Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Investigation of improved electron confinement in low density/shear reversal L-mode discharges		
OP-XP-411	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

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Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Investigation of improved electron confinement in low density/shear reversal L-mode discharges **OP-XP-411**

1. Overview of planned experiment

Electron transport seems to be the main challenge to the NSTX confinement. During density scans in XP223 it was however consistently observed that the electron temperature increases and its profile broadens during early beam injection at low density ($\langle n_e \rangle \approx$ 2-2.5 10^{13} cm^{-3}), versus the intermediate density case ($\langle n_e \rangle \approx$ 4-5 10^{13} cm^{-3}). Indications of a broad region of magnetic shear reversal are obtained in the low n_e case from the USXR data and from TRANSP magnetic diffusion calculations (Fig. 1).

A first goal of the proposed XP is to clarify if shear reversal is the principal cause for improved electron confinement, or if the lower density/collisionality is also a determining factor. In other words, how does electron transport look in the following conditions ?

- low density / reversed q
- low-density / flat q
- high density / flat q
- high density / reversed q

The observations so far being that the typical NSTX operating regime number III has poor electron confinement, while number I has improved confinement.

For an answer to the above questions we will produce discharges *with* and *without* conditions promoting *shear reversal*, at *low* and *high density*. Conditions conducive and less conducive to shear reversal will be obtained by varying the *current ramp-rate* and *beam timing* around the values used in XP223.

Data from an early XP on flux consumption indicates that the ramp-rate can change the current profile, as shown by l_i in Fig. 2. The largest change occurs between 3 and 6 MA/s. Thus, by comparing *fast ramp-rate/early beam* discharges with *slow ramp-rate/late beam* ones it is likely that significant changes in the magnetic shear profile can be obtained.

Further on, it is of interest to increase beam power beyond that in XP223. First, this will assess the response of the T_e profiles to increased heating and second, it will enable comparing low and high density discharges having same power input per particle.

Another goal of the XP is to better document the increase in ion transport estimated in the low density regime. Neon injection will be used to assess particle transport, while core turbulent density fluctuations will be measured by the upgraded UCLA reflectometer. Low density and L-mode operation will allow probing deeper into the core.

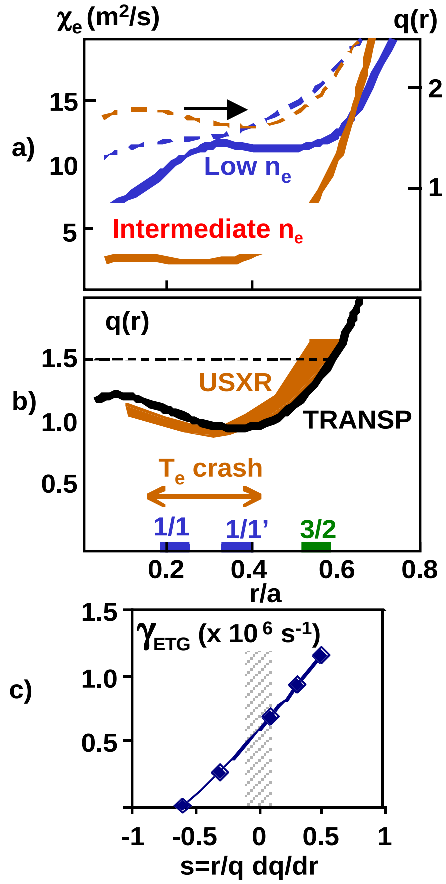

Fig. 1 *a) A large χ_e decrease (solid lines) is observed from early on (t≈0.19 s) in the low n_e plasma. TRANSP predicts reversed q-profile in this case (dashed lines).*
b) q-profile estimated from the radial location of MHD modes and TRANSP predicted profile (t≈0.3-0.32 s).
c) Growth rates of ETG ($k_\theta\rho_i$ ≈35) modes computed by GS2 at r/a≈ 0.4 and t=0.29 s in the reduced χ_e case, as a function of magnetic shear, s. For |s| < 0.1 (shaded area) the ballooning approximation in GS2 may be expected to be less accurate.

