L-H transition and pedestal studies on MAST (EXC/2-3Ra)

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L-H Threshold Studies in NSTX (EXC/2-3Rb)

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Thanks to the co-authors

EXC/2-3Ra: L-H transition and pedestal studies on MAST

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EXC/2-3Rb: L-H Threshold Studies in NSTX

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H-mode access – ion species, shaping, 3D fields and I_p

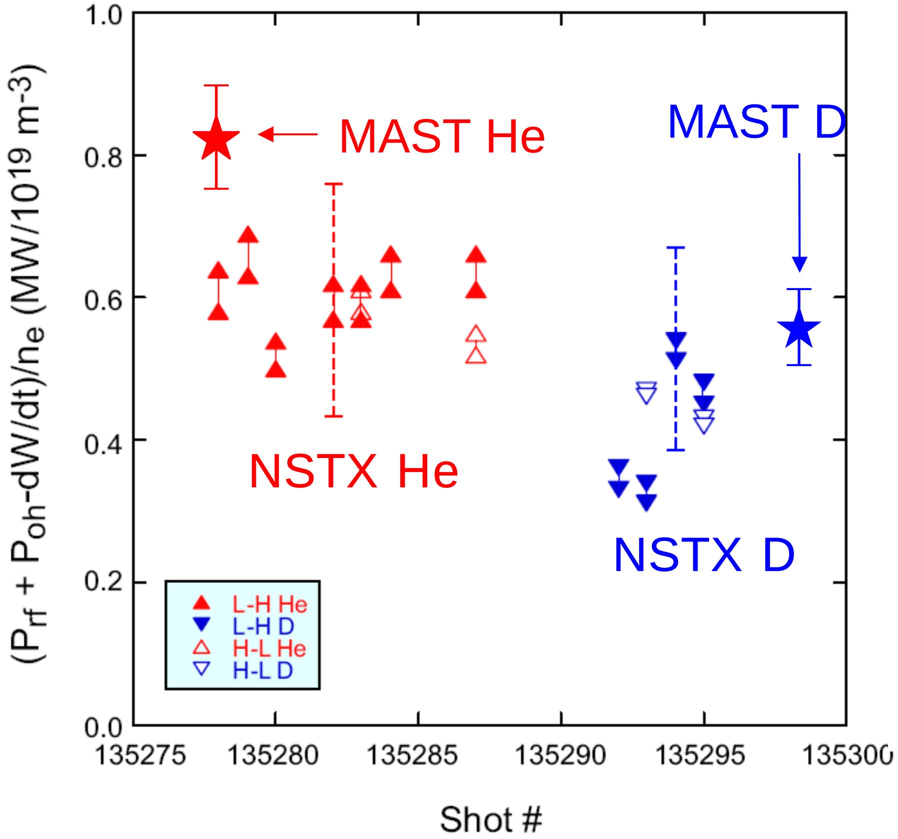
The L-H transition – E_r, T_e, and n_e

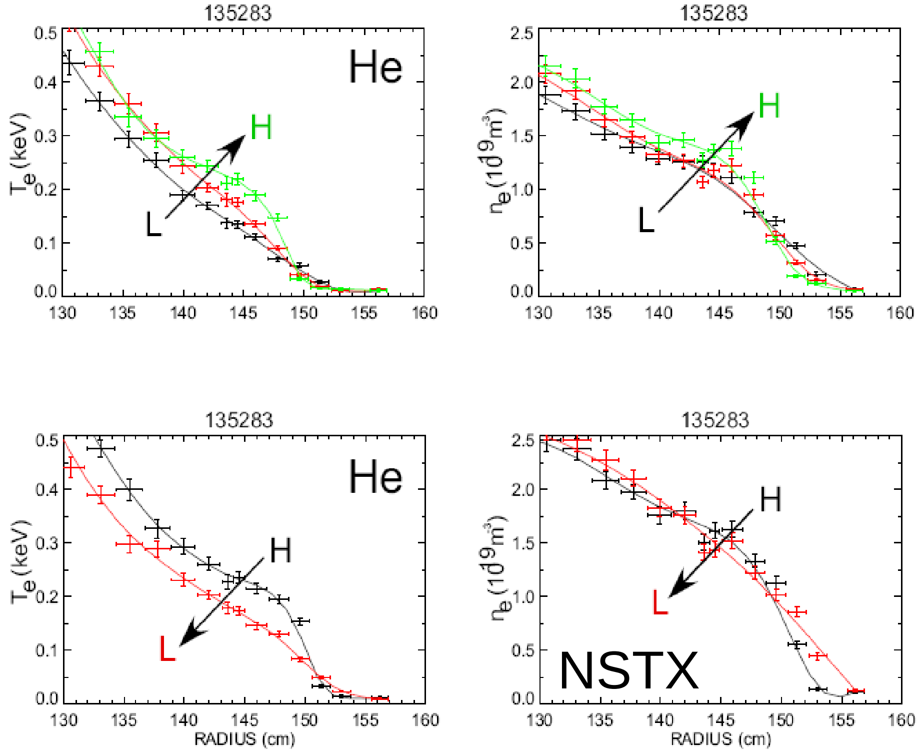
The Pedestal – H_H~1, T_i and edge current

Summary

D has lower P_{LH} then He

- <u>NSTX</u>: P_{LH}^{He}~ (1.2-1.4) P_{LH}^{D} (RF heating)
  - He: Profiles used to determine L-H and H-L transition.
- <u>MAST</u>: P_{LH}^{He}~ 1.5 P_{LH}^{D} (D-NBI heating, ~85% He, ~15% D)
- <u>NSTX:</u> No power hysteresis between L-H and H-L.



