Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Transport of Fast Ions by Fishbones and TAEs		
XP-607	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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RLM - Run Coordinator: R. Raman	Date
Responsible Division: Experimental Research Operations	

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

Fast-ion Transport by Fishbones and TAEs XP-607

1. Overview of planned experiment

The goal of this experiment is to measure simultaneously the internal structure and fluctuation amplitude of both TAEs and fishbone instabilities and the fast-ion transport they cause for a quantitative comparison with theory.

2. Theoretical/ empirical justification

Fast-ion transport is important because it alters the power, momentum, and particle sources of the plasma. Ultimately, it should be possible to calculate fast-ion transport from the wave fields associated with instabilities. In conventional tokamaks, arguably the most successful effort of this type was the comparison of neutron, neutral-particle, and diamagnetic loop measurements during the fishbone instability in PDX/PBX with theory and simulations by Roscoe White. A similar understanding of fast-ion transport in the ST is desirable. In this study, we concentrate on fishbones for two reasons. First, it is interesting to search for differences between conventional tokamaks and spherical tokamaks and the fishbone is very well documented in conventional tokamaks. Second, fishbones that cause sudden ~10% drops in neutron rate are readily produced so, from a practical standpoint, this is the easiest instability to diagnose. Also, the soft x-ray and reflectometer diagnostics have already detected strong internal fluctuation signals for the fishbone instability.

In XP 449, the same plasmas that had strong fishbones late in the discharge had strong TAE activity earlier. In this experiment, we want to measure the internal eigenfunction and fast-ion transport during both fishbones and TAEs. The fishbone data may be easier to obtain but the TAE data are arguably more important. Alpha particles may drive Alfven eigenmodes unstable in ITER and other burning plasma experiments. If they do, the most important practical issue is the resultant fast-ion transport. Remarkably, in the only published studies of this important issue, the calculated transport by TAEs is much smaller than the measured losses. To resolve this discrepancy and benchmark theoretical predictions for ITER, detailed measurements of internal fluctuations and of fast-ion profiles are essential.

Another result from the XP 449 experiment was evidence of three-wave coupling between TAEs and fishbones. Further documentation of this phenomenon will be attempted. Yet another result from XP 449 was the observation of "angelfish"—rapid frequency chirping of modes in the MHz frequency band. As a piggyback experiment, if angelfish are observed, we will apply HHFW to see if ion cyclotron acceleration alters the nonlinear dynamics.

3. Experimental run plan

The goal of the experiment is to obtain at least one condition with strong fishbone instabilities and at least one condition with strong TAEs and acquire a complete set of diagnostic measurements by all available fast-ion and fluctuation diagnostics. Since virtually all of the relevant diagnostics work better at low density, a L-Mode target plasma is essential.

1. Establish the target condition: L-mode with strong fishbones that cause sudden drops in the neutron rate (2-8 shots). Initial target is #113534 (helium fill gas, 4.5 kG, 0.8 MA, Source C at 90 keV, inner wall limiter).
    - If the fishbones are weak, add Source B at the time of interest or lower the plasma current or lower the toroidal field.
2. Document this condition (4 shots). Include NPA spatial scan at four midplane radii that match the SSNPA sightlines.
3. Repeat with Source A (4 shots).
4. One Source C shot with Source A at end of pulse for MSE q profile measurement.
5. One shot in deuterium for more accurate neutron determination of losses and better CHERS data. (*Note: it will be necessary to use a larger deuterium gas puff than usual to achieve the desired density and to avoid the possibility of a runaway discharge.*)
6. One shot with shortened beam pulses to determine active/passive contributions to the SSNPA and NPA signals.
7. If the TAEs were not strong early in the discharge, adjust the plasma conditions to obtain stronger TAE activity. Possibilities include more beam power or a lower toroidal field (0-4 shots).
8. If a new condition was established with stronger TAE activity, document this condition with a NPA spatial scan (4 shots). If Source A was not already used, take one shot with Source A for MSE; also one shot in deuterium (0-2 shots).
9. Lower the beam voltage of Source C to 65 keV from the reference condition (4 shots for NPA scan and 1-2 shots with Source A pulse for MSE).
10. Lower the toroidal field from the reference condition. If the H-mode can be avoided, document (5-7 shots).
11. Lower the plasma current from the reference condition (5 shots).

