**Princeton Plasma Physics Laboratory**

# NSTX Experimental Proposal

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|---|---|---|
| Title: **MHD/ELM stability dependence on thermoelectric J, edge J, and collisionality** | | |
| **OP-XP-1031** | Revision: **1.0** | Effective Date: *(Approval date unless otherwise stipulated)* Expiration Date: *(2 yrs. unless otherwise stipulated)* |

## PROPOSAL APPROVALS

| | |
|---|---|
| **Responsible Author: S.A. Sabbagh, T.E. Evans, L.E. Zakharov, J-W. Ahn, J. Canik, R. Maingi, J.W. Berkery, J.M. Bialek, S. Gerhardt, J-K. Park, Y-S. Park, H. Takahashi, K. Tritz, et al.** | Date **6/1/10** |
| **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: **MHD/ELM stability dependence on thermoelectric J, edge J, and collisionality** No. **OP-XP-1031**

AUTHORS: **S.A. Sabbagh, T.E. Evans, L. Zakharov, …** DATE: **6/1/10**

## 1. Overview of planned experiment

The present experiment aims to test the role of field-aligned and toroidal current, and plasmas collisionality on ELM stability, making connection to general macroscopic stability. The experiment would test a model of ELM stability including ideal MHD linear stability vs. edge toroidal current, and the influence of field-aligned thermoelectric currents on non-linear stability. This investigation and these physics elements are consistent with existing work focusing on the alteration of pedestal pressure gradient on ELM stability (e.g. R. Maingi, et al., Phys. Rev. Lett. **103** (2009) 075001). The present work explores additional physics that may clear up apparent incongruities from present experiments regarding ELM stability (e.g. XP818 "ELM Mitigation with Midplane Control Coils") with the goal of understanding ELM stability physics and explore techniques of ELM mitigation. The XP addresses NSTX milestones R10-1, R10-3, and ITPA experiments MDC-2, and PEP-25.

## 2. Theoretical/ empirical justification

XP818, which attempted to mitigate ELMs using 3-D fields successfully altered ELM stability, but left us with more questions than answers. That XP aimed to expand prior results from an NSTX XP by T.E. Evans, et al., that used only n = 3 DC fields to attempt ELM mitigation. XP818 went a step further by using calculated 3D field spectra expected to be favorable for ELM mitigation, based on Chirikov profile analysis (by J-K. Park) and DIII-D experimental experience. Both vacuum and IPEC calculations were conducted, and three favorable field configurations were found – n = 2, n = 3, (Figure 1) and n = "2+3". A reduced $q_{95}$ target plasma was thought to be favorable, based on DIII-D experience. This later evidence was based on field pitch angle alignment with key resonant surfaces in DIII-D. Even in those cases, DIII-D has demonstrated ELM mitigation only in small windows of $q_{95}$. The DIII-D results do show that the q profile is an important parameter for ELM stability, and that one should scan q if possible, to ensure that one is not missing a narrow window in q space for mode mitigation.

In reality, XP818 did not mitigate ELMs. Instead, ELMs were triggered by the application of the non-axisymmetric field configurations thought favorable from the standpoint of computed Chirikov profiles. In more detail, the ELM frequency changed, and compound ELM events were produced, as observed in the change of $D_\alpha$ light emission and USXR measurements when AC non-axisymmetric fields were applied (Figure 2). These results provided further support for other XPs (e.g. J. Canik, et al.) that produced successful triggering of ELMs "on-demand". Early plasmas in XP818 indicated that AC application of the "favorable" non-axisymmetric fields was superior, but by the end of the experiment, DC fields were also producing similar changes to the AC fields regarding the alteration of ELM dynamics.

