Perturbative electron transport experiments using pellet injection in NSTX

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

Johns Hopkins University

M. Bell, R. Bell, S. Kaye, H. Kugel, B. LeBlanc, L. Roquemore

PPPL

C. Bush, R. Maingi

ORNL

V. Soukhanovskii

LLNL

ABSTRACT

- Motivation:
  - electron thermal transport dominant in beam heated NSTX H-mode
  - unusual features: global T_e crashes after Type-I ELM, flat core T_e at high beam power

- Experiment:
  - heating power and q-profile independently varied and the T_e profile perturbed with pellets

- Results:
  - clear differences in the electron response with both power and q
  - unexpectedly large effect from q-profile
  - perturbed electron transport about 10^2 faster than particle one
  - magnetic and/or high-k electrostatic transport possible in NSTX

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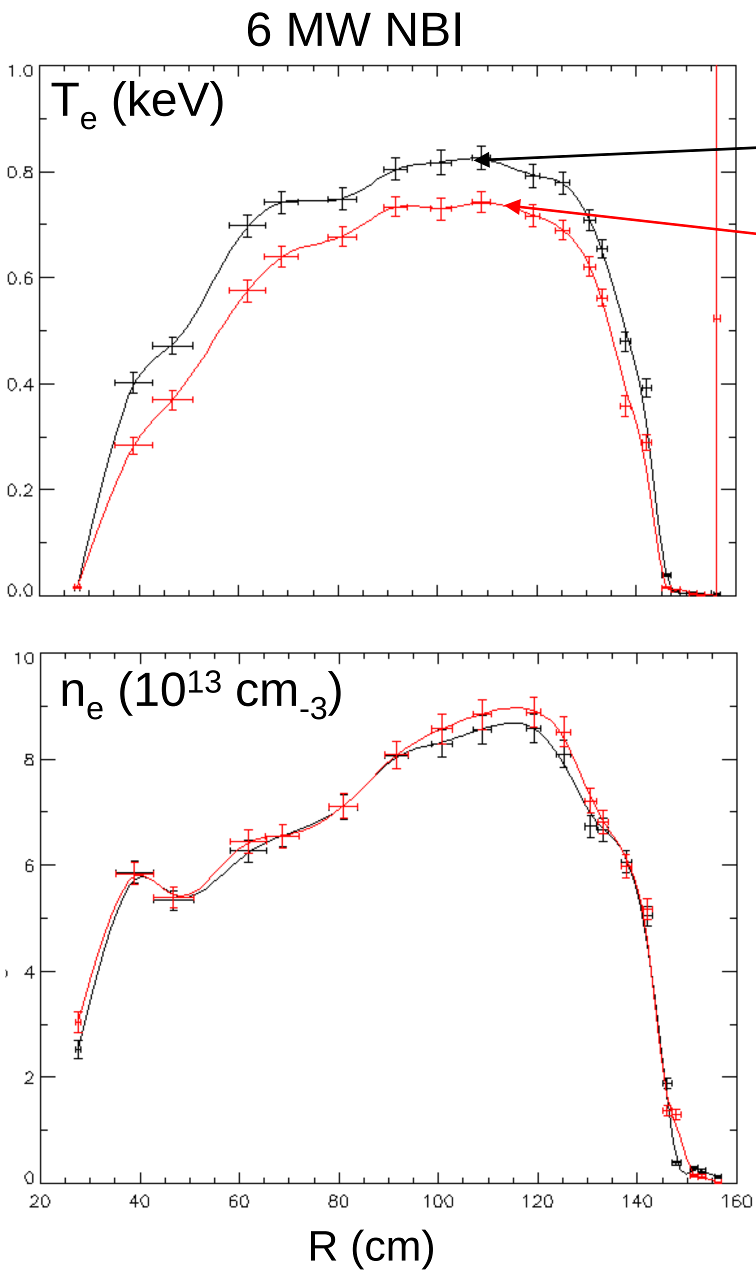
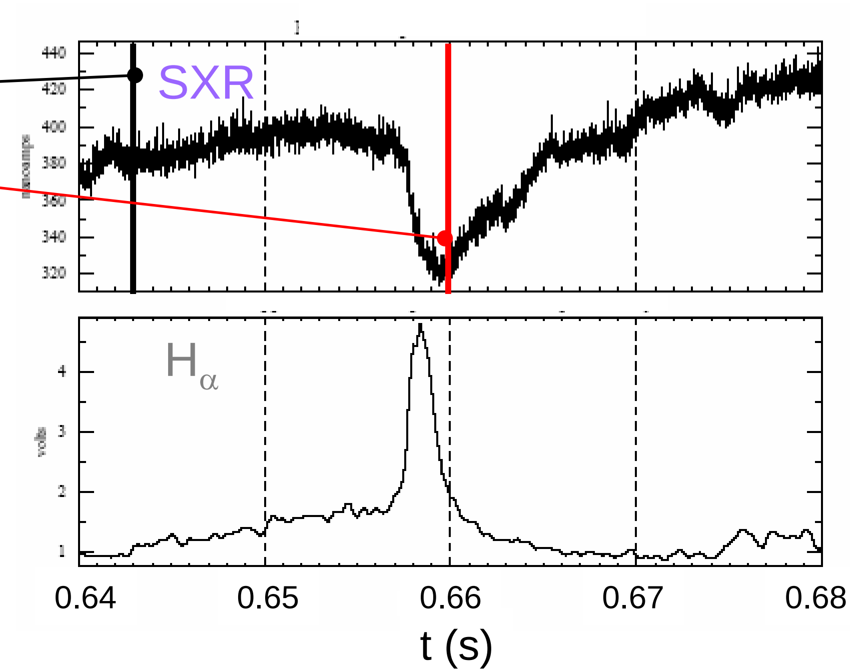
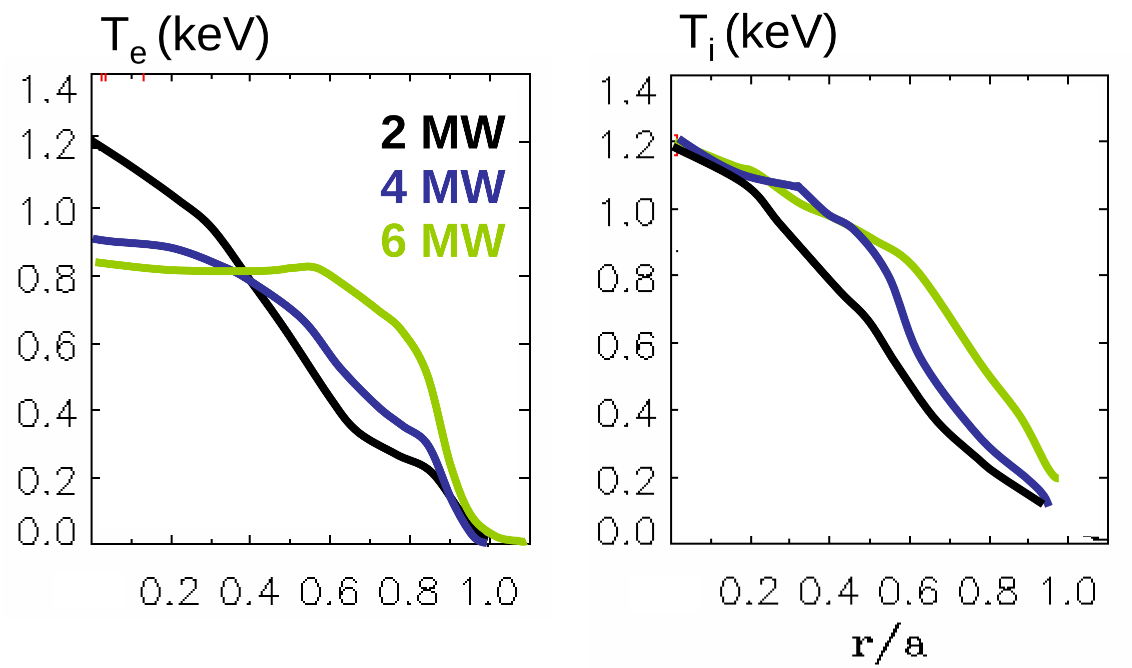
Motivation: T_e globally perturbed after Type-I ELM

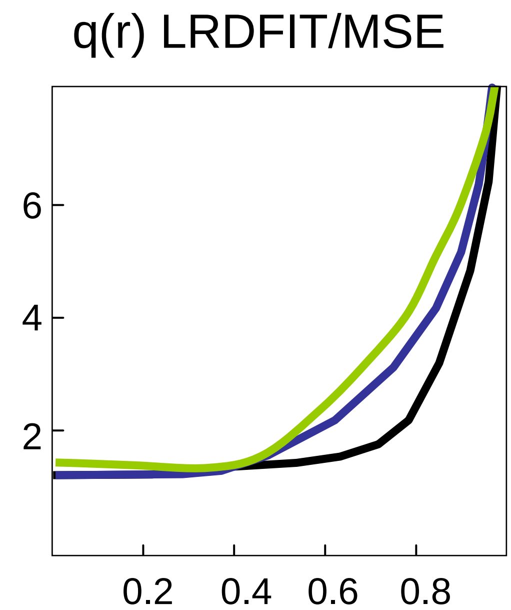




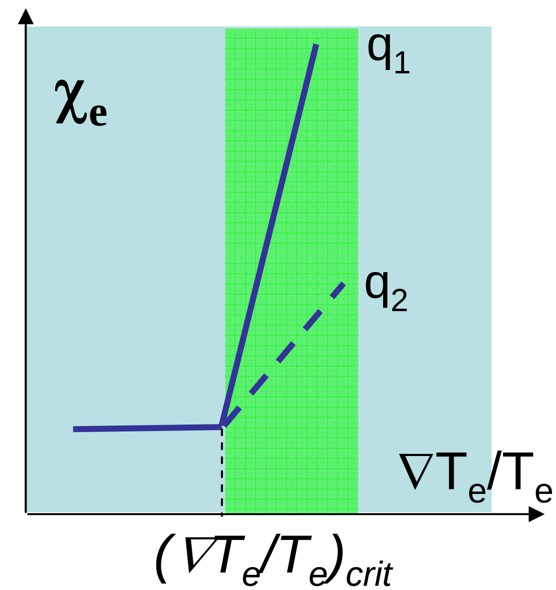
- Density profile little perturbed
- $\nabla T_e/T_e$ unchanged at drop
- Suggests stiff T_e profile at high heating power

