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Review of HHFW Heating Properties for H-mode Plasmas in NSTX

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Results Review

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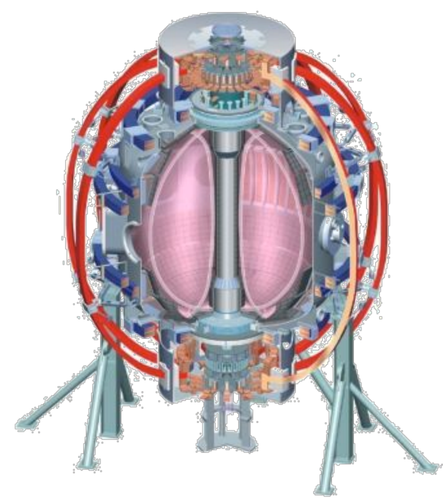

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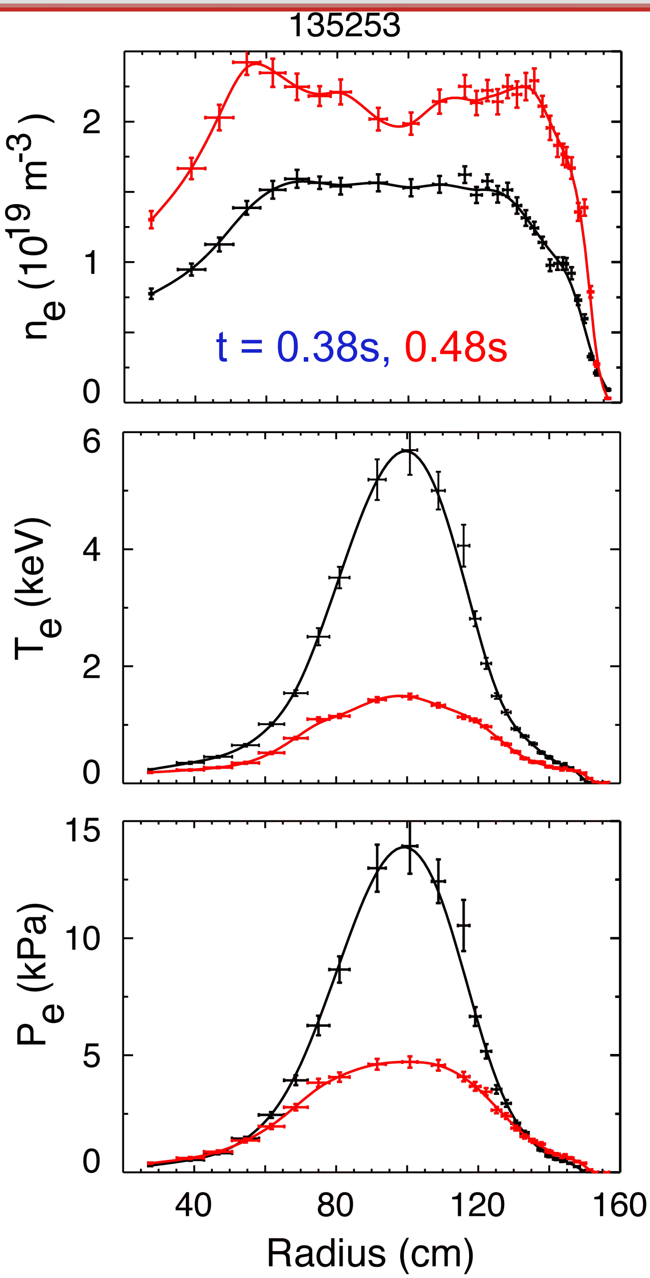
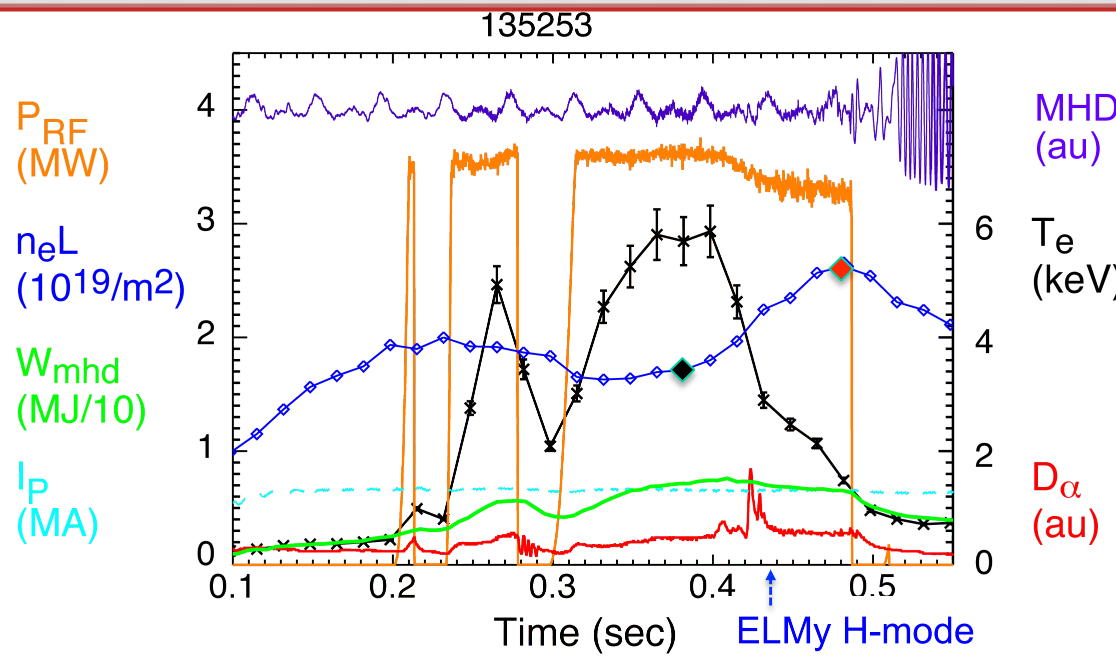
Review of HHFW heating properties for H-mode plasmas in NSTX

Outline:

- H-mode with HHFW alone
  - Effect of ELMs on core heating
  - Sustained stored energies with programming of P_{RF} down to ~ 1.4 MW in the ELM-free-like H-mode regime
  - Very narrow ELM heat deposition around strike radius with fast IR camera
- H-mode with NBI and HHFW
  - Broader ELM heat deposition around strike radius with fast IR camera
  - Divertor tile currents found to track position of RF “hot” zone associated with edge power loss

