Joint XMP

Optimization of pellet injection for transport studies

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Study of perturbative electron transport vs. magnetic shear

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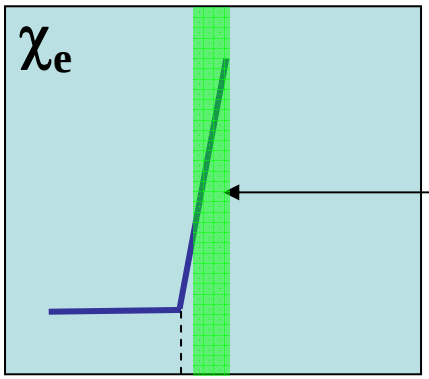
Critical gradient paradigm for electron transport

(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'

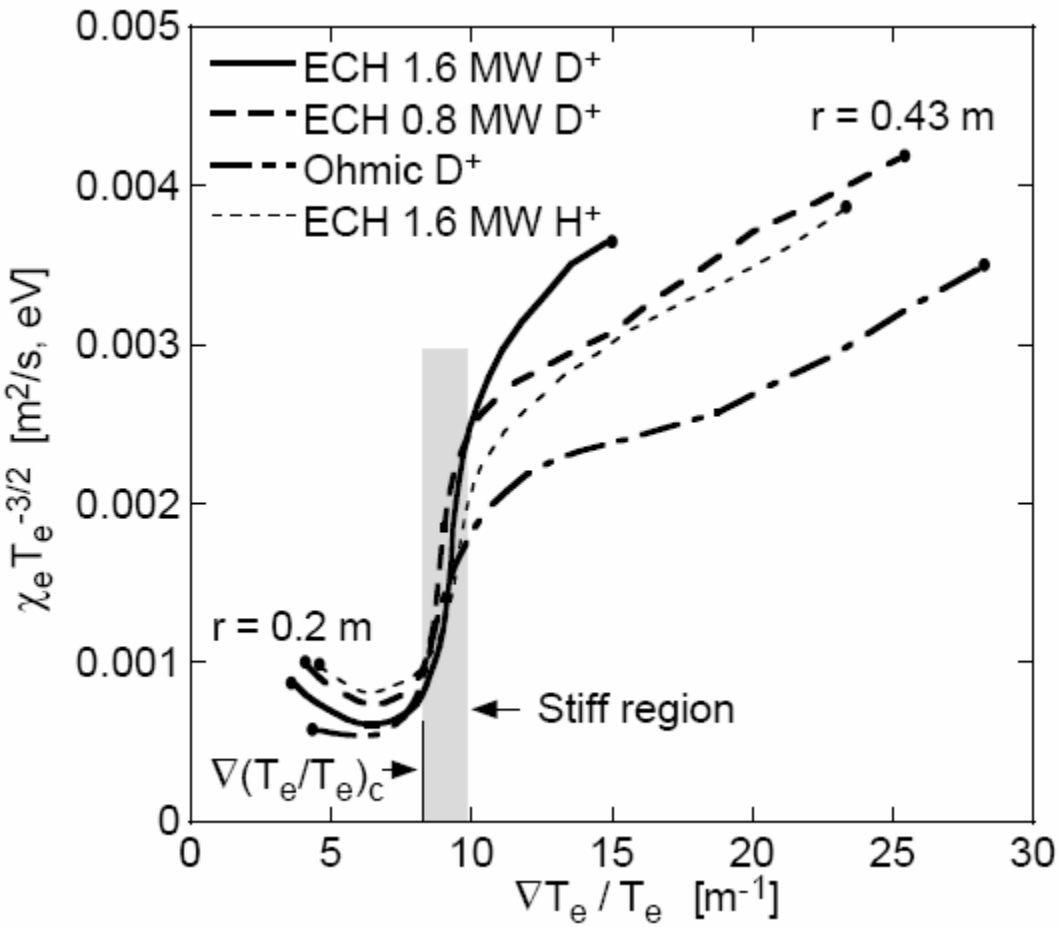
- $\nabla T_e/T_e\,(r) \approx (\nabla T_e/T_e)_c \approx$ const.
- $T_{core} \sim T_{edge}$
- $\chi_e^{pert} >> \chi_e^{PB}$

Three parameter model applied at JET using controlled T_e perturbations (Garbet, Mantica 2004)

