Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

Title: **Error field sensitivity of 2/1 NTM onset thresholds at high and low rotation**		
OP-XP- 810	Revision: **e**	Effective Date: **02/07/08** Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author: R.J. Buttery	Date
ATI – ET Group Leader: S.A. Sabbagh	Date
RLM - Run Coordinator: : M. 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: **Error field sensitivity of 2/1 NTM onset thresholds at high and low rotation** No. **OP-XP- 810**

AUTHORS: **R. J. Buttery, S. Gerhardt, R. J. La Haye** DATE: **02/07/08**

1. Overview of planned experiment

This is the first of a two part proposal to explore rotation and error field effects on NTM β_N thresholds. In this first part we propose an experiment to measure the influence of n=1 error fields in lowering 2/1 NTM β_N limits. This is important in determining likely influence on NTM onset thresholds and error field correction requirements. The study further assesses this affect at high and low rotation, in order to determine whether there is an increased error field sensitivity at low rotation. Rotation would be varied by using different levels of n=3 braking. This is important in identifying whether there is a trend towards greatly increased likelihood of 2/1 modes, as low rotation ITER/DEMO-like plasmas are approached, particularly if error fields are not fully removed. Both elements provide key data on helping understand tearing mode onset mechanisms and error field physics.

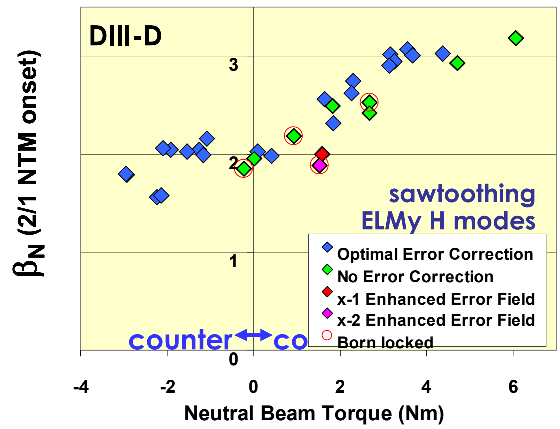
It should be emphasized that this is a two part proposal, and so further justification of this work is in the context of a second part, which would need to be performed with reverse Bt and Ip, to allow counter beam injection. This second part would considerably extend the rotation scan to explore possible asymmetries in NTM thresholds behaviour between co and counter rotation. In particular it would be important to (a) confirm such asymmetries exist; (b) determine if thresholds rise, level off or fall as counter rotation increases, by varying n=3 braking; (c) identify which is the key parameter that governs behaviour and what this might imply about the governing NTM threshold physics.

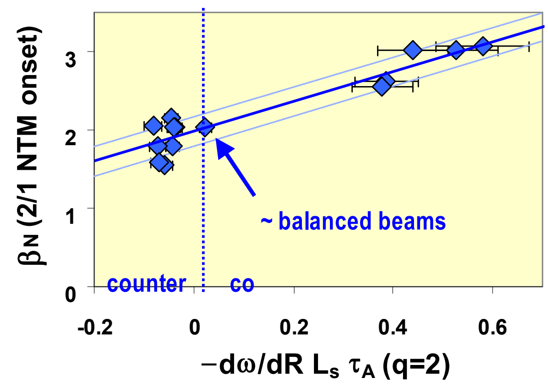
To this end, the assessment committee is invited to further comment on the value of the extension to counter rotation, and encourage NSTX coordinators to consider scheduling of a reverse Bt and Ip campaign to enable the second part to occur.

2. Theoretical/ empirical justification

Theoretically NTM thresholds might be expected to depend on rotation for a number of reasons. Decreased rotation might be associated with decreased shielding of various triggering instabilities. Rotation also enters into much of the underlying physics governing mode stability, such ion polarisation currents, delta prime, and wall stabilisation effects. As most present devices and NTM data are based on high rotation co-injected plasmas, for future low rotation burning devices, it becomes important to understand the trends in the rotation parameter. Such studies also help provide crucial insights into the triggering and threshold physics (exploring processes and which parameters govern trends), which are if anything even more important in having confidence to extrapolate to future devices.