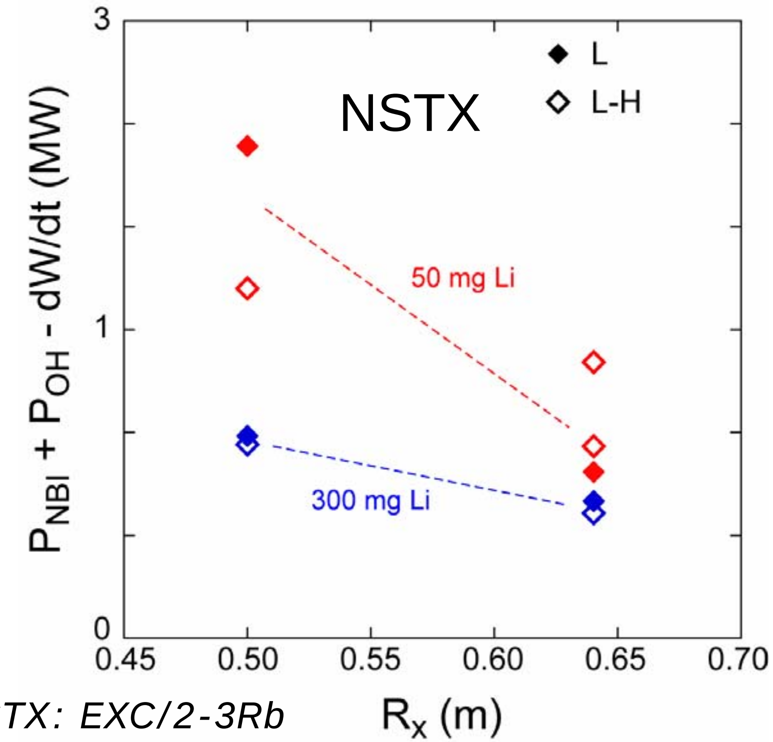


NSTX: EXC/2-3Rb

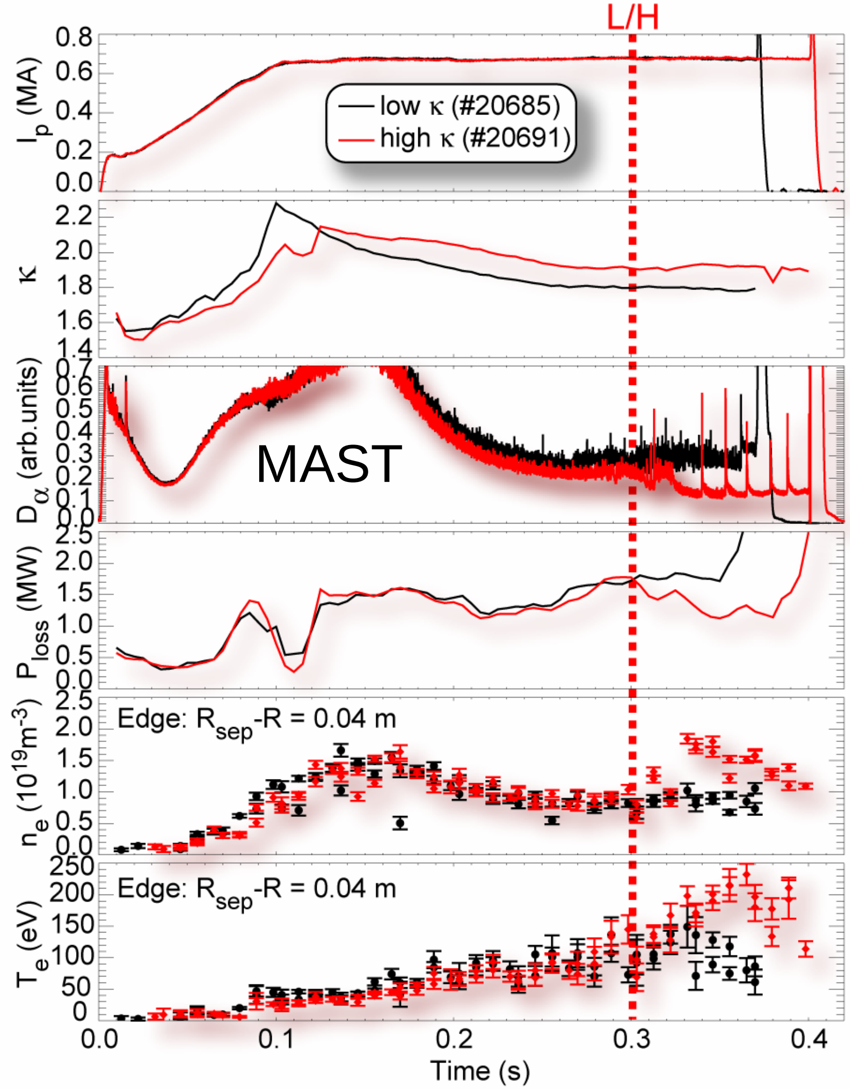
H-mode access better at high κ and low δ

- MAST: better H-mode access with increased κ.
  - No change in E_r due to shape change.
- NSTX: Lower P_{LH} with lower δ (larger X-point radius R_x.)

MAST: EXC/2-3Ra



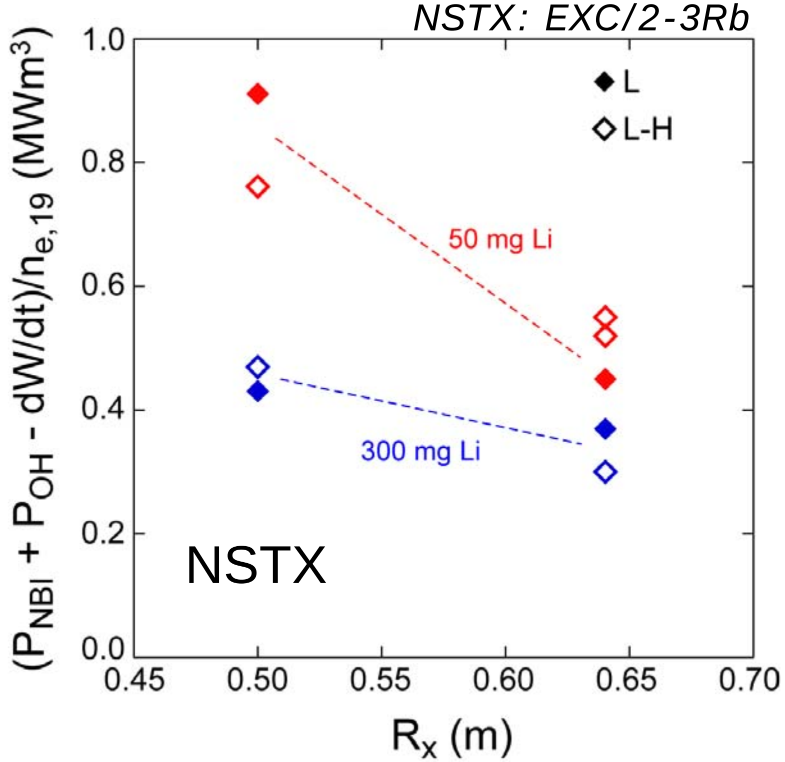
NSTX: EXC/2-3Rb



Li “wall” and lower X-point ⇒ lower P_{LH}

- NSTX: Li evaporation lowers P_{LH}.
  - Less recycling due to increased pumping.
  - Change is larger at high δ.
- MAST: Lower P_{LH} with lower X-point.
  - SN plasma shifted down (similar in DN by κ change).
  - Change in L_c is unlikely to cause change in P_{LH} ⇒ recycling?

