



ALBA STATUS AND ALBA II UPGRADE

ESLS RF meeting 2025 – Cerdanyola del Vallès, Spain

22/10/2025

Ignasi Bellafont on behalf of the ALBA RF group



OUTLINE

- **Introduction:** ALBA Light Source
- **Operation:** Statistics and issues
- **New Developments:** 3rd HC, 1.5 GHz SSPA, DLLRF, IC3, arc detectors, DRFF
- **ALBA II upgrade:** General overview, stability studies, TBL, trip compensation system
- **Summary**

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INTRODUCTION - ALBA

- **ALBA** is a **3 GeV**, 3rd generation synchrotron light source located in Barcelona, Spain
- User operation since 2012
- **13 beamlines** currently in operation, dedicated to life and material science, solid-state physics. 2 more under construction
- Upgrade towards **4th generation** planned for 2030, ALBA II

Parameter	Value	Unit
Energy	3.0	GeV
Beam current	250	mA
Circumference	268.8	m
Emittance	4.5	nm·rad
Losses per turn	1.1	MeV
Momentum compaction factor	$8.9 \cdot 10^{-4}$	



INTRODUCTION - ALBA

- **Booster:** 1 x 5-cell PETRA type cavity, $V_{\max}$ 1.1 MV, fed with a 50 kW BTESA SSPA
- **Storage Ring:** 6 x EU HOM damped NC cavity, $V_{\max}$ 600 kV, fed with 2 x 80 kW L3 IOT amplifiers

Parameter	Value	Unit
RF frequency	500	MHz
Number of cavities	6	
Total voltage	3.0	MV
Shunt impedance	$3.3 \cdot 10^6$	Ω
Unloaded quality factor	29500	
Coupling factor	2.6	
Total beam power	275	kW



EU HOM damped cavity



IOT transmitter



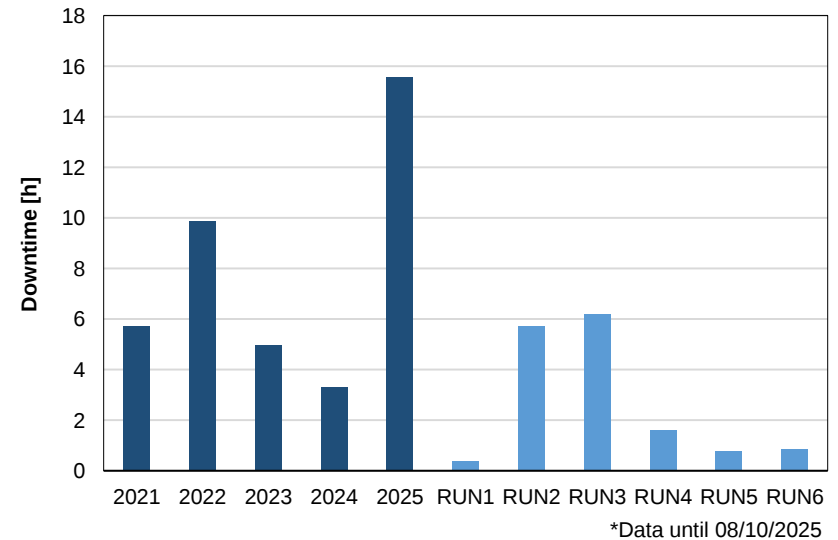
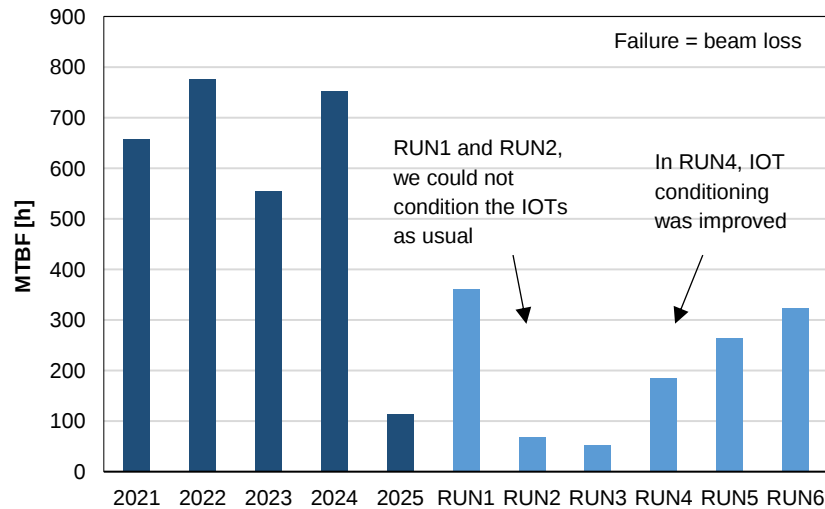
BO SSPA

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STATISTICS - RF Operation

Failures: beam losses due to RF



- 2024 was a good year for the RF, with the lowest total machine downtime due to RF ever recorded
- This year, 2025, we have experienced an extraordinary amount of failures, and consequently downtime, mostly due to:
 1. **IOT degradation** following a deliberate change in settings, which was intended to improving power efficiency (explained with more details in the next slide)
 2. **Aging** of several **electronic** components that monitor system parameters and trigger interlocks

ISSUES - IOT body currents spike

- In 2023 and 2024, the IOT operation settings were changed in order to **lower the energy consumption** and extend the IOT lifetime

	HVPS V	IOT I_{bias}	Avg. power consumption
Before	37 kV	0,20 A	953 kW
After	35 kV	0,05 A	878 kW

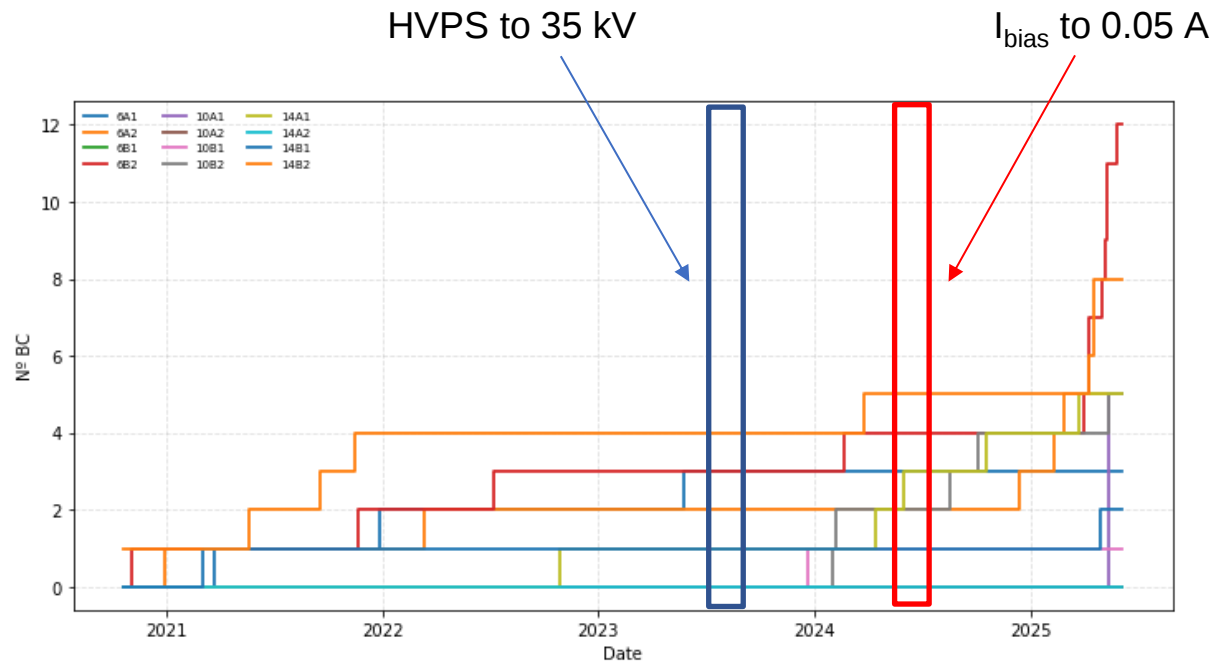
- Final power savings were around 7.8 %
- However, the low HVPS voltage and I_{bias} current drove the IOTs into a non-optimal region, **worsening beam focus** and increasing electron interception on internal surfaces, which triggers the body currents
- The reduced beam power and internal loading at low operating points made the **surface stabilization** to be significantly **slower**, resulting in uncomplete conditionings between RUNs