Not least, recent observations from DIII-D have confirmed these concerns (*top figure overleaf*) but also raised some interesting puzzles in this regard, showing an asymmetry in threshold behaviour between net co and counter rotation, although so far being unclear on whether counter rotation points confirm the downward trend or level off. The basic trend of a lowering of thresholds with co-rotation was also observed on NSTX in 2007. Further analysis of DIII-D data suggested possible mechansims related rotation shear changing delta prime may be most consistent with the trends observed (*see lower figure*).





The introduction of n=1 error fields proposed for the 2008 experiments adds a further dimension to this study. Firstly, error field sensitivity is generally expected to increase at low rotation [eg Fitzpatrick papers], and so error fields might be expected to play a role in triggering modes in low rotation devices that they do not in present strongly co-injected devices (where co- rotation virtually eliminates error field effects below the no wall beta limit). Secondly error fields have been observed to combine with NTM drives [Buttery, EPS 2005], effectively lowering the 2/1 NTM beta limit. The combination of these two observations raises the prospect for a considerably enhanced drive for tearing mode onset in a low rotation device. Thus experiments probing this point are important – to determine whether standard intermediate β_N scenarios are more prone to error fields triggering tearing at low rotation than at high rotation. Again the use of error fields, and observation of processes and trends provides good potential for further physics understanding of the NTM onset process, and so implications for future devices. In particular n=1 fields might brake the plasma more locally via a resonant interaction at q=2, and/or lead to partial tearing of the plasma to trigger NTM onset. The studies also test the basic theoretical expectation that error fields should be expected to penetrate more easily at low rotation than high rotation.

With respect to the two part nature of the proposal, the first part of this experiment addresses the latter of the above paragraphs, while the future extension to counter Bt and Ip plasmas would greatly help elucidate some of the underlying physics governing rotation dependencies.

3. Experimental run plan

This proposal is for a half day experiment to meet the first part (co-rotation aspect) of the above described goals. The experiment is closely related to XP801, which measures rotation dependencies in the decay of 2/1 mode to assess the underlying marginal beta physics – both experiments are based on the same reference discharges and are somewhat complimentary (XP810 studying mode onset, XP801 does mode decay). However, in XP810 there is a substantial risk that mode onsets with n=1 fields applied may generate locked modes and prevent progress to the decay phase. Thus the experiments have been decoupled, although some mutual benefit is expected, with opportunities to gain test data for XP810 in XP801 (which goes first) and take any key missing points from XP801 in XP810 (if locked mode problems can be ironed out).

The experiment configuration is based on a 2007 experiment (XP739, XP740) which had high q_{95} (helps avoid locked mode) and applied n=3 fields. For the dedicated half day of XP810, we would start from the optimal configuration (including and shot redevelopment) obtained in XP801, which is expected to happen a few days earlier. (The XP801 re-optimization might include optimization of the plasma elongation, or maybe even plasma current, compared to 2007 references – we will adopt such changes).

Shot design notes:

- All shots would be set up to have a power staircases to trigger the 2/1 NTM. (Power steps preferred to beta feedback). 3rd beam will be modulated at 50% and switched on an off to achieve half beam steps.
- In some shots a stationary n=3 field would be applied to achieve a new reduced rotation. Level of n=3 (if applied) would probably be fixed to around 750A (subject to revision arising from assessment of XP801). n=3 should be applied early to establish steady-ish rotation level.
- A shot to shot scan would be made in level of n=1 field. This would vary from optimal error correction to substantial error fields that trigger locked modes.
- After mode onset we aim to avoid mode locking or cause mode unlocking by (at some preprogrammed time): (i) applying step down in power; (ii) switching back to optimal error correction (iii) switching off n=3 field, at least for a short interval. In this way it is hoped that a second phase with relatively benign rotating 2/1 mode can be obtained for further data for XP801.