NSTX: EXC/2-3Rb



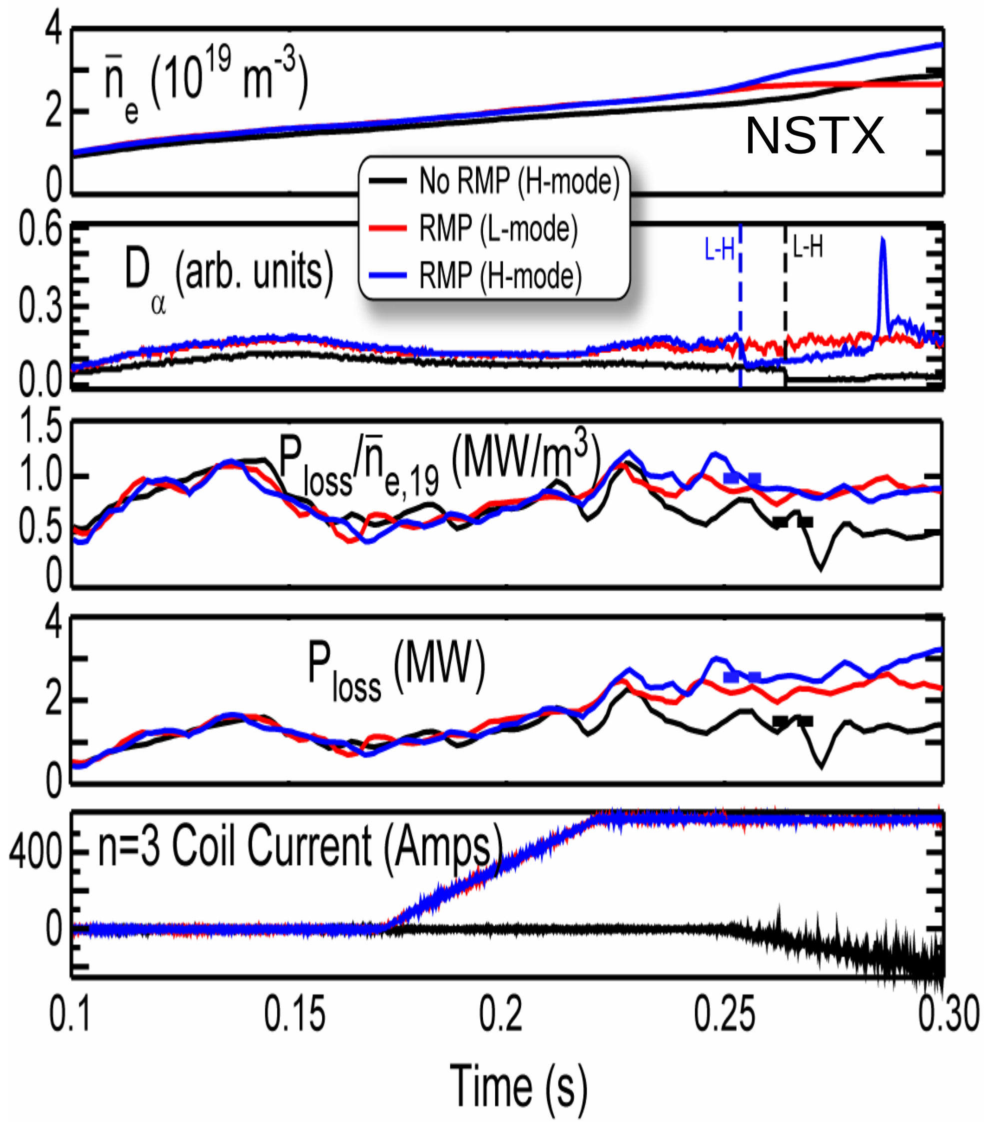
Z_{mag} (m)	R_x (m)	Z_x (m)	P_{LH} (MW)	$\bar{n}_e$ ($10^{19}m^{-3}$)	S_{pl} (m^2)	δ_l	δ_u	κ	q_{95}	L_c (m)
0.21	0.58	−1.25	1.3	2.5	21.5	0.44	0.18	1.67	3.5	13
0.10	0.59	−1.12	2.6	2.3	21.6	0.39	0.26	1.71	3.8	12
0.0	0.57	1.12	< 1.8	2.7	24.5	0.42	0.42	1.91	6.6	16
0.0	0.57	1.04	1.8	2.6	23.4	0.42	0.42	1.80	5.5	13

MAST: EXC/2-3Ra

Magnetic n=3 perturbation increases P_{LH}

- NSTX: Factor of <2 increase in P_{LH}/n_e with the application of n=3 perturbation fields (RMP).
  - mid-plane coils.
  - No change in poloidal or toroidal edge rotation.
- MAST: P_{loss} increased by 80% with n=3 RMP (see A. Kirk EXD/8-2).
  - 30% increase leads to a delayed L-H transition.
  - Upper and lower coil array.
  - More positive E_r with RMP.

