Perturbative studies of electron transport in NSTX

D. Stutman, K. Tritz, L. Delgado Aparicio, M. Finkenthal
Johns Hopkins U.

R. Bell, S. Kaye, H. Kugel, B. LeBlanc, F. Levinton, M. Redi, E. Synakowski, S.S. Medley, J. Menard, D. Mikkelsen, G. Rewoldt
PPPL

S. Sabbagh
Columbia U.

S. Kubota
UCLA

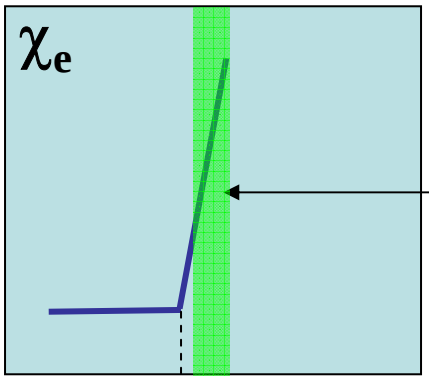
Critical gradient paradigm for electron transport

(Ryter 2001)

gyro-Bohm behavior

Critical gradient
for TEM, ETG turbulence

$$\chi_e = T_e^{3/2}[\xi_0 + \mathcal{G}(\nabla T_e/T_e - (\nabla T_e/T_e)_c)]$$



$R/L_{Te} = R/(T_e/\nabla T_e)$

'Stiff transport'

$\nabla T_e/T_e\,(r) \approx (\nabla T_e/T_e)_c \approx$ const.

$T_{core} \sim T_{edge}$

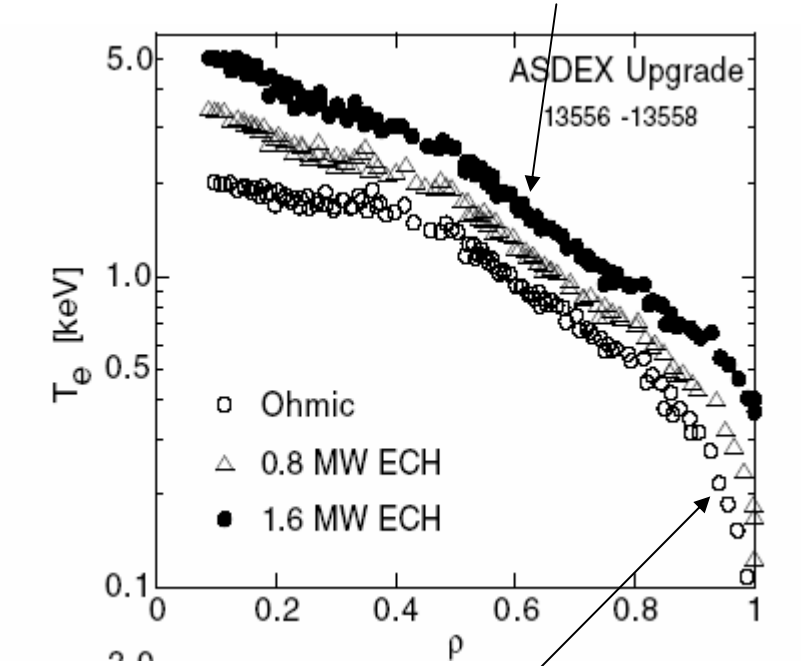
$\chi_e^{pert} >> \chi_e^{PB}$

Three parameter model recently applied to JET (Garbet, Mantica 2004)

$$\chi_T = \chi_s q^\nu \frac{T}{eB}\frac{\rho_s}{R}\left(\frac{-R\partial_r T}{T} - \kappa_c\right) H\left(\frac{-R\partial_r T}{T} - \kappa_c\right) + \chi_0 q^\nu \frac{T}{eB}\frac{\rho_s}{R}$$

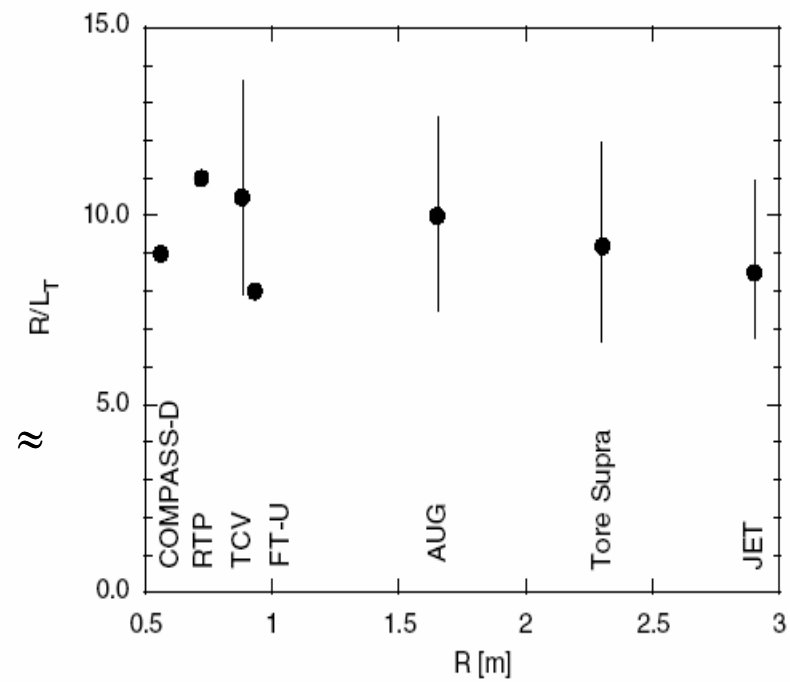
Evidence for critical gradient in tokamaks

$\nabla T_e/T_e\,(r) \approx$ const.



