NSTX

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Energy Confinement Enhancement and Pedestal Growth Triggered by an ELM in NSTX

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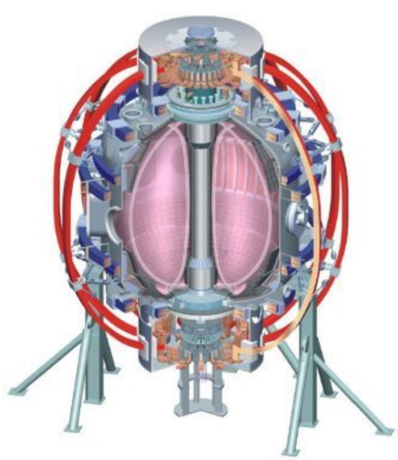
16th International Workshop on Spherical Torus
NIFS, Toki, Japan
Sept. 27-30, 2011

PPPL Princeton Plasma Physics Laboratory



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Confinement and Pedestal Temperature Enhancement Triggered by an ELM: the Enhanced Pedestal H-mode

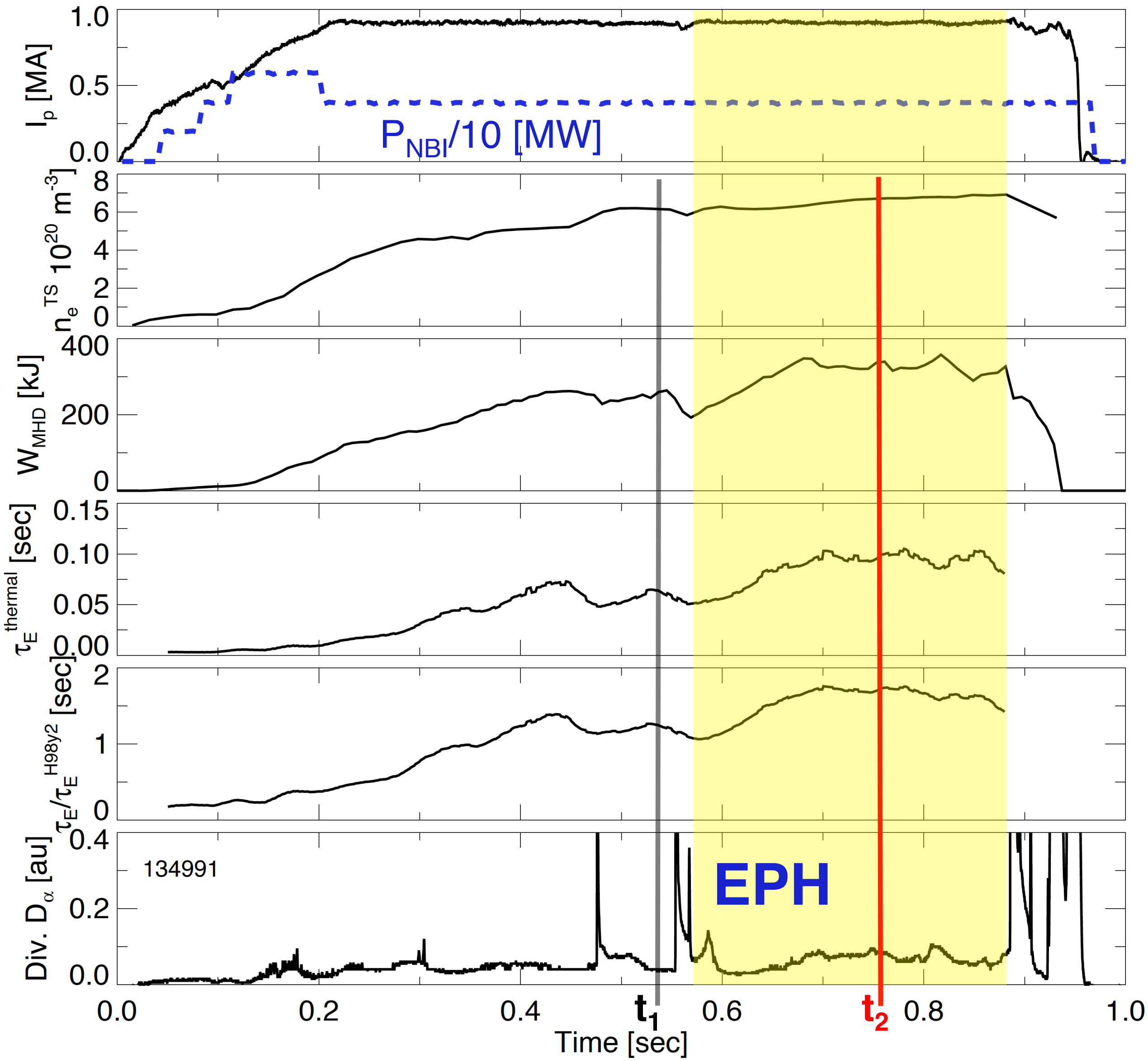
- Energy confinement in NSTX H-modes is generally 0.7-1.1* ITER98y2 scaling
  - H_{98y2} is ~ 0.7-0.9 without lithium, 1.0-1.1 with lithium
  - A few next step ST designs based on ~ 50% higher τ_E

- An improved confinement scenario with enhanced pedestal T_e, T_i in H-mode observed several few years ago
  - Triggered by large ELM, either naturally occurring or triggered with pulsed n=3 fields
  - Local v_ϕ drag near edge, leading to high E_r shear
  - Highest normalized τ_E in NSTX, with $H_{89P} \leq 3.5$ and $H_{98y2} \leq 1.7$ *when combined with lithium operation*
  - Pulse length up to 300 msec (~ 3 τ_E)
  - Density ramp arrested; possibly due to enhanced turbulence

OUTLINE

- Discharge characteristics and profile changes
- Changes to edge turbulence
- Prospect for reliable triggering, extension, and discussion

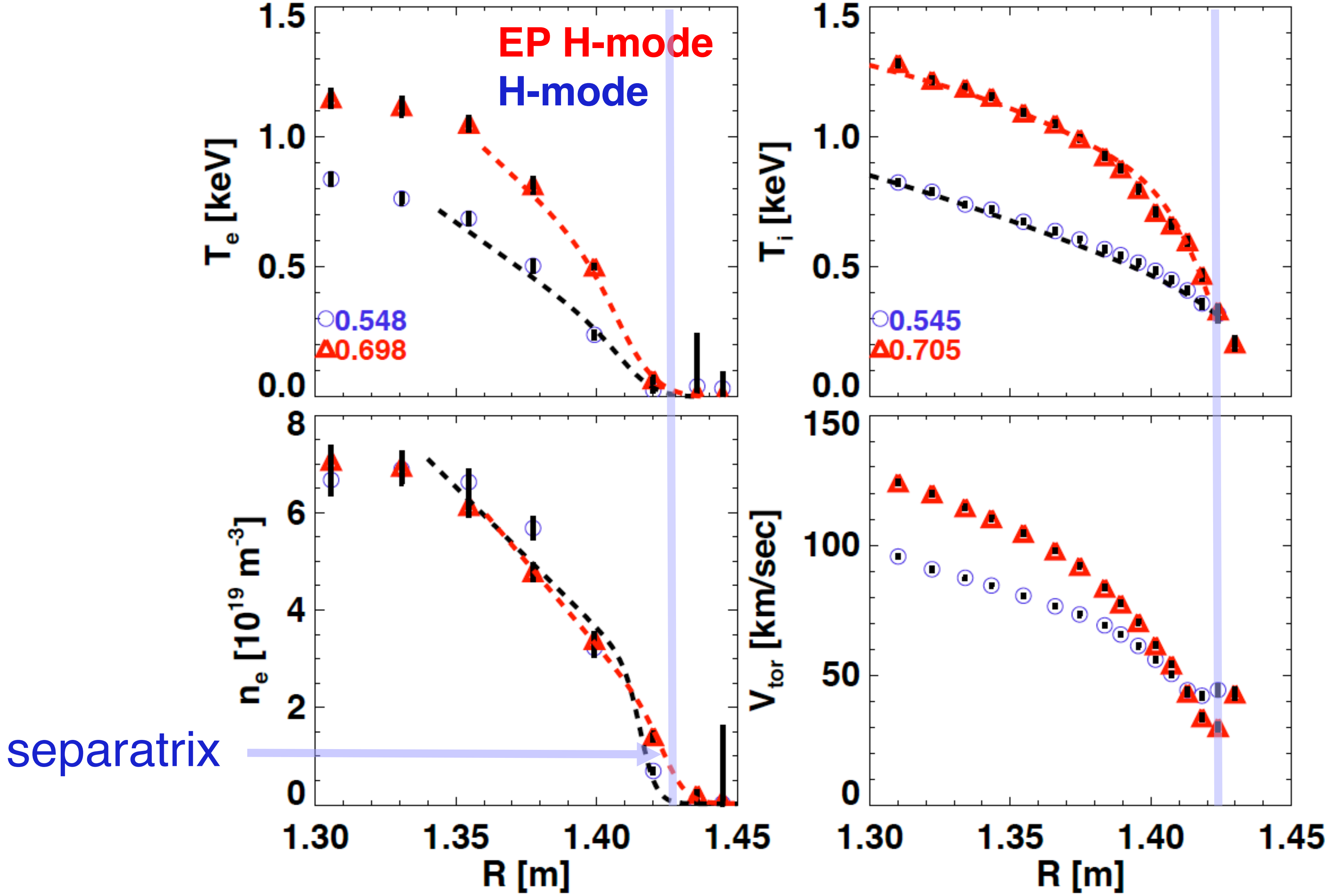
Long pulse EPH-mode phase observed for up to ~ 300 msec (~ 3 τ_E)



- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- Nearly flat n_e
- $W_{MHD} \leq$ 350 kJ
- $\tau_E \geq$ 80 msec for 225 msec
- $H_{98y2} \leq$ 1.7
- Natural ELM trigger for EPH

