Princeton Plasma Physics Laboratory
NSTX Experimental Proposal

Title: **Effect of Pitch Angle on MHD-induced Energetic Ion Redistribution or Loss Measured using Neutral Particle Analyzer Vertical Scanning**

OP-XP-807	**Revision: 0**	Effective Date: *(Ref. OP-AD-97)* Expiration Date: *(2 yrs. unless otherwise stipulated)*

PROPOSAL APPROVALS

Responsible Author:	Date
ATI – ET Group Leader:	Date
RLM - Run Coordinator:	Date

Responsible Division: Experimental Research Operations

Chit Review Board (designated by Run Coordinator)

MINOR MODIFICATIONS (Approved by Experimental Research Operations)

NSTX EXPERIMENTAL PROPOSAL

TITLE: **Effect of Pitch Angle on MHD-induced Energetic Ion Loss Measured by Neutral Particle Analyzer Vertical Scanning**	No. **OP-XP-807**
AUTHORS: **S.S. Medley**	DATE: **Apr 7, 2008**

1. Overview of planned experiment

The Neutral Particle Analyzer (NPA) on NSTX can be remotely scanned horizontally on a shot-to-shot basis. At any horizontal tangency radius, the NPA can also be scanned vertically from the mid-plane downwards through an angular range of ~ 20 degrees. The vertical 'minor' radius of the scan is localized to the intersection of the NPA sightline with the neutral beam(s).

The experimental plan is to inject Sources A and B and C into a highly reproducible, long pulse H-mode plasma with strong MHD activity and scan the NPA in vertically to obtain radial energetic ion profile along the Z-axis localized at the footprint of the beams. Approximately 15 shots are required for a vertical scan.

2. Theoretical/ empirical justification

In 2007, a NPA vertical scan was performed in XP-707 at R_{tan} ~ 80 cm using Sources A, B, and C @ 90 keV and is documented in PPPL-4270. The pitch angle range that was sampled is shown by the shaded blue regions in Fig. 1: i.e. the energetic ions were strongly passing.

The goal of this proposal is to obtain comparable NPA vertically scanning measurements except at a pitch angle that is as small as possible consistent with the spectra exhibiting all E_b, $E_b/2$ and $E_b/3$ NB injection energy components for the purpose of experimentally determining whether MHD-induced redistribution of energetic ions is sensitive to particle pitch angle. The shaded green regions in Fig. 1 show that measurements at approximately half the previously used pitch angle (R_{tan} ~ 80 cm giving $v_{||}/v$ ~ 0.75 – 0.90) which nevertheless still provide a full energy spectrum can be obtained at R_{tan} ~ 40 cm giving $v_{||}/v$ ~ 0.45 – 0.50.

