XP946 - HHFW Heating and Current Drive Phase Scans in H-mode Plasmas - Hosea/Ryan

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- This XP addresses **Research Milestone R(10-2)** *Characterize High-Harmonic Fast Wave (HHFW) heating, current drive, and current ramp-up in deuterium H-mode plasmas.*
- Assess heating efficiency, plasma loading, power channels and edge losses in H-mode plasmas.
- Primary operational goal is to develop techniques with the upgraded, double end-fed antennas to couple HHFW power to H-mode plasmas, produced in combination with neutral beams.
- A secondary operational goal is to characterize the loading characteristics of ELMs present during the RF operation.
  - Aid in the design either of an ELM dump to shunt reflected power to a dummy load or a power notching system so that RF energy is not fed into the ELM plasma.

XP946 is a continuation of XP835

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- Devoted one day in 2008 to XP835 at < 2MW.
  - Only 4 of the six transmitters were operational for 150º phasing.
  - Power at -90º phasing limited by large plasma gaps
- New antennas with expected higher power limits for 2009

GOALS OF XP835 in 2008 still apply

- 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

XP946 - 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)

H-mode conditions in order of anticipated difficulty for HHFW

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- 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 or program outer gap to keep load constant.
  - Can H-mode be sustained with HHFW?
- HHFW-driven H-mode
  - Time of L-H transition less predictable
  - Future work

Core HHFW Electron Heating Observed in Deuterium NBI H-Mode Plasma

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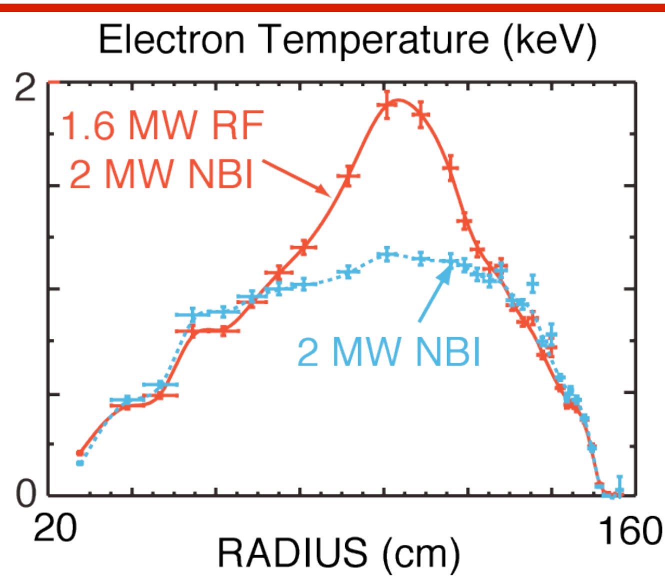