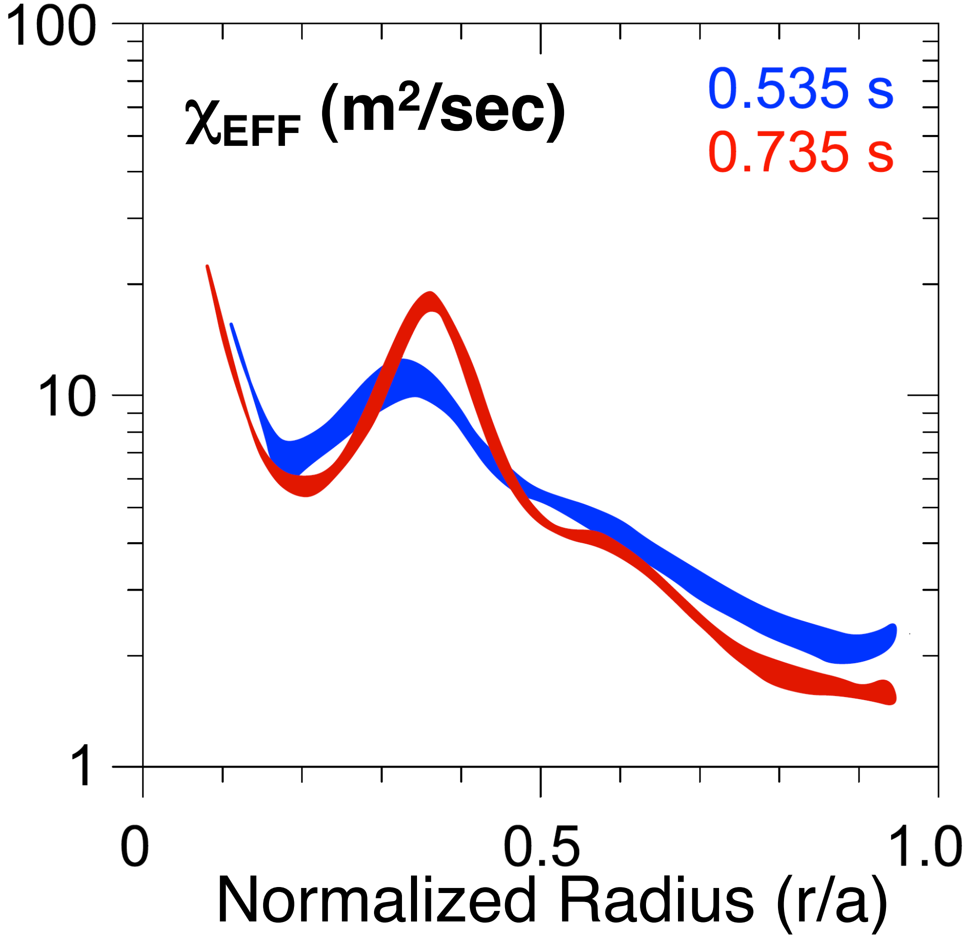
Maingi, PRL 2010
Maingi, JNM 2009

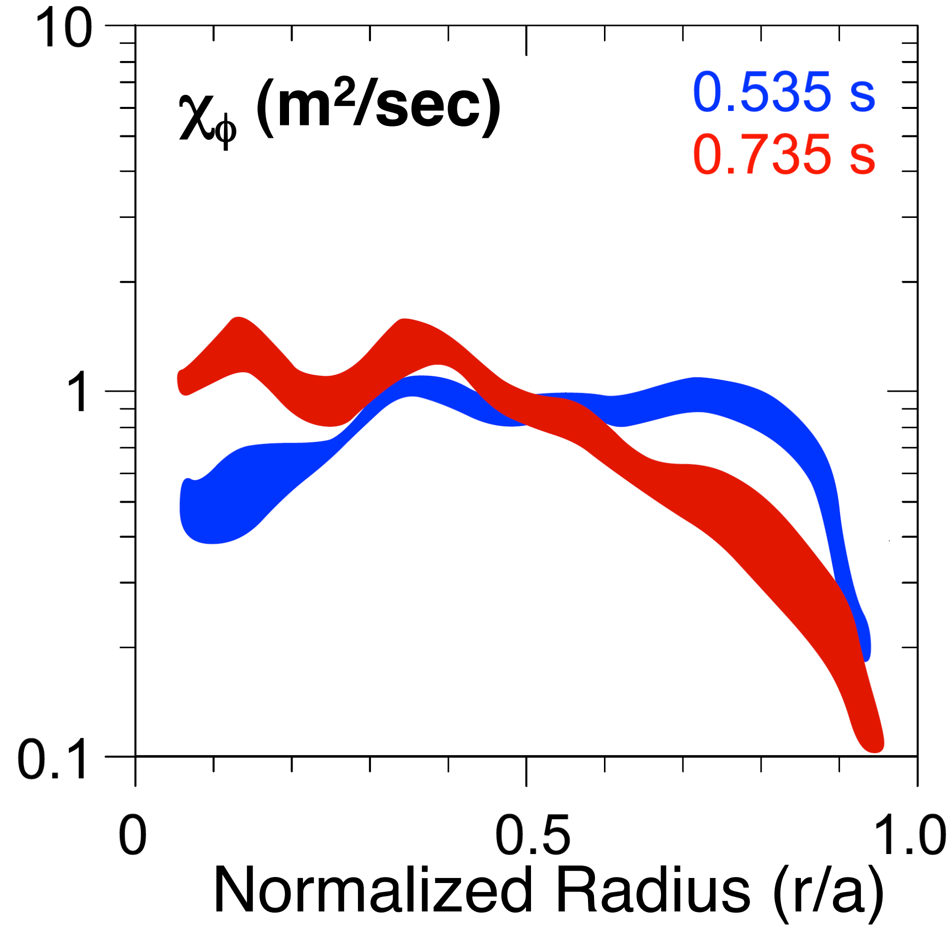
Thermal barrier: Edge T_e, T_i double, with a reduction in the edge n_e gradient, and an increase in v_ϕ shear



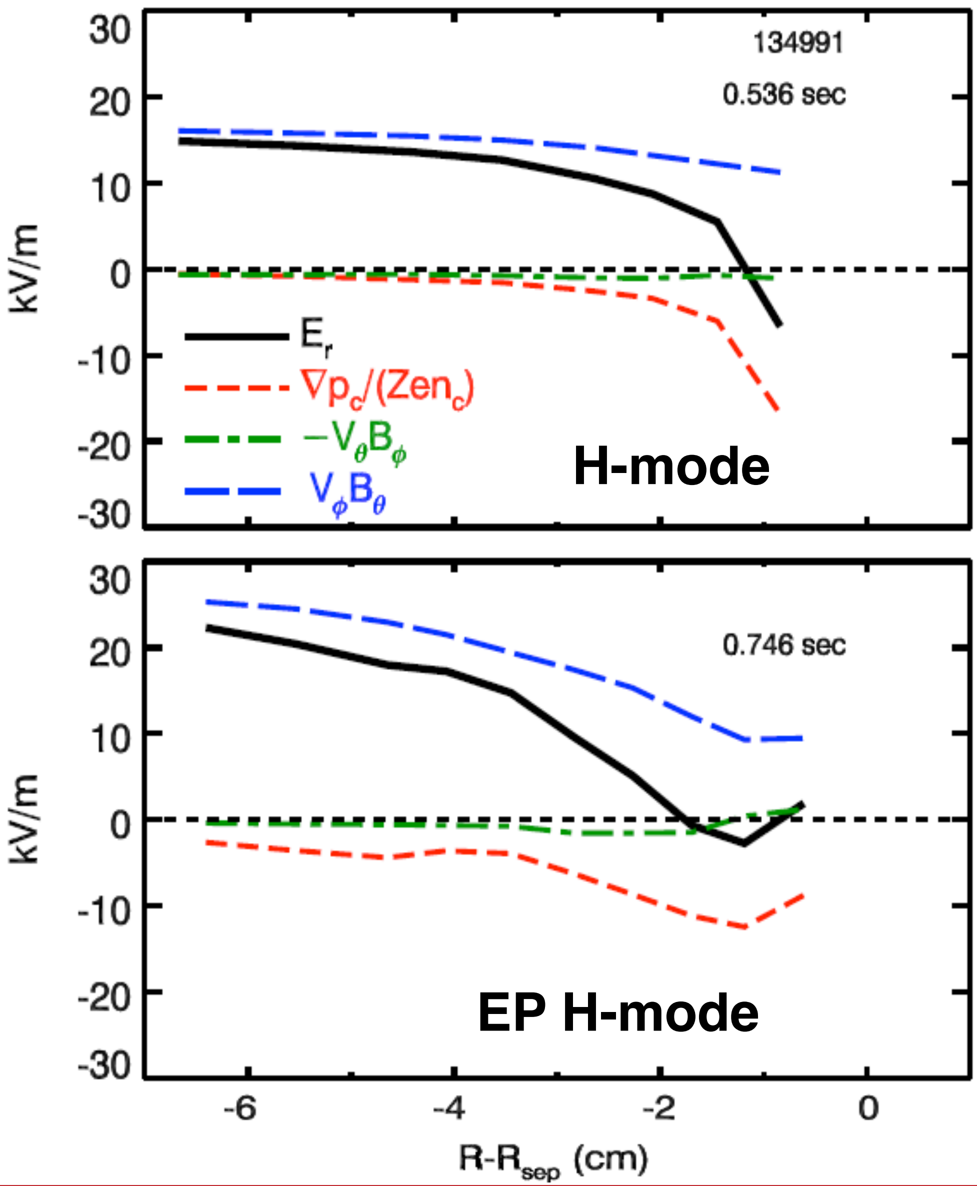
Thermal and angular momentum transport reduced in outer half of plasma

