Discussion of XP 835
HHFW Heating and CD Phase scans in NB Deuterium H-mode plasmas

Phil Ryan, Joel Hosea

R. Bell, L. Delgado-Aparicio, E. F. Jaeger, S. Kubota, B. LeBlanc, F. Levinton, C. K. Philips, S. Sabbaugh, G. Taylor, K. Tritz, J. Wilgen, J.R. Wilson

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Goals of Experiment

- Develop operation techniques for using HHFW in H-mode plasmas.
  - Obtain sufficient loading to couple power without arcing.
  - Handle L-H mode transitions.
  - Handle ELMs (may be future development)
- Determine HHFW power channels in H-mode
  - Edge heating (ions & electrons)
  - Damping on fast beam ions
  - Core electron heating

H-mode conditions in order of anticipated difficulty for HHFW

- HHFW into NBI-established H-mode.
  - Match to constant plasma load.
  - Concerns are low loading, antenna protection
  - Can outer gap be started at ~ 7 cm and moved to ~ 5 cm during H-mode?
  - What is minimum density at which H-mode can be sustained?
- NBI-triggered H-mode in HHFW-heated plasma.
  - L-H mode transition changes plasma load.
  - Time of transition may be predictable.
  - Change array phase to keep load constant or other tricks.
    - Programming gap may be one of other tricks
  - Can H-mode be sustained with HHFW?
- HHFW-driven H-mode
  - Time of L-H transition less predictable
  - Future work

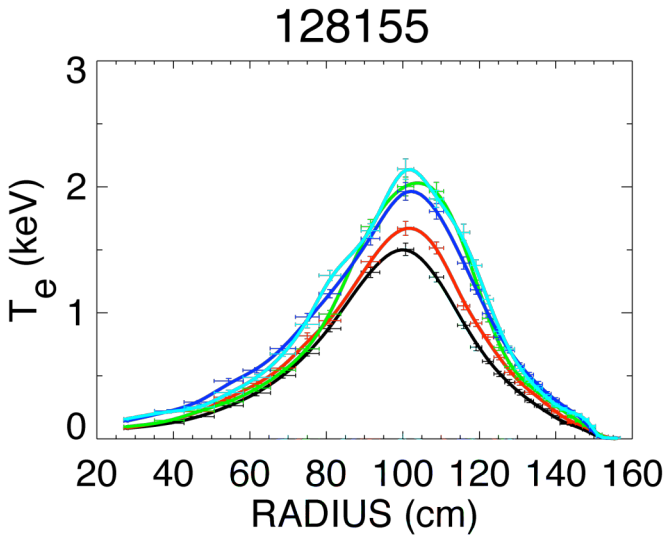
Previous HHFW/H-mode operation

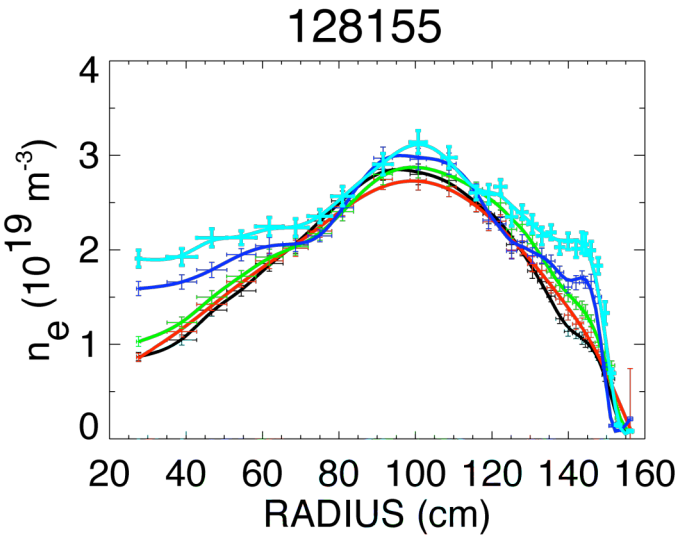
- 2004: XP 413 - HHFW and NB (LeBlanc)
  - NBI into HHFW pre-heated plasmas
    - W_{mhd} and neutron rate increases observed
    - Low efficiency
  - HHFW into NBI-driven H-mode plasmas
    - Waves do no seem to reach plasma core
- 2004: XP 425 - HHFW-only H-modes (LeBlanc)
  - $I_p \approx 0.6\text{-}0.8$ MA, $B_T \approx 0.45$ T, medium density DND
  - $k_{//} = 14$ and 7 m^{-1} at $I_p = 0.6$ MA, $k_{//} = 14$ m^{-1} at $I_p = 0.8$ MA
- 2008: MP 26 - HHFW conditioning in D_2 (Hosea)
  - $I_p = 0.65$ MA, $B_T = 0.55$ T, low density LSN, 1.7 MW at -150º
  - 70 kV, 40 ms NB during HHFW - RF-sustained H-mode
  - 90 kV, 40 ms NB during HHFW - H-mode tripped RF

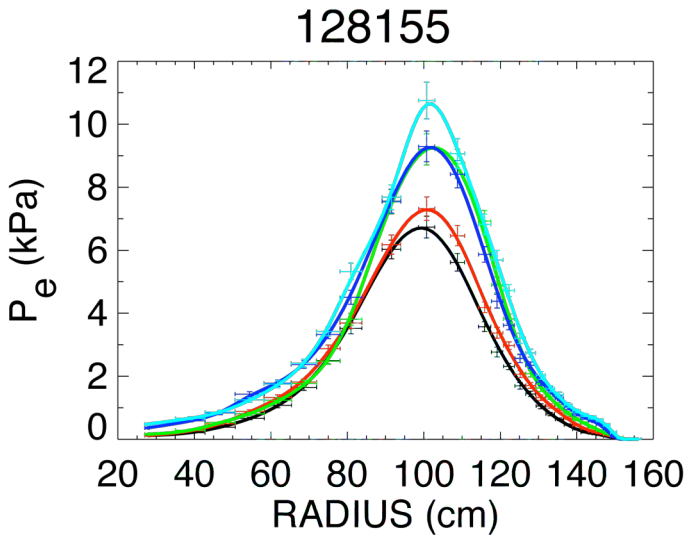
MP 26: 1 Apr 08 – Coupling to H mode - 70 kV beam

