NSTX

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Triggered Enhancement Confinement and Pedestal Expansion in NSTX: The Enhanced Pedestal H-mode

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R. Maingi, J.M. Canik
S. Gerhardt, S. Kaye,
and the NSTX team

OAK RIDGE National Laboratory
PPPL PRINCETON PLASMA PHYSICS LABORATORY

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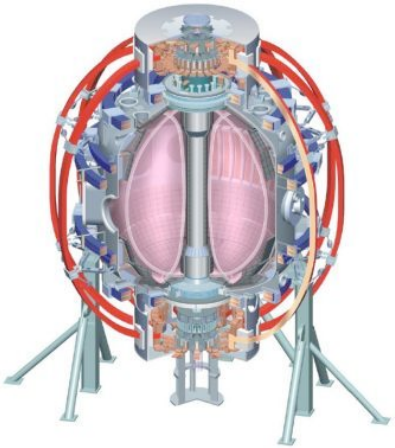

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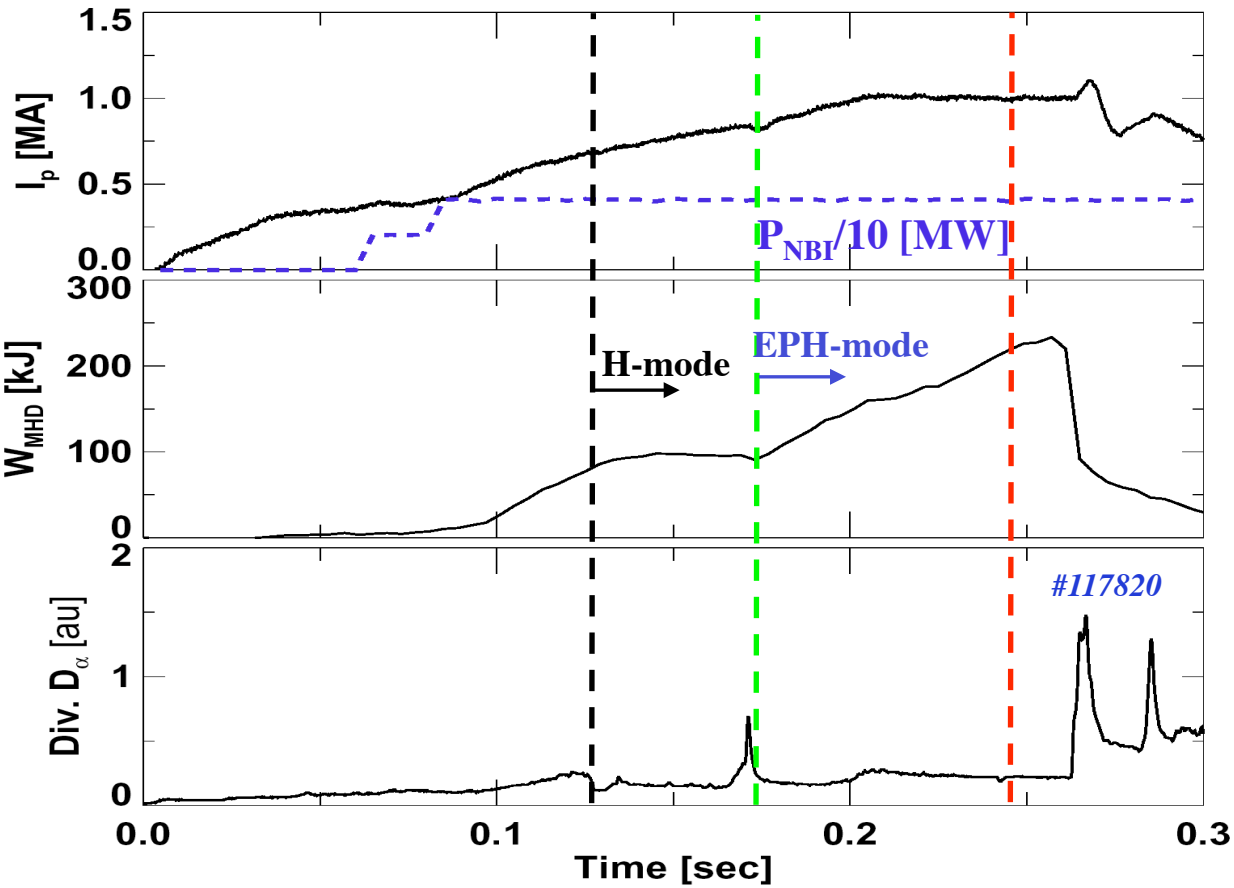
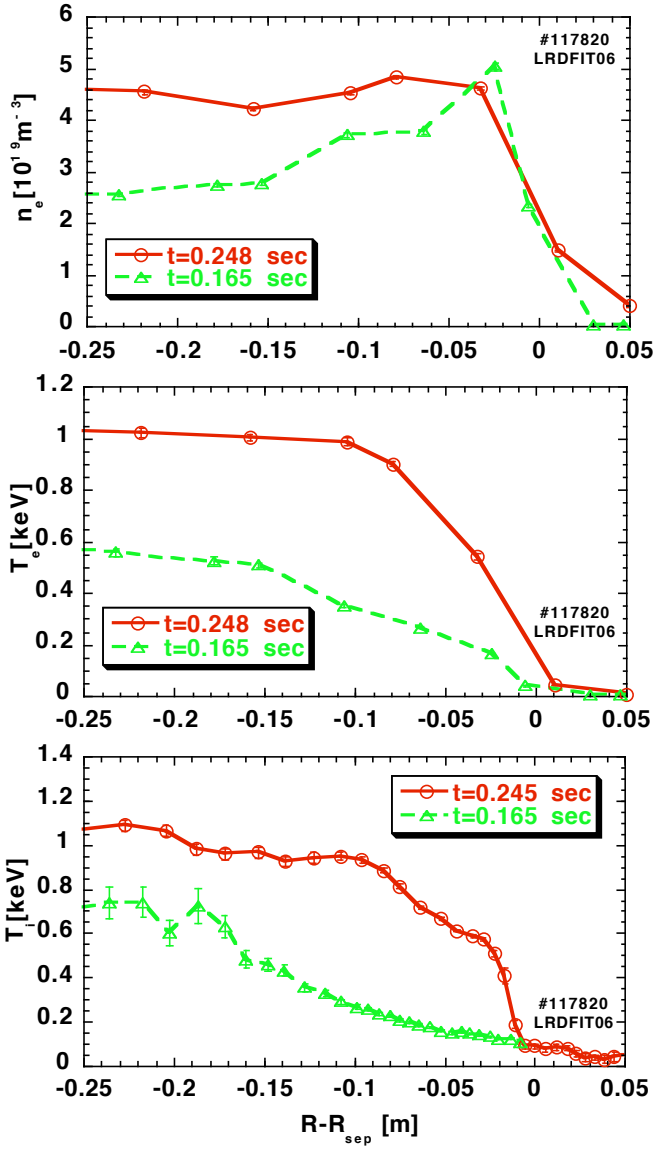
The Enhanced Pedestal H-mode (EPH) has favorable characteristics and improved long pulse prospects

- Energy confinement in NSTX H-modes is generally 0.8-1.2* ITER98y2 scaling
  - Note that τ_E increases stronger with B_t and weaker with I_p than 98y2
  - Several next step ST designs based on ~ 50% higher τ_E
- A transition to a (transiently) improved confinement with enhanced H-mode pedestal T_e, T_i observed a few years ago
- Characteristics of EP H-mode
  - Highest normalized energy confinement of any regime in NSTX, with H89P $\leq$ 3.5 and H98y2 $\leq$ 1.8
- Prospects for increasing pulse length
  - Can be triggered by large ELM or RMP-triggered ELM(!), with pulse length $\leq$ 3 τ_E (up to 300 msec) observed in 2009

Transition to an Enhanced Pedestal H-mode enables lower pedestal $\nu_{e,ped}^{*} \sim 0.1$ in NSTX

