NSTX

Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

Triggered Confinement and Pedestal Temperature Enhancement in NSTX H-mode Dsicharges

College W&M
Colorado Sch Mines
Columbia U
Comp-X
General Atomics
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Maryland
U Rochester
U Washington
U Wisconsin

Rajesh Maingi, OAK RIDGE National Laboratory

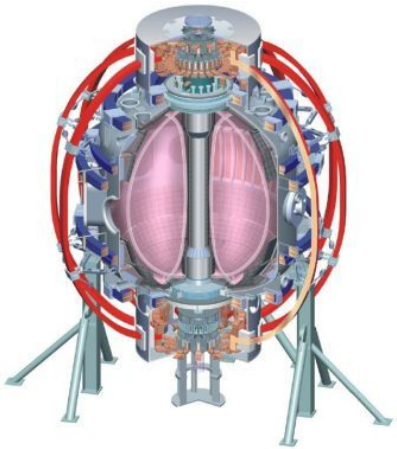
R.E. Bell, J.M. Canik, S.P. Gerhardt, S.M. Kaye, B.P. LeBlanc, T.H. Osborne, E.D. Fredrickson, J.E. Menard, J.-K. Park, S.A. Sabbagh

and the NSTX Research Team

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

52nd APS DPP meeting
Chicago, IL USA
8-12 Nov 2010

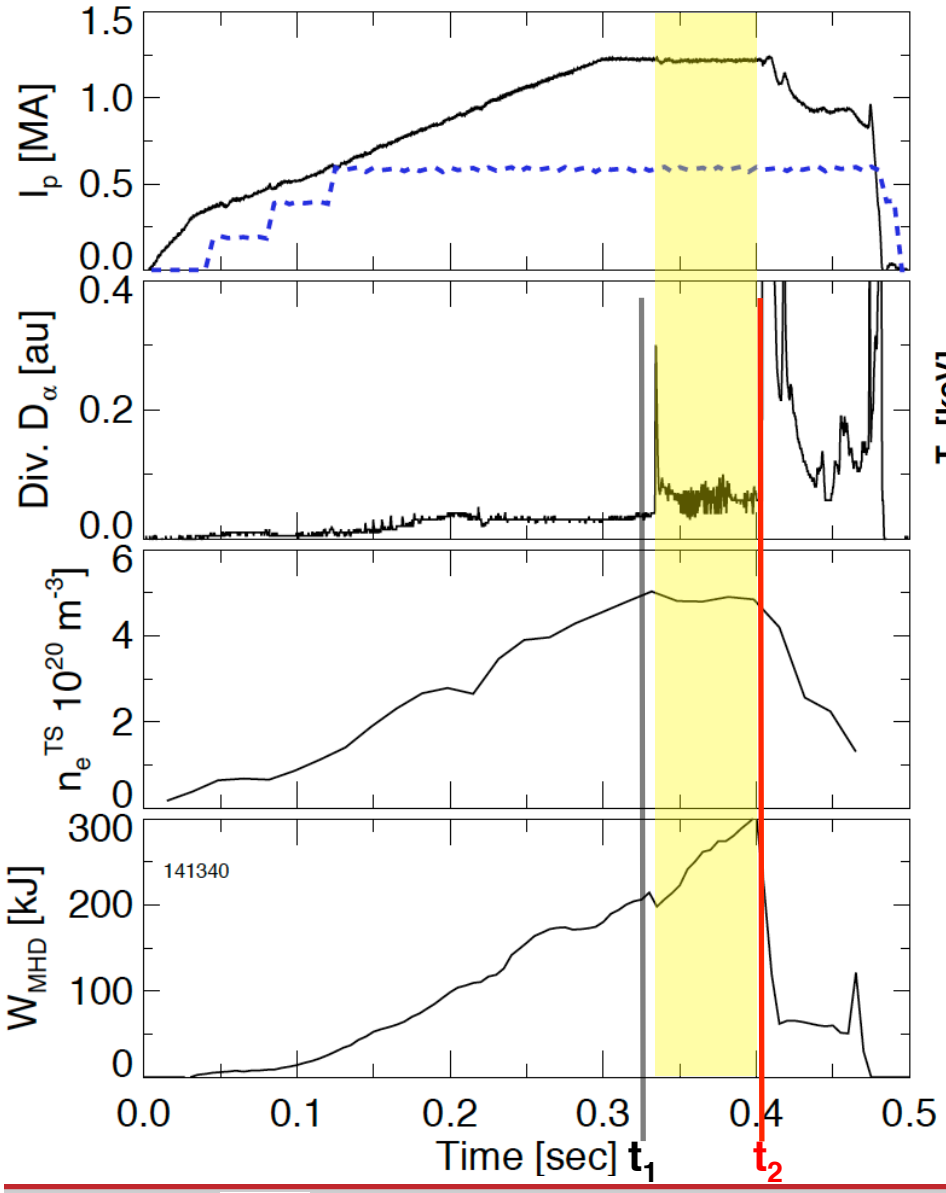
PPPL PRINCETON PLASMA PHYSICS LABORATORY

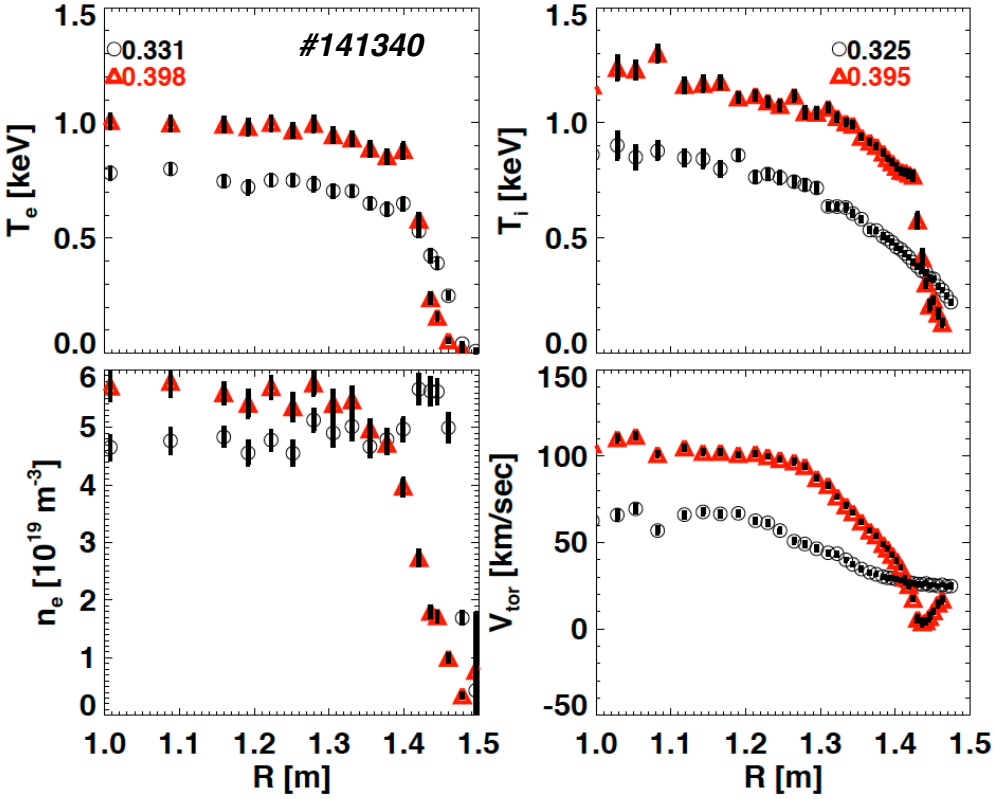


Confinement and Pedestal Temperature Enhancement Triggered by an ELM: the Enhanced Pedestal H-mode

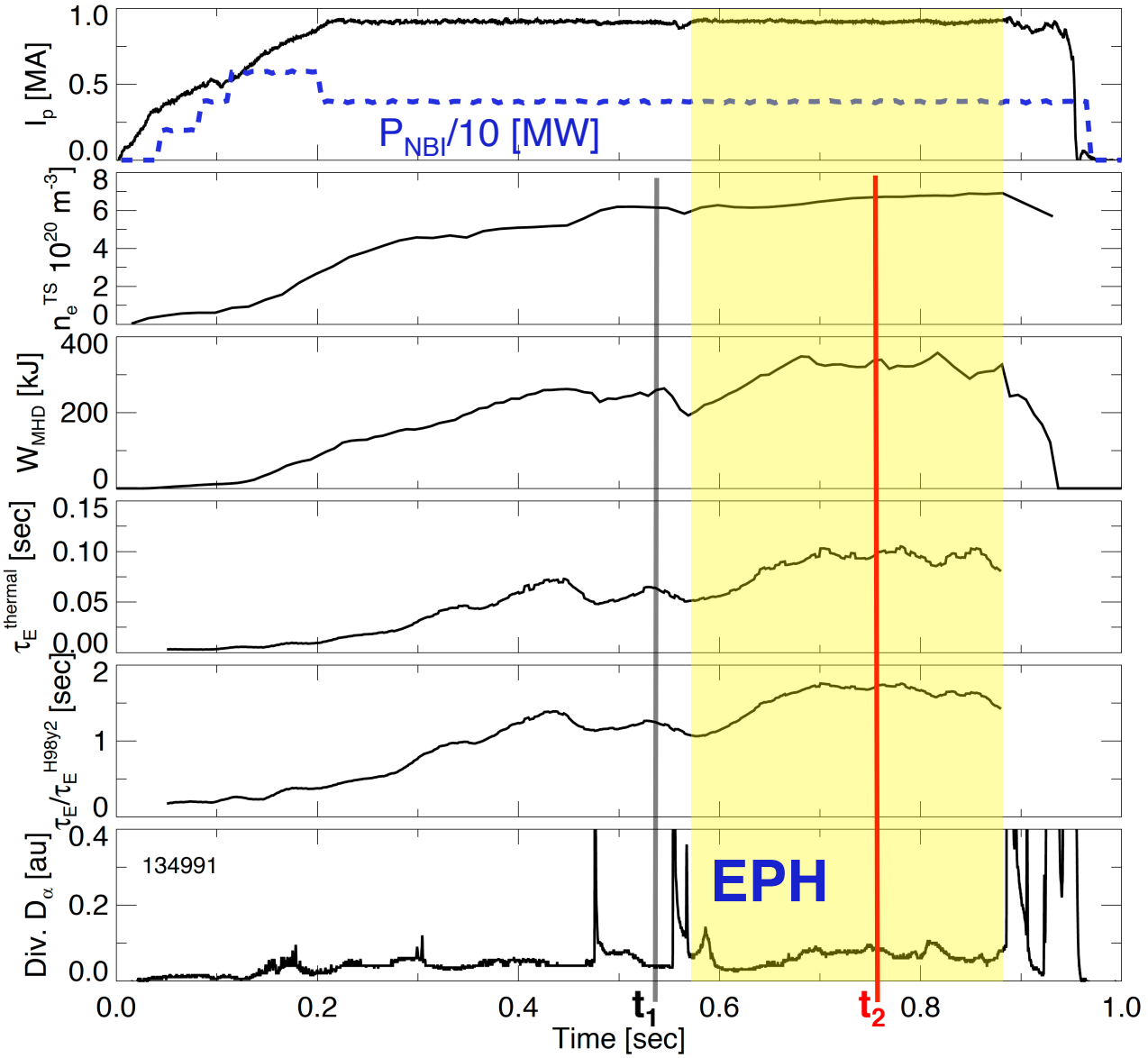
- Energy confinement in NSTX H-modes is generally 0.8-1.1* ITER98y2 scaling
  - HH98y2 is ~ 0.7-0.9 without lithium, 1.0-1.1 with lithium
  - A few next step ST designs based on ~ 50% higher τ_E
- An improved confinement scenario with enhanced pedestal T_e, T_i in H-mode observed several few years ago
  - Observed mostly in I_p ramp phase, but a few examples in flat-top
  - Triggered by large ELM, either naturally occurring or triggered with pulsed n=3 fields
  - Highest normalized τ_E of any regime in NSTX, with HH89P $\leq$ 3.5 and HH98y2 $\leq$ 1.7
  - Pulse length up to 300 msec (~ 3 τ_E)