Motivation: T_e flattens at high P_{NB}





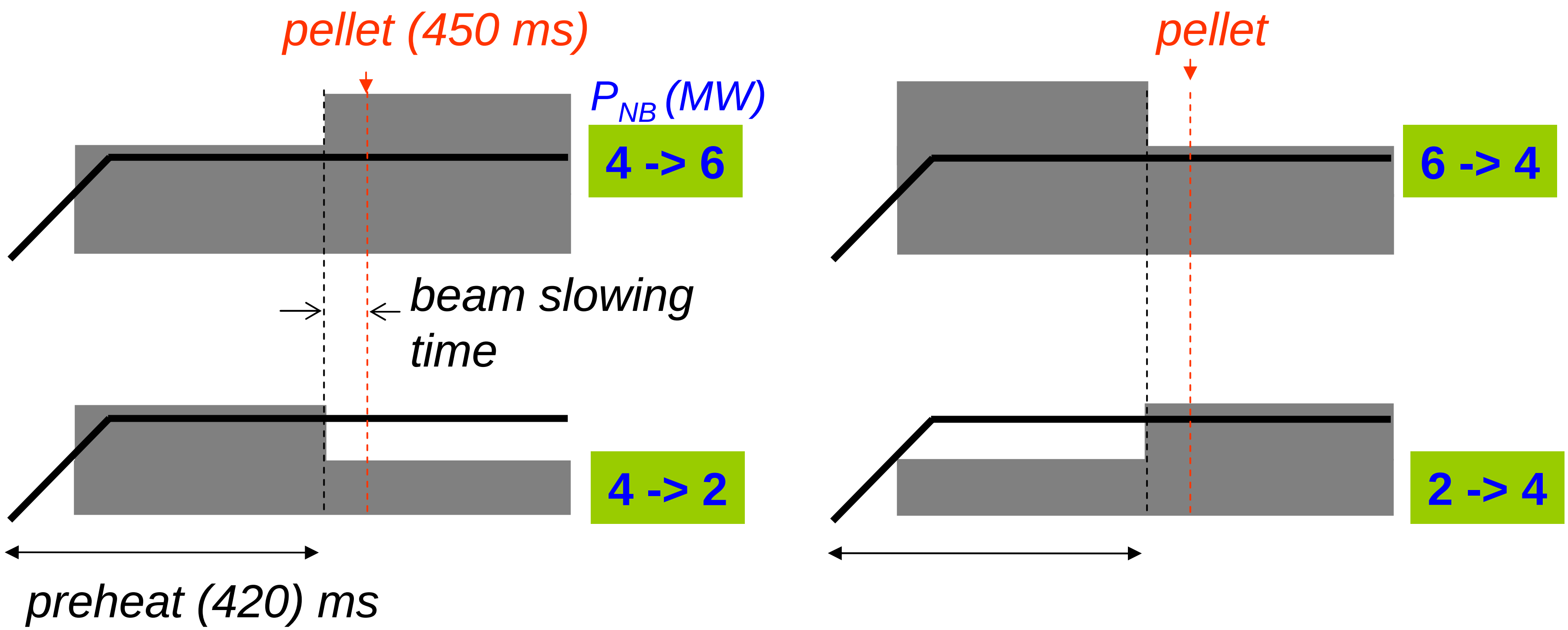
- 1 MA, 4.5 kG, high-κ, -δ, 'small-ELM', t ~ 0.42 s
- At high P_{NB} most of the T_e gradient at r/a > 0.7
- T_i gradient changes less
- Heat flux (critical gradient) and/or q-profile effect ?
- Study perturbed electron transport vs. P_{NB}, and q



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

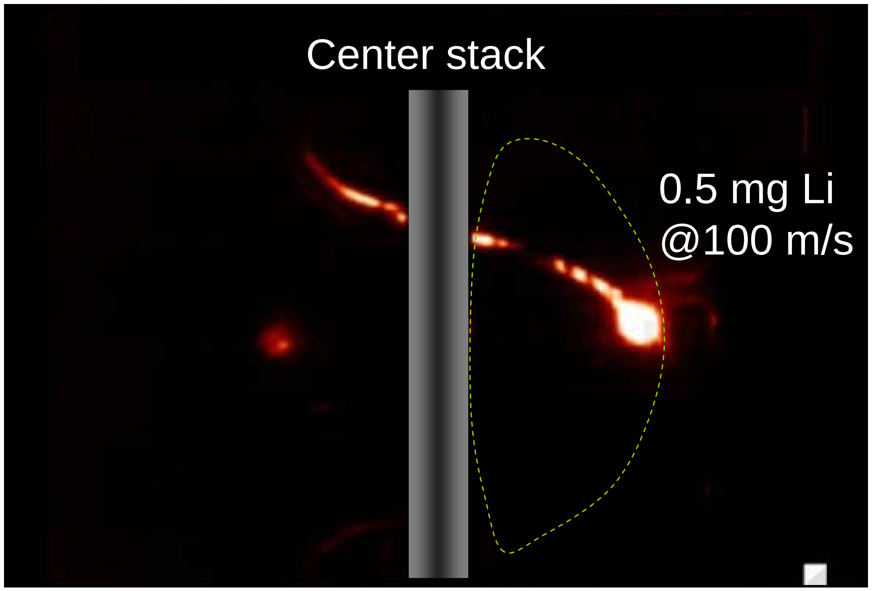
I) P_{NB} change at fixed q

II) q change at fixed P_{NB}

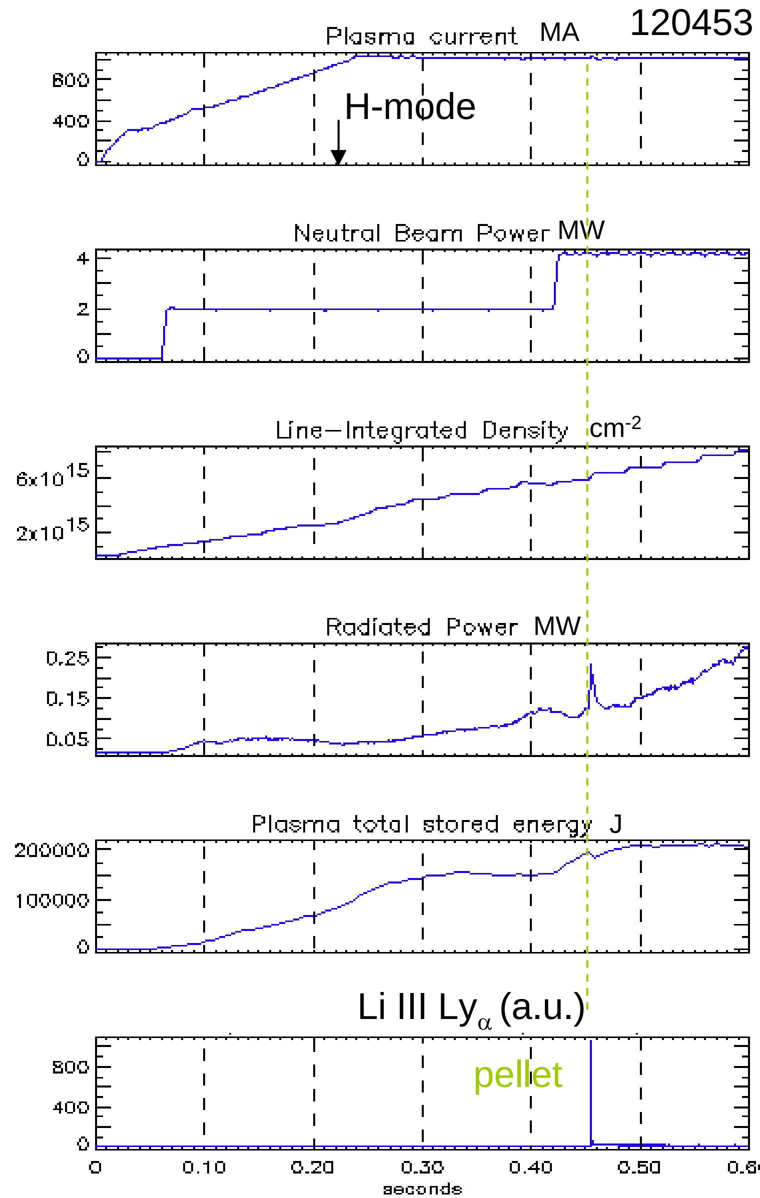


- Preheat to 'freeze-in' q-profile -> vary P_b -> pellet perturbation
- Vary frozen-in q-profile by varying preheat power