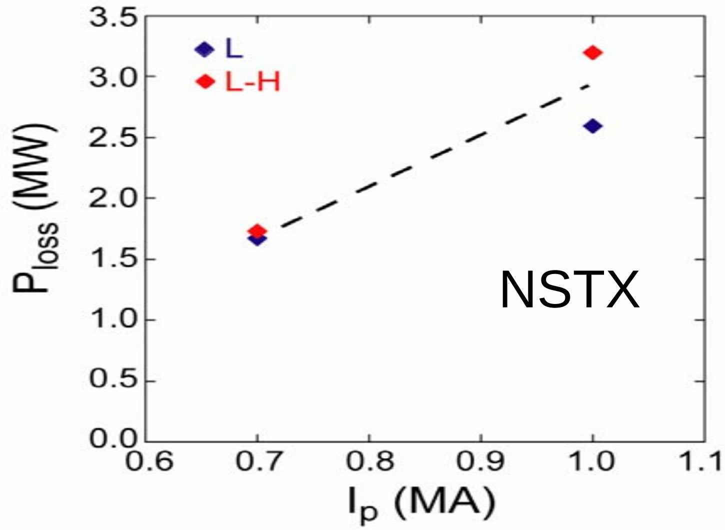
NSTX: EXC/2-3Rb

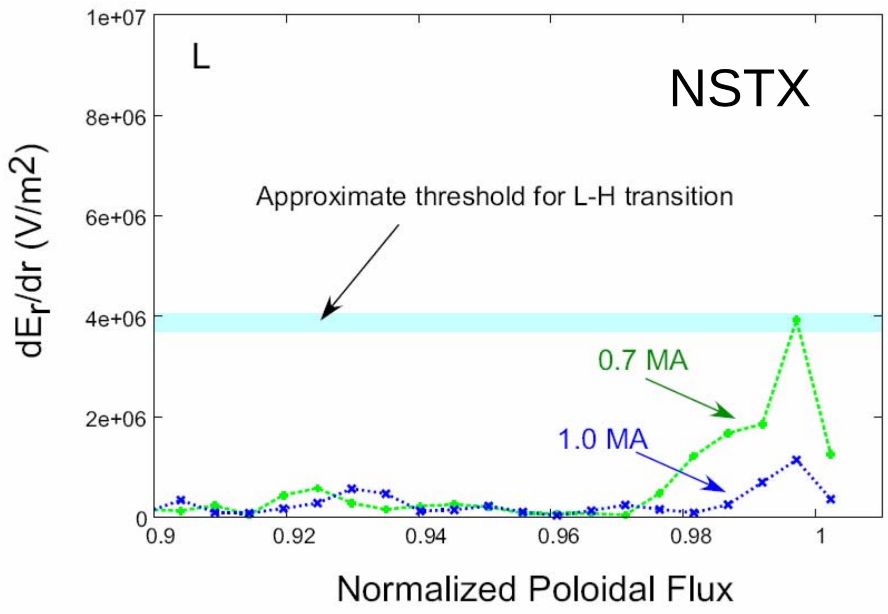


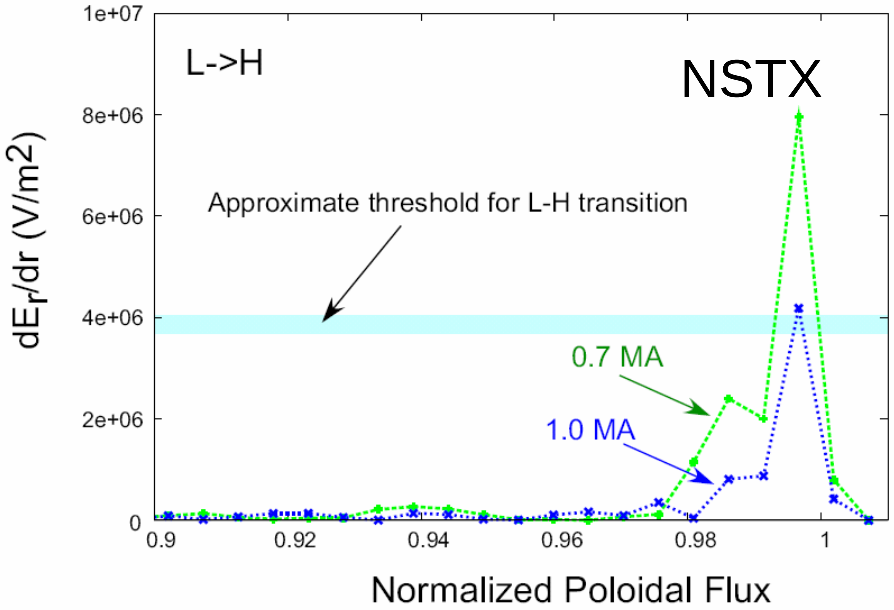
NSTX: $P_{LH} \propto I_p$ correlates with ∇E_r

- $P_{LH} \propto I_p$ observed
- E_r modelled with XGC0.
- Lower I_p $\Rightarrow$ larger orbit losses $\Rightarrow$ higher ∇Er at edge
  - $\nabla E_r \sim 4$ MV/m^2 threshold for L-H transition at any I_p

NSTX: EXC/2-3Rb



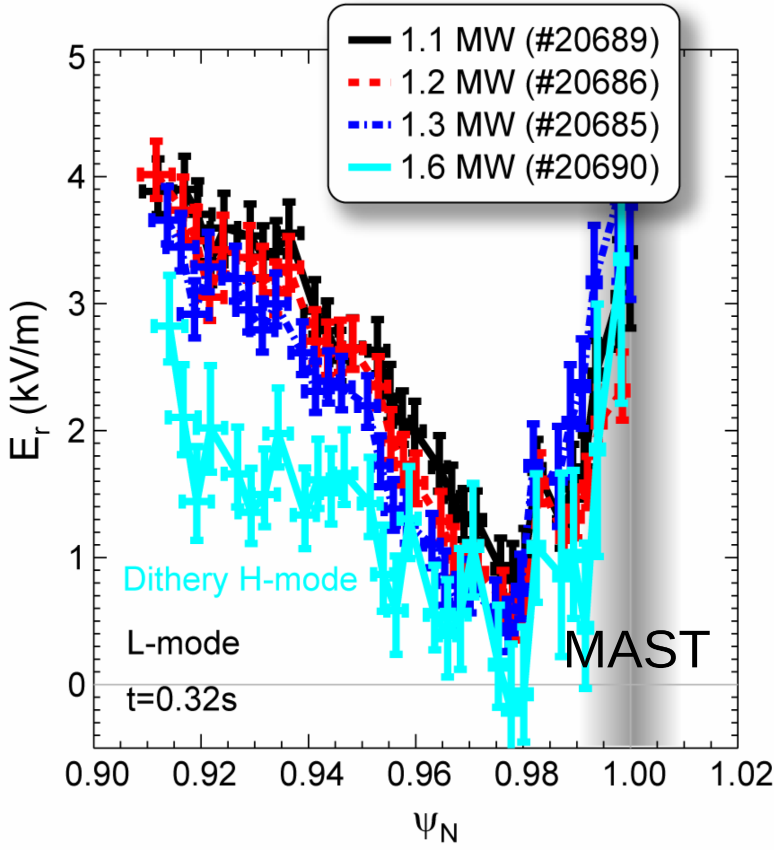


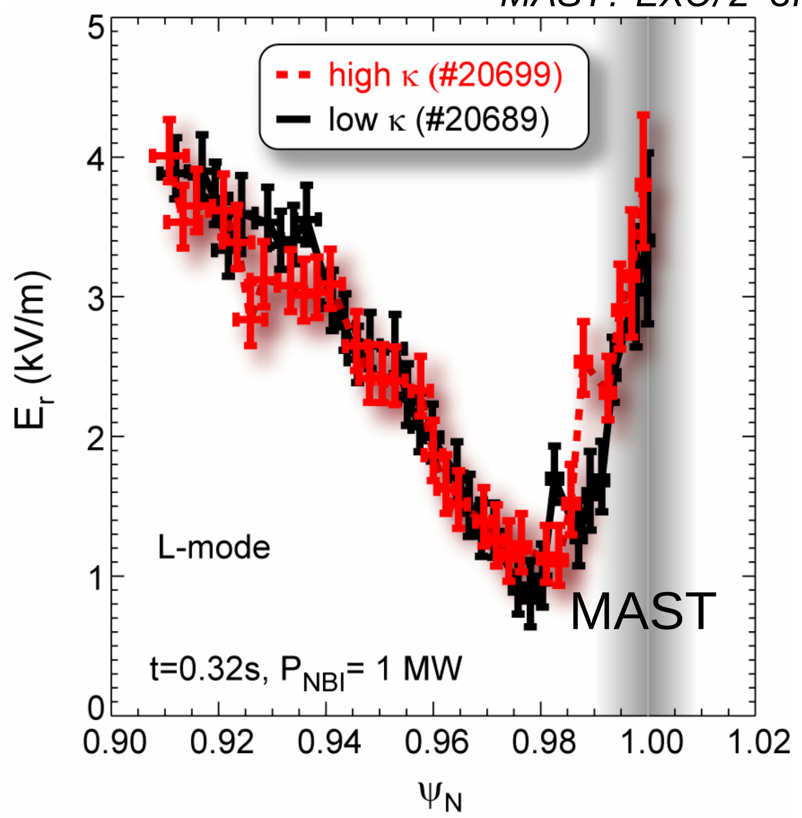


MAST: ∇E_r does not correlate with P_{LH}

- L-mode E_r not changed by power scan or change in κ (1.8-1.9).
- Application of n=3 RMP ⇒ E_r more positive ⇔ loss of H-mode.
  - But, power increase ⇔ again no change in E_r
- $\omega_{E\times B} > \gamma_{max}$ sufficient but not necessary ⇔ $\tilde{\omega}_{E\times B}$?

