XP-534 Investigation of perturbative electron transport vs. magnetic shear using pellet injection

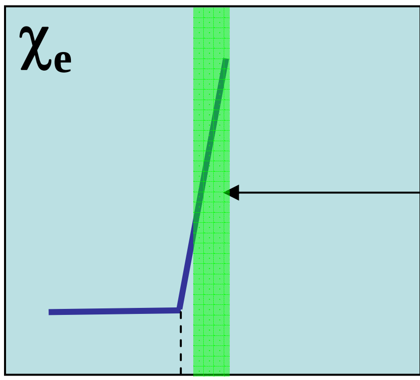
D. Stutman, K. Tritz, L. Delgado-Aparicio, M. Finkenthal *(JHU)*
H. Kugel, R. Kaita, R. Bell, E. Fredrickson, S. Kaye, B. LeBlanc, S. Medley, J. Menard, D. Mikkelsen, G. Rewoldt, L. Roquemore, E. Synakowski *(PPPL)*
F. Levinton *(Nova Photonics)*
S. Sabbagh *(Columbia University)*
R. Maingi *(ORNL)*
S. Kubota *(UCLA)*

Critical gradient paradigm for electron transport

gyro-Bohm behavior

Critical gradient for TEM, ETG turbulence

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



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

'Stiff transport'

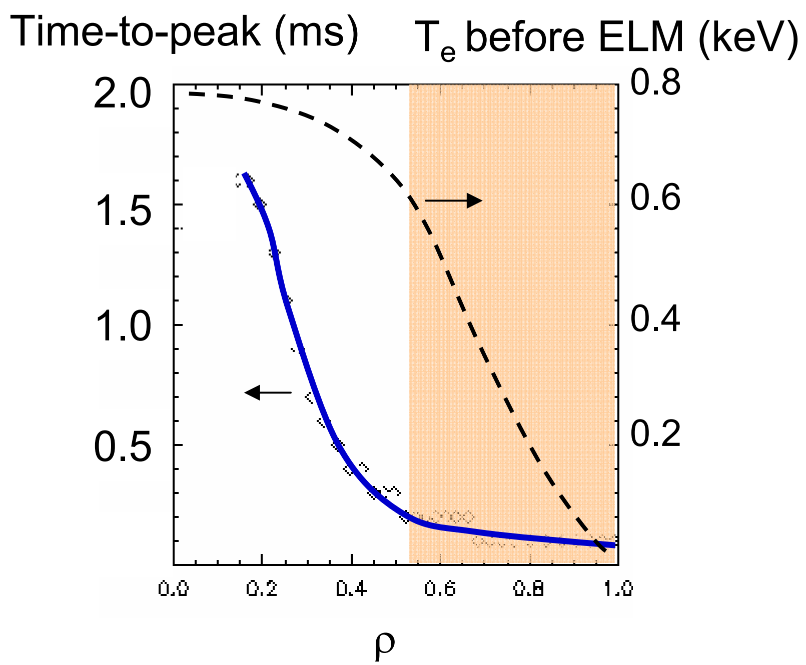
- $\nabla T_e/T_e\,(r) \approx (\nabla T_e/T_e)_c \approx$ const.
- $T_{core} \sim T_{edge}$
- $\chi_e^{pert} >> \chi_e^{PB}$

