Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: **NTV physics at varied $\nu_i^*/q\omega_E$ and search for offset rotation in NSTX**		
OP-XP-933	Revision: **1.1**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: S.A. Sabbagh	Date: 5/9/09
ATI – ET Group Leader: S.A. Sabbagh / S.P. Gerhardt	Date
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)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **NTV physics at varied $\nu_i^*/q\varpi_E$ and search for offset rotation in NSTX** No. **OP-XP-933**

AUTHORS: **S.A. Sabbagh, R.E. Bell, J.W. Berkery, et al.** DATE: **5/9/09**

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1. Overview of planned experiment

Briefly describe the scientific goals of the experiment.

The neoclassical toroidal viscosity (NTV) braking torque will be investigated over a range of $\nu_i^*/q\omega_E$ to determine if the expected $T_i^{2.5}$ scaling occurs in all values tested, and if the expected saturation of NTV at increased radial electric field actually occurs. This is an important result for future devices operating at low ν_i, and for both low and high rotation devices (e.g. NSTX-U, ITER, ST-CTF). In addition, the NTV offset rotation will be investigated. This effect was found in DIII_D (Garofalo, 2008), but is not yet determined in NSTX. While not necessary, reversed I_p operation will allow better determination of the offset rotation.

2. Theoretical/ empirical justification

Brief justification of activity, including supporting calculations as appropriate. Describe *briefly* any previous or related experiments.

Plasma rotation damping due to the application of non-resonant magnetic fields was observed in NSTX and compared to NTV theory (W. Zhu, et al., PRL 2006). While non-resonant magnetic braking is a key tool for rotation control in NSTX, and has been used in other devices, certain aspects of the physics that allow confident extrapolation to future devices are unclear.

Two major uncertainties are the scaling of the NTV torque with ion collisionality, and the expected saturation of the torque at high ExB frequency, ω_E. In addition, the expected range of applicability of fluid theories as a function of collisionality have not been fully tested experimentally. Earlier work (Zhu PRL 2006) and experiments using $n = 2$ braking and lithium deposition in 2008 showed the experimental results to be consistent with NTV theory in both magnitude and profile in the "1/ν" regime of collisionality (Figure. 1). The range of applicability for this theory is expected to be $q\omega_E < \nu_i/\varepsilon < \varepsilon^{0.5}\omega_{Ti}$. In NSTX, the right hand inequality is met ($\nu_i^* < 1$), but in the usual strongly co-NBI heated operating regime, it is met in the region of peak braking torque, but barely. It is expected that if $q\omega_E > \nu_i/\varepsilon$, the NTV torque will saturate due to the high radial electric field set up by the sufficiently large non-ambipolar flux that defines NTV. From past NSTX experiments, with effective NTV braking, it is unclear that this condition is met.

In addition, an "offset" rotation, related to the gradient in the T_i profile, is expected from theory. While this effect has been observed in DIII-D (Garofalo, 2008), it has not yet been determined in NSTX. One possibility is that the offset velocity might be sufficiently small (it should be a few kHz) to be below the typical rotation threshold for $n = 1$ resonant braking to occur (typically generated by tearing modes). In the present experiment, the application of lithium, and $n = 1$ error field correction will be used to best eliminate resonant braking, to conclude whether or not the offset rotation is observed in NSTX.

