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XP 825 & 835
Heating and CD Phase Scans in L-Mode and H-mode Deuterium Plasmas

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P. M. Ryan (ORNL)

for the NSTX Wave-Particle Interaction Team

Culham Sci Ctr
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NSTX Results Review
PPPL August 7, 2008

HHFW Operation in 2008

- The HHFW system was in use for 20 days during the run and supported 10 individual XPs.
- There were two full days and three half days of HHFW antenna conditioning with plasma under MP-26 in 2008.
  - Plasma conditioning both before and after the introduction of Li.
  - Vacuum conditioning in the evenings before extended HHFW operation.
  - This conditioning enabled the HHFW system to operate reliably in supporting the NSTX experimental program.
- Two and a half days were devoted to HHFW XPs
  - One and a half days to XP825 (HHFW Heating of L-Mode Deuterium Plasmas).
  - One day to XP835 (HHFW Heating of H-Mode Deuterium Plasmas)
- Some of the best HHFW results came while providing rf heating support to experiments in the Wave-Particle Interaction and other Topical Science Groups.

Heated D, He Plasmas to 5 keV with 3.1 MW of $k_{||} = 14\ m^{-1}$ (XP821 - High-k Scattering - Mazzucato)

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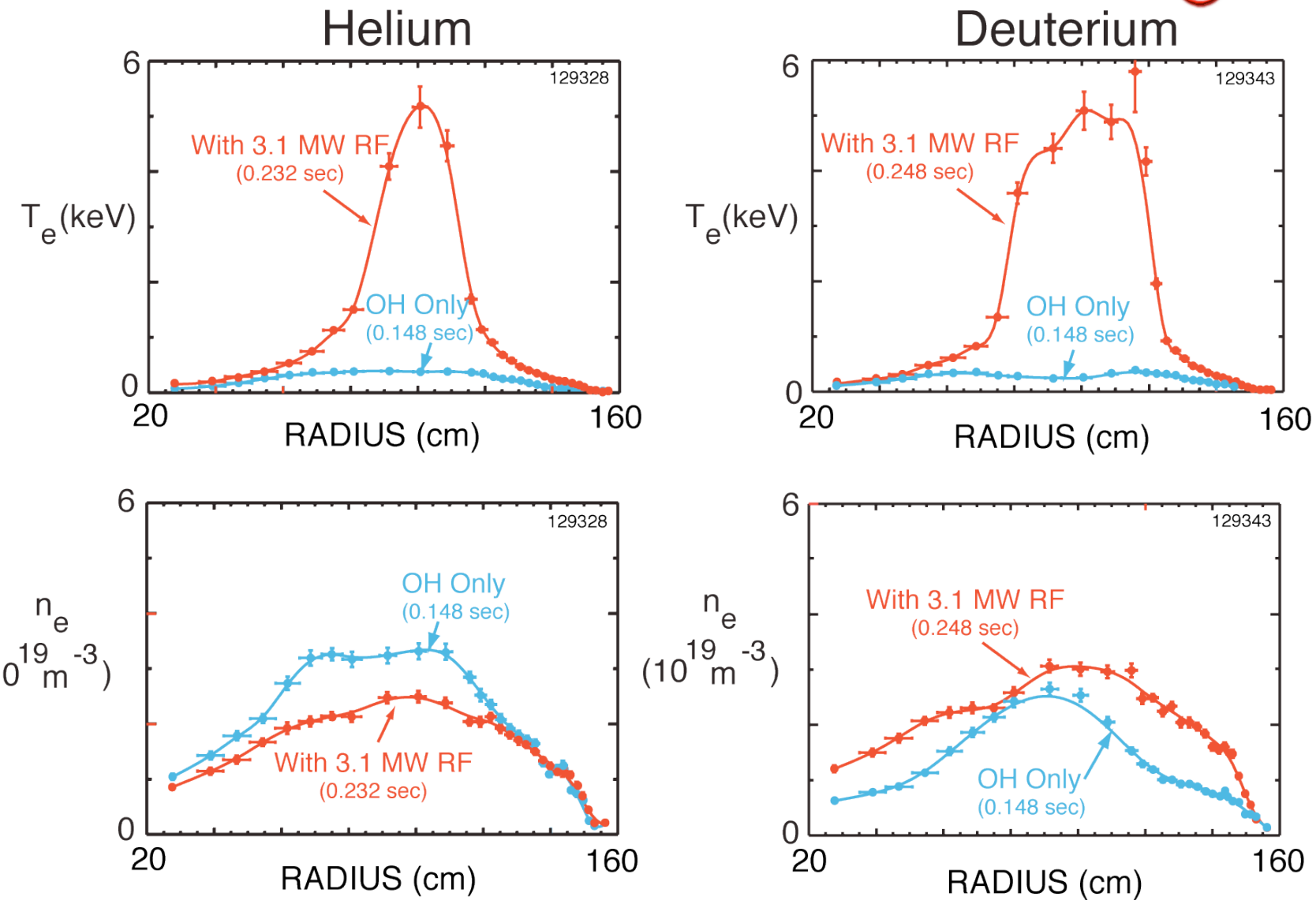

