Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **NTV behavior at low ion collisionality and maximum variation of ω_E**

OP-XP-1062	Revision: **0**	Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: S.A. Sabbagh	Date **9/15/10**
ATI – ET Group Leader: S.A. Sabbagh	Date
RLM - Run Coordinator: E. Fredrickson	Date

Responsible Division: Experimental Research Operations

RESTRICTIONS or MINOR MODIFICATIONS
(Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **NTV behavior at low ion collisionality and maximum variation of ω_E** No. **OP-XP-1062**
AUTHORS: **S.A. Sabbagh, R.E. Bell, J.W. Berkery, et al.** DATE: **9/15/10**

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1. Overview of planned experiment

The neoclassical toroidal viscosity (NTV) braking torque will be investigated over the maximum range of $\nu_i^*/nq\omega_E$ possible to determine if the expected $T_i^{2.5}$ scaling occurs in all values tested, or, if the expected saturation of NTV at low values of this ratio and increased radial electric field occurs. Also, the observed stronger braking found in XP933 at low ω_E will be examined with the rotation evolution changed – the result can then be compared to superbanana plateau theory. These would be important results 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 (A. Garofalo, PRL 2008), but is not yet determined in NSTX. A new approach to determine the offset rotation is proposed using RF heating to reduce the input torque and operate closer to zero rotation.

2. Theoretical/ empirical justification

Plasma rotation damping due to the application of non-resonant magnetic fields was observed in NSTX several years ago and was quantitatively compared to neoclassical toroidal viscosity (NTV) theory for n = 1 and n = 3 fields (W. Zhu, et al., PRL 2006). More recently, NSTX showed non-resonant braking with n = 2 fields, and quantitative consistency with variation of NTV braking with ion temperature ($T_i^{5/2}$) (Sabbagh, et al. NF 2010). 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, the expected saturation of the torque at high ExB frequency, ω_E, and the behavior of the NTV torque at low ω_E. In addition, the expected range of applicability of fluid theories as a function of collisionality has not been fully tested experimentally. Earlier work on NSTX and experiments using $n = 2$ braking and lithium deposition in 2008 showed NSTX experimental results to be consistent with NTV theory in both magnitude and profile in the "1/ν" regime of collisionality. The range of applicability for this theory is expected to be $nq\omega_E < \nu_i/\varepsilon < \varepsilon^{0.5}\omega_{Ti}$. In NSTX H-mode plasmas, the right-hand inequality is typically met ($\nu_i^* < 1$) in the strong braking region of the profile. However, the left-hand side is barely, or not met in the region of peak braking torque at high plasma rotation. It is expected that if $nq\omega_E > \nu_i/\varepsilon$, the NTV torque will saturate due to the high radial electric field set up by the sufficiently large non-ambipolar flux that defines NTV.

The NTV braking torque was investigated over a range of $\nu_i^*/nq\omega_E$ 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. Good progress in this variation was made in XP933 NTV physics at varied $\nu_i^*/q\omega_E$ (Sabbagh, et al.) (Figure 1). The present experiment aims to expand the operational range tested in XP933, using the new LLD capability if possible to reduce ν_i^*. In addition, the NTV offset rotation will be further investigated. This effect was found in DIII-D (Garofalo, PRL 2008), but is not yet clearly observed 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, and associated resonant braking). XP933 did not yield a clear, direct observation of a large NTV offset velocity, but this may become more apparent as plasma rotation is reduced to values lower than attained in XP933. Present results indicate that this offset is small (on the order of ~ 1 kHz or less), with no indication that it is in the counter-Ip direction, as expected by theory. Investigation continues, including investigation of the hypothesis that the offset may not be limited to the counter-Ip direction, and may vary over the plasma profile. Also, a new approach to determine the offset rotation is proposed using RF heating to generate to heat the plasma with greatly reduced input torque compared to co-NBI heating. The procedure is to generate plasma rotation with RF at the highest T_i, W_{tot} possible, diagnosing the plasma rotation in a similar fashion to Hosea/Podesta's 2009 experiment (Figure. 2) using short NBI pulses. This procedure would be repeated for different *initial* values of n = 3 braking field, to determine if the initial plasma rotation changes in the different n = 3 applied field conditions. Note that if NTV offset is indeed only in counter-Ip direction, the wf profile must change (it's presently counter in core, co at the edge).

