Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: Spatial Localization of MHD-induced Energetic Ion Loss during H-mode Discharges in NSTX

OP-XP-504	**Revision: 0**	Effective Date: 02/12/05 *(Ref. OP-AD-97)* Expiration Date: 02/12/07 *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Author:	**S. S. Medley**	Date
ATI – ET Group Leader:	**R. Wilson**	Date
RLM - Run Coordinator:	**J. E. Menard**	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

Title: Spatial Localization of MHD-induced Energetic Ion Loss during H-mode Discharges in NSTX **No.: OP-XP-504**

1. Overview of planned experiment

The Neutral Particle Analyzer (NPA) on NSTX can be remotely scanned horizontally on a shot-to-shot basis. As shown in Fig. 1, the NPA sightline intersects the neutral beam injection paths and can be scanned from a tangency radius of R_{tan} = 125 cm (viewing co-going ions) to R_{tan} = - 75 cm (viewing counter-going ions). The experimental plan is to scan the NPA horizontally during a sequence of highly reproducible H-mode discharges to obtain the anisotropic beam ion distribution during the MHD-induced energetic ion loss phase of the discharge. Approximately 16 shots will be required for the horizontal scan.

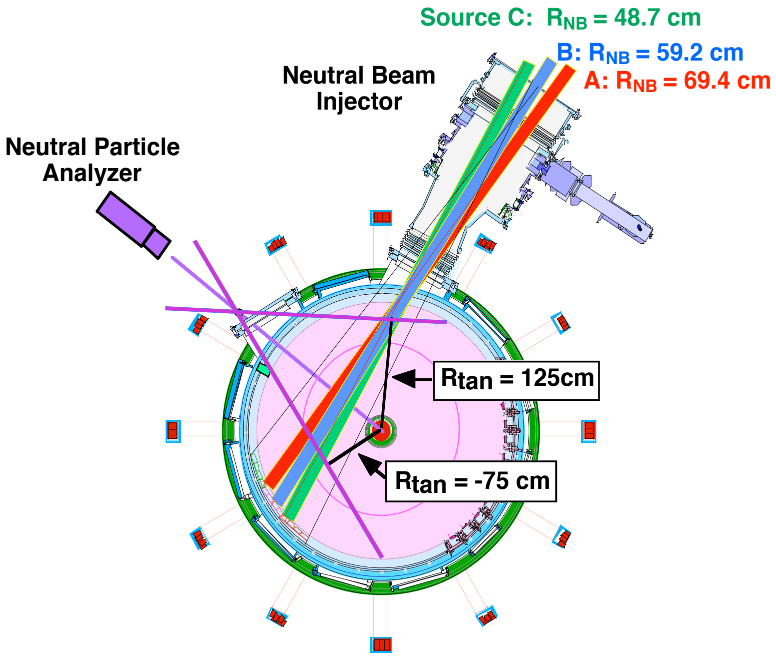

Figure 1. Layout of the neutral particle analyzer on NSTX illustrating the horizontal scanning range.

2. Theoretical/ empirical justification

2.1 NPA Horizontal Spatial Scan

MHD-induced loss of energetic ions during H-mode discharges has already been documented [1]. As shown Fig 2, this loss usually occurs for ion energies $E > E_b/2$ though such loss has also been observed to extend to lower energies. The loss was observed to scale with the NPA sightline tangency radius and the NB injection energy as shown in Fig. 3.