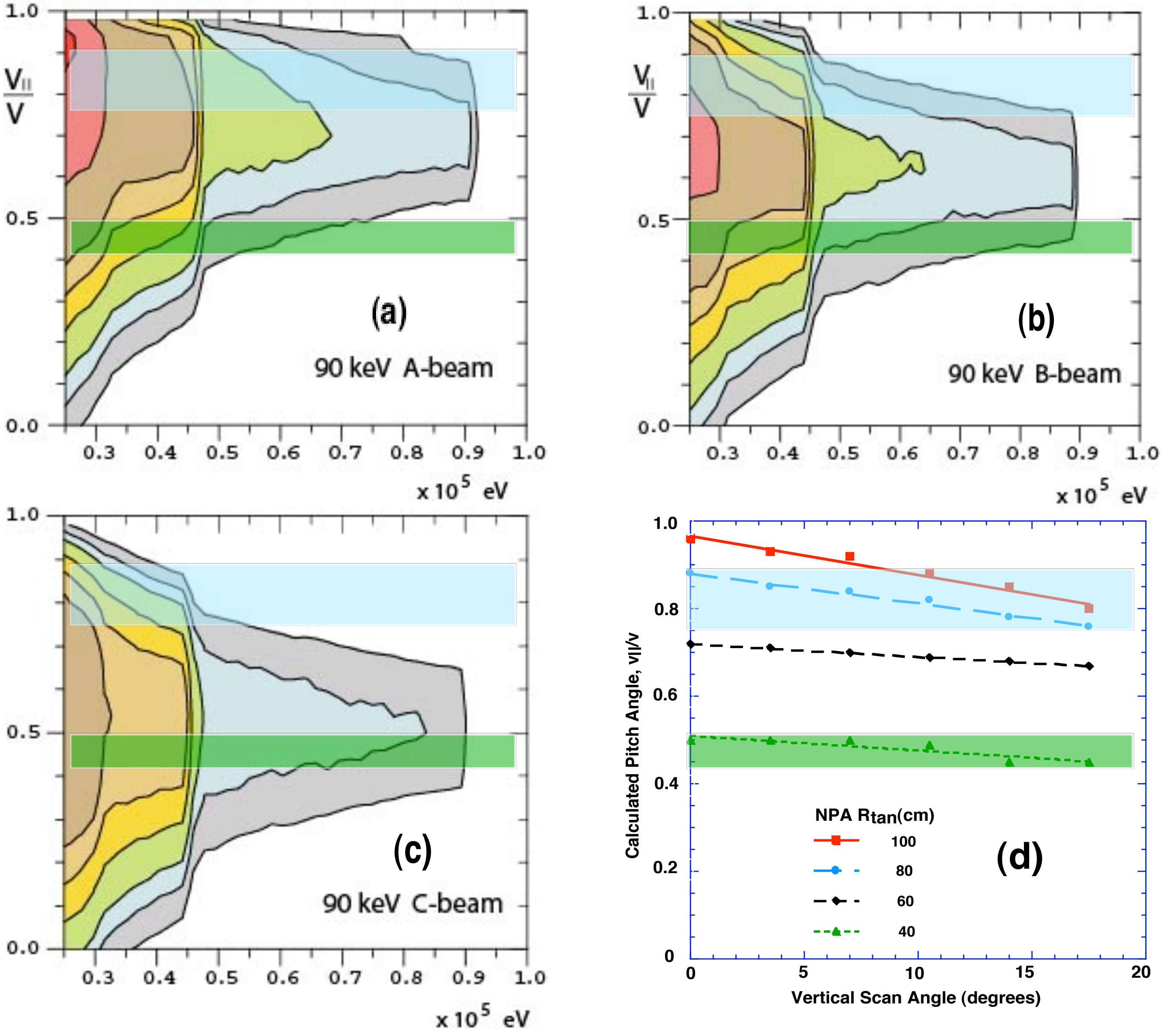


Figure 1. Comparison of pitch angle range for XP-707 NPA vertically scanning measurement at R_{tan} = 80 cm (blue) with range at R_{tan} = 40 cm (green) proposed herein. TRANSP volume-averaged pitch angle distributions for NSTX Sources A, B & C @ 90 keV are provided courtesy of E. Ruskov, UC Irvine.

3 Experimental run plan

The prime requirement for the NPA vertical scan is the existence of robust MHD activity with f < 200 kHz that includes bursting EPMs, 'continuous' TAEs and f < 10 kHz 'kink-type' MHD. In the presence of such activity, usually CAE/GAE-type activity with f > 200 kHz simultaneously exists for most of the discharge duration. Testing whether such activity bu itself can cause redistribution of energetic ions is the secondary goal of this experimental proposal.

The desired target plasma conditions are shown in Fig. 2. An H-mode discharge is required with machine parameters that do not tax the production of highly reproducible plasmas yet is representative of 'long-pulse' plasmas with large *AE and low-n, low-f MHD activity of interest to a broad range of experiments on NSTX. For reference discharge SN122631, the f > 200 kHz activity had a mode amplitude of $(\delta B/B)_{rms} \sim 2.5\text{x}10^{-3}$ mGauss and f < 200 kHz activity peaked at $(\delta B/B)_{rms} \sim 100\text{x}10^{-3}$ mGauss giving $\boldsymbol{\delta B_{Low}/\delta B_{High} \sim 40}$**.**

Some additional highly desirable features of the target discharge are: an electron density rise to a stable flattop beyond ~ 0.5 s and an early stable outer gap. Variations in these quantities could modify the beam deposition profile and thus appear as a 'faux' energetic-ion redistribution (PPPL-4235). Gas fuelling at Bay K should not be used as this could modulate the background neutral density and hence the charge-exchange flux in the region of the NPA sightline.