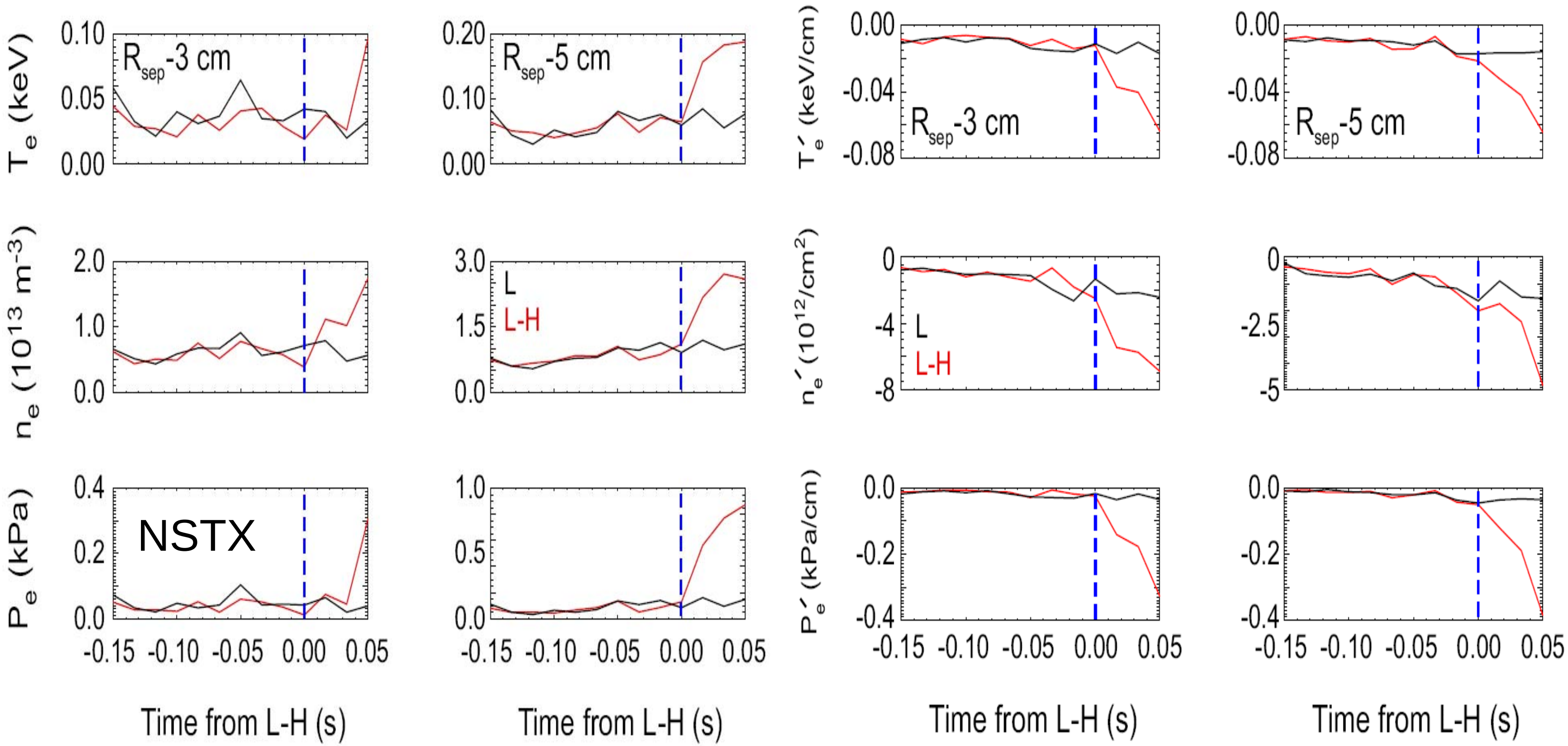
MAST: EXC/2-3Ra





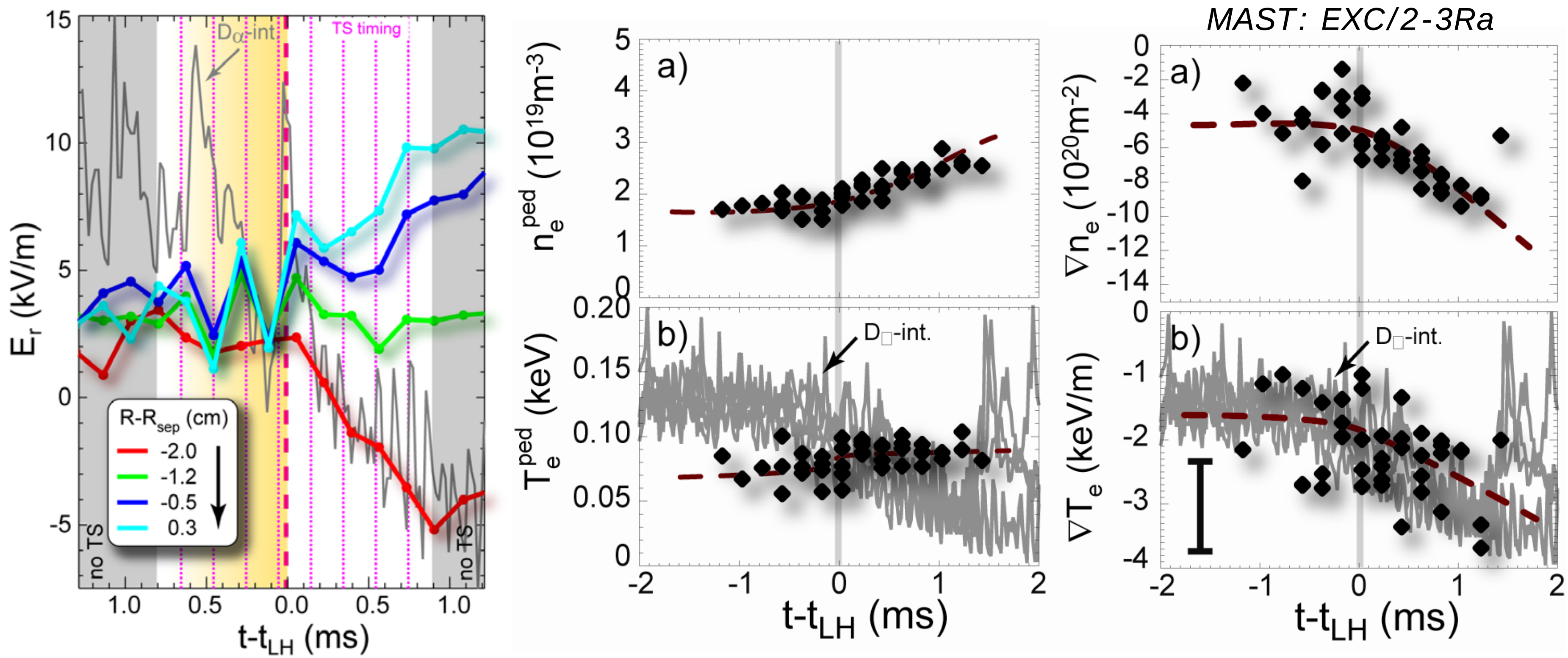
No slow evolution towards critical T_e, ∇T_e …

NSTX: EXC/2-3Rb



- NSTX: No change in T_e, n_e, p_e or their gradients prior to the L/H transition.
  - Time resolution not sufficient to resolve evolution during the transition.
- Clear increase of gradients after the transition.

