NSTX

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The Enhanced Pedestal H-mode: Characteristics and Long Pulse Prospects

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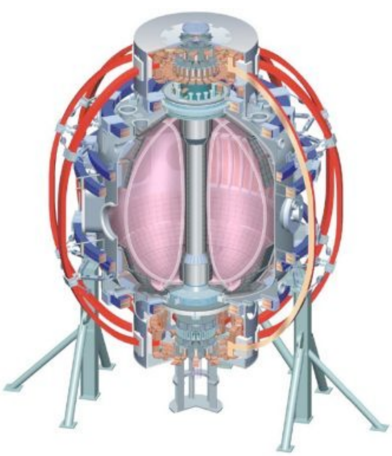
With thanks to S. Kaye, and M. Bell for analysis

Monday Physics Meeting
PPPL, Princeton NJ
1 Mar 2009



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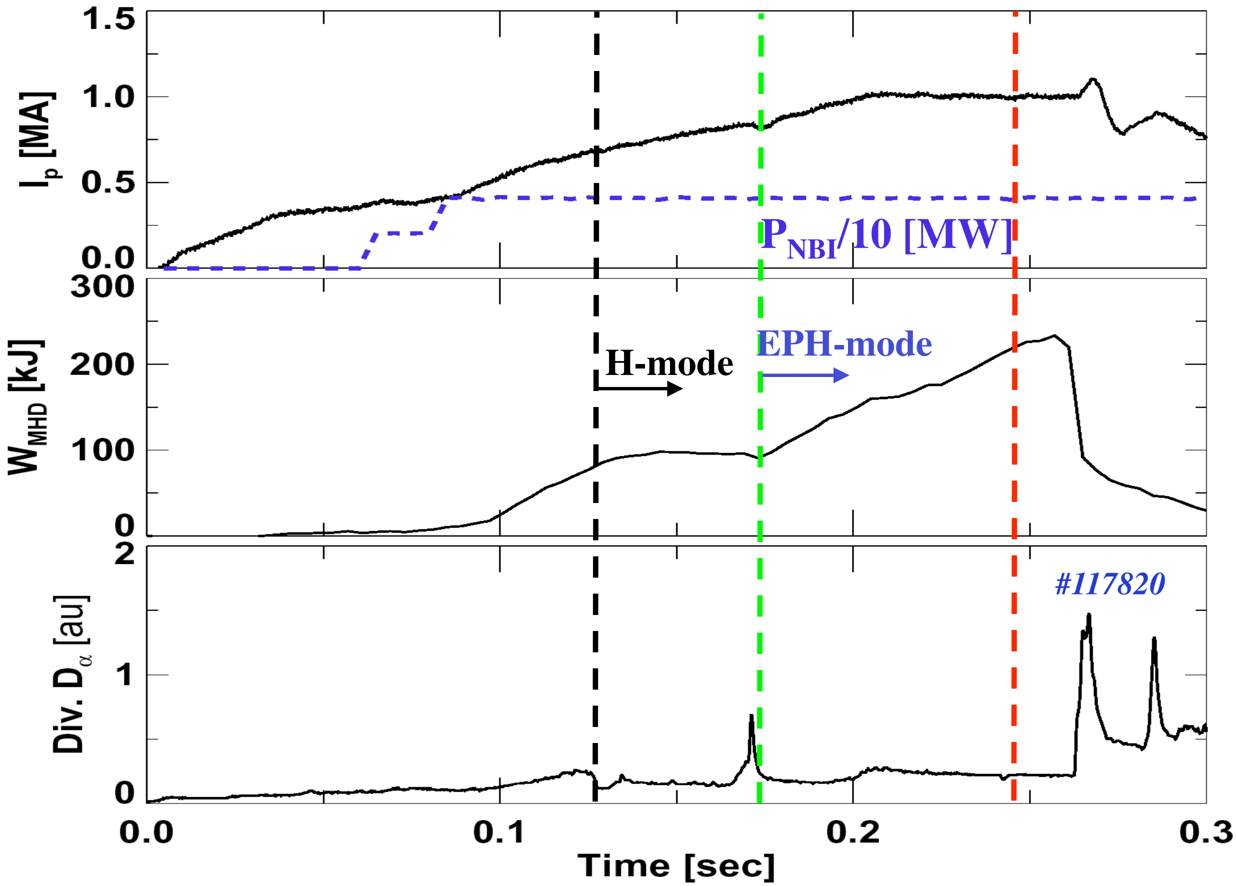
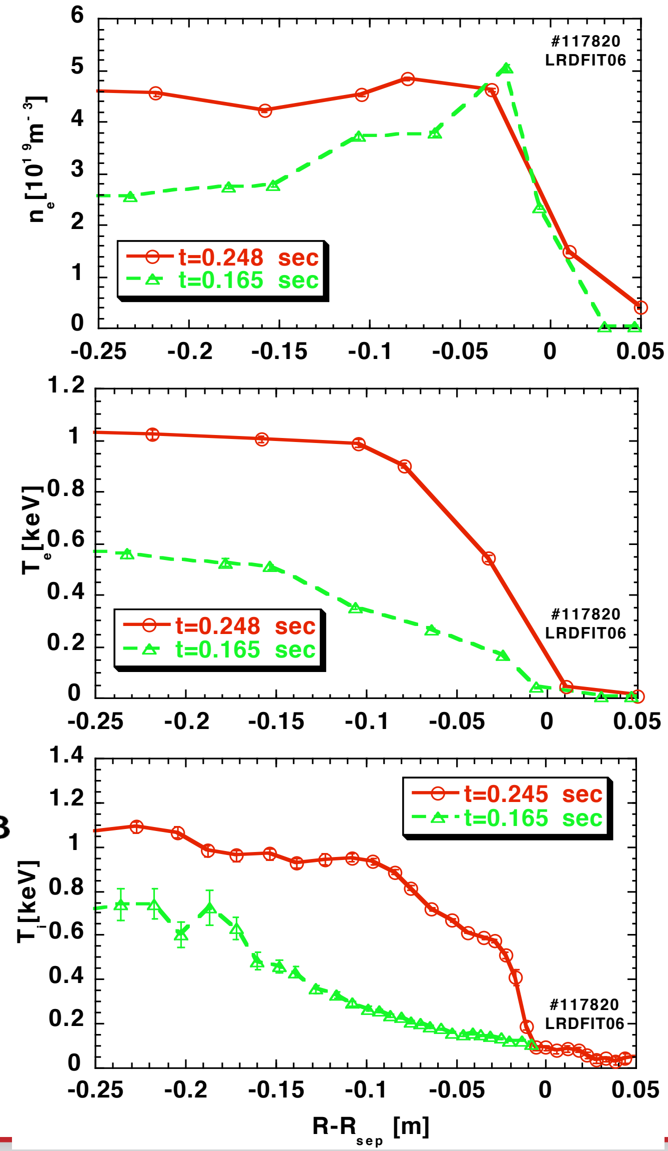
The Enhanced Pedestal H-mode (EPH) has favorable characteristics and improved long pulse prospects

- 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 $\leq 3\ \tau_E$ (up to 300 msec)
- *A PRL manuscript is being prepared*