EP H-modes observed during I_p ramps in high I_p discharges





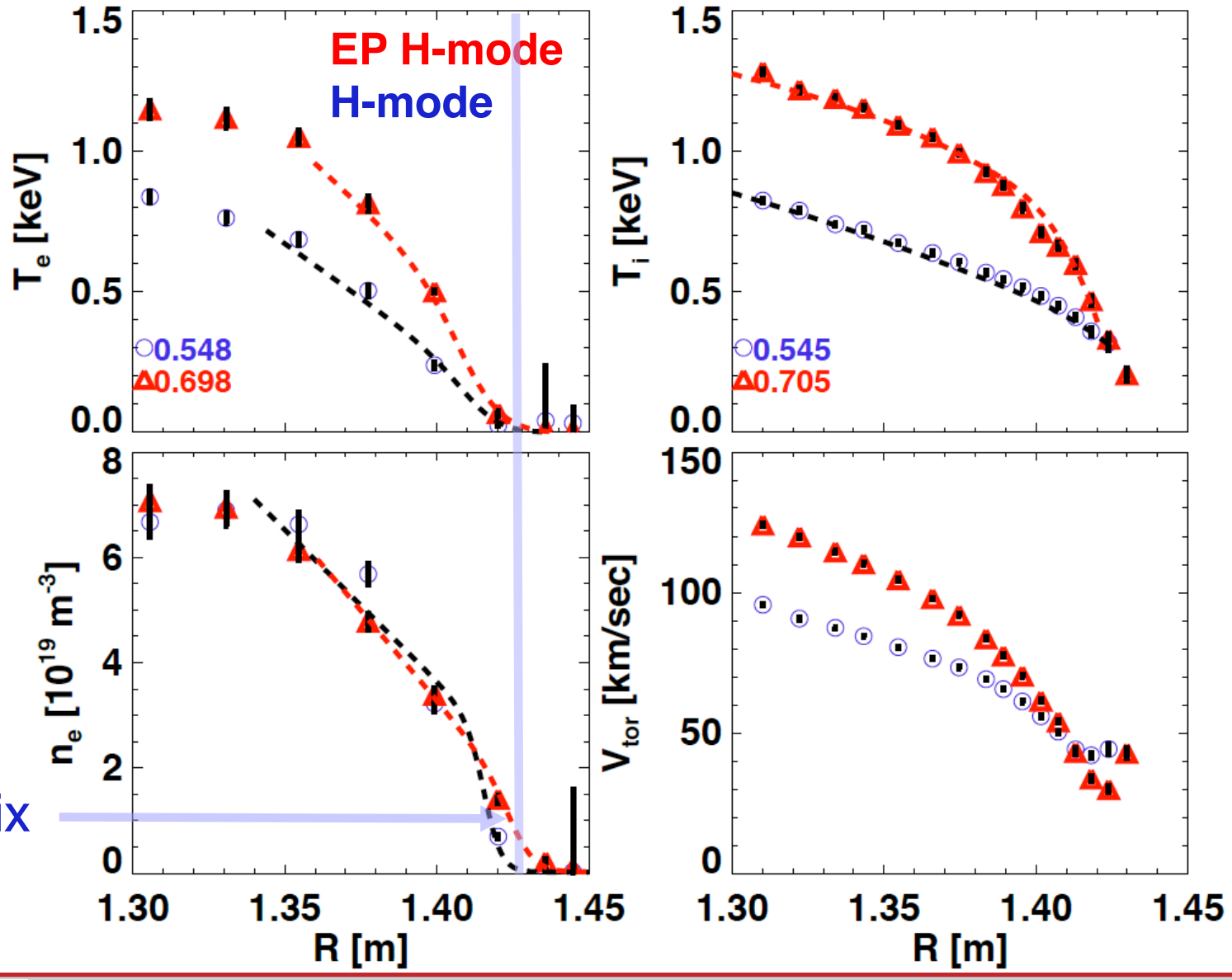
EPH-mode phase also observed in flat-top, for up to ~ 300 msec (~ 3 τ_E)



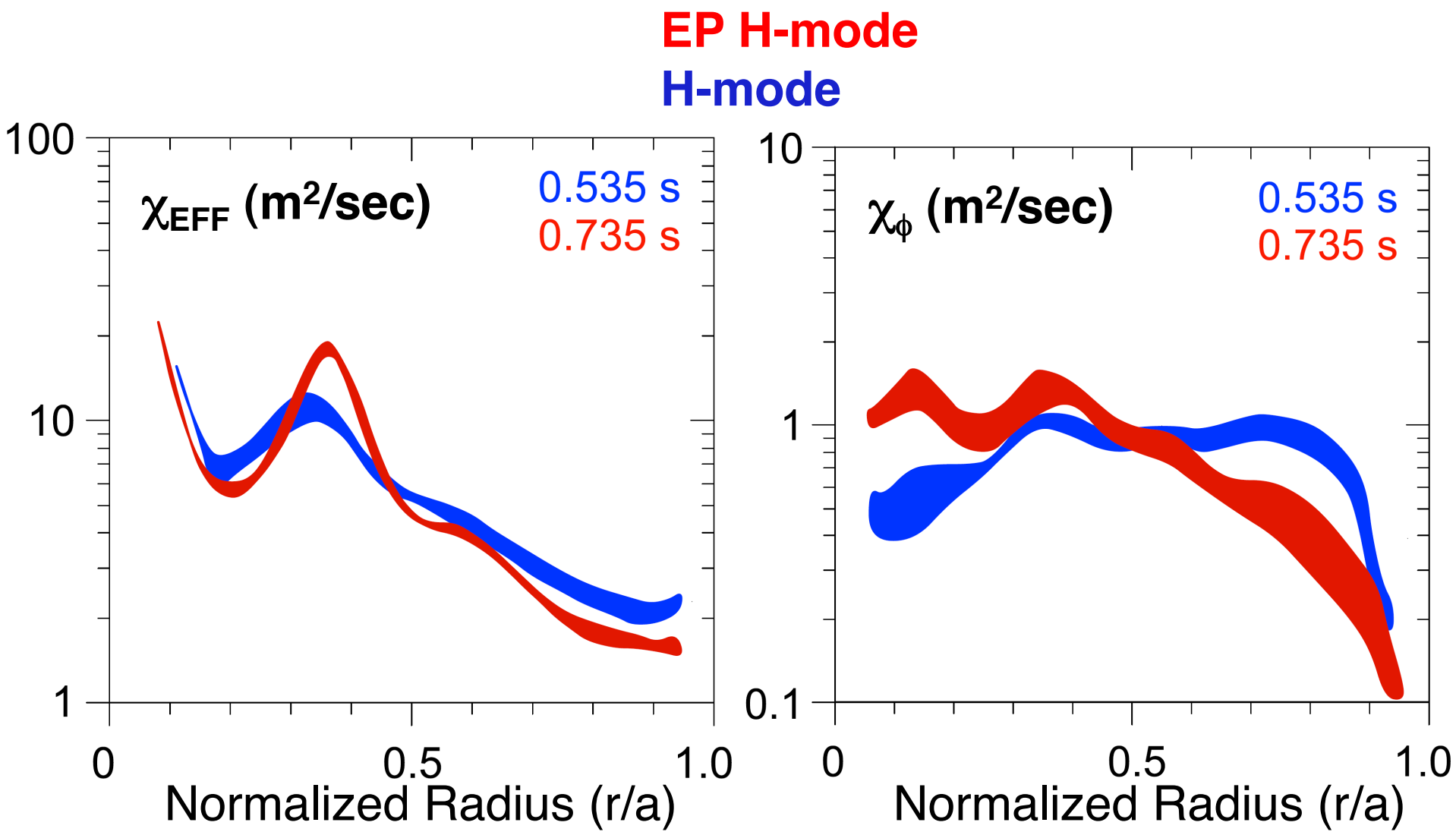
- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- $W_{MHD} \leq$ 350 kJ
- $\beta_N > 6.5$
- $\tau_E \geq$ 80 msec for 225 msec
- H97L $\leq$ 3
- Natural ELM trigger for EPH