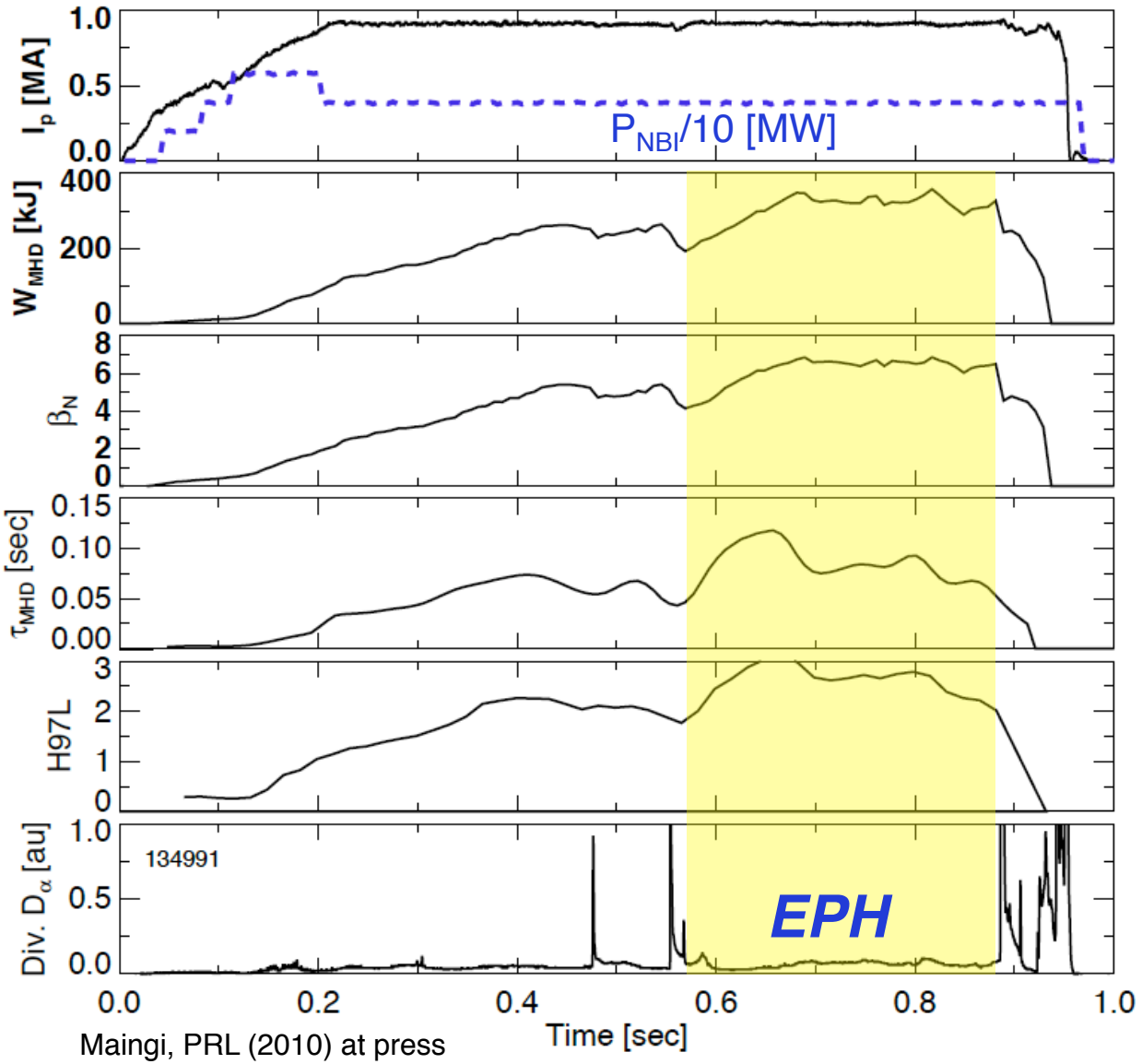




- ***Note: Pedestal $\nu_e^{*} \sim 0.5$-1 in H-mode***

Maingi, JNM 390-391 (2009) 440

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



Maingi, PRL (2010) at press

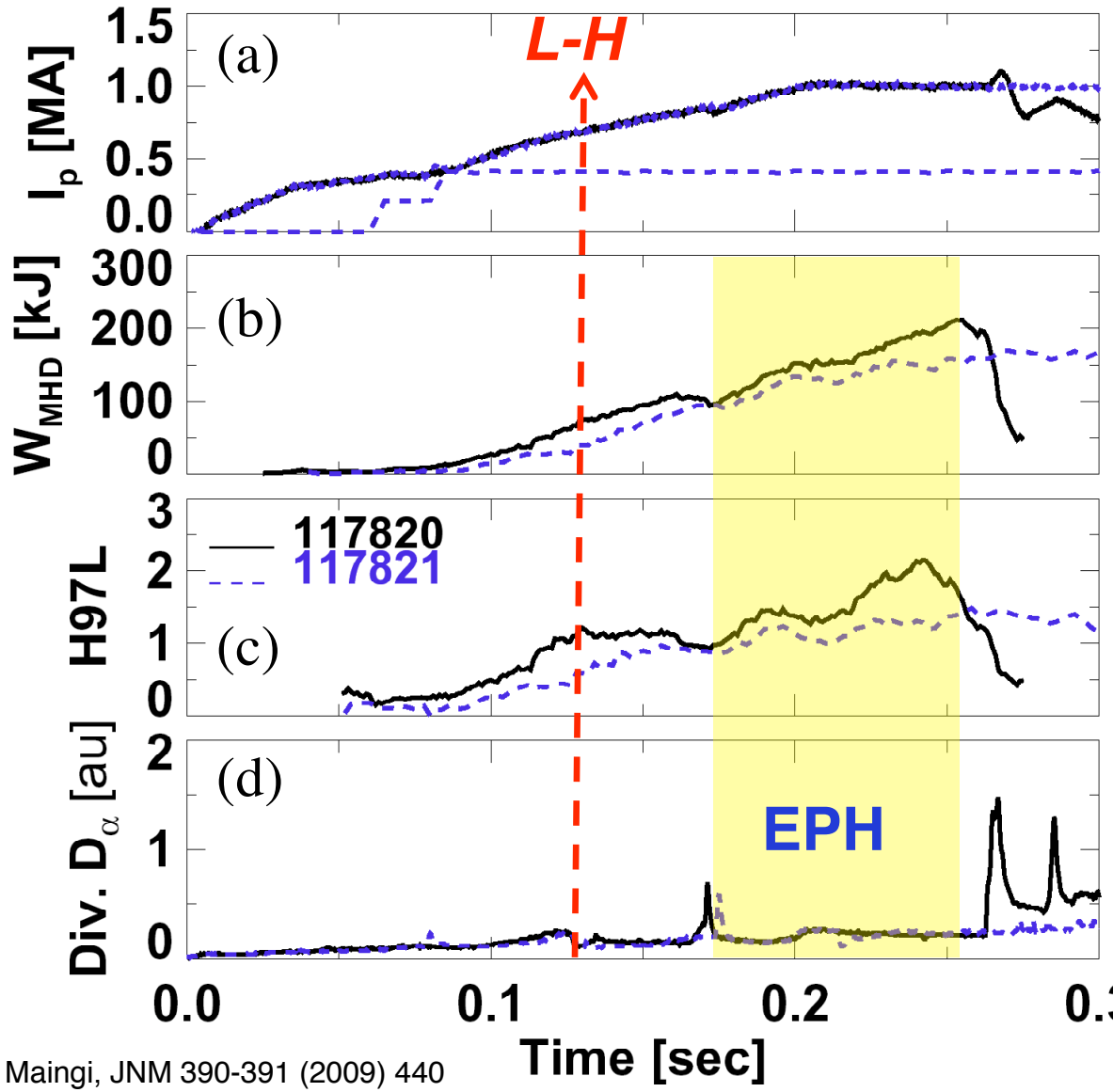
- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- $W_{MHD} \leq 350$ kJ
- $\beta_N > 6.5$
- $\tau_E \geq 80$ msec for 225 msec
- H97L ≤ 3
- Natural ELM trigger for EPH
- Not sure of termination event

Common Enhanced Pedestal H-mode Characteristics

- A second transition to enhanced confinement and high pedestal T_e, $T_i \leq 700$ eV
  - Second transition after large ELM, either natural or triggered by 3D fields
  - W_{MHD} ramps ~ linearly in time for ~ 0.1 s, typically dW/dt ~ $0.4*P_{NBI}$
  - $H_{H97L} \geq 2.5$, and as high as 3.5 transiently
  - EP H-mode phase observed during I_p ramp or flat-top
- Common feature: edge v_ϕ develops large gradient, with a large drag, often near the q=3 surface
- Low loop voltage, high β_N (due partly to low pressure peaking factor)

✓ *high performance, long pulse candidate*

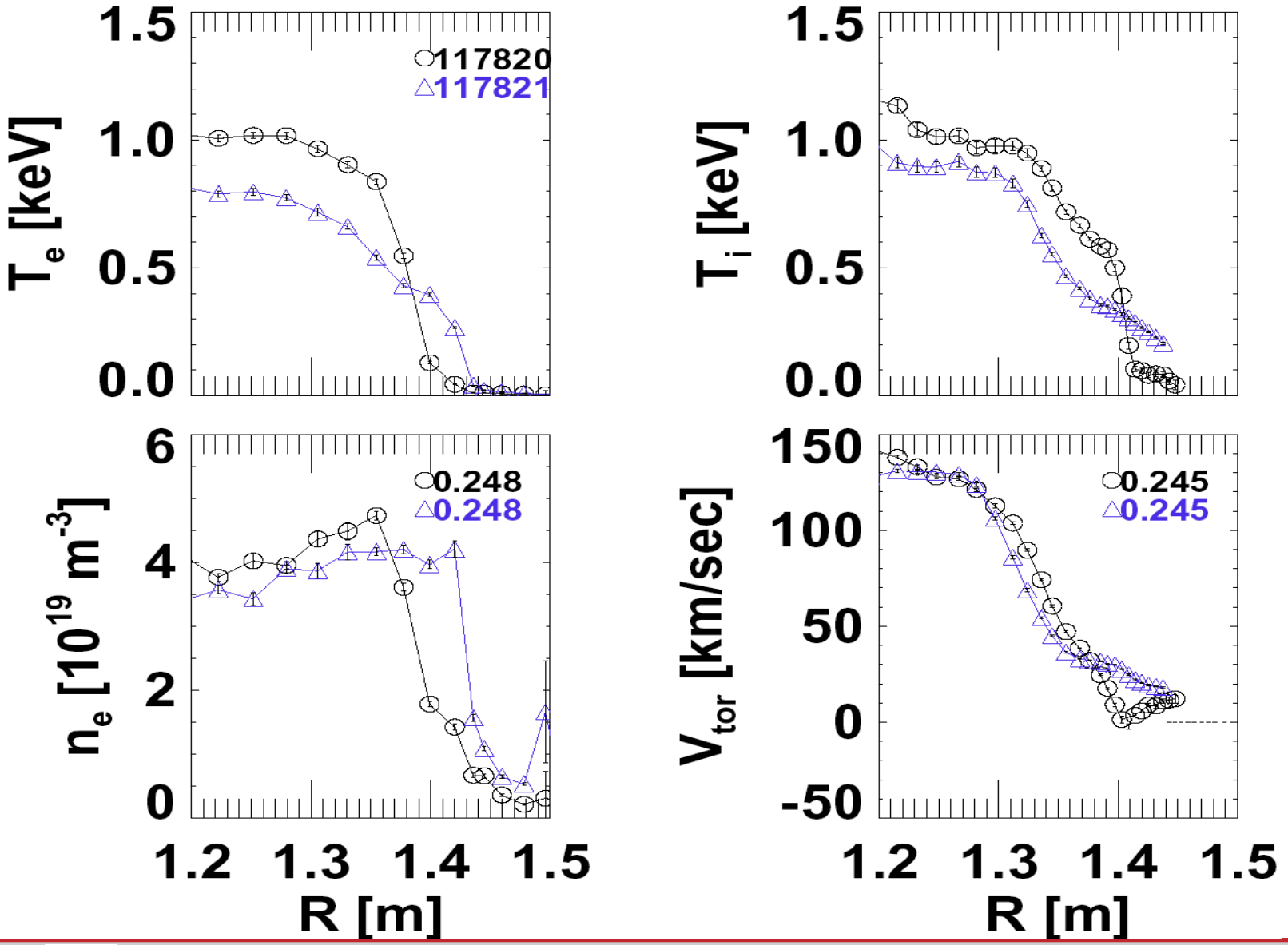
Comparison of Standard and EP H-mode evolution



