Real-time control of the N-II emission front by nitrogen seeding in TCV

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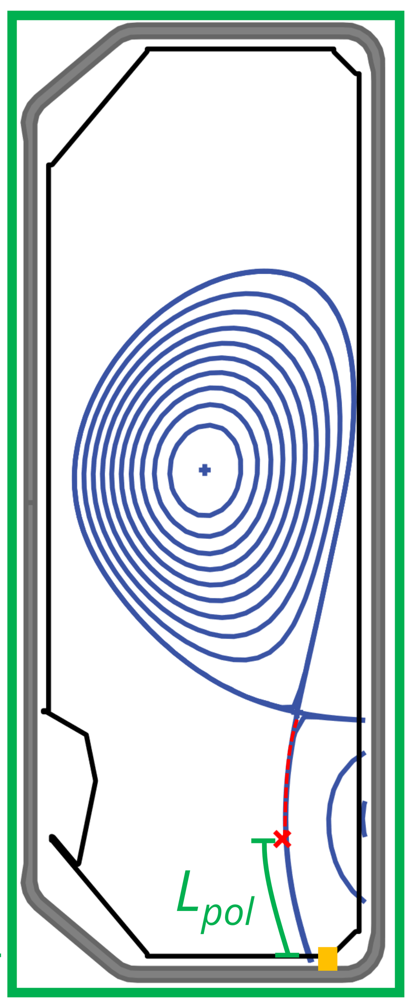
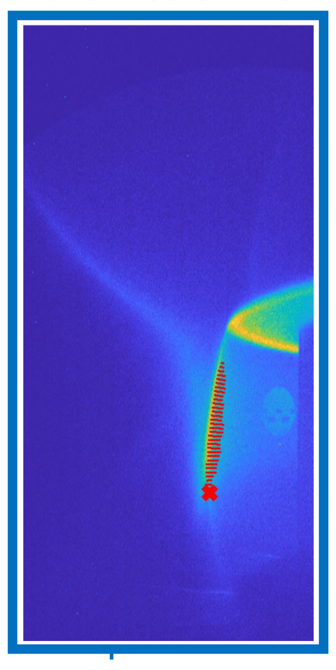
Motivation and introduction

Control of the heat exhaust

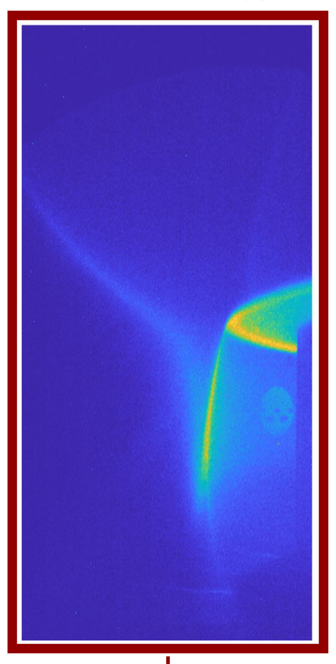
- Unmitigated, expected power fluxes impacting the divertor target exceed present-day engineering limits.
- Real-time feedback control of plasma detachment is required to maintain low target fluxes.
- We apply the systematic approach of [1] where control of the C-III emission front was demonstrated using D_2 fueling, to direct seeding of impurities as envisioned for metal-walled machines like DEMO [2].
- We show the first results of real-time detachment control using nitrogen seeding in TCV.
- As opposed to fueling, nitrogen seeding facilitates detachment access with diminished influence on density [3].



