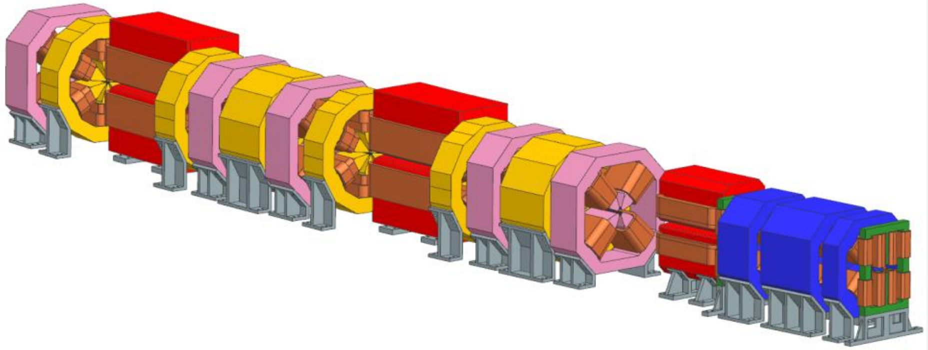
23rd International Magnet Measurement Workshop: IMMW #23



Magnet group activities at ALBA

Jordi Marcos on behalf of ID and Magnets group

07 October 2024

IMMW #23

Outline

- **ALBA: today and upgrade plans**
- **Magnets for ALBA II**
- **Magnetic measurement activities at ALBA**
- **Conclusions**

Outline

- **ALBA: today and upgrade plans**
- Magnets for ALBA II
- Magnetic measurement activities at ALBA
- Conclusions

What is ALBA?

- **ALBA** is a **3rd generation Synchrotron Light facility** in operation for users since **2012**, located in Cerdanyola del Vallès, close to **Barcelona**.

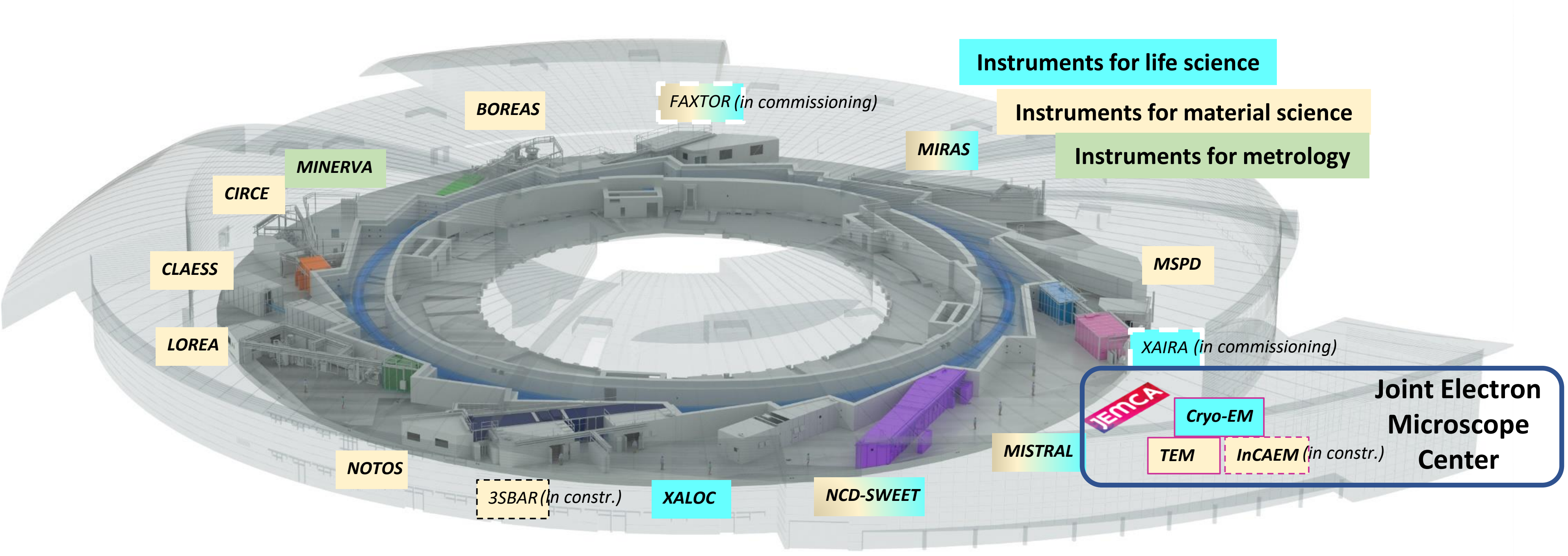
Aerial view of ALBA site

Synchrotron light sources in Europe

Inside Main Building

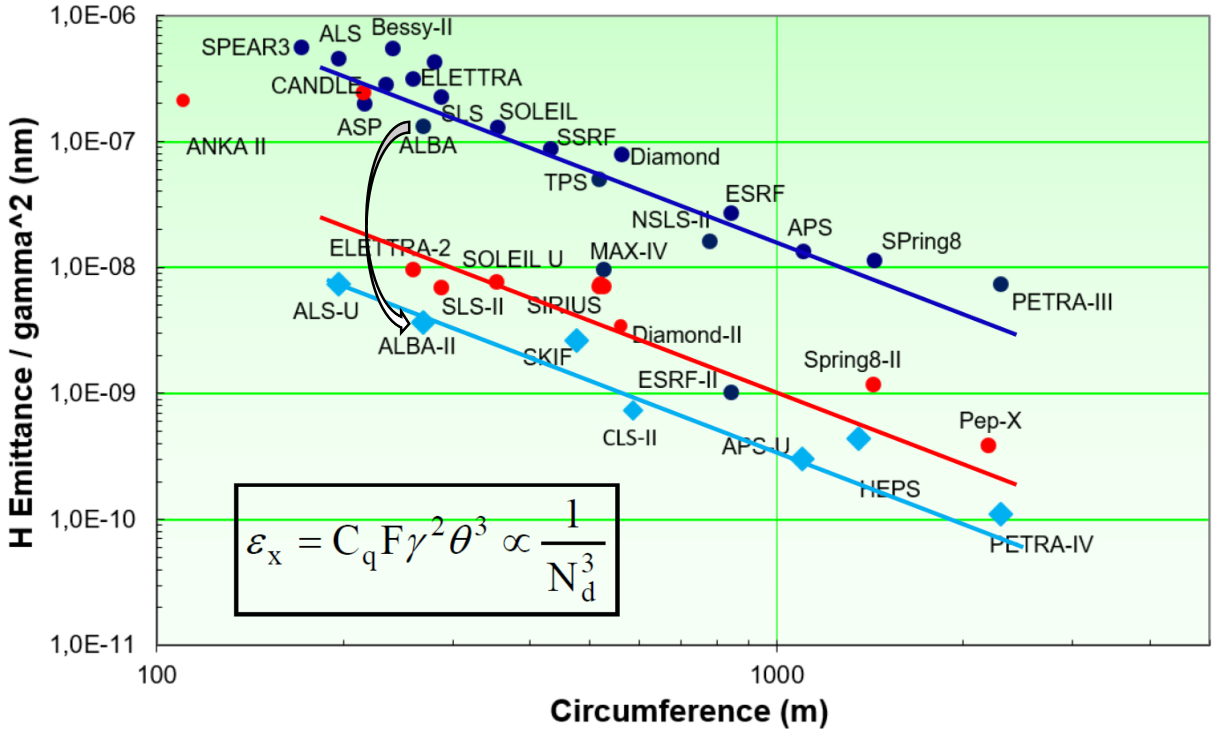
ALBA today

- ALBA currently has **11 BLs in operation**, **+2** in **final commissioning stage**, and **+1** in **construction**.
- **2 Electron Microscopes** are in operation, an additional **+1** to be installed in 2025.



ALBA upgrade plans

- Following the worldwide wave of **upgrade plans for 3rd generation facilities**, aimed to **decrease the beam emittance** and to **became diffraction limited** at higher photon energies, **ALBA** started thinking in its own upgrade in **2018**.



Reproduced from: R. Bartolini "Overview of ongoing 4th generation light source projects worldwide", 7th DLSR Workshop (2021)

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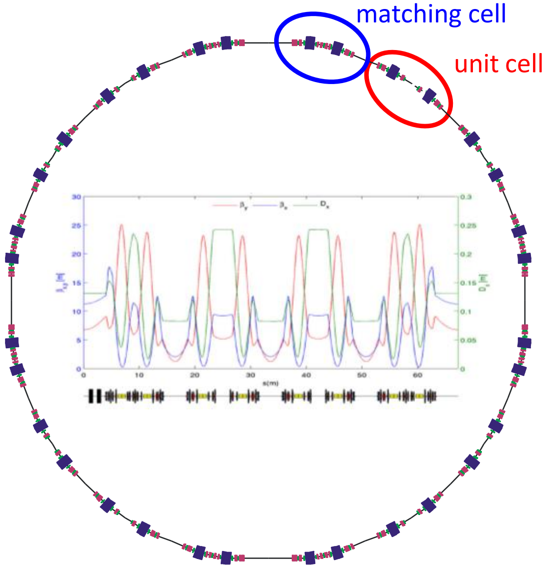
ALBA upgrade plans



	ALBA	ALBA II
Energy	**3 GeV**	**3 GeV**
Circumference	268.8 m	268.8
Symmetry	4-fold	4-fold
Lattice	8×2-DBA cells	16×5BA cells
Emittance	**4.5 nm·rad**	**~200 pm·rad**
Nº of cells	8+8	16
# of straights	4 / 12 /8	4 / 4 / 8 (16)
Straight length	7.8 / 4.0 / 2.3m	4.7 / 4.4 / 3.5 m

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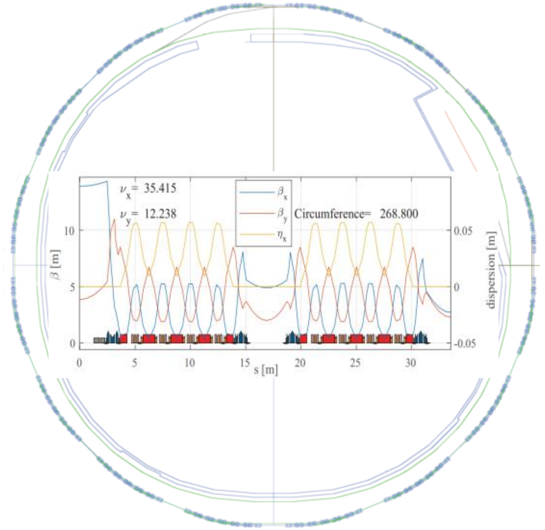

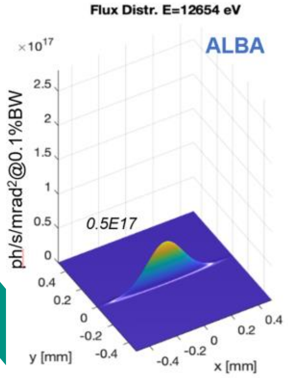

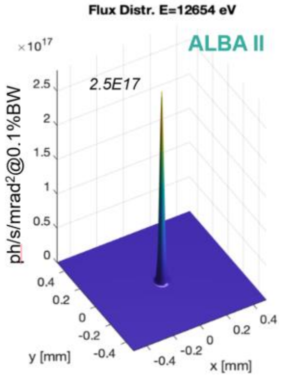

M. Carlà et al. “Status of the ALBA II lattice studies”, **IPAC24, THPC01**

ALBA upgrade plans

- We received the **approval from our Governing body** to start **ALBA II design study** on **Dec 2020**.
- The **tentative cost** for the upgrade is **120M€**, to be added to ALBA budget along **10 years** (increase of **30%** on average).
- The project's **White Paper** was issued on **Jun 2023**.
- The **upgrade project has been approved by ALBA's council** on **May 2024**, but we are **still waiting** for it to be included into **Government budget** (hopefully along 2025).
- A **4-year** project (**ALBA01**) devoted to the development of prototypes and funded with **7.5M€** started on **2022**.

ALBA upgrade plans

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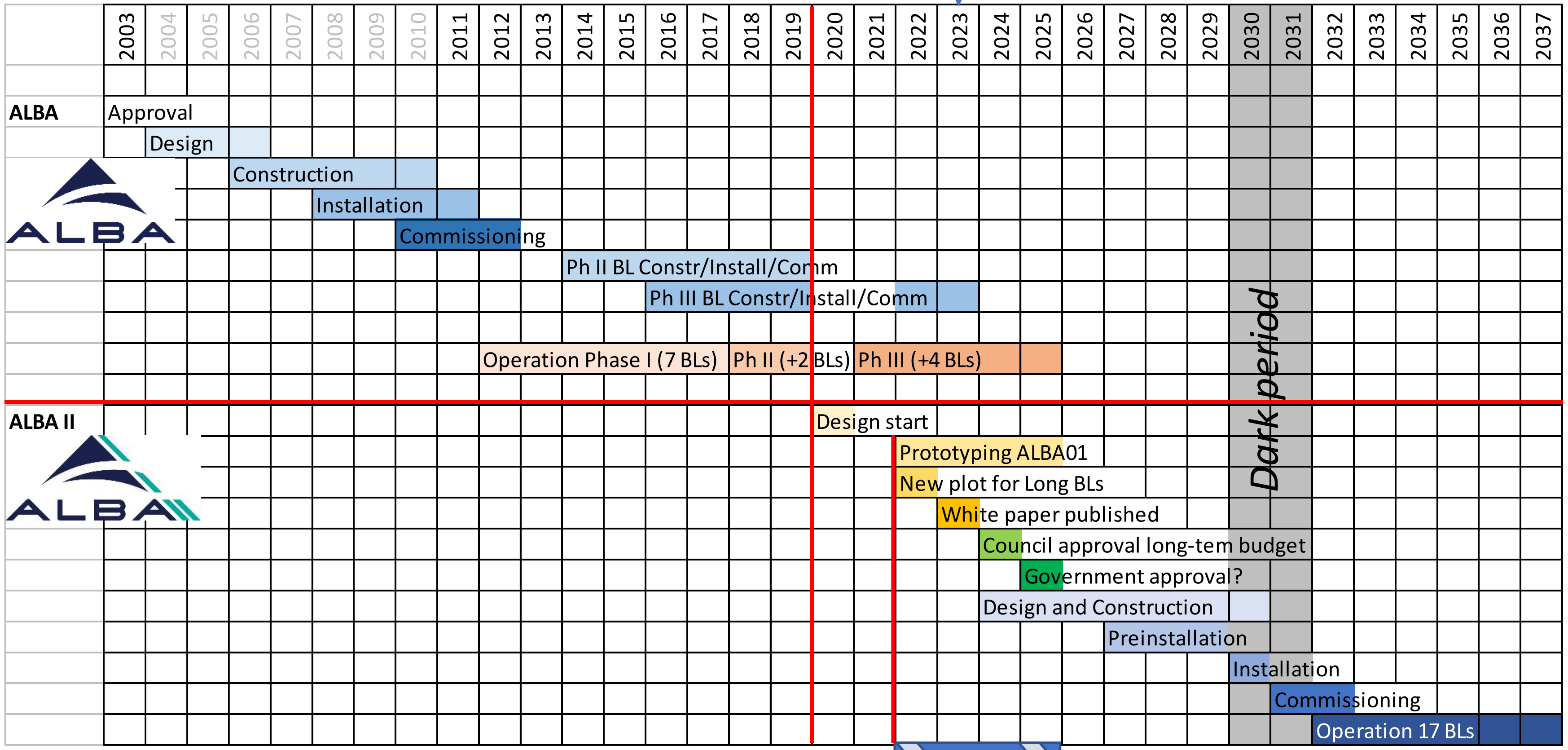
- **ALBA II timeline**

