Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: Characterization of Fast Ion Power Absorption Dependencies with the High Harmonic Fast Wave

OP-XP-214	**Revision: 0**	Effective Date: 3/1/2002 *(Ref. OP-AD-97)* Expiration Date: 3/1/2003 *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Author: A. Rosenberg	Date
ATI – Task Force Leader: J. R. Wilson	Date
RLM – Run Coordinator: R. Maingi	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

Overview of Experiments

The primary goal of this experiment is to characterize the dependence of fast ion absorption of the high harmonic fast wave (HHFW) on various parameters, particularly B_t, $k_{||}$, and beam energy. In addition, we would like to scan the NPA on identical shots to aid in determining the fast ion distribution function. Previous experiments and computational predictions indicate ion absorption increases with decreasing $k_{||}$. (Fig. 3) A set of DIII-D experiments (Fig. 1) has shown a neutron rate and stored energy spike when a deuterium harmonic is on the magnetic axis, and simulations have shown the deposition profile for both fast ions and electrons moving further off-axis with decreasing B_t. (Fig. 2)

The strength, energy spectrum, and absorption properties of the tail as a function of beam energy are fairly untested. There may also be a resonance shifting due to the introduction of a fast ion drift velocity. In the 60-90 kV NBI regime, the beam heating power should scale as the applied voltage to the 5/2 power. This scaling means the heating power is changed from 2.23 to 0.8 MW as the applied voltage is dropped from 90 kV to 60 kV.

The long term goal of this experiment is to find an ideal parameter range for current drive and/or heating with HHFW RF and beams active simultaneously in an ST plasma. This data will also be of critical importance to the author's thesis.

Theoretical/Empirical Justification, Conditions and Requirements

The interaction between the HHFW and fast ions is a new and important research area. Neutral beams are included in any reactor scenario as a means of fueling and heating the plasma. The HHFW is currently being explored as a means of heating and driving plasma current. In NSTX's campaign over the summer of 2001, a clear fast ion tail was observed on the NPA when the HHFW and NBI were active simultaneously. Neutron detector and ion loss probe signals provided further evidence. This occurred for essentially every shot there was a significant overlap in RF and NBI power traces. The XPs where this was observed were not focused on comprehensively exploring this phenomenon. Simulations have since been performed to better determine the effects of varying easily manipulated parameters.

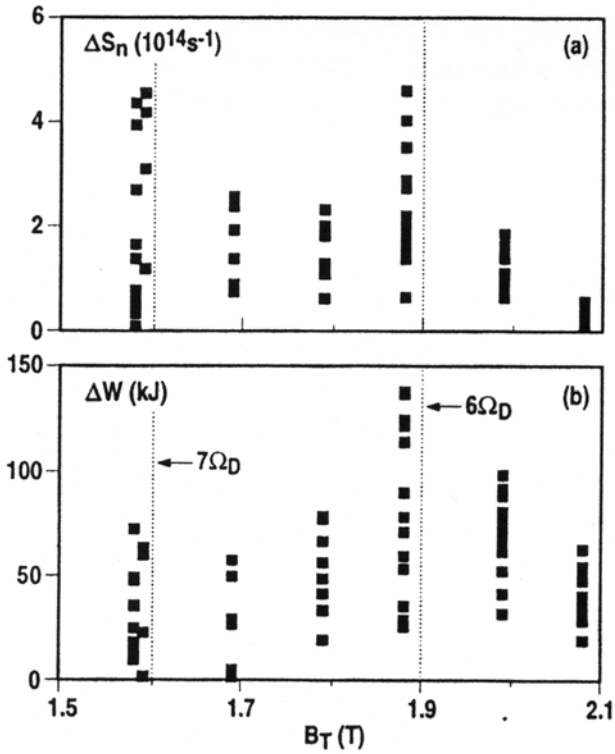


Figure 1: Anomolous neutron rate and stored energy spikes at resonances in DIII-D. (C. C. Petty, '95)

