DEPENDENCE OF THE PERTURBED ELECTRON TRANSPORT ON HEAT FLUX AND Q-PROFILE IN THE NSTX H-MODE

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Abstract

The T_e profiles are observed to flatten with increasing beam power P_{NB}, in the 'standard' NSTX H-mode. In addition, at high power, the Type-I ELMs produce global, ms time scale T_e crashes of large amplitude. To try and separate the roles of the heating power and q(r) in these effects, we performed experiments in which the background, or preheat power and q(r) were independently varied and the electron transport perturbed with P_{NB} steps and Li pellets.

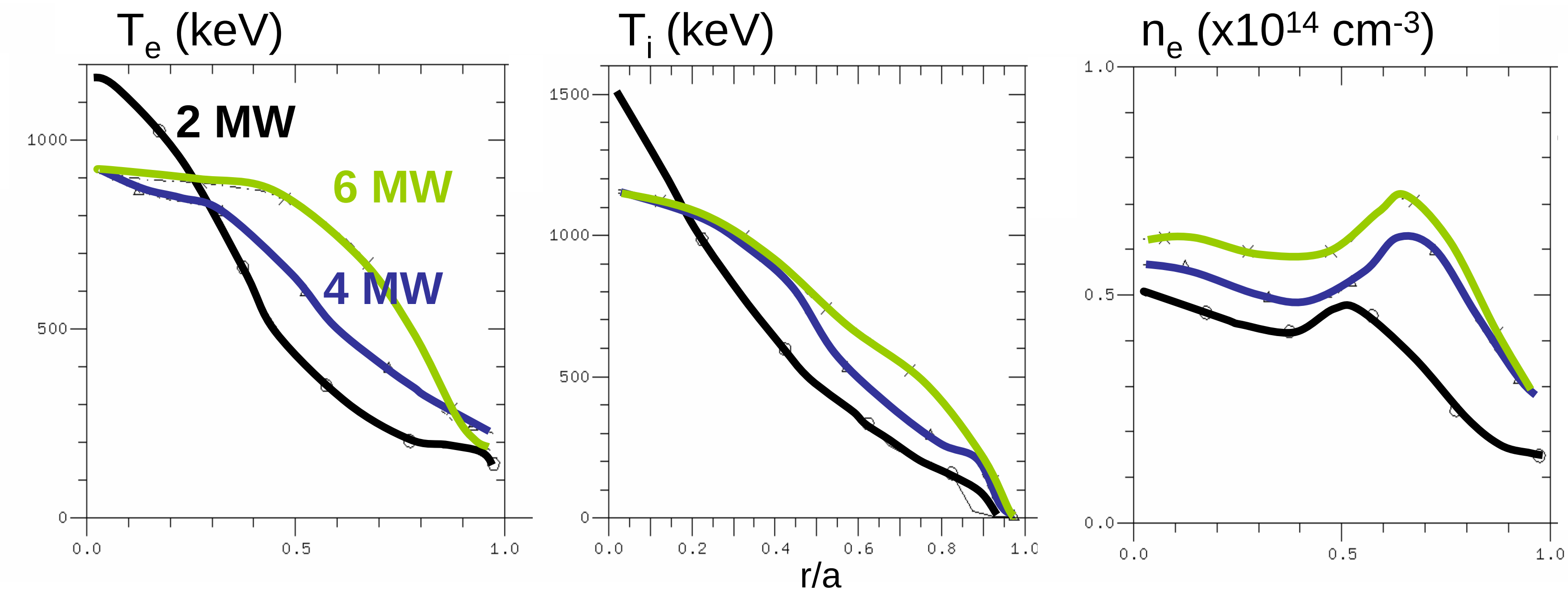
The results at fixed q show that at high power the central χ_e reaches very large values, while at low power it strongly decreases. These trends are confirmed by the perturbative experiments. At high power the pellet cold pulse rapidly propagates to the plasma center, while at low power the pulse is strongly damped in the inner plasma.

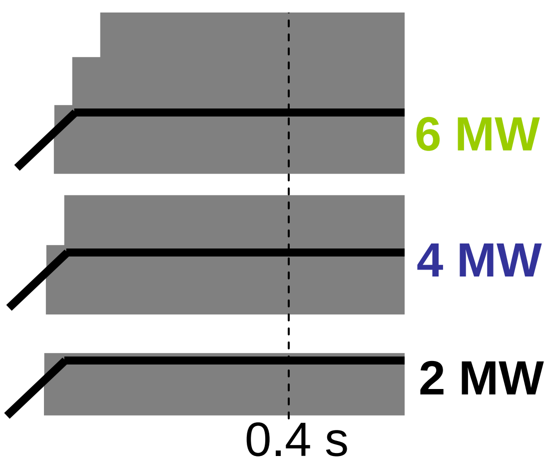
The q change at fixed P_{NB} has also profound effects on electron transport. With the narrow q-profile resulting from early heating at high P_{NB} (the 'standard' NSTX H-mode scenario), very large central χ_e, together with global and rapid T_e perturbations following pellet injection are observed. With the broader q(r) resulting from heating at low P_{NB}, χ_e strongly decreases and the cold pulse slows down inside the q=2 surface. Since the magnetic shear is comparable in the two cases, these observations seem to suggest a role for low order rational-q surfaces in NSTX electron transport.

As an explanation for the very large central χ_e observed with early heating at P_{NB}, we propose magnetic turbulence. This would be consistent with the two orders of magnitude gap observed between the electron heat diffusivity and the impurity diffusivity in the 'standard' NSTX H-mode.

Unusual broadening of thermal profiles with P_{NB} in NSTX

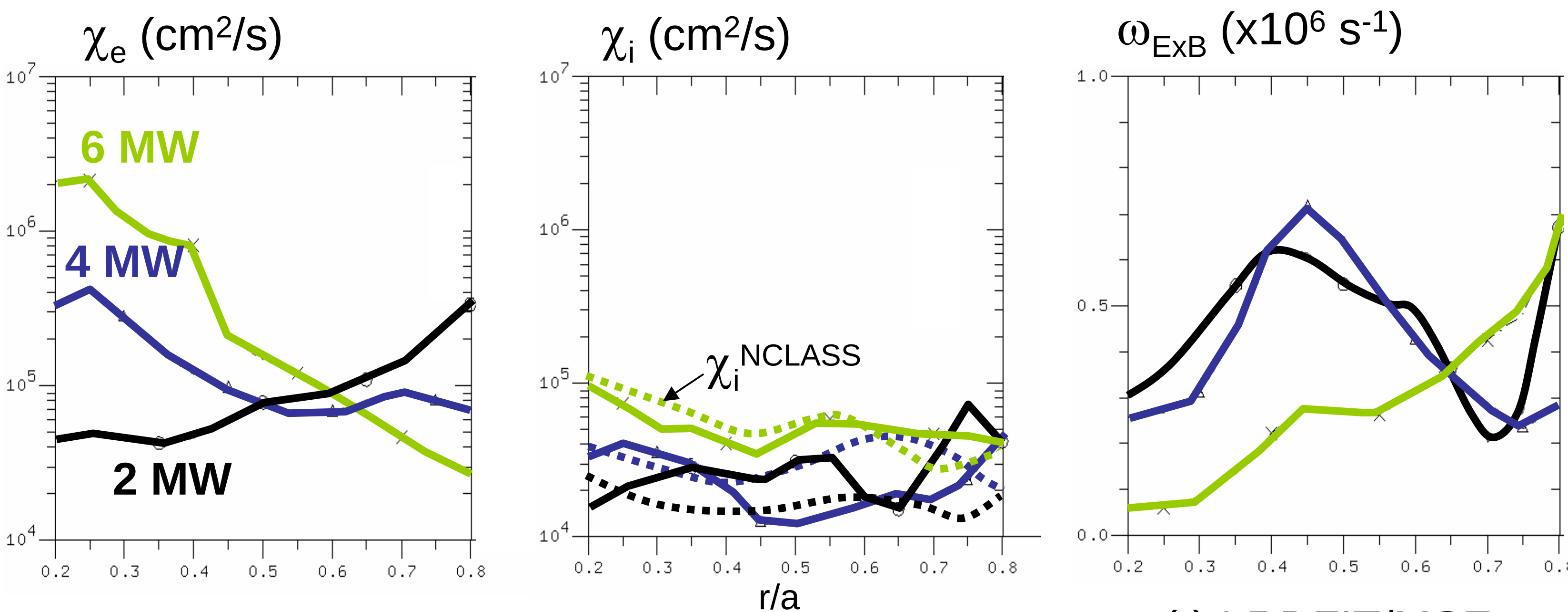
Early heating, 1 MA, 4.5 kG, ELM-free/small-ELM H-modes, t=0.4 s



