Princeton Plasma Physics Laboratory **NSTX Experimental Proposal**		
Title: Investigation of improved electron confinement in low density/shear reversal L-mode discharges		
OP-XP-403	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*
PROPOSAL APPROVALS		
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MINOR MODIFICATIONS (Approved by Experimental Research Operations)		

NSTX EXPERIMENTAL PROPOSAL

Title: Exploration of improved electron confinement in low density/shear reversal L-mode discharges

1. Overview of planned experiment

Electron transport seems to be the main challenge to the NSTX confinement, with stiff electron temperature profiles in most plasma conditions. 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 ($\langle n_e \rangle \approx 2\ 10^{13}$ cm^{-3}), versus the intermediate density case ($\langle n_e \rangle \approx 4\ 10^{13}$ cm^{-3}). As shown in Fig. 1a, this is consistent with a large reduction in the core χ_e. Although the ion transport appears to increase in the low n_e case, the large reduction in the dominant electron loss makes for ≈ 25% higher W_{tot} and τ_E at low density. 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. 1b).

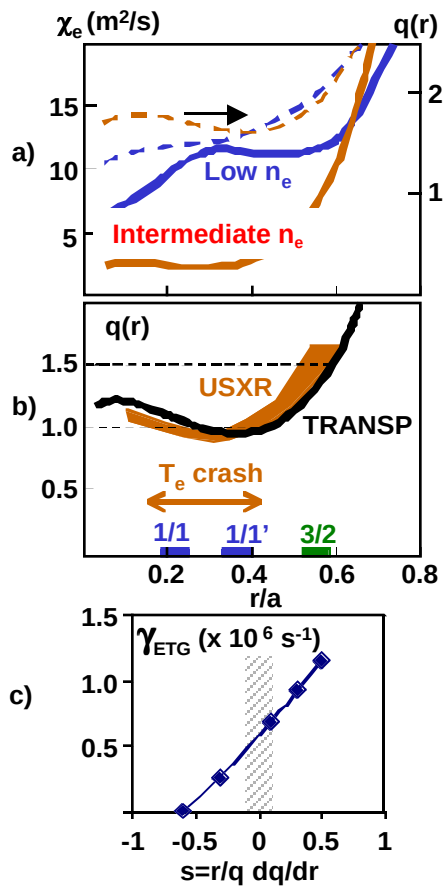

Fig. 1 *a) A large χ_e decrease (solid lines) is observed from early on (t≈0.19 s) in the low n_e plasma. TRANSP predicts reversed q-profile in this case (dashed lines).*
b) q-profile estimated from the radial location of MHD modes and TRANSP predicted profile (t≈0.3-0.32 s).
c) Growth rates of ETG ($k_\theta \rho_i \approx 35$) 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.

The first goal of the proposed XP is to more clearly establish if shear reversal is the principal cause for improved electron confinement, or if the lower density (collisionality) is the determining factor. This will be done by producing at low density discharges with and without conditions promoting shear reversal. Conditions conducive and less conducive to shear reversal will be obtained by varying the current ramp-rate, as well as κ and δ around the values used in XP223. The plasma current will also be ramped up above the 1MA level used in XP223, to further broaden the region of possible negative shear. Finally, we will inject beams earlier than in XP223 (30 ms instead of 80 ms), since in MAST this was estimated to also favor shear reversal.

Using the above conditions we will then assess if the improved electron confinement obtains *only* in conditions conducive to reversal, or if it at low density electron transport improves also in conditions favoring monotonic or flat q-profiles. (The correlation between the extent/evolution of the region of improved electron transport and that of estimated reversal is less telling, since as

discussed below, the reversal might also be an effect rather than the cause for reduced transport.)

Further on, we will try increasing the density in one of the high electron confinement scenarios, in order to see if the higher collisionality brings electron transport back to its usual level. If it does, as discussed below, this would indicate that collisional effects like micro-tearing could play a significant role for electron transport.

A second goal of the XP is to assess the 'stiffness' of the T_e profiles in the improved electron confinement regime. For this, we will increase the beam heating power at low density and ramp-rate conditions where the highest T_e gain was observed. Time permitting, RF power will also be added for further direct heating of the electrons.

Finally, a third goal of the XP will be to better document the apparent increase in ion transport in the low density regime. Both density and magnetic fluctuations will be monitored with the highest possible bandwidth and coverage, to see if there is a difference compared to the intermediate density situation. The low density will allow for fluctuation measurements deeper in the core with the upgraded reflectometry systems on NSTX.

For operational reasons, we will first produce the low density conditions and only after that proceed to higher density.