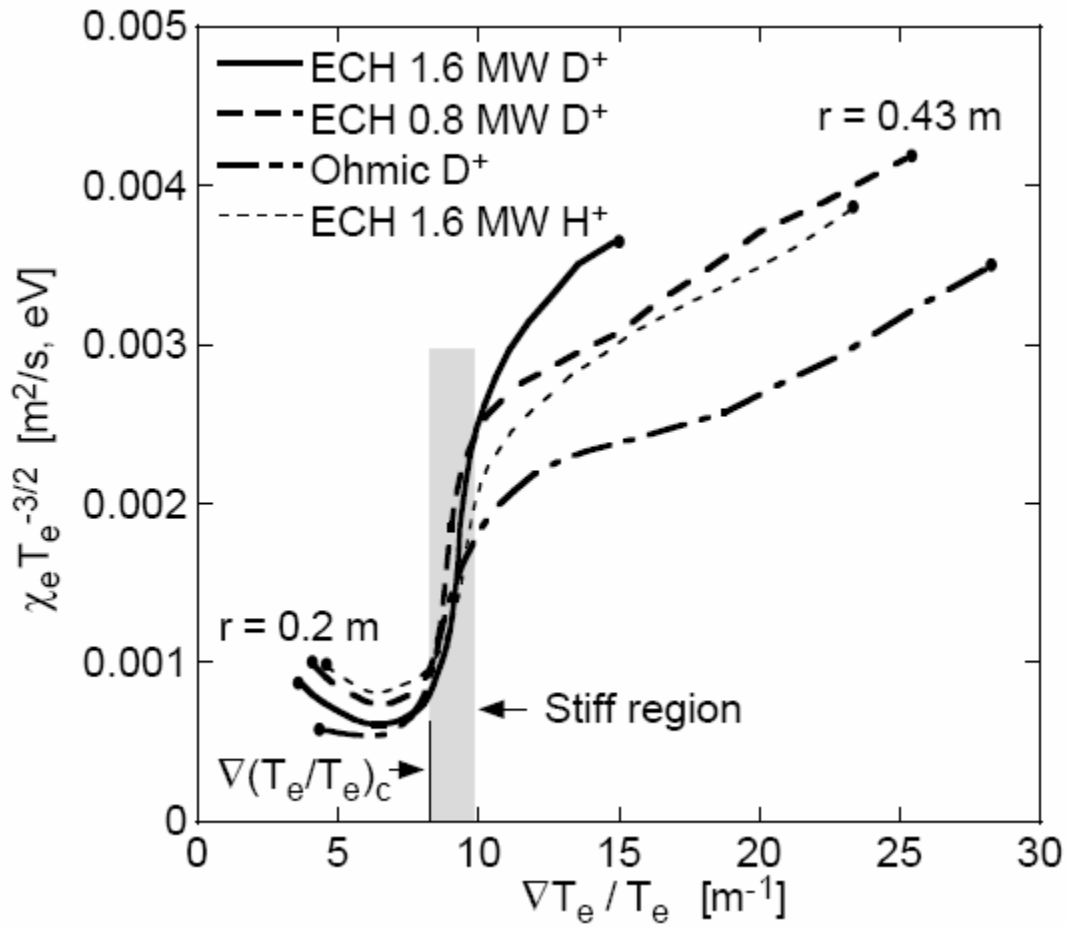
$T_{core} \sim T_{edge}$

$R/LT_e \approx 10$ ($\rho \approx 0.5$, electron heating)

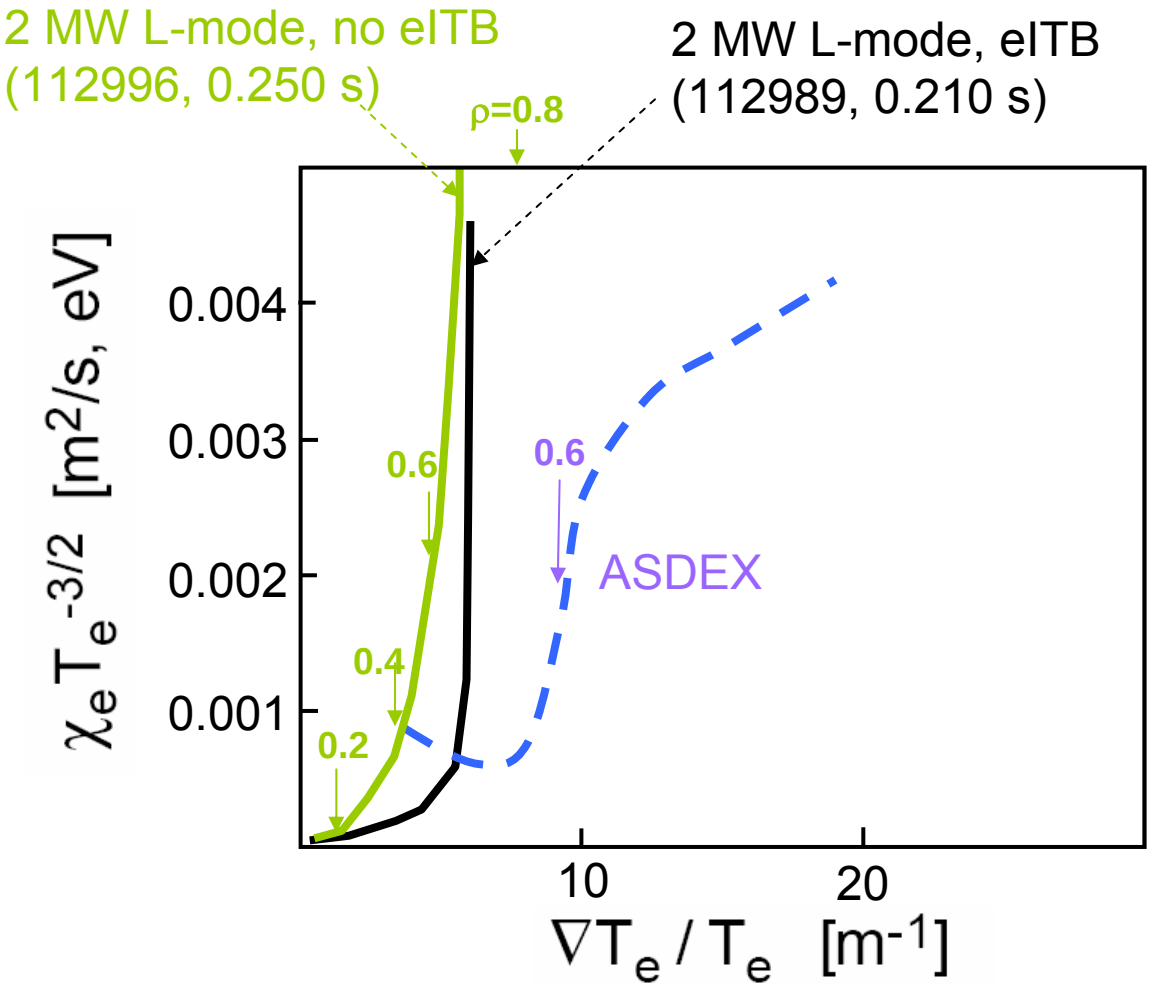


Critical gradient evident in scaled χ_e^{PB} profiles

ASDEX L-mode (Ryter 2001)