The target discharge SN122631 exhibiting robust MHD activity is well established and highly reproducible. Extension of the proposal to determine whether or not CAE activity at f > 400 kHz by itself can drive energetic ion redistribution requires a target discharge that has both a robust 'MHD active' phase and a 'MHD quiescent' period of ~ 200 ms (i.e. longer than the beam ion slowing down or pitch angle scattering times). The criterion for 'quiescent' is that for the MHD activity with f < 200 kHz MHD, the mode amplitude, $\delta B/B$, according to the Mirnov spectrogram is reduced by an order of magnitude or more. Since MHD-driven diffusion of energetic ions scales as $(\delta B/B)^2$, redistribution should be reduced by a factor of ~ 10^{-2}. An example of a possible candidate target discharge is SN124819 as illustrated by the waveforms in panels (a) and (b) of Fig. 3 wherein notching of Source B appears to trigger and extended "low-f quiescent" period. In panel (c), the Mirnov spectrogram shows that f < 100 kHz EPM/TAE activity is 'quiescent' in the period t ~ 0.55 – 0.75 s. CAE/GAE activity with 400 < f(kHz) < 2000 persists for the entire discharge. Thus the period t ~ 0.55 – 0.75 s provides a window to investigate the effect of f > 400 kHz activity during a quiescent period of f < 100 kHz activity. For SN124819, the mode amplitude for f > 400 kHz is $(\delta B/B)_{rms} \sim 2.5\text{x}10^{-3}$ mGauss. For the f < 100 kHz activity during the quiescent phase, the mode amplitude was $(\delta B/B)_{rms} \sim 10\text{x}10^{-3}$ mGauss: i.e. an order of magnitude less than 'normal' but still larger than the f > 400 mode amplitude. Even thought $(\delta B/B)_{rms}$ for f > 400 kHz is ~ 10x less than that for f < 100 kHz, high-f couples more effectively to energetic ions so therefore could induce significant loss. Panel (d) shows that the energetic ion flux measured by the NPA shows variable depletion during 'quiescent' phase, but the viewing tangency radius (R_{tan} = 110 cm) was not optimal for this experiment. In Panel (b), it can be seen that a 25% excess of the TRANSP-calculated neutron rate above the measured value exists during most of the discharge. Even during the 'low-f Quiescent' phase, however, $\boldsymbol{\delta B_{Low}/\delta B_{High} \sim 4}$ **: i.e. the discharge is not truly free of low-f MHD activity.**