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

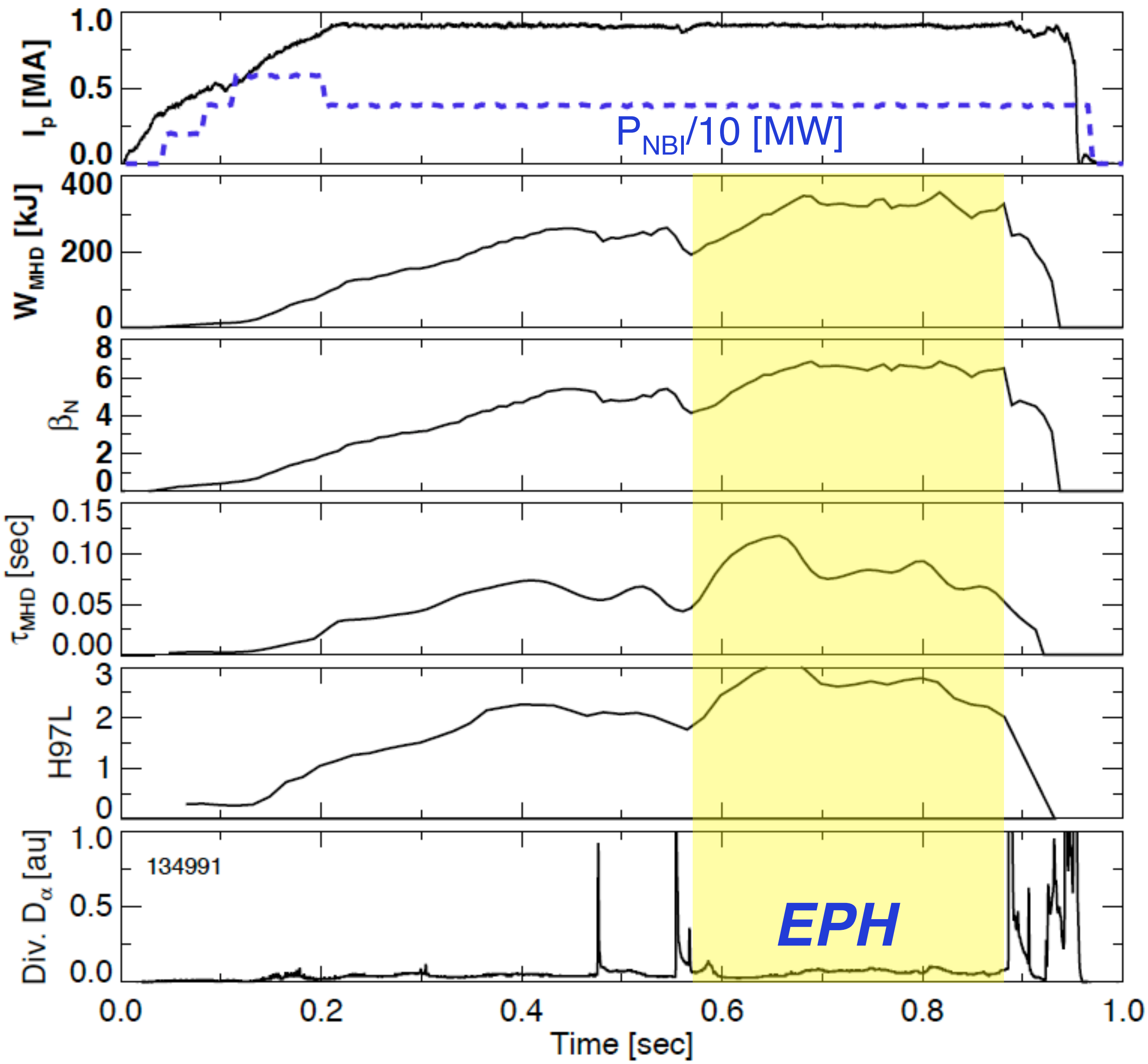




- ***Note: Pedestal ν_e^* ~ 0.5-1 in H-mode***

Maingi, JNM 390-391 (2009) 440

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



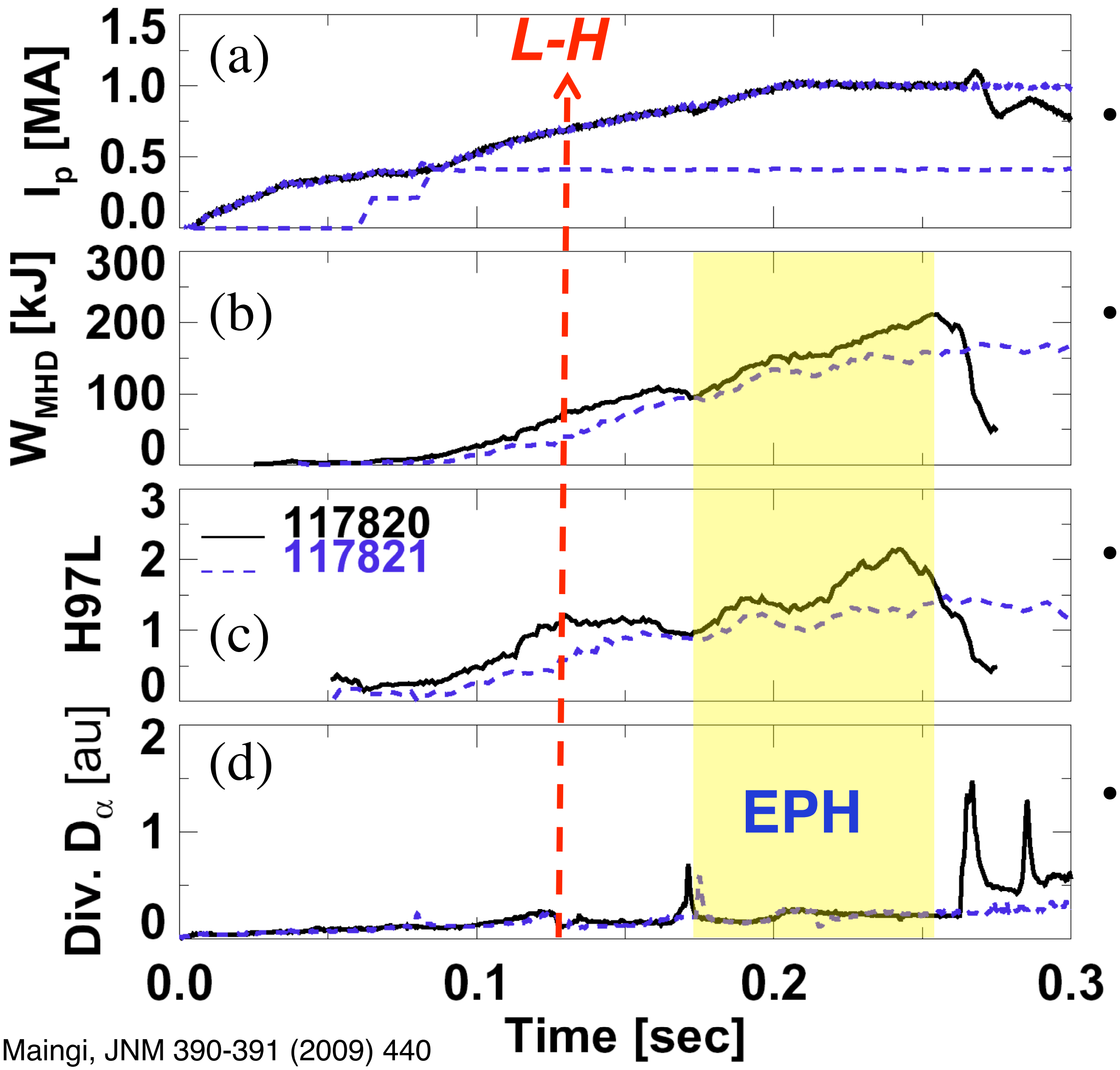
- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- $W_{MHD} \leq$ 350 kJ
- β_N > 6.5
- $\tau_E \geq$ 80 msec for 225 msec
- H97L $\leq$ 3
- Natural ELM trigger for EPH
- q_{min}=1 crossing probably ends EPH (not RWM)

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, 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, typically 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



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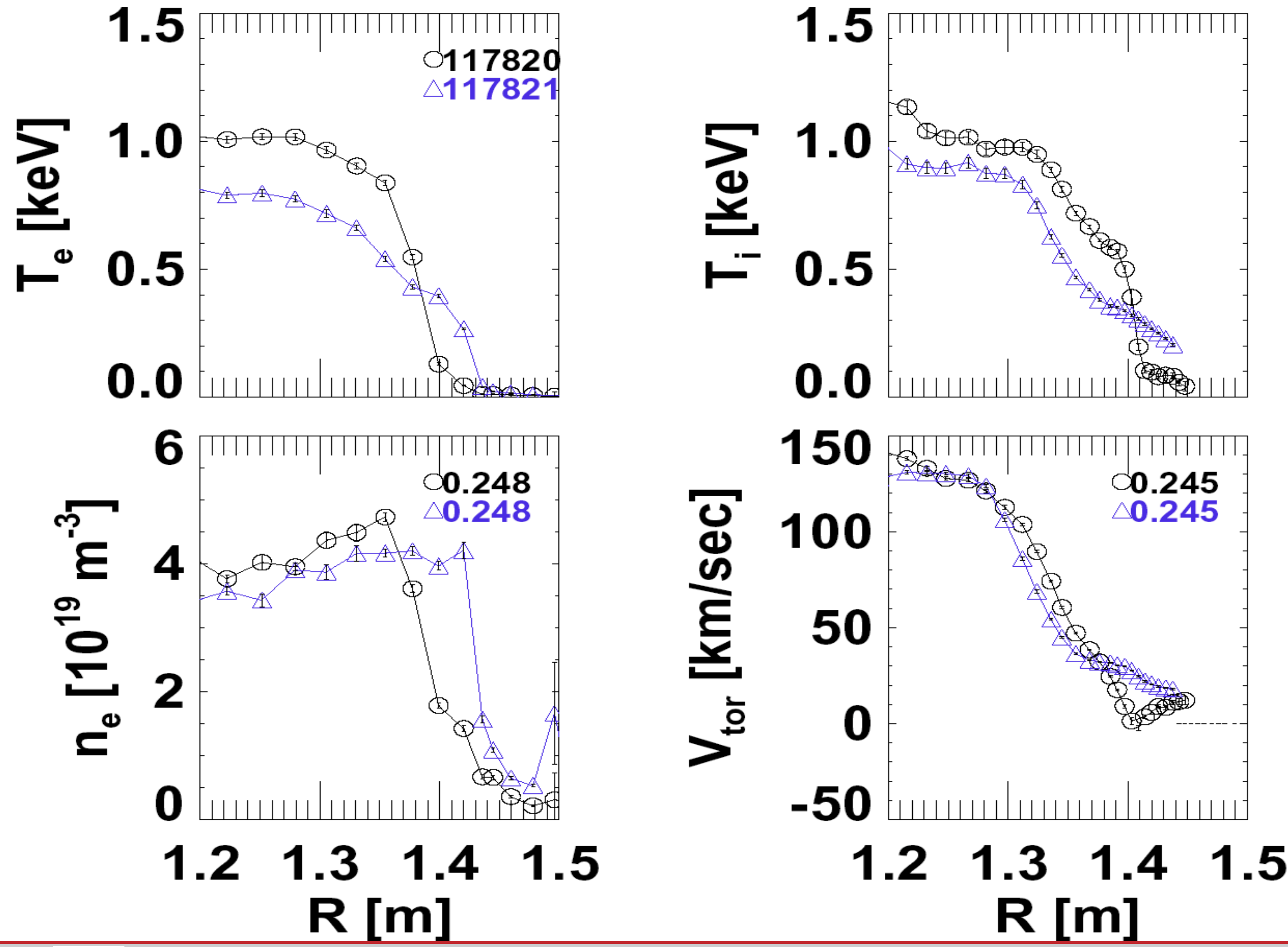
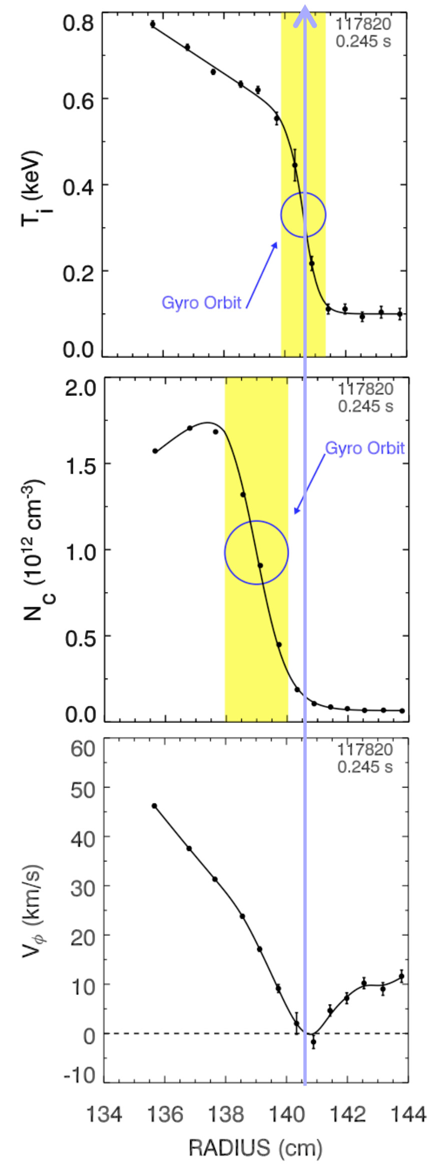
- Same I_p, P_{NBI}
- Higher W_{MHD} during EPH
- Higher H97L during EPH
- ELM trigger for EPH

