Princeton Plasma Physics Laboratory

NSTX Machine Proposal

Title: **FIDA/ssNPA/sFLIP checkout**		
OP-XMP-	Revision**: 0**	Effective Date: Expiration Date: *(2 yrs. unless otherwise stipulated)*

Proposal Approvals

Responsible author: **D. Liu, W. W. Heidbrink, D. S. Darrow et al.**	Date
ATI (NSTX Physics Ops):	Date
RLM (NSTX Expt. Research Ops):	Date

Responsible Division: **Experimental Research Operations**

Procedure Requirements

designated by RLM

	NSTX Work Permit		T-MOD (OP-AD-03)
	Independent Review		ES&H Review

RESTRICTIONS AND MINOR MODIFICATIONS

Approved by RLM

REVIEWERS (designated by RLM)		
Organization/Position	Name	Signature
ATI	D. Mueller	
Test Director		
Independent Reviewer		
NB system		
RF systems		
FCPC systems		
Diagnostics		

TRAINING (designated by RLM)

Training required: No ■ Yes ☐ Instructor ______________________

Personnel (group, job title or individual name)	Read Only	Instruction	Hands-On

RLM ________________________________

1. Overview:

The FIDA and ssNPA systems, which include tangential-FIDA, vertical-FIDA, radial-ssNPA and tangential-ssNPA, are critical diagnostics to characterize the confinement of fast ions from the new 2nd NBI on NSTX-U. The main purpose of this XMP is to check and optimize the performance of these fast ion diagnostics, and assure they are ready to support the "Beam ion confinement of 2nd NBI line" experiment and whole group's research. To be more specific, the XMP has four major goals:

(i) Check the accuracy of two background subtraction approaches (beam modulation vs. passive views) for the FIDA systems

(ii) Compare the phase space response of vertical-FIDA and tangential-FIDA, radial-ssNPA and tangential-ssNPA. In principle, tangential-FIDA and tangential-ssNPA are more sensitive to passing particles, while vertical-FIDA and radial-ssNPA are more sensitive to trapped particles.

(iii) Optimize the angle of the filter of f-FIDA systems

(iv) Test s-FLIP diagnostic

and two secondary goals:

(i) Assess the FIDA spectral and intensity response for different neutral beam sources.

(ii) Obtain one quiescent plasma (where fast ions are expected to behave classically and fast ion distriubton is well modelled) for TRANSP/ FIDAsim simulations.

The main approach is to inject neutral beams with many different modulation patterns and source mix in quiescent L mode plasmas, and check the FIDA/ssNPA background/passive signals and diagnostic response in phase space. The background signal check can be done with neutral beam modulations. To verify the diagnostic response in phase space, it will require varying the fast-ion distribution, which in experiment can be achieved by injecting different neutral beam sources.

2. Justification:

Both FIDA and ssNPA diagnostics rely on the charge-exchange reactions between beam ions and beam neutrals. They are indirect measurements of fast ion distribution in a small portion of velocity space. Tests of these systems in a controlled scenario are required to gain confidence in the data interpretation, primarily for three reasons. First, tangential-FIDA and ssNPA systems are new/upgraded diagnostics. Also, experimentally the capability of inferring the background signal from the passive view/beam modulation is critical for the FIDA measurements. More importantly, the relation between the fast ion distribution function and the raw data is complicated; hence the diagnostic response in phase space must be assessed directly.

3. Plan:

Many different and unusual neutral beam injection patterns will be used in this XMP. The run plan is divided into two parts based on the neutral beam energy. Part A requires NB source 1A (R_{tan}=70cm) operated at 90kV and all the other sources at 65kV. Part B needs NB source 1A (R_{tan}=70cm), 1C (R_{tan}=50cm), and 2A (R_{tan}=130cm) with E_{inj}=90kV and all the other sources at 65kV. It is envisioned that this XMP will be ran in two half-days, the first half day focusing on Part A and the other half day for Part B. All the discharges for Part A and Part B will be similar to the "template" discharge as shown in Figure 1. The plasma conditions and neutral beam timing are given below.

Baseline conditions: NSTX-like plasma, B_t~0.5T, I_p~1MA, density 3-4x10^{13} cm^{-3}, deuterium gas, L mode, reference discharge NSTX 128742 (exact conditions are not crucial). Optimize the settings in the ramp-up to avoid early low-frequency MHD. Neutral beam 1A at 90kV will be used to pre-heat the plasma and slow down the evolution of the q profile. The target q_{min} is 2-2.5 around 0.2s. The current flat-top is expected to be around 0.5s, and it is assumed the flat-top starts at 0.2s and ends at 0.7s in this XMP.