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

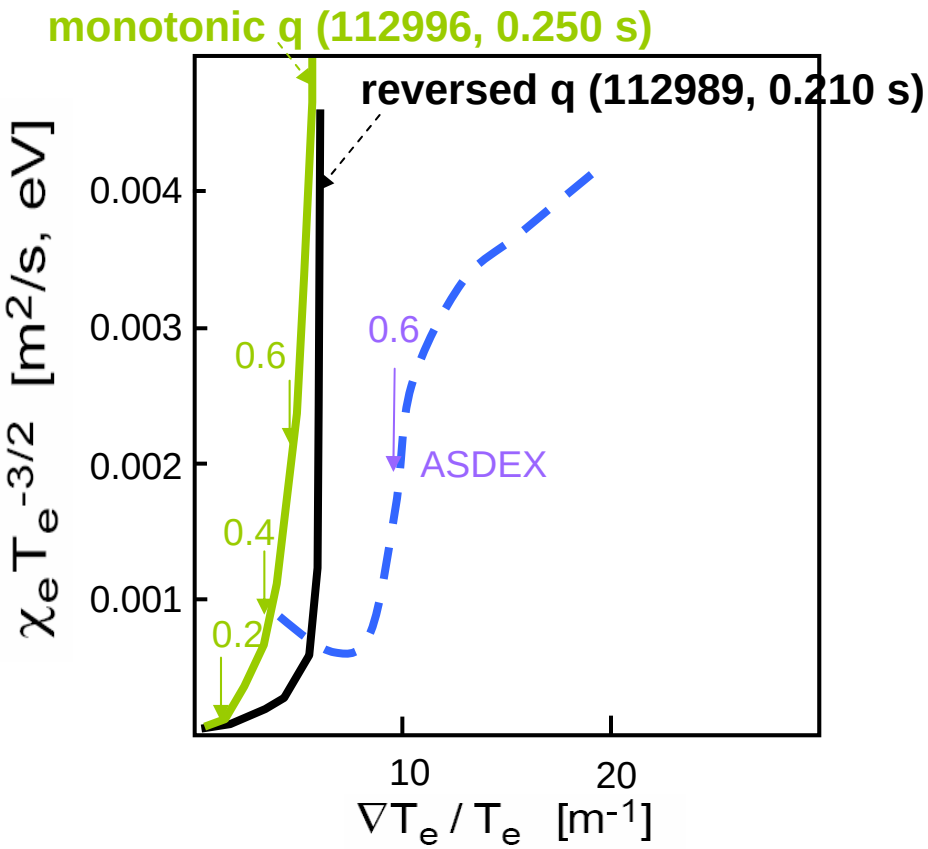
Critical gradient evident in scaled χ_e^{PB} in tokamaks

ASDEX L-mode (Ryter 2001)

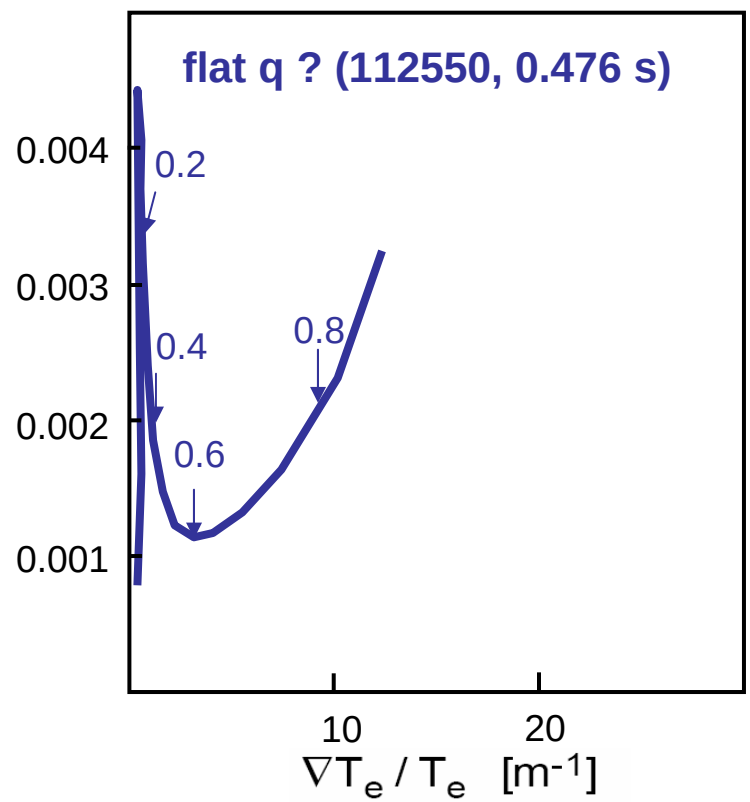


Critical gradient picture different in NSTX ?