Comparison of Standard and EP H-mode profiles



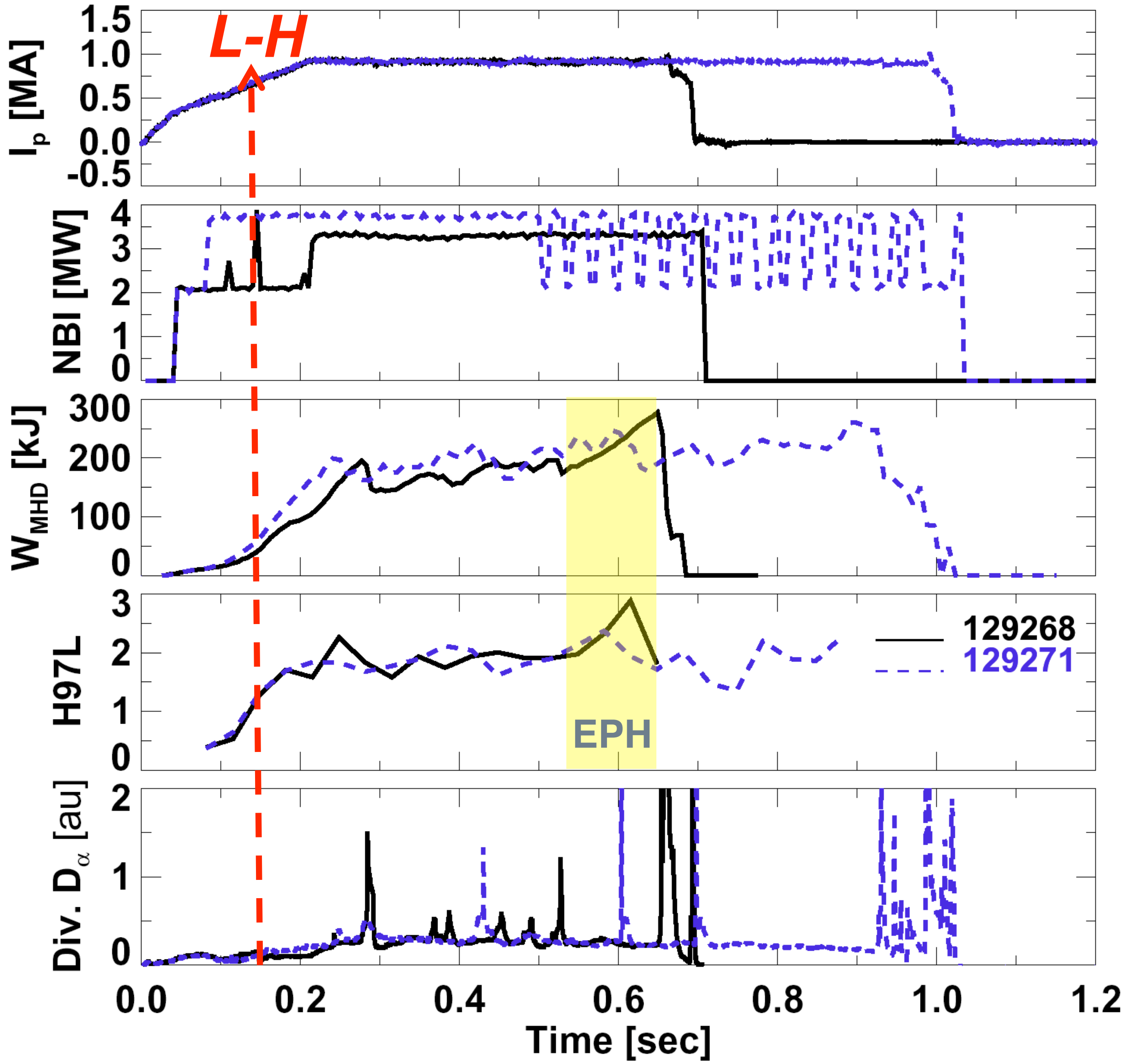
Enhanced Pedestal H-mode barrier width size comparable to gyro-diameter

- 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?
- Reduced v_ϕ seems to be in center of high ∇T_i region



