**Princeton Plasma Physics Laboratory**

# NSTX Experimental Proposal

## Title: Comparison of NTV among tokamaks (n = even fields, $\nu_i$ scaling)

| | | |
|---|---|---|
| **OP-XP-804** | Revision: **1.1** | Effective Date: **3/1/08**<br>Expiration Date:<br>*(2 yrs. unless otherwise stipulated)* |

## PROPOSAL APPROVALS

| | |
|---|---|
| **Responsible Author: S.A. Sabbagh** | Date: |
| **ATI – ET Group Leader: S.A. Sabbagh** | Date |
| **RLM - Run Coordinator: M.G. Bell** | Date |

**Responsible Division: Experimental Research Operations**

**Chit Review Board** (designated by Run Coordinator)

**MINOR MODIFICATIONS** (Approved by Experimental Research Operations)

# NSTX EXPERIMENTAL PROPOSAL

TITLE: **Comparison of NTV among tokamaks (n even, $\nu_i$)** No. **OP-XP-804**
AUTHORS: **S.A. Sabbagh, R.E. Bell, J.W Berkery, S. Gerhardt, et al.** DATE: **3/1/08**

---

## 1. Overview of planned experiment

The key goal of the experiment is to examine the viscous torque due to the application of even parity non-axisymmetric fields (spectra with significant $n = 2$, 4 and 6 components) in plasmas with different ion collisionality and normalized beta. If these applied fields are effective at slowing the plasma rotation, as shown in NSTX for odd-parity fields[1] (XP524 and many other experiments), the results will be used as a further test of neoclassical toroidal viscosity (NTV) theory and to more directly compare to $n = 2$ applied field experiments in JET and MAST, which have different conclusions on the effectiveness of n = 2 magnetic braking at present. A key parameter in the theory is ion collisionality. This parameter will be varied to examine the effect on magnetic braking with even parity fields.

## 2. Theoretical/ empirical justification

NTV theory has been successful in both qualitatively and quantitatively describing magnetic braking due to non-resonant, non-axisymmetric applied fields and the resistive wall mode, with the first quantitative agreement reported on NSTX. This technique has been used to slow plasma rotation for several years now in NSTX (Fig. 1) and it has been used successfully in JET with an $n = 2$ field configuration. The effect appears to be weaker in DIII-D for $n = 3$, perhaps due to differences in non-axisymmetric field coil geometry. Braking experiments using $n = 2$ fields were performed last year in MAST, with small changes to the plasma rotation initially after field application, and no change later in the discharge. The present experiment is part of a larger effort to compare non-resonant magnetic braking between devices. For closest comparison to JET and MAST, NSTX will be operated with an $n = 2$ field configuration. This configuration has a broader $n$ spectrum than just $n = 2$. It is significant that $n = 2$ field configurations in NSTX have both strong $n = 2$ and $n = 4$ components, as well as weak $n = 1$ (Fig. 2). Therefore, strong braking due to additional applied $n = 1$ field is not expected in this configuration. A key element of the experiment and subsequent analysis is the comparison of results in NSTX to other devices. To date, MAST has provided the most information for their $n = 2$ braking result. The collision, bounce, and ExB drift frequency profiles have been compared between NSTX and MAST for magnetic braking targets (Fig. 3). NTV theory suggests that strongest braking will occur in regions of the plasma with lower collisionality as long as $\omega_E$ is sufficiently low, so that $\omega_E < \nu_i/\varepsilon < \varepsilon^{0.5}\omega_{Ti}$. In NSTX, these frequencies are comparable in the region of peak NTV torque (Fig. 3a). One difference between the MAST target plasma with lower observed braking is a larger $\omega_E$ compared to the other frequencies (Fig. 3b). This might lead to the weaker braking in past MAST experiments, but full analysis of the NTV braking torque is required, and will be compared between NSTX, MAST, and other experiments once this experiment is conducted. This comparison would then be expanded to compare results to JET plasmas if the data for the latter experiment is made available. Comparison to DIII-D is planned for $n = 3$ braking experiments.

---

[1] W. Zhu, S.A. Sabbagh, R.E. Bell, *et al.*, *Phys. Rev. Lett.* **96** (2006) 225002.