Shallow Li pellet used for controlled T_e perturbation

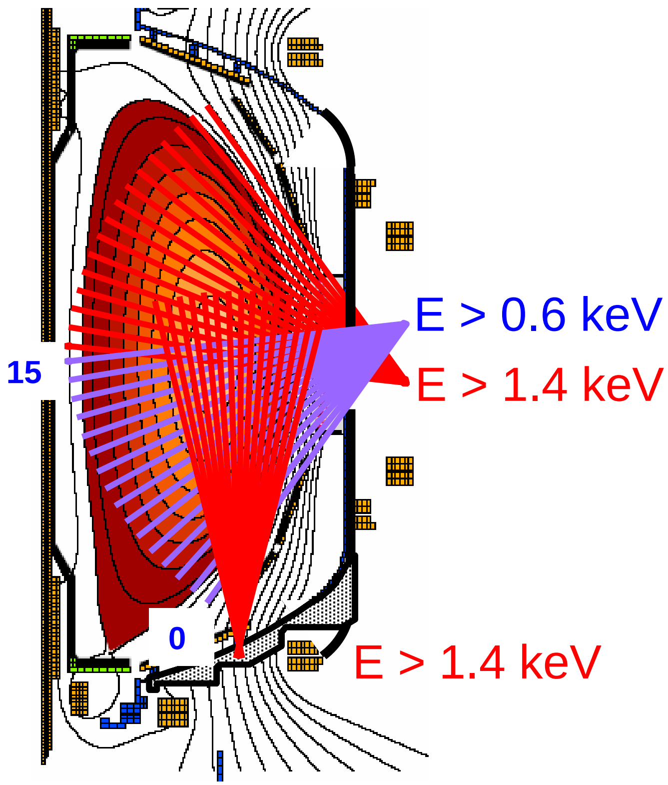


- Pellet ablates near edge
- Small density perturbation
- Only few % equilibrium change



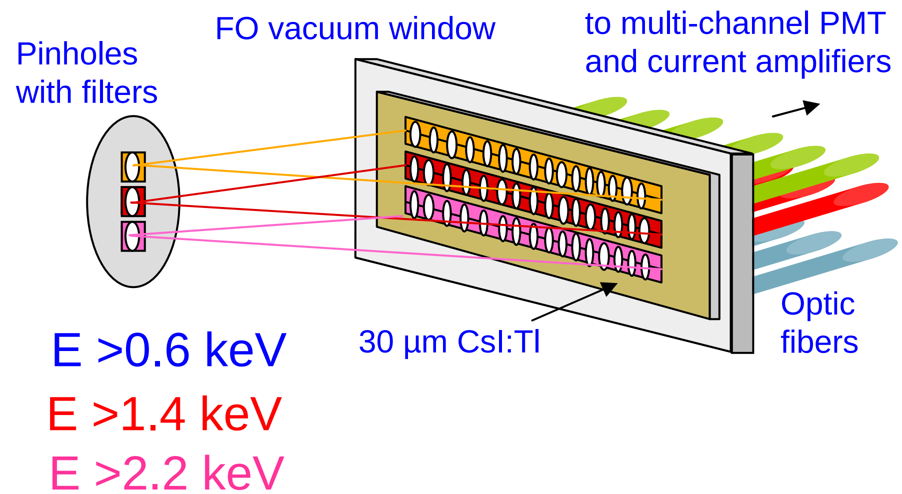
‘Multi-color’ SXR arrays used for fast T_e measurement