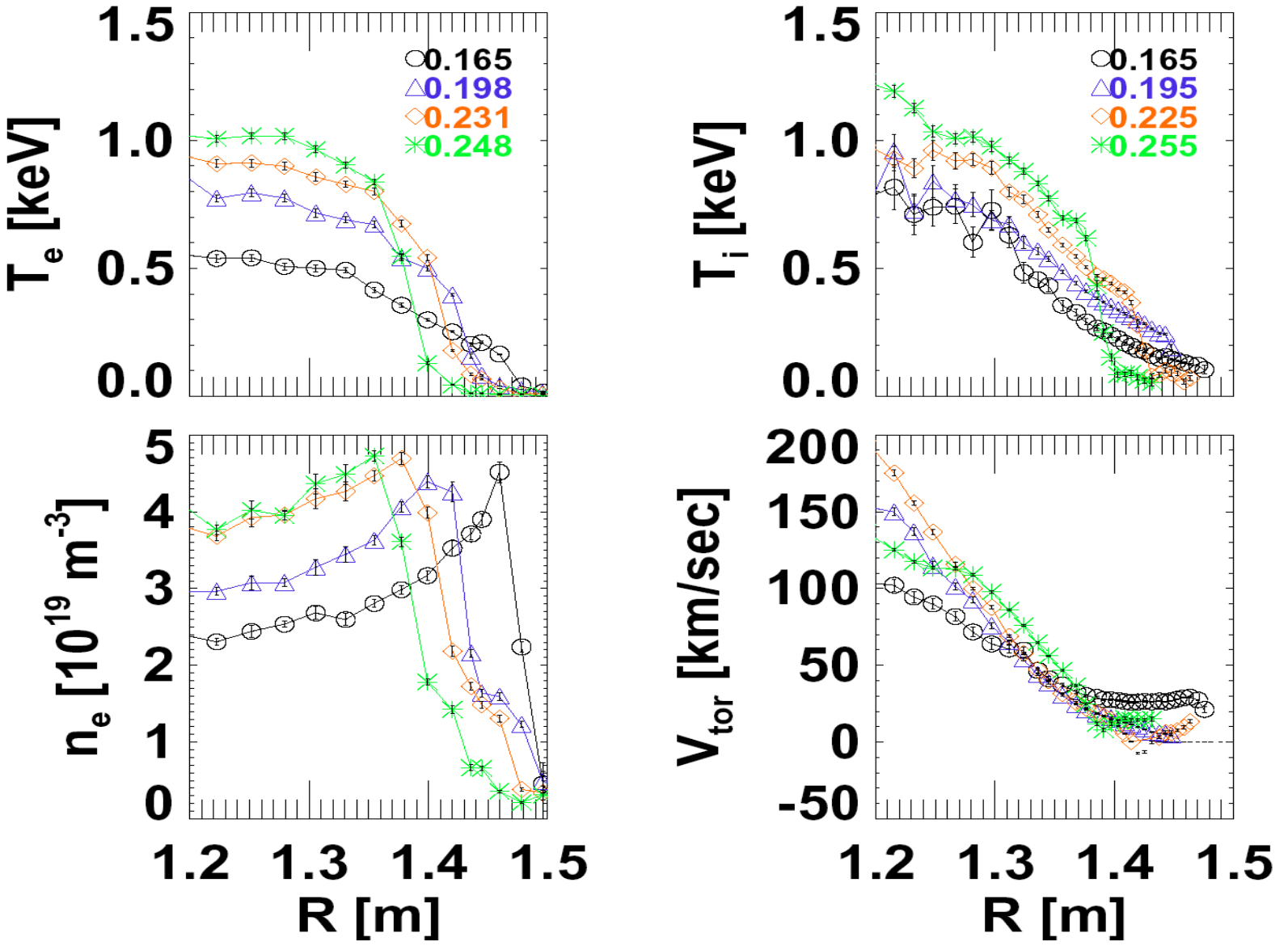
Maingi, JNM 390-391 (2009) 440

- Same I_p, P_{NBI}
- Higher W_{MHD} during EPH
- Higher H97L during EPH
- ELM trigger for EPH

Comparison of Standard and EP H-mode profiles



EP H-mode profiles evolved continuously during I_p ramp

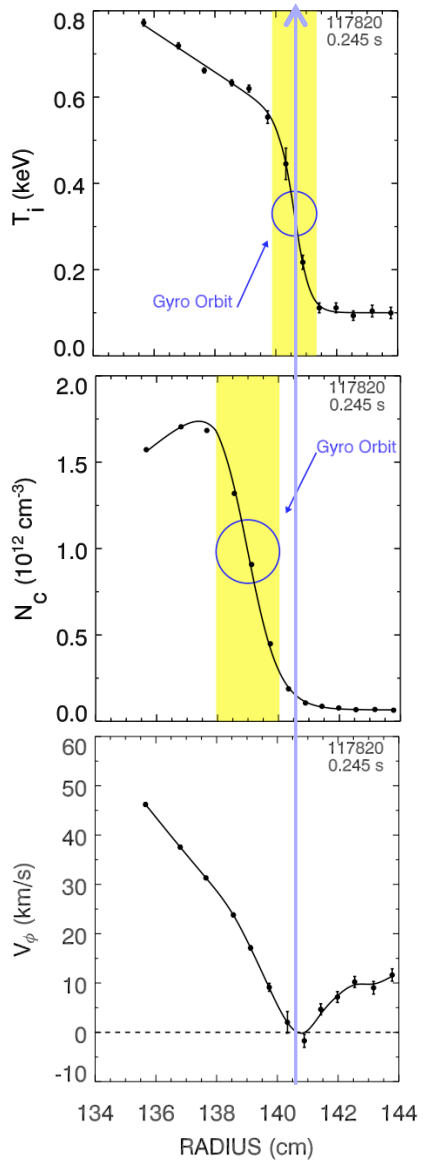


Enhanced Pedestal H-mode barrier width size comparable to gyro-diameter

- Edge scale lengths for both T_i and n_C approach the gyro-diameter during EPH-mode

- Ion gyroradius $\rho_i \sim 0.7$ cm relative to |B|, owing to combination of local $T_i \sim 350$ eV and and |B| ~ 0.35 T at outer midplane
  - ➢ Approaching or at the fundamental limit on the gradient scale length?

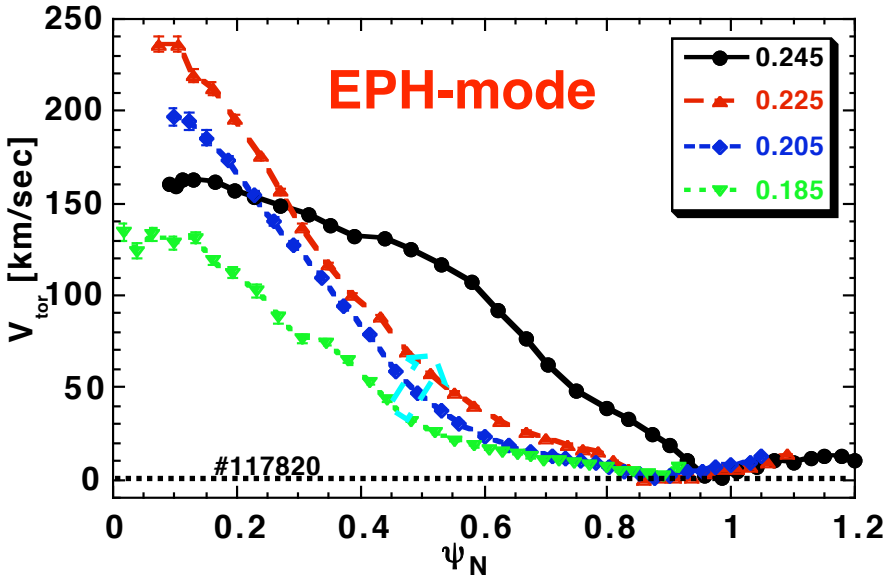
- Minimum v_ϕ seems to be in center of highest ∇T_i region