Run plan: (*shot estimates ~~presume 2 shots taken per 1 good shot~~*)

1. Reproduce optimal n=1 error correction case, with no n=3 field, matching preprogrammed coil current to those obtained with dynamic error field correction (run with dynamic correction, then without, but pre-programme to match n=1 coil currents). Ramp power to get mode (noting above shot design points). 2-4 shots. (*This point might be reduced to a single 'touch base' if dynamic correction optimised ahead of experiment day, ~~or~~ if n=1 EF correction is considered small in the light of XP801 results).*

2. Repeat (1) holding at two beams (or 1.5 beams) and ramping n=1 fields (*to get top corner of scan*). 2 shots

3. *If time is short and good data obtained from (2) some or all of this item may be delayed till after item 5:*
   Fill in / extension points to (2). Repeat (1) with different ~~fixed~~ levels of n=1 error field. This might start with n=1 levels higher than threshold identified in (2) (*to get top most corner of scan – unless this suggest a level so high immediate disruption seems inevitable*), then look to intermediate points, below threshold identified in (2), then increasing amplitude in the opposite phase to the correction phase. 4 shots min / 8 max.

4. Repeat optimal correction point from (1) with fixed n=3 field (likely 750A – exact level gauged from XP801) during onset phase. 2 shots.

5. *Again, should aim to start with top corner point first with high n=1 field.*
   Repeat scan in items (2-3) in presence of fixed n=3 field. 6 shots min / 10 max.

Total 16-26 shots for full scan (at two run shots per good shot), although minimal scan might be 4 good shots (*But neglects piggy back data from XP801, and can be adjusted as below*).

If time is short we go to proof of principal with corners of scan in n=3 and n=1 fields. But if we are lucky, XP801 will meet some of above goals, and reduce shot requirements. If problems seeing error field effect, further points could ramp error field at fixed power to establish if error field has a role.

Note items (1) and (3) provide best scope for further data for XP801 – second phase would be dictated by that – items (2) and (4) may provide further scope with decreasing probability as n=1 fields are increased (dependent on scope to avoid mode locking/get mode unlocking).

For reference, run plan for second day (counter Bt and Ip) would resemble following. Here the scan is in n=3 field value, and n=1 error field will stay at optimal correction most of the time, as aim is just to vary rotation and see effect on β_N threshold.

1. *Establish optimal error correction case in counter rotation with power tramp to 2/1 mode*
2. *Repeat (1) with varying levels of n=3 field to brake plasma (eg 530, 750, 1061A)*
3. *Possible further probing of high n=3 field case form (2) with additional n=1 field.*

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

Toroidal Field: BT=-4.4 kG

Plasma Current: within range 0.7 - 1.1MA, dependent on XP801 scan (present planned value is 1.0 MA).

Shape: NSTX 123873 with variation (as XP801)

Beams: Enough power to excite 2/1 mode. 2 needed but 3 desirable for finer tuning of power ramp down.

Essential Diagnostics: Magnetics (fast and slow), RWM detectors, MSE

CHERS for core Ti and rotation

Thomson

SXR for island width (USXR operators present please)