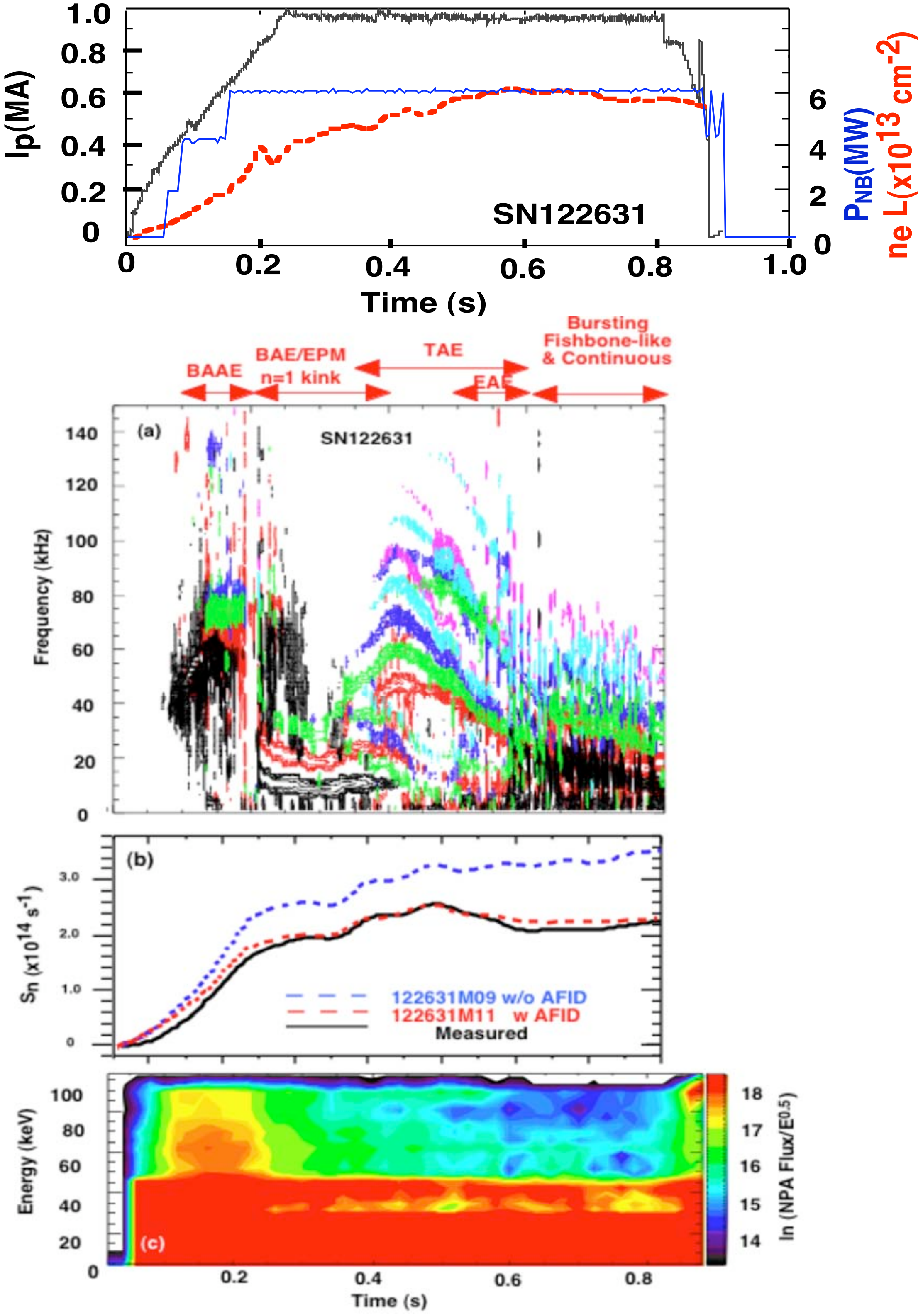


Figure 2. Target plasma for NPA vertical scan of energetic ion redistribution due to MHD activity with f < 200 kHz. H-mode onset occurs at t ~ 0.2 s.

