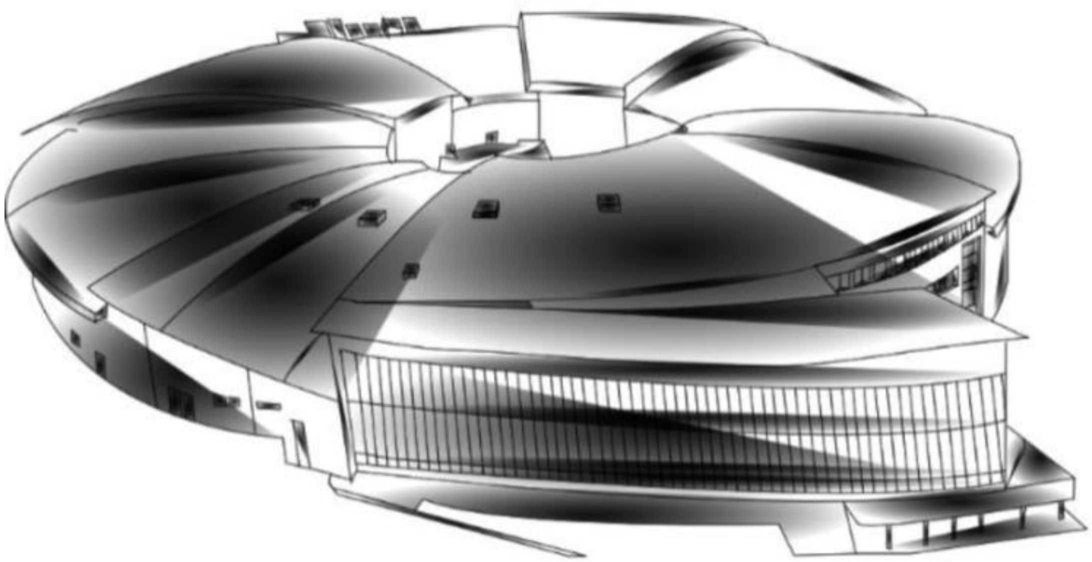
General status of ID magnetic measurements laboratory at ALBA

Dr. Josep Campmany

on behalf of Jordi Marcos, Valenti Massana, Llibert Ribó, Roberto Petrocelli and Fulvio Becheri

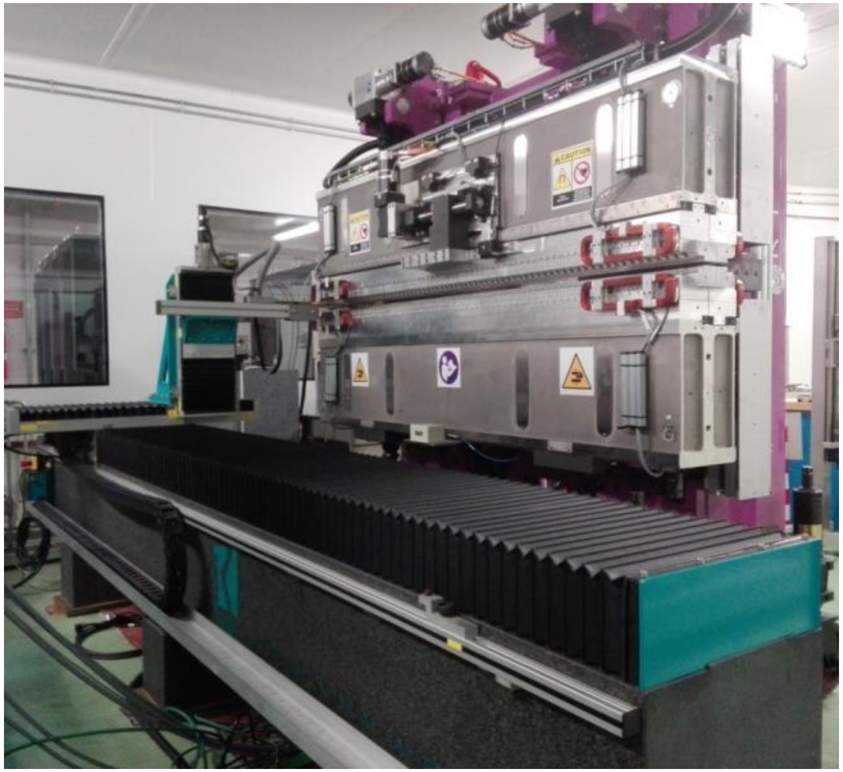


IMMW21

1 **Measurements made in 2017-2019**	**2** **New rotating coil shaft for measuring narrow gap devices**
3 **3D Helmholtz coils setup**	**4** **Further improvements**