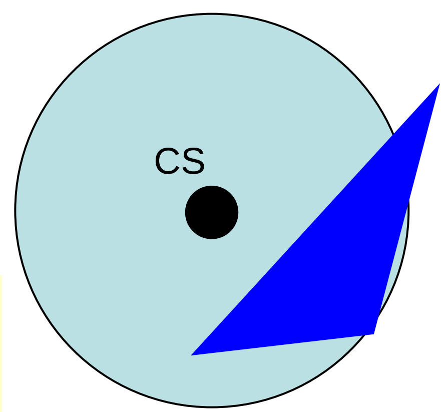
Poloidal SXR diode arrays



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

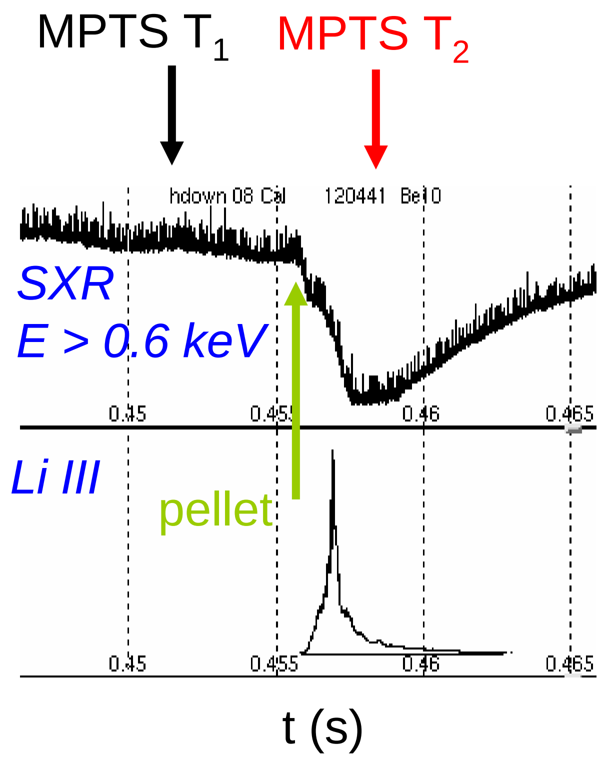
Tangential ‘optical’ SXR array

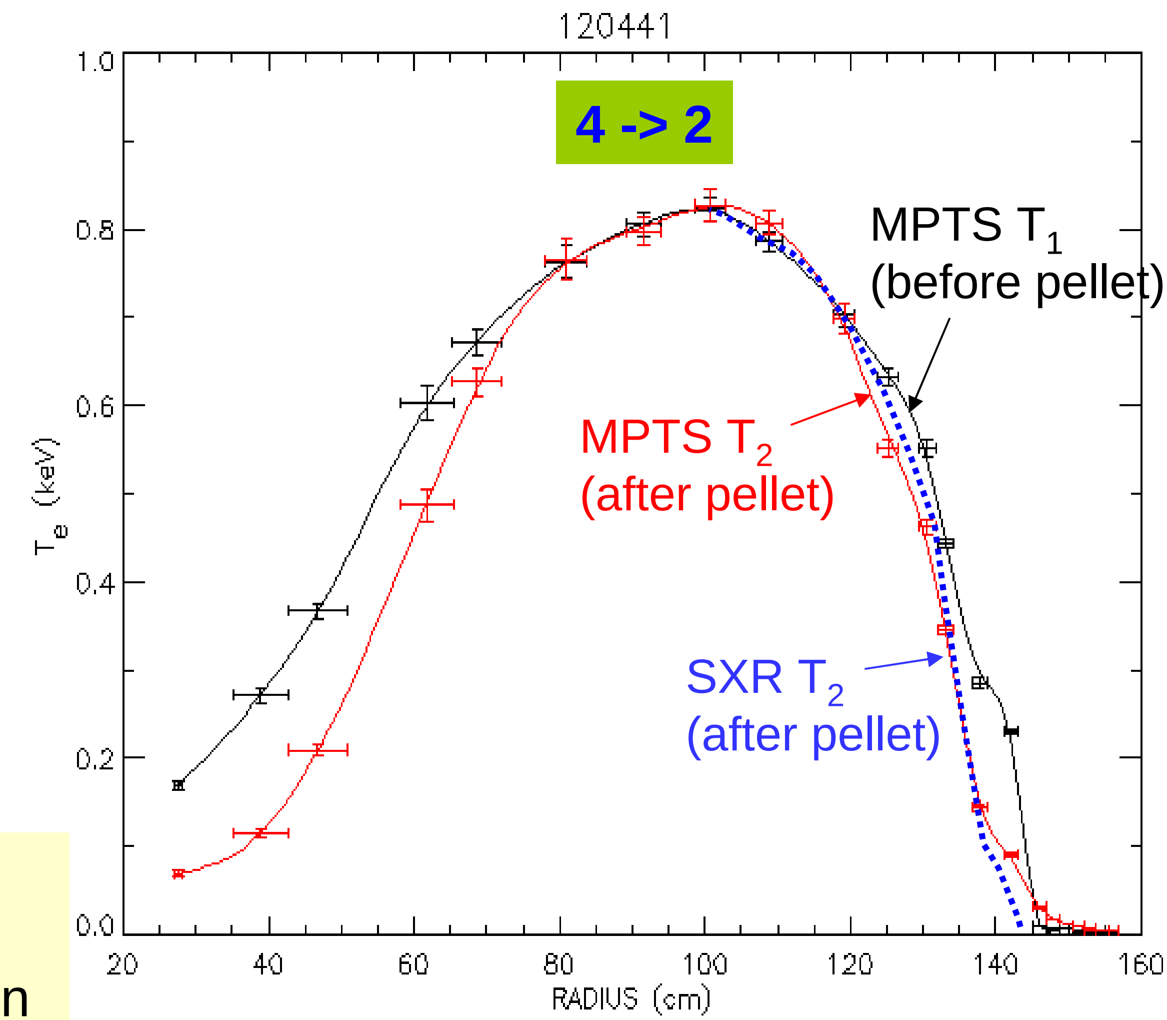




$\Delta r \sim 4$ cm
$\Delta t \sim 100$ µs

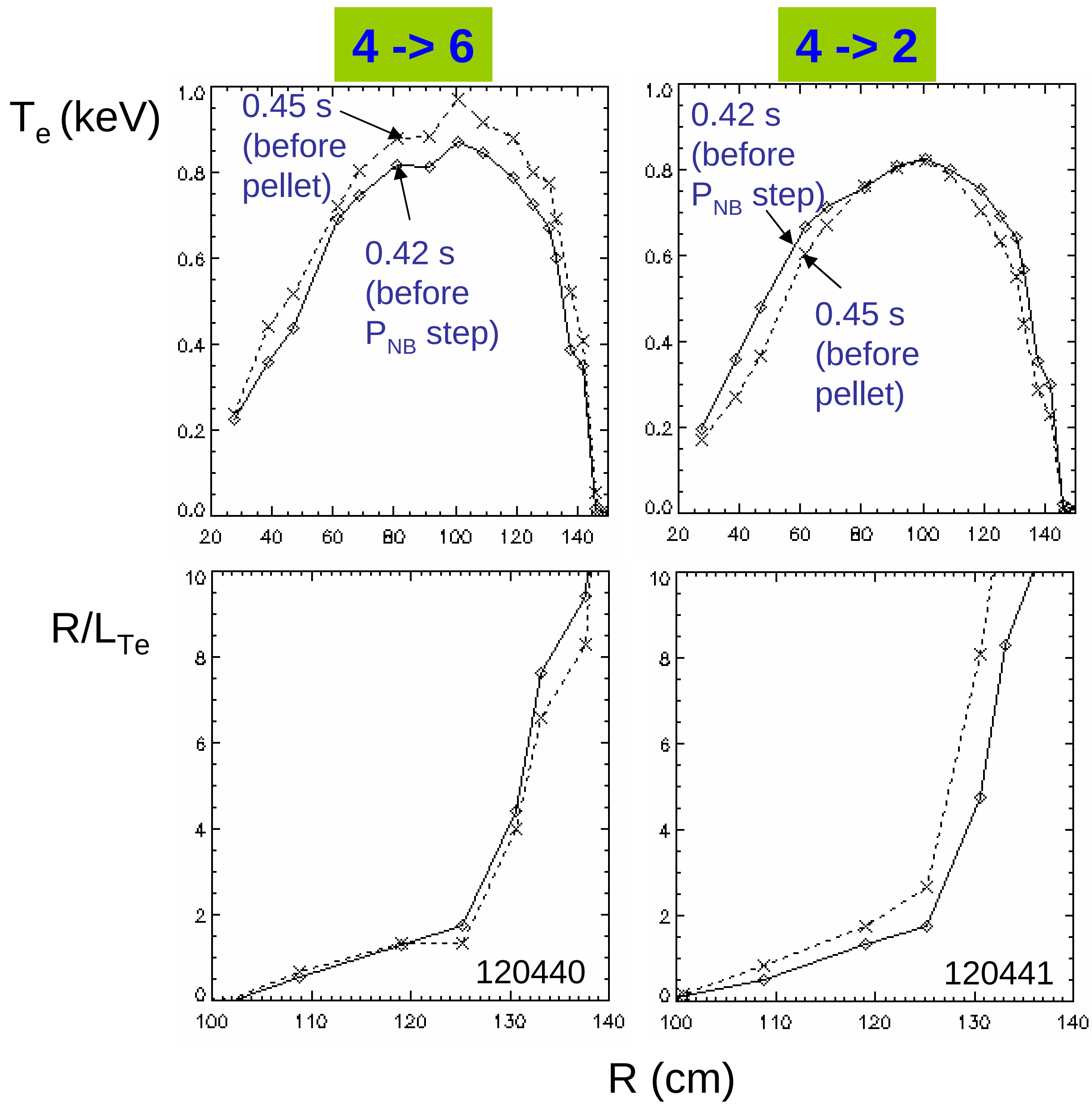
SXR T_e agrees with MPTS



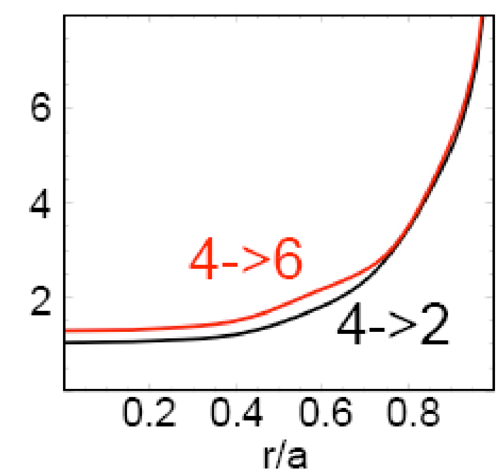


- $T_e(r)$ 'propagated in time' between multi-point Thomson scattering (MPTS) points, using SXR intensity ratios

Results: T_e responds differently to P_{NB} changes at fixed q

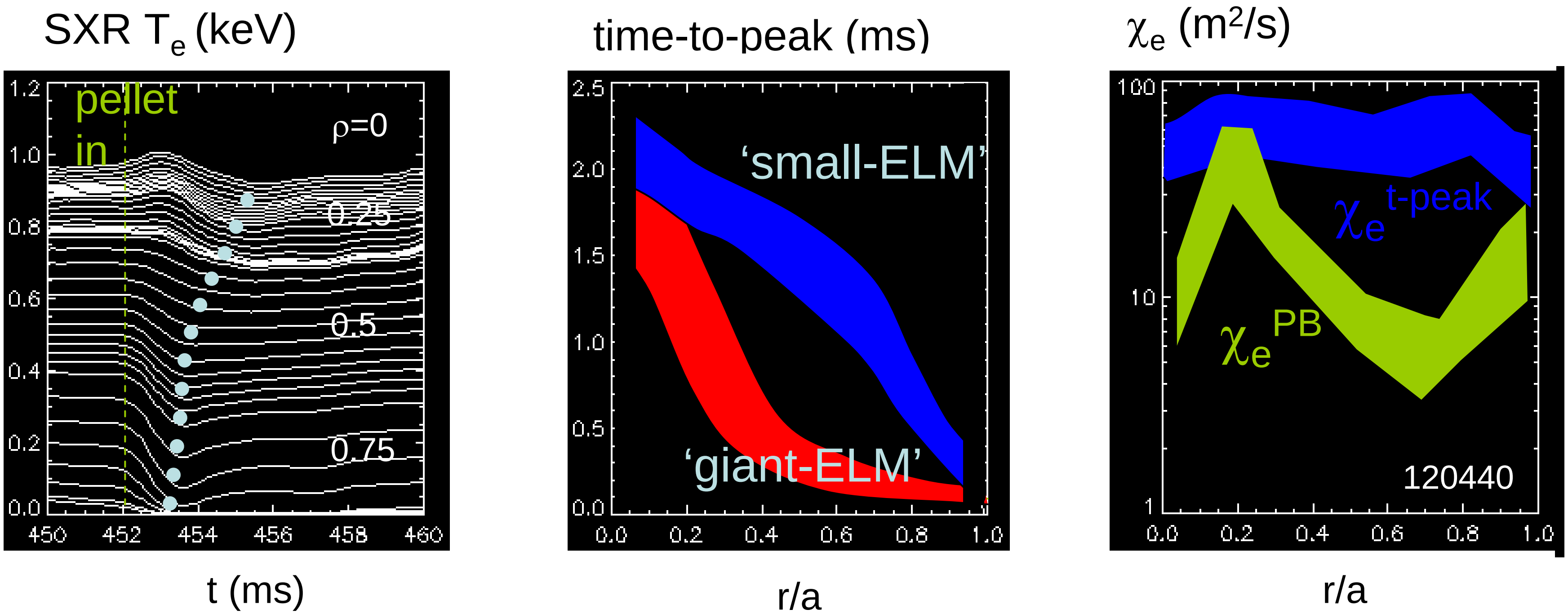


- Global T_e increase after P_{NB} increase
- R/L_{Te} ~ constant
- No decrease in central T_e after P_{NB} drop
- R/L_{Te} increases
- Little change in q-profiles (LRDFIT/MSE)