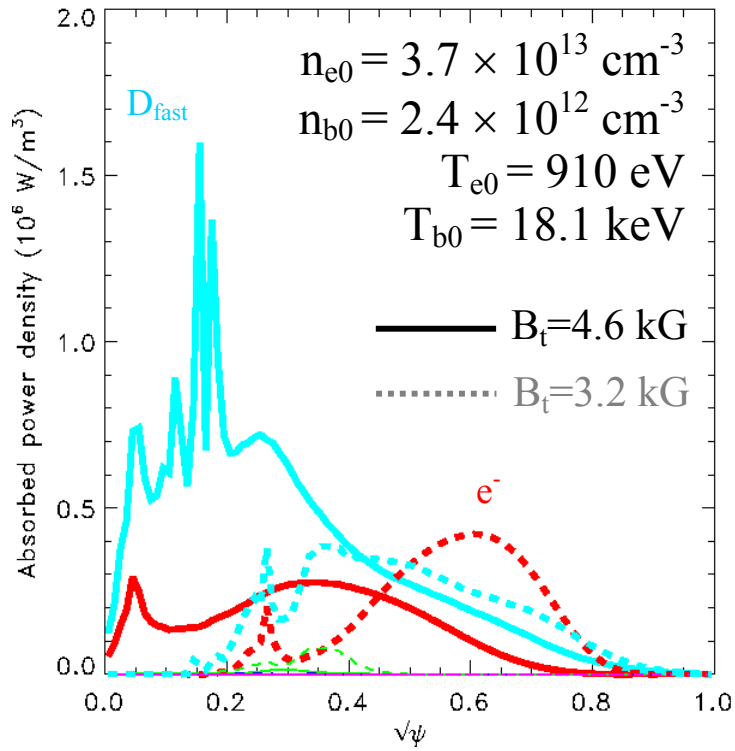


Figure 2: HPRT computed deposition profiles for electrons and fast ions at B_t = 4.6 and 3.2 kG in NSTX, shot 105927, t=230ms.

TRANSP was used to calculate fast ion energy and particle density profiles, and this information was used to estimate an effective Maxwellian temperature for the fast ion population. This, along with EFIT and Thomson data, was fed into HPRT, a 2-D hot plasma ray-tracing code that computes power deposition profiles. A B_t scan was performed with this code keeping I_p constant, the result shown in Figure 2. This scan ran between 4.6 kG and 3.2 kG on-axis, including deuterium resonances 9 through 12. The deposition profiles for both fast ions and electrons appear to move further off-axis with decreasing B_t, and at $k_{||}$ = 7 m^{-1} the power-absorbed split shifts from ~ 30% e^-, 70% fast ions at high B_t to a 50/50 split at low B_t. Experimentally, this may be evident in a decreased central electron, and possibly bulk ion, temperature with decreasing B_t. The NPA may also see its strongest signal further off-axis. The deposition profiles showed no evidence of dramatic changes when the axis was at a deuterium resonance, though as evidenced in DIII-D in Fig. 1, the neutron rate and stored energy may be more strongly affected.

The dependence of HHFW ion absorption on $k_{||}$ has been predicted (most notably by J. Menard, '99 and C. Lashmore-Davies, '98) and generally accepted for many years, however this has remained largely untested, partly due to a general lack of bulk ion absorption in NSTX. With NBI, ion absorption seems quite evident, so the prediction that ion absorption increases with decreasing $k_{||}$

becomes testable. Figure 3 demonstrates a dramatic change in both deposition profile and power split. (The power split is predicted to change from 58% e^-, 41% fast ions for $k_{\|} = 14m^{-1}$ to 14% e^-, 85% fast ions for $k_{\|} = 3.5m^{-1}$.) This should be observed in decreasing central T_e with decreasing $k_{\|}$, along with increased T_i, NPA signal, neutron rate, and/or ion loss signal. The neutron rate gave some indication of this in the single set of similar shots (106319 and 106320) with different phasings, but the data set needs to be greatly expanded.

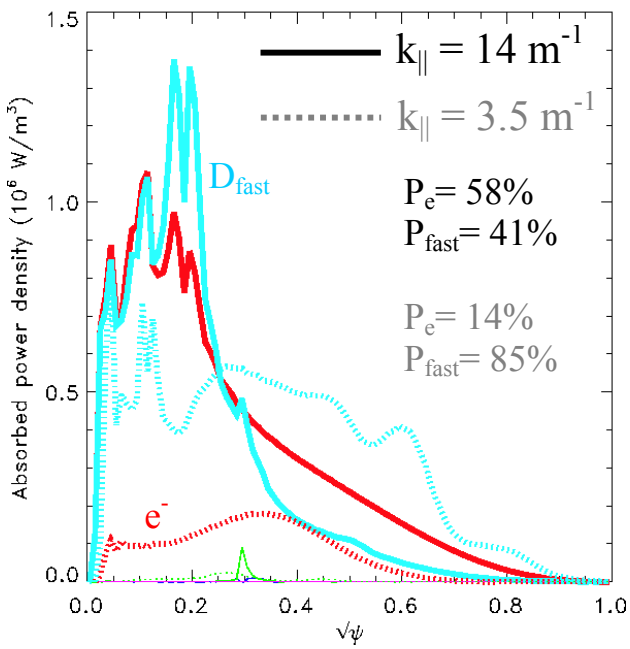


Figure 3: HPRT calculated deposition profiles at $k_{\|}$ = 14 and 3.5 m^{-1} in NSTX, shot 105927, t=230ms.

