Collectively Driven Fast Ion Loss StudiesPrinceton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: Collectively Driven Fast Ion Loss Studies

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PROPOSAL APPROVALS

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RLM - Run Coordinator: S. Kaye	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

1. Overview of planned experiment

The experiment has two goals. The first is to document the scaling of TAE/f.b. induced losses with gross plasma parameters such as plasma current or toroidal field, and in second order, current and density profile shapes, which may affect the localization of the modes, will also be explored. Implicit in this goal is some notion of the effect of these parameters on mode amplitude and structure. To this end, the second goal is to acquire as much information as possible on the structure and amplitude of the modes.

2. Theoretical/ empirical justification

Spherical tokamak (ST) reactors, with intrinsically low magnetic fields, are particularly susceptible to fast ion driven instabilities. The 3.5 MeV alpha particles from the D–T fusion reaction in proposed ST reactors will have velocities much higher than the Alfvén speed. The Larmor radius of the fusion alphas, normalized to the plasma size, will also be larger than for conventional aspect ratio tokamak reactors. The resulting longer wavelengths of the Alfvénic instabilities will be more effective in driving fast ion loss. It is important to extend the predictive capabilities, as developed on conventional aspect ratio tokamaks, to low aspect ratio and to benchmark the results on present ST devices.

Neutral beam heated plasmas in NSTX typically have a wide range of fast ion driven instabilities extending from fishbone-like modes at frequencies of 10's of kHz through the toroidal Alfvén eigenmodes (TAE) at frequencies of order 100 kHz and up to Compressional or Global Alfvén eigenmode (CAE or GAE) frequencies of over 1 MHz.

Enhanced fast ion losses have been correlated with both the TAE-like and fishbone-like modes, but there is no observed degradation in performance correlated with the appearance of CAE activity. However, there are some indications that the modes do affect the fast ion distribution. Bursts of CAE activity in some cases appear to trigger the growth of the lower frequency fast ion driven instabilities, explainable by CAE-induced transport of fast ions in either real or velocity space.

TAE/f.b. induced losses may decrease with higher plasma current and/or toroidal field due to smaller Larmor and bounce orbit size. This may both ameliorate fast ion transport as well as change the character of the TAE. Likewise, lowering the beam voltage will also reduce the orbit sizes, but change the fast ion beta and $V_{Alfvén}/V_{beam}$. Scans of all of these parameters are desired, but that may not be possible within one run day.

It has also been suggested that TAE will be stabilized above some critical beta. The theoretical basis for this is that the Landau damping, proportional to thermal beta, will stabilize the TAE. TAE have been observed to nearly the highest beta's reached thus far in NSTX, but a careful study of TAE amplitude and fast ion loss fractions vs. thermal beta should be part of this experiment.

The empirical observation is that TAE only become large when q(0)>>1, typically just below 2 (as inferred with efit). In this experiment it is therefore desirable to keep q(0) as high as possible. A scan of q(0) will be an intrinsic result from each shot (although convoluted with beta and other parameters…).

3. Experimental run plan

The experiment will begin by duplicating shot 108530 in which clear TAE-induced losses were seen. The plasma current is 650 kA in this shot, TF current was 52 kA and beam power was 3.2 MW. The plasma current scan should start from ≈ 500 kA and extend to 1 MA.

"Day 1"

A) Current scan, TF 53 kA, a&b at 80 kV. (7-10 shots)

Reproduce 108530 (Ip = 650 kA, TF = 53 kA) at lowest reasonable density to maximize fast ion beta. Take several shots to determine reproducibility.

Duplicate condition at Ip = 500 kA, TF = 53 kA.

Continue to plasma currents of 800 kA and 1 MA.

B) Beta scan (2-5 shots)

Pick "best" condition. Increase beam power to three sources. Increase beam voltage to raise power further.

C) q(0) scan using beam timing (as time permits)

Open/close gaps by changing q(0) evolution with NBI. Most strong TAE with q(0) > 1.5.

