Princeton Plasma Physics Laboratory

NSTX Experimental Proposal

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

OP-XP-303	**Revision:**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Authors: D. Stutman, R. Bell, C. Bourdelle, D. Darrow, M. Finkenthal, S. Kaye, B. LeBlanc, J. Menard, D. Pacella, B. Stratton, E. Synakowski, K. Tritz	Date
ATI – ET Group Leader: B. LeBlanc	Date
RLM - Run Coordinator: S. Kaye	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

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 ST confinement. During density scans in XP-223 it was consistently observed that the electron temperature increases and its profile broadens at low density ($\langle n_e \rangle \approx 2\ 10^{13}$ cm^{-3}). At the same time, the ion confinement did not appear to degrade, as shown by high ion temperatures and total stored energy and energy confinement time (Fig.1). Significant indications of magnetic shear reversal are seen in the USXR data.

We propose to first explore the behavior of the electron profiles in this low density/shear reversal regime, then try and optimize it, and finally to try and further increase the electron and global confinement through the recently predicted beta-prime mechanism. In particular, we will first assess the response of the electron temperature profiles to gradual increases in the beam heating power at low density. Further on, since we surmise that shear reversal is responsible for the improved confinement, we will try and maximize the electron confinement gain through optimization of the current ramp-rate. At the optimized current rate we will then apply increasing amounts of RF power, in order to attempt additional direct heating of the electrons. At this stage of the experiment we should therefore have achieved an improved electron confinement regime optimized at high field.

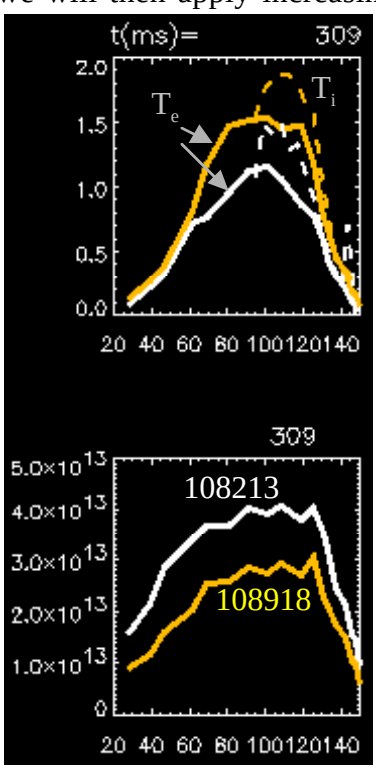

Fig.1 T_e, T_i and n_e profiles at 'standard' and low density (1 MA/4.5 kG/1.5 MW)

Using this regime as a basis, we will then finally explore the theoretically prediction that an increase in the gradient of beta above a certain threshold can trigger a further confinement increase in NSTX (C. Bourdelle *et al*, in preparation). The central beta (and implicitly beta-prime) will be increased by progressively lowering (at fixed q_{cyl}) the magnetic field in the above optimized regime. Thus, in addition to exploring new regimes relevant to the understanding of electron transport in NSTX, a result of our experiments may be an improved core confinement scenario relevant for both L-mode and H-mode conditions.

The following scans are planned.

P_{beam} scan at low n_e:

Neutral beam power will be gradually increased above the value of 1.5 MW used in XP 223, to see how the electron profiles respond to beam heating at low density. Magnetic field will also be increased from the value of 4.5 kG in XP223, to a value 5.5 kG. This because it has been observed that the confinement degrades less with power at higher fields. The higher field will also delay the

appearance of q=1 surface(s) and of the associated internal reconnections, which were observed to reduce the gain in electron temperature.

I_p ramp rate scan at fixed P_{beam} and low n_e:

In order to test the hypothesis that shear reversal is responsible for the enhanced confinement and eventually maximize the electron confinement gains, the current ramp rate will be varied in an attempt to find the conditions most conducive to high confinement/shear reversal.

RF power scan at fixed P_{beam} and low n_e:

In order to more directly test the response of the electron profiles to an additional electron heating source and also further increase beta, we will then apply increasing amounts to RF power to a medium power, beam heated discharge established during the beam power and current ramp-rate scans.

B_t decrease at fixed q_{cyl} and low n_e:

Finally, in order to attempt triggering the beta-prime turbulence stabilization mechanism, we will gradually lower the external field at fixed q_{cyl}, using as baseline the previously optimized beam and RF heated discharge. Since, as shown in XP223, the dominant electron transport is basically field independent, this will have the effect of increasing the central beta and therefore its gradient.