XP825 - HHFW Heating/CD Phase Scans in Deuterium L-mode Plasmas

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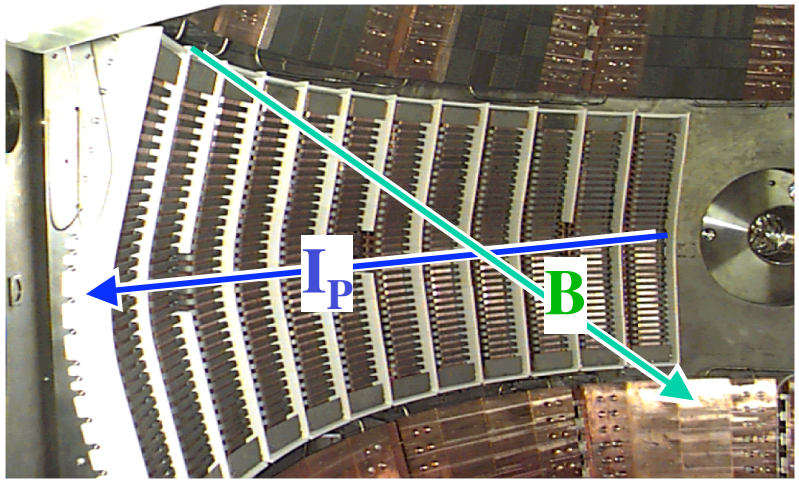
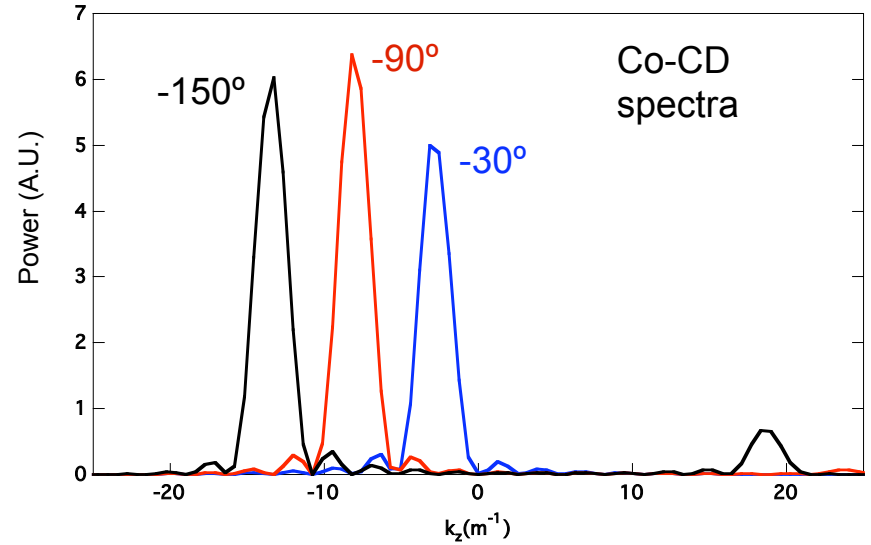
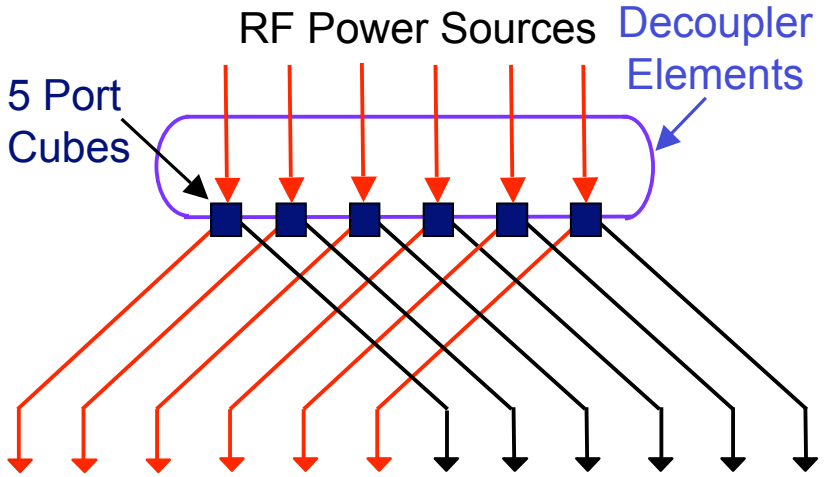
- Motivation:
  - Determine if the improvements in power coupling in helium plasmas arising from increased field (5.5 kG) and lower edge density operation could be carried over to deuterium plasmas.
- Objectives:
  - Keep edge density low enough to prevent wave propagation near the wall.
  - Determine heating efficiency dependency on wavenumber (inverse wavelength).
  - Determine current relaxation time with time-resolved MSE measurements of HHFW driven current (by moving NBI blips in time)
- One day with NBI and no LITER.
- Half day with LITER and no NBI

NSTX HHFW Antenna Array Toroidal Spectrum Highly Directional For Phase Shifts of ±30º, ±90º and ±150º