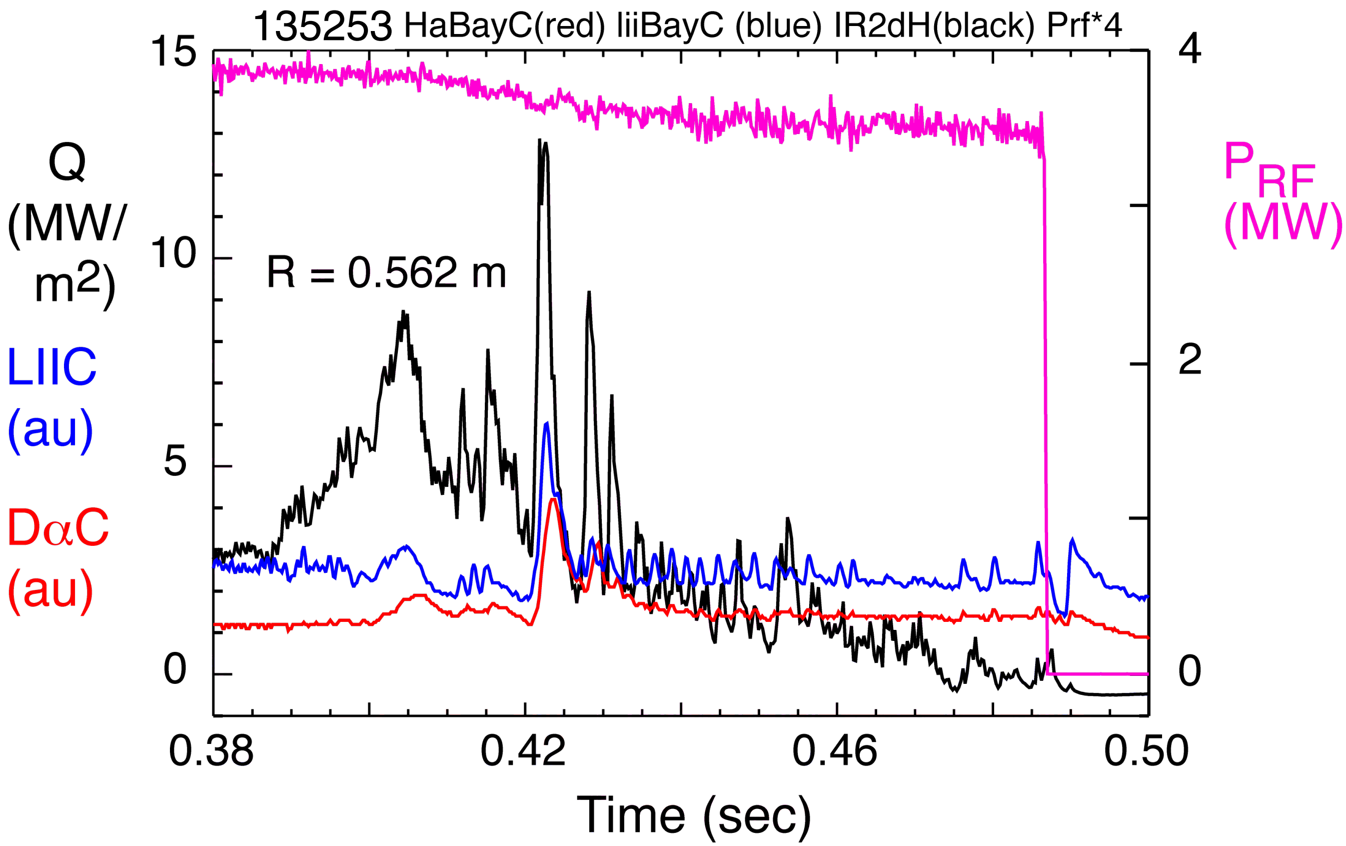
RF-only H-mode Thomson scattering characteristics





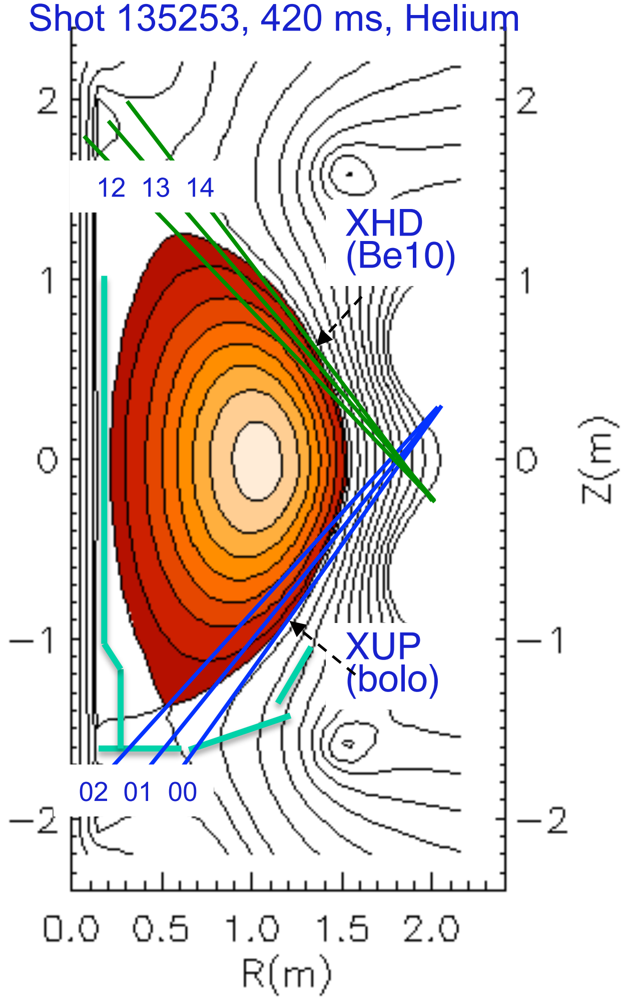
- Transition to ELMy H-mode is accompanied by:
  - Steepening of edge density gradient
  - D_α indication of large ELMs
  - Drop off of $T_e(0)$
  - Increase in reflected RF power
  - Strong decrease in electron stored energy

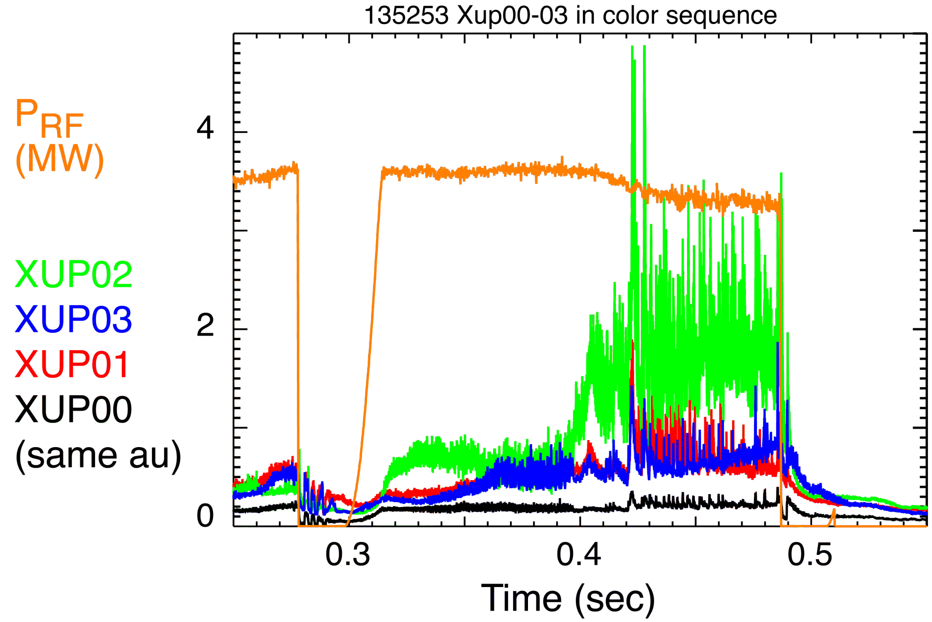
ELM heat deposition at the outer strike radius is very large as measured with the fast IR camera at Bay H

