Third Harmonic System Status for ALBA and ALBA-II

J. Ocampo on behalf of the ALBA RF group

19/03/2024

Overview

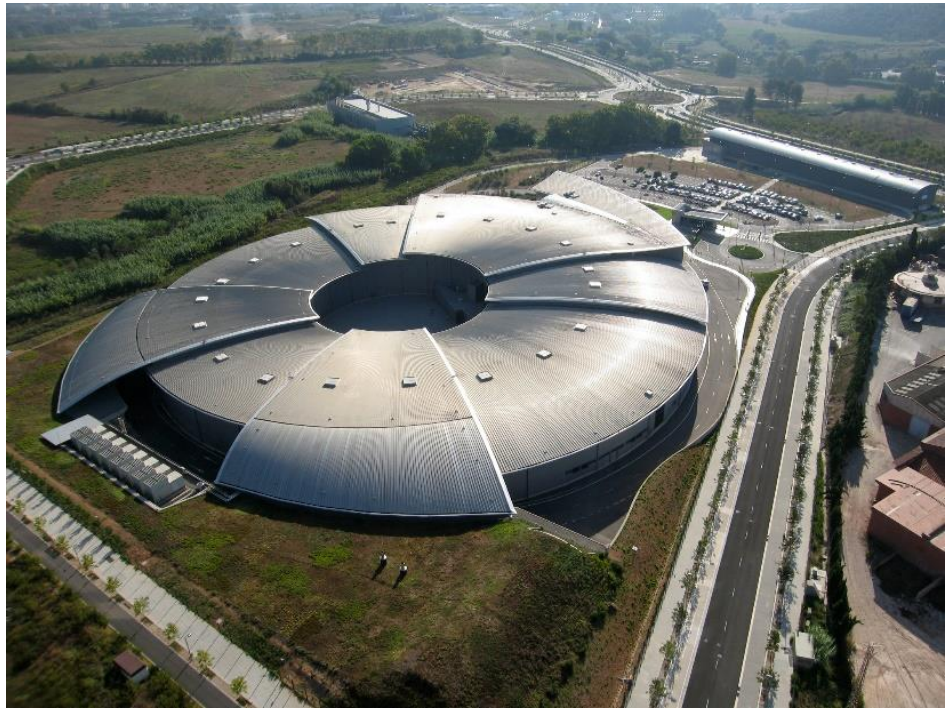
- ALBA overview
- 1.5 GHz hardware for ALBA and ALBA II
- Harmonic RF system installation for ALBA
- Calculations on the Harmonic RF system for ALBA II

ALBA Overview

- ALBA is a 3rd generation light source
- In user operation since 2012
- 12 beamlines currently in operation

Energy	3.0	GeV
Current	250	mA
Circumference	268.8	m
Momentum compaction factor	8.9E-4	-
Loses per turn	1.1	MeV
Emittance	4.5	nm·rad

- Upgrade to 4th generation (ALBA-II) is foreseen for 2030



ALBA RF Overview

EU HOM damped cavity

IOT transmitter

BO SSPA

- Storage ring RF:
  - 6x NC EU HOM-damped cavities at 500kV
  - 12x 80kW L3 L-4444C IOTs

RF frequency	500.0	MHz
Total voltage	3.0	MV
Cavity shunt impedance	3.3	MΩ
Unloaded quality factor	29500	-
Coupling factor	2.7	-
Beam power	275	kW

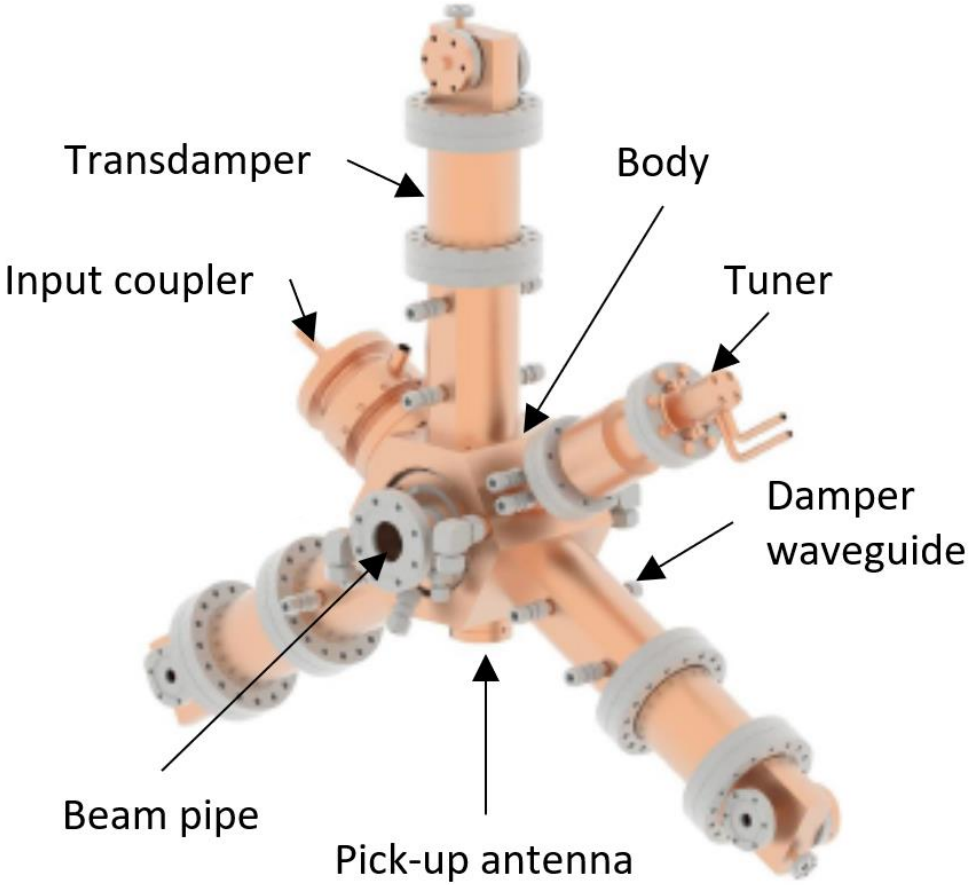
  - No harmonic RF system (yet...)
- Booster RF:
  - 5 cell PETRA cavity
  - 55kW BTESA SSPA

