COMMENT TALK - HC SIMULATIONS FOR ALBA-II

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HarmonLIP 2022 - 11/10/2022

OUTLINE

- ALBA-II storage ring & HC motivation
- Current RF baseline parameters
- General considerations
- Baseline - NC active HC simulations
- Compared alternatives - NC/SC passive
- Summary and conclusions

ALBA Active Harmonic EU Cavity

ALBA-II STORAGE RING

ALBA-II storage ring v 2022.9	
Energy [GeV]	3
Circumference [m]	268.80
Harmonic number	448
Current [mA]	300
Momentum compaction factor	$0.8 \cdot 10^{-5}$
Equilibrium emittance [pm·rad]	136
Energy loss with IDs [MeV]	0.97
Natural RMS bunch duration [ps]	6.17
Natural Touschek lifetime FC [h]	3.4 h

- As all the other 4^{th} generation light source upgrades, the lower equilibrium emittance comes with much lower momentum compaction factor and thus a lower bunch length and **Touschek lifetime**
- A **higher harmonic RF system** is thus needed to enhance the bunch length and place the lifetime within reasonable values

$$\tau_T \propto \frac{\sqrt{\varepsilon_y}\,\sigma_s}{I_b}\,\delta_{acc}^{a}$$

RF PARAMETERS

- ALBA has designed a 3rd harmonic normal conducting active cavity based on the main HOM 500 MHz ones (see J. Ocampo talk tomorrow)
- In order to check the **stability** of the proposed system and cross check the analytical calculations, we have run 6D **tracking simulations** (see next slides)
- Complementarily, a 3HC prototype is being tested at BESSY-II (see A. Matveenko talk). Dedicated simulations of the cavity performance will be validated with the **experimental results**

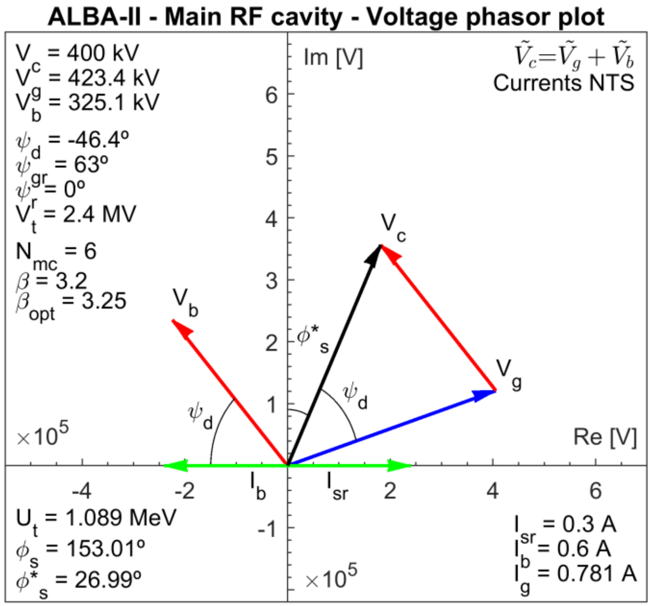
ALBA-II RF system v 2022.9	
Main RF voltage [MV]	2.4
Harmonic RF voltage [kV]	700
Number of cavities (main / hh)	6 / 4
Main RF frequency [MHz]	500
Harmonic RF frequency [MHz]	1500
HC type	NC-HOM
HC shunt impedance [MΩ]	1.1
HC quality factor	13000
Optimal bunch lengthening UFP	5.5

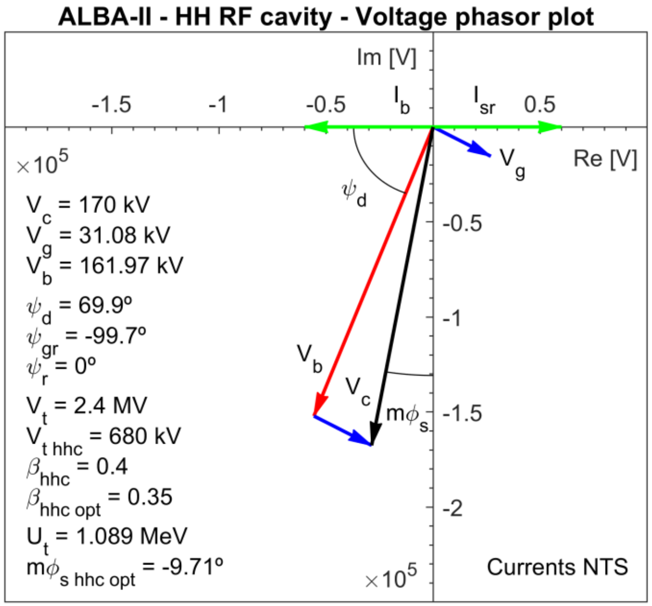
SIMULATION CONSIDERATIONS

- The tracking simulations have been performed with the parallel version of Elegant. The main objective, for the time being, is the lifetime evaluation
- All simulations have been performed for the nominal fundamental voltage and current (2.4 MV and 300 mA). The harmonic voltage has been varied to find the **highest stable operation point** (up to an optimal value of around 180 kV per cavity)
- To study the stability of the system, the stability over the beam passes of the beam energy, bunch duration, RF voltage and the control loop output has been watched, among other parameters
- Each bunch has been generated with 10000 particles, with Gaussian distribution and a bunch length belonging to 0 kV of harmonic voltage. The bunches are then naturally lengthened up to their new stable value owing to the third harmonic system
- The simulation starts at **nominal beam current and RF voltage**, with the cavities already **pre-loaded**