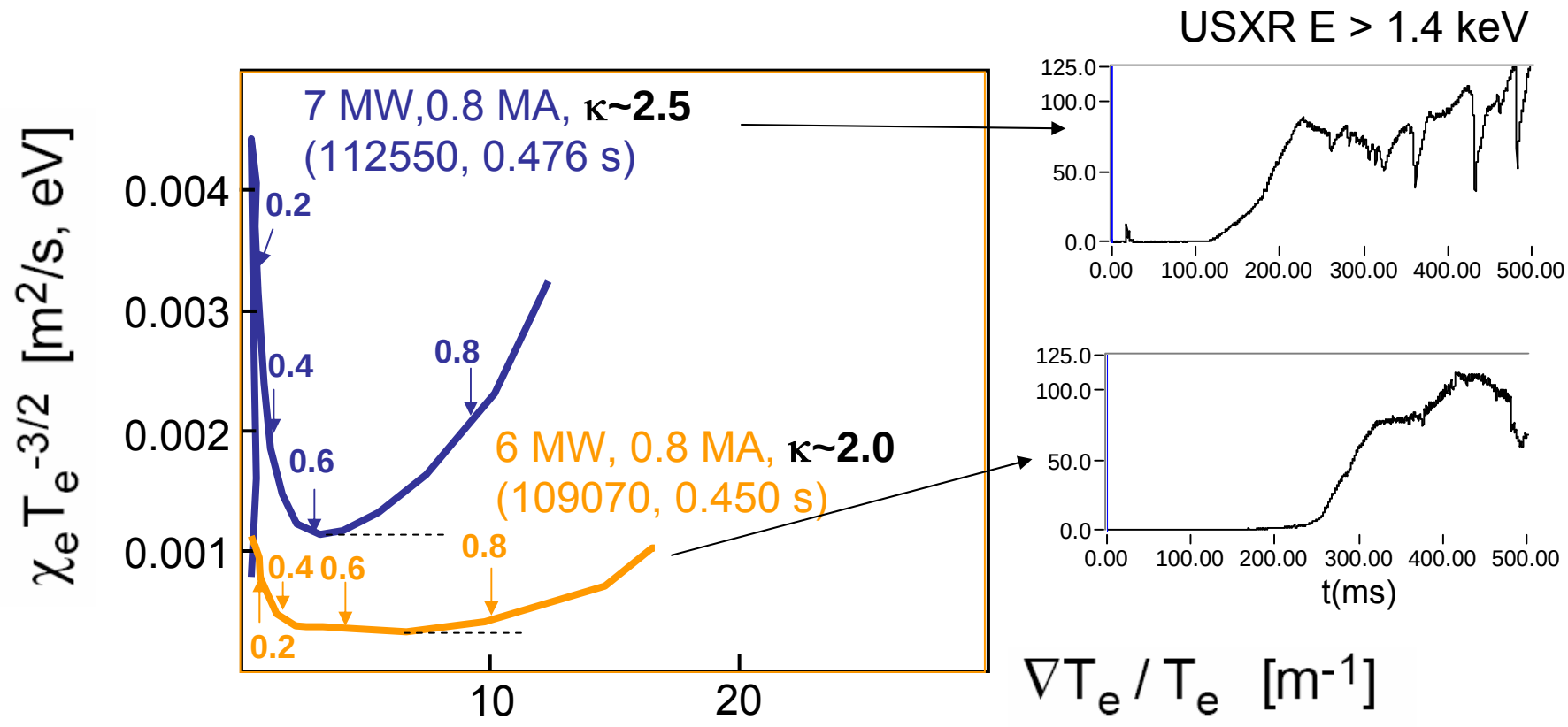


NSTX L-mode has lower critical gradient ?



- Critical gradient significantly increased by eITB/negative shear, while stiffer transport outside ?

Is electron transport stiffness 'causing' Type-I ELMs?



- In H-mode critical gradient higher, transport less stiff than in L-mode ?
- Appearance of strong Type-I ELMs seems to correlate with higher 'stiffness'
- Could it be that 'Type-I' ELMs are just 'regular' ELMs interacting with the stiff electron transport at high input power?
- Perturbative transport studies can directly probe $\partial\chi_e / \partial(\nabla Te)$

Goals of proposed XP

- Measure $\partial\chi_e / \partial(\nabla Te)$ to obtain 'critical gradient' model parameters for:
  - low n_e L-modes without eITB
  - low n_e L-modes with eITB
  - H-modes at increasing heating power ('simulate' Type I ELMs)
  - H-modes at increasing beta, elongation

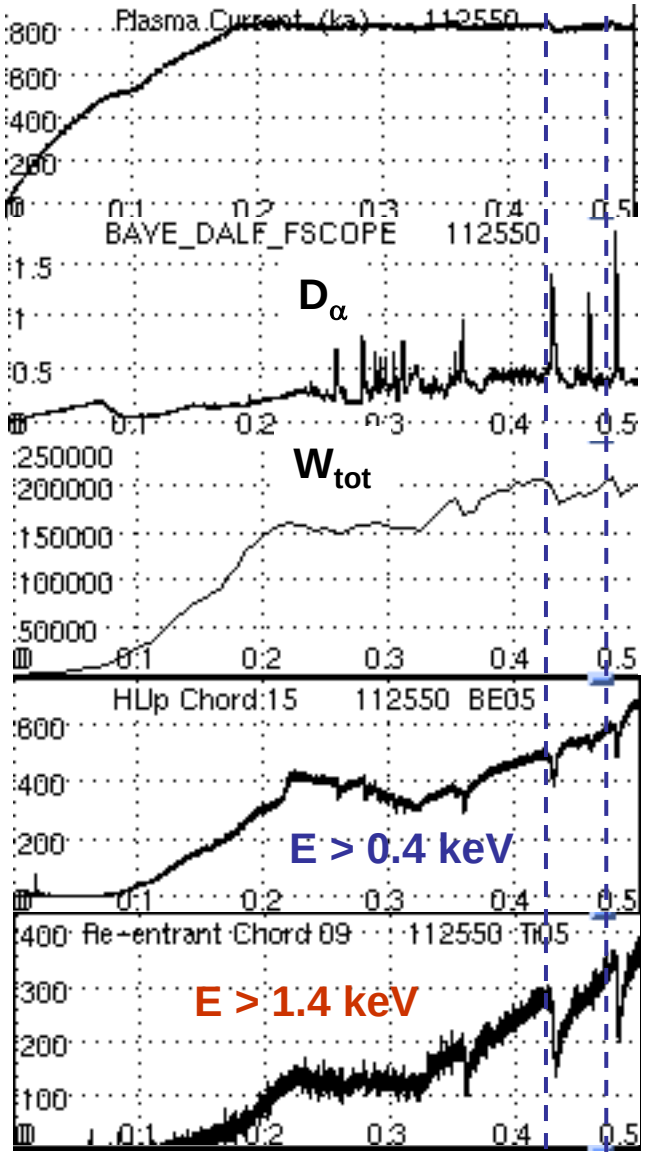
- Questions addressed are ITPA relevant:
  - role of magnetic shear in electron stiffness
  - role of beta (elongation ?) in electron stiffness
  - is the Type-I ELM transport rather than MHD controlled (compare 'artificial' ELMs with 'natural' ELMs from K. Tritz XP)

