LONGITUDINAL INSTABILITY STUDIES IN THE PSB

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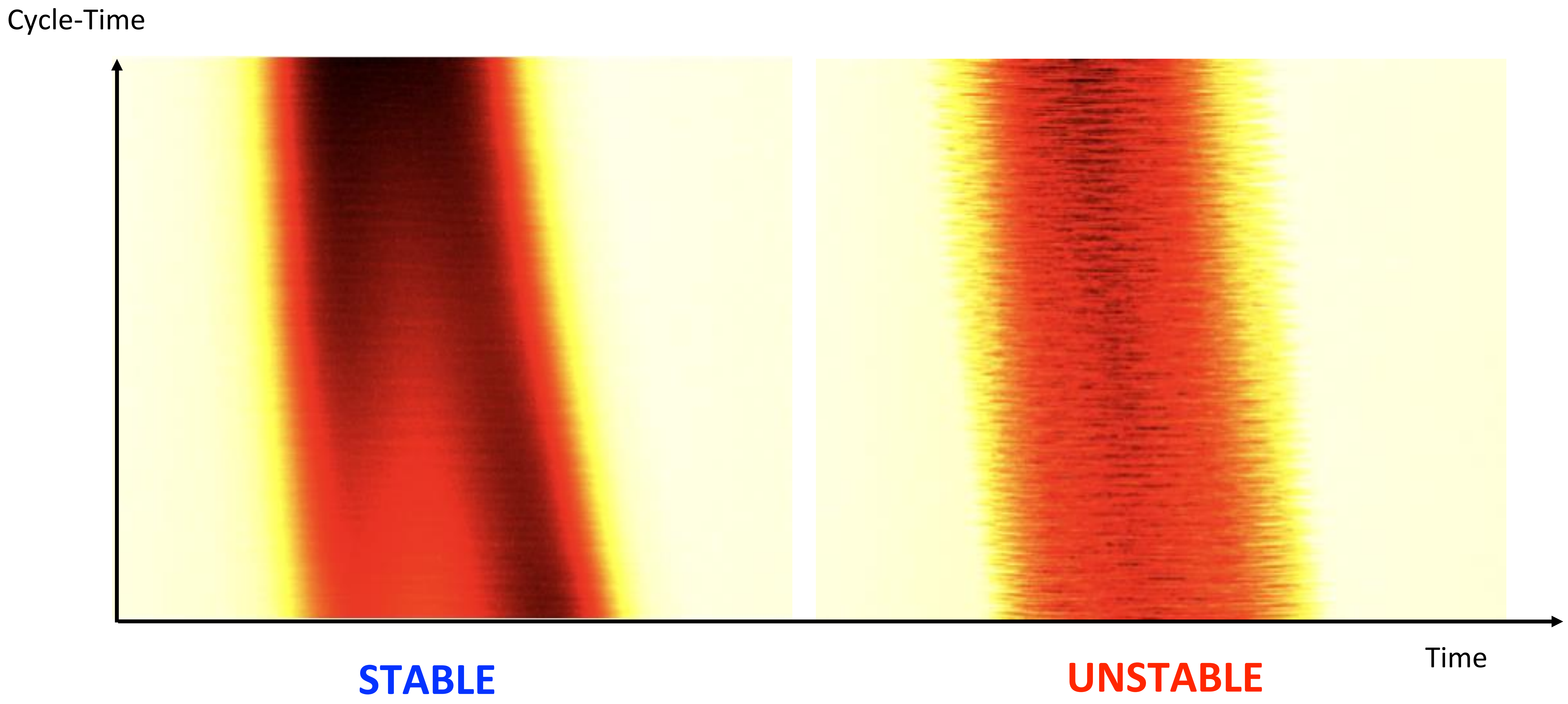
INTRODUCTION - Problem

Stability studies during LS2 in the longitudinal plane do not match with current observations.
➔ instability in single RF, predicted to be stable
➔ dual harmonic RF restores stability but predicted to be unstable



Needed studies:

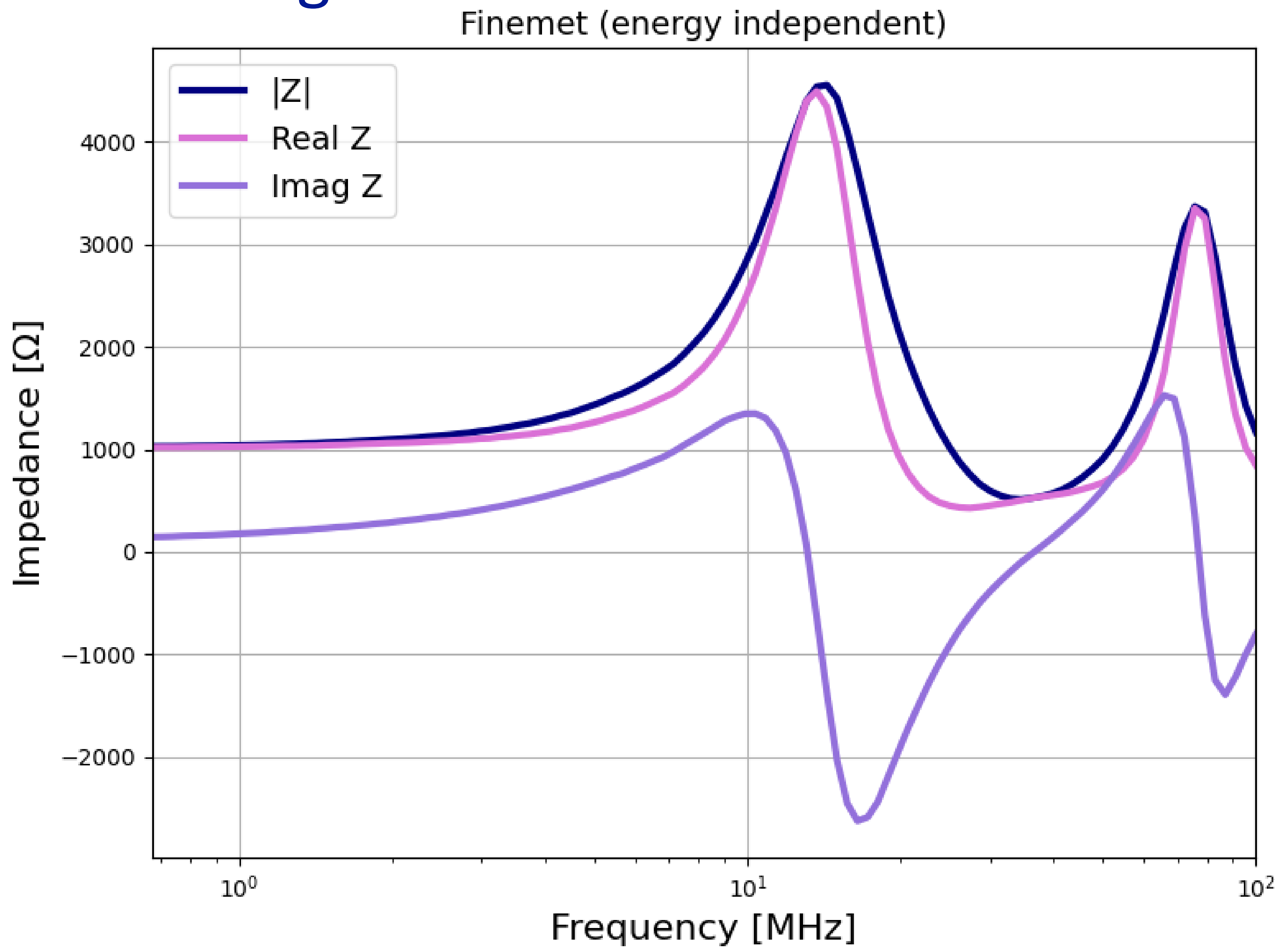
- Instabilities characterization
- Understanding of the discrepancy between simulations and measurements
- Feedback modelling

Open question:
Longitudinal limitation for high-intensity beams in the PSB?

INTRODUCTION - MDs

PSB longitudinal impedance model to be tested exploiting various techniques and configurations.

Cause/Effect	Longitudinal Impedance
Real Part	Synchronous phase shift
Imaginary Part	Bunch lengthening/shortening, Synchrotron frequency shift



MDs main objectives:

- Voltage and intensity scans to identify instability thresholds
- Measurements of transient and steady-state beam loading
- Effect of cavity feedback loops on beam stability

→

GOAL: reproduce MDs results in simulations and optimize parameter-space for high-intensity beams

PSB LLRF Servoloops

Cavity loops action → Modelling purpose ➔ macro-particle tracking simulations when loops are active possible