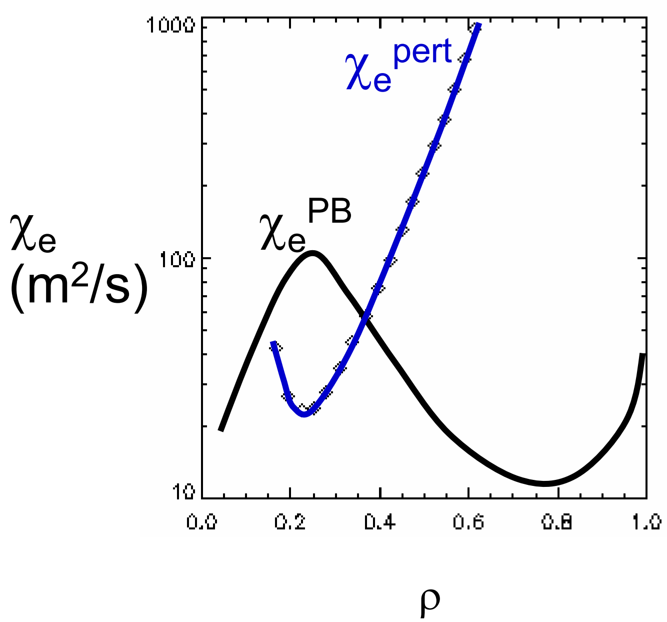
Garbet, Mantica 2004

- Empirical/theoretical model generally supported in tokamaks
- Does it apply on NSTX ?

Fast cold pulse propagation from ELM in NSTX

As in Inagaki *et al*, PPCF 04





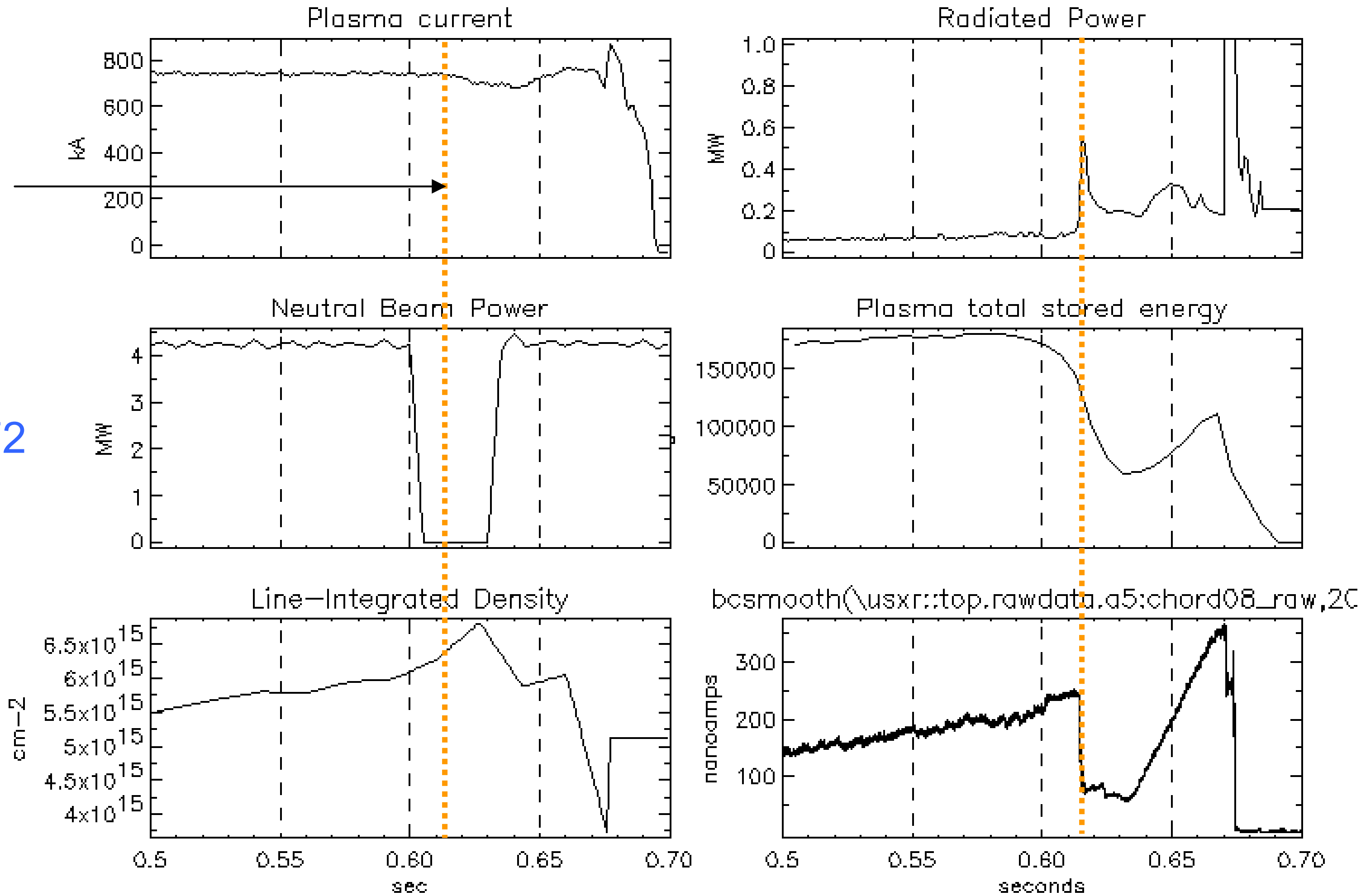
- Rapid perturbed transport where T_e gradient large, decreasing where T_e gradient decreases
- Investigate critical gradient using controlled T_e perturbation from pellets