Cold pulse affects entire plasma at high beam power

4 -> 6

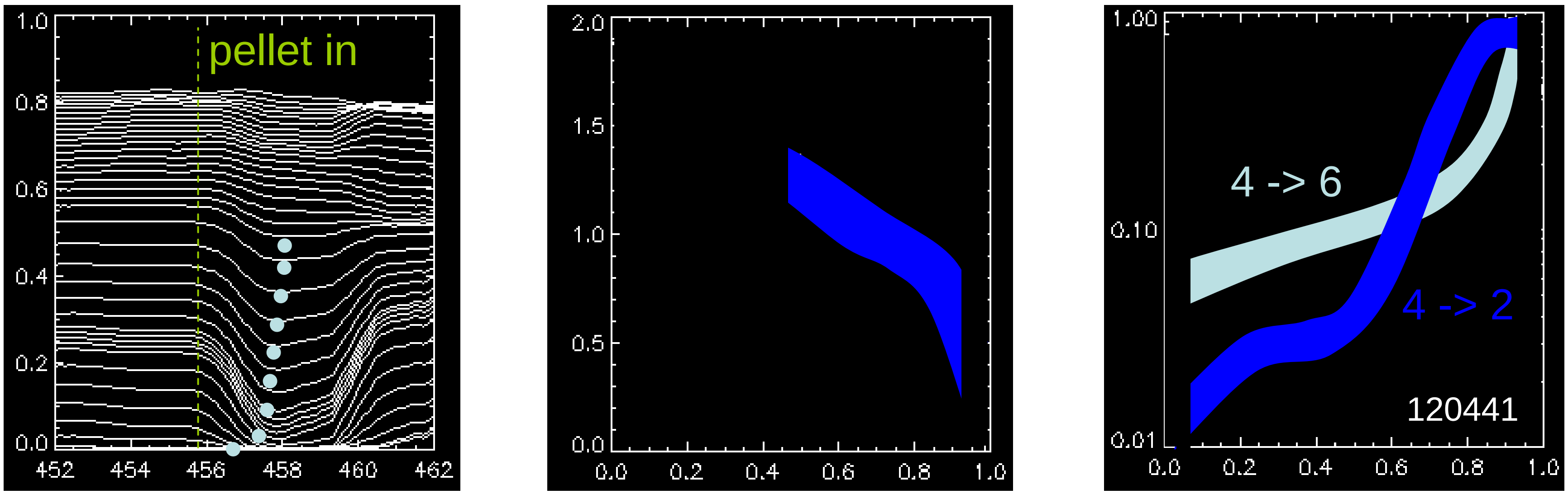


- Time-to-peak of perturbation ~ 2 ms-> χ_e^{pert} ~ several tens of m^2/s
- Time-to-peak nevertheless decreased in outer plasma of 'small-ELM' H-mode, as compared to 'giant-ELM' case
- Correlation between ELMs and perturbed transport (talk by K. Tritz)

At reduced power cold pulse is damped in the center

4 -> 2

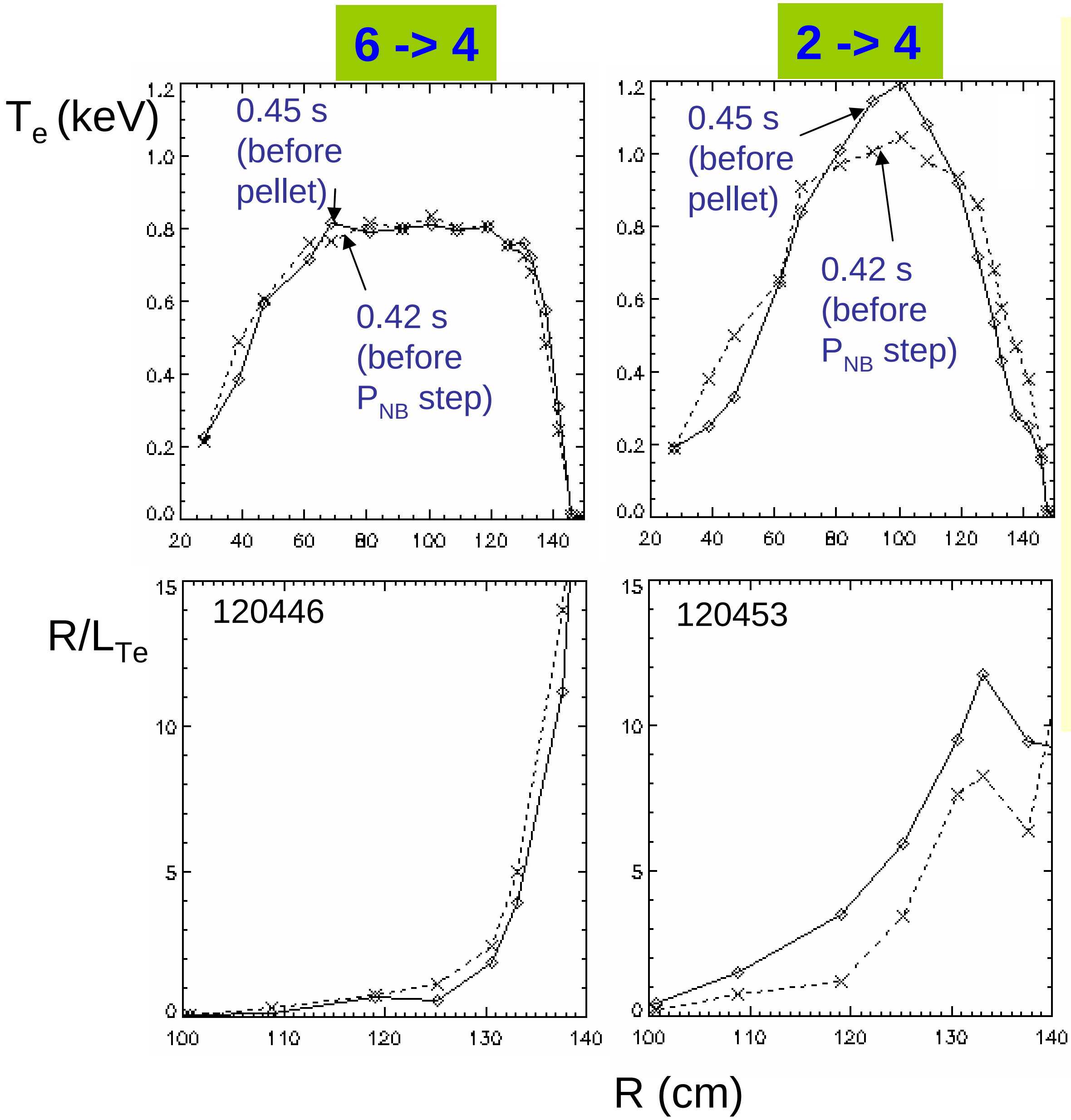
SXR T_e (keV) Time-to-peak (ms) Perturbation amplitude



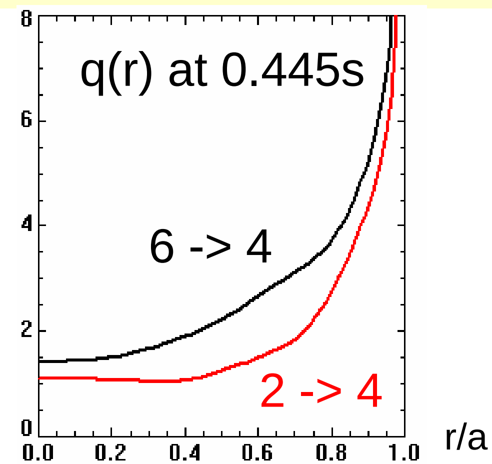
t (ms) r/a r/a

- Much reduced perturbation in central plasma (see also MPTS)
- Propagation in the outer plasma still rapid
- Critical gradient for r/a<0.5 is between 2 MW and 6 MW; likely lower outside

T_e response to q changes at fixed P_{NB} also different



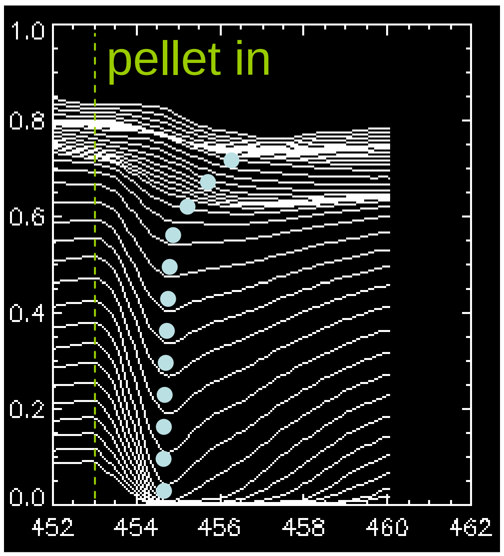
- T_e profile unchanged at high preheat power
- Central T_e and gradient increase at low power
- Lower q in the 2 -> 4 case (LRDFIT/MSE)
- 2->4 *scenario resembles hybrid-mode ?*



Rapid propagation at all radii at high preheat power

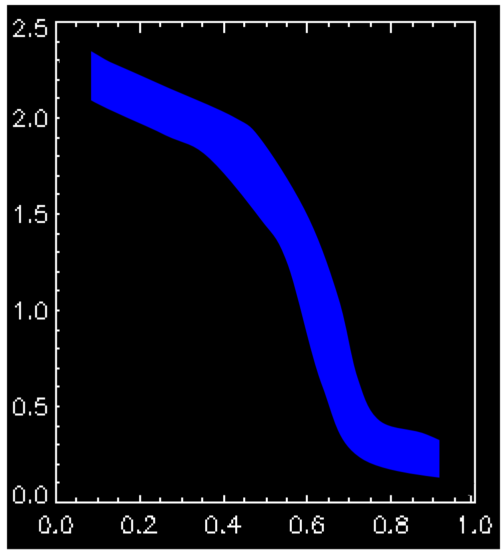
6 -> 4

SXR T_e (keV)