ALBA II White Paper (Jun '23)

https://www.cells.es/en/assets/pdfs/science/alba-ii-whitepaper.pdf/



Project ALBA01

"Enabling advanced technologies for ALBA II"

Outline

- ALBA: today and upgrade plans
- **Magnets for ALBA II**
- Magnetic measurement activities at ALBA
- Conclusions

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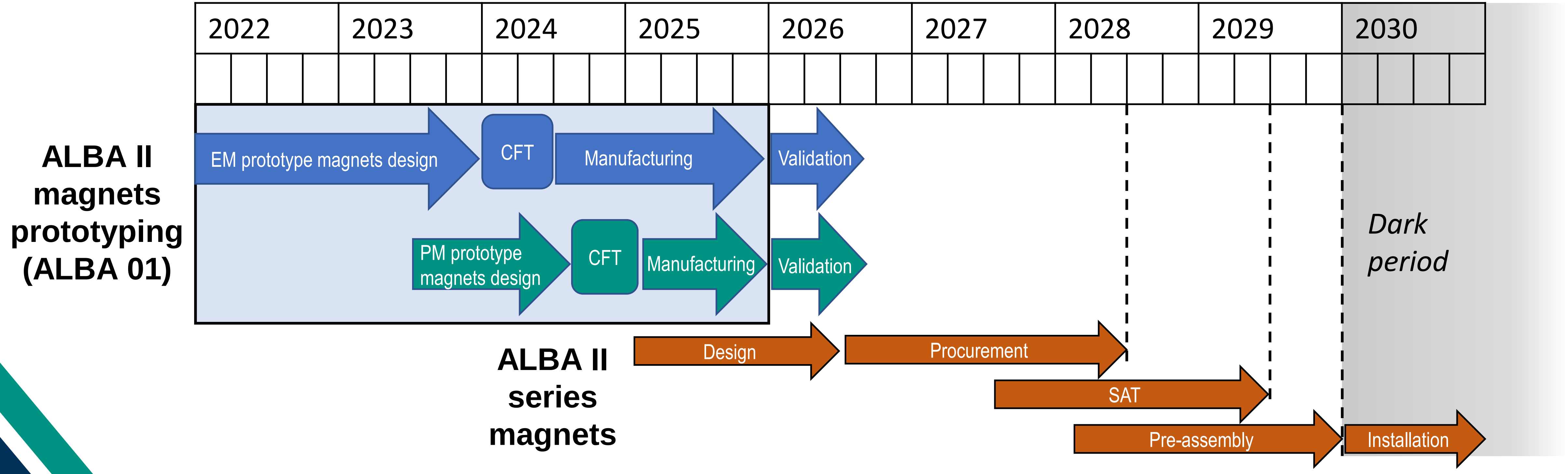
ALBA II magnets

- The responsibility for **ALBA II magnets design**, **procurement** and **acceptance/characterization** falls into **Insertion Devices and Magnets Group** at ALBA.



ALBA II magnets

- We have **completed the group's expansion** that started at the end of 2021. ✓

Insertion Devices, Magnets and Front Ends Section

Jordi Marcos
Section head and coordination

IDs & Magnets Group

Valentí Massana
Magnetic design
Meas. Lab.

Maisui Ning
Magnetic design

Andrea Fontanet
Magnetic design
IDs
Meas. Lab.

Bo Zhang
Magnetic design

FEs Group

Raquel Monge
FE design & maintenance

Support engineers

Pol Salmerón
ALBA II magnets mechanical design

José Ramón García
ID and Meas lab mech. engineer

Support operator

Manuel Rodríguez

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ALBA II magnets

- One of the **difficulties** to design the magnets for an **upgrade project** (usually within **tight schedule** and with **constraints** inherited from parent facility) is having a **frozen lattice**.
- **Evolution of ALBA II lattice** (still on-going…):

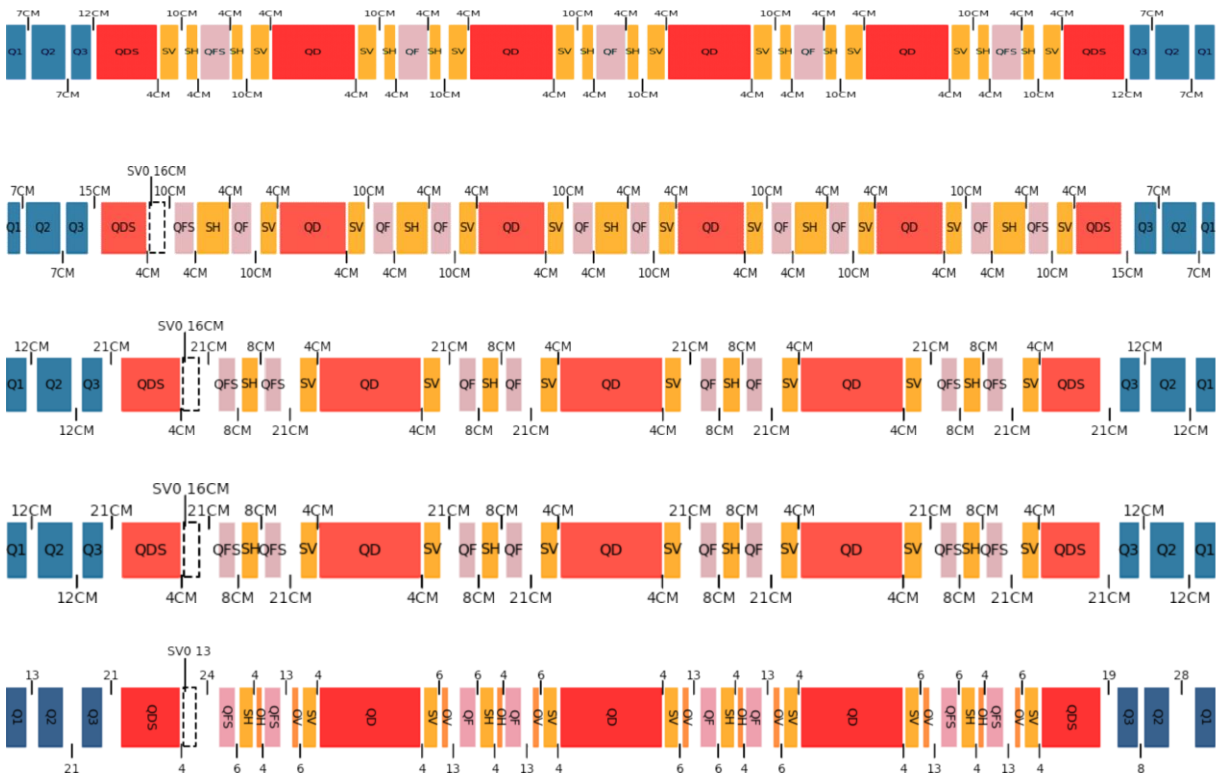
Early 2021 — **ALBA2L001** — First released **6BA lattice** (published IPAC21).

Apr 2023 — **ALBA2L002** — Modification **6BA** to improve injection and correction of chromaticity (published IPAC23)

Dec 2023 — **ALBA2L003** — Lattice relaxed to **5BA** to get more space and flexibility

May 2024 — **ALBA2L004** — Modification of **5BA** lattice to improve tune shift with amplitude (published IPAC24)

Oct 2024 — **ALBA2L005** — Introduction of **octupoles** into **5BA** lattice to help improving DA



ALBA II magnets

- Given that the **prototyping project has its own timing** (all items shall be received by the **end of 2025**), prototype magnets have been **designed according to the lattice version available at each moment**.

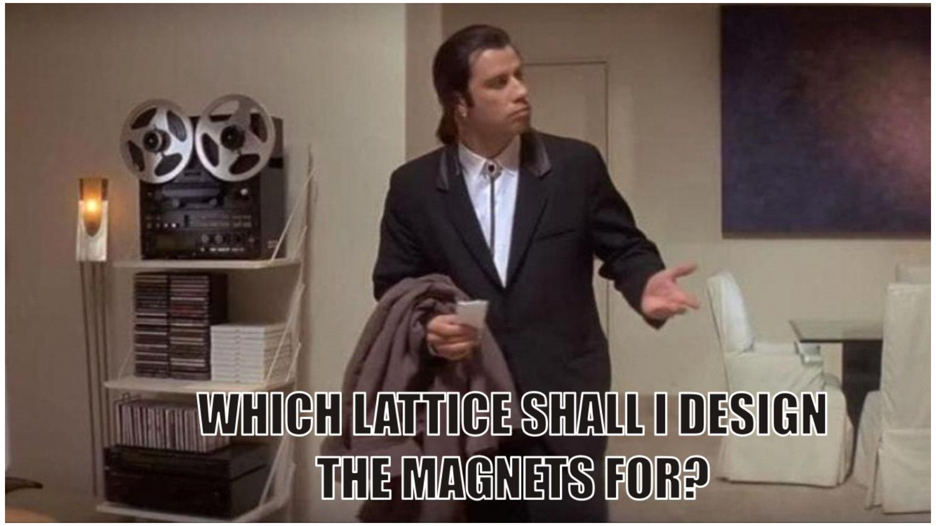
Early 2021 — **ALBA2L001** (6BA)

Apr 2023 — **ALBA2L002** (6BA) → **Resistive magnet prototypes CfT**

Dec 2023 — **ALBA2L003** (5BA) → **PM magnet prototypes CfT**

May 2024 — **ALBA2L004** (5BA)

Oct 2024 — **ALBA2L005** (5BA)



Even if the **prototypes will be different from the magnets for the final lattice**, we are confident that the **lessons learnt from them will be useful for the design of the final series magnets**.

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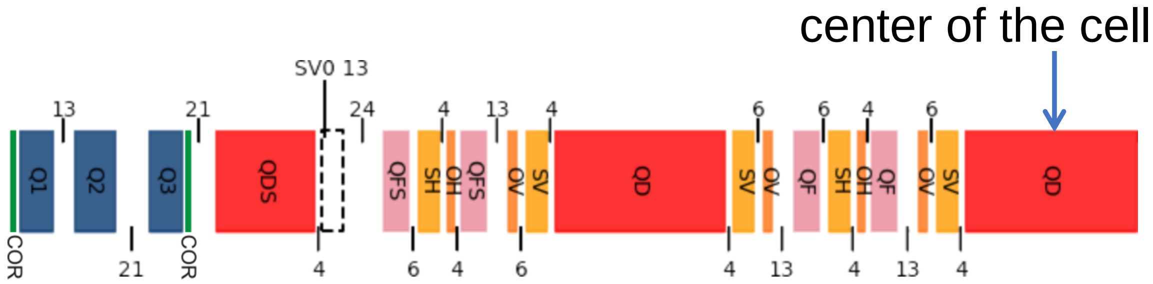
ALBA II magnets

- **As per today, ALBA II** lattice is based in **16 identical 5BA cells**, with **12 magnet types**, for a total of **720 individual magnets** (currently 264 magnets at ALBA SR)

Function	Types	# per cell	total	Leff [mm]	B [T]	G=B’ [T/m]	S=½B’’ [T/m²]	O=⅙B’’’ [T/m³]
Bending	QD	3	48	1050	1.05	-13.0		
	QDS	2	32	605	1.04	-15.2		
Reverse Bend	QF	4	64	160	-0.52	+65.0		
	QFS	4	64	160	-0.46	+70.0		
Quadrupole	Q1	2	32	200		≤110		
	Q2	2	32	250		≤110		
	Q3	2	32	200		≤110		
Sextupole	SH	4	64	130			≤5000	
	SV	7	112	130			≤5000	
Octupole	OH	4	64	50				≤2.5e5
	OV	7	112	50				≤2.5e5
Fast Corr	CORR	4	64	40	10 T·mm (0.5mrad) in both planes			
TOTAL		45	720					

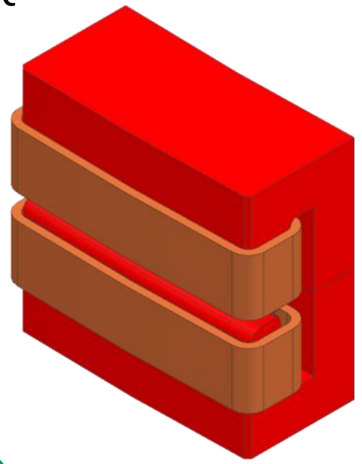


Distances between effective lengths in [cm]

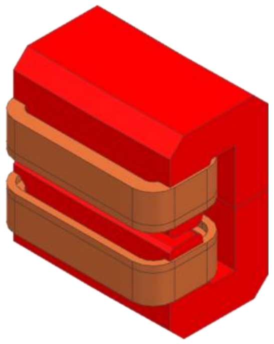
ALBA II magnets

- **Main dipoles** (**QD** and **QDS**) have transversal gradient, with a moderate gradient-to-field ratio. They have been implemented as **2-pole conventional C-shape magnets**, with a **vertical opening** of **20mm**.
- In the case of **QDS**, where field tuning is not mandatory, **a pure PM version has been designed**.
- In the case of **QD**, an alternative **“Superbend” version** with a central high-field pole (**3.2T, 10.2mm pole gap**) powered with NdFeB blocks has been developed for dipole BLs requiring **higher critical energies**.