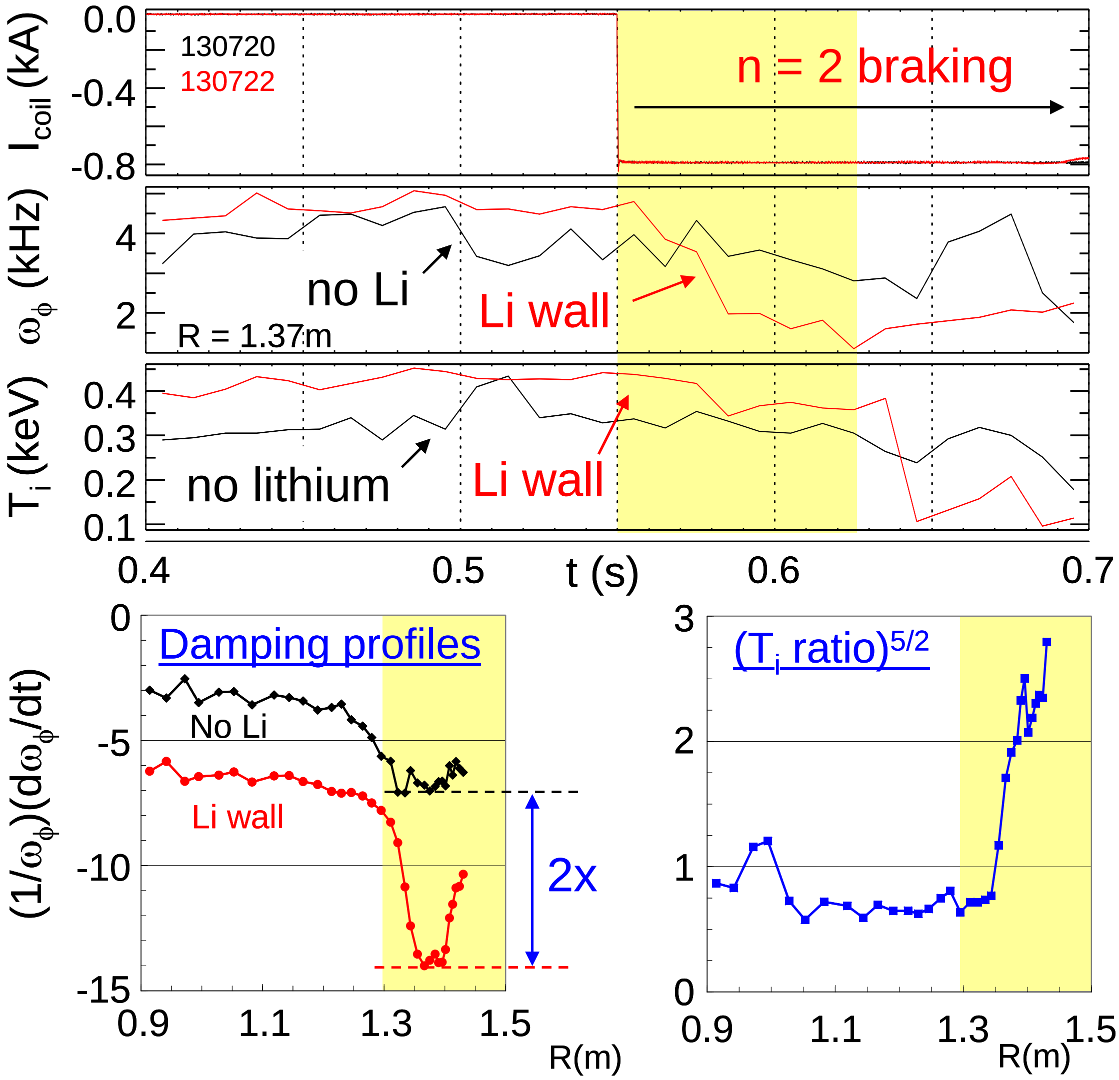

Figure 1: XP804 result (2008) showing consistency of NTV torque with $T_i^{2.5}$ scaling.

3. Experimental run plan

Describe experiment in detail, including decision points and processes.

It is usual that non-resonant braking in NSTX is supplemented by resonant braking as rotating n = 1 modes appear. This precludes accurate non-resonant NTV evaluation. It desirable to maintain the pure non-resonant braking for as long as possible. To do this, $n = 1$ EFC and lithium will be utilized to delay or eliminate rotating n = 1 MHD. The non-resonant braking profile will be examined from different initial ω_E (at $\nu_i^* < 1$). The initial n = 3 braking field will be changed to vary the initial wE, then additional steps will be used to change the braking magnitude, providing a perturbation analysis of the braking torque at each step. Between steps, a quasi-steady-state will be reached. If $\nu_i^* / q\,\omega_E(\mathrm{R}) > 1$, the $T_i^{2.5}$ scaling should be observed. If $\nu_i^* / q\,\omega_E(\mathrm{R}) < 1$, either a saturation in braking, or another scaling should be observed.

The NTV offset rotation will be examined by allowing a second quasi-steady-state in ω_ϕ to be reached after each change in braking current amplitude. If counter-injection capability becomes possible in NSTX data, the best conclusion will come from performing these discharges with counter-injection in addition to co-injection.