L3 IOT at ALBA

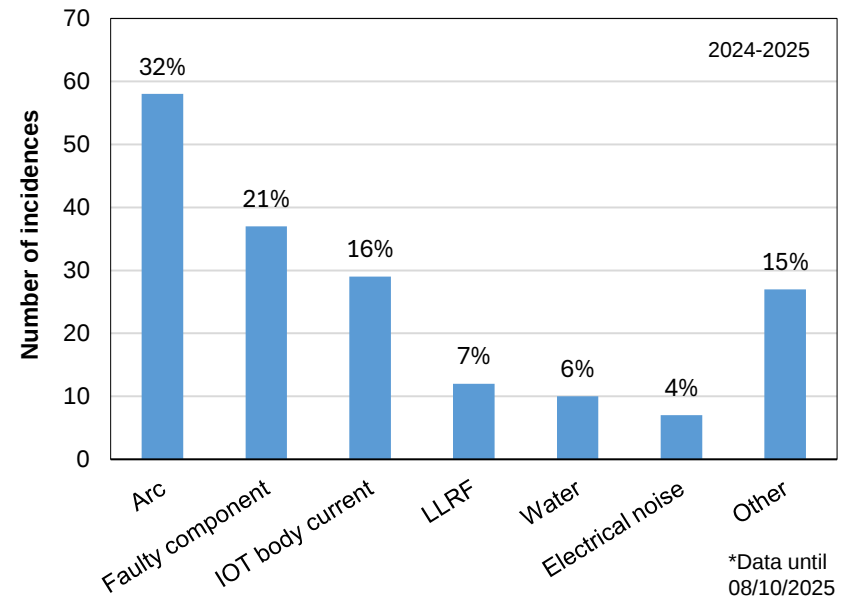
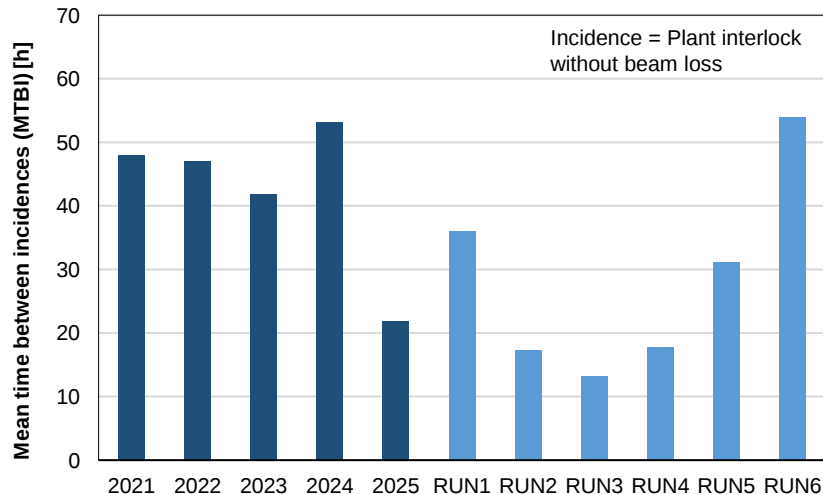
ISSUES - IOT body currents spike

- In the figure below the increase in **body currents** can be observed after the change of settings
- It was therefore decided to **revert** to the previous settings
- IOTs are now being conditioned between runs with higher efficiency, and we are **recovering** their **good performance**



STATISTICS - RF Operation

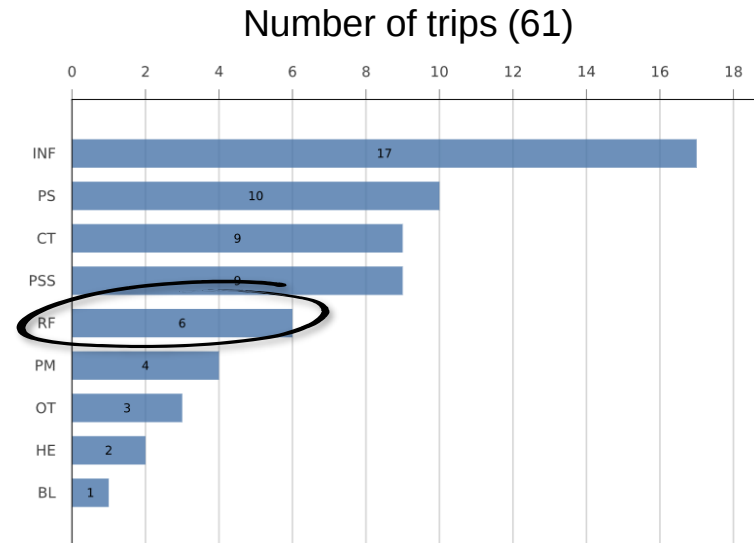
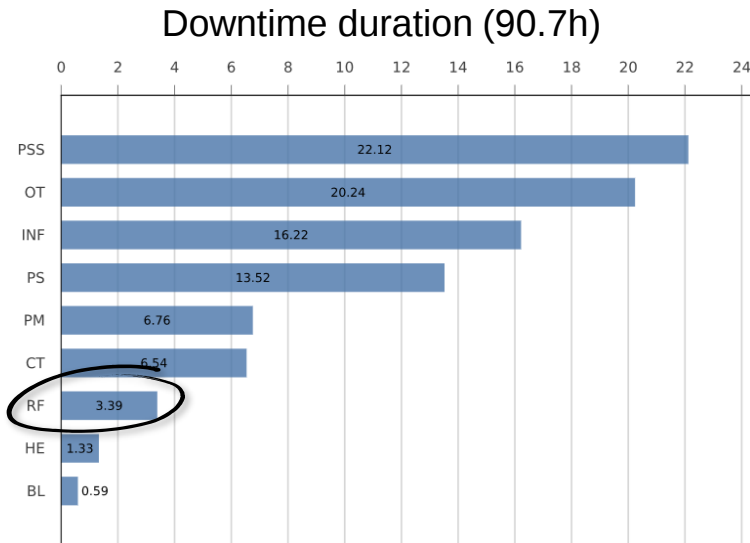
Incidences: RF plant interlocks, but no beam loss



- After **improving** the **conditioning** process and **replacing faulty components**, the **MTBI** returned to **normal levels** during the last RUN
- In most RUNs, the **majority of incidents** are **arcs**, which can account for more than 70% of the total occurrences. Further analysis showed that over 90% of these arcs were fake. To address this, a new arc detection system has been acquired, capable of filtering out such false events

STATISTICS - RF Operation

No-beam events per subsystem in 2024



- In 2024, only **3.7%** (3.4 h) of the **total downtime** (90.7 h) was due to the RF
- RF beam losses are usually **easy to recover**, taking less than 20 min to solve