How does pellet injection look so far

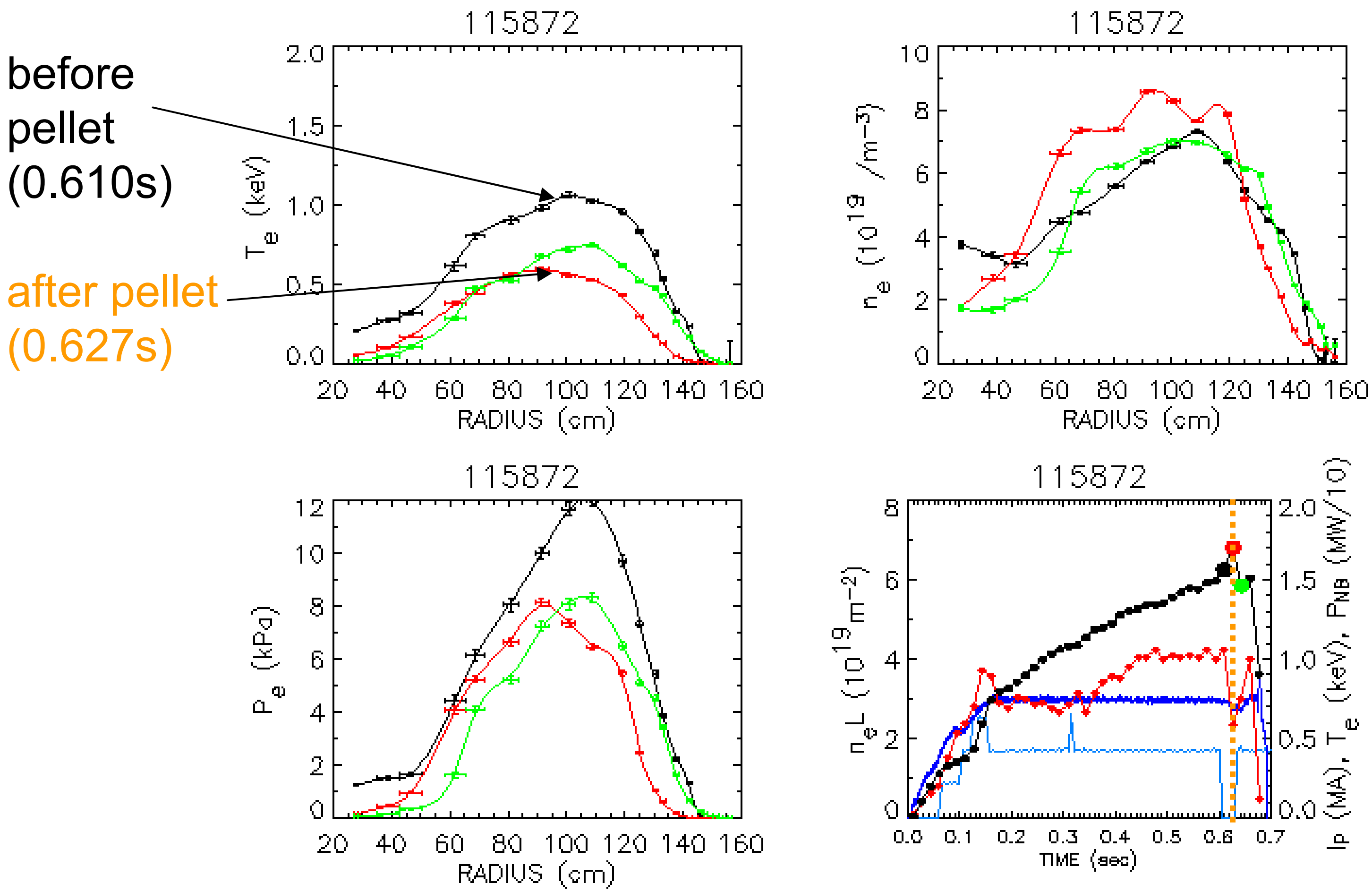
1.7 mg Li (0.1 x N_{plasma}) in 4 MW H-mode with beam notch