LOREA undulator

2017/05/24→2017/07/21



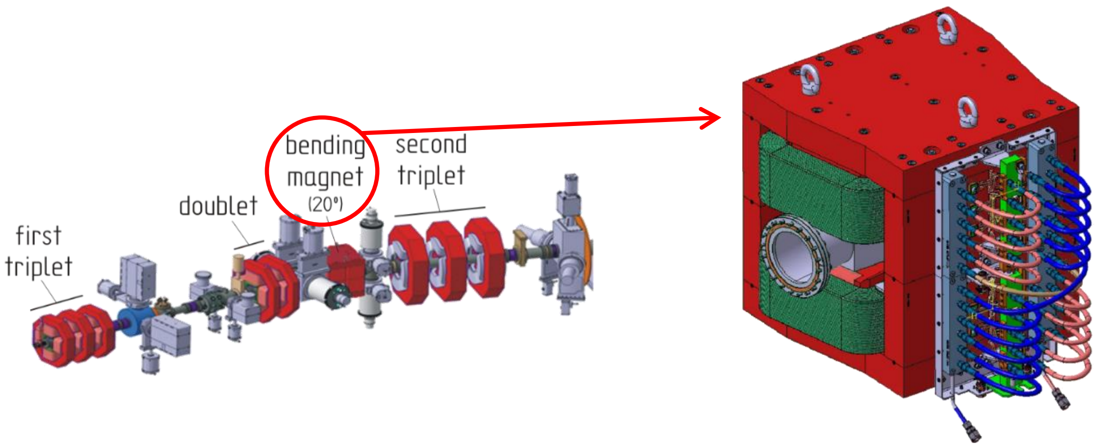
- Undulator for Phase-II beamline LOREA at ALBA

Undulator characteristics	
Period [mm]	125
Length [m]	2.15
Minimum gap [mm]	13
$B_{vertical}$ [Tesla]	1.09
$B_{horizontal}$ [Tesla]	1.06
$B_{circular}$ [Tesla]	0.76
$B_{diagonal}$ [Tesla]	0.45

- **Cross check** of factory measurements using **Hall probe** and **Flipping Coil** benches

LIPAc magnets

We have continued our collaboration with **CIEMAT** (Spain) carrying out measurements for **LIPAc** of magnets had been manufactured by **Elytt Energy** (Spain).



Dipole characteristics	
Number of magnets	1
Deflection angle [deg]	20
Aperture [mm]	136
Magnetic Length [m]	0.7
Max. current [Amp]	100
Max. Field [Tesla]	0.33
Int Field [T·m]	0.2154
$\Delta B/B$	$<10^{-3}$
Energy [MeV]	9 (D^+)

High Energy Beam Transfer

- 3×**quads** second triplet
- 1×**bending magnet**

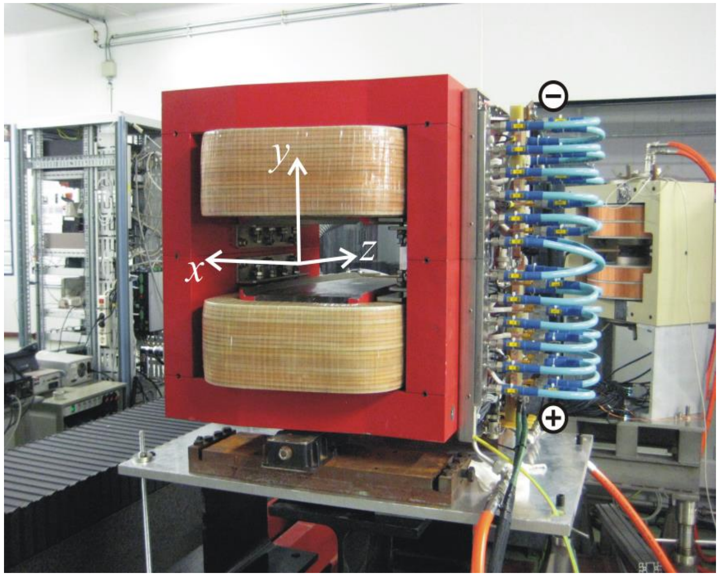
(first triplet and doublet quads already measured on 2016-17, see IMMW20 presentation)