Neutral beam timing: employ source 1A@90kV during current ramp-up (60-200ms) and near the end (650-700ms) of flat-top to get MSE and CHERS measurements, see Figure 1. There are various beam modulation patterns during the current flat-top, which is named as "NB modulation phase" in Figure 1. A detailed description of neutral beam source mix and modulation patterns during the "NB modulation phase" is given in Tables 1 and 2.

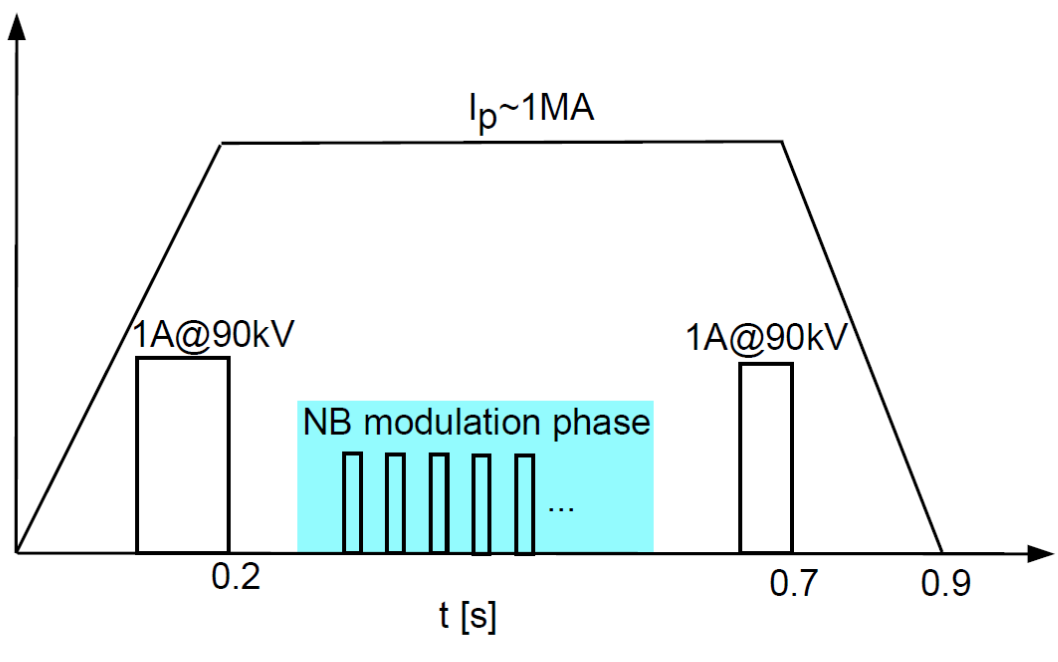


Figure 1: Template discharge. NB source 1A@90kV is employed in the ramp-up phase and the end of flat-top to get MSE and CHERS measurements. During the "NB modulation phase" (blue shaded region), there are various neutral beam mix and modulation patterns.

Part A [10+2 optional shots]: NB source 1A at 90kV; all the other sources at 65kV

(1) Development of quiescent L mode plasma with n_e=3-4x10^{13} cm^{-3} at t=200 ms [~5 shots]

- Start with NBI modulation pattern I in Table 1
- It is essential to make the plasma go into a quiescent L mode scenario in this XMP. Two techniques can be used: (a) adjust inner gap to achieve a center-stack limited configuration, (b) lower beam energy to 65kV except the neutral beam source 1A. Should the plasma go into H mode, consider the following options: (a) bias the plasma upward, (b) change elongation, (c) delay NB injection or change NB period, (d) use high-field side fueling, and/or (e) adjust plasma density. The development of quiescent L mode plasma will benefit multiple XMPs and XPs.
- Once the density n_e is between 3-4x10^{13} cm^{-3} at t=0.2s, keeps the gas fueling the same for all the discharges in this XMP.
- Optimize the settings in the ramp-up to avoid/minimize early low frequency (f<50 kHz typically) MHD, e.g. modifying the current (or q-profile) evolution by adjusting beam timing, plasma current, and/or plasma density
- It is expected that the target quiescent L mode plasma will be achieved within four shots. After that, try one more shot with NBI modulation pattern II and then move to step (2)

Note: the quiescent L mode discharge(s) developed in this step will also be used to check background/passive signals for t-FIDA, v-FIDA, and r-ssNPA systems.

