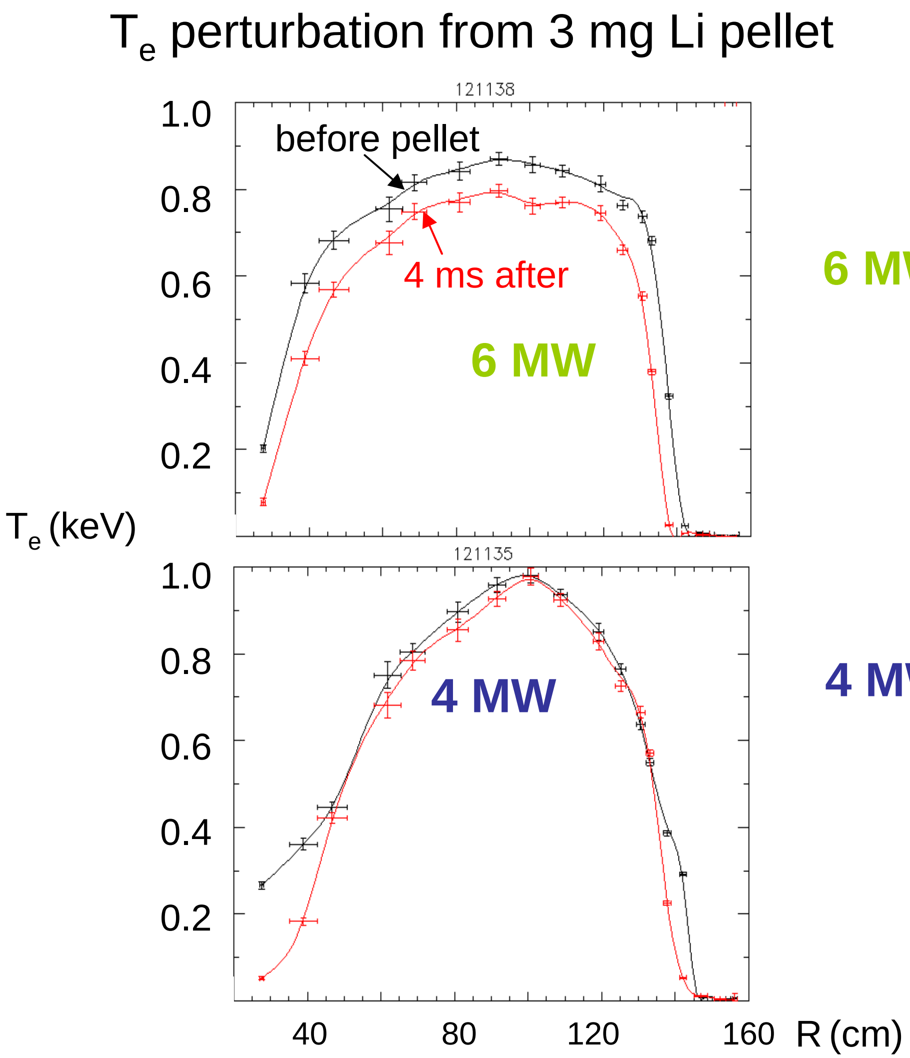
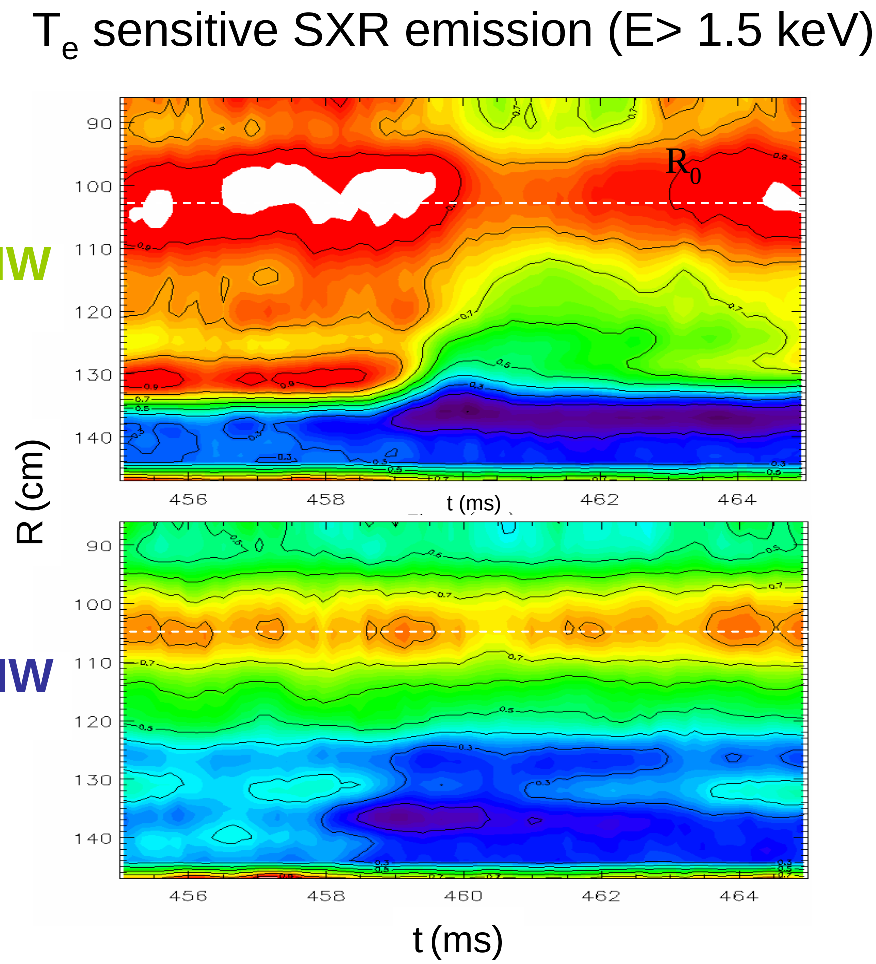


- Fast ion diffusivity increased in TRANSP to study effects of fast ion redistribution
- Order of magnitude increase in D_{fast} does not change χ_e much, while neutron rate decreases well below experiment
- Conclusion holds even when D_{fast} increase limited to r/a < 0.5

