NSTX EXPERIMENTAL PROPOSAL - OP-XP-944

Title: HHFW Heating/CD and Edge Effects in L-mode plasmas

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ET – Wave Physics

1. Objectives of the experiment:

Heating in D_2 L mode:

- Power accountability (core heating efficiency, edge losses, divertor losses)
- Power losses to divertor as a function of pitch angle (I_p, LND vs UND, reverse B_t) and array phasing.
- Find H-mode power threshold as a function of I_p and array phasing.

CD in D_2 L mode:

- Phase scan for HHFW CD with time-resolved MSE
  - ➢ Use conditions of shots 107899 and 107907 (at 5.5 kG) if required to show loop voltage change
- MSE beam blip at end of HHFW pulse and progressively move it forward in time upon succeeding shots to determine the current relaxation time
- Determine the effect of co-, cntr-CD, and heating on stability of NBI-driven plasmas.

Heating and CD in D_2 L mode

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2. Theoretical/ empirical justification

- This XP is a continuation of XP825 which showed that HHFW heating efficiencies in deuterium L-mode plasmas could made comparable to those in He plasmas, provided the edge density could be kept suitably low.
- The second half of XP825, time resolved MSE measurement of CD, was not run due to lack of neutral beams.
- Last year's HHFW operation in H-mode (XP835) indicated power flow to divertor could be an important edge loss mechanism. Want to take advantage of higher power HHFW array to measure core heating vs edge heating as a function of array phase, edge density, and magnetic pitch angle in L-mode plasmas.
- Need increased power (3-4 MW) to improve the MSE CD measurement.

k_ϕ Dependence of HHFW Heating Efficiency in Deuterium Similar to Helium Plasmas

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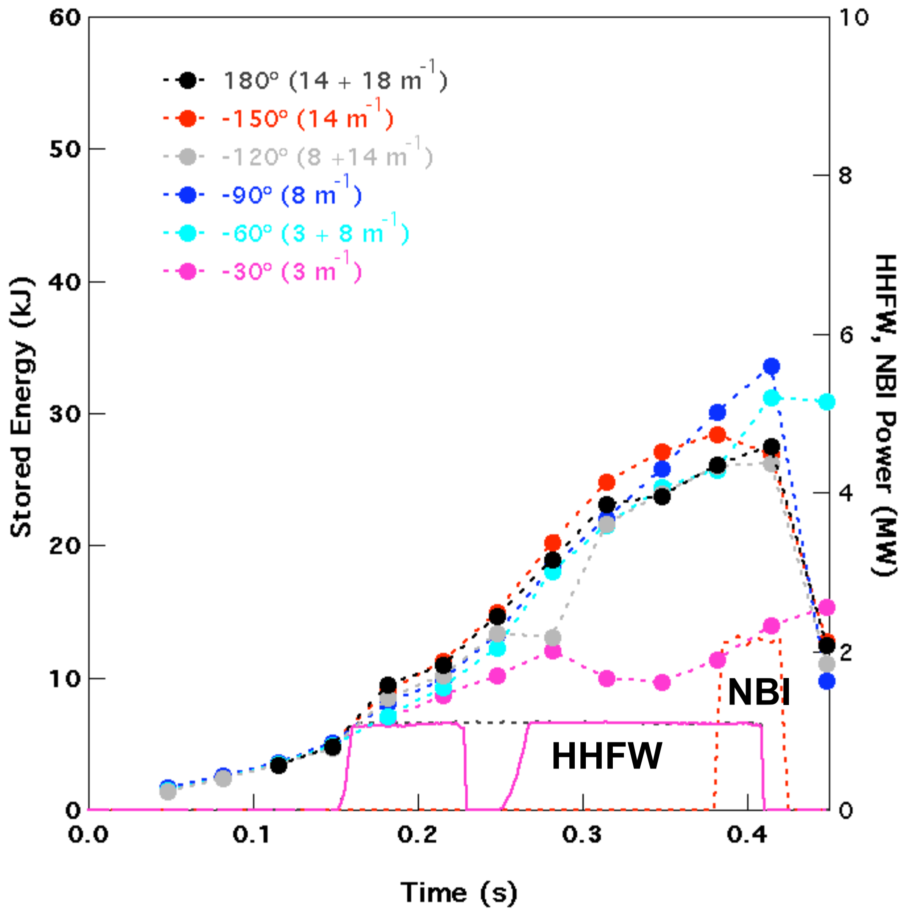
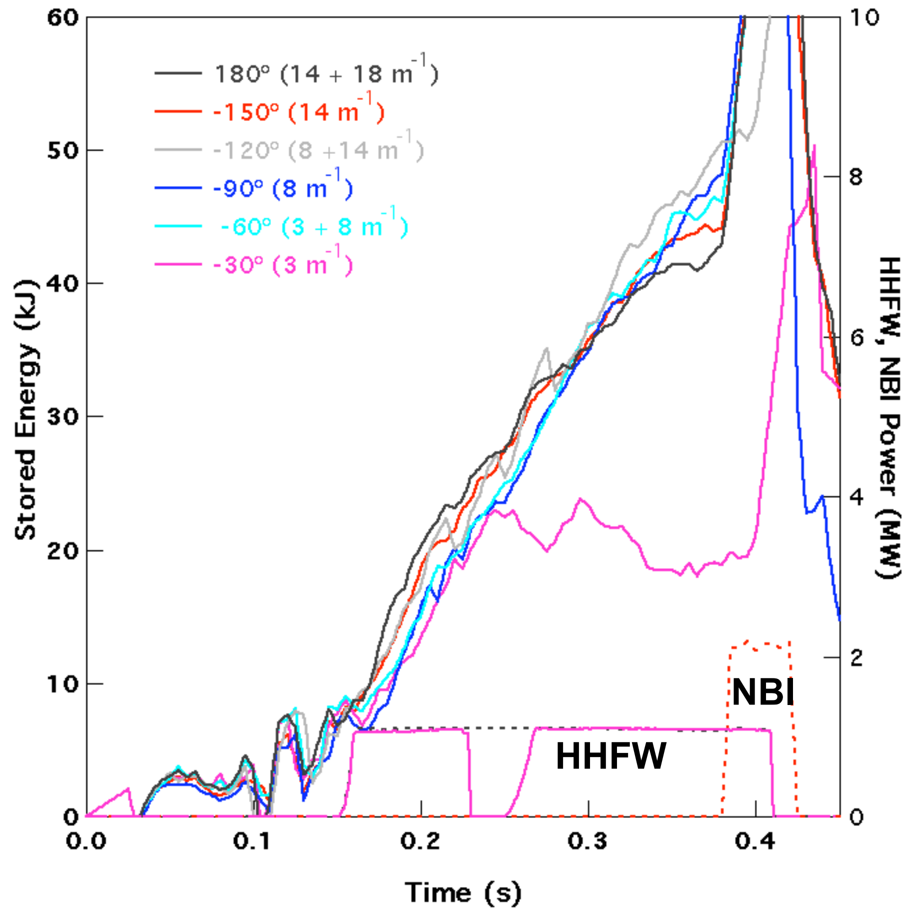
Stored Energy in Electrons