Low n_e/power L-mode



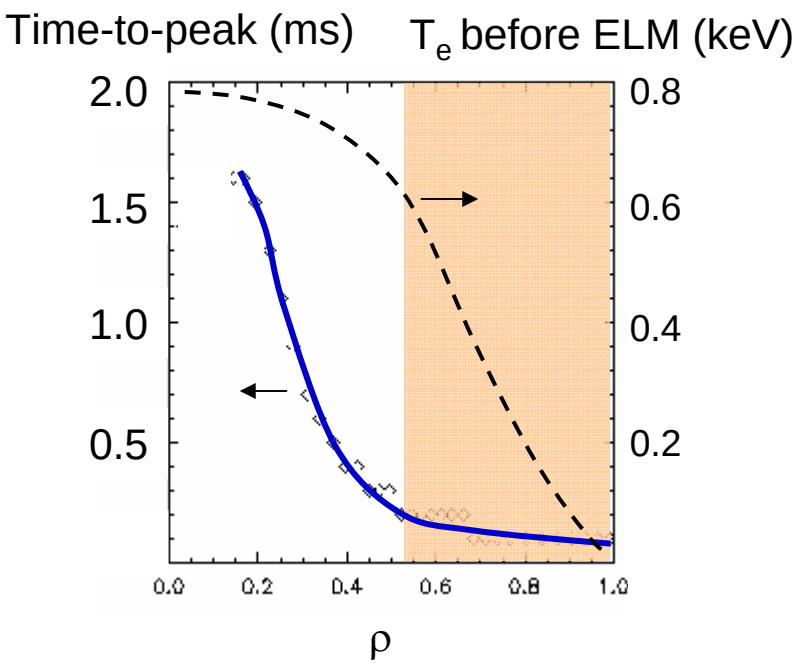
High n_e/power H-mode

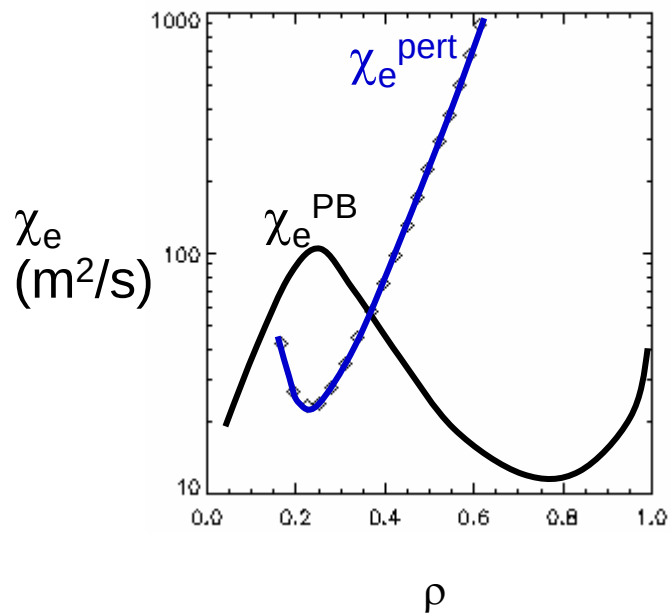


- L-mode: very low critical gradient, increasing with negative shear
- H-mode: puzzling core picture, critical gradient moves to periphery ?
- χ_e^{pert} profile from Type-I ELM also very different from χ_e^{PB}
- Magnetic shear knob on electron transport in low n_e L-modes (XP411)

χ_e^{pert} from ELM markedly different from χ_e^{PB}

Model from Inagaki *et al.* PPCF 04 (neglects ion damping)





