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Early H-mode impurity confinement reduction combined with snowflake for impurity and density control

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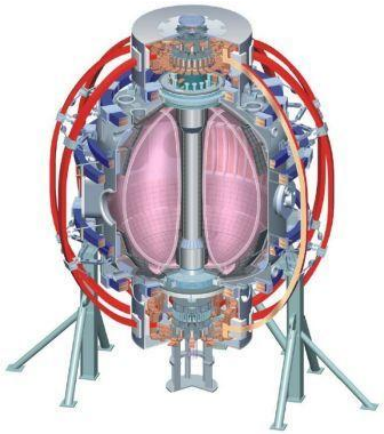

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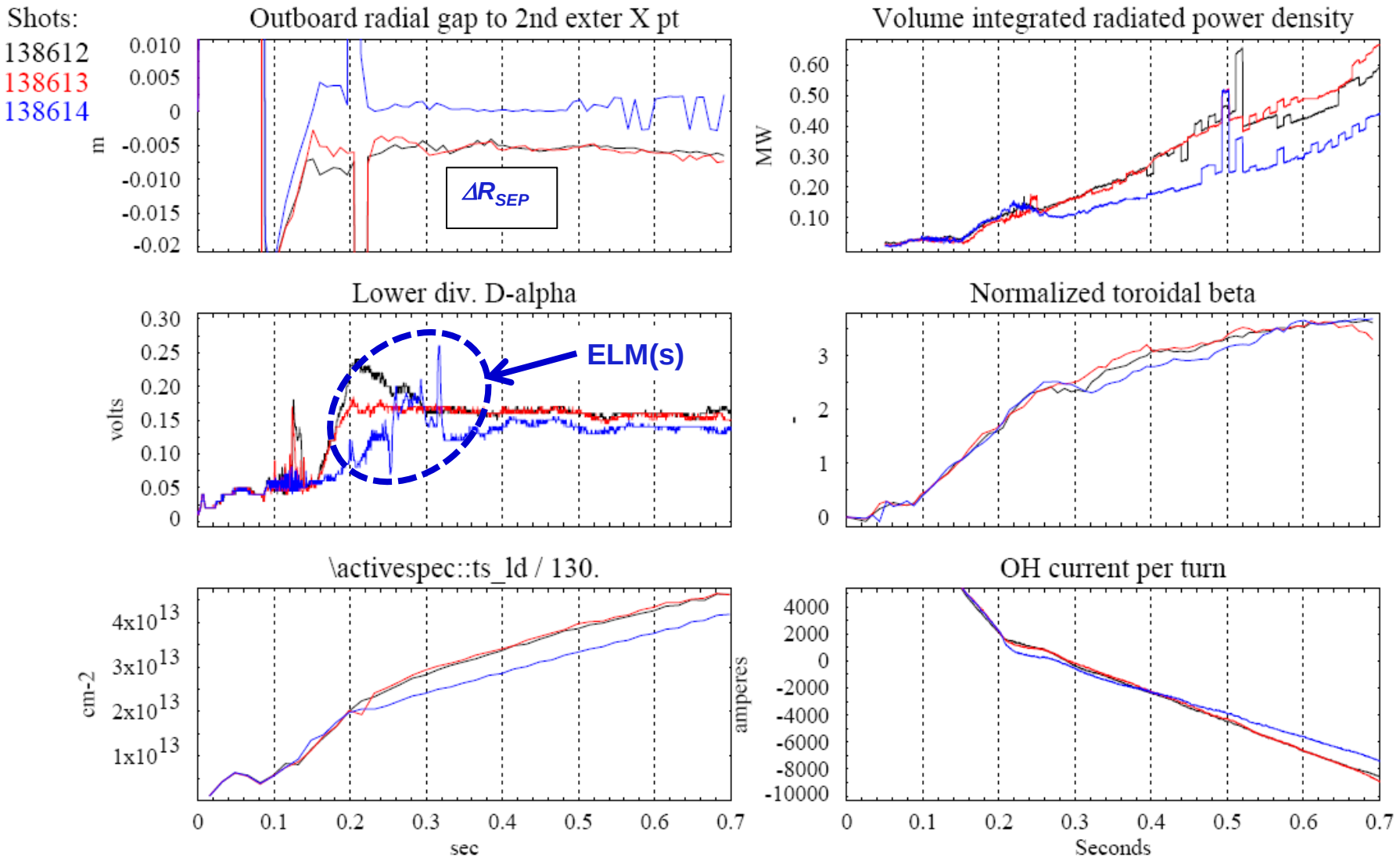
Overview