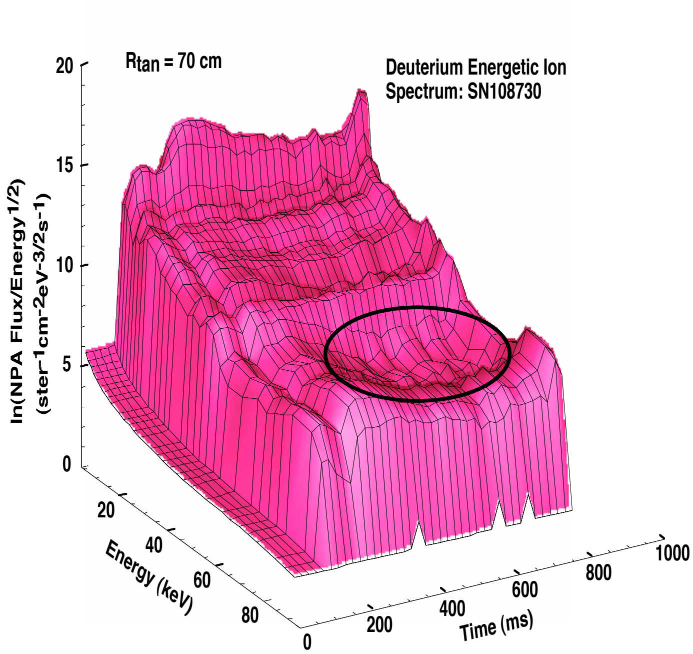

Figure 2. Following H-mode onset, the NPA spectra show significant loss of energetic ions typically only for $E>E_b/2$ (encircled region).

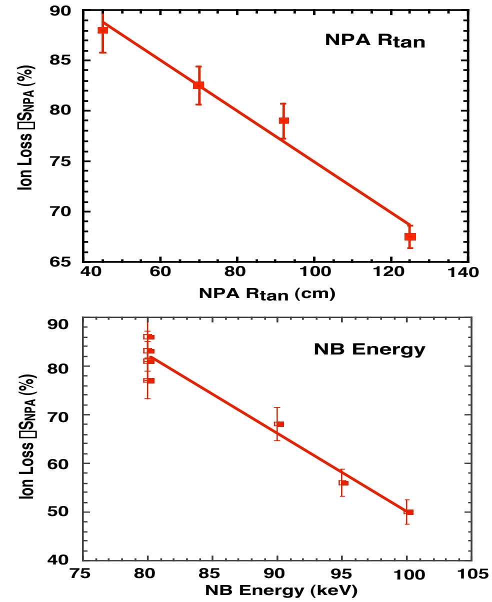

Figure 3. MHD-induced energetic ion loss was observed to decrease with increasing NPA tangency radius, R_{tan}, and NB injection energy.

The results of ORBIT modeling [1] offer an explanation for the observed reduction of ion loss with increasing NPA tangency radius, R_{tan}, beam injection energy, E_b. With regard to the beam energy scaling, higher energies drive more beam current resulting in increased peaking of the current profile in the core. As a result, the q-profile should be more monotonic causing the MHD modes that drive the loss to be shifted closer to the core thus reducing the resonant ion loss. With regard to diminished loss with increasing NPA tangency radius, the NPA spatial localization at the NB intersection diminishes with increasing R_{tan} and the observation region becomes out-shifted to include a greater fraction of trapped particles that are not affected by the MHD-induced ion loss according to the ORBIT modeling. Unfortunately, these plausible explanations of the MHD-induced energetic ion loss scaling could not be adequately verified with the extant database because the evolution of discharge parameters was not sufficiently controlled. A controlled scan to examine such scaling is the subject of this XP.

Preliminary evidence for spatial localization of the MHD-induced energetic ion loss is shown in Fig. 4. TRANSP simulation shows that the energetic ion distribution is highly anisotropic and the flux exhibits a peak around the injection tangency radius, as illustrated in Fig. 4. The higher energy region depletes with decreasing tangency radii which corresponds to decreasing pitch angle. This is simply because with tangential injection, few ions a born with small pitch angles and the passing ions slow down before pitch angle scattering is able to populate this region of the energetic ion distribution.