- Rapid perturbed transport in the T_e gradient region, decreasing inside

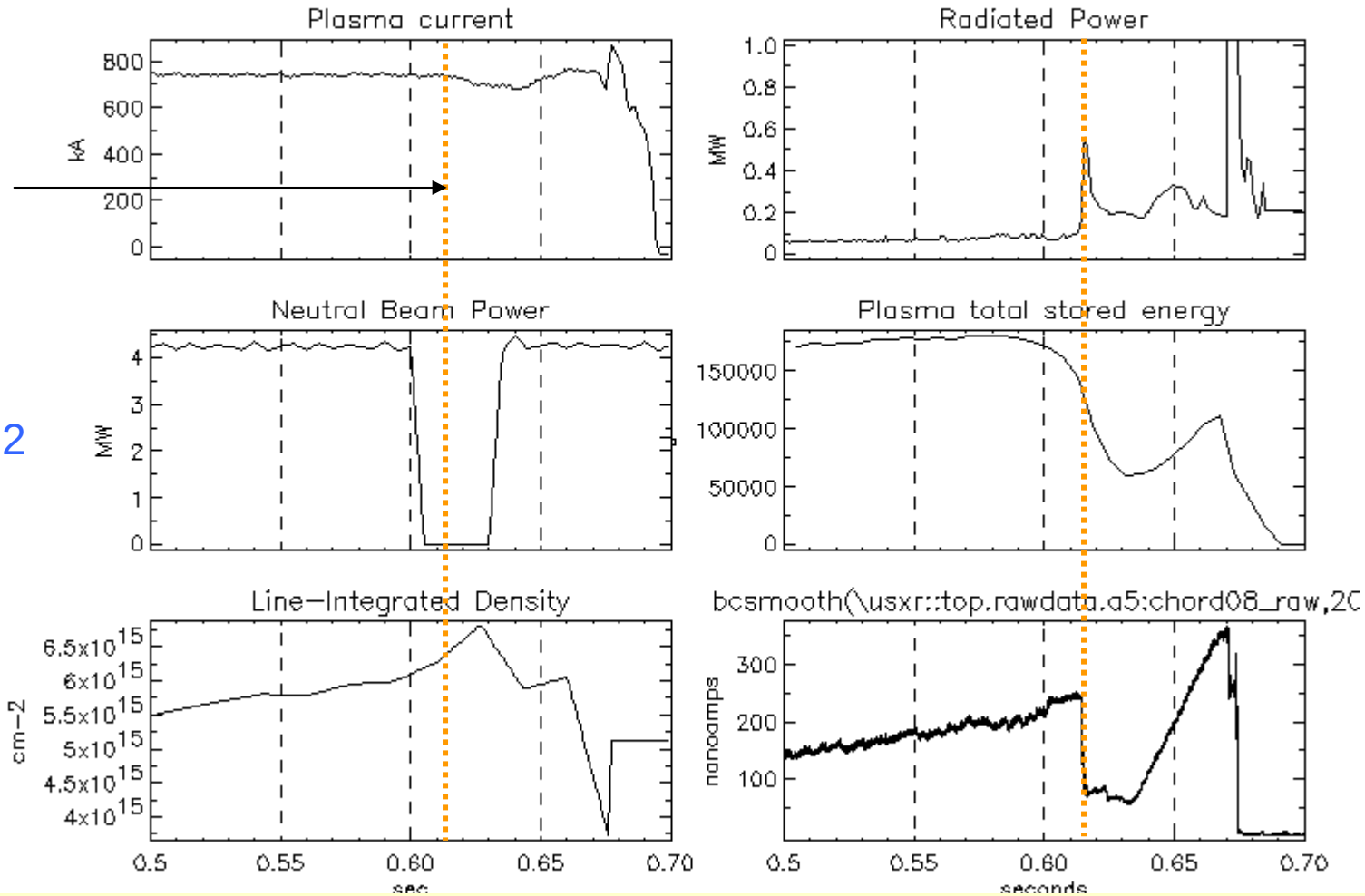
- Goal of proposed work: study critical gradient behavior using controlled T_e perturbation from low-Z pellet

