Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **HHFW absorption in NB-heated plasmas**

OP-XP-1012	Revision:	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: B. LeBlanc	Date
ATI – ET Group Leader: G. Taylor	Date
RLM - Run Coordinator: E. Fredrickson	Date

Responsible Division: Experimental Research Operations

RESTRICTIONS or MINOR MODIFICATIONS
(Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

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1. Overview of planned experiment

This experiment is aimed at characterizing the amount of RF power coupled into the core of neutral beam (NB) heated deuterium plasmas on NSTX (Milestone R10-2). The characterization is done as a function of phasing among antenna straps, outer gap and - time permitting - magnitude of the magnetic field and of the fast ion gyro-radius. The proposed scenario will provide data for both L- and H-mode plasmas. The requested run time is 1 day.

2. Theoretical/ empirical justification

During HHFW heating on NSTX there are large uncertainties on the fraction of RF power which is actually coupled to the plasma core (Taylor, APS invited 2009). This information is required to assess the efficiency of schemes for heating and current drive based on RF injection (NSTX Milestone R10-2). In the past, estimates have been made based of edge PDI ion heating (T. Biewer et al., Phys. Plasmas **12** (2005) 056104) and evolution of the stored energy during HHFW power modulation (J.C. Hosea et al., Phys. Plasmas **15** (2008) 056104). A general observation from previous experiments is that RF power that reaches the core is absorbed primarily by fast ions and electrons. The power coupled to the core plasma has been estimated from the measured neutron production rate enhancement, which is routinely observed during HHFW heating (LeBlanc, APS invited 2009). The analysis is based on a new version of the TORIC code recently implemented into TRANSP, that can calculate the wave propagation and power deposition for HHFW waves. Then, CQL3D is used on a single time point basis to infer the power absorbed by fast ions. The resulting neutron rate during HHFW heating is then compared with the measured one. In addition to the TORIC/CQL3D codes, simulations of NSTX plasmas based on the newly developed ORBIT-RF code have also made good progress in 2009 (Choi, APS invited 2009).

The same analyses will be repeated for this experiment and complemented by direct measurements of the fast ion profile and energy spectrum, available from the suite of fast ion diagnostics (FIDA, NPA and ssNPA). The preliminary work done in 2008 and 2009 (Liu, Plasma Phys. Control. Fusion **52** (2010) 025006 and Podestà, RF Conference invited 2009) has already demonstrated the potential of a joint experimental and modeling effort to understand the RF power absorption process on NSTX.

3. Experimental run plan

The experiment combines two distinct phases, in order to obtain data from both L-mode and H-mode deuterium plasmas. The first phase (L-mode) replicates the scenario obtained in shot#128741. After an initial pulse of 100ms with NB source A @ 90kV, the useful time window for measurements starts with constant HHFW injection (P_{rf}~2MW) and a single NB source (C@75kV) modulated with 10/20ms

ON/OFF up to 340ms. Compared to shot#128741, a higher NB power will be used to increase the signal on the fast ion diagnostics. The proposed duty cycle should be low enough to keep the plasma in L-mode and avoid to destabilize MHD and Alfvénic activity (TAE, EPMs). NB and RF injection turn off at 340ms. After a 10ms notch for diagnostic purposes the second phase, modeled upon shot#130608, begins. NB source A @ 90kV is turned ON again at 350ms. This should be enough to trigger the transition into H-mode, assuming an adequate high-field side fueling and Lithium deposition. If that does not happen, a second NB source at low beam voltage (B @ ~60kV) will be introduced. The NB source(s) will stay ON up to 630ms. Two pulses of RF power (P_{rf}~3MW, if the step in RF power does not cause trips) are planned, from 400ms to 550ms and from 600ms to 660ms. The proposed timing of the NB and RF sources is summarized in Fig. 1 below. Modifications of NB and RF timing may be required to optimize the discharge, e.g. to avoid strong MHD activity.

The starting conditions are B_{tor}=5.5kG and I_{pl}=900kA, with central density ~4 x 10^{19} m^{-3} at ~400ms. The RF phasing is for $k_{//}$=13 m^{-1}, and the outer gap ~4cm. Once the scenario is established, two scans will be performed. First, the RF phase is changed from $k_{//}$=13 m^{-1} to -8 m^{-1}. If time permits and enough power is coupled to the core plasma (e.g. a clear increase in the neutron rate is observed) the case with $k_{//}$=-3 m^{-1} will also be investigated. Second, for each value of the phasing the outer gap is varied from 4cm to 6cm and 8cm. Three comparison shots without RF are foreseen, i.e. one for each value of the outer gap.

After completion of this shot matrix, the "best" conditions of outer gap and phasing will be identified on the basis of RF coupling to the core plasma and quality of the discharge (no MHD, good signal-to-noise on the fast ion diagnostics). The toroidal field is lowered to 4.5kG and to 3.5kG to evaluate the dependence of the RF coupling to the core plasma upon resonance location and fast ion gyro-radius. Given the deterioration of antenna coupling at the lowest toroidal field, a maximum of 3 shots will be dedicated to the B_{tor}=3.5kG case. If time permits, a scan of the NB voltage (60, 75 and 90kV) during the initial L-mode phase at B_{tor}=5.5kG and optimal phasing/outer gap will be performed.

The number of "good" discharges for a successful experiment is ~20, achievable in one day of operations.