pellet in pedestal t=0.613

115872

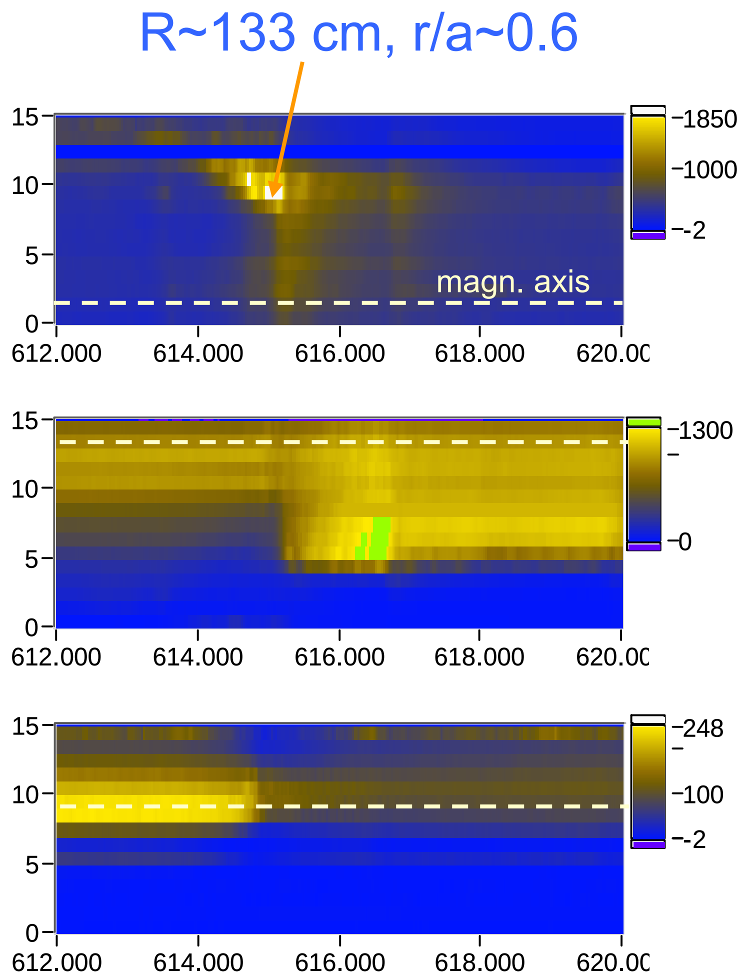


- Notch believed to reduce ablation by fast ions at the edge
- Large W_{tot}, smaller n_e perturbation (W_{tot} rolls over before pellet ?)