How does pellet injection look so far

1.7 mg Li (1.6×10^{20} atoms) in 4 MW H-mode with beam notch

pellet in pedestal t=0.613

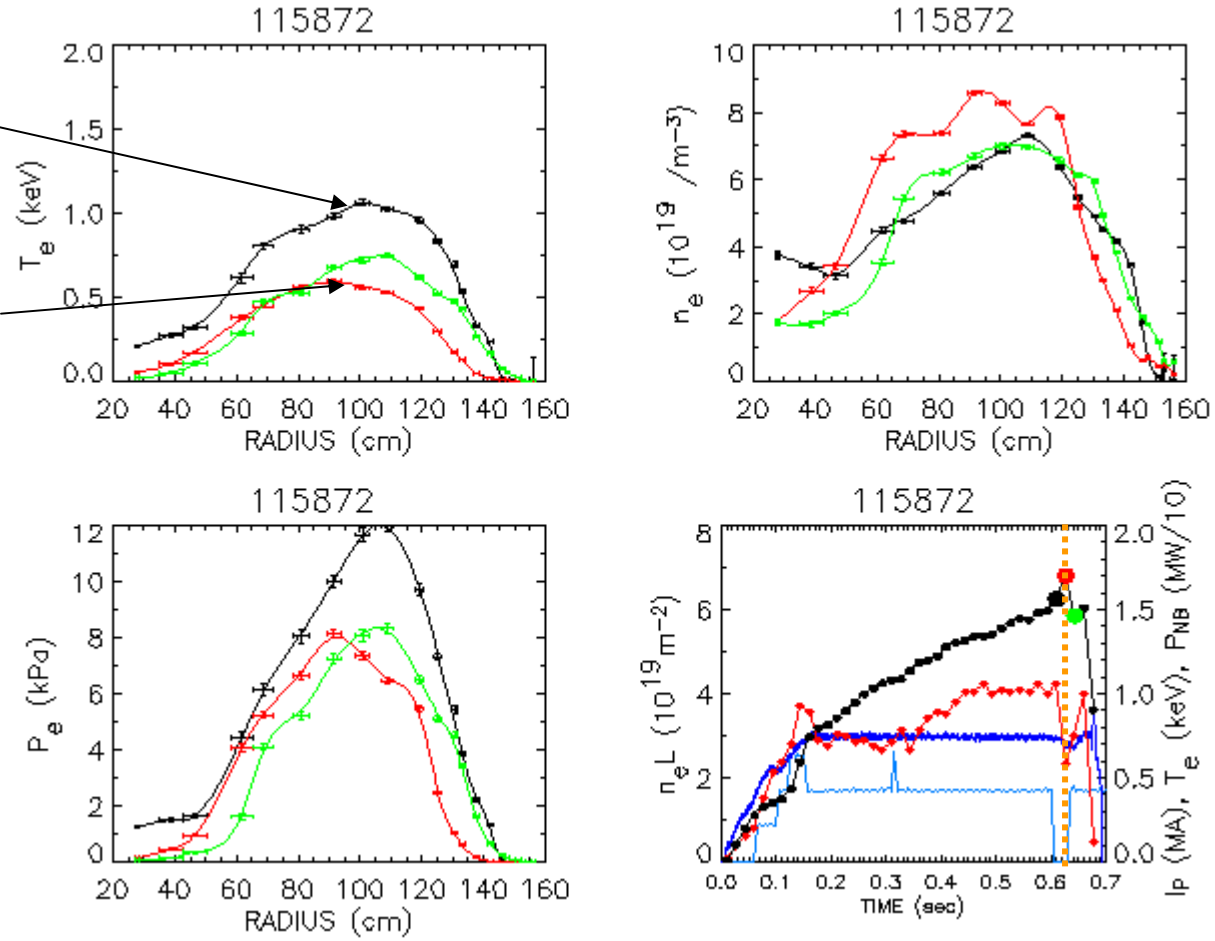
115872



- Large T_e, smaller n_e perturbation -> try smaller pellets and/or no notch
- Plasma particle inventory = 9×10^{20} particles
- Note: stored energy begins to roll over before pellet reaches pedestal

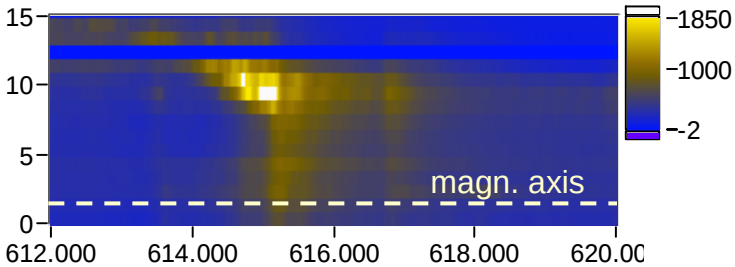
before pellet (0.610s)

after pellet (0.627s)



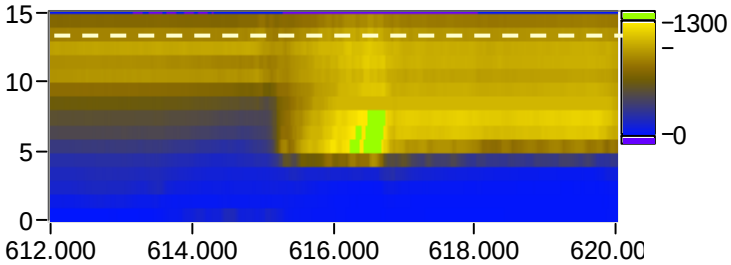
Multi-color USXR gives good picture of pellet perturbation

Hor. up
E>0.1 keV



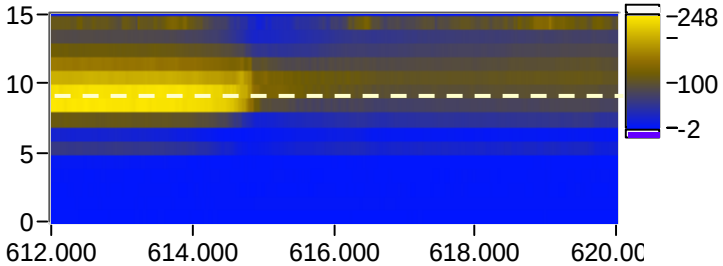
Strong C Ly_{α} marks pellet deposition (likely CX between C^{6+} and neutral Li)

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

Goals of joint XMP and XP

- Develop pellet injection as a perturbative transport tool for L- and H-mode

- Study perturbed T_e gradient vs. magnetic shear changes in L- and H-mode (*T&T milestone*)

- Apply 'multi-color' USXR technique for perturbative transport:
  - poloidal diode system
  - tangential 'optical' system (initial testing stage)