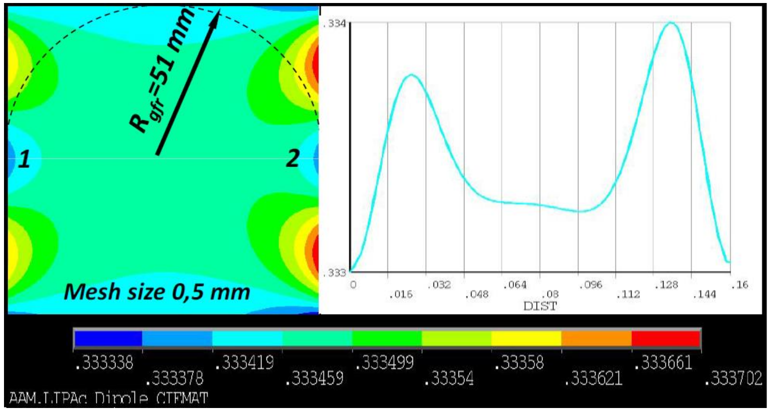
- Determine **transfer function** at magnet center $B(I)$
- Determine **field homogeneity** at center
- Determine **multipoles along trajectory**

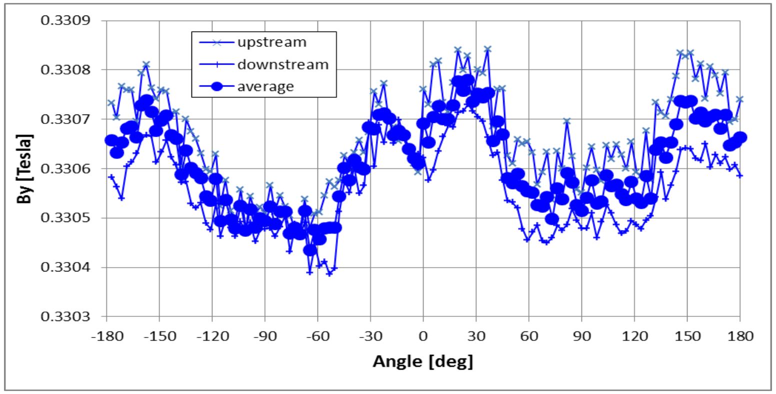
Dipole for LIPAc HEBT: field homogeneity

2017/11/02→2017/11/29

- To determine **field homogeneity**, Hall probe scan along a **circle** with radius $R_{ref} = 51mm$ at central plane ($z = 0$)







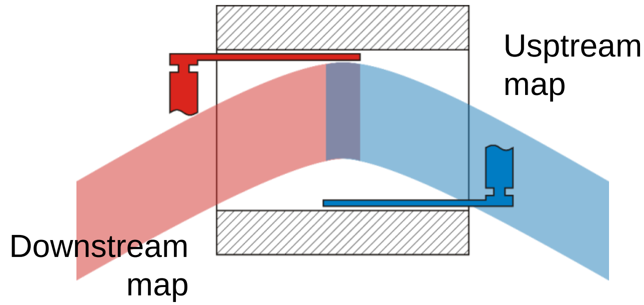
- Field **homogeneous** within $\mathbf{0.5 \times 10^{-3}}$