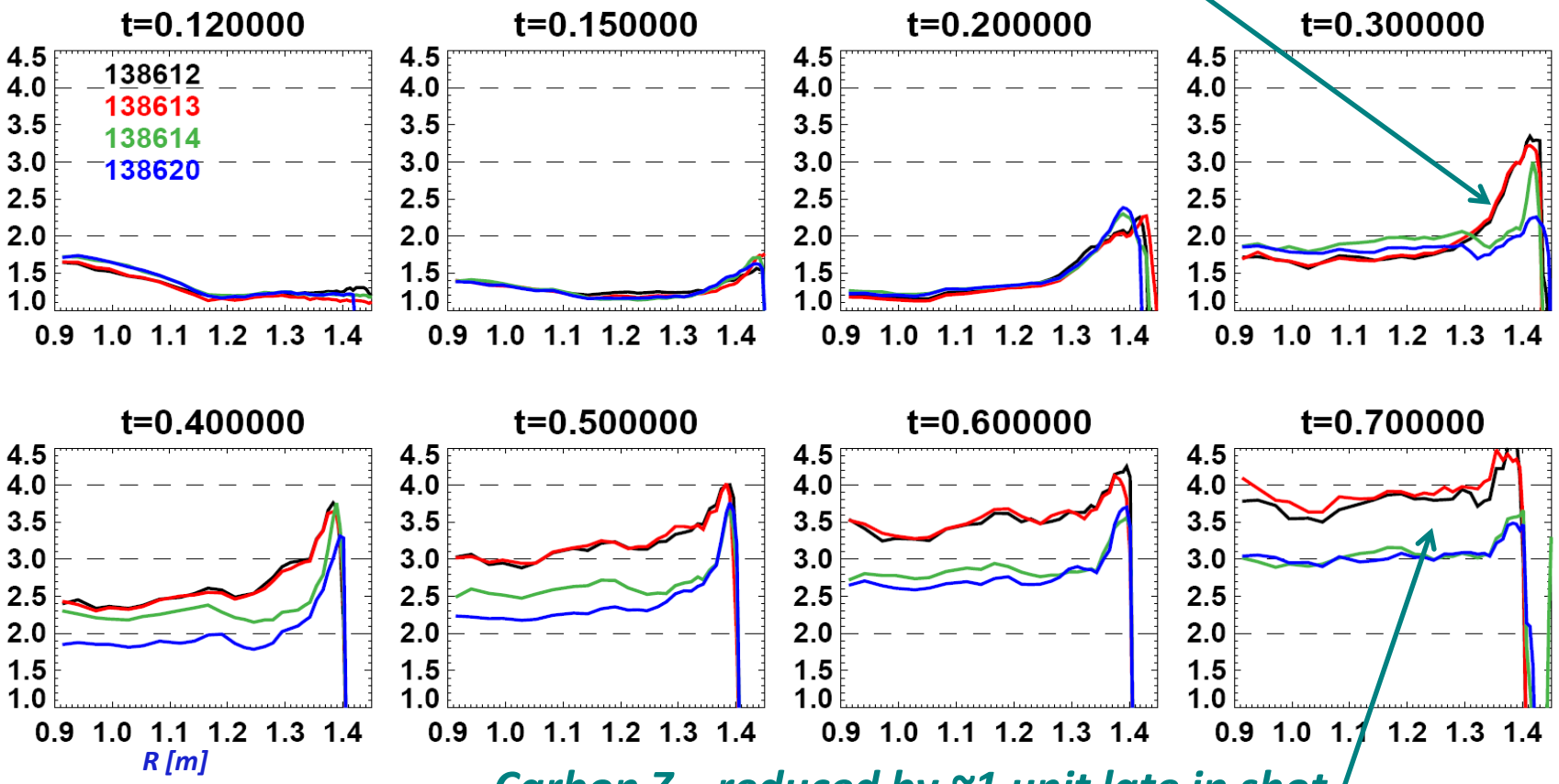
- Goal: Achieve stationary D, C inventories in flat-top *without* flat-top ELMs (paced or natural)
- Approach: Combine early impurity expulsion (t < 0.3s) with later impurity source reduction (snowflake, …)
- Background:
  - Lithium ELM-free H-modes commonly exhibit a rapid C impurity accumulation from t=0.15 to 0.3s.
  - Shortly after the early H-mode transition, there is typically a rapid build-up of C near the plasma edge which then slowly diffuses inward during the current flat-top.
  - Previously, upward magnetic balance excursions have been useful for triggering early ELMs to flush some of the edge C and reduce the overall C inventory.

