Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: Multi-mode beam fast ion loss power scan

OP-XP-7??	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Multi-mode beam fast ion loss power scan ***Assess the effects of supra-Alfvénic fast ion driven instabilities on driven current in the plasma core*** **OP-XP-7??**

1. Overview of planned experiment

This experiment combines ideas from three proposals. The first was a continuation of XP608 from the 2006 campaign to document a quiescent, beam heated plasma for the purpose of benchmarking the TRANSP beam and bootstrap current calculations (and the calculation of the beam fast ion profile). The second proposal was to document TAE avalanche events with the full range of fast MHD diagnostics, fast ion diagnostics and full equilibrium diagnostic set (including MSE). The third proposal was to explore the power (fast ion beta) dependence of TAE Avalanche events. It will also include a vertical NPA scan in quiescent plasmas and plasmas with fast ion MHD (TAE avalanches and probably fishbones). An attempt will also be made to do some preliminary work on HHFW beat-wave excitation of TAE or possibly CAE modes and HHFW stabilization/suppression of Angelfish in a piggy back mode.

The reference shot for the second two proposals was shot 113544, or for a more modern shot with different beams 120124. Both were 800 kA shots with toroidal field current of 53 kA. However, the reference shot for the quiescent proposal was 121210, which also had 800 kA, but at a toroidal field current of 47 kA.

The first part of the experiment will be to reproduce 121210, then increase the TF current to 53 kA, reproducing the 120124 target. (Actually, the current ramp rate was slightly faster in 120124, so the next step will be to change that, also.) If a quiescent regime can be found for the target shot 120124 (with source C at ≈ 60 kV), the density will be raised and sources B&C will be injected at 60 kV. Beam voltage will then be increased, and so on until the highest power quiescent condition is found. The best result for a quiescent plasma will then be documented with a vertical NPA scan, and a scan in time of source A turn-on to get the q-profile evolution. This may also be an opportunity for some correlation-reflectometry work, and if there have been promising results from HHFW-beatwave excitation experiments, they could be tried in this quiescent plasma with reflectometry

Following the documentation, source voltage will be increased and/or density lowered until TAE bursts reappear. The best example of TAE avalanches were seen in shot 113544. This shot used both source A and B at 65 kV. It would be better if the avalanches could be

generated with sources B and C, reserving source A at 90 kV for the MSE diagnostic. Shot 113546 had reasonable TAE avalanches, but they were accompanied by n=1 fishbones.

The experiment cannot be done as piggy-back. Multiple shots at the right condition needed for NPA scan. Shots must be in L-mode, with central density ≈ 3.5 x $10^{13}/cm^3$ to optimize reflectometer data. Depending on number of reflectometer channels, might need small density scan, maybe 10-20% variation.

TRANSP bootstrap and beam driven current models have not been benchmarked at low aspect ratio. Interpretation of measured current profile evolution obviously requires an accurate model for these currents.

A clean benchmarking requires an MHD quiescent discharge. This would be a high density, low beam voltage discharge. Source A would need to be stepped through to measure q-profile evolution (Source A would be at 90 kV, and would excite broad spectrum of *AE modes which might redistribute the fast ions).

HHFW beat-wave excitation of TAE will be attempted in piggy-back mode during this XP. Details will be worked out with RF group prior to executing XP, but overall strategy would be to notch neutral beams, whence the *AE activity should decay on ms timescales, and pulse the HHFW with half of the sources shifted in frequency by ≈ 50 kHz to 100 kHz. (The ability to sweep frequency in time would be very helpful.) n=3 rotation braking might be desirable to aid in matching TAE frequency, avoiding theoretical issues relating to sheared rotation.

2. Theoretical/ empirical justification

Fast-ion redistribution or losses due to fast ion modes in ITER or other fusion reactors is expected to be through multi-mode transport, *e.g.*, Alfvén avalanches. NSTX is well situated to the study of Alfvén avalanches. Avalanches have been observed [Fredrickson, NF 06], but in plasmas prior to routine availability of MSE. To simulate the effect of avalanches on fast ion confinement, we need to measure the amplitude (and confirm the radial eigenmode structure) of each mode involved in the avalanche. We need the q-profile and other

equilibrium data for NOVA calculations of mode structure. The upgraded NPA and sFLIP may also help confirm the details of the predicted affect on fast ion transport.

3. Experimental run plan

Part A (first run day):

Goal is to reproduce quiescent target plasma similar to 121210, then extend quiescent regime to parameters similar to those for shot 120124 (higher field, fast current ramp). Plasmas will be in L-mode for this initial experiment; a future XP might extend this work to H-mode regime.