HHFW antenna extends toroidally 90˚

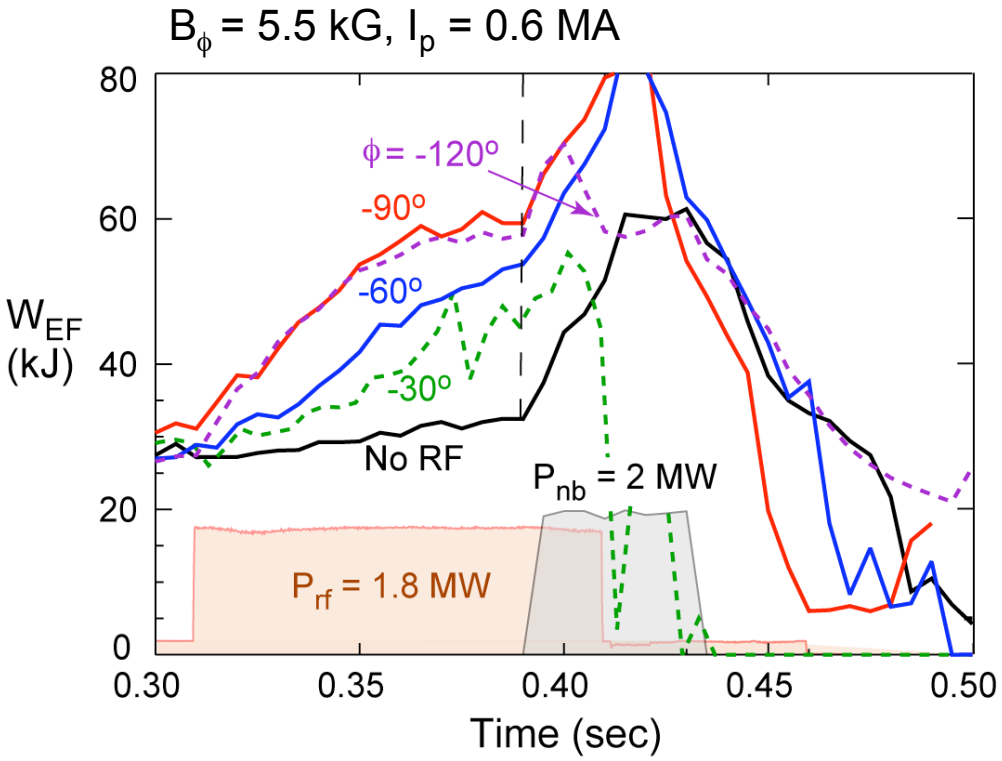


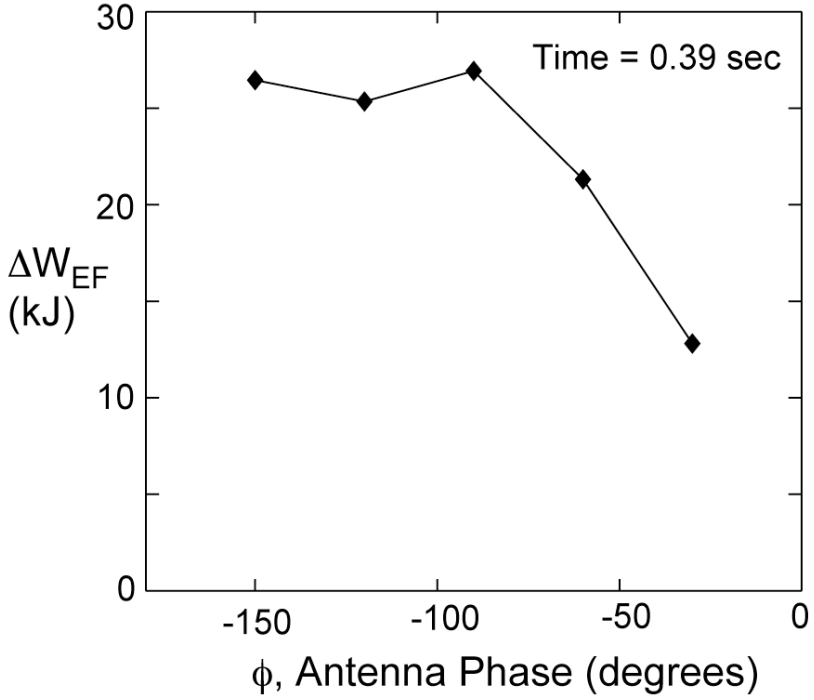


- Straps in each loop fixed at 180º out of phase.
- Phase between adjacent loops easily adjusted between 0º to 180º.
- Full 12-element array operation for $\Delta\phi$ = ±30º, ±90º, ±150º.
- Large B pitch affects wave spectrum in plasma core.

Previous Operation in He Showed Heating Efficiency Maintained for $\phi \geq -90^o$ ($k_\phi \geq -8\ m^{-1}$) at $B_\phi = 5.5$ kG

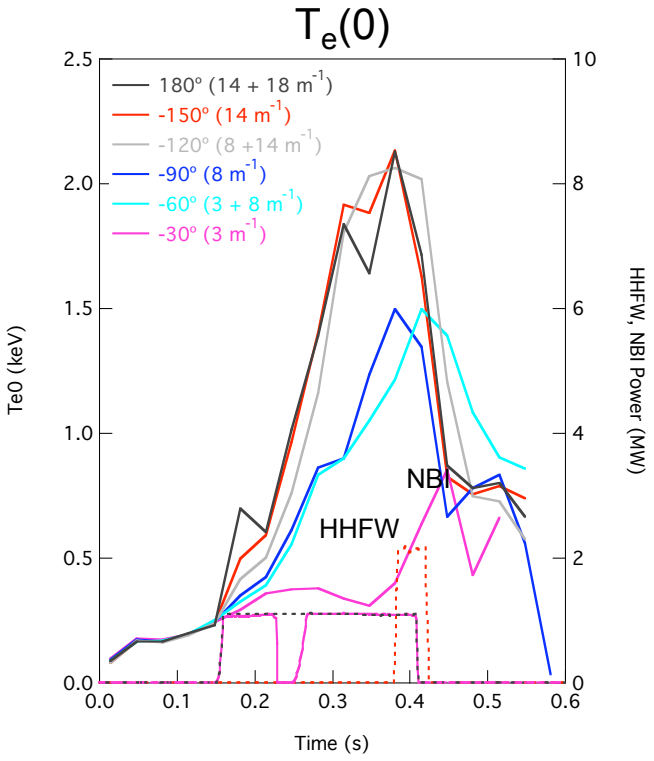
- Heating efficiency at strap-to-strap antenna phase, $\phi = -30^o$ approximately half the efficiency at $\phi = -90^o$