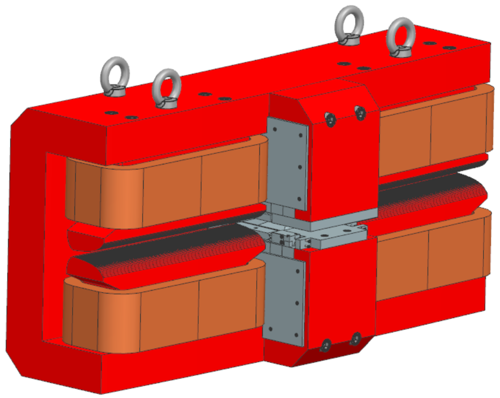
QD resistive version

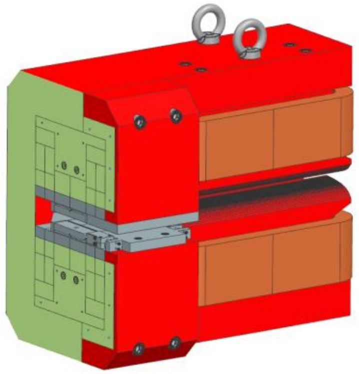


QDS resistive version (embedded coils)

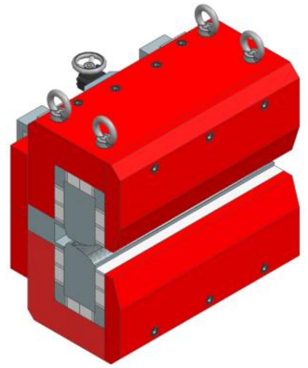


QD “superbend” version (hybrid resistive+PM)





QDS PM version



ALBA II magnets

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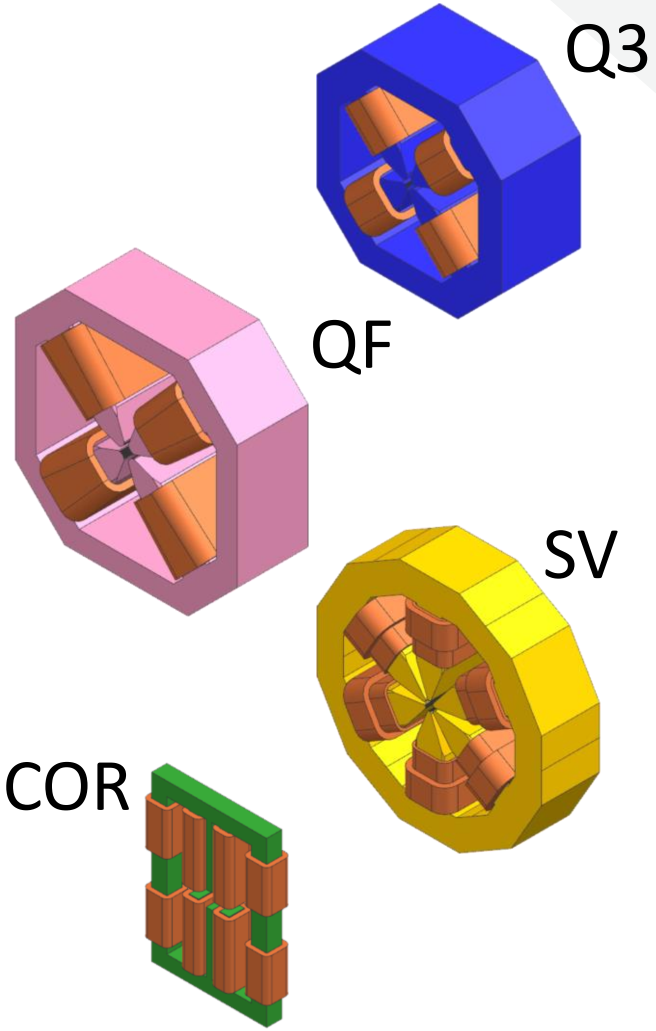
- **Pure quadrupoles** at the end of each cell (**Q1-Q2-Q3**) have a common transversal geometry and an **aperture diameter** of **20mm**, allowing them to reach up to **110T/m** with an **efficiency >90%**.
- **Reverse bends** (**QF-QFS**) require a high gradient **(~70T/m**) and a moderate field **(~0.5T**), and hence they have been implemented as **horizontally displaced quadrupoles** (**5-8mm**). Due to this, a larger **aperture diameter** of **~28mm** is required.
- **Sextupoles** (**SH-SV**) shall reach **5000T/m^2** and they shall include correctors for H/V position and skew quadrupole. An **aperture diameter** of **23mm** has been used.
- **Fast correctors** (**COR**) integrate a **horizontal and vertical steerer** on the **same yoke**, with a **6-pole design** similar to the one developed for ESRF-EBS.
- **Octupoles** (**OH-OV**)… we will look into them when we are back in Barcelona.



ALBA II magnets

- **All magnet types** (except octupoles) are **currently being prototyped**. Prototypes will be received by the **end of 2025**, and they will be used to test/verify:
  - **Different magnet technologies**: EM vs PM, conventional vs embedded coils…
  - **Magnetic performance** of the developed designs: field/gradient levels, linearity/efficiency, multipolar content, magnetic axis stability with current, cross-talk between main component and correctors for sextupoles…
  - **Mechanical accuracy** issues: pole machining precision, repeatability upon dismounting/remounting, tolerances coil manufacturing, compactness of the engineering design (power/water distribution systems)…
  - **Mechanical integration** aspects: mounting mechanism on girders, vacuum chamber assembly…
  - **Cross-talk effects between adjacent magnets**.
- **Characterization** will be carried out at **Magnetic Measurements laboratory** at **ALBA**.

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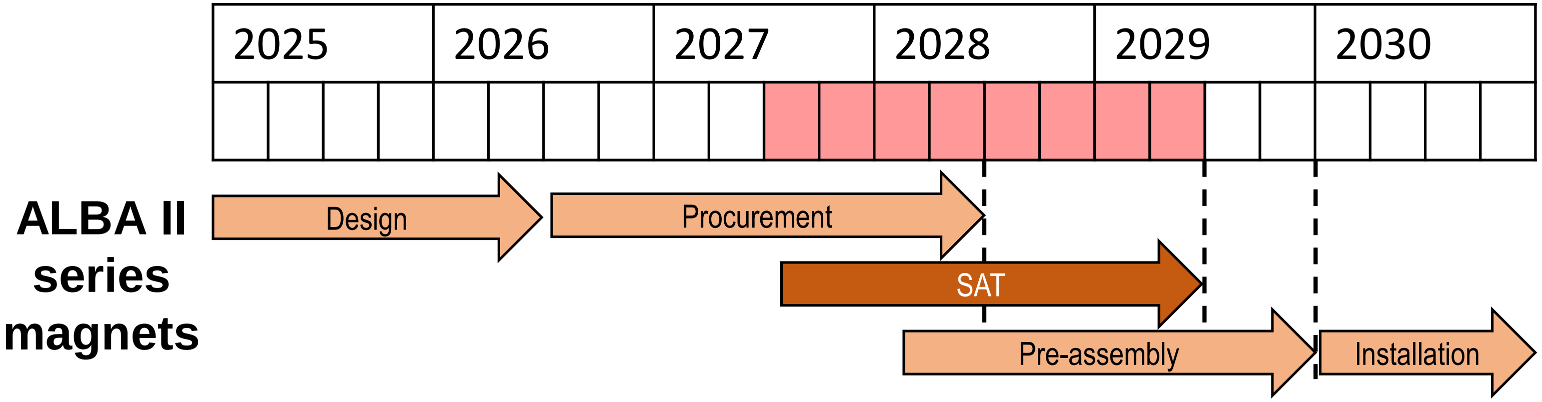
ALBA II magnets

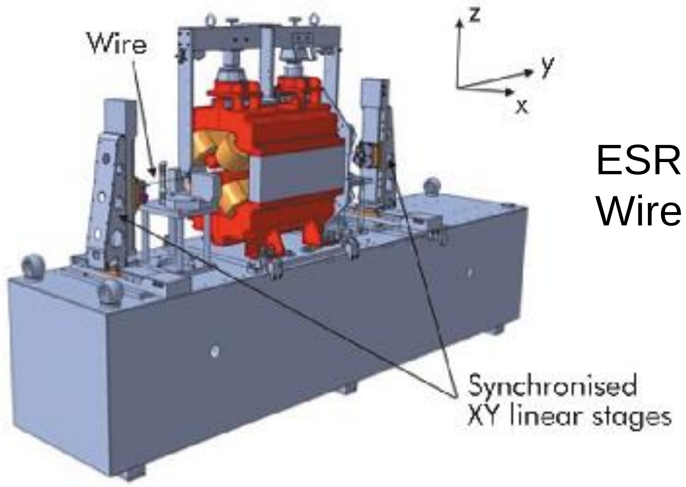
- In the case of the **series magnets**, the **strategy for the characterization is still under development**.
- We will explore the **possibility of outsourcing at least a part of the characterization to manufacturing companies**, but taking into account the experience from other labs **our “Plan A” assumes that the characterization will be carried out in-house**.
- We will have to characterize:
  - **80 curves magnets** (QD and QDS) → **Hall probe** bench
  - **640 straight magnets** (multipolar magnets of all sorts) → **Stretched Wire (SW)** bench
- According to the current plan, we are allocating **2 years** to **characterize all the magnets**.



ALBA II magnets

- For the **Hall probe measurements** we will use the **existing system** (**x1**) at our Magnetic Measurements Lab. Assuming 180 working days per year, we will have at least **4 days to characterize each dipolar magnet**.
- In the case of **Stretched Wire (SW) measurements**, assuming **1 day/magnet** and 180 working days per year, we **will need at least two** (**x2**) **systems** in order to complete the task (**640 magnets**) within 2 years.
  - We are in the process of procuring one system → hopefully to be at ALBA by the **end of 2025**.
  - The second system will be procured later on (it will not be needed until mid 2027).

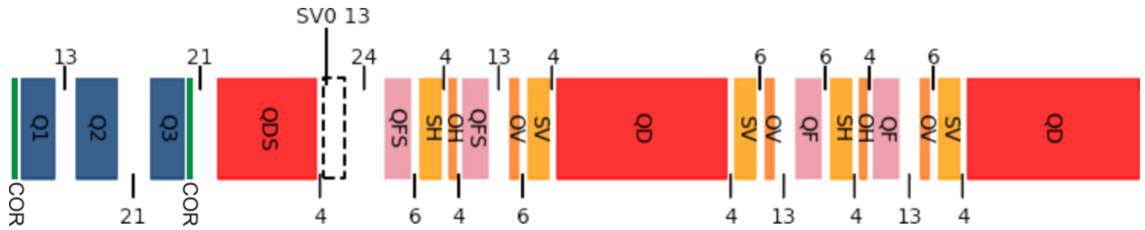
Conventional Hall probe bench (ALBA)



ESRF Stretched Wire bench

ALBA II magnets

- By the moment Beam Dynamics group at ALBA has set an **error budget** for **magnets positioning** of **30μm *rms***.
- With this error allowance, our initial plan is **fiducializing individual magnets using SW bench** (which according to ESRF provides an **accuracy of 20μm in both planes**). Each **magnet will have its own support allowing to adjust horizontal/vertical position and roll angle**, and they will be **mounted on the girders according to the obtained fiducialization data**.
- **No magnetic verification of the relative alignment between the magnets** assembled on each girder (vibrating wire measurements or similar) is intended.

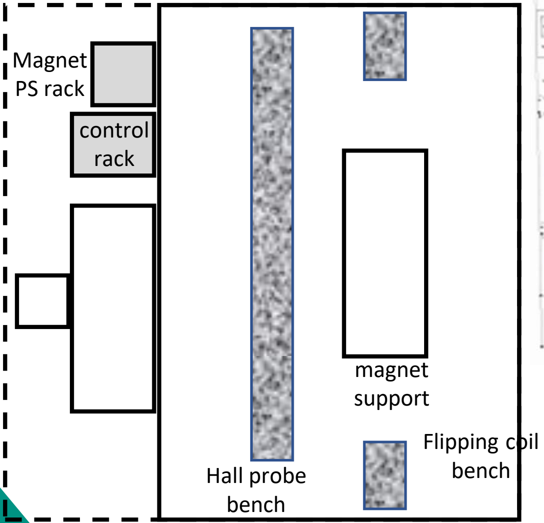


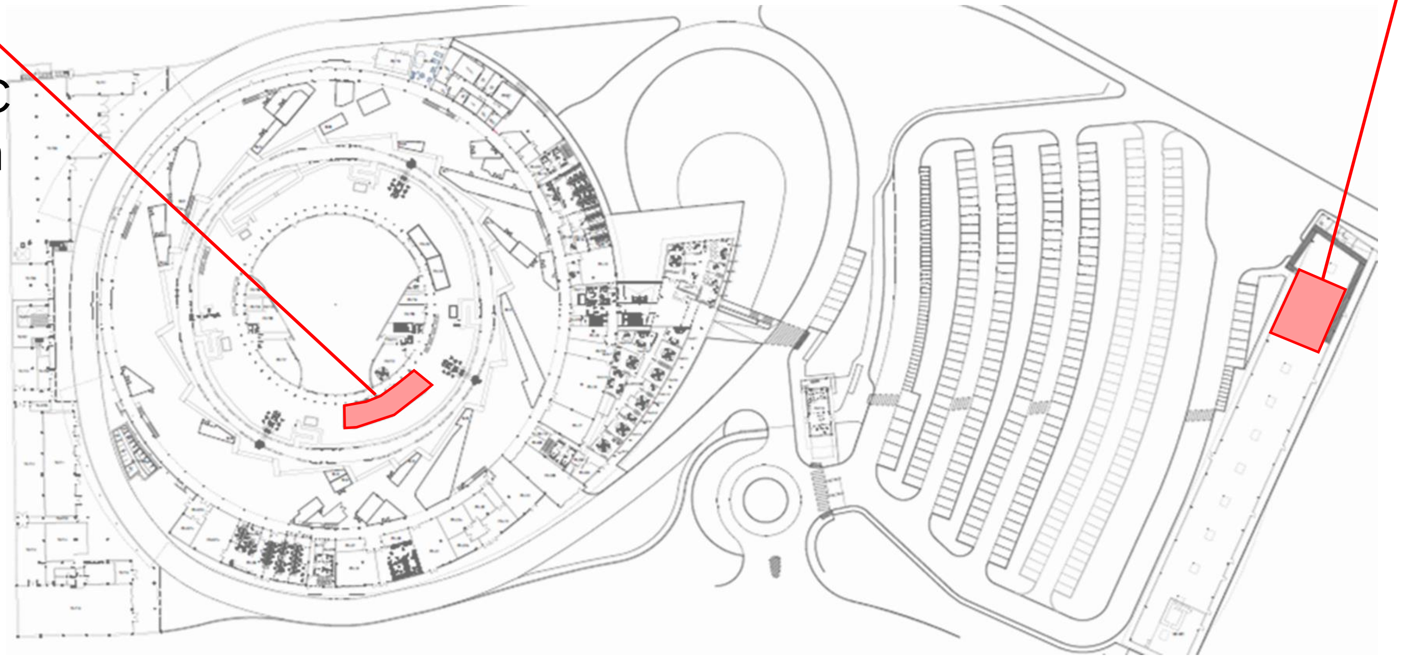
ALBA II magnets

- **Spaces for magnetic characterization**

ID lab (existing)