No, or minimal notch and smaller pellet perturbation needed for transport

Multi-color USXR gives picture of pellet perturbation



Hor. up
E>0.1 keV

Strong C Ly_a at pellet deposition (likely CX between C^{6+} and Li^0)

Hor. down
E>0.4 keV

Pedestal cooling increases the low energy continuum

Re-entrant
E>1.4 keV

Core cold pulse decreases the high energy continuum

XP 534 goals

- Develop pellet injection as a perturbative transport tool in L- and H-mode
- Desired: - no notch or minimal notch (10 ms, at least one beam on)
  - highest penetration speed for shortest perturbation
- Study perturbed T_e gradient vs. magnetic shear changes in L- and H-mode
- Further develop ‘multi-color’ USXR for perturbative transport:
  - poloidal diode system
  - tangential ‘optical’ system in further experiments
- Experiments will also provide Li III Ly_a light for JHU turbulence Telescope

Run strategy

Little discharge development time -> compare established scenarios:

Low n_e L- (115734,src A) vs. High n_e ELM-free H- (115872, src A+B)

(reversed shear) (flat q)

(i) Li pellet in L-mode at t ≈ 0.36 s, for few tens of percent ΔT_e at r/a ≥ 0.7 (MPTS timed at ~3 ms after pellet penetration shown by USXR)

- knobs: pellet size (2/1/0.5 mg), velocity (15/7.5 cm/ms), 10 ms beam notch

(ii) Measure L-mode cold-pulse propagation with optimal pellet

(iii) **B** pellet in H-mode at t ≈ 0.36 s, for similar edge T_e perturbation

(iv) Measure H-mode cold-pulse propagation with optimal pellet

(v) Time permitting, pellet perturbations with changed magnetic shear

- L-mode: vary beam source and n_e (XP223)
- H-mode: vary beam timing (XP411)

Two shots per condition

Proposed shot matrix

B pellets into ELM-free H-mode 115872:
0.8 MA, LSN, Src. A + B at 90 kV, t_{pellet}=360 ms

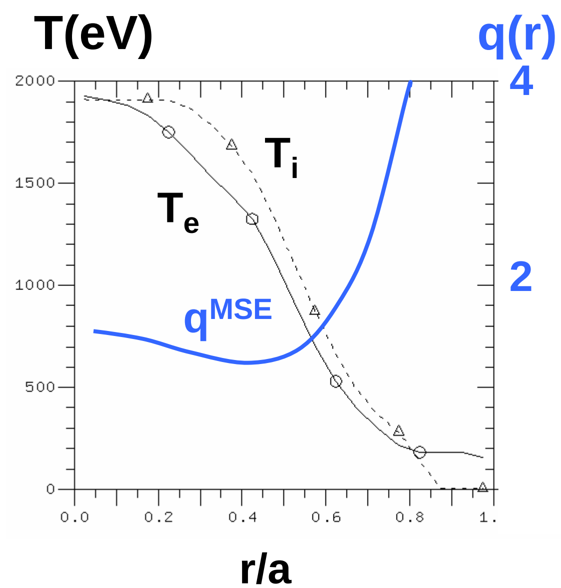
	10 ms notch (350-360 ms)	Pellet mass (mg)	Velocity (m/s)	No of shots
	no	2	150	2
	no	1	150	2
	no	0.5	150	2
if perturbation too small				
	Src. B	2	150	2
	Src. B	1	150	2
if perturbation still too small				
	All sources	0.5	75	2
Use optimized pellet injection with changed shear				
Delay all beams in 115872 by 100 ms, inject at 360 ms				2
Inject into 115500 (1 MA, DND, Src. A+B+C at 90 kV) at t=0.2, 0.3, 0.4s				3

Li pellets into low n_e L-mode 115734:
1 MA, DND, Src. A at 90 kV, t_{pellet}=360 ms