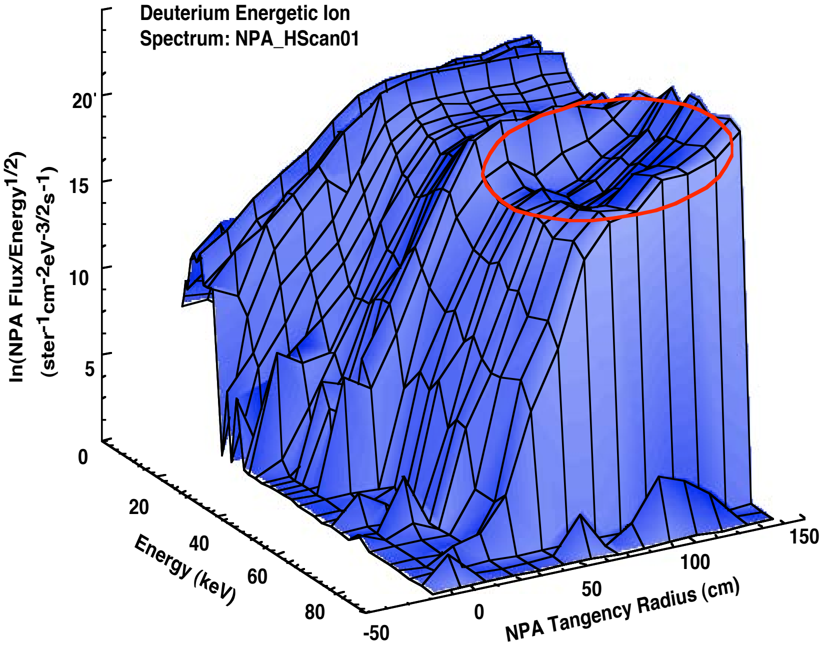

Figure 4. MHD-induced energetic ion loss is expected to be localized in a spatial region around 60 < R_{tan}(cm) < 115 (encircled region).

2.2 NB Energy Scan

The role of beam driven current in the energetic ion loss process will be studied by performing a beam energy scan. If circumstances permit, a 3-point neutral beam energy scan of Source B will be performed at an appropriate NPA tangency radius determined from the preceding horizontal spatial scan. Source A must remain at 90 keV in order to obtain MSE data. Desired beam energy points in the scan are 70, 80 90 and 100 keV, one of which (probably 90 keV) will already be available. Another data point will be obtained by turning Source B off after the discharge has entered H-mode. Should the discharge drop out of H-mode, an attempt will be made to sustain the H-mode by modulating Source B.

In the ion loss studies to date, coexistence of the H-mode and low-n, low-f MHD activity have been inextricably linked. Obtaining H-mode discharges without this MHD activity would be of interest to unravel the roles of the H-mode and MHD factors. Changing the H-mode onset time from early (e.g. 112157) to later (e.g. 112088) has no effect since the MHD activity similarly shifts in time. Also, MHD activity alone preceding H-mode onset does not cause ion loss (e.g. 109828 in [1]). When a discharge drops out of H-mode during the course of the shot, MHD activity terminates and so does the ion loss (e.g. 11923). The beam energy scan could conceivably shed light on this issue. The beam driven current will be modified by changing the injection voltage, causing the q-profile to evolve and hence the spatial location and perhaps the move structure of the MHD activity. Other ways of altering the MHD activity are being persued.

Reference:

[1] S. S. Medley *et al.*, 2004 Nucl. Fusion **44** 1158

3. Experimental run plan

3.1 NPA Horizontal Spatial Scan

The experimental plan is to scan the NPA horizontally during a sequence of highly reproducible H-mode discharges to obtain the anisotropic beam ion distribution during the MHD-induced energetic ion loss phase of the discharge.

The desired target plasma conditions are as follows. An H-mode discharge is required with machine parameters that do not tax the production of highly reproducible plasmas. The target plasma should be in a typical NSTX operating range:

e.g. 0.8 - 1.0 MA, $B_T = 4.5$ kG, $n_e(0) \sim 3 - 5\times10^{13}$ cm^{-3}.

The possibility of operating at lower B_T is difficult to assess. In 2004, NSTX discharges run at $B_T = 3.0 - 3.4$ kG and $I_p = 0.8 \pm 0.2$ MA that exhibited energetic ion loss were neither quiescent (IREs, locked modes etc.) not very reproducible. No discharges were run in the range $3.4 < B_T < 4.4$ so operation in this range would require discharge development time.

The scan will start at the maximum tangency radius of R_{tan} ~ 125 cm to near the minimum tangency radius of R_{tan} ~ - 75 cm in 25 cm steps and then reverse the scan direction to fill in the intermediate tangency radii for a total of 16 shots. The 3D energy and spatial spectra will be accumulated and plotted between shots to monitor data quality.

3.2 Neutral Beam Energy Scan

A 3-point neutral beam energy scan of Source B will be performed at an appropriate NPA tangency radius determined from the preceding horizontal spatial scan. Desired beam energy points in the scan are 70, 80 90 and 100 keV, one of which (probably 90 keV) will already be available. Another data point will be obtained by turning Source B off after the discharge has entered H-mode. Should the discharge drop out of H-mode, an attempt will be made to sustain the H-mode by modulating Source B. Time permitting, additional shots will be taken to attempt modifying the low-n MHD activity during the H-mode phase.

