Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **HHFW Heating and Edge Effects in H-mode Plasmas**

OP-XP-946	Revision: **0**	Effective Date: **7/7/09** *(Approval date unless otherwise stipulated)* Expiration Date: **7/7/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Authors: P. Ryan	Date 7/7/09
ATI – ET Group Leaders: G. Taylor	Date 7/7/09
RLM - Run Coordinator: R. Raman	Date 7/7/09

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **HHFW Heating and Edge Effects in L-mode Plasmas** No. **OP-XP-946**

AUTHORS: **P. Ryan, J. Hosea, R. Bell, B. LeBlanc, C.K. Phillips, G. Taylor, J. Wilgen, J.R. Wilson** DATE: **June 25, 2009**

1. Overview of planned experiment

The primary goal of this experiment is to develop operational techniques to couple HHFW power to H-mode plasmas, produced in combination with neutral beams. Comparisons of RF plasma loading and heating efficiency as a function of array phasing (spectral wavenumber) in H-mode will be made with previous operation in L-mode. Power deposition channels (edge heating of ion and electrons, damping on fast beam ions, and core electron heating) will be determined. This is a continuation of XP835, albeit with a new antenna power-feed configuration. Last year's experiment only operated for one day and did not complete phase 1; only four of the six transmitters were operation for the -150º phasing study.

2. Theoretical/ empirical justification

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*

HHFW/NBI H-mode experiments were carried out in 2004 with Ben LeBlanc as the principal investigator under XP413. The first part of the experiment applied NBI modulations to an HHFW pre-heated plasma; stored energy and neutron rates increased compared to NBI alone, but the efficiency was low. The second part of the experiment applied HHFW to an NBI-driven H-mode plasma. There was little indication that the HHFW power was coupling through the edge (small changes in Te, W, Sn). These experiments used $B_T(0) = 0.45$ T.

Core heating was observed in NBI-driven H-mode for the first time in 2008, primarily as a result of Li conditioning to control the edge density. A new antenna with higher power capability will be employed in 2009.

One operational challenge anticipated with running HHFW power in H-mode plasmas is the lower plasma loading, due to steeper density profiles in H-mode and to larger gaps (which may be necessary to protect the antennas from NBI-heated plasmas). This reduced loading could limit the power delivered by the HHFW antennas. We plan to establish the minimum gap at which the array can operate reliably into H-mode profiles as a function of phase shift (launched wavelength), as well as determining the heating efficiency for these cases. These issues will be addressed during the first phase of the experiment by applying HHFW into an NBI-established H-mode, after density profiles and outer gap have stabilized.

Techniques to maintain RF power coupling through the L-H mode transition will be developed during the second phase of the experiment, when a NBI pulse will be applied to an HHFW-heated L-mode plasma to send it into H-mode. During the antenna conditioning operation last year (XMP-26), a 40 ms NBI pulse into an HHFW-heated, L-mode plasma triggered a transition into H-mode. H-mode was maintained for the remaining 100 ms of the RF power application for 70 kV, 1.1 MW NBI, even though the density profile steepened and moved away from the antenna (128155). Profile steepening and movement were more pronounced during the transition to H-mode when 90 kV, 2 MW NBI was used as the trigger (128157). As a result of this transition, the antenna voltage increased and the RF transmitters tripped, terminating H-mode operation.

3. Experimental run plan

Phase 1: HHFW into NBI-Driven H-mode

A. PHASE, GAP, POWER SCAN (~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 is quiescent)

•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

B. CURRENT SCAN (~9-10 shots)

•Increase I_p to 1.2 MA; with 7 cm gap, run -150º, -90º, +90º phase shifts

•Decrease I_p to 0.9 MA and repeat (looking for field line mapping to antenna/divertor hot spots)

•Decrease $_{Ip}$ to 0.8 MA and repeat

•Decrease I_p to 0.6 MA and repeat

Phase 2: NBI-triggered, HHFW-driven H-mode
Last year, limited attempts at phase 2 were 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.