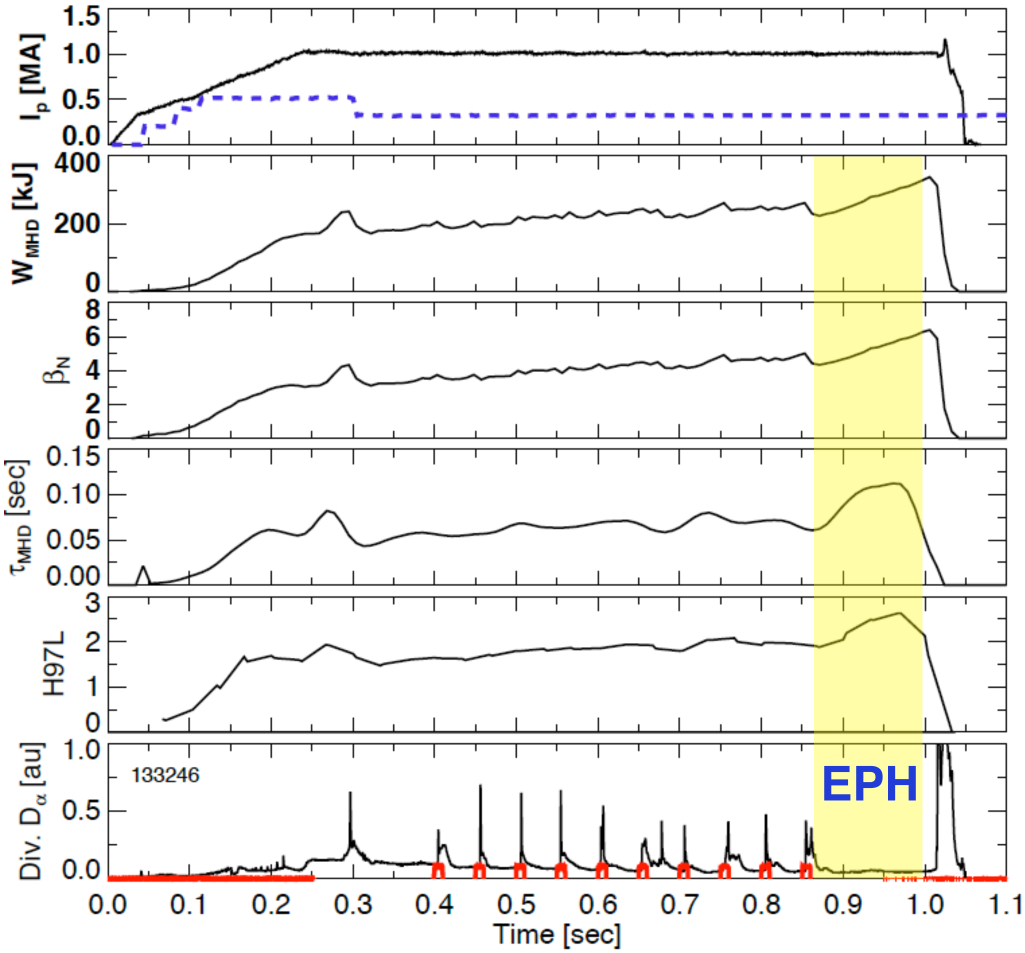
R. Bell

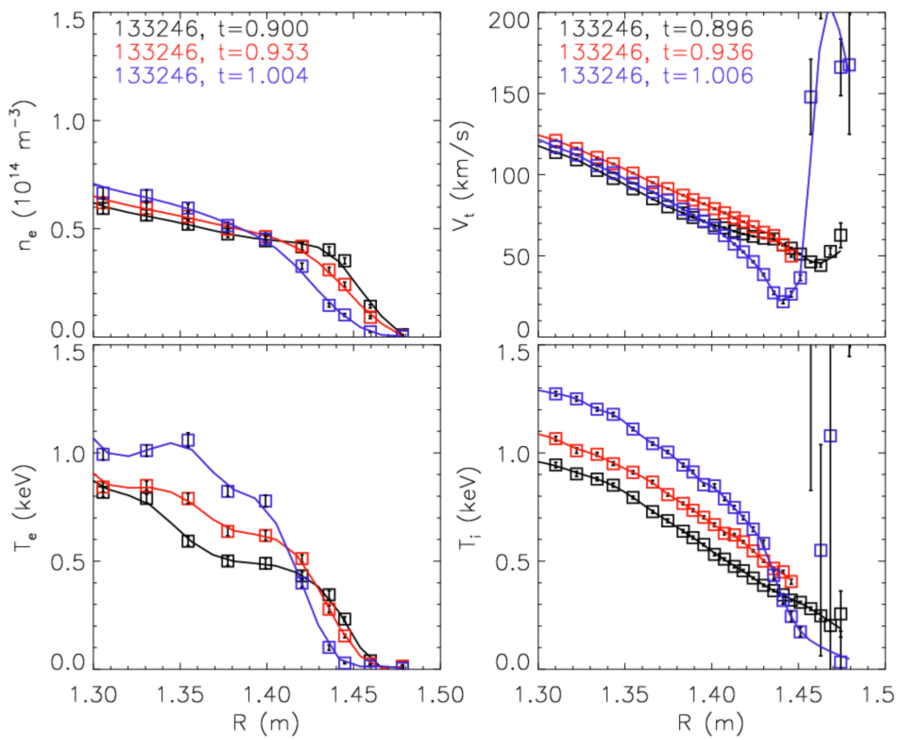
Spontaneous EPH-mode also observed during I_p flat-top



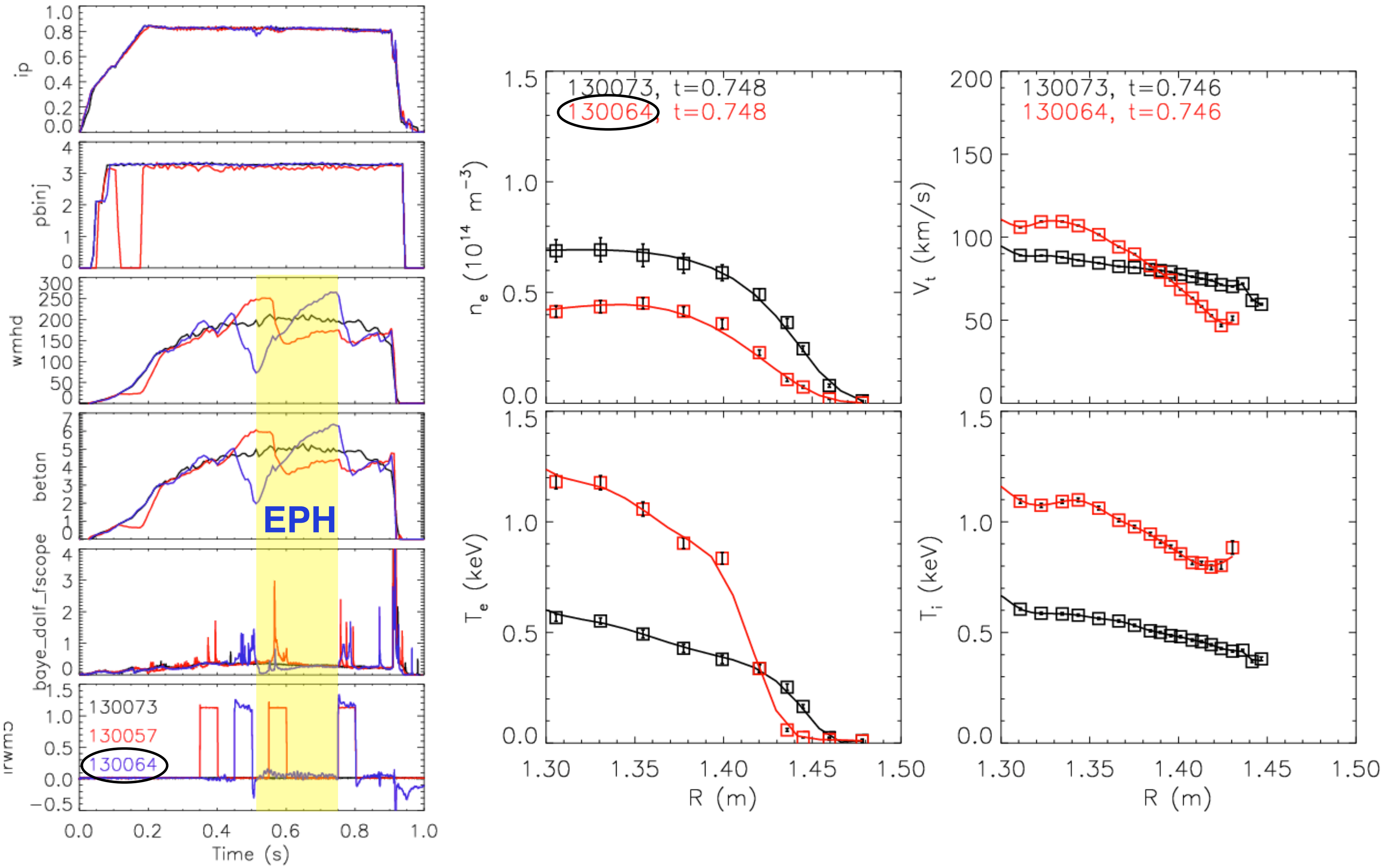
- Same I_p, P_{NBI}
- Lower P_{NBI}
- Higher W_{MHD} during EPH
- Higher H97L during EPH
- ELM trigger for EPH