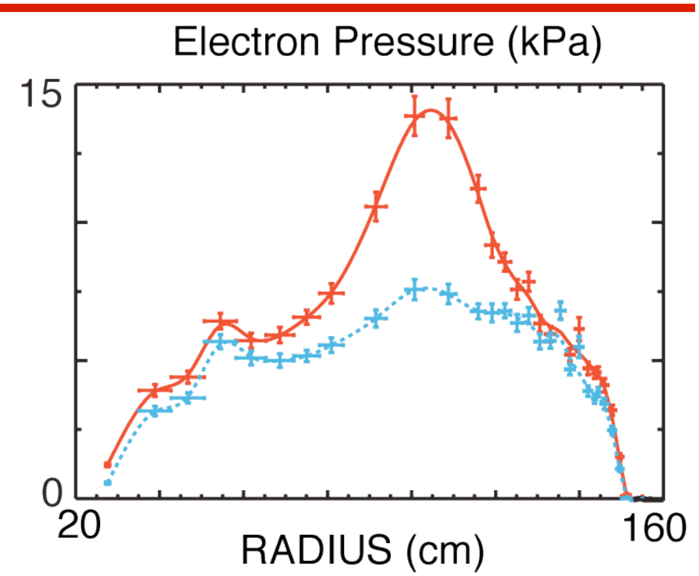

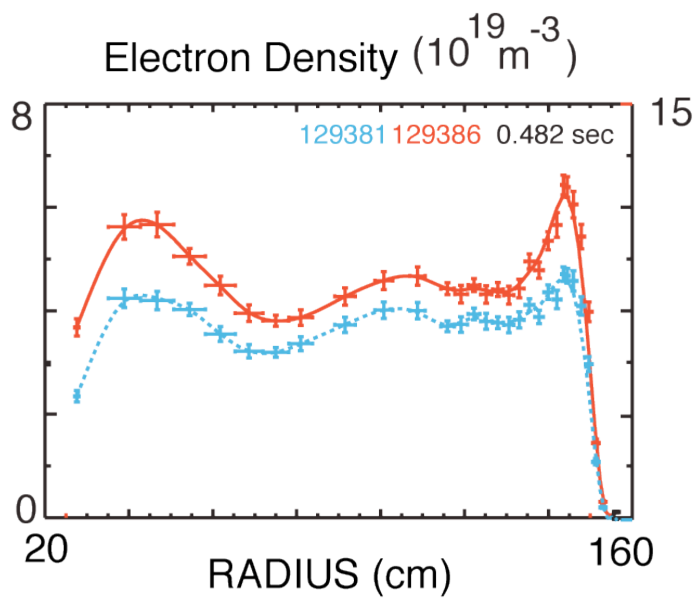

- 180º phasing (±14 m^{-1})
- XP829 – Magnetic Shear Effects on Transport (Yu)

Core electron heating observed for -150º phasing Lower efficiency for -90º phasing.