No fast evolution of E_r, ∇E_r, T_e, ∇T_e …

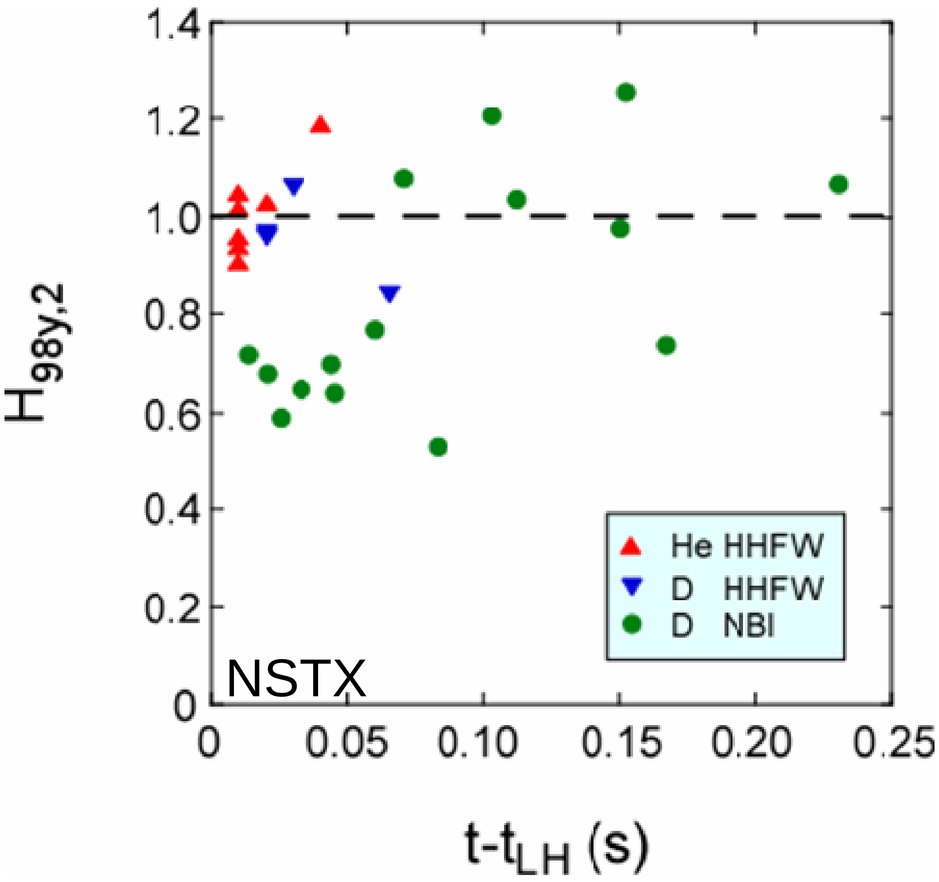


- MAST: no changes in E_r, T_e, n_e or their gradients prior to the L/H transition ($\Delta t < 0.2$ ms)
  - T_e hardly changes through the transition, but n_e and ∇n_e does.
  - E_r and ∇E_r evolve on fastest time scale ($\tau \sim 0.6$ ms).
- L-mode filaments suppressed in less than 0.1ms (visible light)
  $\Rightarrow$ Profiles evolve as consequence of "abrupt" change in transport.

NSTX: RF gives faster access to H_H~1

- With RF H_H~ 1 can be accessed within 10ms of the L-H transition.
  - Type-III ELMy phase (H_H~0.8) eliminated by Li conditioning (see also EXD/2-2).
- With beams access to H_H~1 is delayed by ~50 ms.
  - ~τ_E or 1 – 2 slowing fast-ion down times.
- Physics behind this is not yet clear.