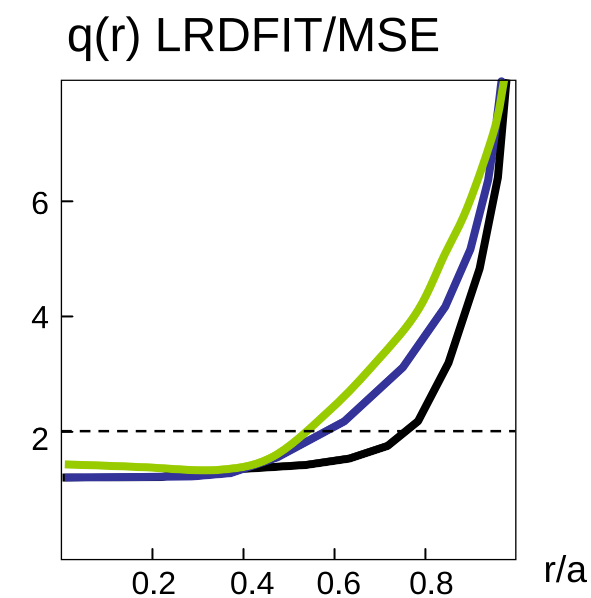


- With early heating at high P_{NB} most of the T_e gradient at r/a > 0.6
- Fast ion redistribution by MHD not a likely factor
- Lower density at lower P_{NB} might play a role

Broadening mainly caused by rapid electron transport



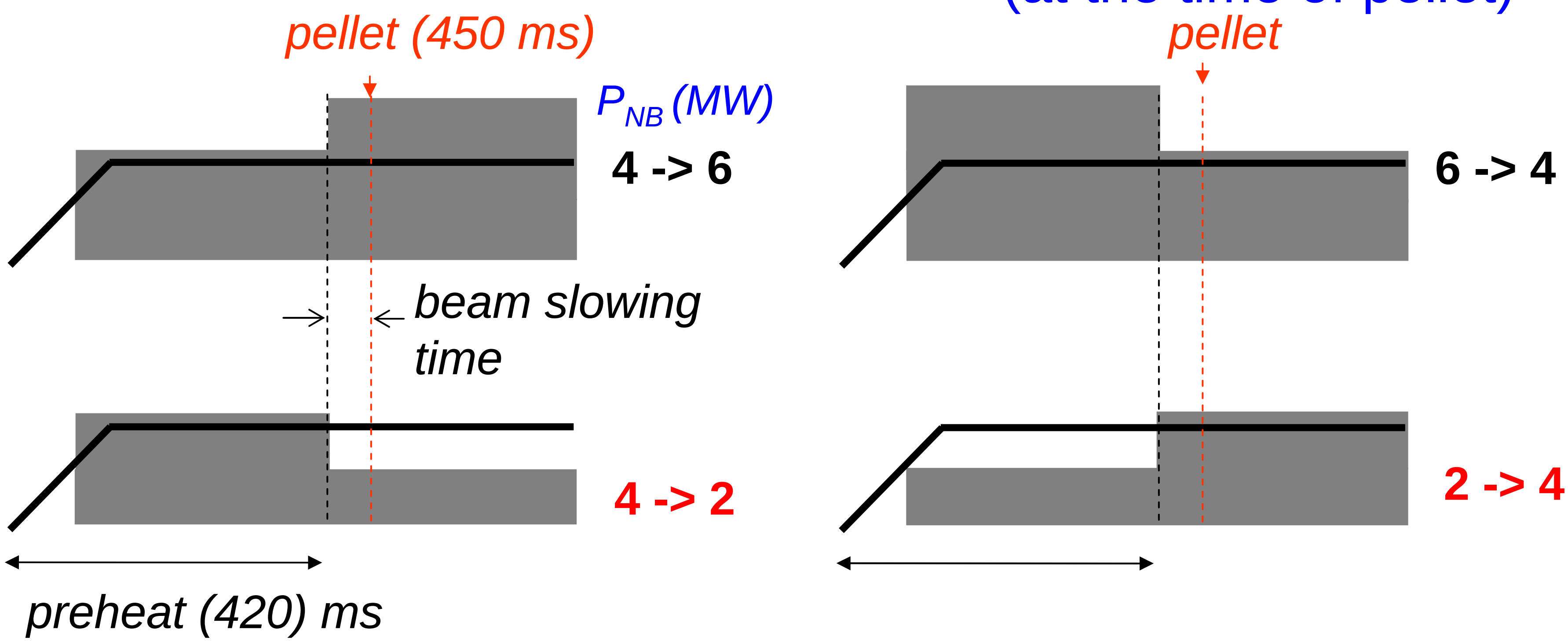
- Very large change in magnitude, shape of χ_e
- χ_i varies much less (around neoclassical)
- v_t, ω_{ExB} reduced at highest power
- q-profile narrows with increasing P_{NB}
- Study effects of heating and q-profile on the perturbed electron transport