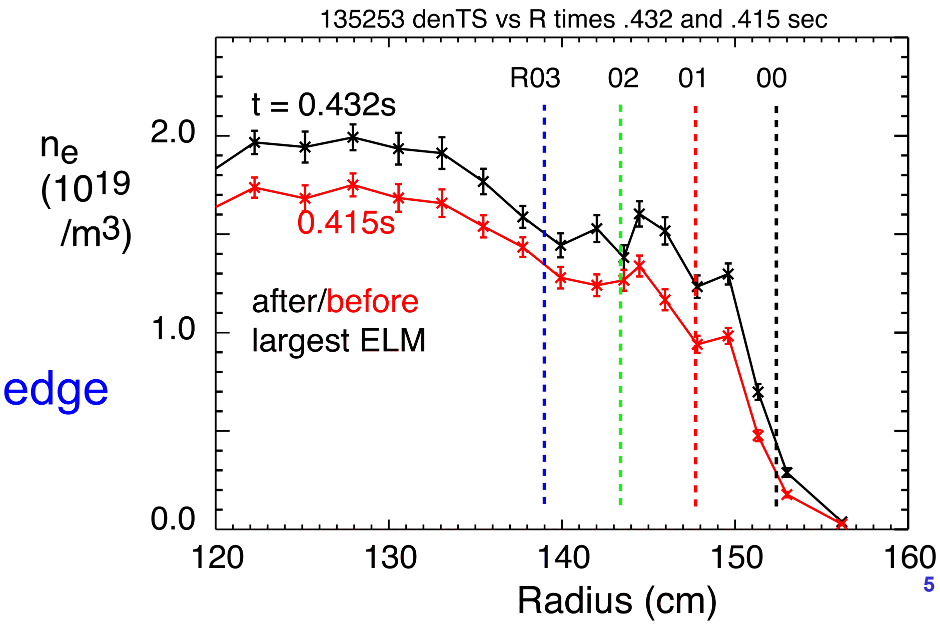


- The Bay H fast IR heat deposition measurement, Q, clearly shows the ELM heat deposition on the lower divertor plate at R = 0.562 m (divertor strike radius)
- Small effect of largest ELM is evident on the net RF power
  - ELMs are located away from the antenna

ELM effect on soft X-ray (bolo) signals is peaked inside the last closed flux surface