1.5 GHz hardware for ALBA and ALBA-II

Harmonic EU Cavity

Central frequency	1499 MHz
Shunt impedance	1,1 MΩ
Quality factor (Q_0)	13000
Tuner range	12.4 MHz
Input power	16 kW
Accelerating voltage	200 kV
Longitudinal HOM impedance	≤ 5 MΩ. MHz
Transverse HOM impedance	≤ 50 kΩ/m
HOM damping	External load through Transdampers

- Series CfT. to be awarded soon



For much more about this cavity check presentation by P. Solans

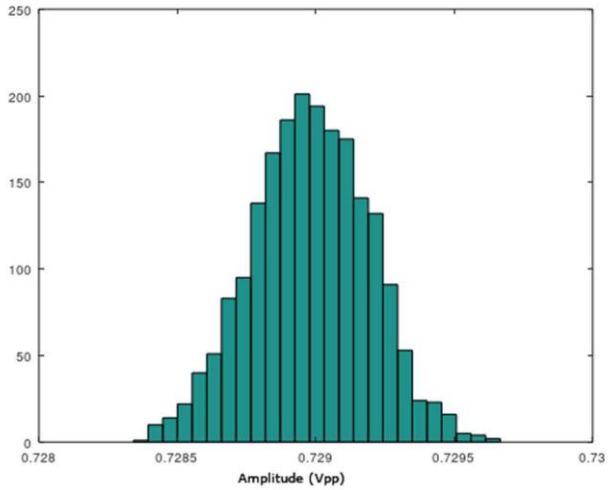
1.5GHz SSPA prototype

- 1.5 GHz 5 kW SSPA prototype
  - 2x 2,5 kW modules
  - 5 MHz bandwidth (3dB)
- GaN transistors to maximize efficiency
  - 72% drain efficiency
  - 50.1% wall efficiency
  - Adjustable drain voltage
- Prototype SAT approved in October 2022
- 📢📢 4x20kW Series CfT. published last week!

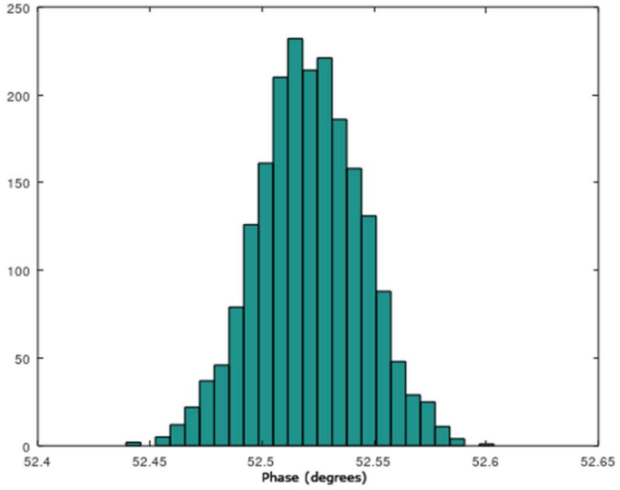
COMMTIA

- 500 MHz and 1.5 GHz new DLLRF hardware for ALBA and ALBA II
  - uTCA based
  - 20x ADC 16-bit
  - 500 MHz: Direct RF sampling
  - 1.5 GHz: Down conversion to 500 MHz
  - Non-IQ demodulation
  - Precision spec.: 0,05% amplitude, 0,1º phase
  - 2 DAC for direct RF output
  - MO input for internal PLL
- FAT last week (successful!)

SAFRAN



FAT ADC amplitude distribution (1dBm).
Measured precision 0,029%



FAT ADC phase distribution (1dBm).
Measured precision 0,023º

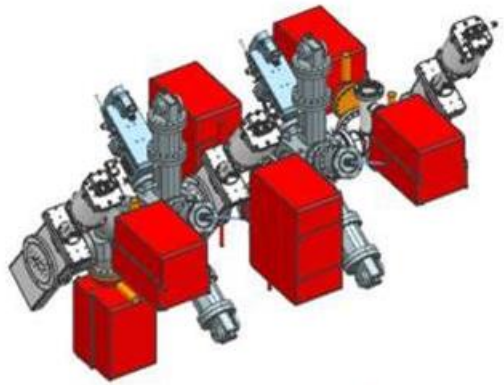
Harmonic RF system installation for ALBA

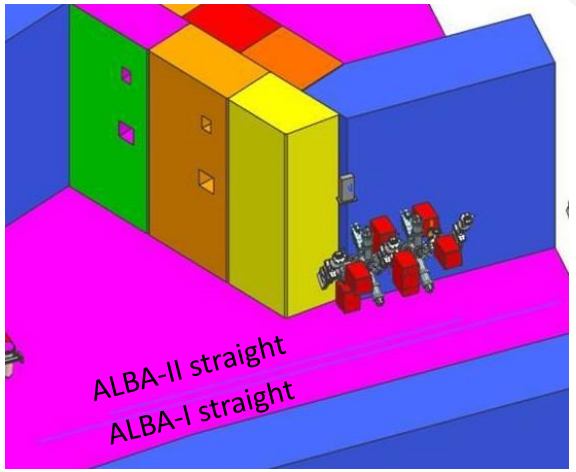
Why add an Harmonic RF system for ALBA?

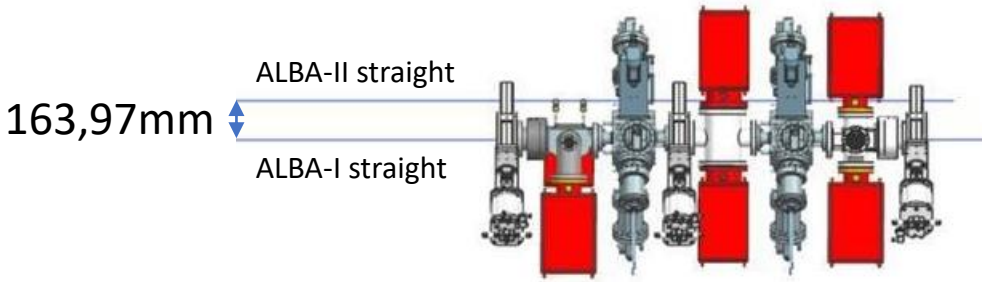
- Lifetime improvement (not needed but always welcome)
  - Reduce injection time for top-up
  - Reduce stress on the injector hardware
  - Reduce radiation
- Develop knowhow and associated techniques so they are ready when needed for ALBA II
  - TBL compensation
  - Trip compensation
  - Improve models to predict beam instabilities
- Budget is available