Experiment: P_{NB} and q varied and T_e perturbed

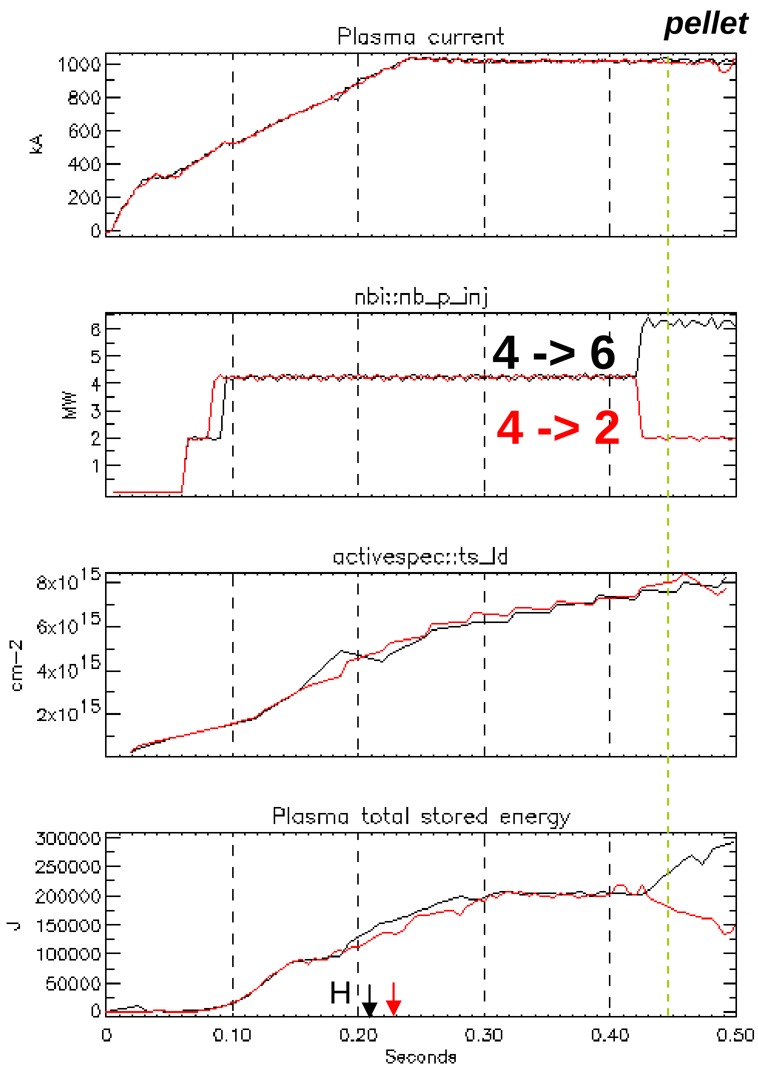
I) P_{NB} change at fixed q

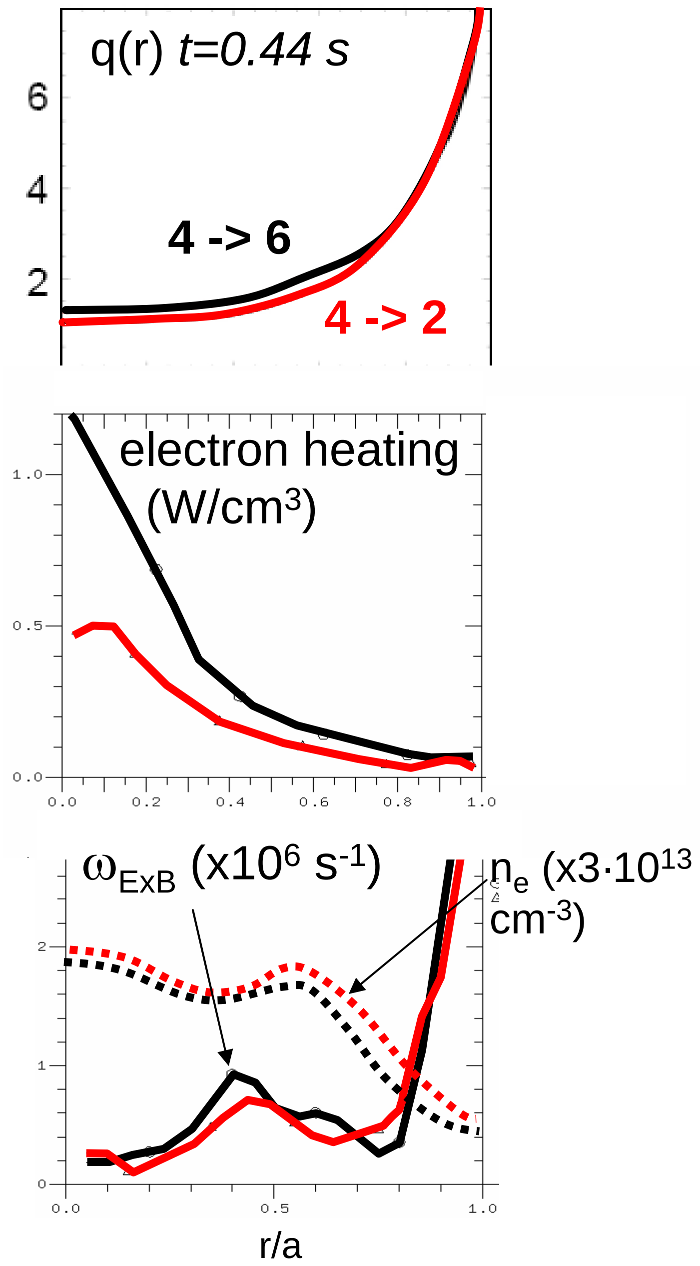
II) q change at fixed P_{NB} (at the time of pellet)



- Preheat to 'freeze-in' q-profile -> step P_{NB} and perturb with pellet
- 'Frozen-in' q-profile varied by varying preheat power
- Study both ΔP_{NB} and pellet perturbations

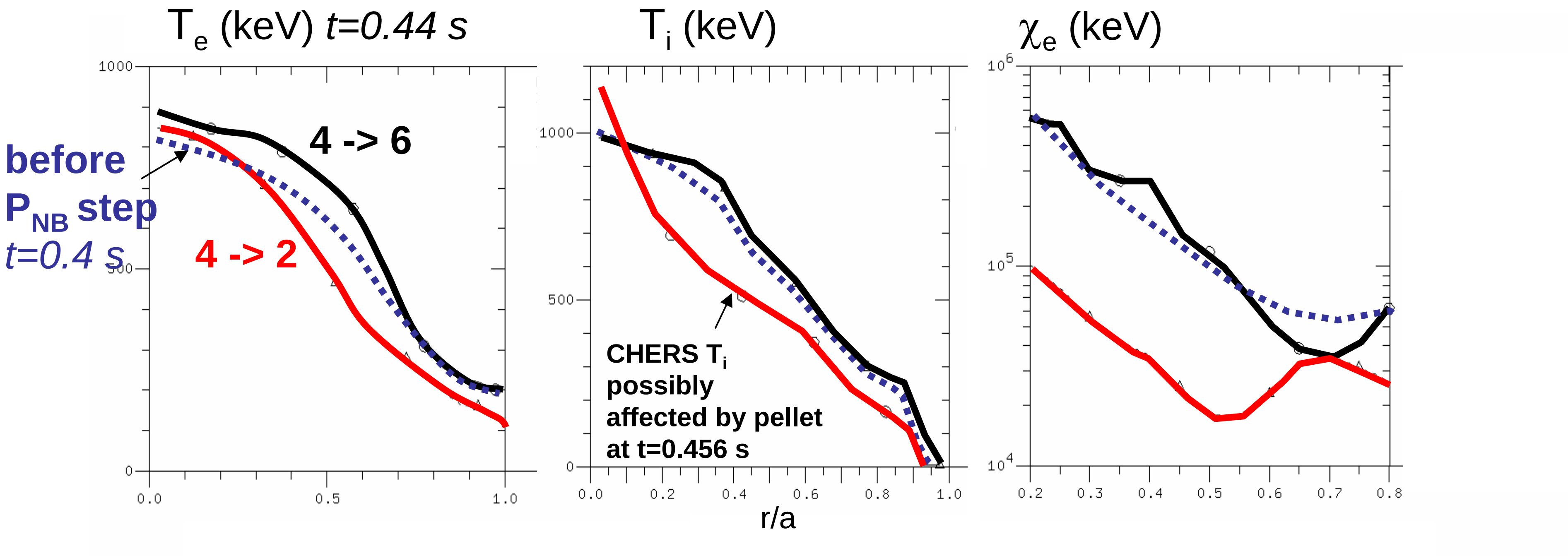
I) Large change in electron heating achieved at fixed-q