The proposed XP should help understand what causes strong electron transport in NSTX. In addition, we may achieve an improved electron/global confinement regime optimized at relatively low beta. Using this regime as a basis, we will then explore in a follow-up XP the theoretically prediction that an increase in the gradient of beta above a certain threshold may trigger a further confinement increase in NSTX.

2. Theoretical / empirical justification

Good ion confinement is consistently observed in L-mode NBI heated plasmas in NSTX. The electron confinement on the other hand appears to be quite poor. A significant change was observed however in low density discharges in XP223. Figure 2 illustrates the dependence of the central electron temperature as a function of the central density, for single beam heated discharges in XP223. A clear increase, with possibly a threshold character is seen at low density.

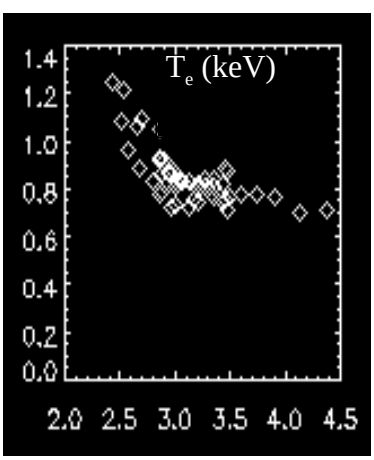

Fig.2 *Central T_e as a function of central n_e (x 10^{13} cm^{-3}) in XP223 (200-300 ms average)*

At the same time negative magnetic shear is indicated by USXR data and TRANSP calculations in the improved electron confinement regime. Simplifying the picture, possible causes for the reduced electron transport 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 lower density is the main cause, implying that electron transport depends on collisionality in NSTX. In

this event, shear reversal would be rather 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. 2c (K. Hill, C. Bourdelle), decreasing magnetic shear should reduce ETG turbulence, with negative shear completely suppressing the ETG activity. (Interestingly, as observed by C. Bourdelle, this seems opposite to recent predictions at large aspect-ratio, where decreasing magnetic shear *increases* the drift wave turbulence [Fourment *et al*, PPCF 2003].

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.

i) 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

ii) 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 beam and RF 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 will be of interest in a follow-up XP, in which we will attempt testing the predicted 'beta-prime' turbulence stabilization mechanism (C. Bourdelle, PoP 2003).

Finally, 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.

As concerns experimental techniques, for an objective 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. For an assessment of q profile changes with discharge conditions we will attempt using X-ray imaging of the core shape with the GEM detector, as well as mode identification with the USXR arrays. However, TRANSP magnetic diffusion calculations will likely be the principal tool for q-profile estimates.

Availability of an MSE constraint for the central safety factor would of course strongly benefit this XP.

Lithium pellet conditioning would also be very desirable for a reduction in D_2 recycling.

Neon injection will be used in some of the discharges to assess changes in particle transport.

3. Experimental run plan

The experiment will be run at 4.5 kG, using shot 108918 as a basis (DND, κ=1.9, δ=0.6-0.7, $<n_e>\approx$ 2 1013 cm^{-3}, I_p= 1 MA, 5 MA/s current ramp rate, P_{beam}=1.6 MW at 80 kV).

For single source operation we will use source C, since it was observed to produce less MHD activity. The voltage will be increased to 90 kV however, in order to increase the power to 2 MW. Source A and B will be set at 80 kV/1.6 MW.

We will obtain two shots per condition, with the second one having a 10-20 ms beam blip around 350 ms for an improved CHERS background measurement.

Although there are other possible scenarios for producing shear reversal, we choose to make only incremental departures from 108918 conditions, so as to minimize the time spent on discharge development.

1. *Restore conditions in which improved electron was observed at low density and verify that effect is still present* ***(2 shots).***

2. *Move beam injection time to 30 ms* ***(2 shots)***

3. *Increase, κ, δ by 10%* ***(2 shots)***

4. *I_p ramp rate scan:*
   6 MA/s ***(2 shots),*** *7 MA/s* ***(2 shots),*** *4 MA/s* ***(2 shots****), 3 MA/s* ***(2 shots****)*

5. *Continue I_p increase to 1.2 MA at ramp-rate giving highest T_e gain* ***(2 shots)***

6. *Beam power scan at 1 MA and ramp-rate giving highest T_e gain:*
   C+B @ 0.2 s ***(2 shots),*** *C+B +A @ 0.2 s* ***(2 shots)***

7. *At the highest beam power sustainable, add RF heating after electron confinement improves with beams: 1.5 MW* ***(2 shots)****, 3 MW* ***(2 shots****)*

8. *N_e increase at the current ramp rate and beam power giving highest T_e gain:*
   $\langle n_e \rangle \approx 3.5\ 10^{13}$ cm^{-3} ***(2 shots)***, $\langle n_e \rangle \approx 5\ 10^{13}$ cm^{-3}, ***(2 shots)***

9. *Time permitting, add RF to high n_e, high electron confinement discharge (2 shots)*

General operating conditions:

Beam setup: source C at 90 kV injecting at 30 ms (80 ms) and sources A and B at 80 kV. RF phasing will be that determined in earlier experiments to give best heating in conjunction with the beams.