Perturbative experiments also support power balance



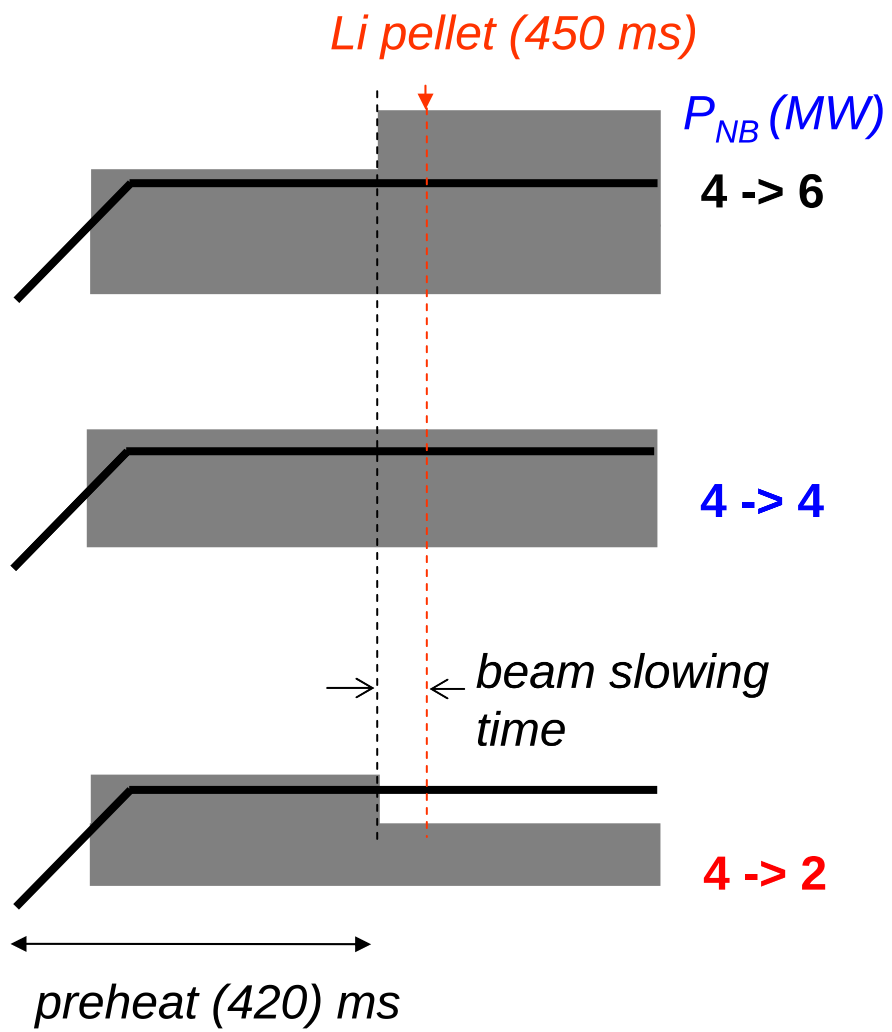


- Global, rapid T_e perturbation at high P_{NB}
- Only peripheral perturbation at reduced P_{NB}

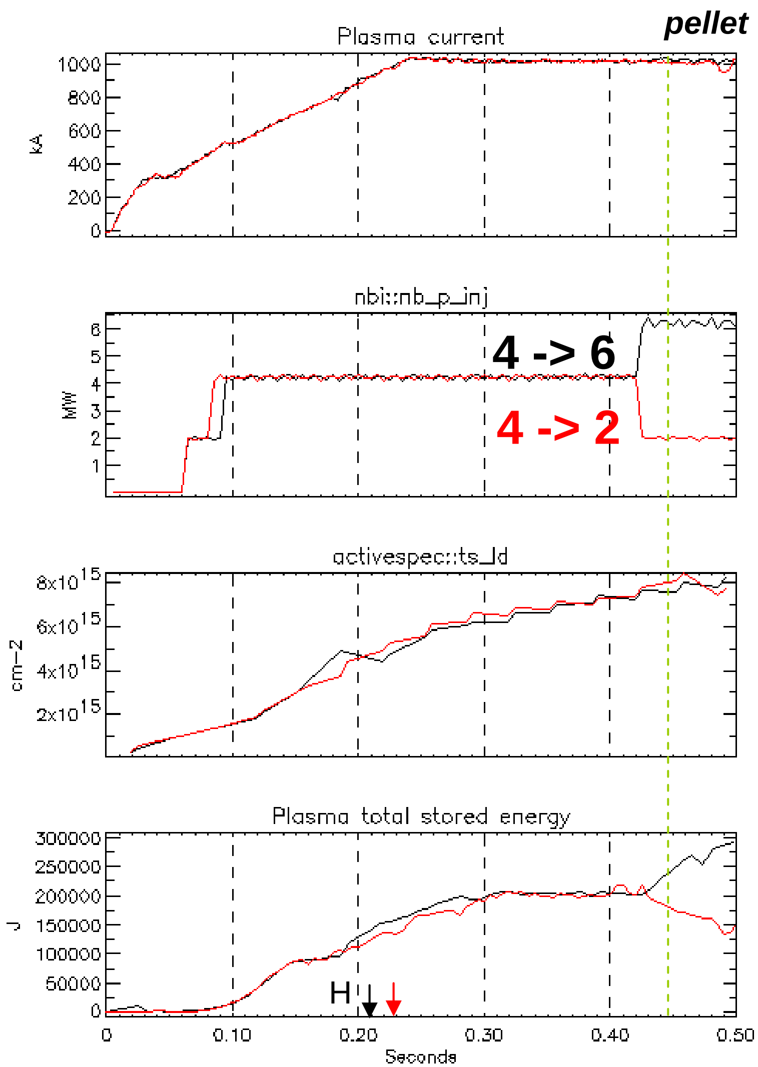
Experiment I: Vary electron heating at fixed q-profile

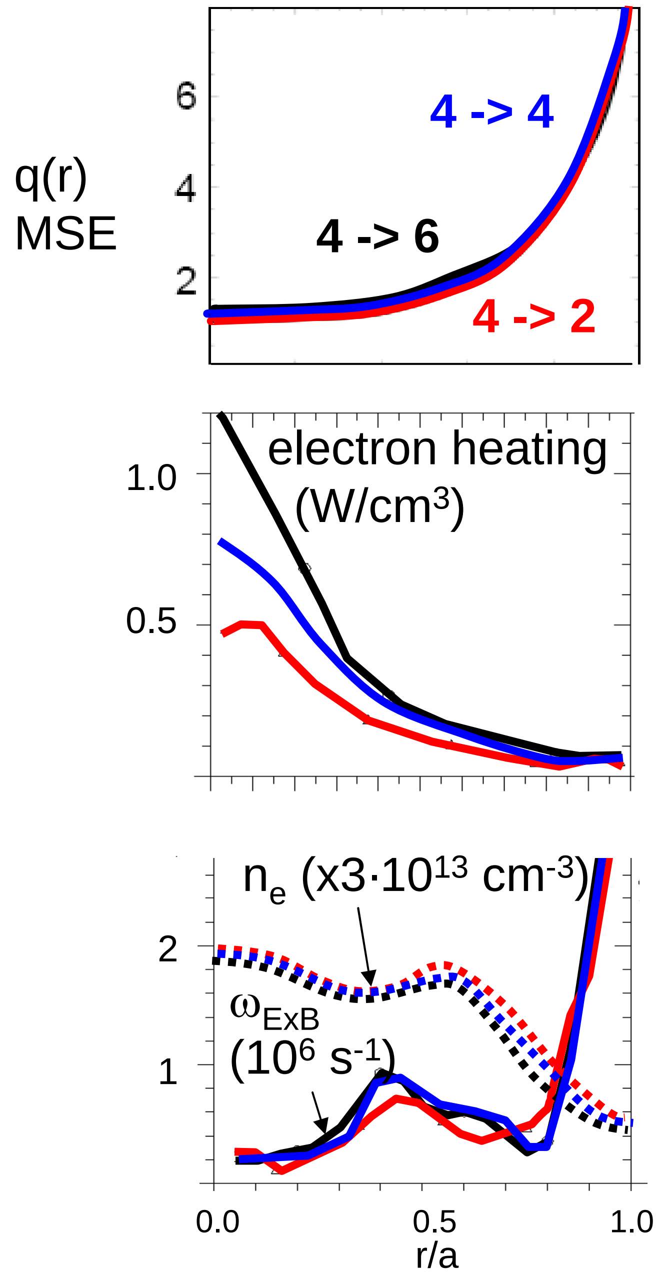
- Both P_{NB} and q vary in the above
  (large q effects, see below)

- Simple experiment to study effect of electron heating at fixed-q:
  - preheat to 'freeze-in' q
  - vary P_{NB}
  - measure equilibrium and perturbed electron transport after one beam slowing time