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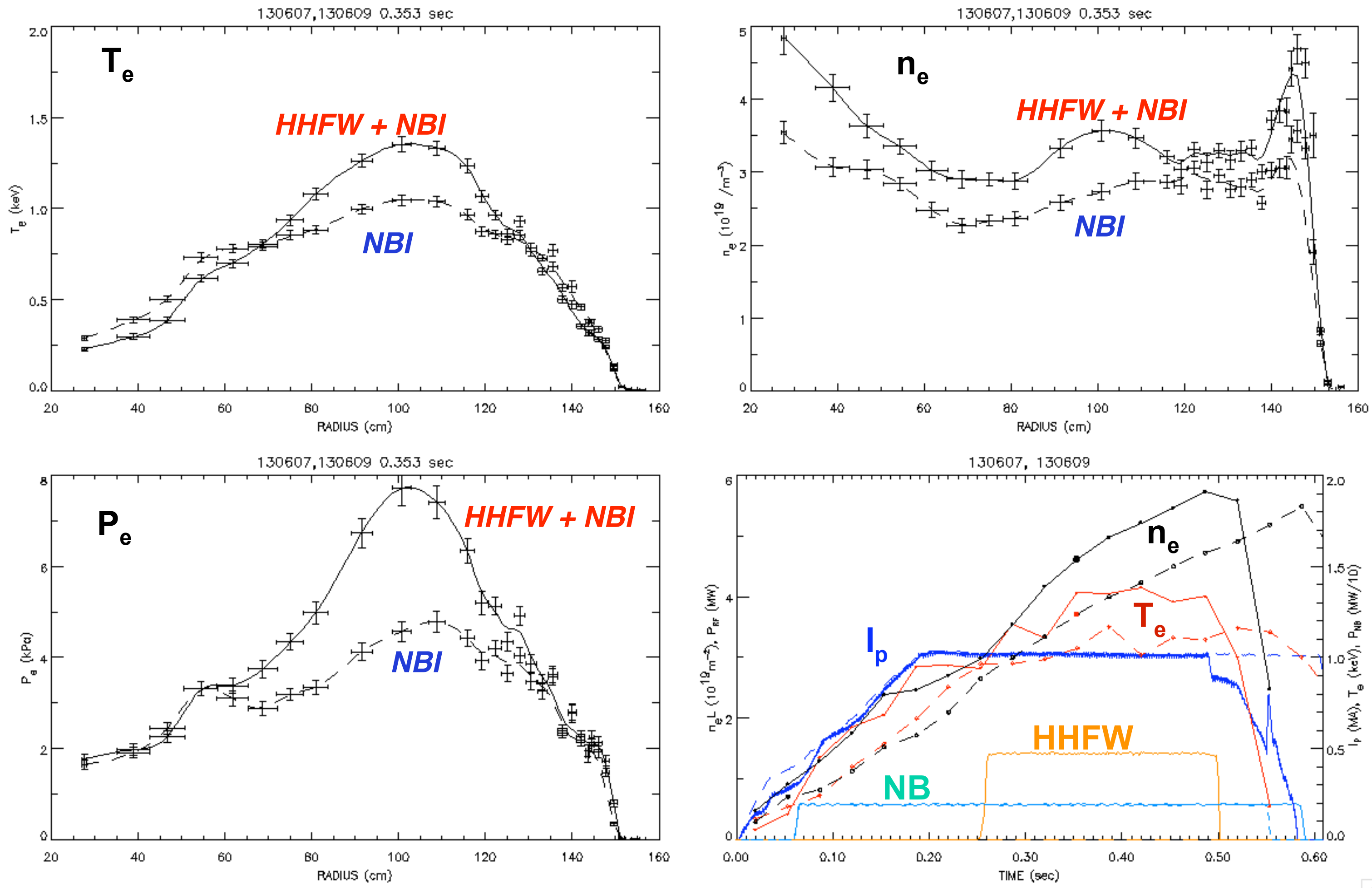
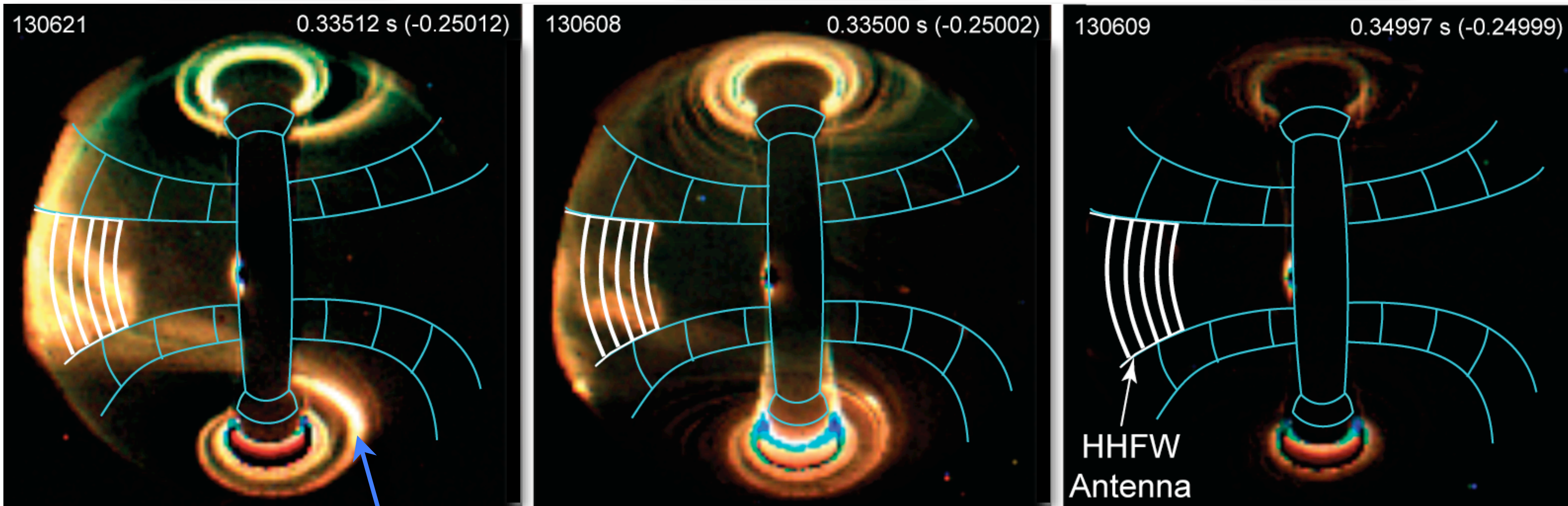
20 mg/min Li evaporation plus He glow discharge between shots was needed to reduce edge density enough to heat core electrons



