Princeton Plasma Physics Laboratory

NSTX-U Experimental Proposal

Title: **Test Critical Gradient Model of Alfven Eigenmode Transport**		
OP-XP-1524	Revision: **0**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS	
Responsible Author: W. Heidbrink	Date
SG, TSG or TF Leader (assigned by RC):	Date
Run Coordinator (RC):	Date
Responsible Division: Experimental Research Operations	

RESTRICTIONS or MINOR MODIFICATIONS

(Approved by Experimental Research Operations)

NSTX-U EXPERIMENTAL PROPOSAL

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AUTHORS: **W. Heidbrink, EP Group** DATE: **6/9/15**

1. Overview of planned experiment

The goal of this experiment is to modulate the fast-ion transport in plasmas with different levels of Alfven eigenmode (AE) activity in a search for a threshold for "stiff" fast-ion transport.

2. Theoretical/ empirical justification

The concept for this experiment is inspired by studies of thermal transport, such as the one described in [1]. In that experiment, the electron temperature gradient was altered shot-to-shot to put the plasma above and below the threshold for marginal stability for the trapped electron mode. At each condition, a small amount of electron cyclotron heating power was modulated. An ECE diagnostic measured the response of the T_e profile to this modulation. From these data, the electron heat flux was inferred. A rapid jump in transport was observed at the TEM threshold.

A fast-ion experiment patterned after this concept was tested on DIII--D with excellent results. One neutral-beam source was on constantly in every shot for active FIDA and SSNPA measurements. A second source injected a modulated square wave on every shot. The additional sources were used to vary the average beam power shot-to-shot; this varied the strength of AE activity. At low power and low AE activity, the modulated fast-ion flux was negligible but, above a certain threshold in AE activity, the modulated fast-ion flux rapidly increased.

The development of critical-gradient models to predict fast-ion transport in future devices is a vigorous area of current research: Princeton, GA, and NIFS theorists are all presently testing their models against the DIII-D data. The different models postulate different reasons for the onset of strong fast-ion transport. There were many differences between AE activity in DIII-D and NSTX. Irrespective of whether a critical gradient is observed in this NSTX-U experiment, a well-conducted experiment that follows the DIII-D methodology will provide a crucial validation test for the developing theoretical models.

[1] J.C. Hillesheim et al., PRL **110** (2013) 045003.

3. Experimental run plan

Source 1B is viewed by many of the FIDA and SSNPA diagnostics, so it will probably be the active beam for the experiment. To insure that the lowest power point has weak fast-ion transport, source 1B will operate at 65 kV. If Source 1A does not drive appreciable mode activity, then it will replace 1B as the primary active beam.

The FIDA and SSNPA diagnostics should <u>not</u> view the modulated source, so one of the sources in beam-line 2 will be the modulated source (probably 2B). It will be modulated throughout the discharge with a square wave that is on for 20 ms and off for 20 ms. (The DIII-D experiment used a period of 54 ms.

Since the anticipated slowing-down time is shorter in NSTX-U, a shorter period is desirable. A 40 ms period is the minimum allowed by the Neutral Beam group.)

Source 1A will operate at 90 kV. If it is not the primary active beam, on the low-power shots, it will inject before & after the time of interest to obtain MSE data.

Another source—probably 2C—will operate at 70 kV in order to provide a relatively fine step in beam power (and AE activity) if a transport threshold is observed. The other sources will operate at 90 kV.

The sources for the eight power levels are the following. In the two low-power cases, 1A will inject prior to the time of interest to trigger an H-mode and to provide good CHERS and MSE data (also another pulse after the time of interest).

1. 1B/2B
2. 1B/2B/2C
3. 1B/2B/1A
4. 1B/2B/1A/2C
5. 1B/2B/1A/2A
6. 1B/2B/1A/2A/2C
7. 1B/2B/1A/2A/1C
8. 1B/2B/1A/2A/1C/2C

It is desirable to perform the entire scan in H-mode. It is likely that the density will monotonically increase throughout the time of interest. Minimizing this change is desirable but not essential to the success of the experiment; shot-to-shot reproducibility in the density evolution is more important.

1) Establish baseline condition using power level #3. Test whether the lowest power shot can use 1A/2B. If not, try the low-power condition (power level #1) to test whether similar plasma conditions are preserved (3 good shots).

2) Perform power scan (6 good shots).

4) Switch to a different modulated source and repeat (8 shots).

5) If a threshold for stiff transport is observed on a diagnostic signal, vary the beam power across the threshold in finer power steps by lowering the beam voltage on selected sources (2 shots).

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

A minimum of 5 neutral beam sources are required. The FIDA, SSNPA, neutron, and magnetics diagnostics are essential. This experiment should be scheduled after the neutral-beam checkout, XP1522.