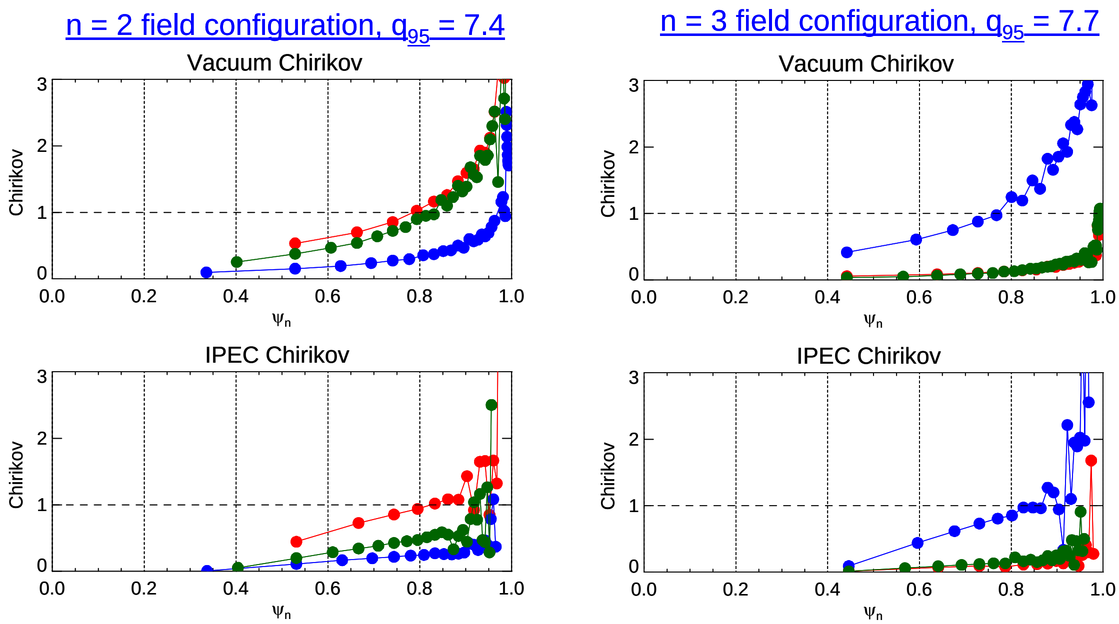


*Figure 1 Chirikov island overlap profiles for NSTX plasmas with n = 2 applied field configuration (left column) and n = 3 field configuration (right column). Upper rows are calculated using the vacuum applied field, while the second row of profiles is calculated including the ideal plasma response using the IPEC code. Experience from DIII-D showed that a Chirikov parameter of 1.0 or greater at a normalized psi above 0.85 led to ELM mitigation in narrow windows of q.*

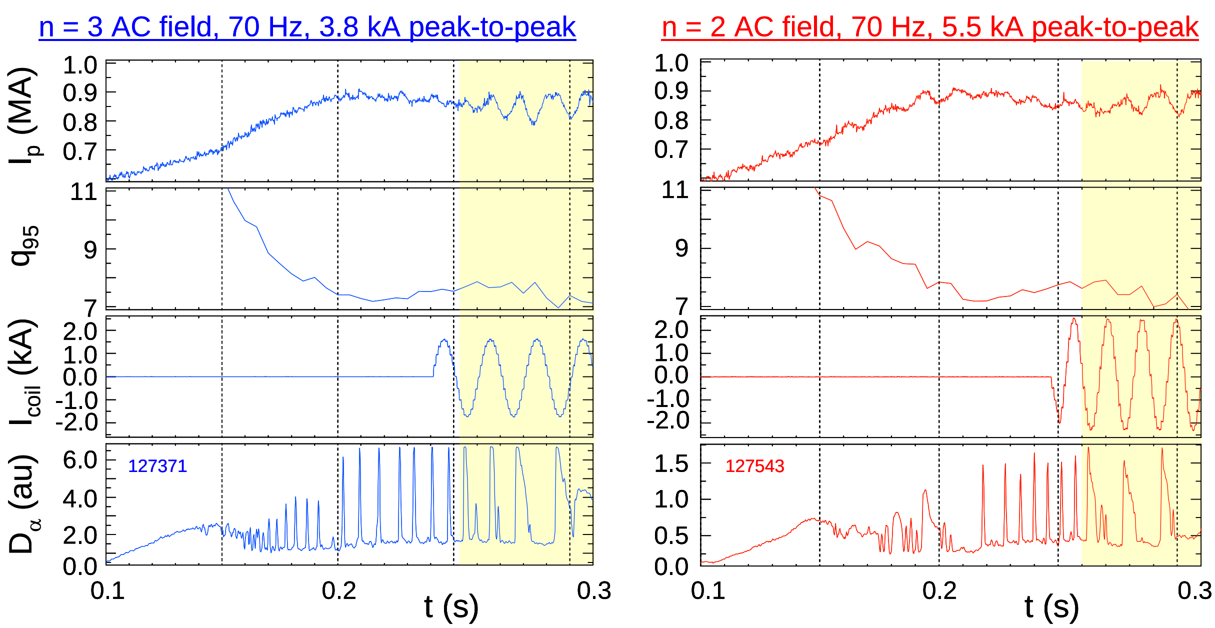


*Figure 2 Effect of applied non-axisymmetric fields on ELM dynamics in NSTX. Both cases are AC applications of the fields, with the left column illustrating the effect of the n = 3 field configuration, and the right column illustrating the effect of the n = 2 field configuration.*

The ELM stability did not change as expected when these fields were applied, but the changes to the ELM dynamics were compelling enough to warrant further understanding. What physics model can explain these unexpected results, and can the understanding lead to ELM mitigation techniques?

