## Princeton Plasma Physics Laboratory
# NSTX Experimental Proposal

| | | |
|---|---|---|
| Title: **Characterization of the L to H-mode transition in D and He plasmas with symmetrically phased HHFW heating** | | |
| **OP-XP-1036** | Revision: | Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)* |

## PROPOSAL APPROVALS

| | |
|---|---|
| **Responsible Author: Devon Battaglia** | Date |
| **ATI – ET Group Leader: Howard Yuh** | Date |
| **RLM - Run Coordinator:** | Date |
| **Responsible Division: Experimental Research Operations** | |

## RESTRICTIONS or MINOR MODIFICATIONS
(Approved by Experimental Research Operations)

# NSTX EXPERIMENTAL PROPOSAL

TITLE: **L to H-mode transition in D and He plasmas using HHFW heating** No. **OP-XP-1036**

AUTHORS: **D. Battaglia, S. Zweben, Y. Ren, G. Taylor, R. Maingi, S. Kaye** DATE:

## 1. Overview of planned experiment

The goals of this experiment are to characterize the change in turbulence during the L- to H-mode transition in deuterium and helium plasmas, to determine the L- to H-mode power threshold on NSTX when using symmetrically phased HHFW heating and to characterize the dependence of the high-k turbulence in L-mode discharges versus $Z_{eff}$.

## 2. Theoretical/ empirical justification

A priority of ITPA is to relate the power threshold of the L- to H-mode transition in helium plasmas to the scaling database for deuterium plasmas since the first operation phase of ITER is expected to use non-deuterium plasmas. This experiment builds on previous NSTX results (XP941) that demonstrated that the LH power threshold is similar for D and He plasmas when the heating power is normalized to the line averaged density (figure 1).

XP941 used HHFW heating with -90 degree (anti-symmetric) phasing. This phasing provides both heating and current drive, but also leads to a significant power deposition at the plasma edge, leading to a low heating power efficiency (~20%). The power transmission through the plasma edge is strongly coupled to the edge density, which is not well controlled in discharges. As a result, the error bars for the power threshold calculation in XP941 approached 60% (see figure 1). Also, the strong SOL heating may have skewed the interpretation of the power threshold. XP941 used discharges with Ip = 600 kA and Bt = 4.5 kG, which is compatible with RF operations, but did not provide suitable conditions for the GPI turbulence diagnostic.

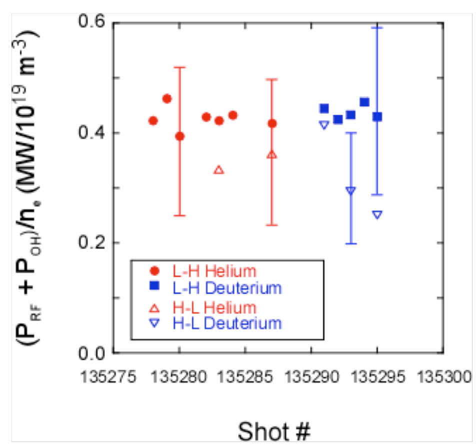


**Figure 1** Ohmic heating plus the electron heating from RF normalized to the line-averaged density for D and He plasmas (XP941).

This XP will utilize 180 degree (symmetric) HHFW phasing since it is less sensitive to the edge density and should reduce the uncertainty in the RF heating power calculation. This XP will also aim to operate with $I_p/B_t$ = 2 MA/T so that the edge turbulence during the LH transition period can be measured using the GPI diagnostic.

The GPI diagnostic provides an unparalleled capability for characterizing edge turbulence. This allows NSTX to test the conventional theory that the L-H transition is driven by edge turbulence suppression through shear flows, zonal flow or possibly GAMs. This XP will provide a valuable comparison to the characterization of the turbulence during the LH transition in NBI heated plasmas

(XP929) and will help elucidate the 2-D turbulence structure and velocity fields before, during and after the transition.

In XP-735, plasmas were found near marginal stability for the critical gradient of the electron temperature gradient mode, which is very sensitive to $Z_{eff}$. An additional goal of this experiment is to measure high-k fluctuations in nearly identical L-mode Deuterium and Helium plasmas (i.e. different values of $Z_{eff}$).

## 3. Experimental run plan

The anticipated target for $I_P/B_T$ = 2 MA/T is $I_P$ = 900 kA, $B_T$ = 4.5 kG. The HHFW has been operated previously at $B_T$ = 4.5 kG, but with $I_P$ only as high as 700 kA. Therefore, this XP is contingent on the development of a suitable target discharge in the RF conditioning XMP. Ohmic-only L- and H-mode discharges with $I_P$ = 900 kA and $B_T$ = 4.5 kG have been demonstrated in previous XPs (ex:XP506). The target LSN shape, NBI pre-heat timing, lithium deposition, and LLD operation used in the RF conditioning XMP will be used for all discharges in this XP.