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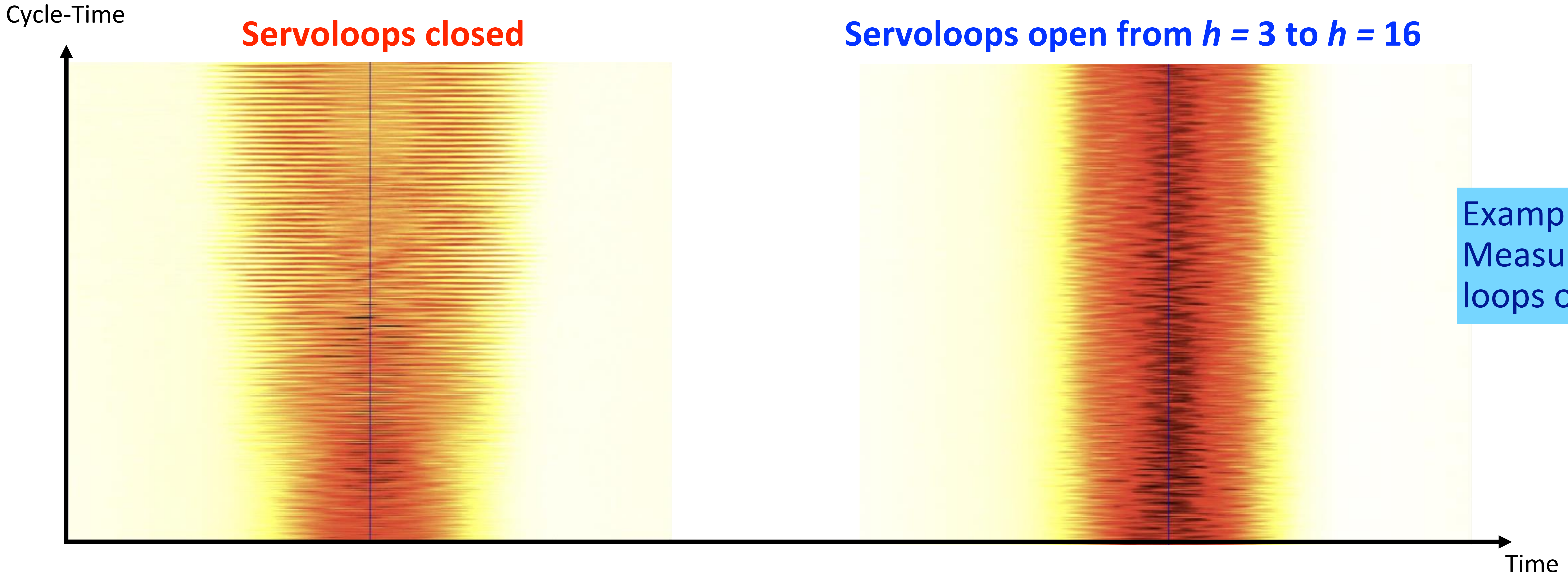
Unexplained instability with loops active



Example with **MD12145:**
Measuring the effect of the servo loops on the quadrupole frequency shift

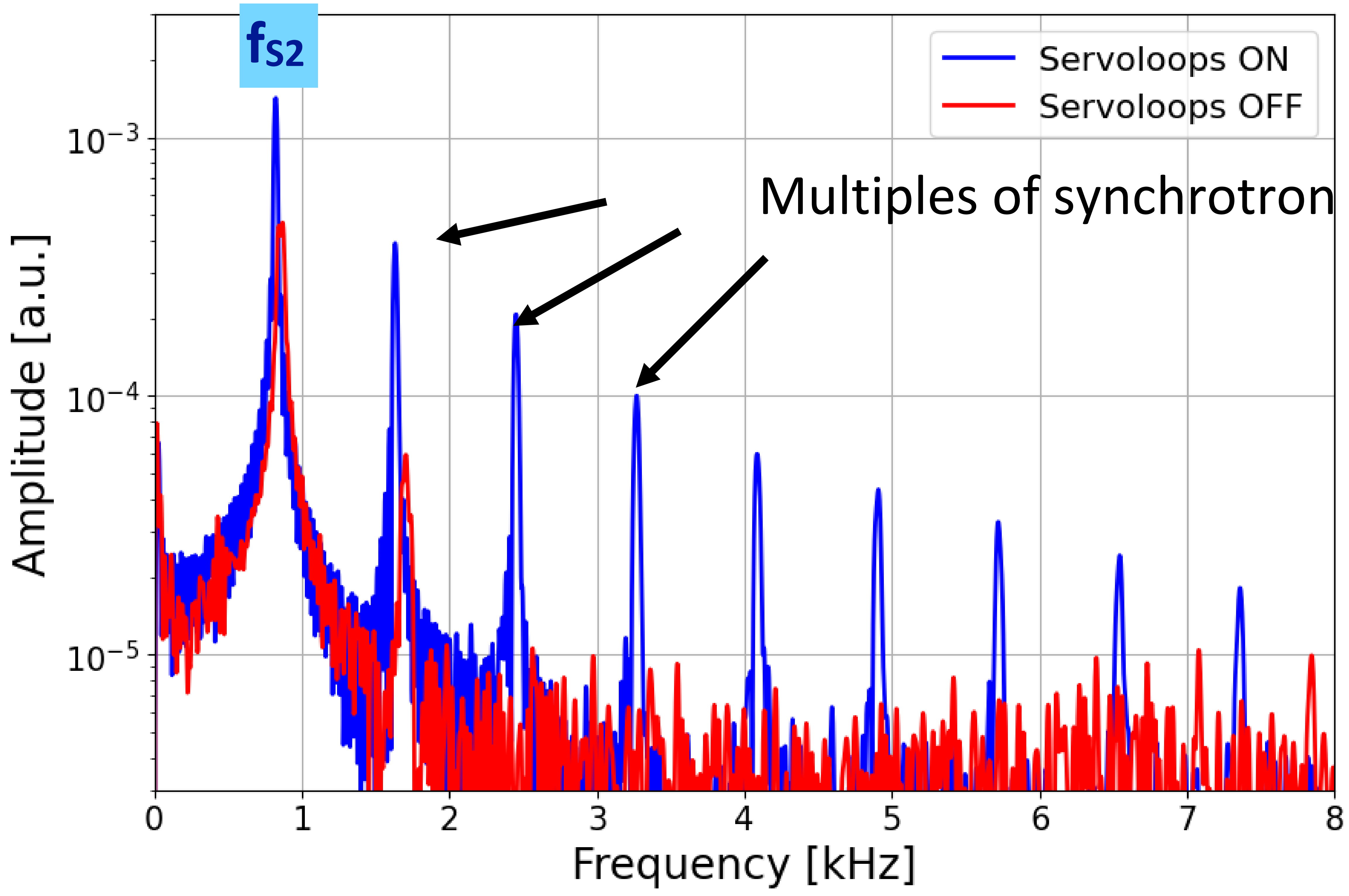
PSB LLRF Servoloops

Cavity loops action

Modelling purpose ➔ macro-particle tracking simulations when loops are active possible

Unexplained presence of higher synchrotron oscillation modes with loops active

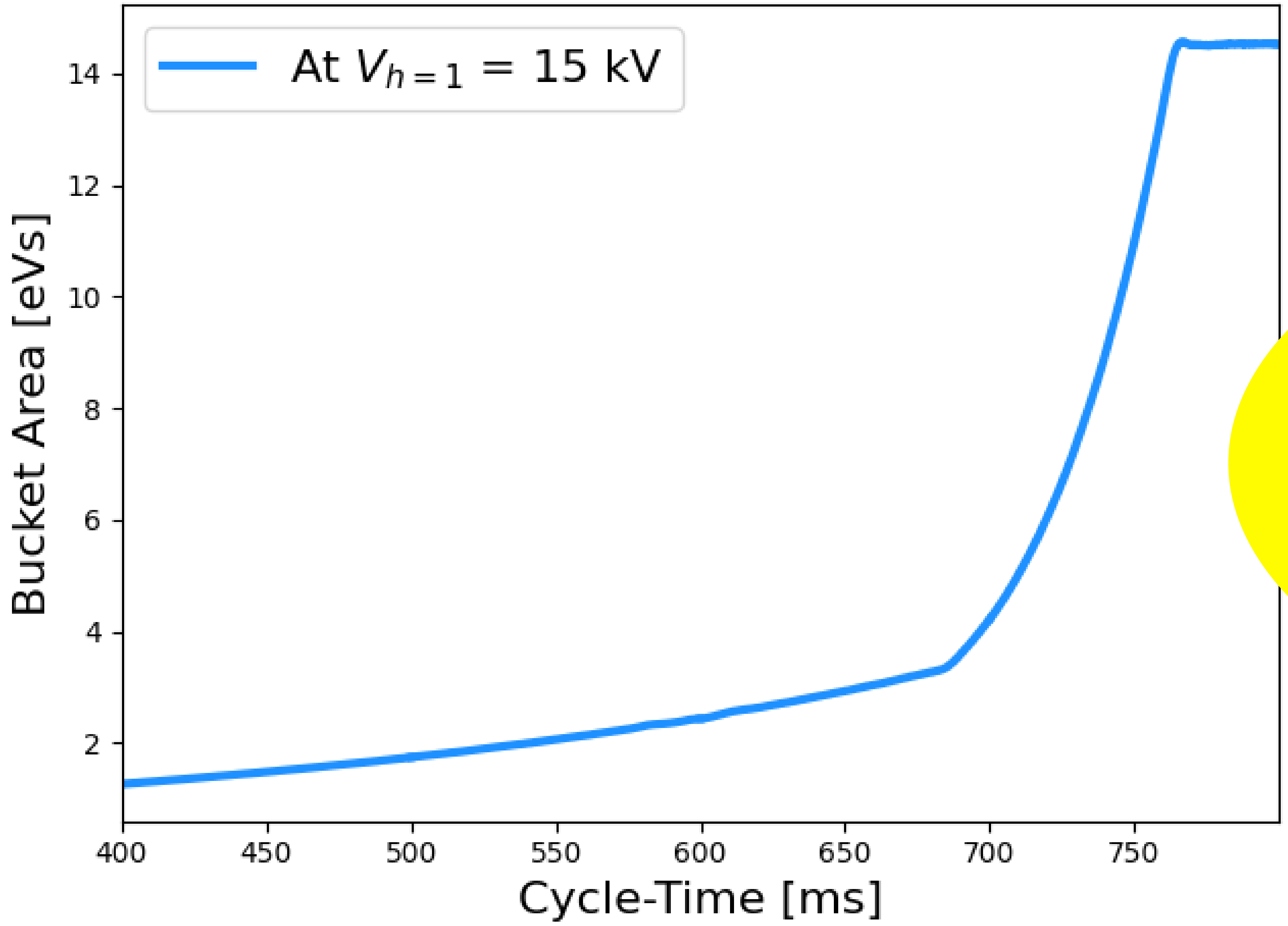
Example with **MD12145:**
Acquisitions at **long 1.4 GeV**
with induced quadrupole oscillations.
These oscillations happen with twice the synchrotron frequencies **f_{S2}**



