Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Study of TAE and TAE-induced fast ion transport in L-mode, center-stack limited deuterium plasmas**

OP-XP-916	Revision: **0**	Effective Date: **4/9/09** *(Approval date unless otherwise stipulated)* Expiration Date: **4/9/11** *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: M. Podestà	Date 4/7/09
ATI – ET Group Leader: G. Taylor	Date 4/7/09
RLM - Run Coordinator: R. Raman	Date 4/7/09

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: TAE studies in L-mode deuterium plasma
No. **OP-XP-916**
AUTHORS: M. Podestà, N. Crocker, D. Darrow, E. Fredrickson, G. Fu, N. Gorelenkov, W. Heidbrink, S. Kubota, D. Liu, S. Medley
DATE: 2/17/09

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1. Overview of planned experiment

The proposed experiment has three major goals:

- (i) Develop a target L-mode, center stack limited deuterium plasma, with presence of Alfvénic instabilities (especially TAEs and, possibly, RSAEs)
- (ii) Provide an extensive dataset for code validation and comparison between experiments and theory/modeling of beam-driven TAEs (possibly, RSAEs).
- (iii) Study the dependence of TAEs (possibly, RSAEs) and induced fast-ion transport on plasma and fast-ion parameters.

Several scans are planned. These include, in order of priority :

1. Plasma rotation via n=3 braking → mode coupling, modification of TAE gap structure
2. Toroidal magnetic field → fast-ion gyroradius
3. Plasma density → damping of TAEs
4. Discharge optimization for code validation
5. Electron temperature via HHFW heating [if time permits & HHFW is available] → damping of TAEs
6. NPA vertical scan and f-FIDA filter angle scan [if time permits] → fast-ion velocity-space dynamics
7. Elongation → mode structure, edge q-profile [if time permits]

The highest priority is to obtain a complete dataset for points 1 to 4. Then, points 5 to 7 will be considered, especially in the case of an extended (20 weeks) run period.
For point no. 1, the error-field correction coils (EFC, configuration : non-resonant n=3 braking) will be used to minimize plasma rotation, hence the velocity shear, compatibly with plasma stability and absence of locked modes. A reduced shear broadens the TAE gap and lowers the coupling to the continuum, thus making TAEs more unstable. Therefore, the rotation may potentially prove to be an important control mechanism for TAE instabilities not only via the introduction of strong continuum damping and their radial localization. Moreover, a reduced rotation simplifies the interpretation of the experimental data and the comparison with theory/modeling. If a suitable scenario is achieved, and depending on the influence of EFC coils on the quality of data from NPAs and reflectometer diagnostics, EFC coils will be used at the optimum current value identified at point no. 1 for the rest of the XP. Within each scan, except for points no. 1, 5 and 6, the injected neutral beam power and timing will be varied to investigate the existence of a threshold for the destabilization of TAEs (and possibly RSAEs) and for the occurrence of TAE avalanches.
Results from the past years indicate that the TAE dynamics is usually characterized by a sequence of linear (or *quasi-stationary*), bursting and avalanching phases. In point 4, particular attention will be paid to reproduce discharges where the quasi-stationary phase of TAEs is clearly visible, and lasts sufficently long (a few slowing-down times, ~50ms) for its successful characterization, as required for code validation purposes. In addition, the study of the bursting/avalanching phases will permit to assess the impact of the coupling between TAE modes on their nonlinear dynamics, and how this regulates the degree of turbulence, leading to avalanches.

Except for point 2 (toroidal field scan), experiments will be run at the maximum possible toroidal magnetic field of 5.5kG. A high B_{tor} is helpful under several aspects. First, TAEs are more easily destabilized at high B_{tor}, as observed in the 2008 campaign. Second, the lower ratio between fast-ion and Alfvén velocity is more relevant to extrapolate NSTX results toward high-field devices, such as ITER. Third, smaller gyroradii makes it easier the comparison with numerical codes. Also, interpretation of data from diagnostics such as FIDA will benefit from a smaller fast ion gyroradius. Finally, a high magnetic field is preferable to enhance the coupling of HHFW power to the plasma.

Fast-ion dynamics associated with AEs will be documented by the extensive set of NSTX fast-ion diagnostics (NPA, ssNPA, FIDA, sFLIP, neutron detectors). The mode structure will be measured by the 5-channel reflectometer system (upgraded to 8 channels for the second part of the XP), providing the required input for analysis codes such as NOVA-k and M3D-k. Other diagnostics strictly necessary for this XP are MSE for q-profile documentation and CHERS (possibly, pCHERS) for plasma velocity measurements. By measuring internal TAE amplitude, and modeling it with NOVA/ORBIT and M3D codes, NSTX observations will also help to address the open issue of fast-ion transport. For example, a recent analysis of DIII-D data with NOVA/ORBIT resulted in a very low fast-ion transport, approximately 25 times lower than the measured transport.