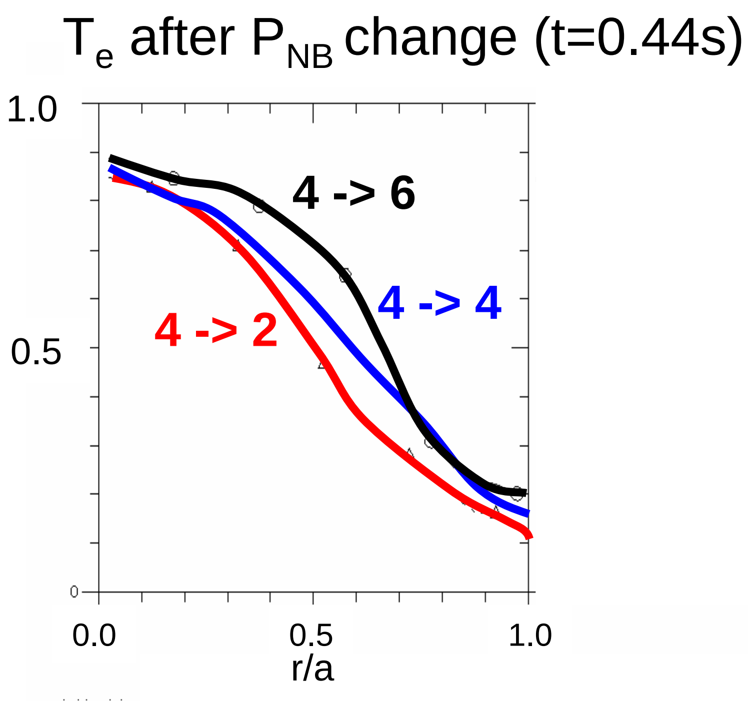
Large change in electron heating achieved at fixed-q

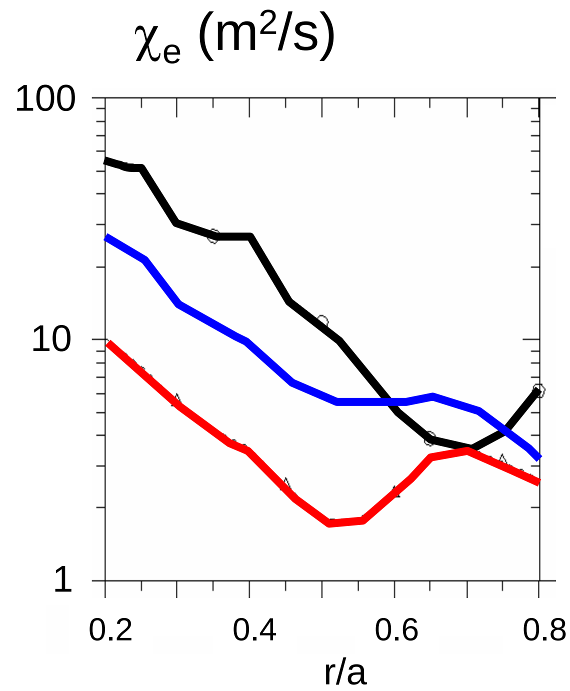




• ω_{ExB}, n_e, also kept fixed

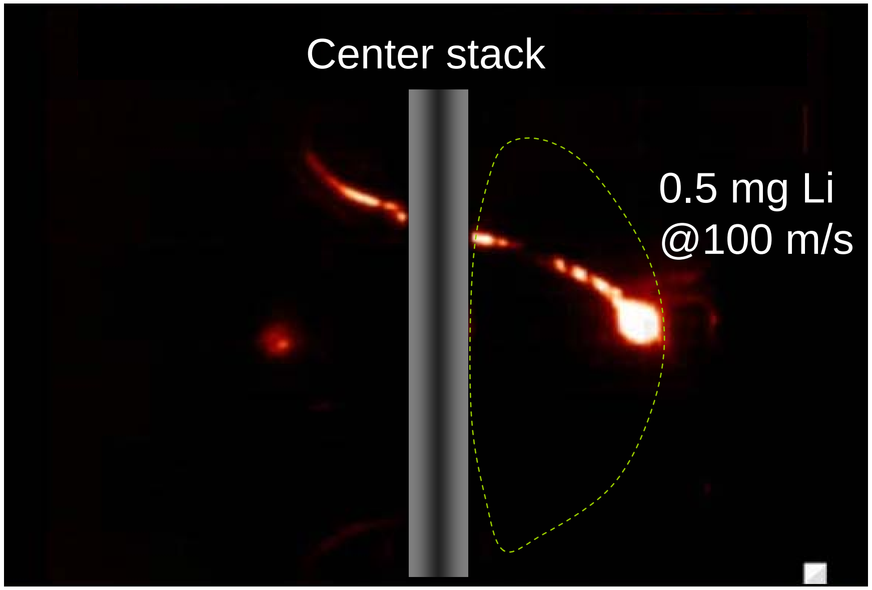
Electron transport changes strongly with heating power

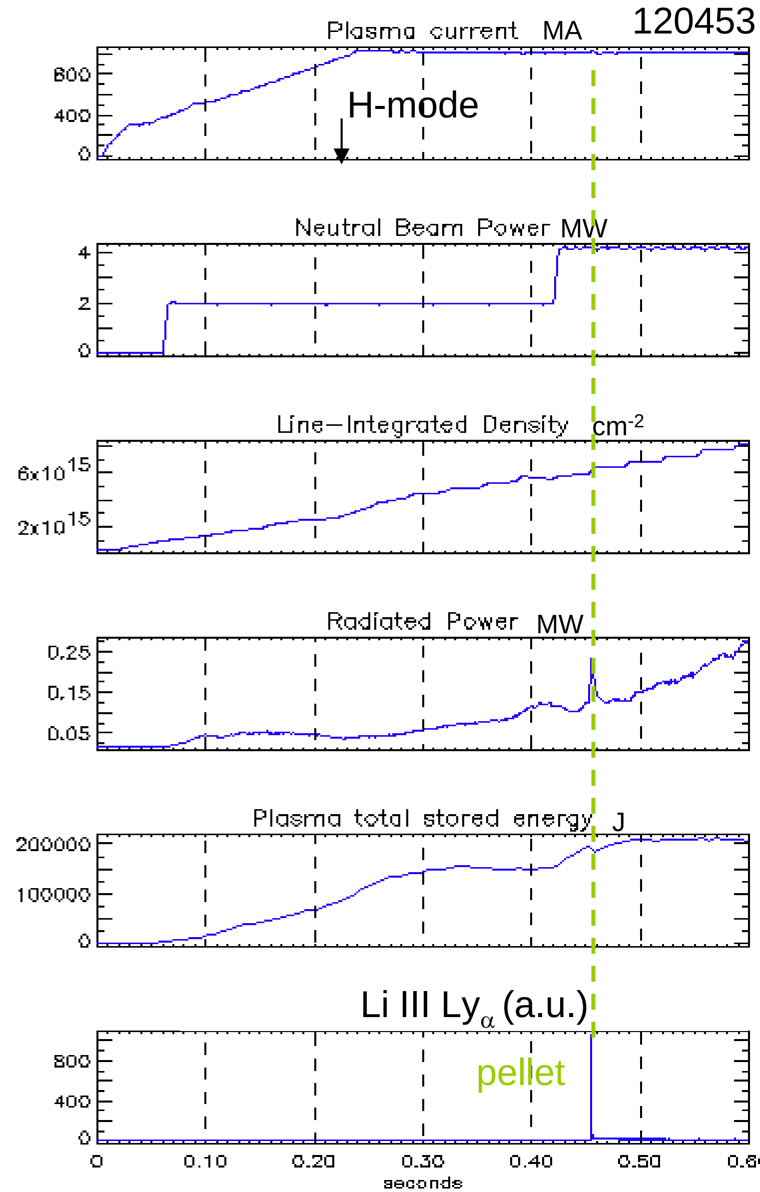




- T_e profile broadens at high P_{NB}, narrows at reduced P_{NB}
- Power balance shows large increase in core χ_e ($r/a < 0.6$) with increasing P_{NB}
- Effect now clearly correlated with change in electron heating