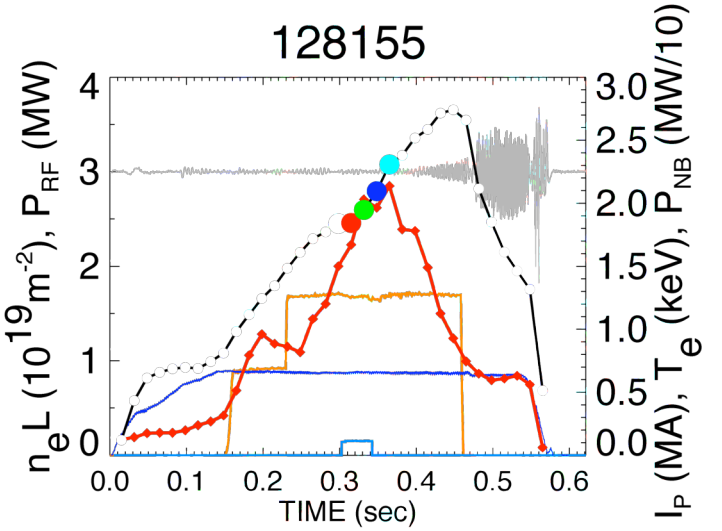
1.7 MW HHFW at -150º

H mode with 70 kV beam





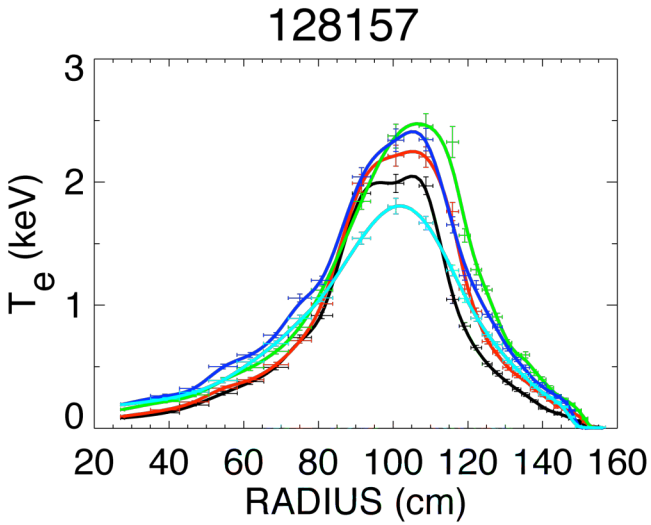


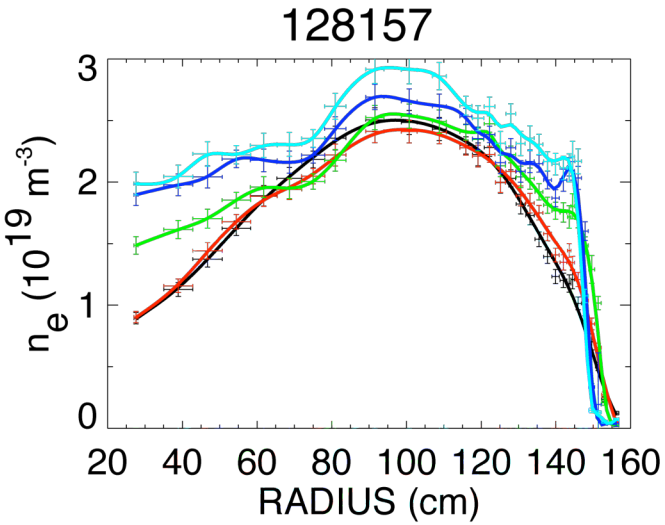


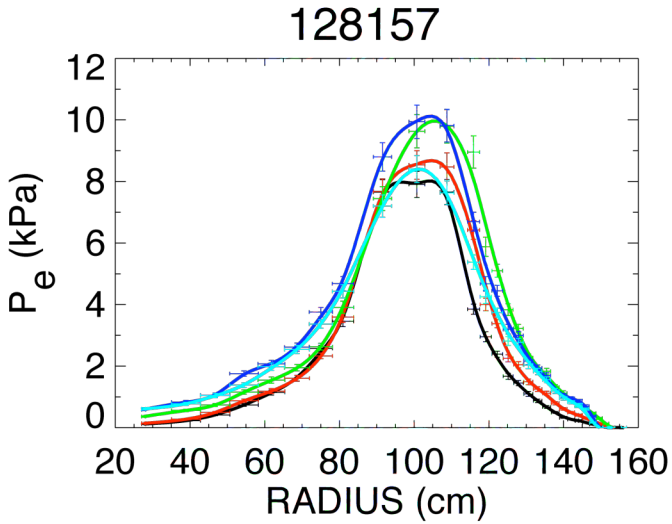
MP 26: 1 Apr 08 – Coupling to H mode - 90 kV beam