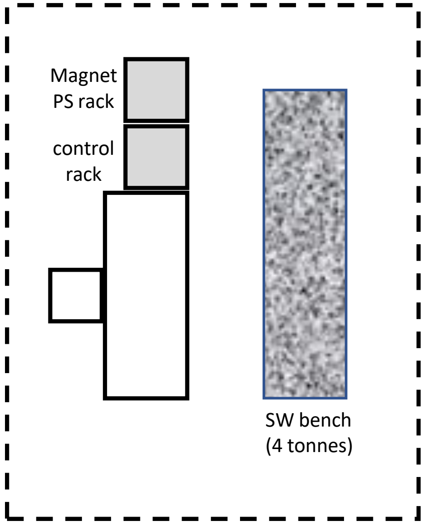
- **150m²** total surface
- Temp controlled ±0.1ºC
- **25m²** Hall probe bench test area





Warehouse (proposed)

- **200m²** reserved for magnets test area
- Temp control?
- **2×20m²** SW test area



Outline

- ALBA: today and upgrade plans
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- **Magnetic measurement activities at ALBA**
- Conclusions

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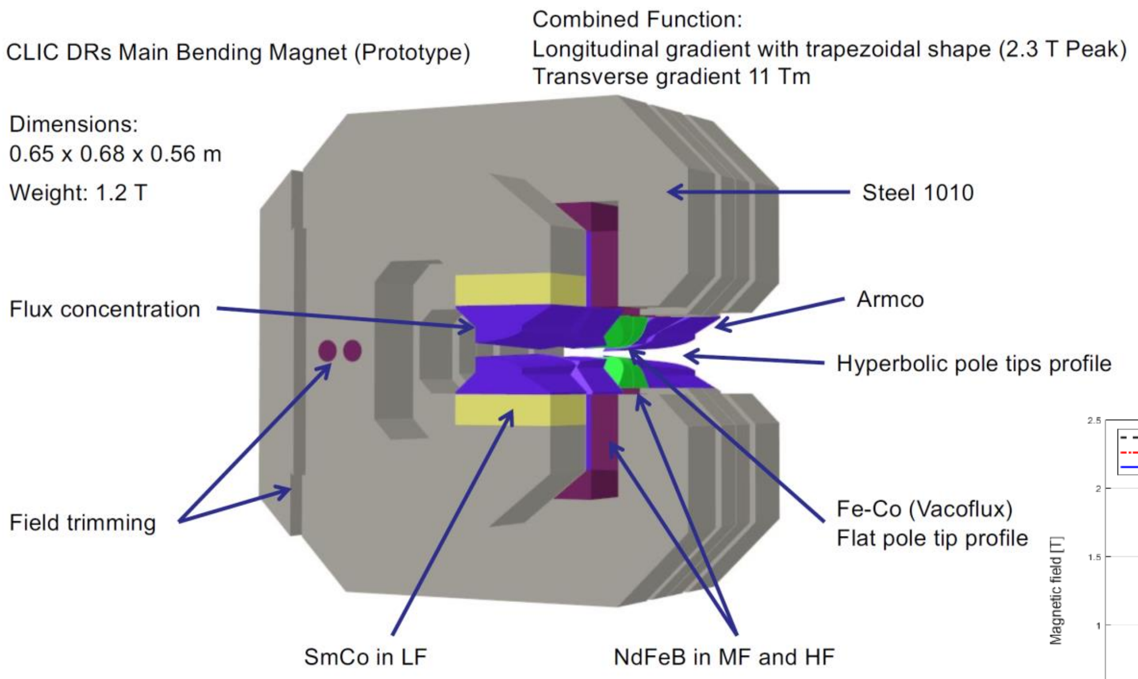
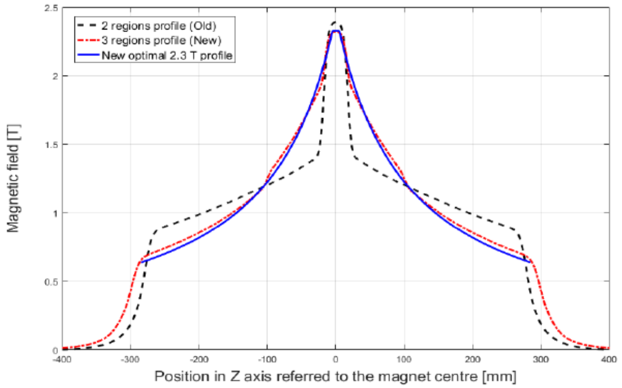
Magnetic measurement activities at ALBA

- Characterization of **Permanent Magnet longitudinal gradient dipole** for **CIEMAT**.



Drawings courtesy of M.A. Domínguez (CIEMAT)



Magnet characteristics	
e-beam energy [GeV]	2.98
Peak field [T]	2.4
Iron length [mm]	560
Central gap [mm]	12.7
GFR diameter [mm]	10
Deflection angle [deg]	4
Sagitta [mm]	5.06
Trans. Gradient [T/m]	~11

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Magnetic measurement activities at ALBA

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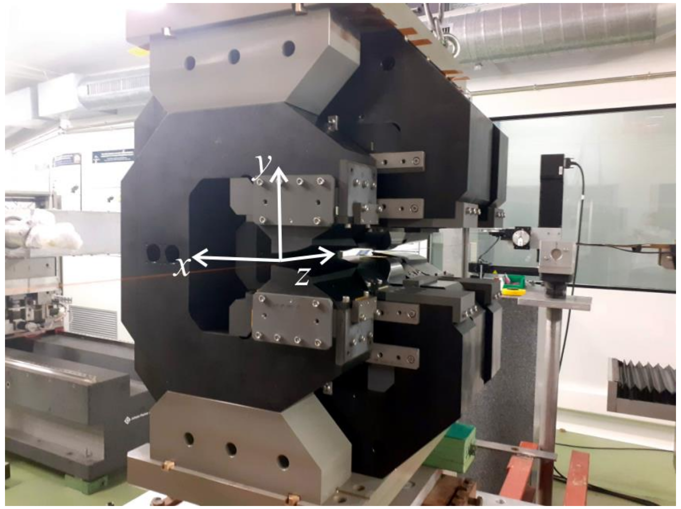
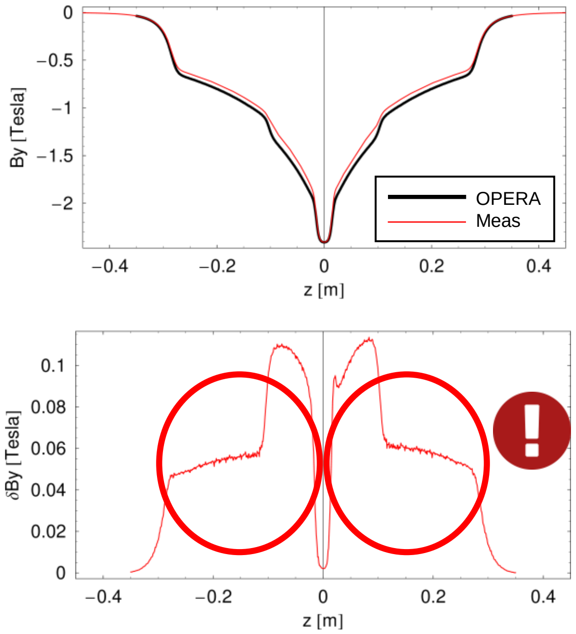
- The **magnet has already been characterized** on **Nov 2021**, and results reported in last IMMW (**IMMW22** https://indico.cnpem.br/event/2/contributions/27/).
- In particular, a **5-6% field defect in the medium and low field poles was observed**, and preliminary associated to a **missing anneal of Armco poles**.

Hall probe field mapping



Magnetic field profile along *z* at *x*=*y*=0



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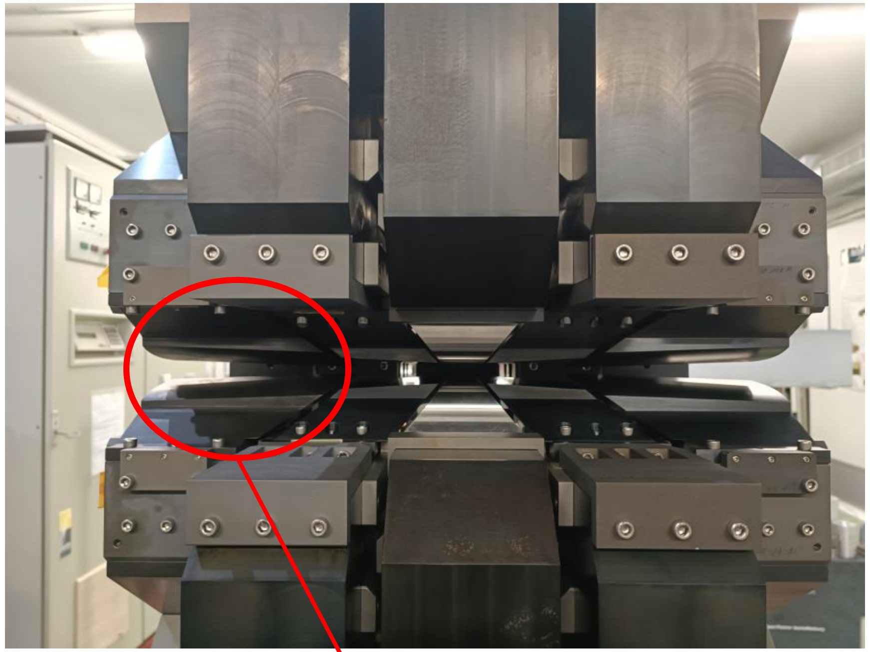
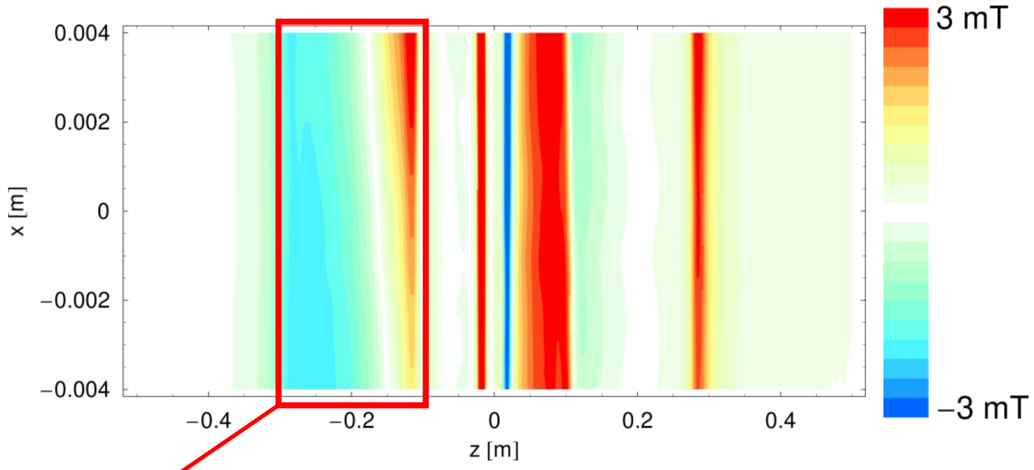
Magnetic measurement activities at ALBA

- On **Oct 2023**, after the **Armco poles of one of the low field poles have been remanufactured including an annealing procedure**, the magnet was **sent back to ALBA** for characterization with conventional **Hall probe bench**.



Differences in measured B_y between Nov 2021 and Oct 2023 → within **±3mT** !



Only those LF poles were modified

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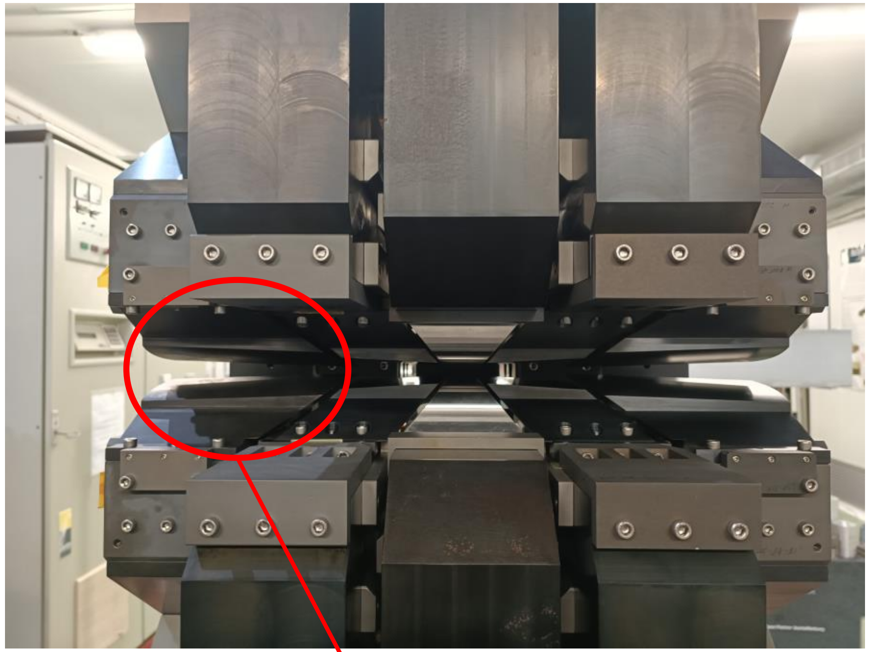
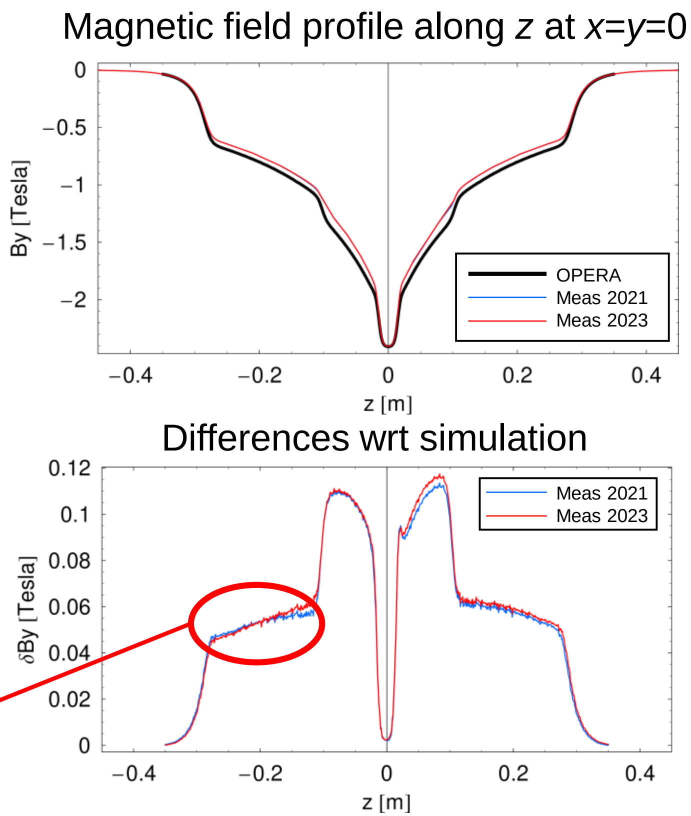
Magnetic measurement activities at ALBA

- We concluded:
  - The reason for the **missing field** has to be looked for somewhere else.
  - We confirmed the **repeatability of our system** over a long period of time.