Pellet perturbation also used to probe electron transport

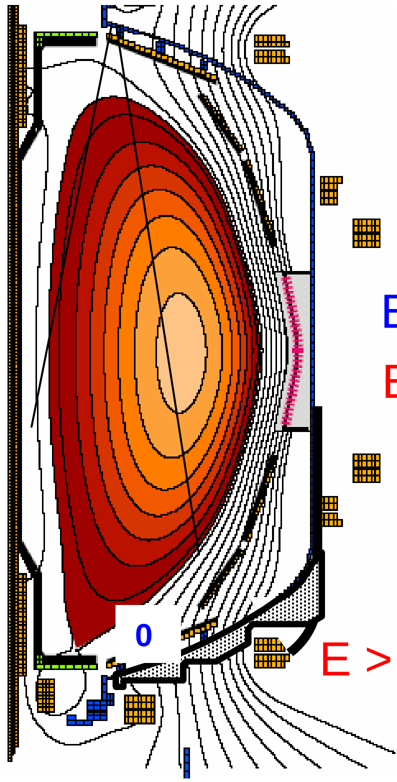




- Pellet ablates near edge
- Small density perturbation
- Only few % equilibrium change

'Multi-color' SXR arrays used for fast T_e measurements

Poloidal SXR diode arrays



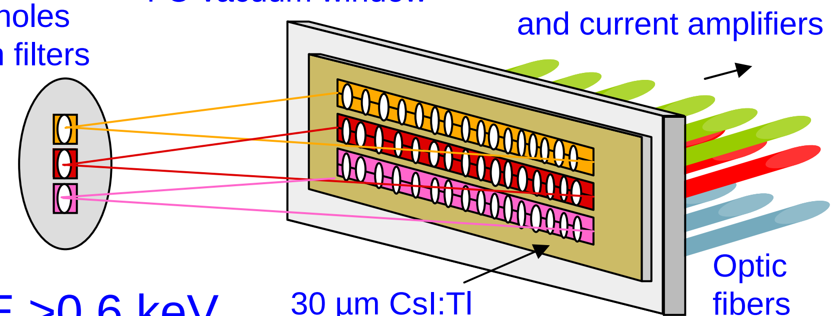
E > 0.6 keV

E > 1.4 keV

E > 1.4 keV

$\Delta r \sim 2$ cm
$\Delta t \sim 2$ µs

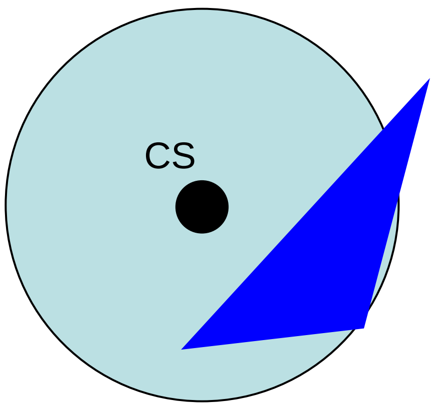
Tangential 'optical' SXR array



E >0.6 keV

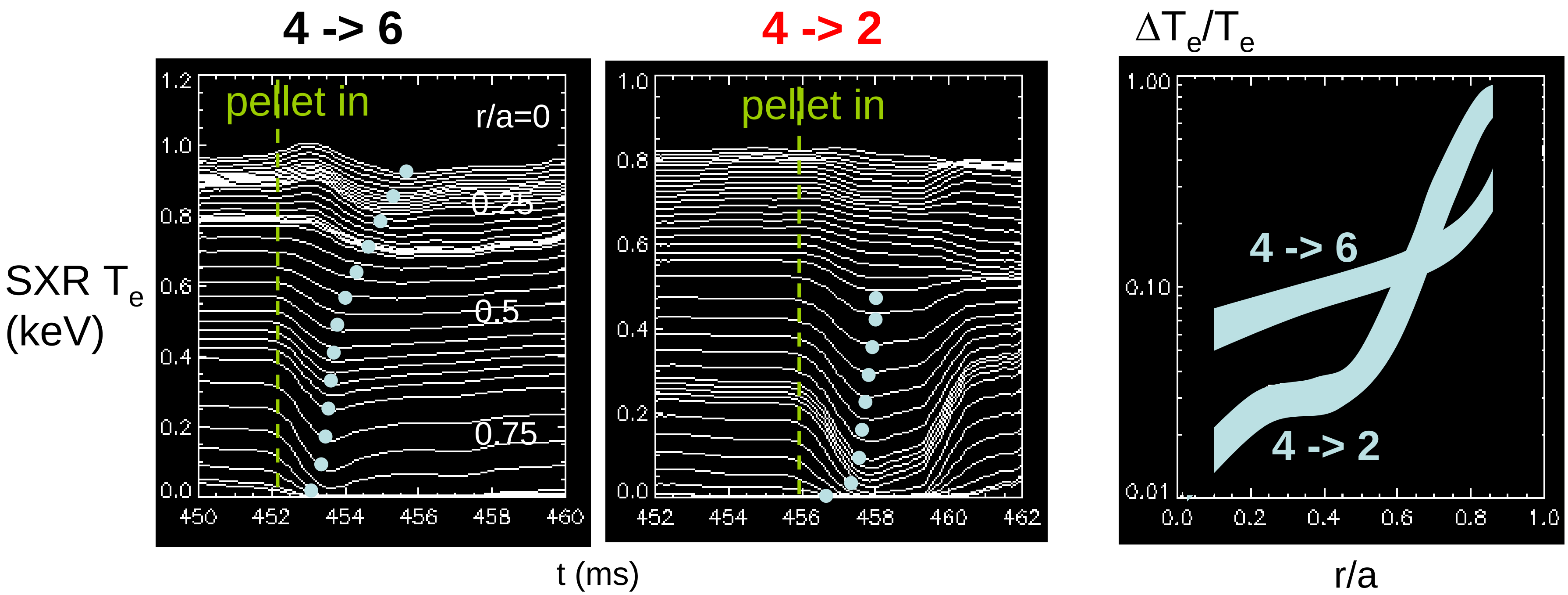
E >1.4 keV

E >2.2 keV



$\Delta r \sim 4$ cm
$\Delta t \sim 100$ µs