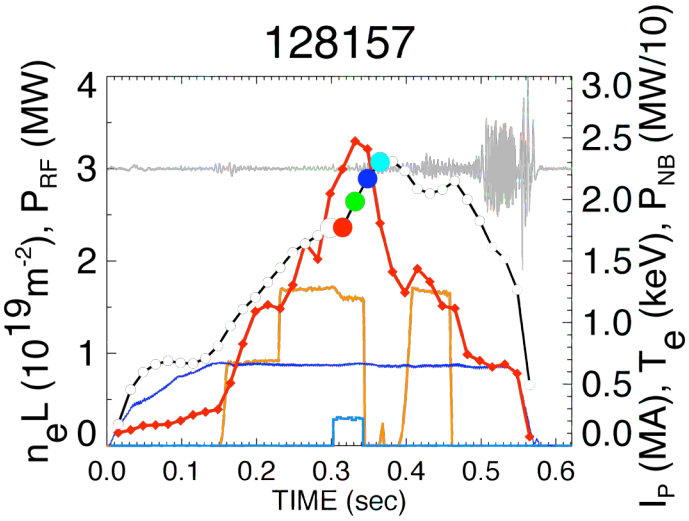
1.7 MW HHFW at -150º

H mode with 90 kV neutral beam

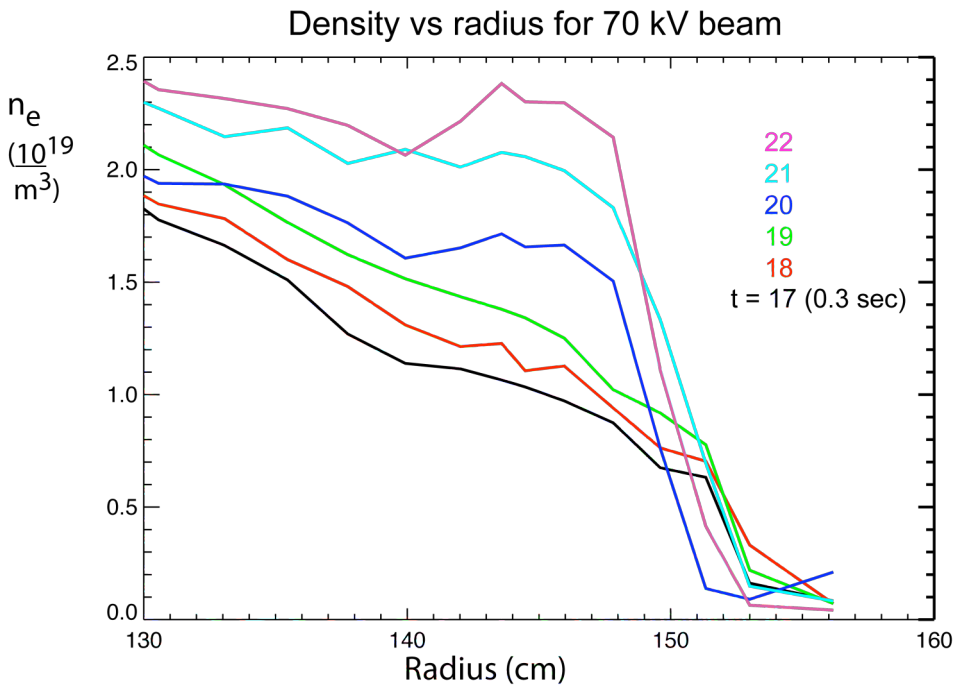


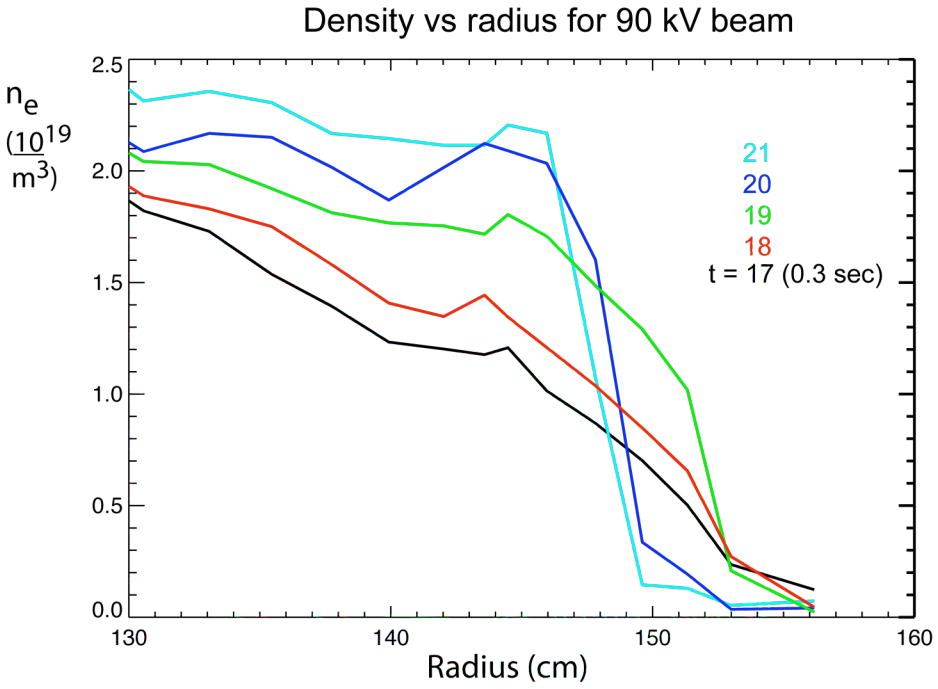






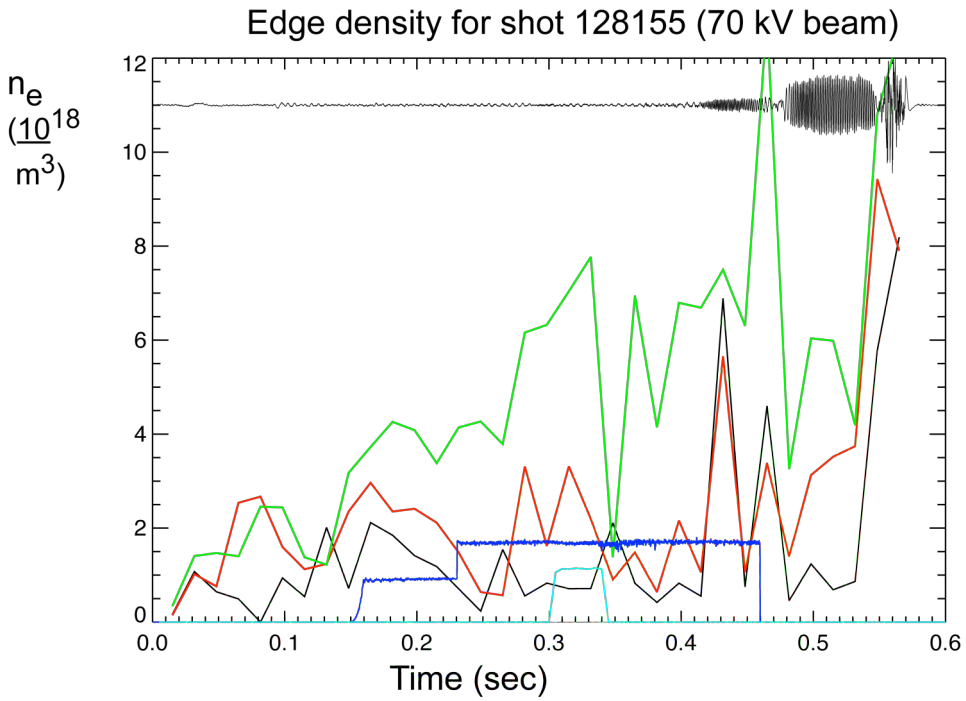
Edge density appears to be pushed away more for higher beam voltage

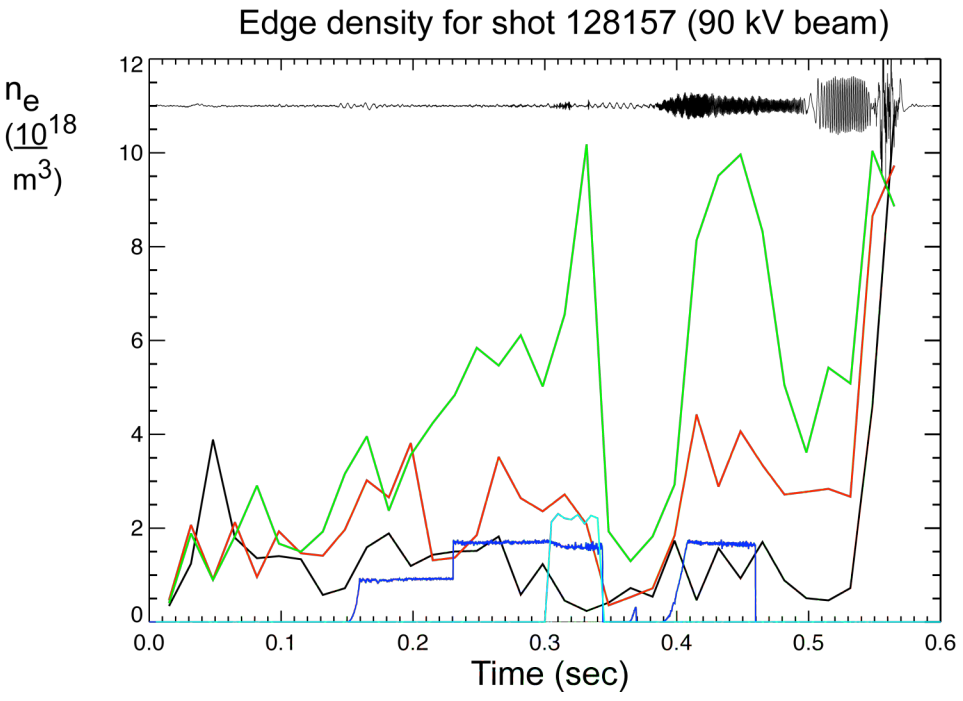




- Caused by reaction of plasma control to beam?
- Do we need to increase edge density in H mode?

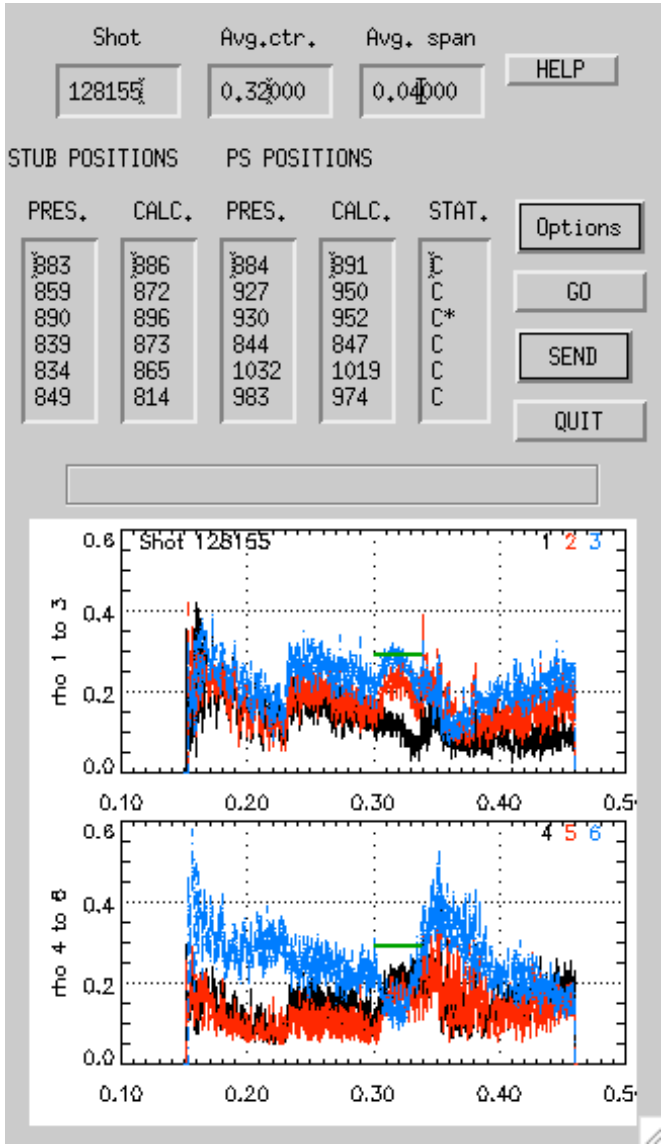
Interaction of NB with antenna is greater at higher NB V (power)