Only those LF poles were modified



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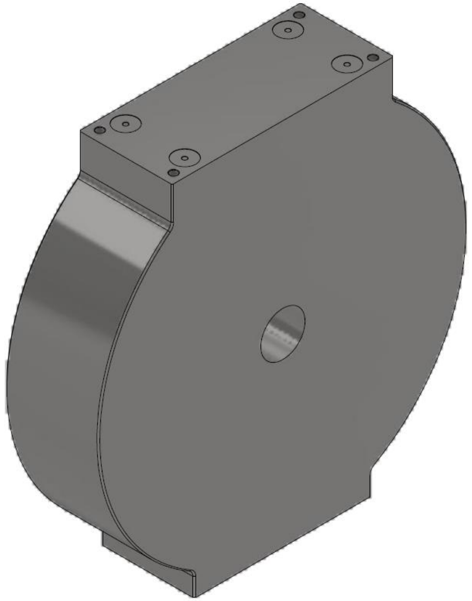
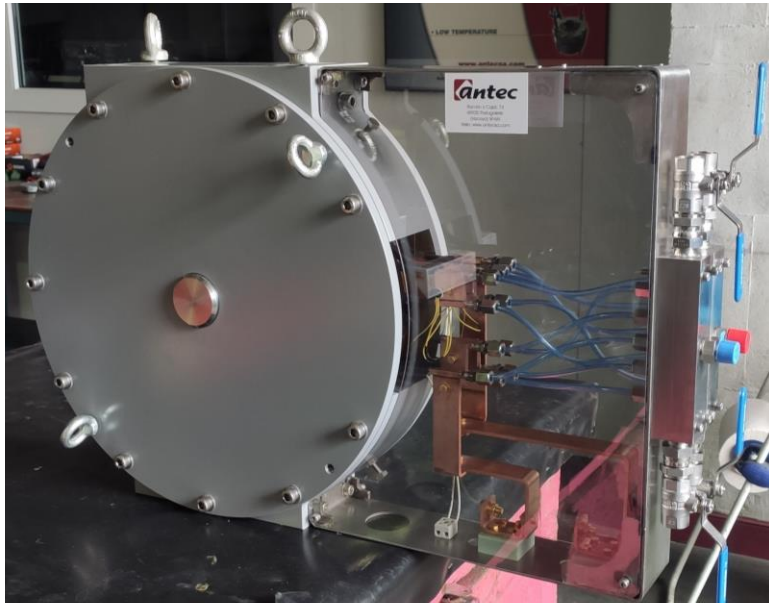
Magnetic measurement activities at ALBA

- Characterization of **solenoid for C-band gun** for **INFN-LNF**





  - Field maps and integrated field homogeneity
  - Magnetic axis
  - Excitation curve

Magnet characteristics	
# of coils	1
Peak field Bz [T]	0.67
Int field ∫ Bz [T·mm]	64
Int field homogeneity	$<5\times10^{-4}$
GFR diameter [mm]	20
Aperture ∅ [mm]	60
Length [mm]	126
Nominal current [A]	184

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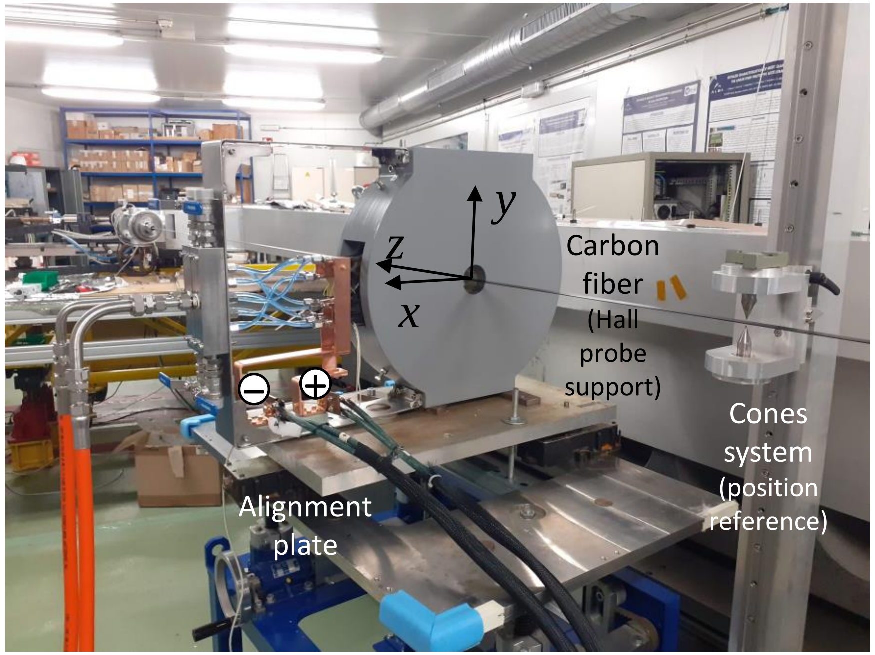
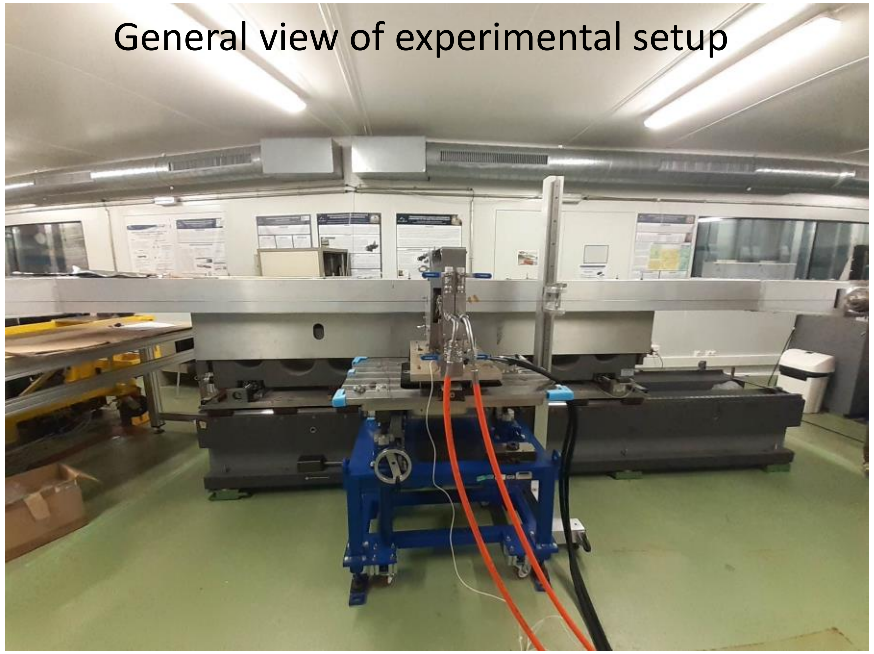
Magnetic measurement activities at ALBA

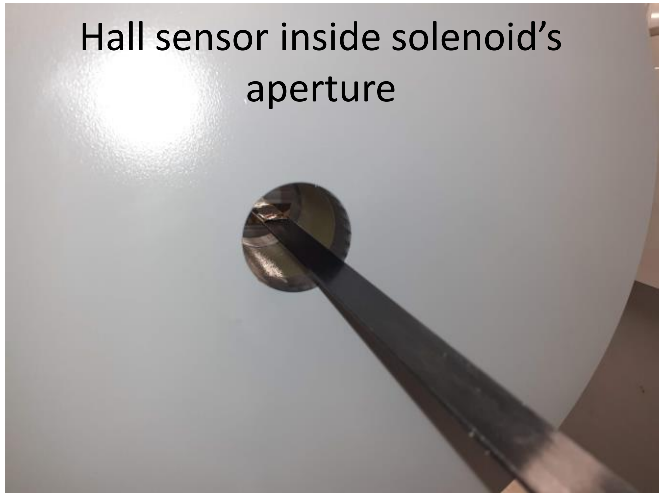
- Measurements carried out with **Hall probe bench for closed structures** at ALBA (presented at **IMMW19** and **IMMW20**)

IMMW19 INTERNATIONAL MAGNETIC MEASUREMENT WORKSHOP

IMMW20 International Magnetic Measurement Workshop 4th – 9th June 2017, Diamond Light Source







- **Magnetic field** measured along **1-m long lines** with **1mm sampling step**.

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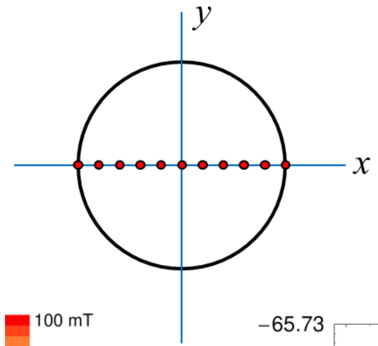
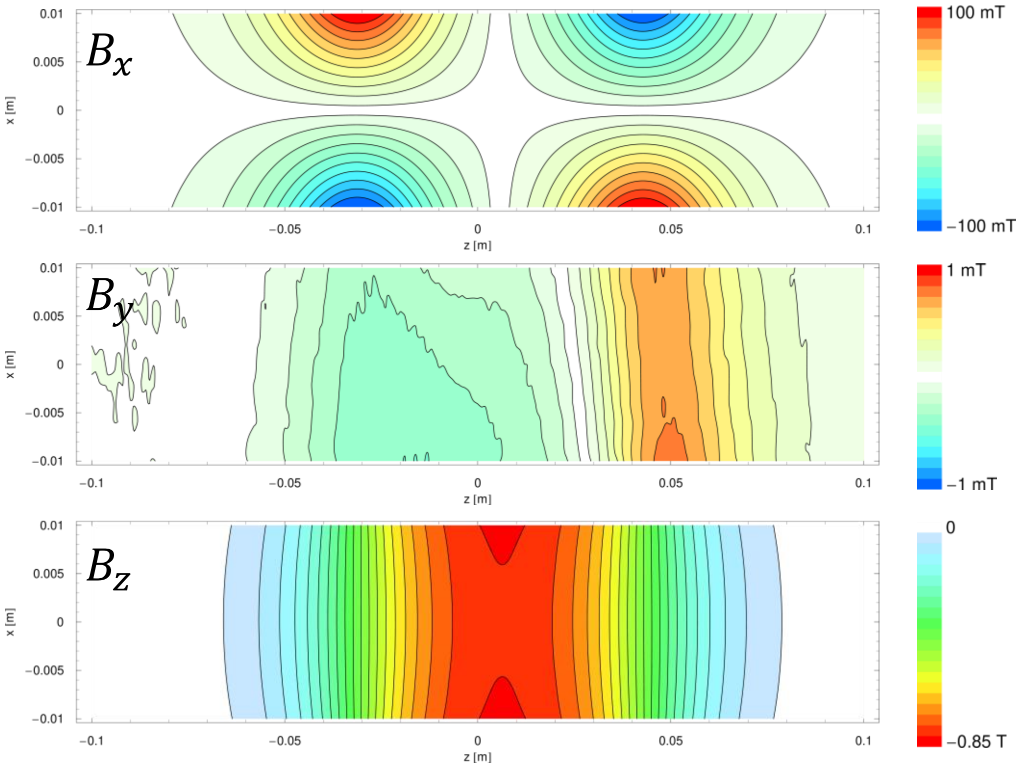
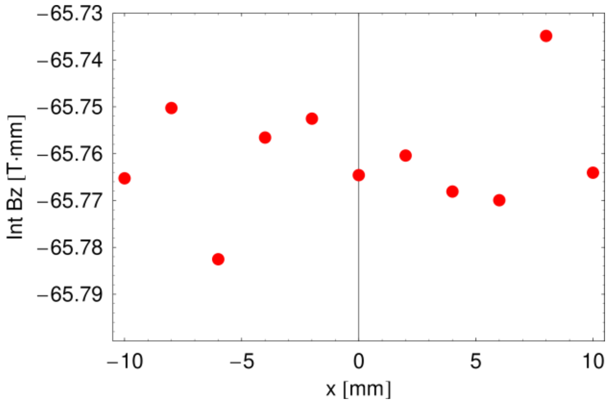
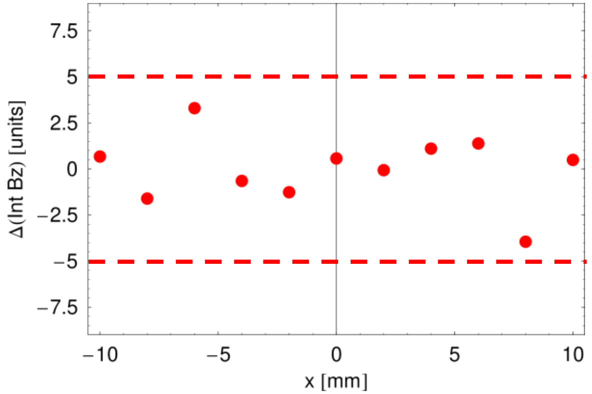
Magnetic measurement activities at ALBA