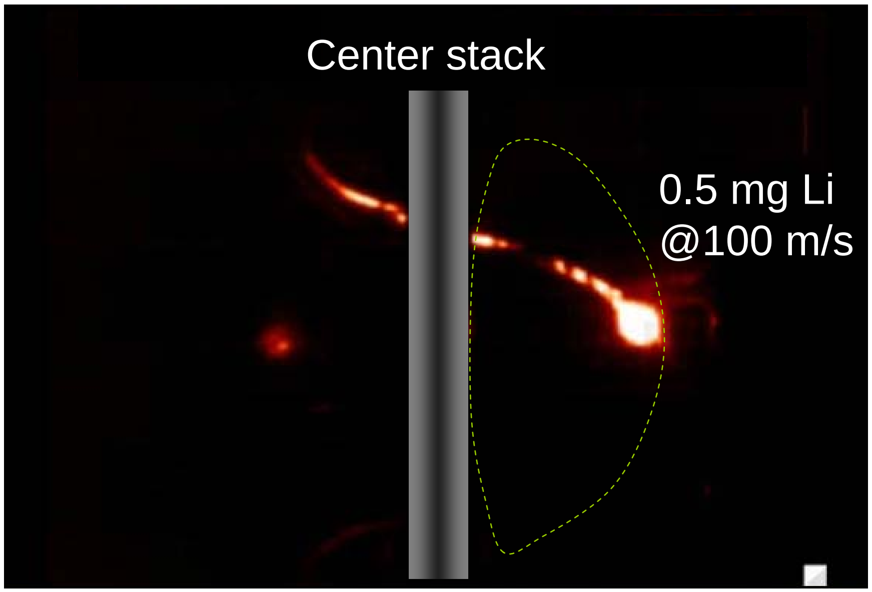
- ω_{ExB}, n_e, also do not significantly change

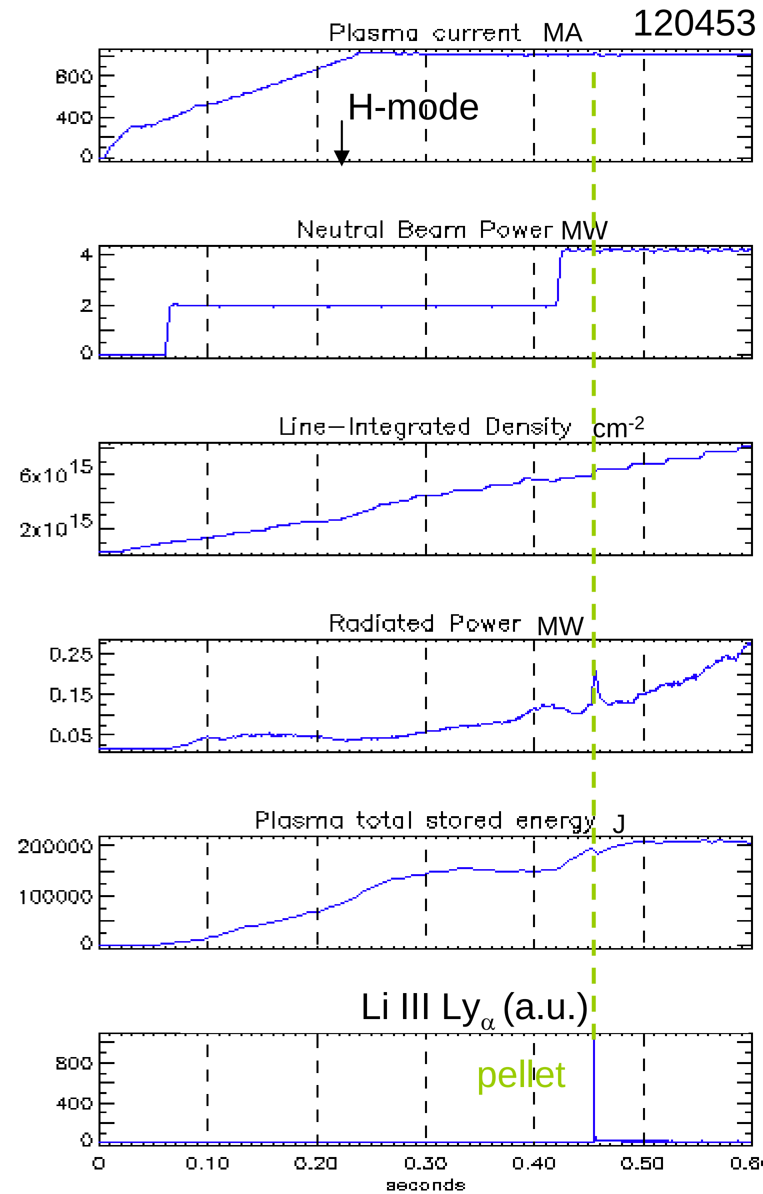
Electron transport changes differently at P_{NB} step/drop



- Central χ_e does not change much at 4->6 step, but large absolute values prevent substantial T_e increase
- Central χ_e strongly decreases after 4->2 drop $\rightarrow$ discharges at P_{NB} > 2 MW likely far from marginal stability
- Within uncertainties, ion transport *increases* after 4->2 drop

Pellet perturbation further used to probe electron transport

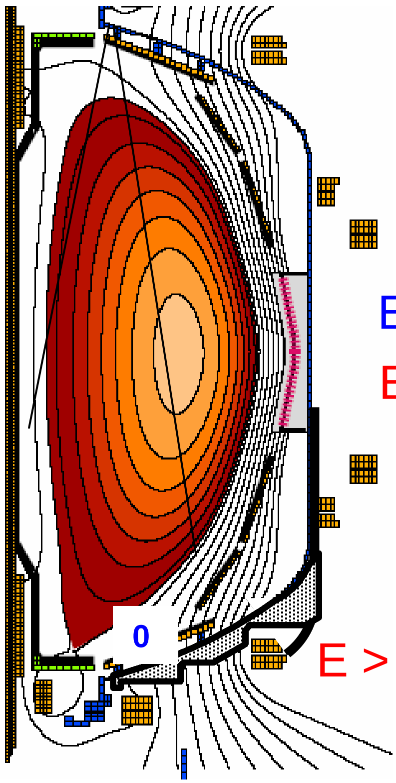




- Pellet ablates near edge
- Small density perturbation
- Only few % equilibrium change