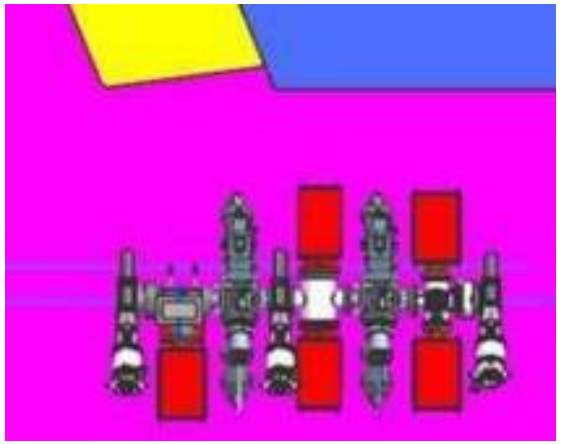
Harmonic cavities installation layout for ALBA

- Install 4 harmonic cavities
- Install in ALBA-I as close as possible to final position in ALBA-II
- 2 straight sections reserved for RF in ALBA-II, close to currently empty sections





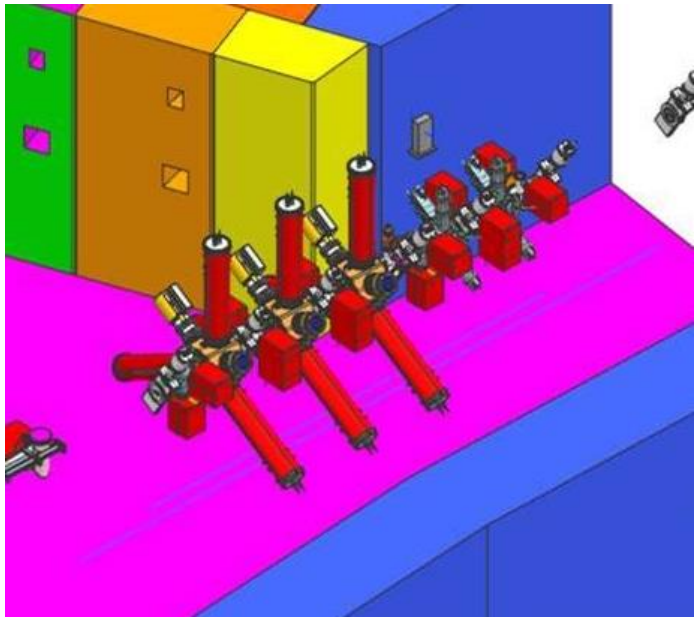


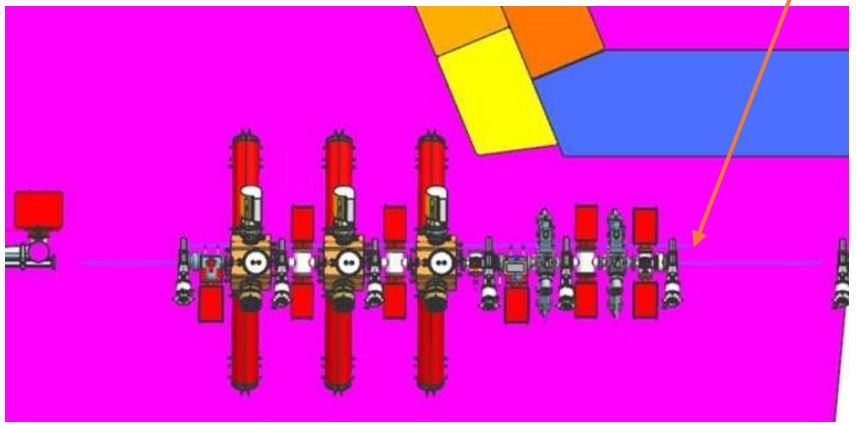


Figures by O. Traver

RF layout for ALBA II

- ALBA-I main cavities will be reused for ALBA-II
- Main cavities will be moved to the new straight section when the 500MHz SSPA arrive, even if this happens before ALBA-II