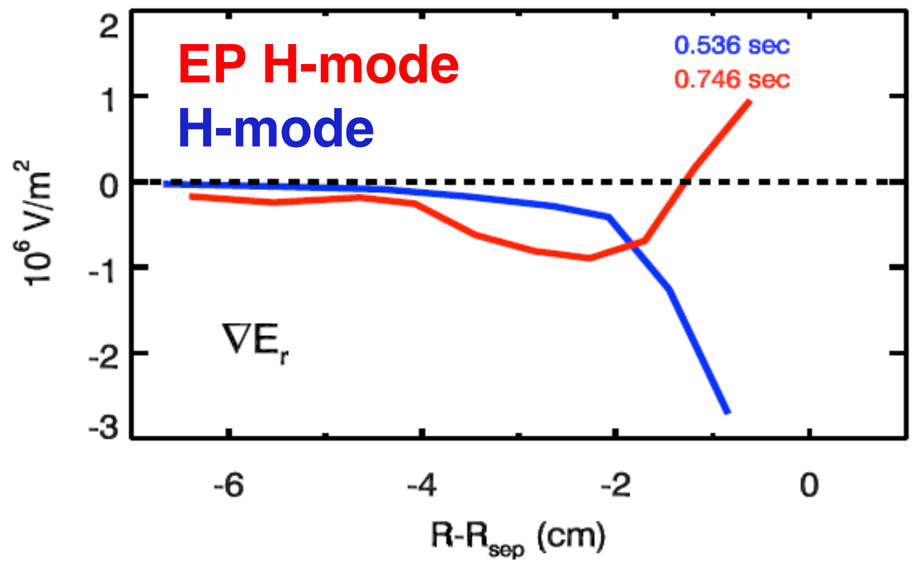
EP H-mode
H-mode



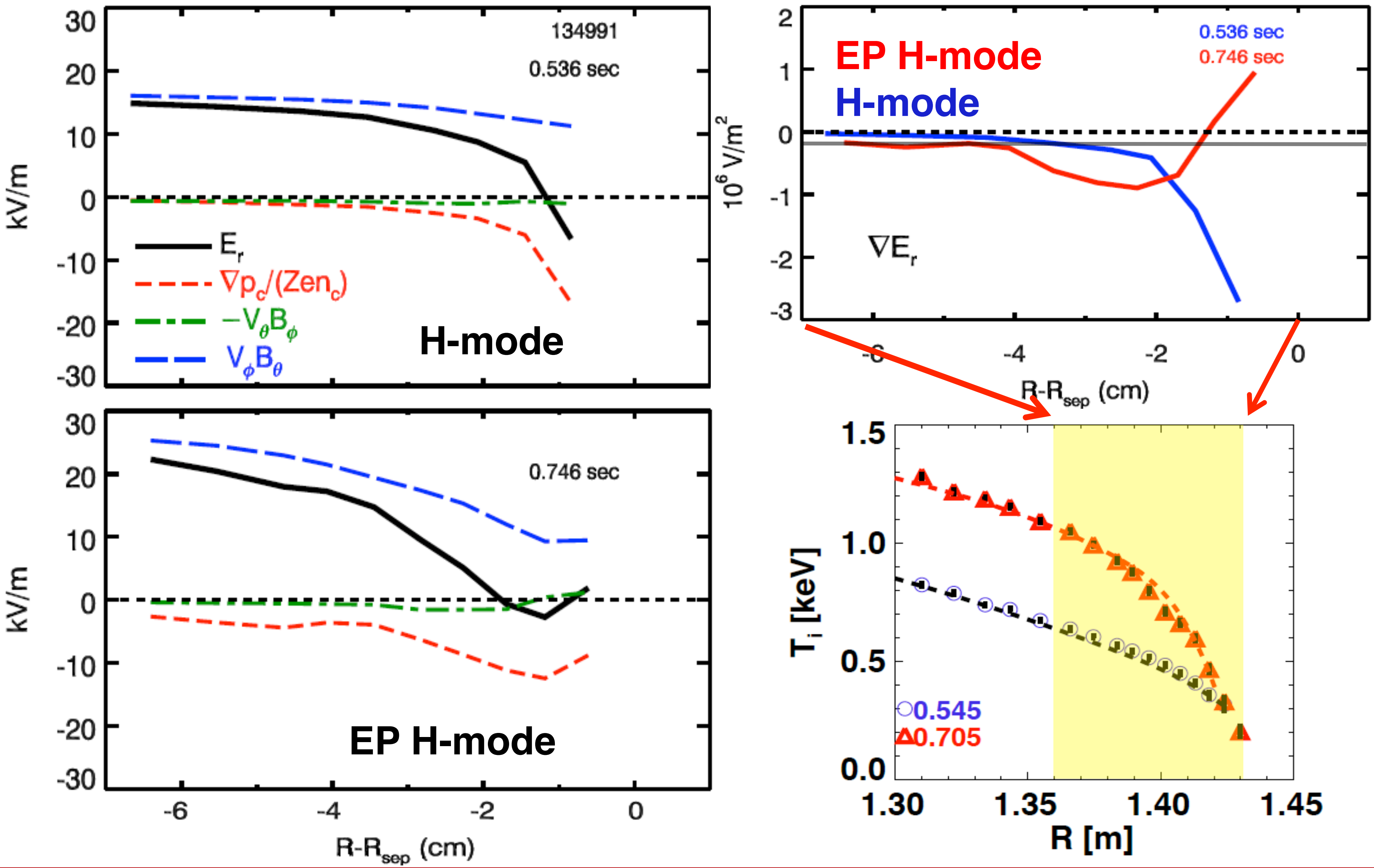


Radial shear in V_ϕ profile correlated with large region of E_r shear during EP H-mode

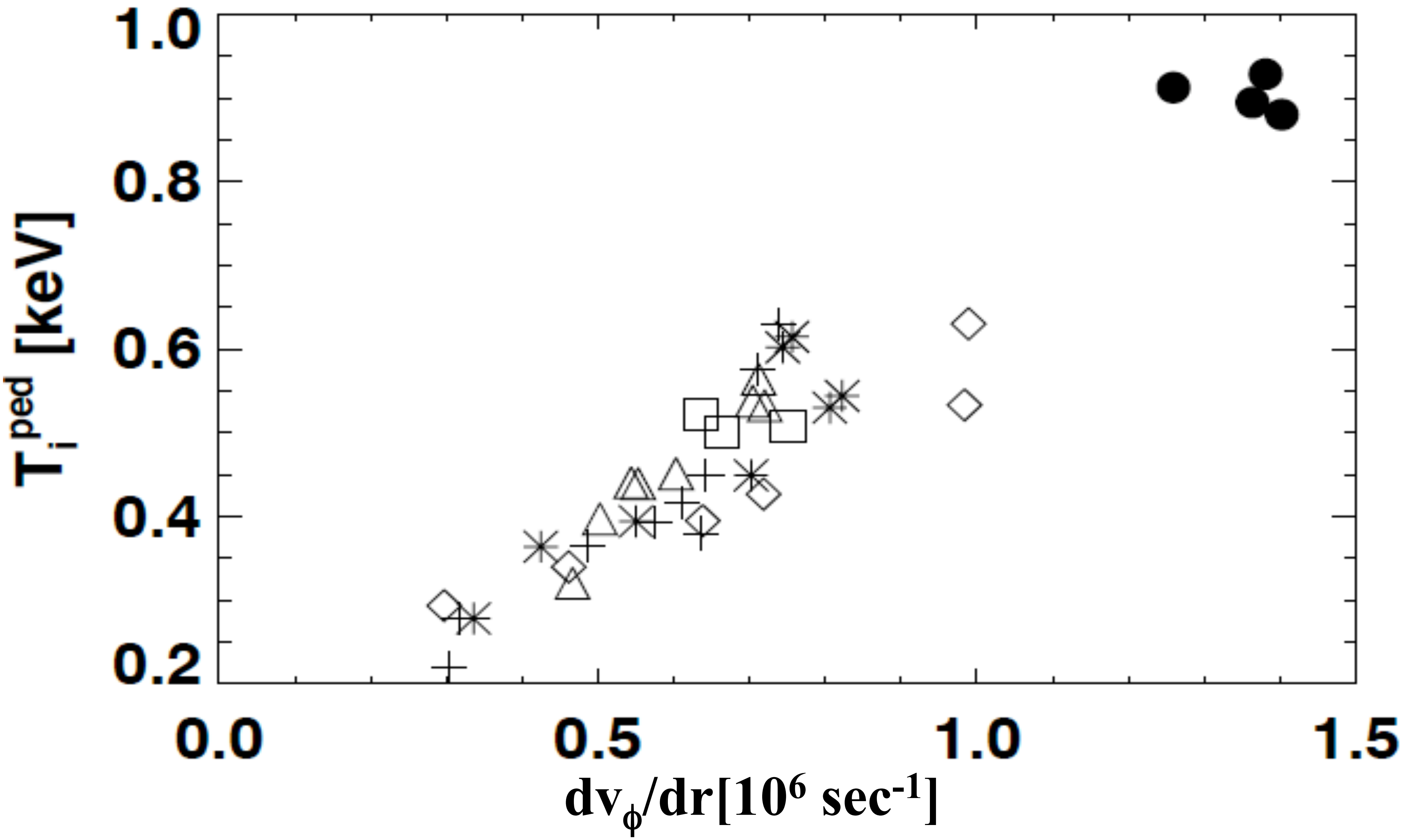




Radial shear in V_ϕ profile correlated with large region of E_r shear during EP H-mode