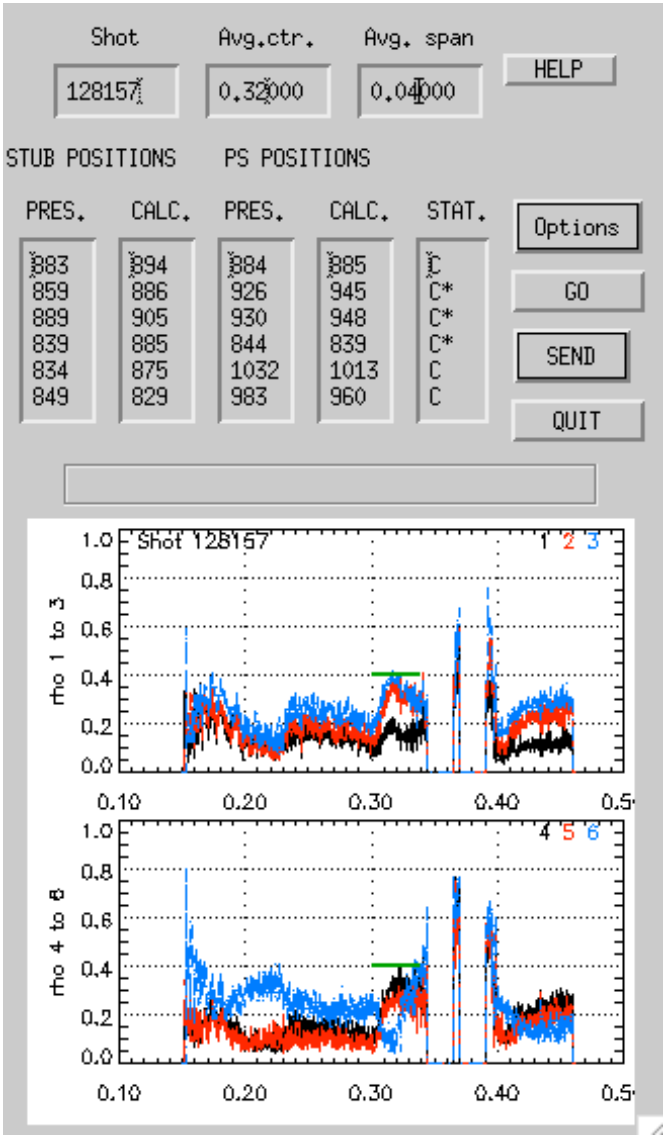


Rho typically increases during H mode

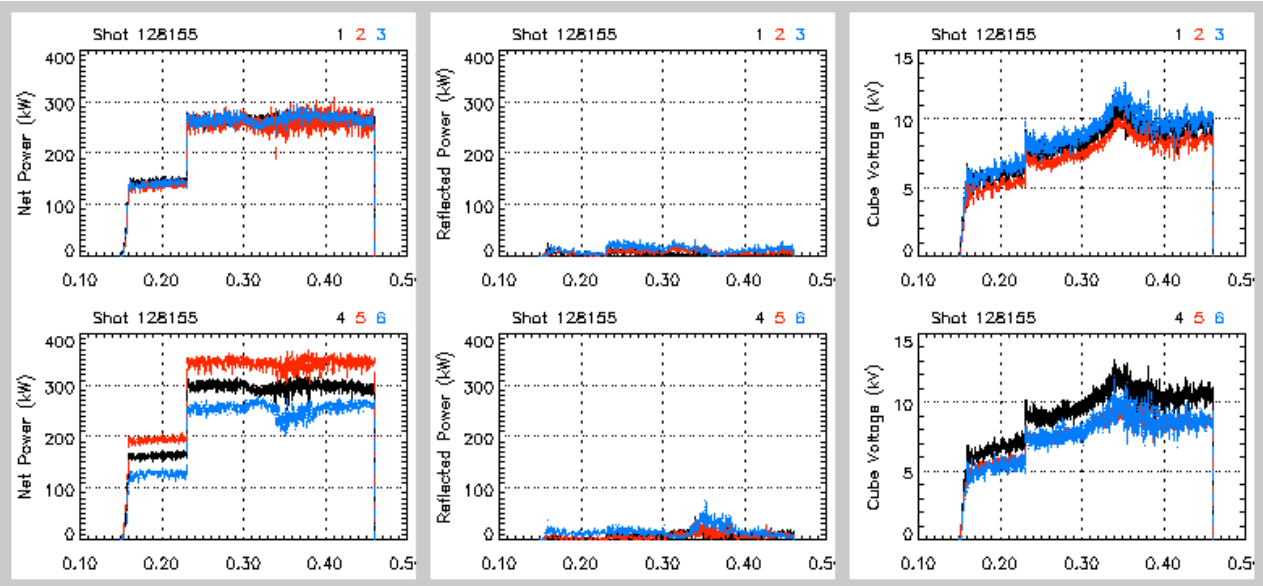
V = 70 kV



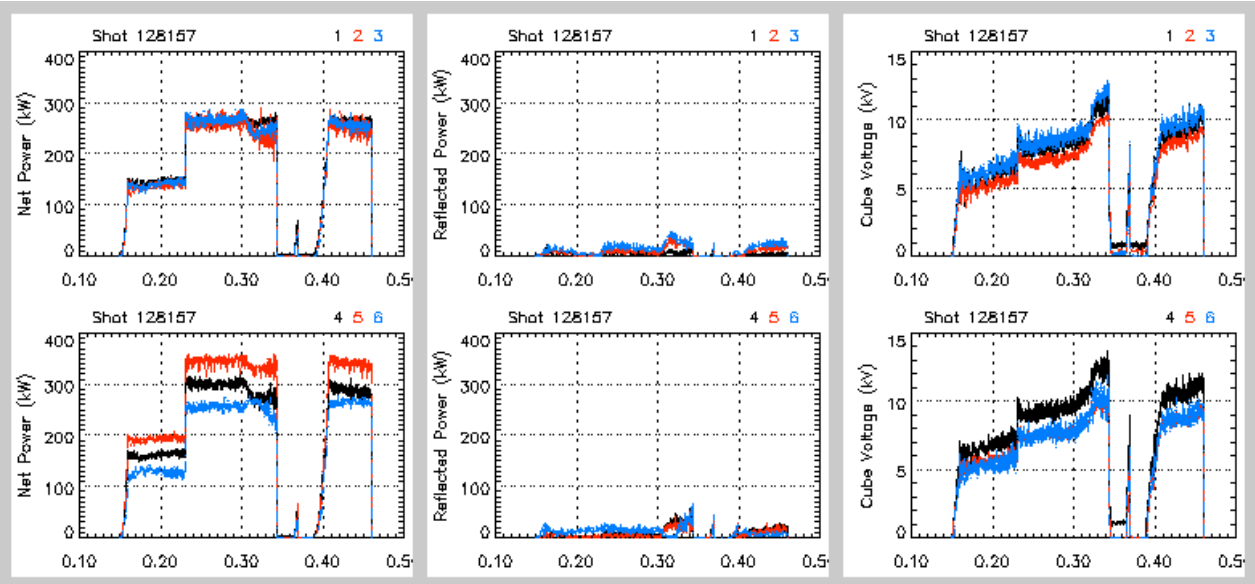
V = 90 kV



Antenna voltage suggests loading decreases during H-mode



V = 70 kV



V = 90 kV

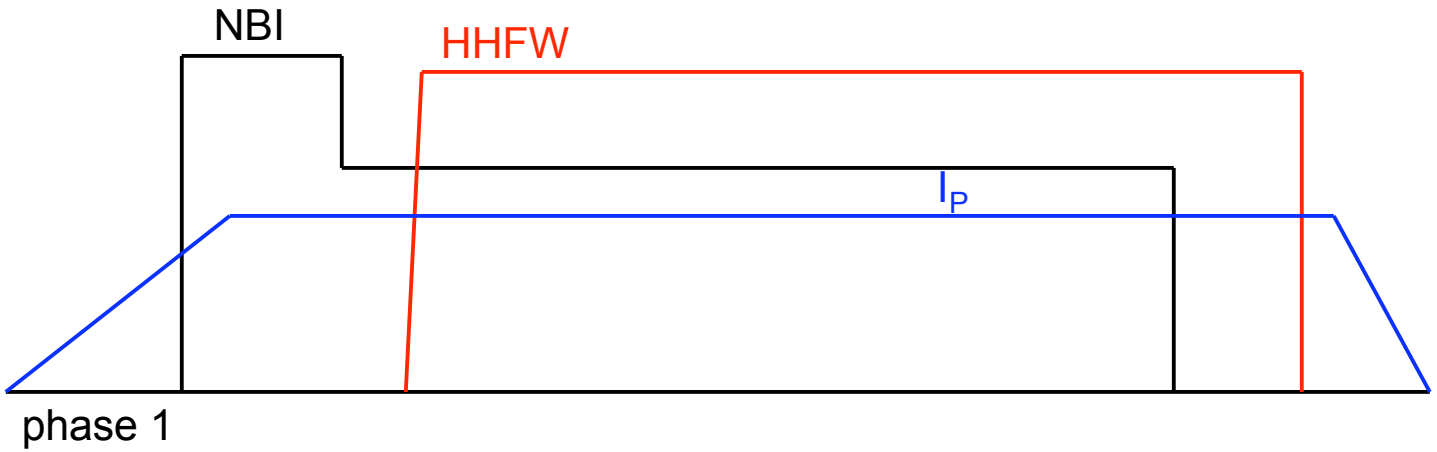
Shot List

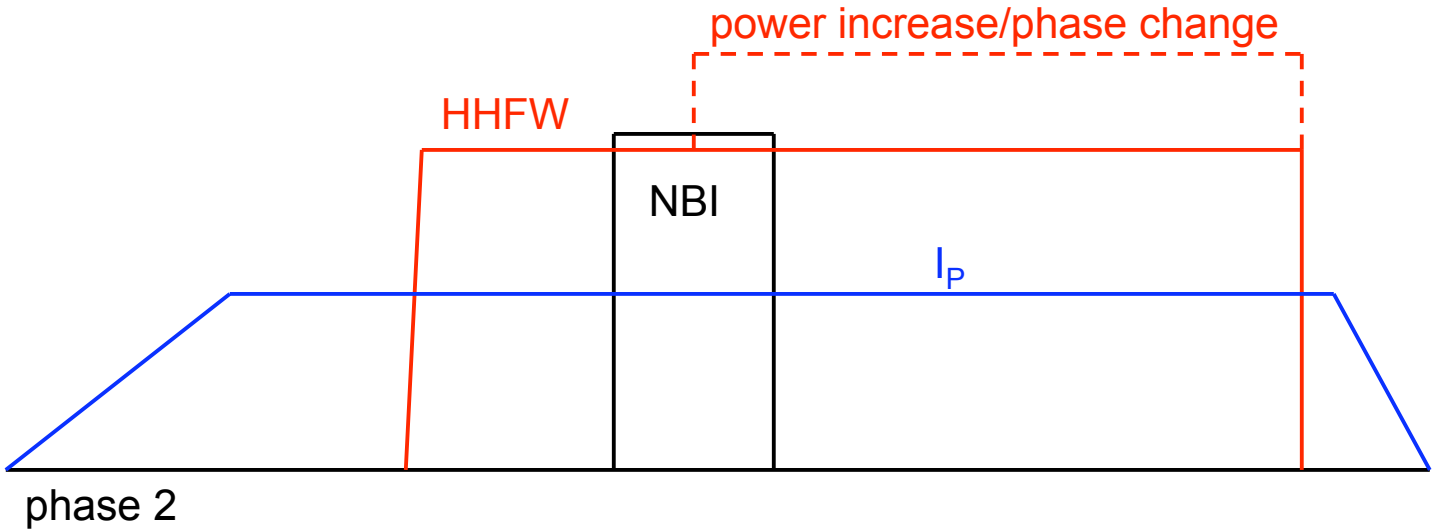
- Target plasma TBD: D_2, CS feed, 5.5 kG, I_p ~ 0.65-0.8 MA (I_p chosen for MHD stability and beam confinement.)
- Phase 1: HHFW into NBI-driven H-mode
  - Establish minimum NB power for stable H-mode.
    - Begin with NB source A throughout
    - Add NB source B if required for as short a duration as possible and then handoff to HHFW
    - Keep density as low as possible
    - Keep edge density at desired level by adjusting outer gap if possible
  - Outer gap 7 cm, phase -150º, increase RF power until V_{cube} > 10 kV
  - Outer gap 7 cm, phase -90º, increase RF power until V_{cube} > 10 kV
  - Repeat above for outer gap of 5 cm
  - Repeat above for outer gap of 7 cm ⇒ 5 cm
  - Chose gap that gave best results above, increase beam voltage (to study coupling to fast tail), -90º and -150º phasing.
  - Return to minimum beam voltage, best gap, +150º and +90º phase.
  - Prepare for phase two: turn off NBI and match RF at -150º and -90º in L-mode plasma.

Shot List (continued)

- Phase 2: NBI-triggered, HHFW driven H-mode
  - Set target to that of shot 128155
  - -150º phasing, trigger H-mode with 70 kV, 40 ms beam.
  - Add 90 kV 40 ms pulse for MSE at end of HHFW H-mode phase.
  - If H-mode transition trips RF due to decreased loading, try
    - Programing plasma to move closer to antenna after beam comes on.
    - Switching to -90º phasing (higher loading) during beam.
    - Matching to H-mode loading, tolerate reflected power during L-mode.
  - If H-mode is not sustained even if RF does not trip, increase HHFW during the NBI trigger.
  - Increase NBI power.
  - Repeat with 90 kV, 40 ms beam.
  - Repeat with 90 kV 100 ms beam.
  - Repeat with -90º phasing.