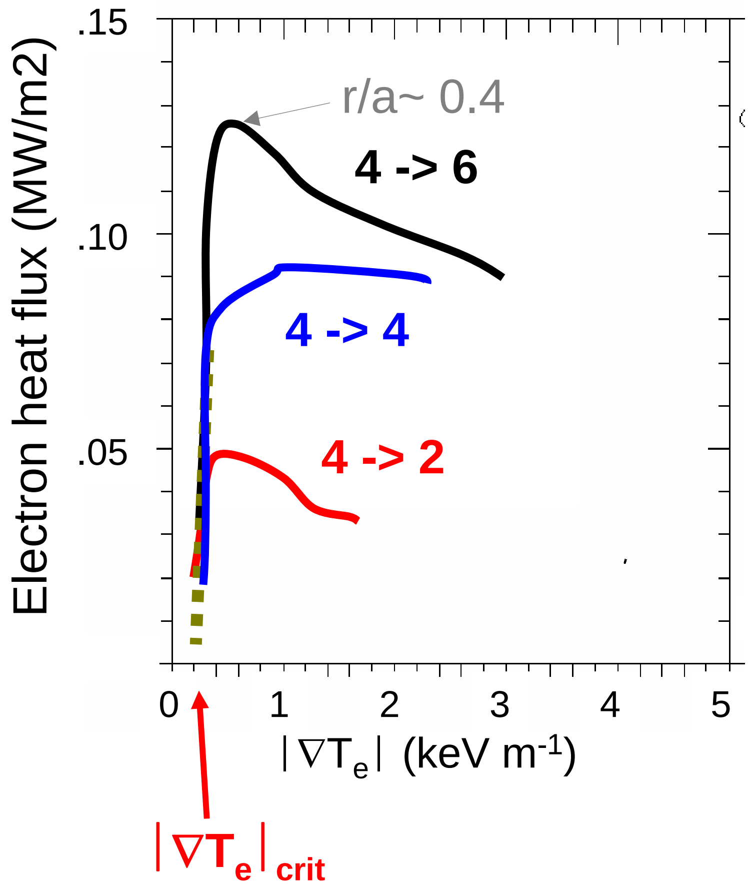
Perturbative picture consistent with power balance



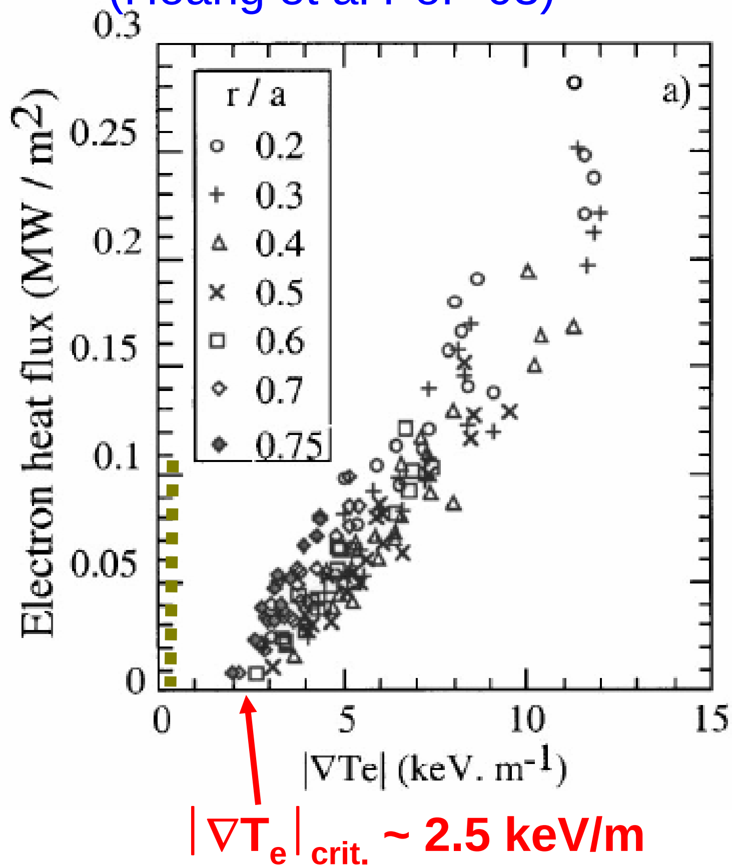
- In 4->6 case the cold pulse reaches plasma axis in ~ 2 ms
- In 4->2 case pulse strongly damped inside r/a < 0.6, faster recovery of perturbed profiles in the outer plasma
- Rapid electron transport at high P_{NB} confirmed also by ELM cold pulse (K. Tritz, this meeting)

Results suggest low $|\nabla T_e|_{crit.}$ in NSTX core

Critical T_e gradient in NSTX

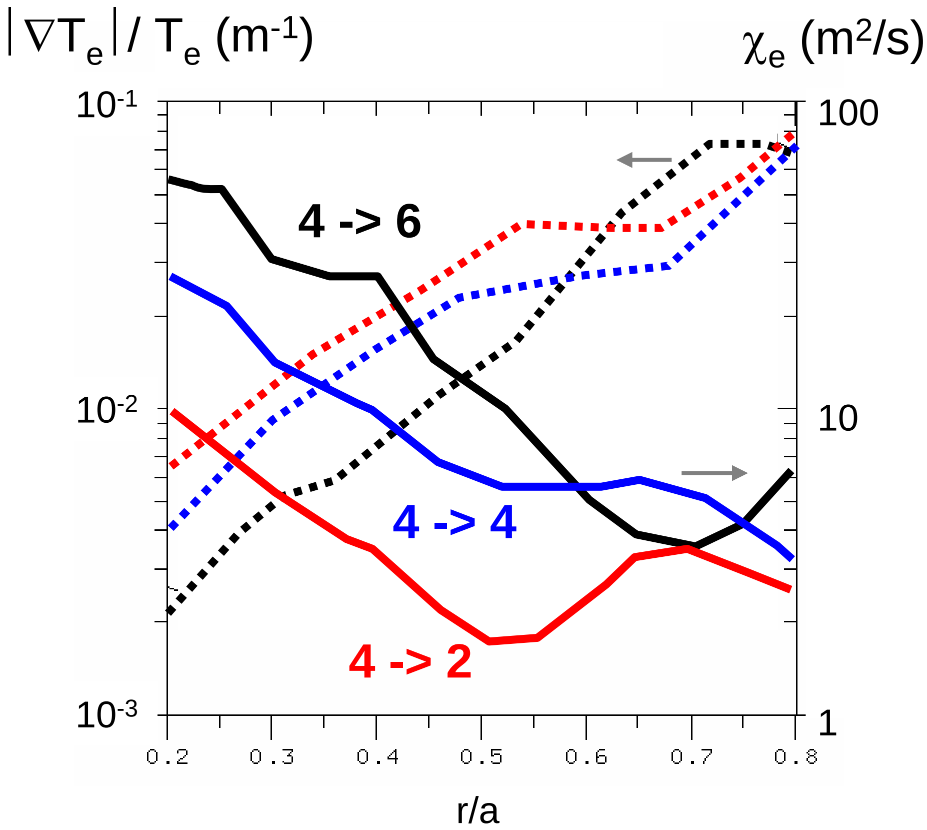


Critical T_e gradient in Tore Supra (Hoang et al PoP 03)



