Experimental Exploration of Electron Confinement in NSTX*

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Motivation

- NSTX is well suited to study electron thermal transport because:
  - The higher β is expected to enhance electromagnetic turbulence effects on transport
  - HHFW heating provides, in theory, a means to heat the bulk electrons directly
- Some insight into the electron thermal transport can be gained by comparing transport in HHFW and/or NBI heated plasmas
  - Compare spinning and non-spinning plasmas

Plan of this Poster

- Review of the status of the HHFW driven H-mode plasmas
- Results from plasma heating experiments using combinations of HHFW and NBI power

New Results from 2004 Experiments

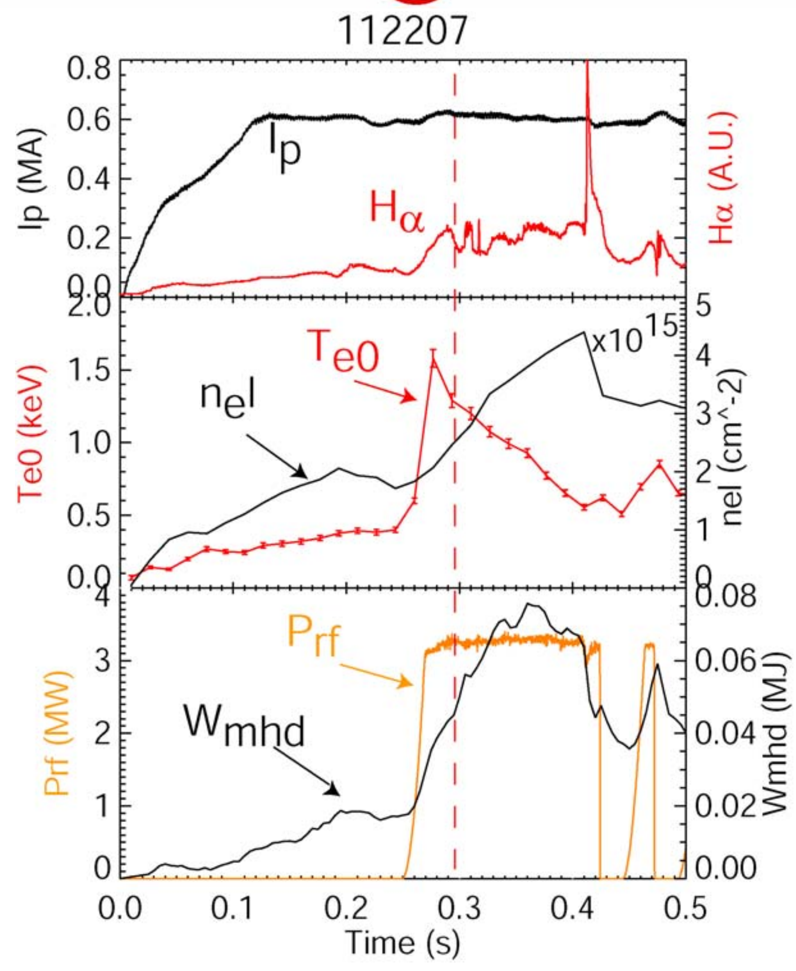
HHFW Driven H-mode Plasmas

NSTX

- Developed a dependable DND HHFW H-mode plasma
  - Separate plasma fueling from antenna coupling
  - CS gas injector and/or DND geometry
- Expanded operational envelope
  - Ip ≈ 0.3-0.5 MA, B_T ≈ 0.37 - 0.45 T, low density, LSN
  - $k_{//}$ = 14 m^{-1}
- New range achieved
  - Ip ≈ 0.6-0.8 MA, B_T ≈ 0.45 T, medium density DND
  - $k_{//}$ = 14 and 7 m^{-1}
- Document HHFW H-mode plasma
  - Many discharges with beam blips
  - ERD documentation

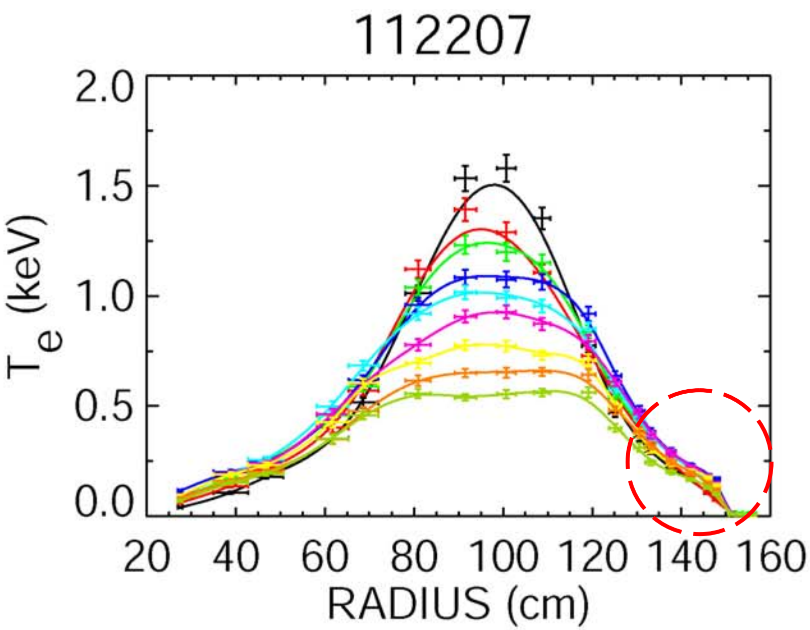
HHFW Driven H-mode Plasma

- More reliable H-mode operation obtained at lower I_p like 0.6 MA shown here
- The H_α drop signature is less telling than with NBI plasmas, because of antenna SOL interaction
- A decrease of T_{e0} is often observed after H-mode onset, but W_{mhd} continues to climb (See profiles on next slide.)

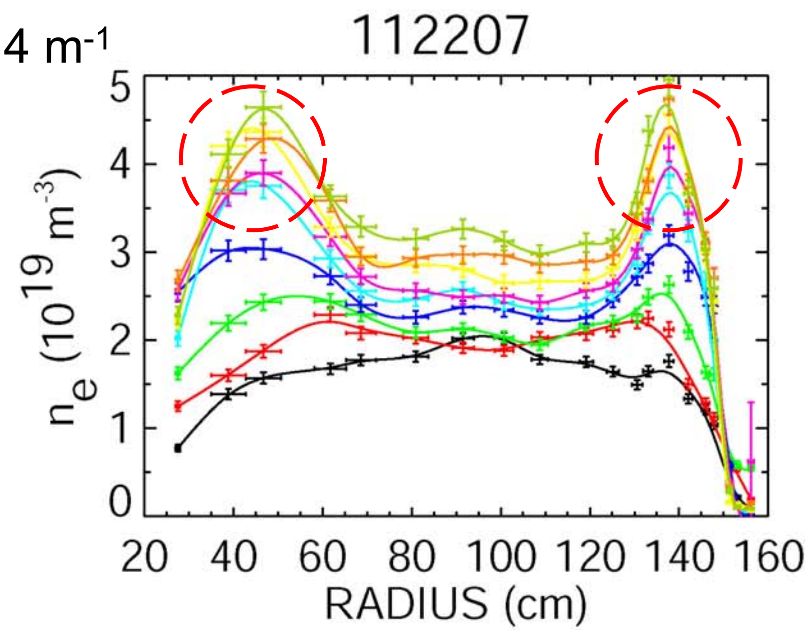


HHFW H-Mode Plasma Profiles

Most reliable way to identify HHFW H-mode plasmas is by looking at the Thomson scattering profiles. One observes T_e pedestal and n_e "ears" at the edge.



$k_{//}$ = 14 m^{-1}

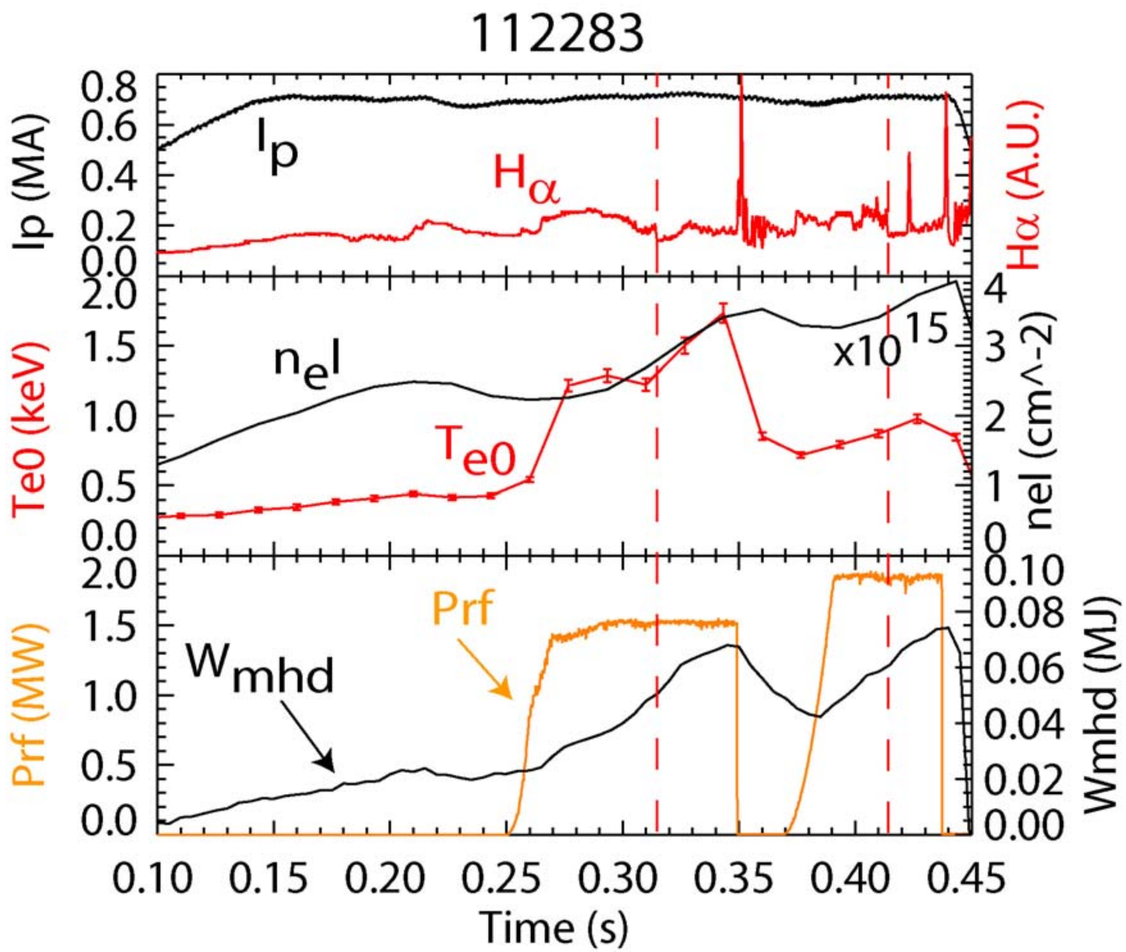


HHFW H-mode Obtained with $k_{//} = 14\ m^{-1}$

The HHFW power was stepped up to 1.5 MW and later on to 1.8 MW.