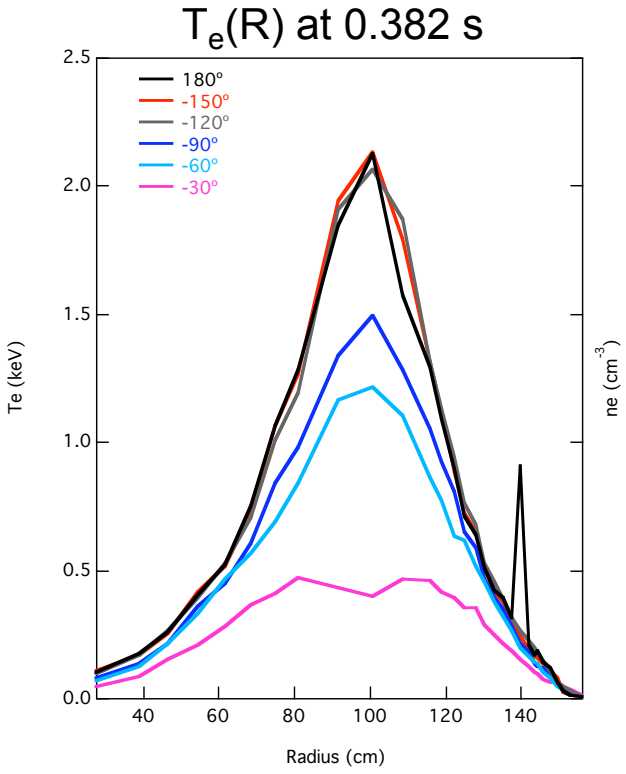


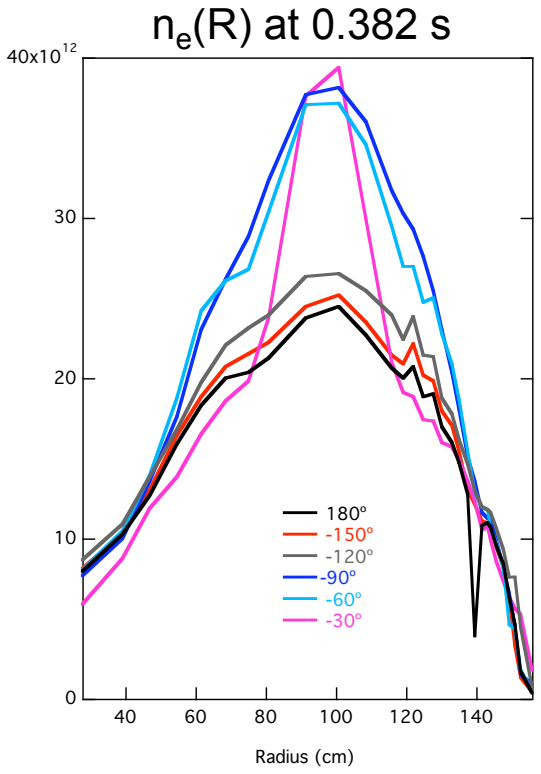


XP825 - Phase scan showed strong dependence of HHFW heating on $k_{||}$ in L-mode deuterium plasmas

- Array phase shift scanned from -180° to -30°, in 30° increments (128657,61-63,65-66)
- Behavior of electron profiles in D plasmas comparable to results for helium plasmas







Central T_e heating rate faster for high wavenumber (short wavelength) phasings

Higher wavenumber phasings lead to centrally peaked Te profiles

Lower wavenumber phasings increase central density

$k_{||}$ Dependence of HHFW Heating Efficiency in D_2 Similar to He Plasmas

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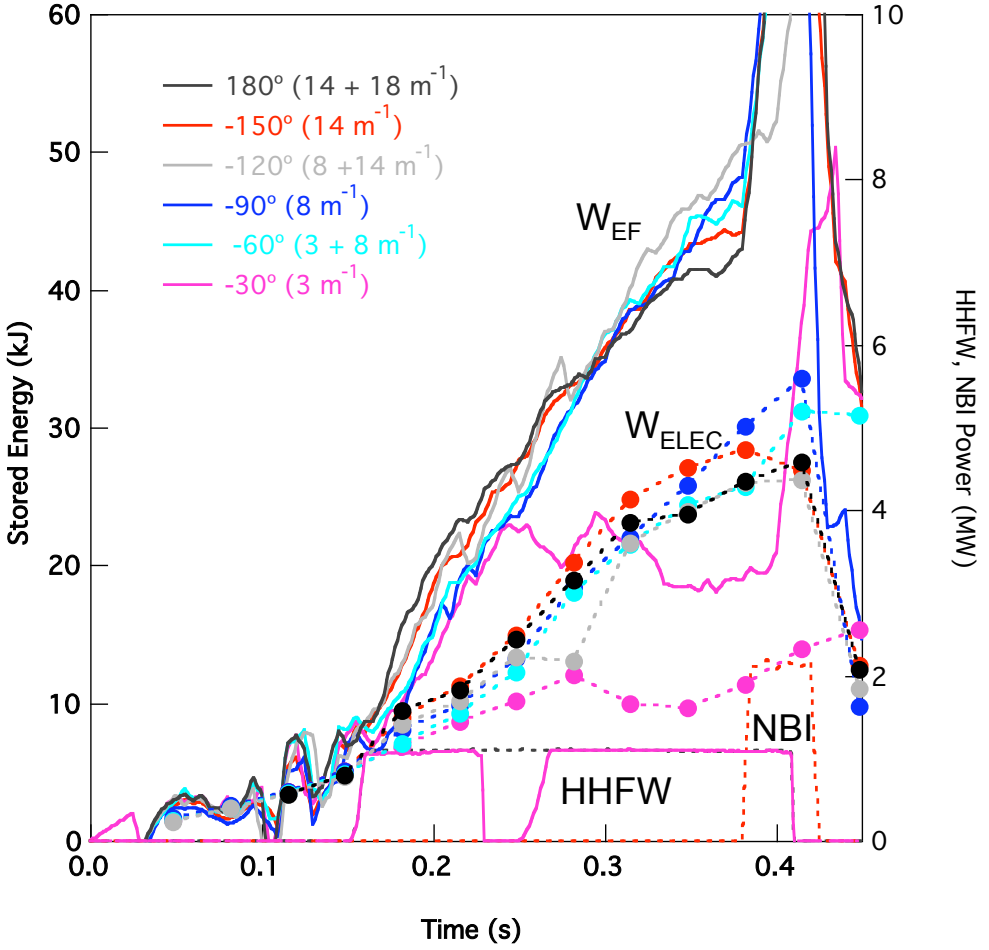
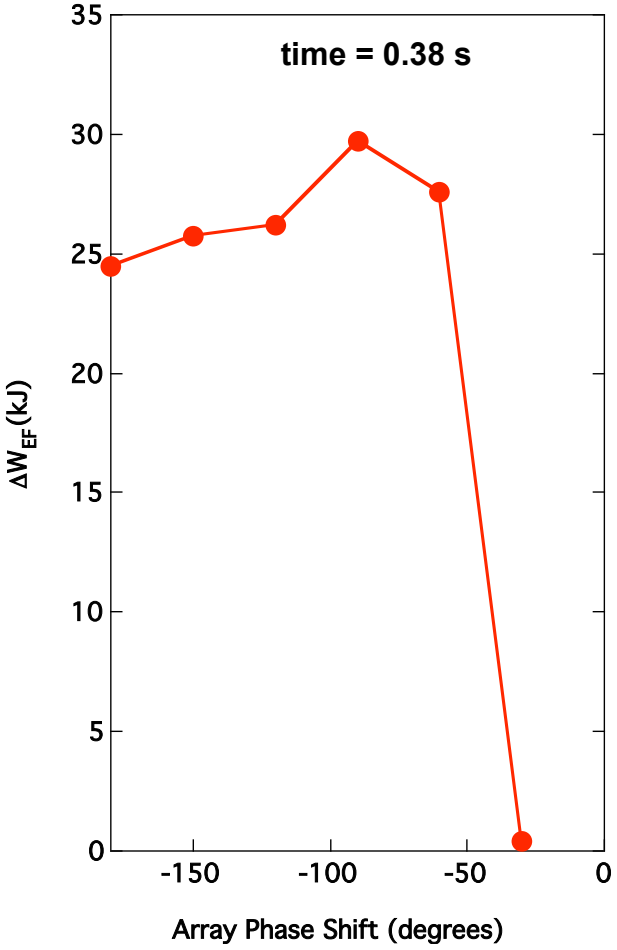
Stored energy (total and electron)