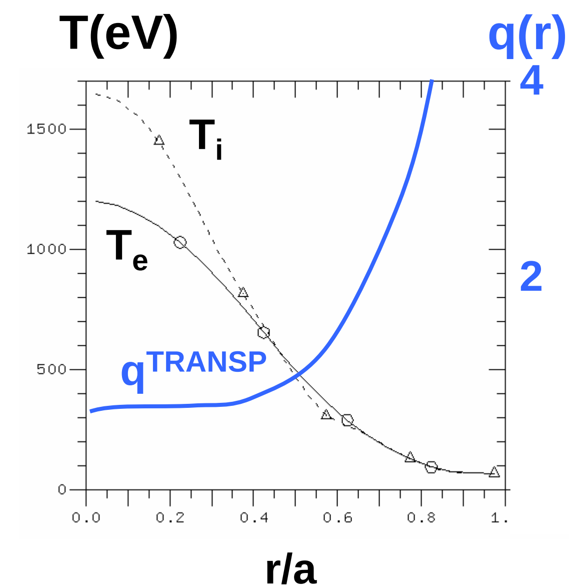
	10 ms notch (350-360 ms)	Pellet mass (mg)	Velocity (m/s)	No of shots
	no	2	150	2
	no	1	150	2
	no	0.5	150	2
if perturbation too small				
	Src. A	1	75	2
	Src. A	0.5	75	2
Apply optimized pellet injection with changed shear				
Replace Src. A with Src. C				2
Using Src. C, increase n_e by 50%, as in 108213				2