(2) Characterization of FIDA/ssNPA background/passive signals and diagnostic response in phase space [5+2 optional shots]

- one shot with modulation pattern III in Table 1 to check t-ssNPA background signals
- one shot with modulation pattern IV in Table 1
  one shot with modulation pattern V in Table 1
  to check t-FIDA and v-FIDA diagnostic response in phase space.
- one shot with NBI modulation pattern VI for TRANSP/FIDAsim verification
- [optional]If time permits, one shot with NBI modulation pattern VII in table 1
  one shot with NBI modulation pattern VIII in Table 1
  to check the t-FIDA and v-FIDA response to different neutral beam sources.
- one shot with NBI modulation pattern IX and plasma current to 0.7MA for sFLIP checkout.

Part B [10+2 optional shots]: NB source 1A, 1C, and 2A at 90kV; all the other sources at 65kV

(3) Scan of the filter angle of two f-FIDA systems [~7 repeat shots]

The scan of the filter angle of f-FIDA systems may be completed in piggyback if there are many (>7) repeat shots (or shots with >200ms repeat phase) with NBI in other XMPs, for example, in "Initial H-mode access on NSTX-U" XMP. If that is the case, move to step (4). Otherwise, use the following steps to perform the scan of the filter angle in this XMP.

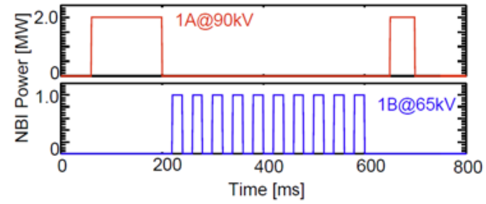
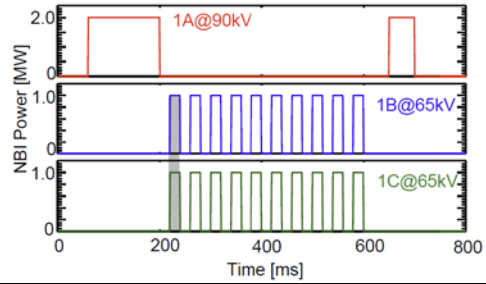
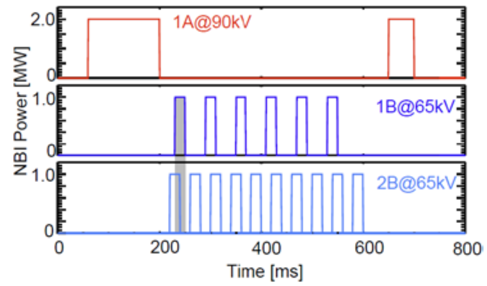
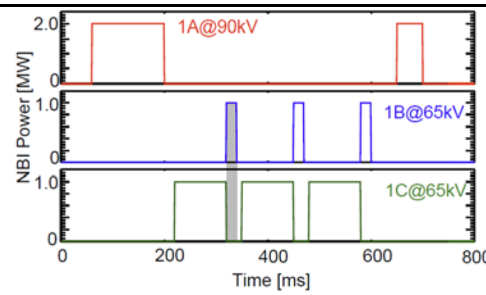
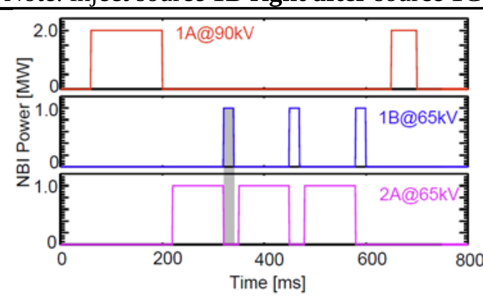
- Use the same target plasma developed in Part A (1). The reference discharge will be determined after the run of part A.
- Apply the beam modulation pattern X in Table 2.
- Values of the filter angle: 0,2,4,6,-2,-4,-6 degrees

Note: The filter angle determines which portion of fast-ion spectrum will be collected by PMT.