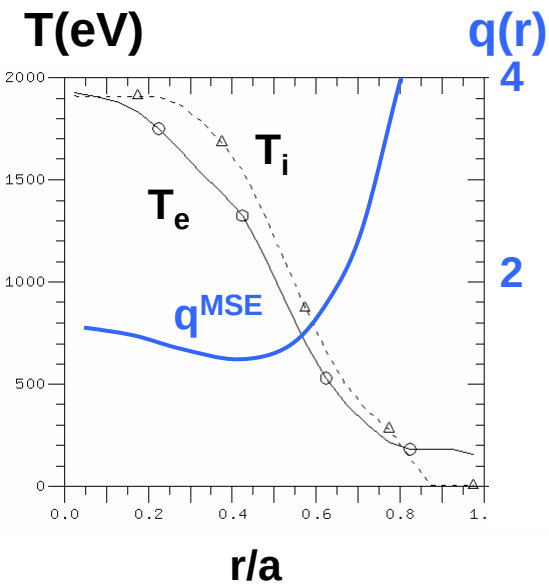
- Strategies for magnetic shear changes (*within limited run time*)
  - L-mode: vary beam source and n_e (XP223)
  - H-mode: vary beam timing (XP411)

- Analysis with JET critical gradient model

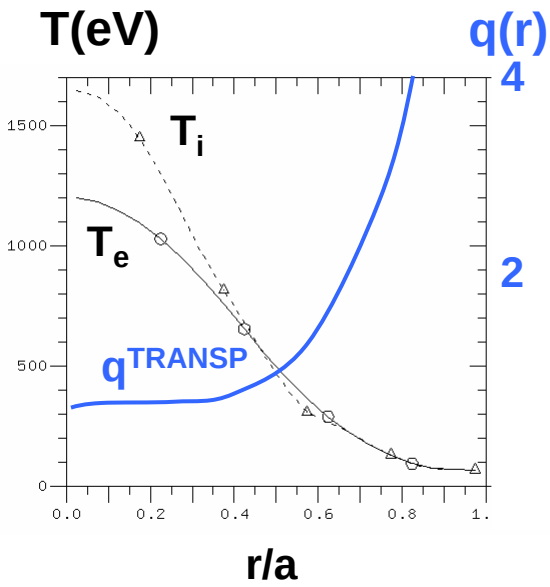
- Experiments will also provide Li III Ly_α light for new JHU Telescope

Magnetic shear variation in L-mode

115734, Src. A, $\int n_e L \approx 3.0 \times 10^{15}$



108213, Src. C, $\int n_e L \approx 4.4 \times 10^{15}$

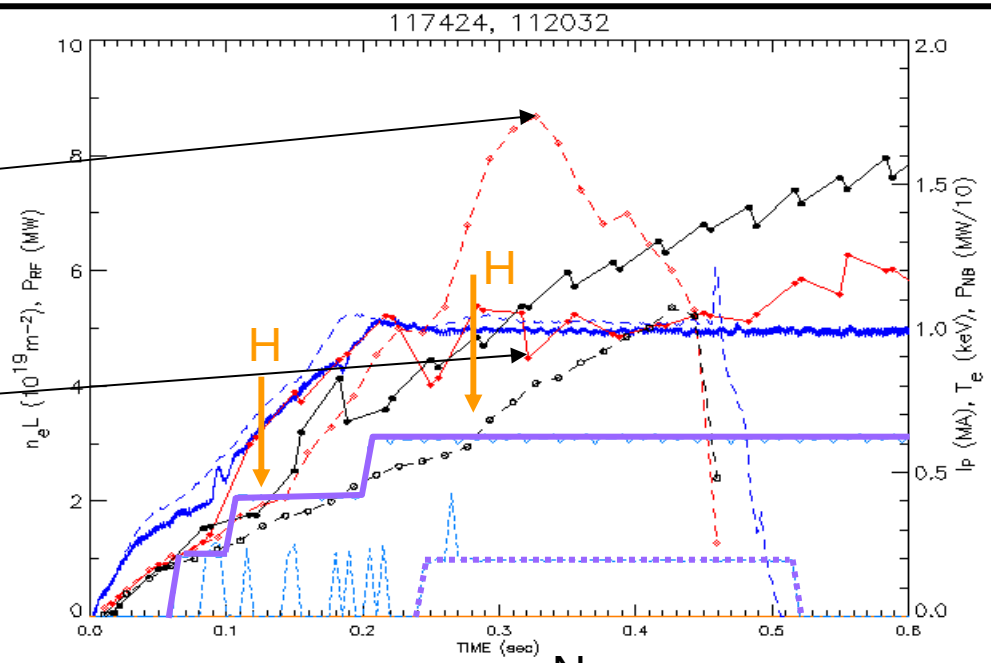


- Large shear changes with I_p ramp/beam time difficult this run (XP522)
- Moderate shear reversal however consistently obtained at low n_e
- Use change of source/higher n_e to reduce T_e and flatten q(r) (XP 223)