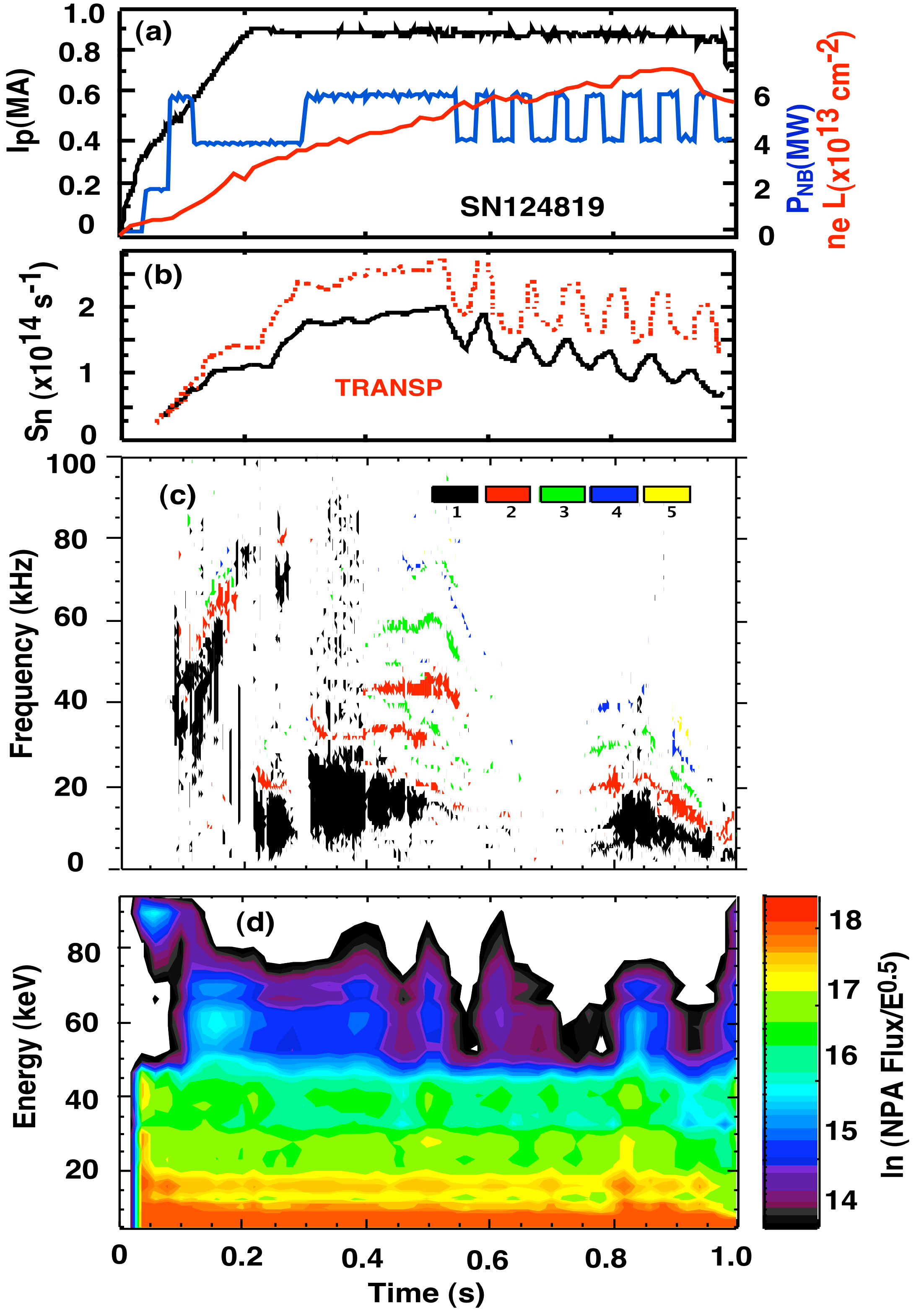


Figure 3. Target plasma for NPA vertical scan of energetic ion redistribution due to MHD activity with f > 200 kHz.

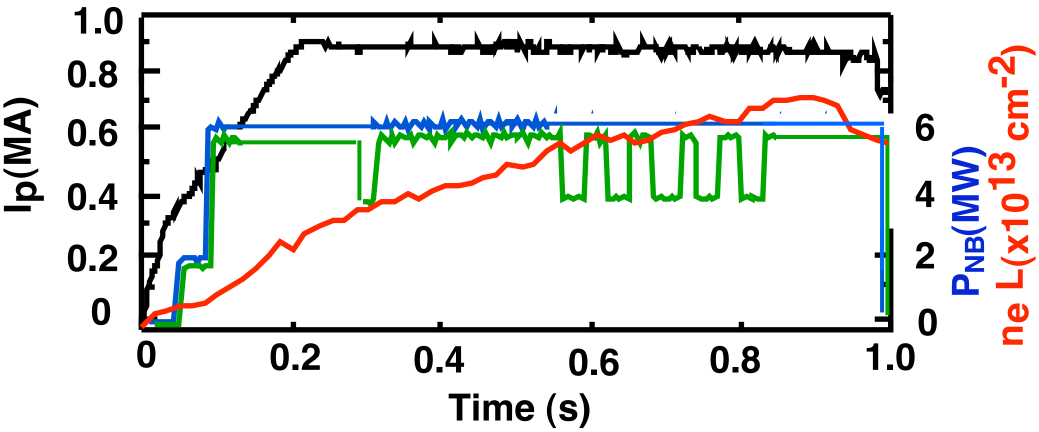
Run Plan Details

- Target Discharge Setup

1) Develop target discharge with robust MHD activity at f < 100 kHz using SN124819. Include Source B notches: δt = 10 ms at t ~ 200-300 ms for FIDA and a train of 3- 5 notches (depending on pulse length) with δt = 30 ms off/on starting at t ~ 550 ms to induce MHD quiescent period.

2) During target development, scan horizontal tangency radius for optimal NPA spectrum and modulation: R_{tan} = 50, 60, 70 cm.