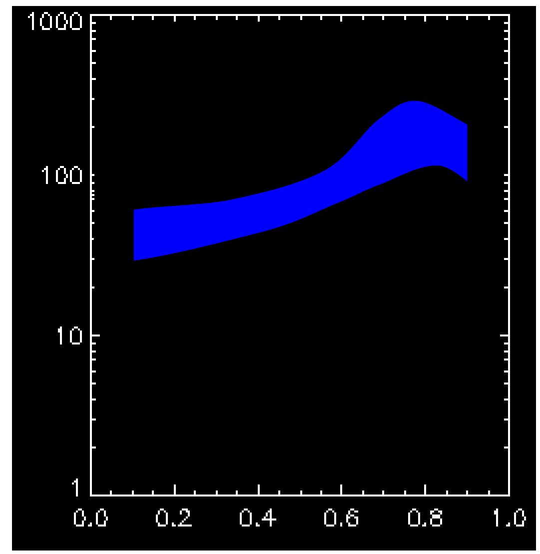
t (ms)

time-to-peak (ms)



r/a

$\chi_e^{t\text{-}peak}$ (m^2/s)

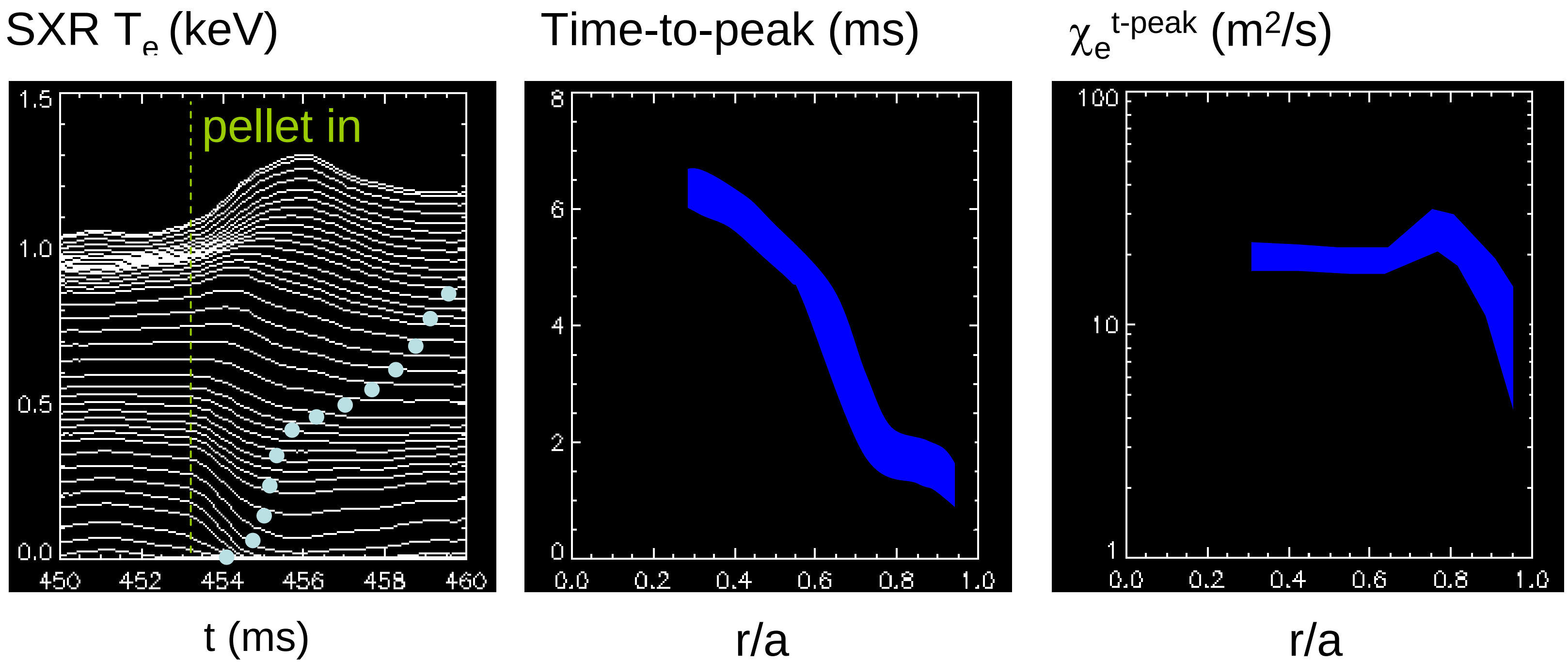


r/a

- Very fast propagation in the outer plasma
- Central region also perturbed after ~ 2 ms
- Worst transport situation overall

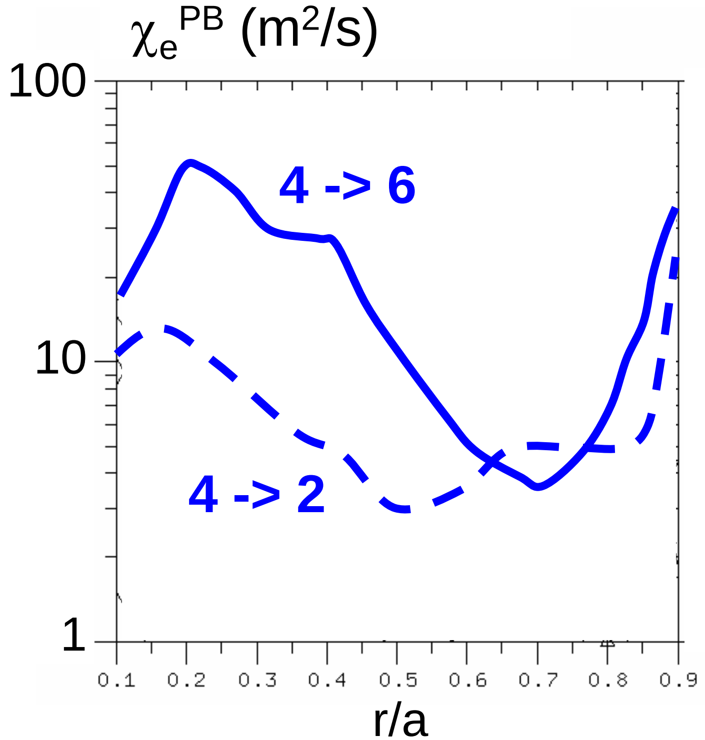
At reduced preheating cold pulse is much slower

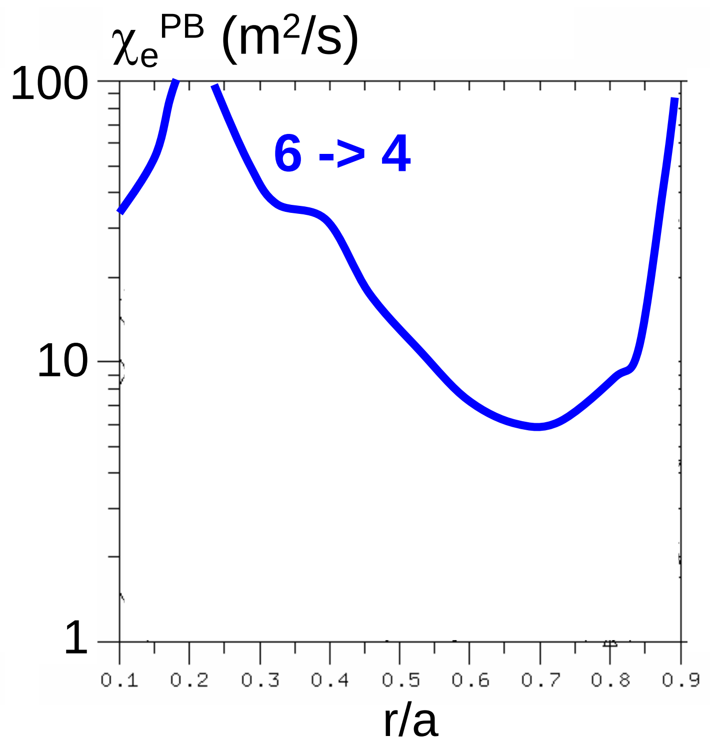
2 -> 4



- Much slower cold pulse and reduced χ_e^{pert} at all radii
- 'Polarity reversal' of T_e perturbation inside q=1 radius
- Best transport situation overall
- Low-order rational surfaces at large radii make the difference ?

Equilibrium electron transport shows comparable trends



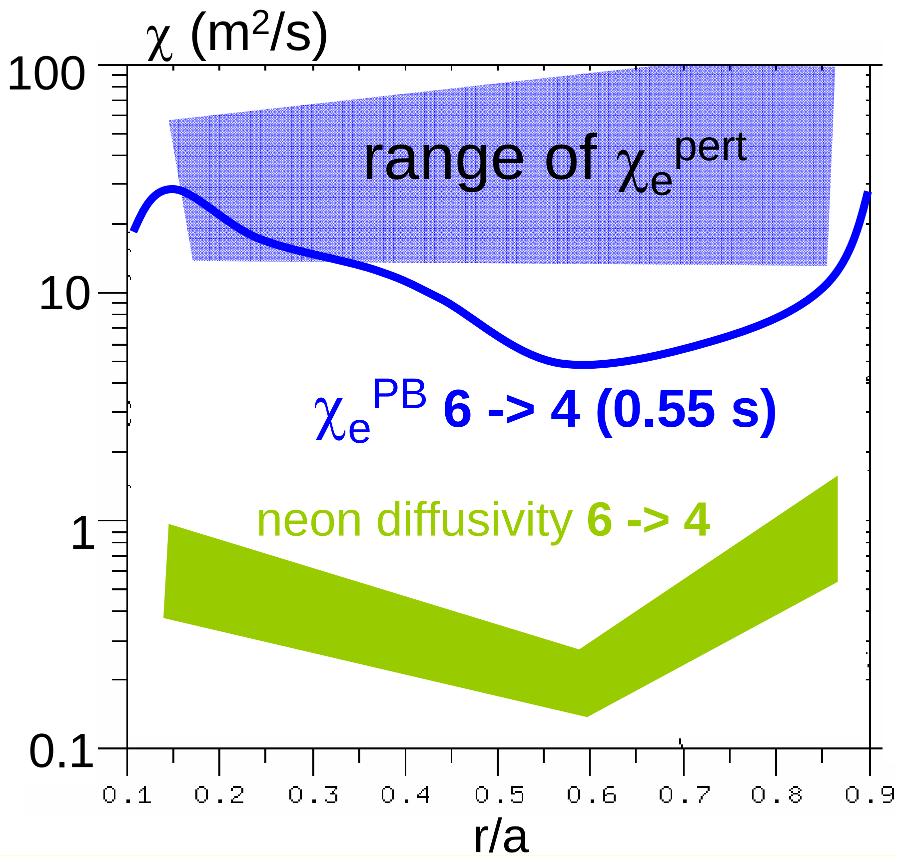


t=0.435 s

- Large decrease in central transport when heat flux is reduced

- Large change with q-profile (TBD)
- Worst electron transport with q-profile obtained with early heating at high power (main NSTX scenario)