NC ACTIVE HC - BASELINE

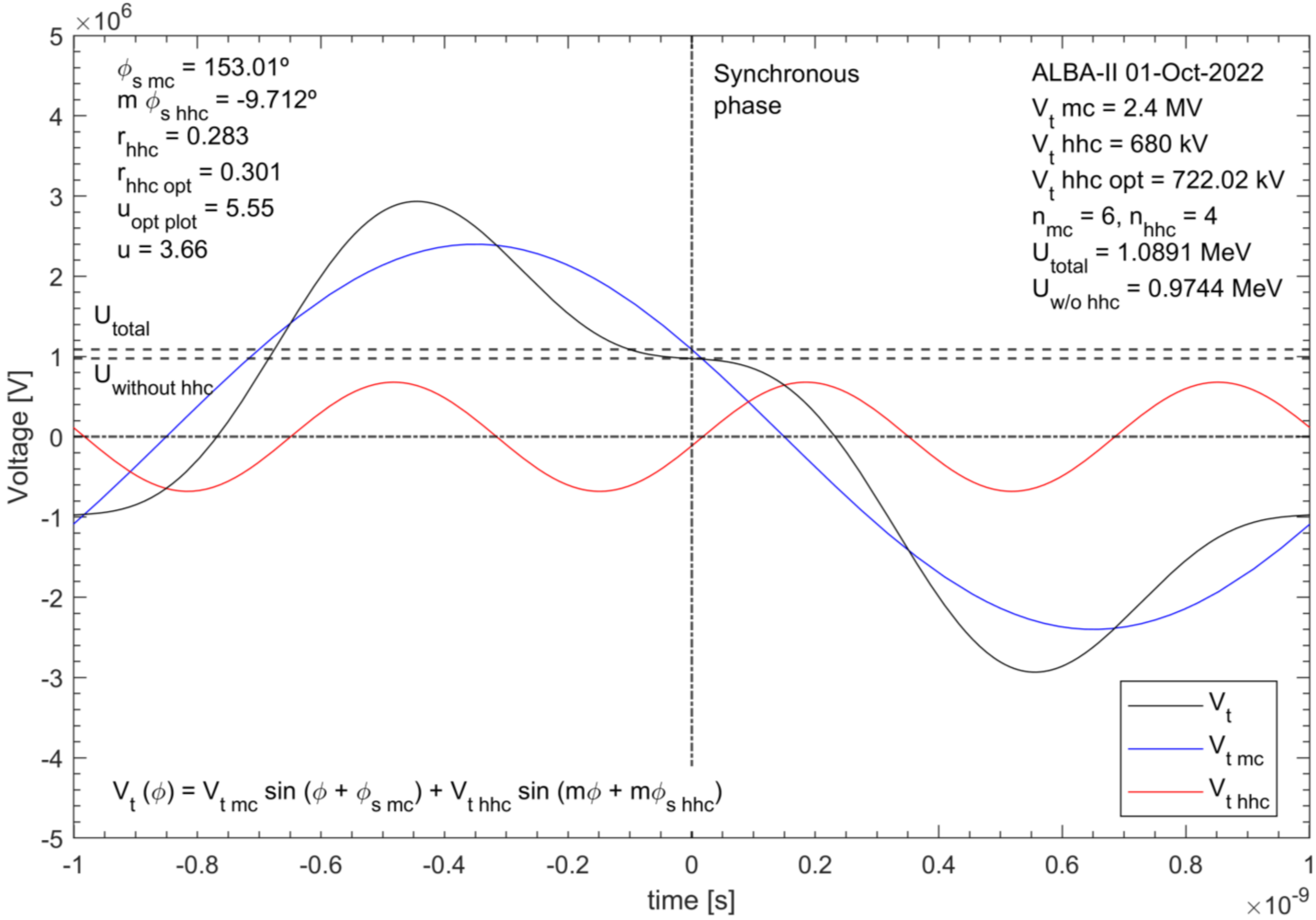
NC ACTIVE HC - BASELINE



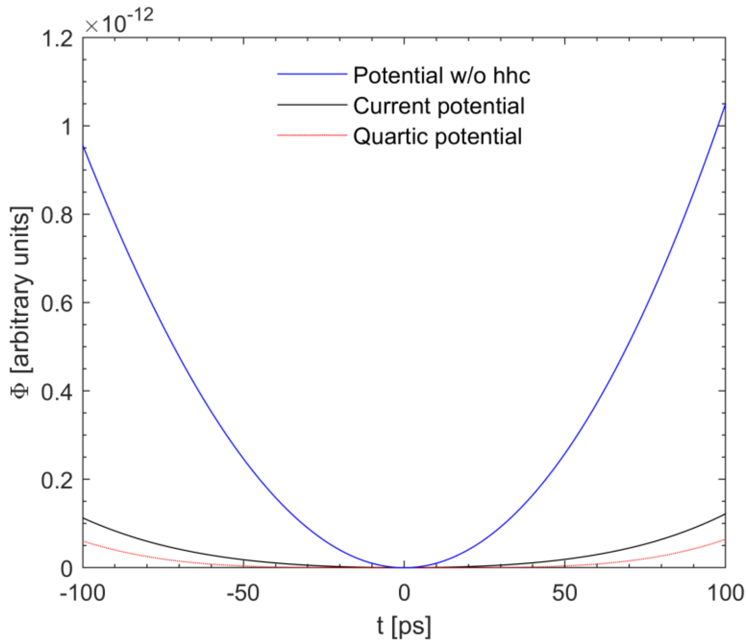


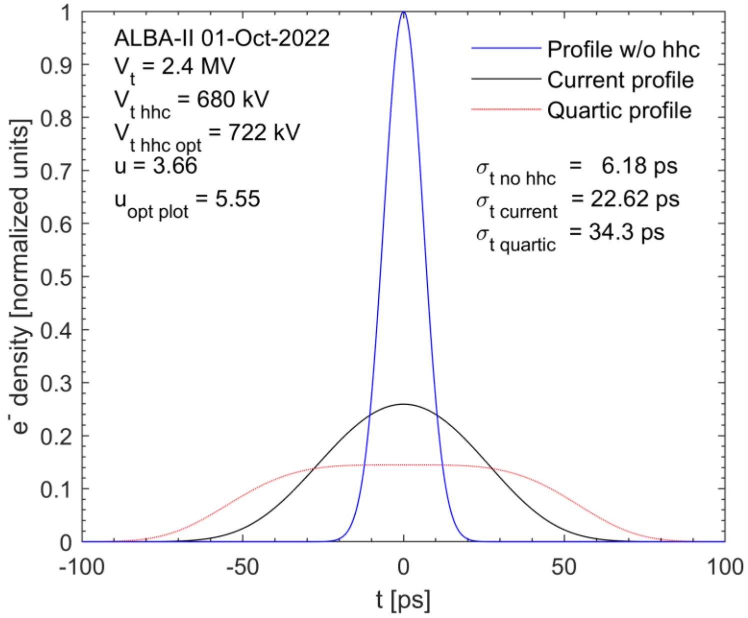
- To reach 170 kV in each HC, 4.56 kW are supplied by the transmitters and 8.6 kW by the beam
- For each main cavity, around 79 kW are supplied, resulting in a 69% of efficiency