- **Horizontal field map** at I_{nom}=184A





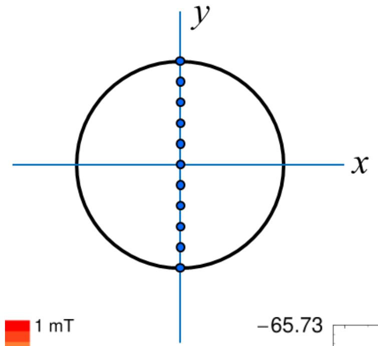


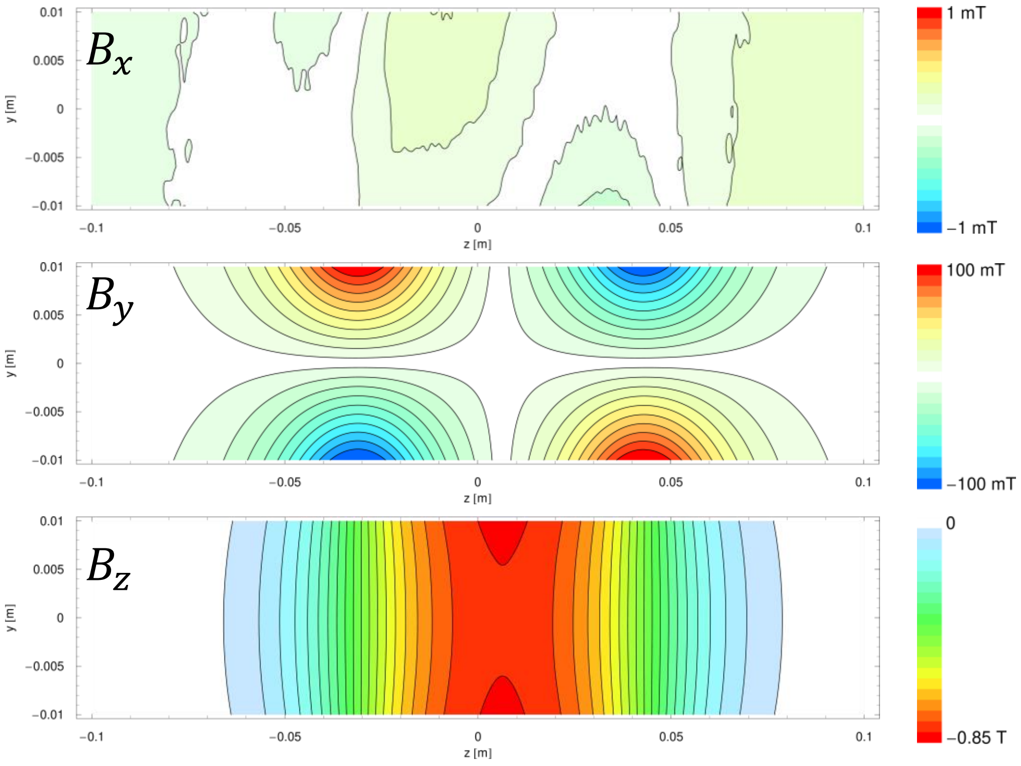


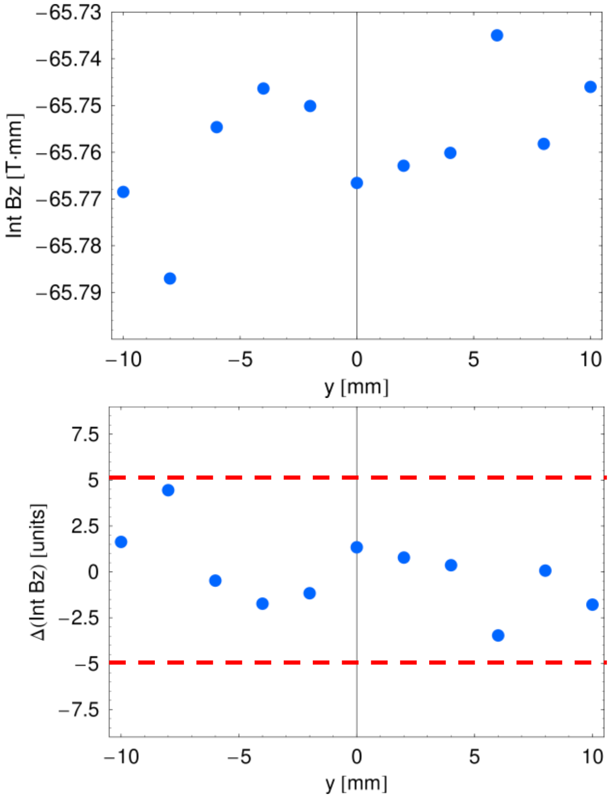
Field integral variation within $\pm 5 \times 10^{-4}$

Magnetic measurement activities at ALBA

- **Vertical field map** at I_{nom}=184A





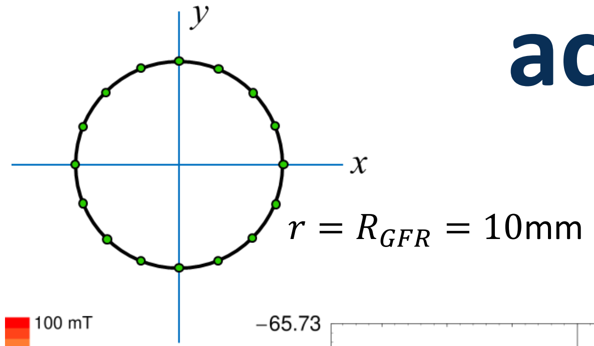


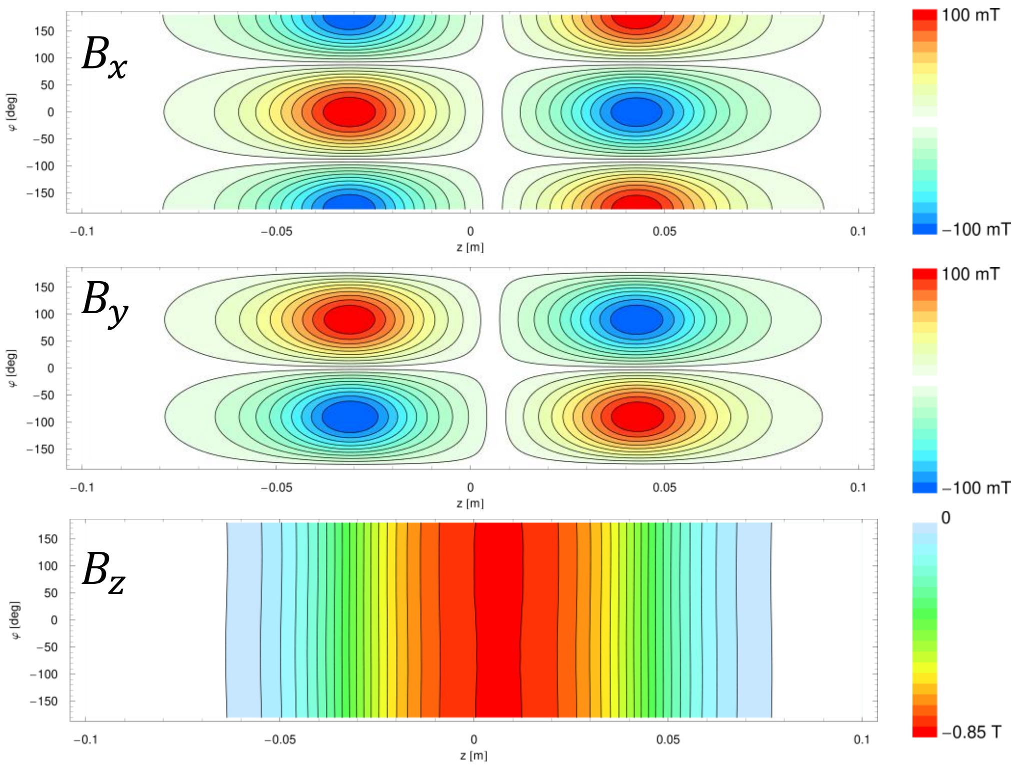
Field integral variation within $\pm 5 \times 10^{-4}$ ✓

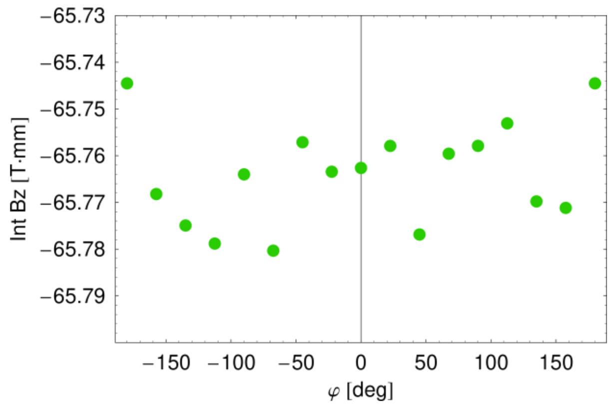
IMMW #23

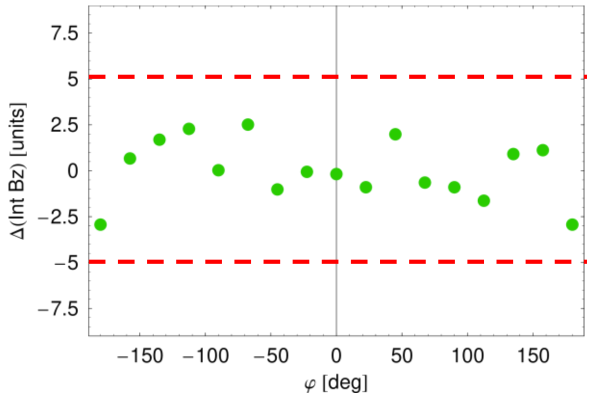
Magnetic measurement activities at ALBA

- **Cylindrical field map** at I_{nom}=184A







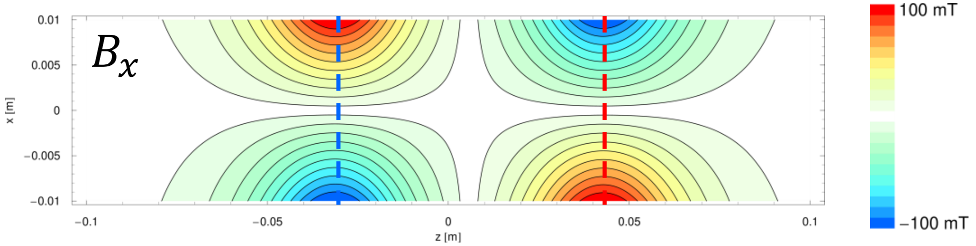


Field integral variation within $\pm 5 \times 10^{-4}$

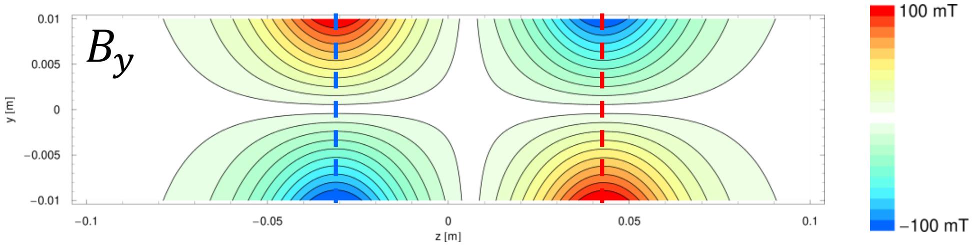
Magnetic measurement activities at ALBA

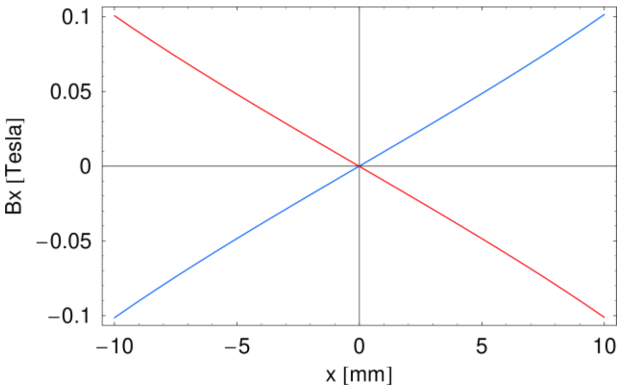
- **Magnetic axis →** **zero of minor components in the fringe field region**

Horizontal field map



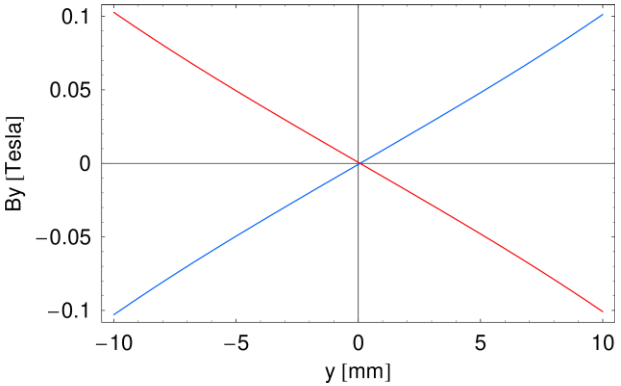
Vertical field map





$x_{in} = -6\ \mu m$

$x_{out} = -15\ \mu m$



$y_{in} = +72\ \mu m$

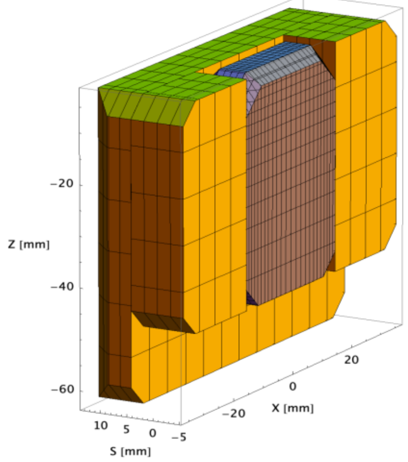
$y_{out} = +73\ \mu m$

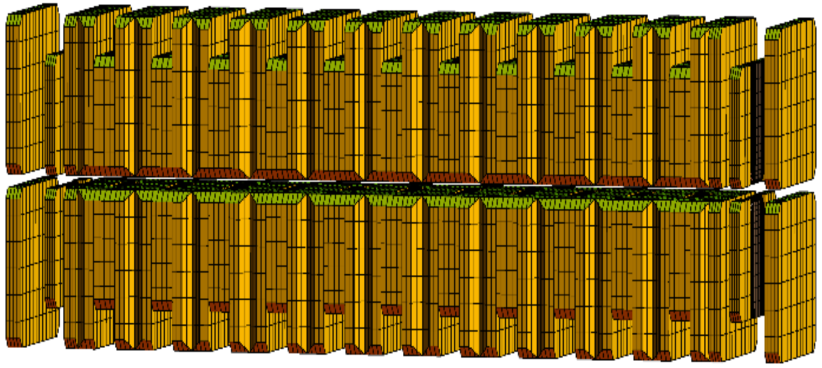
IMMW #23

Magnetic measurement activities at ALBA

- **Insertion Device** for **FAXTOR beamline** at **ALBA** (fast X-ray microcomputed tomography at high resolution): **in-vacuum multipole wiggler MPW54**