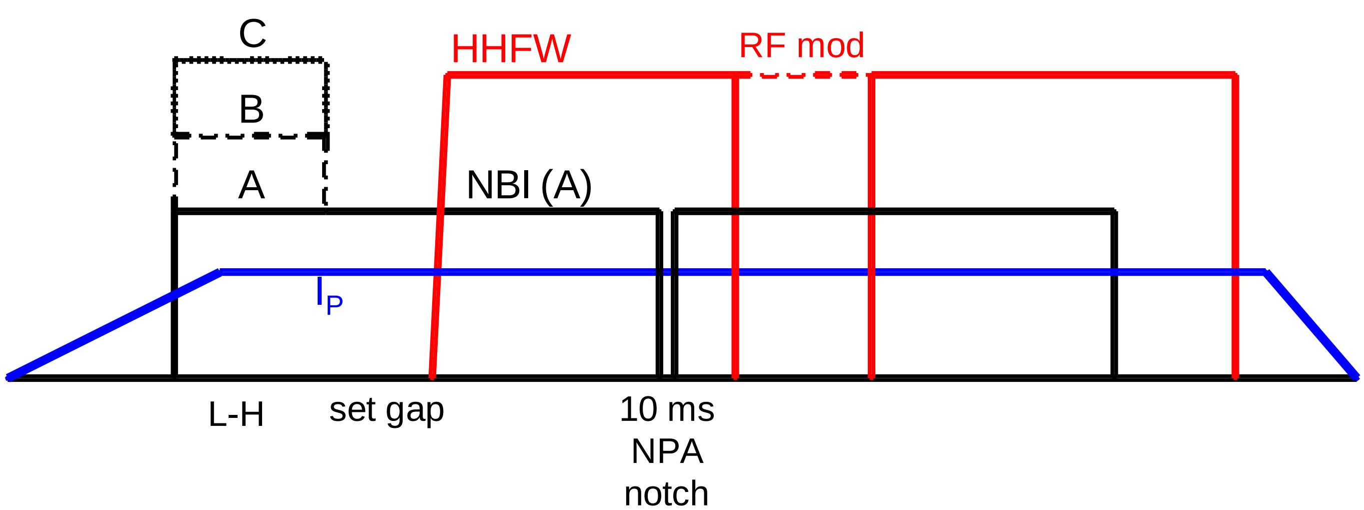
•Set target to that of shot 128155

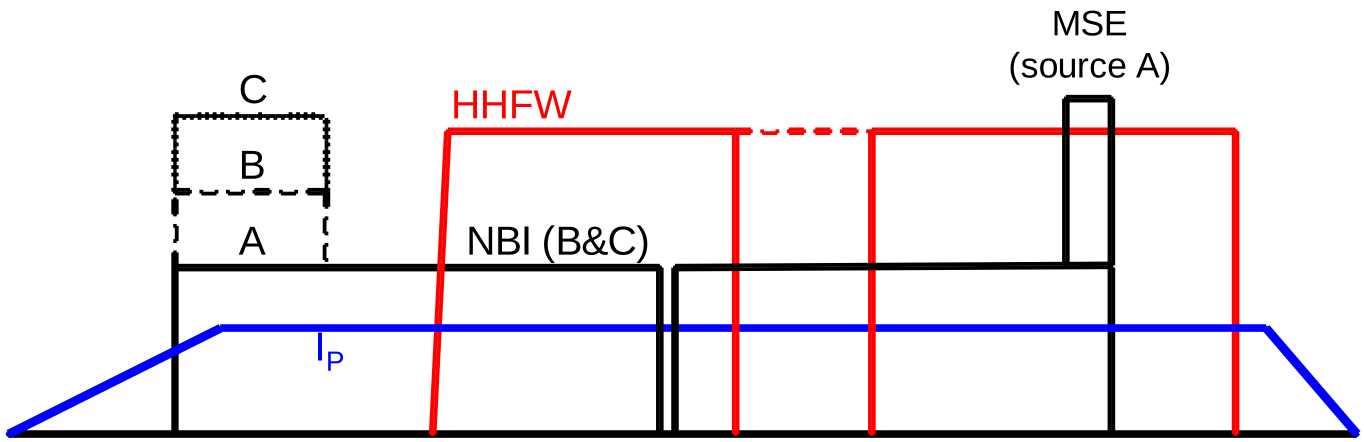
- -150º phasing, trigger H-mode with 70 kV, 40 ms beam (B).
- Add 90 kV 40 ms pulse (A) for MSE at end of HHFW H-mode phase.
- If H-mode transition trips RF due to decreased loading, try:
  - Programming plasma to move closer to antenna after beam comes on.
  - Switching to -90º phasing (higher loading) 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.