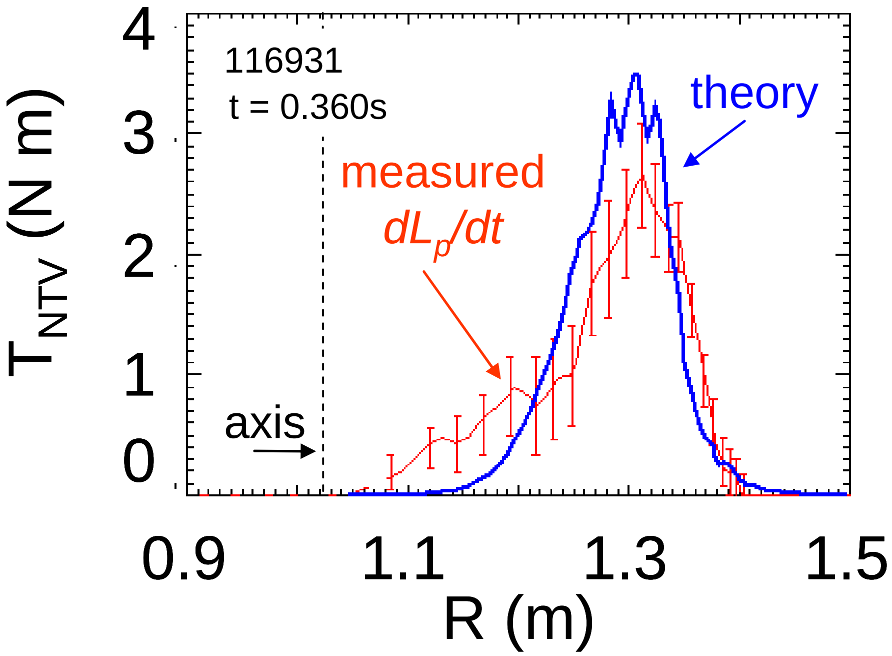

*Figure 1: Comparison of experimental change of angular momentum profile to theoretically computed NTV torque profile (from Ref. 1).*

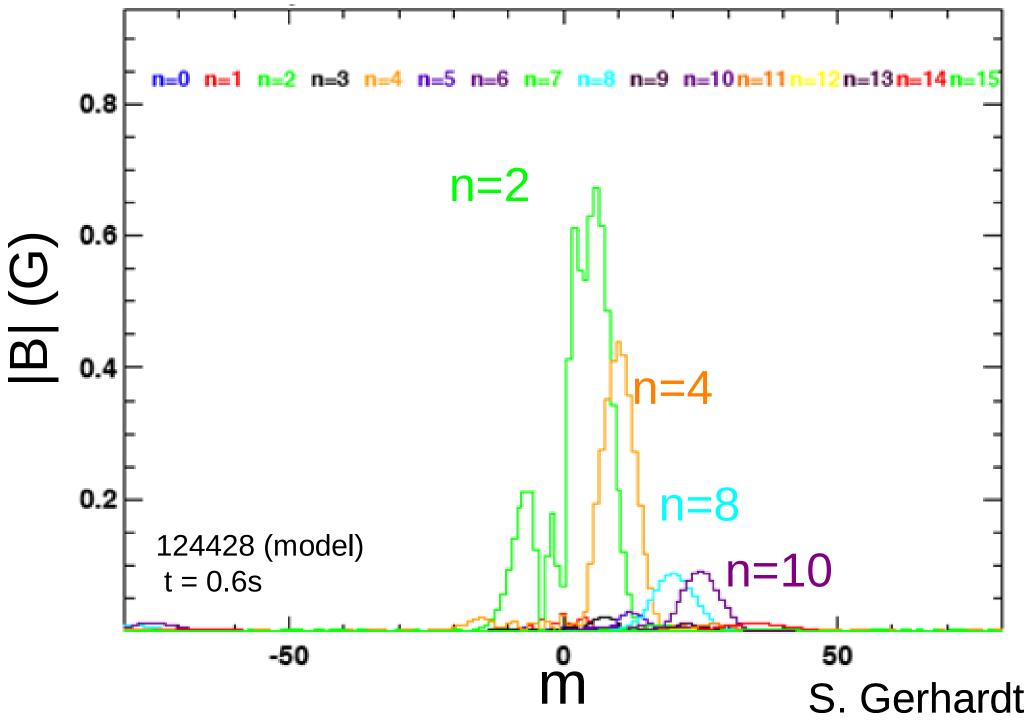

*Figure 2: n and m spectrum at r/a ~ 0.8 for n = 2 applied field configuration in NSTX from midplane RWM coil set with diametrically-opposed coils wired in series.*