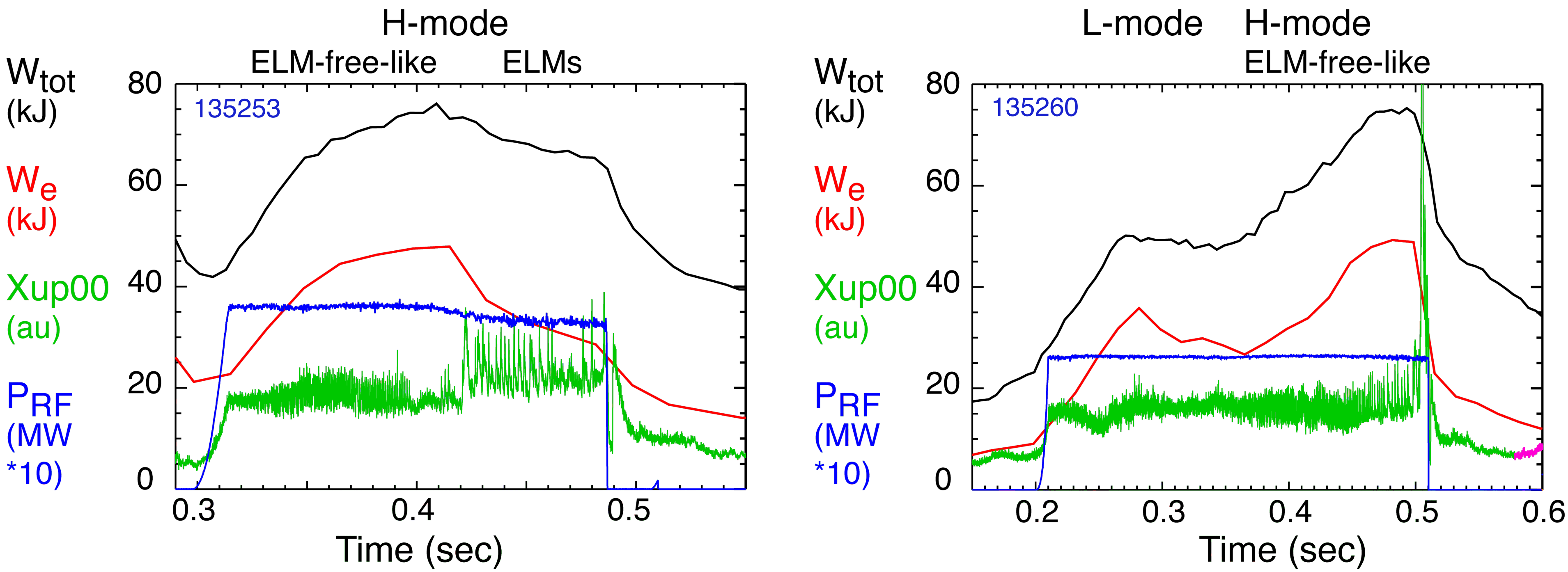






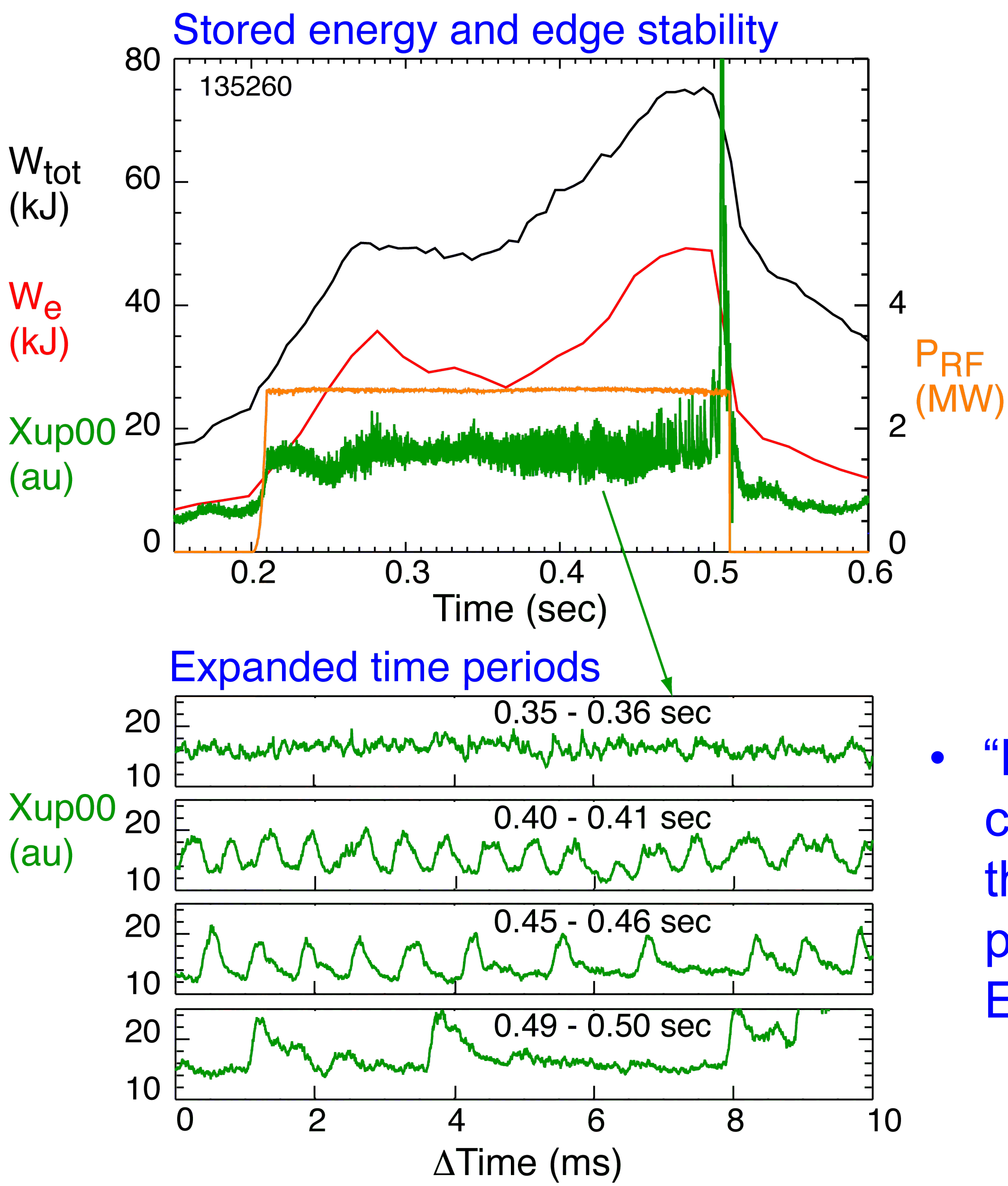
- Xup (bolo) peaks strongly on third cord into edge of plasma - at top of pedestal (or at X-point)
- ELM-free-like (oscillations followed by small ELMs) H-mode is evident prior to 0.39 sec

ELMs reduce heating efficiency for the RF H-mode as for the NB H-mode case



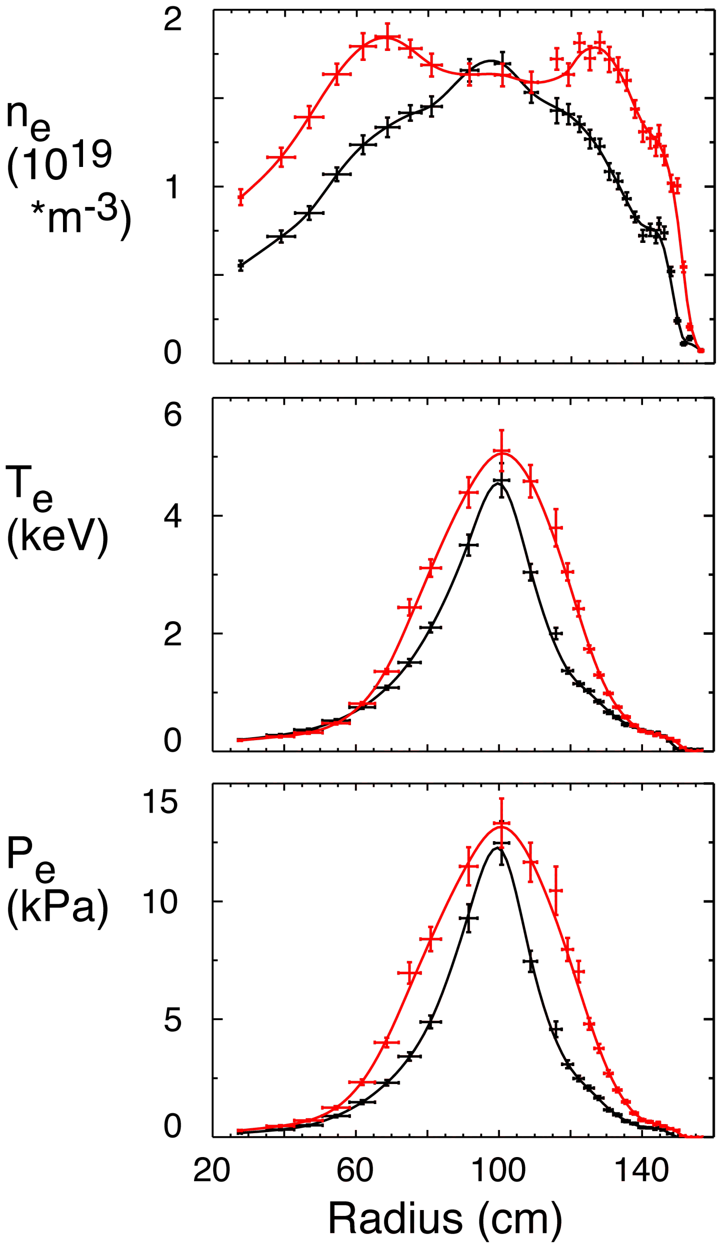
- At P_{RF} = 3.7 MW ELM-free-like transition to ELMy H-mode results in greatly reduced stored energies W_{tot} and W_e
- At P_{RF} = 2.7 MW L-mode slowly transitions to ELM-free-like H-mode and stored energies increase accordingly
- Large ELM at end of the 2.7 MW RF pulse strongly reduces the stored energies

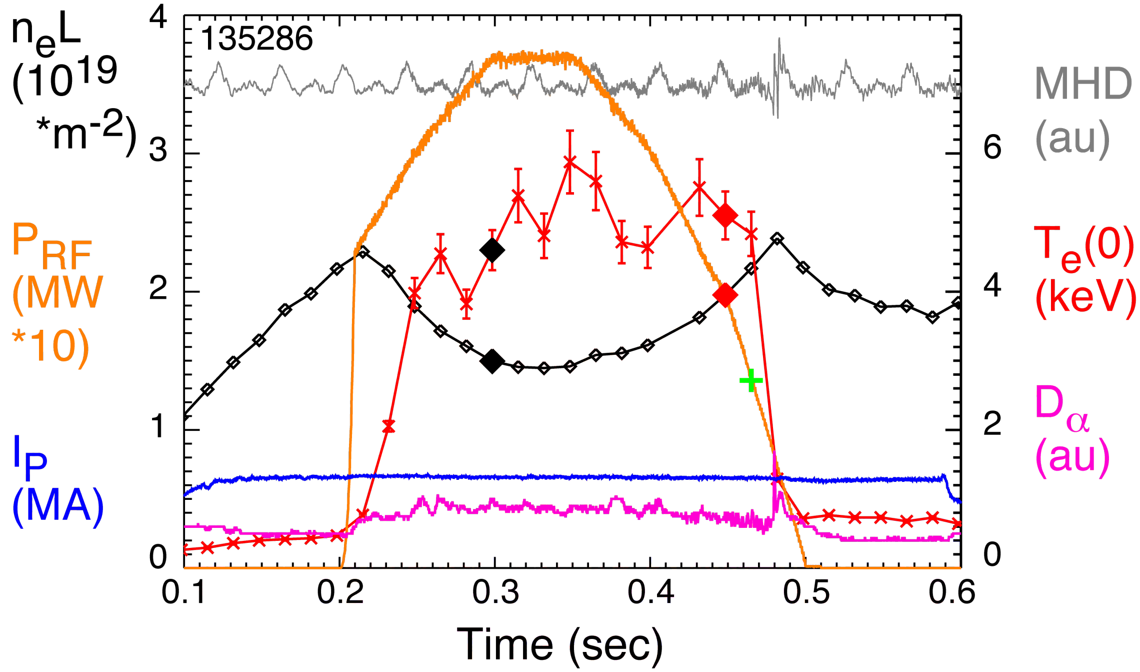
Stored energy increase period is accompanied by edge oscillations and small ELMs