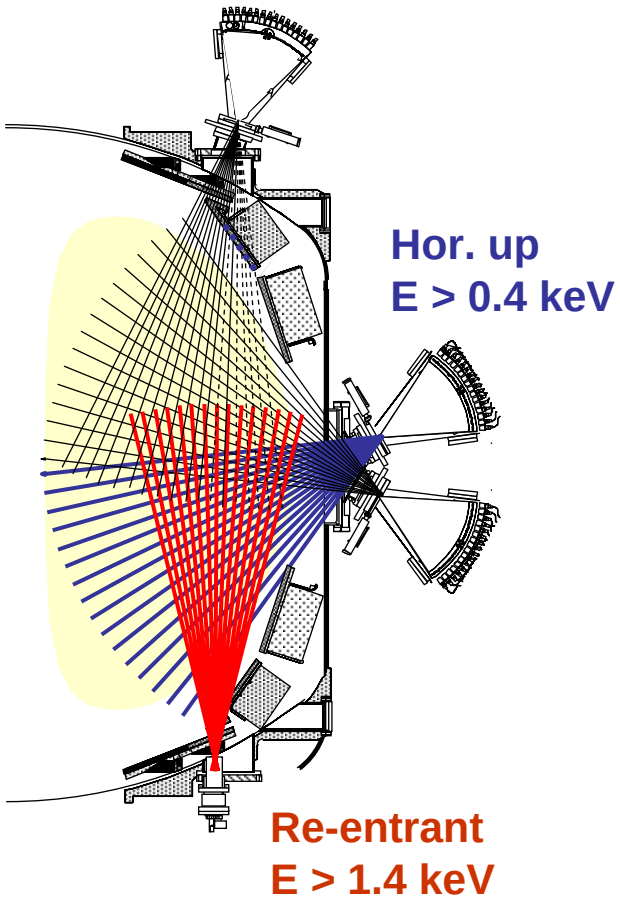
- Tools for controlled T_e perturbations:
  - C pellets and/or supersonic gas injector (Ne)
  - Neutral beam modulation

- Tools for measuring T_e perturbations:
  - 'two-color' poloidal USXR system
  - 'three-color' tangential optical SXR array (new diagnostic)

- Theoretical tools for 1st principles comparison, a la JET

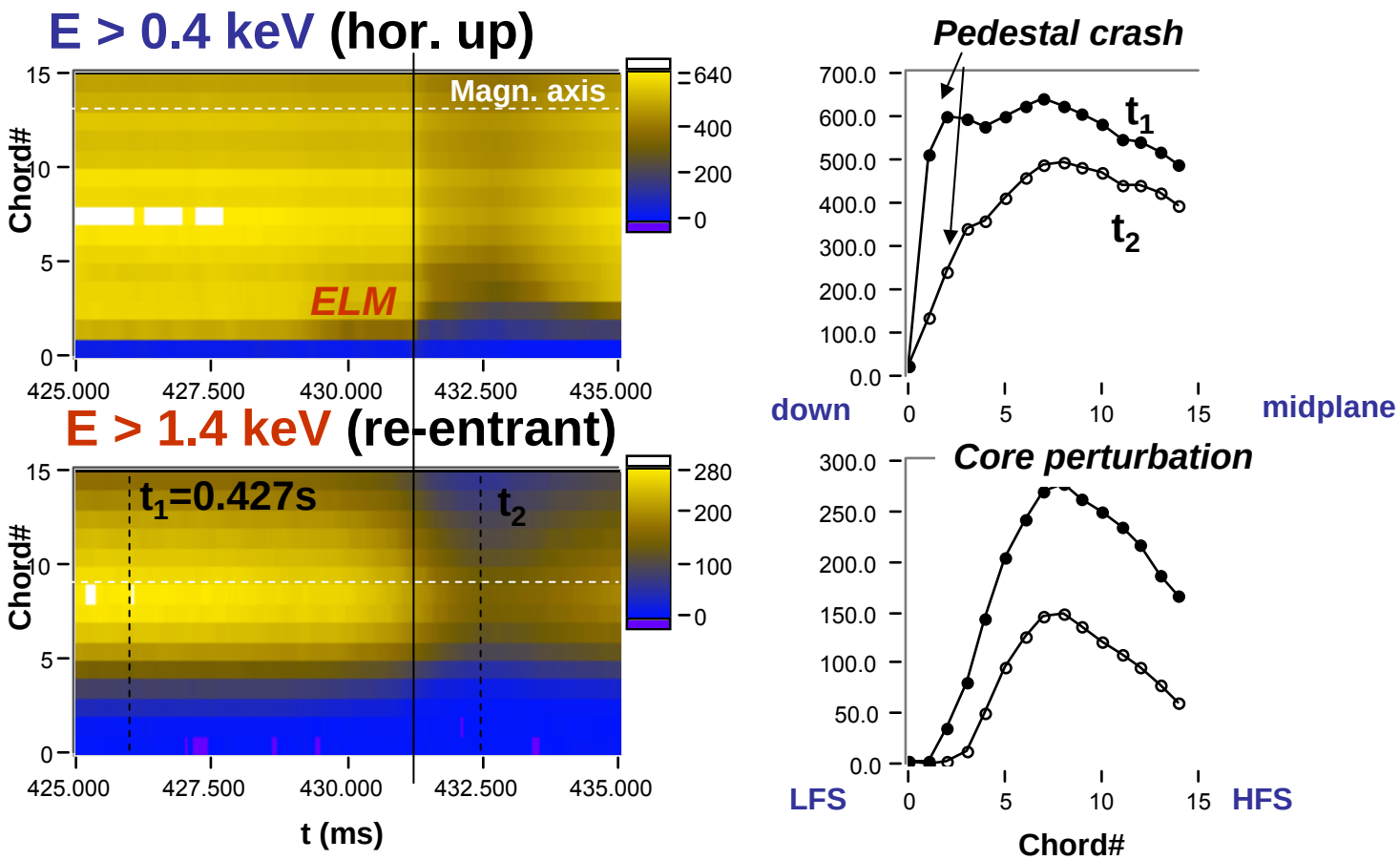
‘Two-color’ USXR system for T_e perturbations