(4) Characterization of FIDA/ssNPA diagnostic response in phase space [2+2 optional shots]

- One shot with beam modulation pattern XI in Table 2
- One shot with beam modulation pattern XII in Table 2
  to check t-FIDA, v-FIDA, t-ssNPA, r-ssNPA diagnostic response in phase space.
- [optional] One shot with beam modulation pattern XIII and one shot with beam modulation pattern XIV in Table 2 to check ssNPA energy response and phase response.
- One shot with NBI modulation pattern XV and plasma current 0.7MA for sFLIP checkout.

Table 1: neutral beam modulation patterns and source mix for Part A (10 shots + 2 optional shots)

Pattern #	Priority	NB Source	E_{inj} [keV]	Start Time [ms]	# of pulses	On time [ms]	Off time [ms]	NBI modulation pattern and notes
I [maximum 4 shots]	1	1B	65	220	10	20	20	
II [1 shot]	1	1B	65	220	10	20	20	
		1C	65	220	10	20	20	
III [1 shot]	1	*1B (?)*	*65 (?)*	***230 (?)***	*6 (?)*	*20 (?)*	*40 (?)*	
		2B	65	220	10	20	20	Notes: (1)If there are strong MHD in #II, then source 1B is not used (2)If source 1B is used, inject source 1B **10ms later** than source 2B
IV [1 shot]	1	1B	65	**320**	3	20	110	
		1C	65	220	3	100	30	Note: inject source 1B **right after** source 1C
V [1 shot]	1	1B	65	**320**	3	20	110	
		2A	65	220	3	100	30	Note: inject source 1B **right after** source 2A