Phase 3: HHFW-driven H-mode

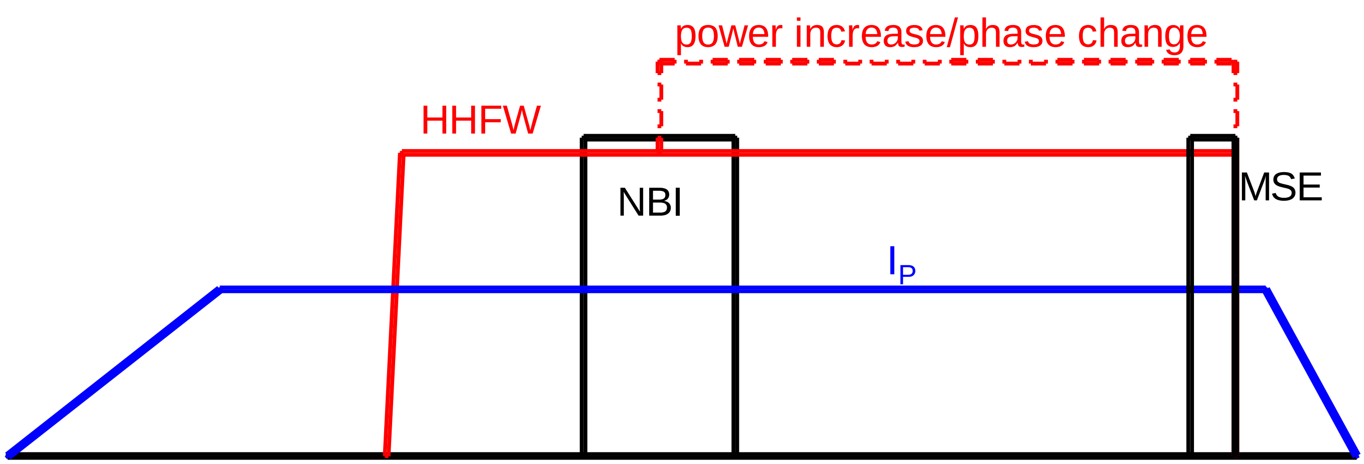
- Set matching to the NBI-driven H-mode load for -150º phasing at 5 cm gap.
- Set the reflection coefficient trip threshold to 0.8, limit pulse length to ~100 ms.
- Increase power from 0.5 MW until H-mode is triggered, absorbing high reflected power during L-mode mismatch. Match to H-mode when it is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

PHASE 1: HHFW INTO NBI-DRIVEN H-MODE (90 and 70 keV beams)





PHASE 2: NBI-TRIGGERED, HHFW-DRIVEN H-MODE



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

Stable, reproducible plasma conditions are required for the quantitative comparisons of this XP. NB sources A (90 kV), B (70 kV), and C (70 kV) are needed. In addition to standard diagnostics like Thomson scattering, critical diagnostics include:

- EFIT with high time resolution
- Reflectometry for edge density and PDI
- Reflectometry for wave measurements for opposite side from antenna
- Edge probe for PDI
- Gap RF probes for leakage
- 4 RF probe(s) for edge RF field
- MSE for some shots for effects on current