- Horizontal up and re-entrant arrays used to measure T_e crash at Type-I ELM

‘Two-color’ USXR profiles show different evolution

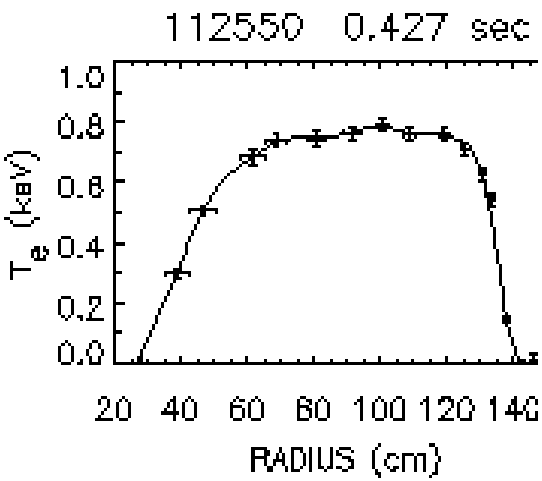


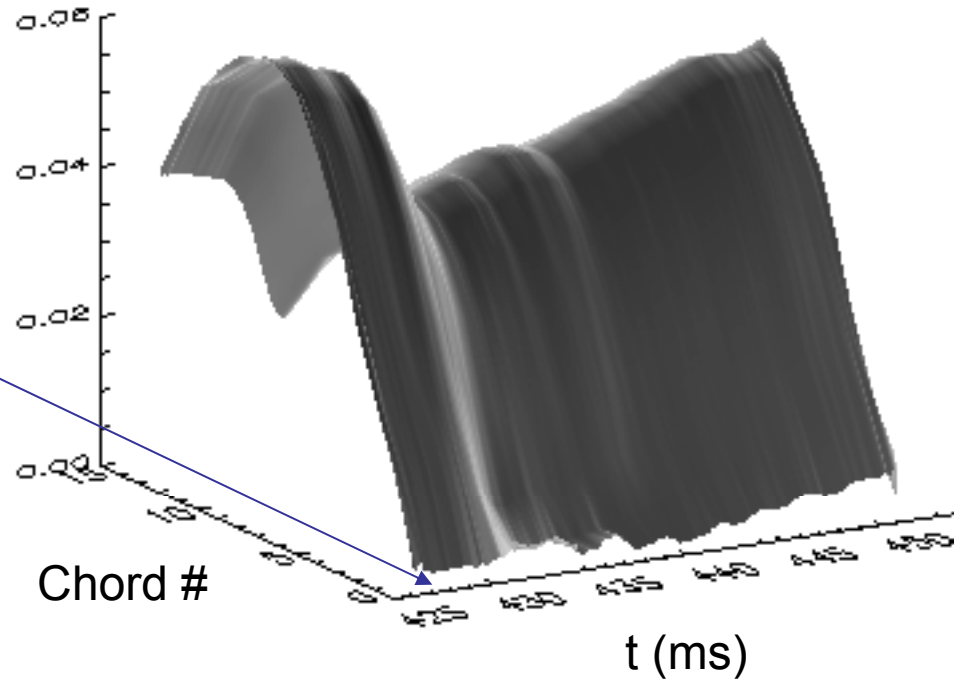
- Low energy profile shows rapid pedestal crash
- High energy profile indicates fast ‘cold pulse’ propagation in the core
- No reconnection evident in the core (transport rather than MHD effect)
- Fast EFIT shows only few % equilibrium change