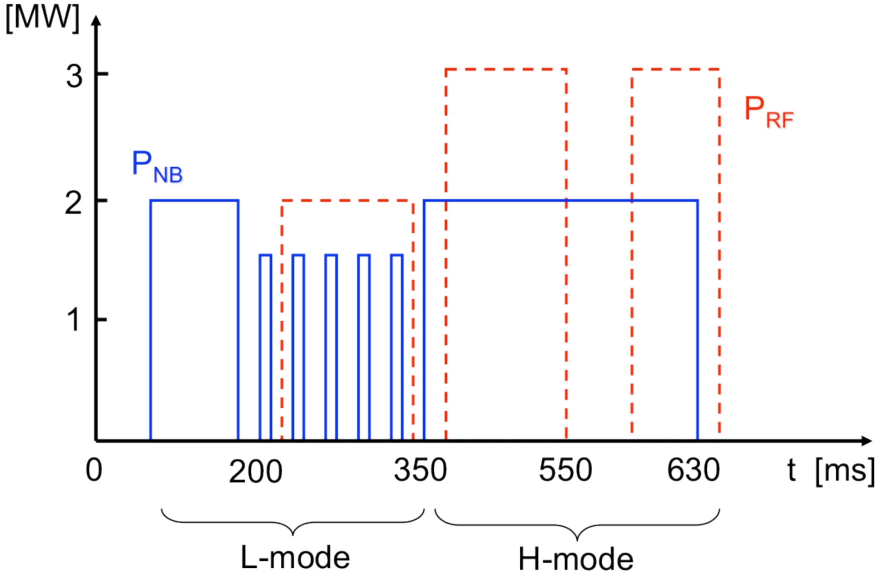

Figure 1: Proposed timing for NB (solid) and HHFW (dashed) power.

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

Previous conditioning of the HHFW antenna to achieve a maximum power of ~4MW is required.

Two NB sources (namely B & C) will be used at de-rated voltage (minimum 60kV).

The NB power required for the L → H mode transition at t ~ 400 ms will be estimated from previous XPs to evaluate the effects of Lithium and LLD on plasma operation, and their possible use in this experiment.

Thomson scattering and CHERs/pCHERs must be operational to monitor the evolution of plasma profiles, velocity and edge density.

All fast ion diagnostics (neutrons, FIDA, NPA, ssNPA and sFLIP) must be operational.

Divertor infrared cameras are desired to obtain additional information on the RF interaction with the edge plasma.

5. Planned analysis

TRANSP, TORIC, CQL3D and possibly ORBIT-RF codes will be used to calculate the RF absorption by fast ions and by the thermal plasma, as well as the resulting effects on the neutron rate and stored energy.

6. Planned publication of results

Results will be published in journals such as PoP, PPCF and/or NF within one year from the experiment and presented at the major plasma physics meetings (IAEA, APS, etc.).

Three papers are foreseen:

- Dependence of fast ion absorption profile upon RF phasing
- Efficiency of RF coupling to the core plasma versus RF phasing and outer gap (i.e. edge conditions)
- Comparison/validation of RF codes, e.g. CQL3D and ORBIT-RF

PHYSICS OPERATIONS REQUEST

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Brief description of the most important operational plasma conditions required:

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified: 128741, 130608

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

I_{TF} (kA): **66** Flattop start/stop (s): **0, 0.8**

I_P (MA): **0.9** Flattop start/stop (s): **.2, .7**

Configuration: **LSN**

Equilibrium Control: **Outer gap / Isoflux** (rtEFIT) **/ Strike-point control** (rtEFIT)

Outer gap (m): **0.04 to 0.08** Inner gap (m): Z position (m): **0**

Elongation: Triangularity (U/L): OSP radius (m):

Gas Species: **D** Injector(s): **high-field side**

NBI Species: **D** Voltage (kV) **A: 90** **B: 65** **C:** 90 Duration (s): **600ms**

ICRF Power (MW): **<4** Phase between straps (°): **13,-8,-3m^{-1}** Duration (s): **400ms**

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

LITERs: t.b.d. Total deposition rate (mg/min): **t.b.d.**

LLD: t.b.d. Temperature (°C): **t.b.d.**

EFC coils: Off Configuration:

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		x
Bolometer – divertor		
Bolometer – midplane array		
CHERS – poloidal	x	
CHERS – toroidal	x	
Dust detector		
Edge deposition monitors		
Edge neutral density diag.		
Edge pressure gauges		
Edge rotation diagnostic	x	
Fast cameras – divertor/LLD		x
Fast ion D_alpha - FIDA	x	
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP	x	
Filterscopes		
FIReTIP		
Gas puff imaging – divertor		
Gas puff imaging – midplane		
Hα camera - 1D		
High-k scattering		
Infrared cameras		x
Interferometer - 1 mm		
Langmuir probes – divertor		x
Langmuir probes – LLD		x
Langmuir probes – bias tile		
Langmuir probes – RF ant.	x	
Magnetics – B coils	√	
Magnetics – Diamagnetism		
Magnetics – Flux loops	√	
Magnetics – Locked modes		
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		
Magnetics – RWM sensors		
Mirnov coils – high f.	x	
Mirnov coils – poloidal array		x
Mirnov coils – toroidal array	x	
Mirnov coils – 3-axis proto.		

Diagnostic	**Need**	**Want**
MSE	x	
NPA – E‖B scanning	x	
NPA – solid state	x	
Neutron detectors	x	
Plasma TV		
Reflectometer – 65GHz		
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		x
Reflectometer – SOL		
RF edge probes		
Spectrometer – divertor		
Spectrometer – SPRED		
Spectrometer – VIPS		
Spectrometer – LOWEUS		
Spectrometer – XEUS		
SWIFT – 2D flow		
Thomson scattering	x	
Ultrasoft X-ray – pol. 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 tang. pinhole camera		