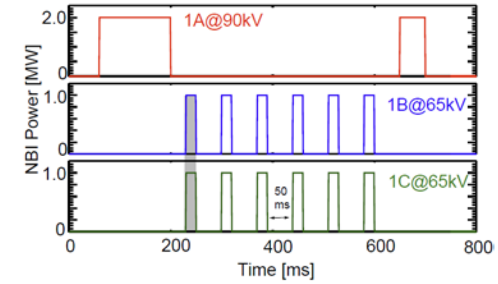
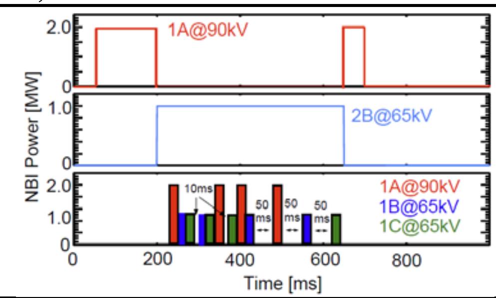
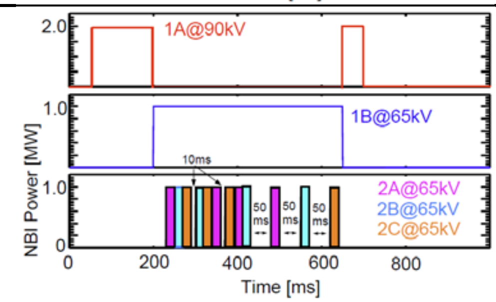
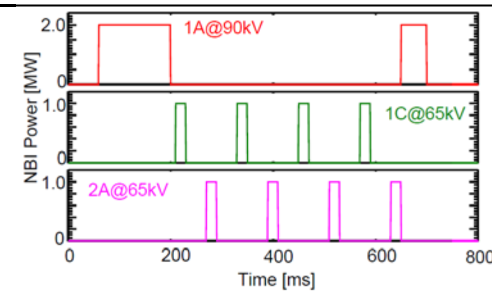
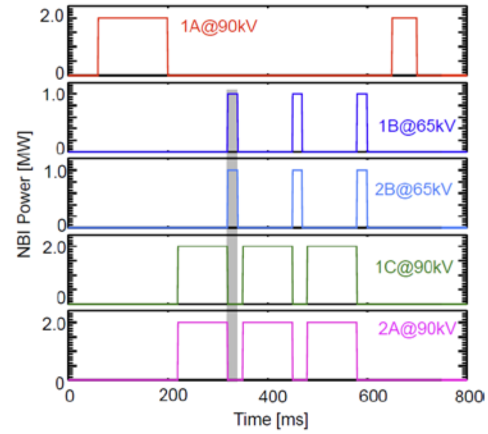
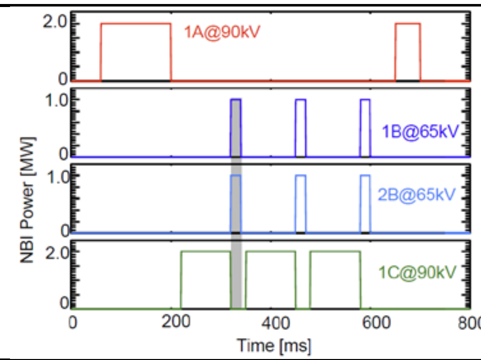
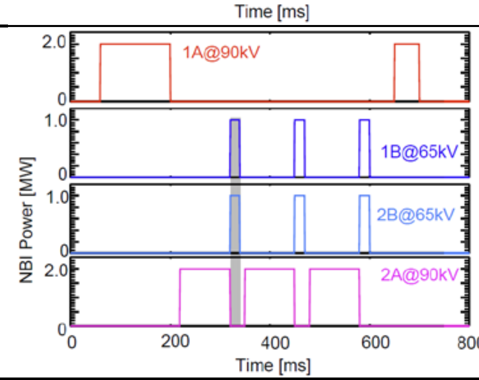
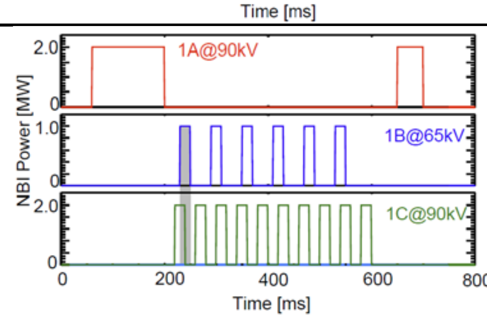
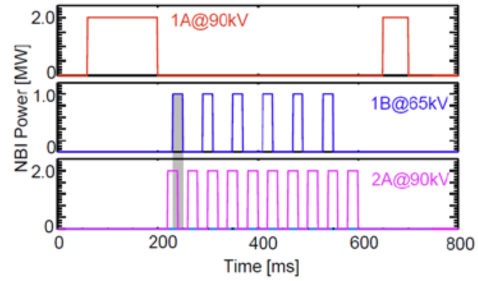
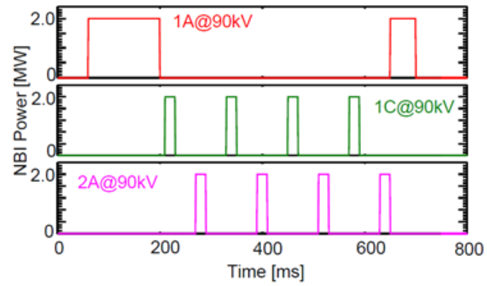
VI [1 shot]	1	1B	65	**230**	6	20	50	
		1C (?)	*65 (?)*	***230 (?)***	*6 (?)*	*20 (?)*	*50 (?)*	Notes: (1)If there are strong MHD in pattern #II, then source 1C is not used
VII [1 shot] Optional	2	2B	2B	**200**	1	450		
		1A	**90**	220	4	20		
		1B	65	**240**	4	20		
		1C	65	**260**	4	20		
VIII [1 shot] Optional	2	1B	65	**200**	1	450		
		2A	65	220	4	20		
		2B	65	**240**	4	20		
		2C	65	**260**	4	20		
IX [1 shot]	1	1C	65	**210**	4	20	100	
		2A	65	**270**	4	20	100	Note: set $\mathbf{I_p}$**=0.7MA** for sFLIP checkout

Table 2: neutral beam modulation patterns and source mix for Part B (7? + 3 shots +2 optional shots)

Pattern #	Priority	NB Source	E_{inj} [keV]	Start Time [ms]	# of pulses	On time [ms]	Off time [ms]	NBI modulation pattern and notes
X [repeat shots, Maximum 7 shots]	1	1B	65	**320**	3	20	110	
		2B	65	**320**	3	20	110	
		1C	90	220	3	100	30	
		2A	90	220	3	100	30	
XI [1 shot]	1	1B	65	**320**	3	20	110	
		2B	65	**320**	3	20	110	
		1C	90	220	3	100	30	
XII [1 shot]	1	1B	65	**320**	3	20	110	
		2B	65	**320**	3	20	110	
		2A	90	220	3	100	30	
XIII [1 shot] Optional	2	1B	65	**230**	6	20	40	
		1C	90	220	10	20	20	Note: inject source 1B **10ms later** than source 1C

<table>
<tr><td rowspan="2">XIV
[1 shot]

Optional</td><td rowspan="2">2</td><td>1B</td><td>65</td><td>230</td><td>6</td><td>20</td><td>40</td><td rowspan="2">