The last major variables we would like to explore are the neutral beam energy and source. One may expect increased absorption with increased fast ion energy, but simulations indicate that it may actually be roughly independent (~30% e^-, 70% fast ions). On the other hand, the ray tracer is currently assuming an effectively Maxwellian fast ion distribution function, which is of particularly questionable validity for this scan (and a major purpose for the thorough NPA scan that will follow). Due to the fact that for the desired energy range, beam power is roughly proportional to (beam voltage)$^{5/2}$ as per the Child-Langmuir law, a combination of beam sources will be used in some shots to avoid changing both total power and energy simultaneously.

The final day will consist of a detailed NPA scan, both vertically and horizontally, at 2 phasings for otherwise identical shots. This is necessary to gain information on the fast ion distribution function, and estimate the power contained in the tail. The characteristics of these shots will be determined from previous data.

Experimental Run Plan (3 days)

Day 1

0. Recreate RF-induced fast ion tail, observe with NPA (1-5 discharges)

    a. Dial up shot 107242, dropping flat top to 800 kA (160 ms rise time, 250 ms flat top), NBI Source A at 1.6 MW from t = 160 ms to 300 ms, B_0 = 4.4 kG, NPA position set to midplane, pointing to center stack

b. RF time window changed for this shot to t = 130 – 270 ms, $k_{||} = 7\ m^{-1}$, $P_{RF} = 2.5$ MW

c. If no observed tail, switch to shot 105913 (no changes), NPA at $R_{tan} = 70$cm, then delay RF and NBI to overlap flat top

1. B-field scan (11 – 18 discharges)

   a. If not all diagnostics (neutron detectors, Thompson, ion loss probes, CHERS) up and ready by tail observation, repeat last shot with them ready if at all possible (0-1 shots)

      i. Measured B_0 should be ~ 4.7 kG, check this

      ii. If MHD above 330 ms reduced, may extend RF and NBI traces

   b. Maintain current trace, decrease B_0 to 3.2 kG, scan NPA back to 0 cm, take shot (1)

   c. Switch to $k_{||} = 14\ m^{-1}$ (1)

   d. Switch back to $k_{||} = 7\ m^{-1}$, set B_0 to 3.75 kG, again maintaining current (1)

   e. Scan NPA vertically to –20 cm, repeat Shots a.,b.,d. (3)

   f. Scan NPA vertically to –40 cm, repeat Shots a.,b.,d. (3)

      i. Decision point, should future NPA scans be reduced or extended in range?

   g. Scan NPA back to 0 cm, extend RF time window through t = 300 ms, scan B_0 within shot from 3.2 kG at t = 160 ms to 4.4 kG at 300 ms. (1)

   h. If neutron rate spikes found at on-axis resonances during Shot f., repeat without RF. (0-1)

   i. Return RF time window to Shot a. Increase flat top I_p to 1.2 MA. Take shot. (1-4)

      i. Decision point: skip 1.j. and go directly to 2.a.? Vary B or $k_{||}$ at high I_p?

   j. Return I_p to 800 kA. If trend observed (central T_e decrease and/or tail localized off-axis with lower B_0) in Shots a. – h., dial B_0 to 4.2 kG – take shot, then 3.95 kG, then 3.6 kG, 3.45 kG, and 3.3 kG. (0-5)

Day 2

2. $k_{||}$ scan (5-7 discharges)

   a. Return to shot 0. Take shot if time permits. (0-1)

   b. Switch to $k_{||} = -7\ m^{-1}$, take shot if time permits (0-1)

   c. Switch to $k_{||} = 14\ m^{-1}$, take shot (3)

      i. Scan NPA vertically to –20 cm

      ii. scan to –40 cm

   d. Scan NPA back to 0cm, take shots at $k_{||}$= 3.5 and 10.5 m^{-1} (2)