- CHERS for ion temperature
- FIDA for energetic ion tails
- NPA and SS-NPA for energetic ion tail
- EDR for edge ion heating
- Neutron measurements for core ion heating
- Soft x-rays
- high-k scattering
- Visible brehmmstralung

5. Planned analysis

Expected results:

- Heating efficiency in versus wavenumber:
  - Core heating from EFIT stored energy
  - 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, current profiles
- Plasma profiles, core and edge, for permitting predictions of wave propagation damping and CD characteristics

Planned analysis:

- Compare efficiencies versus wavenumber to those for deuterium L-mode
- Determine if stability with NBI is dependent of antenna phase
- Benchmarking of RF codes that calculate high harmonic ion cyclotron damping on energetic beam ions

6. Planned publication of results

Results will be presented in 2009 APS-DPP invited paper (Atlanta). Publication will follow in *Physics of Plasmas*.

A. PHYSICS OPERATIONS REQUEST

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(use additional sheets and attach waveform diagrams if necessary)

Describe briefly the most important plasma conditions required for the experiment:

Phase 1: 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.

Phase 2: Set target to that of shot 128155, -150º phasing, trigger H-mode with 70 kV, 40 ms beam (source B).

Previous shot(s) which can be repeated: 130621 for phase 1, 128155 for phase 2

Previous shot(s) which can be modified:

Machine conditions *(specify ranges as appropriate, strike out inapplicable cases)*

I_{TF} (kA): **-53 – -65** Flattop start/stop (s): **0/0.7**

I_P (MA): **0.4 – 1.2** Flattop start/stop (s): 0.1/0.6

Configuration: LSN

Equilibrium Control: **Outer gap / Isoflux** (rtEFIT)

Outer gap (m): **0.05-0.1** Inner gap (m): **~0.04** Z position (m): **0.0**

Elongation κ: Upper/lower triangularity δ:

Gas Species: **D** Injector(s): **Inner wall to start**

NBI Species: **D** Voltage (kV) **A: 90 B: 70 C: 70** Duration (s): **0.04 - 0.5**

ICRF Power (MW): **3-4** Phase between straps (°): **Various**

Duration (s): 0.15 – 0.5 modulated

CHI: **Off** Bank capacitance (mF):

LITERs: On Total deposition rate (mg/min): **20 mg/min to start, adjust as needed**

EFC coils: Off Configuration: **Odd / Even / Other** *(attach detailed sheet)*

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
Bolometer – tangential array	√	
Bolometer – divertor	√	
CHERS – toroidal	√	
CHERS – poloidal	√	
Divertor fast camera	√	
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		√
Edge pressure gauges		√
Edge rotation diagnostic	√	
Fast ion D_alpha - FIDA		√
Fast lost ion probes - IFLIP		√
Fast lost ion probes - SFLIP		√
Filterscopes	√	
FIReTIP		√
Gas puff imaging		
Hα camera - 1D		√
High-k scattering		
Infrared cameras	√	
Interferometer - 1 mm		√
Langmuir probes – divertor		√
Langmuir probes – BEaP		
Langmuir probes – RF ant.		√
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Pickup coils	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents	√	
Magnetics – RWM sensors	√	
Mirnov coils – high f.	√	
Mirnov coils – poloidal array	√	
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.		

Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
MSE	√	
NPA – E||B scanning		
NPA – solid state		
Neutron measurements		√
Plasma TV	√	
Reciprocating probe		
Reflectometer – 65GHz	√	
Reflectometer – correlation	√	
Reflectometer – FM/CW	√	
Reflectometer – fixed f	√	
Reflectometer – SOL	√	
RF edge probes	√	
Spectrometer – SPRED	√	
Spectrometer – VIPS	√	
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray arrays	√	
Ultrasoft X-rays – bicolor	√	
Ultrasoft X-rays – TG spectr.		√
Visible bremsstrahlung det.	√	
X-ray crystal spectrom. - H		√
X-ray crystal spectrom. - V		
X-ray fast pinhole camera		√
X-ray spectrometer - XEUS		√