NC ACTIVE HC - BASELINE



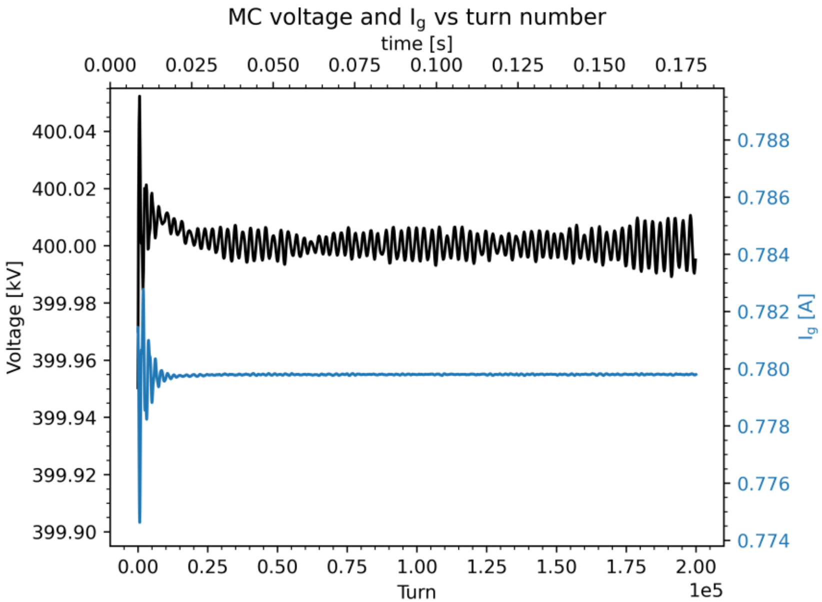
NC ACTIVE HC - BASELINE

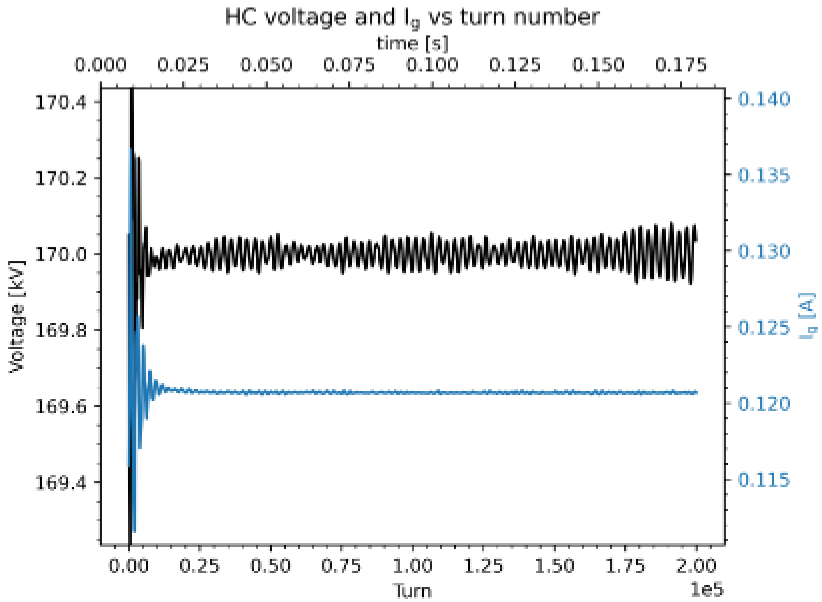




NC ACTIVE HC - BASELINE

Full filling pattern - MC vs HC

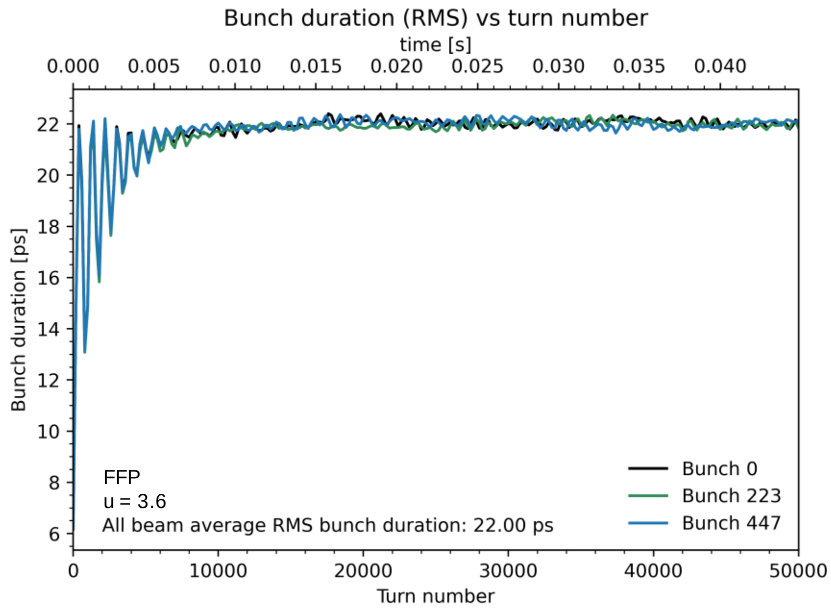


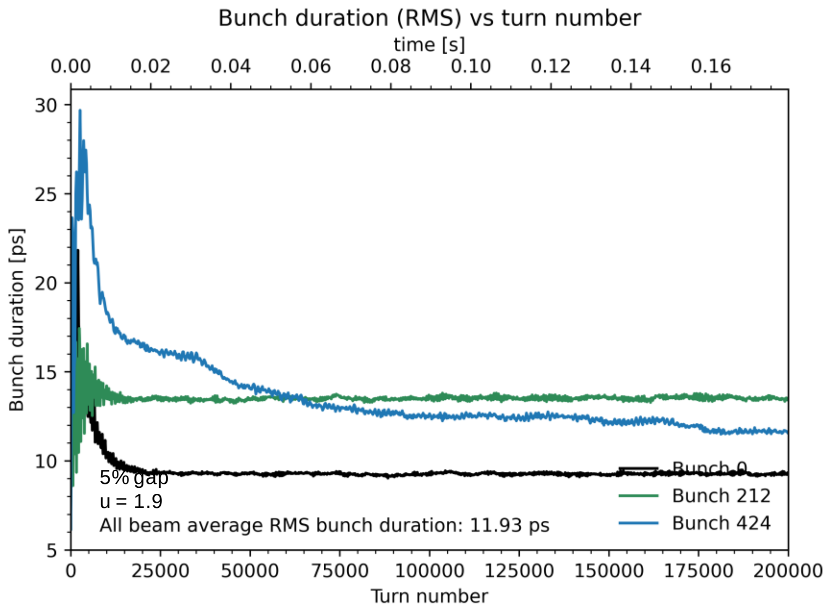


- The PI feedback loop is stable. The control action converges rapidly and the voltage values remain stable around their setting