Real-time algorithm detects divertor leg and emission front



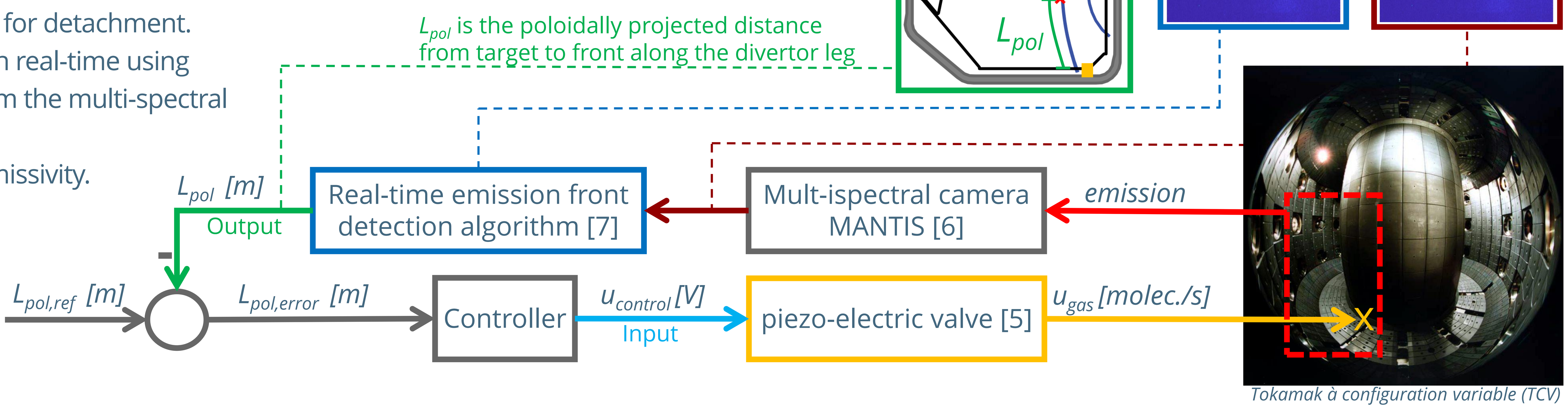
Raw image as seen by MANTIS with N-II filter



Experimental set-up

The control-loop

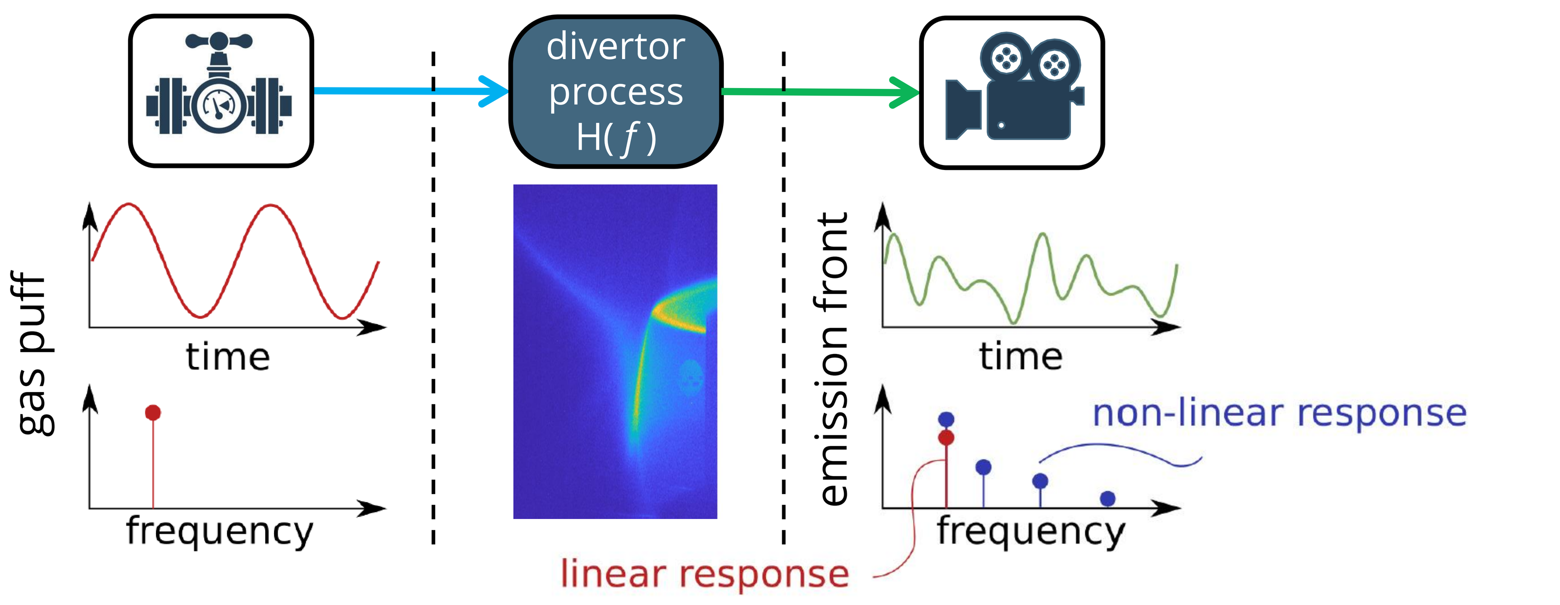
- Divertor plasma is diagnosed by using the N-II emission front location (approx. 6.5 eV [4]) as a precursor for detachment.
- The NII emission front location is tracked in real-time using spectrally filtered images (N-II 399 nm) from the multi-spectral camera MANTIS [6].
- The front is defined as 50% decrease of emissivity.
- The front is actuated by injection of N_2 in the divertor by a piezo-electric valve.
- Experiments are performed in ohmic L-mode with I_p = 340 kA.