Maingi, PRL 2010

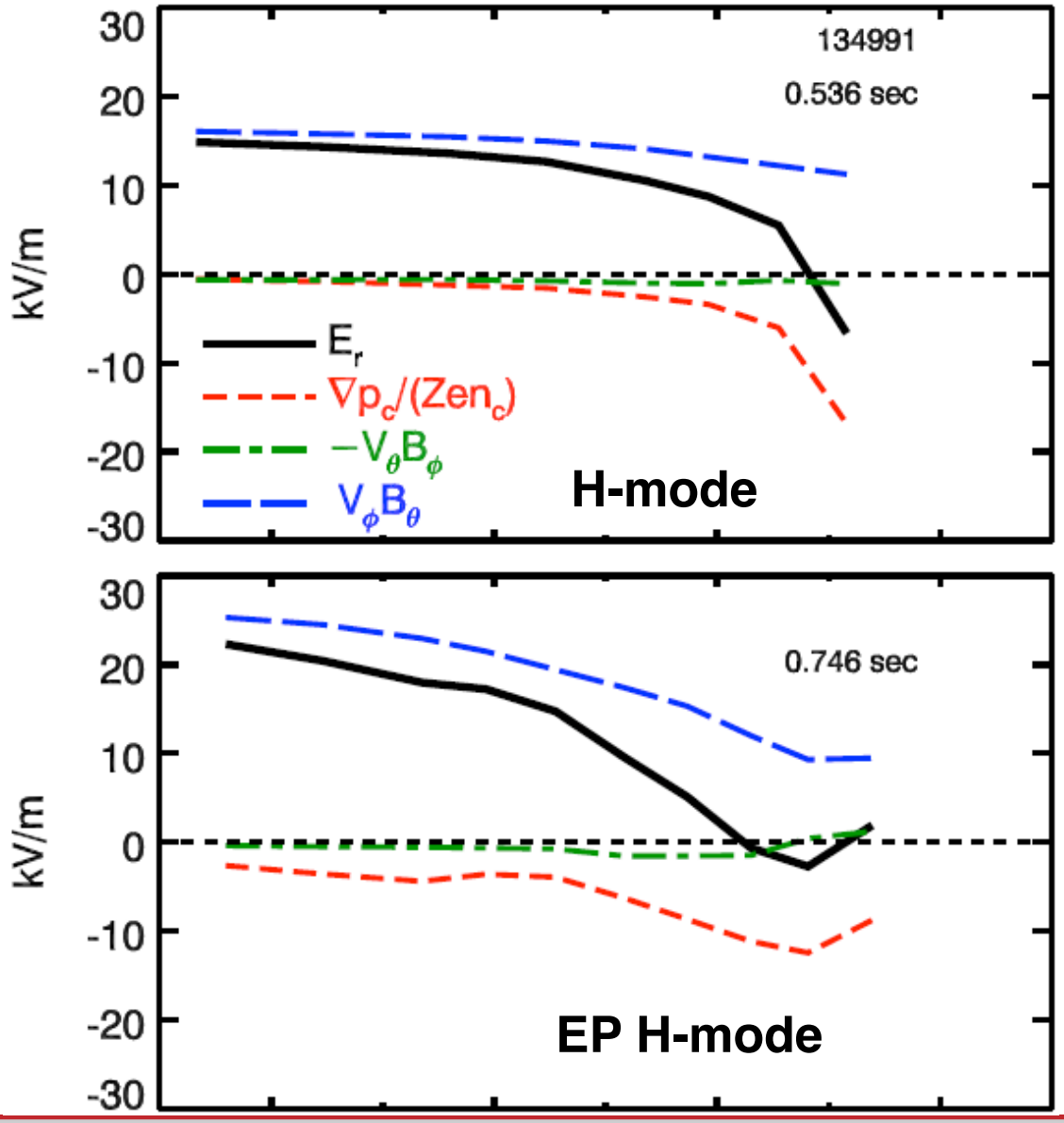
Thermal barrier: Edge T_e, T_i double, with a reduction in the edge n_e gradient, and an increase in v_ϕ shear



Thermal and angular momentum transport reduced in outer half of plasma

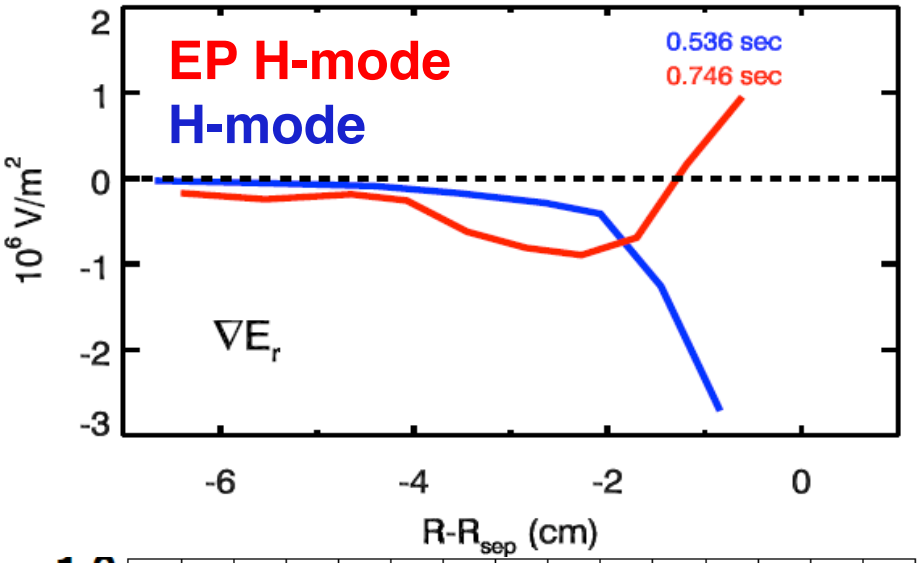


Radial shear in V_ϕ profile leads to large region of E_r shear during EP H-mode

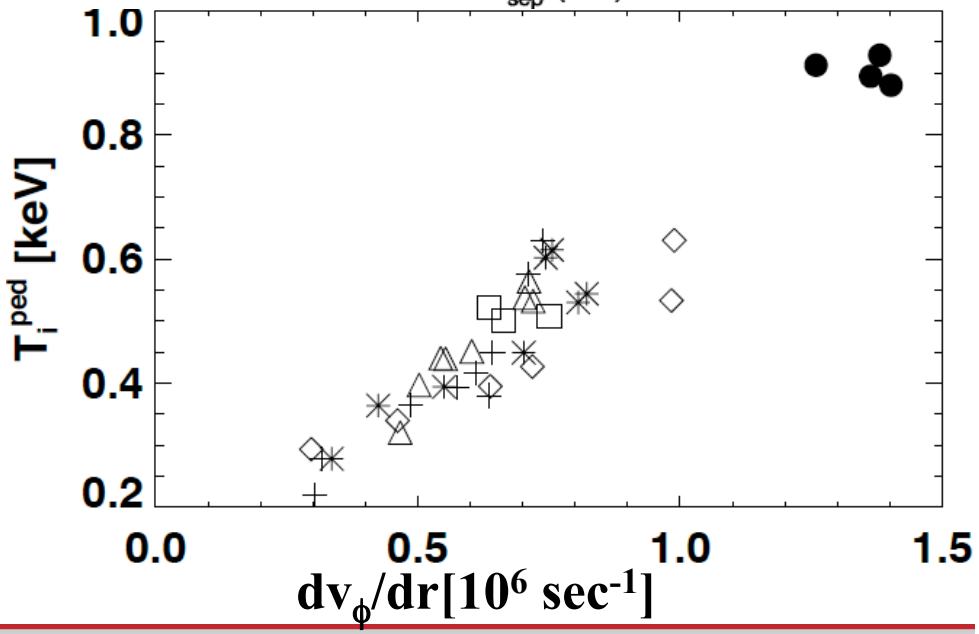


Spatial extent of significant E_r shear region doubled in size during EP H-mode

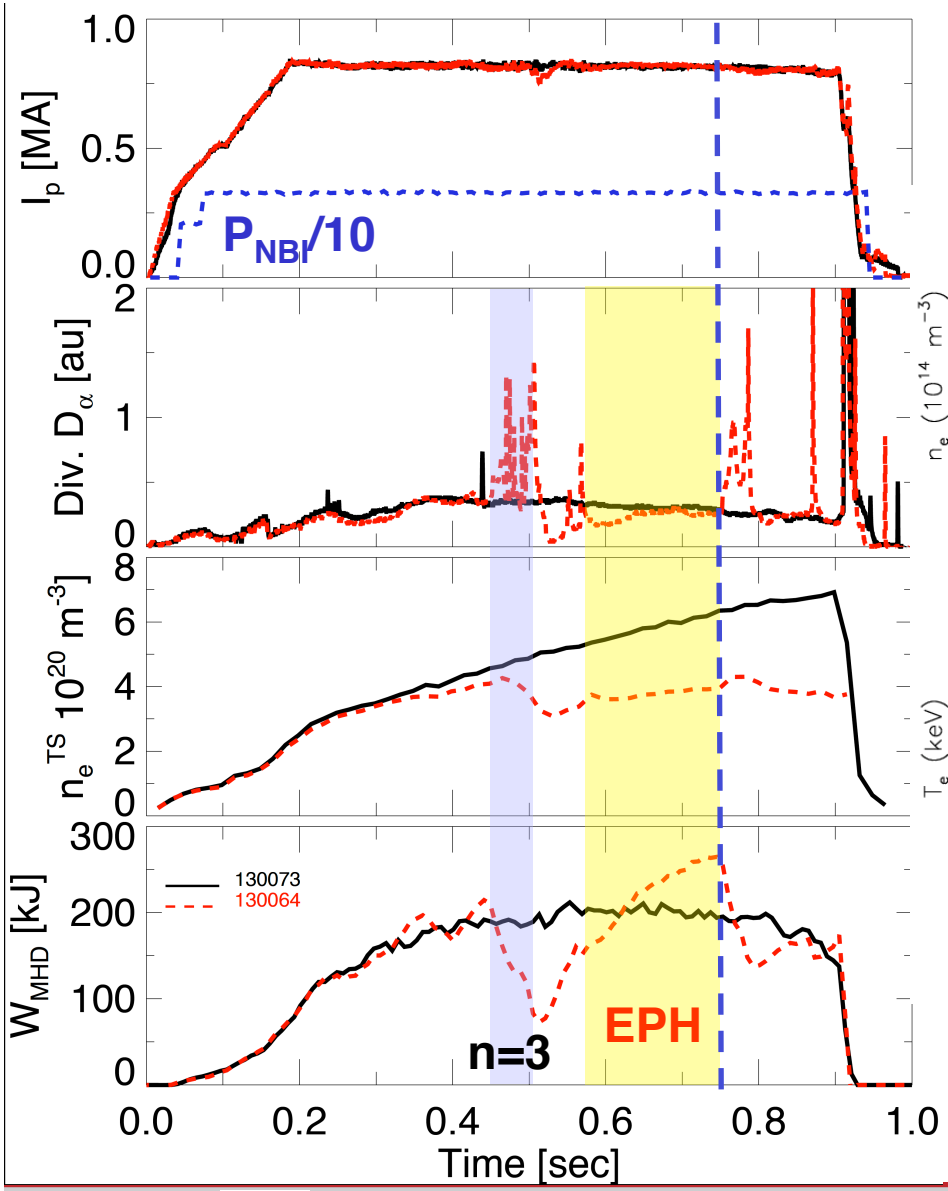
- Spatial region of large Er shear doubled from ~ 2 cm to ~ 4 cm in EP H-mode