Finally, in a half day of experiments at 6 kG we will try and extend the duration of the high electron confinement stage by operating for a longer time above q=1. RF power will then be added to maximize beta/stored energy. Once beta maximized, we will finally perform a B_t ramp-down, for a first attempt at triggering the predicted beta-prime turbulence stabilization mechanism.

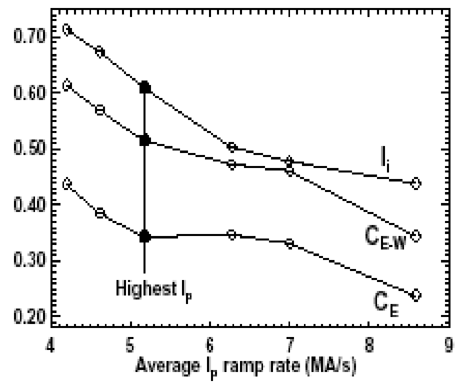

Fig. 2 *Internal inductance l_i (current peaking) decreases with ramp-rate (J. Menard, NF 2001)*

- We will first produce the low density conditions and only after that proceed to higher density.
- Reproducible low density operation will be insured by using the new GDC/He discharge/GDC technique.
- H-modes will be allowed only late in the discharge, after electron confinement has already improved. Several strategies of increasing force will be used as needed to keep the plasma out of H-mode:
  - Small gap (≈ 1 cm), or Center Stack (CS) limited operation
  - low field side (LFS) fueling
  - lower dome fueling
  - Re-limiting the plasma after diverting
  - De-rating the power of the earliest beam source below the H-mode threshold

- A major benefit for the proposed XP is the availability of two MSE channels, measuring around r/a ≈ 0 and r/a ≈ 0.5. This should be sufficient to constrain EFIT for a distinction between flat and significantly reversed q-profiles. *Since MSE is based on the source A beam, this will be used as the earliest beam.*
- To assist the CHERS background measurement with a single source, a 20 ms beam notch will be inserted later in the shot. However, for a more reliable T_i, V_t measurement the shots obtained in the *main conditions* highlighted above will be *repeated with two beam sources*. This will also enable a first assessment of the response of the T_e profile to increased power.
- Finally, for a metric of the electron confinement gain during the experiment we will use the height and gradient of the T_e profile in the major radius coordinate.

2. Theoretical/ empirical justification

Possible causes for the reduced electron transport in low density discharges are:

i) Negative shear is directly, or indirectly responsible, while the low density serves only to promote shear reversal (e.g., through higher heat input per particle)

ii) The low density is the main cause, implying that electron transport depends on collisionality in NSTX. In this event, shear reversal could be a consequence of the increased core T_e (slower current diffusion)

Of the above, shear reversal is theoretically predicted to have a direct effect on electron microstability in NSTX. As shown by the GS2 results in Fig. 2 (K. Hill, C. Bourdelle), decreasing magnetic shear should reduce ETG turbulence, with negative shear completely suppressing the ETG activity.

Another important hint from the TRANSP and GS2 analysis of low and intermediate density plasmas in NSTX is that significantly negative shear might be needed to reduce electron transport, while discharges with $|s| \approx 0$ might still have poor electron confinement. Further investigation of this observation through scanning a range of q-profiles would be important, since the ST core has 'naturally' $|s| \approx 0$.

There is also the theoretical possibility of a collisional effect on electron transport in NSTX. Thus, recent GS2 calculations by M. Redi seem to indicate the appearance of long wavelength micro-tearing modes in conditions of high density ($\langle n_e \rangle \approx 6\ 10^{13}\ cm^{-3}$) and monotonic magnetic shear [M. Redi *et al*, EPS 2003]. Being a resistive effect, micro-tearing modes would naturally be related to collisionality.