T_i pedestal height correlates with edge toroidal rotation shear

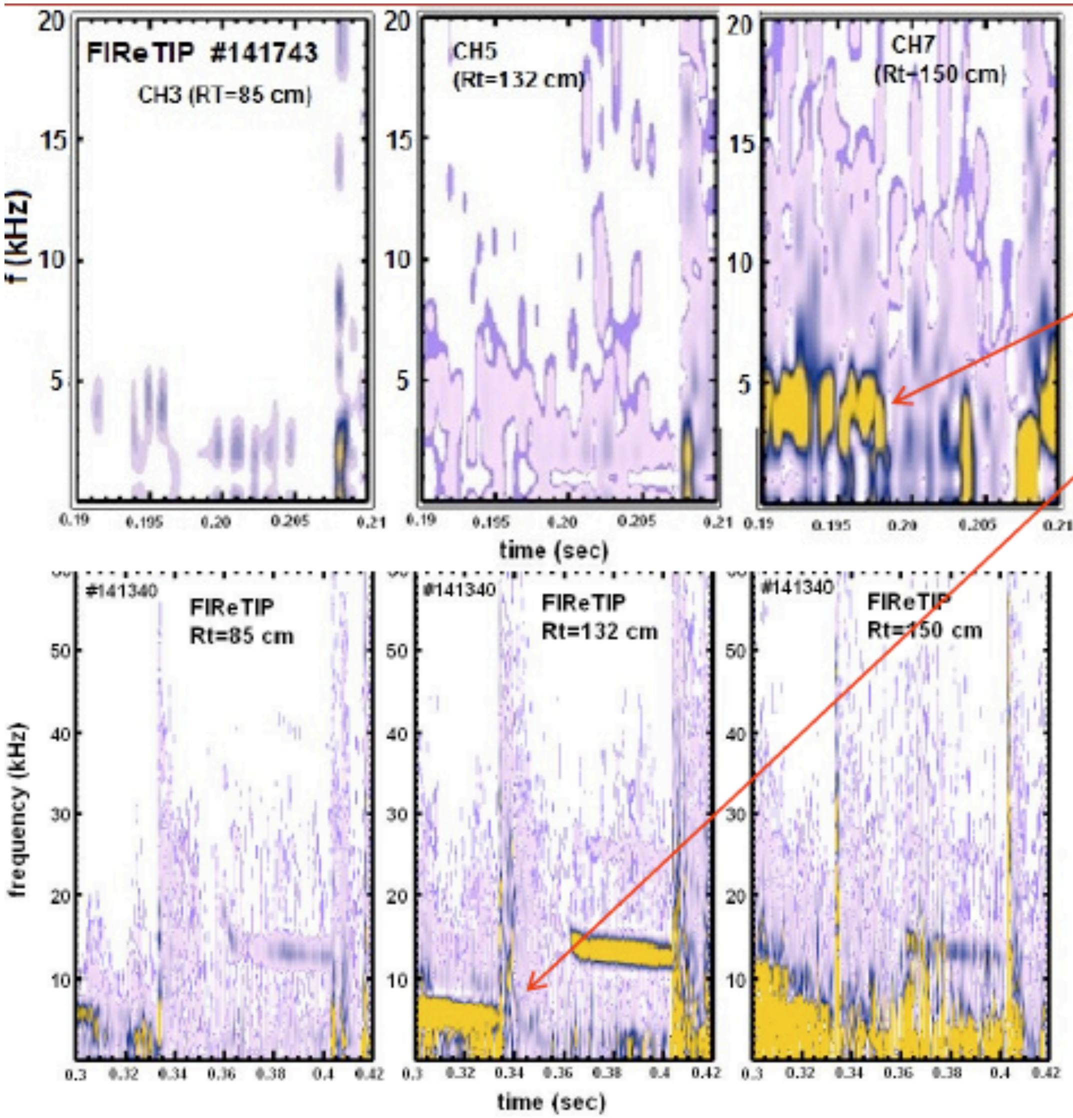


OUTLINE

- Discharge characteristics and profile changes
- Changes to edge turbulence
- Prospect for reliable triggering, extension, and discussion

Turbulence from interferometry drops after EP H-mode transition, similar to drop after L-H transition

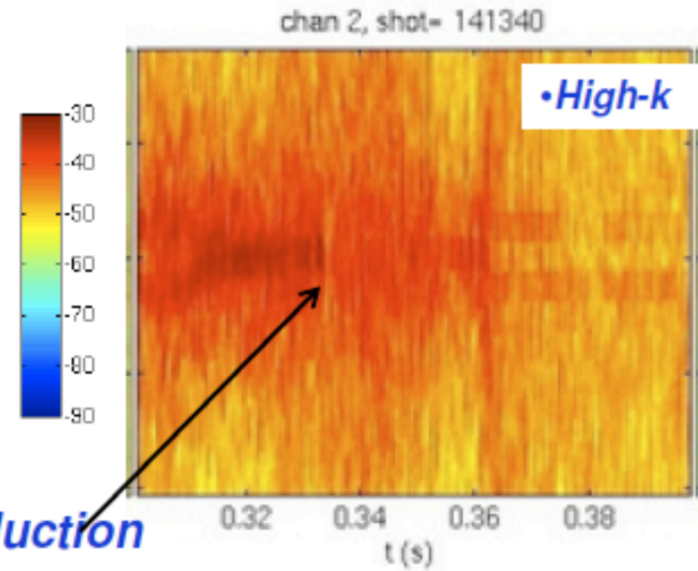
- FIReTIP n_e fluctuation spectrum
- H-mode vs. EPH-mode