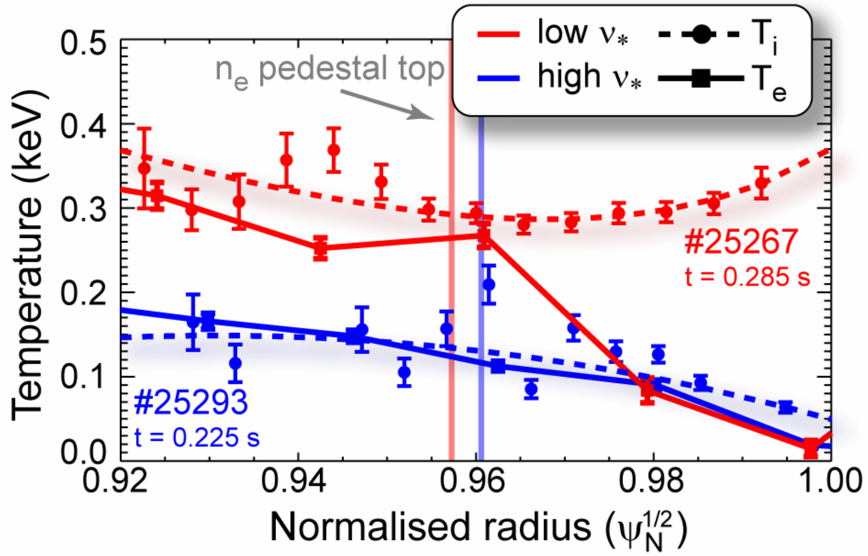
NSTX: EXC/2-3Rb

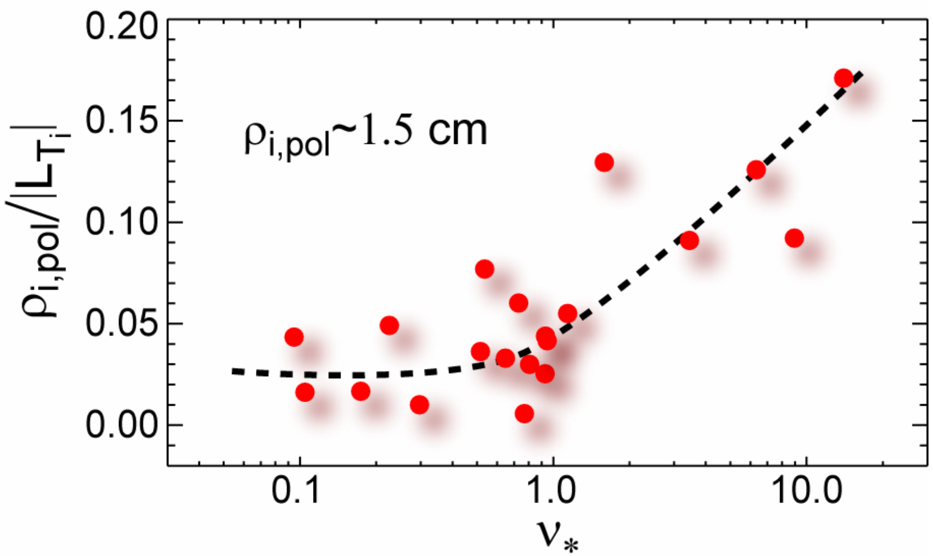


MAST: Flat T_i profile in the banana regime

MAST: EXC/2-3Ra

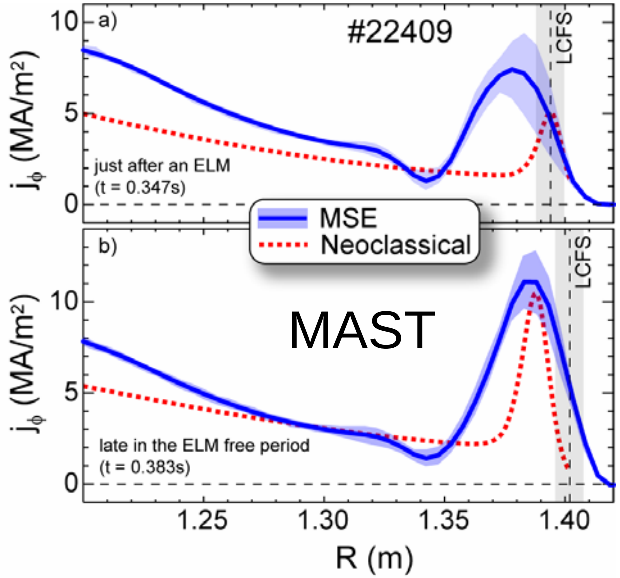
- Edge gradient of T_i depends on collisionality.
  - Low ν_* $\Rightarrow$ almost no gradient, $T_i >> T_e$ at separatrix.
- Banana regime: if $L_\perp \sim \rho_i^{pol}$ whole pedestal closed system $\Rightarrow$ $L_{Ti} >> \rho_i^{pol}$ [Kagan et.al. PoP 50 (2008) 085010].
- Flat T_i also observed on NSTX (R. Maingi EXD/2-2).

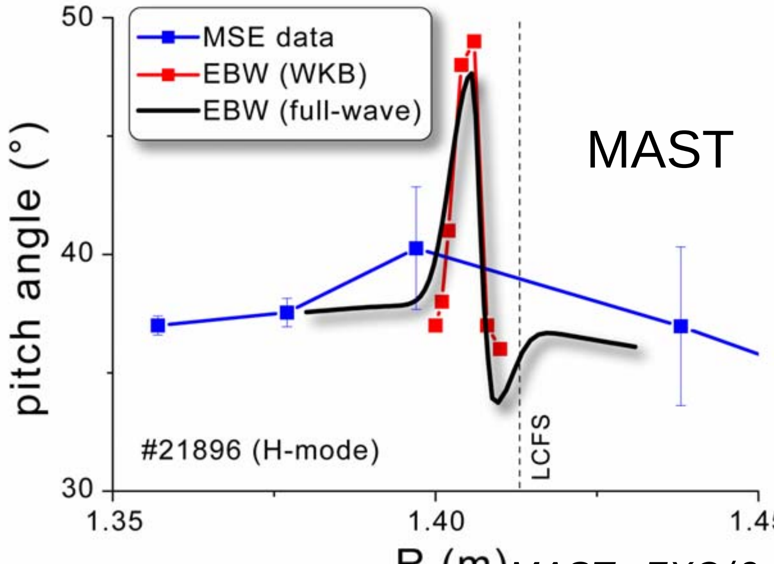




MAST: Neoclassical prediction of j_ϕ too low

- Unique measurements of edge pitch angle, $\gamma_m \Rightarrow$ edge j_ϕ
  - Motional Stark Effect (MSE)
    - *Δt=2ms, ΔR=2cm.*
  - 2D analysis of electron Bernstein emission (EBE)
    - *Δt~ 40 ms, ΔR~0.2cm.*
- Change γ_m larger than can be explained by neocl. calculation.
  - MSE broader $j_\phi(R) \Leftrightarrow$ spatial resolution?
  - EBE suggests narrow profile, but total current agrees with MSE.
    - *Requires negative edge current.*
- Standard neocl. theory valid with $\rho_i^{pol} \sim \rho_I \sim \Delta_{ped}$?

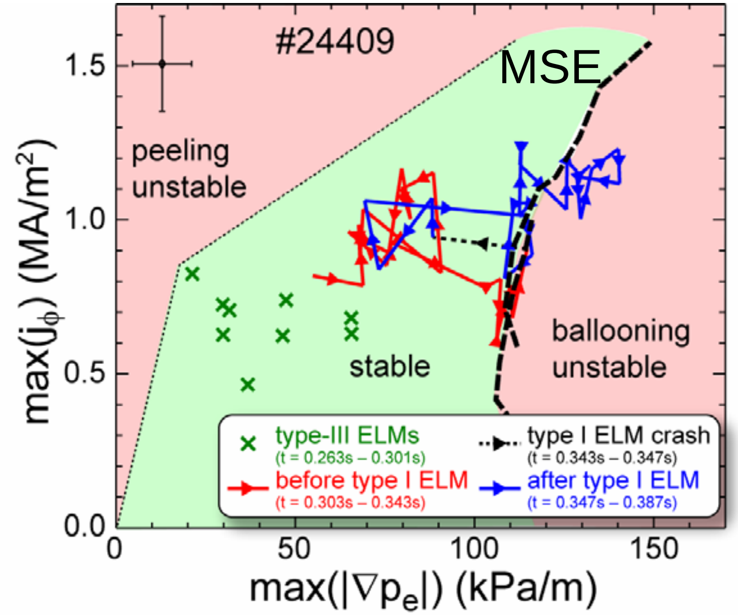


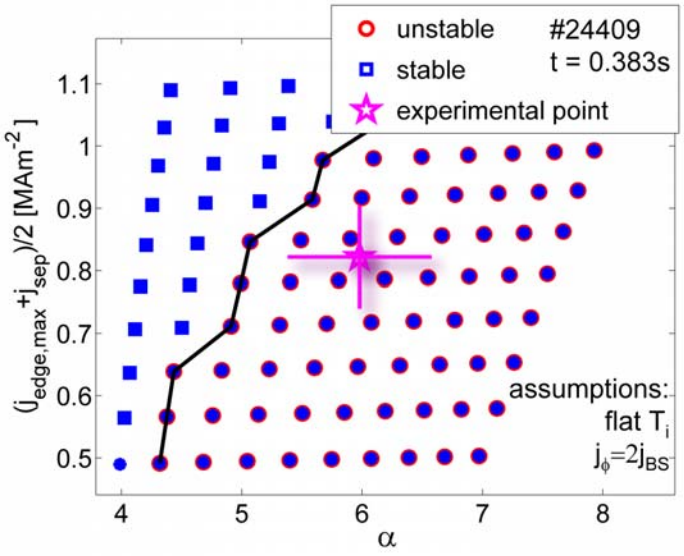


MAST: EXC/2-3Ra

MAST: Peeling-ballooning model seems incomplete

- Experimental trajectory in broad agreement with peeling-ballooning model.
  - NSTX see R. Maingi (EXD/2-2).
- Profiles linger at or above stability boundary for several 10 ms – 20 ms.
  - could be increase in Δ_{ped} ⇔ little evidence.
- max(j_ϕ) from MSE ⇔ probably too low!
- Profiles more unstable with higher j_ϕ and flat T_i.
- New EBE 36 antenna imaging system.
  - fast, high spatial resolution.