Shot timing


NBI
HHFW
I_P
phase 1


power increase/phase change
HHFW
NBI
I_P
phase 2

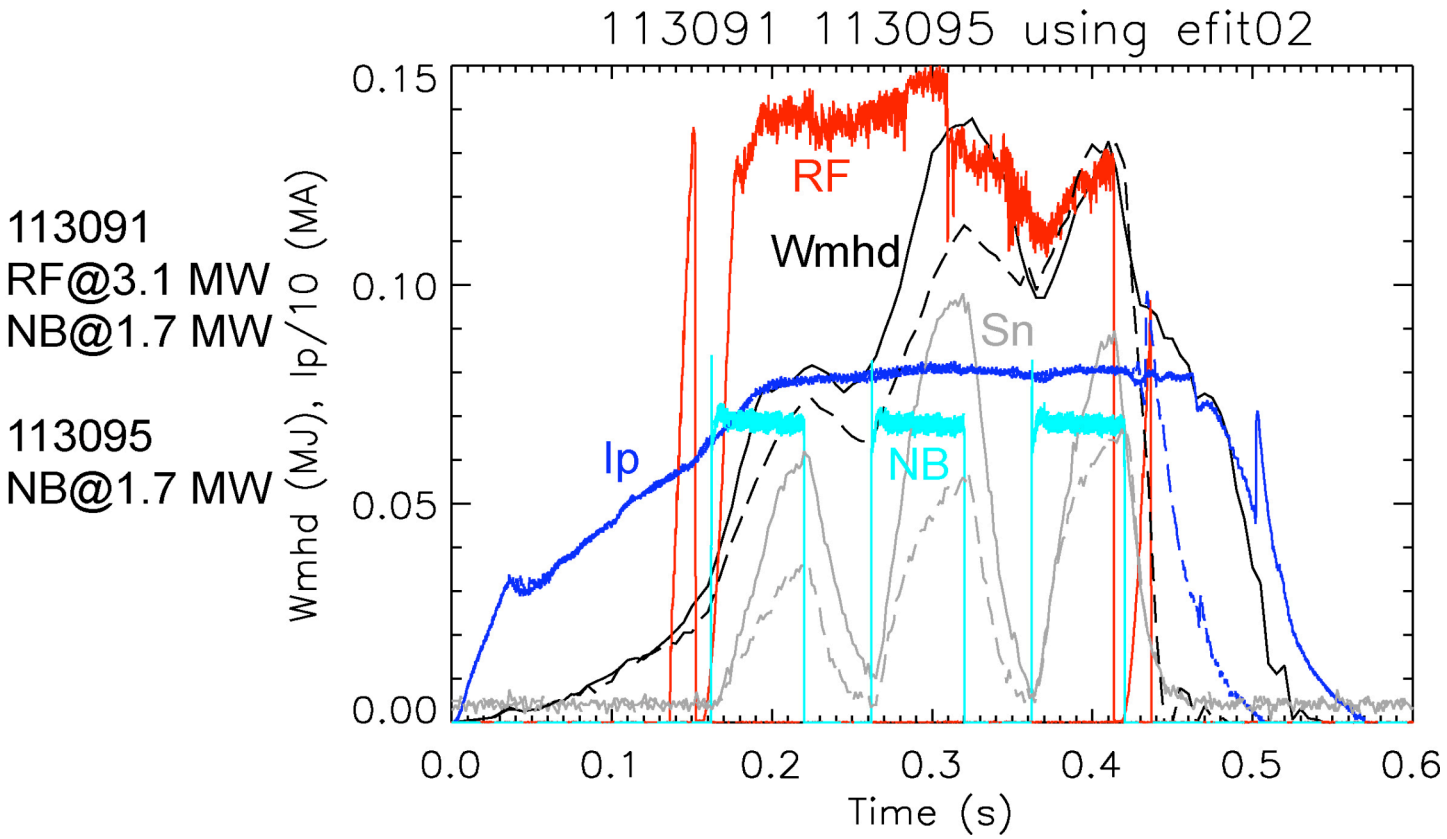
Desired Diagnostics

- Edge reflectometer
- Thomson scattering
- CHERS
- MSE
- FIDA
- NPA
- Soft x-rays
- high-k scattering

backup material

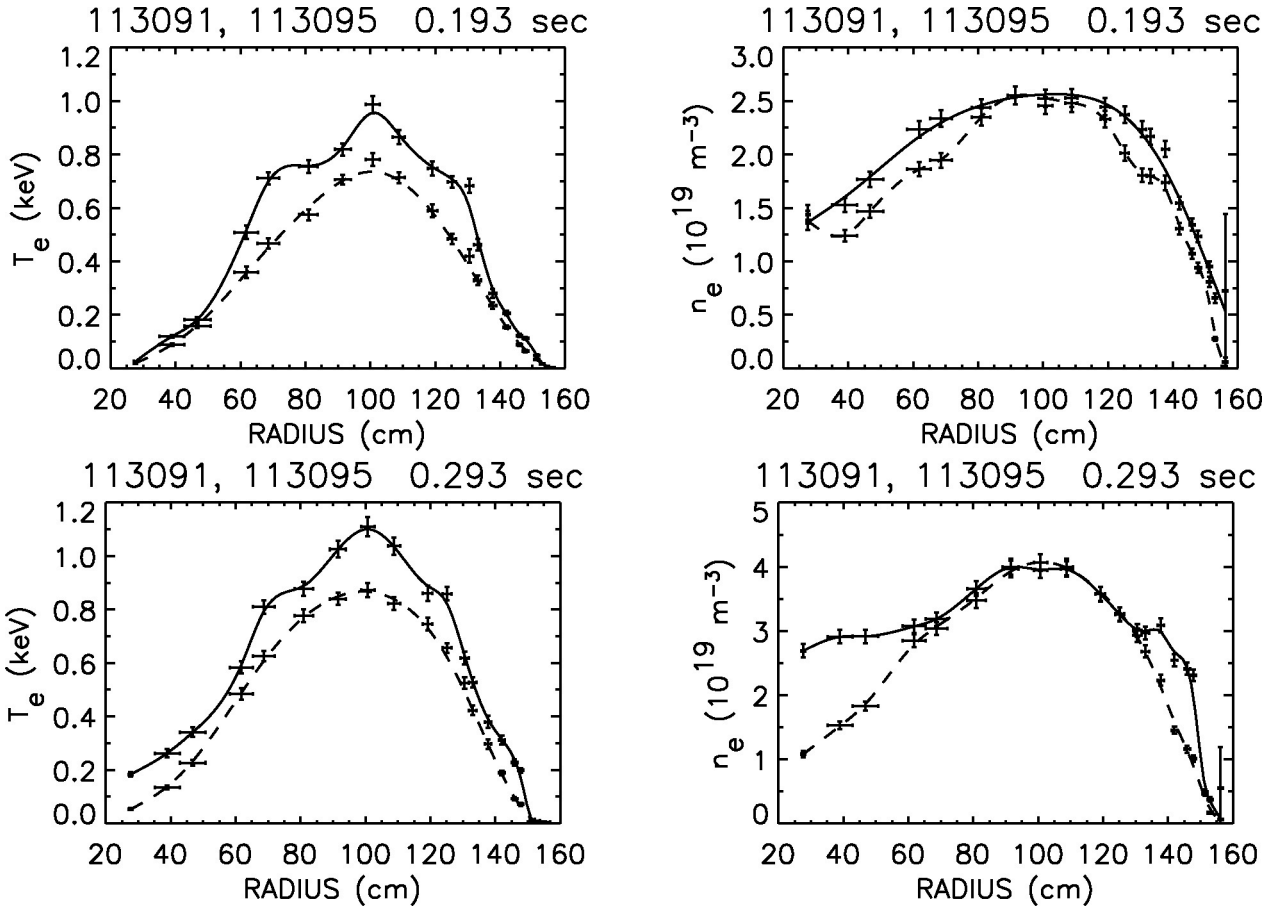
XP413 NBI Pulses into HHFW Heated Plasma