The first 1/2 day will be run with helium. The goal of the first target discharge is to establish the RF power level where the LH transition occurs. If no LH transition is observed or an LH transition is observed during the $I_P$ ramp, the gas programming would be altered to aid or hinder the transition. If this solution is not sufficient, the $I_P$ could be raised (higher $P_{LH}$) or lowered (smaller $P_{LH}$) while maintaining $I_P/B_T$ = 2 MA/T.

Details of the first target discharge:

- $I_P/B_T$ = 2 MA/T (aim for $I_P$ = 900 kA, $B_T$ = 4.5 kG)
- $I_P$ ramp with OH. May use low-power NBI preheat to lengthen pulse, provided H-mode is not triggered during $I_P$ ramp.
- Ramp RF power to max RF power over 100 – 200 ms during $I_P$ flattop
- L- to H-mode transition during RF ramp (determined using build-up of $T_e$ pedestal)
- GPI measurement near best guess of transition time
- NBI blip (Source A for 20 ms) following start of RF flattop
- Maintain RF power flattop ~ 100 ms. Then ramp down over ~ 50 ms.
- No error field correction (avoid switching noise)

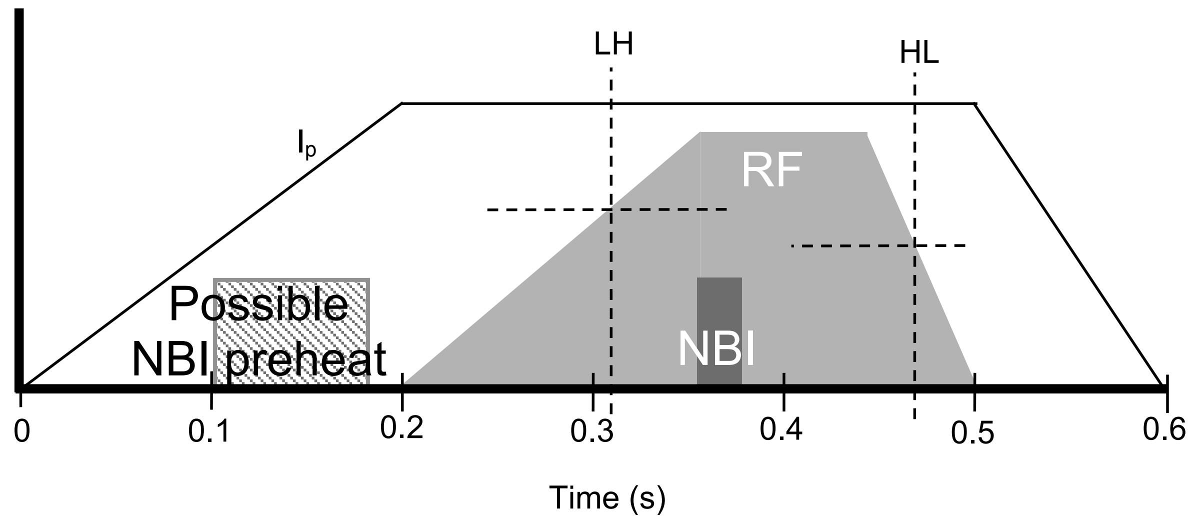


**Figure 2** Timing and shape of $I_P$, $P_{RF}$ and $P_{NBI}$ for the first target discharge

The RF heating power is determined by measuring the change in the stored energy following a step in the RF power. The second target discharge will have discrete steps in the RF power instead of continuous ramps. This discharge will be repeated about six times with the final two RF power steps altered each time. The goal is to get three discharges with an LH transition for the GPI measurement and three discharges without an LH transition (fully L-mode) for the high-k measurements. Details of the second target discharge:

- 3 or 4 RF power steps up to LH power threshold. The steps should be separated by about 50ms.
- RF power flattop for ~100ms
- A single step down following RF power flattop to approximate HL power threshold
- 30 ms GPI measurement at beginning of max RF power
- NBI blip (Source A for 20 ms) ~ 30 ms after beginning of max RF power
- Repeat discharge a number of times. If the following is observed . . .
    - LH transition: Decrease max RF power by ~10% for the next shot
    - No LH transition: Increase max RF power by ~10% for the next shot