5. Planned analysis

If relatively steady AE activity is observed, the analysis will utilize the tools developed to analyze the DIII-D data. The data are conditionally averaged and the modulated flux is inferred. The fast-ion source is obtained from TRANSP and FIDASIM runs. New analysis will be required to quantify the AE activity. A case near threshold will be prepared for validation studies by our theoretical collaborators.

If the AE activity is bursty (as in NSTX), new techniques will need to be developed to analyze the results.

6. Planned publication of results

The most likely outcome is a full-length journal article in *Nuclear Fusion.*

7. Estimated Neutron Production

Based on the number of shots, plasma current levels, and expected durations, estimate the maximum neutron production of this experiment. See calculator in Appendix #2 for this calculation.

# of Shots used in Estimate: 24   Estimated Total Neutron Production: 4.8e15

PHYSICS OPERATIONS REQUEST

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Reproducible H-mode. The truth is that we'll select an NSTX-U shot. A reasonable NSTX shot is 140740.

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified:

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

B_T Range (T): **0.55** Flattop Duration (s): **2**

I_P Range (MA): **0.7** Flattop Duration (s): **1**

Configuration: **DN**

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

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

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

Gas Species: **D** Injector(s):

NBI Species: **D** Heating Duration (s):

Voltage (kV) 50 cm (1C): 60 cm (1B): 70 cm (1A):

Voltage (kV) 110 cm (2C): 120 cm (2B): 130 cm (2A):

ICRF Power (MW): Phase between straps (°): Duration (s):

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

LITERs: Off / On Total deposition rate (mg/min) or dose per discharge (mg):

EFC coils: Off/On

DIAGNOSTIC CHECKLIST [1]

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Beam Emission Spectroscopy		
Bolometer – midplane array		
CHERS – poloidal		
CHERS – toroidal	**x**	
Divertor Bolometer (LADA)		
Divertor visible cameras		
Dust detector		
Edge deposition monitors [2]		
Edge neutral density diag.		
Edge MIGs [2]		
Penning Gauges [2]		
Edge rotation diagnostic		
Fast cameras – divertor [2]		
Fast ion D_alpha - poloidal	**x**	
Fast ion D_alpha - toroidal	**x**	
Fast lost ion probes - IFLIP		
Fast lost ion probes - SFLIP	**x**	
Filterscopes [2]	**x**	
FIReTIP		
Gas puff imaging – divertor		
Gas puff imaging – midplane		
Hα cameras - 1D [2]		
Infrared cameras [2]		
Langmuir probes – divertor		
Langmuir probes – RF		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism		
Magnetics – Halo currents		
Magnetics – RWM sensors		

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MAPP		
Mirnov coils – high f.	**x**	
Mirnov coils – toroidal array	**x**	
MSE-CIF	**x**	
MSE-LIF		
Neutron detectors [2]	**x**	
Plasma TV		
Reflectometer – 65GHz		**x**
Reflectometer – correlation		
Reflectometer – FM/CW		
Reflectometer – fixed f		
Reflectometer – SOL		
SSNPA [2]	**x**	
RF edge probes		
Spectrometer – divertor		
Spectrometer – MonaLisa		
Spectrometer – VIPS		
Spectrometer – LOWEUS		
Spectrometer – XEUS		
TAE Antenna		
Thomson scattering	**x**	
USXR – pol. Arrays		
USXR – multi-energy		
USXR – TG spectr.		
Visible Brems. det. [2]		

Notes:

[1] Check marks in this table do not guarantee diagnostic availability. Check with diagnostic physicists or research operations management to ensure diagnostic coverage.

[2] In some cases, a given line represents multiple diagnostics. For instance, there are multiple SSNPAs, multiple IR cameras, multiple neutron detectors, and multiple Langmuir probe arrays.

Appendix #1: Allowed Neutral Beam Power vs. Pulse Duration

Heating of the primary energy ion dump limits the beam duration to that given in the following table[1]:

Acceleration Voltage [kV]	MW per Source	MW per Beamline	Pulse Length [s]
65	1.1	3.2	8
70	1.3	3.8	7
75	1.5	4.5	6
80	1.7	5.1	5
85	1.9	5.8	4
90	2.1	6.4	3
95	2.4	7.1	2
100	2.6	7.7	1.5
105	2.8	8.4	1.25
110	3.0	9.0	1

Table A1: Beam power and pulse length as a function of acceleration voltage

Appendix #2: Table for neutron rate estimations:

Change only the blue cells					
I_p Range [kA]	Center of I_p Range [kA]	Number of Discharges	Typical Discharge Time [s]	Assumed Neutron Rate [N/s]	Fluence at this I_p [N]
0<I_p?400	200	0	0	0.00E+00	0.00E+00
400<I_p?600	500	0	0	1.00E+14	0.00E+00

Table A2: Neutron Emission Rate Calculator. Double click to open in excel for automatic calculation. Change only the blue cells.

[1] J.E. Menard, et al., Nuclear Fusion **52**, 2012 (83015)