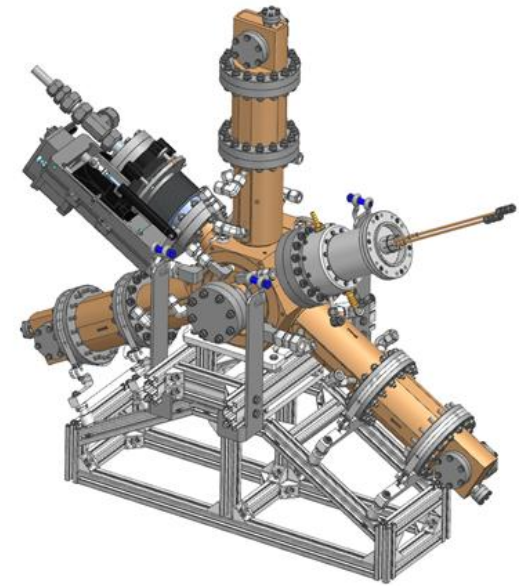
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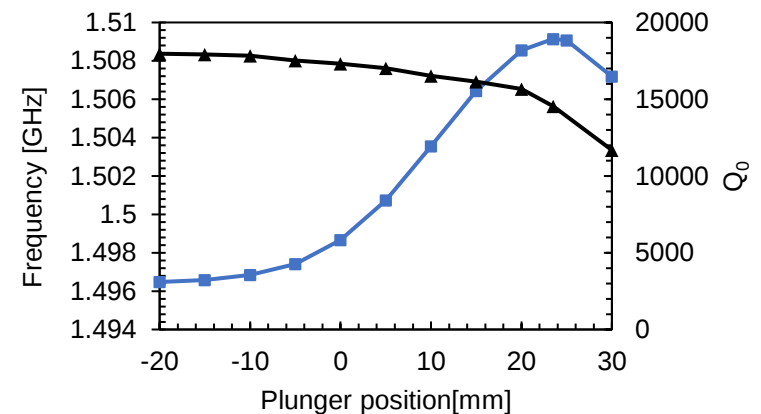
NEW DEVELOPMENTS - 3rd harmonic cavity

- In order to **increase the beam lifetime** of its 4th generation upgrade, ALBA designed a **new 3rd harmonic cavity**, based on the EU HOM Damped 500 MHz cavity
- A **prototype was tested** during 2023-2025 at BESSY II, in a collaboration of three institutions (ALBA, HZB and DESY)
- **Manufacturing** of the definitive cavities is **ongoing** (5 cavities). Contract was awarded to RI (Research Instruments)
- Cavities 1 and 2 tuned. Final vacuum testing ongoing. Delivery expected for November 2025
- Cavities 3, 4 and 5 ready to tune. Delivery expected for January 2026

P. Solans et al., DOI: [10.18429/JACoW-IPAC25-WEBD2](https://doi.org/10.18429/JACoW-IPAC25-WEBD2)

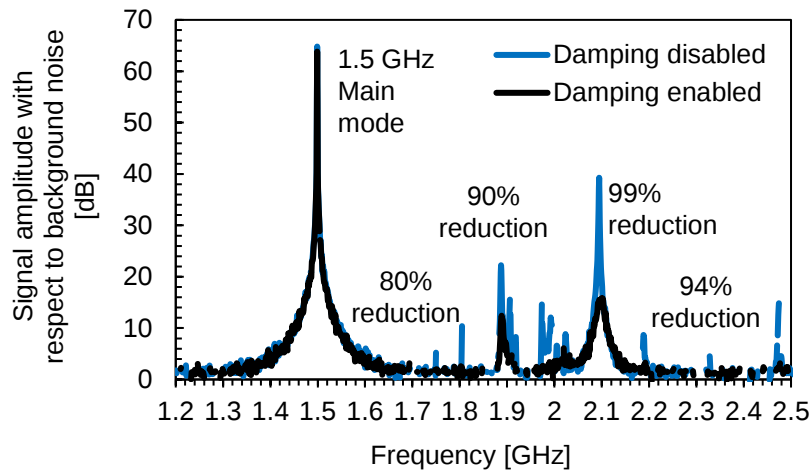


3HC model

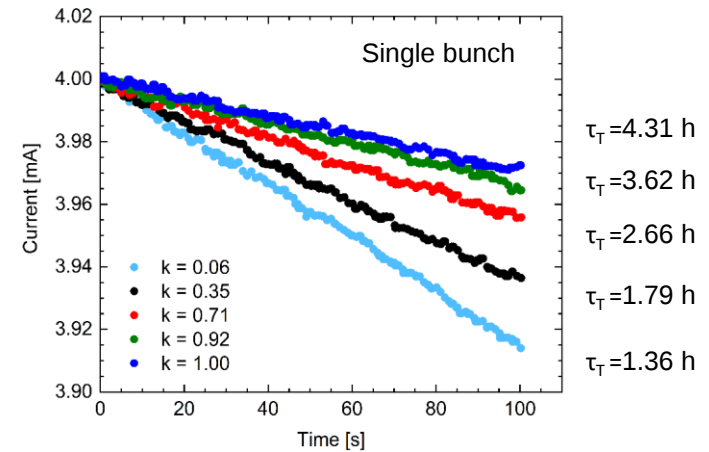


Resonant frequency and Q_0 vs plunger position before final brazing

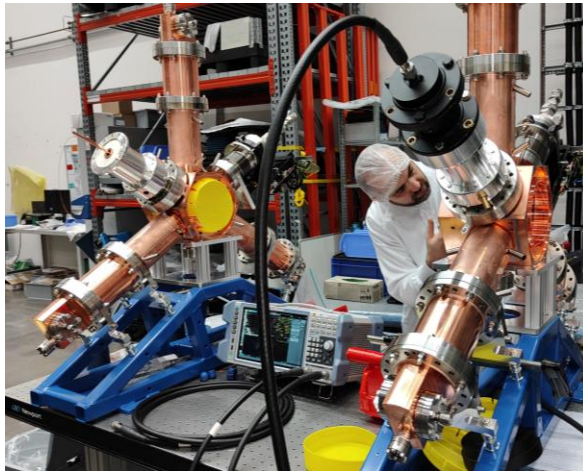
NEW DEVELOPMENTS - 3rd harmonic cavity



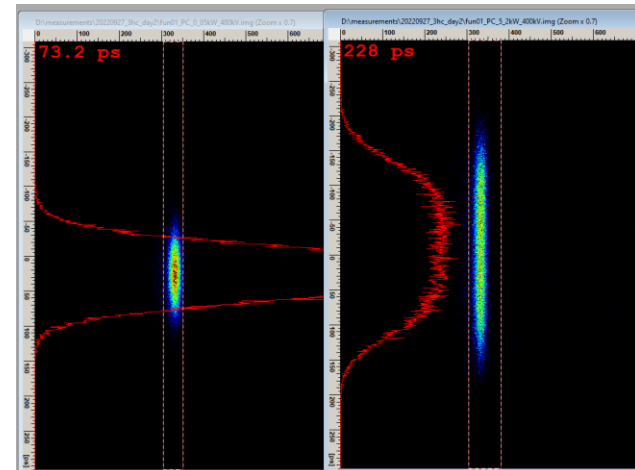
Cavity voltage spectrum before and after HOM damping activation