MPTS T_e profile 'propagated' by USXR modeling

Ratio of E > 1.4 keV / E > 0.4 keV
line integrated emission

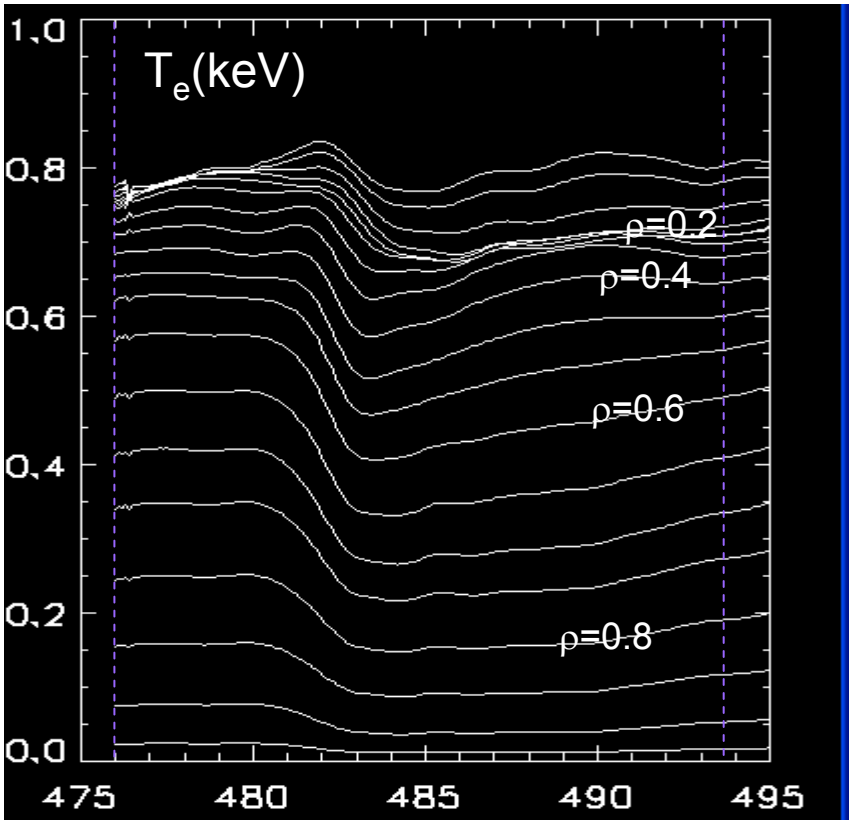
MPTS T_e at t_1=0.427





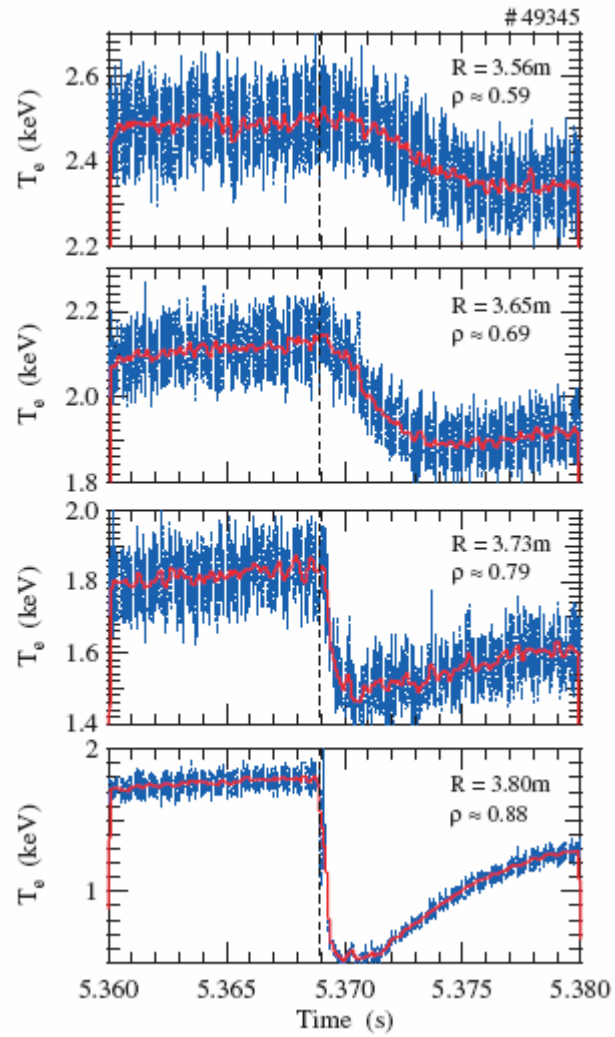
- USXR profiles first fitted for approximate n_C, n_O profile
  (coronal equilibrium radiative coefficients + magnetic surface mapping)
- Ratio of profiles then fitted with $T_e(r,t_1)^{MPTS}+\delta T_e(r,t)$ (relative change
- n_e, n_z perturbation neglected
  (USXR ratio *not* sensitive, also only few % perturbation from MPTS)

MPTS t_1 #112450 MPTS t_2



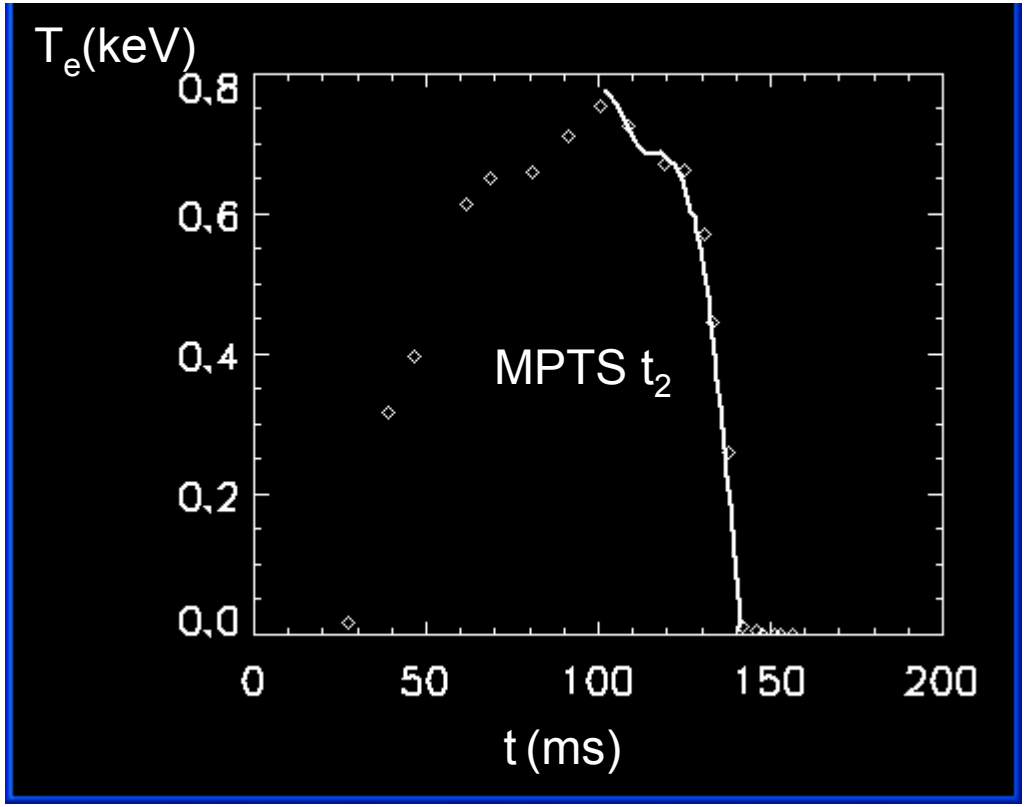
t (ms)

JET (Sarazin 2002)