NC ACTIVE HC - BASELINE

Full filling pattern vs 5% gap

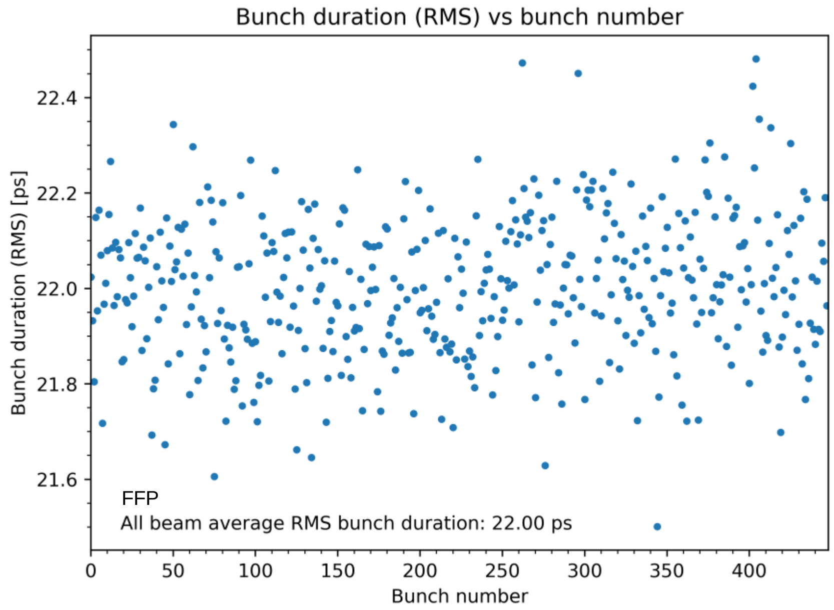


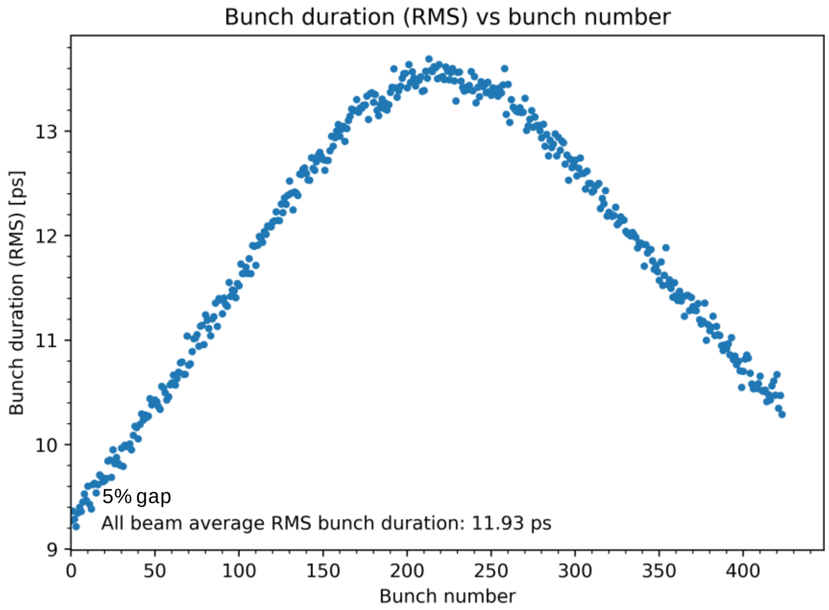


- The transient beam loading originated from a gap in the beam is also calculated. Around a 46% of bunch lengthening would be lost with a 5% gap
- For the time being, only a simple PI loop has been studied

NC ACTIVE HC - BASELINE

Full filling pattern vs 5% gap

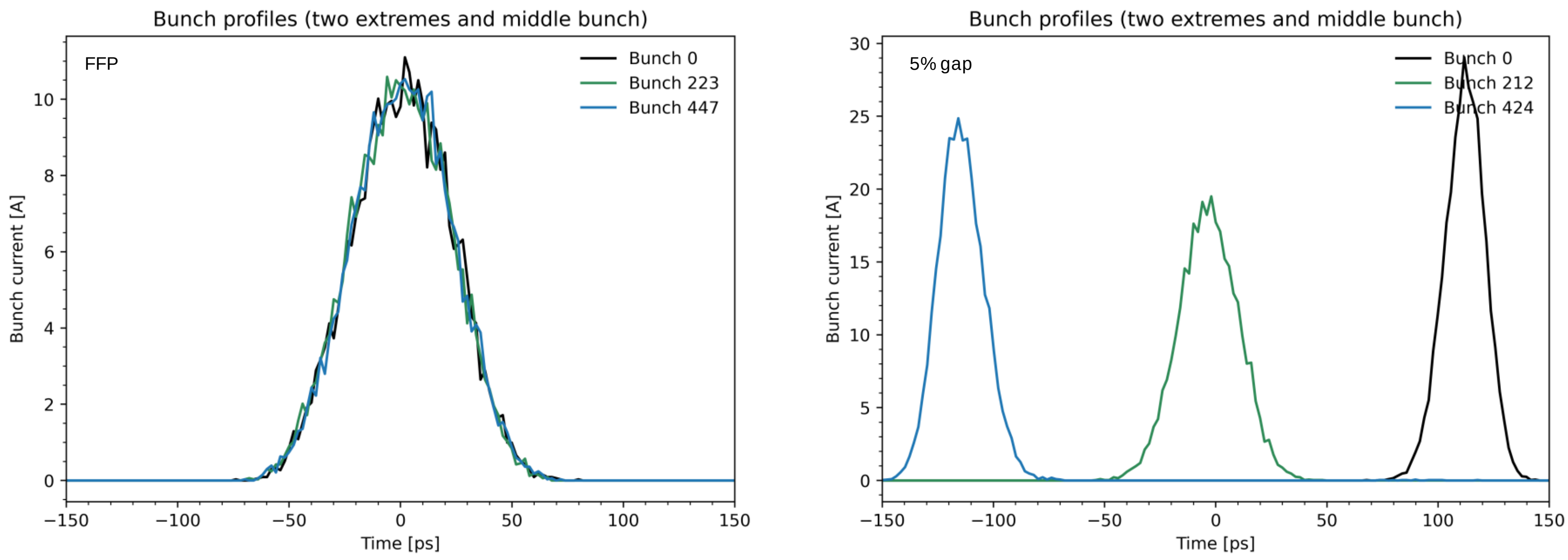




- The transient beam loading makes a non-uniform bunch duration along the bunch train, so each bunch would end having a different lifetime