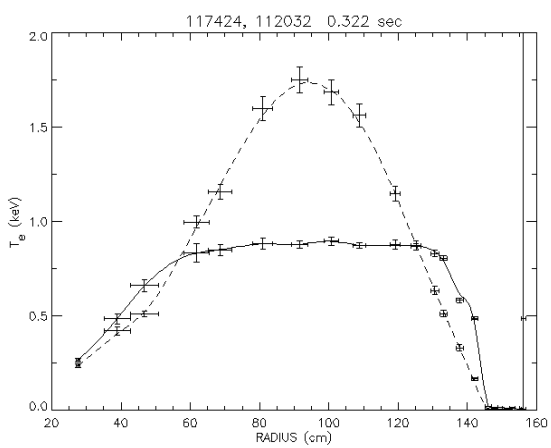
Magnetic shear variation in H-mode

112032, late A

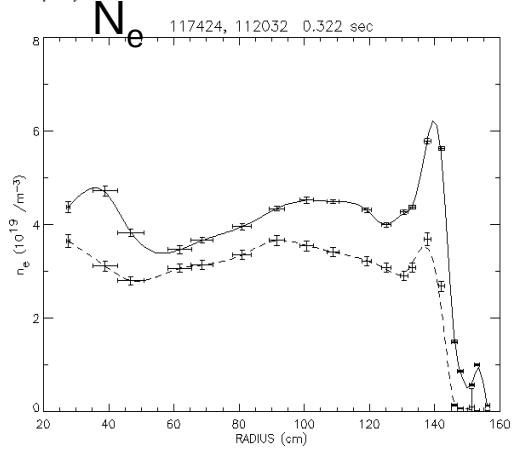
115872, early A+B, C



T_e

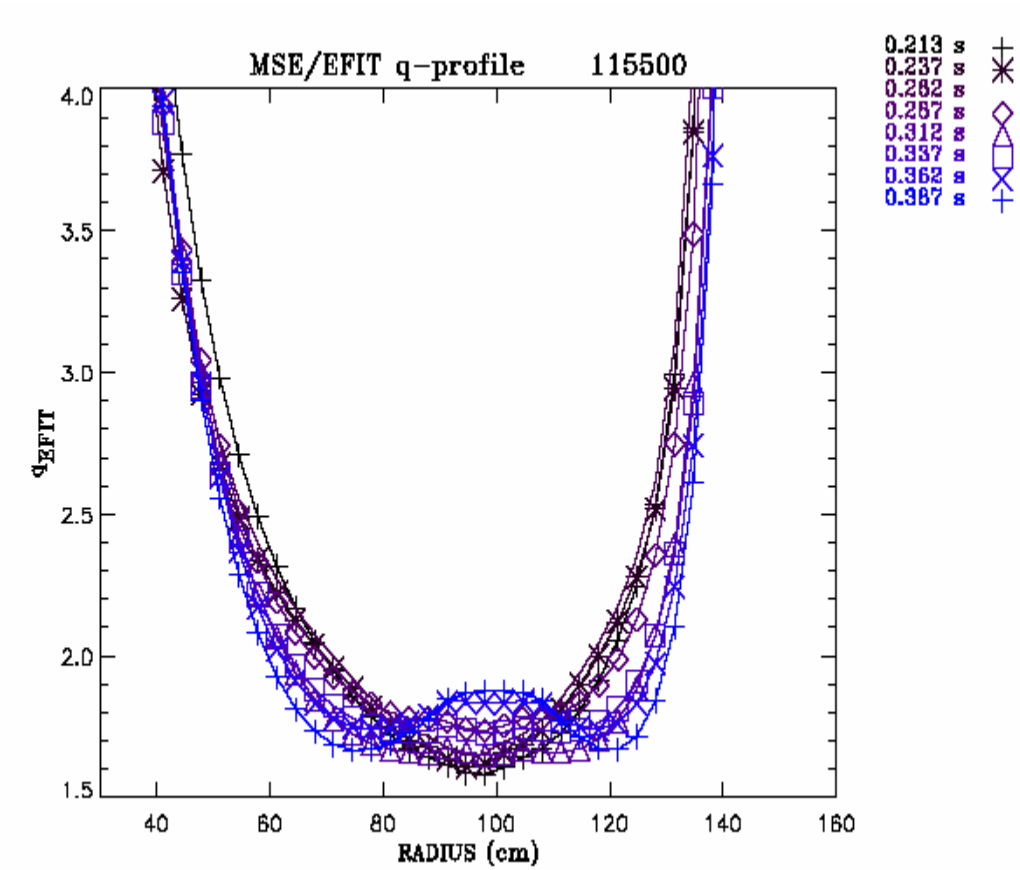


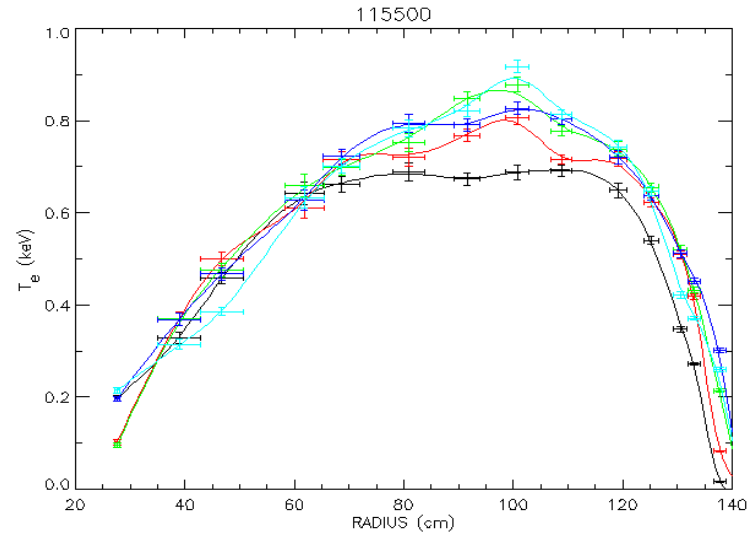
N_e

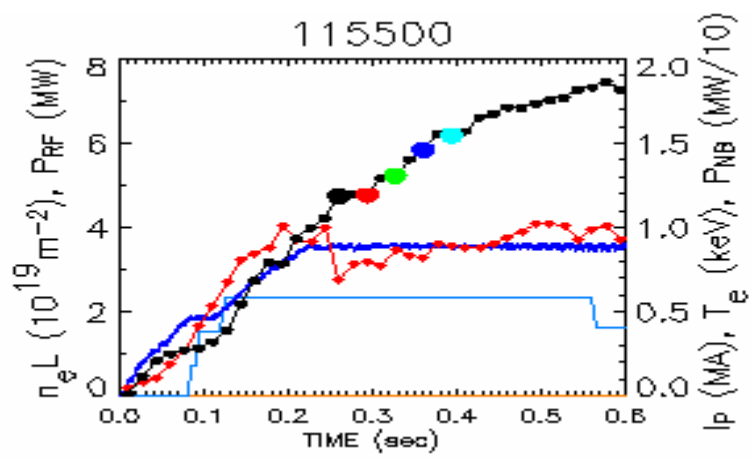


- High T_e and peaked profile with late H-mode; likely also different shear
- Delay beam injection for ELM-free H-mode with changed shear (hints also from XP522)

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







Proposed run strategy

- Little discharge development possible -> *compare first the established scenarios:*
  Low n_e L-mode (115734,src A) vs. High n_e, ELM-free H-mode (115872, src A+B)

(i) Optimize L-mode pellet injection for measurable but moderate edge T_e perturbation at t ≈ 0.35 s (e.g., ≈ 30-40% at r/a ~ 0.7, from MPTS a few ms after pellet)

- Li pellets with/without beam notch, 0.5 mg/1 mg /2.0 mg, 75 ms^{-1}/150 ms^{-1}
  (Li likely better suited for low n_e L-mode)

(ii) Measure cold-pulse propagation at t ≈ 0.35 s with optimal pellet

(iii) Develop pellet injection for measurable but moderate pedestal T_e perturbation in H-mode (e.g., 30-40% at r/a ~ 0.7, from MPTS a few ms after pellet)