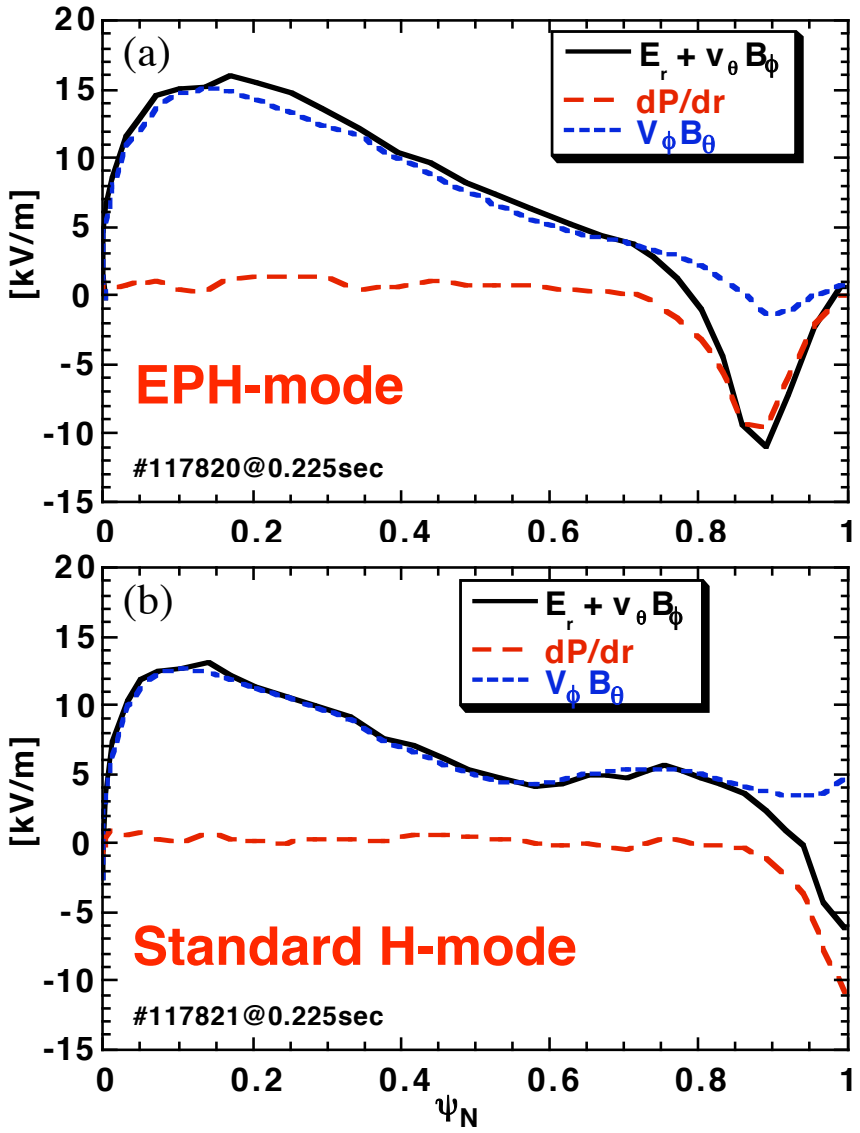


R. Bell

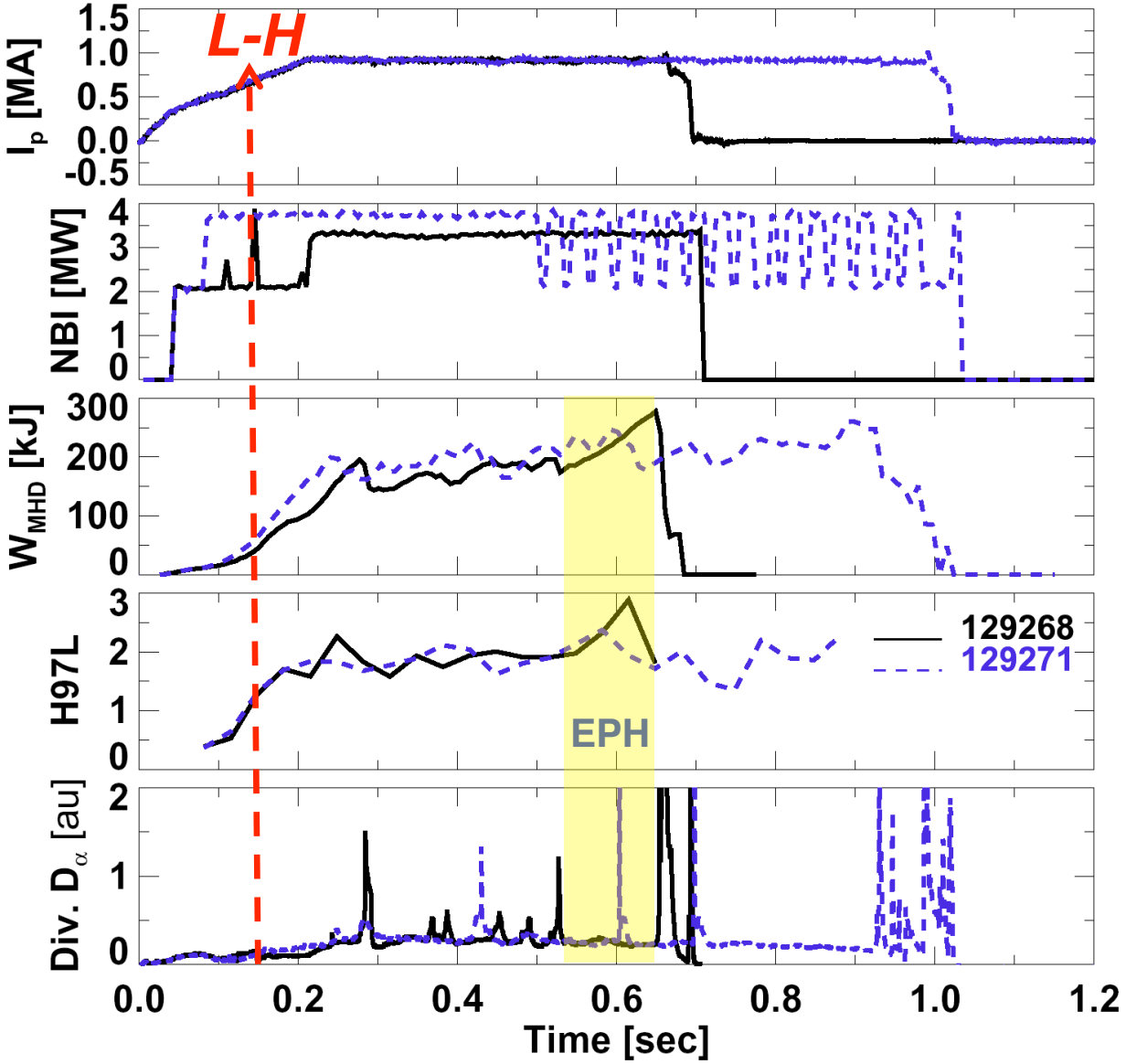
Changes in v_ϕ accompany high $T_{e,i}^{ped}$ in Enhanced Pedestal H-mode

- First order radial force balance: $E_r+v_\theta B_\phi=v_\phi B_\theta+\nabla P_c/6eN_c$
- EPH mode has $v_\phi \sim 0$ near separatrix, probably due to drag from an island, such that ∇P term dominates v_ϕ over large region
- Large ∇v_ϕ indicative of large E_r'
- v_θ negligible (recent measurement)



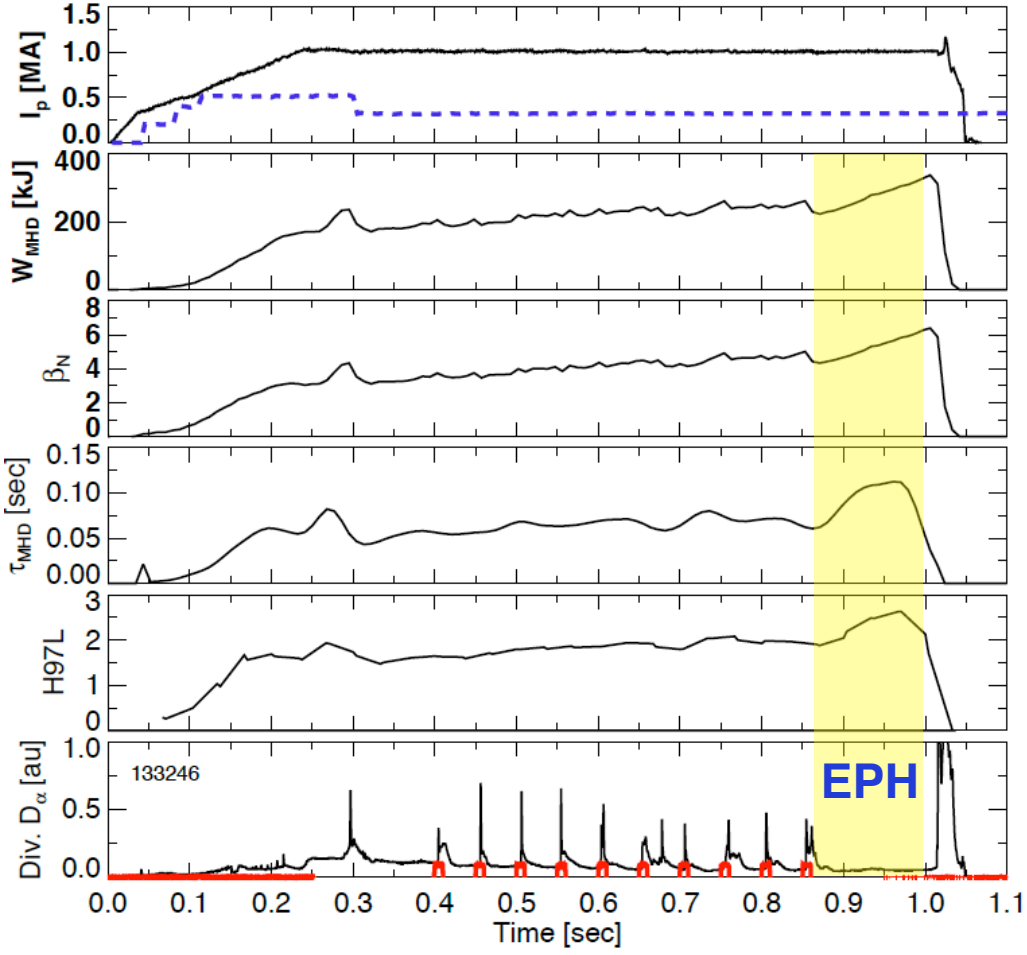


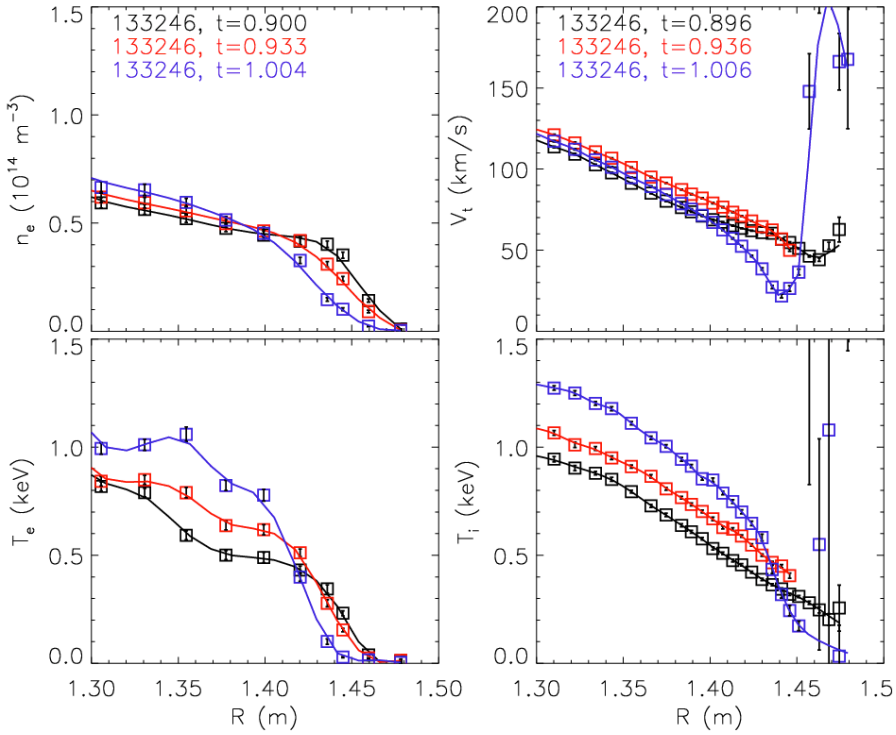
Spontaneous EPH-mode also observed during I_p flat-top