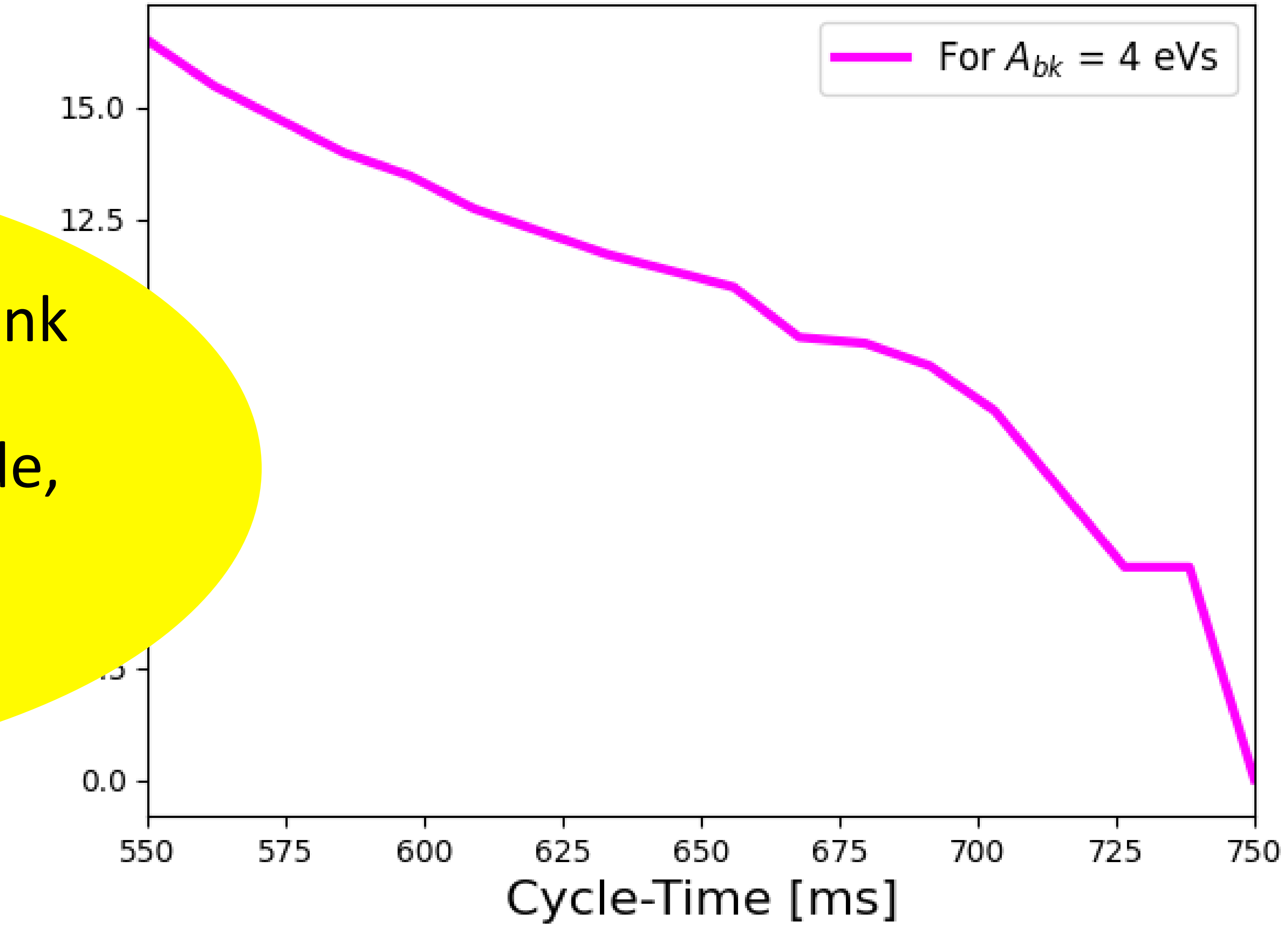
MDs - Instability thresholds

Measurements of **single-bunch instabilities thresholds in single harmonic** during PSB ramp.

➔ Two MDs (**MD10085**), two RF configurations : **Constant Voltage (CV)** and **Constant Bucket Area (CBA),** after matching the bunch in Double RF.



Possibility to interpret and link instabilities to intensity, emittance, voltage amplitude, synchrotron frequency spread...



+

Variable A_{bk} during acceleration, variable filling factor for constant longitudinal emittance.

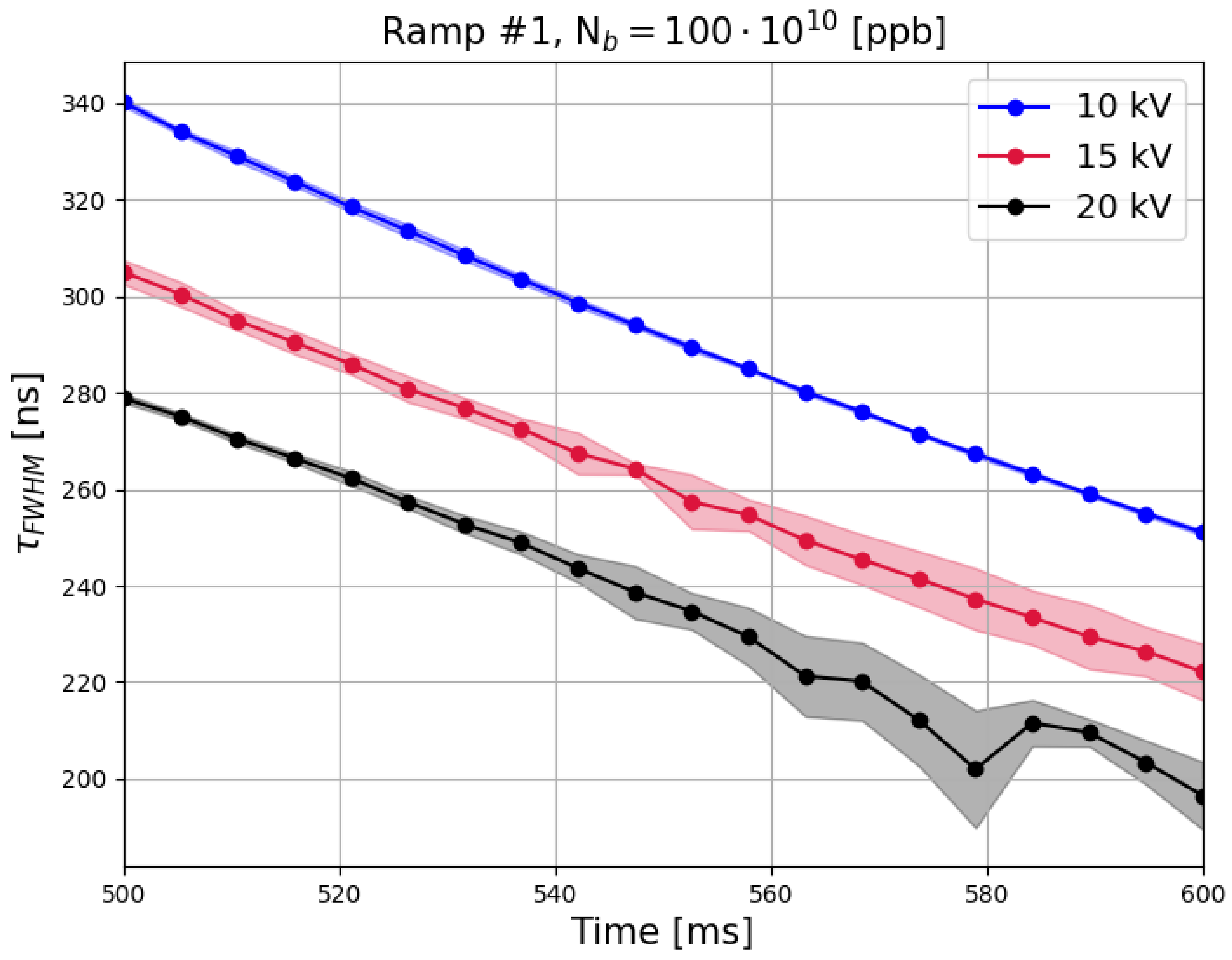
Cavity loops action

Constant A_{bk} during acceleration, fixed filling factor for constant longitudinal emittance.