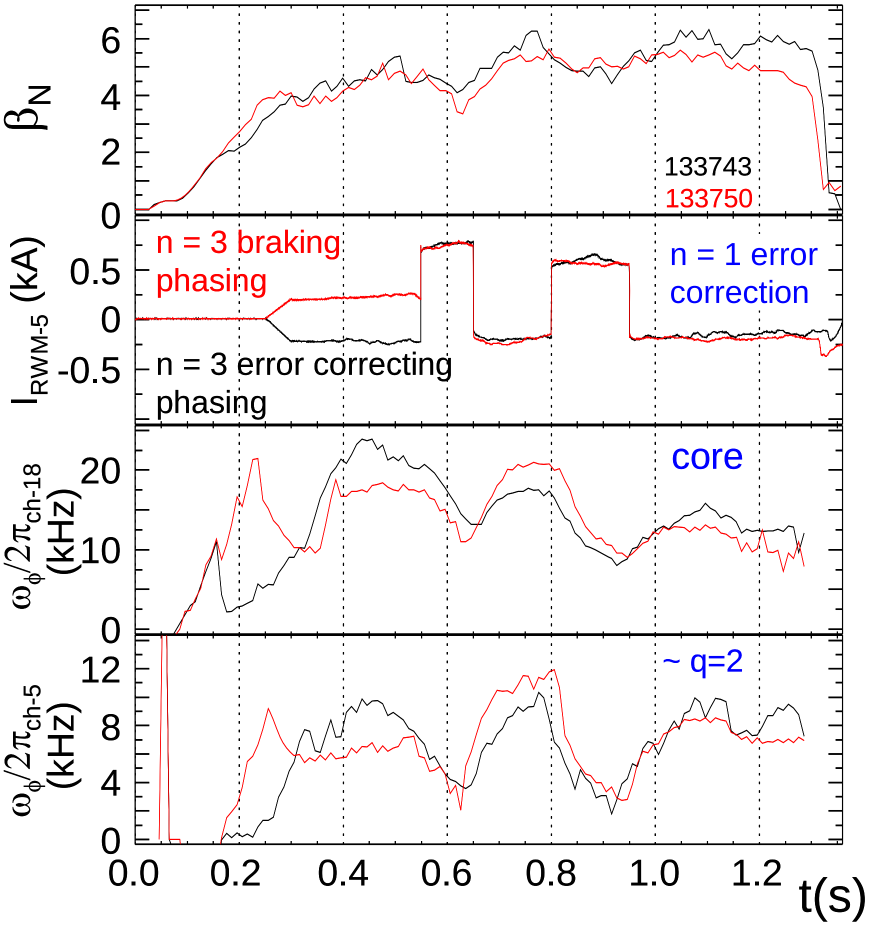

Figure 1: Example of variations of NTV braking made in XP933.

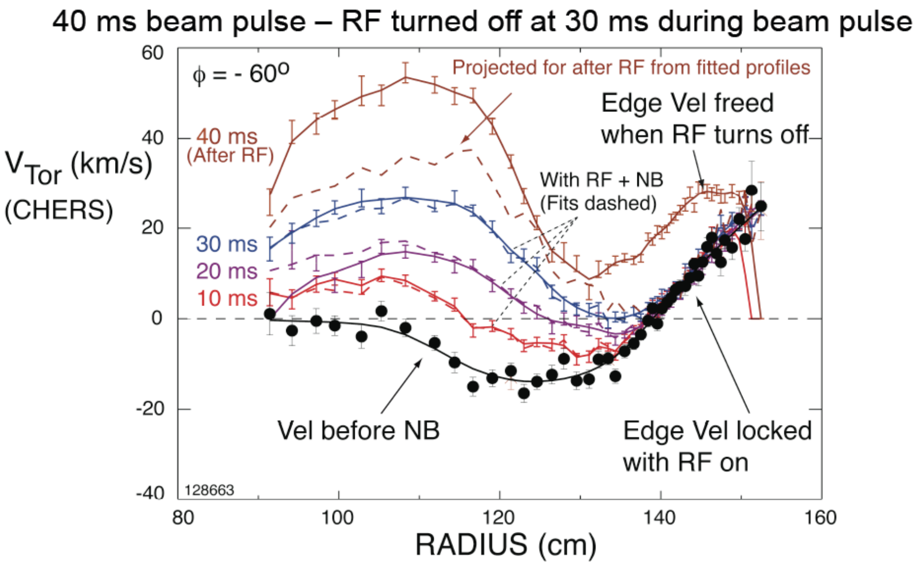

Figure 2: Rotation profiles measured during Hosea/Podesta RF XP (2009).