A candidate physics model to test is based on current drive for the instabilities, rather than pressure drive. Regarding linear stability, toroidal current can destabilize / stability edge kink / peeling-type instabilities. This can be tested by examining if a plasma near marginal stability to ELMs can be driven unstable by increasing the toroidal current density in the edge region of the plasma. The reverse is also an important test – can unstable ELMs be stabilized by decreasing the edge toroidal current density? Also, a key proposed hypothesis of the non-linear evolution of the ELM dynamics involves the effect of field-aligned currents that are driven by thermal gradients (thermoelectric, or TE currents) that form along the field line. A recent reference giving an overview of the model was published by T.E. Evans, et al., (Jour. Nucl. Mat. **390-391** (2009) 789.) Some aspects of the model are congruous with the observations of XP818, especially that 3D applied field configurations used in separating the stable and unstable invariant manifolds of the separatrix can lead to larger ELM instability drive by producing a larger TE current. The proximity of the X-point to the vessel walls is also expected to change the magnitude of the TE currents.

## 3. Experimental run plan

The experiment will use the simplest techniques possible to produce variations in thermoelectric currents that should change the non-linear dynamics of the ELMs, and edge toroidal current density, which should change the linear stability of the modes. The relative importance of these two effects can also be compared.

The magnitude of the TE currents are expected to change based on (i) Z-position of the separatrix perturbed by the applied 3D field (homoclinic tangle), and (ii) the magnitude of the applied 3D field. It would be best to keep the plasma shape fixed, and change Z, but maintaining a precise boundary shape is not expected experimentally as Z is changed. After discussion with NSTX physics operators, the best approach is to choose a target shape, attempt changing the Z position in the PCS with the boundary shape fixed. Once the plasma is moved sufficiently off the midplane to become vertically unstable, the combination of changing (i) DRSEP and (ii) plasma “squareness” (PF3 controlling the boundary) should be used. Note that changing DRSEP along keeps the X-point position fixed (undesirable here). Optionally, when available, strike point control and X-point control (upper and lower) could be used.

Edge toroidal currents can be changed by relatively slow $I_p$ ramping, both positive and negative. Also, the q profile in the edge region is expected to be important, but it is presently unclear what resonant surfaces are most important. L. Zakharov has suggested that the region outside the pedestal is ergodized. If so, the low order rational surfaces just outside the pedestal region are important. To examine the importance of the q in the edge region, $I_p$ ramps will be conducted first allowing q to vary, and then repeated with q held fixed by ramping the toroidal field to hold q constant.

**XP1031 MHD/ELM stability dependence on thermoelectric J, edge J, and ν - Run plan**

| Task | Number of Shots |
|---|---|
| 1) Generate target | |
| A) Preferable is LSN ELMing plasma target (shot 137564), suitable for +/- Z movement | 2 |
| - (choose 3D field magnitude based on XP818 experience: n = 3 configuration also allows use of n = 1) | |
| - Plasma control: suggest (i) PF3-boundary position (squareness), (ii) DRSEP, (option: use outer SP control) | |
| 2) Vary TE current connection length at fixed 3D field | |
| A) LSN: vary Z until ELMs appear or disappear (three Z positions) | 5 |
| B) DND: | 2 |
| C) USN: (two Z positions) - (contrast grad(B) drift direction / effect to (A)) | 4 |
| 3) Vary 3D field amplitude | |
| A) near marginal condition from (2), still ELMing, decrease n = 3 field until ELMs go away | 3 |
| B) near marginal condition from (2), not ELMing, increase n = 3 field until ELMs return | 3 |
| 4) Vary toroidal current density near the edge | |
| A) near marginal condition from (2), still ELMing, decrease Ip with slow ramp, attempt ELM stabilization | 3 |
| B) near marginal condition from (2), not ELMing, increase Ip with slow ramp, for ELM destabilization | 3 |
| C) redo (A) and (B) with TF ramp up/down to keep q approximately fixed | 4 |
| 5) Vary collisionality with LLD | |
| A) Rerun successful conditions above at reduced collisionality with LLD | 16 |
| Total: | 29; 16 |