3.3 Run Plan Details

Specifics of the shot sequence and certain decision points are presented here.

- **Horizontal Scan**

Shot Number	Horizontal Position(cm)	
1	125	☐
2	100	☐
3	75	☐
4	50	☐
5	25	☐
6	0	☐
7	-25	☐
8	-50	☐
9	-75	☐
10	-12.5	☐
11	12.5	☐
12	37.5	☐
13	62.5	☐
14	87.5	☐
15	112.5	☐
16	125	☐

If the spectra for shots 7 – 9 show little variation, shot 10 can be omitted. The beam energy scan to follow will require ~ 5 shots for a total of 21 shots, excluding MHD suppression options.

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

Machine:	4.5 kG, 0.8 – 1.0 MA, $n_e(0) \sim 3 - 5\times10^{13}$ cm^{-3}, GDC between shots
Beams:	Sources A and B @ 90 keV deuterium initially
ICRF:	None
Diagnostics:	Magnetics and MSE for EFIT equilibria, full kinetic profiles of electrons, ions and impurities are essential.

5. Planned analysis

TRANSP simulation of the NPA beam energy distributions will be performed both to model the measured spectra and to determine the effect of energetic ion loss on other discharge parameters of interest, such as the spatial distribution of beam driven current and torque input for toroidal roatation. MPTS, CHERS, MSE, magnetics data and EFIT magnetic equilibria are essential for this analysis.

6. Planned publication of results

The goal is to publish the results of this XP in Nuclear Fusion within a year after the XP is performed. The results of this XP will be supplemented as deemed appropriate by measurements derived from XP-417 where the anisotropic NB spatial energy distribution and vertical beam footprint were measured in loss-free L-mode discharges

PHYSICS OPERATIONS REQUEST

Title: Spatial Localization of MHD-induced Energetic Ion Loss during H-mode Discharges in NSTX **No.: OP-XP-504**

Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **53 (4.5 kG)** Flattop start/stop (s): **0/1.0**

I_P (MA): **0.8** Flattop start/stop (s): **0.2/0.6**

Configuration: **DN**

Outer gap (m): **0.10** Inner gap (m): **0.01 – 0.05**

Elongation □: **2.0 – 2.1** Triangularity □: **0.4 – 0.5**

Z position (m): **0.00**

Gas Species: **D** Injector: **Inboard**

NBI - Species: **D** Sources: **A/B** Voltage (kV): **90** Duration (s): **0.5**

ICRF – Power (MW): **0** Phasing: **NA** Duration (s): **0**

CHI: **Off**

Previous shot number for setup: **112157**

DIAGNOSTIC CHECKLIST

Error! Reference source not found. Spatial Localization of MHD-induced Energetic Ion Loss during H-mode Discharges in NSTX **OP-XP-504**

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	✓		
Filtered 1D cameras		✓	
Filterscopes		✓	
FIReTIP	✓		Monitor “core” MHD activity
Gas puff imaging			
High-k scattering			
Infrared cameras		✓	
Interferometer – 1 mm			
Langmuir probes - PFC tiles			
Langmuir probes - RF antenna			
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 Rate (2 fission, 4 scint)	✓		
Neutron collimator			
Plasma TV		✓	
Reciprocating probe			
Reflectometer - FM/CW			
Reflectometer - fixed frequency homodyne			
Reflectometer - homodyne correlation			
Reflectometer - HHFW/SOL			
RF antenna camera			
RF antenna probe			
Solid State NPA	✓		
SPRED		✓	
Thomson scattering - 20 channel	✓		
Thomson scattering - 30 channel		✓	
Ultrasoft X-ray arrays	✓		Localize $n < 3$, $f < 50$ kHz activity
Ultrasoft X-ray arrays - 2 color	✓		
Visible bremsstrahlung det.		✓	
Visible spectrometers (VIPS)		✓	
X-ray crystal spectrometer - H			
X-ray crystal spectrometer - V			
X-ray PIXCS (GEM) camera			
X-ray pinhole camera			
X-ray TG spectrometer			