- "ELM-free-like" period is characterized by edge oscillations that peak on top of density pedestal and are followed by small ELMs

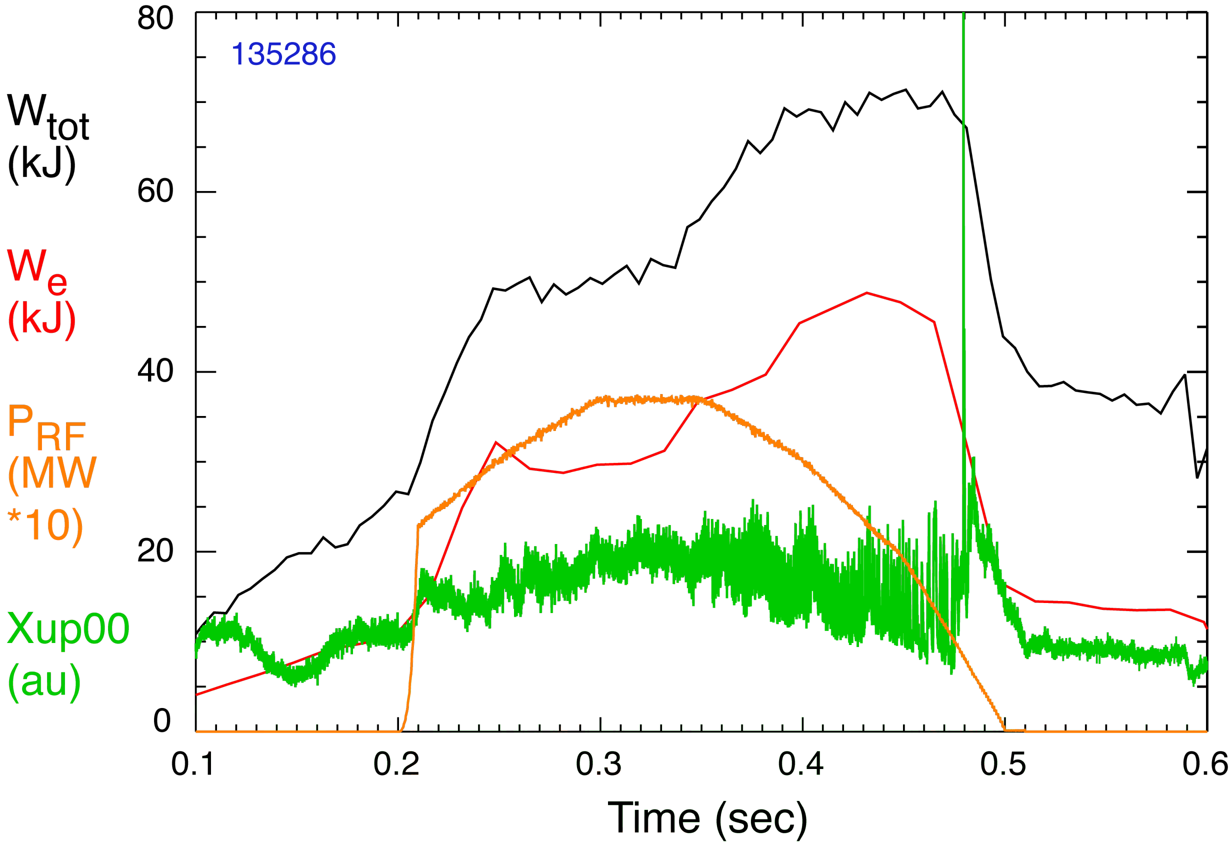
Slow fall of P_{RF} results in sustainment of high $T_e(0)$ and core electron heating even down to P_{RF} < 1.4 MW





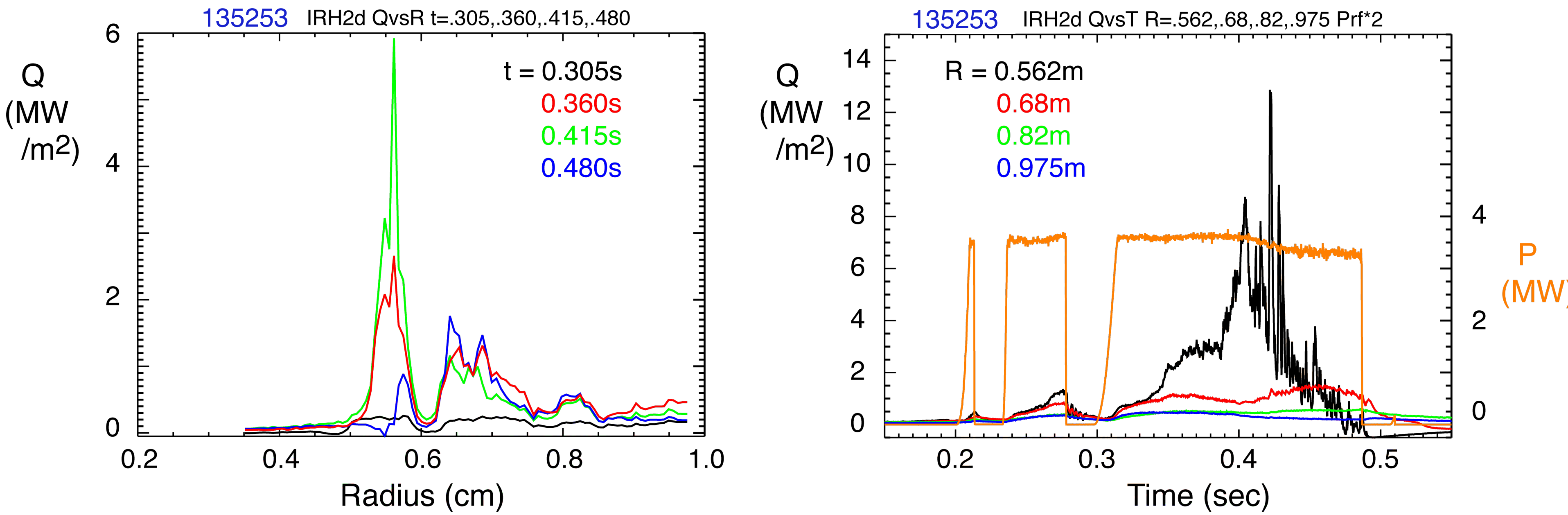
- Slow transition to H-mode from L-mode as power is ramped to 3.7MW
- During slow ramp down of P_{RF}, the core temperature is maintained and broadened in radius even down to 1.36 MW
- Large ELM at even lower power strongly reduces the stored electron energy and marks the transition back to the L-mode