- L\H transition
- EPH- mode transition

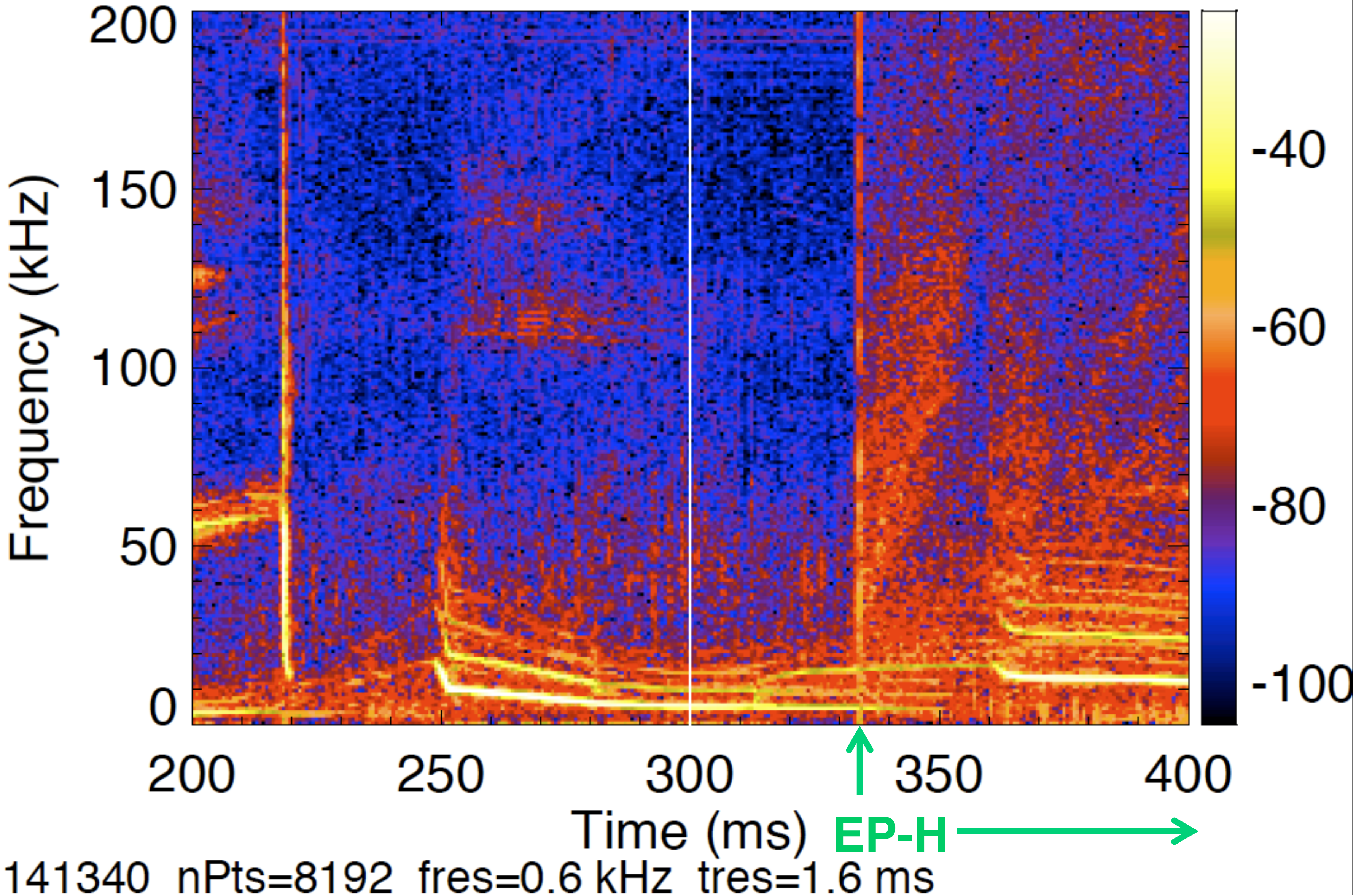
KCLee, NSTXRF 2011

- ► both reduced fluctuations
- but at different location

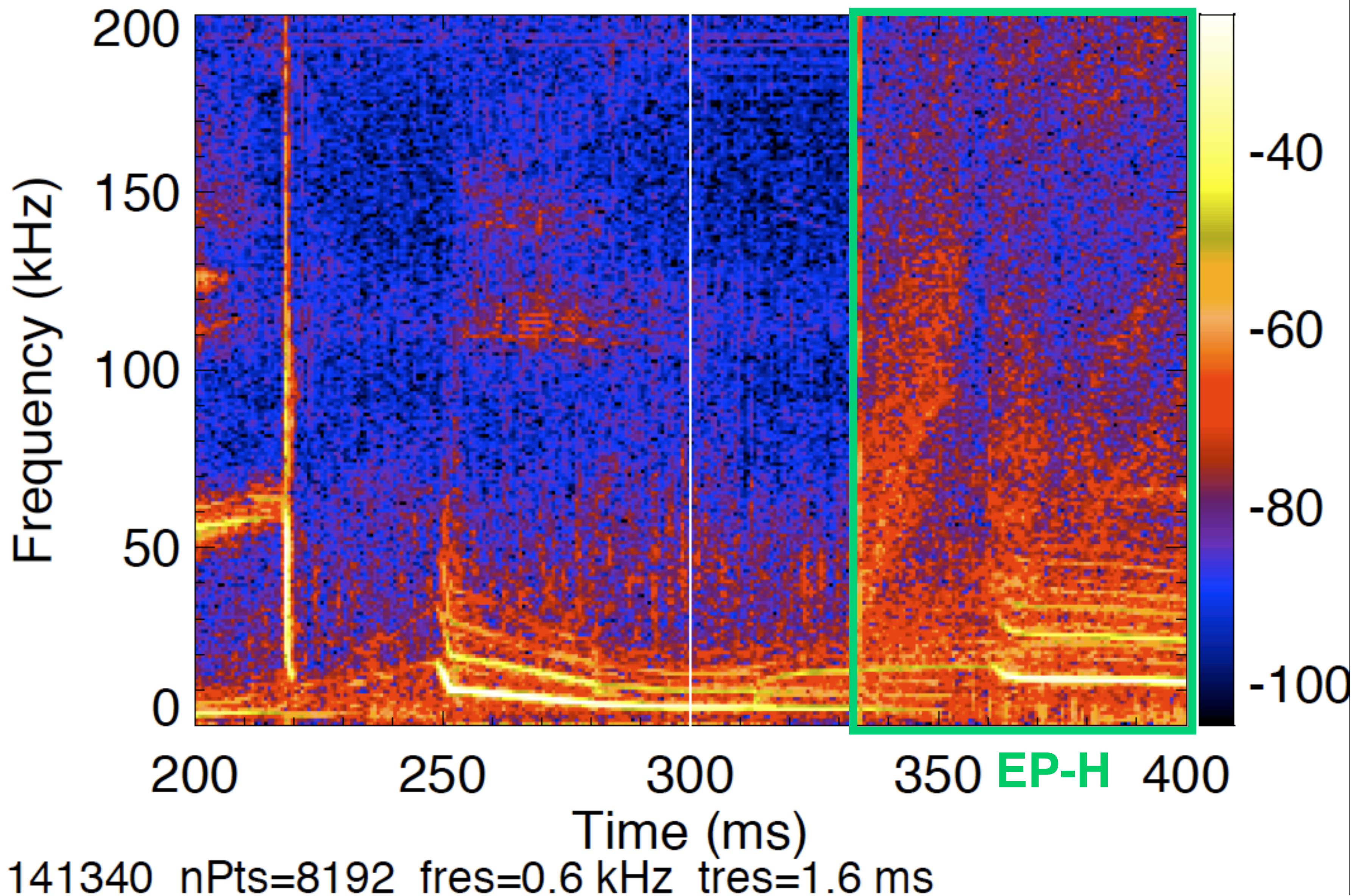


- Intensity : magenta < dark blue < yellow
- *reduction*

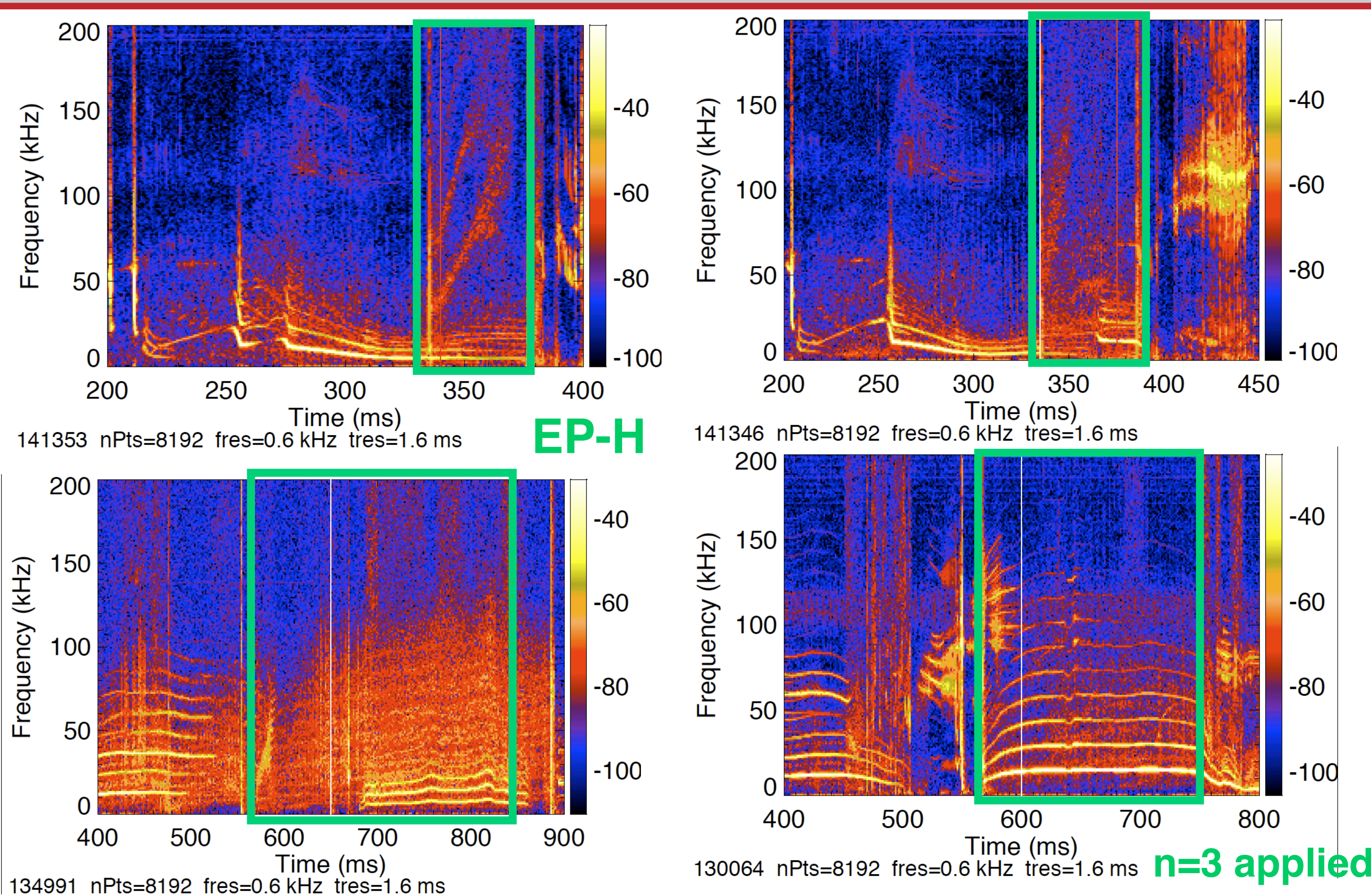
Magnetic fluctuations increase after EP H-mode transition - cause dN/dt reduction?



Magnetic fluctuations increase after EP H-mode transition - cause dN/dt reduction?