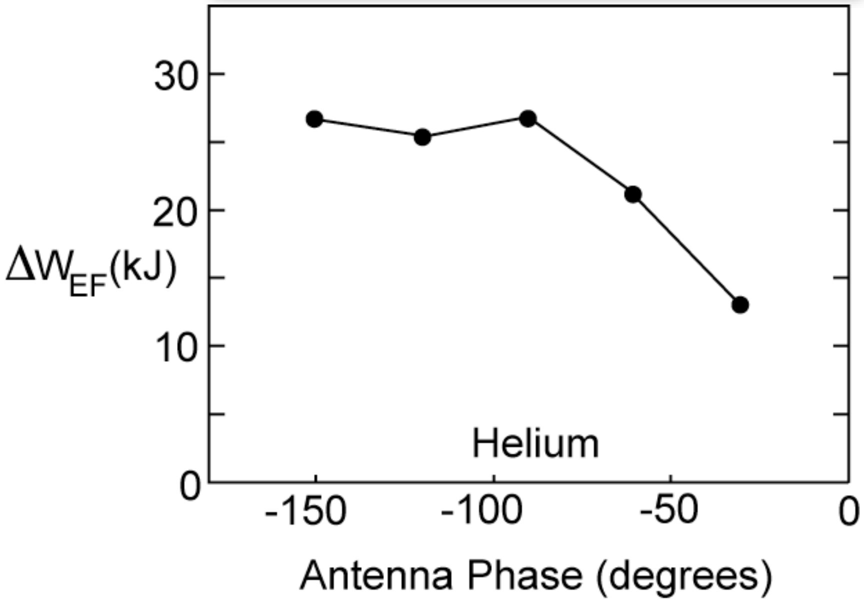
Total Stored Energy



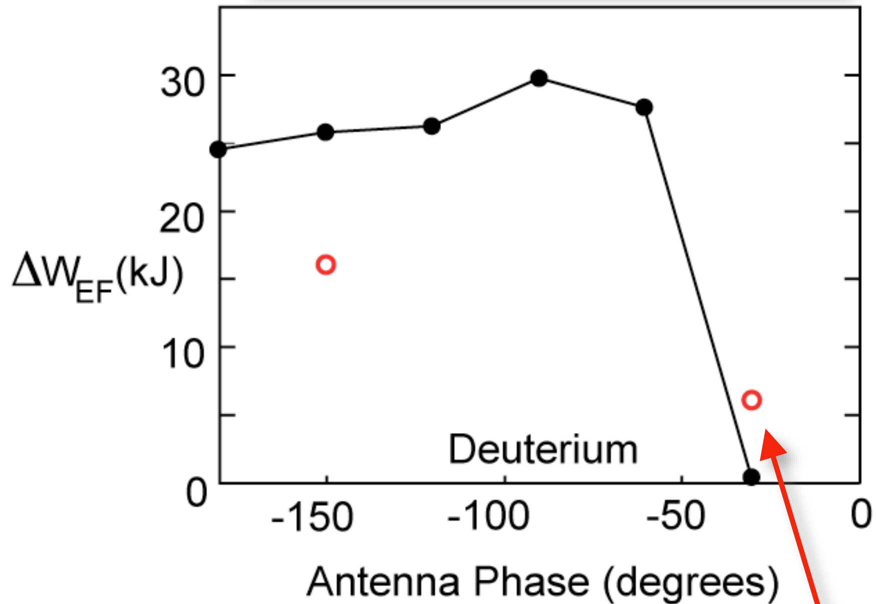
Heating efficiency drops for $|\Delta\phi| < 60^o$ due to high edge density and MHD

RF-Induced Increase in Electron Stored Energy Comparable in He & D Plasmas

P_{rf} ~ 1.8 MW in He_4 plasmas
(~ 80 ms duration)



P_{rf} ~ 1.1 MW in D plasmas
(~230 ms duration)



Noticeable increase in ΔW_{EF} with -30° phasing in D plasmas with Li edge conditioning, even with shorter rf duration (67 ms)

HHFW Heating and Edge Effects in L mode

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3. Experimental run plan -- 1.5 days of run time (~ 35 good shots)

- **Phase Scan (day 1):** Nominal conditions B_T = 0.55 T, $n_e(0)$ ~ 3e19 m^{-3}, I_p = 1 MA, gap ~ 5 cm, LSN (ref shot TBD during RF conditioning XMP):
  - HHFW on at t ~ 0.2 s, 300–400 ms pulse length
  - Phase scans at -150º, -90º, -30º, +90º (±90º important for future ELM dump operation).
  - Power 3, 4, 5 MW for each phase scan (or until H-mode threshold reached)
  - At highest power for each phase, one shot with 10 MHz modulation for power deposition, transport measurements.
  - Apply 90 kV NB pulse at end of RF pulse for MSE (30 ms overlap) - use 70 kV beam to measure T_i and rotation (are separate beams needed for these diagnostics?)
- **Current Scan (day 2):**
  - -90º phasing, highest reliable power, reduce Ip to 0.9, 0.8, 0.7 MA and observe divertor with IR camera (and wide angle fast visible light camera)
- **Upper Divertor Scan (day 2):**
  - -150º and -90º phasing, USN, I_p = 1 MA, highest reliable power, observe divertor with IR camera (and wide angle fast visible light camera)
- **Reverse B-field:**
  - Repeat selected scans with reverse B-field to change pitch angle

HHFW CD in L mode

Phase scan for HHFW CD with time-resolved MSE

(Day 2) 1/2 Day ~ 12 good shots

With NB pulse near end of RF pulse:

- 1 shot @ 14 m^{-1} (180^o)
- 1 shot @ -8 m^{-1} (-90^o)
- 1 shot @ +8 m^{-1} ($+90^o$)

❖ Check that loop voltages are responding to CD phase. If not change conditions

With NB stepped in toward start of RF pulse

- 2 shots @ +8 m^{-1} ($+90^o$)
- 2 shot @ -8 m^{-1} (-90^o)
- 1 no RF shot

(Additional shots may be required to set matching for each $k_{||}$.)