Stored energies increase during the fall of P_{RF} in ELM-free-like H-mode period



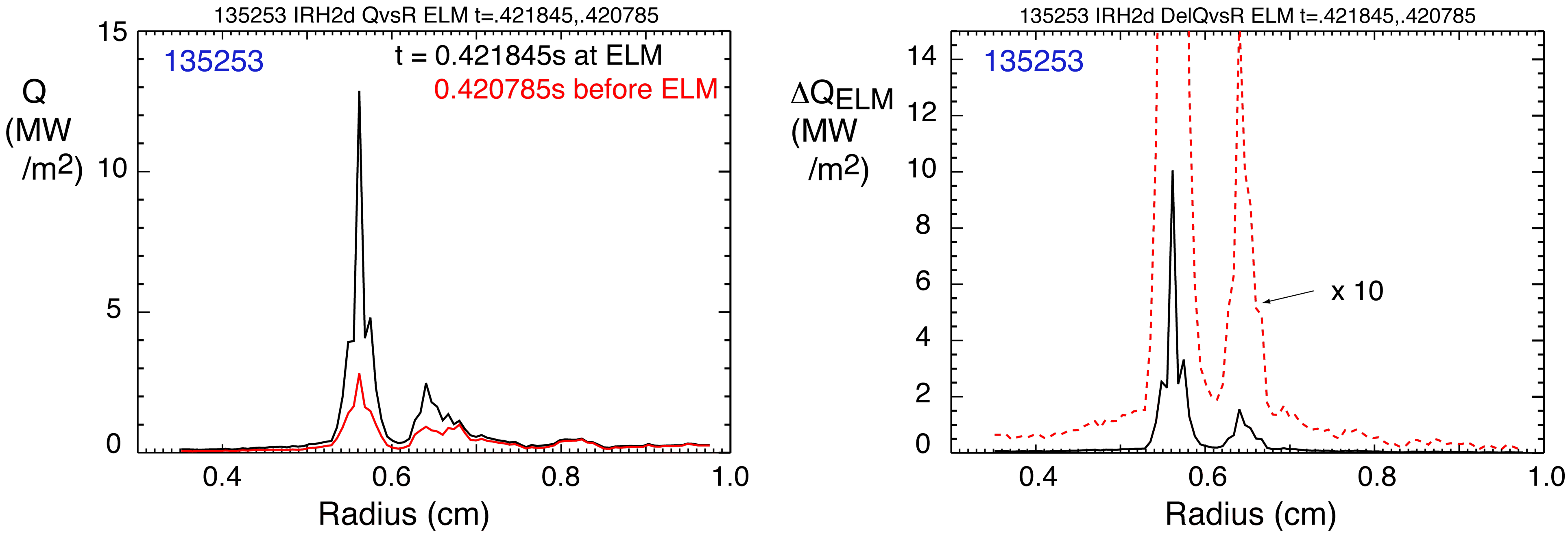
- Both W_{tot} and W_e begin to increase just prior to the end of the 3.7 MW flat top of the RF power waveform
- Both stored energies attain values during the RF power ramp down comparable to the previous levels shown for 3.7 MW and 2.7 MW flat RF power pulses
- Evidently in ELM-free-like H-mode operation little power is needed to sustain the stored energies (a strong change in radial transport is indicated)

Fast IR at Bay H clearly shows time response of heating on bottom divertor plate



- Heating at the strike radius increases strongly with transition to ELMy H-mode
- Fast IR (Bay H) shows ELM energy deposition on lower divertor plate to be localized near the outer strike radius – 0.562 m

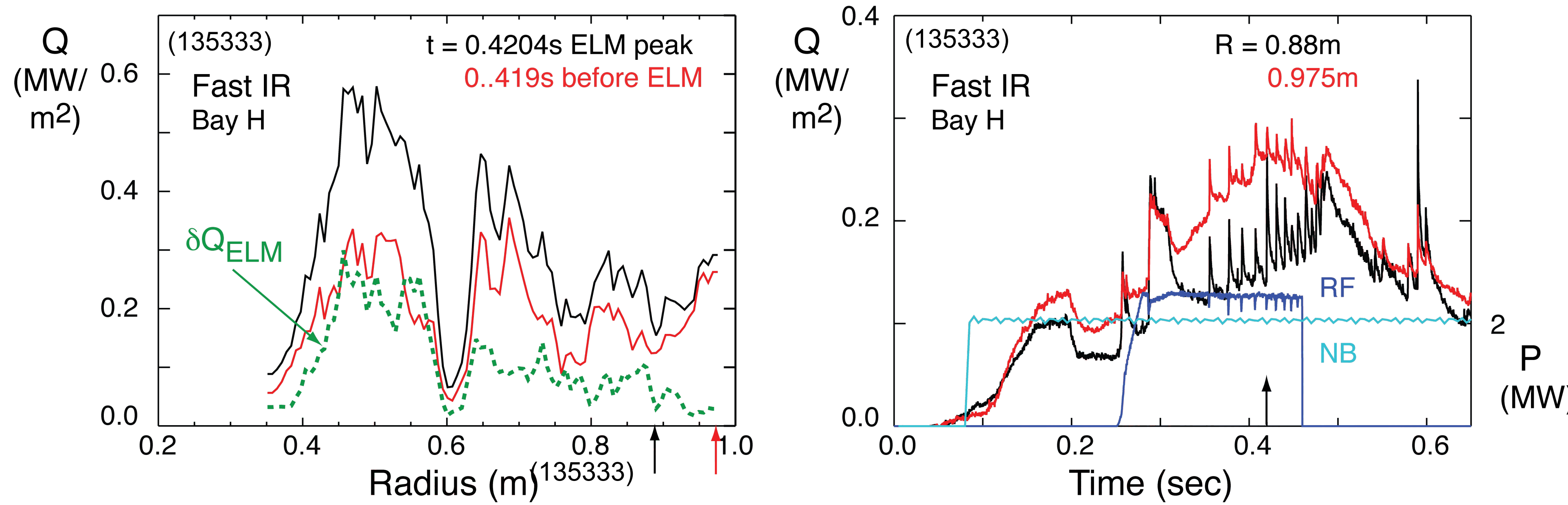
RF produced ELM deposits most of its energy in the vicinity of the outer divertor strike radius



- Very little ELM heat is deposited away from the strike point in absence of energetic beam ions
- ELM deposition has very small effect on RF edge heating “hot” zone (>1.2 m)