An important observation was found during non-resonant braking with lithium wall preparation in connection to NTV theory. The theory expects that at sufficiently low values of ω_E, (near and below grad-B drift frequency) NTV should increase significantly as the plasma enters the superbanana plateau regime (K.C. Shaing et al., PPFC 51 (2009)). Figure 3 shows a result consistent with this hypothesis, in which a plasma at constant applied field and plasma beta (which should yield constant NTV braking) exhibits a significant increase in braking at sufficiently low ω_E. Over a large region of the plasma, where the braking is maximum, the plasma is in the “1/ν” scaling regime, and with ω_E near zero, enters the superbanana plateau regime. Only a few shots of this type have been produced. The present experiment aims to produce this condition with different n = 3 braking current evolution to best determine the onset conditions required to produced the enhanced non-resonant braking.

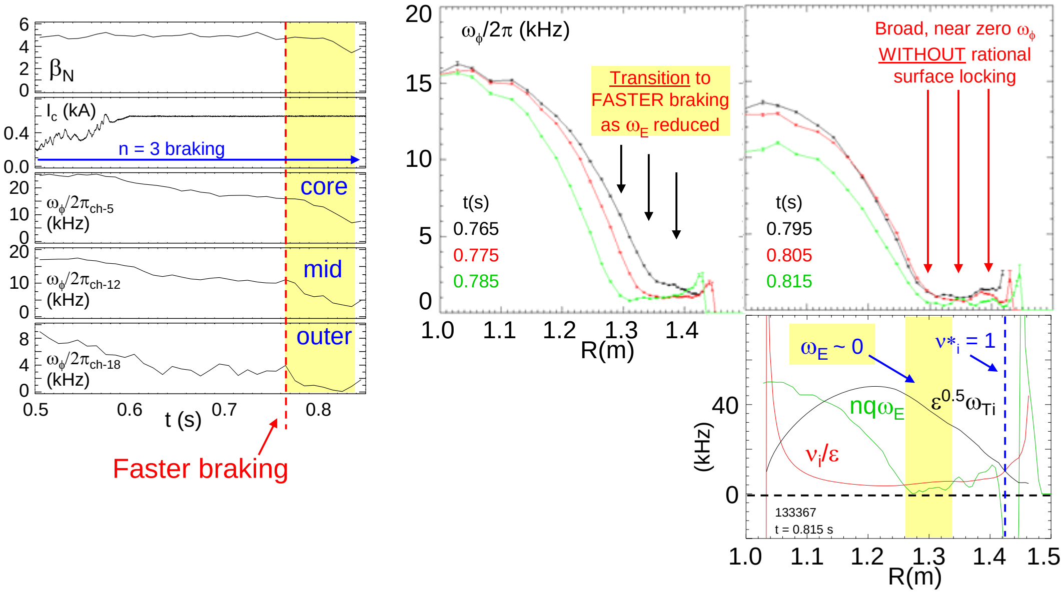

Figure 2 - Increase of non-resonant magnetic magnitude at fixed applied field and plasma normalized beta at low ω_E

3. Experimental run plan

In addition to the approaches described above to examine the NTV offset rotation, we additionally write in the use of reverse I_p for this study. While not available in 2010, the ability may become available in 2011, and examination of the NTV offset rotation using reverse I_p would fall under this XP.