Note: inject source 1B 10ms later than source 1C</td></tr>
<tr><td>2A</td><td>90</td><td>220</td><td>10</td><td>20</td><td>20</td></tr>
<tr><td rowspan="2">XV
[1 shot]</td><td rowspan="2">1</td><td>1C</td><td>90</td><td>210</td><td>4</td><td>20</td><td>100</td><td rowspan="2">

Note: set I_p=0.7MA for sFLIP checkout</td></tr>
<tr><td>2A</td><td>90</td><td>270</td><td>4</td><td>20</td><td>100</td></tr>
</table>

In case not all neutral beam sources are available, this XMP requires at least three NB sources 1A, 1C (or 1B), and 2A (or 2B) with injection energy of 65kV and 90kV. The run plan for Part A and Part B will be changed accordingly.

Backup plan part A [8+3 development shots]: source 1A@90kV; all the other sources@65kV

(1) Development of quiescent L mode plasma with n_e=3-4x10^{13} cm^{-3} at t=200 ms [~5 shots]

- Start with NBI modulation pattern I in Table 3
- It is essential to make the plasma go into a quiescent L mode scenario in this XMP. Two techniques can be used: (a) adjust inner gap to achieve a center-stack limited configuration, (b) lower beam energy to 65kV except the neutral beam source 1A. Should the plasma go into H mode, consider the following options: (a) bias the plasma upward, (b) change elongation, (c) delay NB injection or change NB period, (d) use high-field side fueling, and/or (e) adjust plasma density. The development of quiescent L mode plasma will benefit multiple XMPs and XPs.
- Once the density n_e is between 3-4x10^{13} cm^{-3} at t=0.2s, keeps the gas fueling the same for all the discharges in this XMP.
- Optimize the settings in the ramp-up to avoid/minimize early low frequency (f<50 kHz typically) MHD, e.g. modifying the current (or q-profile) evolution by adjusting beam timing, plasma current, and/or plasma density
- It is expected that the target quiescent L mode plasma will be achieved within four shots. After that, repeat one more shot to check FIDA and r-ssNPA background/passive signals and then move to step (2)

(2) Characterization of FIDA/ssNPA background/passive signals and diagnostic response in phase space [6 shots]

- one shot with modulation pattern II in Table 3
  one shot with modulation pattern III in Table 3 to check ssNPA background signals
- one shot with modulation pattern IV in Table 3
  one shot with modulation pattern V in Table 3
  to check t-FIDA and v-FIDA diagnostic response in phase space.
- one shot with NBI modulation pattern VI in Table 3 for TRANSP/FIDAsim verification
- one shot with NBI modulation pattern VII in table 3 and plasma current to 0.7MA for sFLIP checkout.

Backup plan part B [8+3 development shots]: source 1A, 1C (or 1B) and 2A(or 2B)@90kV

(3) Scan of the filter angle of two f-FIDA systems [~7 repeat shots]

The scan of the filter angle of f-FIDA systems may be completed in piggyback if there are many (>7) repeat shots (or shots with >200ms repeat phase) with NBI in other XMPs, for example, in “Initial H-mode access on NSTX-U” XMP. If that is the case, move to step (4). Otherwise, use the following steps to perform the scan of the filter angle in this XMP.

- Use the same target plasma developed in backup plan Part A (1). The reference discharge will be determined after the run of part A.
- Apply the beam modulation pattern VIII in Table 4.
- Values of the filter angle: 0,2,4,6,-2,-4,-6 degrees