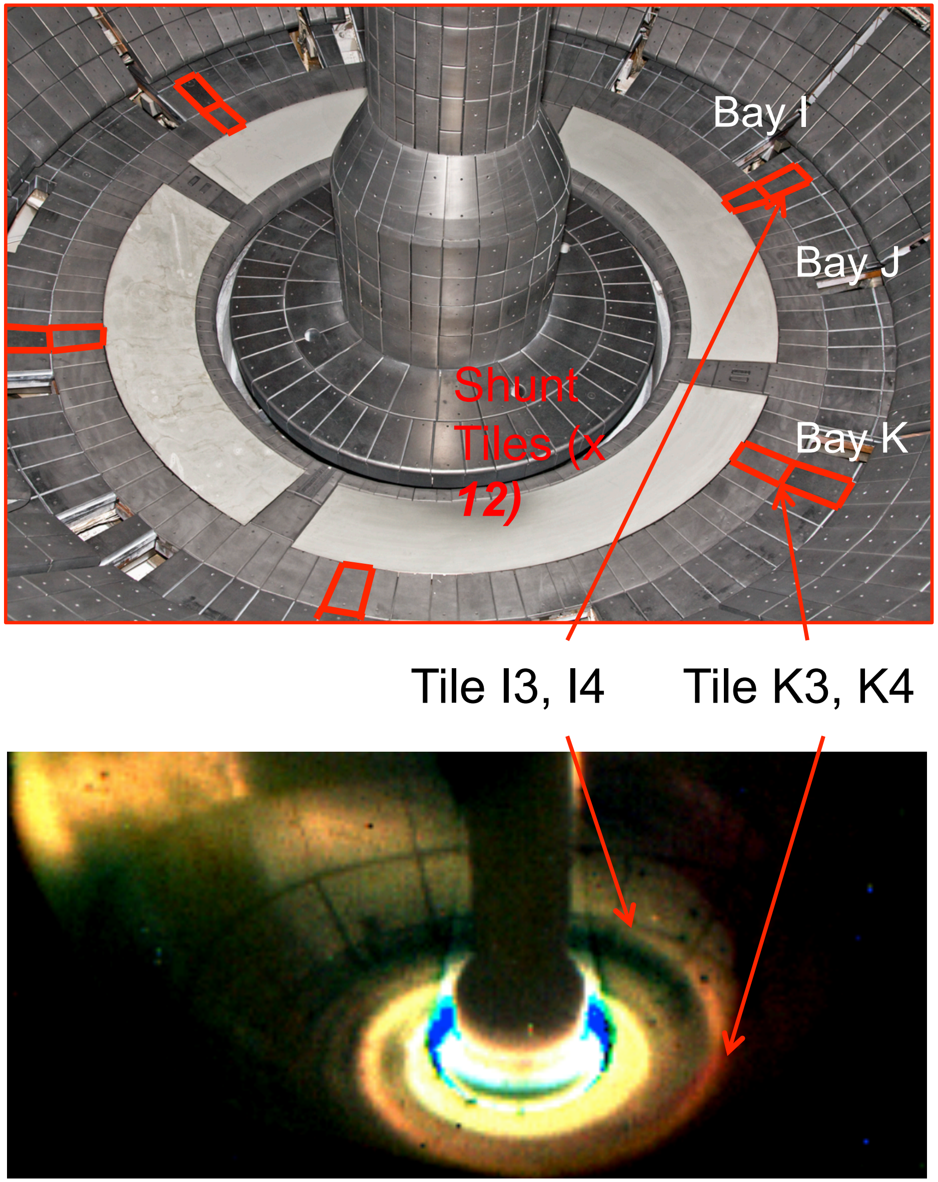
ELM power deposition about the strike radius is broader for the NBI + HHFW ELMy H-mode

Fast IR at Bay H with antenna phase ϕ_A = -90°, B_T = 4.5 kG, I_P = 0.8 MA



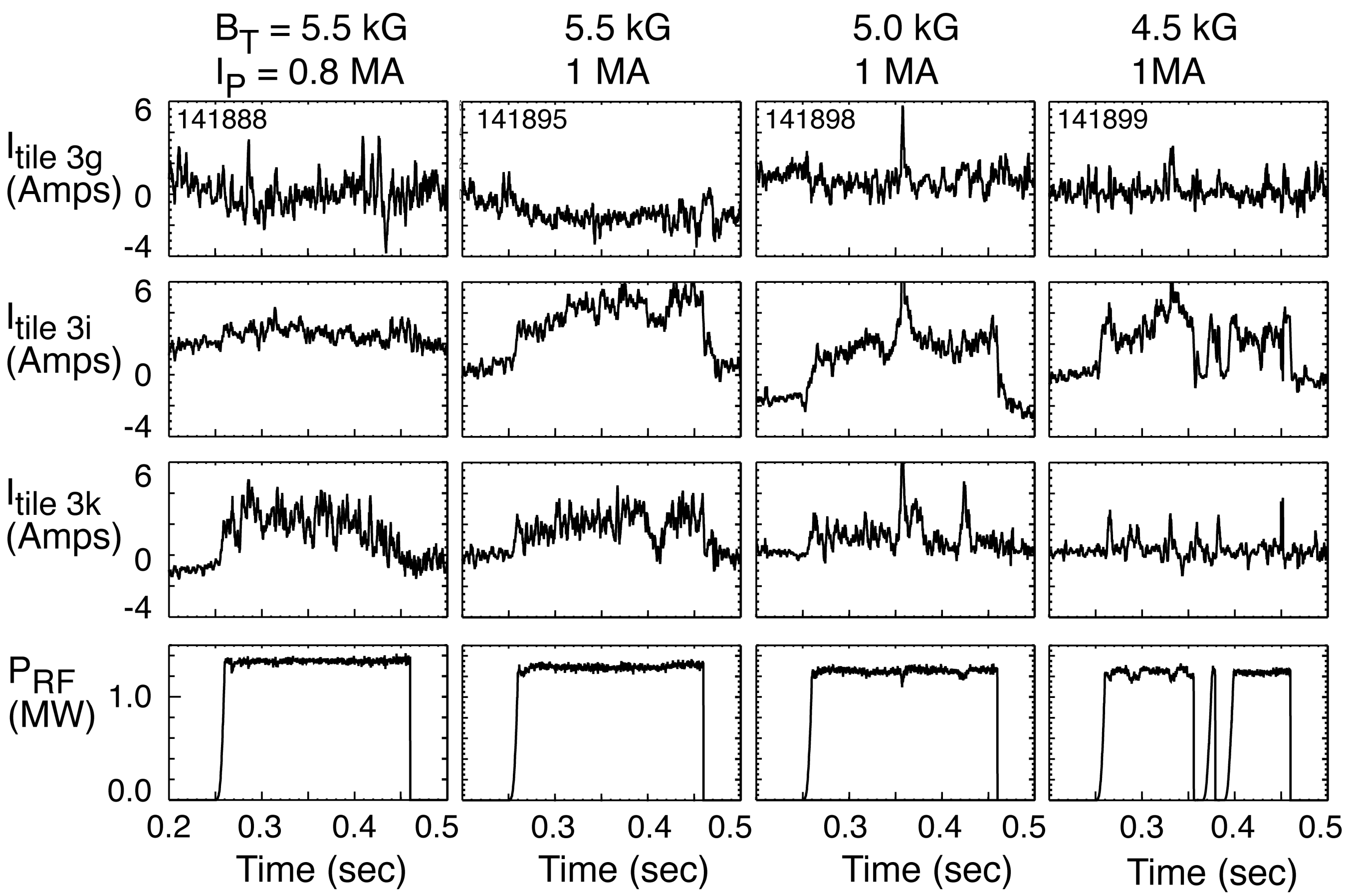
- Fast IR camera shows ELM heat deposition peaked at outer strike radius – falling to a low value towards the RF heated zone (R ~ 1.1 m)
- Experiments have begun to determine the ELM effect on the primary RF edge heating zone at Bay H at higher magnetic field pitch (e.g., 4.5 kG, 1 MA) – effect would appear to be small