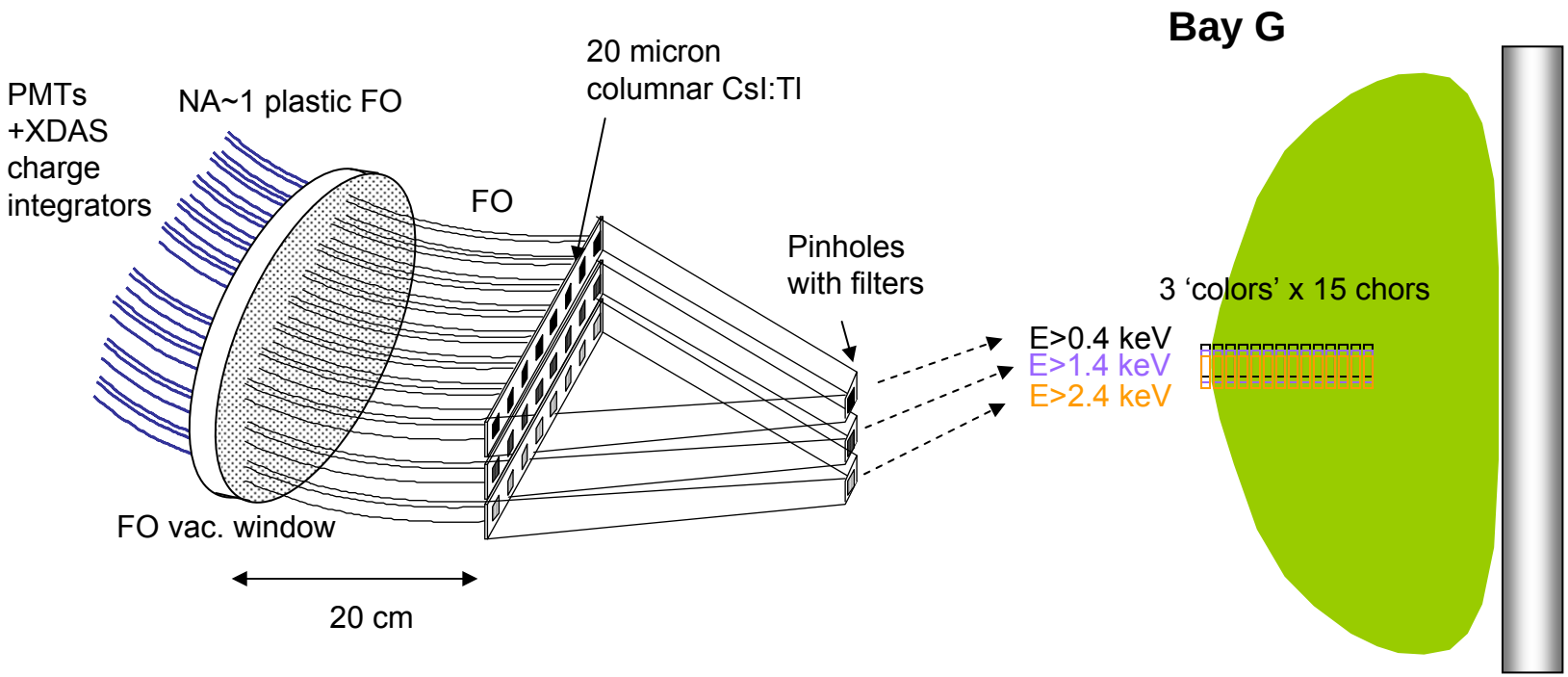
- T_e perturbation reaches the center in ~ 1.5 ms
- Also fast/deep propagation in JET (why is the ELM 'edge localized ?)
- Slight polarity inversion of T_e perturbation near the axis ?

Subsequent MPTS T_e profile at t_2 well reproduced



- In H-mode, the 'two-color' poloidal measurement applicable for $\delta T_e \gtrsim 20$ % (hollow profiles, different plasma volumes, SNR limitations of fast USXR)
- In first stage of XP use the USXR arrays (also top) for L-mode studies
- In second stage of XP use new 'multi-color' Optical SXR system for improved accuracy with H-mode profiles and small perturbations

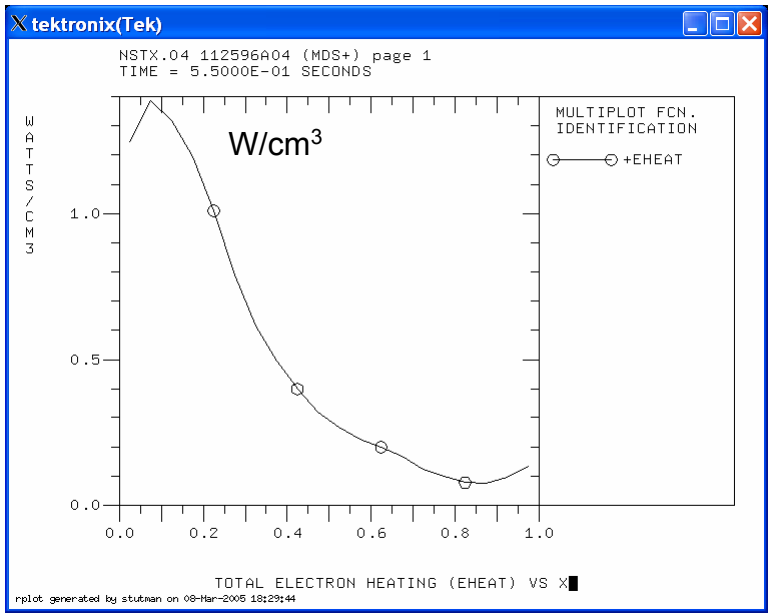
New ‘three-color’ tangential Optical SXR Array



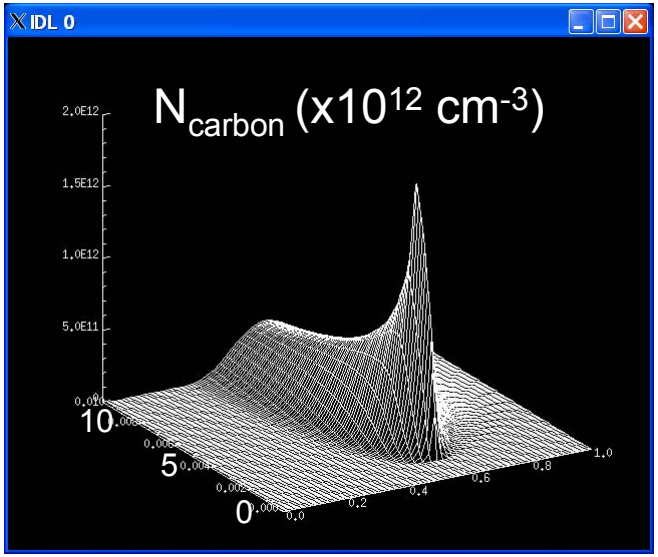
- Main difficulty with ‘multi-color’ technique is viewing different plasma volumes
- OSXR array enables viewing the same volume at multiple energies
- Charge integrators (0.1-1ms) instead of μs amplifiers for improved SNR
- Tangential view for Abel inversion of emissivity
- Operational @1 ms integration time for H-mode part of XP, later in the run
- 0.1 ms time integration dependent on XDAS software development