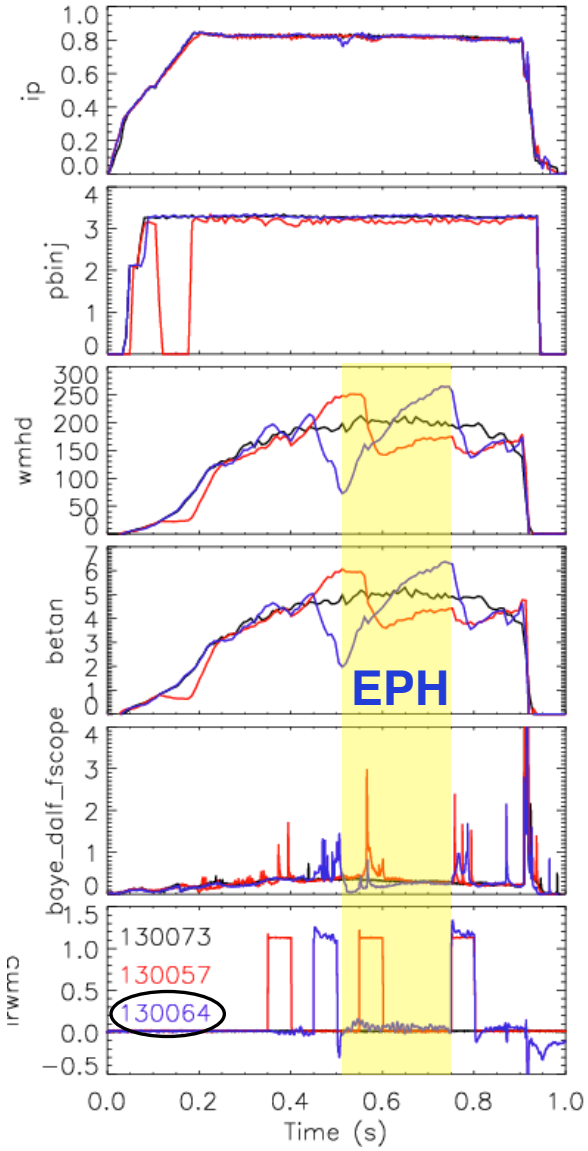
- Same I_p, P_{NBI}
- Lower P_{NBI}
- Higher W_{MHD} during EPH
- Higher H97L during EPH
- ELM trigger for EPH

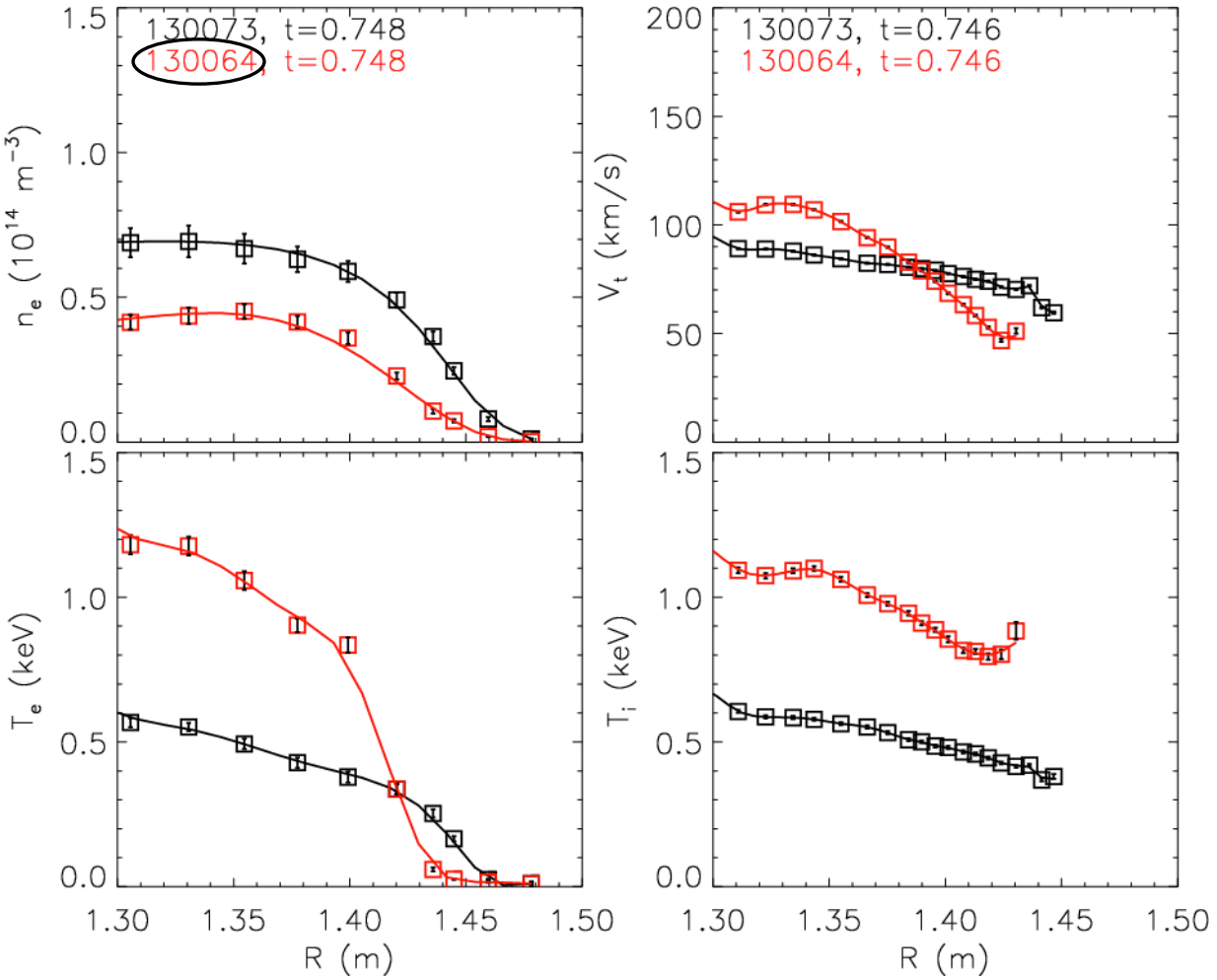
3D fields used for ELM pace making may trigger EPH during periods when 3D fields switched off



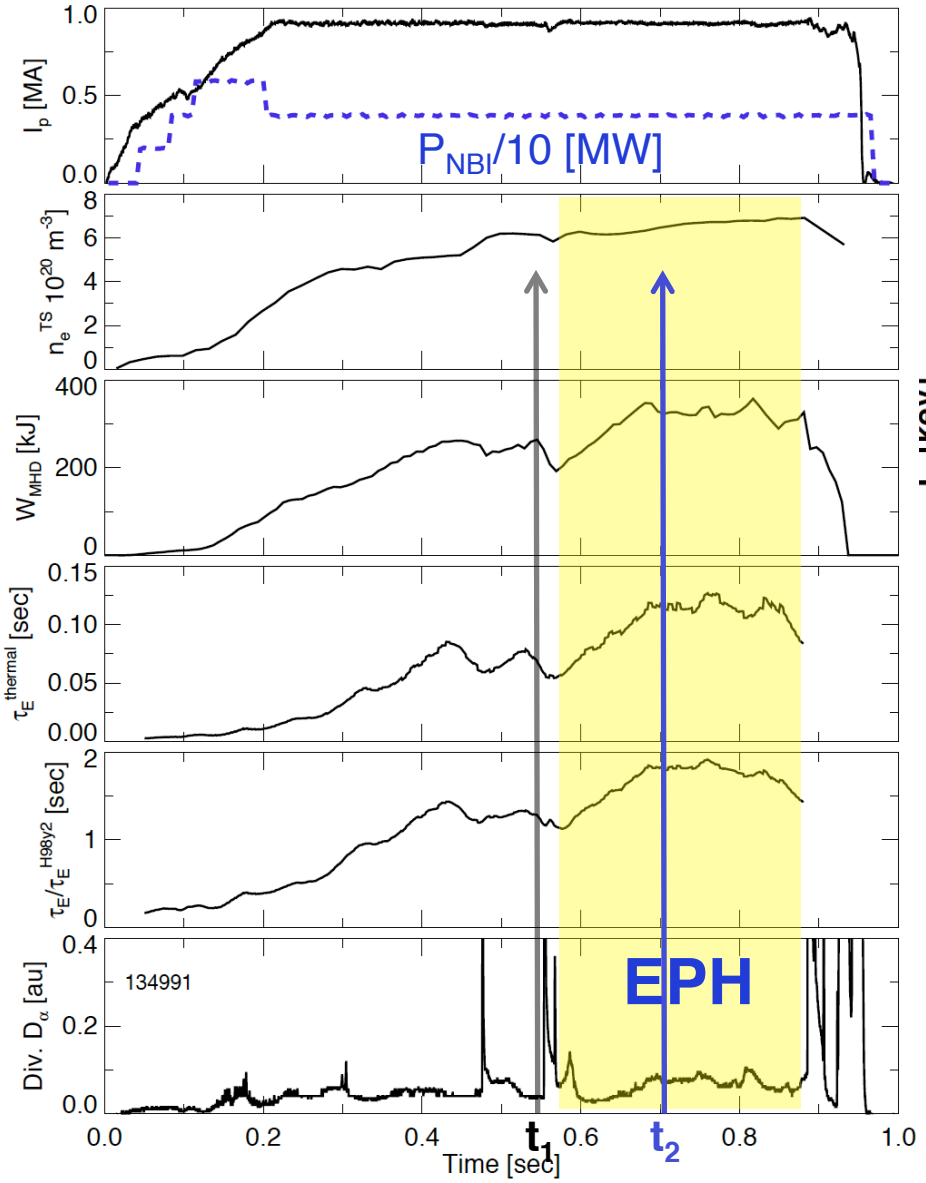


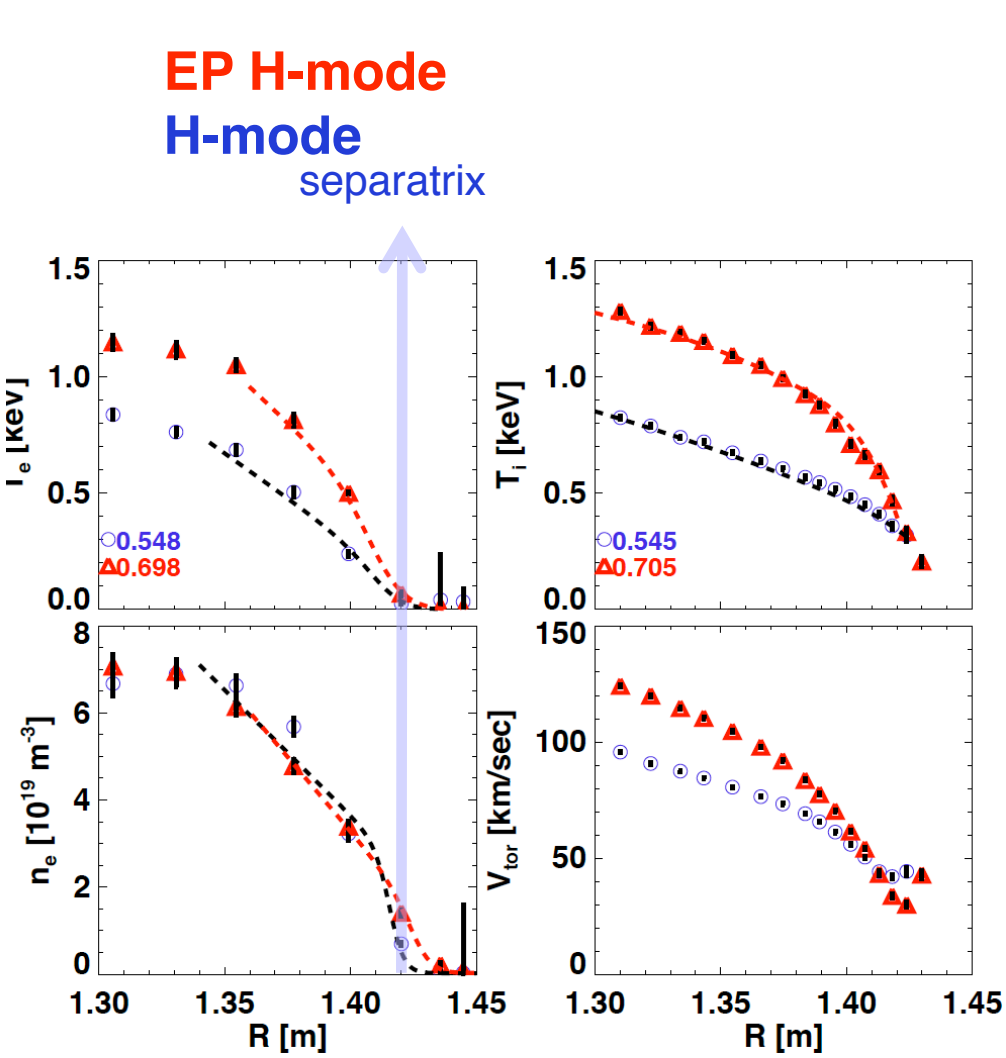
EPH may occur naturally in recovery period following ELM/braking triggers