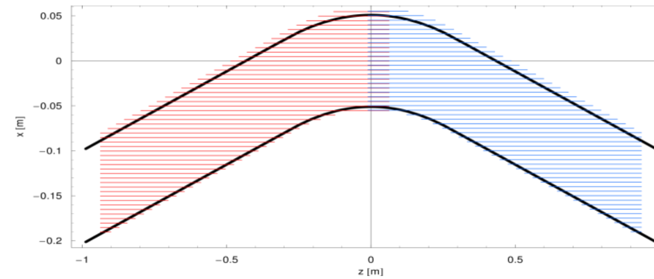
Dipole for LIPAc HEBT: integrated field

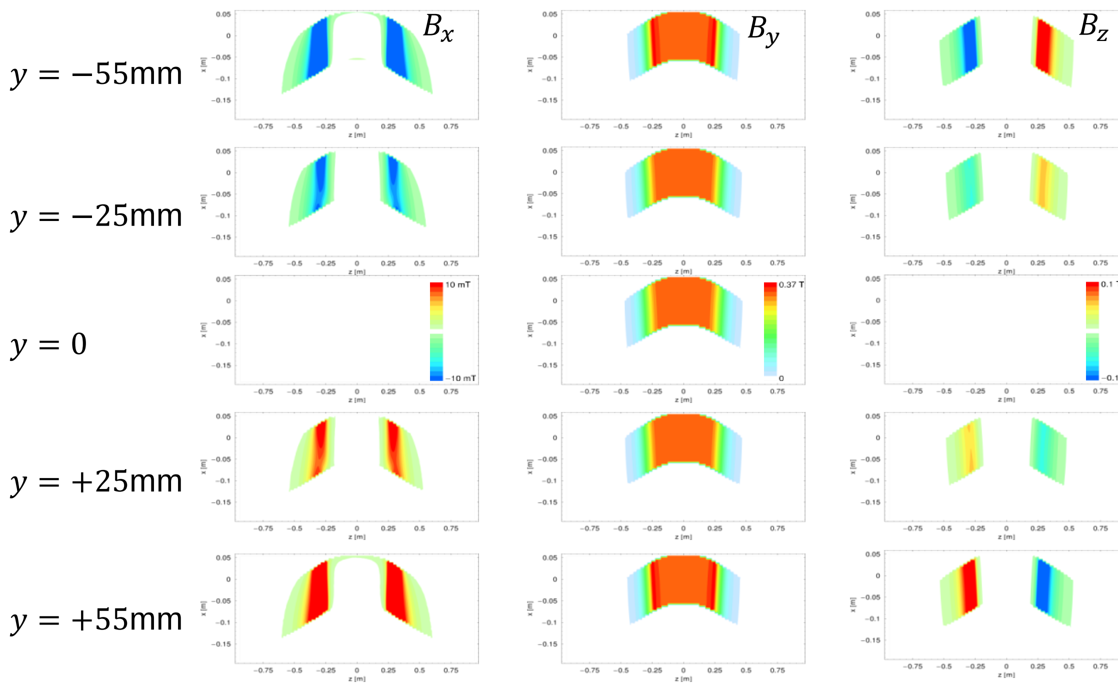
- Field maps have been measured at **different vertical** (y) positions

- To determine **integrated field** and **multipoles along trajectory**, magnetic field has been scanned along a **rectangular grid** adapted to the shape of the trajectory, with sampling step **1mm×5mm** (longitudinal × horizontal) and covering the requested good field region (R_{ref} = 51mm)

- Measurements have been carried out from **both sides** of the magnet, with an **overlapping of 73mm** in the central region, and obtained maps have been **combined** into a single one.