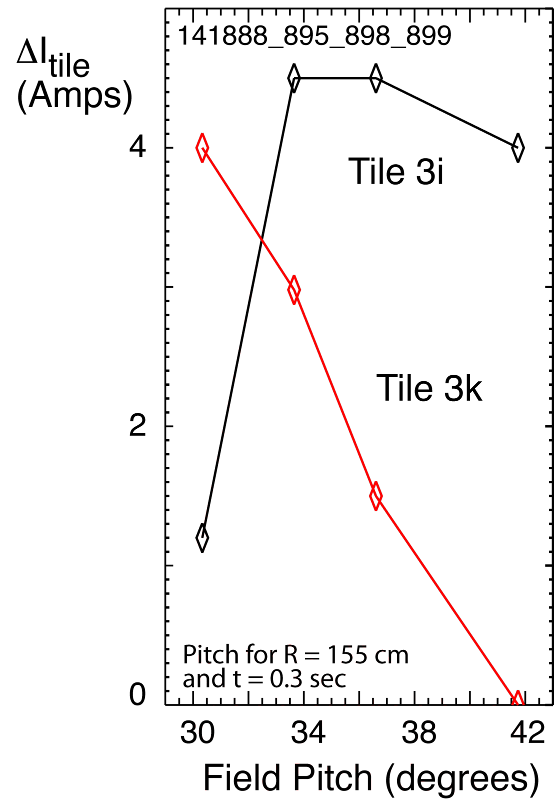
Divertor tile currents are used to track presence of RF fields (sheath) and driven currents



- Tiles in row 3 and 4 of divertor plate are instrumented with Rogowski sensors
- Bay I and K tiles are in line with “hot” zone for RF edge deposition

Divertor tile currents in row 3 show movement of RF hot zone across tiles as magnetic field pitch is increased

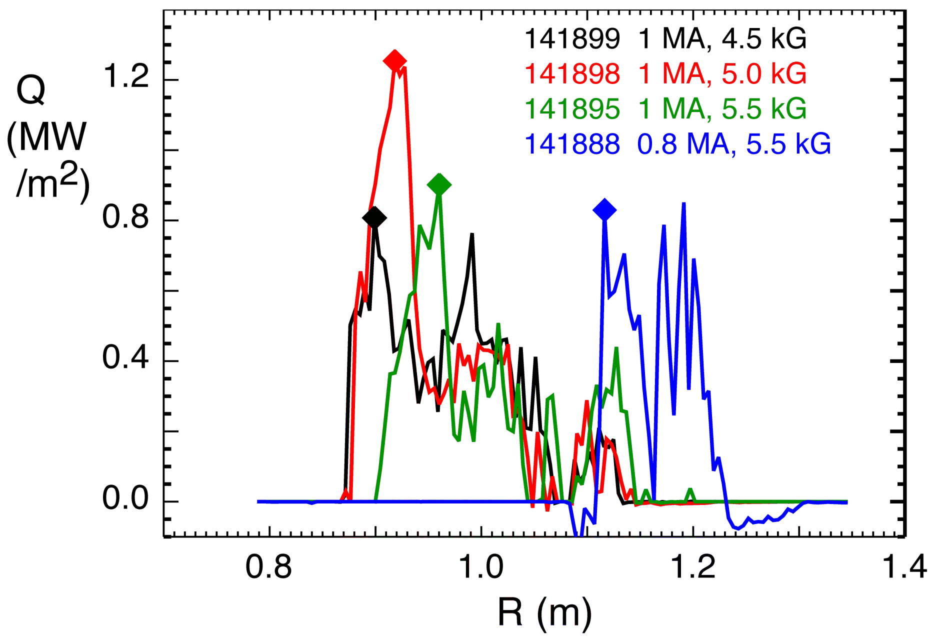




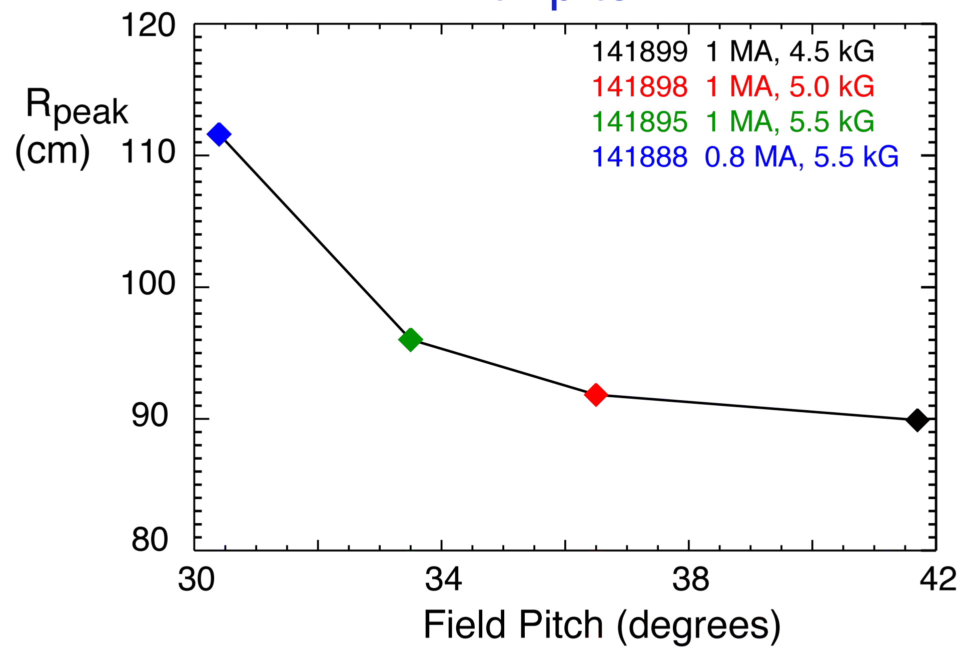
- $\Delta I_{tile\ 3k}$ decreases and $\Delta I_{tile\ 3i}$ increases as magnetic field pitch increases and RF spiral hot zone moves toward the center stack

Tile currents in row 3 are consistent with RF hot zone movement measured with the fast IR camera at Bay H

Fast IR at Bay H vs field pitch for t = 0.450 sec



Shift of RF hot zone with pitch



- Movement of RF hot zone with magnetic field pitch is relatively fast in the lower pitch range but slows considerably in the higher pitch range

Significant results

- ELM energy deposition is peaked around the outer divertor strike radius and may contribute little to the RF hot zone
  - ➢ Elms cause a large increase in energy deposited to the divertor peaked around the outer divertor strike radius
  - ➢ ELM-induced energy deposition is much more peaked near the outer divertor strike radius in RF-only case, perhaps due to absence of fast-ions from NBI

- Programming RF power reduction to delay ELMs maintained core stored energy in RF-only case
  - ➢ Elevated total and electron stored energies obtained for ELM-free-like conditions at 3.7 MW and maintained for P_{RF} ramps down to 1.36 MW
  - ➢ Transport properties in the ELM-free-like RF H-mode regime appear to support elevated stored energies with significantly reduced RF core heating power
    - – Modeling is needed to balance RF power deposition and transport properties
- Investigation of interaction of the RF edge drive with the outer divertor plate has begun
  - ➢ Tile currents track well with the location of the RF “hot” zone
  - ➢ RF “hot” zone moves toward the center post with increasing magnetic field pitch