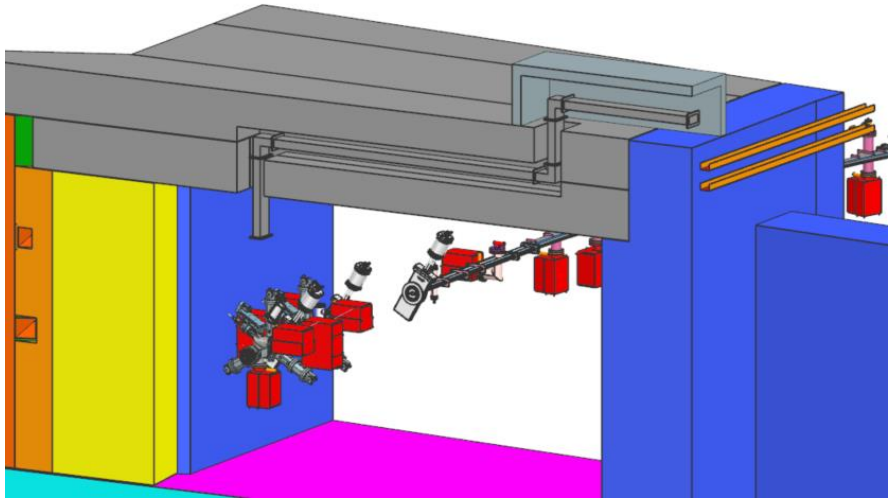


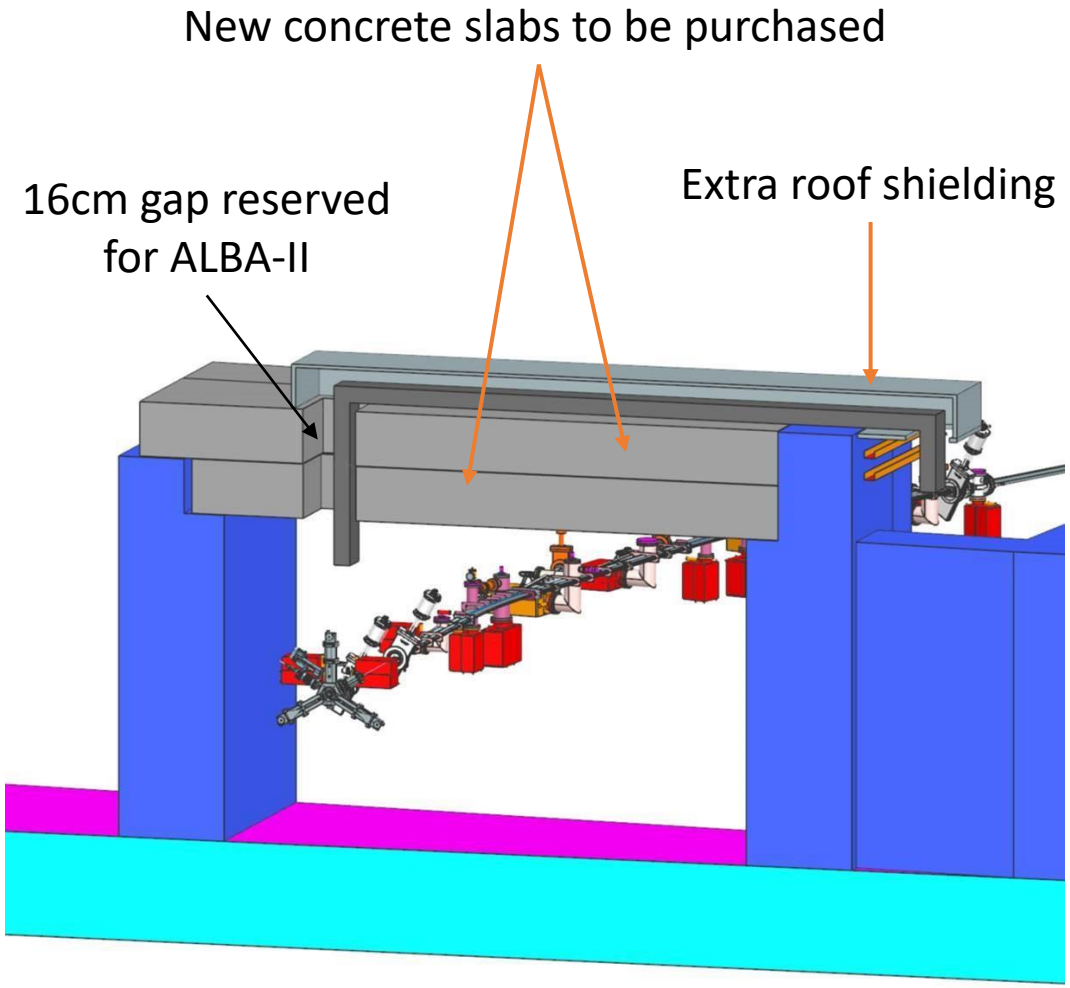


Figures by O. Traver

Waveguide chicane

- No chicane for waveguides exists in future RF locations
- New roof shielding slabs will need to be purchased





Figures by O. Traver

ALBA 3rd harmonic project schedule

- 500 MHz LLRF install: December 2025
- 1.5GHz LLRF install: Summer 2026
- Harmonic cavities:
  - Conditioning Q2 2026
  - Installation: Summer 2026

- 1.5GHz SSPA series: Partial deliveries start early 2026
- Waveguides, circulators, loads...:
  - CfT. to be released early 2025
  - Delivery expected for Q2 2026

Project	*Subtask*	2023-S1	2023-S2	2024-S1	2024-S2	2025-S1	SS	2025-S2	WS	2026-S1	SS	2026-S2
Main and 3rd harmonic system (3HS) LLRF upgrade	*CfT*											
	Comissioning											
	Installation											
3HS Cavities	*CfT*											
	Conditioning											
	Installation											
3HS High power transmitters (SSPA)	*CfT*											
	Installation											
3HS Waveguides (WG + circ. + load + WATRAX)	*CfT*											
	Installation											