2. Theoretical/ empirical justification

In the past years, the study of AEs (in particular, of TAEs and TAE avalanches) and associated fast-ion transport on NSTX has mainly focused on helium L-mode plasmas. The results achieved so far indicate a strong dependence of the dynamics of TAEs and of avalanches on specific parameters such as the injected neutral beam power. The dependence upon the toroidal magnetic field has been only marginally explored in 2008, indicating that higher fields are more favorable for the destabilization of TAEs. Fast-ion loss and redistribution induced by TAE avalanches have been observed. Up to 40% of the fast-ion population can be expelled from the central plasma in a single event, with a consequent, strong decrease in the neutron rate. At present, no (or very limited) experimental results are available on other dependencies, such as on the plasma shape and on the details of the q-profile. Moreover, the use of helium as working gas has implied disadvantages for several diagnostics (neutron detectors, FIDA, …). In addition, the 'diverted' plasma configuration makes more difficult a detailed analysis of the dynamics of AEs using numerical codes (NOVA-k and M3D-k), which are based on specific assumptions about plasma shape (up/down symmetry, boundary conditions at the plasma edge, etc.).

Considering the possible implications for stability, fusion performance and current-drive efficiency in higher-field devices such as ITER, a deeper understanding of TAE dynamics is required to improve our predictive capability. The proposed experiment will provide a good case for code validation and for the comparison between experimental results and theory. The possibility of interpreting the observed mode dynamics on the basis of theories on weakly turbulent systems will be explored.

3. Experimental run plan

The run plan is divided into two parts: part#1, which includes target plasma development and a first set of parameter scans, and part#2 for dedicated measurements for experiment/code comparison and to complete the plasma parameter scans. The time allocation is 1 day for each part.

Part#1: Target plasma development*, total of about 16 shots*

- Reload shot#128455, but use Deuterium instead of Helium as working gas, with low-field side fueling. Adjust inner gap to achieve a center-stack limited configuration. Set toroidal field to 5.5kG.

- Beam timing: source A @ 90kV on from 90ms to 220ms, and from 360ms to 410ms; from 410 ms to 600ms, modulate source A with 50% duty cycle, 10 ms on/10 ms off; source C @ 75kV from 220ms to 350ms; source B @ 75kV from 290ms to 350ms. (see Note#1 below about NB timing).
- Adjust density for reflectometer measurements: maximum should be ~$3.2 \times 10^{19} m^{-3}$ at t=300ms
- Check for presence of TAE modes
- If TAEs and avalanches are observed: success! Move on to *part#1, parameter scans*
- If TAEs, but no avalanches, are observed: increase source C voltage up to 90kV in steps of 5kV
- If no TAEs are observed, move NB sources turn-on back by 50 ms, i.e. closer to the scenario adopted during the 2008 campaign (XP-819)
- If TAEs, but no avalanches, are observed: increase source C voltage up to 90kV in steps of 5kV
- If no TAEs are observed, increase source C voltage up to 90kV in steps of 5kV, then source B voltage up to 90kV in steps of 5kV
- If no TAEs are observed with all sources at max. voltage, reload second reference shot and re-run the previous procedure: set toroidal field to 5.5kG, increase source C voltage, change beam timing [AND/OR: decrease plasma current?], increase source B voltage.

During this procedure, and depending on the measured q-profile, the plasma current will be varied to reproduce the conditions observed in the reference shot.

Note#1: The neutral beam timing is modified with respect to the reference shot. The goal is to extend the time window during which TAEs are observed. A period with NB modulation is added after 410ms for diagnostics validation purposes. A 10ms beam notch is introduced from 350ms to 360ms to check the background and noise levels for diagnostics such as FIDA, NPA and ssNPA.

Note#2: Low-frequency (f < 50kHz, typically) kink-like modes must be avoided, e.g. by modifying the current (q-profile) evolution by adjusting beam timing, plasma current, plasma density.

Note#3: Keeping the plasma into L-mode is essential for this experiment. Should the plasma go into H-mode, the following options will be considered: (i) bias the plasma upward, (ii) change elongation, (iii) change NB timing, (iv) adjust density, (v) use different shot as model.

Part#1: Parameter scan*, total of about 30 shots*

All scans start from the target scenario achieved in part#1. The use of EFC coils to slow down plasma rotation is envisaged from (ii) to (vii), as discussed in the Overview.

(i) *Plasma rotation*. EFC coils turn on at 200ms, with initial value of current of 500A. Run "binary search" to optimize the current in the EFC coils, checking the effect on plasma braking from the CHERS. Repeat until a stable configuration with substantially reduced rotation is attained. If TAEs or TAE avalanches disappear, raise NB injection voltage (source C). [max. 8 shots].