Lifetime measurements with different ratios of optimal 3HC voltage at BESSY II



3HC Research Instruments factory test

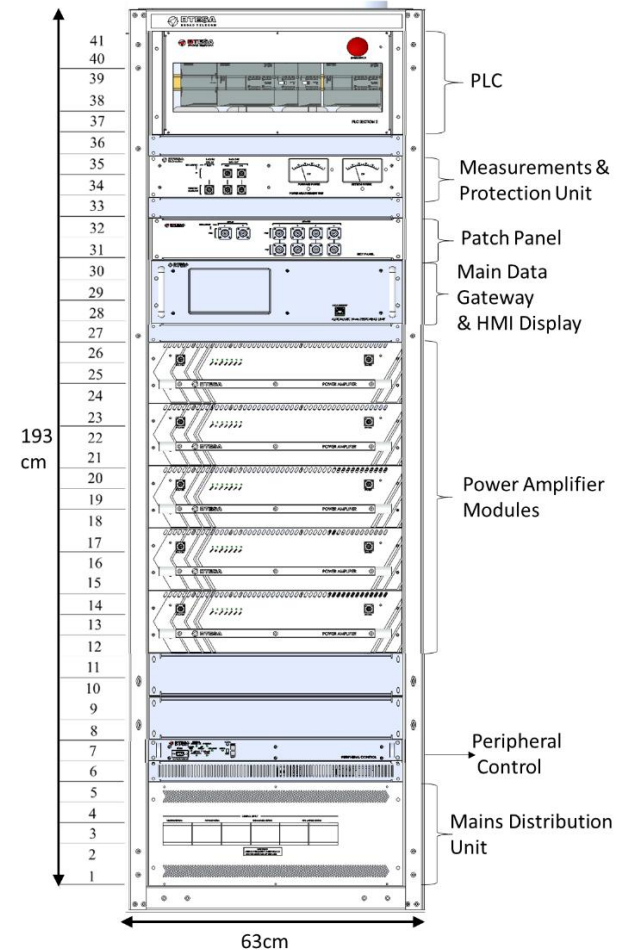


ALBA-HZB-DESY 3HC commissioning

NEW DEVELOPMENTS – 3rd Harmonic SSPA

- Call for tender (CFT) was published at beginning 2024 for 4 x 1.5 GHz **20 kW SSPA**, to feed the **active 3HC**
- Contract awarded to **BTESA**
- Each amplifier rack will consist of six modules
- Assembly of the prototype for the first amplifier module is already in progress
- The Site Acceptance Test (**SAT**) is scheduled for **September 2026**

Parameter per amplifier module	Value	Unit
P1dB	67	dBm
Module Gain	80.4	dB
BW	5	MHz
SNR	72	dB
Water Flow	9.55	l/min



NEW DEVELOPMENTS - 500 MHz DLRFF

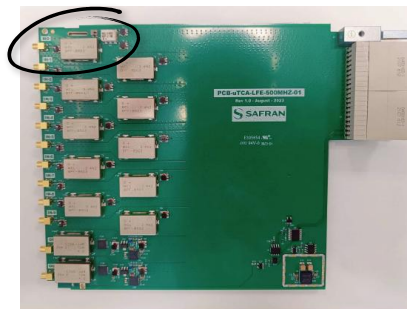
SAFRAN produced and delivered custom made design of the fundamental **LLRF** system. It includes:

- uTCA platform NATIVE-R2 Chassis
- SoC Zynq UltraScale+ FPGA from Xilinx
- 20x ADC: 250 MSPS and 16 bit (PIN, MAX: 10 dBm)
- 4x DAC: 2.5 GSPS and 16 bit (POUT, MAX: 8 dBm)
- 64x GPIO
- 2 GB DDR4 memory for postmortem analysis: 32 bits @ 160 MHz
- No down/up conversion: Direct sampling
- External reference: Master oscillator

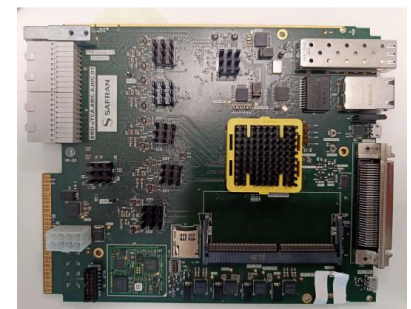


uTCA chassis

MO
↓



RTM Board (Analogue)



AMC Board (Digital)

S. Shaker et al., doi:[10.18429/JACoW-IPAC25-THPS133](https://doi.org/10.18429/JACoW-IPAC25-THPS133)

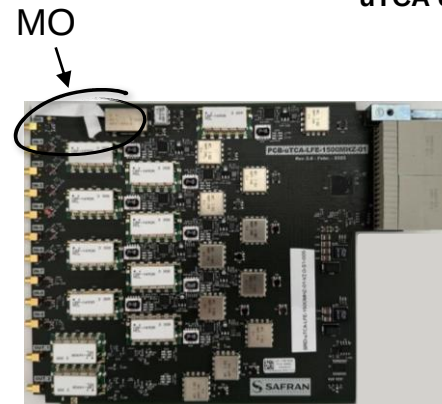
NEW DEVELOPMENTS - 1500 MHz DLRFF

SAFRAN produced and delivered custom made design of the harmonic **LLRF** system. It includes:

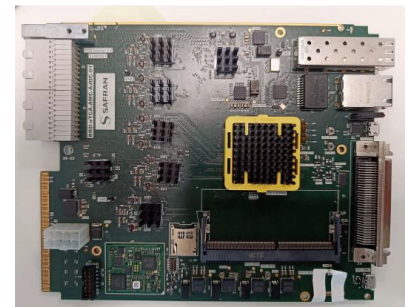
- uTCA platform NATIVE-R2 Chassis
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- 64x GPIO
- 2 GB DDR4 memory for postmortem analysis: 32 bits @ 160 MHz
- Down/up conversion: IF = 250 MHz
- External reference: Master oscillator



uTCA chassis



RTM Board (Analogue)



AMC Board (Digital)

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NEW DEVELOPMENTS - 3rd harmonic system

- Complete harmonic system installation foreseen for ALBA in 2026

Subsystem	Subtask	2023-S1	2023-S2	2024-S1	2024-S2	2025-S1	SS	2025-S2	WS	2026-S1	SS	2026-S2	WS
Main and 3rd harmonic system (3HS) LLRF upgrade	CfT												
	Installation												
3HS Cavities	CfT												
	Conditioning												
	Installation												
3HS High power transmitters (SSPA)	CfT												
	Installation												
3HS Waveguides (WG+Circ+load)	CfT												
	Installation												
Main system Waveguides (WG)	CfT												
	Installation												
Main system high power transmitters (SSPA)	CfT												
	Installation												

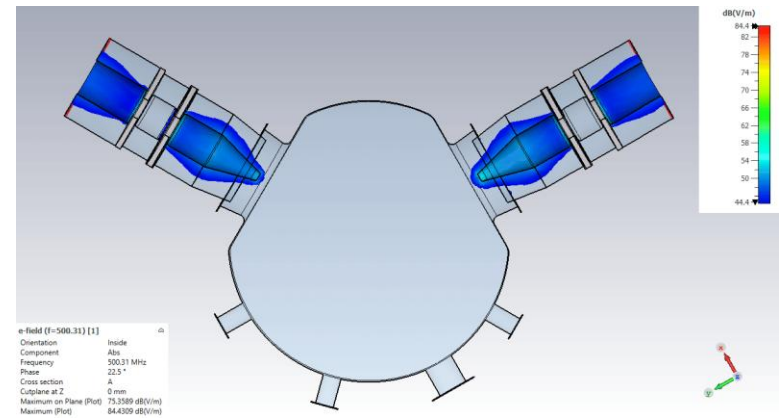
▲
We are here

NEW DEVELOPMENTS – IC3 Conditioning Cavity

- IC3: Input Coupler Conditioning Cavity. Designed to **condition 2 input couplers at the same time**. This need was identified after several IC failed during these 13 years of operation
- Pillbox-like cavity with dual coupler ports
- Corners chamfered to maximize coupling (minimize losses)
- Maximum design power is **160 kW CW**
- Manufactured by AWGE
- Manufactured in stainless steel with a **copper layer** grown by electrodeposition (cost ½ or even 1/3 than traditional manufacturing)