Neon injection will be used throughout the experiment to probe the ion transport, as has been done in XP223.

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 major challenge for the NSTX transport research is therefore to understand the reasons behind low electron confinement and ultimately, its improvement. In XP223, as well as in most other experiments, it is consistently observed that the electron profiles are very stiff in almost all experimental conditions. A significant change was observed however in low density regimes in XP223. Figure 2 illustrates the dependence of the central electron temperature as a function of central density, for all 1.5 MW beam heated discharges in XP223. A clear increase (with possibly a threshold character) is seen at low density. Possible interpretations of this effect are:

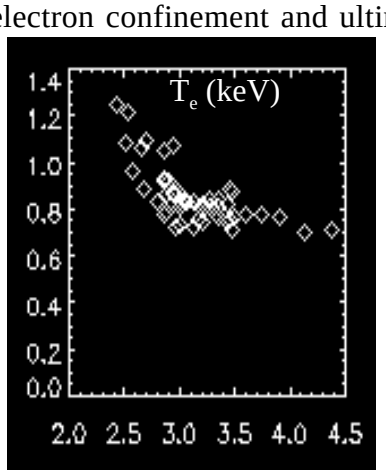

Fig.2 Central T_e as a function of central n_e (x 10^{13} cm^{-3}) in XP223 (200-300 ms average)

I) electron transport is intrinsically density (collisionality) dependent)

II) neutral beam heating of electrons improves at low density

III) Some magnetic shear reversal occurs at low density

and suppresses the electron turbulence. Reversed shear is suggested by USXR data, which shows off-axis sawteeth (implying the existence two q=1 surfaces) later in the discharge. TRANSP simulations using magnetic diffusion for the current profile also predict shear reversal in these discharges.

Of the above, shear reversal is well known to have an effect on confinement. A preliminary microstability assessment in these discharges (C. Bourdelle) also indicates that negative, or low central shear can have a strong effect on electron confinement in NSTX, through suppression of the ETG turbulence.

Collisionality has not been observed to have a significant effect on electron confinement in large aspect ratio tokamaks. Global confinement in L-mode increases weakly with density (up to a limit). On the contrary, increased trapping at low density should enhance electron transport through trapped electron modes (TEM).

Improved beam penetration and more central heating of electrons at low density may be a factor. In this view it is however puzzling that both the electron and ion temperature concurrently increase in these discharges, since ions should be less coupled to electrons at low density.

The definitive separation of the causes for improved electron confinement at low density may at present be difficult due to the absence of an accurate q-profile diagnostic and to the difficulties in the global power balance. However, it would still be worthwhile testing the effects of increased beam and RF power and current ramp rate in conditions of improved electron confinement. The beam and RF power scans will give a measure of the change in T_e profile stiffness at low density, while the I_p ramp rate scan may help confirm the shear reversal hypothesis. In any case, from a practical point of view it is estimated that an improved electron/global confinement regime may be achievable at low density, through empirical optimization of the heating power and current ramp-rate. This may be characterized by steeper electron and beta profiles than previously achieved in NSTX.

Recent GS2 calculations by C. Bourdelle predict that in addition to the well known turbulence suppression caused by shear reversal, in the high beta ST plasma an additional mechanism may become operative, the ‘beta-prime’ mechanism. This consists in the decrease of both long and short wavelength turbulence, when the beta gradient exceeds a certain threshold. The possibility therefore exists for a positive feedback mechanism in the ST confinement, since reduced transport would further steepen the beta gradient.

As such, we propose to exploit the steeper electron profiles we expect at low density/shear reversal, in an attempt to further increase confinement through the beta-prime effect. As mentioned, this would be done by first maximizing the achievable beta-prime in conditions of low density/shear reversal at high field, and then increasing beta-prime through a reduction in the magnetic field at fixed q_{cyl}

Besides shedding light on the effects of beta on electron confinement, if successful this experiment could pave the way towards higher confinement NSTX operating scenarios, in which an initial increase in confinement achieved by temporary shear-reversal then allows ‘tunneling’ to a self-sustained high confinement regime based on beta-prime stabilization.

As concerns new experimental techniques, we will use hard X-ray core imaging for an assessment of the *changes* in the q-profile. The FTU GEM detector (and the PPPL tangential camera if available) will be used to measure the shape of the central flux surfaces. This information will then used to constrain the EFIT reconstruction, using the code recently developed by Dr. Tritz at Wisconsin. The USXR arrays will also be used to localize rational surfaces of same q, as has been done in shear reversal studies on JET. Availability of MSE diagnostic and possibly Li pellet wall conditioning could also strongly benefit these experiments.