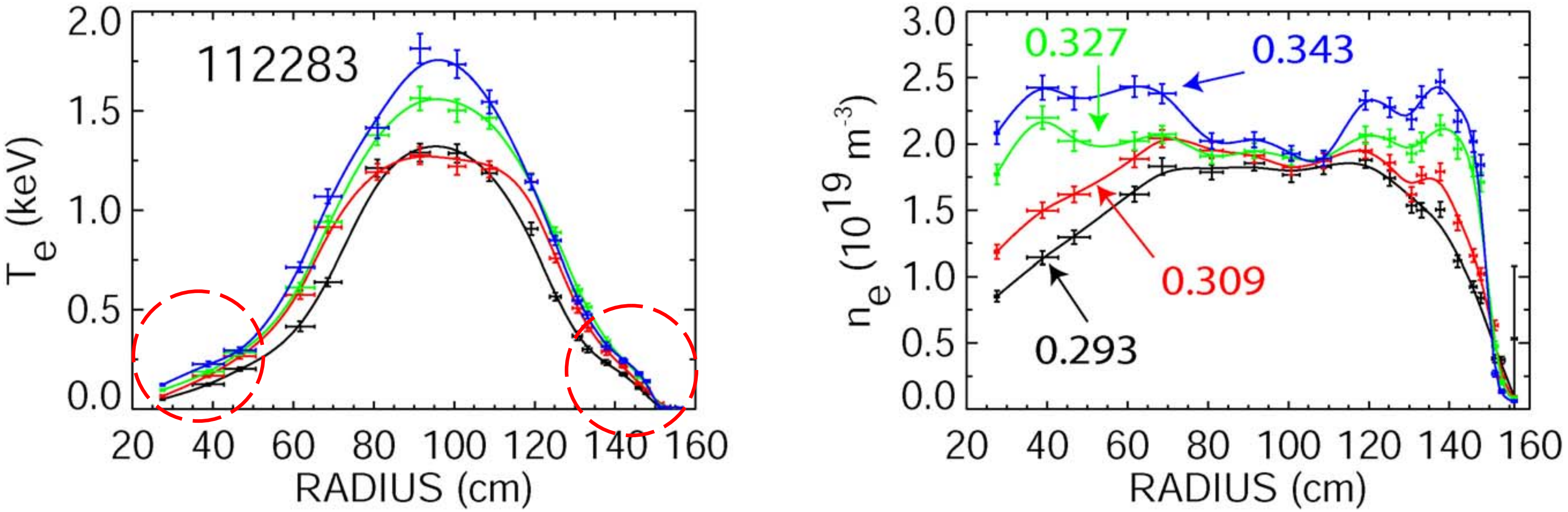
Two transitions are observed, at 0.315 s and at 0.415 s, corresponding to the two power levels. (See dashed lines.)

H_α trace drops can be confirmed with the Thomson scattering data.



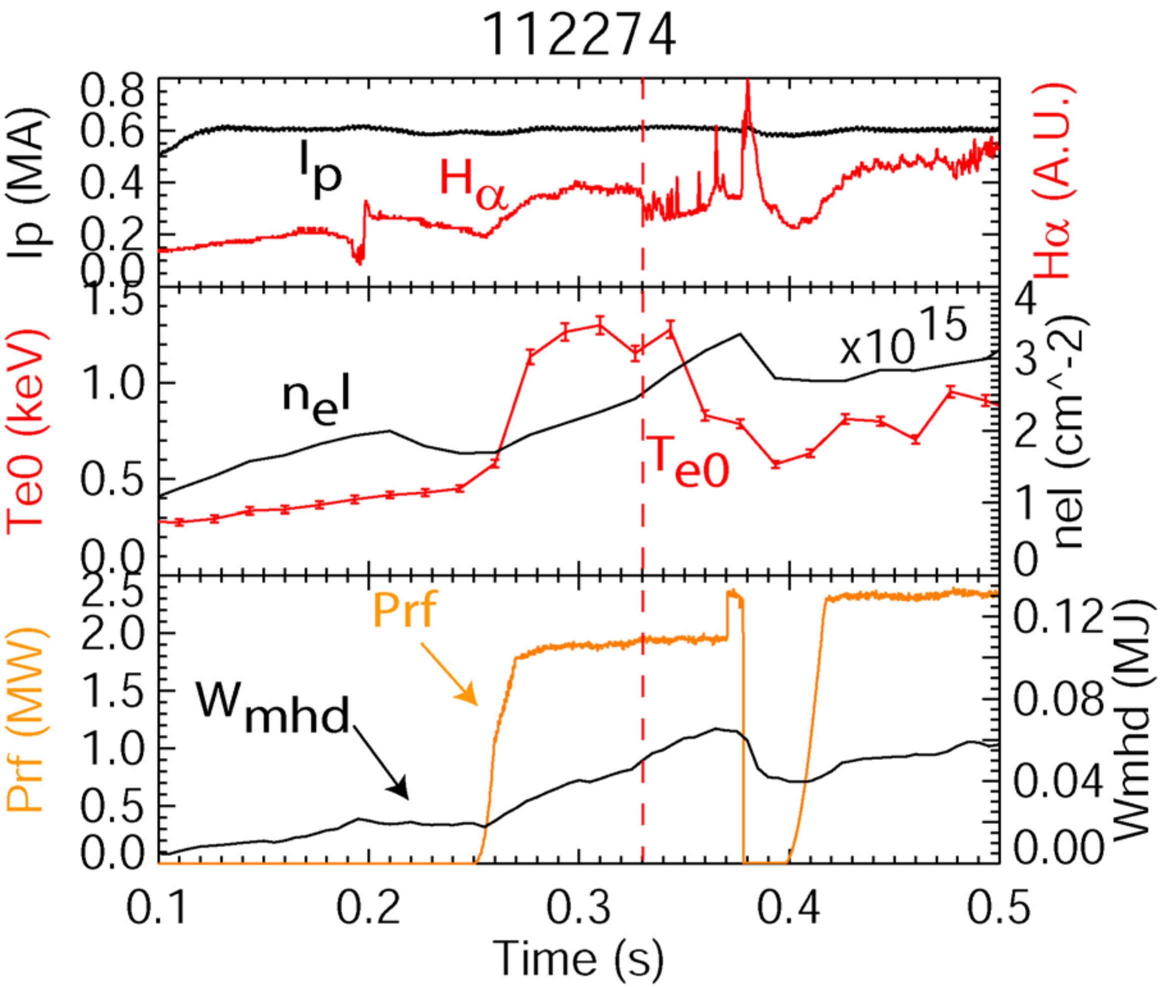
Thomson Scattering Data for 1st Transition

- Confirm the 0.315 s transition time with the Thomson scattering data
- n_e pedestal develops between TS time points 0.309 s and 0.327 s
- T_e pedestal is also seen