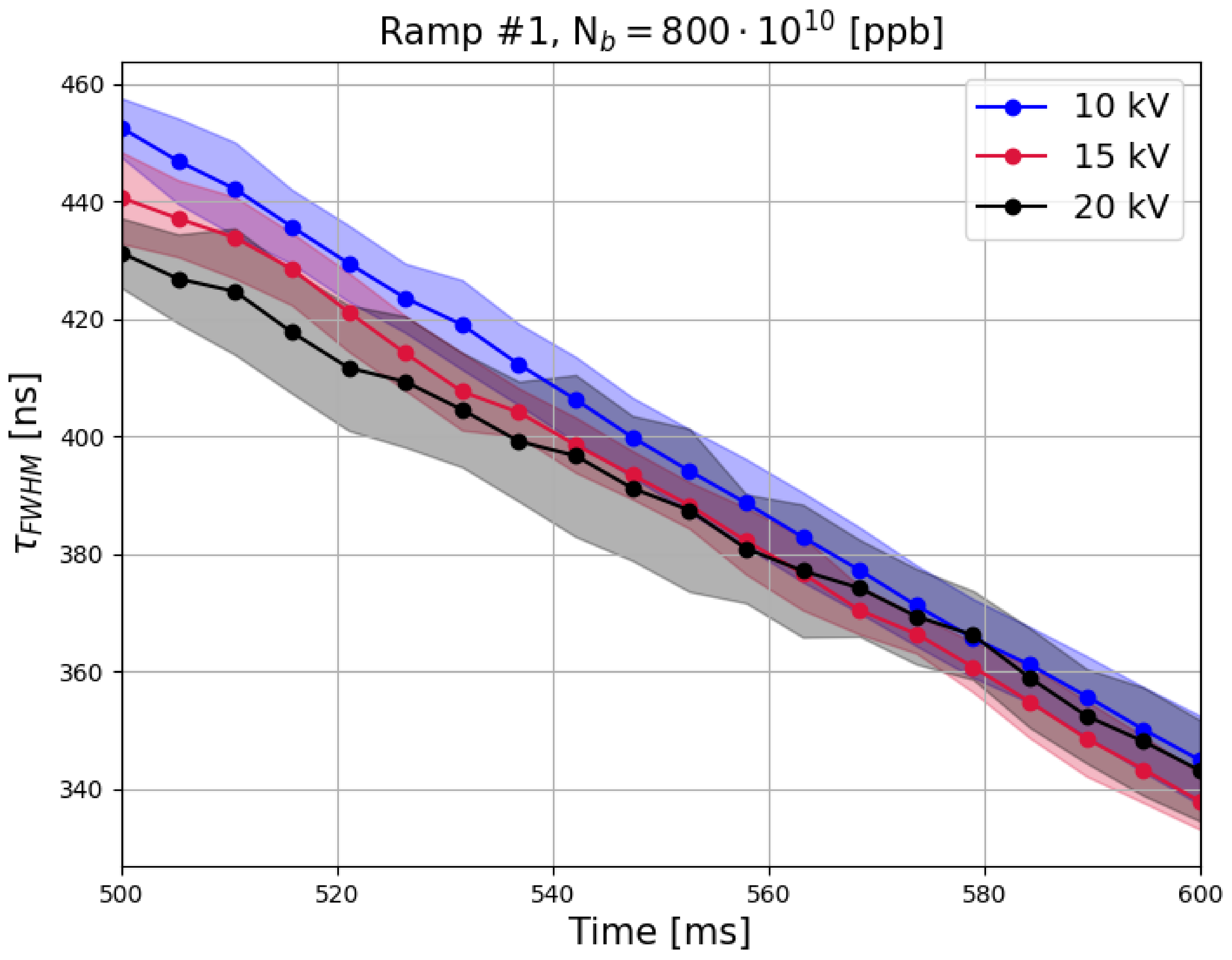
MDs - Instability thresholds - CV

- **MD10085** (2023)
- 2 GeV cycle
- Scans in intensity, three voltage values
- Cavity servoloops in open and closed loop
- Beam loops disabled

First 100 ms with lowest and highest intensities, servoloops active



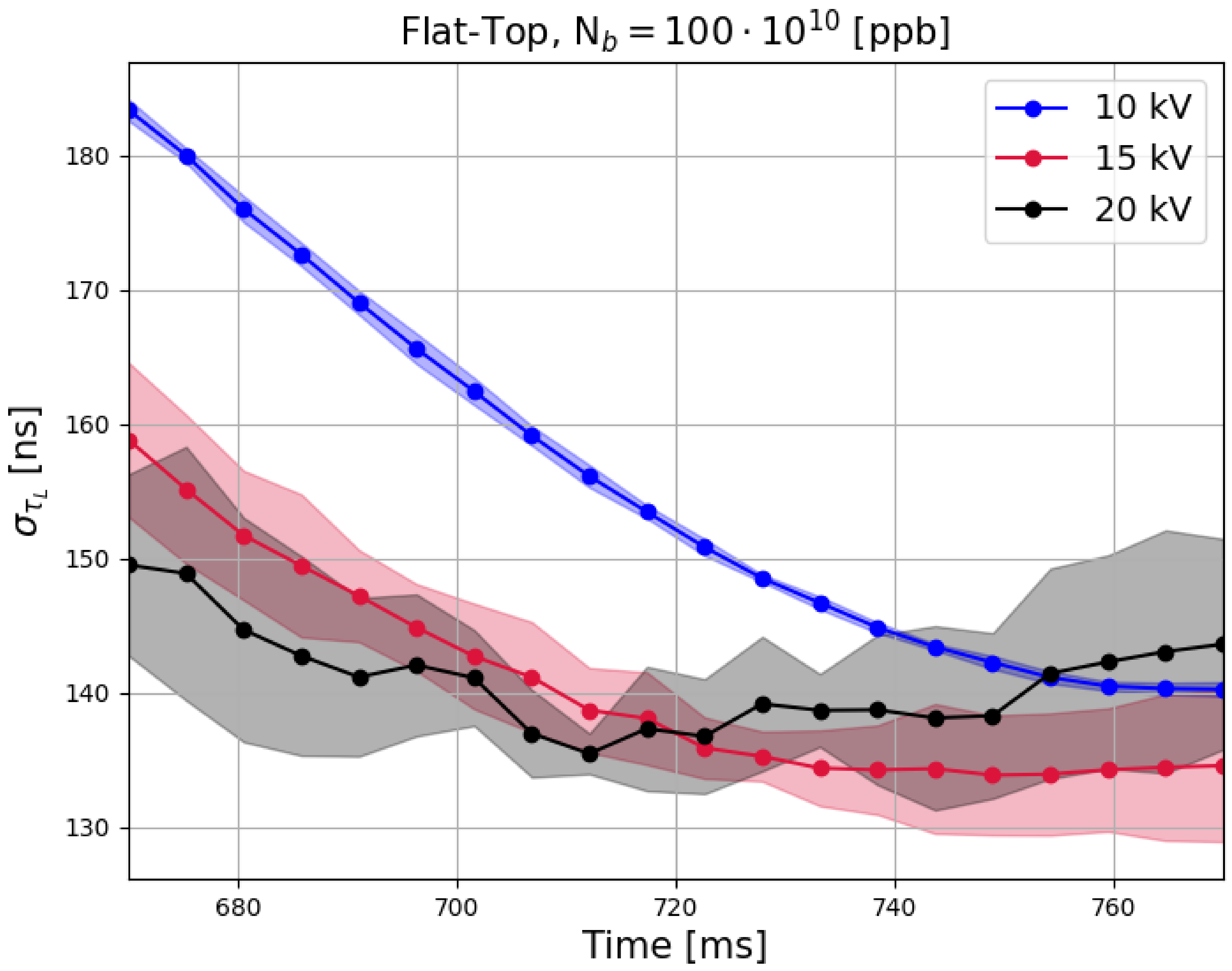
At ~ 0.73 GeV oscillation content observed



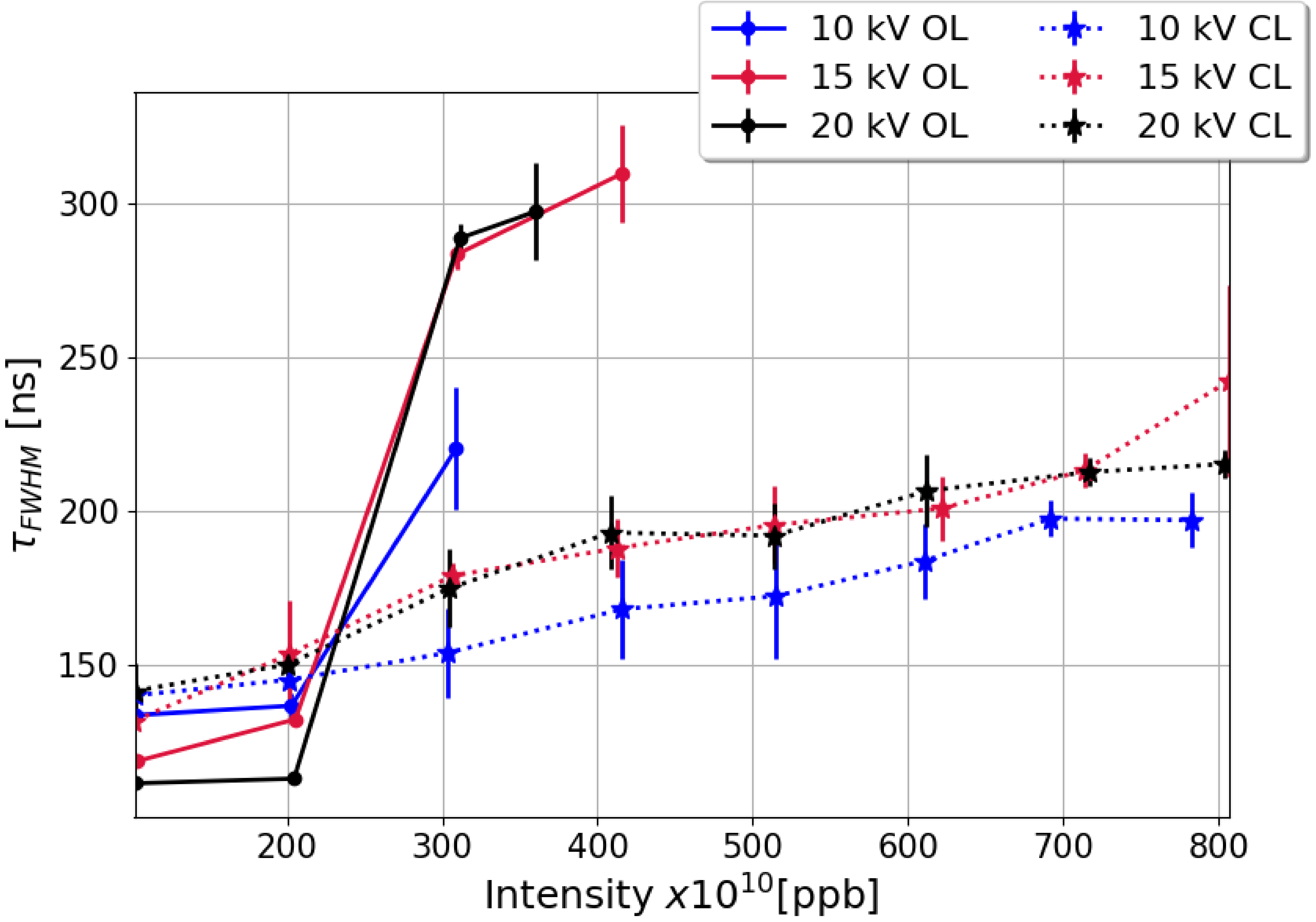
Bunches already ‘unstable’

MDs - Instability thresholds - CV

At Flat-Top energy stability is preserved for smaller voltage in closed-loop ➔ higher filling factor