Methods

System Identification

- Controller design requires a dynamic model of the process from input to output.
- Such a dynamic model can be obtained by injecting periodic excitations on the process input and measuring the response of the process output.
- The relative magnitude and phase of the output with respect to the input gives a Frequency Response Function (FRF) model $H(f)$ to be used for controller design.



Controller Design

- The FRF model is used to design a controller with the loop shaping technique.
- Loop shaping is a systematic controller design method to obtain desired frequency depended performance and robustness margins.
- Note, designing a feedback controller $C(f)$ for dynamical system $H(f)$ has trade-offs:

Example, changing from low to high gain feedback means:

- A larger frequency range with a low tracking error.
- A larger frequency range with disturbance suppression.

however:

- Amplification of high frequency sensor noise.
- Large control input signals: actuator saturation.

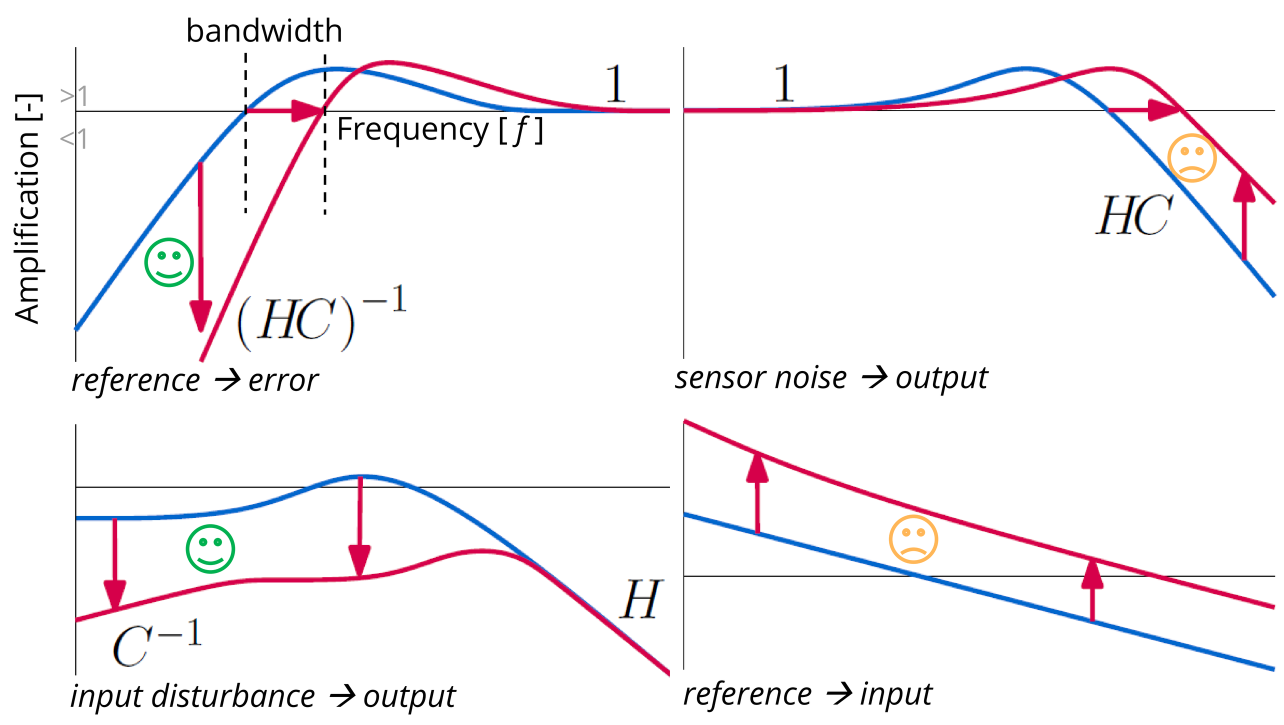


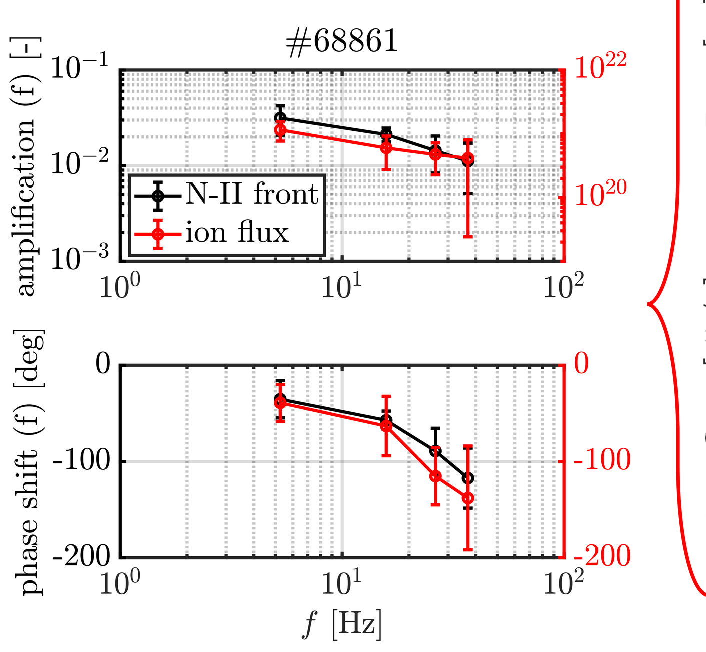
figure adapted from [8]