‘Multi-color’ SXR arrays used for fast T_e measurement

Poloidal SXR diode arrays



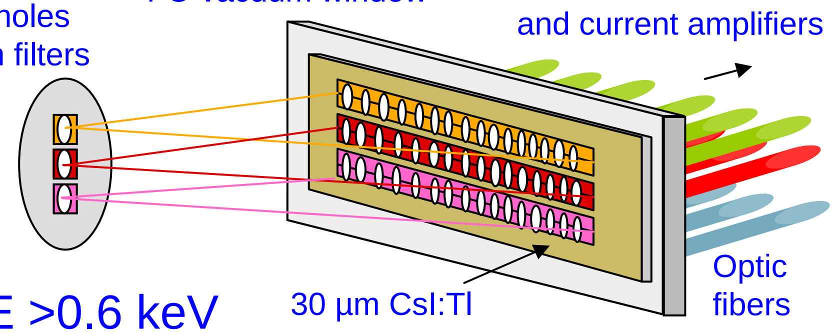
E > 0.6 keV

E > 1.4 keV

E > 1.4 keV

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

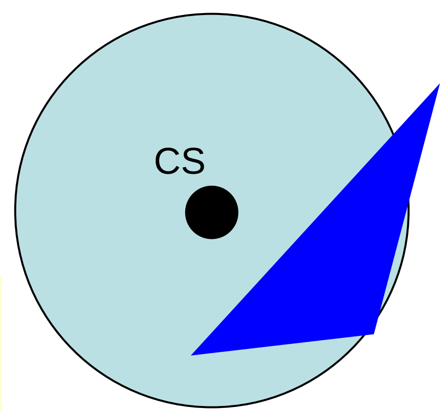
Tangential ‘optical’ SXR array



E >0.6 keV

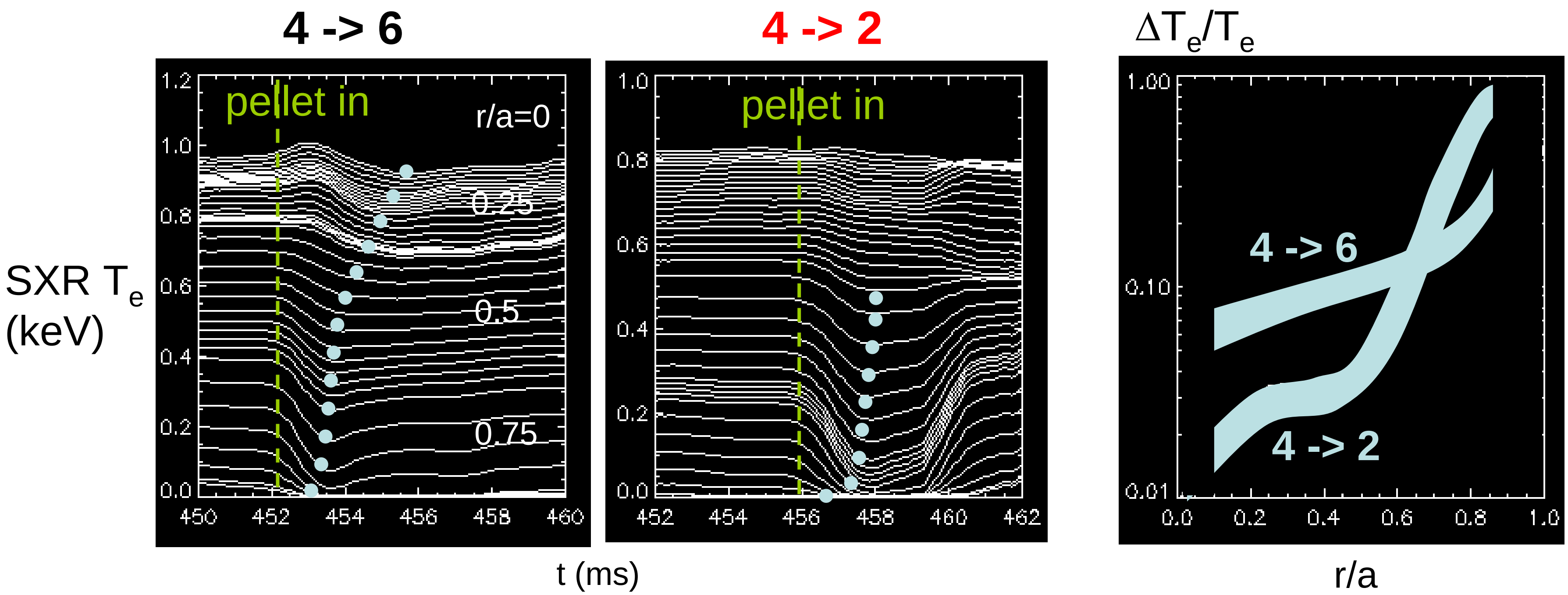
E >1.4 keV

E >2.2 keV



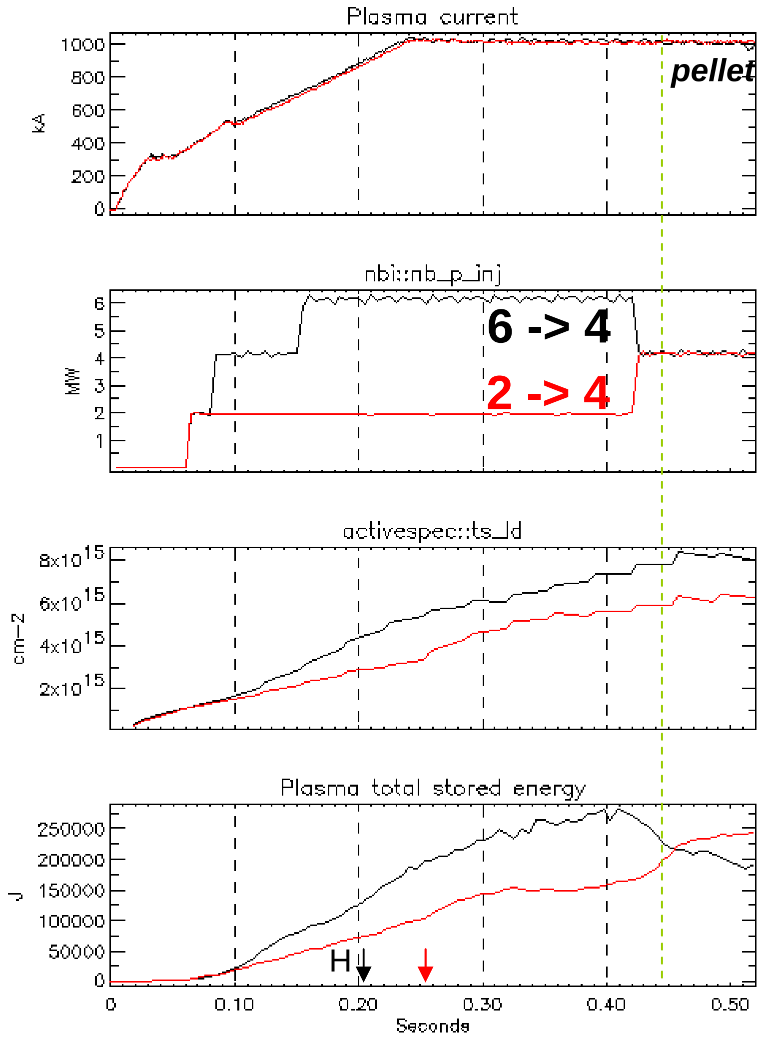
$\Delta r \sim 4$ cm
$\Delta t \sim 100$ µs