The present XP tries to differentiate between the above possibilities.

- If at low density we see a decrease in electron confinement when eliminating conditions conducive to shear reversal, this would strongly point to the negative shear rather than collisionality as the determining factor
- By increasing the density in discharges having improved electron confinement, we can see if the higher collisionality cancels the confinement gain. If it does, one can eventually surmise that at high density micro-tearing modes play a significant role.

It is also important to assess the effects of increased power on the T_e profile in conditions of improved electron confinement. From a theoretical point of view this will allow comparison with 'critical gradient' models, while from an operational point of view it might lead to steeper electron and beta profiles than previously achieved in NSTX. This last aspect is of interest in a follow-up part of the XP, in which we will attempt testing the predicted 'beta-prime' turbulence stabilization mechanism (C. Bourdelle, PoP 2003).

Also, verifying and trying to explain the apparent increase in ion transport in the improved electron confinement regime is also an important goal of the XP. As such, the experiment will strongly benefit from core density fluctuation measurements possible with the upgraded reflectometry system.

Finally, for the proposed XP we need to assess *relative changes in the q profile* with discharge conditions, rather than obtain accurate, absolute q-profiles. For this, the MSE EFIT constraint at two radial points should suffice. From Fig. 1, it appears that the magnetic axis and mid-radius would be the best choices. We will also use X-ray imaging with the GEM detector, mode identification with the USXR arrays, as well as TRANSP magnetic diffusion calculations for q-profile estimates.

3. Experimental run plan

- The experiment will be run using shot **108794** as a basis: DND, κ=1.9, δ=0.6-0.7, 4.5 kG $\langle n_e \rangle \approx$ 2.5 10^{13} cm^{-3}, I_p= 1 MA, 5 MA/s current ramp rate, source A, P_{beam}=1.5 MW at 80 kV.

- Beam sources:
  - we will use ***A*** *at 80 kV* (1.6 MW) as the primary (earliest) source, since it is needed for MSE measurements
  - the second source will be B, also at 80 kV. A constant delay of 40 ms will be used between A and B when operating with two sources
  - a 10 ms notch will be inserted in beam A at ≈ 300 ms in order to improve the CHERS background measurement

- The priority conditions are as follows:

i) Low n_e + fast ramp-rate + early injection (reversed q)
ii) Low n_e + slow ramp-rate + late injection (flat q)
iii) High n_e + slow ramp-rate + late injection (flat q)
iv) High n_e + fast ramp-rate + early injection (reversed q)

- After each priority condition is obtained with one source, we will *repeat it using two sources* (A+B), in order to increase the accuracy of the CHERS measurement.

- In addition, once a priority condition established with two sources, it will be *repeated using neon injection* for an assessment of particle transport.

- Time permitting, we will execute also intermediate conditions using two sources.

Shot list (priority conditions in blue)

Src.	Ramp (MA/s)	T_{inj} (ms)	$\langle n_e \rangle$ ($x10^{19}m^{-3}$)	D	Ne inj.
A	5	80	2.5	x	
A	5	40	2.5	x	
A	5.5	40	2.5	x	
A	6	40	2.5	x	
A+B	6	40/80	2.5	x	x
A	4	120	2.5	x	
A	3	200	2.5	x	
A+B	3	200/240	2.5	x	x
A	3	200	5	x	
A+B	3	200/240	5	x	x
A	4	120	5	x	
A	5	40	5	x	
A	5.5	40	5	x	
A	6	40	5	x	
A+B	6	40/80	5	x	x

Total = 19 useful shots

1/2 day at 6 kG

- Reproduce highest electron confinement shot from Day 1 at 6 kG
- Increase beam power to 6 MW and add RF power to maximize beta/stored energy/pulse length at high field, through improved electron confinement
- Attempt beta-prime stabilization through B_t ramp-down