3. Beam energy scan (8-10 discharges)

   a. Return to shot 0. Switch to 4.4 kG, maintaining current trace (as per 1f.) Set beam to Source A, 90 kV (P ~ 2.23 MW). Take shot. (3)

      i. Scan NPA vertically to –20 cm

      ii. scan to –40 cm

b. Same for Source B (1-3)
    i. Decide whether to scan NPA here. If yes, scan NPA vertically to –20 cm
    ii. scan to –40 cm
c. Set Source A and Source B to half the power simultaneously (each P ~ 1.12 MW, V ~ 68.2 kV) (3)
    i. Scan NPA vertically to –20 cm
    ii. scan to –40 cm
d. Set beam to Source A, 60 kV. Take shot. (1)

The below chart is a summary of the scans over Days 1 and 2.

	NPA Position			
B_0 (kG)	0	-20 cm	-40 cm?	$k_{\|\|}$ (m^{-1})
4.4				7
3.2				7
3.2				14
3.75				7
Scan 3.2 at 160 to 4.4 at 300ms				7, RF through 300ms
Repeat scan?				No RF
4.4, I_p=1.2MA				7, original RF
4.2, I_p=800kA?				7
3.95				7
3.6				7
3.45				7
3.3				7
4.4?				7
4.4				-7
4.4				14
4,4				3.5
4.4				10.5
Set B_0=4.4				Set $k_{\|\|}$=7
NBI Source A P(MW), V(kV)				NBI Source B P(MW), V (kV)
2.23MW, 90kV				0
0				2.23MW, 90kV
1.12MW, 68kV				1.12MW, 68kV
.809MW, 60kV				0

Day 3

4. NPA scan (20)
    a. From previous shots, decide on B-field and beam energy for thorough NPA scan (default, shot 0). Also choose primary phasing order to concentrate on (ph1), and alternate (ph2).

Nominal power traces: NPA Source A from t = 70 – 390 ms, RF from t = 180 – 250 ms at one phase, 290 – 360 ms at the other

b. Aim NPA at midplane, R_{tan} = 100 cm, take shot at ph1. (1)

c. Same, shot at ph2. (1)

d. Switch back to ph1. Radially scan NPA to R_{tan} = 107, 114, and 121 cm. Take shot at each. (3)

e. Switch to ph2. Take shot. (1)

f. Switch to ph1. Radially scan NPA to R_{tan} = 128, 89, 78, and 67 cm. Take shot at each. (4)

g. Radially scan NPA to center stack. Take shot. (1)

h. Decision point: shot at ph2 here redundant? If not, take shot. If so, switch to ph2 at next vertical scan and take shot, then switch back. (1)

i. Decision point: Currently planning to scan through full vertical range from 0 to –50 cm. If previous shots indicate smaller range desired, adjust following numbers accordingly.

j. Scan vertically to -7 cm, -14 cm, -21 cm, -28 cm. Take shot at each. (4)

k. Switch to ph2. Take shot. (1)

l. Switch to ph1. Scan vertically to -35 cm, -42 cm, -50 cm. Take shot. (3)

Required machine, beam, ICRF and diagnostic capabilities:

1. NSTX will be operated at plasma currents between .8 and 1.2 MA .
2. RF at ~2.5 MW
3. NBI capable of being tuned from 60-100kV. The following beam voltages correspond to the following heating powers per source: 60 kV ~ 0.8 MW, 65 kV ~ 1.0 MW, 70 kV ~ 1.2 MW, 75 kV ~ 1.4 MW, 80 kV ~ 1.7 MW (i.e. $P_{NB} \sim V_{NB}I^{5/2}$).
4. H_2 concentration should be under 5%.
5. The following diagnostics are required: Thomson Scattering, magnetics, scanning NPA, neutron detectors, lost ion probes, CHERS, Mirnov coils, the X-Ray array, filterscopes, bolometers, and plasma TV.
6. The following diagnostics are useful: VB, VIPS, PHA, edge reflectometer and SXR.

Planned Analysis

1. Ion absorption will be monitored with the NPA, CHERS, neutron detectors, and lost ion probes. Electron absorption will be monitored with Thomson Scattering.
2. HPRT will be used to calculate the absorbed profiles. With data from the NPA, it will (hopefully) be improved to calculate absorption for a fast ion distribution function.

3. TRANSP will be used to compare predicted with measured neutron rates, and compute fast ion energy and particle density.

Experimental Results Summary

1. Initial results presented at the APS DPP02 meeting in Rosenberg's presentation.
2. More detailed results will be published in Rosenberg's thesis.