Calculations on the Harmonic RF system for ALBA-II

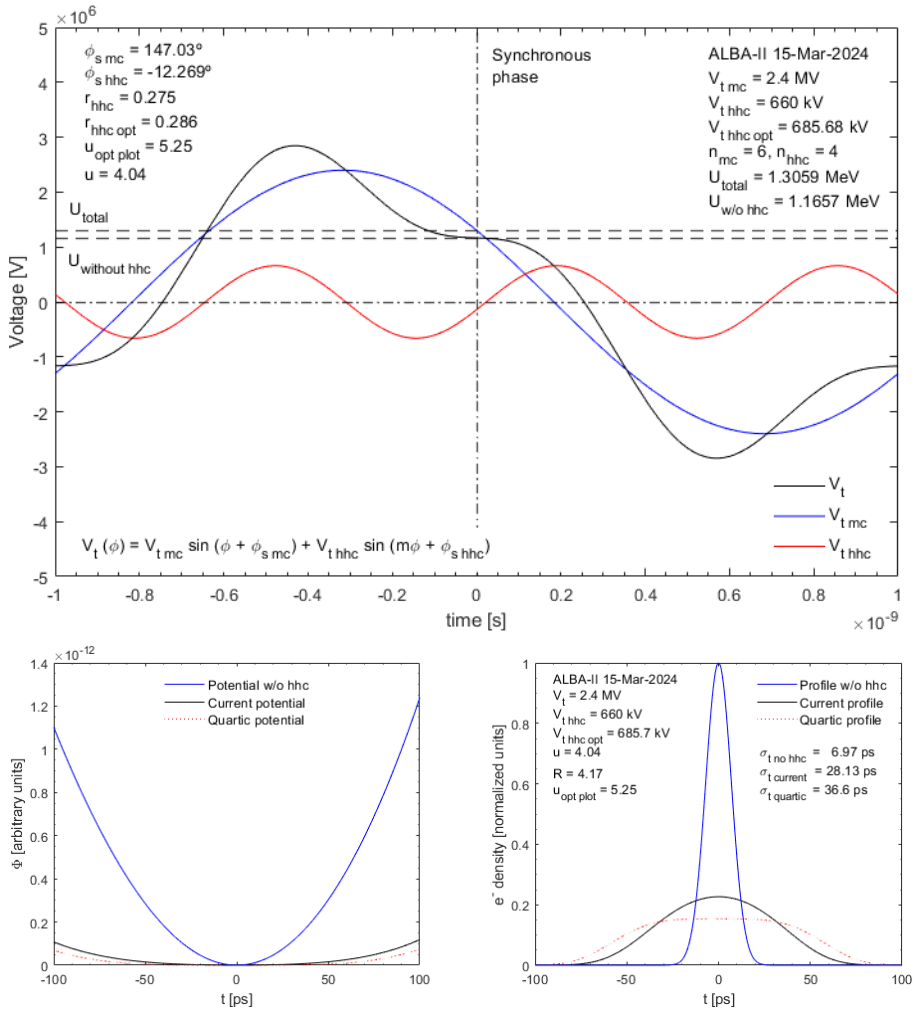
ALBA-II

ALBA-II storage ring parameters		
Beam energy	3	GeV
Circumference	268.8	m
Main RF frequency	500	MHz
Beam current	300	mA
Momentum compaction factor	$9.6 \cdot 10^{-5}$	
Equilibrium emittance	186	pm·rad
Energy loss with IDs	1.13	MeV
Natural RMS bunch duration	6.97	ps
Natural Touschek lifetime FC	5.5	h

- An Harmonic RF system will be needed for ALBA-II in order to achieve a reasonable lifetime
- An active RF system based on the Harmonic EU HOM damped cavity will be used

Theoretical bunch profile for ALBA-II

- Flat potential bunch:
  - Lengthening factor: 5.25x
  - Resulting length: 36.6ps
  - Flat potential harmonic voltage: 685kV
- Bunch lengthening limited by Periodic Transient Beam Loading Instability.
- According to Elegant simulations, our maximum stable:
  - Lengthening factor: 4.04x
  - Resulting length: 28.13ps
  - Stable harmonic voltage: 660kV



Calculations by I. Bellafont

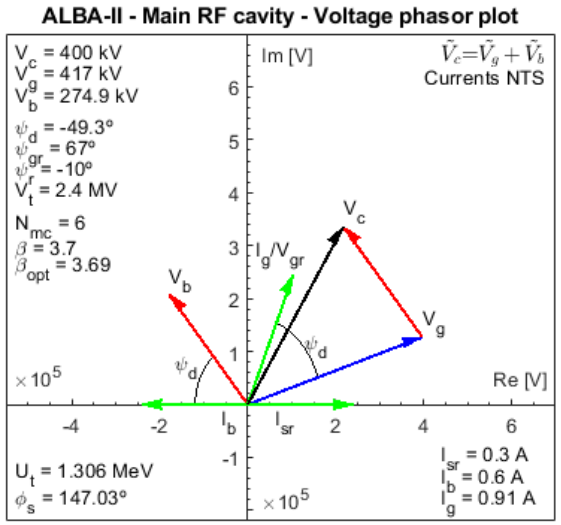
Harmonic system configuration for ALBA II

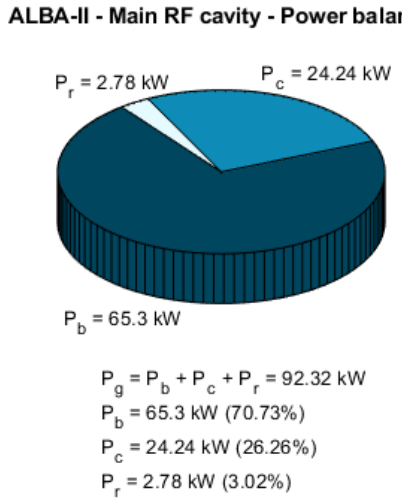
- 6x main cavities

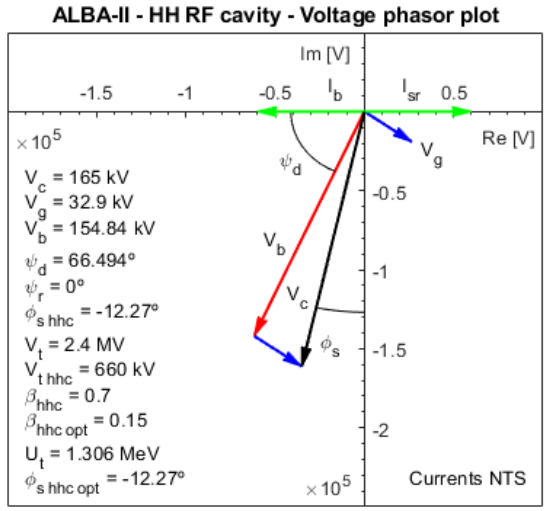
Total voltage	2.4	MV
β	3.7	
Beam power	392	kW
Total RF power	554	kW