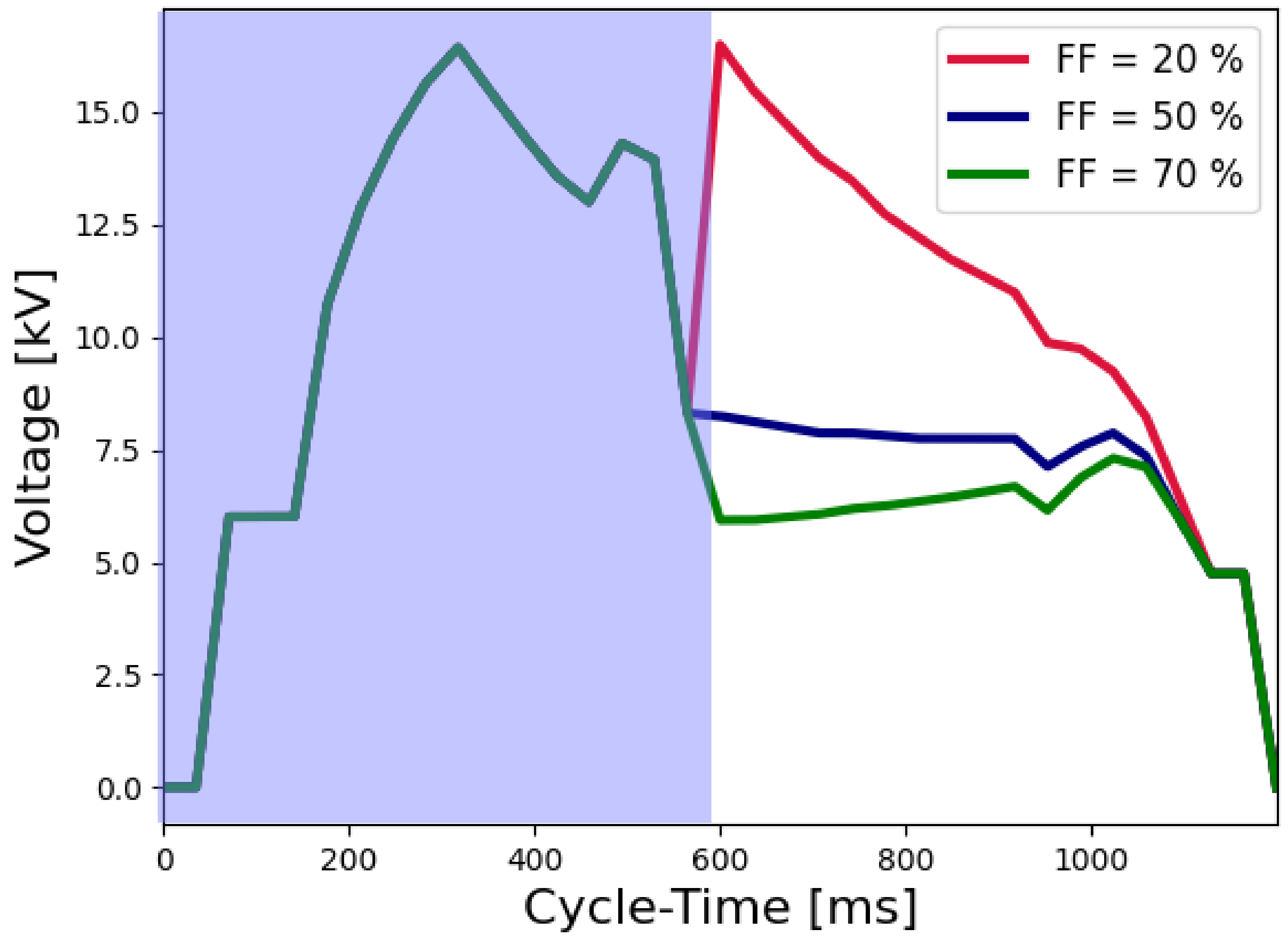
At Flat-Top strong instability at 200 · 10^{10} with beam loss in open-loop

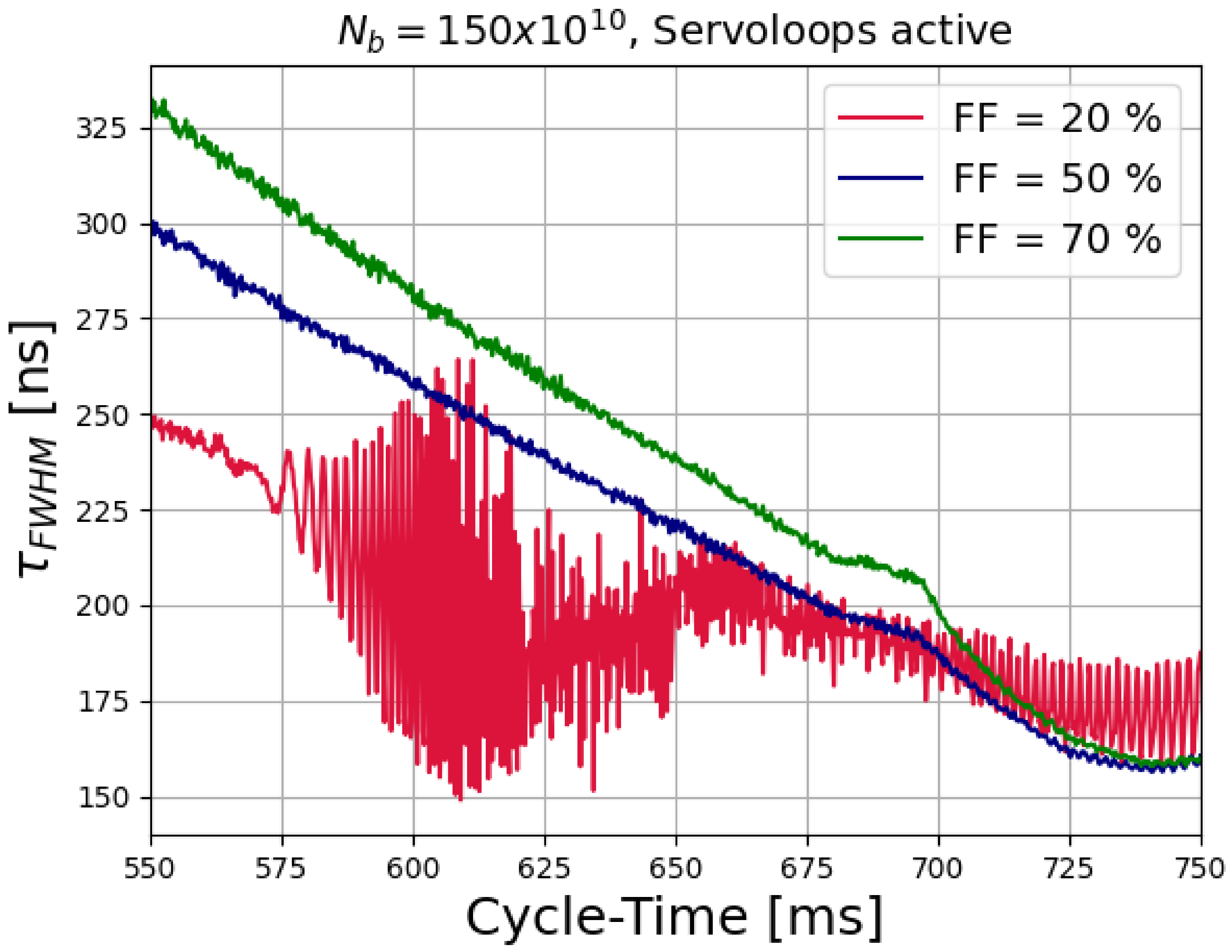


MDs - Instability thresholds - CBA

- **MD10085** (2024)
- 2 GeV cycle
- Scans in intensity (changed only with nr of turns) three filling factors
- Cavity servoloops in open and closed loop
- Beam loops enabled
- Adiabatic transition between DRF and SRF, before the start of instabilities