- B pellets with/without beam notch: 0.5 mg/1 mg/2.0 mg, 75 ms-1/150 ms-1
  (B likely better suited for pedestal penetration in high n_e H-mode)

(iv) Measure cold-pulse propagation at t = 0.35 s with optimal pellet

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

Two shots per condition

Proposed shot matrix

		10 ms notch	0.5 mg	75 m/s 150 m/s	
L-mode	Li	10 ms notch	1.0 mg	75 m/s	(2 x 5 shots)
		no notch	1.0 mg	150 m/s	
		no notch	2.0 mg	150 m/s	
		10 ms notch	0.5 mg	75 m/s 150 m/s	
H-mode	B	10 ms notch	1.0 mg	75 m/s	(2 x 5 shots)
		no notch	1.0 mg	150 m/s	
		no notch	2.0 mg	150 m/s	

Time permitting, use optimized pellet perturbation with changed magnetic shear

Measurement and interpretation issues

- Aim to minimize (~10 ms) or eliminate the beam notch
- Pellet $n_e x n_z$ perturbation could be estimated also from the multi-color USXR
- Line integrated δn_e also from interferometry
- T_i perturbation from NPA in fast T_i mode and δW_{tot}-δW_{el} (small at ELM)
- TRANSP, EFIT with ~ 0.1 ms resolution
- All fluctuation diagnostics of interest
- Theoretical χ^{pert} predictive capability (a la JETTO, ASTRA)