"Day 2"

A) Toroidal field scan at "constant q", q-scan (8-12 shots)

Using the same beam configuration, repeat shot at lower TF current, 40 kA and plasma current, 500 kA. This maintains a nominally constant q(a) with ref. shot.

Go to higher TF, 65 kA and plasma current, 800 kA, again at nominally constant q.

B) Ip scan at constant TF (with part A) (2-5 shots)

Take 500 kA and 650 kA shots at TF of 65 kA to scan q.

Take several shots at each condition as density will probably not remain constant.

C) Density scan (2-5 shots)

Again, using "best" condition, try to change density. H-mode not required at this stage as change in density profile shape is also desired.

"Day 3"

D) Beam voltage scan (2-5 shots)

Raise beam voltage to 90 or 95 kV. (Drive modes more strongly.)

E) Beam voltage/power scan in L-mode (2-5 shots)

Raise beam voltage to 90 or 95 kV. Destabilize modes in L-mode type plasma, if possible. Will provide better core data.

In this first exploration of fast ion loss scaling, it is desirable to at least sample the scans proposed in A-C. Completeness in these scans should be sacrificed, if necessary, to realize at least some data for each of parts A-C.

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

This XP requires an operational NBI system. As it will rely heavily on the diagnostic capability to detect high frequency modes, the high-n and high-f Mirnov arrays should be functional. (High n is desired for mode analysis of lower frequency modes.) The multi-channel heterodyne reflectometer is also strongly desired/required. The neutron diagnostic will be the primary indicator of fast ion losses, but FLIP and NPA should also be available for this experiment. In the past the soft x-ray cameras have detected TAE activity at the limit of their bandwidth. Recent improvements in the acquisition system should make this diagnostic more valuable and every effort should be made to schedule the experiment when the faster soft x-ray cameras are available. Analysis of the results, beyond simple empirical scaling, will require detailed profile data; thus, Thomson scattering, CHERS are required and MSE would be highly desirable.

5. Planned analysis

Power balance analysis requires EFIT and TRANSP. Higher level analysis requires TRANSP to feed parameters to codes such as NOVA-k, M3D-k, HINST, etc.

6. Planned publication of results

The initial results will likely be suitable for a Journal article. If more extensive data on plasma parameters is available, allowing for more extensive analysis and simulations, further articles could be written.

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **65** Flattop start/stop (s): **0/0.5**

I_P (MA): **1.1** Flattop start/stop (s): **0.2/0.5**

Configuration: **Inner Wall / Lower Single Null / Upper SN / Double Null**

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

Elongation κ: _____, Triangularity δ: _____

Z position (m): **0.00**

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

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): **95**, Duration (s): **0.5**

ICRF – Power (MW): ____, Phasing: **Heating / CD**, Duration (s): _____

CHI: **On / Off**

Either: List previous shot numbers for setup: **108530**

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

Diagnostic	**Need**	**Desire**	**Instructions**
Bolometer – tangential array			
Bolometer array - divertor			
CHERS	✔		
Divertor fast camera			
EBW radiometer			
Edge pressure gauges			
Edge rotation spectroscopy			
Fast lost ion probes	✔		
Filterscopes			
FIReTIP		✔	
Gas puff imaging			
H□ camera - 1D			
Infrared cameras			
Interferometer - 1 mm			
Langmuir probe array			
Magnetics - Diamagnetism	✔		
Magnetics - Flux loops	✔		
Magnetics - Locked modes			
Magnetics - Pickup coils	✔		
Magnetics - Rogowski coils	✔		
Magnetics - RWM sensors			
Mirnov coils – high frequency	✔		
MSE		✔	
Neutral particle analyzer	✔		
Neutron measurements	✔		
Plasma TV	✔		
Reciprocating probe			
Reflectometer – core	✔		
Reflectometer - SOL			
SPRED			
Thomson scattering	✔		
Ultrasoft X-ray arrays	✔		high bandwidth acquisition, soft x-ray foils
Visible bremsstrahlung det.			
Visible spectrometer (VIPS)			
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray GEM camera			
X-ray pinhole camera			