3) Backup reference discharge is a fiducial with modified NBI timing.



- NPA Vertical Scan Sequence:

Shot Number	**Vertical Angle (degrees)**	
1	0	☐
2	3.0	☐
3	6.0	☐
4	9.0	☐
5	12.0	☐
6	15.0	☐
7	18.0	☐
8	16.5	☐
9	13.5	☐
10	10.5	☐
11	7.5	☐
12	4.5	☐
13	1.5	☐

Total shots: 10 – 16, including setup.

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

Machine:	4.5 kG, 0.9 MA, $n_e(0) \sim 6\text{x}10^{13}$ cm^{-3} and GDC between shots
Beams:	Sources A, B, C @ 90 keV deuterium
Diagnostics:	Magnetics for EFIT equilibria and full kinetic profiles of electrons, ions and impurities are essential as well as MSE, USXR, FIReTIP and sFLIP data.

5. Planned analysis

TRANSP simulation of the NPA beam energy distributions and profiles will be performed to compare with measurements. There should be no lithium contamination since the analysis depends critically on comparing TRANSP and measured neutron yields: i.e. the measured Z_{eff} profile must be known as accurately as possible. sFLIP measurements covering the duration of the discharge are essential for distinguishing between energetic ion redistribution and loss.

6. Planned publication of results

The goal is to publish the results of this XP, supplemented as deemed appropriate by additional measurements, in Nuclear Fusion within a year after the XP is performed provided that the treatment of NB halo neutrals in the TRANSP analysis code is appropriately upgraded.

PHYSICS OPERATIONS REQUEST

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Machine conditions (specify ranges as appropriate)

I_{TF} (kA): **-53** Flattop start/stop (s): **-0.02 / 1.35**

I_P (MA): **0.9** Flattop start/stop (s): **0.2 / 1.0**

Configuration: **LSN H-mode**

Outer gap (m): **0.09 – 0.11** Inner gap (m): **0.06 – 0.09**

Elongation κ: **2.3 – 2.4** Upper/lower triangularity δ: **0.4 – 0.5**

Z position (m):

Gas Species: **D** Injector(s): Outer midplane / Inner midplane

NBI Species: **D** Sources: **A/B/C** Voltage (kV): **90** Duration (s): **1.0**

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

CHI: Bank capacitance (mF):

LITER: Off

Previous shot numbers for setup: **124819 (or a recent fiducial, e.g. 12322)**

DIAGNOSTIC CHECKLIST

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Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
Bolometer – tangential array		√
Bolometer – divertor		
CHERS – toroidal	√	
CHERS – poloidal		√
Divertor fast camera		
Dust detector		
EBW radiometers		
Edge deposition monitors		
Edge neutral density diag.		√
Edge pressure gauges		√
Edge rotation diagnostic		
Fast ion D_alpha - FIDA		√
Fast lost ion probes - IFLIP	√	
Fast lost ion probes - SFLIP	√	
Filterscopes		√
FIReTIP	√	
Gas puff imaging		
Hα camera - 1D		
High-k scattering		√
Infrared cameras		√
Interferometer - 1 mm		
Langmuir probes – divertor		
Langmuir probes – BEaP		
Langmuir probes – RF ant.		
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Pickup coils	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		
Magnetics – RWM sensors		
Mirnov coils – high f.	√	
Mirnov coils – poloidal array	√	
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.		

Note special diagnostic requirements in Sec. 4

Diagnostic	**Need**	**Want**
MSE	√	
NPA – ExB scanning	√	
NPA – solid state	√	
Neutron measurements	√	
Plasma TV		√
Reciprocating probe		
Reflectometer – 65GHz		√
Reflectometer – correlation		√
Reflectometer – FM/CW		√
Reflectometer – fixed f		√
Reflectometer – SOL		√
RF edge probes		
Spectrometer – SPRED		√
Spectrometer – VIPS		√
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray arrays	√	
Ultrasoft X-rays – bicolor	√	
Ultrasoft X-rays – TG spectr.		√
Visible bremsstrahlung det.	√	
X-ray crystal spectrom. - H		
X-ray crystal spectrom. - V		
X-ray fast pinhole camera		√
X-ray spectrometer - XEUS		