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

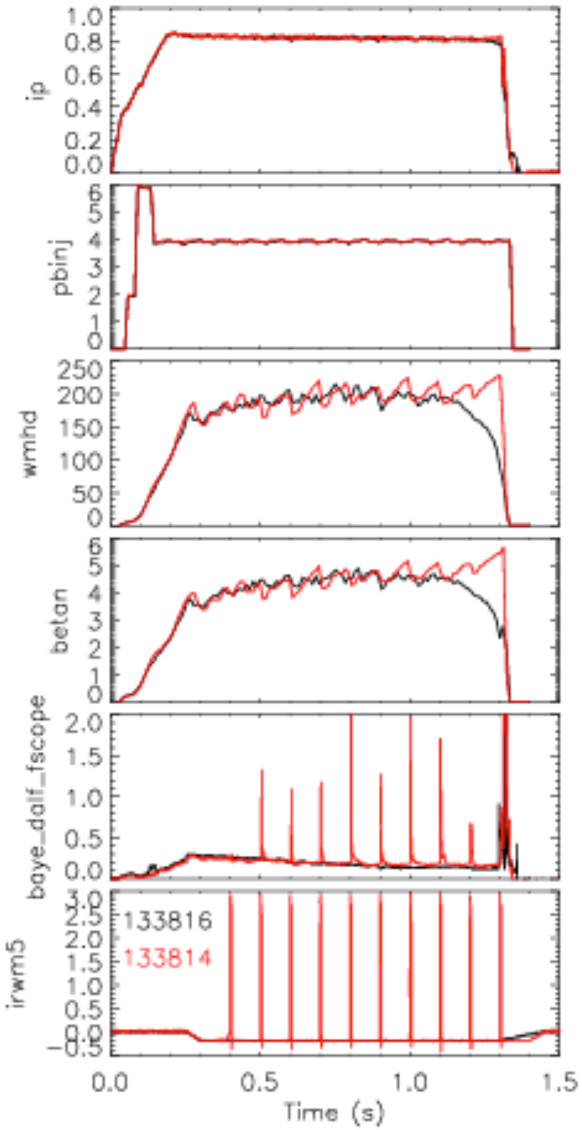


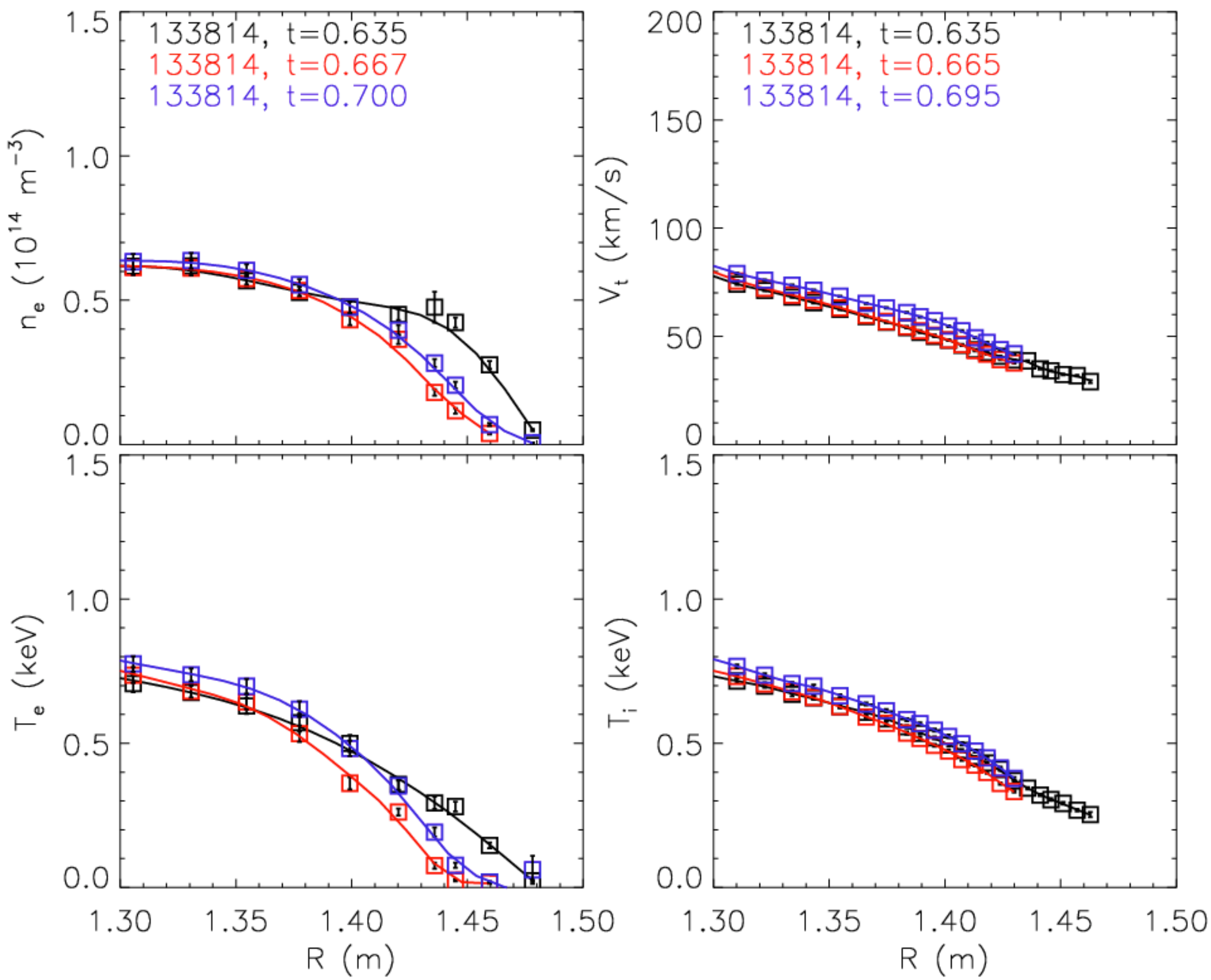


EPH may occur naturally in recovery period following ELM/braking triggers

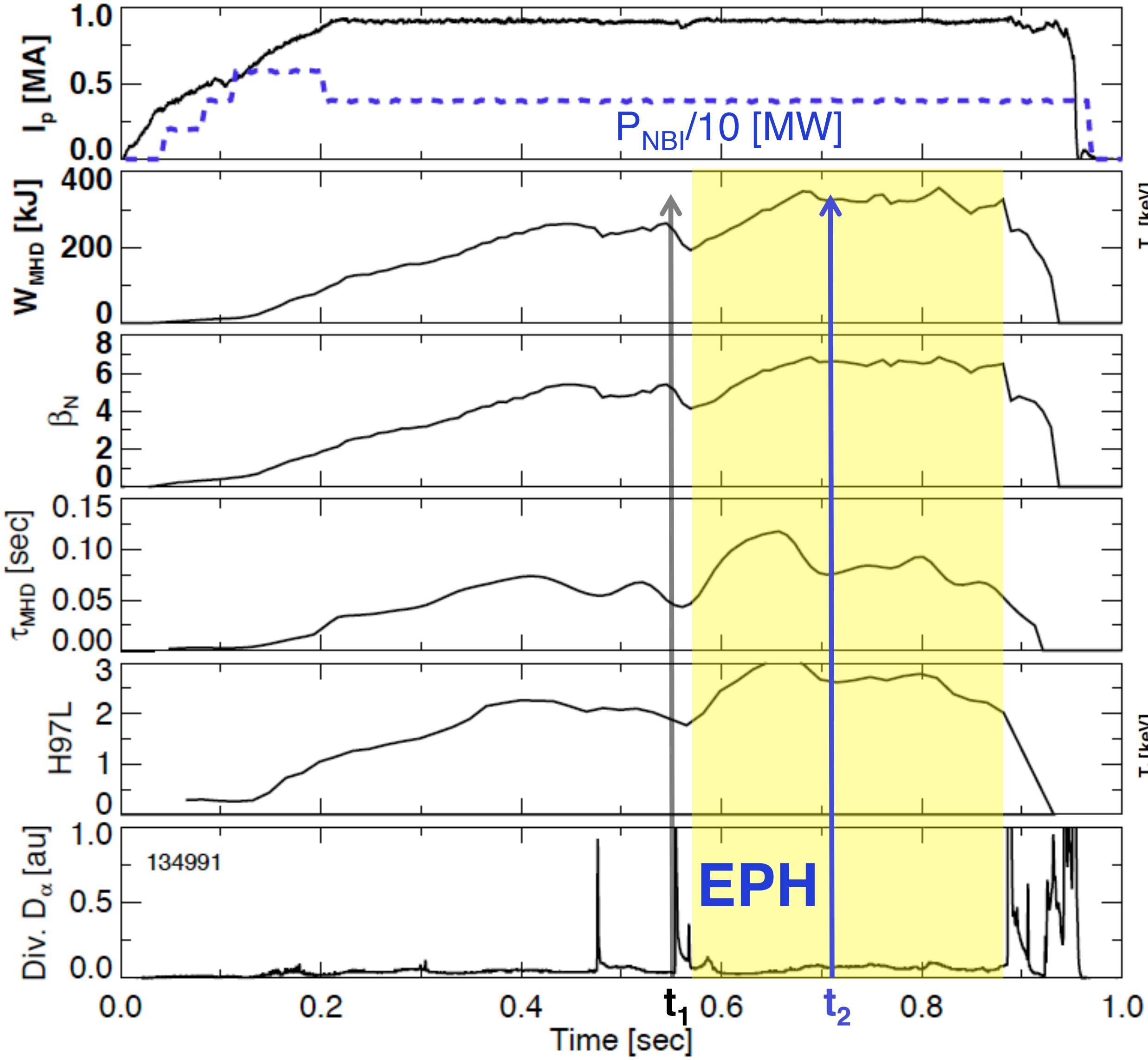


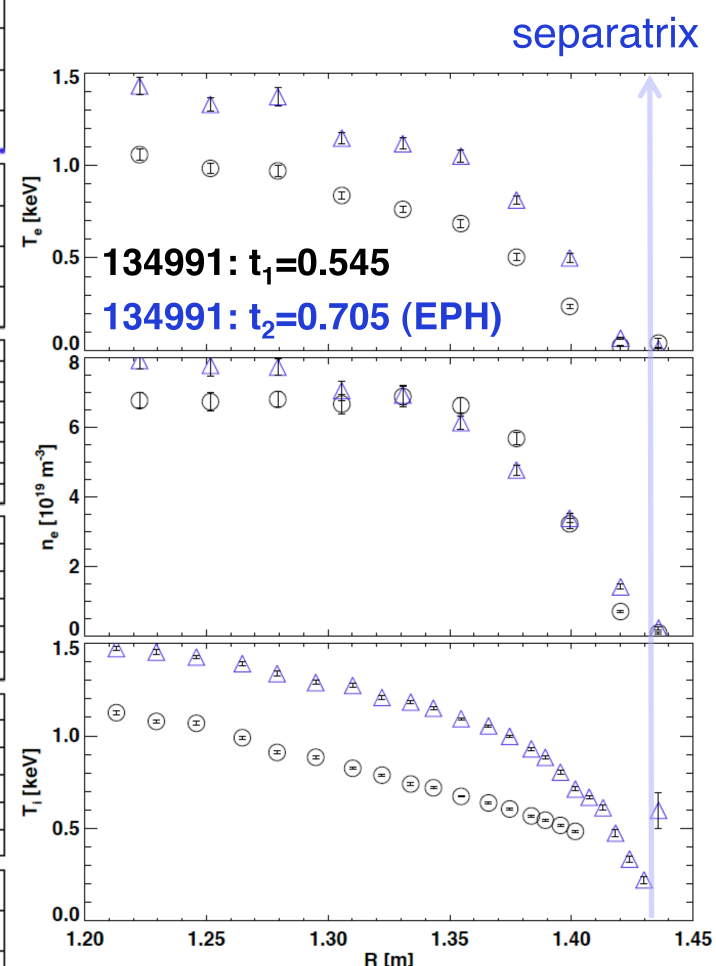
During infrequent ELM triggering, EPH may be triggered during each *quiescent* period!?