Stronger Interaction Along Field Line at Lower Phase/Longer Wavelength

P_{rf} = 1.8 MW, P_{nbi} = 2 MW, I_p = 1 MA, B_T = 5.5 kG

$\Delta\phi$ = - 90° | $\Delta\phi$ = - 150° | No RF



- "Hot" region in outboard divertor much more pronounced at $\Delta\phi$ = -90° than $\Delta\phi$ = -150°
  - Linked with region in front of HHFW antenna along field lines
  - Intensity is dependent on phase, dies away after RF turns off, in ~ 20 ms for $\Delta\phi$ = -90° and 8 ms for $\Delta\phi$ = -150°

Summary of Initial HHFW H-mode operation

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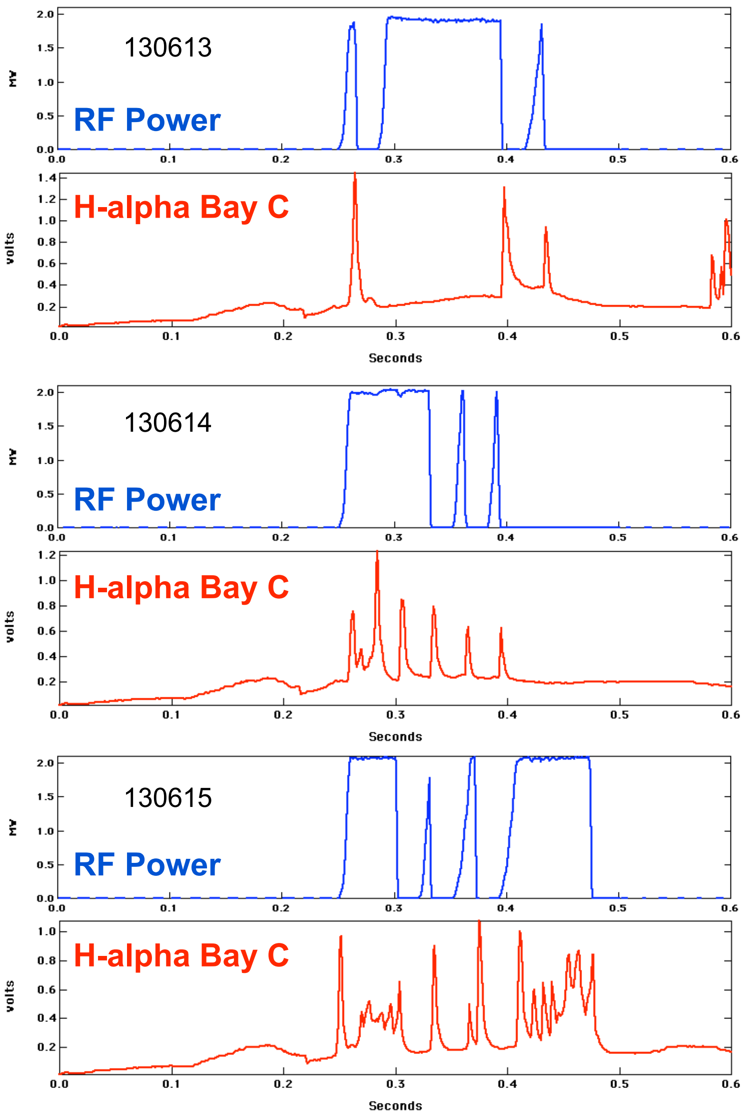
ELMs at -90º Phasing