Perturbed particle transport much slower than electron



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

$$\Downarrow$$

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

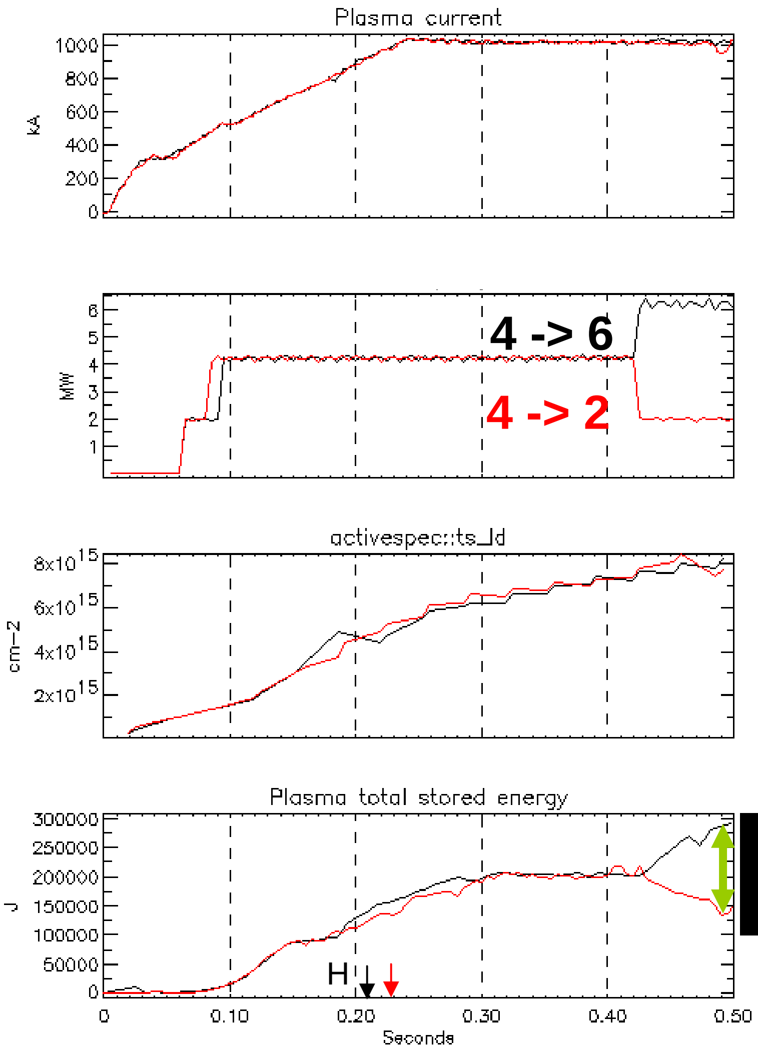
$$\Downarrow$$

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

(Rechester & Rosenbluth 1978)

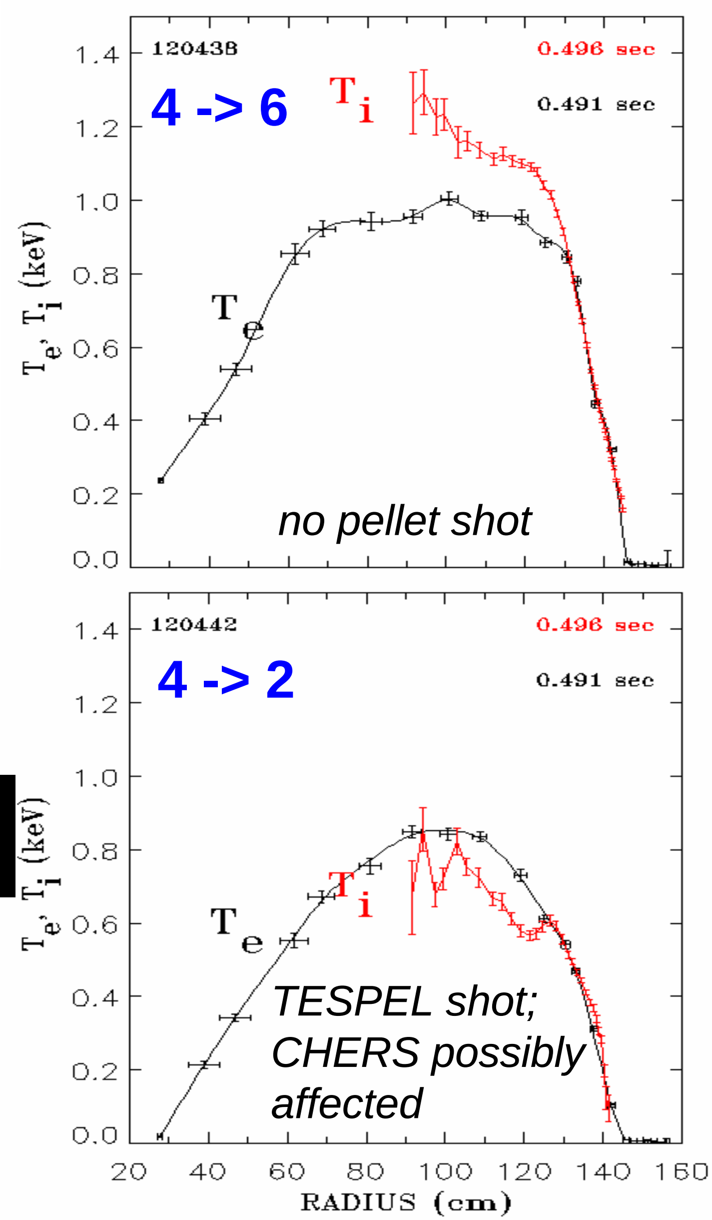
- Particle diffusivity close to neoclassical -> low-k turbulent transport likely suppressed (see poster by L. Delgado)
- Experimental $\chi_e/D_{Ne} \sim \mathcal{O}(10^2)$ -> magnetic or/and high-k turbulence likely behind rapid electron transport in NSTX