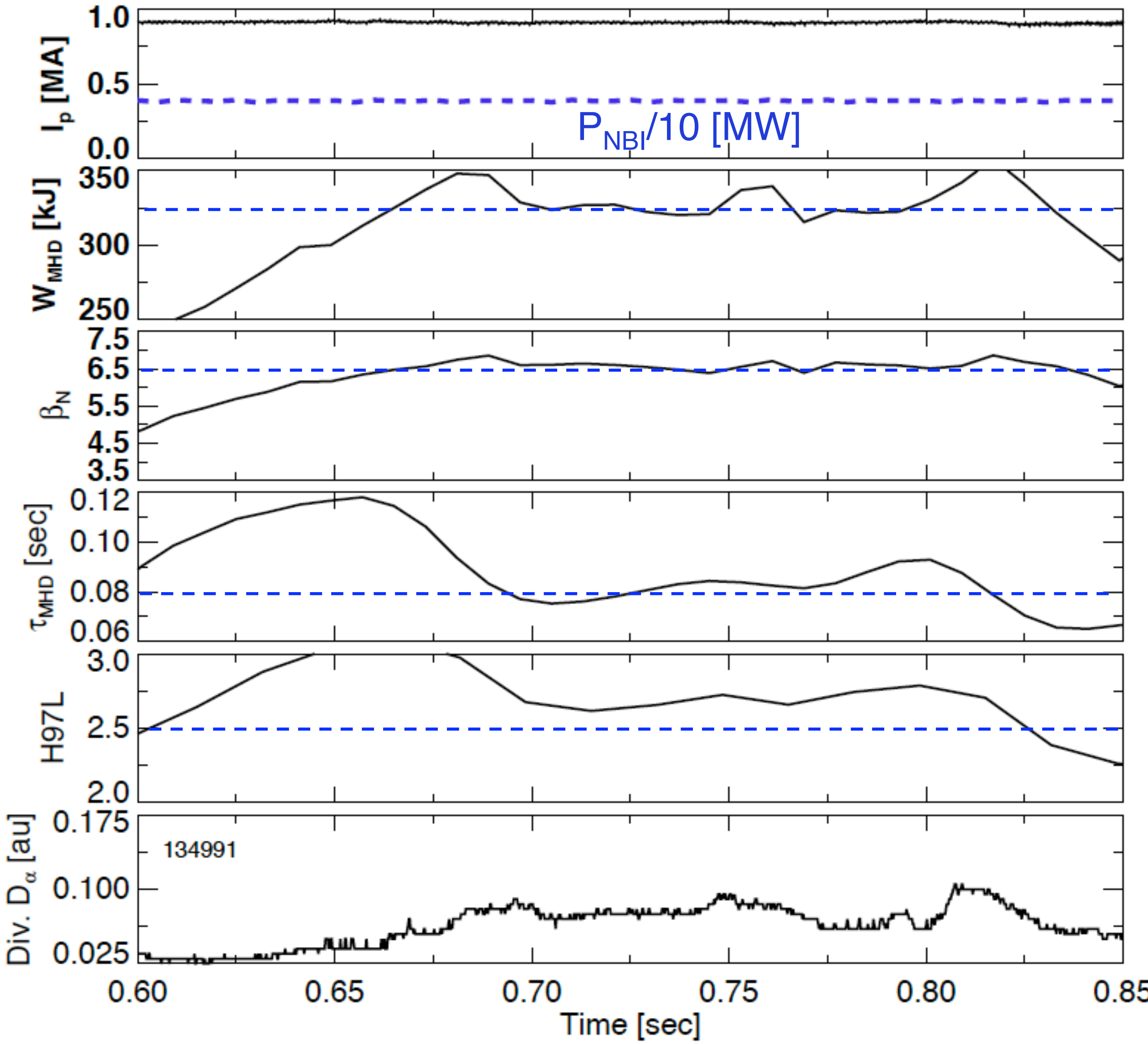


EPH-mode phase observed for several τ_E, up to ~ 300 msec



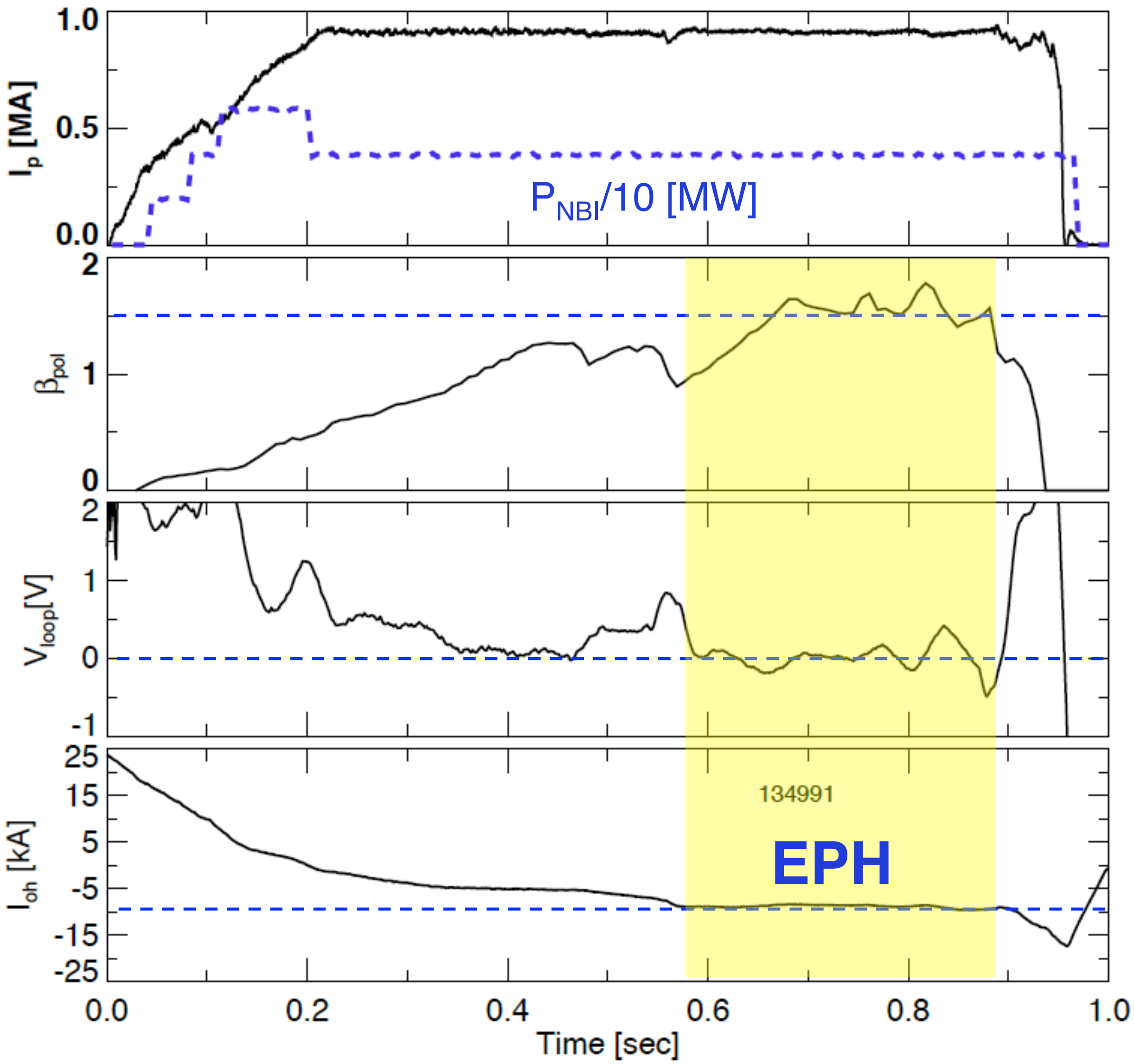


High β_N phase maintained for 2 τ_E



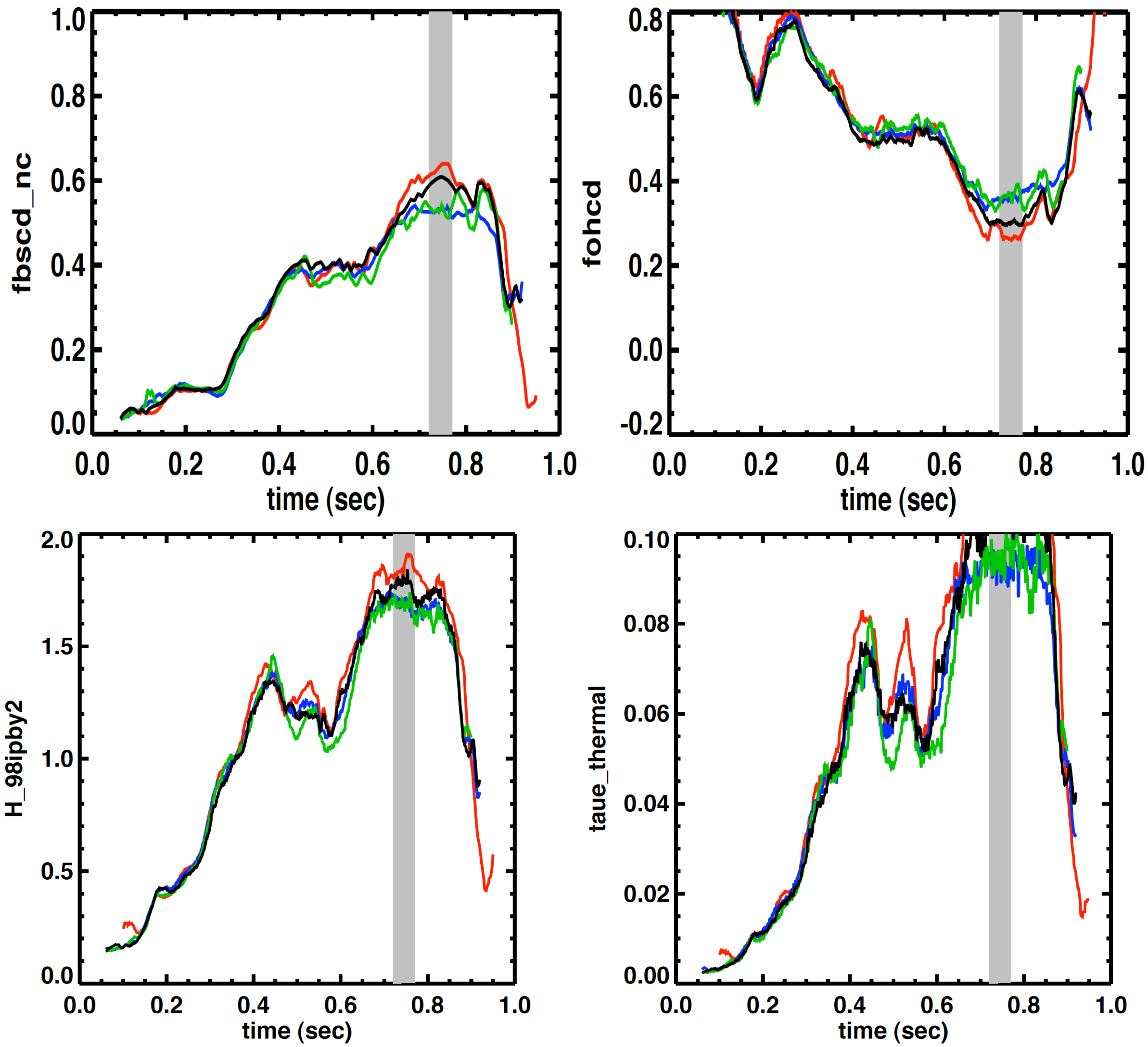
- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- $W_{MHD} \simeq$ 325 kJ
- $\beta_N \sim$ 6.5
- $\tau_E \geq$ 80 msec for 225 msec
- H97L $\geq$ 2.5
- EPH phase is ELM-free