(ii) *Toroidal magnetic field*. Change B_{tor} from the original 5.5kG to 4.5kG and 3.5kG. Adjust plasma current in order to keep the same q-profile as in the reference shot. For each value, perform a quick scan of NB power by changing the injection voltage of source C (steps of 5kV in the range 65kV to 90kV) [max. 8 shots].

(iii) *Density*. Decrease density from original $3.2 \times 10^{19} m^{-3}$ (t~300ms) to ~$2 \times 10^{19} m^{-3}$. Perform a scan of NB power by changing the injection voltage of source C (steps of 5kV in the range 65kV to

90kV). Look for appearance of rSAE, if not present in target shot. If rSAEs are observed, refine power NB scan to identify threshold condition. If not, increase density to >4.2 x $10^{19}m^{-3}$ and repeat NB power scan. [max. 6 shots].

Part#2: Parameter scan*, total of about 28 shots*

(iv) *Code validation.* Identify the optimum scenario for code validation from part#1 (in particular, points (ii) and (iii)). Extend the duration of the quasi-stationary phase of TAEs by suppressing source B: the goal is to have a long (>50ms) period during which TAEs do not show bursting/avalanching behavior. If bursts and avalanches are still observed, decrease source C voltage in steps of 5kV. Starting from this configuration, modify the NB timing (e.g. by anticipating the turn-on of source C) in order to affect the amplitude of TAEs during their quasi-stationary phase. [max. 8 shots].

*** Decision point*:

- Move to point (v) if HHFW is available, with RF power up to at least 2MW.
- If good data are collected by NPA and ssNPA and the target discharge is well reproducible (at least up to 400ms), move to point (vi).
- If time permits, conclude with point (vii).

(v) *Electron temperature* [optional, depends on HHFW availability]. Back to target plasma. Adjust RF timing so that HHFW fires ~30ms after the onset of TAE activity. The duration of RF phase will be about 200ms. Start from P_{RF}=2MW, check if any modification of TAE dynamics is observed (e.g. from magnetics, reflectometer). If any change is visible, proceed with P_{RF}=1MW, then refine the scan in steps of 250kW: increase P_{RF} if no changes are observed compared to the reference discharge; otherwise, decrease P_{RF}. No NB power scan is planned in this case. [max. 6 shots].

(vi) *NPA vertical scan & f-FIDA scan* [optional, if time permits]. Back to target plasma as developed in part#1. Perform a vertical scan with the NPA to document the fast-ion distribution. Range of the scan to be determined depending on the specific plasma configuration achieved in part#1. In parallel, perform a scan of the f-FIDA filter angle to focus on different portions of the fast-ion spectrum. Values of the filter angle: 0, 10, 2, 8, 6, 4 degrees. [max. 8 shots].

(vii) *Elongation*. Push elongation to k<1.8, then to k>2.2. Keep NB power as in the target discharge. The goal of this scan is to explore the achievable range of kappa starting from the target plasma. At the same time, the scan will provide data on the behavior of TAEs with different values of q-edge, which will vary depending on the plasma shape. [max. 6 shots].

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

The run time for this XP should be allocated in order to have an initial day to develop the target plasma, and perform a first set of scans, then the remaining day after the upgrade of the 8-channel reflectometer is completed.

For part#1, the 5-channel reflectometer will be used, with the possibility of having two additional channels in the density range 0.9 - 2 x $10^{19}m^{-3}$. The completion of the upgrade of the 8-channel reflectometer is needed to run the final day of the XP.

The reflectometers will NOT be available before the first week of March 2009.

A low level of impurities (especially oxygen) is required to have good FIDA data.

The injection voltage for the NB sources B and C will be 65kV → 95kV. The timing of the NB sources will be optimized during the experiment (part#1).

MSE and magnetics are needed for both part#1 and #2. Availability of HHFW (with RF power up to 2MW) is highly desirable for the T_e scan.

5. Planned analysis

EFIT/LRDFIT, TRANSP, NOVA-k, M3D-k, GKM (if/when available), ORBIT

6. Planned publication of results

Results will be published in the major plasma physics journals (PoP, PPCF, Nuclear Fusion) within one year from the experiment.

PHYSICS OPERATIONS REQUEST

TITLE: TAE studies in L-mode deuterium plasma No. **OP-XP-916**
AUTHORS: M. Podestà, N. Crocker, D. Darrow, E. Fredrickson, G. Fu, N. Gorelenkov, W. Heidbrink, S. Kubota, D. Liu, S. Medley DATE: 2/17/09

Describe briefly the most important plasma conditions required for the experiment:

Center-stack limited configuration. L-mode plasma, central density ~$3.2 \times 10^{19} m^{-3}$, low impurity level.

NB sources B and C operated at 65 → 95kV injection voltage (start at 75kV for both). Timing will be optimized during the XP.