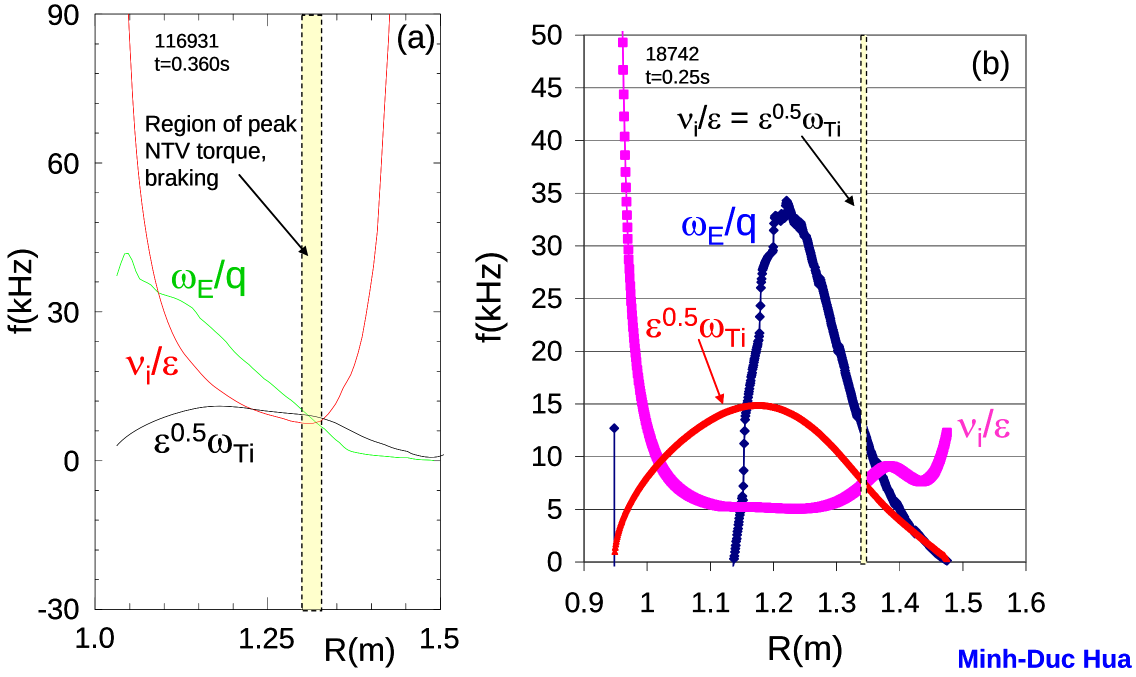

*Figure 3: Comparison of ExB, ion collisionality, and ion bounce frequency profiles for (a) NSTX and (b) MAST target plasma for magnetic braking. The NSTX plasma (that has had both n = 1 and n = 3 braking applied in the past) shows the region of peak torque for the n = 3 configuration.*

Present NTV theory as used in Ref. 1 has a strong inverse dependence on ion collisionality. For a given field configuration, the dominant scaling for NTV in reduced collisionality regimes is $\delta B^2(p_i/\nu_i)\varepsilon^{1.5}\omega_\phi$. The ion collisionality dependence has not been extensively tested, but is potentially important for future low collisionality devices such as ITER. The inverse dependence is expected to saturate if radial electric field effects dominate due to strong NTV, or otherwise. This provides strong motivation for comparing plasmas of different $\nu_i$ in NSTX, as well as making cross-machine comparisons in this study.

## 3. Experimental run plan

Similar to past NTV experiments, it is best to eliminate strong resonant modes during the NTV measurement, so a target plasma discharge with a time period free of strong rotating modes will be chosen. DC pulses of $n$ = 2 fields will be chosen to examine non-resonant braking and spin-up in different plasma with varying $\nu_i$ profiles. The non-axisymmetric field pulses will be spaced to sample different plasma beta to examine possible resonant field amplification (RFA) effects by varying the proximity to the no-wall limit. Variation of ion collisionality will be attempted in H-mode to determine the affect on rotation damping and compare to theory. Reversed $I_p$ operation may allow evaluation of the $\omega_\phi$ offset term expected from the NTV theory (~ few kHz). This operation is considered low probability for the CY2008 run, but is included for completeness for possible operation this years, or in future years.