ID characteristics	
Magnetic configuration	Planar hybrid
Period length [mm]	54
PM blocks	NdFeB (B_r=1.25T)
Iron poles	Vanadium Permendur
Number of periods	5.5
Magnetic length [mm]	362
Minimum magnetic gap [mm]	5.2
Maximum peak field [T]	2.5
Maximum K	11.5





5½ periods wiggler RADIA model (courtesy of AVS)

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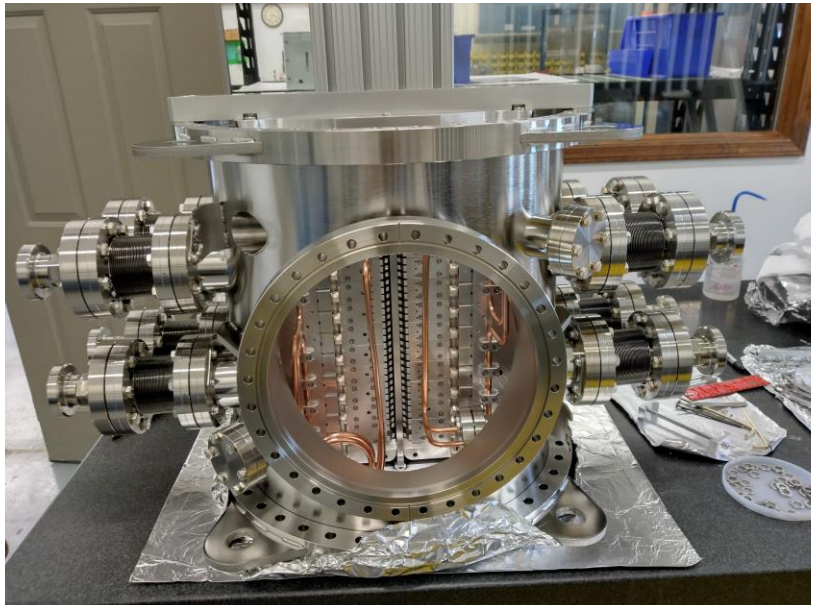
added value solutions

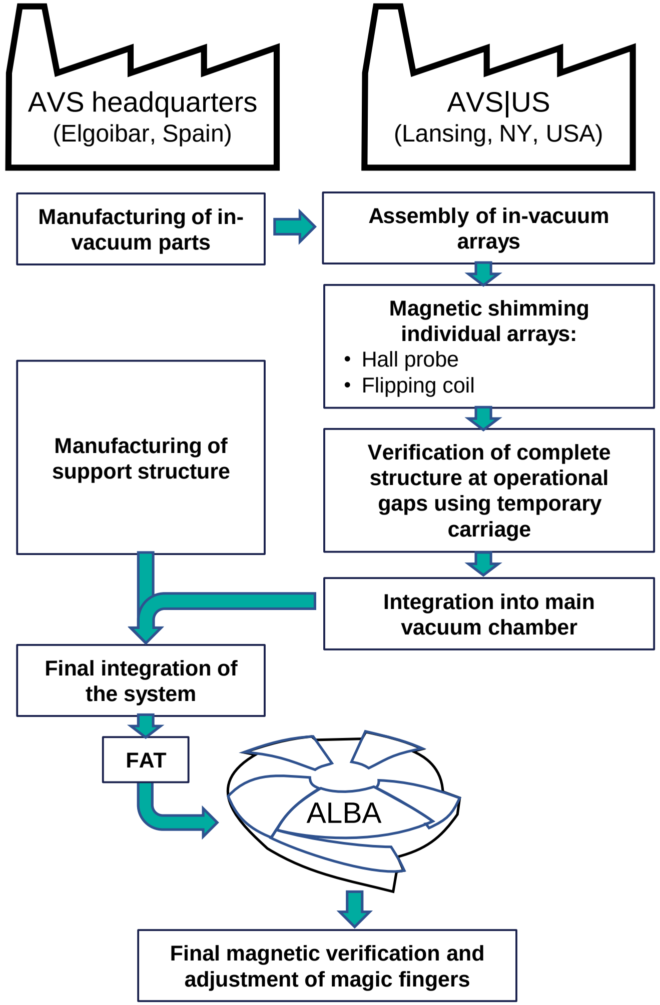
Magnetic measurement activities at ALBA

- **Magnetic arrays** were **adjusted by the manufacturer** (AVS|US) on a **temporary support carriage**, but a **characterization of the system after its integration** into the final support structure was missing, and **shall be carried out at ALBA upon delivery**.
- The **adjustment of the magic fingers** shall also be done at ALBA.

Combined arrays on temporary carriage



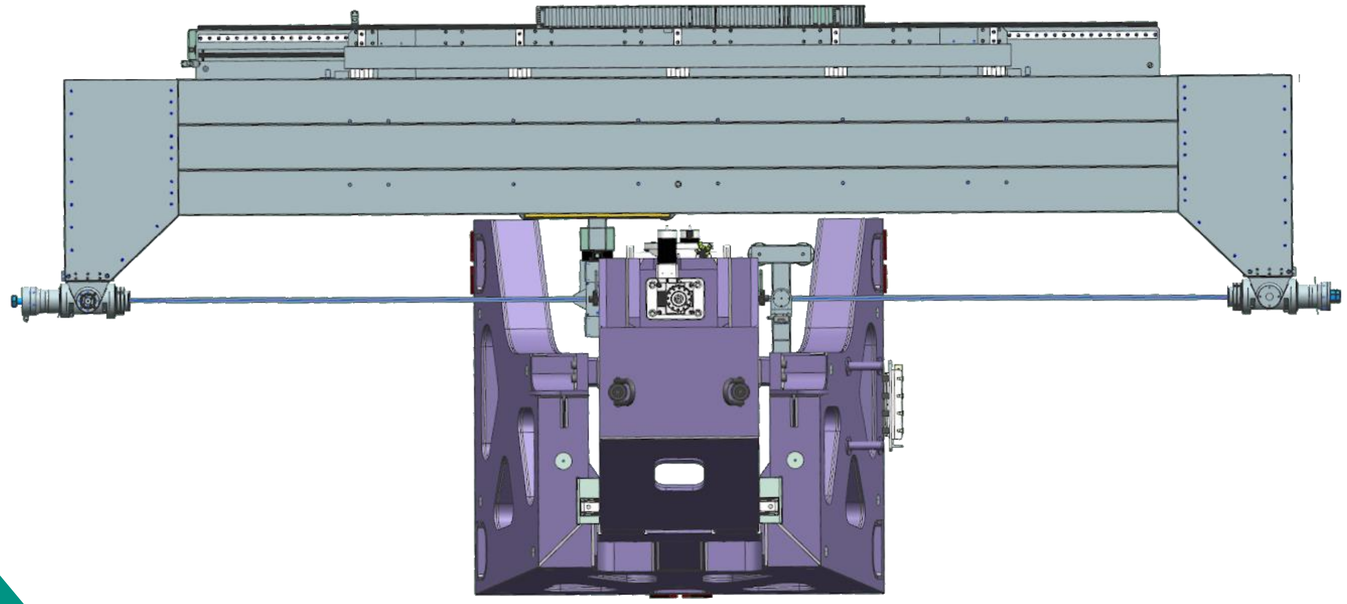
Assembly into vacuum chamber prior to shipping

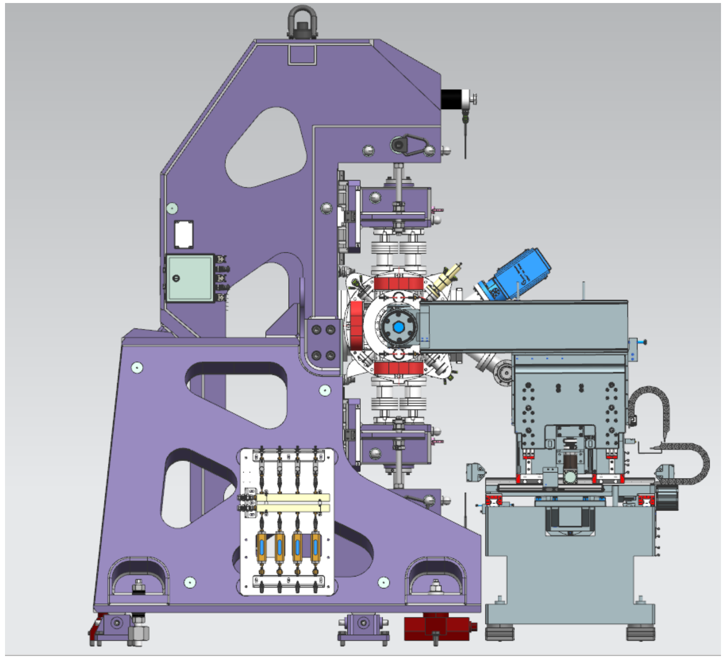


IMMW #23

Magnetic measurement activities at ALBA

- ID was delivered to ALBA on **Oct 2022** (just after IMMW22).
- **Magnetic characterization** was carried out using **Hall probe bench for closed structures** (local field data) and **flipping coil** (field integral adjustment).

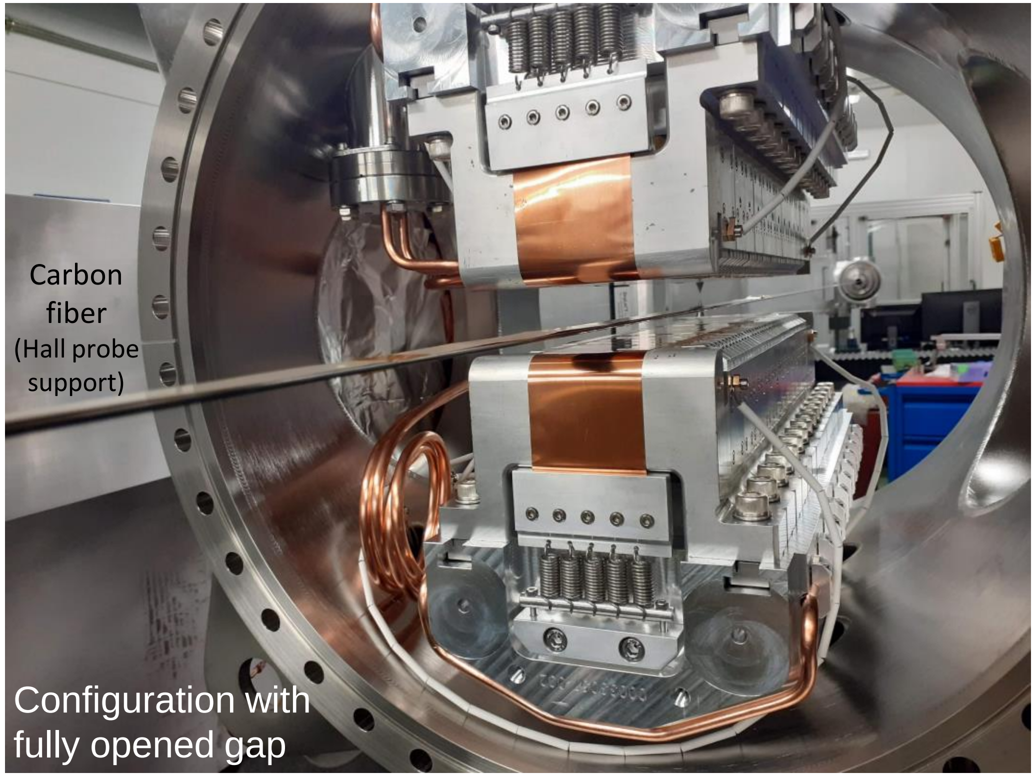




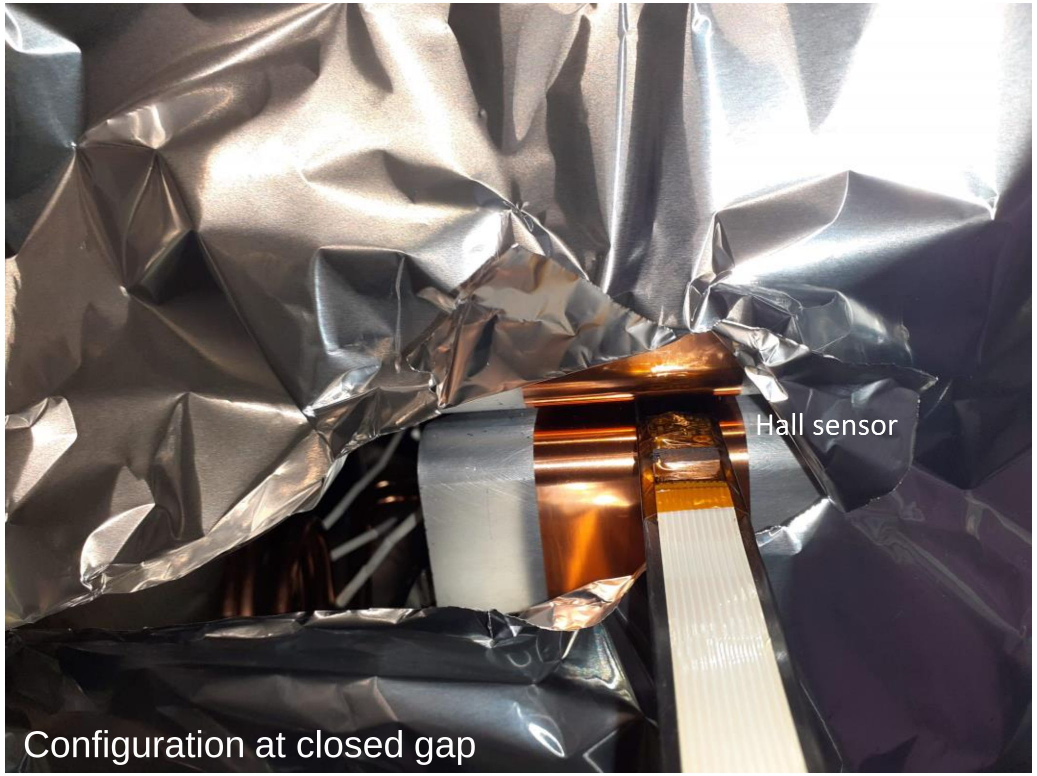
IMMW #23

Magnetic measurement activities at ALBA

- These measurements brought us the opportunity to **test the Hall probe bench for closed structures** for **mechanical gaps down to 5mm**.