IC3 cavity being tested for leaks



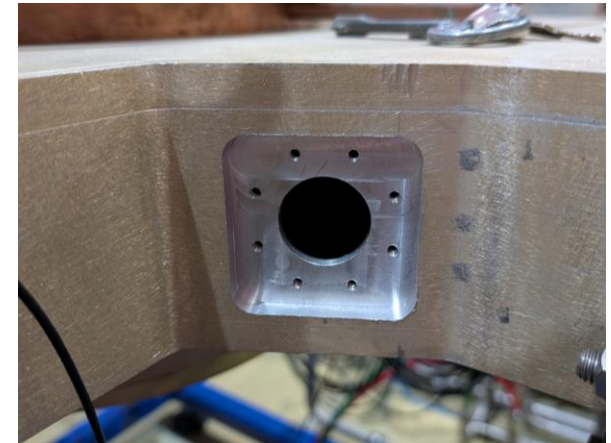
Simulation of RF power entering the cavity

NEW DEVELOPMENTS- Arc Detectors

- In ALBA, we got around **4-7 arcs** per month
- It was discovered that around **90% of them** were **fake** arcs, caused by scintillation, electrical noise, etc.
- In order to filter out the fake ones, a **new arc detector system**, designed by **CERN**, was acquired from MicroStep-MIS, which has 4 photodiodes and an algorithm to differentiate fake from real arcs. It has also been used in the ESRF, with positive results
- Installed in one plant as a test. **No more arcing in waveguide components**
- Arcs still present in the cavity at voltage above 500 kV when there is beam, so we believe they are real
- Fake arcs detected when the beam is lost, in all the detectors placed inside the tunnel, but in this case it does not matter since the beam is already lost



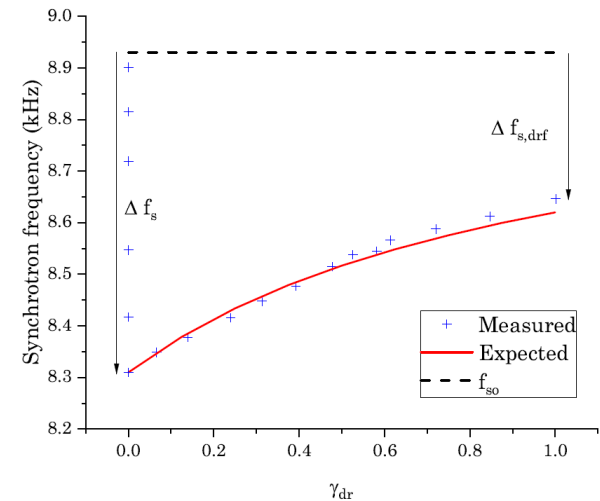
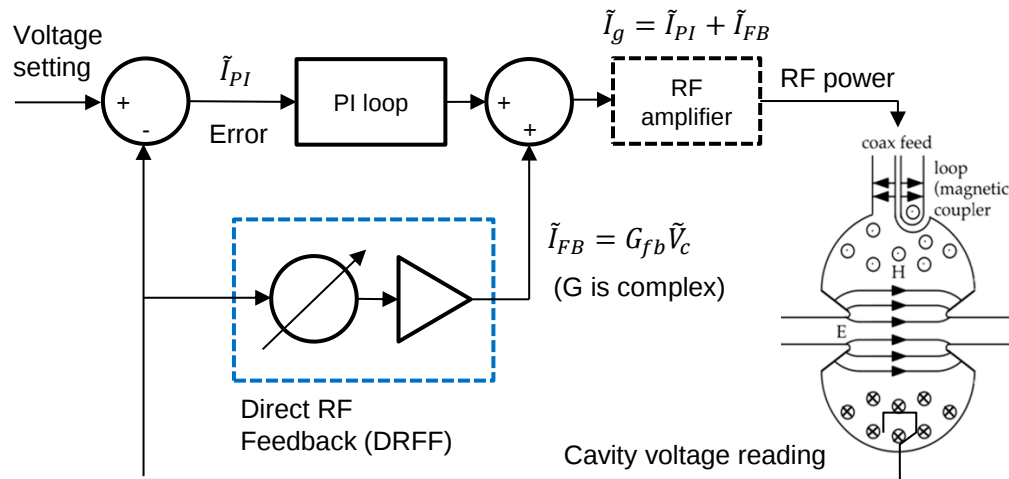
Main components of the new arc detector system



Hole in the circulator drilled to install the new arc detector

NEW DEVELOPMENTS - DRFF

- We are studying the use of a **Direct RF Feedback (DRFF)** to improve the bunch lengthening performance of the harmonic system in ALBA II, by virtually lowering the R/Q ratio and then **mitigate** the Periodic Transient Beam Loading (**PTBL**) instability
- We have already **implemented and tested** a digital DRFF in the main cavities achieving virtual R/Q reductions [1]
- We plan to implement a DRFF module in elegant, the simulation software we use to simulate and predict the double RF system stability, to **predict its efficacy** in our upgrade



1. P. Solans et al., DOI: [10.18429/JACoW-IPAC2024-WEPR76](https://doi.org/10.18429/JACoW-IPAC2024-WEPR76)

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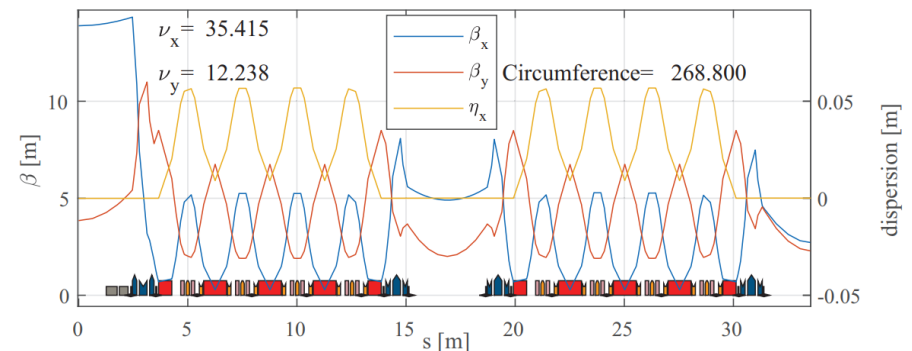
ALBA II – General overview

- **ALBA II** will be the upgrade of ALBA, aimed at having a much lower beam emittance (around **23 times lower**)
- The **storage ring** will be replaced, while the booster ring and LINAC will remain unchanged.
- Installation and commissioning planned for 2030, **operation** expected in **2032**



ALBA II facilities

Parameter - vA2L005D	Value	Unit
Energy	3.0	GeV
Beam current	300	mA
Circumference	268.8	m
Emittance	200.5	pm·rad
Losses per turn	1.07	MeV
Momentum compaction factor	$1.0 \cdot 10^{-4}$	



ALBA II optical functions for half a quadrant of the SR

F. Pérez et al., DOI: [10.18429/JACoW-IPAC2024-TUPG02](https://doi.org/10.18429/JACoW-IPAC2024-TUPG02)

ALBA II – General RF overview

- **Booster RF:** Same as in ALBA, 1 x 5-cell PETRA type cavity, fed with a 50 kW BTESA SSPA
- **Storage Ring:** 6 x EU HOM damped NC cavity + 4 x New EU HOM damped NC 3H cavity