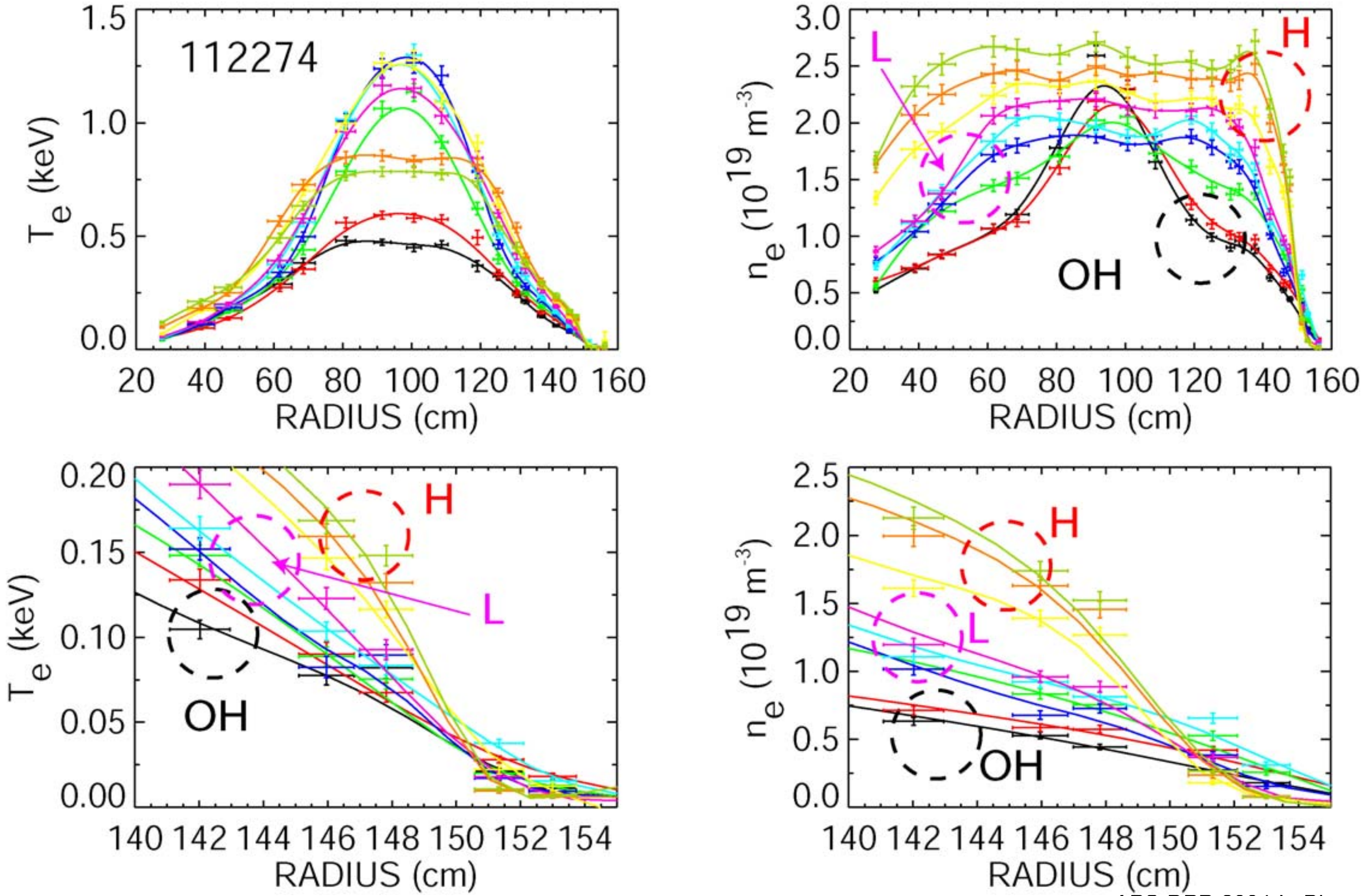
H mode Obtained with $k_{//} = 7\ m^{-1}$

- H-mode with $k_{//} = 7\ m^{-1}$
- Transition time marked with dashed line
- H mode lasts until end of 1st HHFW pulse (see next slide)
- W_{mhd} and $n_e l$ reduced after H mode ends



TS Profile Details for 7 m^{-1} H-mode Plasma

Nine consecutive TS times 0.243-0.377s. Phases "OH", "L" and "H" are indicated by dashed circles. Edge details shown in lower panels.



H-Mode Threshold Changes with $k_{//}$

$P_{thres} \leq 1.5$ MW for $k_{//} = 14\ m^{-1}$ and ≈ 2.0 MW for $k_{//} = 7\ m^{-1}$

$k_{//} = 14\ m^{-1}$

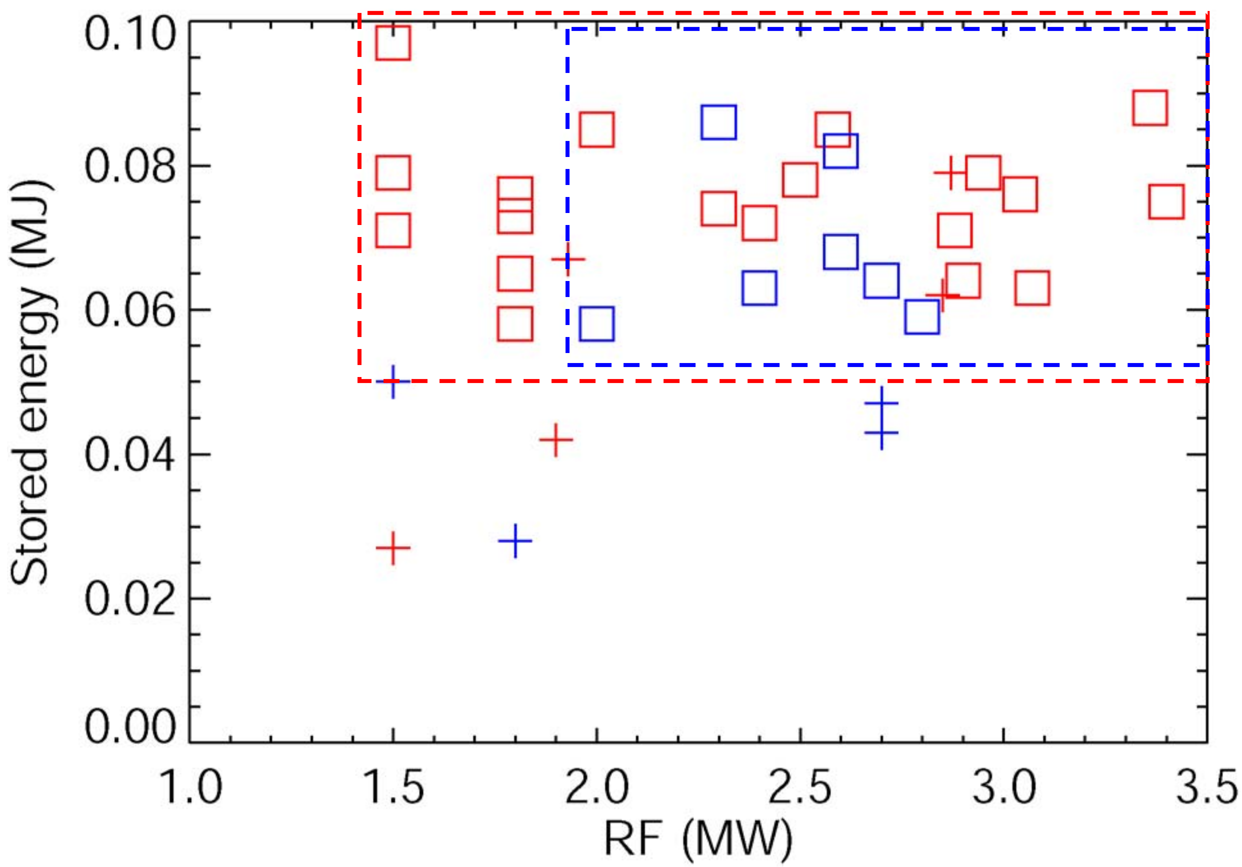
$k_{//} = 7\ m^{-1}$

Box = H mode

Plus = L mode

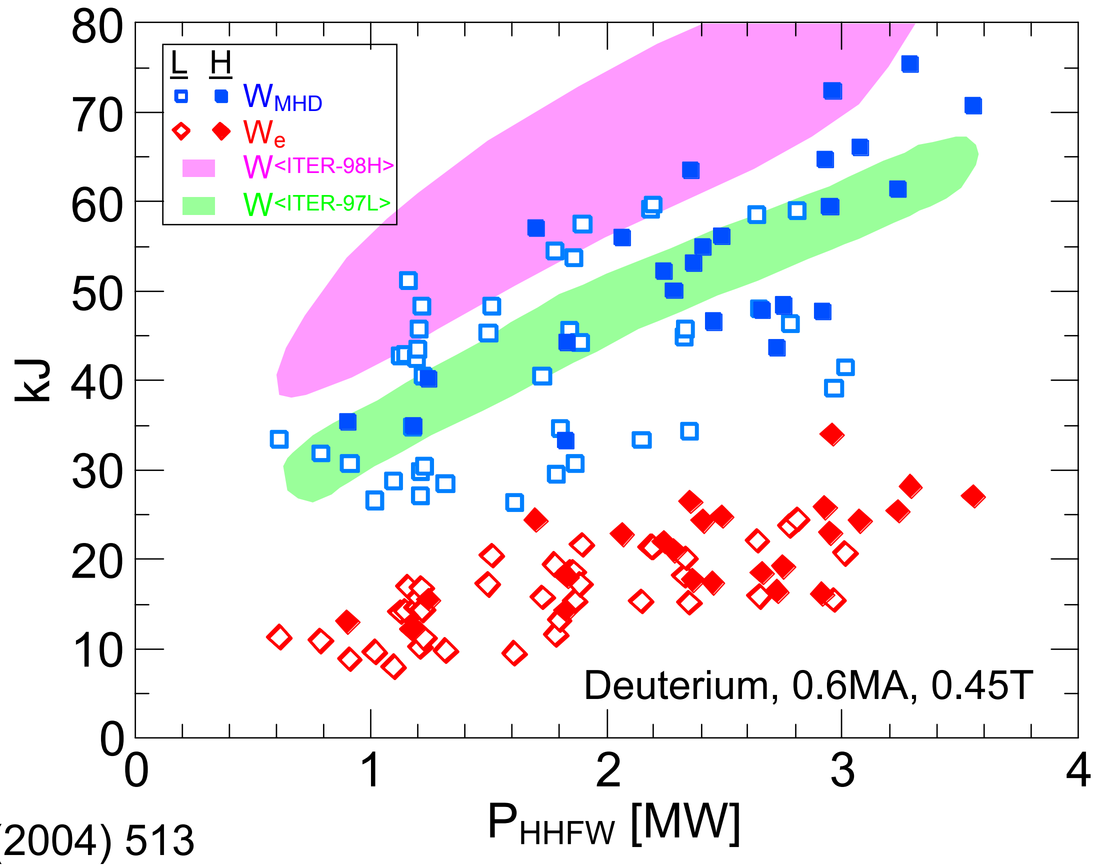
$I_p = 0.6\text{-}0.8$ MA

$B_T = 0.45$ T



HHFW Plasmas *vs.* ITER-97L and -98H Scalings

- L- and H-mode data mingle together, similar to NBI H mode*
- But HHFW H mode scales less strongly: ≤ 1.5x97L, ≤ 1x98H