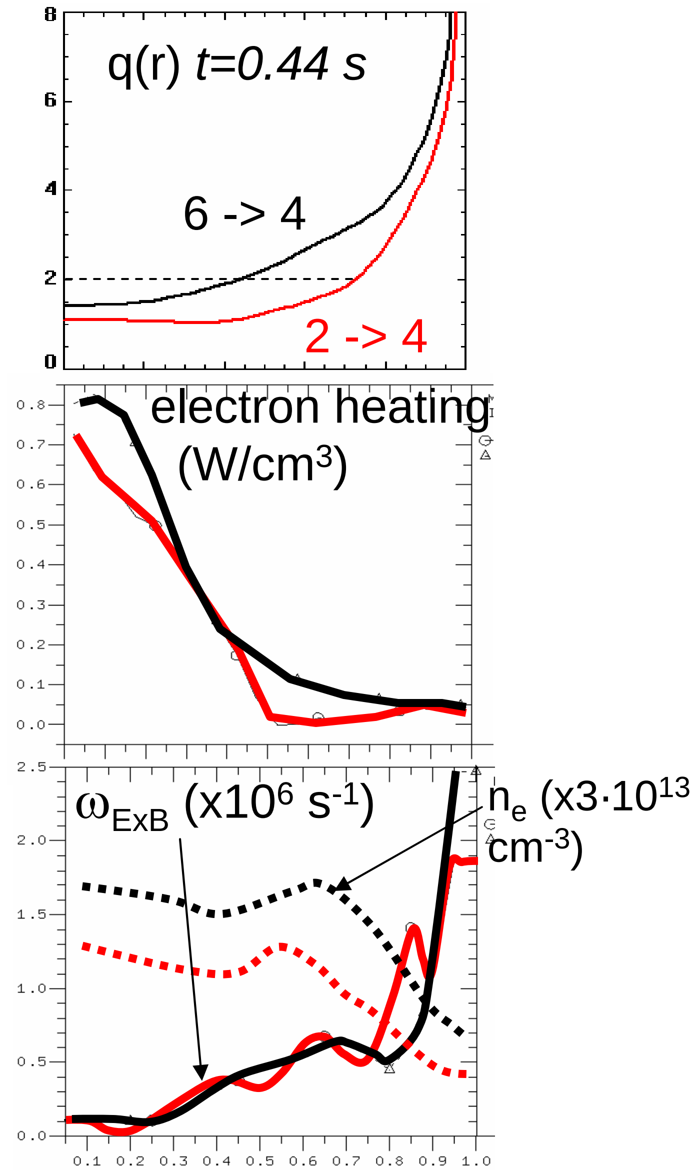
Perturbative study confirms trends from power balance



- 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 central electron transport at high P_{NB} confirmed also by ELM cold pulse measurements

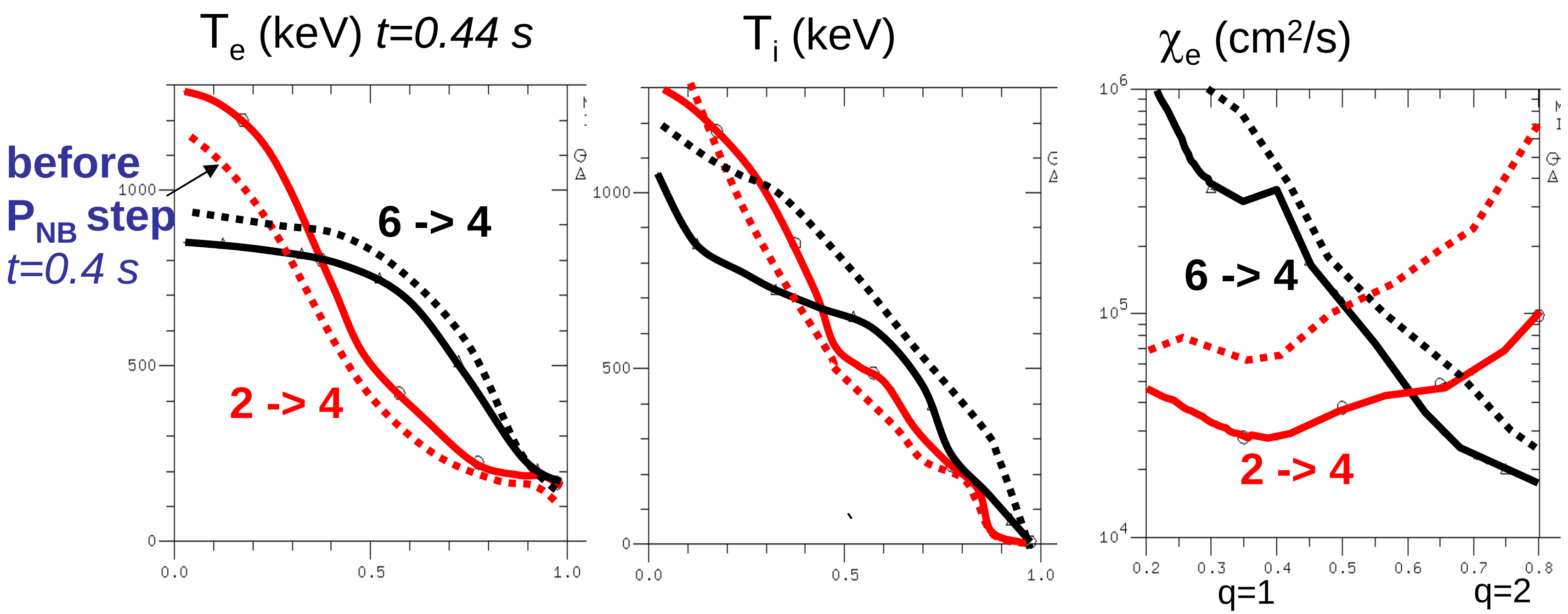
II) Change in q at similar electron heating also achieved