XP1005: modified bias of fiducial plasma after early H-mode reduces plasma density, radiated power, flux consumption



XP1005: Bias change from -7mm to 0 reduces impurity confinement and/or generation and reduces C Z_{eff} by -1

Like 2009 result, size of H-mode C impurity "ear" near t=0.3s influences late Z_{eff}



Motivates testing combinations of this + snowflake + divertor D puff + SGI + …

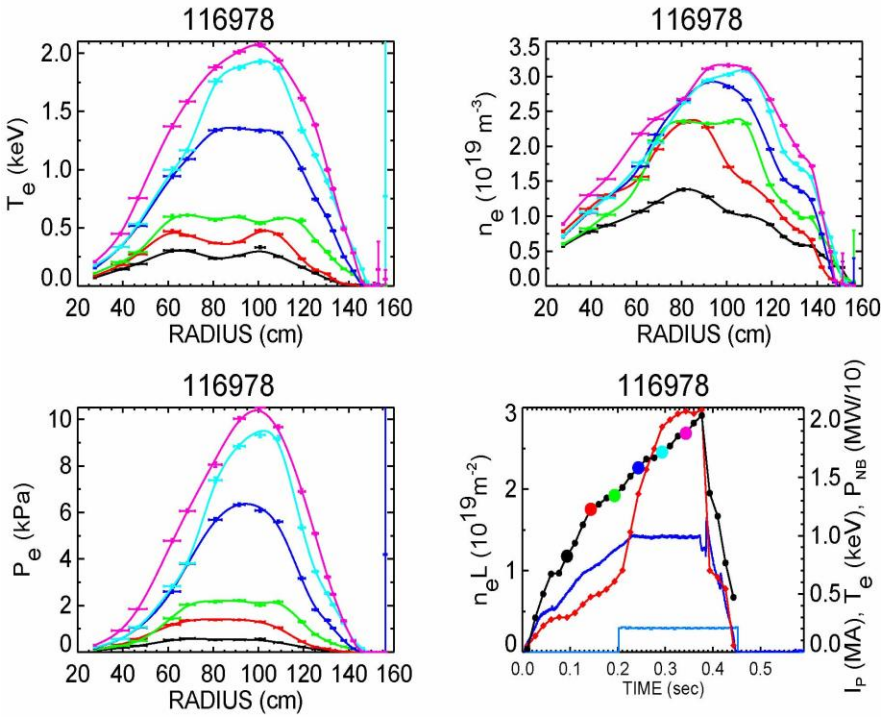
Experimental Approaches (1)
(2 run days requested, 1 day minimum)

- Attempt to reproduce early upward DRSEP excursion triggering of ELM to reduce C density ear after early H-mode (0.5 day)
- During the current ramp-up, or during the early I_P flat-top, reduce the inner gap toward/to zero briefly to induce an ELM/H-L back-transition to expel C impurities (0.3 day)
  - Vary how hard and how long plasma is pushed onto CS
  - The NBI heating and beta may need to be reduced/modified during this time to avoid pressure-peaking disruption.
- Delay the early H-mode by reducing the inner gap and maintaining a (nearly) IBD limited plasma (0.5 day)
  - Then pull LSN early during I_P flat-top to transition to H-mode.
  - Keep HFS gas timing fixed at early H-mode timing to densify plasma before H-mode transition.
  - Again, the NBI heating and beta may need to be reduced/modified during this time to avoid pressure-peaking disruption.

Additional details on delaying H-mode

- Keeping plasma on CS until 0.2s + delayed low P_{NBI} is/was recipe for high-performance RS L-mode - example below:
- Try similar approach for L→H:
  - Start from fiducial-like shot, but at 0.7-0.8MA to maintain long pulse
  - Use inner gap control to keep plasma (nearly) limited
  - Use inner gap increase and maybe I_P flat-spot to trigger H-mode, and scan the H-mode transition time
  - Reduce/modify early NBI heating to avoid beta limit as necessary
- Assess impurity evolution
- Then try re-attaching to CS, assess impact of back-transition

From XP538 "RS scenario developed by Stutman and Levinton to establish a plasma suitable for HHFW operation"



Experimental Approaches (2)

- Similarly, attempt to trigger ELM during ramp-up/very early flat-top with large RMP pulse: try n=3 and n=2 RMP (0.5 day).
  - Scan the amplitude and timing of the pulses since q_{95} is varying rapidly during the ramp-up.
  - Is ELM triggering with n=3 and/or 2 more difficult early in flat-top?
  - This part could possibly be done jointly with other proposals that use RMP pulses later in the shot for ELM pacing
- Assuming one of the above techniques works reliably, transition from a high-delta fiducial plasma shape in the flat-top to high-delta snow-flake divertor shape (0.2 day)
  - Aim is to reduce the peak heat flux and impurity source late in shot
- Compare plasma impurity and main-ion density evolution to fiducial plasma evolution