

**Princeton Plasma Physics Laboratory  
NSTX Experimental Proposal**

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

**OP-XP-920**

Revision: **2**

Effective Date:  
*(Approval date unless otherwise stipulated)*  
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*(2 yrs. unless otherwise stipulated)*

**PROPOSAL APPROVALS**

**Responsible Authors: G. Taylor & D. Mueller**

Date

**ATI – ET Group Leaders: G.Taylor/D. Mueller**

Date

**RLM - Run Coordinator: R. Raman**

Date

**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 of Low  $T_e(0)$ ,  $I_p$  Plasmas**

No. **OP-XP-920**

AUTHORS: **G. Taylor, D. Mueller, J.C. Hosea, C. Kessel,**

DATE:

**B.P. LeBlanc, C.K. Phillips,**

**June 15, 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  $\sim 3$  MW of  $k_\phi = \pm 8$  m<sup>-1</sup> ( $\pm 90^\circ$  antenna phasing) and  $-14 + -18$  m<sup>-1</sup> ( $180^\circ$  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<sup>-1</sup> ( $180^\circ$ ) 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<sup>-1</sup> 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<sup>-3</sup> 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  $n_e(0) \sim 6-9 \times 10^{18}$  m<sup>-3</sup>. 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  $I_p < 200$  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 with  $I_p = 200$  kA, instead of 300 kA. Adjust outer gap to be 5-10 cm and introduce lithium at 20 mg/min and adjust evaporation rate as necessary later for good RF coupling. **(10 shots)**
2. If the  $I_p = 200$  kA plasma is stable add  $k_\phi = -8$  m<sup>-1</sup> (-90°) HHFW power, coupled from 100 – 600 ms. Increase RF power to ~ 3 MW. Adjust lithium evaporation rate, gas injection rate and outer gap to optimize HHFW heating efficiency. **(10 shots)**
3. Repeat (2) with  $k_\phi = 14 + 18$  m<sup>-1</sup> (180°) heating. **(5 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°) power, coupled from 100 – 600 ms. Increase power to ~ 3 MW. **(5 shots)**
6. Repeat (4) with  $k_\phi = 14 + 18$  m<sup>-1</sup> (180°) heating. **(5 shots)**
7. Repeat (4) with  $k_\phi = -8$  m<sup>-1</sup> (-90°) heating, **(5 shots)**
8. Repeat (7) with  $k_\phi = +8$  m<sup>-1</sup> (+90°) heating. **(5 shots)**
9. Perform a density scan with  $k_\phi = -8$  m<sup>-1</sup> (-90°) 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 CHERS data acquisition from 580 to 600 ms.

This experiment requires stable and reproducible plasmas at very low flattop plasma currents ( $I_p \sim 150$ -200 kA). Reliable HHFW operation up to 3 MW at  $-13$  m<sup>-1</sup> and  $\pm 8$  m<sup>-1</sup> 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<sup>-1</sup> and  $-14 + -18$  m<sup>-1</sup>, 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): 0.15-0.3                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  $\kappa$ :                      Upper/lower triangularity  $\delta$ :

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

NBI Species: **D**    Voltage (kV) **A: 90        B:            C:**        Duration (s): 20 ms

ICRF Power (MW):  $\leq$  **3.0**        Phase between straps ( $^\circ$ ):  **$\pm 90, 180$**

Duration (s): **0.075-0.6**

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		
H $\alpha$ 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 – EIB 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		√