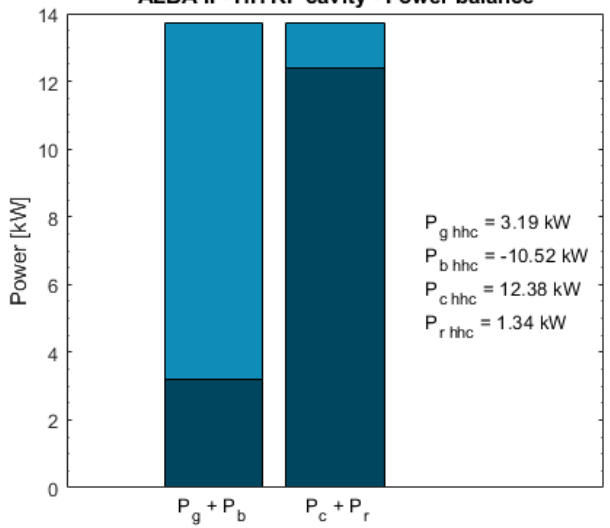
- 4x harmonic cavities

Total voltage	660	kV
β	0.7 ~ 1	
Beam power	-42	kW
Total RF power	13	kW





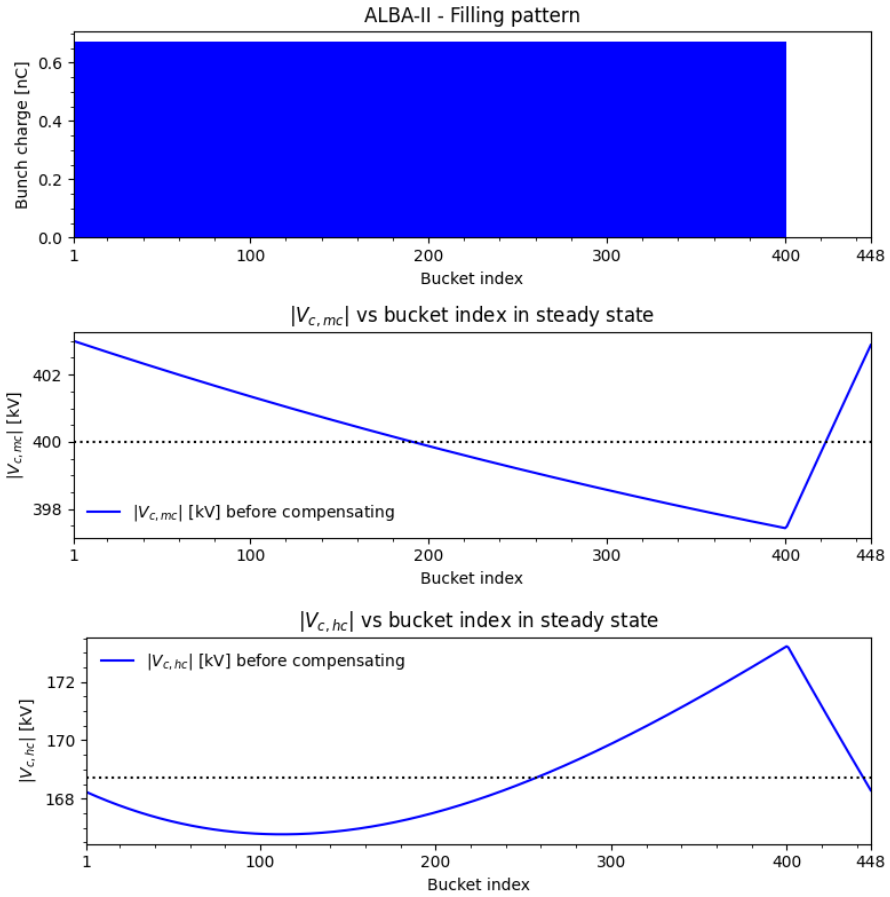




Calculations by I. Bellafont

Transient beam loading in ALBA-II

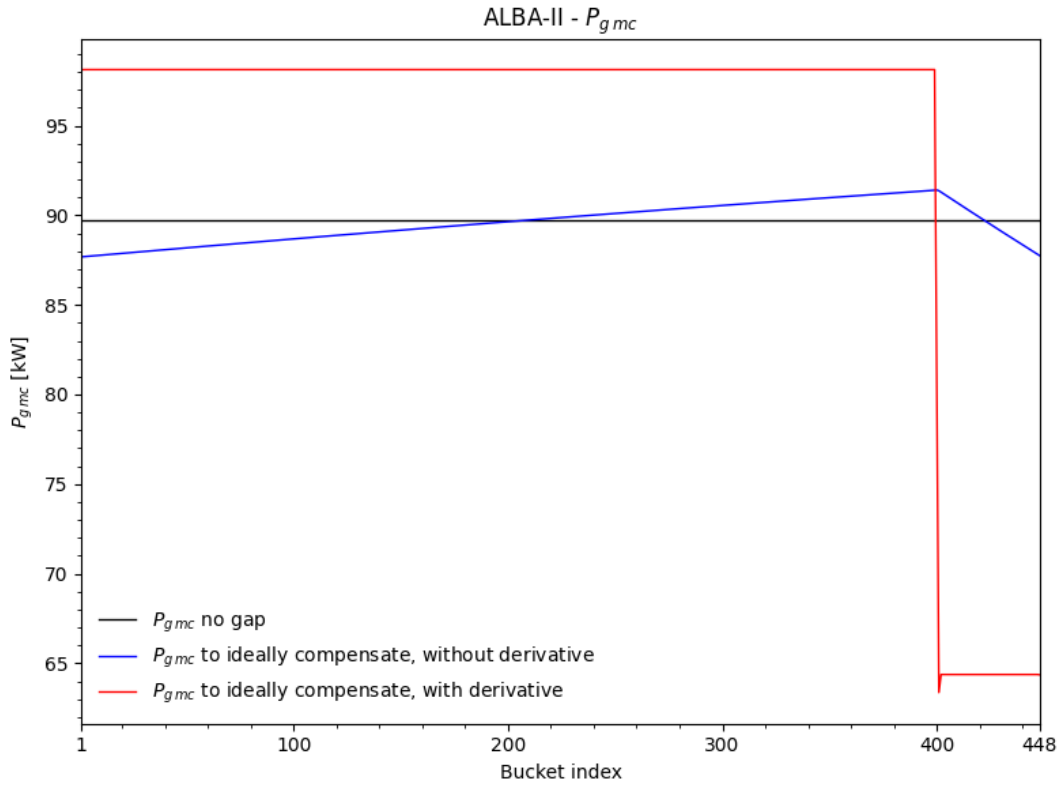
- To avoid ion trapping, a 10% gap is foreseen for ALBA-II
- Non constant beam loading produces a voltage variation
  - Main cavities:
    - Amplitude distortion:13,7%
    - Phase distortion: 1,5º
  - Harmonic cavities:
    - Amplitude distortion: 3.6%
    - Phase distortion: 7,5º
- Average bunch length reduced from 28.13ps down to 18.5ps