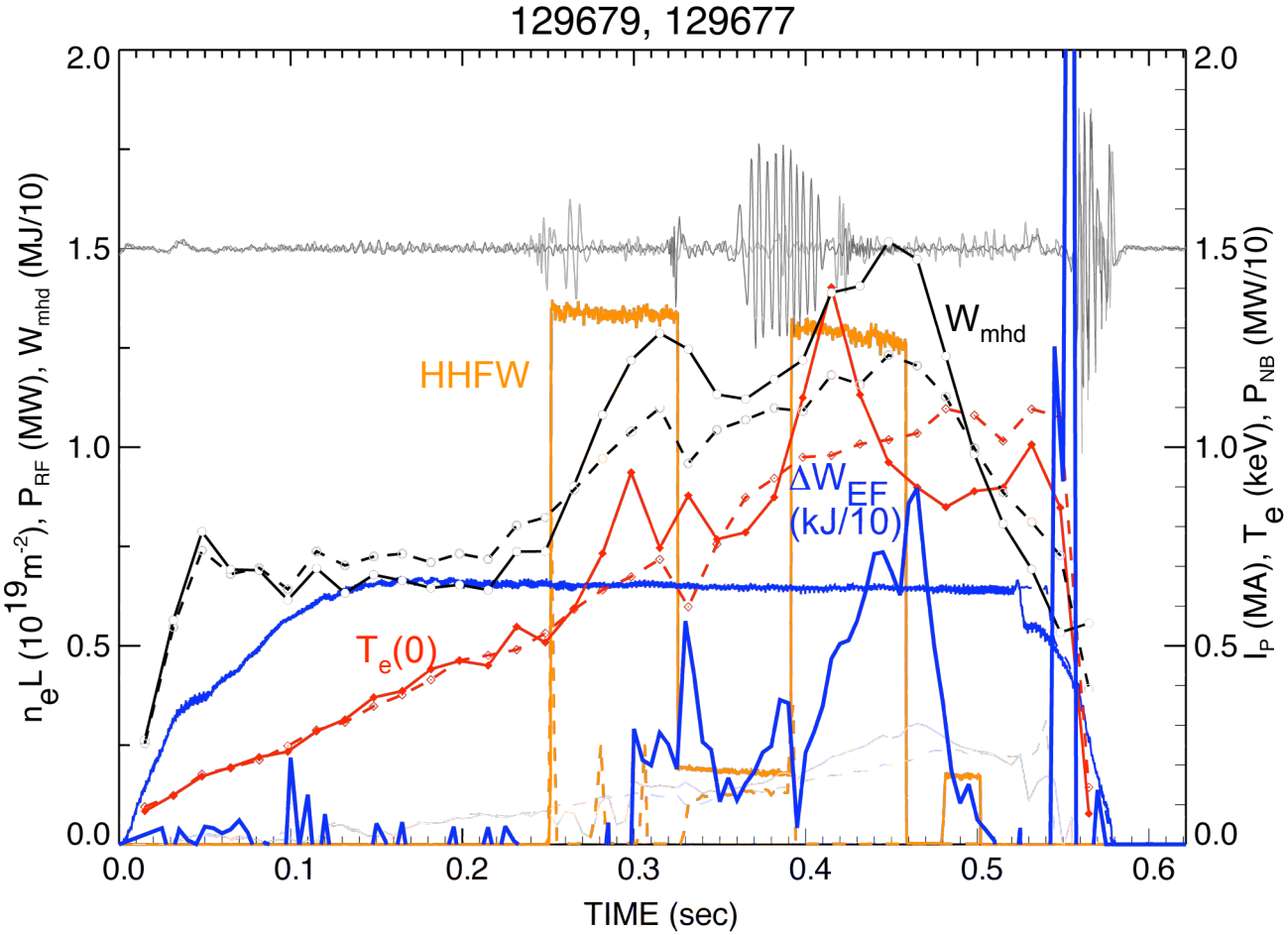


Heating efficiency drops for $|\Delta\phi| < 60°$



Heating in D Plasma at 3 m^{-1} Seen After Li Wall Conditioning

- First observation of core heating in D plasmas for $k_{||}$ = 3 m^{-1} ($\Delta\phi$ = -30º)
- LITER evaporation rate of 20 mg/mn was used to reduce edge density