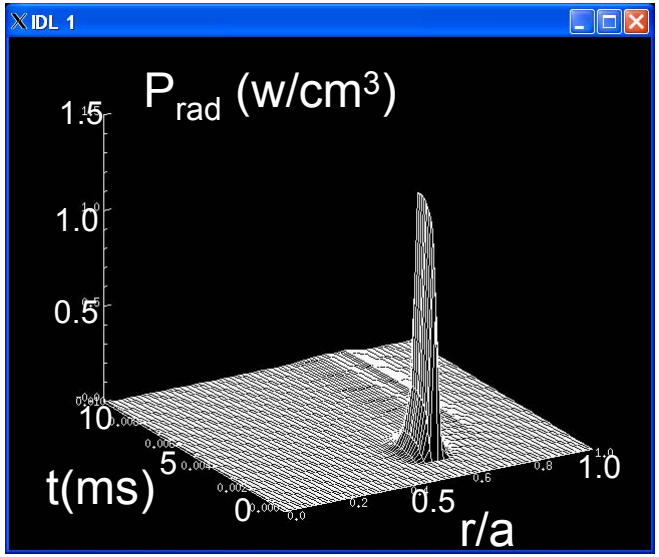
C pellets for T_e perturbations

Electron heating power 7 MW H-mode



510^{18} C atoms injected at r/a ~ 0.6

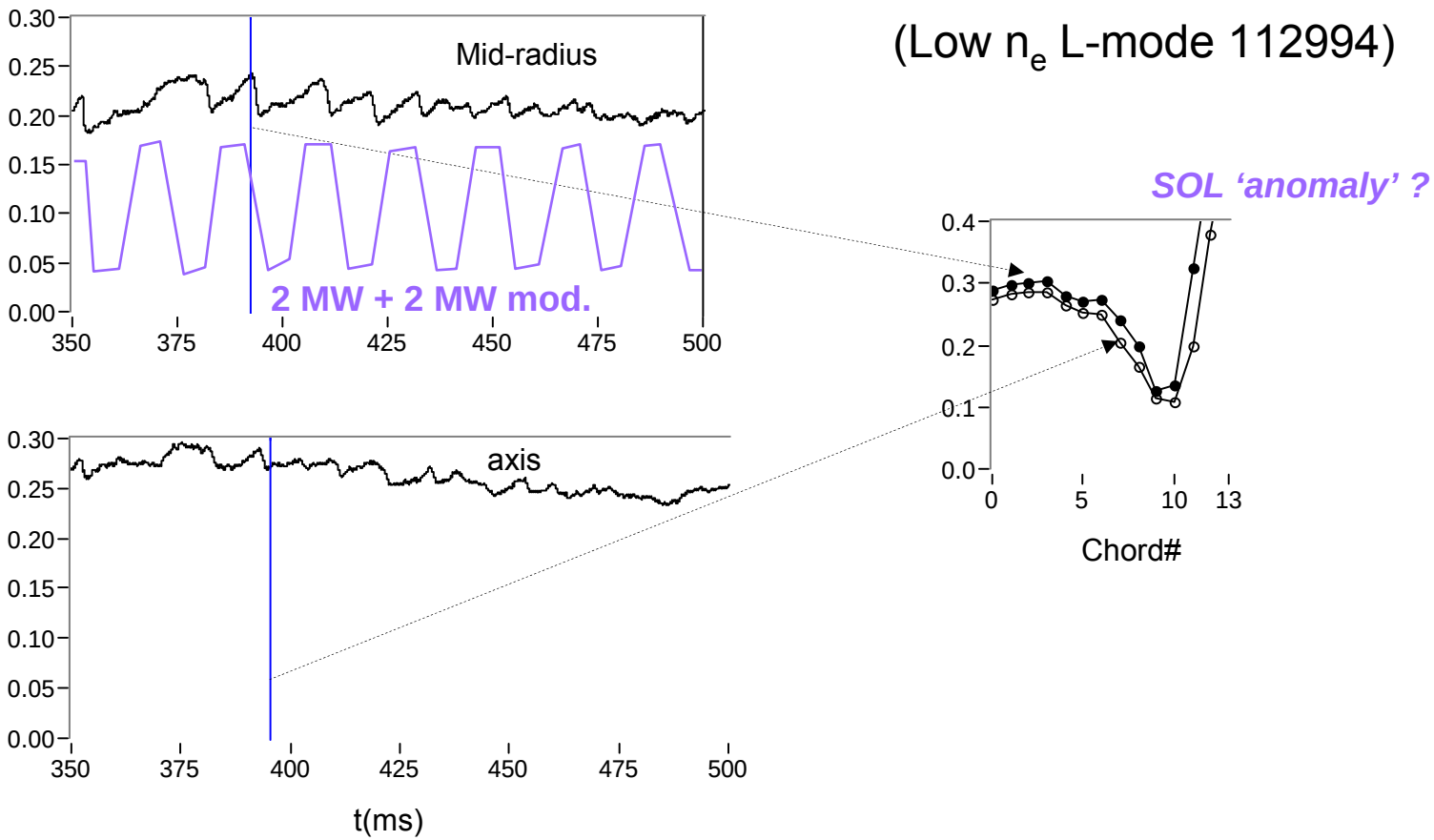




~ 10% of few milligram C pellet at r/a > 0.6 makes P_{rad} ~ $P_{heat\ elec.}$

Modulated NBI for T_e perturbations

Intensity ratio $\frac{E > 1.4 \text{ keV (H_up)}}{E > 0.4 \text{ keV (H_down)}}$



- Beams not usually used for δTe, but in NSTX heat mainly electrons
- USXR system could see such modulations

Proposed run strategy

- XMP: test C pellet and SGI (Neon) as source of edge T_e perturbation

- Part I, L-mode experiments (mid-run):

  C pellets and NBI modulation + poloidal USXR system

- Part II, H-mode experiments (late-run):

  NBI modulation + Optical SXR system at 1ms integration

  C pellets + Optical SXR system at 0.1ms integration, if available

Measurement and interpretation issues

- Pellets will make also (slower) $n_e x n_z$ perturbation
- Could however be estimated also from the USXR profiles
- Line integrated δn_e also from interferometry
- T_i perturbation main question: NPA in fast T_i mode ?
- TRANSP, EFIT with ≤ 1 ms resolution
- Fluctuation diagnostics
- Theoretical χ^{pert} predictive capability a la JETTO, ASTRA ?