Observed W_{mhd} and Neutron (S_n) Increases
S_n increase larger than for W_{mhd}



HHFW Increases Te compared to reference NBI-only plasma

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

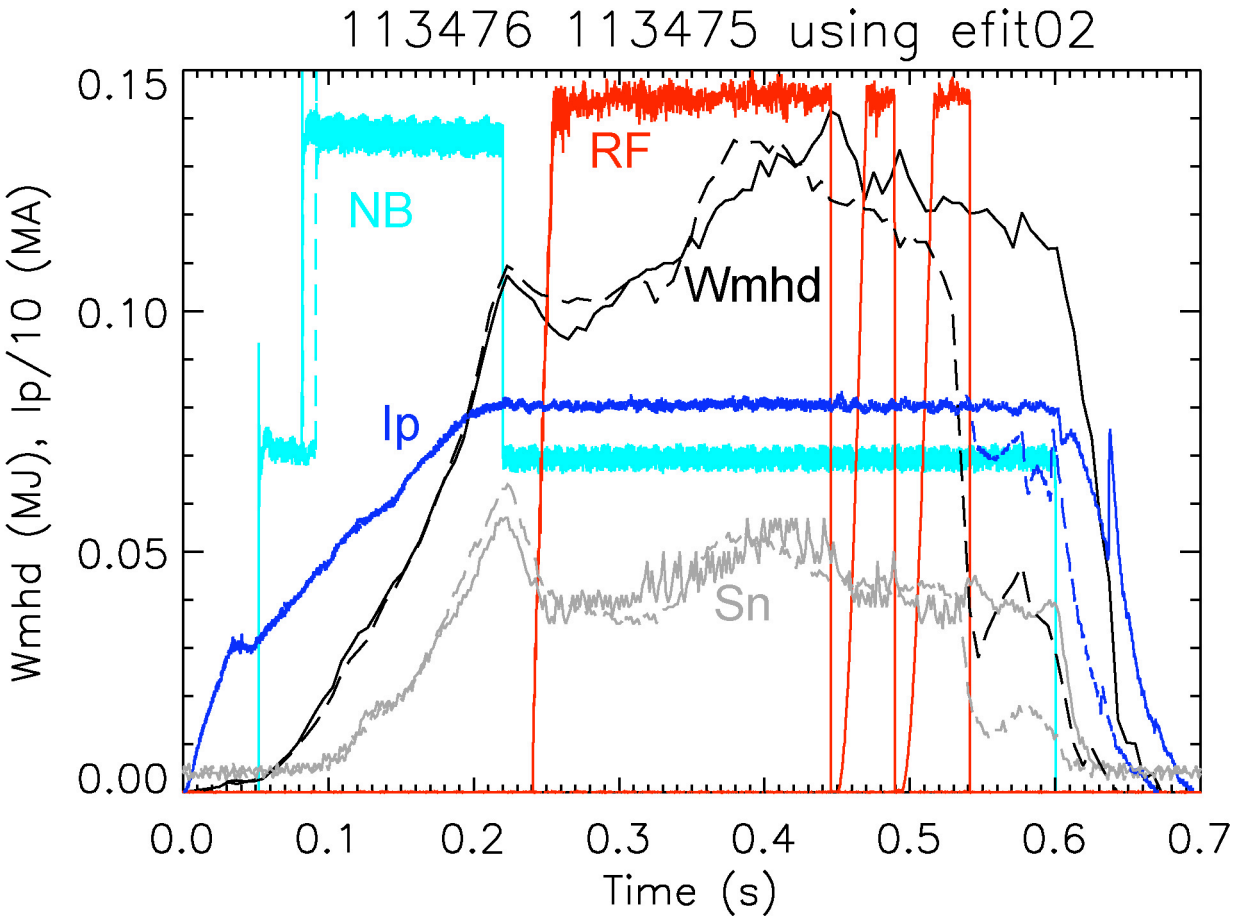


XP413 HHFW into NBI Driven H-mode Plasma

Small Effects On W_{mhd} and Neutron (S_n) Are Reproducible
Seem more compatible with edge effects than heating