Common feature: magnetic fluctuations increase after EP H-mode transition



OUTLINE

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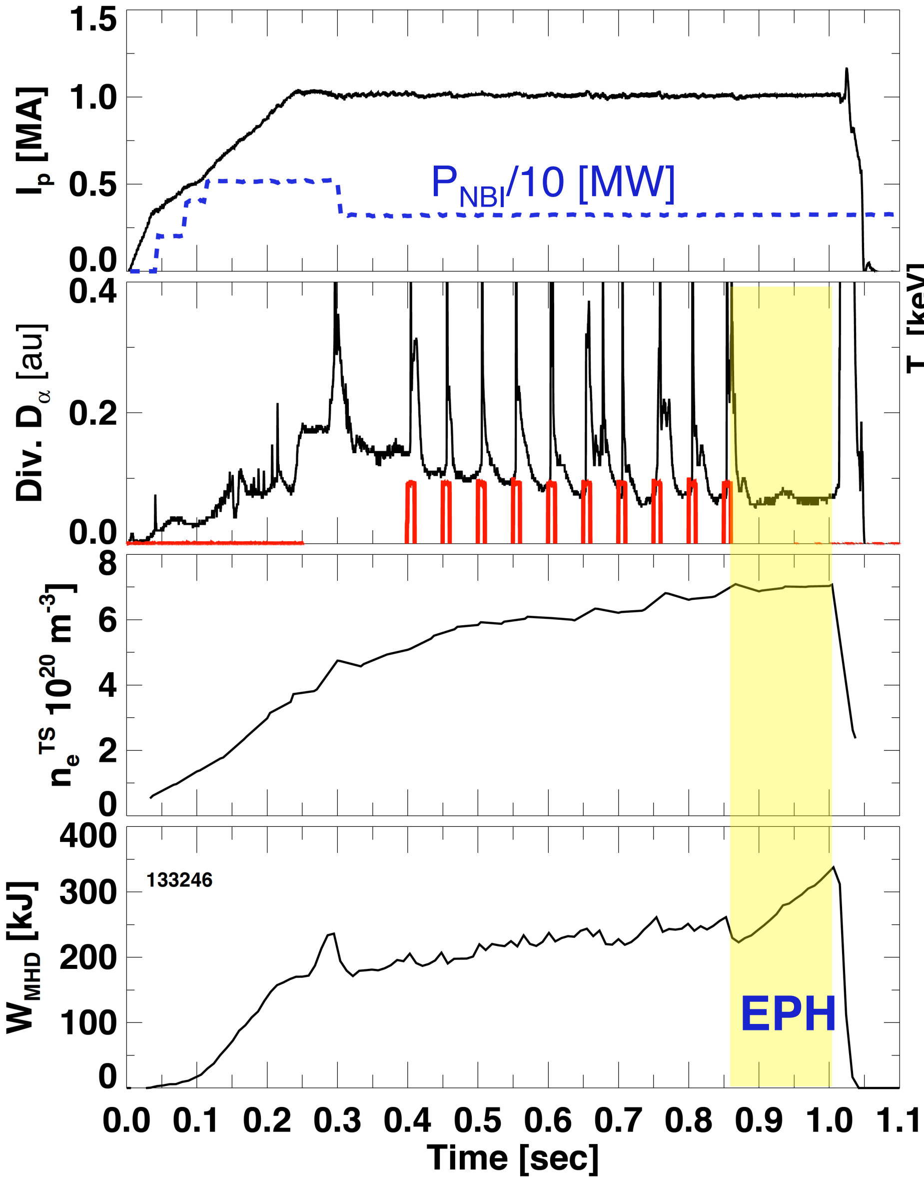
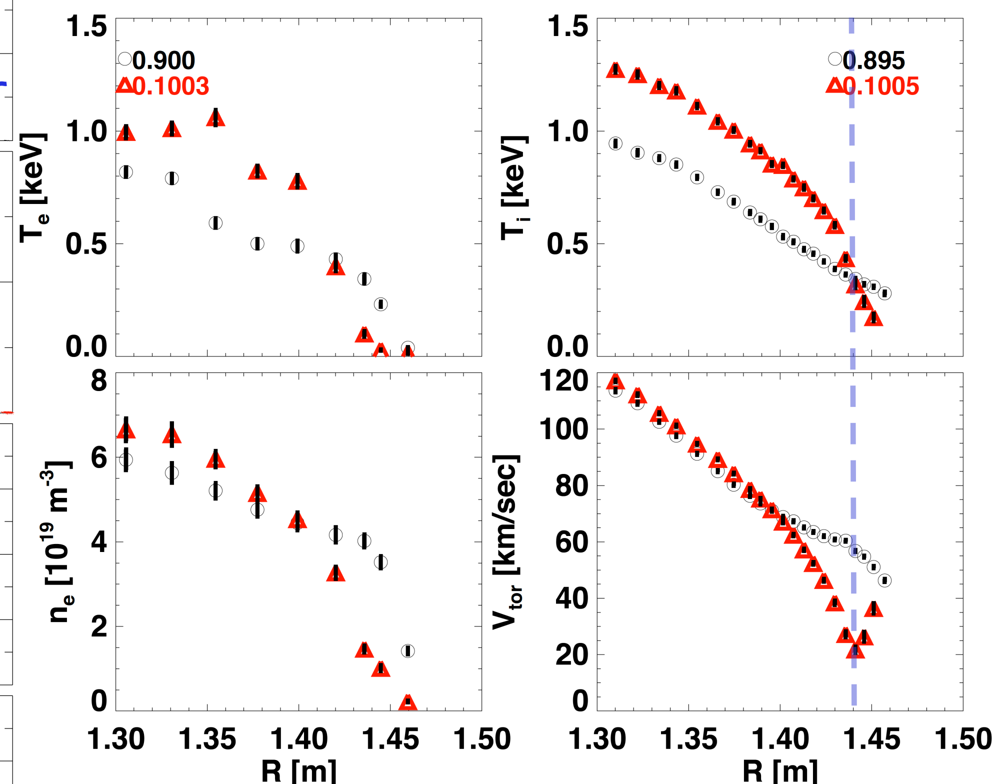
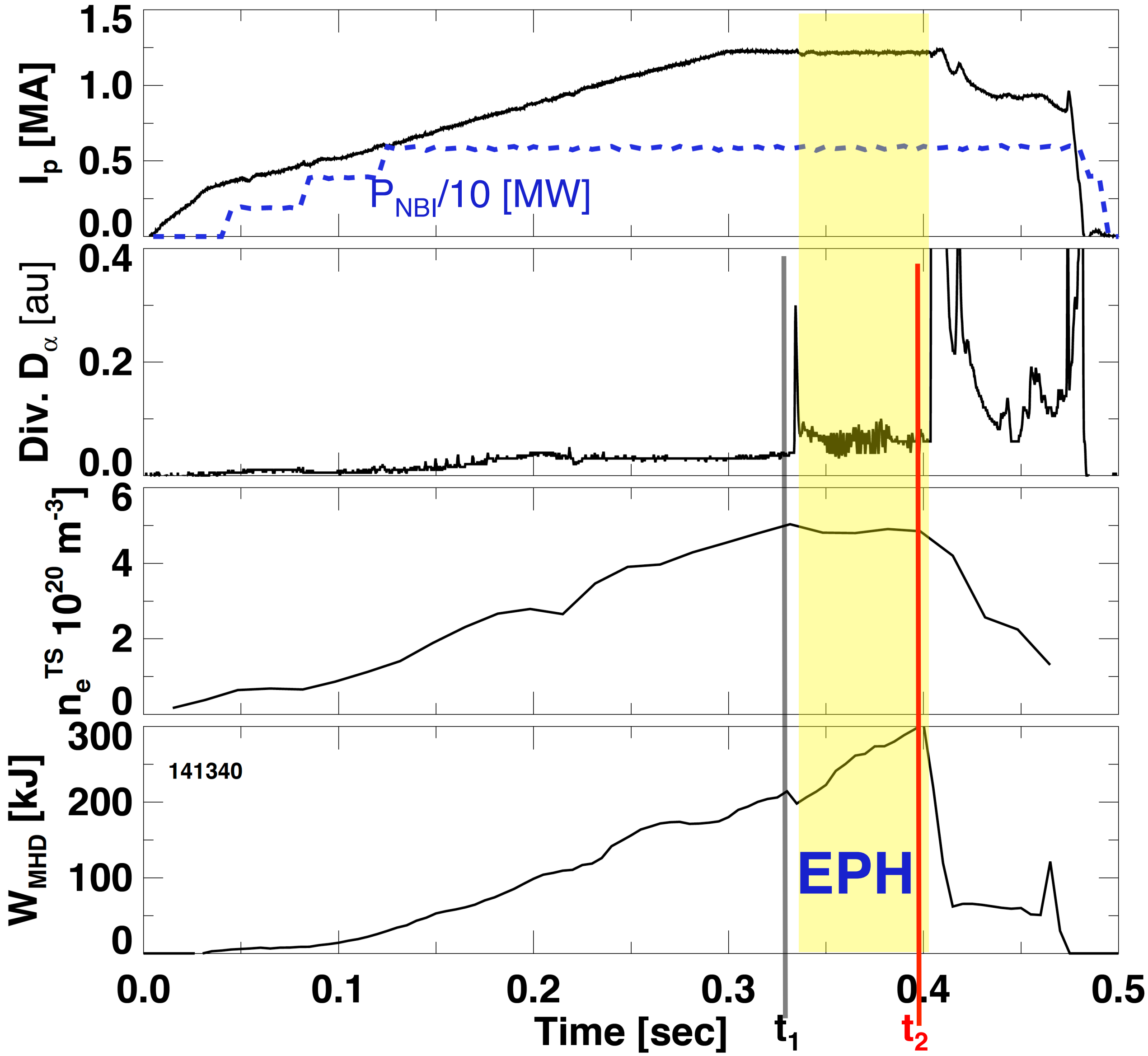
3D fields used for ELM pace-making can trigger EP H after 3D fields switched off



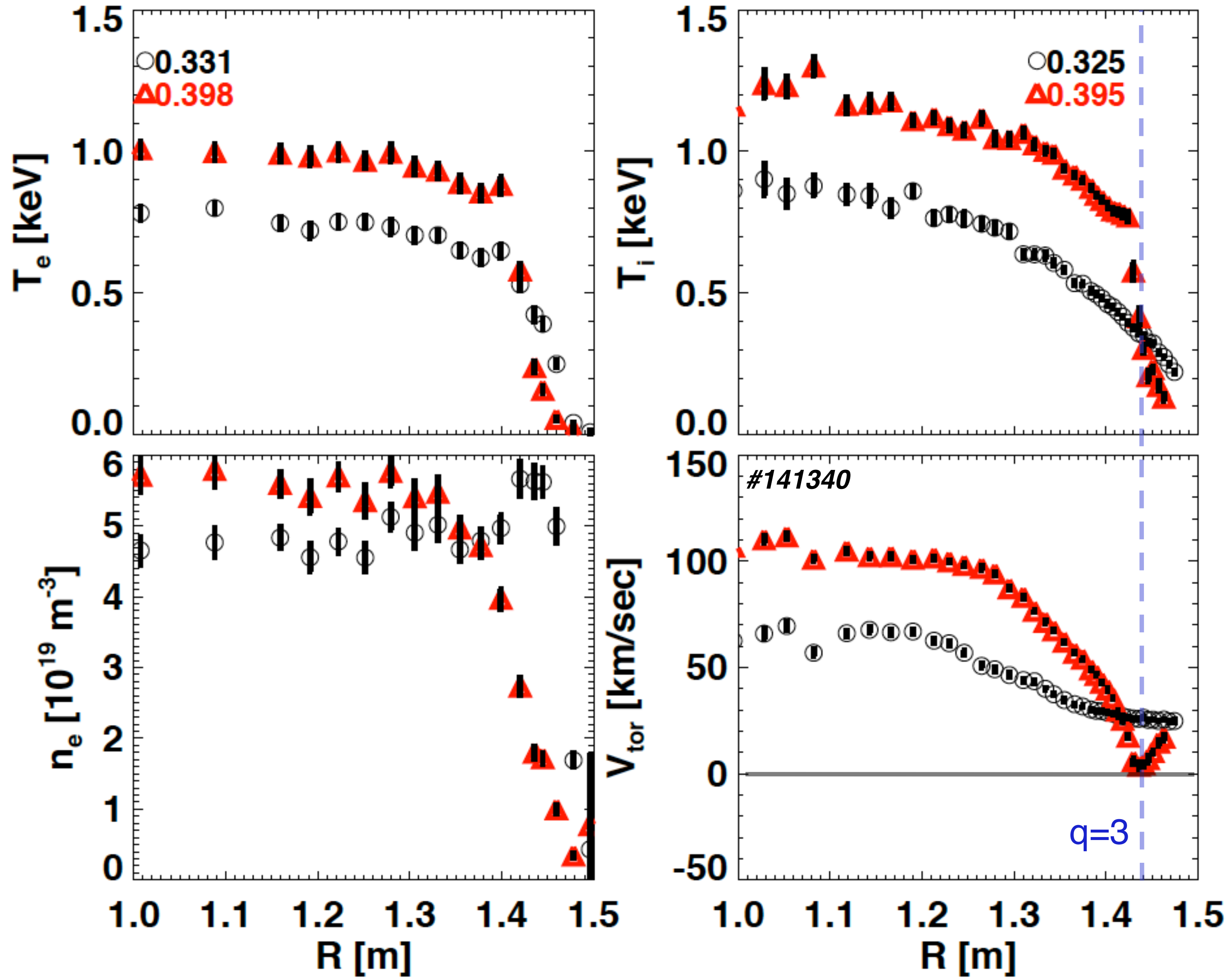


Reproducible access to EP H-modes observed in high I_p discharges, but duration < τ_E