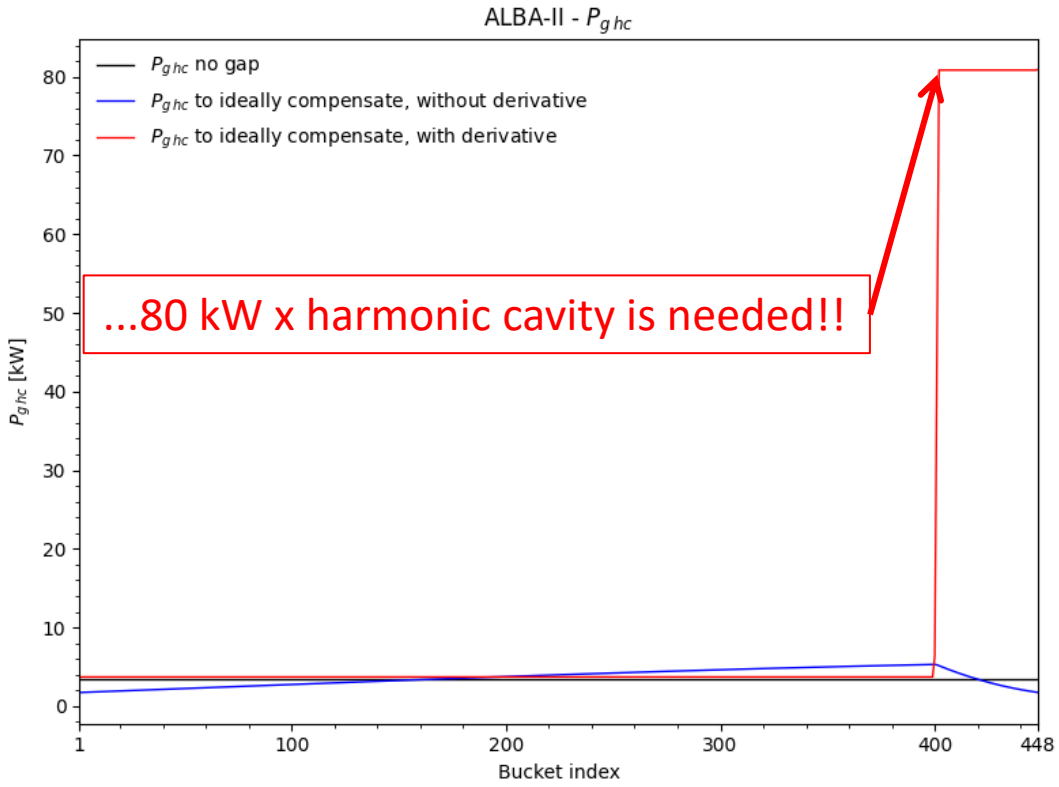


Calculations by I. Bellafont
See also Studies on transient beam loading generated by the superconductive harmonic cavity by Marco Lonza

Transient Beam Loading Compensation

RF drive can be changed to compensate the beam loading transient, but...

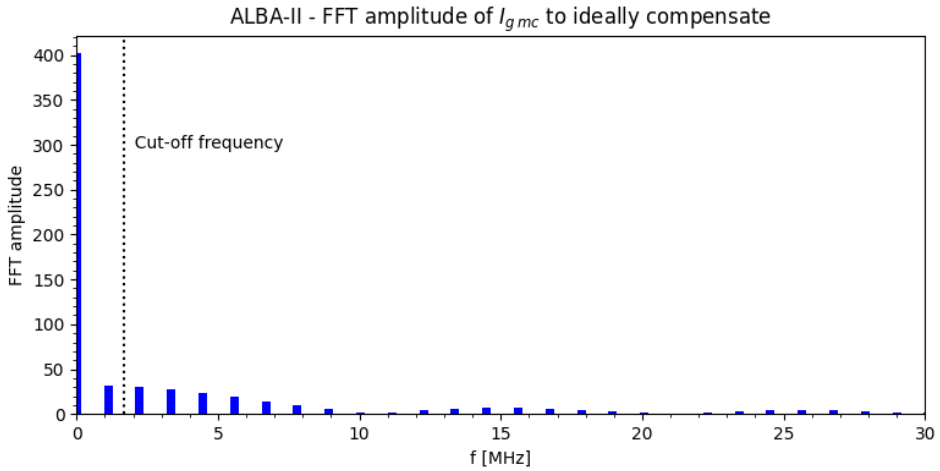


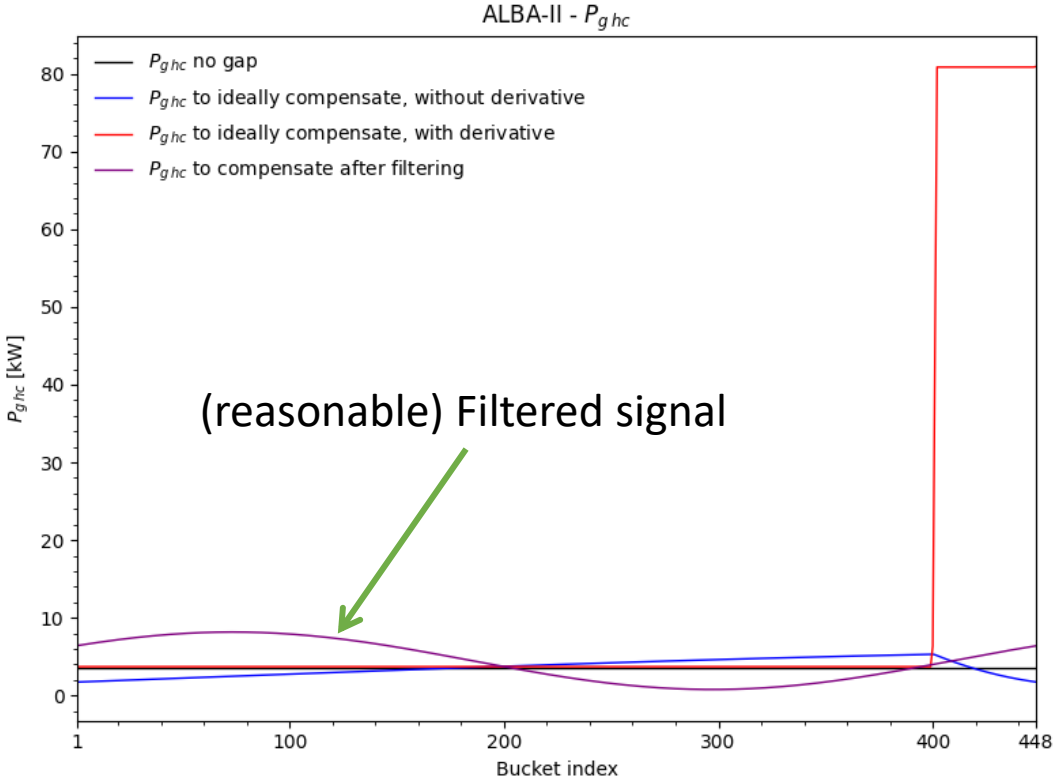


Calculations by I. Bellafont
See also Reduction and compensation of the transient beam loading effect in a double rf system of synchrotron light sources by Naoto Yamamoto