NC ACTIVE HC - BASELINE

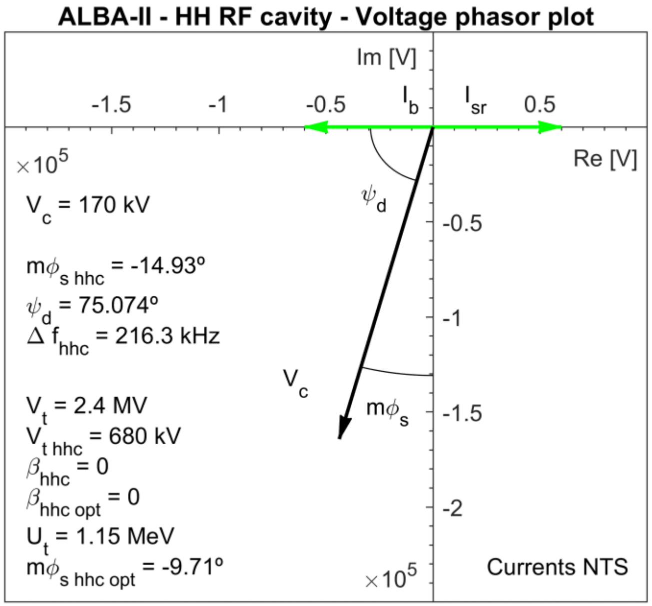
Full filling pattern vs 5% gap

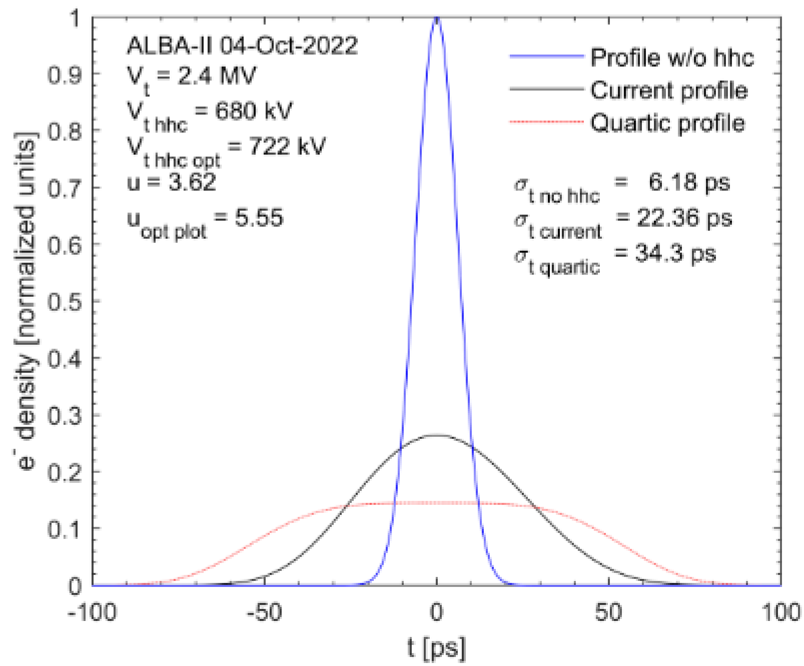


- Not being around the optimal harmonic voltage, the bunch shape still looks Gaussian