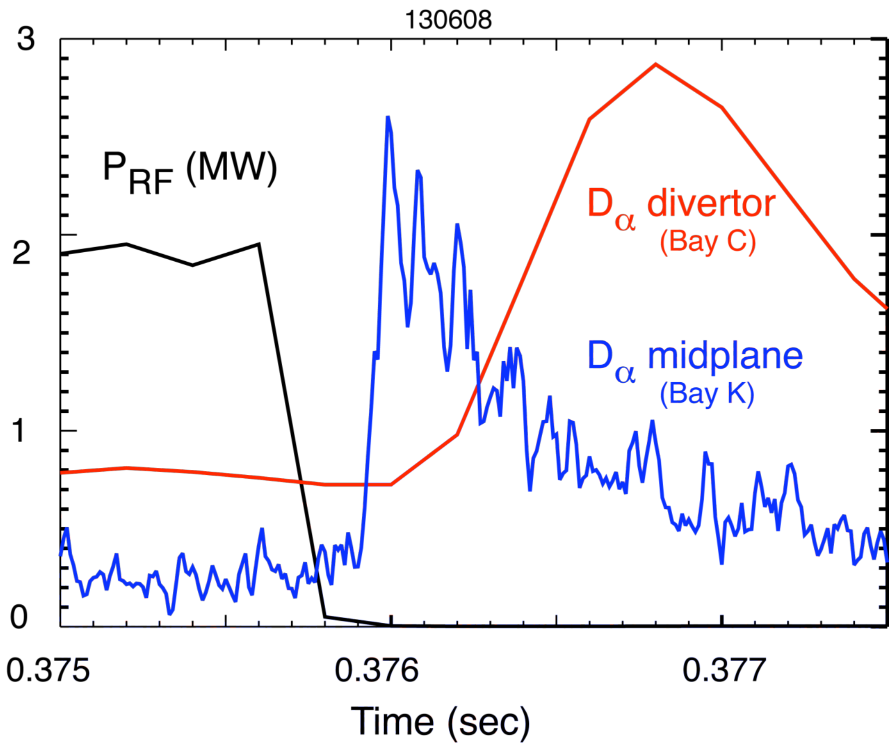


- Low plasma loading at large gaps (6-7 cm for -150º and 8-9 cm for -90º) limited power to 2 MW.
  - Could have gone to 3 MW at -150º with all six transmitters
  - Strap upgrade should help increase power.
- Operation at -90º frequently had ELMs during the RF. ELMs also seen at -150º.
- ELMs associated with RF trips.
  - The data obtained during this operation will help with the design of an arc/ELM discriminator and ELM dump for 2010.
- Initial attempt at controlled NBI-triggered H-mode transition was unsuccessful.
  - Plasma would go into H-mode before the NBI trigger, tripping the RF due to mismatch on load transition.

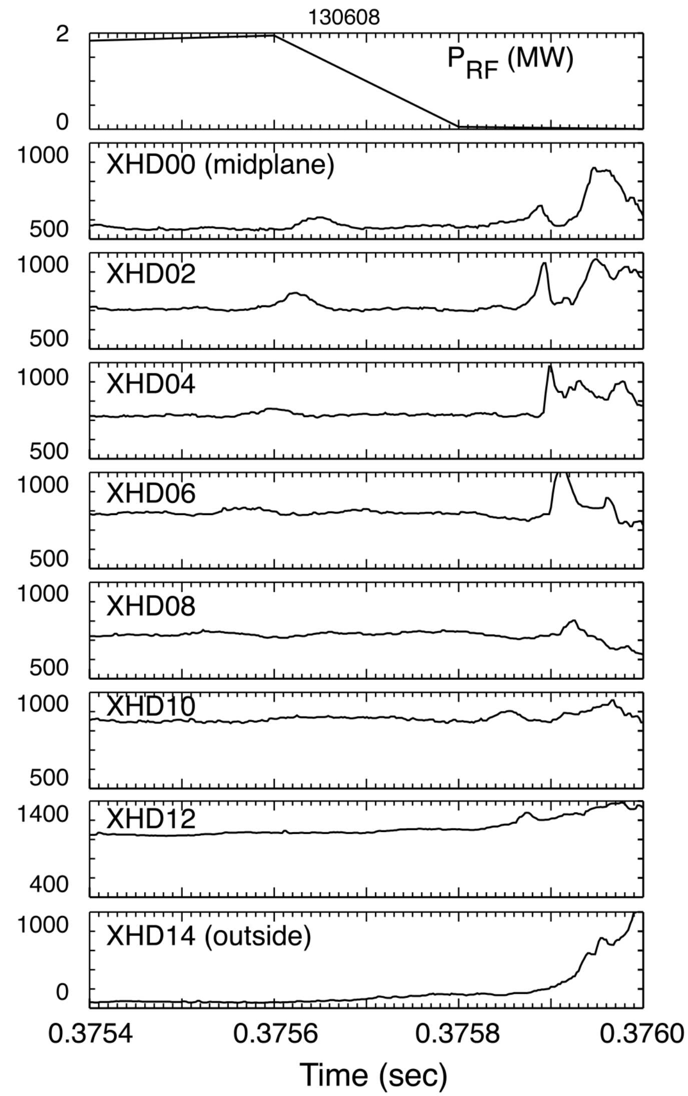
Precursors to the divertor D_{alpha} signal are responsible for the arc