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 0.3-0.4

- H98y2 between 1.6 and 1.8, with τ_E^{th} between 90-100 msec

S. Gerhardt, S. Kaye

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

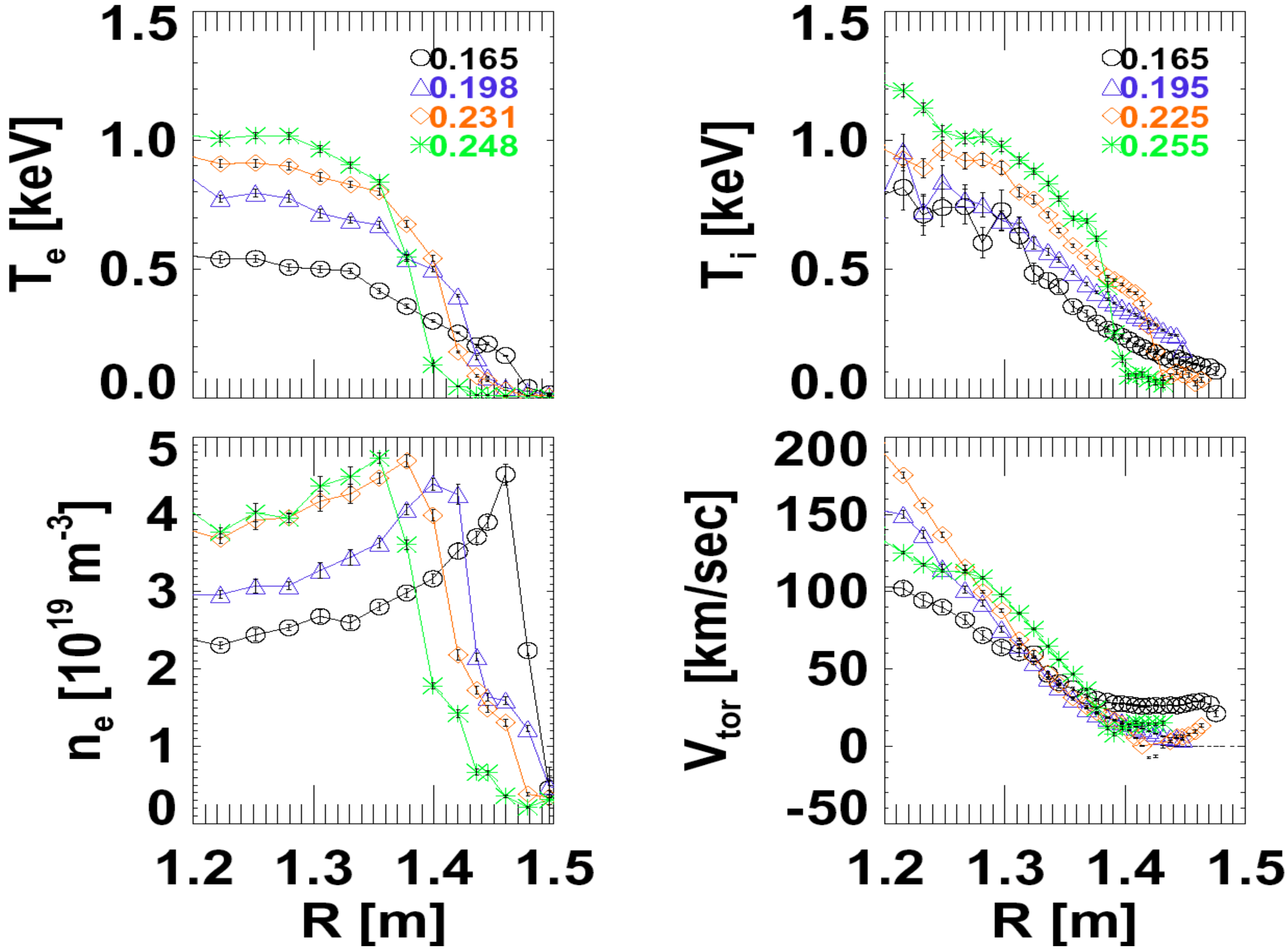
- Initiating EPH-mode:
  - Lithium conditioning for ELM-free conditions
  - Either fast RMP trigger of a large ELM(5 Hz?), or longer RMP pulse with several ELMs: both seem to work
  - Since density profile control may be important, *SGI may provide easier access (longest pulse EPH had SGI*)
- Sustaining 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

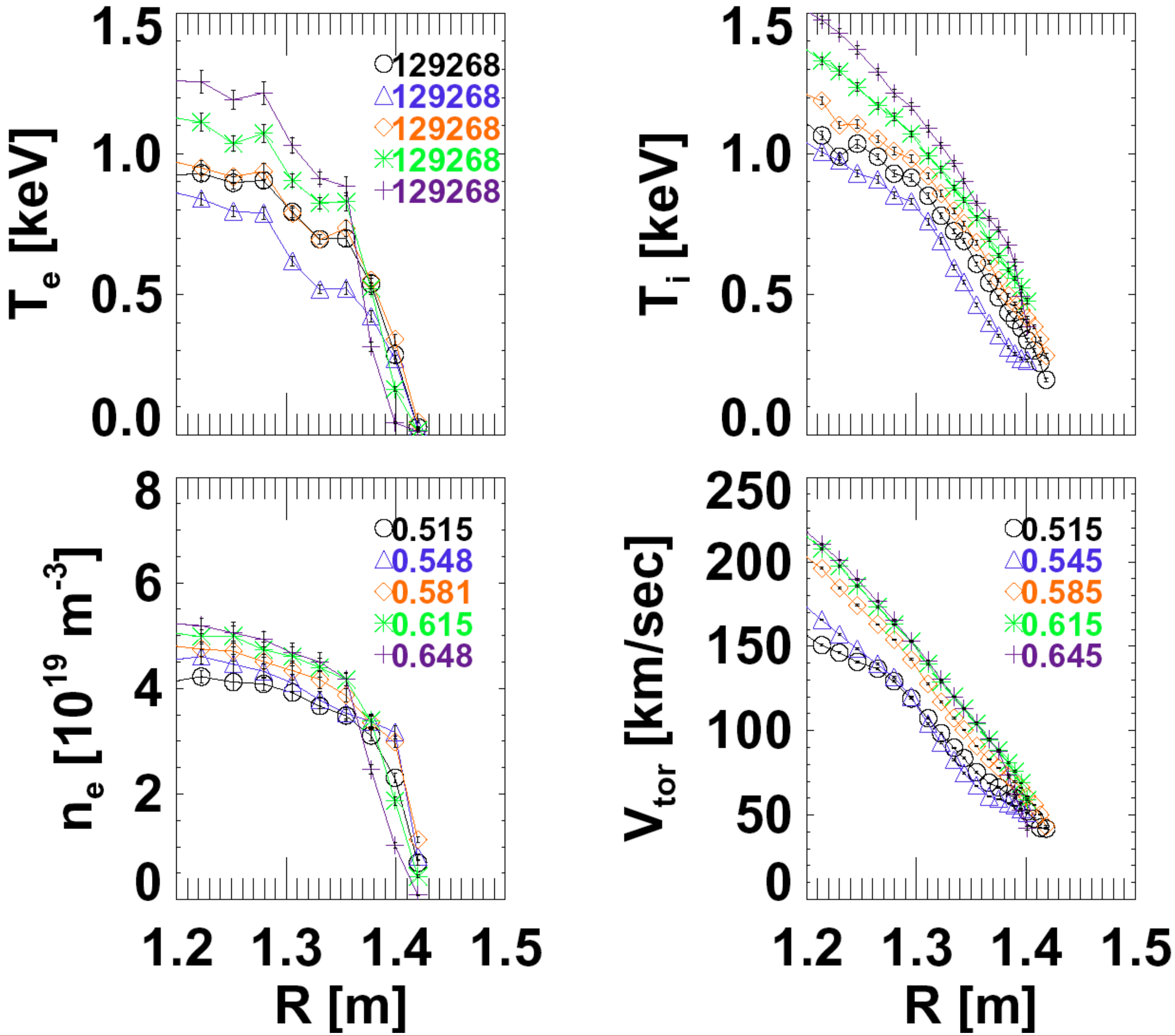
- EP H-modes occur naturally following large ELMs, or can be triggered with 3D fields
- Recently, EPH phases were obtained during I_p flat-top for several τ_E
- With the advent of β feedback on NBI and good n=1 feedback, extending the pulse length and using EPH as a high-performance target is enticing