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

Three neutral beam sources are essential. Essential fluctuation diagnostics: Fixed-frequency quadrature reflectometers, profile reflectometer, 1mm interferometer, FIRETIP (multiple chords), USXR and TOSXR arrays, edge magnetics (HN array, polarization measurement coils). Essential fast-ion diagnostics: neutrons, NPA, SSNPA, sFLIP. Essential for calculation of the fast-ion distribution function and the resultant transport: Thomson scattering, CHERS, MSE.

5. Planned analysis

Basic experimental analysis (EFIT, magnetic spectrographs, toroidal mode number, expected versus measured neutrons) will be performed for all discharges. TRANSP will compute the distribution function in the best cases with and without the *ad hoc* fishbone model for comparison with the fast-ion data. Models of the MHD eigenfunction will be compared with the internal fluctuation data. Finally, the validated model fields and fast-ion distributions will be used in White's ORBIT code to compute the expected losses.

6. Planned publication of results

Two major articles (one on the fishbone and one on the TAE) are anticipated within one year of completion of the experiment.

PHYSICS OPERATIONS REQUEST

Fast-ion Transport by Fishbone Instabilities **XP-607**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): 41-53 Flattop start/stop (s): 0/0.75

I_P (MA): 0.6-0.8 Flattop start/stop (s): 0.25/0.5

Configuration: Inner Wall

Outer gap (m): 0.03, Inner gap (m): 0

Elongation κ: 1.9, Triangularity δ: 0.4

Z position (m): **0.00**

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

NBI - Species: **D**, Sources: **A/B/C**, Voltage (kV): 90 --> 65, Duration (s): 0.4

ICRF – Power (MW): 2, Phasing: 14 m^{-1}, Duration (s): 0.05

CHI: none

Either: List previous shot numbers for setup: 113534

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

Fast-ion Transport by Fishbone Instabilities Error! Reference source not found.

Diagnostic	Need	Desire	Instructions
Bolometer – tangential array		X	
Bolometer array - divertor			
CHERS	X		
Divertor fast camera			
Dust detector			
EBW radiometers			
Edge deposition monitor			
Edge pressure gauges			
Edge rotation spectroscopy			Only available by special request of T. Biewer @ MIT
Fast lost ion probes – IFLIP	X		
Fast lost ion probes – SFLIP	X		
Filtered 1D cameras			
Filterscopes		X	
FIReTIP	X		
Gas puff imaging			
High-k scattering			
Infrared cameras		X	
Interferometer – 1 mm			
Langmuir probes - PFC tiles			
Langmuir probes – RF antenna			
Magnetics – Diamagnetism		X	
Magnetics – Flux loops	✓		
Magnetics – Locked modes			
Magnetics – Pickup coils	✓		
Magnetics – Rogowski coils	✓		
Magnetics - RWM sensors			
Mirnov coils – high frequency	X		
Mirnov coils – poloidal array	X		
Mirnov coils – toroidal array	X		
MSE	X		
Neutral particle analyzer	X		
Neutron Rate (2 fission, 4 scint)	X		
Neutron collimator		X	
Plasma TV			
Reciprocating probe			
Reflectometer - FM/CW			
Reflectometer - fixed frequency homodyne	X		
Reflectometer - homodyne correlation			
Reflectometer - HHFW/SOL			
RF antenna camera			
RF antenna probe			
Solid State NPA	X		
SPRED		X	
Thomson scattering - 20 channel	✓		
Thomson scattering - 30 channel		X	
Ultrasoft X-ray arrays	X		
Ultrasoft X-ray arrays - 2 color			
Visible bremsstrahlung det.	X		
Visible spectrometers (VIPS)			
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray pinhole camera			