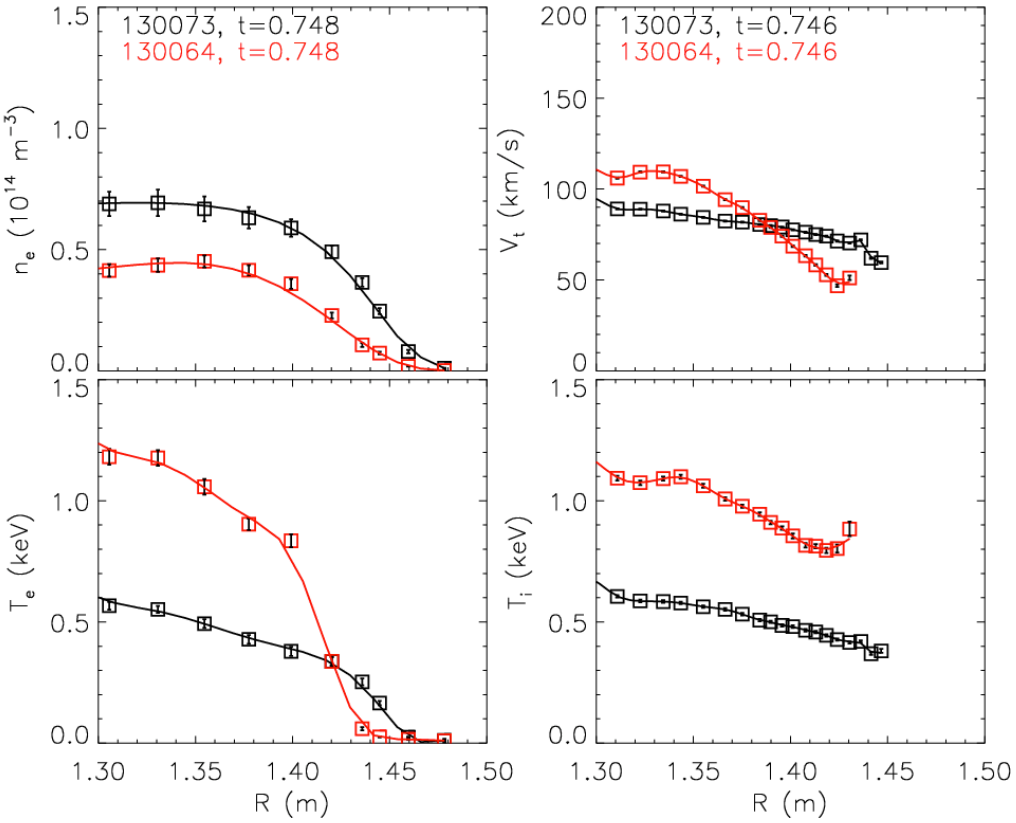


- T_i pedestal height correlates with edge toroidal rotation shear



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





Comparisons with other enhanced confinement regimes

- Similarities 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
- Differences from VH-mode
  - EP H-mode triggered by an ELM
  - EP H-mode often initiated with localized drag on v_ϕ (often @q=3)
  - EP H-mode last for up to 3 τ_E; terminated by e.g. RWM
- Comparison with QH-mode
  - Higher H-factor in EP H-mode, no obvious sign of EHO(?)
- Comparison with I-mode
  - Thermal transport barrier, with no enhancement of particle transport

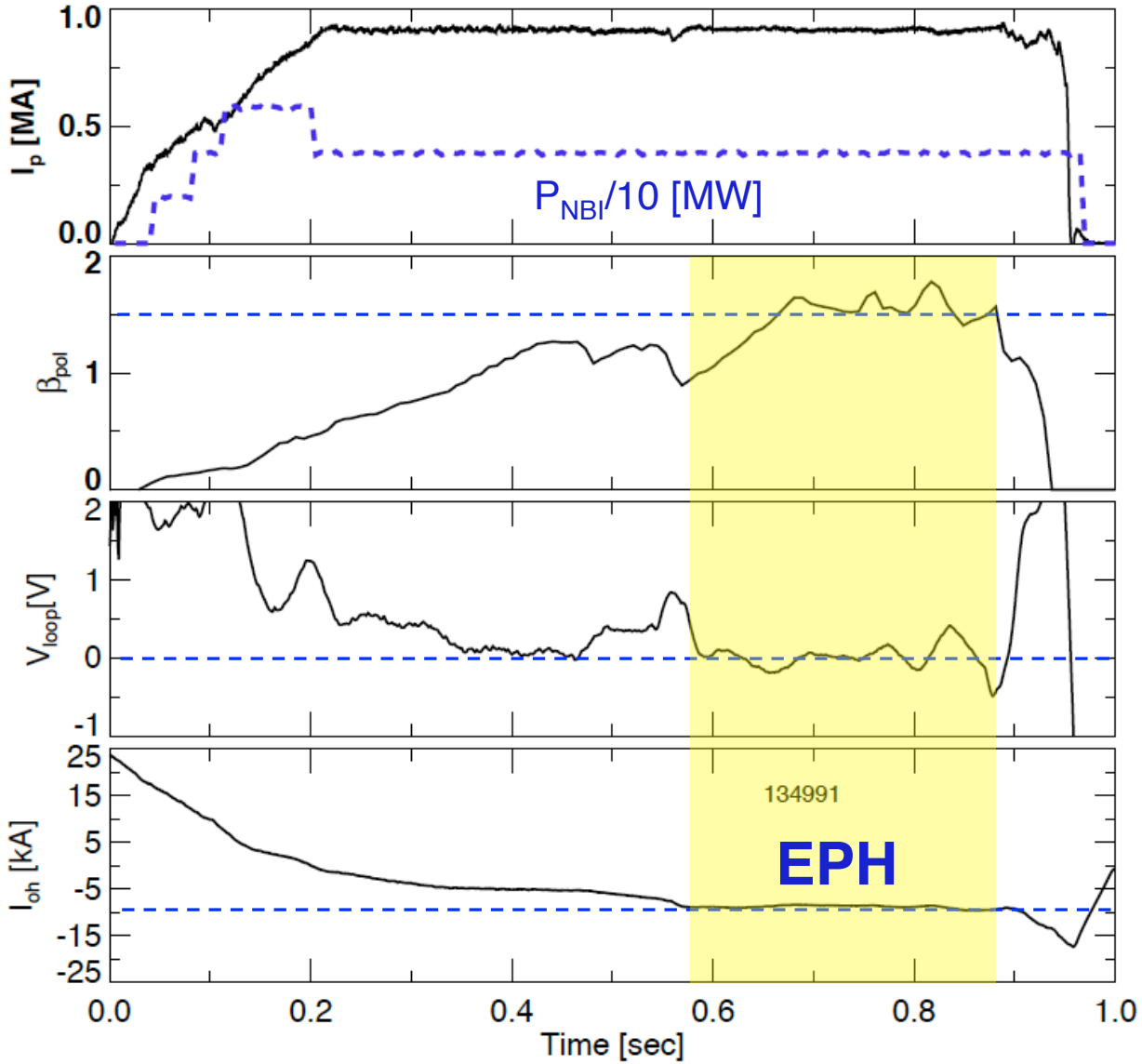
The Enhanced Pedestal H-mode has an improved thermal barrier above H-mode, without an enhancement of particle confinement

- A second transition to enhanced confinement and high pedestal T_e, $T_i \leq 700$ eV
  - Second transition after large ELM, either natural or triggered by 3D fields
  - W_{MHD} ramps ~ linearly in time for ~ 0.1 s
  - $H_{H98y2} \leq 1.7$, in an ELM-free regime
  - EP H-mode phases 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*

Backup

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

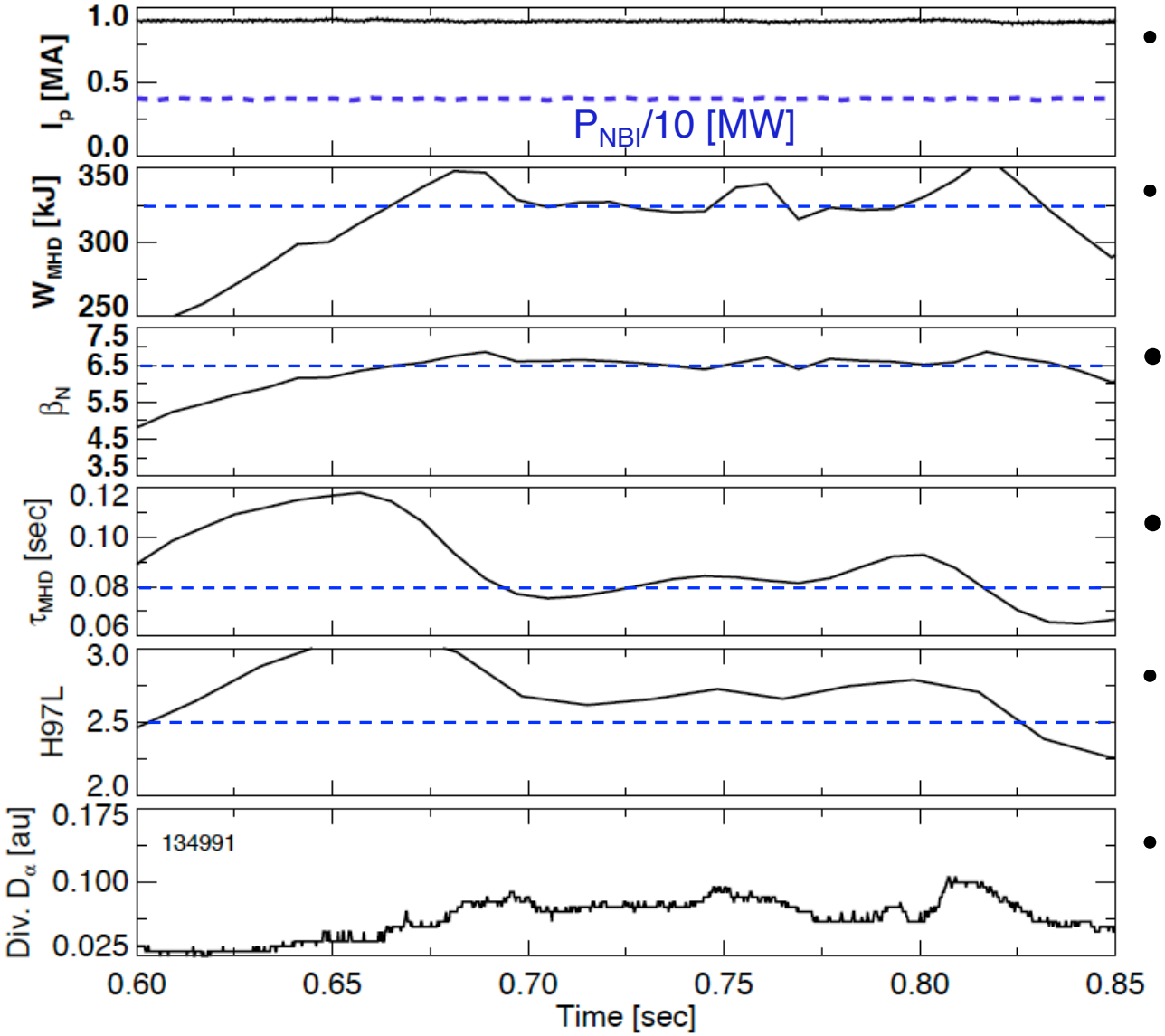


- I_p = 0.9 MA, P_{NBI} = 3.8 MW
- β_p ~ 1.5, very high for 0.9 MA
- Loop voltage low during EPH, due to high bootstrap
- Very little or no flux consumption