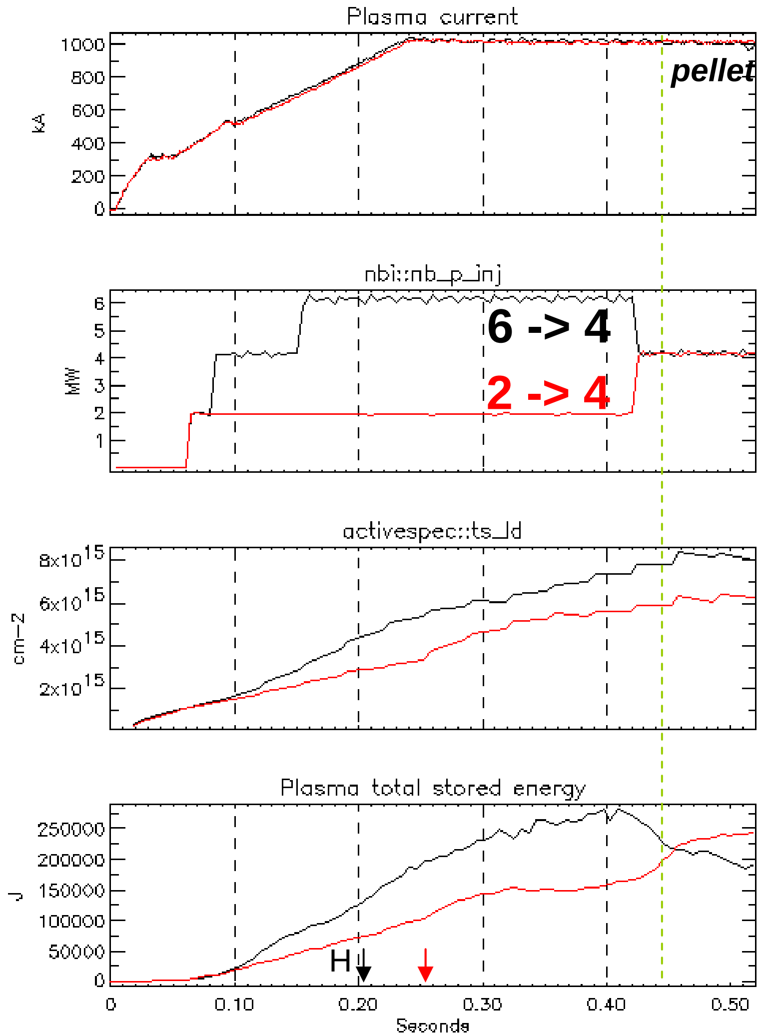
- Higher B_t may improve electron transport in NSTX (S. Kaye et al, NF07)

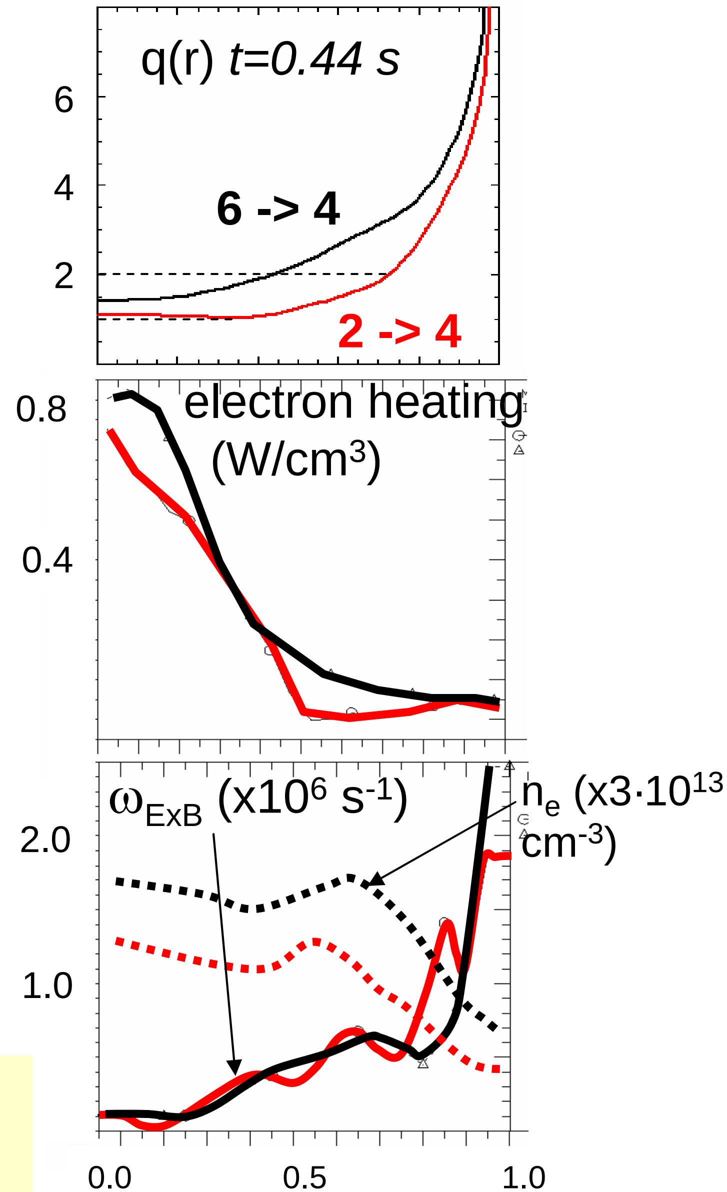
Is heat flux driving electron transport ?



- Transport level does not correlate with T_e gradient, but with heating level
- Heat flux driven transport in ‘avalanche’ models (e.g., Garbet and Waltz, PoP98)
- Might explain rapid transport with little thermal gradient in NSTX center, inside ITBs

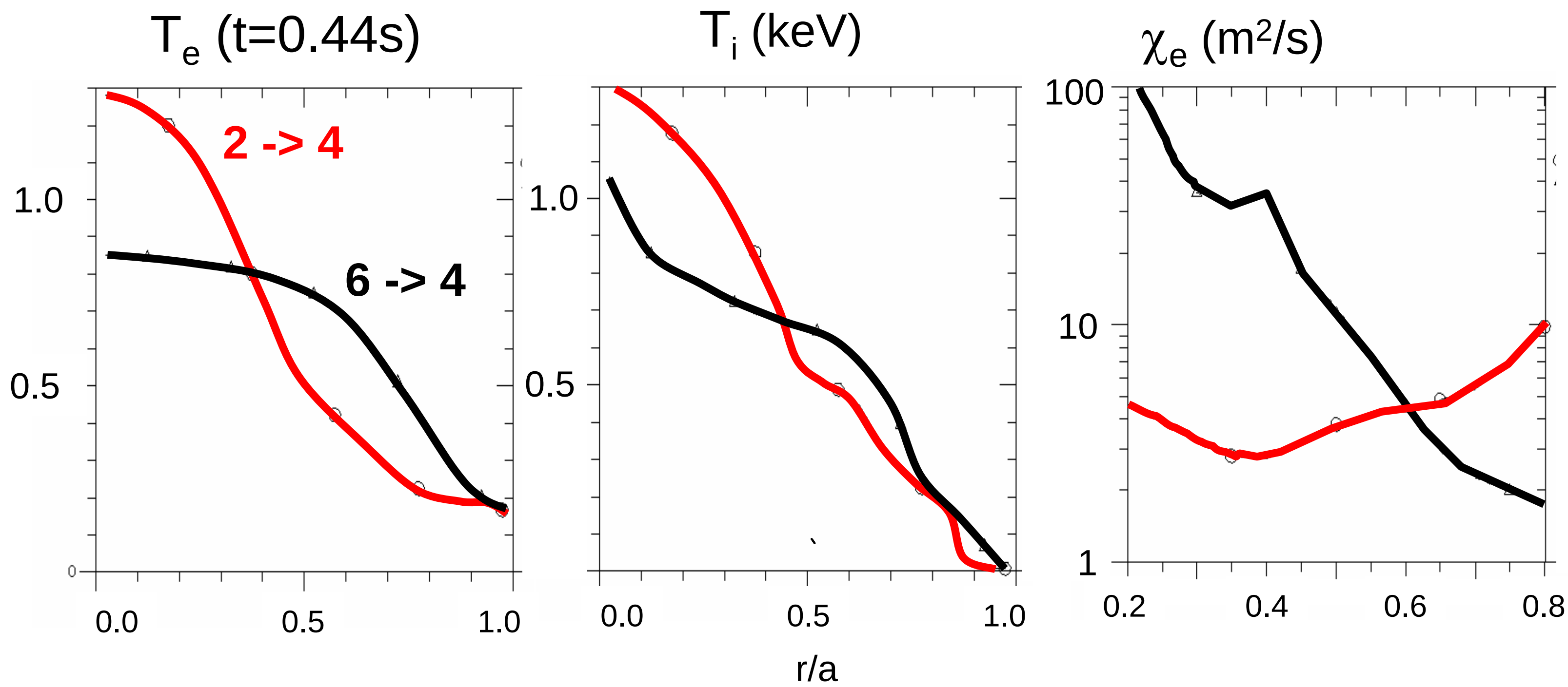
Experiment II: Vary q-profile at fixed electron heating