Parameter	Value	Unit
Main RF voltage	2.4	MV
Harmonic RF voltage	680	kV
Number of cavities (MC / HC)	6 / 4	
Main cavity voltage	400	kV
Harmonic cavity voltage	170	kV
Main RF frequency	500	MHz
Harmonic RF frequency	1500	MHz
Bunch lengthening HFP	3.9	
Bunch length HFP	31.6	ps

ALBA II RF system
vA2L005D

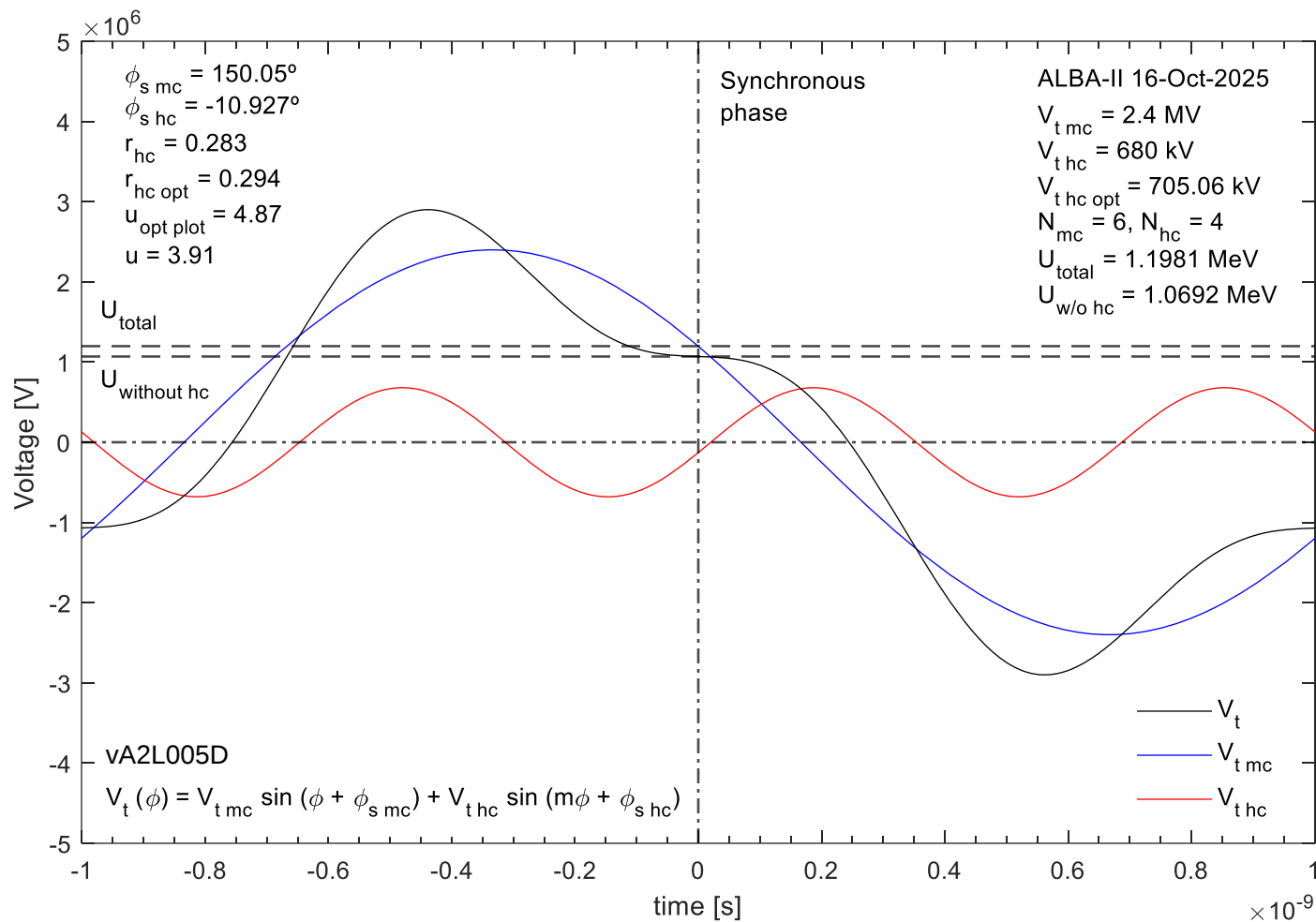


6x Main NC RF cavity
400 kV - 500 MHz



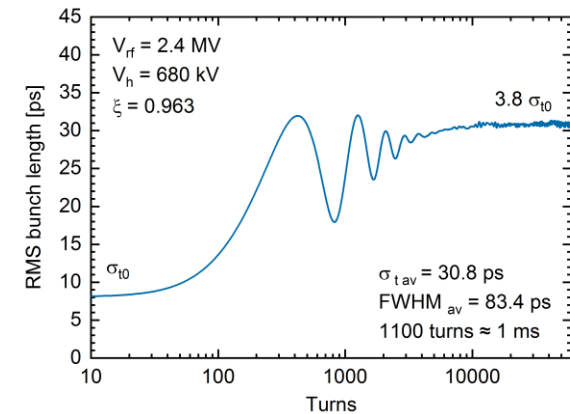
4x Harmonic NC active RF
cavity
170 kV - 1500 MHz

ALBA II – General RF overview

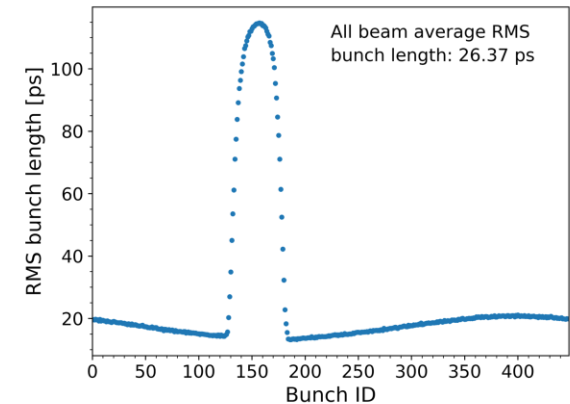


ALBA II – Stability studies

- To evaluate the system stability, several **particle tracking simulations** have been carried out using elegant
- The simulations include the **RF cavities' impedance**, synchrotron radiation damping, a PI control loop, a linear transformation matrix and quantum fluctuations. At this stage, no additional impedance sources are considered
- Each simulation tracks 10,000 particles per bunch over 200,000 turns, corresponding to approximately 0.2 s of real time.
- The simulation, the bunch shape and phase, cavity voltage, beam energy, and emittances are monitored and used to assess the overall system stability
- The simulations predict the onset of **PTBL** instabilities for flatness factors above $\xi = 0.963$. The HC voltage is therefore limited to 680 kV, with 705 kV corresponding to the flat potential (FP) condition.



