Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **HHFW Heating of Low $T_e(0)$, I_p Plasmas**

OP-XP-920	Revision: **0**	Effective Date: **7/21/09** *(Approval date unless otherwise stipulated)* Expiration Date: **7/21/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Authors: G. Taylor & D. Mueller	Date 7/21/09
ATI – ET Group Leaders: G. Taylor / D. Mueller	Date 7/21/09
RLM - Run Coordinator: R. Raman	Date 7/21/09

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

Although the primary goal is to study heating of low current plasmas, a secondary goal is to look for current drive.

NSTX EXPERIMENTAL PROPOSAL

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AUTHORS: **G. Taylor, D. Mueller, J.C. Hosea, C. Kessel,** DATE:
B.P. LeBlanc, C.K. Phillips, **July 20, 2009**
R. Raman, P.M. Ryan

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1. Overview of planned experiment

This experiment tests HHFW heating of low I_p plasmas as a precursor to studying HHFW-assisted I_p ramp-up in the Solenoid-Free Start-up Topical Science Group. The experiment will use the new HHFW double-feed antenna and the increased lithium conditioning coverage available in 2009 to improve on previous HHFW electron heating results obtained with low I_p and $T_e(0)$ plasmas. The goal of the experiment is to couple ~ 3 MW of $k_\phi = \pm 8\ m^{-1}$ ($\pm 90^o$ antenna phasing) and $-14 + -18\ m^{-1}$ (180^o) antenna phasing) HHFW power into a deuterium plasma with $I_p \leq 200$ kA.

2. Theoretical/ empirical justification

A major goal of the 30 MHz HHFW program on the NSTX is to generate bootstrap current overdrive during non-inductive I_p ramp-up. TSC I_p ramp-up simulations predict that coupling 6 MW of HHFW power into the I_p ramp-up can result in bootstrap current overdrive. 85% bootstrap current fraction was achieved in XP-521 by coupling 2.5 MW of $-14 + -18\ m^{-1}$ (180^o) HHFW power into an $I_p = 250$ kA deuterium plasma. The goal of this experiment is to couple HHFW power into plasmas with $I_p \leq 200$ kA. HHFW-assisted I_p ramp-up experiments have recently benefited from lithium wall conditioning, which reduces the edge density, improving HHFW heating efficiency. Last year XP-817 successfully coupled HHFW power, with $k_\phi = -8\ m^{-1}$ current drive phasing, into lithium-conditioned deuterium plasmas. 550 kW of RF power coupled after the initiation of a CHI start-up plasma increased $T_e(0)$ from 3 to 15 eV when $n_e(0) \sim 4 \times 10^{18} m^{-3}$ and $I_p \sim 100$ kA. Also, 1.1 MW coupled into the early phase of the Ohmically-heated I_p ramp-up, when I_p was ramping from 100 kA to 300 kA, increased $T_e(0)$ from 140 to 700 eV, when $n_e(0) \sim 6\text{-}9 \times 10^{18} m^{-3}$. HHFW low I_p experiments in 2009 will benefit from the recent HHFW antenna upgrade from single-end fed straps to double-end fed straps, which should provide higher power than was previously achieved, as well as allowing coupling of HHFW power during a wider range of plasma edge conditions.

3. Experimental run plan

This experiment should take two run days to complete, since it is expected that considerable effort may be needed to develop a plasma with $I_p \leq 200$ kA.

Before starting the experiment the rtEFIT control should be setup to operate at low I_p, with I_{pmin} set to 150 kA **(D. Gates)**

1. Setup 600 ms I_p flattop plasma, similar to 123712 ($B_T = 5.5$ kG, deuterium), but initially with $I_p = 500$ kA, instead of 300 kA. Add $k_\phi = -8\ m^{-1}$ (-90^o) HHFW power, coupled from 150 – 500 ms, with a 50 ms ramp-up in power at the start of the RF pulse. Increase RF power to ~ 3 MW, while adjusting

lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency. **(5-10 shots)**

2. Run a sequence of shots, reducing I_p in 100 kA increments from 500 kA to as close to 200 kA as possible while coupling ~3 MW of $k_\phi = -8$ m^{-1} (-90^o) HHFW power. Adjust lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency. Take no RF shot at the lowest I_p achieved with good RF coupling **(5-10 shots)**

3. Repeat (1) and (2) with $k_\phi = 14 + 18$ m^{-1} (180^o) heating. **(10 shots)**

4. If the 200 kA HHFW experiments are successful reduce $I_p < 200$ kA, and as close to $I_p = 150$ kA as possible while still maintaining plasma position control so that the outer gap is 5-10 cm. **(5-10 shots)**

5. Add $k_\phi = -8$ m (-90^o) power, coupled from 150 – 500 ms, with a 50 ms ramp-up in power at the start of the RF pulse. Increase power to ~ 3 MW. **(5 shots)**

6. Repeat (4) with $k_\phi = 14 + 18$ m^{-1} (180^o) heating. **(5 shots)**

7. Repeat (4) with $k_\phi = -8$ m^{-1} (-90^o) heating. **(5 shots)**

8. Repeat (7) with $k_\phi = +8$ m^{-1} (+90^o) heating. **(5 shots)**

9. Perform a density scan with $k_\phi = -8$ m^{-1} (-90^o) heating. **(5-10 shots)**

10. If sufficient current drive is observed in (7) and (9), adjust RF pulse to start as soon as I_p reaches the flattop value. Then use open loop OH programming to provide no Ohmic drive after plasma current reaches the minimum value, (< 200 kA at approximately 25 ms). **(5 shots to get start time, 5-10 shots to perform CD with Ohmic current flat)**

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

This experiment should follow HHFW conditioning and higher power HHFW experiments XP-944 and XP-946. This experiment needs rtEFIT isoflux control for the outer gap. An NBI blip from source A at 90 keV should be added for MSE and CHERS data acquisition from 480 to 500 ms and 530 to 550 ms.

This experiment requires stable and reproducible plasmas at very low flattop plasma currents (I_p ~ 150-200 kA). Reliable HHFW operation up to 3 MW at -14 + -18 $m^{-1}$and ±8 m^{-1} is also required. Thomson scattering data are required for core and edge electron heating data. For analysis of edge power loss and coupling efficiency the experiment requires SOL reflectometry and edge ion heating data from edge rotation diagnostic, and Thomson scattering edge T_e and n_e data.

5. Planned analysis

Planned analysis includes analysis of heating efficiency at $k_\phi = \pm 8$ m^{-1} and -14 + -18 m^{-1}, TRANSP and GENRAY/CQL3D modeling.

6. Planned publication of results

The results will be submitted for publication.

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:

I_p as low as possible, preferable $I_p < 200$ kA. Stable, reproducible plasma with outer gap = 0.05 – 0.1 m.

Request D. Mueller and/or Dave Gates as operator for low I_p operation.

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified: 123712

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

I_{TF} (kA): 66 Flattop start/stop (s): 0/0.7

I_P (MA): 0.15-0.5 Flattop start/stop (s): 0/0.6

Configuration: **LSN**

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

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

Elongation κ: Upper/lower triangularity δ:

Gas Species: **D** Injector(s): **Gas programming should be similar to shot 123712**

NBI Species: **D** Voltage (kV) **A: 90 B: C:** Duration (s): Two 20 ms blips; 480-500 ms 530-550 ms

ICRF Power (MW): **≤ 3.0** Phase between straps (°): **±90, 180**
Duration (s): **0.35**

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		√