- D_α for ELM responds after the arc
- USXR detects activity in range of time for the arc
- Faster digitization is being implemented for tracking the arc time

D_α response after arc



USXR (bolometer mode)



Phase 1 Shot List: HHFW into NBI-driven H-mode

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PHASE, GAP, POWER SCAN (Day 1 ~20-25 good shots)

- Target plasma 130621: D_2, CS feed, 5.5 kG, I_p ~ 1 MA (I_p chosen for MHD stability and beam confinement.)
- Source A (2 MW at 90 kV) was able to achieve stable H-mode last year
  - Use NB source A throughout (90 kV), with 10 ms notch for NPA
  - Keep density as low as possible while maintaining stability
  - 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, full & modulated RF pulse.
  - Observe power effect on ELMs, ELMs tripping RF, modulation (either during ON or OFF) triggering ELMs.
  - repeat for phase -90º
- Repeat above for outer gap of 5 cm for highest previous power
- Repeat above for outer gap of 7 cm ⇒ 5 cm (after edge quiescense)
- Return to best gap, repeat for +90º phase. Is co/cntr CD observable with MSE? Does CD direction have effect on ELMs, edge properties?
- Lower beam voltage to study coupling to fast ion tail
  - Best gap, substitute B&C (70 kV) for A (90 kV), same total power
  - -90º and -150º phasing.
  - 40 ms source A beam blip for MSE

Phase 1 Shot List: HHFW into NBI-driven H-mode

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CURRENT SCAN (Day 2 ~9-10 shots)
- Decrease I_p to 0.9 MA; with 7 cm gap, run -150º, -90º, +90º phase shifts
- Decrease I_p to 0.8 MA and repeat (looking for field line mapping to antenna/divertor hot spots
- Decrease I_p to 0.6 MA and repeat

GAS PUFFING EXPERIMENT (Future)
- Puff gas along field line connecting antenna.
- Observe effect on loading, heating efficiency

REVERSE FIELD OPERATION
- Repeat selected scenarios when B-field is reversed. Observe hot spots.