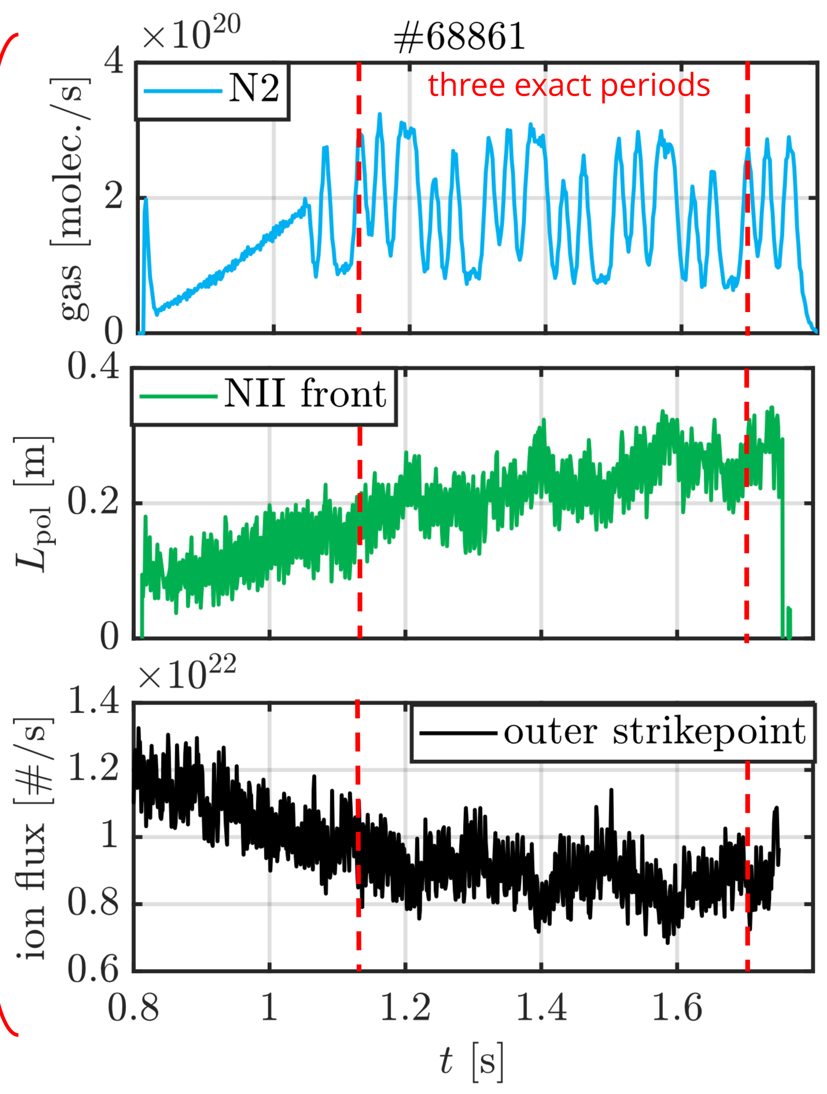
Results

I. Single shot to obtain an FRF model to design a controller.
II. Successful control in next shot.
III. Moving the front down proves difficult, likely N_2 accumulation.

I.

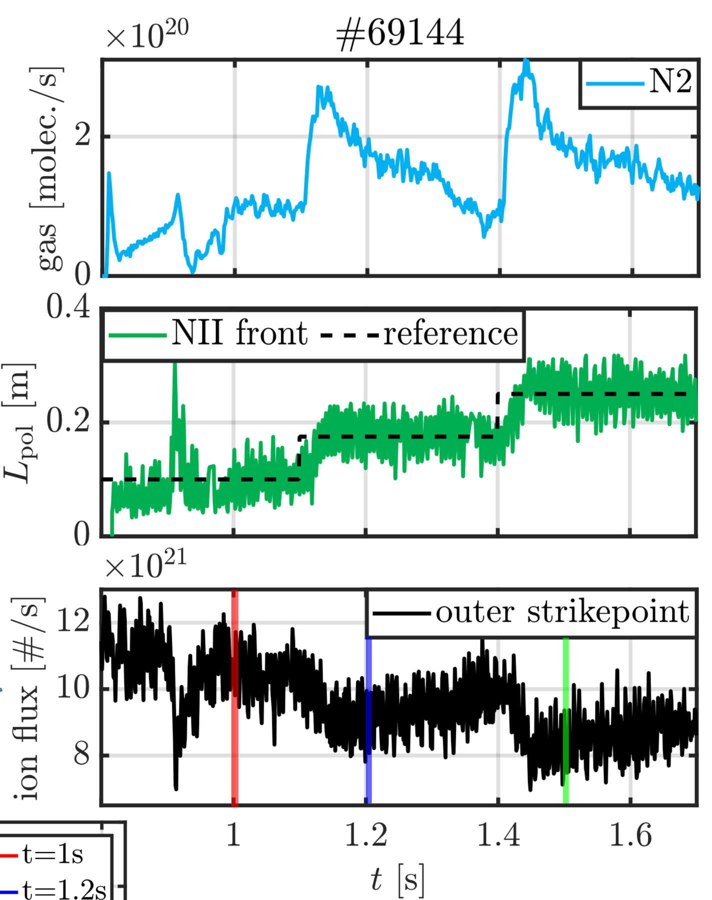
- Identification of FRF input-ouput model from N_2 seeding to N-II front position using a multisine with four excited frequencies.
- Compensation for non-periodic behavior is (e.g. drift) is done using the LPM [9].