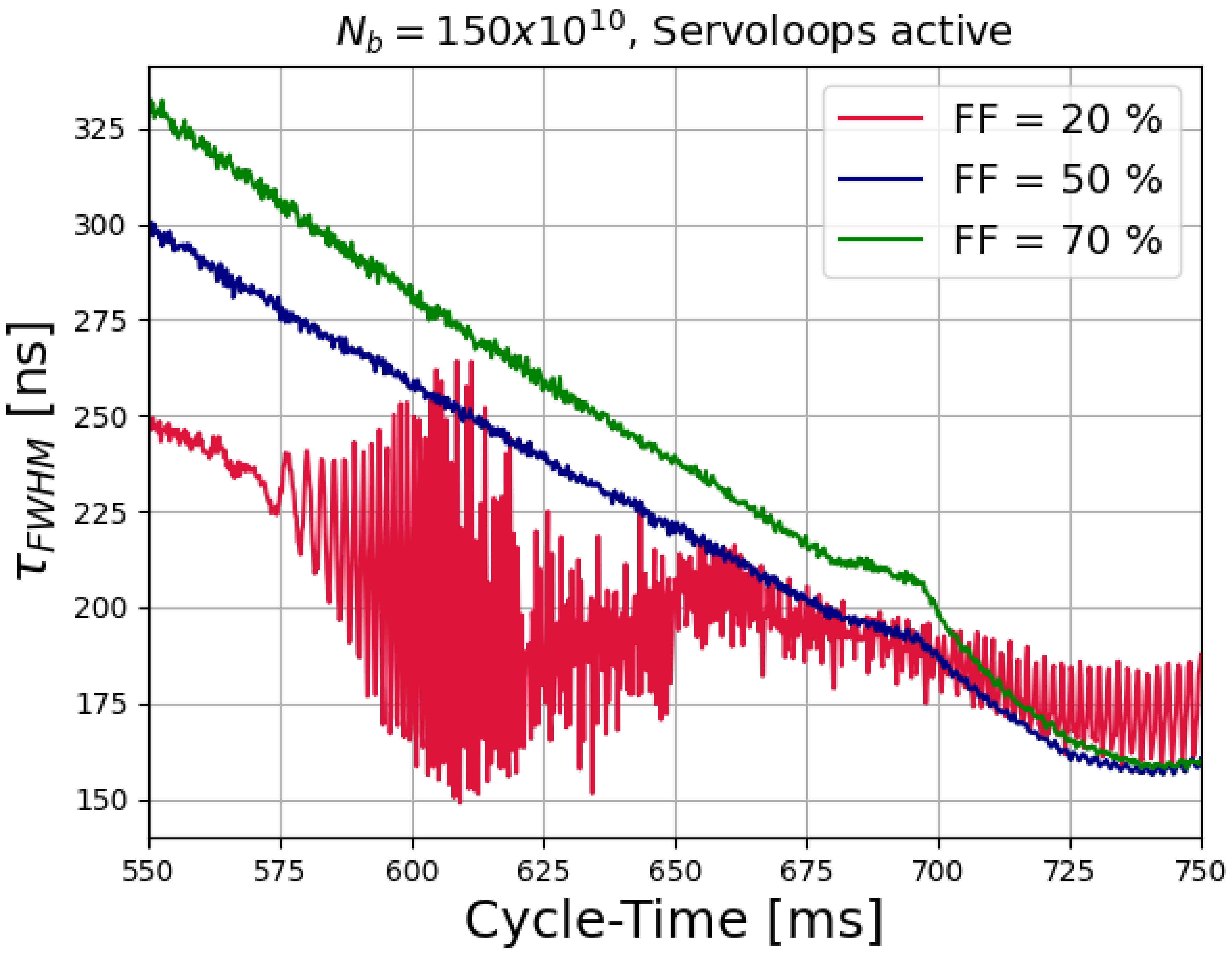
Double RF area ➔ matching at low energy

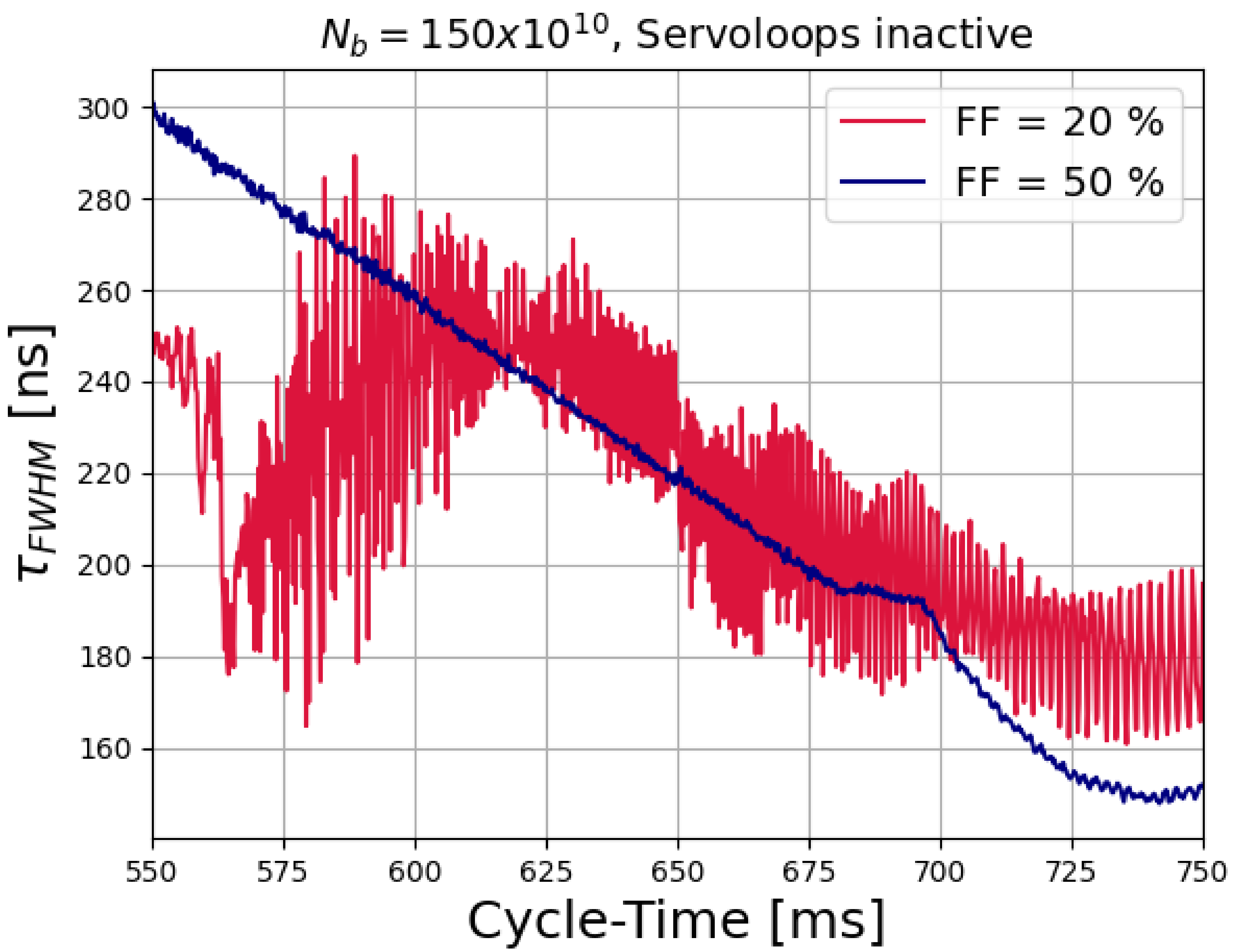




Big bunch length oscillations at for 20 % filling factor ➔ expected for the low incoherent synchrotron frequency spread

MDs - Instability thresholds - CBA

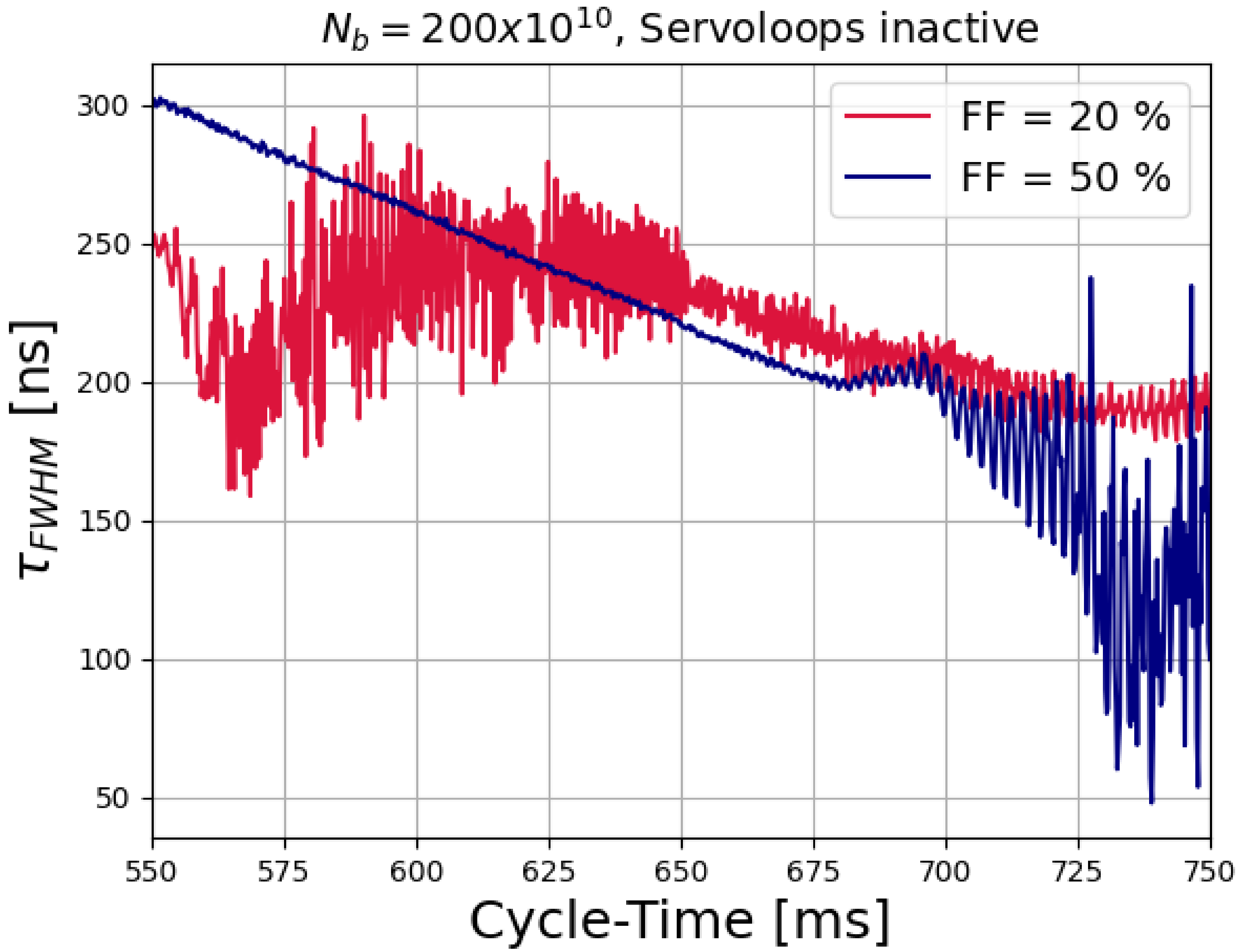




When servoloop compensation inactive at $150 \cdot 10^{10}$:

- 20 % still unstable
- 50 % still stable
- 70 % not possible to measure (loss)

MDs - Instability thresholds - CBA



When servoloop compensation inactive at $200 \cdot 10^{10}$:

- 20 % still unstable
- 50 % unstable
- 70 % not possible to measure (loss)

SUMMARY AND PLANS FOR 2025

- Cause of unexpected longitudinal instabilities in single harmonic under investigation
- Cavity servoloops appear to cause instabilities under certain conditions
- 2024 MDs: many short parallel sessions focused on instability characterization
- Two RF configurations exploited to observe instability and gain information for the cavity controllers modelling
- Possibly many instability source cases spotted , further analysis and comparisons with simulations to do
- 2025 MDs plan: more data on the mechanisms of instabilities, Double RF configuration and transient effects

BACK-UP SLIDES

PSB LLRF Servo-loops

...