6. Experimental run plan

1. NBI setup: Sources A and C at 80 kV and source B at 100 kV. When injecting alone, each source starts at t ≈ 80 ms until shortly before beginning of current ramp-down. For the two-source combination, one starts at 80 ms and the other at 140 ms. 300 ms or longer flat top will be attempted.
2. RF setup: RF will be applied at around 200 ms, after T_e has significantly increased due to beam heating.
3. At least 15 minutes GDC conditioning will be used to maintain low density
4. The plasma current and shaping time-evolution will be that used in shot **108794**. The elongation will be fixed at 1.9 and X-point triangularity at 0.6-0.7 by using the PF1A coils. The plasmas should be double-null diverted during the flat-top for the duration of the discharge flat-top.
5. H-modes will systematically be avoided by controlling the inner gap during the diverted phase as needed. Gas puffing will also be used to prevent the H-mode.
6. The experiments will be run at 1 MA and 5.5 kG. As mentioned, this should enable keeping the q profile above unity
7. The target line-average density will be $2\times10^{19}m^{-3}$
8. The systematic scan in the table below will be used to vary the beam, RF power and current ramp rate. At least 2 shots should be obtained for each configuration and MPTS, CHERS and soft X-ray camera/GEM data for each shot must be acquired. A third shot with Ne injection will be added for several of the conditions. The number of shots needed to complete this XP is **27**. Assuming most shots are successful/useful this XP can be executed in *1 run day*.
9. The prioritization of the shots is as follows. We will first perform the beam power scan which will be followed by the current ramp rate scan and then the RF power scan at the optimal current ramp rate determined through the previous scans. The beta-prime scan will be performed in a second run day, if the first stages are successful. The optimal level of beam and RF power will be determined through the first day scans.

Beam power scan at fixed (5 MA/s) I_p ramp rate							
I_P (MA)	B_T (T)	Src	Power (MW)	n_e-bar ($10^{19}m^{-3}$)	Neon		
1	5.5	A	1.6	2.5	x	x	x
1	5.5	B	2.4	2.5	x	x	x
1	5.5	A+B	4	2.5	x	x	x

I_p ramp rate scan at fixed (2.4 MW) beam power							
I_P (MA)	B_T (T)	Src	Ramp (MA/s)	n_e-bar ($10^{19}m^{-3}$)	Neon		
1	5.5	2.4	4	2.5	x	x	x
1	5.5	2.4	6	2.5	x	x	x
1	5.5	2.4	7	2.5	x	x	x

RF power scan at optimized beam power and I_p ramp-rate							
I_P (MA)	B_T (T)	Src	RF Power	n_e-bar ($10^{19}m^{-3}$)	Neon		
1	5.5	2.4	1	2.5	x	x	x
1	5.5	2.4	2	2.5	x	x	x
1	5.5	2.4	4	2.5	x	x	x

Beta scan at fixed q_{cyl} in shear-reversal optimized regime								
I_P (MA)	B_T (T)	Src	Power (MW)	RF Power	n_e-bar ($10^{19}m^{-3}$)	Neon		
1	5.5	B(+A)	2.4 (4)	TBD	2.5	x	x	x
0.85	4.5	B(+A)	2.4 (4)	TBD	2.5	x	x	x
0.7	3.85	B(+A)	2.4 (4)	TBD	2.5	x	x	x

Total: 36 shots, or 1.5 run days.

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. No CHI will be used.

b) For the 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.

c) 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.

d) RF operational to 4 MW is required

e) GEM is required and tangential SXR camera is desirable

f) MSE and Li pellet wall conditioning are desirable

g) The neutral particle analyzer in the 'Ion temperature' configuration is required

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

7. Planned publication of results

Conferences and Physics of Plasmas

PHYSICS OPERATIONS REQUEST

Title: **OP-XP-303**

Machine conditions (specify ranges as appropriate)

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

I_P (MA): **1** 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**, Triangularity δ: **0.6-0.7**

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): 80/100/80 Duration (s): **<0.5**

ICRF – Power (MW): **1,2,4**, Phasing: **0-pi,0-pi**, 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

Title: Effect of ρ* and rotation on non-H-mode NBI-heated plasmas in NSTX **OP-XP-303**

Diagnostic system	**Need**	**Desire**	**Requirements** (timing, view, etc.)
Magnetics	✓		
Fast visible camera		✓	
VIPS-1		✓	
VIPS-2		✓	
SPRED		✓	
GRITS		✓	
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	✓		