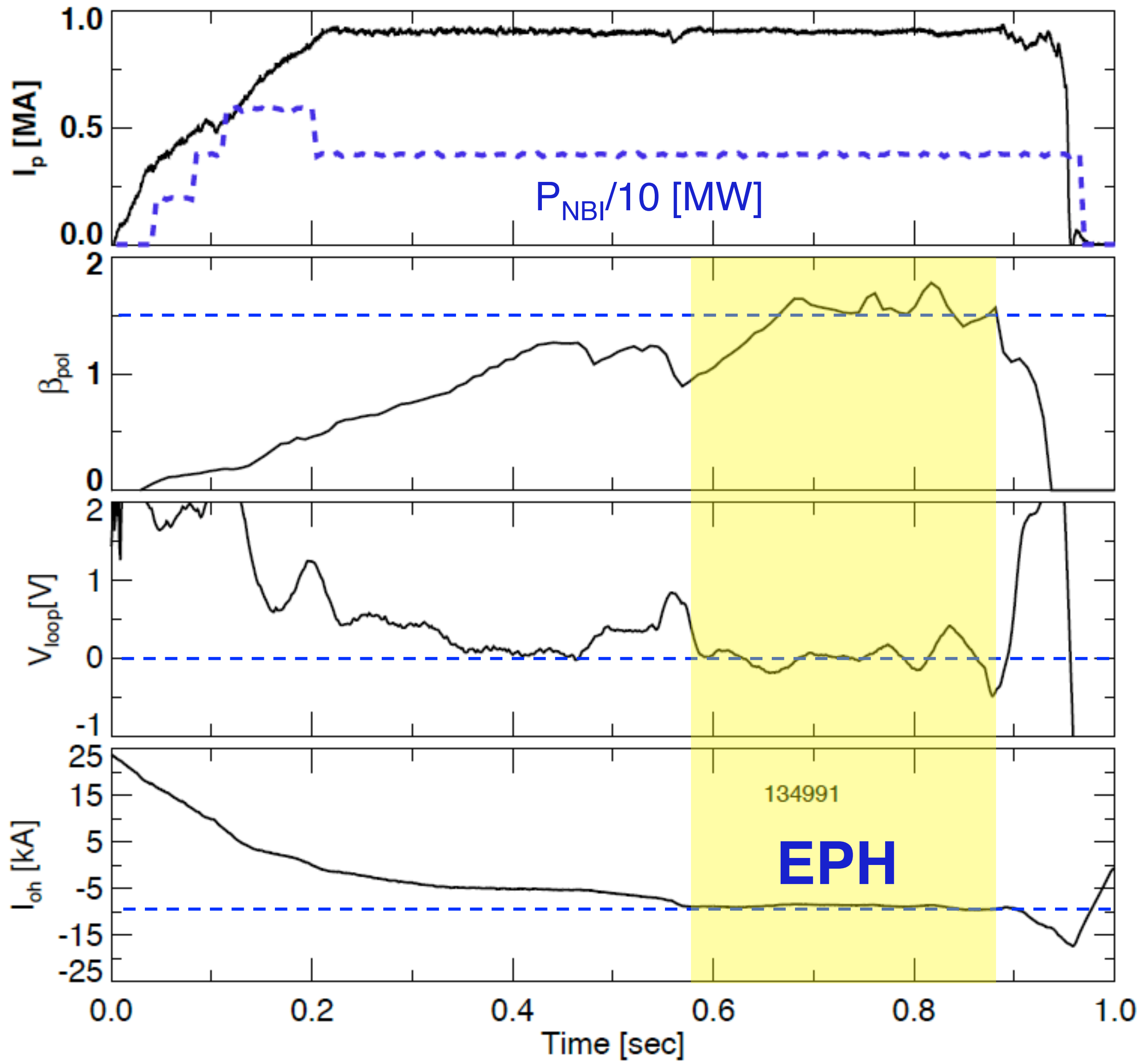


- I_p = 1.3 MA, P_{NBI} = 6 MW
- Natural ELM trigger for EPH
- Nearly flat n_e
- Ramping W_{MHD}

EP H-modes with sharp pedestal correlated with v_ϕ locked to zero near q=3 surface



High β_{pol} results in high bootstrap and non-inductive fraction (f_{NI} ~ 0.65 from TRANSP)



- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- β_p ~ 1.5, very high for 0.9 MA
- Loop voltage low during EPH, due to high bootstrap
- Very little or no flux consumption

Comparisons with other enhanced confinement regimes

- Similarities and differences with VH-mode
  - ✓ Very large spatial region of high E X B shear
  - ✓ Comparable τ_E enhancement with respect to scalings
  - ✓ Low recycling ELM-free scenario, with relatively low impurity accumulation
  - X *EP H-mode triggered by an ELM*
  - X *EP H-mode often initiated with localized drag on v_ϕ (often @q=3)*
- Comparison with QH-mode
  - Higher H-factor in EP H-mode
  - Turbulence does increase, but Edge Harmonic Oscillation (EHO) rare
- Comparison with I-mode
  - Both have enhanced thermal confinement but not enhanced particle confinement, and enhanced fluctuations
  - Access different: EP H transitions from H-mode, not L-mode
  - H98 up to 100% higher in EP H-mode

Many outstanding question on EP H-mode

- Where and by how much does the turbulence change?
- Does lithium enable these in some way?
  - EP H is more frequent in past few years with increasing lithium usage
- What is the role of edge resonances?
  - q=3 special?
- Is EP H-mode some combination of VH-mode and QH-mode?
  - On occasion, Edge Harmonic Oscillation observed
- What is the limit on achievable ‘pedestal width’?
  - Should we be calling this a pedestal even?
- Does shrinking of the plasma boundary play a role?
- How can we reliably trigger on demand? Can we extend?
  - RMP with proper spectrum? Low q_{95}?

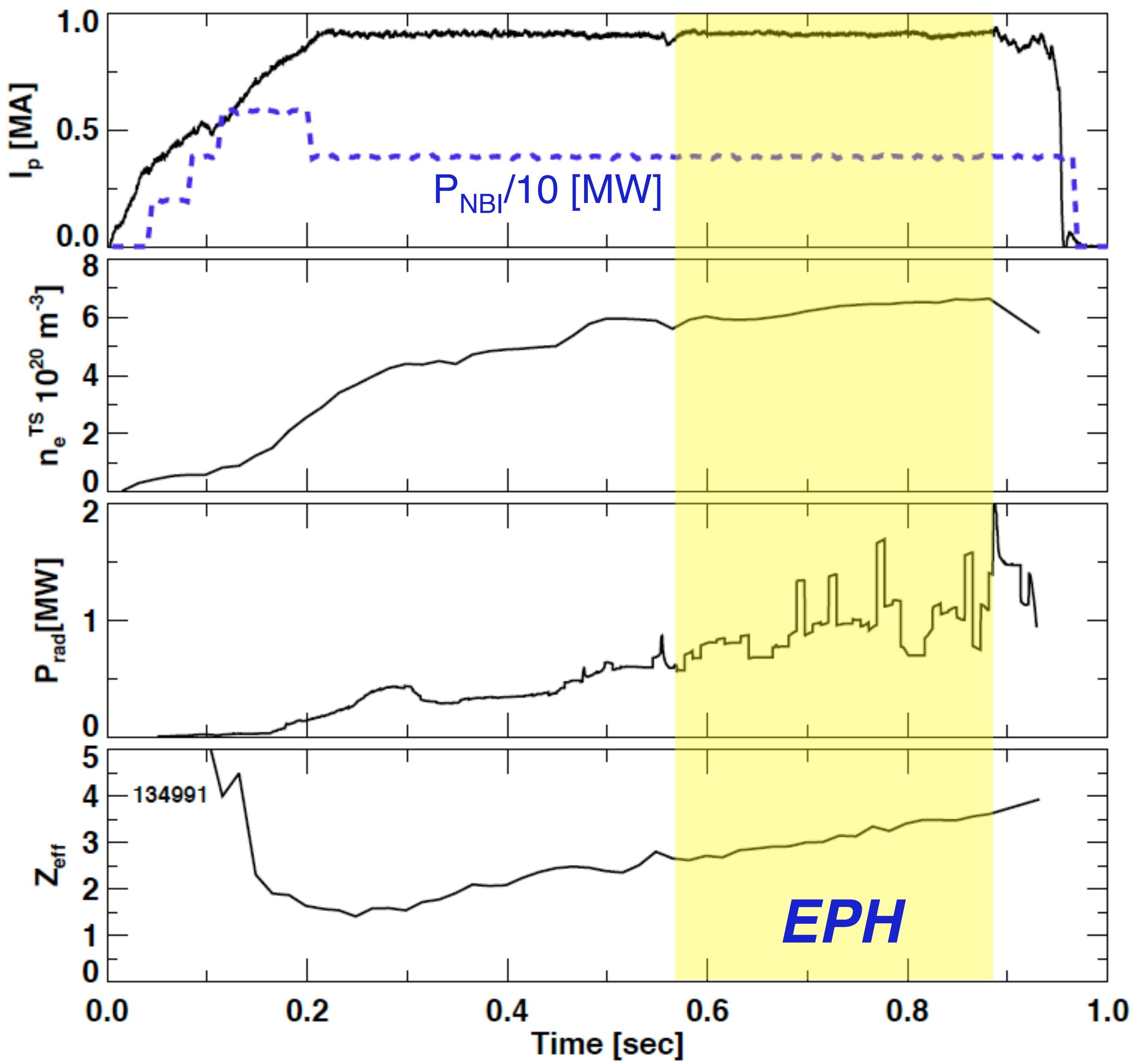
The EP H-mode has an improved thermal barrier above H-mode, without an enhancement of particle confinement