M. Bell

*Nucl. Fusion **44** (2004) 513

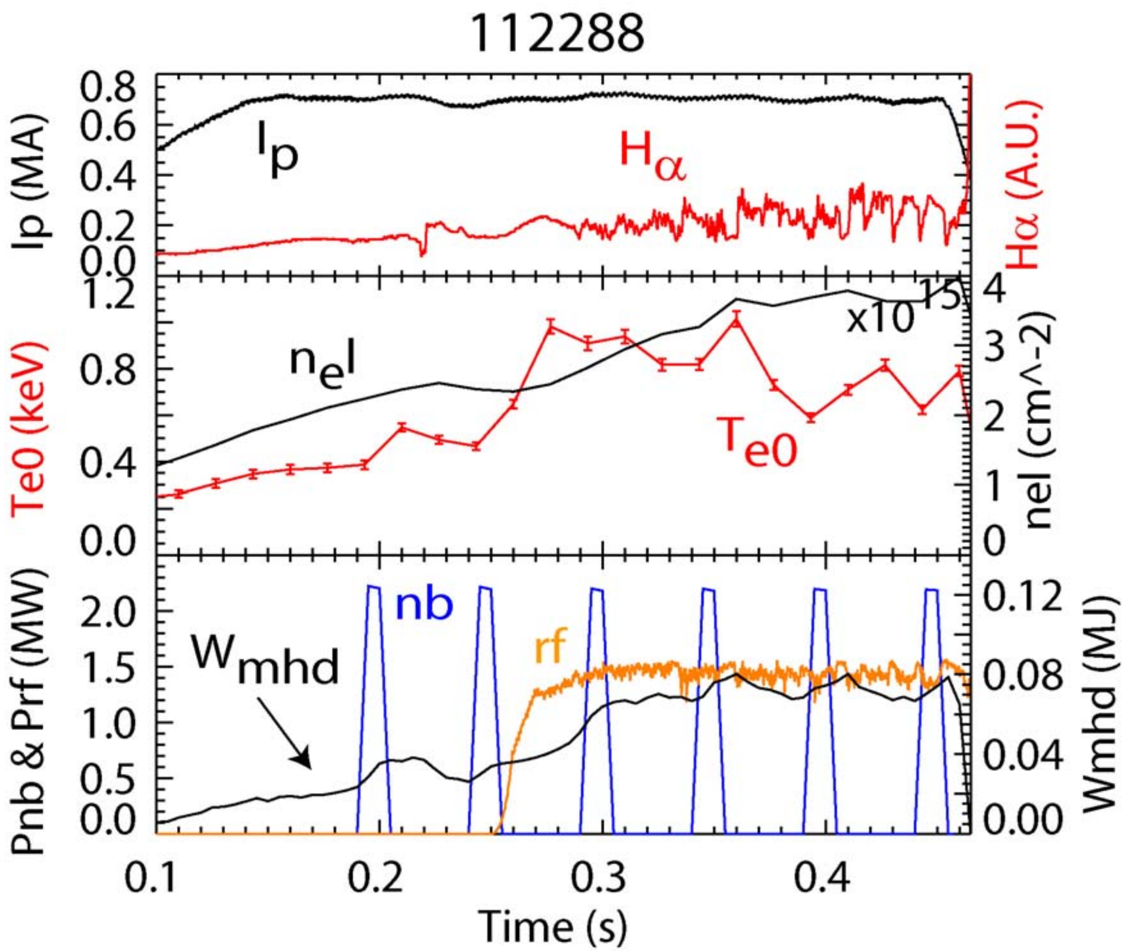
CHERS for Measuring T_i and v_ϕ

CHERS data is needed for TRANSP transport analyses

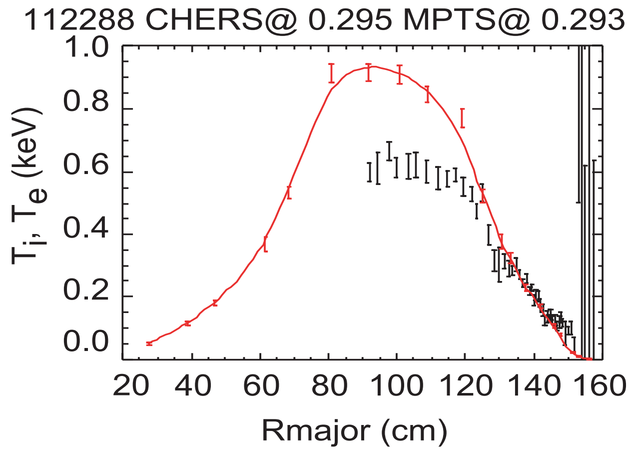
Caution is needed when using CHERS to obtain T_i and $v\phi$, since the beam energy input may not be negligible.

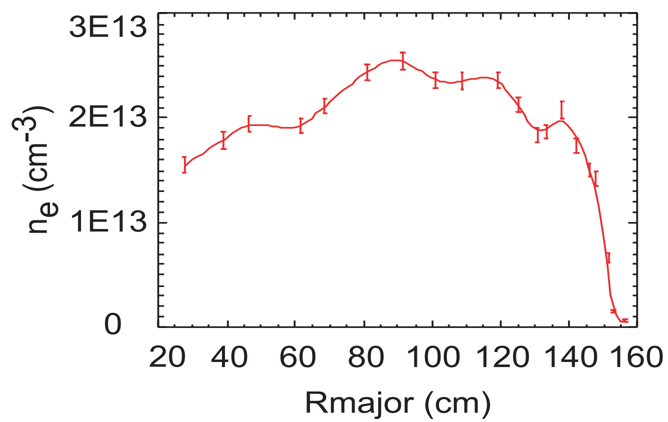
Although I_p is only 0.7 MA, the plasma captures a significant amount of fast particles: W_{mhd} increases by ≈ 10% after each 10-ms beam pulse.

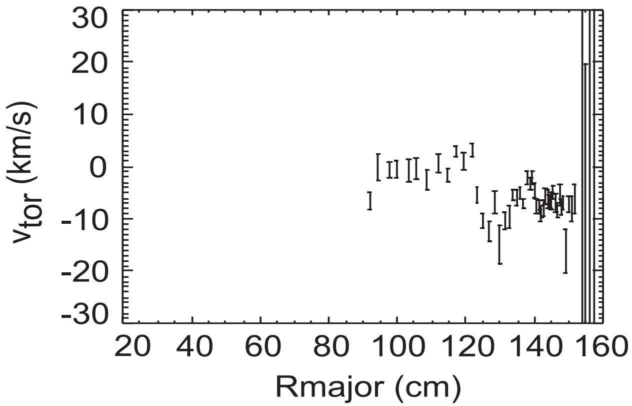
Lower beam power was found to produce CHERS data of limited quality.



CHERS T_i and v_ϕ and MPTS T_e and n_e Data







- $T_i = T_e$ for r/a < 0.5
- $T_e > T_i$ in core
- Small rotation, $v_{tor} < 10$ km/s

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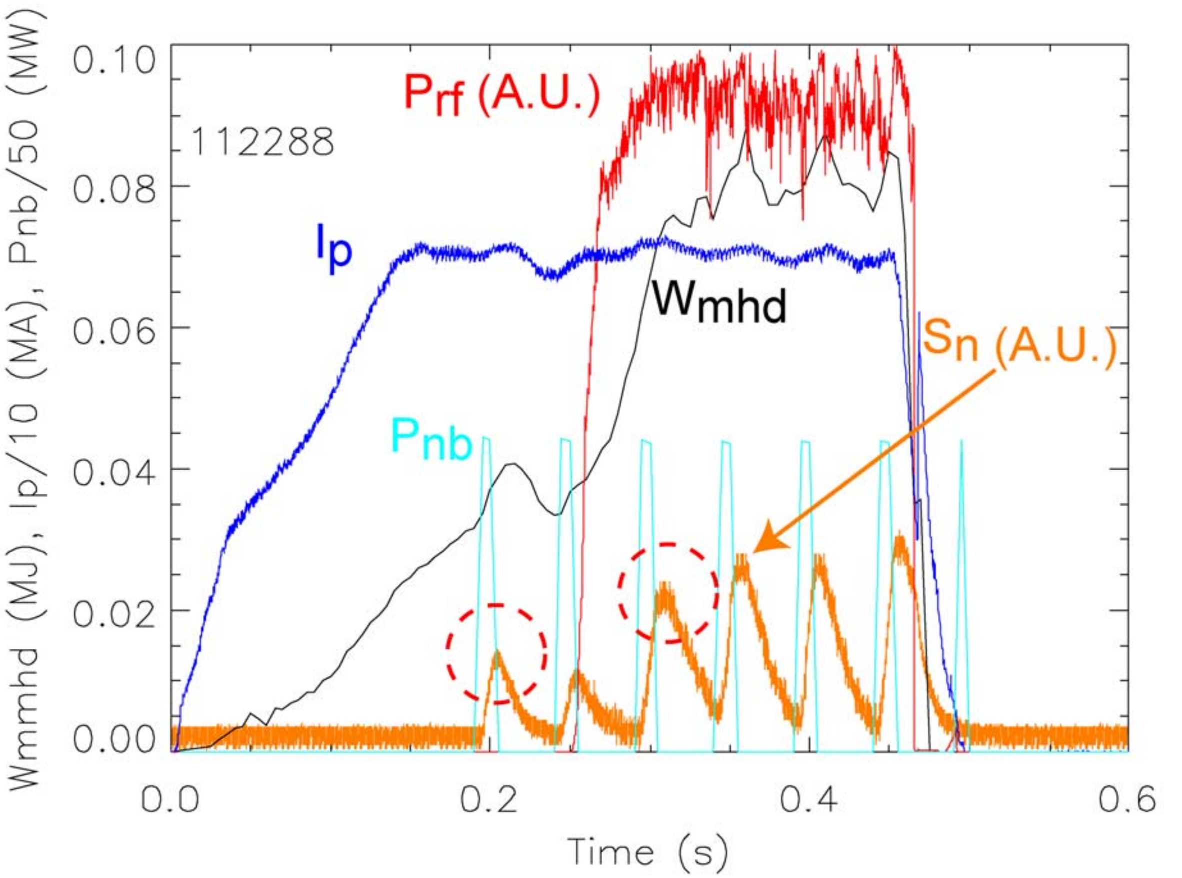
Fast Particles Accelerated by Wave