HHFW CD in L mode

B Continued

Put on long NB pulse and see if reaction depends on phase

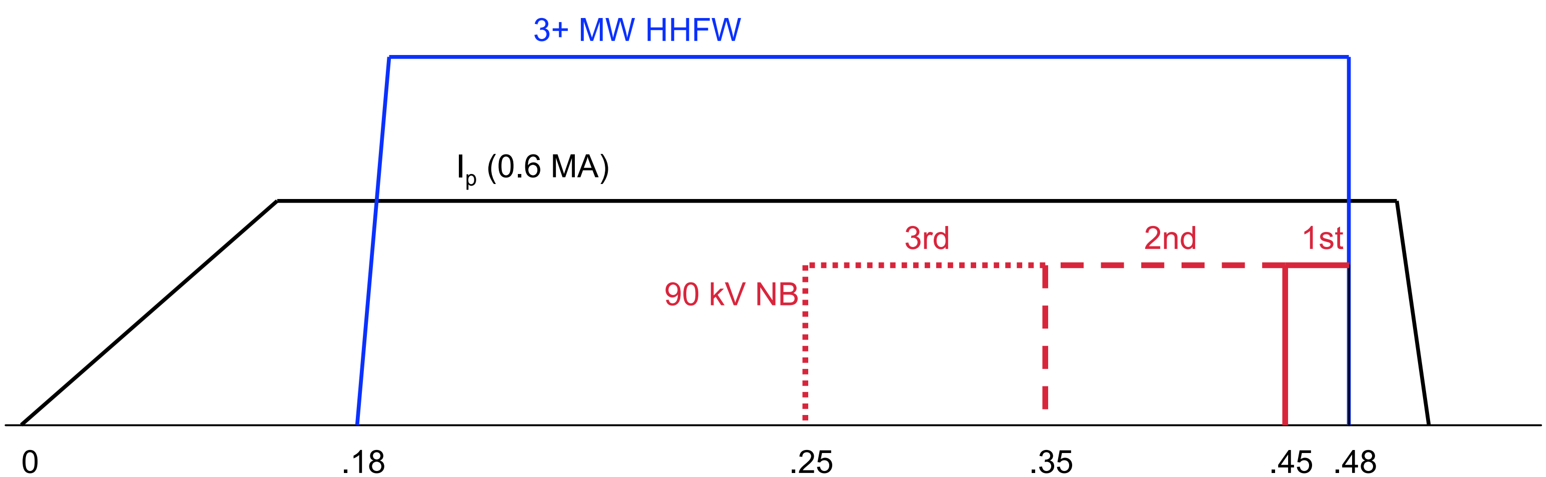
- 1 shot @ -8 m^{-1} (-90^o)
- 1 shot @ +8 m^{-1} (+90^o)
- 1 shot @ 14 m^{-1} (180^o)

These shots are intended to see if we can drive current (or even operate) in the presence of high power NBI. May also go into H-mode. May need to go to 70 kV beams.

Some of this may be accomplished during the time-resolved MSE measurements.

Example of Time-Resolved MSE Measurements

30 ms beam blip positioned at the end of the RF pulse
Increment beam turn-on time by 100 ms on succeeding shots
Establish CD relaxation time and HHFW/NBI stability as a function of phase.



HHFW Heating and CD in D_2 L mode

4. Required machine, NBI, RF, CHI and diagnostic capabilities

Stable or at least reproducible plasma conditions are required for the quantitative comparisons of this XP. Critical diagnostics include:

- Soft x-ray and Mirnov loops for stability
- EFIT with high time resolution for modulation studies
- Thomson scattering for electrons
- Edge rotation diagnostic for edge heating
- IR and Fast Frame Visible Light Cameras
- NPA for edge and core ion heating
- Radiated power diagnostic
- Reflectometry for edge density and PDI
- Reflectometry for wave measurements for opposite side from antenna
- Edge probe for PDI
- Gap RF probes for leakage
- 3 RF probe(s) for edge RF field
- CHERS for some shots for T_i and velocities
- MSE for as required for determining effects on current
- NB pulses needed at 90 kV and 70 kV

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5. Expected results and planned analysis

Expected results:

- Heating efficiency in deuterium L mode vs wavenumber: 14 m^{-1}, -8 m^{-1} (co CD), -3 m^{-1}, -13 m^{-1}, etc.
  - Core heating from EFIT W
  - Core electron heating from Thomson scattering
  - Ion heating and core rotation from Chers
- Edge heating/power loss
  - Edge ion heating from edge rotation diagnostic
  - Edge electron heating from Thomson scattering
  - Rotation effects
- MSE measurements of current drive
  - Co vs counter for conditions where loop voltage is reduced for co
- Loop voltage difference for co/cntr, compare to MSE
- Plasma profiles, core and edge, for permitting predictions of wave propagation damping and CD characteristics

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Planned analysis:

- Compare power coupling efficiencies vs wavenumber to those for helium
- Determine CD profile vs time in RF pulse, CD efficiency and compare with RF code predictions.
- Determine if stability with NB is dependent on antenna phase
- Analysis of wave propagation, damping and CD characteristics from onset density into the core of plasma - along field and perpendicular directions of the ray path, and including collisions - for predicting CD and surface losses
- Benchmarking of RF codes that include surface losses