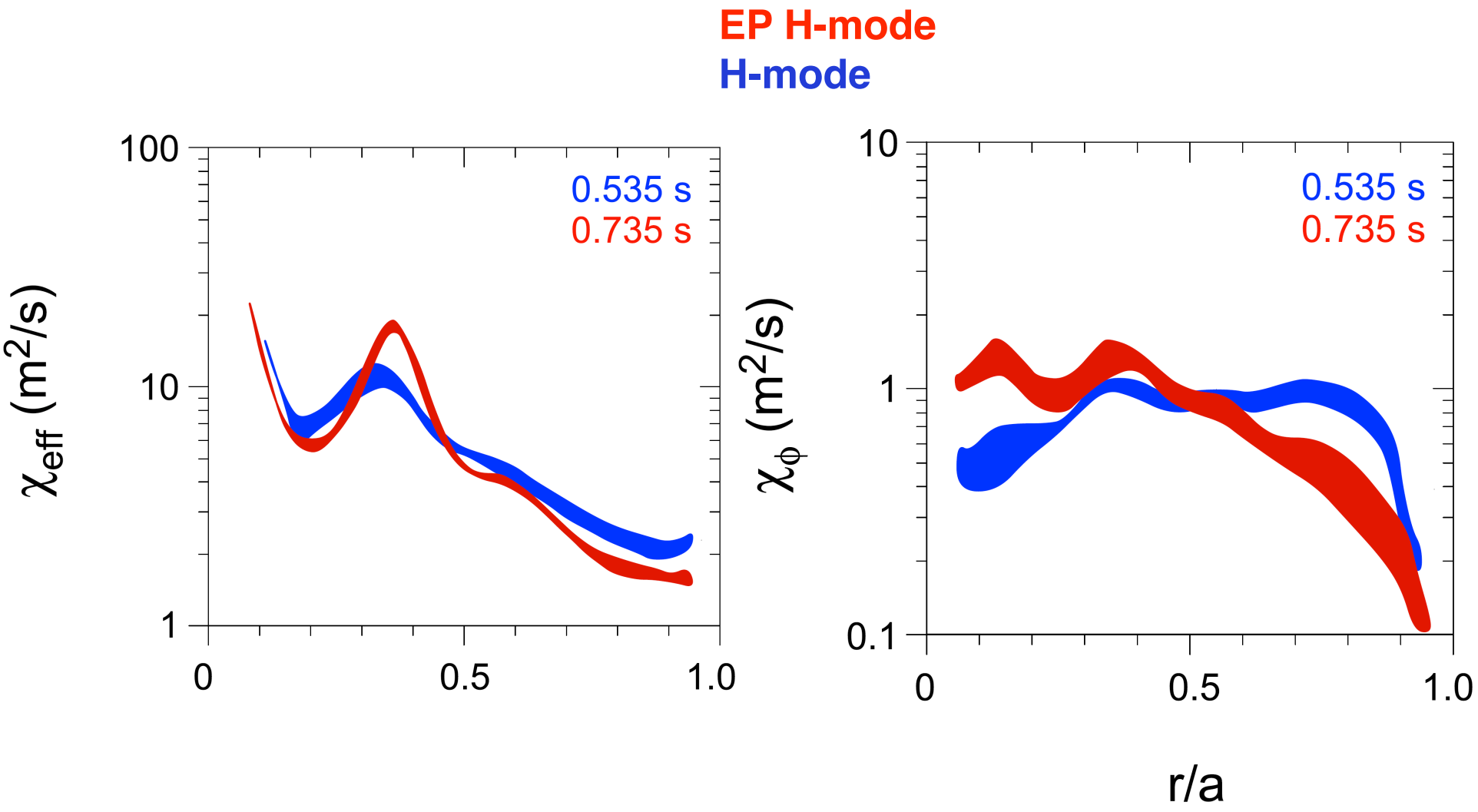


EPH-mode phase observed for several τ_E , up to ~ 300 msec

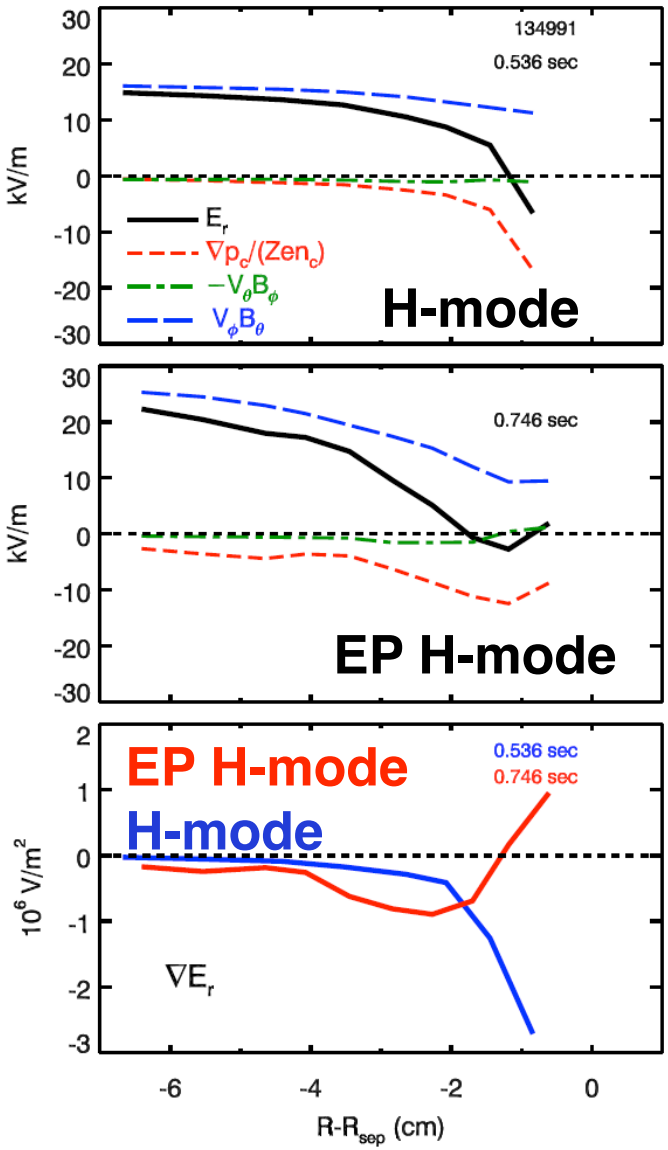




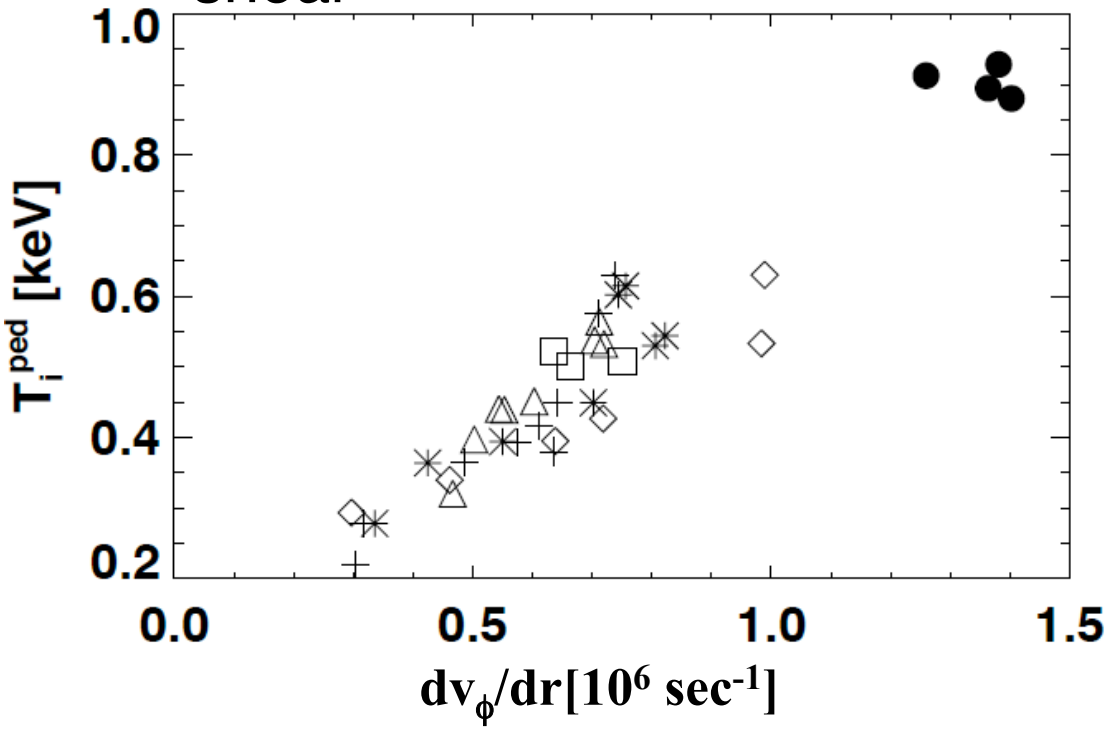
Thermal and angular momentum transport reduced over outer half of plasma