Magnetic shear variation in L-mode

115734, Src. A, $\int n_e L \approx 3.0\times10^{15}$

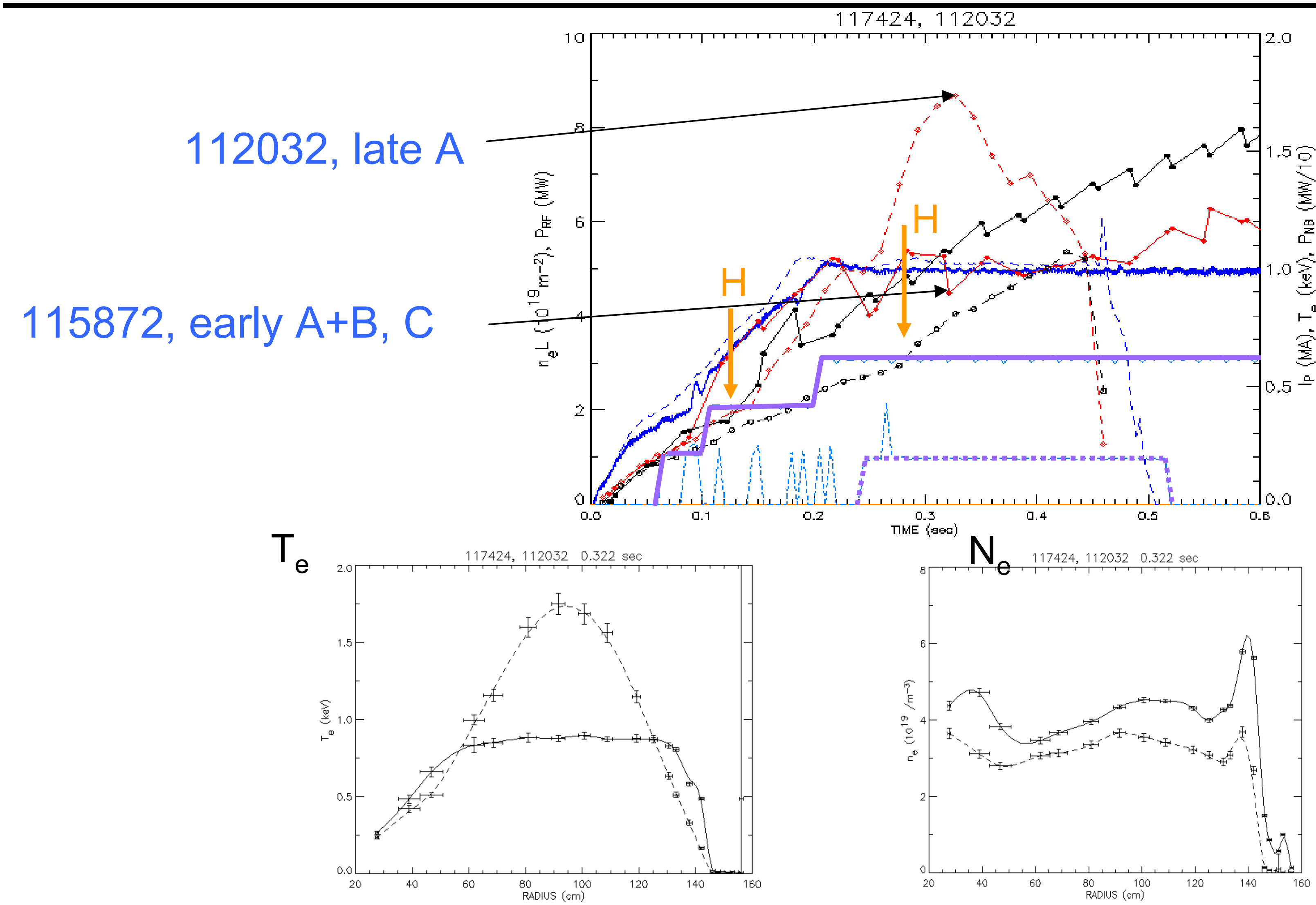


108213, Src. C, $\int n_e L \approx 4.4\times10^{15}$



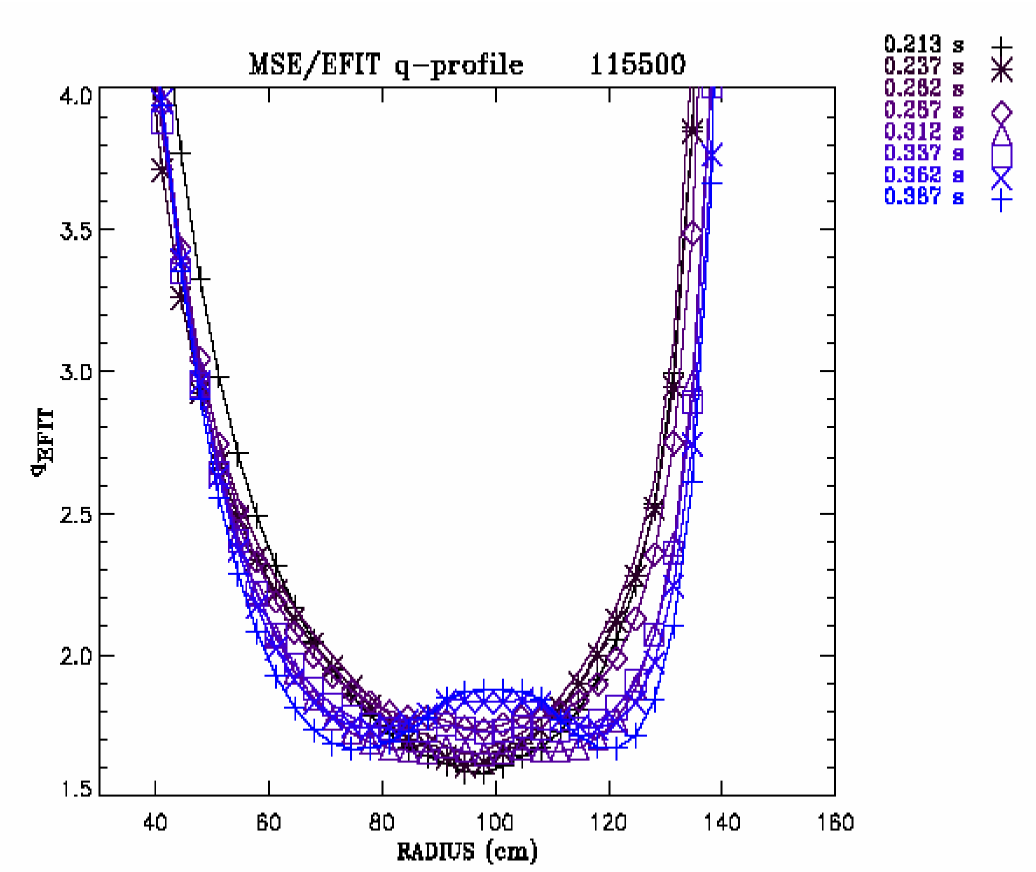
- Large shear changes with I_p ramp/beam time difficult this run (XP522)
- Moderate shear reversal however consistently obtained at low n_e
- Use change of source/higher n_e to reduce T_e and flatten q(r) (XP 223)