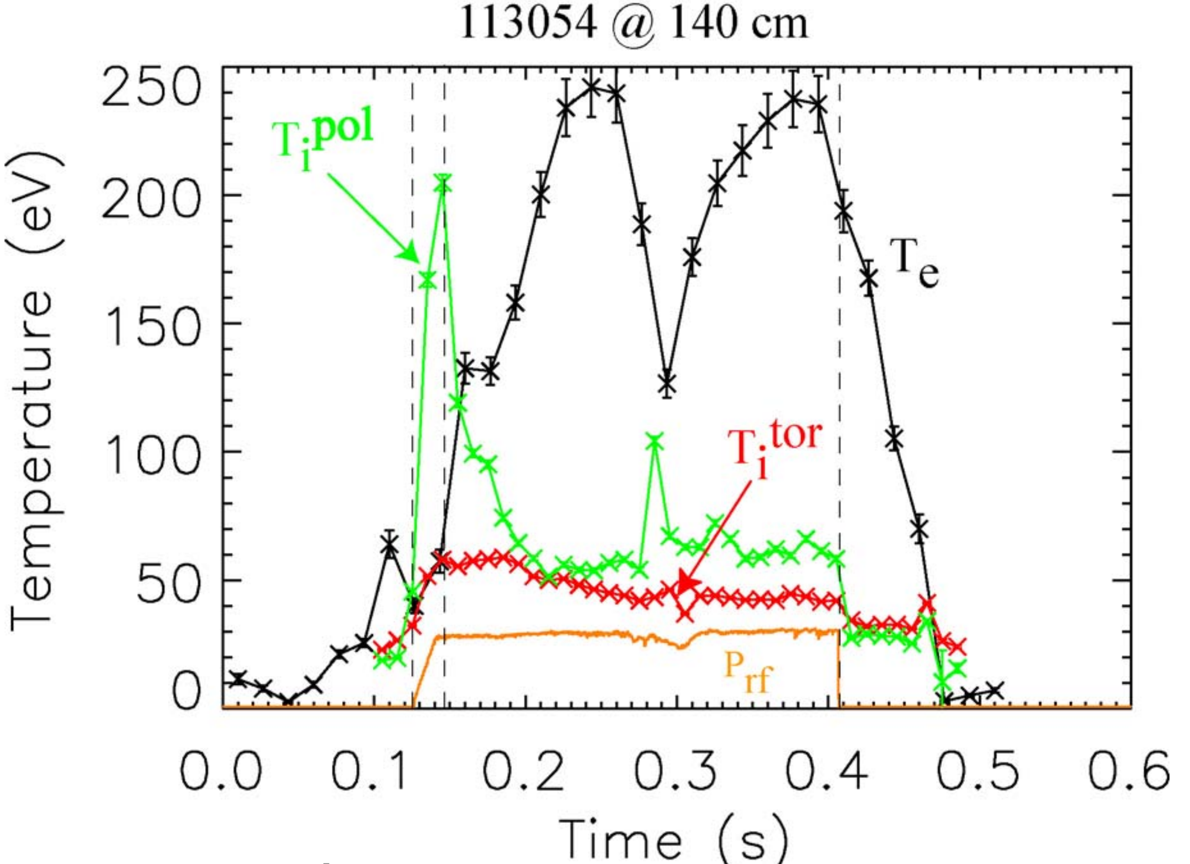
Neutron trace peaks after NB blip turnoff when RF on



ERD Diagnostic Indicates Edge Ion Heating

- Unexpected edge ion heating during HHFW
- Might be explained by parametric decay into IBW wave (T. Biewer RI 1.001)
- Of the order of 20% of the absorbed power could captured at the edge (S. Diem JP1.014)
- $T_i^{pol} > T_i^{tor}$ during HHFW
- T_i^{pol} increase precedes T_e at the HHFW onset
- ERD has a 10-ms integration time

3 MW, $k_{//} = 14\ m^{-1}$



T. Biewer

Combined HHFW & NBI Operation

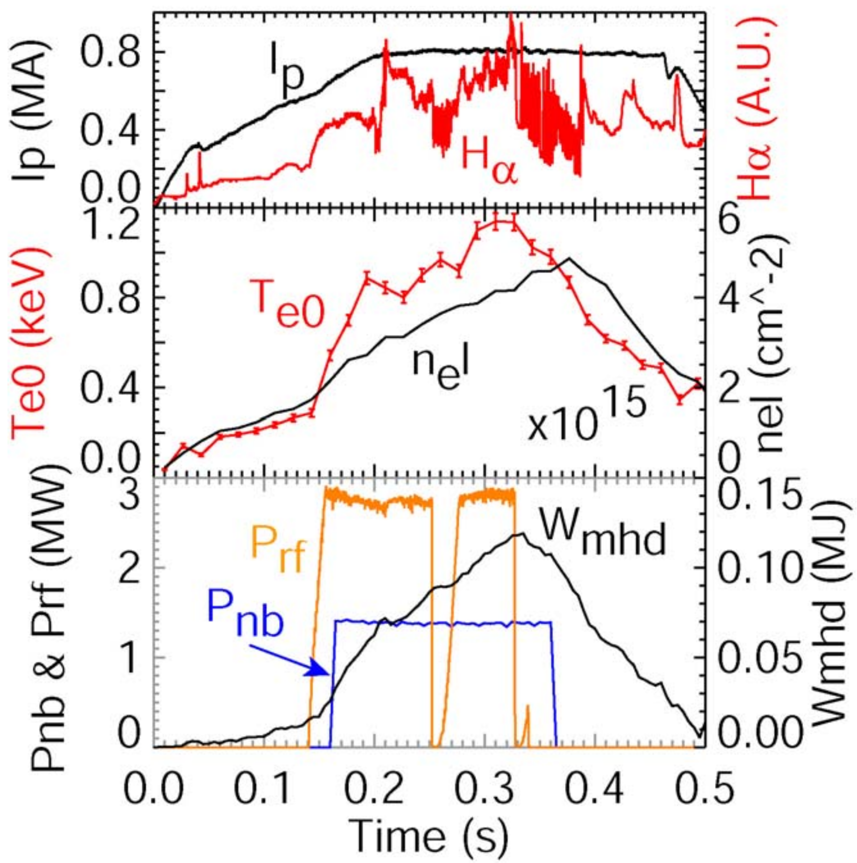
- Use one or two NBI sources at lower energy (70 kV) to reduce antenna plasma interaction, while maintaining a gap ≈ 4 cm

- Start HHFW during L-mode plasma
  - One NBI pulse
  - Three NBI pulses

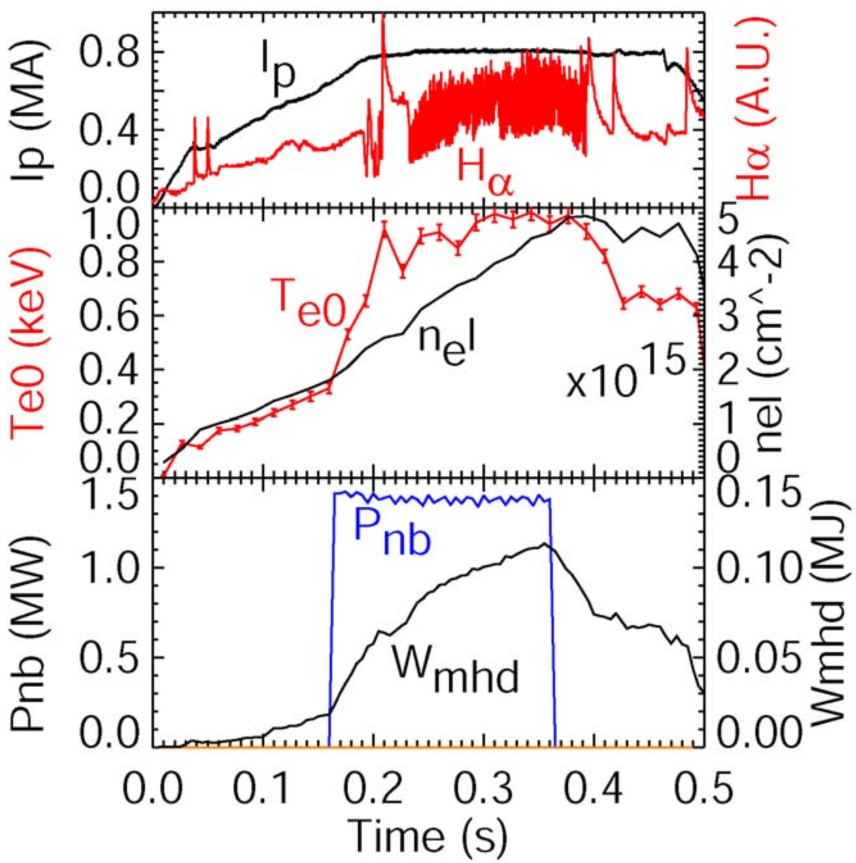
- Start HHFW during H phase of NBI driven H-mode plasma