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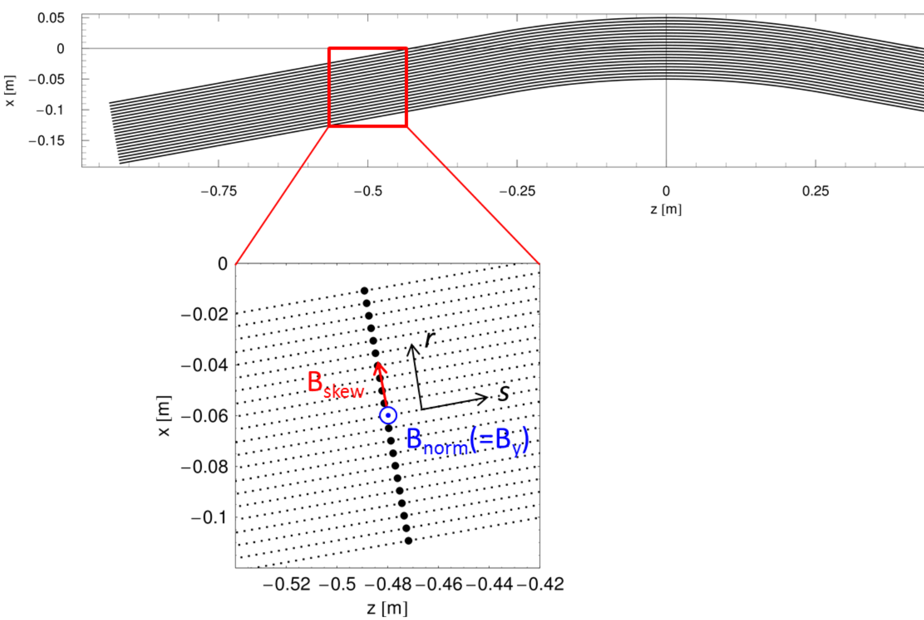
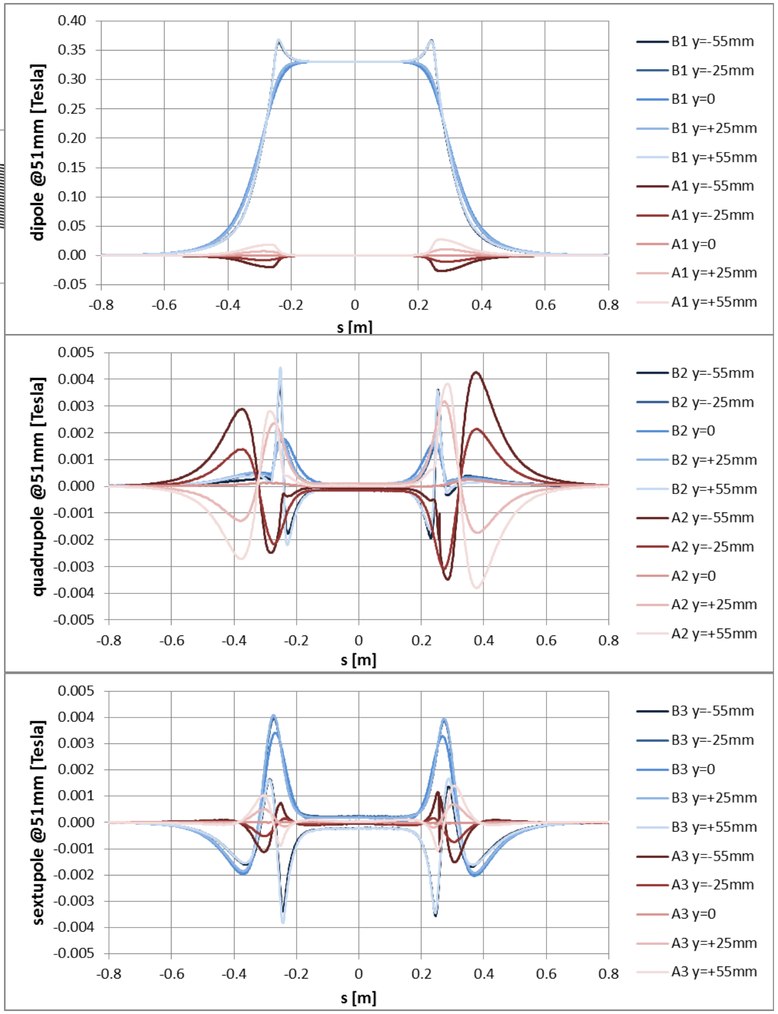
Dipole for LIPAc HEBT: pseudomultipoles

- **(Pseudo)multipoles** along trajectory at different vertical positions have been calculated from field maps



$$B_{norm}(s,r) = \sum_{n=1}^{\infty} B_n(s)\left(\frac{r}{R_{ref}}\right)^{n-1}$$

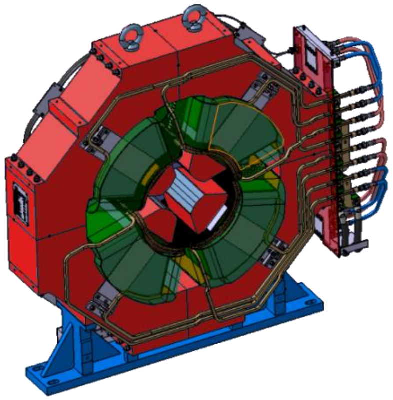
$$B_{skew}(s,r) = \sum_{n=1}^{\infty} A_n(s)\left(\frac{r}{R_{ref}}\right)^{n-1}$$

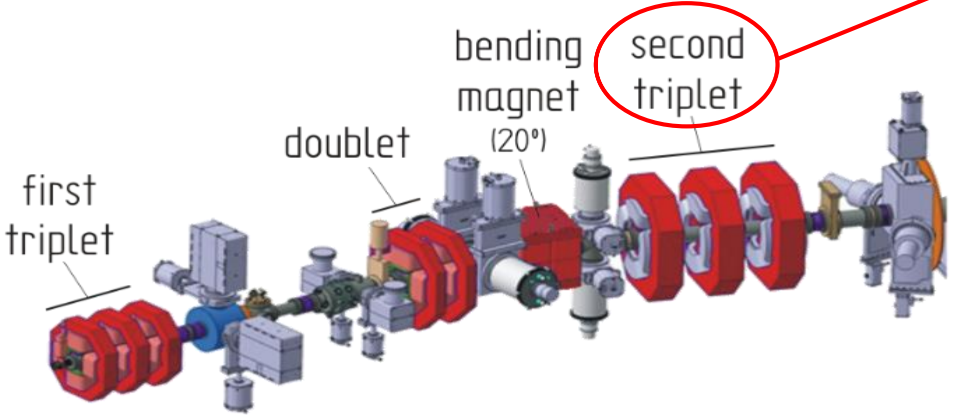


Quadrupole for LIPAc HEBT

2017/11/02→2017/11/29

- Determine **transfer function** for integrated gradient
- Determine **magnetic axis** and **roll angle**
- Determine **harmonic content**