At least 15 minutes GDC conditioning will be used to maintain low density. The experiment will be executed <u>only after fresh boronization.</u> Lithium pellet conditioning is very desirable.

The plasma current, density and shaping time-evolution will be that used in shot **108918**. The elongation will initially be set at 1.9 and X-point triangularity at 0.6-0.7 by using the PF1A coils and then increased by ≈ 10%. The plasmas should be double-null diverted during the flat-top for the duration of the discharge flat-top.

H-modes will systematically be avoided by controlling the inner gap during the diverted phase as needed.

The experiments will be run mostly at 1 MA and 4.5 kG. This should enable keeping the q profile above unity for about 400-450 ms. A higher field would be of interest if available.

The target line-average density for the low density regime will be 2-2.5 $\times 10^{19}$m^{-3}

Two shots should be obtained for each configuration and MPTS, CHERS and soft X-ray camera/GEM data for each shot must be acquired. The number of shots needed to complete this XP is 26-28.

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

a) The XP requires operational NBI and RF systems and the capability of generating double-null diverted discharges with the plasma control system.

b) Fresh boronization required.

c) For neon injection experiments we will use the fast injector at Bay J midplane, regularly used for D_2 fueling. Fueling will be done instead using the Bay K top injector and the inner wall injector.

d) CHERS diagnostic of C / Z_{eff} profiles is highly desired for estimates of the q-profile using TRANSP magnetic diffusion calculations

e) Density fluctuation amplitudes and correlation lengths obtained with microwave reflectometry/interferometry are highly desirable. At low density the reflectometer may enable turbulence measurements deeper in the plasma.

f) High frequency digitization of Mirnov signals is required for TAE diagnostic.

g) RF operational to 3 MW is required

h) GEM is required and tangential SXR camera is desirable

i) MSE q_0 constraint is highly desirable. If possible, MSE measurement of core magnetic fluctuations is also desirable

j) Li pellet wall conditioning is highly desirable

k) The neutral particle analyzer in the 'Ion temperature' configuration is desirable

5. Planned analysis

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

6. Planned publication of results

Conferences and refereed journals.

PHYSICS OPERATIONS REQUEST

Title: **OP-XP-403**

Machine conditions (specify ranges as appropriate)

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

I_P (MA): **1-1.2** Flattop start/stop (s): **0.15/≥ 0.5**

Configuration: **Double Null Diverted**

Outer gap (m): **5-10 cm**, Inner gap (m): **1-5 cm**

Elongation κ: **1.9-2.1**, Triangularity δ: **0.6-0.8**

Z position (m): **0.00**

Gas Species: **D**, **Neon** Injector: **Inner Wall+Bay K top and Bay J respectively**

NBI - Species: **D_2**, Sources: **A/B/C**, Voltage (kV): 80/80/90 Duration (s): **<0.5**

ICRF – Power (MW): **1.5,3** Phasing: **TBD** Duration (s): 0.3

CHI: **Off**

Either: List previous shot numbers for setup: **108918**

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

Title: Effect of ρ* and rotation on non-H-mode NBI-heated plasmas in NSTX **OP-XP-403**

Diagnostic system	**Need**	**Desire**	**Requirements** (timing, view, etc.)
Magnetics	✓		
Fast visible camera		✓	
VIPS-1		✓	
VIPS-2		✓	
SPRED		✓	
Visible filterscopes		✓	
VB detector		✓	
Midplane bolometer		✓	
Diamagnetic flux		✓	
Density interferometer (1mm)		✓	
FIReTIP interf'r/polarimeter		✓	
Thomson scattering	✓		
CHERS	✓		
NPA		✓	
X-ray crystal spectrometer		✓	
X-ray PHA			
EBW radiometer			
Mirnov arrays	✓		
Locked-mode detectors	✓		
USXR arrays	✓		
2-D x-ray detector (GEM)	✓		
X-ray tangential camera		✓	
Reflectometer (4 ch.)		✓	
Neutron detectors			
Neutron fluctuations			
Fast ion loss probe		✓	
Reciprocating edge probe		✓	
Tile Langmuir probes			
Edge fluctuation imaging		✓	
H-alpha cameras (1-D)		✓	
Divertor camera (2-D)			
Divertor bolometer (4 ch.)			
IR cameras (2)			
Tangential SXR		✓	
GEM	✓		