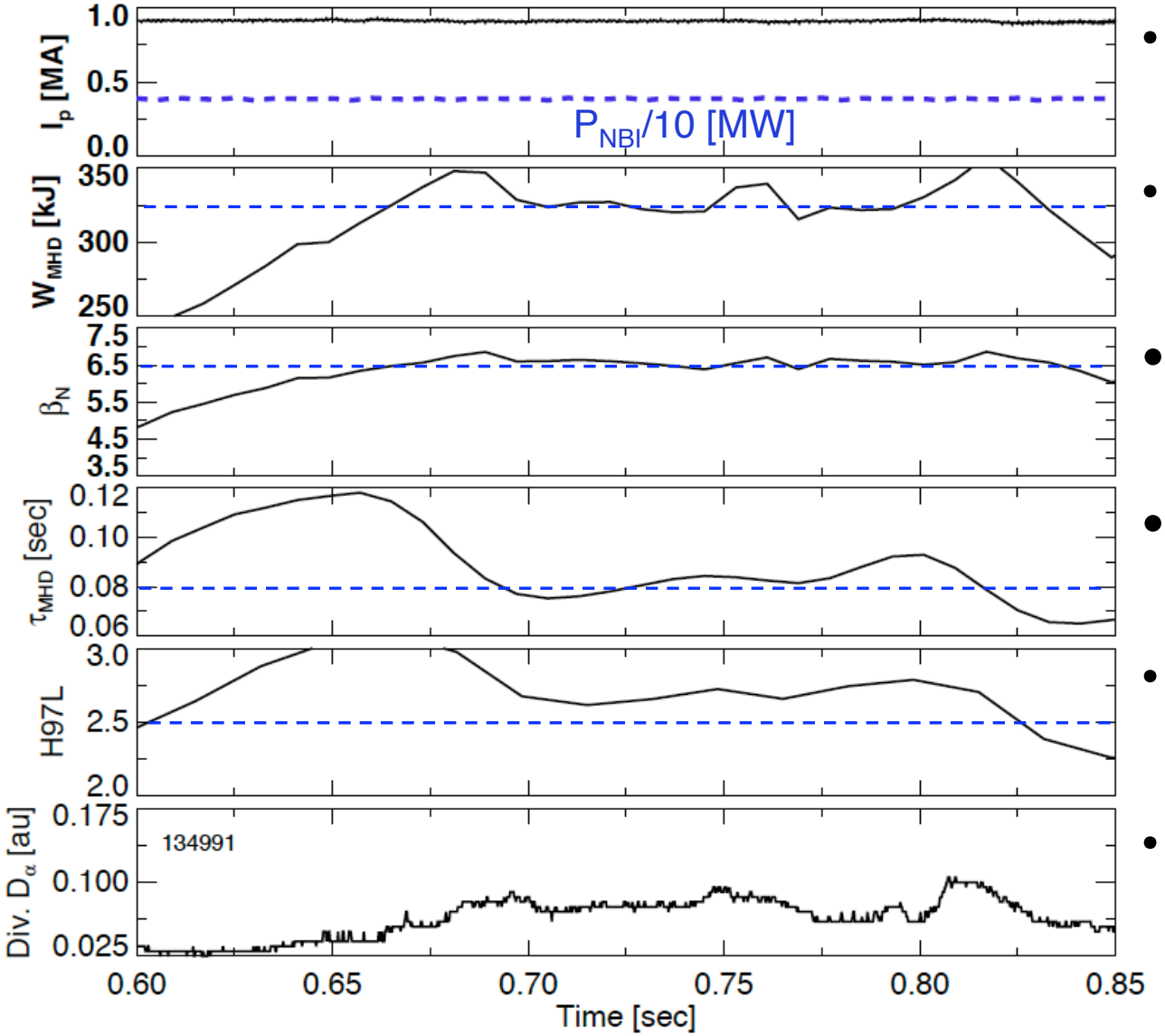
Spatial extent of significant E_r shear region doubled in size during EP H-mode



- T_i pedestal height correlates with edge toroidal rotation shear

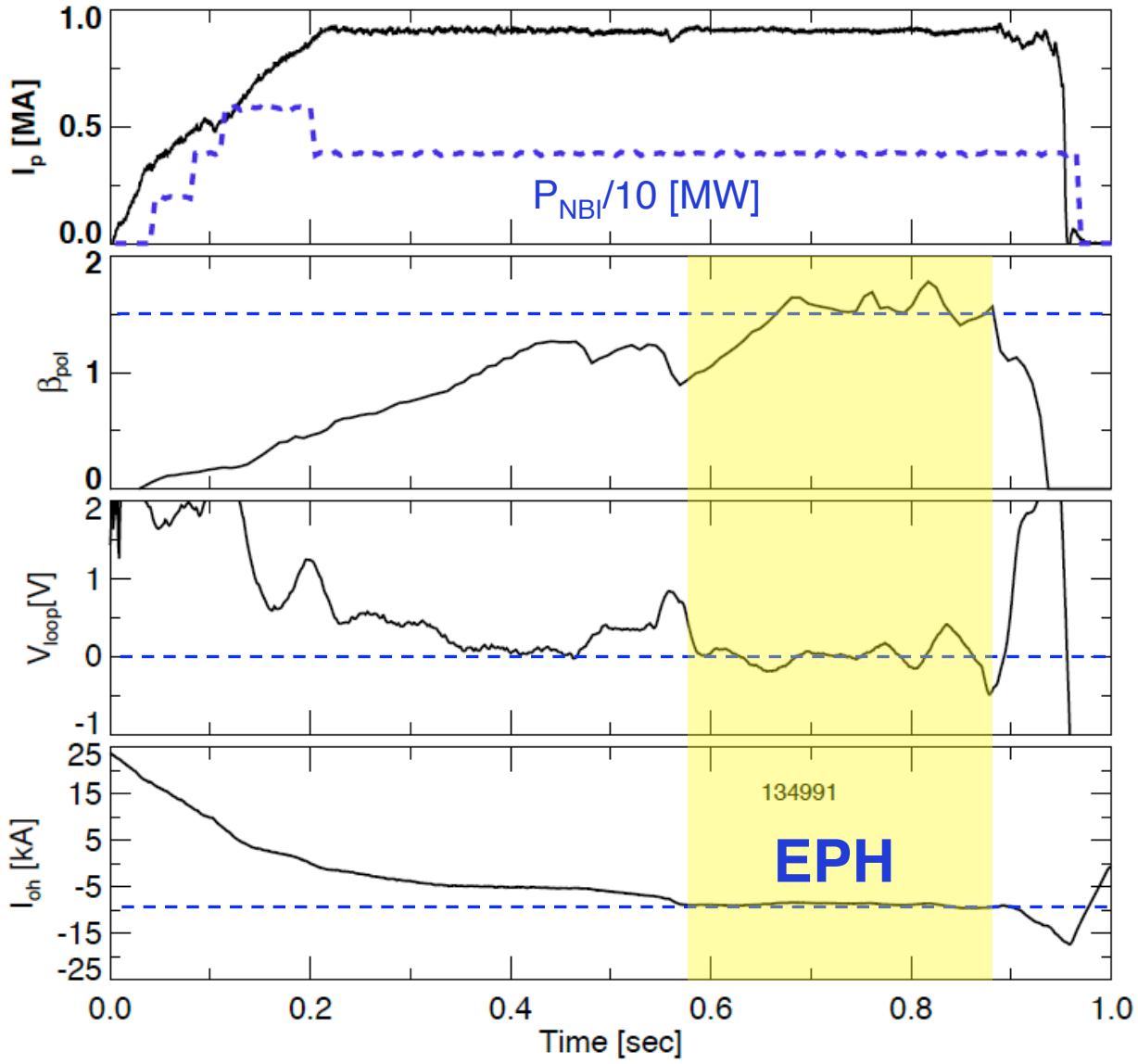


High β_N phase maintained for 2 τ_E



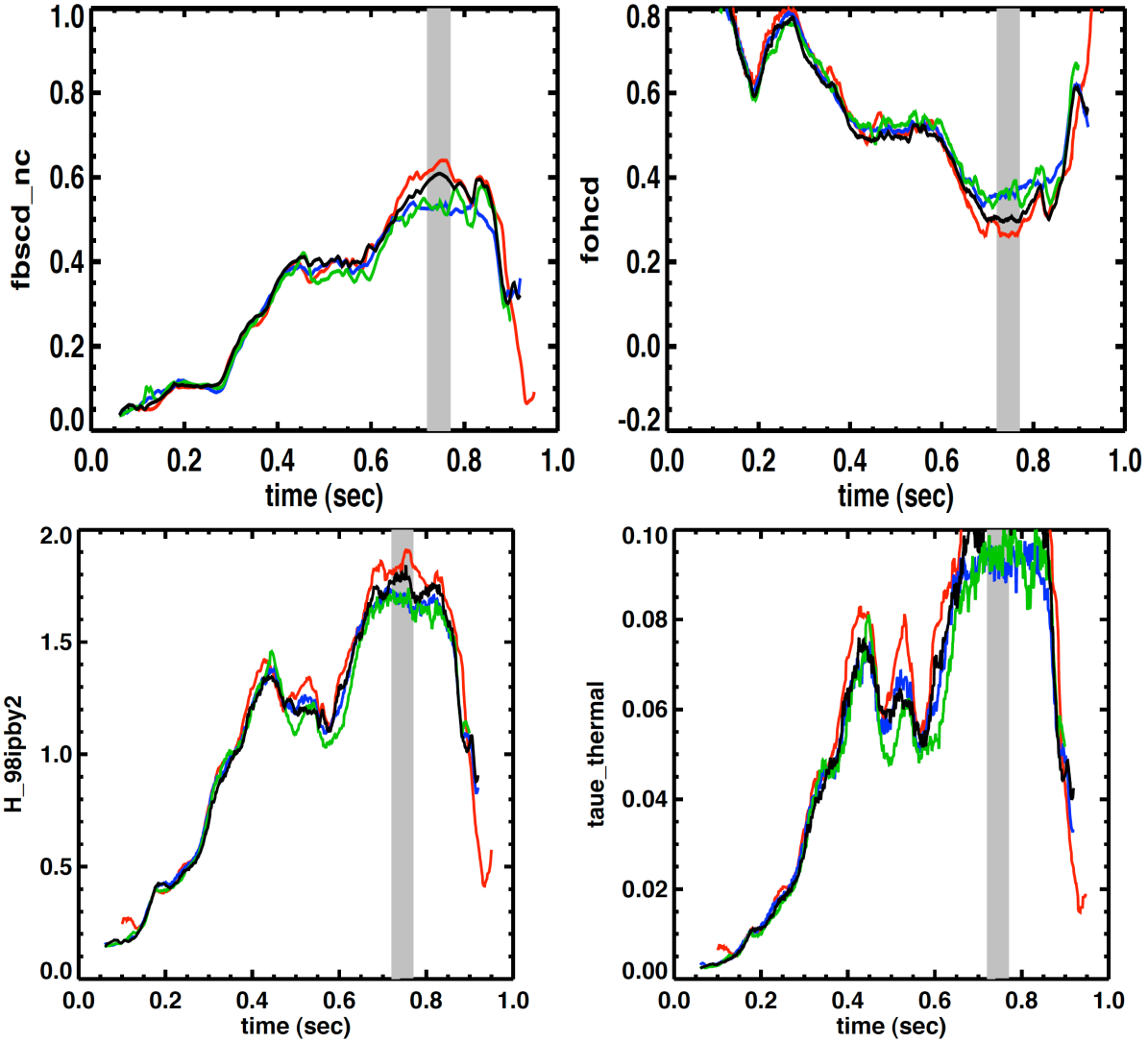
- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- $W_{MHD} \simeq$ 325 kJ
- $\beta_N \sim 6.5$
- $\tau_E \geq$ 80 msec for 225 msec
- H97L $\geq$ 2.5
- EPH phase is ELM-free