Quadrupoles characteristics	
Number of magnets	3
Aperture [mm]	136
Magnetic Length [m]	0.250
Max. current [Amp]	313
Gradient G_0 [T/m]	12.75

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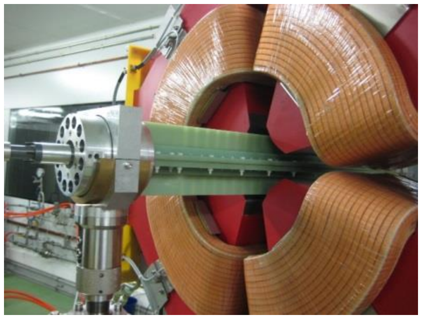
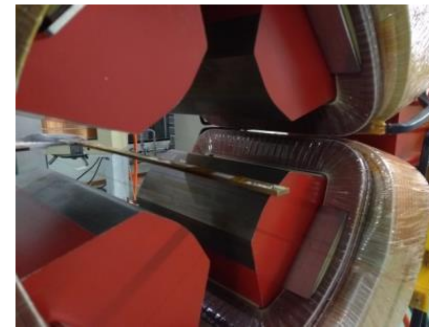
Quadrupoles for LIPAc HEBT

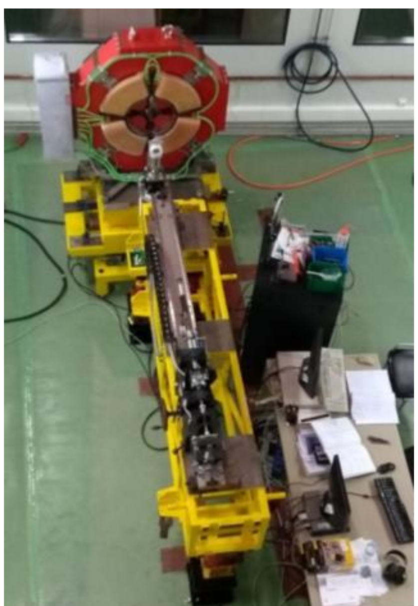




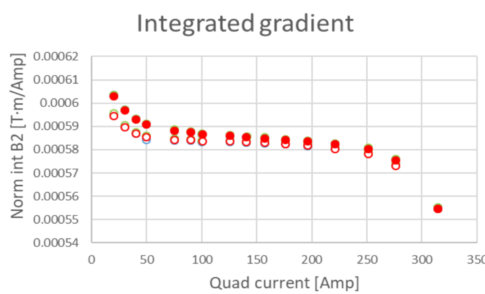
- Rotating coil measurements carried out with **in-house PCB**-based shaft with **∅=130mm**
- Due to the fact that $(L_{iron} + 2 \times \ Aperture) \sim L_{shaft}$

  we have **cross-checked** the obtained integrated gradient by means of a **Hall probe measurement**