HHFW Starts before H-mode Onset

NBI + HHFW 113488



NBI only 113489



Neutrons (S_n) Doubles and Small W_{mhd} Increase

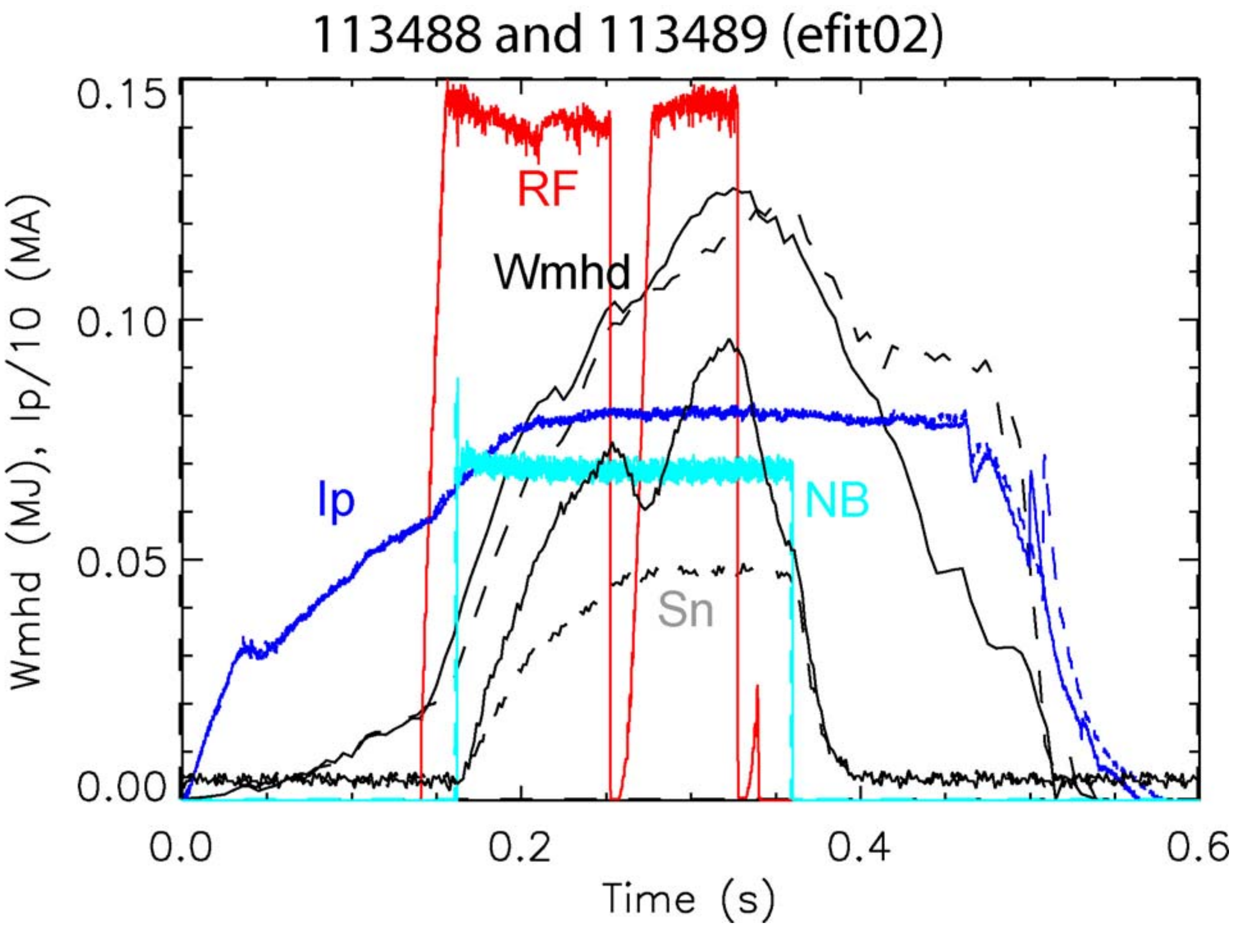
NSTX

HHFW starts before H-mode onset

HHFW+NBI (solid)
NBI (dashed)

113488
RF@2.9 MW
NB@1.8 MW

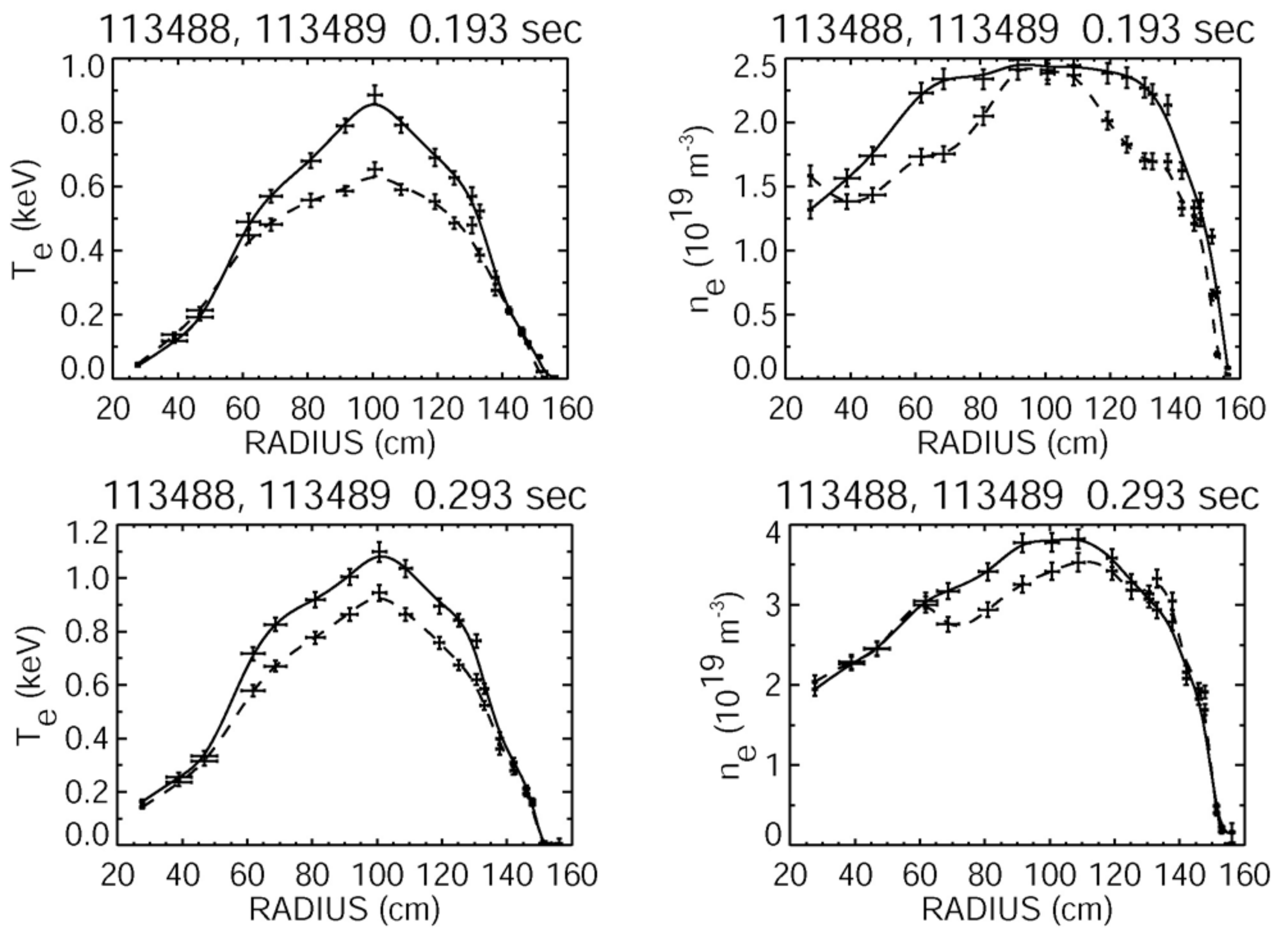
113489
NB@1.7 MW



Greater Core T_e Compared to NBI-only Plasma

<u>HHFW+NBI (solid)</u>
<u>NBI (dashed)</u>

HHFW starts before H-mode onset



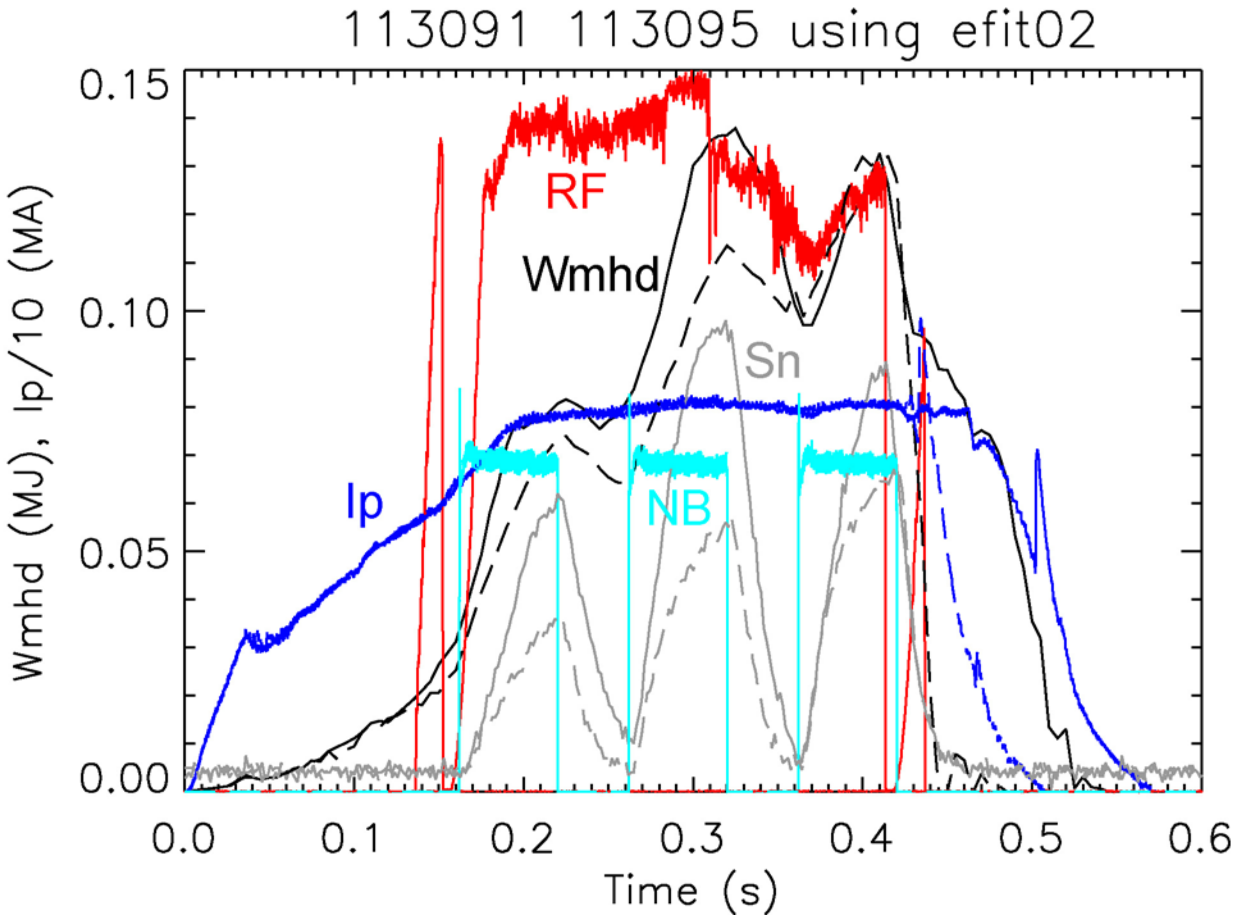
Neutrons (S_n) Doubles and W_{mhd} Increases