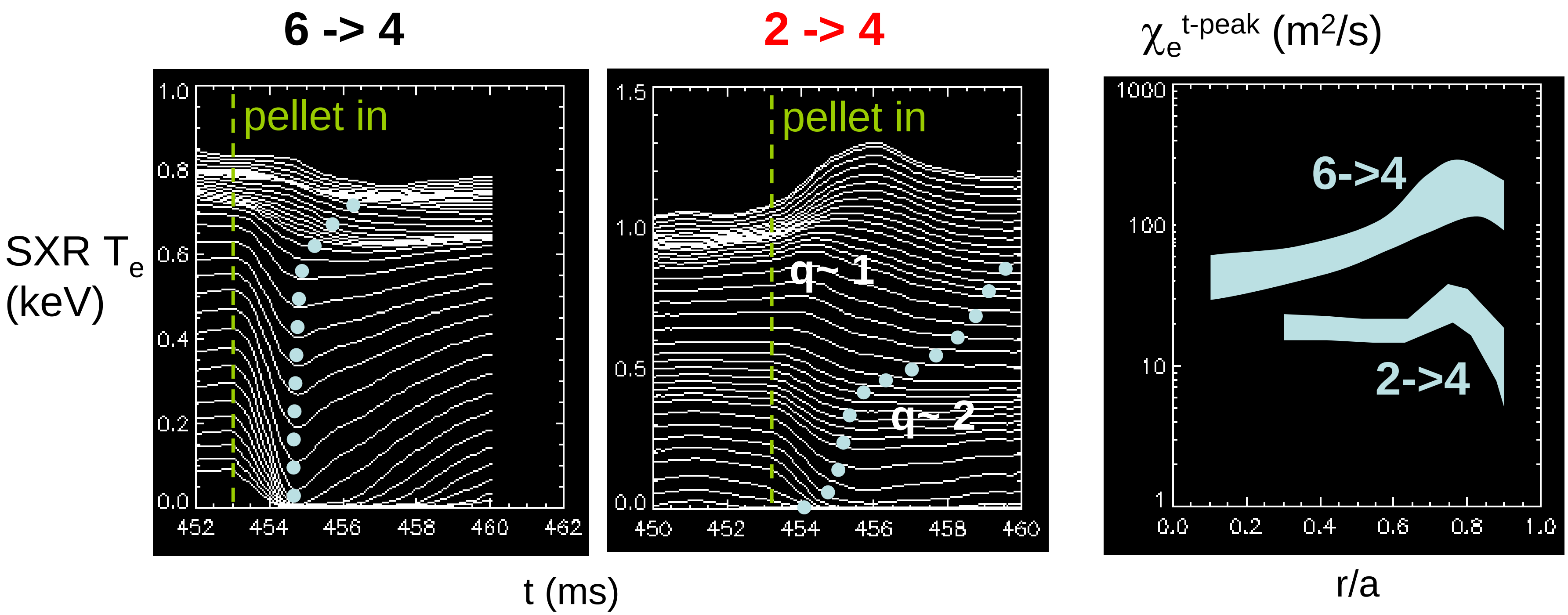
- Vary $P_{preheat}$ to vary q -> bring P_{NB} to common level -> measure transport
- Different q(r) at comparable heating, ω_{EXB}, ~ n_e

Electron transport changes strongly also with q-profile



- Within uncertainties ion transport follows similar trend

Perturbative transport also exhibits q-profile effects

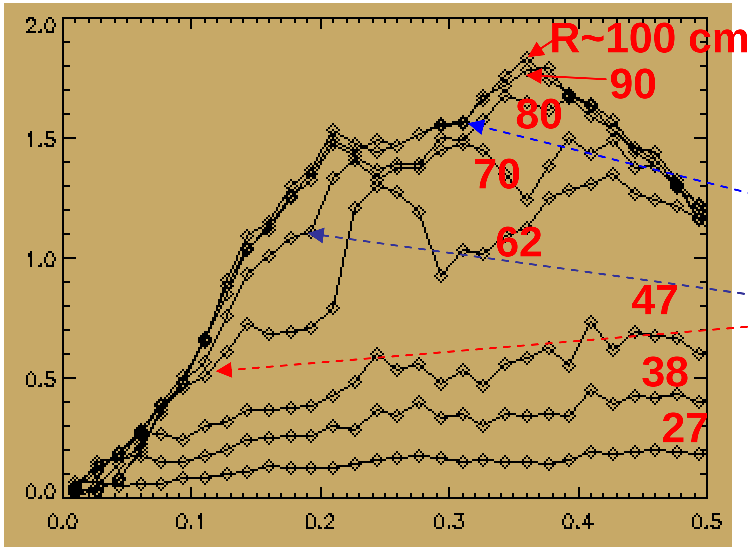


- Rapid, global propagation with the q-profile produced at high $P_{preheat}$
- Slow propagation inside q=2, 'polarity reversal' inside q=1 with q-profile at low $P_{preheat}$
- Role of low order rational-q surfaces in NSTX electron transport?

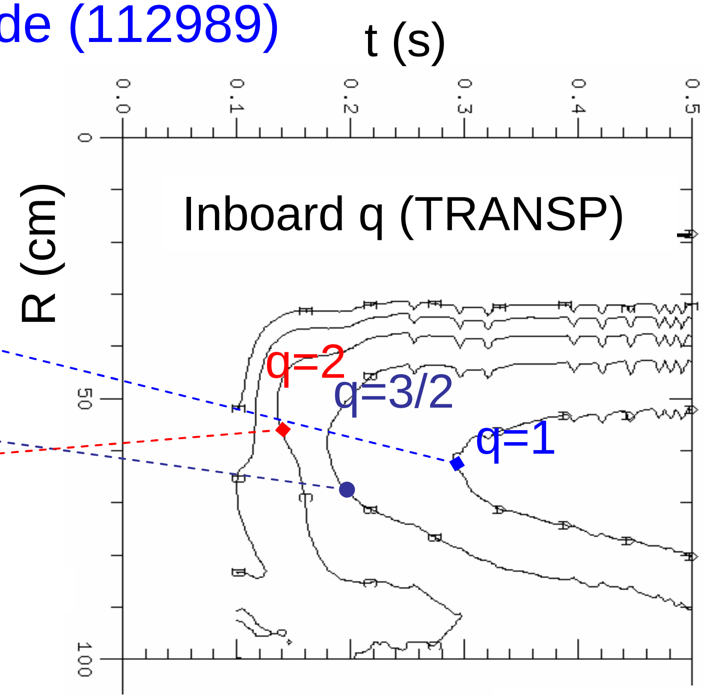
Role of rational-q evident also in negative shear L-mode

2 MW, low n_e L-mode (112989)

Inboard T_e (keV)