Many outstanding question on EP H-mode

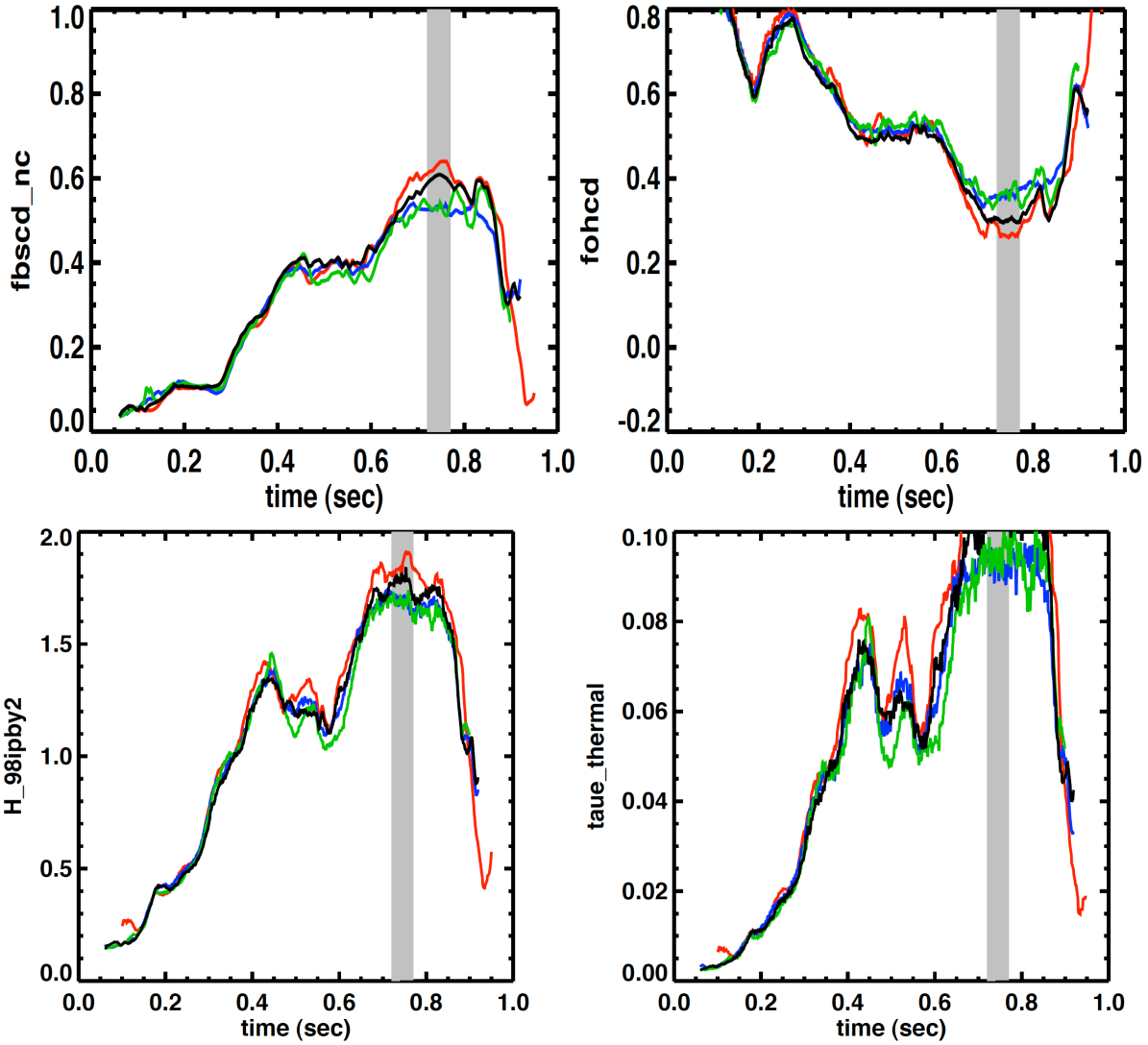
- How can we reliably trigger on demand?
  - RMP with proper spectrum? Low q_{95}?
- What are the changes in the turbulence?
  - FIReTIP indicates 50% reduction in density fluctuations
- Does lithium enable these in some way?
  - More frequent in past few years with increasing Li usage
- What is the role of edge resonances?
  - q=3 special?
- Is it some combination of VH-mode and QH-mode?
  - Need to assess edge turbulence: any EHO here?
- What is the limit on achievable 'pedestal width'?
  - Should we be calling this a pedestal even?

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

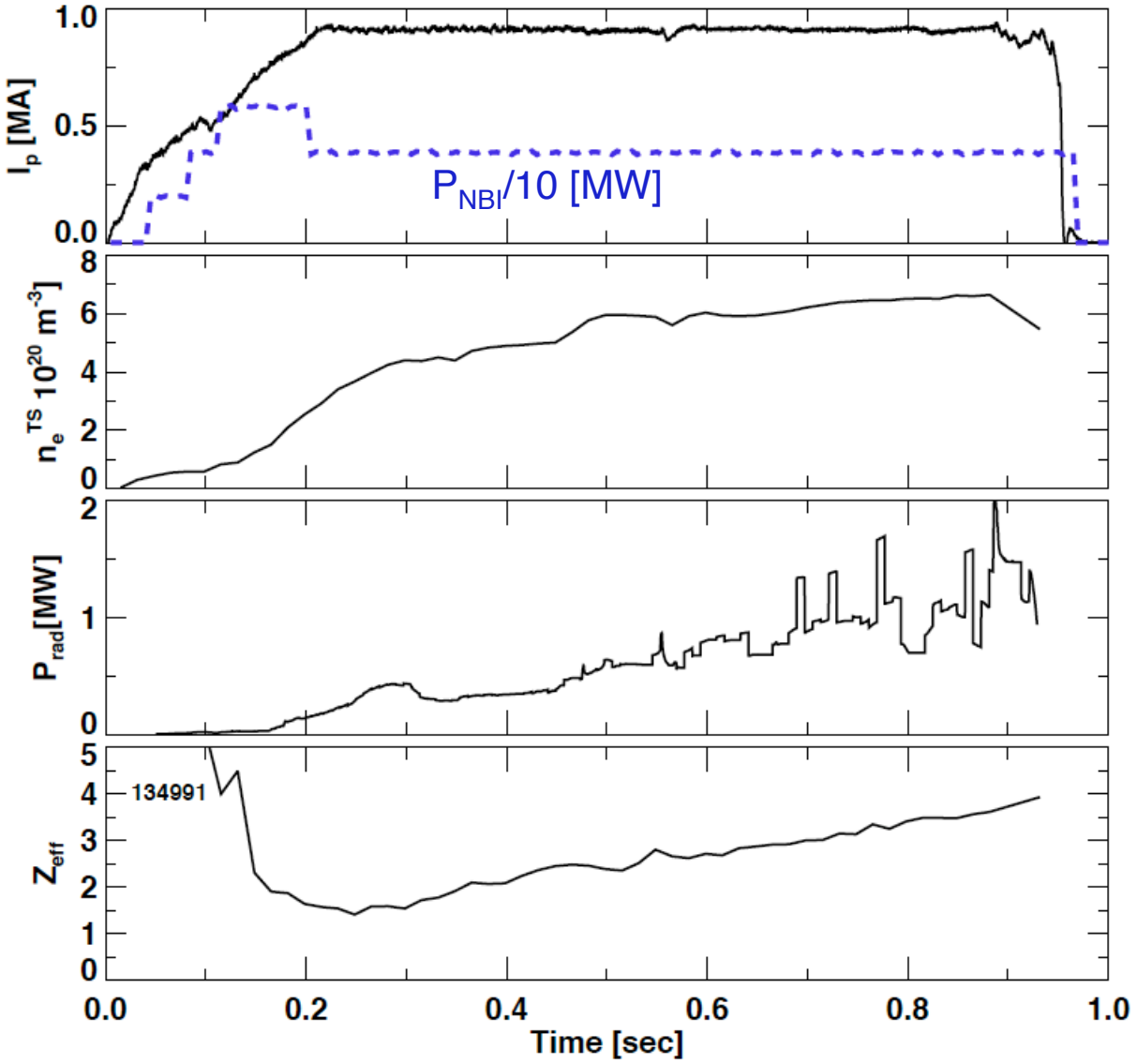
High bootstrap and non-inductive fractions, high thermal τ_E during EPH phase



- 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

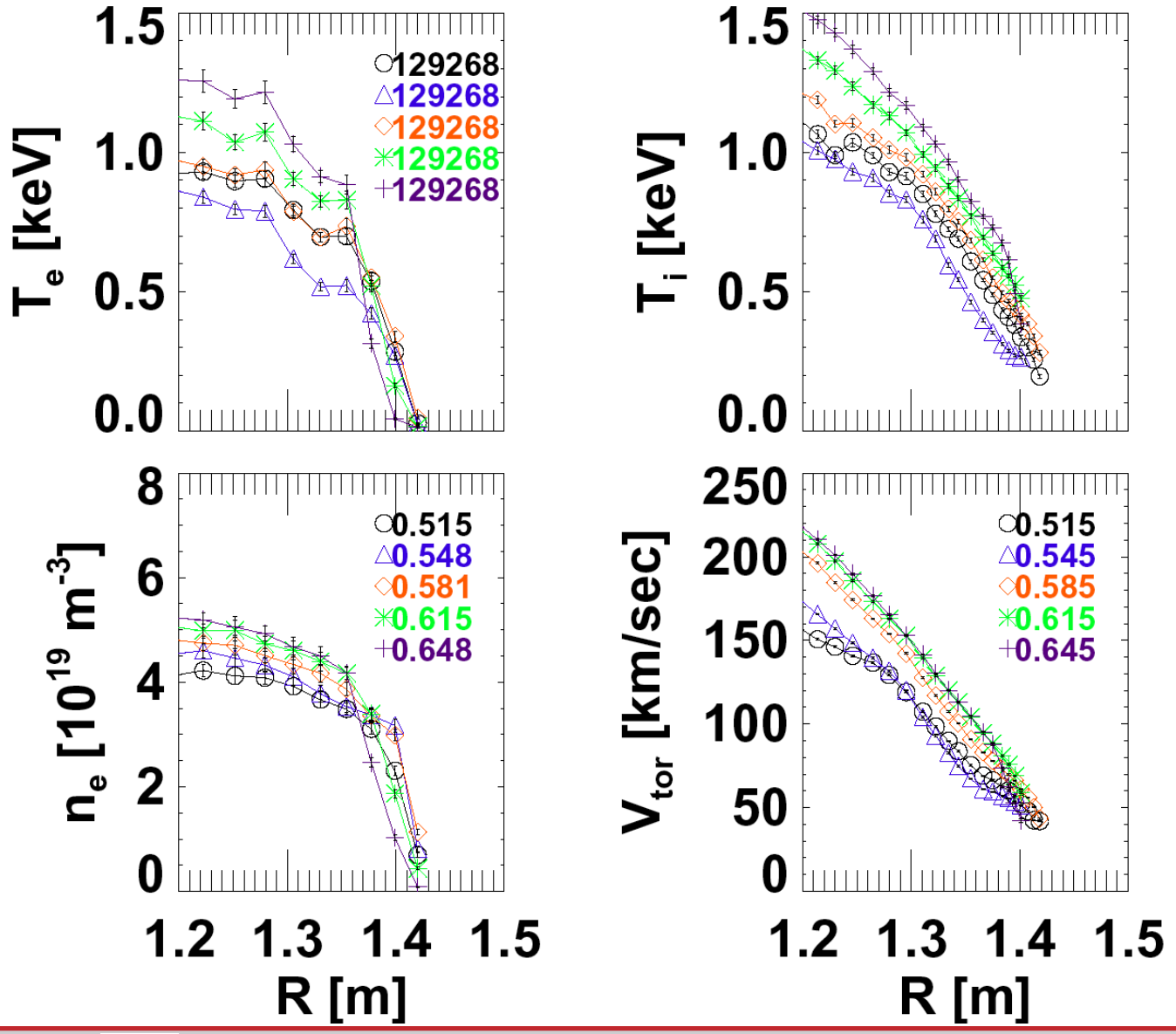
- Initiating EPH-mode:
  - Lithium conditioning for ELM-free conditions
  - Either fast RMP trigger of a large ELM(5 Hz?), or longer RMP pulse with several ELMs: both seem to work
  - Since density profile control may be important, *supersonic gas injection (SGI) may provide easier access (longest pulse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