A1	Reproduce quiescent plasma as in 121210, with source C at ≈ 60 kV	2
A2	Increase toroidal field to ≈ 53 kA (120124), change current waveform	2
A2.1	If not quiescent, increase density to lower beam beta	2
A3	Add source B at ≈ 60 kV,	2
A3.1	If not quiescent, increase density to lower beam beta	2
A3.2	If quiescent increase source B or C voltage in 5 kV steps until TAE appear	4
A4	Document highest power quiescent plasma – step source A at 90 kV Back in time from 0.4s in 0.2 s intervals to document q profile evolution, start Vertical NPA scan	10-15

Part B (second run day):

Goal is to increase fast ion beta in steps until first TAE appear, then continue until TAE avalanches start. First, density will be decreased, if necessary, to optimize reflectometer coverage. Then beam voltage will be increased in 5 kV steps. Best examples of TAE avalanches occurred in shots with sources A&B at 65 kV. We'll try that with B&C at 65 kV

B1	Start with best quiescent case from Part A, lower $n_e(0) \approx 3.5\text{x}10^{13}/\text{cm}^3$	3
B1.1	Document TAE, if they show up at lower density	4
B2	Increase beam voltage in 5 kV increments until TAE avalanches.	4

B3 Document q evolution during avalanches (NPA scan?) 5

Evaluate data acquired to this point, return to conditions where documentation is uncertain. Verify that good reflectometer and MSE data was acquired.

Repeat, as much as possible, at higher field (5.5 kG)

<u>HHFW Beatwave TAE excitation</u>

It would be desirable to attempt HHFW beatwave TAE excitation during this experiment to provide a direct measurement of the TAE damping rate. At some later point in the discharge, around 350 ms, the beams will be notched off for about 100 ms and HHFW will be pulsed on. If this is considered to be useful, the notch will also be put during the TAE avalanches. Planning for this piggy-back operation will depend very much on whether we can get some run time before the experiment, the sweep rate possible for the beat frequency, and the difficulty in analysis of the data.

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

Describe any prerequisite conditions, development, XPs or XMPs needed.
Attach completed Physics Operations Request and Diagnostic Checklist

Part A could be done with the three reflectometer channels available (planned) in the second week. Some small Argon puffing might also be done to boost the soft x-ray signal level.

For Part B, more than the standard three reflectometer channels would be desirable, i.e., during or after the fifth week.

MSE is a must.

n = 3 braking capability is strongly desired.

HHFW with the capability for beat wave launching is strongly desired.

Capability for vertical scan of NPA is highly desired. Alternatively, radial scan might be done.

5. Planned analysis

What analysis of the data will be required: EFIT, TRANSP, etc.

Benchmarking TRANSP beam, bootstrap and fast ion deposition calculations will require extensive TRANSP analysis/simulations.

Study of TAE onset, TAE avalanche threshold will require extensive NOVA-k and M3D-K simulations.

6. Planned publication of results

What will be the final disposition of the results; where will results be published and when?

There should be one paper on TRANSP benchmarking (Fredrickson?).

There should be at least one paper on TAE avalanches (Fu?, Gorelenkov?)

PHYSICS OPERATIONS REQUEST

Multi-mode beam fast ion loss power scan **OP-XP-7??**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **34-52** Flattop start/stop (s): **0.0/1.0**

I_P (MA): **0.800** Flattop start/stop (s): **0.2/0.9**

Configuration: **120124/121210**

Outer gap (m): _____, Inner gap (m): _____

Elongation κ: _____, Triangularity δ: _____

Z position (m): **0.00**

Gas Species: **He**, Injector: **Midplane / Inner wall / Lower Dome**

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **90/60/60**, Duration (s): **0.90**

ICRF – Power (MW): ≈ **2MW**, Phasing: **Beatwave**, Duration (s): **0.2s**

CHI: **On / Off**

Either: List previous shot numbers for setup: **120124/121210**

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

Multi-mode beam fast ion loss power scan **OP-XP-7??**

Diagnostic	**Need**	**Desire**	**Instructions**
Bolometer – tangential array			
Bolometer array - divertor			
CHERS	4		
Divertor fast camera			
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy			
Fast lost ion probes - IFLIP		4	
Fast lost ion probes - SFLIP	4		
Filtered 1D cameras			
Filterscopes			
FIReTIP	4		
Gas puff imaging			
Infrared cameras			
Interferometer - 1 mm			
Langmuir probe array			
Magnetics - Diamagnetism	4		
Magnetics - Flux loops	4		
Magnetics - Locked modes	4		
Magnetics - Pickup coils	4		
Magnetics - Rogowski coils	4		
Magnetics - RWM sensors			
Mirnov coils – high frequency	4		
Mirnov coils – poloidal array	4		
Mirnov coils – toroidal array	4		
MSE	4		
Neutral particle analyzer	4		
Neutron measurements	4		
Plasma TV	4		
Reciprocating probe			
Reflectometer – core	4		
Reflectometer - SOL			
RF antenna camera			
RF antenna probe			
SPRED			
Thomson scattering	4		
Ultrasoft X-ray arrays	4		
Visible bremsstrahlung det.			
Visible spectrometers (VIPS)			
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray PIXCS (GEM) camera			
X-ray pinhole camera			
X-ray TG spectrometer			