HHFW starts before H-mode onset: three NBI pulses

HHFW+NBI (solid)
NBI (dashed)

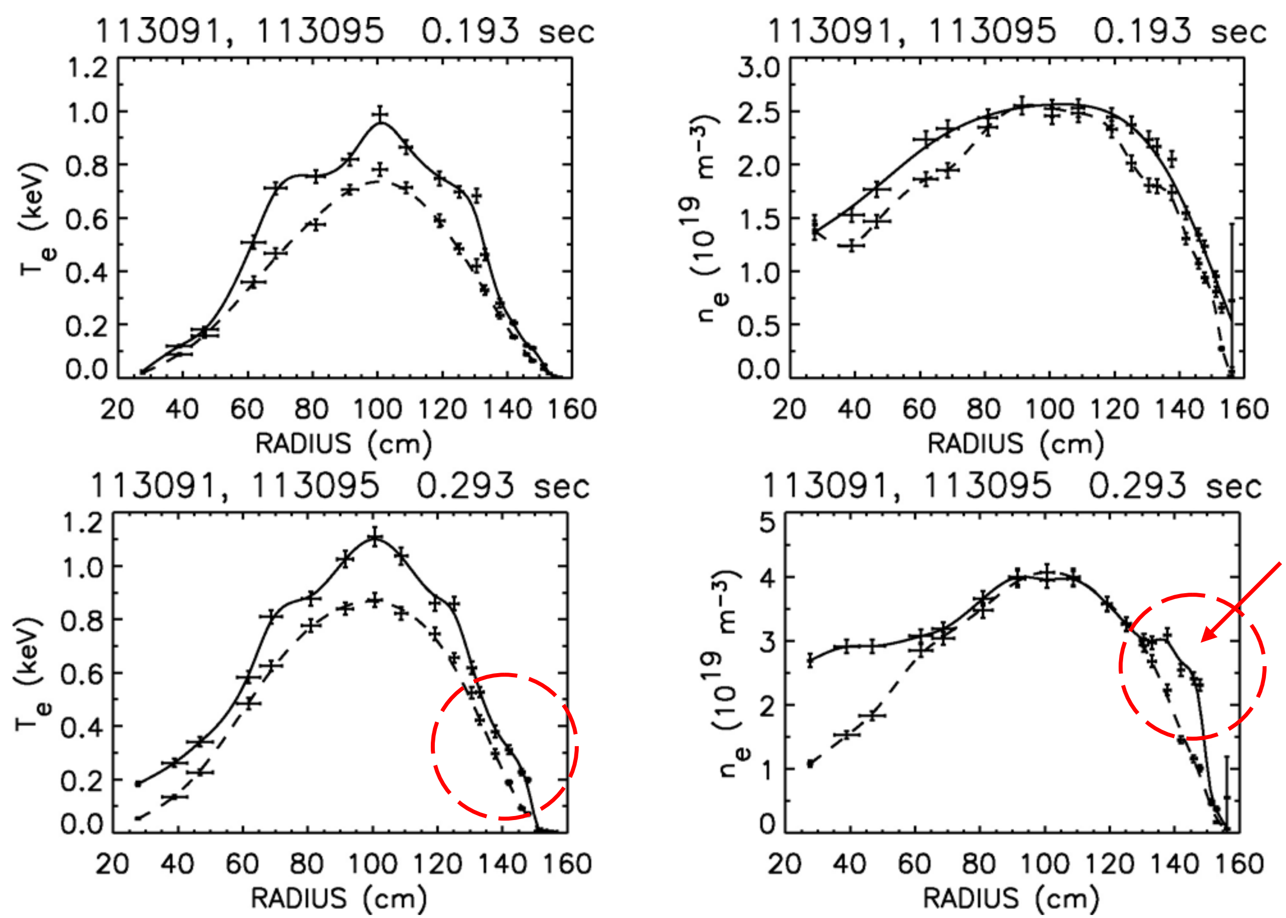
113091
RF@3.1 MW
NB@1.7 MW

113095
NB@1.7 MW



HHFW Increases Core T_e Compared to NBI-only

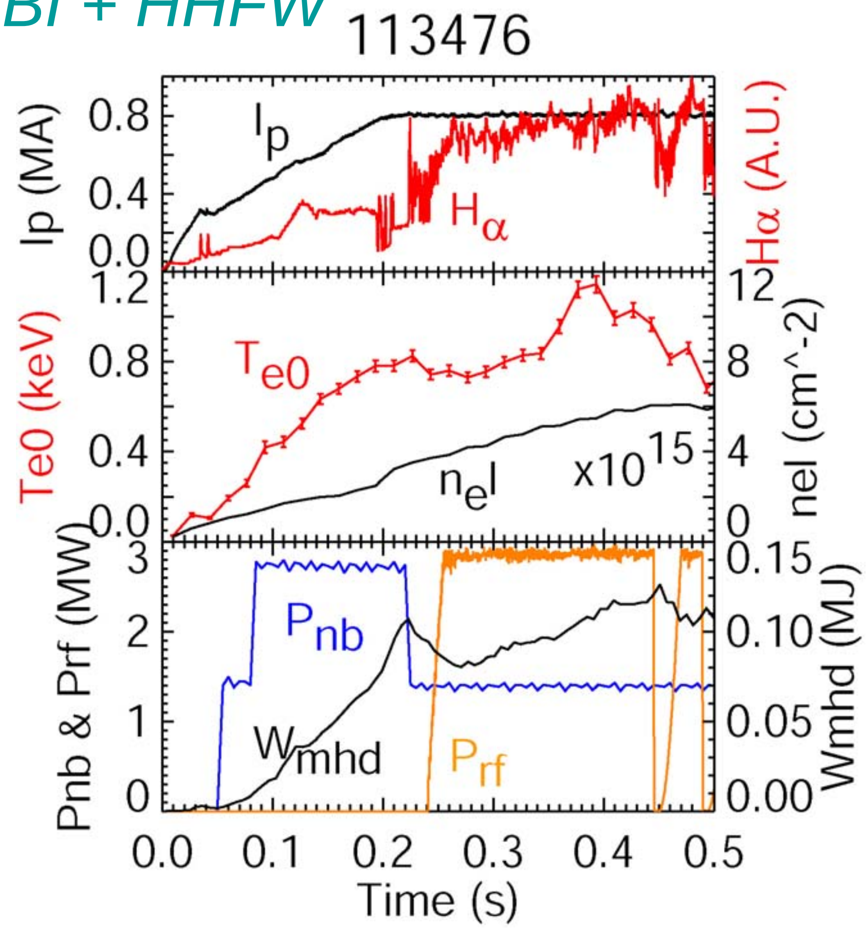
Overlay of HHFW+NBI (solid) and NBI (dash) at 0.193 and 0.293 s