OPTIONS (FOR COMPARISON)
NC/SC PASSIVE

NC PASSIVE HC

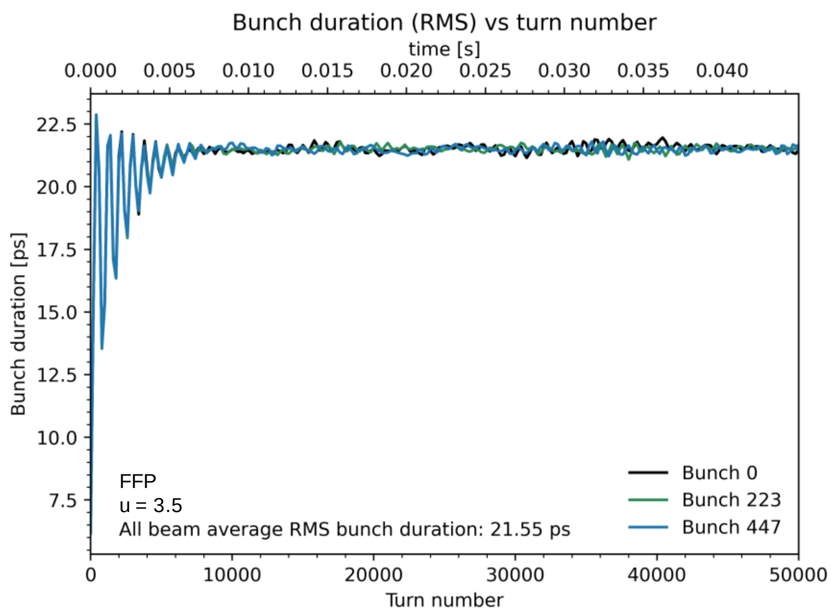


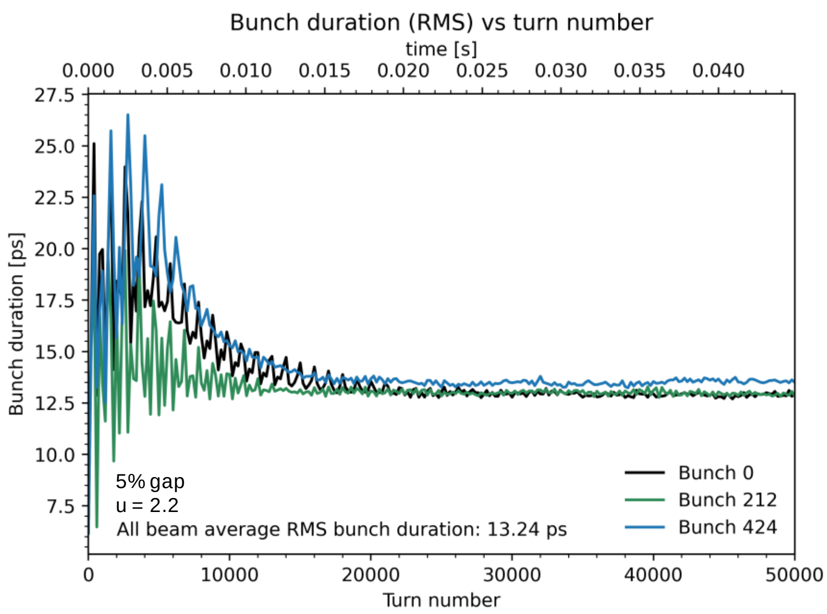


- For full filling pattern, operating the cavities in passive mode allows up to 700 kV of harmonic voltage. For comparison, 680 kV are shown here

NC PASSIVE HC

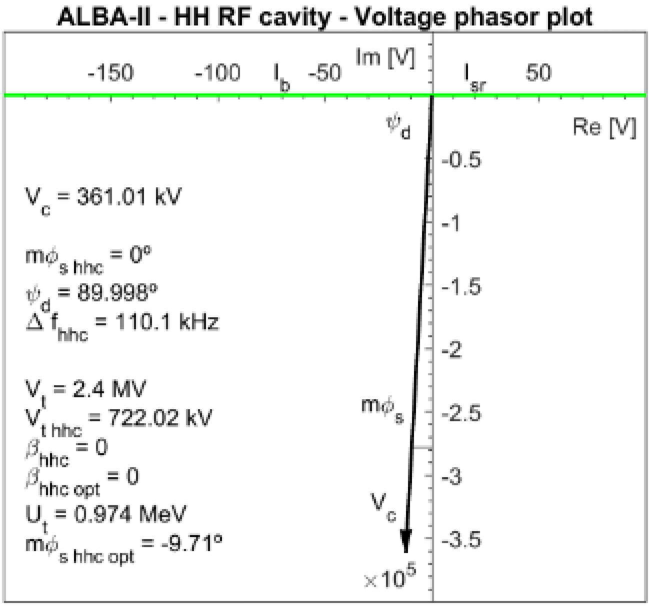
Full filling pattern vs 5% gap

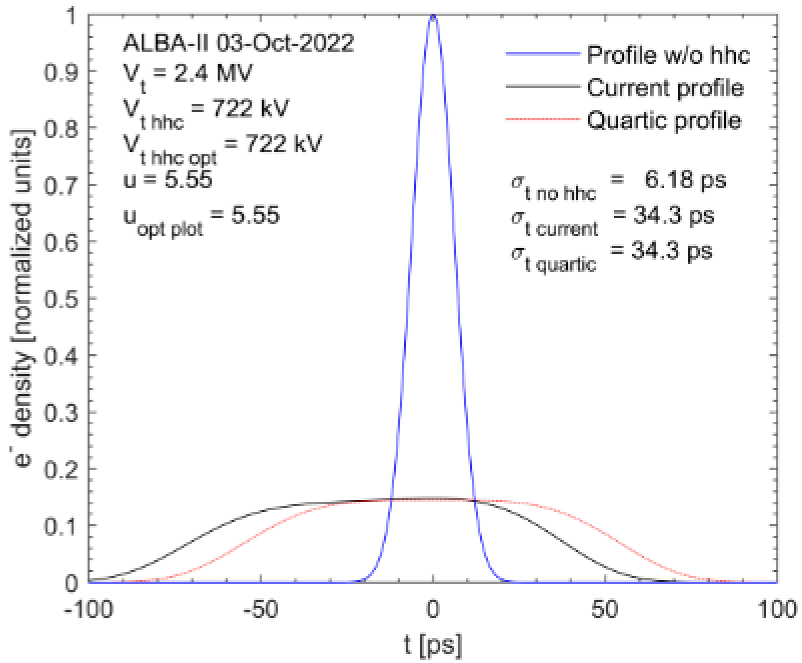




- Around a 39% of bunch lengthening would be lost with a 5% gap, in passive mode. The phase offset would be around 27º from head to tail of the bunch train