The experimental procedure is given in the table below.

Run plan:

Task	Number of Shots
1) Create targets and control shots near ideal no-wall beta limit (similar to 130722)	
(use 133078 fiducial as setup shot, 2 or 3 NBI sources, eventually use LITER)	
A) n = 1 fast FB, no n = 3 field; 3, then 2 NBI sources, no Li, passivate with D glow if needed	2
B) If sufficiently long rotating MHD-free period, apply n = 3 field, 0.8 kA (control shot, no Li)	2
C) Apply lithium, apply n = 3 field at t = 0.55s – for comparison to n = 2 data from 2008	2
D) Bring n = 3 field earlier (t ~ 0.2s), n = 1 EFC 50ms filter starting ~ 0.5s, to prep. for step (2)	2
2) ExB frequency variation	
A) Early n = 3 application (t ~ 0.2s), vary n = 3 current to produce 3 quasi-steady ω_E levels (high beta, high T_i condition)	4
B) Step up n = 3 currents from three different quasi-steady levels produced in 2(A) at t ~ 0.5s (timing depends on rotating MHD); reach quasi-steady state with 3 different braking currents; (try more than one step in n = 3 current (up, or down), allowing quasi-steady-state between each)	4
C) Repeat best cases from above at lower beta, Ti (reduced NBI power)	6
3) Search for NTV offset rotation	
A) If data from step 2(B) insufficient to determine by $\omega_{\phi\text{-}offset} = \omega_\phi - K/\delta B^2$), run other n = 3 amplitudes	2
B) Reversed Ip scans	
Repeat scan 2 above in reversed Ip	14
Total (reversed Ip; standard Ip):	14 ; 24

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.

- RWM coils configured for n = 1, 3 operation

- n = 1 RWM active feedback required

- LITER required

5. Planned analysis

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

NSTX EFIT reconstructions using MSE data will be used for ideal MHD stability analysis using DCON and as input to the VALEN code for RWM feedback analysis. NTV torque profiles will be evaluated using analysis similar to past analyses performed separately by W. Zhu and J.-K. Park, but supplemented with recent modifications by K. Shaing. Kinetic modification to ideal kink/ballooning stability analysis will be evaluated using the MISK code if the proximity to RWM marginal stability is needed.

6. Planned publication of results

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

Results may warrant publication in Phys. Rev. Lett., if new insights into NTV scaling, offset rotation, and regions of applicability in ν_i and ω_E space are concluded. Otherwise the results may be more suitable for Phys. Plasmas or Nuclear Fusion.Results would be shown at the APS DPP 2009 meeting, at the next ITPA MHD stability group meeting (contributes to joint experiment MDC-12), and possibly at the MHD Mode Control meeting in 2009.

PHYSICS OPERATIONS REQUEST

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

- RWM coils configured for $n = 1, 3$ operation
- $n = 1$ RWM active feedback required
- LITER required

List any pre-existing shots:

- 133340 ($\beta_N = 6.6$), 133078 (fiducial); 132558 (1 MA, $\beta_N = 6.5$)

- 133301 (n = 3 correcting, ramped to braking, n = 1 feedback on until t = 0.59s)

Equilibrium Control: Gap Control / rtEFIT(isoflux control):

Machine conditions *(specify ranges as appropriate, use more than one sheet if necessary)*

I_{TF} (kA): 0.4 – 0.5 T Flattop start/stop (s):

I_P (MA): 0.8 – 1.3 Flattop start/stop (s):

Configuration: **Limiter / DN / LSN / USN** *(strike out inapplicable cases)*

Outer gap (m): **0.06-0.10** Inner gap (m): 0.04 Z position (m):

Elongation κ: **2.1 – 2.6** Upper/lower triangularity δ: 0.45 – 0.75

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

NBI Species: **D** Voltages (kV or off) **A: 90** **B: 90** **C: 80-90** Duration (s): ~ 1.0

ICRF Power (MW): Phasing: Duration (s):

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

LITERs: Off / On Total deposition rate (mg/min): **10 - 20**

EFC coils: Off/On Configuration: **Odd / Even / Other** *(attach detailed sheet)*

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

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

Note special diagnostic requirements in Sec. 4

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