Digital cavity controllers, one for each harmonic of f_{REV} (h = 1,…, 16)

Finemet cavity

MDs - Instability thresholds - CV

- **MD10085** (2023)
- 2 GeV cycle
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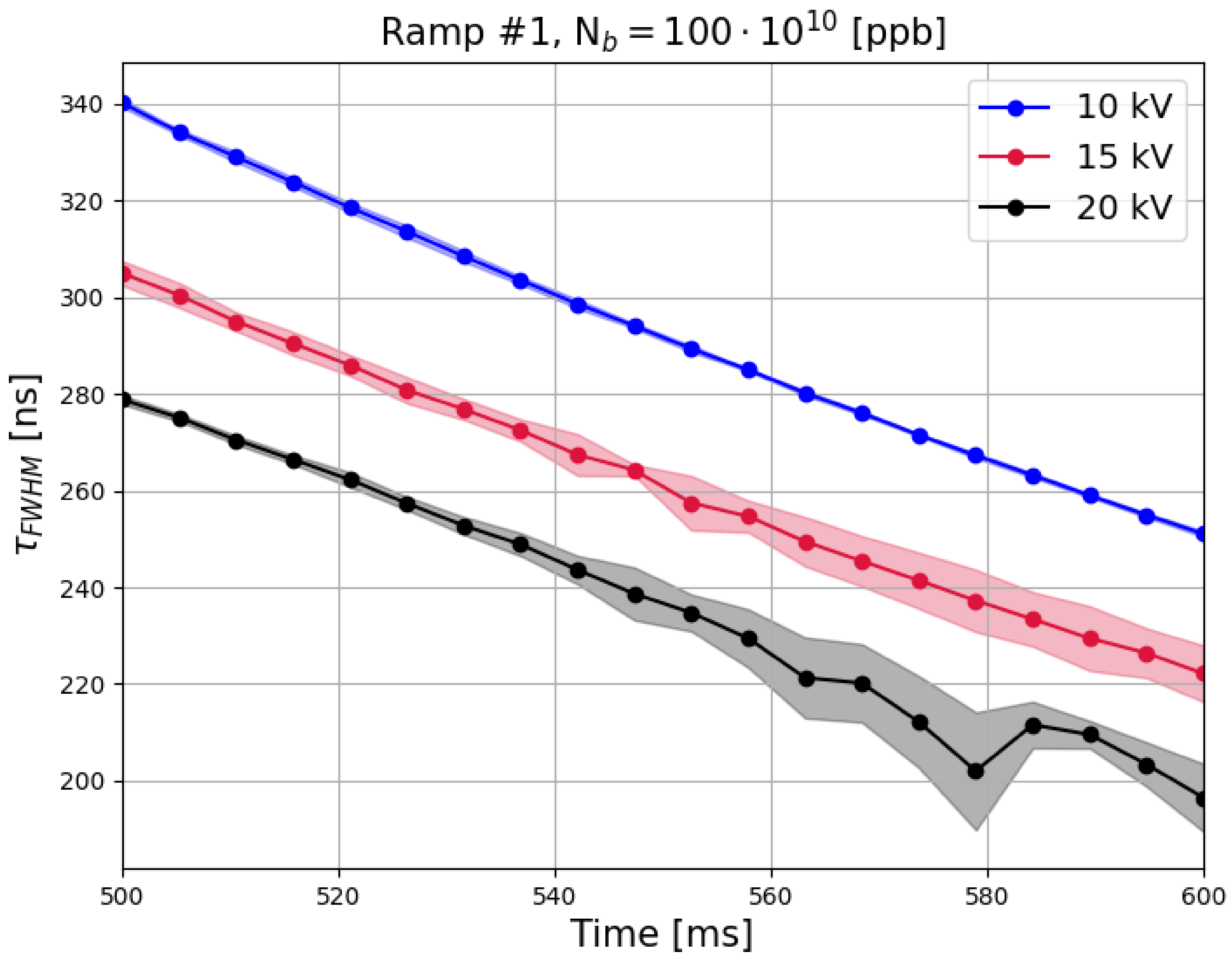
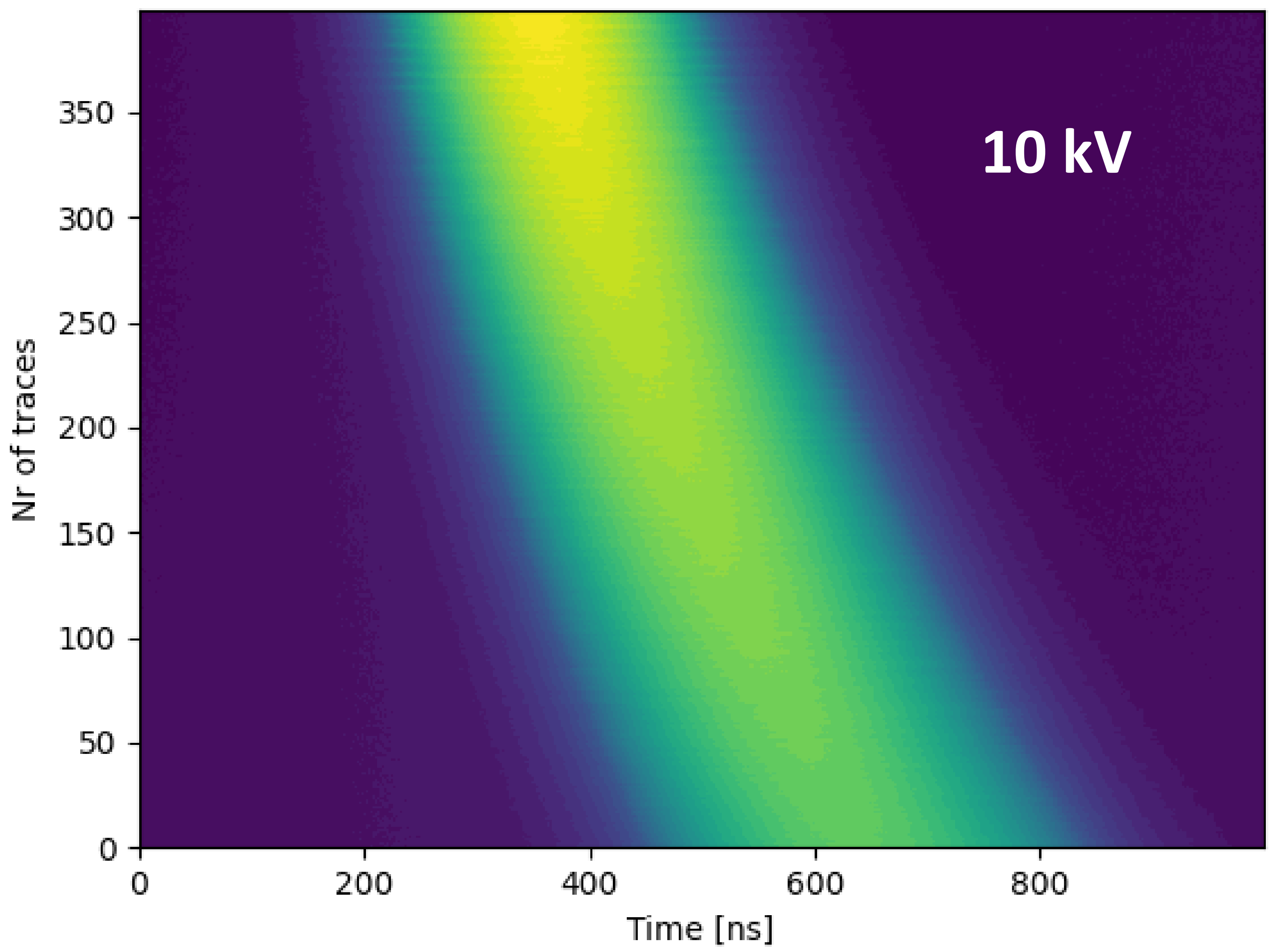
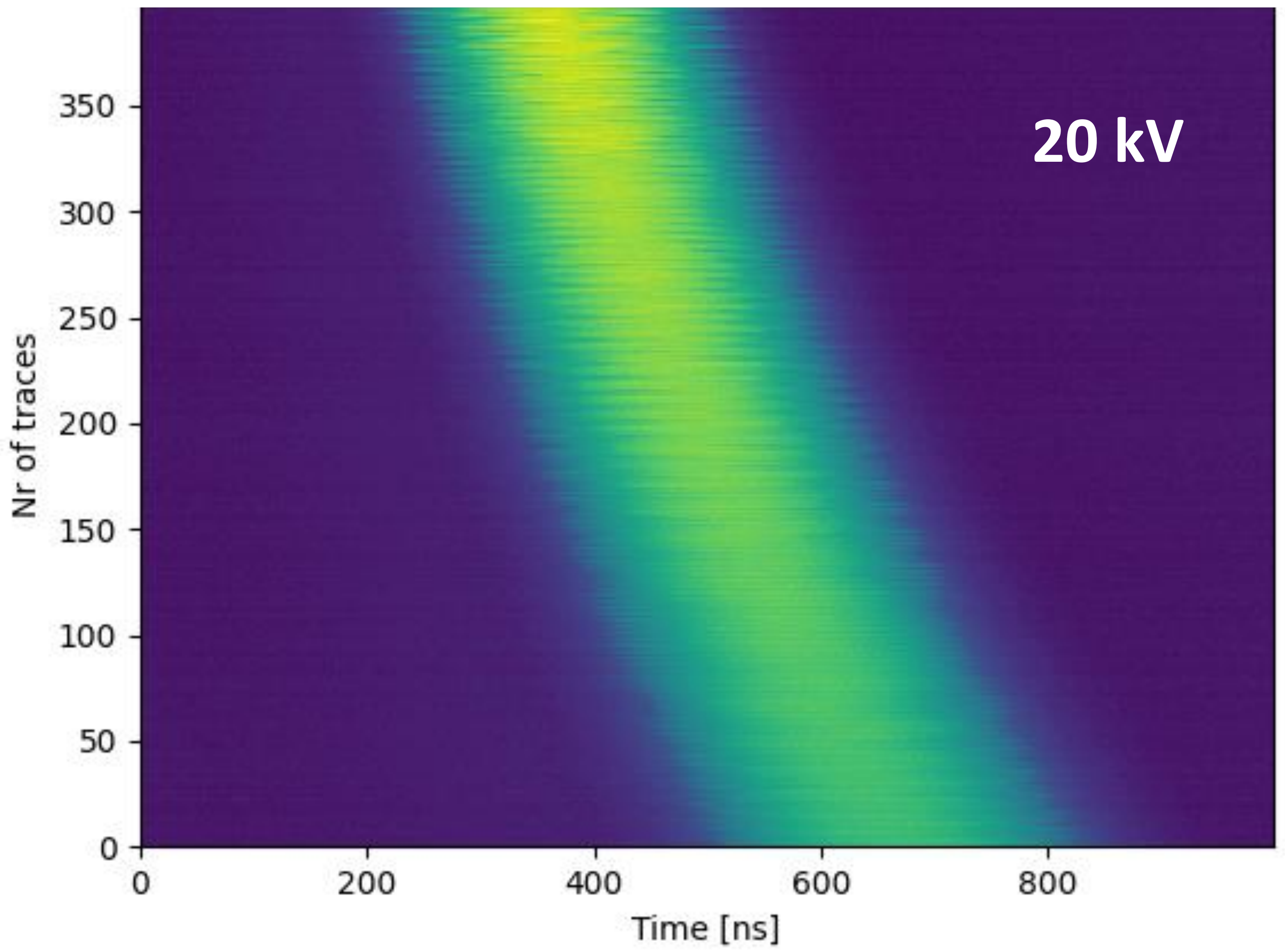
- Beam loops disabled