Shot timing - phase 1

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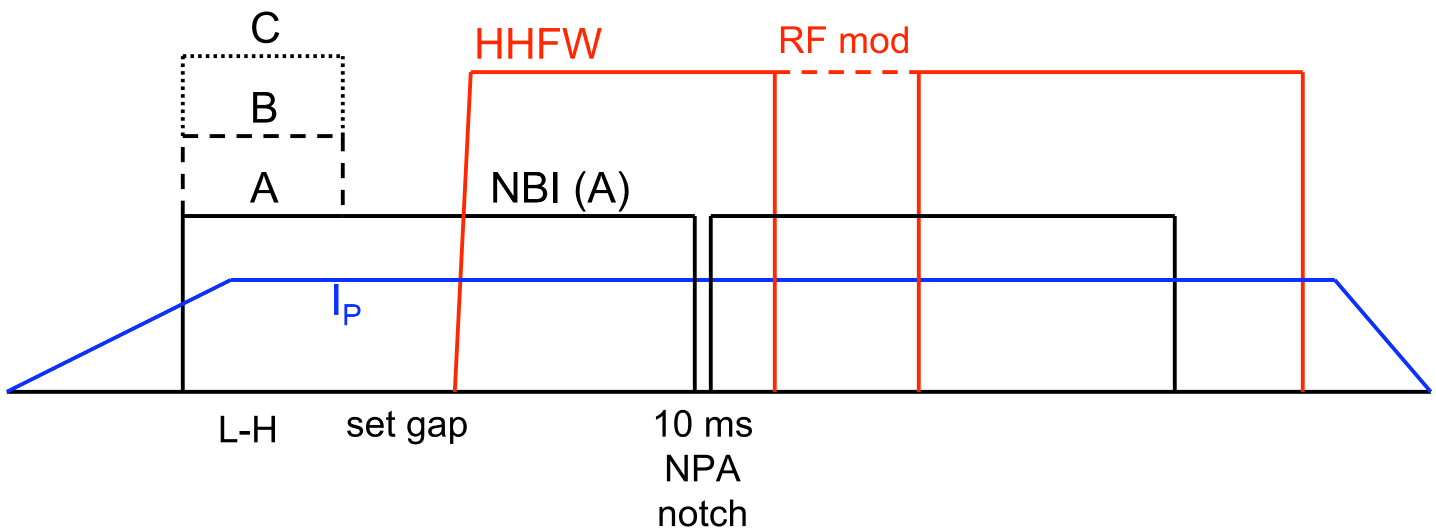
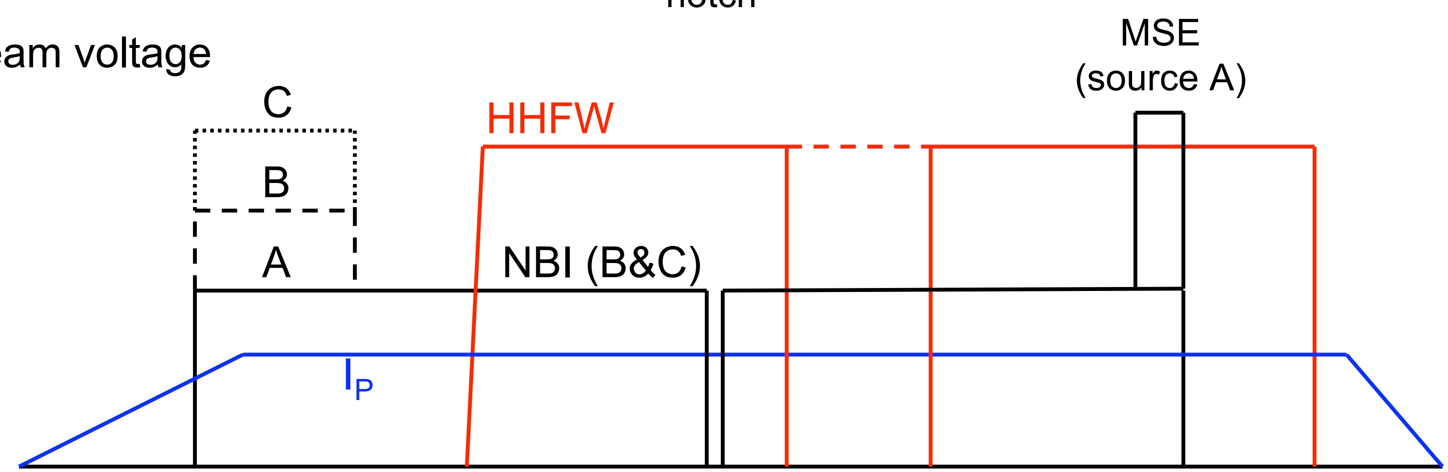
Higher beam voltage