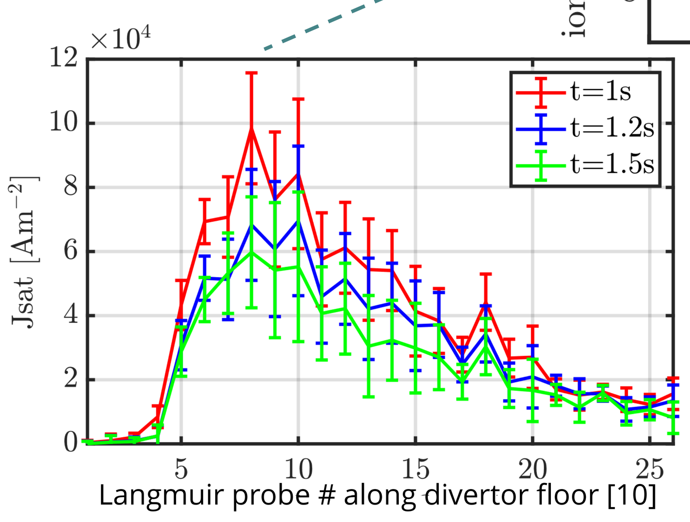




II.

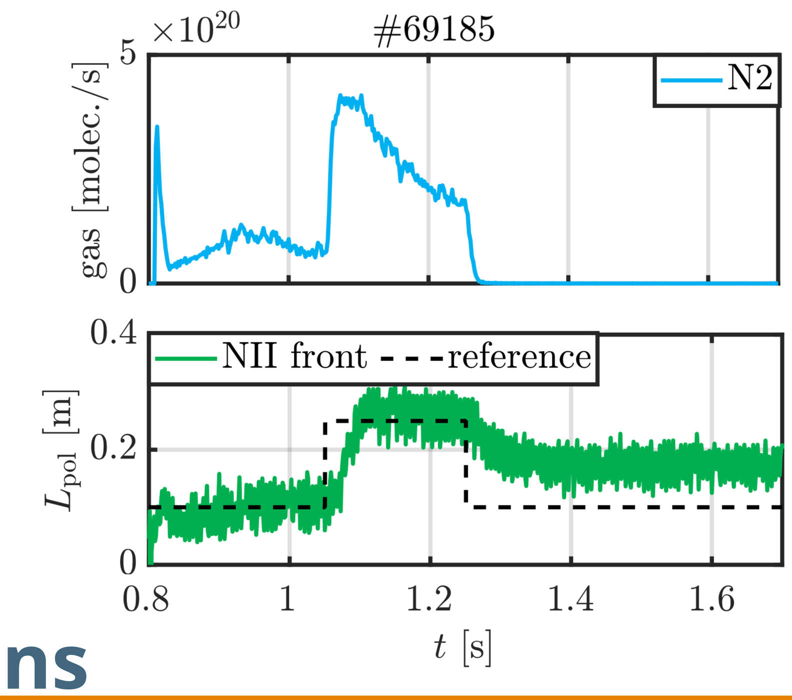
- Good tracking of the N-II front reference.
- Decaying N_2 flux required for constant front position.
- Clear reduction in ion flux to the target and ion saturation current (J_{sat}) profile with a higher N-II emission front location.





III.

- Controller completely closes the valve at 1.25 seconds but the N-II front does not return to the dictated reference.



Conclusions

- An NII front controller using N_2 seeding was designed with a single identification shot. Controller performs well.
- Controlled reduction in peak and total target ion flux.
- NII emission front is difficult to move back down without a pump actuator.

*all errorbars on this poster represent 2σ

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