XP835 - Heating and CD Phase Scans in NB Deuterium H-mode plasmas

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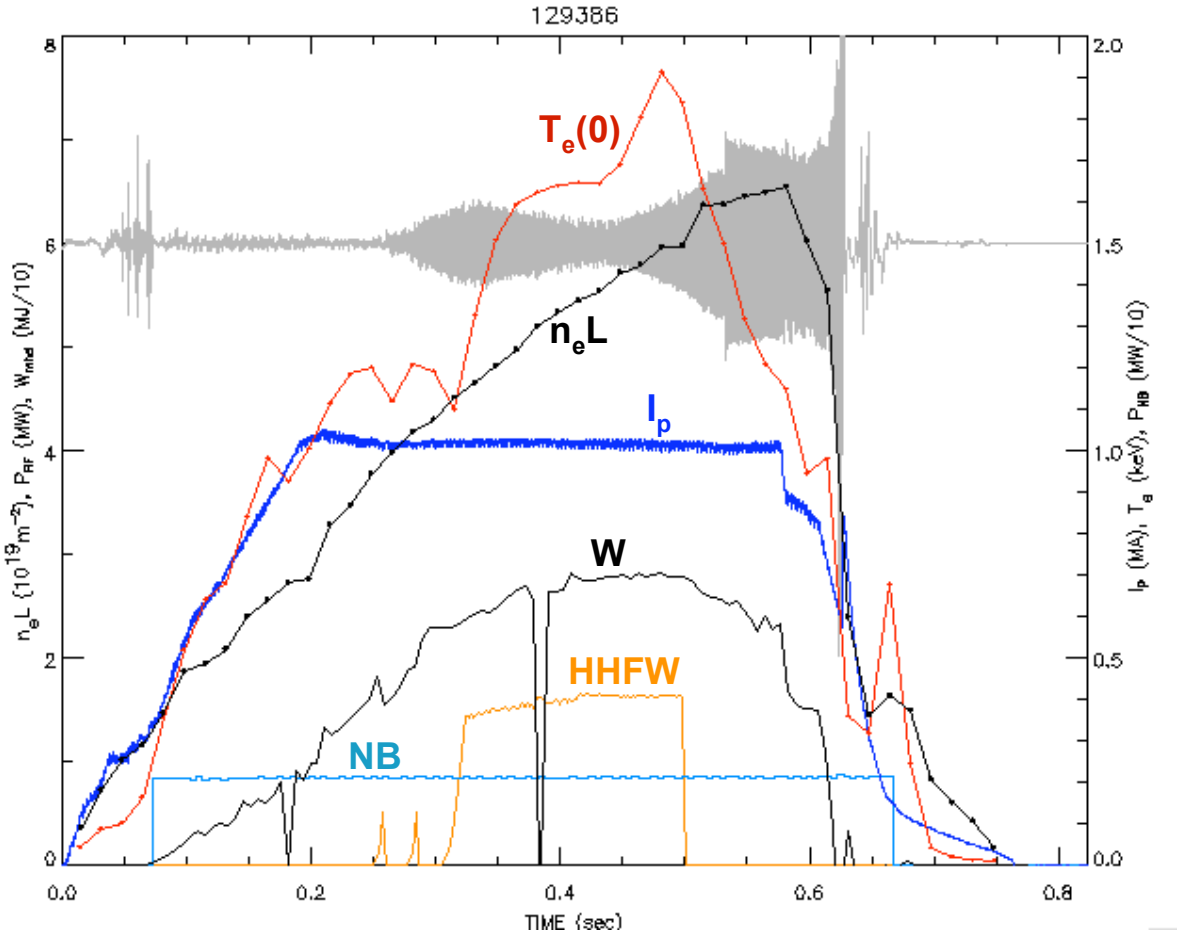
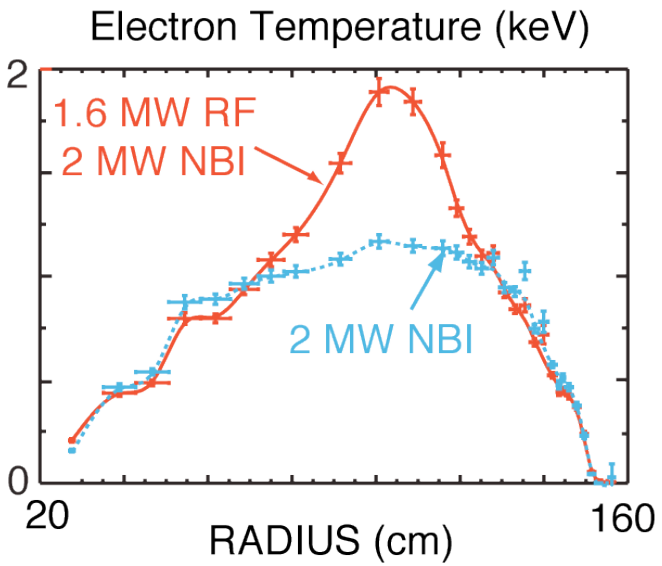
- **Motivation:**
  - Develop operational techniques for employing HHFW in H-mode plasmas.
  - Determine HHFW power channels in H-mode (core electron heating, damping on fast ions, edge plasma heating).
  - Observe HHFW operation during ELMs.
- **Method:**
  - HHFW into NBI-established H-mode
    - Advantage of constant plasma load.
    - Loading/antenna protection trade-off with plasma gap.
  - NBI-triggered H-mode transition during HHFW operation.
    - Controllable H-L transition time?
    - Reduce load transition with array phasing or plasma gap.
  - HHFW-driven H-mode (future work)