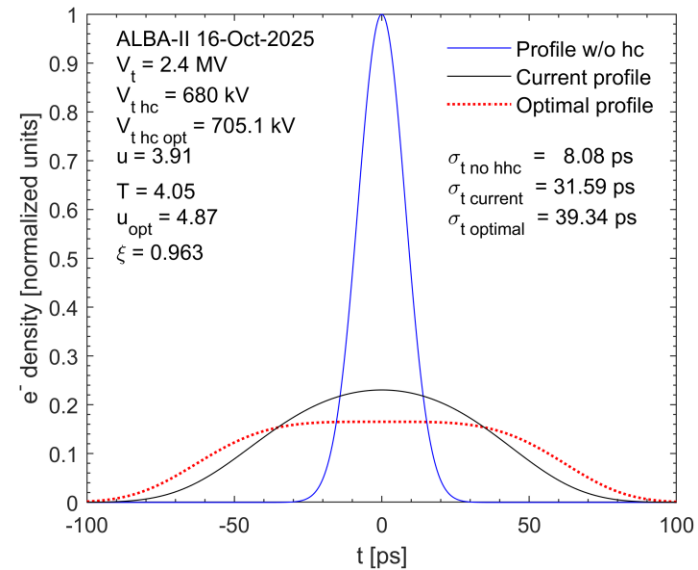
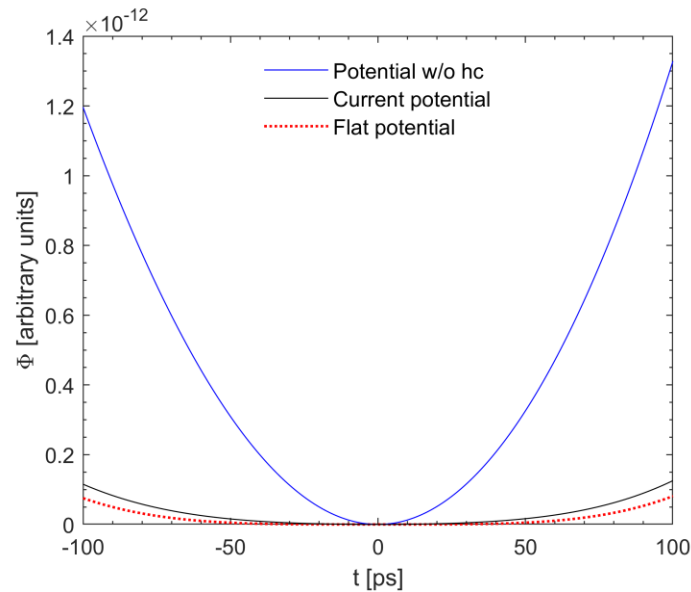
Simulation of the bunch length convergence after the HCs are activated



PTBL instabilities example, using FP settings and HFP

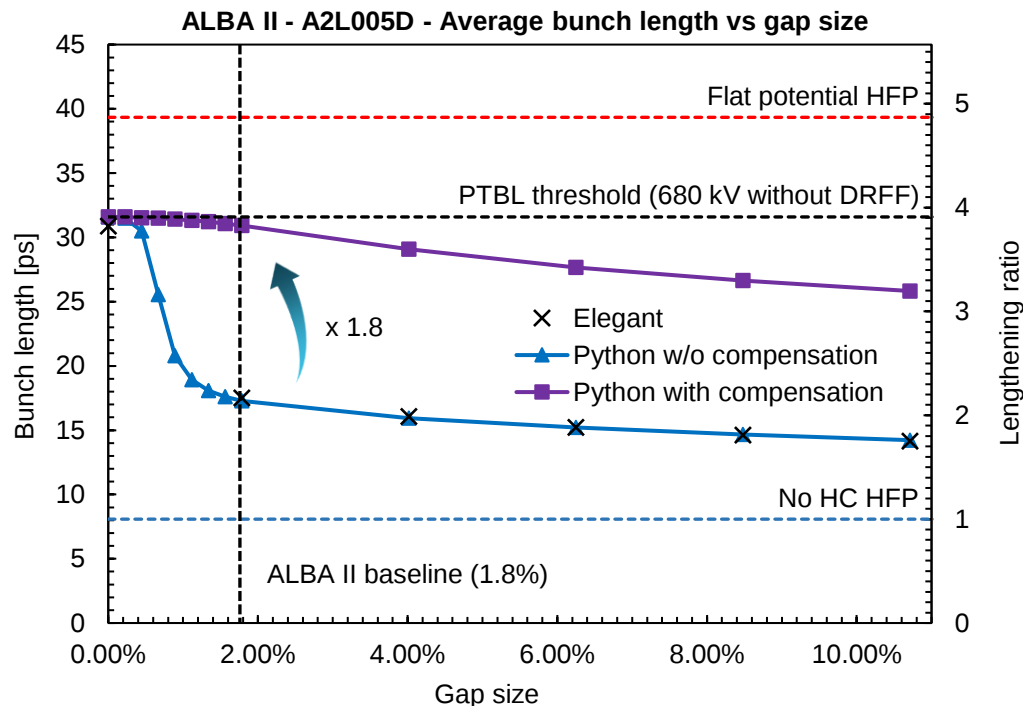
ALBA II – General RF overview

- With a homogeneous filling pattern (HFP), and the 4 x 3HCs, we expect to reach a **bunch lengthening factor of 3.9**, increasing the default 8.08 ps length to approximately 31.6 ps
- Under these conditions, the Touschek lifetime would be then raised from 1.7 h (vA2L006A, assuming 50% emittance coupling) to about **6.6 h**
- By **implementing DRFF**, this lifetime enhancement factor could be **further improved** from 3.9 to close to 4.9, which corresponds to the theoretical maximum



ALBA II – Transient beam loading studies

- A **1.8% gap** in the bunch train is foreseen for ALBA II for ion trapping mitigation. We are planning to use the active capabilities of our 3HC to **compensate** for the related **transient beam loading** (TBL) and mitigate the loss of bunch lengthening attributed to the TBL
- More information will be provided in the talk “[Harmonic EU cavity commissioning operation and TBL compensation](#)” of the HarmonLIP workshop



ALBA II – Trip compensation system

- **Good beam availability** is an essential goal for ALBA II, as it is for ALBA
- The RF system of ALBA currently has around **10 RF interlocks** per month. So 10 potential beam losses due to RF
- When there is a **sudden loss of 400 kV** on RF voltage, combined with additional losses from an unexpected parasitic cavity, the beam transitions from one equilibrium phase to another. The resulting oscillation reduces the total voltage due to increased beam loading, which, at sufficiently high currents, can lead to **beam loss**
- At ALBA, we have a dedicated **Trip Compensation System (TCS)** which raises automatically the RF power and phase delivered to the cavities after a beam loss to **counter** the large beam **oscillations**. To mathematically simulate a trip, we have a **Simulink** model which includes longitudinal dynamics equations and a **RLC cavity** model. It has been compared with experimental results at ALBA, resulting in a **good match**

$$\dot{V}_r + \frac{\omega}{2Q_l} V_r + (\omega - \omega_{rf}) V_i = \frac{\omega R_l}{2Q_l} (\tilde{I}_g + \tilde{I}_b)_r$$

$$\dot{V}_i + \frac{\omega}{2Q_l} V_i - (\omega - \omega_{rf}) V_r = \frac{\omega R_l}{2Q_l} (\tilde{I}_g + \tilde{I}_b)_i$$