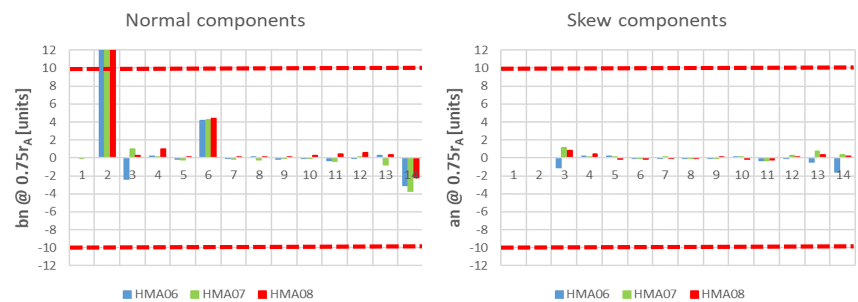
→ Agreement within **0.1%** ✓



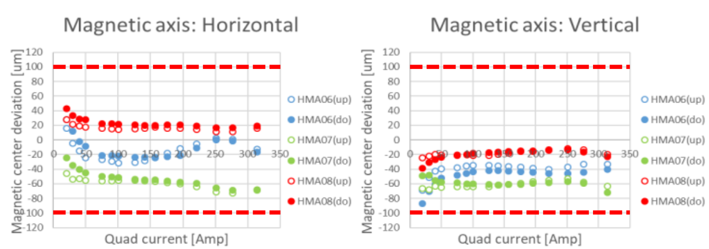
Transfer function



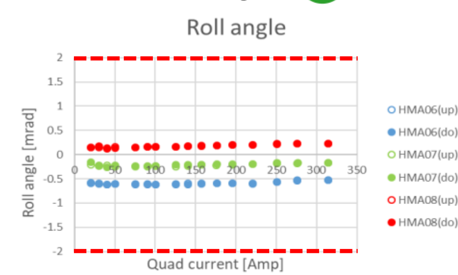
Harmonic content ✓



Magnetic axis deviation ✓



Roll angle ✓

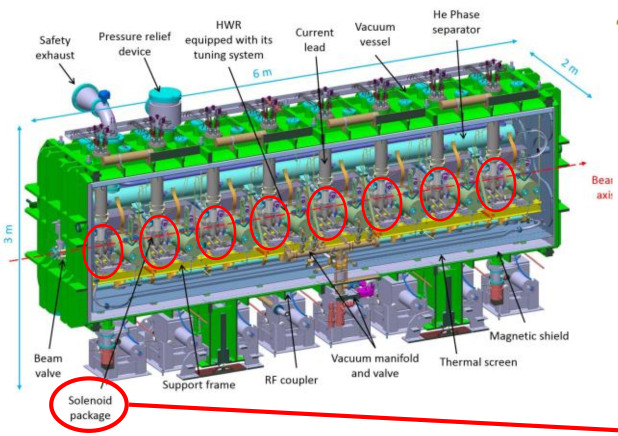


ALBA IMMW21

IFMIF Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

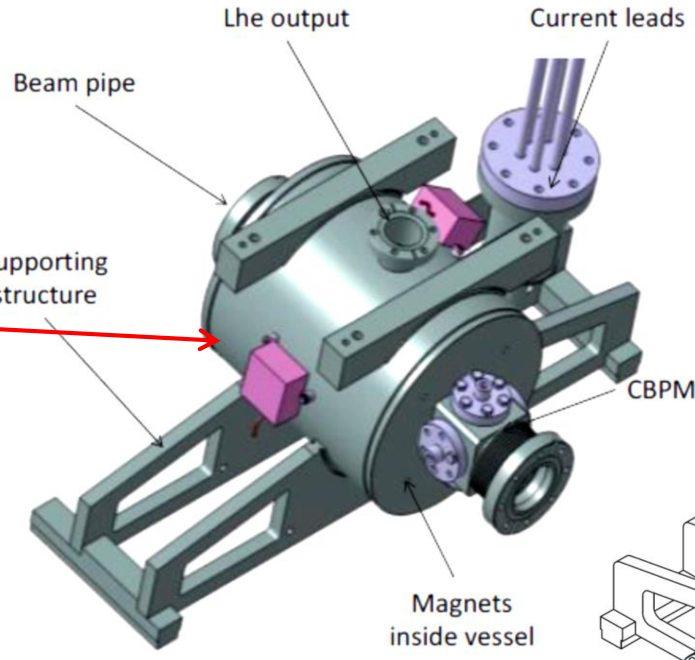
Solenoids for LIPAc SRF LINAC

ELYTT ENERGY



2018/11/05→2019/03/22

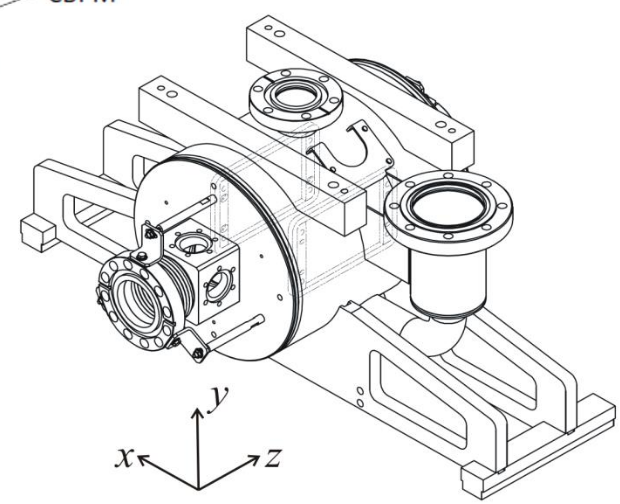
- Determine **magnetic axis position** and **orientation**