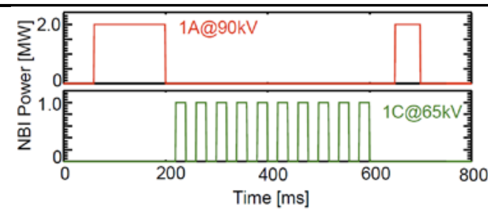
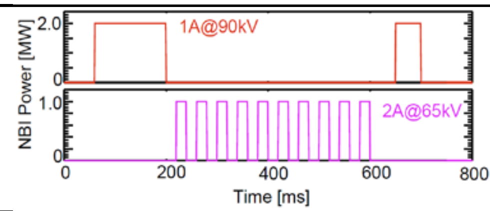
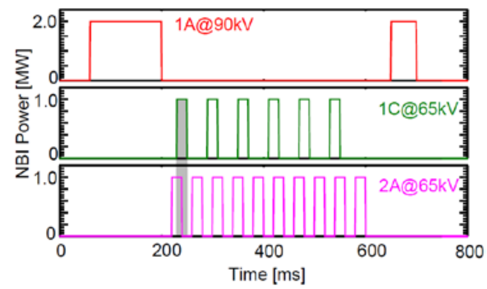
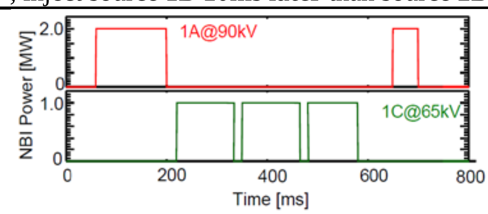
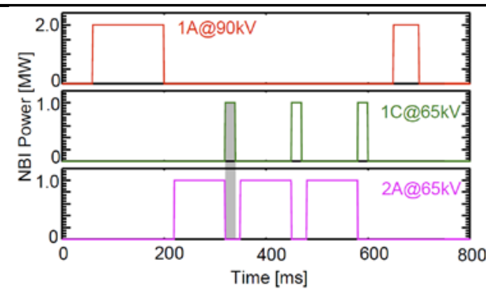
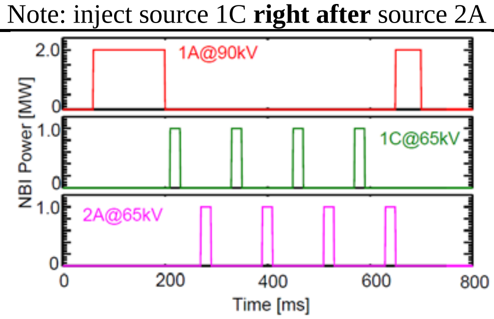
Note: The filter angle determines which portion of fast-ion spectrum will be collected by PMT.

(4) Characterization of FIDA/ssNPA diagnostic response in phase space [2+2 optional shots]

- One shot with beam modulation pattern IX in Table 4
- One shot with beam modulation pattern X in Table 4
  to check t-FIDA, v-FIDA, t-ssNPA, r-ssNPA diagnostic response in phase space.
- one shot with NBI modulation pattern XI in Table 4 for TRANSP/FIDAsim verification

(5) One shot with NBI modulation pattern XII and plasma current 0.7MA for sFLIP checkout.

Table 3: neutral beam modulation patterns and source mix for backup plan part A (~10 shots + 2 optional shots)

Pattern #	Priority	NB Source	E_{inj} [keV]	Start Time [ms]	# of pulses	On time [ms]	Off time [ms]	NBI modulation pattern and notes
I [maximum 5 shots]	1	1C	65	220	10	20	20	
II [1 shot]	1	2A	65	220	10	20	20	
III [1 shot]	1	1C	65	230	6	20	40	 , inject source 1B **10ms later** than source 2B
	1	2A	65	220	10	20	20	
IV [1 shot+ 1 optional]	1	1C	65	220	3	120	10	
V [1 shot+ 1 optional]	1	1C	65	**320**	3	20	110	 Note: inject source 1C **right after** source 2A
		2A	65	220	3	100	30	
VI [1 shot]	1	1C	65	**210**	4	20	100	
		2A	65	**270**	4	20	100	