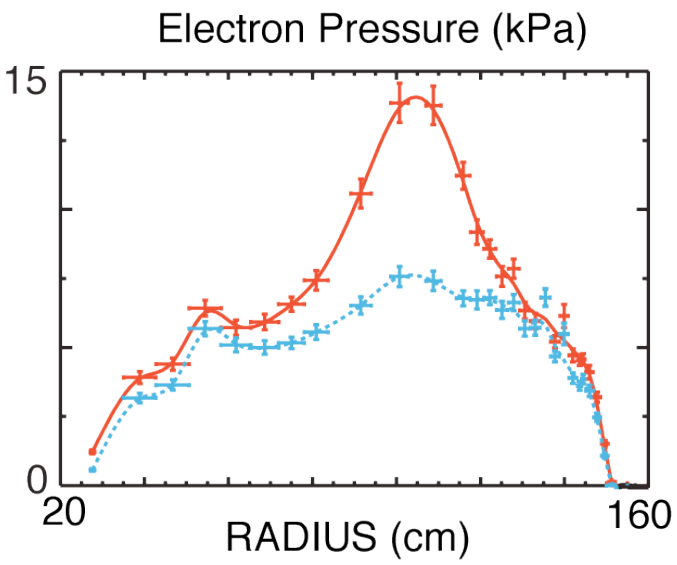
HHFW Heating of NBI-Driven H-mode Plasmas

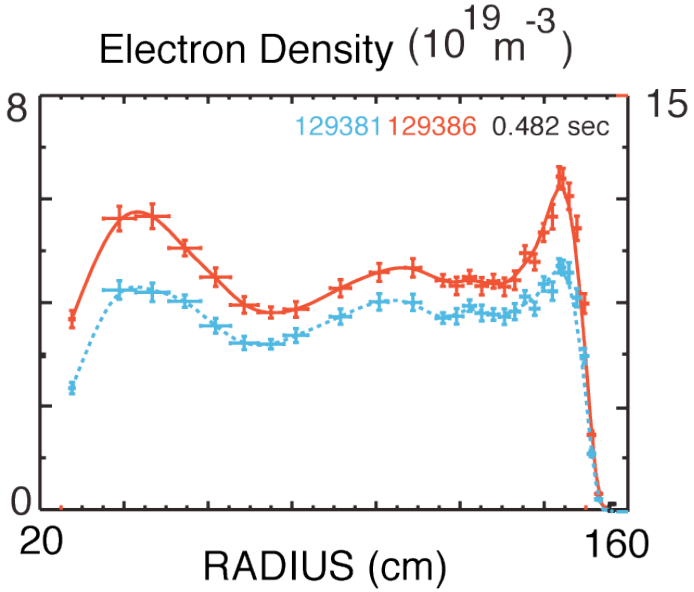
- XP 413 (2004 - LeBlanc) HHFW was not able to heat core of NBI H-mode plasma
- First evidence of heating NBI H-mode plasmas came during XP829 (Magnetic Shear Effects on Transport - H. Yuh)



Recently Measured Core HHFW Electron Heating in Deuterium NBI H-Mode Plasma







- Experiments starting to study HHFW coupling into deuterium H-modes

Core electron heating observed for -150º phasing

Lower efficiency for -90º phasing.