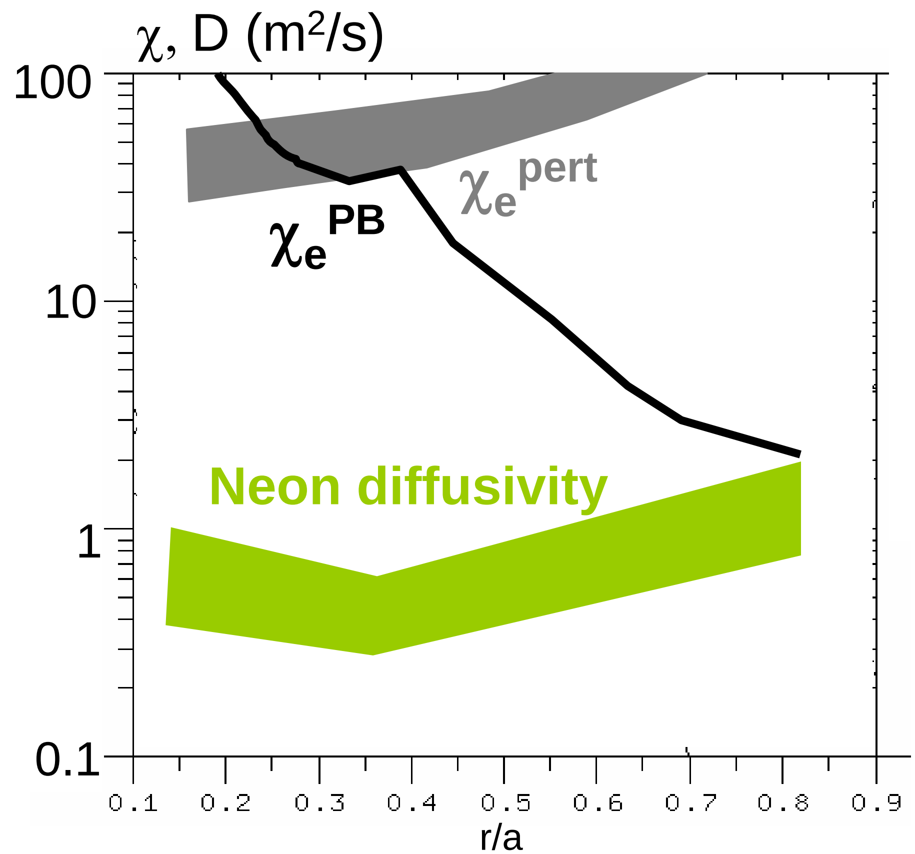


t (s)



- Spontaneous T_e increases when q approaches rational values
- Zonal flow/magnetic geometry effect (M. Austin *et al* PoP 2006)
- NSTX good test bed for zonal flow physics (~$\rho*$)

Magnetic or high-k transport behind large central χ_e?



$$D_{magn} \approx V_{||} (\Delta B_r/B)^2 L_s$$

$$\Downarrow$$

$$D_i \approx \chi_i \approx \chi_e \sqrt{(m_e/m_i)}$$

$$\Downarrow$$

$$\chi_e / D_{Ne} \approx \mathcal{O}(10^2)$$

- D_{Neon} ~ neoclassical (< 1 m^2/s) in high P_{NB} H-modes (L. Delgado this meeting)
- Anomalous transport from low-k electrostatic turbulence likely suppressed
- χ_e >> D_{Neon} -> high-k electrostatic, or magnetic electron transport
- µ-tearing predicted to be active in NSTX H-modes (K. Wong this meeting)

GS2 calculations also point to μ-tearing drive

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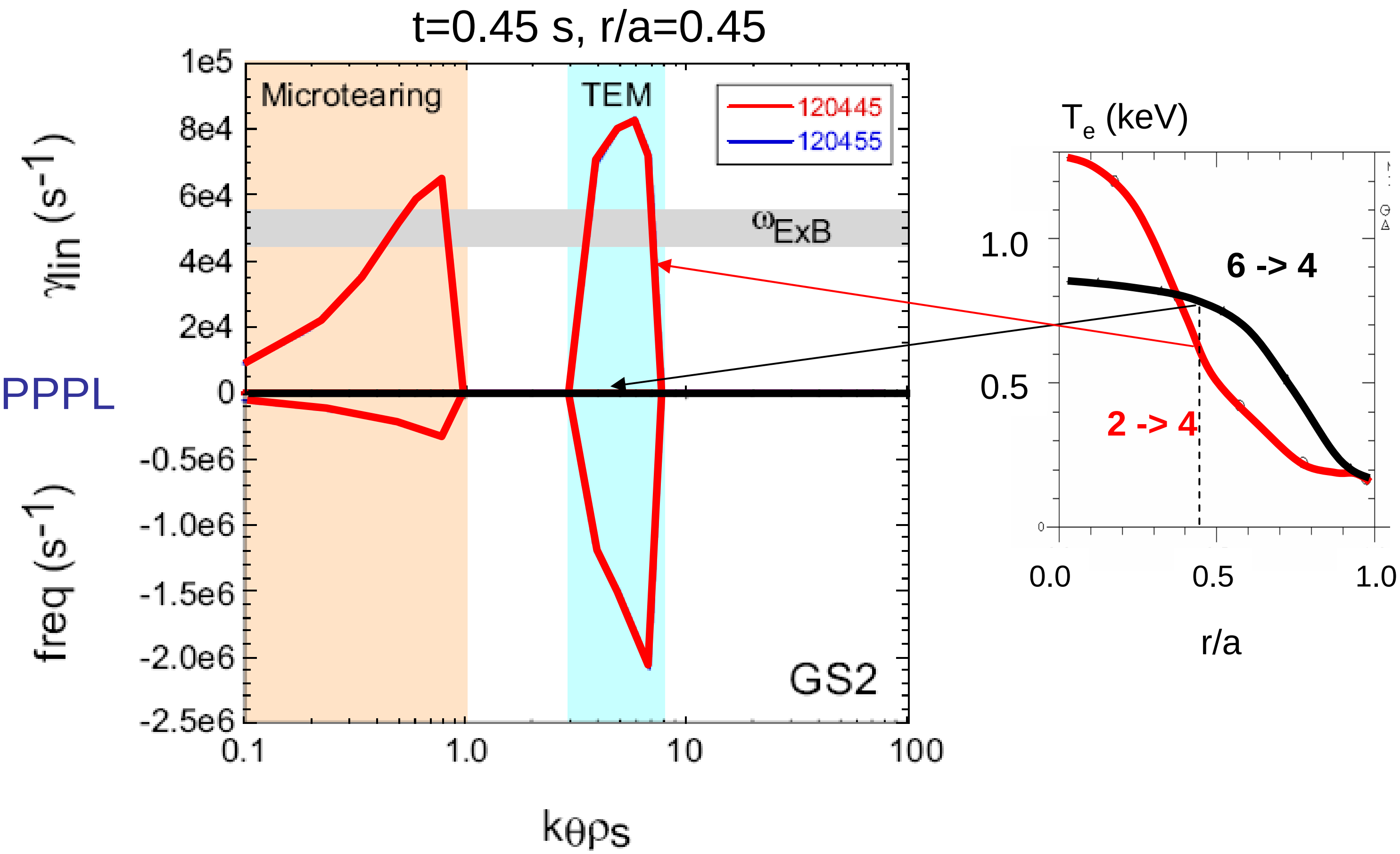

- Linear calculations can only indicate trends (2->4 case has in fact lower χ_e)
- Magnetic and T_e fluctuation diagnostics, non-linear EM calculations needed

Summary

- Simple technique used to study electron transport vs. heating power and q in H-mode
- T_e broadening with P_{NB} consistent with low critical gradient in core plasma
- Heat flux may be driving electron transport in regions with flat T_e
- Indications for ITB formation at low order rational-q surfaces
- μ-tearing simple explanation for electron transport much more rapid than particle one