Note that the target chosen for this XP (137654) is meant to be near marginal stability to ELMs. This shot was taken in 2010, with several neighboring shots with somewhat different characteristics. Some neighboring shots are listed below, showing the differences between them. From this list, only 137564 and 137489 look to be good ELMing targets, that appear to be near marginal stability.

| shot | delta_lower | kappa | Ip(MA) | |
|---|---|---|---|---|
| **137564** | **0.57** | **2.1** | **0.9** | ELMing (ELMs come in later in shot, as DRSEP changes, bottom gap controlled) – this is favored target |
| 137489 | 0.56 | 2.2 | 0.9 | ELMing (original target: bottom gap not well controlled) |
| 137565 | 0.68 | 2.25 | 0.9 | not ELMing (slightly higher shaping than 137564 – indicates this condition is close to marginal |
| 137622 | 0.58 | 2.2 | 0.9 | not ELMing (late in the LLD run, with warm LLD). |

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

Machine capabilities:

The RWM coils should be in the standard odd parity n = 1, 3 configuration. NBI should have three sources available for reliable H-mode access. NBI source C is expected to be reduced to 1 MW power. Note however that target shot 137564 was a high energy confinement plasma that exceeded $\beta_N = 4$ with 2 MW NBI power, so the XP might be run with significantly lower that 6 MW NBI if energy confinement is good.

Diagnostics:

Scrape-off layer currents should be measured in all configurations possible. LLD shunt tiles will be a primary diagnostic for this purpose. Langmuir probes will also be used for this purpose. USXR should be set up for bolometry, on the usual channels, for ELM detection. The fast divertor IR camera should be used of available. LLD fast cameras should also be used if available to determine both the evolution of fast phenomena (e.g. ELM filament dynamics) and slow phenomena (rotation / modulation of striations caused by the applied 3D field.

# 5. Planned analysis

NSTX EFIT reconstructions using MSE data will be used for ideal MHD stability analysis using DCON and PEST. TRIP3D, SURFMN and other codes will be used to analyze magnetic field topology assuming vacuum applied field. IPEC will be used to examine the plasma response to the applied field.

# 6. Planned publication of results

Further development and verification of ELM stability physics is highly desired by the community, and especially for ITER if simple ELM mitigation schemes will follow from such understanding. If the experiment can make conclusions regarding the effect of toroidal and field-aligned currents on ELM stability, the results would be suitable for publication in Nuclear Fusion, PPCF, or perhaps Physical Review Letters. If the results suggest techniques for ELM mitigation based on further physics understanding, a publication in Physical Review Letters would be targeted.

# PHYSICS OPERATIONS REQUEST

TITLE: **<u>MHD/ELM stability dependence on thermoelectric J, edge J, and collisionality</u>** No. **OP-XP-1031**

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**Brief description of the most important operational plasma conditions required:**

- RWM coils configured for $n$ = 1, 3 operation

- Plasma position control using PF3 ("squareness"), and DRSEP, and or Z axis position, whichever is easiest to produce the target plasmas. (optional use of strike-point control and/or X-point control when ready.)

- LITER required (20 - 30 mg/min deposition rate expected)

**Previous shot(s) which can be repeated: 137564 (ELMing target)**

**Previous shot(s) which can be modified: 137564**

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

$I_{TF}$ (kA): **0.3 – 0.55 T** Flattop start/stop (s):

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

Configuration: **Limiter / <u>DN / LSN / USN</u>**

Equilibrium Control: **Outer gap / <u>Isoflux</u>** <u>(rtEFIT)</u> **/ Strike-point control** (rtEFIT)

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

Elongation: **1.9 – 2.5** Triangularity (U/L): **0.37 / 0.55** OSP radius (m):

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

**NBI** Species: **D** Voltage (kV) **A: 90** **B: 90** **C:** 60-90 Duration (s): ~ **1.3**

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

**CHI**: **<u>Off</u> / On** Bank capacitance (mF):

**LITERs: Off / <u>On</u>** Total deposition rate (mg/min): **30 (same as in XP948)**

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

**EFC coils: Off/<u>On</u>** Configuration: **<u>Odd</u> / 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 |
| H$\alpha$ 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 |