5. Planned analysis

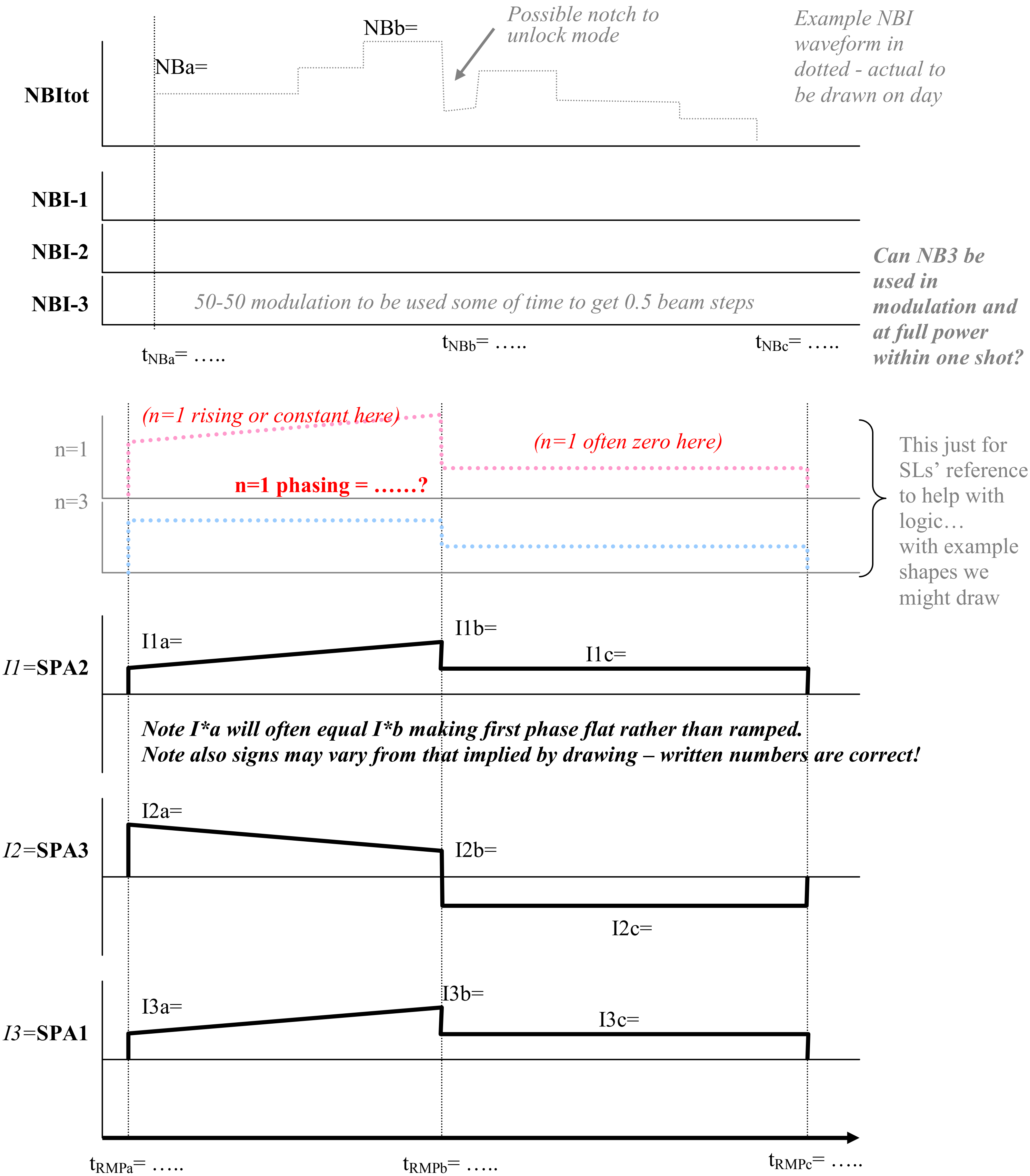
Compiling main tables of results in basic measured parameters. Exploring dependencies against measures of rotation and rotation shear. If possible, ascertaining trend in terms of rotation relative to Eperp=0 frame of reference (to test ion polarisation current model). Analysis of mode onset triggers from spectrograms, correlation with ELMS and sawteeth, checks for appearance of locked modes

6. Planned publication of results

Results could be published as a short letter (?) but in any case would be included in NF journal paper accompanying IAEA presentation, or a similar overview journal paper. The work might also form part of a second paper more generally surveying rotation vs rotation shear effects on NTM thresholds across several NSTX experiments.

Appendix: Shot waveforms vs time – *to be filled out for each RMP change*

(using ready reckoner and/or table overleaf to fill in values)



Time (s)

Table of RMP parameters for shots: ***These to be handwritten on generic plot during the experiment – can be used for XP801 & 810.***

Note stage ‘c’ is set by ramp-down experiment requirements – we assume here a modest level of n=3 is applied only. The level might be expected to vary shot-shot, and might also include some n=1 field in some cases.