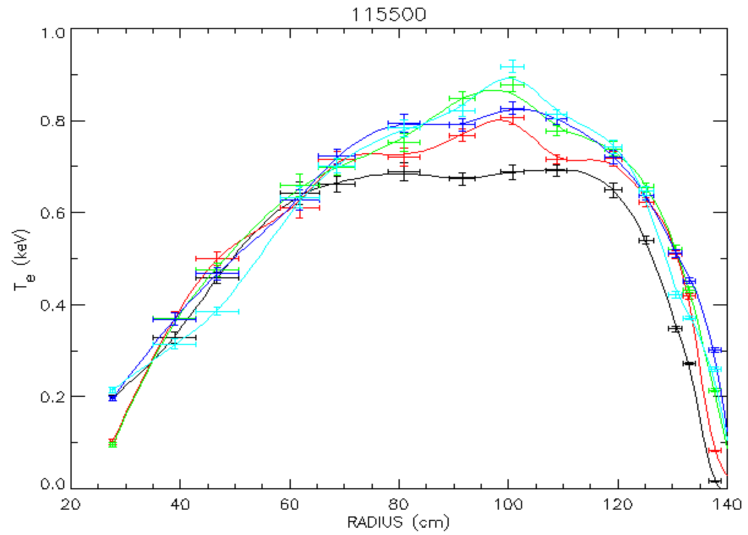
Magnetic shear variation in H-mode

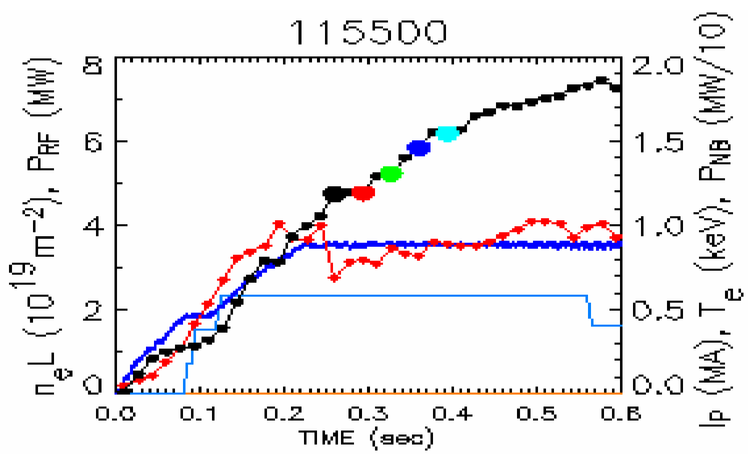


- High T_e and peaked profile with late H-mode; likely also different shear
- Delay beam injection for ELM-free H-mode with changed shear (hints also from XP522)

Or: probe χ_e^{pert} while shear naturally evolves in H-mode







Measurement and interpretation issues

- MPTS, CHERS, MSE synchronized with pellet
- Visible, VUV spectroscopy, plasma camera with B/Li filters
- Pellet $n_e x n_z$ perturbation from multi-color USXR
- Δn_e also from FIR interferometry
- $T_i(t)$ estimate from NPA in fast T_i mode and dW_{tot}-dW_{el} (small at ELM)
- Possible treatments of T_i perturbation (fast CHERS needed at NSTX)

  - neglect change

  - use CHERS profile after pellet

  - use CHERS profile after pellet normalized with NPA change
- EFIT, TRANSP with 0.1 ms resolution
- All fluctuation diagnostics of interest
- GS2 linear stability before and after pellet