PHYSICS OPERATIONS REQUEST

Title: Characterization of Fast Ion Absorption Dependencies with HHFW No. 214

Machine conditions (indicate range where appropriate):

TF: Flattop (kA): **35** Flattop start/stop (s): **.16-.42**

I_p: Flattop (kA): **800-1200** Flattop start/stop (s): **.16-.42**

Position: R_{outer} (m): **1.45-1.5m** Z (m): **0** **Single null**

Gas: Prefill: **D** Puff : **D**

NBI: Power (MW): **0.8-3MW** Start / stop (s): **0.16-0.3s** Voltage (kV): **60-90**

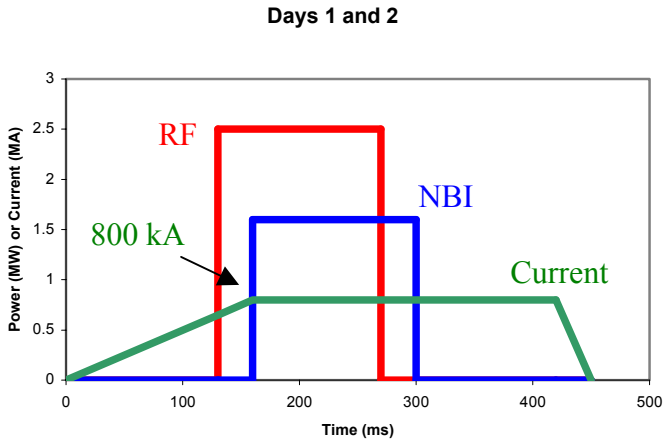
RF: Power (MW): **2.5 MW** Start / stop (s): **0.13-0.27s** Frequency (MHz): **30**

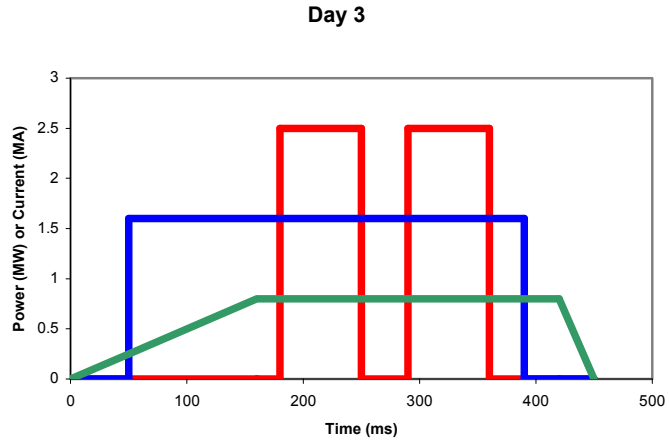
CHI: **Off**

If this is a continuation of a previous run or if shots from a previous run are similar to those needed, provide shot numbers for setup

107242, with RF window shifted to 130ms – 270 ms

If shots are new and unique, sketch desired time profiles and shapes. Accurately label the sketch so there is no confusion about times or values. Attach additional sheets as required.





DIAGNOSTIC CHECKLIST

Title: Characterization of Fast Ion Absorption Dependencies with HHFW No. 214

Diagnostic system	**Need**	**Desire**	**Requirements** (timing, view, etc.)
Magnetics	✓		
Fast visible camera	✓		
VIPS-1		✓	
VIPS-2		✓	
SPRED		✓	
GRITS		✓	
Visible filterscopes		✓	
VB detector	✓		
Midplane bolometer	✓		
Diamagnetic flux	✓		
Density interferometer (1mm)		✓	
FIReTIP interf'r/polarimeter	✓		
Thomson scattering	✓		
CHERS	✓		
NPA	✓		Scanning mode
X-ray crystal spectrometer			
X-ray PHA		✓	
EBW radiometer		✓	
Mirnov arrays	✓		
Locked-mode detectors	✓		
USXR arrays	✓		
2-D x-ray detector (GEM)		✓	
X-ray tangential camera		✓	
Reflectometer (4 ch.)	✓		Scanning mode
Neutron detectors	✓		ZnS necessary
Neutron fluctuations	✓		
Fast ion loss probe	✓		
Reciprocating edge probe		✓	
Tile Langmuir probes		✓	
Edge fluctuation imaging		✓	
H-alpha cameras (1-D)	✓		
Divertor camera (2-D)	✓		
Divertor bolometer (4 ch.)	✓		
IR cameras (2)		✓	
Tile thermocouples		✓	
SOL reflectometer		✓	