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

Required capabilities

- 1 MA, 4.5 kG, sources A and B at 80 kV, injecting from 40ms, with 20 ms notch at t=300 ms
- Target low density 2-2.5 $\times 10^{19} m^{-3}$
- 5 min GDC + He discharge + 5 min GDC for reproducible low n_e operation
- Strategies for early H-mode avoidance, in order of priority:
  -Small gap (≈ 1 cm), or Center Stack (CS) limited operation
  -Low field side (LFS) fueling
  -Lower dome fueling
  -Re-limiting the plasma after diverting
  -10 min GDC + Neon puff
  -De-rating the power of the earliest beam source below the H-mode threshold
- Gas puff setup:
  - Deuterium, He in LFS injectors and lower dome injectors
  - Neon at 110 torr plenum pressure in Bay K top puffer
- Two MSE channels (magnetic axis and mid-radius) operational
- CHERS measurement of T_i, V_t and C , Z_{eff} profiles
- Core reflectometry for turbulent density fluctuation measurement
- High frequency digitization of Mirnov signals
- USXR system in ‘multi-color’ configuration
-

Highly desirable: fresh boronization

4. Planned analysis

The analysis includes EFIT, TRANSP output, gyrokinetic microstability analysis with GS2, NCLASS for the ExB shear evaluation, and MIST for impurity transport

5. Planned publication of results

IAEA, APS and refereed journals.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **24-70** Flattop start/stop (s): _____/_____

I_P (MA): **1** Flattop start/stop (s): **0.14-0.33/> 0.5**

Configuration: **Double Null**

Outer gap (m): **0.05-0.10**, Inner gap (m): 0.00-**0.01**

Elongation κ: **1.9**, Triangularity δ: **0.6-0.7**

Z position (m): **0.00**

Gas Species: **D / He /Neon**, Injector: **D-Midplane / D-Lower Dome /Ne- Top**

NBI - Species: **D**, Sources: **A/B** Voltage (kV): **80**, Duration (s): **0.5**

ICRF – Power (MW): **3**, Phasing: **Heating**, Duration (s): **0.3**

CHI: **Off**

Either: List previous shot numbers for setup: **108794**

Or: Sketch the desired time profiles, including inner and outer gaps, κ, δ, heating, fuelling, etc. as appropriate. Accurately label the sketch with times and values.

DIAGNOSTIC CHECKLIST

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Diagnostic	Need	Desire	Instructions
Bolometer – tangential array		✓	
Bolometer array - divertor		✓	
CHERS	✓		
Divertor fast camera		✓	
Dust detector		✓	
EBW radiometers		✓	
Edge deposition monitor		✓	
Edge pressure gauges		✓	
Edge rotation spectroscopy		✓	
Fast lost ion probes - IFLIP		✓	
Fast lost ion probes - SFLIP		✓	
Fast X-ray pinhole camera		✓	
Filtered 1D cameras		✓	
Filterscopes		✓	
FIReTIP		✓	
Gas puff imaging		✓	
Infrared cameras		✓	
Interferometer - 1 mm		✓	
Langmuir probe array		✓	
Magnetics - Diamagnetism		✓	
Magnetics - Flux loops		✓	
Magnetics - Locked modes		✓	
Magnetics - Pickup coils		✓	
Magnetics - Rogowski coils		✓	
Magnetics - RWM sensors		✓	
Mirnov coils – high frequency	✓		
Mirnov coils – poloidal array		✓	
Mirnov coils – toroidal array		✓	
MSE	✓		
Neutral particle analyzer		✓	
Neutron measurements	✓		
Optical X-ray		✓	
Plasma TV		✓	
Reciprocating probe		✓	
Reflectometer – core	✓		
Reflectometer - SOL		✓	
RF antenna camera		✓	
RF antenna probe		✓	
SPRED	✓		
Thomson scattering	✓		
Ultrasoft X-ray arrays	✓		
Visible bremsstrahlung det.		✓	
Visible spectrometer (VIPS)		✓	
X-ray crystal spectrometer - H		✓	
X-ray crystal spectrometer - V		✓	