Filtering the Transient Beam Loading Compensation signal

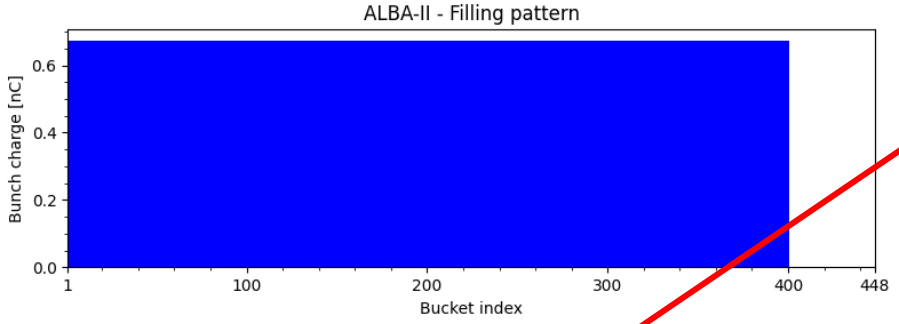
- The signal must be filtered to the bandwidth and power that the cavity can actually accept

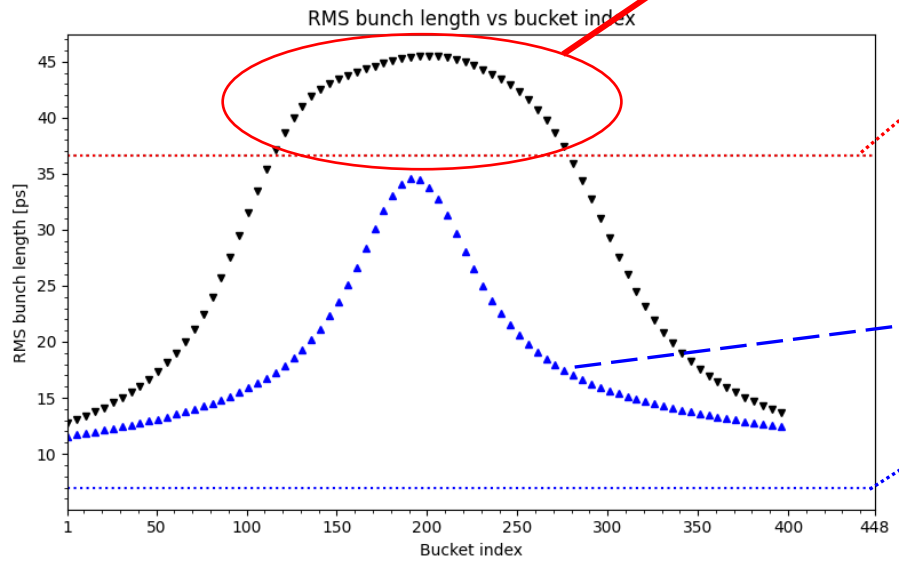




Calculations by I. Bellafont

Compensated bunch length





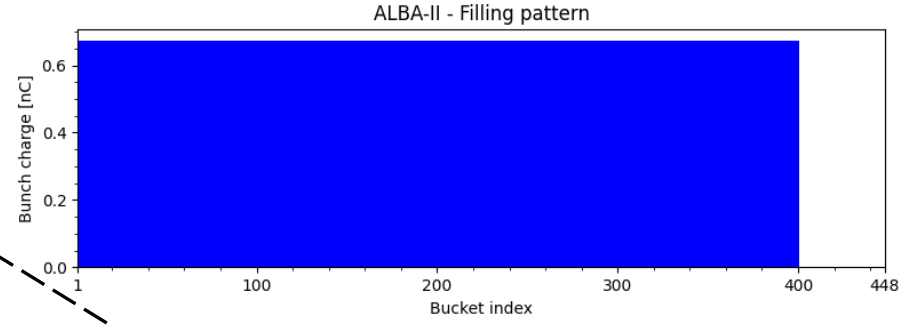
Compensated average bunch length: 30.06ps (4.4x)
Watch out for overstretching!

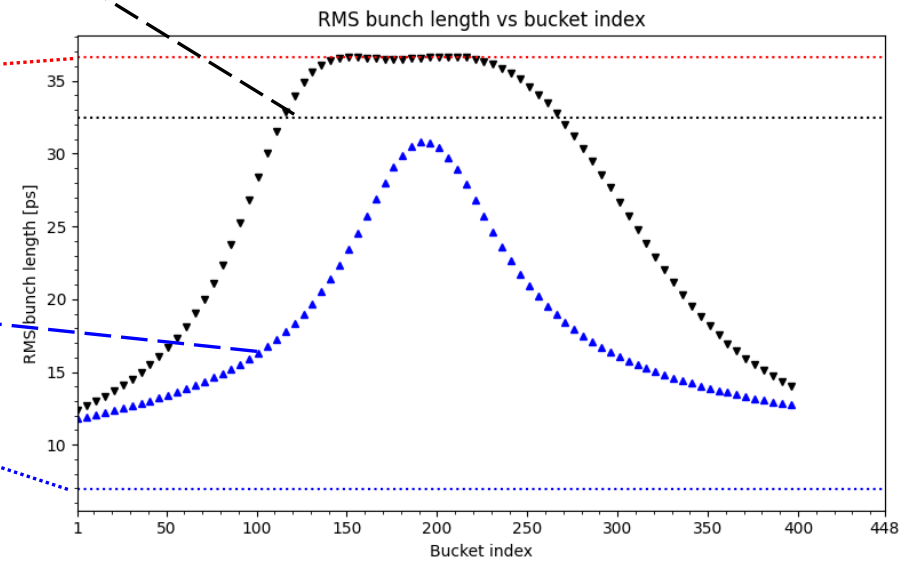
Compensated average bunch length without overstretching: 26.4ps (3.7x)

No gap, harmonic cavities stable bunch length: 36.6ps

Non-compensated average bunch length: 18.8ps

No gap, no harmonic cavities stable bunch length: 7ps





Calculations by I. Bellafont

Summary

- ALBA is on its way to acquire all necessary hardware to install an active 3rd harmonic RF system
- Installation in ALBA will be beneficial both for ALBA and ALBA II
- Transient beam loading effect can be mitigated

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