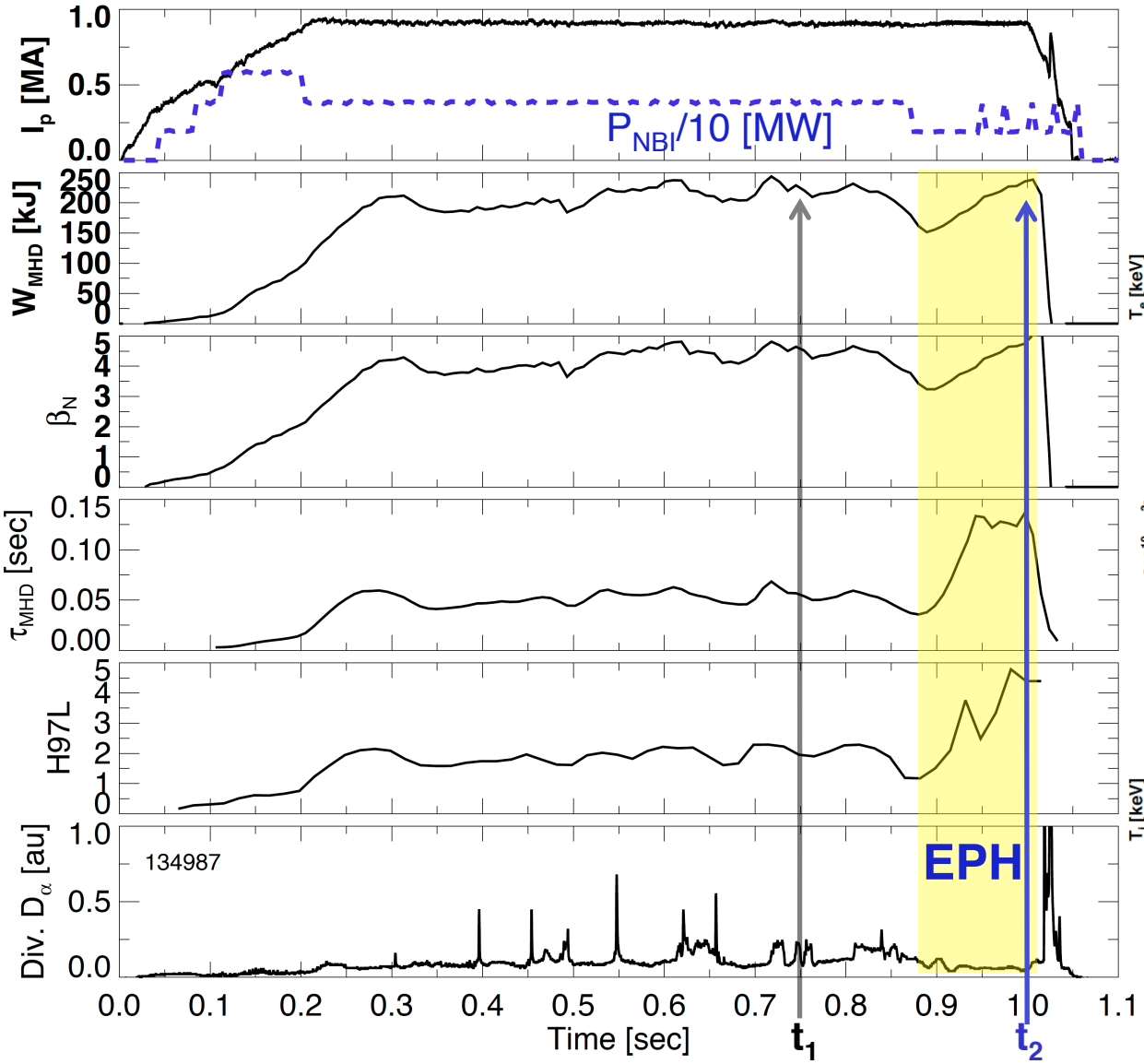
✓ Experiments will be lead by Canik and Gerhardt

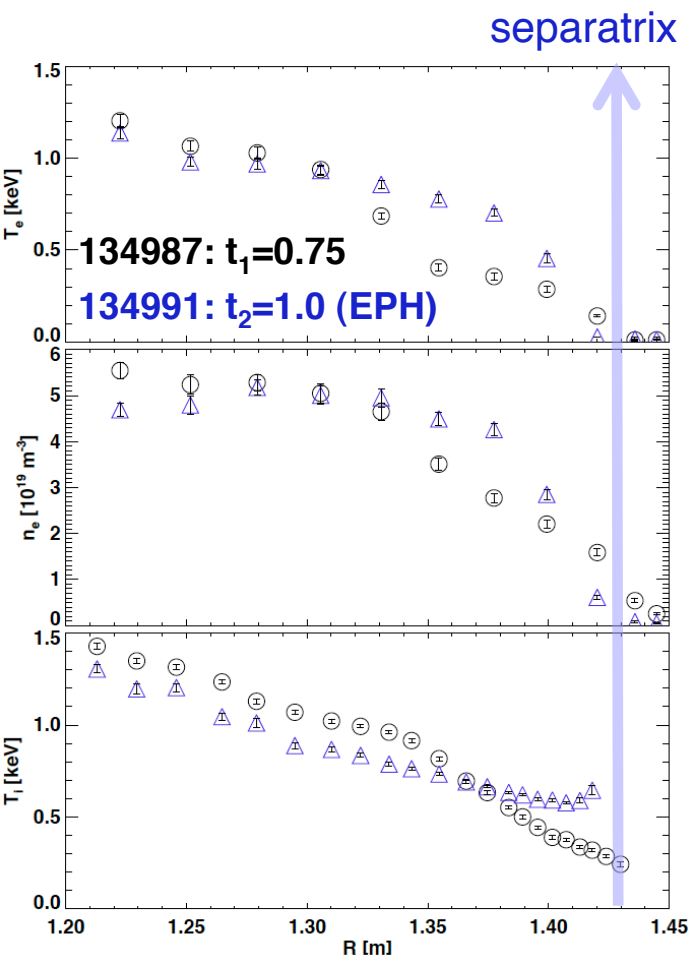
EP H-mode profiles evolve continuously, although recovery from trigger takes a little time



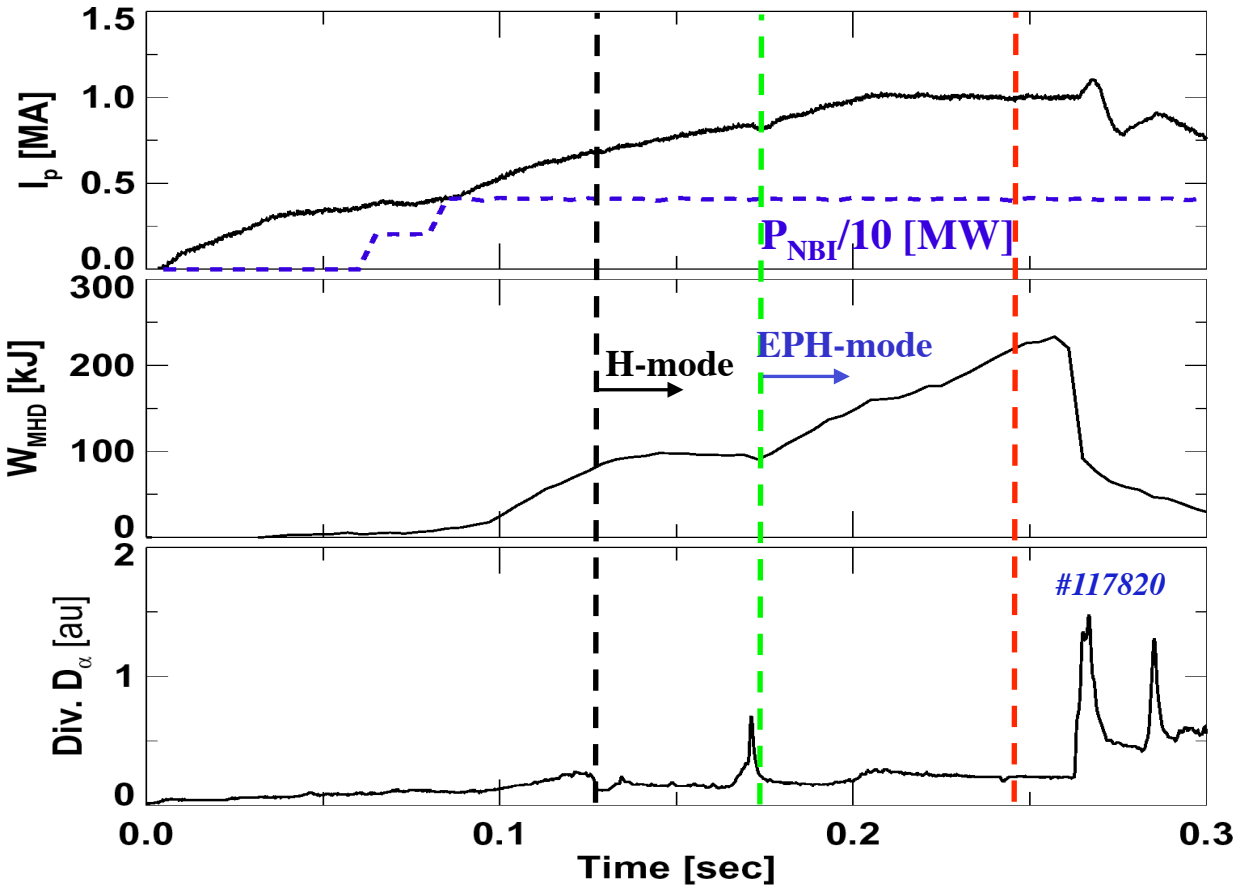
- Discharge had Li evaporation to improve performance in regular H-mode