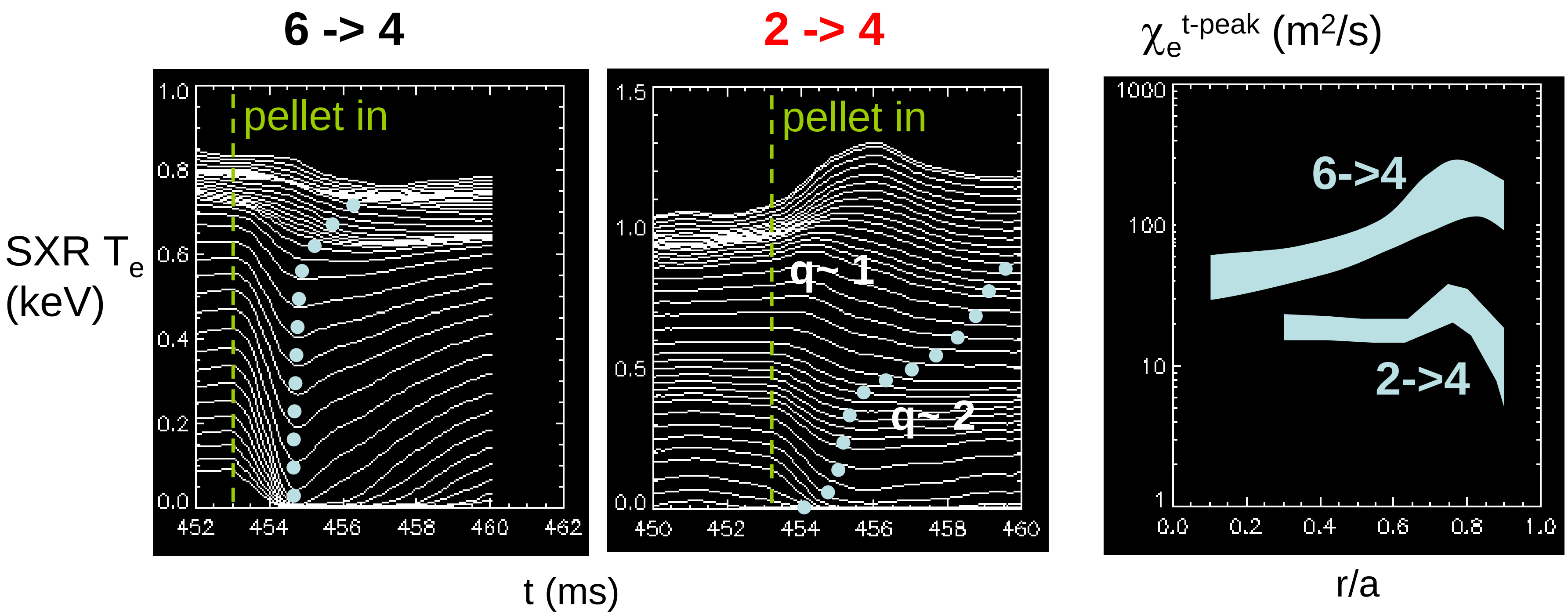
- ω_{ExB} does not significantly change, but n_e lower with 2 MW preheat
- q(r) differs, but magnetic shear similar

Electron transport strongly changes with q-profile



- With q-profile obtaining at low preheat power, χ_e *decreases* at 2->4 step, with electron ITB and slight shear reversal inside q=2
- With q-profile at high preheat power χ_e remains high even when P_{NB} reduced
- Within uncertainties, ion transport follows similar trend

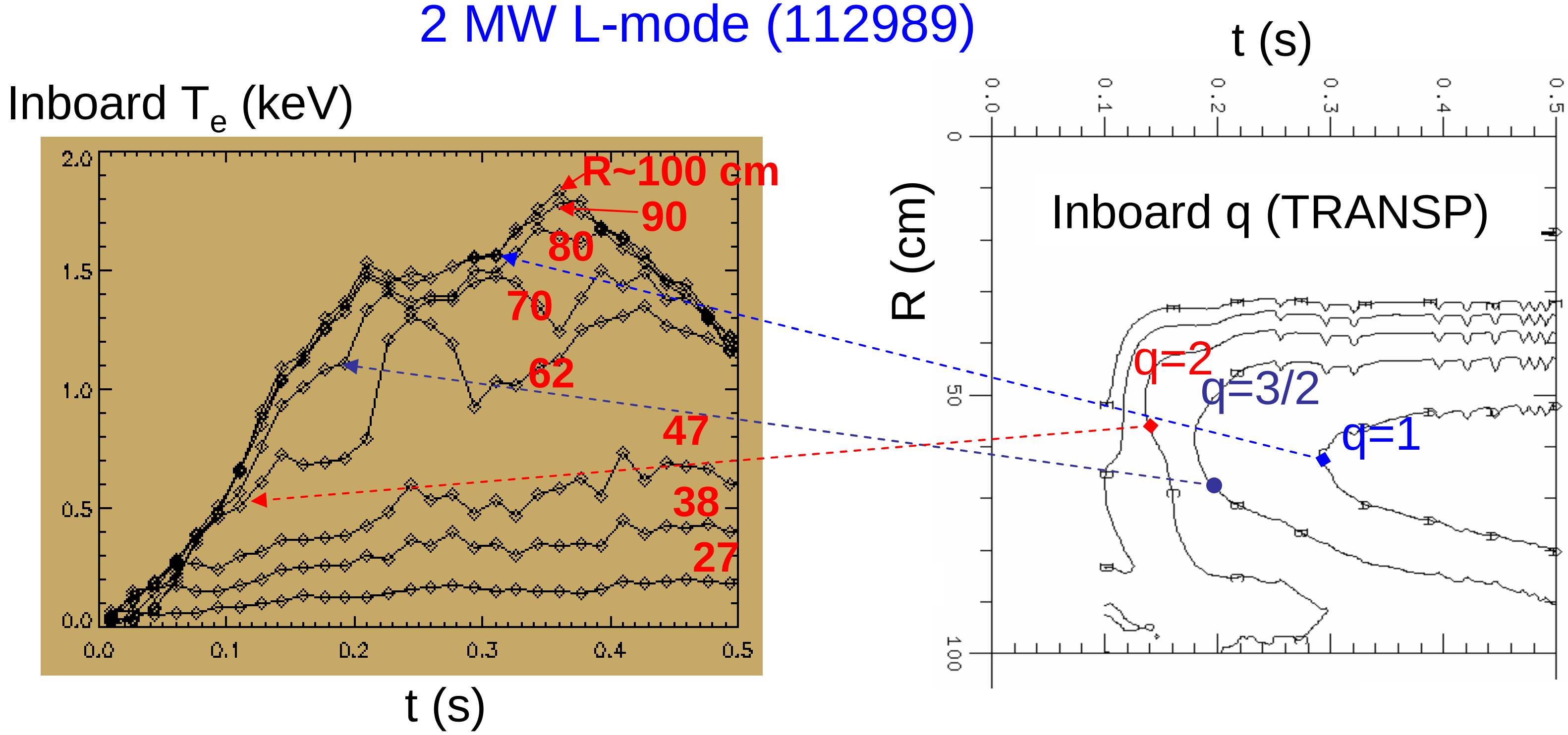
Strong q(r) effect seen also in cold pulse propagation



- Very rapid propagation through entire plasma at high preheat power
- Much slower propagation inside q=2 and ‘polarity reversal’ inside q=1 at low preheat power
- Important role of low order rational-q surfaces in NSTX electron transport?