Configuration with fully opened gap

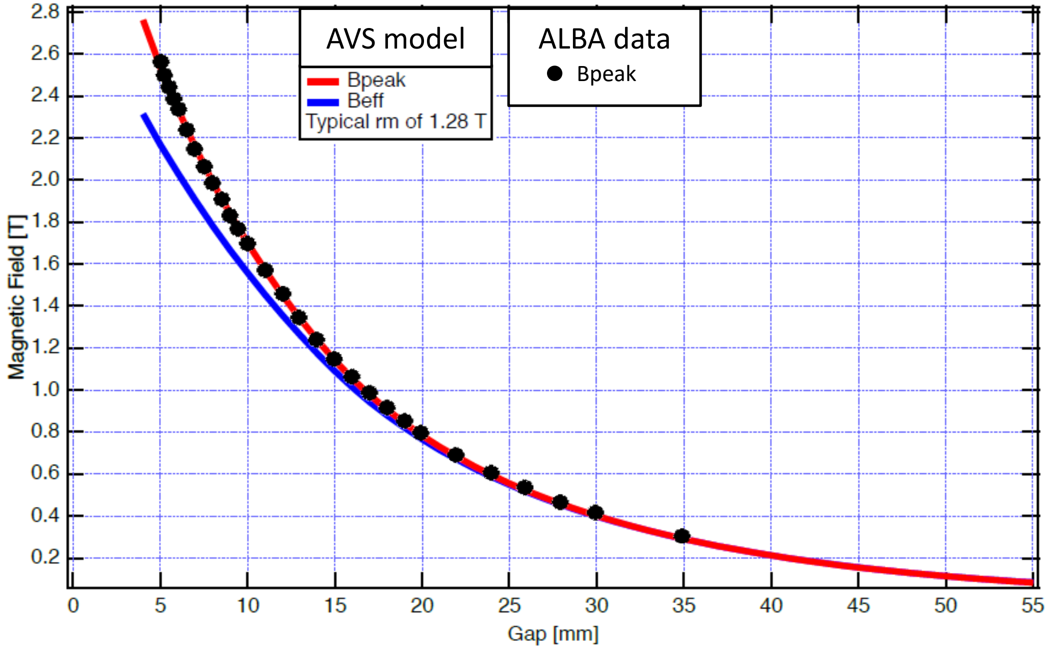


Configuration at closed gap

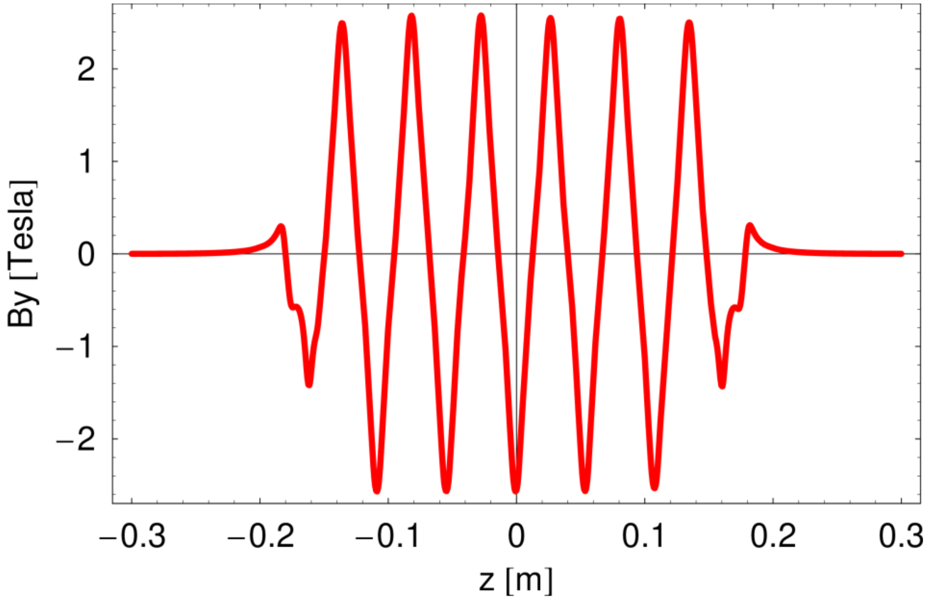
Magnetic measurement activities at ALBA

IMMW #23

- **Fielmaps at different gaps** allowed to obtain the **field vs gap dependence** of the device, and **confirming the predictions from magnetic model**.

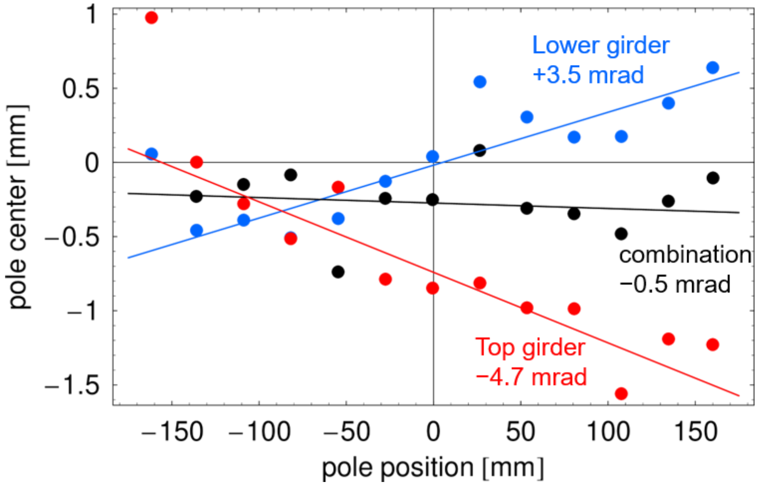


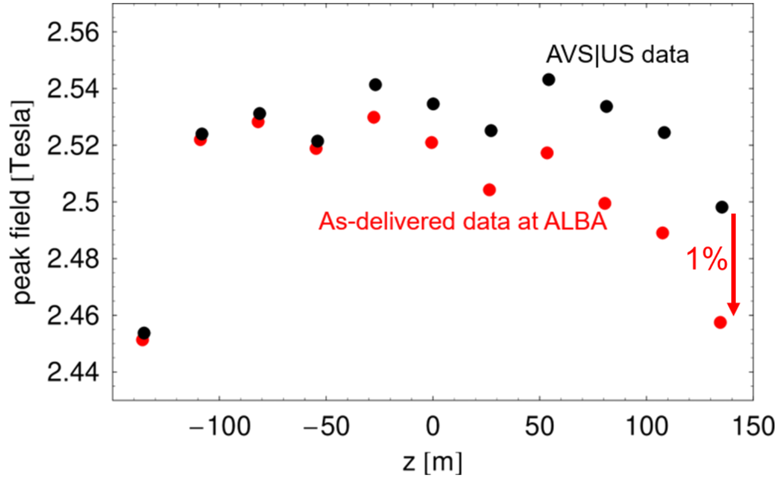
Field profile at minimum gap (5mm):



Magnetic measurement activities at ALBA

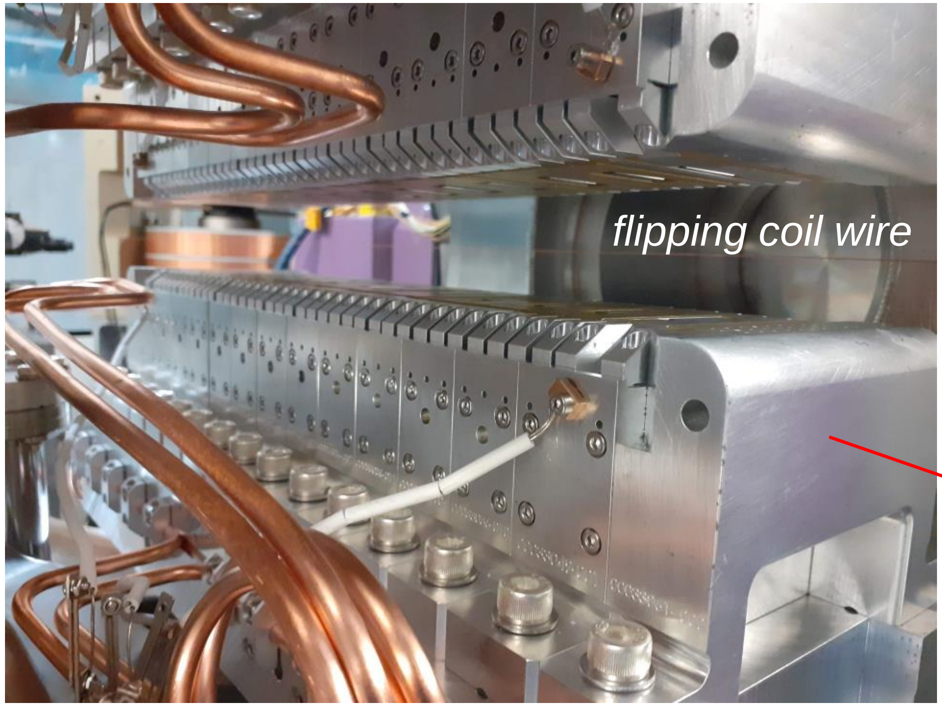
- Measurements close to the surface of each individual array showed that there is a **yaw misalignment between the individual magnetic arrays**.
- This misalignment was **not observed in the measurements carried out at AVS|US**, and hence it was **generated during the integration of the magnetic arrays into the final magnetic structure**.
- Due to the **horizontal roll-off** of the field, the yaw misalignment gives rise to **a decrease of the magnetic peak field along the structure**, **equivalent to a mechanical taper**.
- As a consequence of the tight schedule for installation it was decided **not to correct the misalignment**, once it has been checked that **it didn’t compromise the performance of the device**, neither from a beam dynamics nor radiation output point of view.

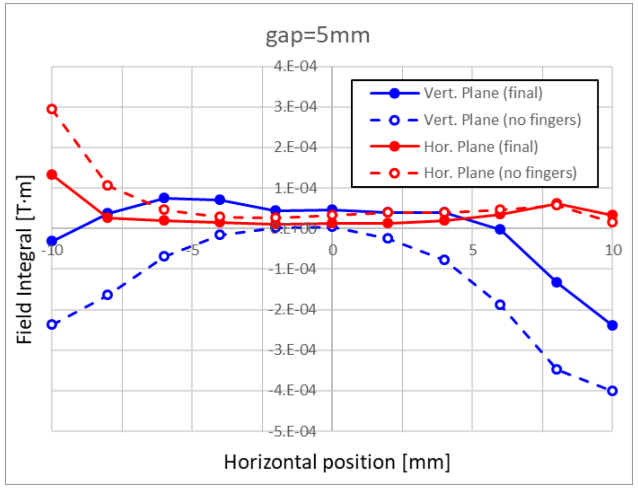


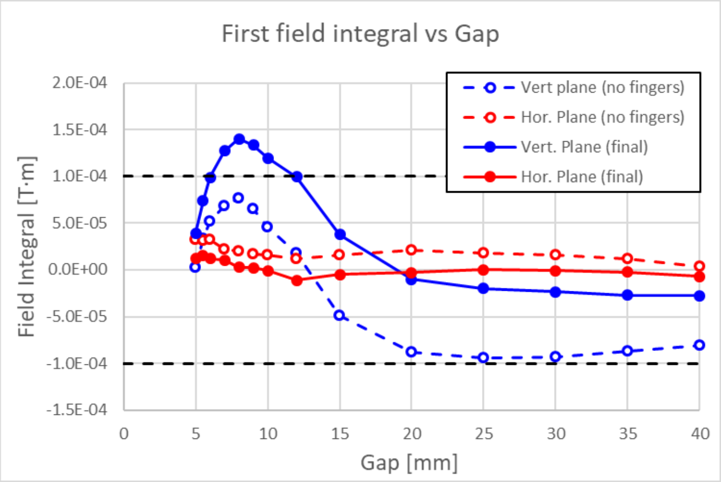


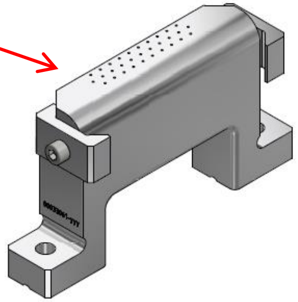
Magnetic measurement activities at ALBA

- **Magic fingers** where adjusted using **field integrals** measured with **flipping coil**.
- Due to tight schedule and problems with the machining of the magic fingers' receptacle, a **limited number of iterations was done**.









Magic fingers holder

Outline

- ALBA: today and upgrade plans
- Magnets for ALBA II
- Magnetic measurement activities at ALBA
- **Conclusions**

IMMW #23

Conclusions & Prospects

- **ID & Magnets group at ALBA** is currently **focused in the design and development of prototypes for ALBA II** upgrade.
- **Along 2025** it is expected to have a gradual **increase in the Mag Meas lab activities**, as we prepare to **receive and characterize the first ALBA II prototypes by the end of that year**.
- One of our **priorities** is completing the procurement of those **pieces of equipment that will be essential for the series magnets characterization**. On top of the **2 existing Hall probe benches** (1 conventional, 1 for closed structures), we have identified that **at least 2 ESRF-type Stretched Wire benches will be required**. **Suggestions are welcome!**

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Conclusions & Prospects

- **Experience gained** with the **characterization of ALBA II prototypes** will be critical to **define the protocols and procedures for the series magnets characterization**.
- In particular, we will need to validate the strategy of **characterizing magnets individually** and **assembling them into girders without further magnetic characterization** (vibrating wire measurements or similar).
- **Hall probe bench for closed structures** is turning out to be a **very useful system** to characterize the **3D magnetic field distribution in difficult-to-access environments**. It will for sure be very helpful to map the **magnetic field distribution of different combinations of ALBA II magnets** in order to analyze **crosstalk effects**.

Questions?