Task	Number of Shots
1) Generate low and high collisionality comparison shots and apply braking	
(use ~fiducial targets established in 2010, 1-3 NBI sources)	
A) (if possible) Operate "high collisionality" comparison shot	2*
B) Operate low collisionality target shot (3 NBI sources, then 2)	2
C) Apply n = 3 braking in low and high collisionality targets	2*
D) (optionally) apply n = 1 EFC 75ms filter in low collisionality plasma (comparison)	1*
2) Generate greater variation of (ni/e)/|nqwE|	
A) Early n = 3 application (t ~ 0.2s), vary n = 3 to produce two different quasi-steady ω_E levels (high beta, high Ti condition); step n = 3 currents from two different quasi-steady levels, reach quasi-steady state with 2 different braking currents; more than one step/shot if long pulse	4
B) (if possible) Rerun most desirable case from 2A) in high collisionality target	2*
C) Concentrate on generating low ω_ϕ (low ω_E) in SBP regime by varying braking WF	4
D) Operate with one NBI source for highest ω_ϕ (high ω_E)	2
3) Determine NTV offset rotation	
A) If desired, supplement shots step 2 to determine by $\omega_{\phi\text{-offset}} = \omega_\phi - K/\delta B^2$) or direct observation	2*
B) RF Approach: RF target (high temperature desired); add NBI late for ω_ϕ diagnosis	4
C) Rerun 3B) with three different braking field magnitudes	4
D) Reversed Ip scans (for future)	
Repeat scans from 2 above in reversed Ip to diagnose NTV offset rotation	10

Total (leveraging survey XP, no optional shots*; no survey XP; Ip; reversed Ip): 20; 29 ; 10

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

- RWM coils configured for n = 1, 3 operation

- n = 1 RWM active feedback desired

- LITER required

- RF capable of producing results equivalent to Hosea/Podesta XP.

5. Planned analysis

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

Some results from this XP are expected to be published as part of a 2010 IAEA Fusion Energy Conference submission and the APS DPP 2010 meeting. 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. These results would also contribute to ITPA MHD stability group meeting, specifically to joint experiment MDC-12.

PHYSICS OPERATIONS REQUEST

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Brief description of the most important operational plasma conditions required:

- RWM coils configured for $n = 1, 3$ operation
- $n = 1$ RWM active feedback desired
- LITER required (~ 20-30 mg/min deposition rate)

Previous shot(s) which can be modified: 133743, 133750 and similar from XP933

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

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

I_P (MA): **0.7 – 1.2** Flattop start/stop (s):

Configuration: **Limiter / [✓ DN / LSN] / USN**

Equilibrium Control: **Outer gap / [✓ Isoflux (rtEFIT)] / Strike-point control** (rtEFIT)

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

Elongation: **2.1 – 2.6** Triangularity (U/L): **0.45-0.75** OSP radius (m): **< 0.5m**

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

NBI Species: **D** Voltage (kV) **A: 90** **B: 90** **C:** 80-90 Duration (s): **~ 1.3**

ICRF Power (MW): **2+** Phase between straps (°): Duration (s):

CHI: **[✓ Off] / On** Bank capacitance (mF):

LITERs: Off / [✓ On] Total deposition rate (mg/min): **30 (same as in XP948)**

LLD: Temperature (°C): **optimal for density pumping**

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**
Beam Emission Spectroscopy		
Bolometer – divertor		**X**
Bolometer – midplane array		**X**
CHERS – poloidal		**X**
CHERS – toroidal	**X**	
Dust detector		**X**
Edge deposition monitors		
Edge neutral density diag.		**X**
Edge pressure gauges		**X**
Edge rotation diagnostic		**X**
Fast cameras – divertor/LLD		**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 – divertor		**X**
Gas puff imaging – midplane		**X**
Hα camera - 1D		**X**
High-k scattering		**X**
Infrared cameras		**X**
Interferometer - 1 mm		**X**
Langmuir probes – divertor		**X**
Langmuir probes – LLD		**X**
Langmuir probes – bias tile		**X**
Langmuir probes – RF ant.		
Magnetics – B coils	√	
Magnetics – Diamagnetism	**X**	
Magnetics – Flux loops	√	
Magnetics – Locked modes	**X**	
Magnetics – Rogowski coils	√	
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 – E||B scanning		**X**
NPA – solid state		**X**
Neutron detectors		**X**
Plasma TV		**X**
Reflectometer – 65GHz		**X**
Reflectometer – correlation		**X**
Reflectometer – FM/CW		**X**
Reflectometer – fixed f		**X**
Reflectometer – SOL		**X**
RF edge probes		
Spectrometer – divertor		
Spectrometer – SPRED		**X**
Spectrometer – VIPS		**X**
Spectrometer – LOWEUS		**X**
Spectrometer – XEUS		**X**
SWIFT – 2D flow		
Thomson scattering	**X**	
Ultrasoft X-ray – pol. 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 tang. pinhole camera		**X**