SC PASSIVE HC

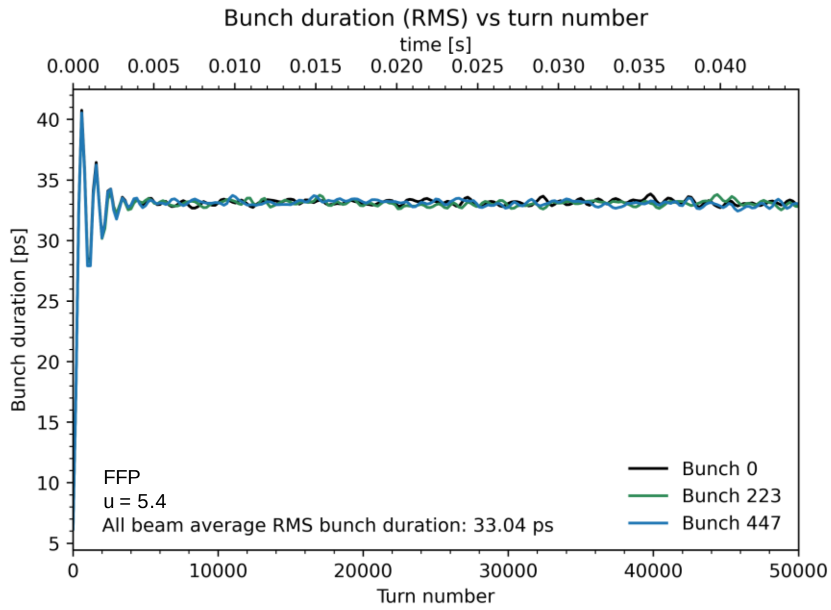


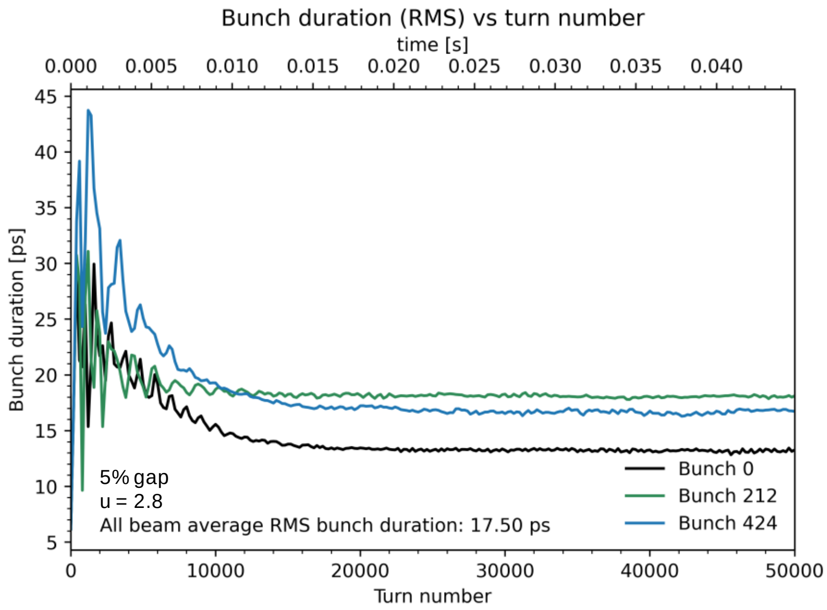


- The CEA SC 3HC parameters have been used as a reference

SC PASSIVE HC

Full filling pattern vs 5% gap





- The superconducting option yields the expected results. It is able to reach the optimal harmonic voltage without entailing beam instabilities

OPTIONS COMPARISON

Option	τ_T UFP (0% gap)
Main 2.4 MV C = 0.5%	0.36 h
Main 2.4 MV C = 100 %	3.4 h

- At least **10 h of Touschek lifetime** (τ_T) are desired for a reasonable reliability and life expectancy of the injection system (around u = 3)

Option	u 0% gap	u 2% gap	u 5% gap
Main 2.4 MV + HH 680 kV active NC	3.6	2.3	1.9
Main 2.4 MV + HH 680 kV passive NC	3.5	2.8	2.2
Main 2.4 MV + HH 722 kV passive SC	5.4	3.8	2.8

SUMMARY AND CONCLUSIONS

- For the time being, the designed active cavity would reach around a 94% of the optimal voltage, yielding around a **3.6 bunch lengthening factor** in full filling pattern
- The transient beam loading effect is specially dramatic in the case of active harmonic cavities, reducing its lengthening performance in almost around a 46% with a 5% gap
- It is mandatory to **further study the potential capability** of the harmonic cavity (altogether with the main one) of mitigating the transient beam loading effect and the beam instabilities by means of the **LLRF**
- Using the designed cavity in passive mode is also viable from the beam dynamics point of view

THANK YOU FOR YOUR ATTENTION

And many thanks to T. Olsson and S. Wang from Diamond for their support on Elegant simulations

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