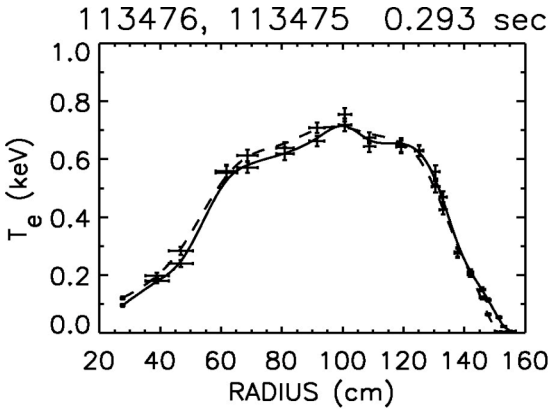
113476
RF@3.0 MW
NB@3.2 MW

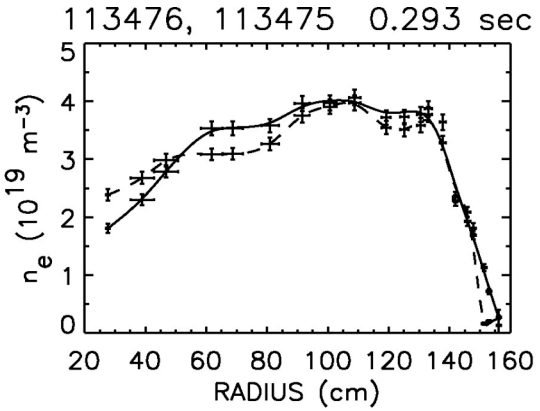
113475
NB@3.1 MW

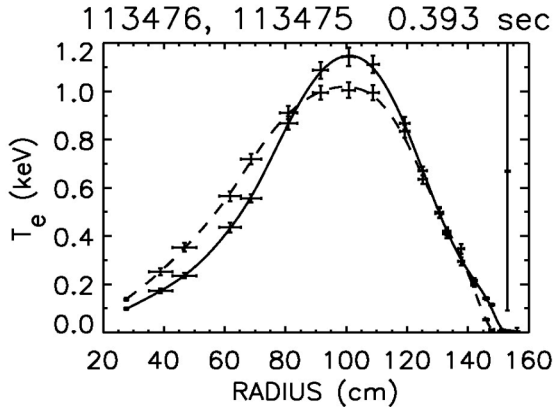


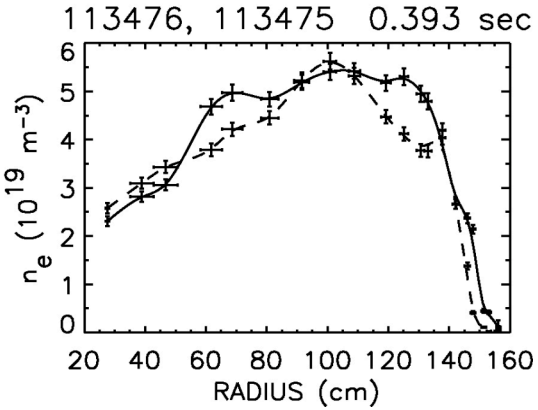
Very Little or No Change in Te

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







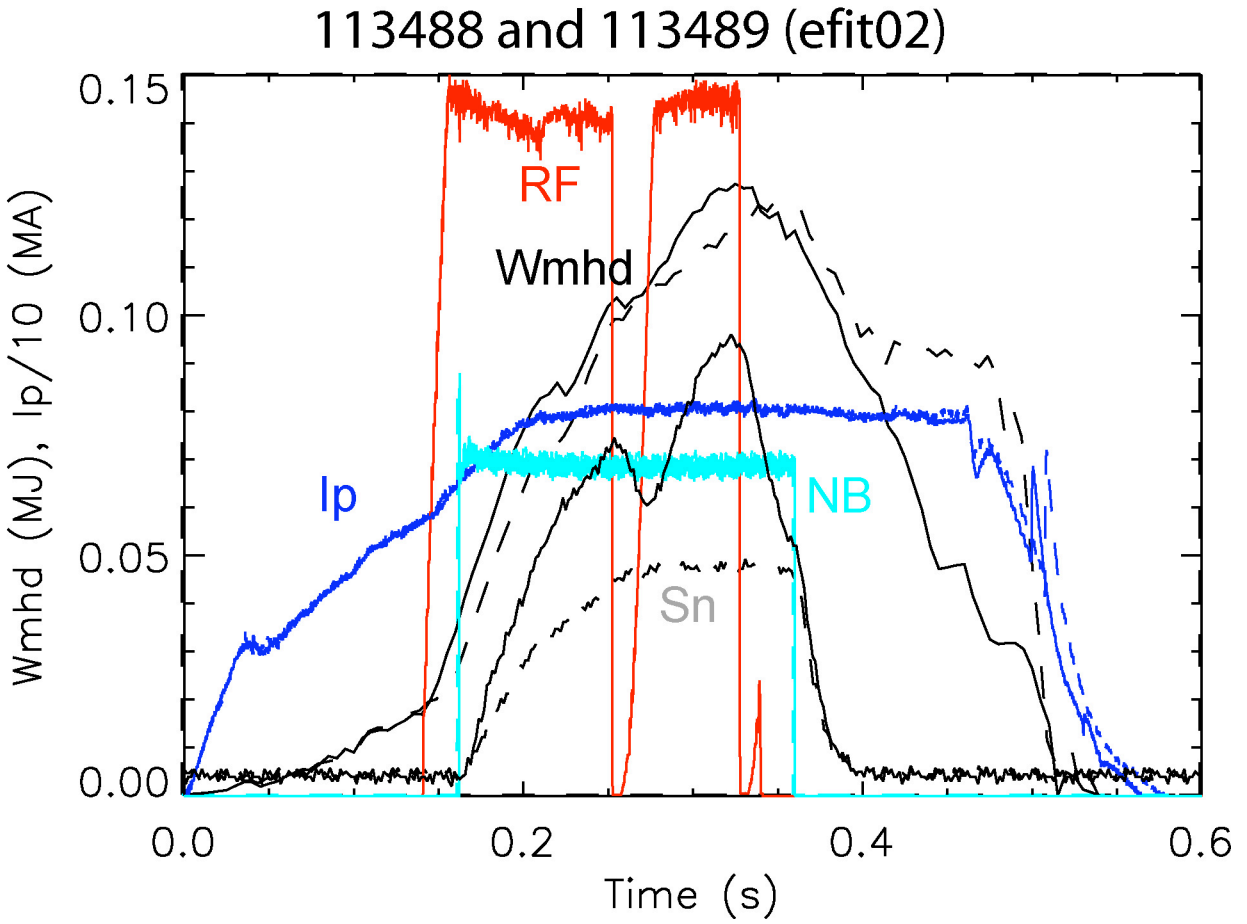


XP413 NBI into Preheated Plasma with HHFW

Observed Wmhd and Neutron (Sn) Increases but poor efficiency

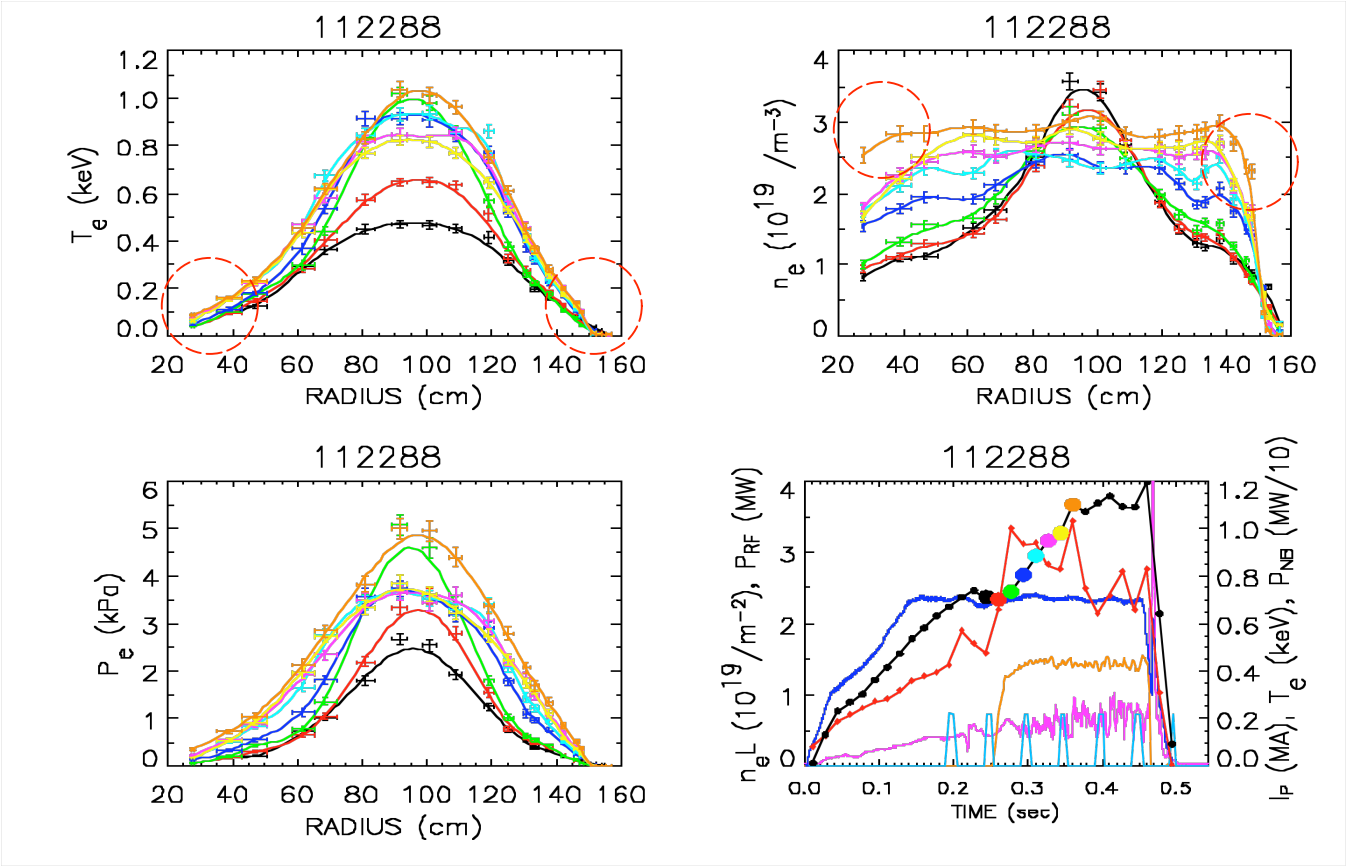
113488
RF@2.9 MW
NB@1.8 MW

113489
NB@1.7 MW



XP425 HHFW H-mode at 0.7 MA

HHFW with beam blips, $k_{//} = 14\ m^{-1}$, 1.5 MW



XP425 HHFW Driven H-mode at 0.8 MA

HHFW only, $k_{//} = 14\ m^{-1}$, 2.0 MW