MDs - Instability thresholds - CV

- **MD10085** (2023)
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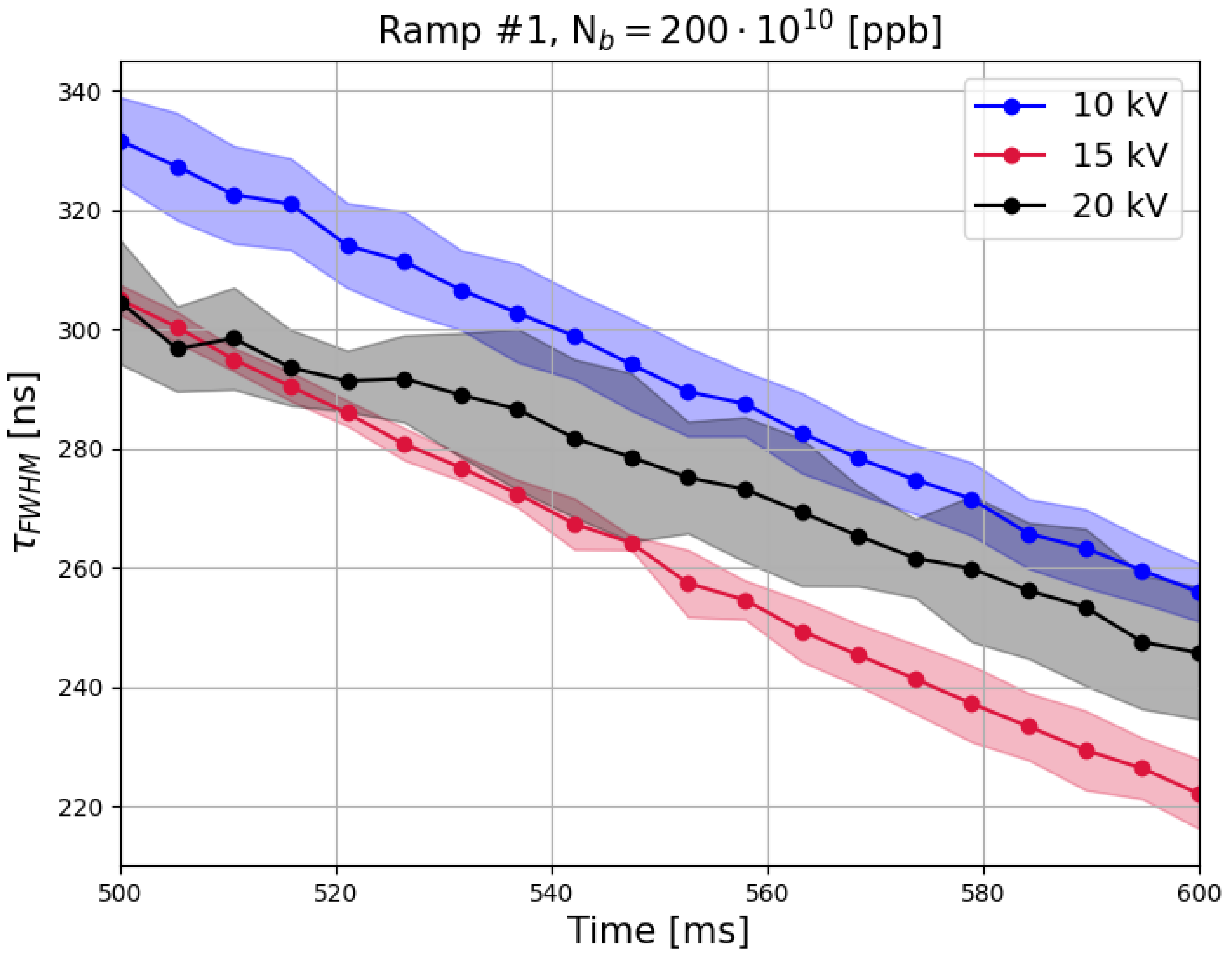
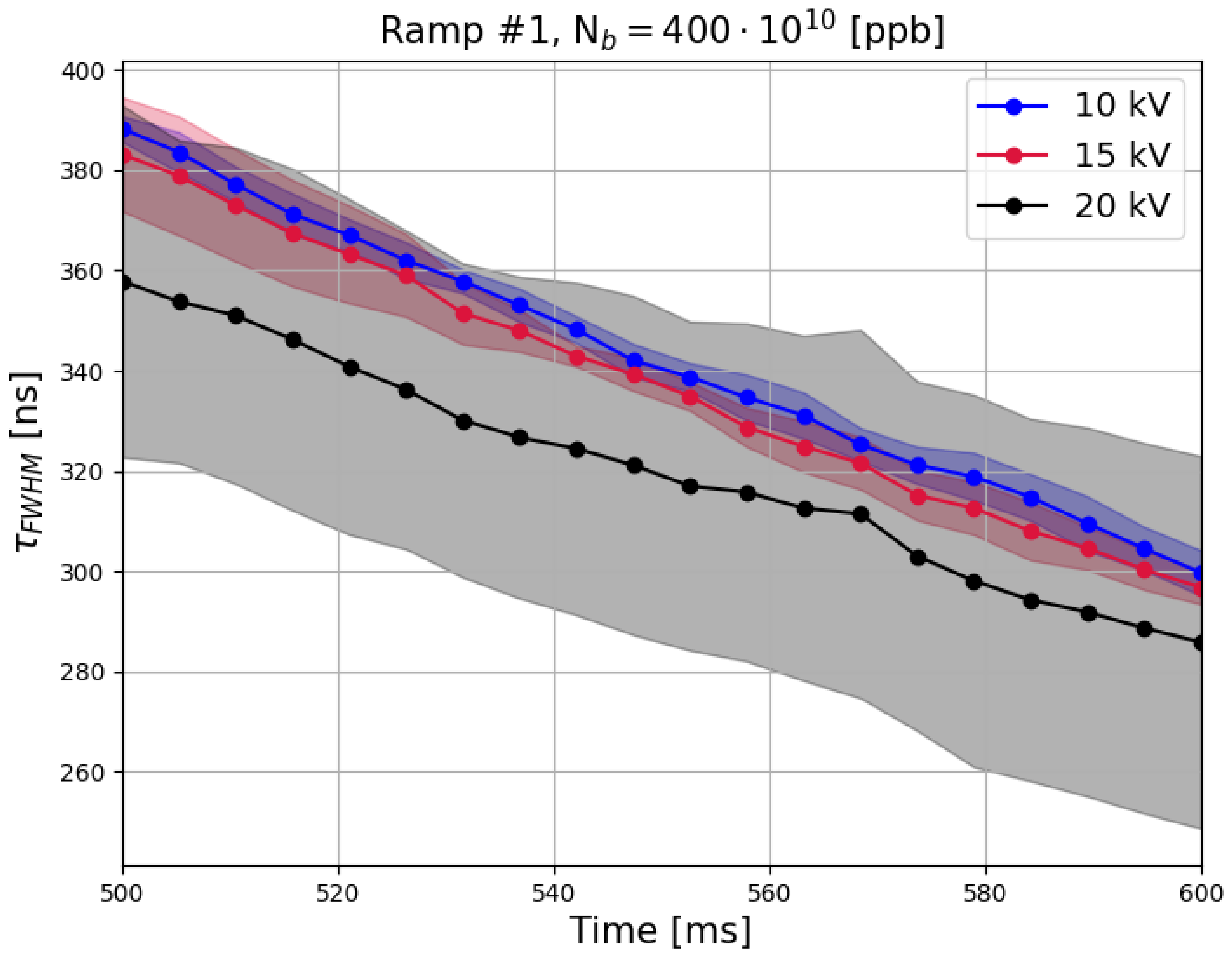
First 100 ms with intermediate intensities, servoloops closed





Big change in the 10 kV case

Huge oscillations for the 20 kV case