EFC coils required (n=3 braking configuration).

HHFW desired, but not strictly necessary for this XP.

Previous shot(s) which can be repeated:

Previous shot(s) which can be modified: 128455 (primary choice), 121522 (backup), 123862 (backup#2)

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

I_{TF} (kA): 44-66kA Flattop start/stop (s): 0/0.7

I_P (MA): 0.9MA Flattop start/stop (s): 0.2/0.6

Configuration: **Center-stack limiter**

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

Outer gap (m): 0.05 Inner gap (m): 0 Z position (m):

Elongation κ: 2 Upper/lower triangularity δ:

Gas Species: **D** Injector(s): low-field side

NBI Species: **D** Voltage (kV) **A:** 90 **B:** 65-95 **C:** 65-95 Duration (s): 0.5

ICRF Power (MW): 2 Phase between straps (°): 180-heating Duration (s): 0.2

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

LITERs: Off Total deposition rate (mg/min):

EFC coils: On Configuration: **Odd, n=3 braking**

PHYSICS OPERATIONS REQUEST / 2

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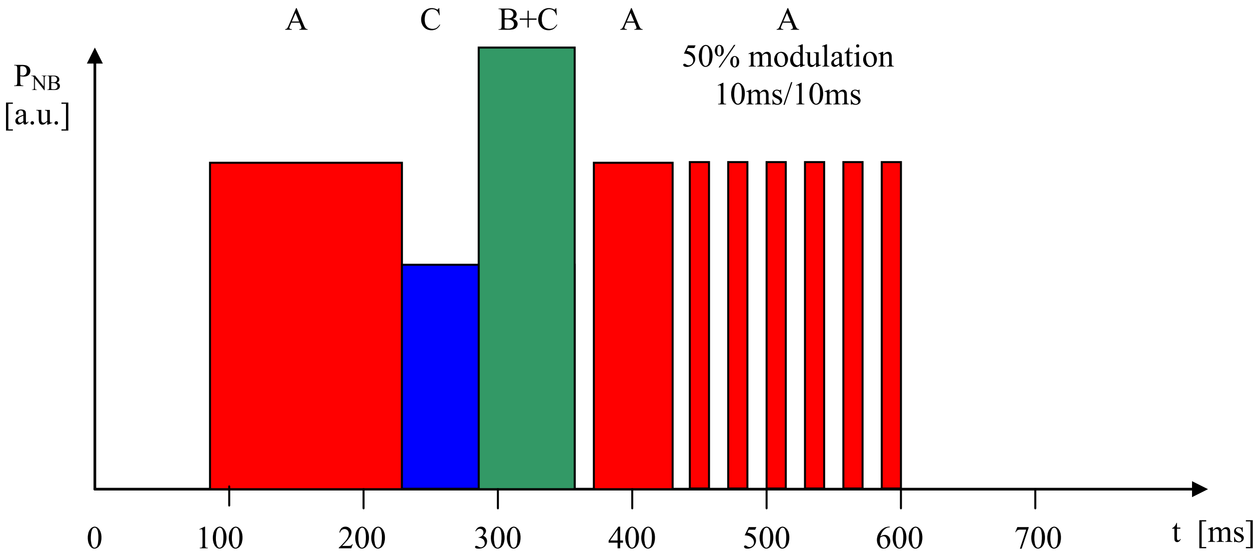
Desired waveform for NB power:



Source A @ 90kV ON from 90ms to 220ms
from 360ms to 410ms
from 410 ms to 600ms (50% d.c. modulation, 10ms ON – 10ms OFF)
Source C @ 75kV ON from 220ms to 350ms
Source B @ 75kV ON from 290ms to 350ms

Note the beam notch from 350ms to 360ms.
Source timing may change during the XP.
Injection voltage for sources B and C will change during the XP.

DIAGNOSTIC CHECKLIST

TITLE: TAE studies in L-mode deuterium plasma No. **OP-XP-916**
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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Bolometer – tangential array		
Bolometer – divertor		
CHERS – toroidal	√	
CHERS – poloidal		√
Divertor fast camera		
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		
Edge pressure gauges		
Edge rotation diagnostic	√	
Fast ion D_alpha - FIDA	√	
Fast lost ion probes - IFLIP		√
Fast lost ion probes - SFLIP	√	
Filterscopes		
FIReTIP	√	
Gas puff imaging		
Hα camera - 1D		
High-k scattering		√
Infrared cameras		
Interferometer - 1 mm		√
Langmuir probes – divertor		
Langmuir probes – BEaP		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism		√
Magnetics – Flux loops	√	
Magnetics – Locked modes		√
Magnetics – Pickup coils		
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		
Magnetics – RWM sensors		√
Mirnov coils – high f.	√	
Mirnov coils – poloidal array	√	
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.	√	

Note special diagnostic requirements in Sec. 4

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