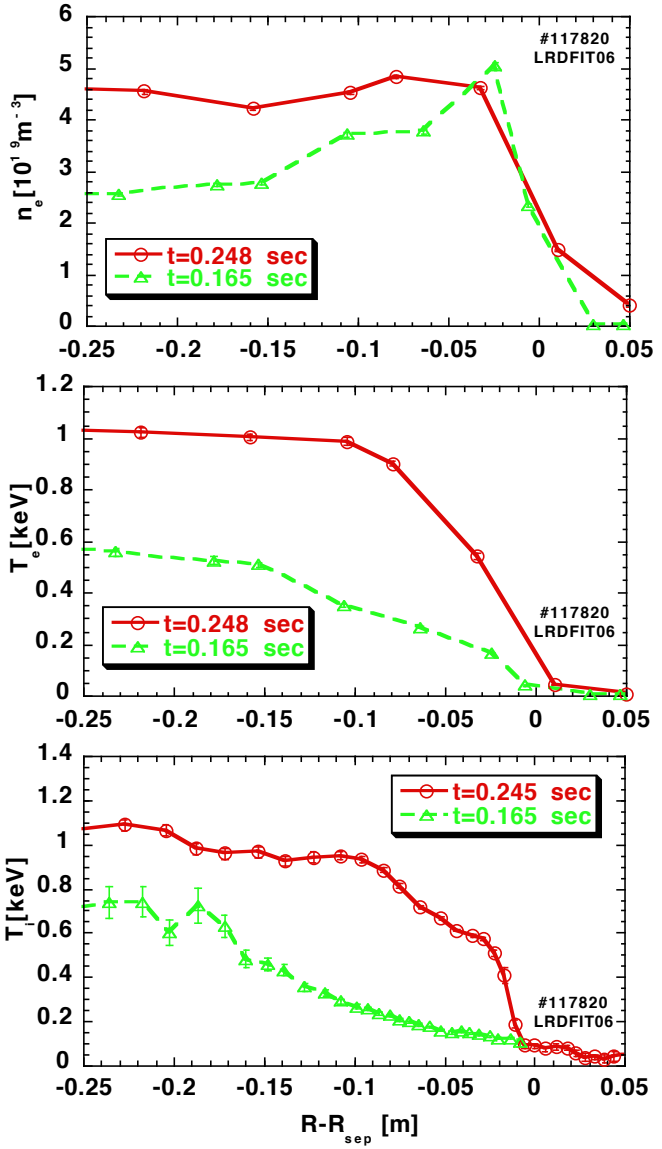
EPH-mode can have transient H89P up to 4





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

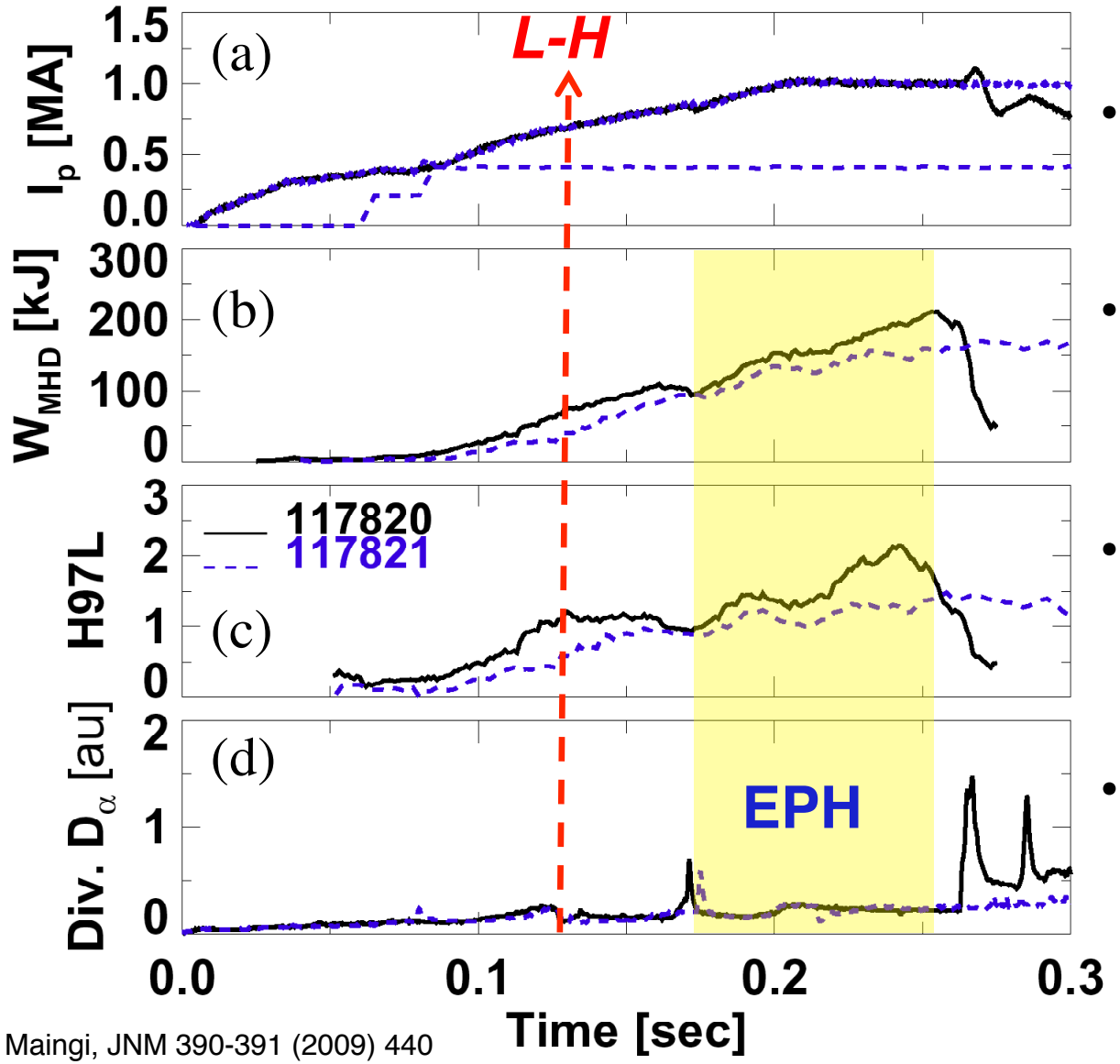




- ***Note: Pedestal $\nu_e^{*} \sim 0.5$-1 in H-mode***

Maingi, JNM 390-391 (2009) 440

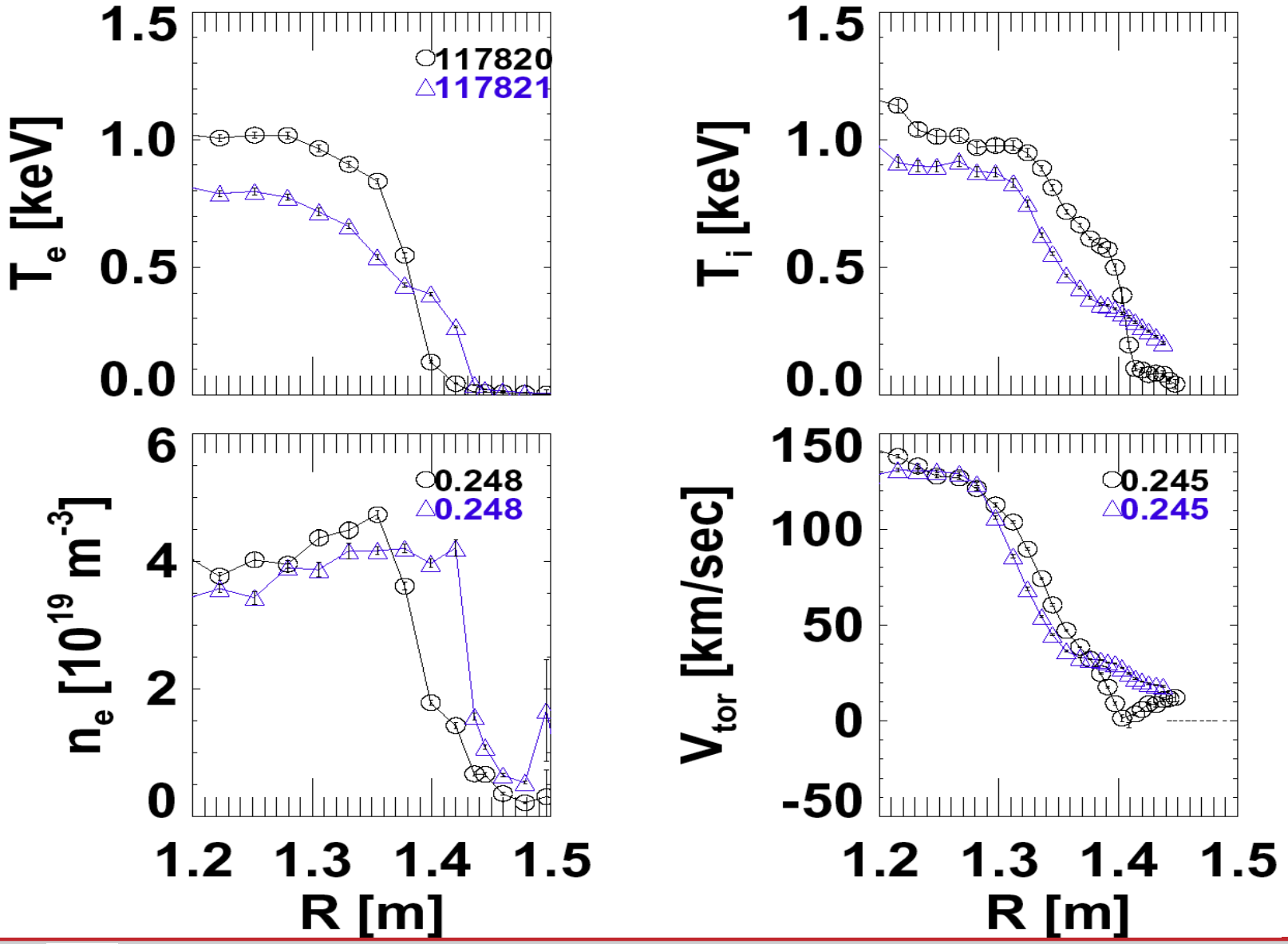
Comparison of Standard and EP H-mode evolution