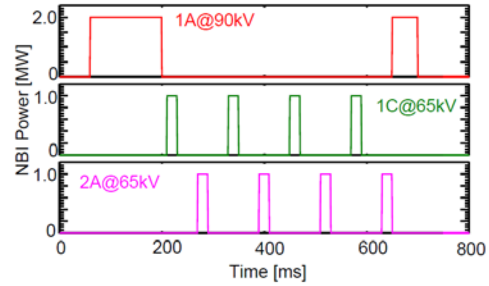
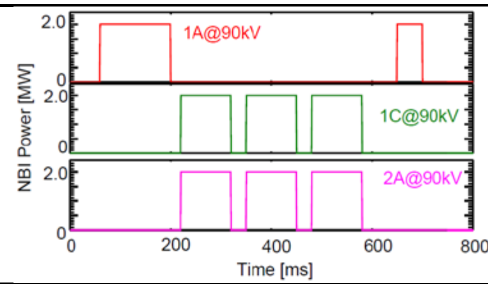
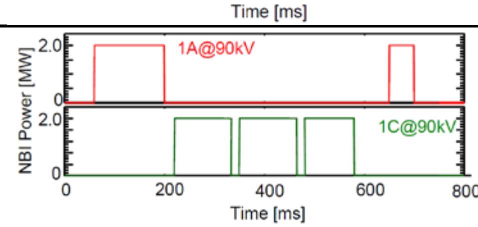
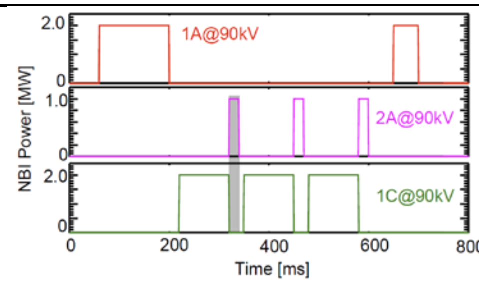
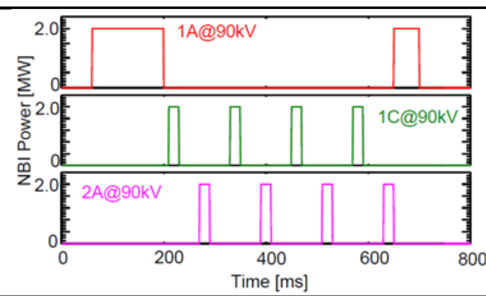
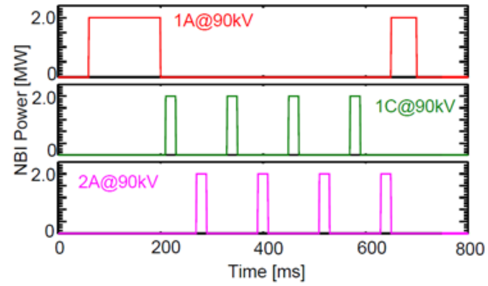
VII [1 shot]	1	1C	65	**210**	4	20	100	 Note: set $\mathbf{I_p}$=**0.7MA** for sFLIP checkout
		2A	65	**270**	4	20	100	

Table 4: neutral beam modulation patterns and source mix for backup plan part B (7? + 4 shots +2 optional shots)

Pattern #	Priority	NB Source	E_{inj} [keV]	Start Time [ms]	# of pulses	On time [ms]	Off time [ms]	NBI modulation pattern and notes
VIII [repeat shots, Maximum 7 shots]	1	1C	90	220	3	100	30	
		2A	90	220	3	100	30	
IX [1 shot+ 1 optional]	1	1C	90	220	3	110	20	
X [1 shot+ 1 optional]	1	2A	90	**320**	3	20	110	
		1C	90	220	3	100	30	
XI [1 shot]	1	1C	90	**210**	4	20	100	
		2A	90	**270**	4	20	100	

<table>
<tr><td rowspan="2">XII
[1 shot]</td><td rowspan="2">1</td><td>1C</td><td>90</td><td>210</td><td>4</td><td>20</td><td>100</td><td rowspan="2">

Note: set I_p=0.7MA for sFLIP checkout</td></tr>
<tr><td>2A</td><td>90</td><td>270</td><td>4</td><td>20</td><td>100</td></tr>
</table>

4. Required machine, beam, ICRF and diagnostic capabilities:

The XMP requires reproducible L mode plasmas with flat-top >0.5s at B_t=0.5T, I_p=1MA. Need 1A/1C/2A operational at 90kV, 1B/1C/2A/2B/2C operational at 65kV. In case not all neutral beams are available, the minimum requirement is three beams: source 1A@90kV, and sources 1C (or 1B) and 2A (or 2B) with injection energy of both 65kV and 90kV. Require Mirnov coils, plasma profile diagnostics (MPTS, CHERS, MSE) and fast ion diagnostics (FIDA, ssNPA, sFLIP, neutron). The machine needs to be relatively clean to avoid impurity contamination on FIDA spectra. Prefer running this XMP at least a week later than the CHERS checkout XMP, at least a week earlier than the "Beam ion confinement from 2nd NBI line" XP1522 so that initial analysis can be done to help optimize the FIDA and ssNPA diagnostics. Neither RF nor CHI is needed.

5. Sign off at run time:

5.1 Permission to Proceed: ______________________________

Physics Operations Head

5.2 Documentation of results:

Documentation of the results completed, attached to proposal and sent to Ops. Center with copies to Cognizant Physicist and Head of Physics Operations.

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Cognizant Physicist/Test Director