Shot ref	t_{RMPa}	t_{RMPb}	t_{RMPc}	I1a	I2a	I3a	I1b	I2b	I3b	I1c	I2c	I3c	Comment for onset experiment
1	.3	.6	.8	0	0	0	0	0	0	+0.75	-0.75	+0.75	No n=1; no n=3; ref point
2a	.3	.6	.8	0	0	0	+0.5	+1.0	+0.5	+0.75	-0.75	+0.75	n=1 ramp 1kA; no n=3
2b	.3	.6	.8	0	0	0	-0.87	0	+0.87	+0.75	-0.75	+0.75	Adjusted n=1 phase
3a	.3	.6	.8	+0.4	+0.8	+0.4	+0.4	+0.8	+0.4	+0.75	-0.75	+0.75	Const n=1; no n=3
3b	.3	.6	.8	-0.69	0	+0.69	-0.69	0	+0.69	+0.75	-0.75	+0.75	…or diff phase n=1
3c	.3	.6	.8	+0.2	+0.4	+0.2	+0.2	+0.4	+0.2	+0.75	-0.75	+0.75	e.g. lower n=1
3d	.3	.6	.8	-0.34	0	+0.34	-0.34	0	+0.34	+0.75	-0.75	+0.75	e.g. lower n=1 diff phase
4	.3	.6	.8	+0.75	-0.75	+0.75	+0.75	-0.75	+0.75	+0.75	-0.75	+0.75	No n=1; 750A n=3
5a	.3	.6	.8	+0.75	-0.75	+0.75	+1.15	+0.05	+1.15	+0.75	-0.75	+0.75	n=1 ramp 800, with n=3
5b	.3	.6	.8	+1.15	+0.05	+1.15	+1.15	+0.05	+1.15	+0.75	-0.75	+0.75	n=1 800, n=3 750
5c	.3	.6	.8	+0.95	-0.35	+0.95	+0.95	-0.35	+0.95	+0.75	-0.75	+0.75	n=1 400, n=3 750
5d	.3	.6	.8	+0.75	-0.75	+0.75	+0.06	-0.75	+1.44	+0.75	-0.75	+0.75	As 5a but 90 degrees
5e	.3	.6	.8	+0.06	-0.75	+1.44	+0.06	-0.75	+1.44	+0.75	-0.75	+0.75	As 5b but 90 degrees
5f	.3	.6	.8	+0.40	-0.75	+1.10	+0.40	-0.75	+1.10	+0.75	-0.75	+0.75	As 5c but 90 degrees

On the fly formulae: ‘a’ kA of n=1 at zero degrees to ‘b’ kA of n=3 → $IRMP = (a/2+b\ ,\ a-b\ ,\ a/2+b)$

‘a’ kA of n=1 at 90 degrees to ‘b’ kA of n=3 → $IRMP = (b-\sqrt{3}/2a\ ,\ -b\ ,\ b+\sqrt{3}/2a)$ where $\sqrt{3}/2 = 0.87$

…a spread sheet has been set up to calculate more values on the fly as needed…

Second table of RMP parameters for shots: ***for modified phasing of n=1 field***

This version for estimated optimum phasing from error correction reference #123898 with –ve OH of 13kA at t=0.6s

Shot ref	t_{RMPa}	t_{RMPb}	t_{RMPc}	I1a	I2a	I3a	I1b	I2b	I3b	I1c	I2c	I3c	Comment for onset experiment
1	.3	.6	.8	0	0	0	0	0	0	+0.75	-0.75	+0.75	No n=1; no n=3; ref point
1b	.3	.6	.8	0	0	0	0	0	0	+0.98	-0.98	+0.28	as 1 with n=1 corn if OH=-13
1c	.3	.6	.8	0	0	0	0	0	0	+0.23	-0.23	-0.46	Pure n-=1 corn; no n=3
2a	.3	.6	.8	0	0	0	-0.5	+0.5	+1.0	+0.75	-0.75	+0.75	n=1 ramp 1kA; no n=3
2b	.3	.6	.8	0	0	0	+0.5	-0.5	-1.0	+0.75	-0.75	+0.75	Reversed n=1 phase cf 2a
3a	.3	.6	.8	-0.4	+0.4	+0.8	-0.4	+0.4	+0.8	+0.75	-0.75	+0.75	Const n=1; no n=3
3c	.3	.6	.8	-0.2	+0.2	+0.4	-0.2	+0.2	+0.4	+0.75	-0.75	+0.75	e.g. lower n=1 amp
4	.3	.6	.8	+0.75	-0.75	+0.75	+0.75	-0.75	+0.75	+0.75	-0.75	+0.75	No n=1; 750A n=3
5a	.3	.6	.8	+0.75	-0.75	+0.75	+0.35	-0.35	+1.55	+0.75	-0.75	+0.75	n=1 ramp 800, with n=3
5b	.3	.6	.8	+0.35	-0.35	+1.55	+0.35	-0.35	+1.55	+0.75	-0.75	+0.75	n=1 800, n=3 750
5c	.3	.6	.8	+0.55	-0.55	+1.15	+0.55	-0.55	+1.15	+0.75	-0.75	+0.75	n=1 400, n=3 750