Lower beam voltage

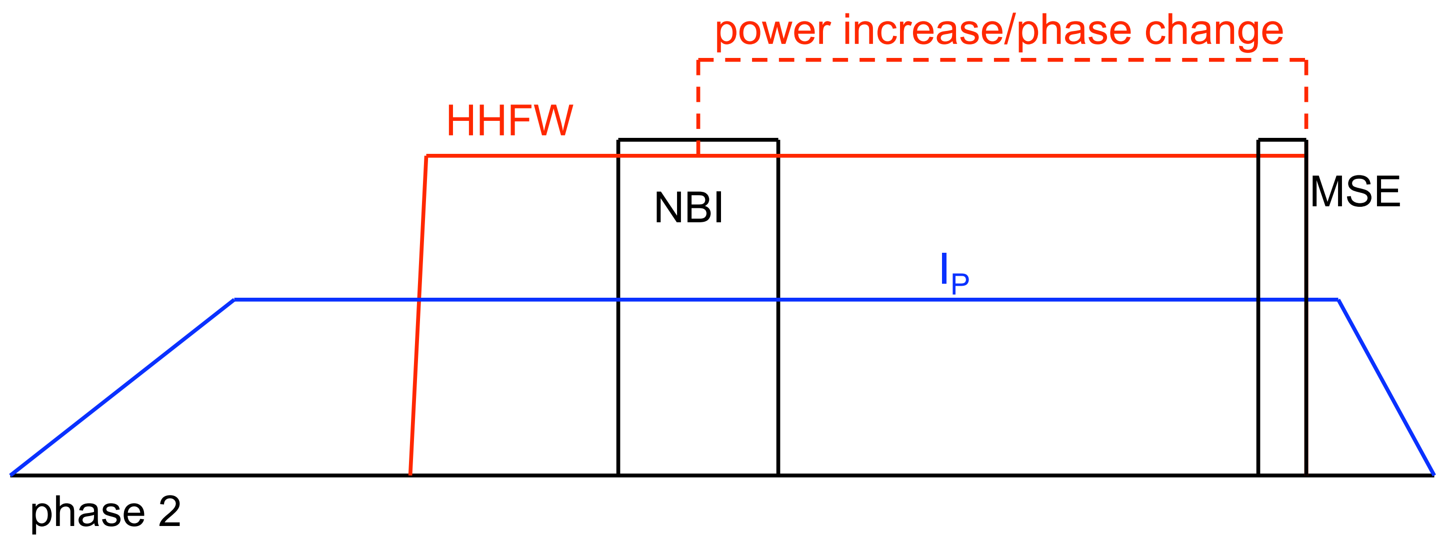


Phase 2 Shot List: NBI-triggered, HHFW-driven H-mode

PHASES 2&3 on Day 2

- Set target to that of shot 128155
- -150º phasing, trigger H-mode with 70 kV, 40 ms beam (B).
- Add 90 kV 40 ms pulse (A) 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 by adding 70 kV, source C.
- Repeat with 90 kV, 40 ms & 100 ms source A.
- Repeat with -90º phasing.

Shot timing - Phase 2



Phase 3 Shot List: HHFW-driven H-mode

Last year, phase 2 was unsuccessful since the RF turn on was sending the plasma into H-mode at less than 0.5 MW of power, before the NBI trigger.

If the same happens this year, go on to phase 3, triggering and sustaining H-mode by HHFW alone.

- Set matching to the NBI-driven H-mode load for -150º phasing at 5 cm gap.
- Set the reflection coefficient trip threshold to 0.8, limit pulse length to ~100 ms.
- Increase power from 0.5 MW until H-mode is triggered, absorbing high reflected power during L-mode mismatch. Match to H-mode when it is initiated.
- Program power increase after L-H mode transition for H-mode sustainment.

Desired Diagnostics

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- Thomson scattering
- Edge reflectometer
- CHERS
- MSE
- IR and fast visible light cameras
- FIDA
- NPA
- Solid State NPA
- Edge Rotation Diagnostic
- Soft x-rays
- high-k scattering
- Visible brehmmstralung
- Neutron measurements