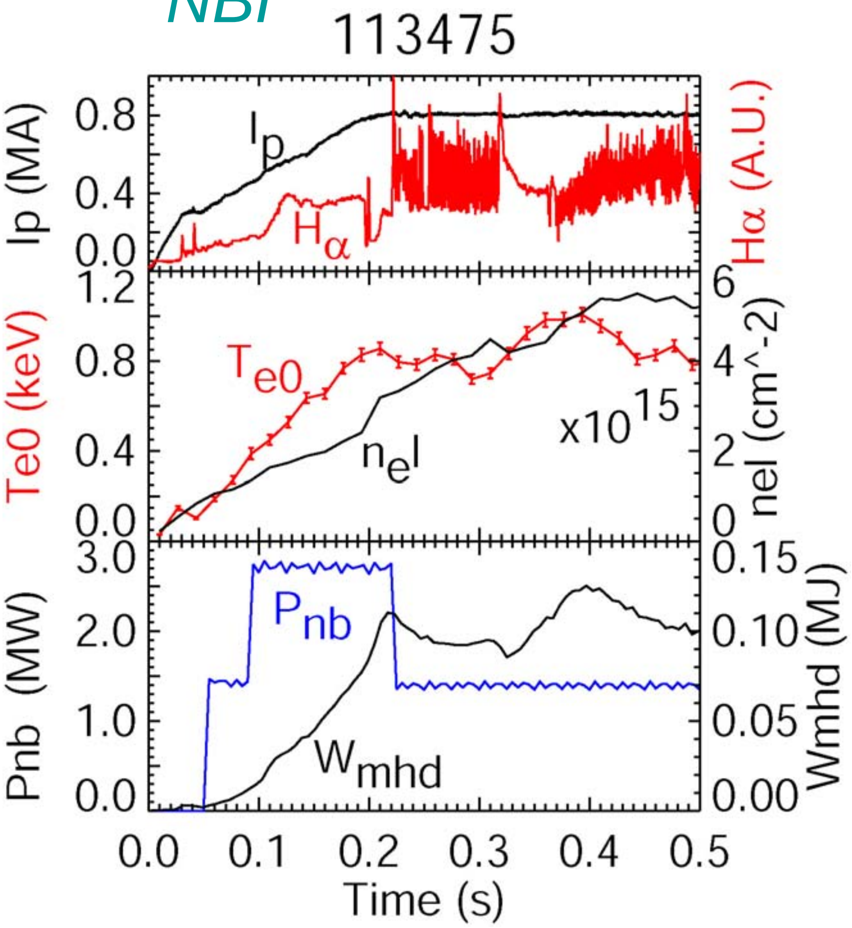
Plasma with HHFW enters H mode

HHFW Starts after H-mode Onset

NBI + HHFW



NBI



Use two NBI sources early on to assure NBI H-mode target plasma

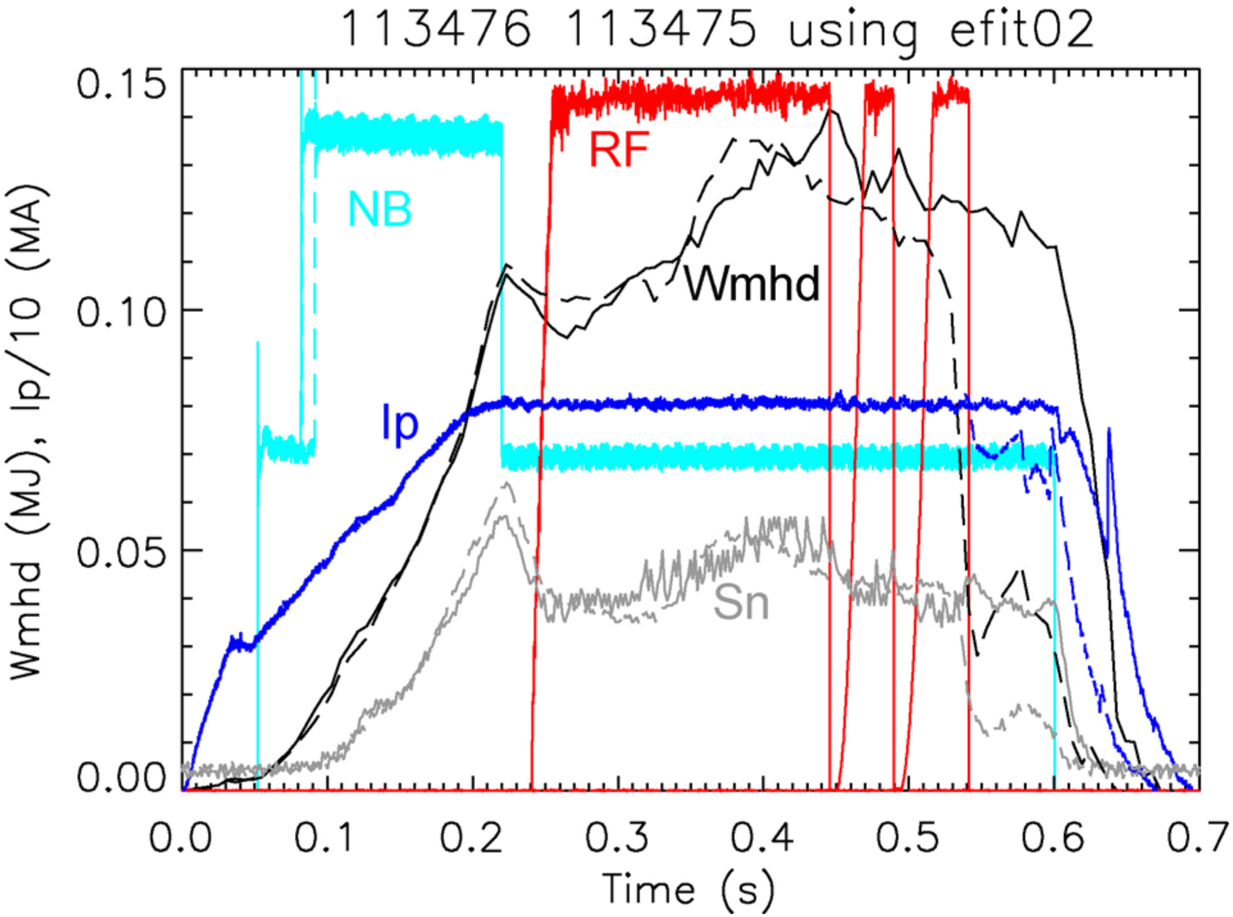
HHFW during NBI Driven H-mode Plasma

W_{mhd} and neutron (S_n) changes are small and reproducible, but appear more related to edge effects than to heating

<u>HHFW+NBI (solid)</u>
<u>NBI (dashed)</u>

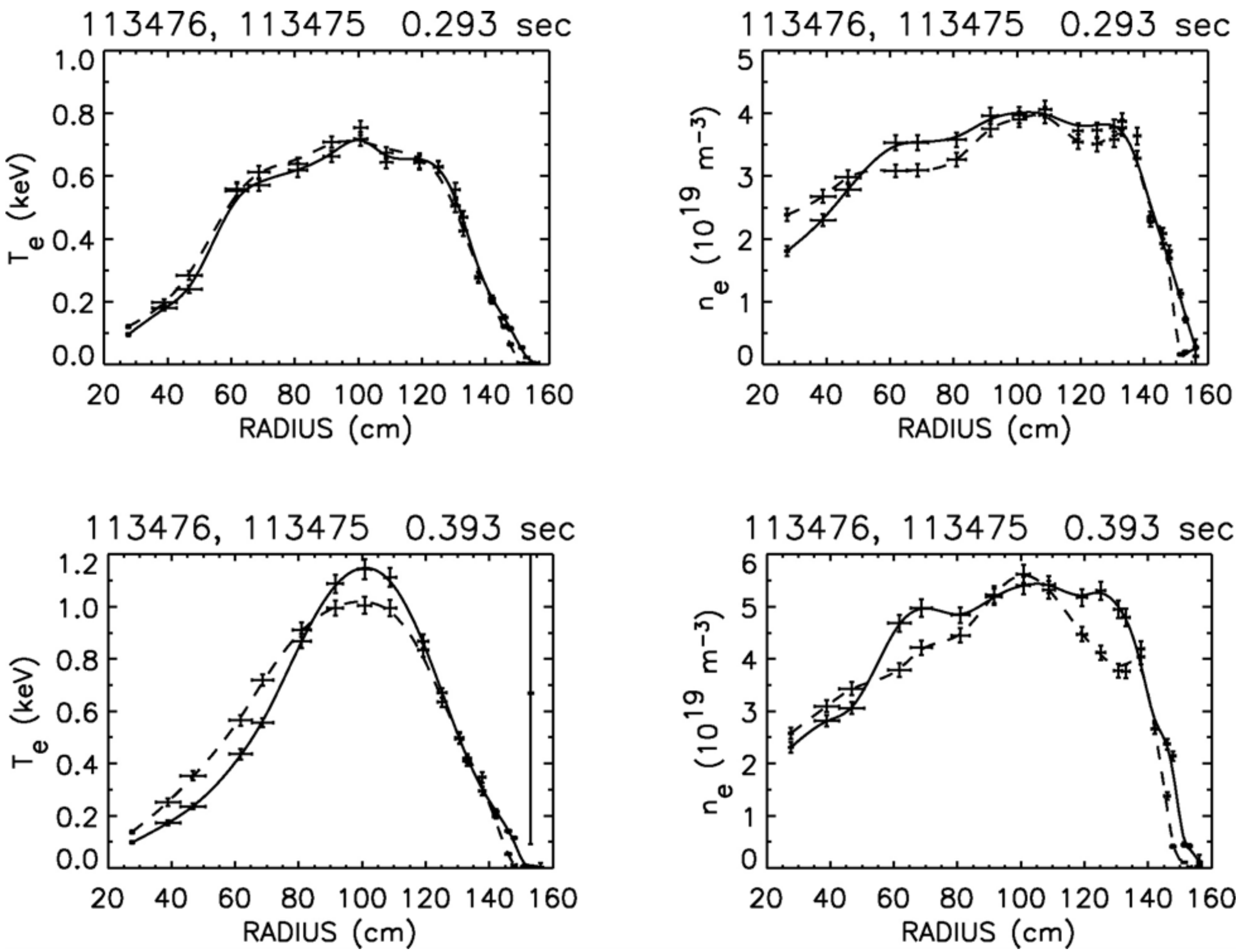
113476
RF@3.0 MW
NB@3.2 MW

113475
NB@3.1 MW



Very Little or No Change in T_e

Overlay of HHFW+NBI (solid) and NBI (dash) at 0.293 and 0.393 s



CONCLUSIONS (1)

- HHFW H-mode plasmas
  - Operational envelope extended to include $k_{//}$ = 14 and 7 m^{-1}, I_p up to 0.8 MA
  - Edge ion heating observed
  - Power threshold ≈ 1.5 MW for $k_{//}$ = 14 m^{-1} and ≈ 2 MW for $k_{//}$ = 14 m^{-1}. The latter could be explained by higher edge ion absorption observed for lower $k_{//}$. (S. Diem JP1.014).
  - NBI blips interact with HHFW and modify the time response of the neutrons.
  - NBI blips increase W_{mhd} by ≈ 10 %

CONCLUSIONS (2)

- Combined HHFW and NBI operation
  - HHFW starts during L-phase
    - Neutron rate double
    - Modest or small W_{mhd} increase
    - T_e increase observed over the extended core region. It is not verified yet whether this T_e increase corresponds the expected HHFW direct electron heating, or results for a trickling down of the HHFW power absorbed by the fast particles

CONCLUSIONS (3)

- Combined HHFW and NBI operation
  - HHFW starts during H-phase
    - Essentially no change in neutron rate or stored energy
    - No T_e increase observed
    - The HHFW does not seem to reach the plasma core
      - It is not understood whether the low edge density associated to the H mode, the edge ion heating generated by wave parametric decay, or other effect is/are responsible for this behavior.
- Analysis work is ongoing

Related Papers at this Meeting

• S. Bernabei,	JP1.011
• J.C. Hosea,	JP1.012
• C.K. Phillips,	JP1.013
• S. Diem,	JP1.014
• Ted Biewer,	RI1.001
• J.R Wilson,	CO3.012
• P. Ryan	CO3.013