T_i appears to change more than T_e with P_{NB} at fixed q



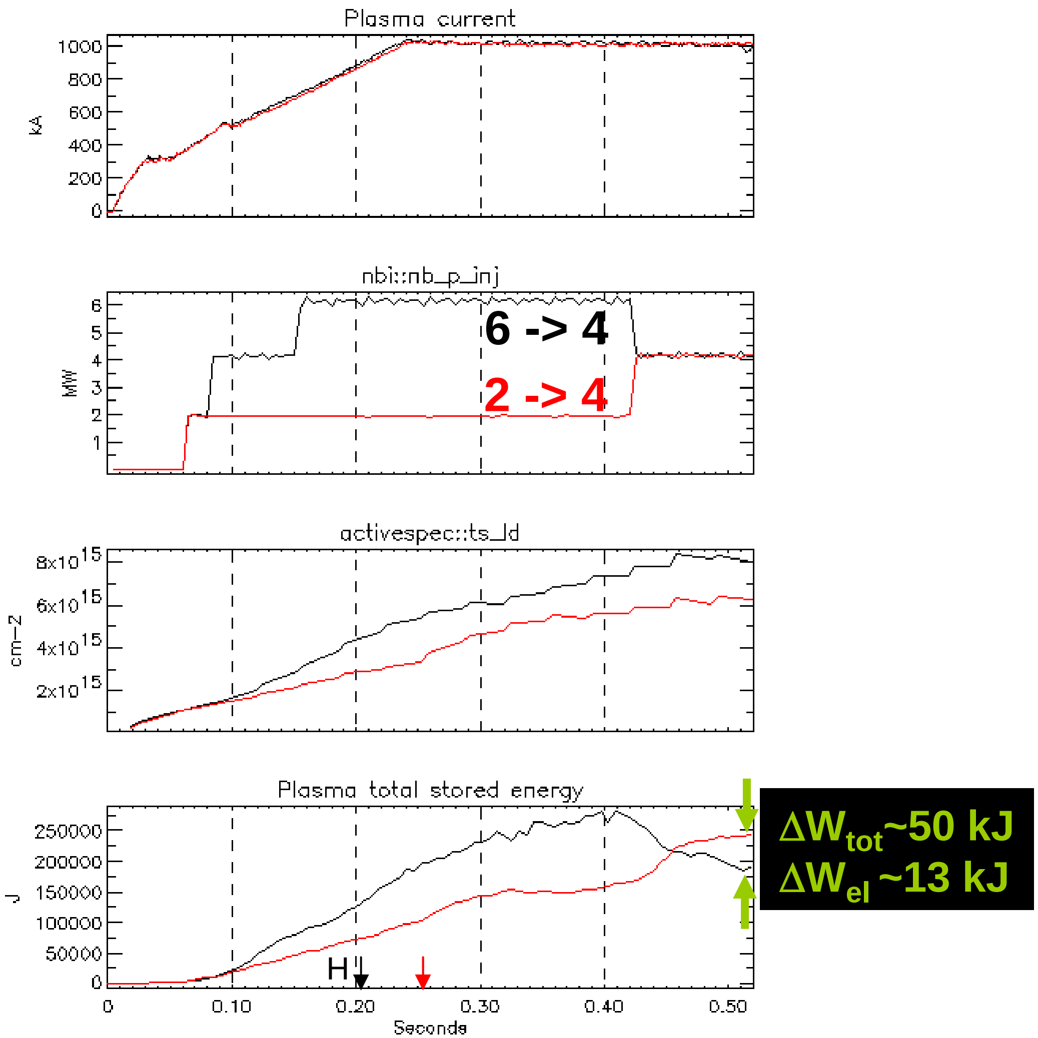
ΔW_{tot}~135 kJ
ΔW_{el} ~40 kJ

t=0.5 s

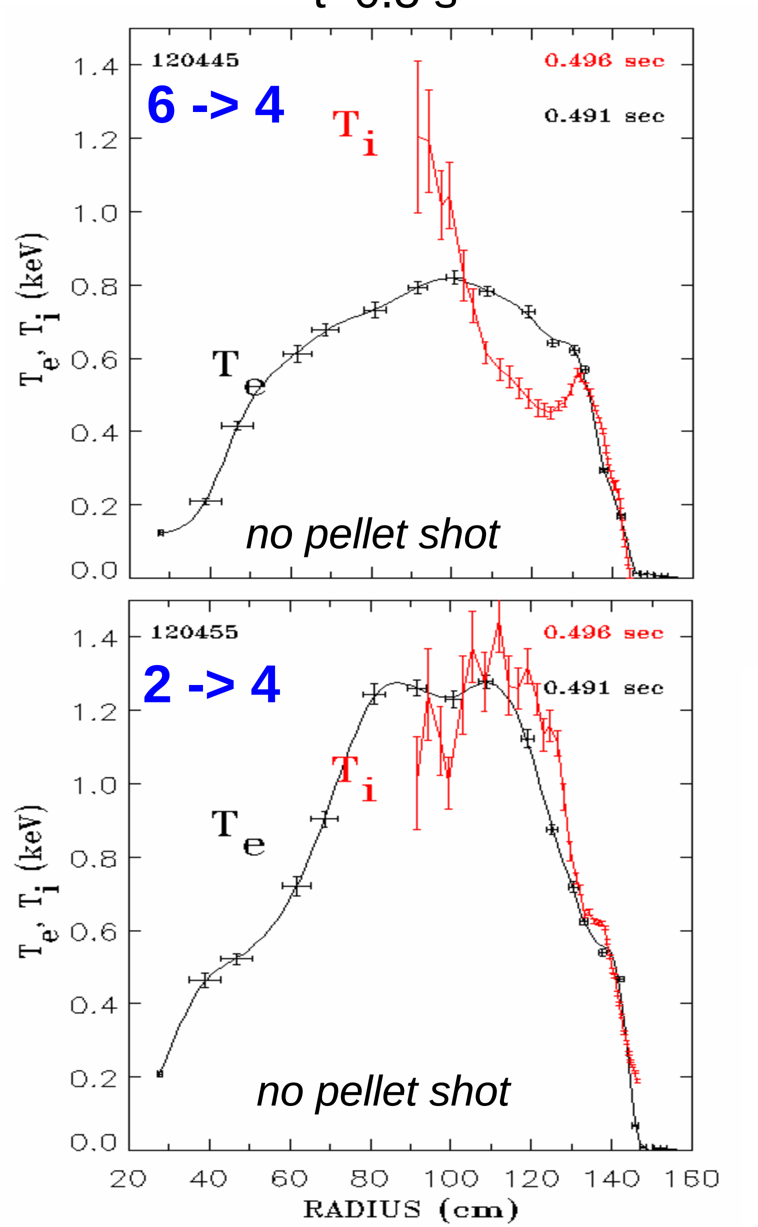


- Most of W_{tot} change due to ions
- Beams heat primarily electrons

Puzzling effects also with q changes at fixed P_{NB}

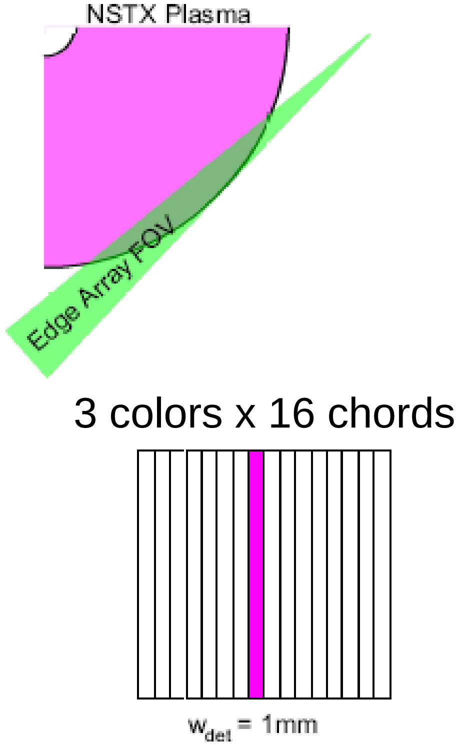


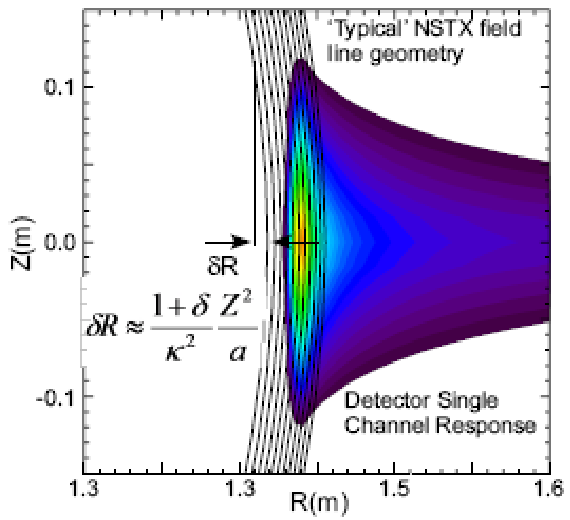
t=0.5 s

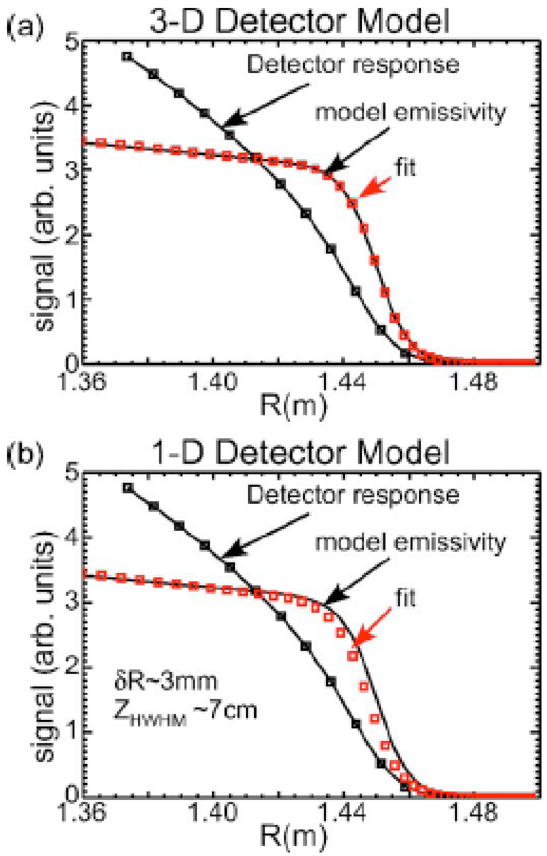


- Unusual T_i profiles when power dropped
- Large difference also in rotation profiles

1-cm resolution multicolor SXR array planned for the NSTX pedestal







- 3-D modeling shows dense coverage ensures good spatial resolution despite line integration

Tritz *et al* RSI 06

Conclusions

- Pre-heat technique for varying P_b at fixed-q and q at fixed P_b is effective
- Cold pulse changes with P_b and q support 'critical gradient' picture
- Changes in equilibrium transport also consistent
- Critical gradient in the center crossed between 2-6 MW ->

  T_e flattening at high power is genuine transport effect
- Edge critical gradient probably lower
- Q-profile has strong effect on H-mode transport, as seen also in L-mode
- Possibly major role for low order rational surfaces, magnetic shear
- Particle transport ~ neoclassical, while electron transport very rapid ->

  magnetic and/or high-k turbulence ?
- 1-cm resolution, multi-color array planned for fast T_e in the pedestal