- A second transition to enhanced confinement and high pedestal T_e, $T_i \leq 950$ eV
  - Second transition after large natural or triggered ELM
  - $H_{98y2} \leq 1.7$, in an ELM-free regime
- Common feature: edge v_ϕ develops large gradient due to a large drag, often near the q=3 surface
  - Velocity minimum corresponds to center of T_i barrier
  - Large spatial region of high E_r shear
- Low loop voltage, high β_N (due partly to low pressure peaking factor)

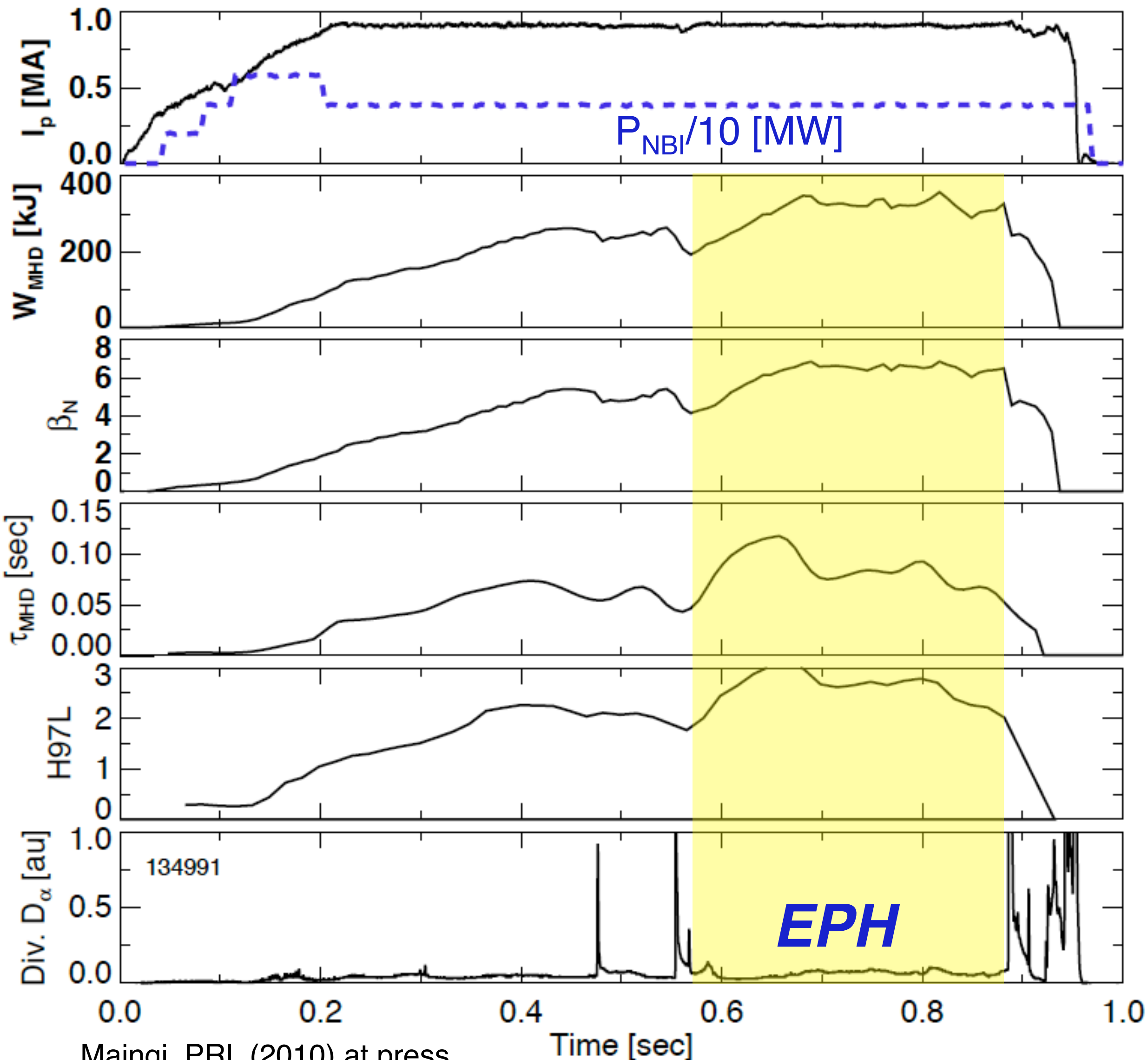
  ✓ *high performance, long pulse candidate (β_N feedback)*

Backup

Long pulse EPH – density still evolving slowly, Z_{eff} rising, but P_{rad} seems reasonable



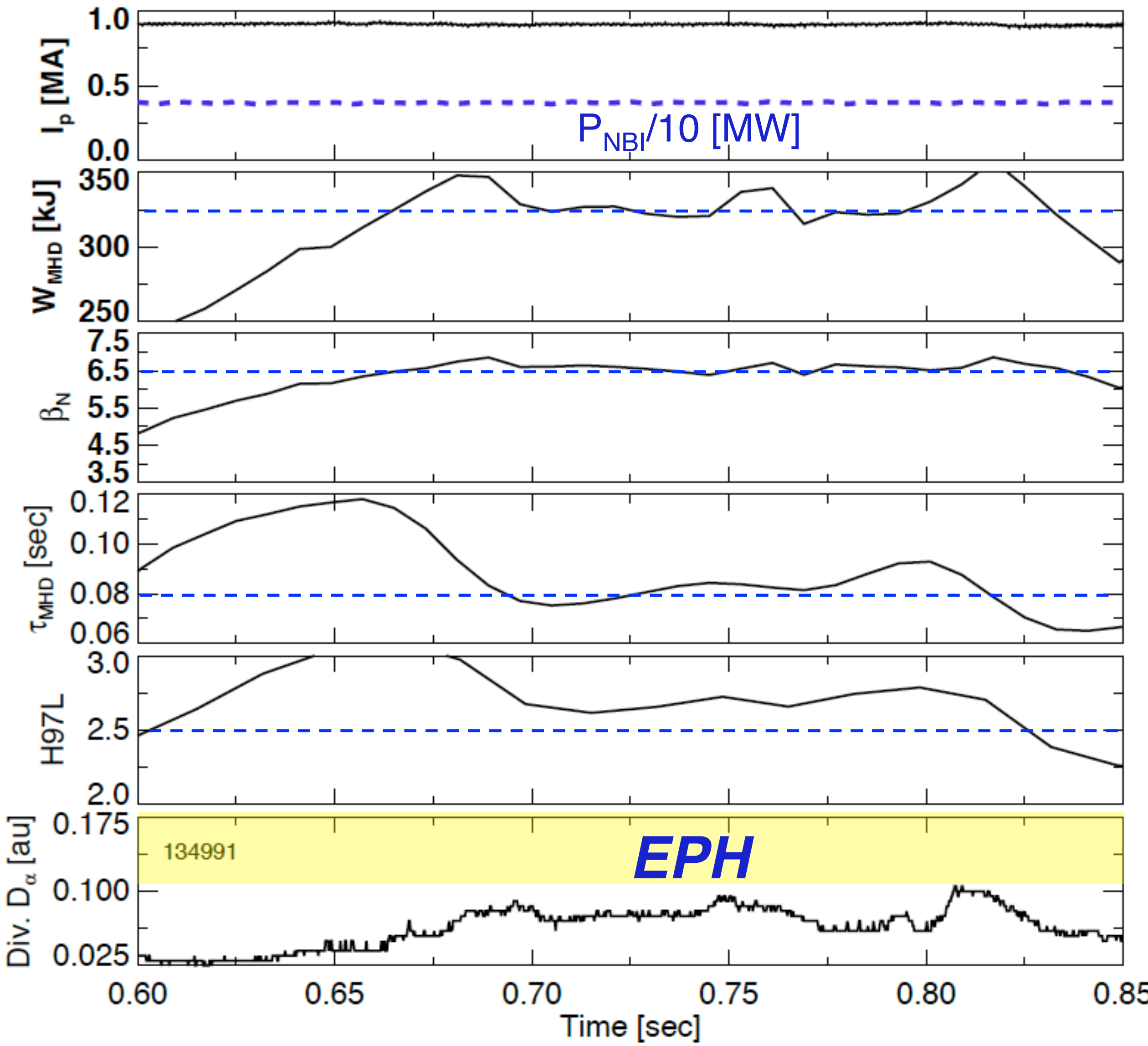
EPH-mode phases up to several hundred msec observed recently (more common with lithium?)



Maingi, PRL (2010) at press

- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- $W_{MHD} \leq$ 350 kJ
- β_N > 6.5
- $\tau_E \geq$ 80 msec for 225 msec
- H97L $\leq$ 3
- Natural ELM trigger for EPH
- Not sure of termination event

High β_N phase maintained for 2 τ_E



- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- $W_{MHD} \simeq$ 325 kJ
- $\beta_N \sim$ 6.5
- $\tau_E \geq$ 80 msec for 225 msec
- H97L $\geq$ 2.5
- EPH phase is ELM-free

EP H-mode phases may occur naturally in recovery period following 3-D fields applied for ELM triggers