On the fly formulae: ‘a’ kA of n=1 at 60 degrees to ‘b’ kA of n=3 → IRMP = (-a/2+b , a/2-b , a+b) with a positive for EF enhancement

…a spread sheet has been set up to calculate more values on the fly as needed…

Comments on choice of RMP options as experiment progresses

Experiment assumes optimal error correction is zero n=1 field*. Actuality may differ – we will neglect this apart from ensuring that any additional n=1 fields are applied with phasing chosen to increase error field rather than cancel it. A small phasing scan may be needed to determine this during XP 801 (day 1) or XP 810 (day 2) – above table and ready reckoner designed to readily calculate SPA currents needed for this.

Specific levels of n=1 may need to be revised from indicative options in the table. For example, the expected maximum workable level of 800A of n=1 may be too low – requiring scans to go higher. Or it might be too high, requiring refined scans to lower n=1 levels. We gauge this by observing what effect the n=1 field has on the plasma (inducing locked modes) and the NTM threshold (fall in β_N).

Similarly n=3 levels may need tuning (eg if they lock up plasma rotation too readily) – though this is not expected given results of XP740 on this point already obtained.

XP 810 aims for minimal four point scan of corners, and then seeks additional 1-3 fill in points in n=1 scan at each of the two n=3 operating points.

If intrinsic errors are a problem, it may be necessary (in XP801 or XP810) to attempt estimate of optimal correction (perhaps executing an n=1 field shot to shot phase scan with amplitude ramp in each shot) to apply as an offset in all cases.

**with respect to first point, this represents a slight compromise in the experiment aims and approach, as dynamic error correction will not be available – so item (1) in the shot plan will just be single point check, and is likely to provided automatically from XP801.*

Relationship of XP 810 with XP801

XP810 benefits from optimisations performed in X801 for shape and Ip value, also…

XP801 is likely to supply both zero n=1 points of XP810 scan (ie with zero and 750A of n=3 applied).

XP801 will attempt modes n=1 levels (incrementally from low values), but may have to abandon if locked modes result.

…so XP810 is happy to cede time to XP801, as this was deemed top priority and should (if reasonably possible) be given time to obtain a decent minimal scan – with additional further data hoped for as XP810 progresses.

PHYSICS OPERATIONS REQUEST

TITLE: **Error field sensitivity of 2/1 NTM onset thresholds at high and low rotation**	No. **OP-XP-810**
AUTHORS: **R. J. Buttery, S. Gerhardt, R. J. La Haye**	DATE: **02/07/08**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-53** Flattop start/stop (s):

I_P (MA): **1.0** Flattop start/stop (s):

Configuration: **DN as in 123873 with adjustments**

Outer gap (m): Inner gap (m):

Elongation κ: Upper/lower triangularity δ:

Z position (m):

Gas Species: Injector(s):

NBI Species: **D** Sources: A,B,C(optional) Voltage (kV): 90 Duration (s):

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

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

EF/RWM coils: **ON; n = 1, n = 3 configurations**

LITER: On / Off

Shot numbers for setup: Shot **123873** for shape and timing will be the start.
See Appendix sheet for EF/RWM coil waveforms for each shot

DIAGNOSTIC CHECKLIST

TITLE: **Error field sensitivity of 2/1 NTM onset thresholds at high and low rotation**	No. **OP-XP-810**
AUTHORS: **R. J. Buttery, S. Gerhardt, R. J. La Haye**	DATE: **02/07/08**

Diagnostic	Need	Want
Bolometer – tangential array		X
Bolometer – divertor		
CHERS – toroidal	X	
CHERS – poloidal		X
Divertor fast camera		X
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		
Edge pressure gauges		
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		
Hα camera - 1D		X
High-k scattering		X
Infrared cameras		
Interferometer - 1 mm		
Langmuir probes - divertor		
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		
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-ray crystal spectrom'r - V		
X-ray fast pinhole camera		X
X-ray spectrometer - XEUS		X