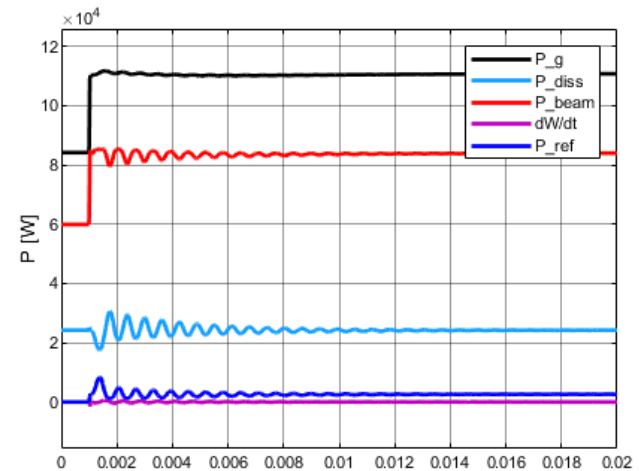
$$\frac{d^2\psi}{dt^2} + 2\alpha_\gamma \frac{d\psi}{dt} - \frac{\Omega_{s0}^2}{\cos\phi_s} (\sin\phi - \sin\phi_s) = 0$$

$$\phi = \frac{\pi}{2} - \psi + \psi_{vt}$$

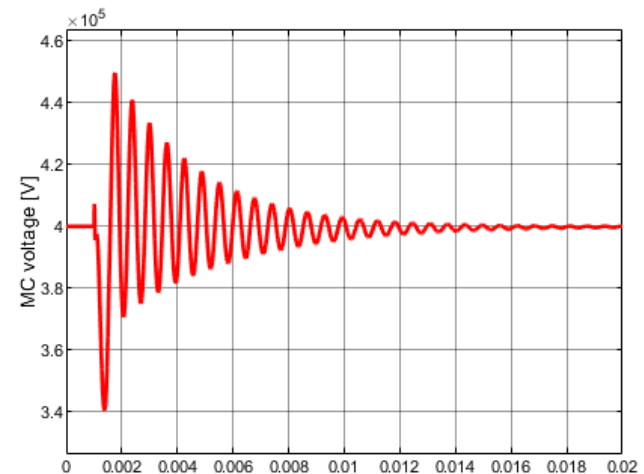


ALBA II – Trip compensation system

- With the **addition** of the **3HCs** to the system, surviving a main cavity (MC) trip becomes **considerably more difficult**:
 - ✓ After a trip, the 3HCs experience **increased losses** due to the beam phase change, which in turn amplifies the phase shift and further destabilizes the system
 - ✓ If the 3HCs do not change anymore, the previous **ratio of V_{HC}/V_{MC}** ratio is **no longer preserved**, leading to a $\xi > 1$ and the appearance of PTBL
- Therefore, we plan to use the generator power to immediately lower the 3HC voltage, **countering its beam loading** and keeping the system's below the PTBL threshold
- In case **Robinson DC** instability arises due to the temporarily low MC voltage, **DRFF** for mode 0 would help to mitigate it (already proven experimentally at ALBA)



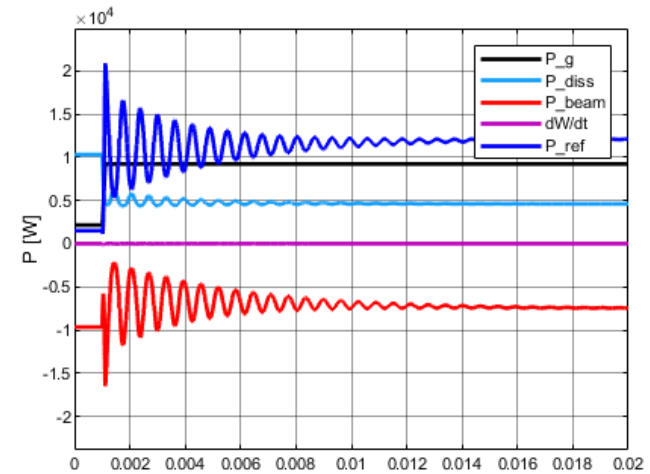
Active MC power balance after a MC trip



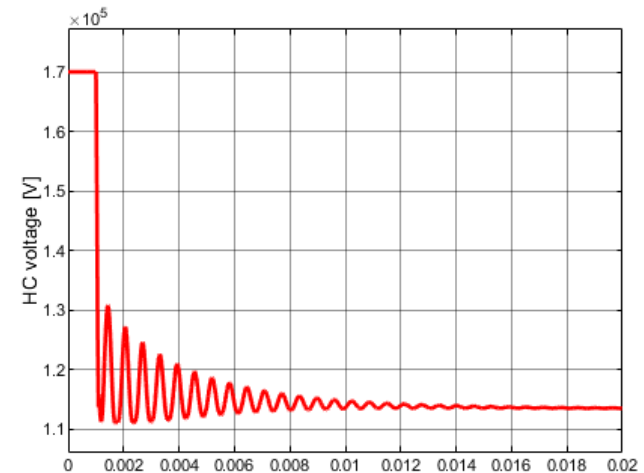
Active MC voltage amplitude after a MC trip

ALBA II – Trip compensation system

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HC power balance after a MC trip



HC voltage amplitude after a MC trip

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SUMMARY

- During 2024 ALBA's RF system achieved the **best performance** ever recorded in the facility, thanks to the continuous **improvements**
- An increase in **RF failures during 2025** was investigated and linked to **IOT degradation** from new power-saving settings and aging electronic devices. These issues are now understood, and performance is recovering after reverting the settings and replacing the aged components
- A significant portion of periodic RF incidents were identified as **fake arcs**. The new arc detection system has been tested and **deemed successful** in filtering these false events
- The **ALBA II RF upgrade** is **progressing well** within its expected schedule. Key components are already being manufactured. After summer 2026 we expect to perform the firsts tests of the 3HCs in passive mode. ALBA II operation expected for 2032.
- TBL compensation and DRFF for PTBL mitigation are being studied. We expect to **increase** the lengthening **performance** of the harmonic RF system thanks to them, reaching around **6.6 - 8.3 h** (vA2L006A) of Touschek lifetime



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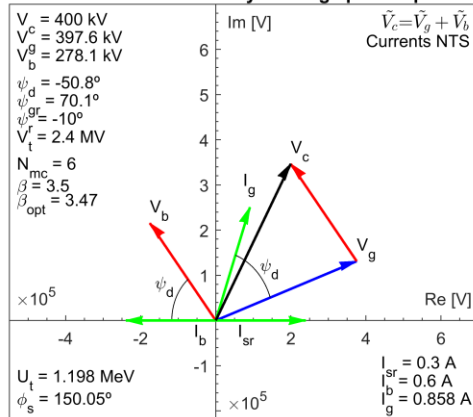
Cerdanyola del Vallès (Barcelona) Spain

Tel: (+34) 93 592 43 00

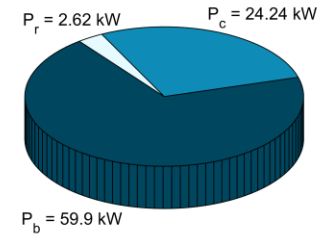
EXTRA SLIDES

ALBA II – General RF overview

ALBA-II - Main RF cavity - Voltage phasor plot



ALBA-II - Main RF cavity - Power balance



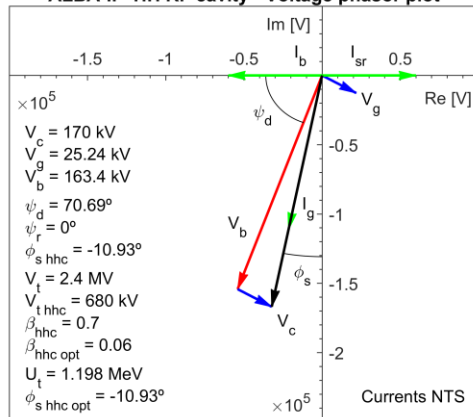
$$P_g = P_b + P_c + P_r = 86.76 \text{ kW}$$

$$P_b = 59.9 \text{ kW} (69.04\%)$$

$$P_c = 24.24 \text{ kW} (27.94\%)$$

$$P_r = 2.62 \text{ kW} (3.02\%)$$

ALBA-II - HH RF cavity - Voltage phasor plot



ALBA-II - HH RF cavity - Power balance