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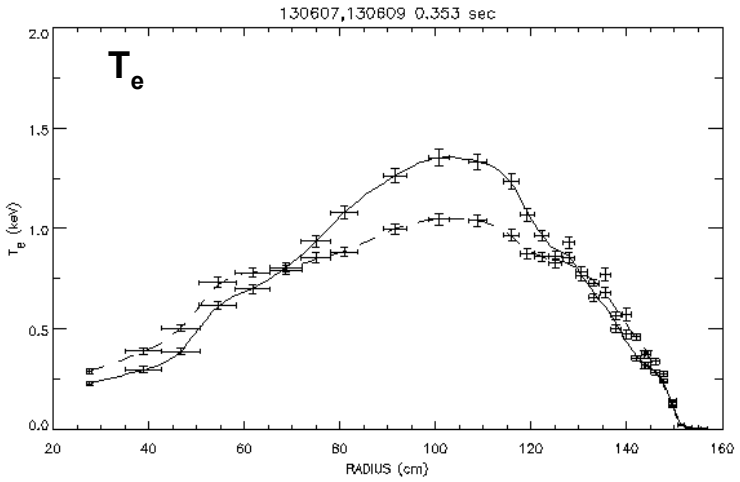
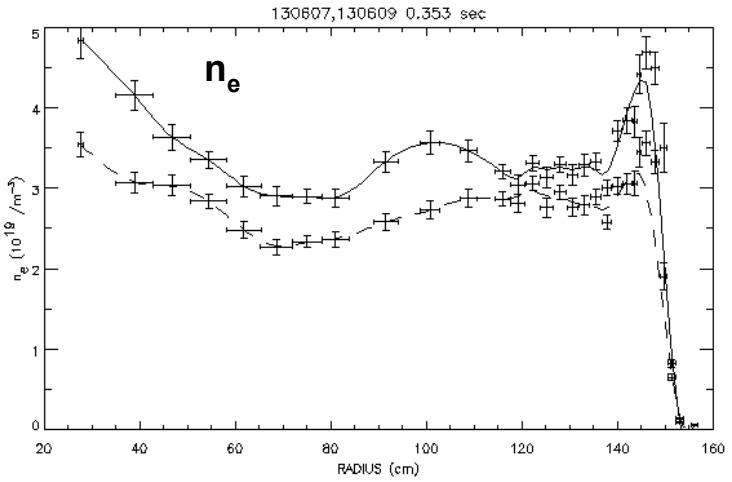
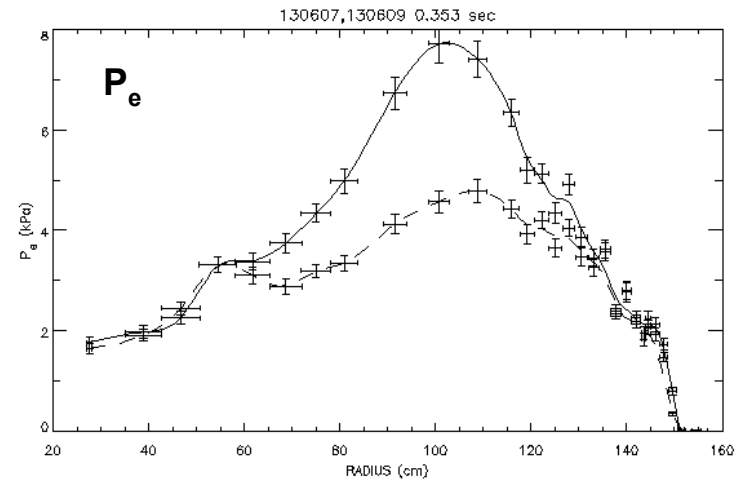
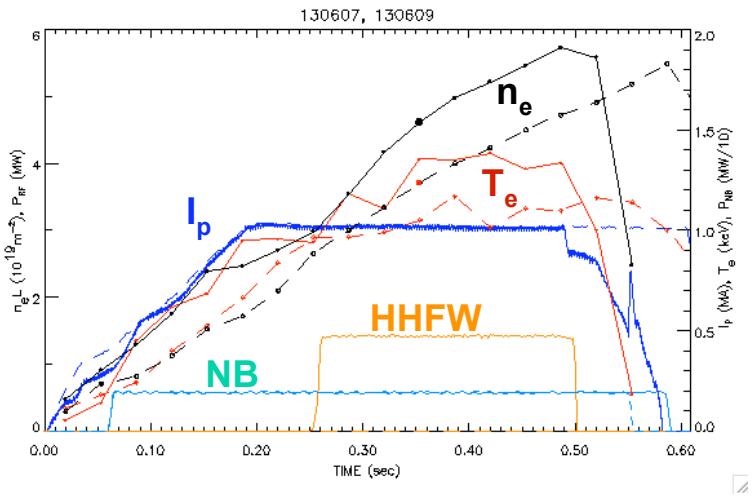
20 mg/min Li evaporation plus He glow discharge between shots was needed to heat

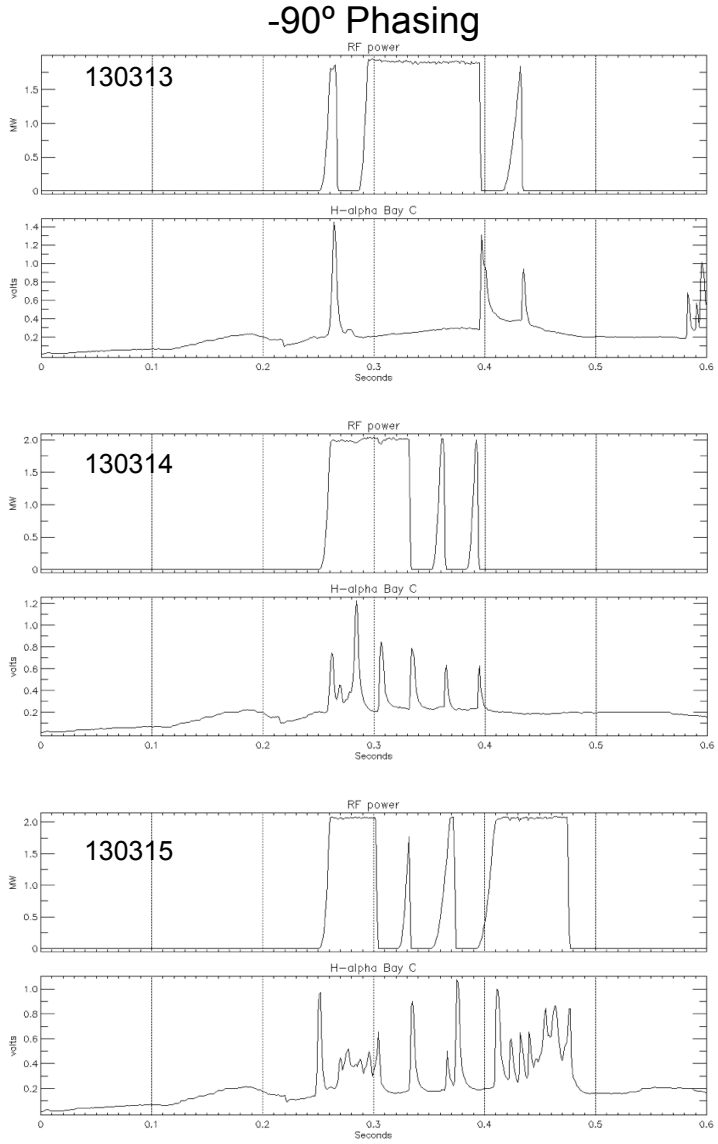








Summary of HHFW H-mode operation



- Low plasma loading at large gaps (6-7 cm for -150º and 8-9 cm for -90º) limited power to 2 MW. Strap upgrade for 2009 should help with this.
- Operation at -150º generally ELM-free.
- Operation at -90º frequently had ELMs during the RF.
- ELMs often tripped the RF off. The data obtained during this operation will help with the design of an ELM dump.
- Plasma would go into H-mode before the NBI trigger, tripping the RF due to mismatch on load transition.