Backup

EP H-mode profiles evolve continuously



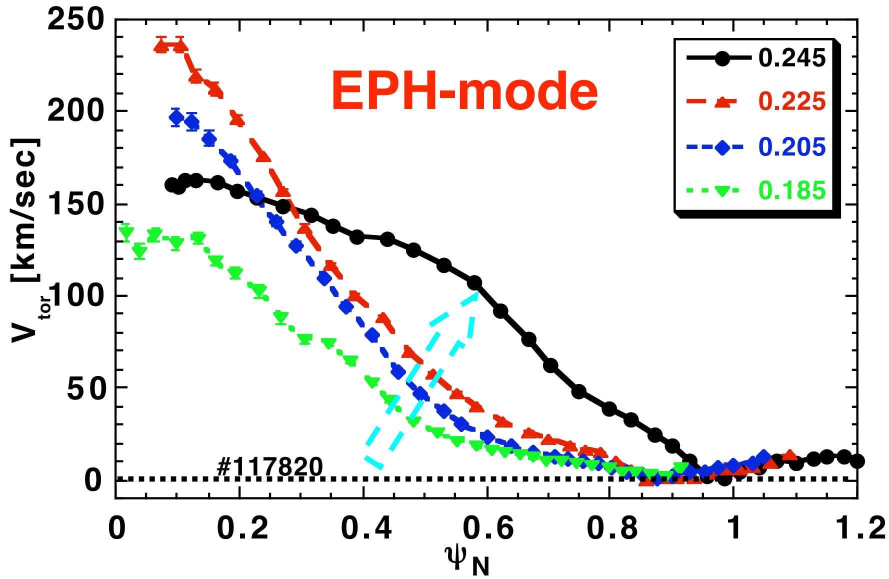
EP H-mode profiles evolve continuously, although recovery from trigger takes a little time

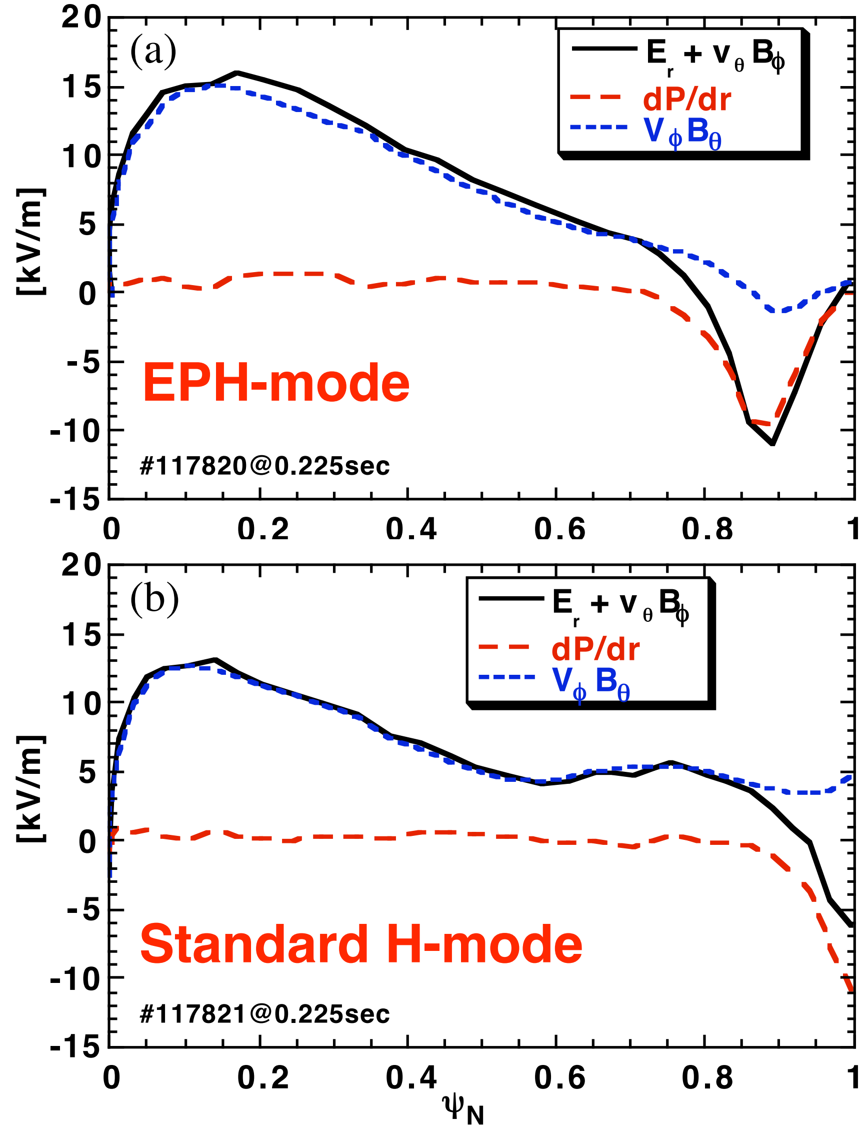


- Discharge had Li evaporation to improve performance in regular H-mode

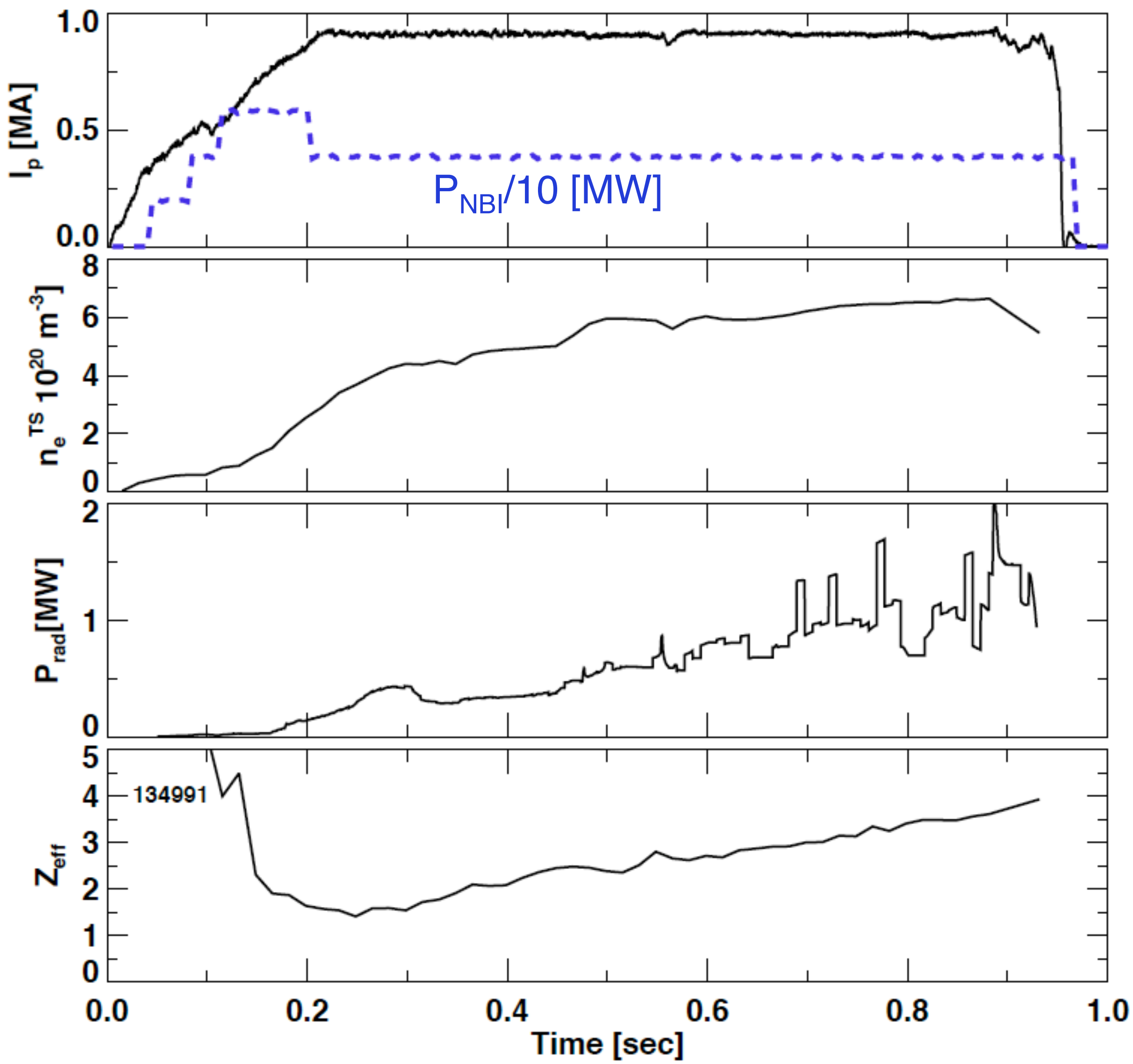
Changes in v_ϕ accompany high $T_{e,i}^{ped}$ in Enhanced Pedestal H-mode

- 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)





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



EPH-mode can have transient H89P up to 4