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

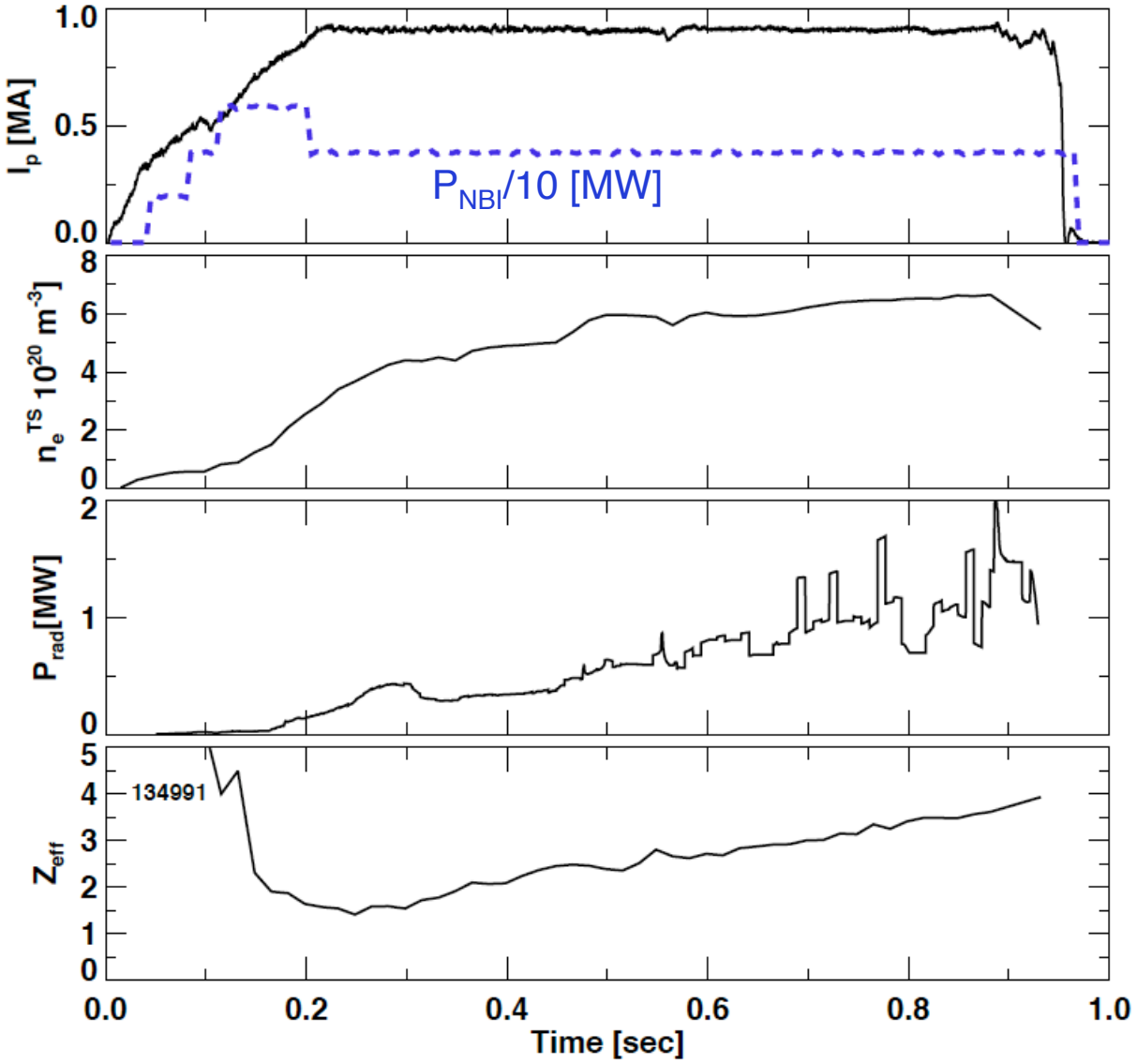
High bootstrap and non-inductive fractions, high thermal τ_E during EPH phase



- f_{bs} between 0.5-0.6, and f_{NI} between 0.6-0.7
- H98y2 between 1.6 and 1.8, with τ_E^{th} between 90-100 msec

S. Gerhardt, S. Kaye

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



EPH-mode would make a decent ASC TSG high performance, long pulse target

- Initiating EPH-mode:
  - Lithium conditioning for ELM-free conditions
  - Either fast RMP trigger of a large ELM(5 Hz?), or longer RMP pulse with several ELMs: both seem to work
  - Since density profile control may be important, *supersonic gas injection (SGI) may provide easier access (longest pulse EPH had SGI*)
- Sustaining EPH-mode:
  - Use β feedback + n=1 feedback to avoid β limit
  - Pre-program NBI reduction, if needed
  - Raise B_t or drop I_p or more shaping to delay q_0=1 crossing

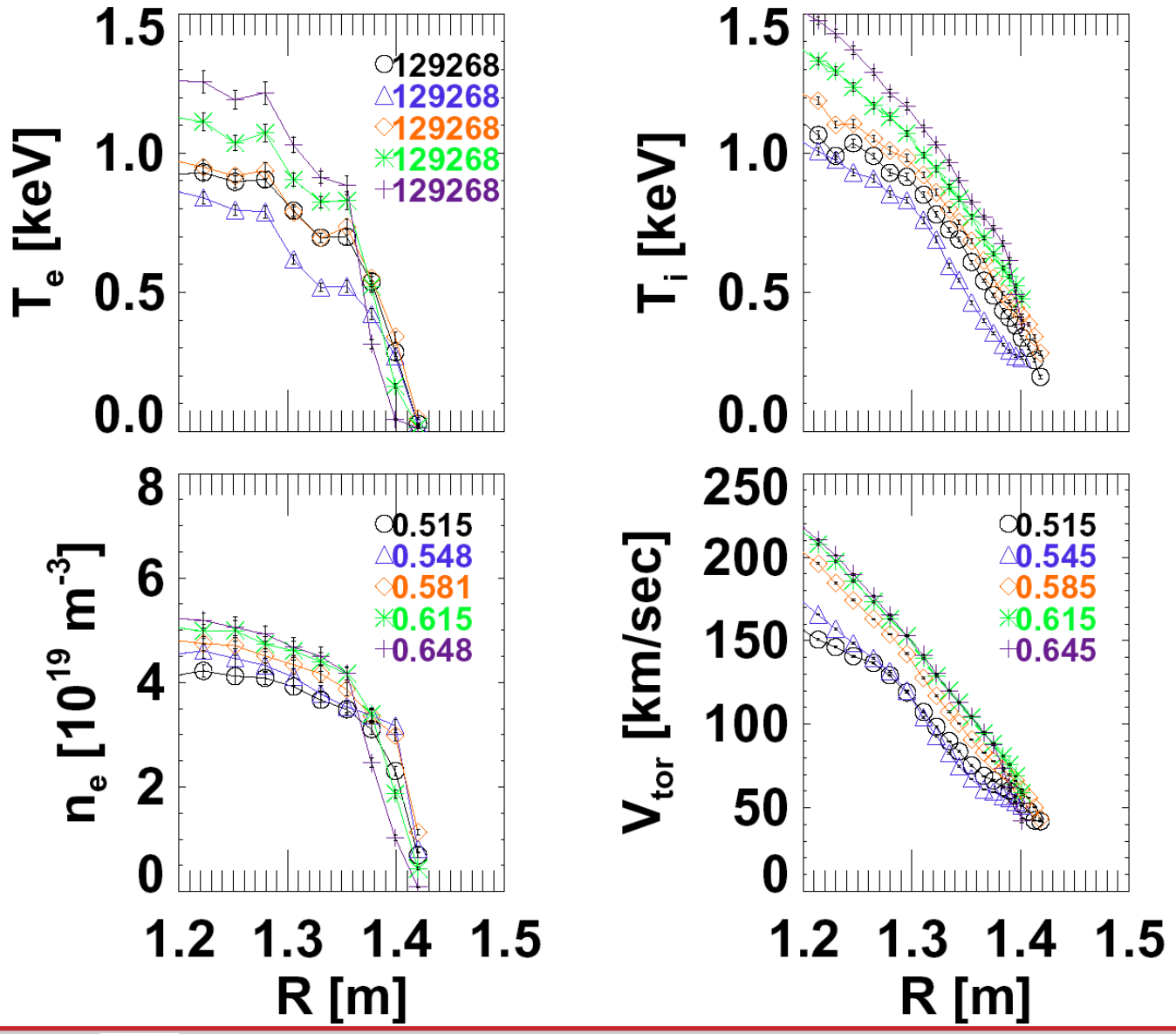
The Enhanced Pedestal H-mode has favorable characteristics and improved long pulse prospects

- EP H-modes occur naturally following large ELMs, or can be triggered with 3D fields
- Recently, EPH phases were obtained during I_p flat-top for several τ_E
- With the advent of β feedback on NBI and good n=1 feedback, extending the pulse length and using EPH as a high-performance target will be attempted in FY10 in NSTX

✓ Experiments will be lead by Canik and Gerhardt

Backup

EP H-mode profiles evolve continuously, although recovery from trigger takes a little time



- Discharge had Li evaporation to improve performance in regular H-mode

EPH-mode can have transient H89P up to 4