**Run plan**:

| Task | Number of Shots |
|---|---|
| 1) Create targets (i) below, but near and (ii) above ideal no-wall beta limit (control shots) | |
| (use 124606 as setup shot, 2 or 3 NBI sources, relatively high $k$ ~ 2.4 to avoid rotating modes) | |
| A) No $n$ = 2 applied field; 3 then 2 NBI sources | 2 |
| 2) Apply n = 2 field | |
| A) Step up $n$ = 2 currents during discharge in 75ms steps, 3 NBI sources | 2 |
| B) Step up $n$ = 2 currents during discharge in 75ms steps, 1 or 2 NBI sources | 2 |
| C) $n$ = 2 DC pulse at steady $\omega_\phi$, measure spin down, pulse off to measure $\omega_\phi$ spin-up, 3 NBI | 3 |
| D) $n$ = 2 DC pulse at steady $\omega_\phi$, measure spin down, pulse off to measure $\omega_\phi$ spin-up, 1 or 2 NBI | 3 |
| E) $n$ = 6 DC pulse at steady *wf*, measure spin down, pulse off to measure *wf* spin-up, 3 NBI | 3 |
| 3) Ion collisionality variation | |
| A) Vary $\nu_i$ at constant $q$, apply $n$ = 2 field during period free of strong rotating modes | 8 |
| B) Increase $n$ = 2 field at collisionality where damping is weakest | 3 |
| 4) Reversed Ip scans | |
| A) Repeat scans 1 and 2 above in reversed $I_p$ | (13) |
| Total (optional): | 26 (13) |

## 5. Planned analysis

Computation of the theoretical NTV damping profile will be compared to experiment, as performed for $n$ = 1 and $n$ = 3 applied fields. Modifications to the theory will also be considered to determine if they are important (e.g. offset rotation speed, multiple trapping states). Ideal stability analysis will be conducted as needed. Novel computation of NTV damping using an upgraded version of GTC-neo has been discussed with Tang and Wang from PPPL theory, and will be considered for this data.

## 6. Planned publication of results

Conclusions from this experiment are important whether or not rotation damping occurs. If it does occur, comparison to NTV theory as performed for $n$ = 1 and 3 field configurations will either support the theory, or point out key differences. If rotation damping does not occur, it could have greater implications for NTV theory. Either case would be useful to compare to other experiments. Significant new findings regarding the theory would justify publication in PRL. The results in any case should warrant publication in Phys. Plasmas or a Nuclear Fusion paper of larger scope. Note that these experiments are mentioned in an extended synopsis submitted to the 2008 IAEA Fusion Energy Conference, and so results would appear in the conference proceedings and associated Nuclear Fusion paper.

# PHYSICS OPERATIONS REQUEST

TITLE: **Comparison of NTV among tokamaks (n even, $\nu_i$)** No. **OP-XP-804**
AUTHORS: **S.A. Sabbagh, R.E. Bell, J.W Berkery, S. Gerhardt, et al.** DATE: **3/1/08**

Machine conditions (specify ranges as appropriate)

$I_{TF}$: 0.35 – 0.55T Flattop start/stop (s):

$I_P$ (MA): 0.7 – 1.1 Flattop start/stop (s):

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

Outer gap (m): **0.06 – 0.10** Inner gap (m): **0.04**

Elongation κ: **2.1 – 2.5** Upper/lower triangularity δ: 0.45 – 0.75

Z position (m):

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

**NBI** Species: **D** Sources: Voltage (kV): 80 - 100 Duration (s): 0.8

(Source A at 90 kV for MSE)

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

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

**LITER: On / Off (XP can run with or without LITER)**

Shot numbers for setup: **124606 (for plasma), 127395 (for n = 2 applied field)**

# DIAGNOSTIC CHECKLIST

TITLE: **Comparison of NTV among tokamaks (n even, $\nu_i$)** No. **OP-XP-804**
AUTHORS: **S.A. Sabbagh, R.E. Bell, J.W Berkery, S. Gerhardt, et al.** DATE: **3/1/08**

| **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 |
| H$\alpha$ camera - 1D | | X |
| High-k scattering | | X |
| Infrared cameras | | X |
| Interferometer - 1 mm | | X |
| Langmuir probes - divertor | | X |
| Langmuir probes – RF ant. | | |
| Magnetics – Diamagnetism | X | |
| Magnetics - Flux loops | X | |
| Magnetics - Locked modes | X | |
| Magnetics - Pickup coils | X | |
| Magnetics - Rogowski coils | X | |
| Magnetics - RWM sensors | | X |

| **Diagnostic** | **Need** | **Want** |
|---|---|---|
| Mirnov coils – high f. | | X |
| Mirnov coils – poloidal array | X | |
| Mirnov coils – toroidal array | X | |
| 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'r - H | | X |
| X-ray crystal spectrom'r - V | | X |
| X-ray fast pinhole camera | | X |
| X-ray spectrometer - XEUS | | X |