Large STs advance H-mode physics basis

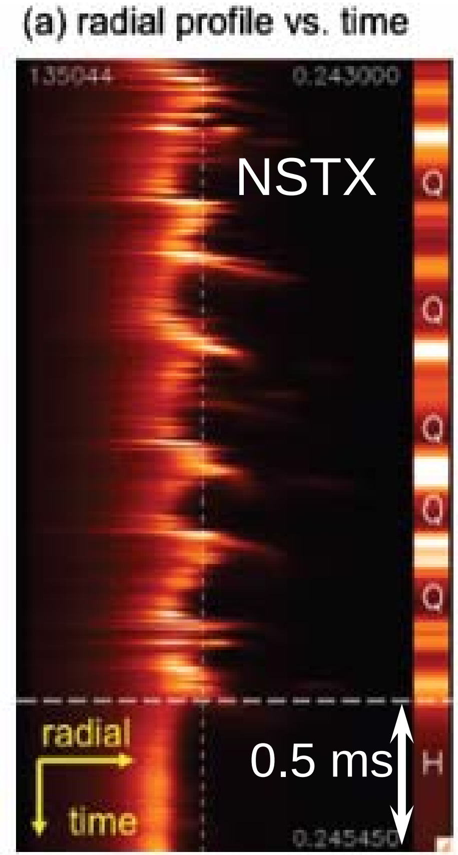
- On MAST and NSTX the L-H power threshold in He is 20% to 50% higher than in D.
  - No difference between P_{LH} and P_{HL} (NSTX).
- Lower δ (NSTX), higher κ (MAST), lower X-point height (MAST) and Li evaporation (NSTX) lower P_{LH}.
- The application of n=3 magnetic perturbations increase P_{LH} (see also EXD/8-2).
- E_r, T_e, n_e or gradients thereof don't change prior to the L-H transition.
  - XGC0 calculations show correlation between ∇E_r and P_{LH}.
- The edge current in H-mode seems to be higher than neoclassical predictions.
  - MAST MSE data can now resolve the ELM cycle.
- Peeling-ballooning model for ELM onset seems incomplete.

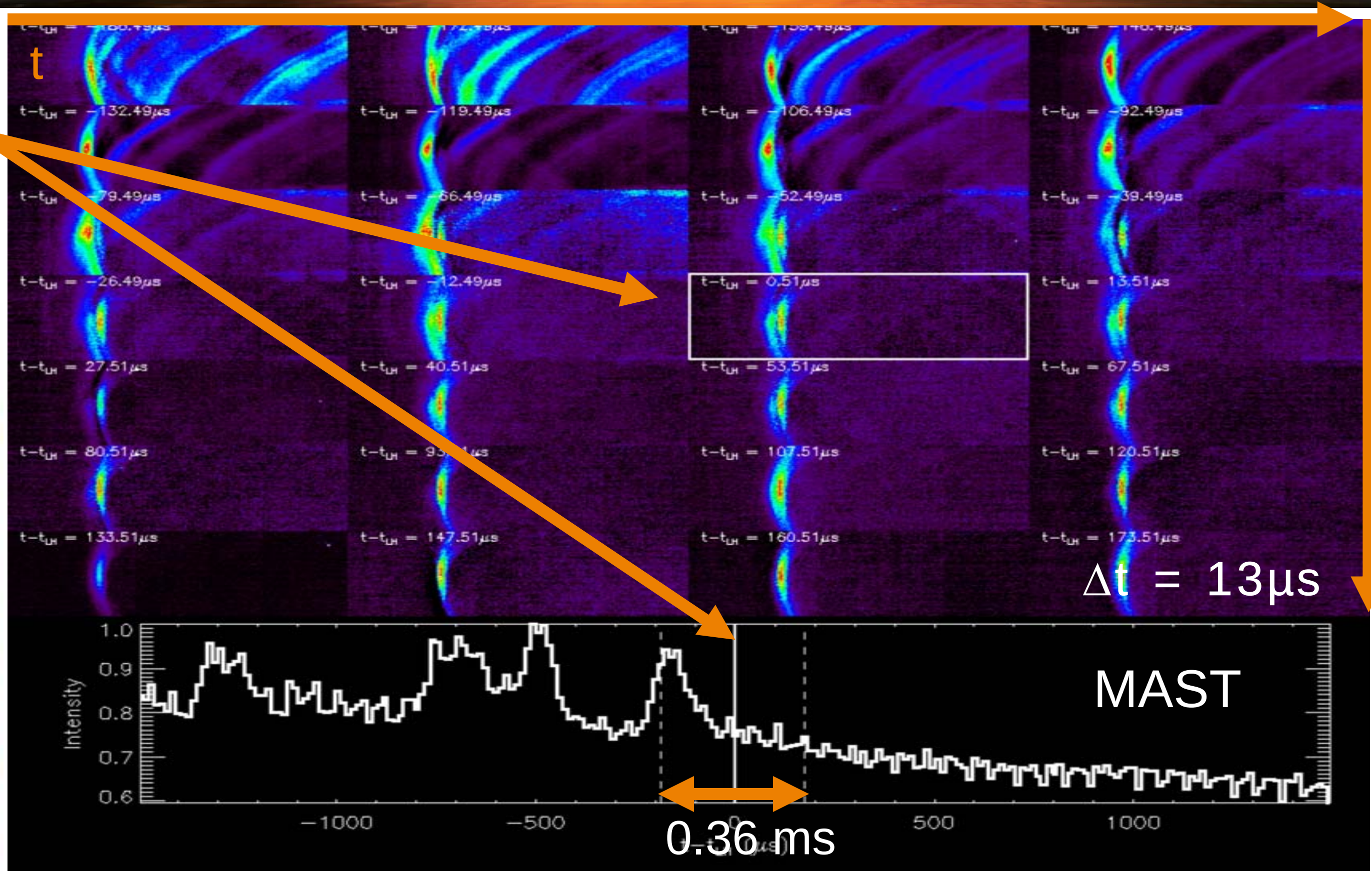
Thank you for your attention

Visible light fluctuations vanish in < 100μs

MAST: EXC/2-3Ra

L/H transition





[S.J. Zweben et.al., Phys. Plasmas, 17 (2010) accepted] (Fig. 8)

- Profiles evolve on slower time scales than fluctuations are suppressed.
- **Profiles react on abrupt change in transport.**