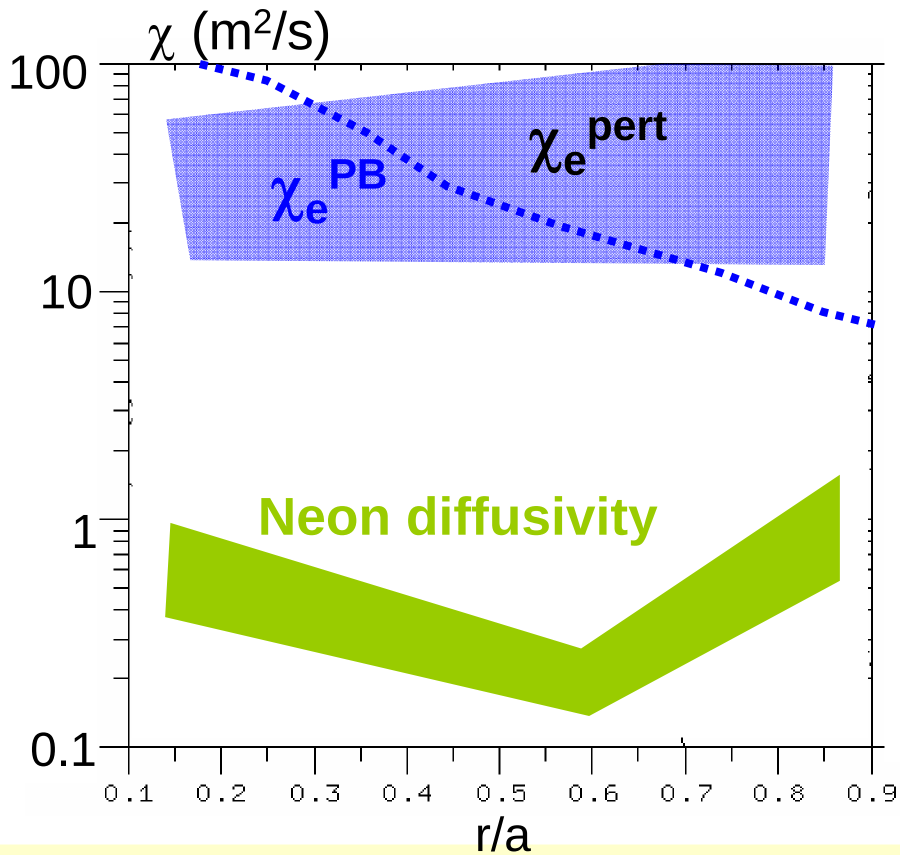
Role of rational-q also evident in low P_{NB}, NCS L-modes

2 MW L-mode (112989)



- Spontaneous T_e increases when q approaches rational values
- Zonal flow/magnetic geometry interaction model (M. Austin *et al* PoP 2006)
- Possibly explanation why q(r) reverses also in ‘slow ramp’ L-modes
- So far however, effect seen only at low P_{NB} (and n_e)
- Difficult to explain with electrostatic turbulence $\chi_e \geq$ tens of m^2/s at high P_{NB}

Is magnetic turbulence behind the large χ_e at high P_{NB}?



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

$$\Downarrow$$

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

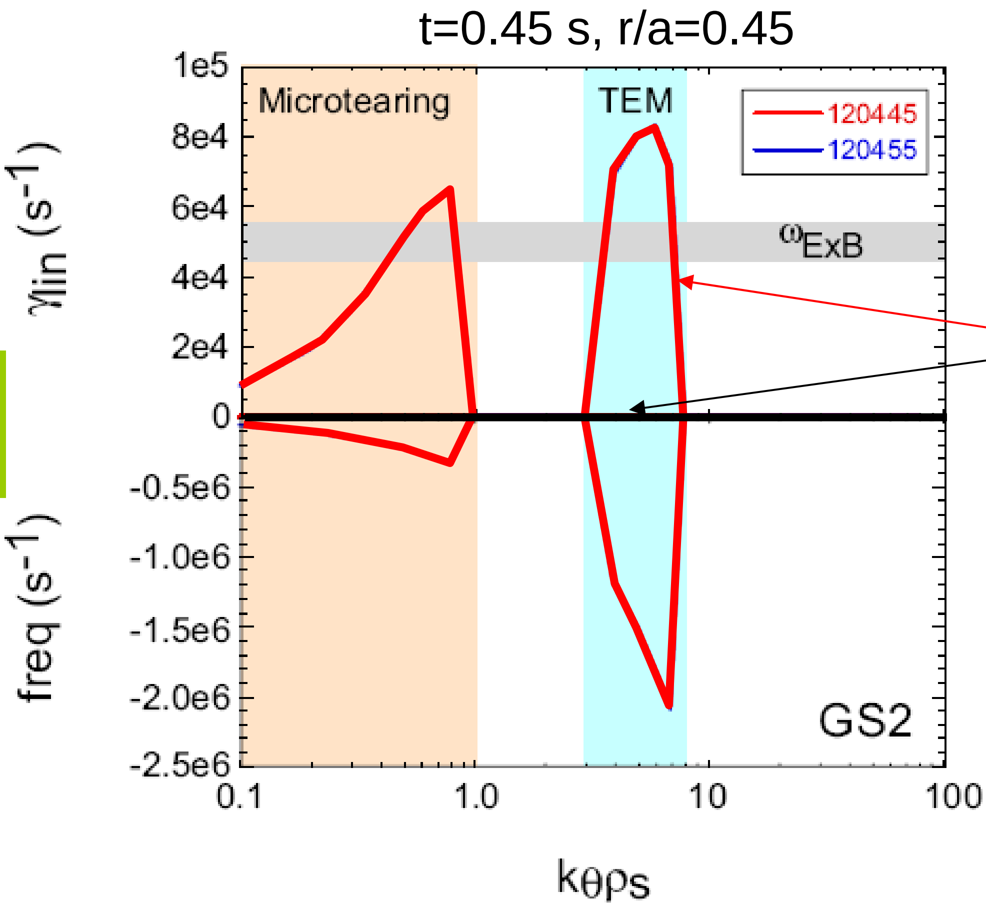
$$\Downarrow$$

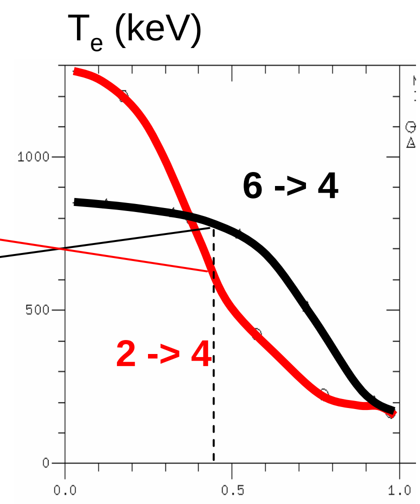
$$\chi_e / D_{Ne} \approx \varnothing (10^2)$$

(Rechester & Rosenbluth 1978)

- D_{imp} ~ neoclassical in high power H-modes (Delgado et al. PPCF 07)
- χ_e^{pert}, χe^{PB} up to ~ 100 times larger
- Magnetic (stochastic) transport would explain gap
- μ-tearing χ_e in the experimental range (K. Wong et al. this meeting)

GS2 calculations also point to micro-tearing drive





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- Linear calculations only indicative of trends (2->4 case has in fact lower χ_e)
- Central T_e flattening at high P_{NB} may nevertheless reflect saturated μ-tearing

Summary

- Simple perturbative technique used to probe electron transport dependence on P_{NB} and q

- Results suggest T_e flattening consistent with low critical gradient in NSTX

- μ-tearing possible mechanism for $\chi_e >> \chi_i$, D_{imp}

- Large ρ^* in NSTX could enhance q-profile / zonal flow effects such as ITB formation at low order rational-q surfaces

- Scaling of perturbed electron transport with B_t, I_p and n_e planned next