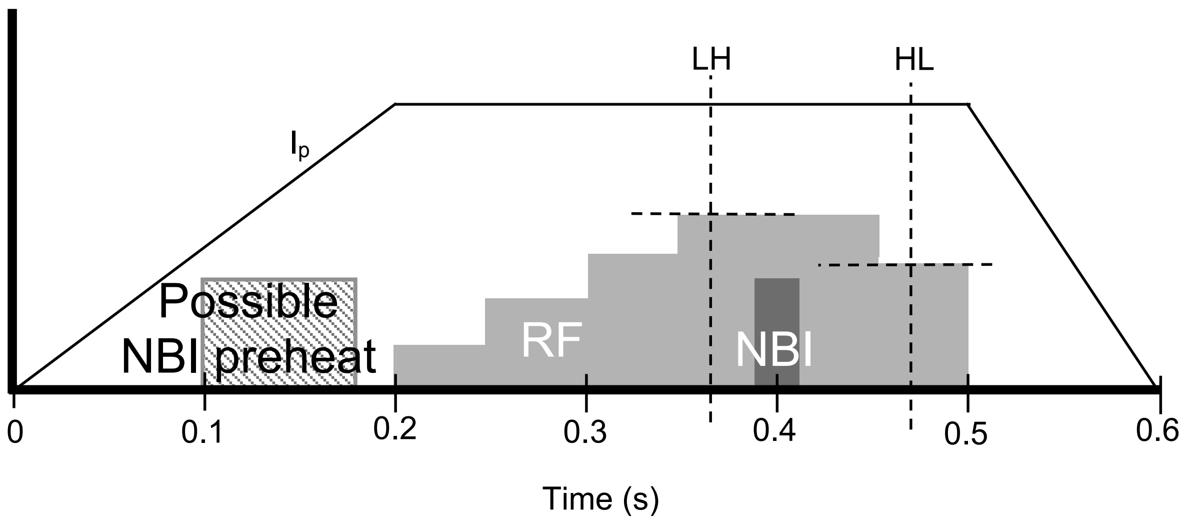


**Figure 3** Timing and shape of $I_P$, $P_{RF}$ and $P_{NBI}$ for the second target discharge

Repeat discharges with D gas for second 1/2 day experiment. Gas programming may be tuned to bring density and temperature profiles in a similar regime as the helium plasmas for the high-k comparisons.

If extra time during either half-day experiment, try to get GPI measurements during an OH H-mode transition by introducing a sharp reduction in $V_{loop}$ at knee of $I_p$ ramp or during $I_p$ flattop (as motivated by XP506).

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

XP must follow an RF conditioning XMP where a target discharge for this XP with $I_P/B_T$ = 2 MA/T is developed. Shape control and stable wall conditions are needed. Source A NBI is required to make CHERS, and possibly BES, measurements. Operation in helium is also required. GPI and high-k are needed. All other turbulence diagnostics are highly desired.

## 5. Planned analysis

EFIT, TRANSP for RF heating power calculation.

GPI – turbulence structure and correlation analysis using existing codes, HOP-V turbulence velocity analysis, bicoherence and other wave-wave coupling analysis. Possible comparison of turbulence correlation lengths to theoretical models, such as XGC-1.

## 6. Planned publication of results

APS-DPP, ITPA, Physics of Plasmas or Nuclear Fusion level paper.

# PHYSICS OPERATIONS REQUEST

TITLE: **L to H-mode transition in D and He plasmas using HHFW heating** No. **OP-XP-1036**

AUTHORS: **D. Battaglia, S. Zweben, Y. Ren, G. Taylor, R. Maingi, S. Kaye** DATE:

*(use additional sheets and attach waveform diagrams if necessary)*

**Brief description of the most important operational plasma conditions required:**

Reliable HHFW, achieve L-H transition during $I_P$ flattop.

**Previous shot(s) which can be repeated:**

**Previous shot(s) which can be modified:** Established in RF conditioning XMP

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

$I_{TF}$ (kA): **52 (4.5 kG)** Flattop start/stop (s):

$I_P$ (MA): **0.9 MA** Flattop start/stop (s): **0.2 – 0.4**

Configuration: **LSN**

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

Outer gap (m): Inner gap (m): Z position (m):

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

Gas Species: **He, then D** Injector(s):

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

**ICRF** Power (MW): **4 MW** Phase between straps (°): **-180** Duration (s): **0.3 s**

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

**LITERs: On** Total deposition rate (mg/min): **Established in XMP**

**LLD:** Temperature (°C): **Established in XMP**

**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** |
|---|---|---|
| Beam Emission Spectroscopy | | X |
| Bolometer – divertor | | X |
| Bolometer – midplane array | X | |
| CHERS – poloidal | X | |
| CHERS – toroidal | | X |
| Dust detector | | |
| Edge deposition monitors | | |
| Edge neutral density diag. | | X |
| Edge pressure gauges | | X |
| 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 | | |
| Filterscopes | X | |
| FIReTIP | | X |
| Gas puff imaging – divertor | | X |
| Gas puff imaging – midplane | X | |
| H$\alpha$ camera - 1D | X | |
| High-k scattering | X | |
| Infrared cameras | | X |
| Interferometer - 1 mm | | X |
| Langmuir probes – divertor | | X |
| Langmuir probes – LLD | | X |
| Langmuir probes – bias tile | | X |
| Langmuir probes – RF ant. | | X |
| Magnetics – B coils | X | |
| Magnetics – Diamagnetism | X | |
| Magnetics – Flux loops | X | |
| Magnetics – Locked modes | | X |
| Magnetics – Rogowski coils | X | |
| Magnetics – Halo currents | | X |
| Magnetics – RWM sensors | | X |
| Mirnov coils – high f. | | X |
| Mirnov coils – poloidal array | | X |
| Mirnov coils – toroidal array | | X |
| Mirnov coils – 3-axis proto. | | X |

*Note special diagnostic requirements in Sec. 4*

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