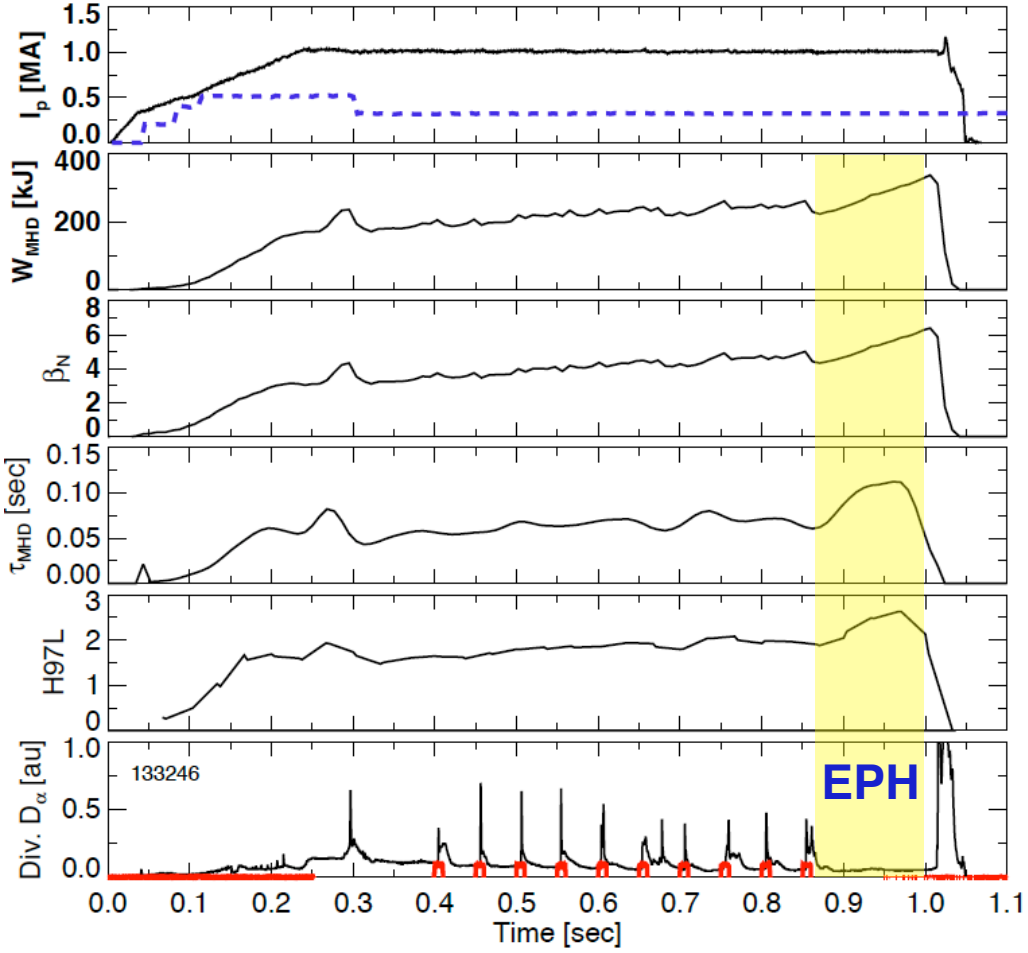
- Same I_p, P_{NBI}
- Higher W_{MHD} during EPH
- Higher H97L during EPH
- ELM trigger for EPH

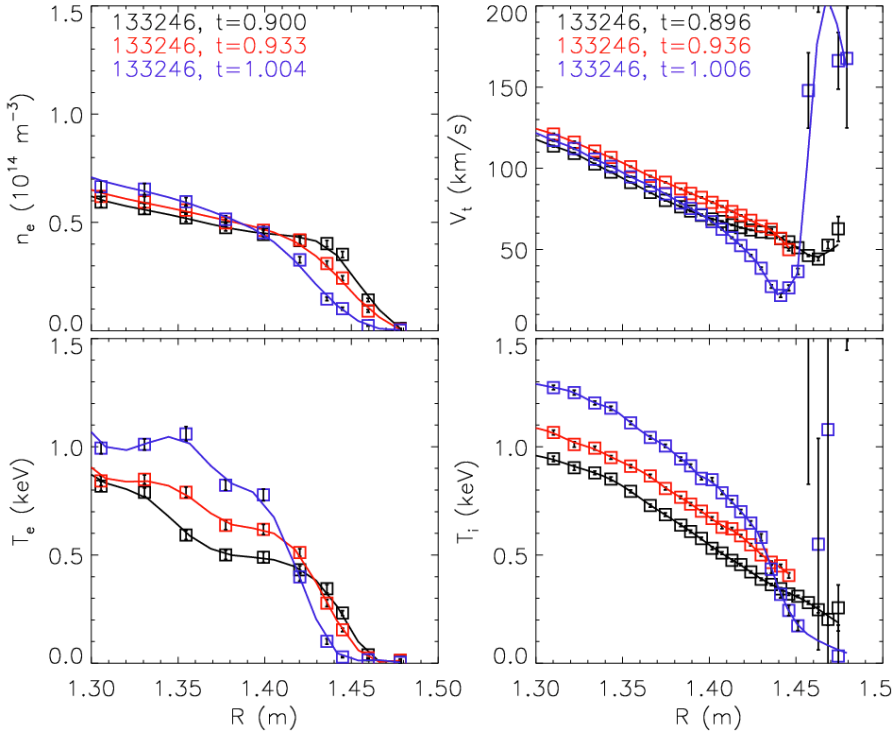
Maingi, JNM 390-391 (2009) 440

Comparison of Standard and EP H-mode profiles



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



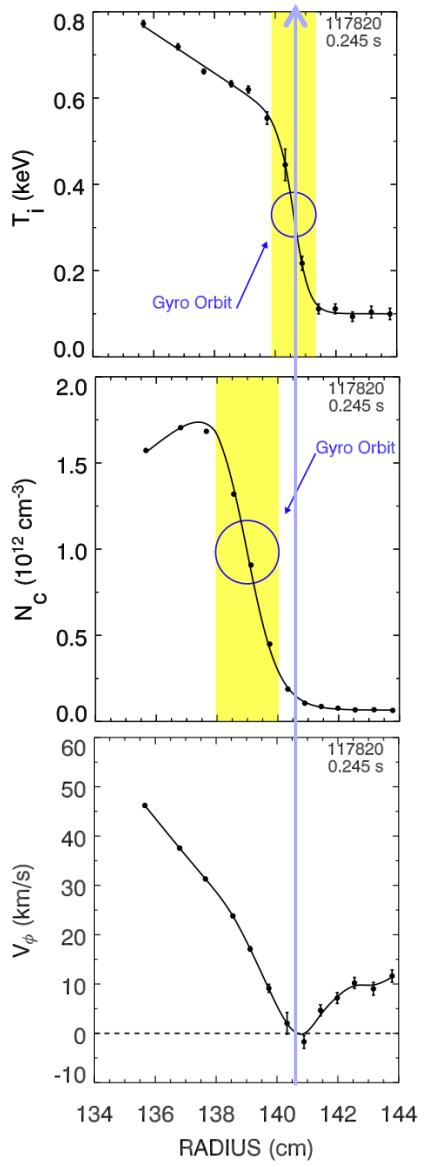


Enhanced Pedestal H-mode barrier width size comparable to gyro-diameter

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

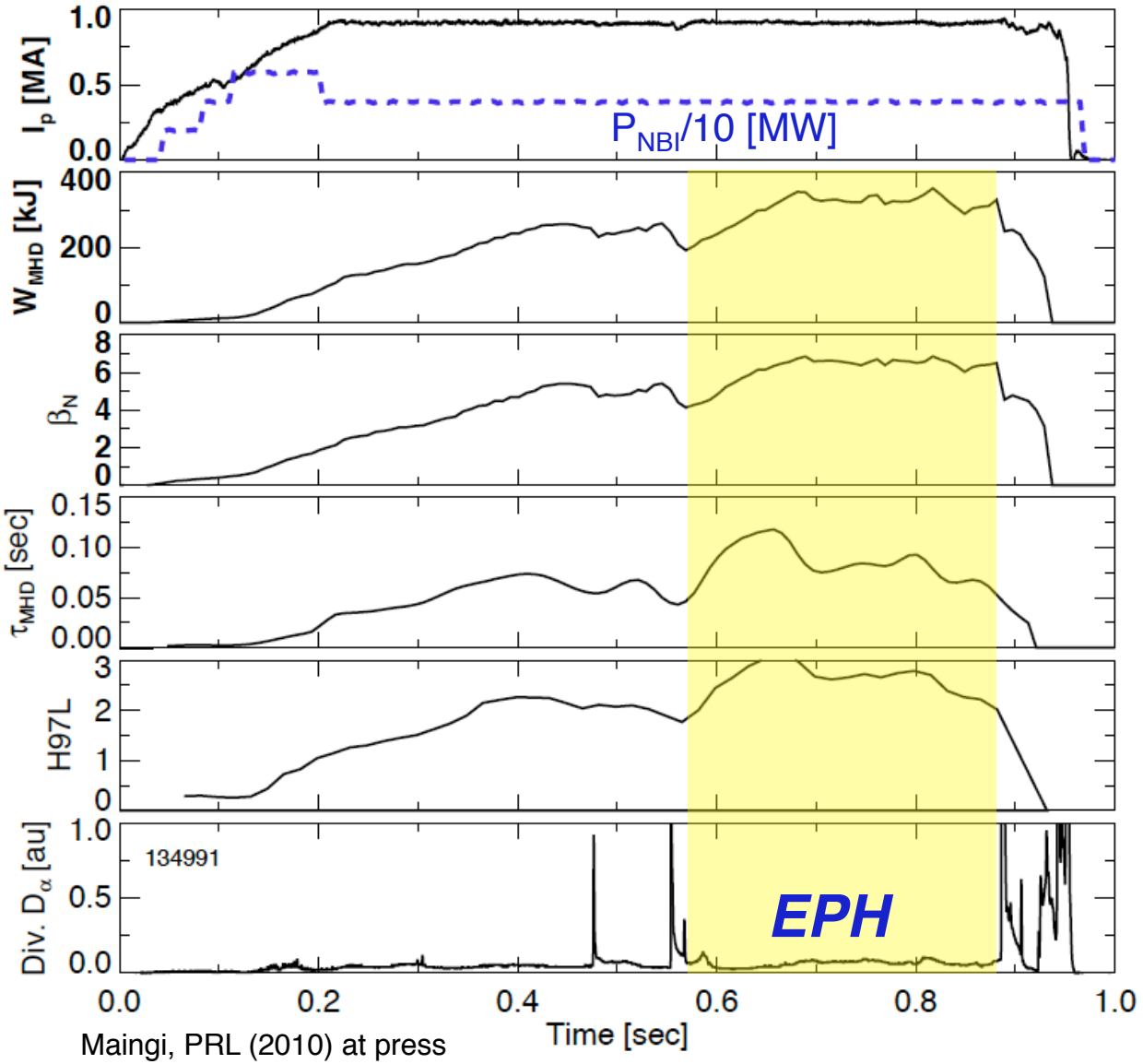
- Ion gyroradius $\rho_i \sim 0.7$ cm relative to IBI, owing to combination of local $T_i \sim 350$ eV and and IBI ~ 0.35 T at outer midplane
  - Approaching or at the fundamental limit on the gradient scale length?

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



R. Bell

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