Superconducting RF LINAC

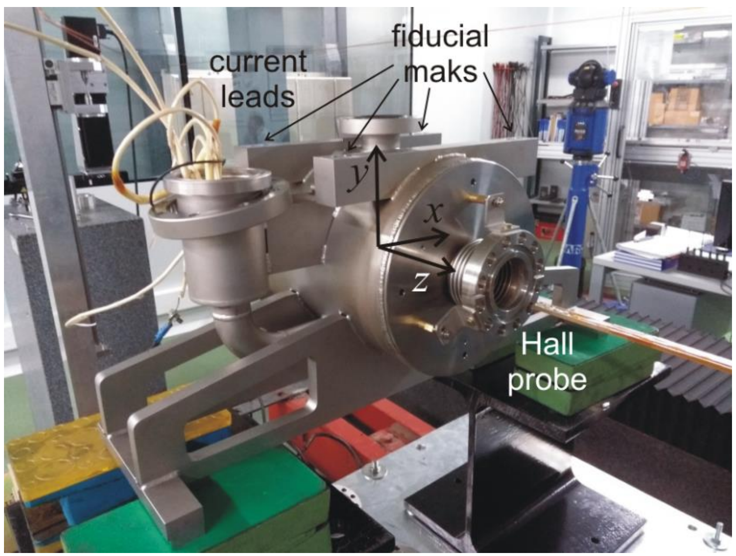
- 8×**SC solenoids**

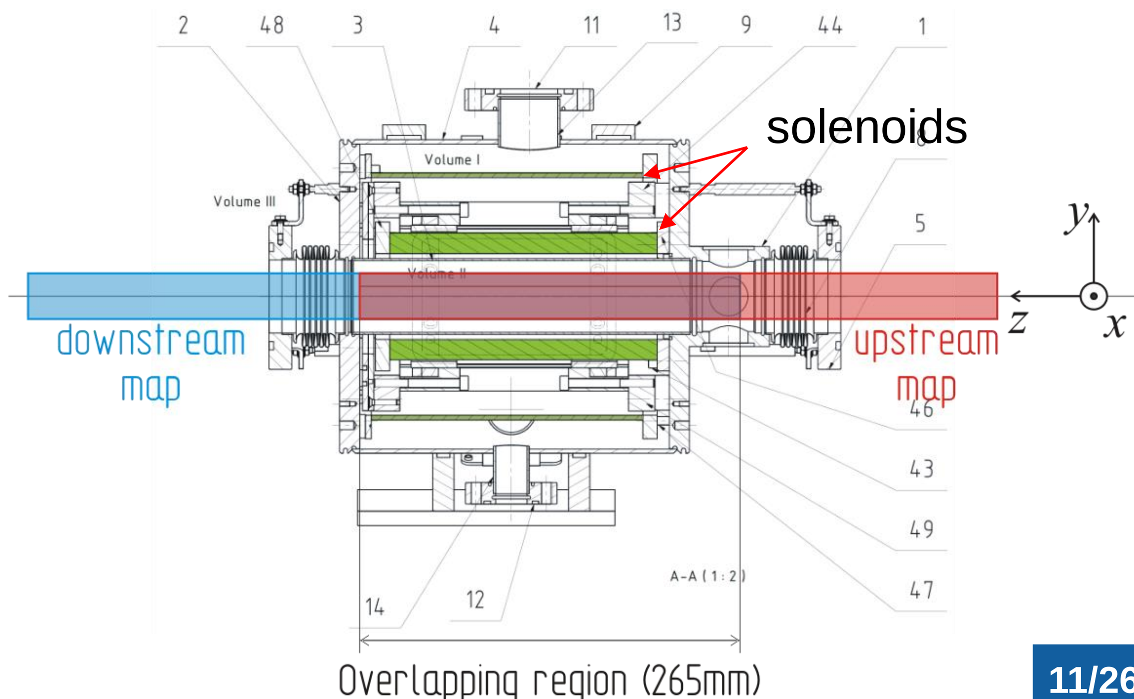
Solenoid characteristics	
Number of magnets	8
Aperture [mm]	50
Solenoid length [m]	0.187
Max. current [Amp]	210
Axial field [T]	5.85



Solenoids for LIPAc SRF LINAC

- Characterization has been carried out at **room temperature** and **low current** (0.4Amp) using Hall probe bench.
- **Horizontal/vertical field maps** have been measured **from each side** and the results have been combined into single horizontal/vertical maps.

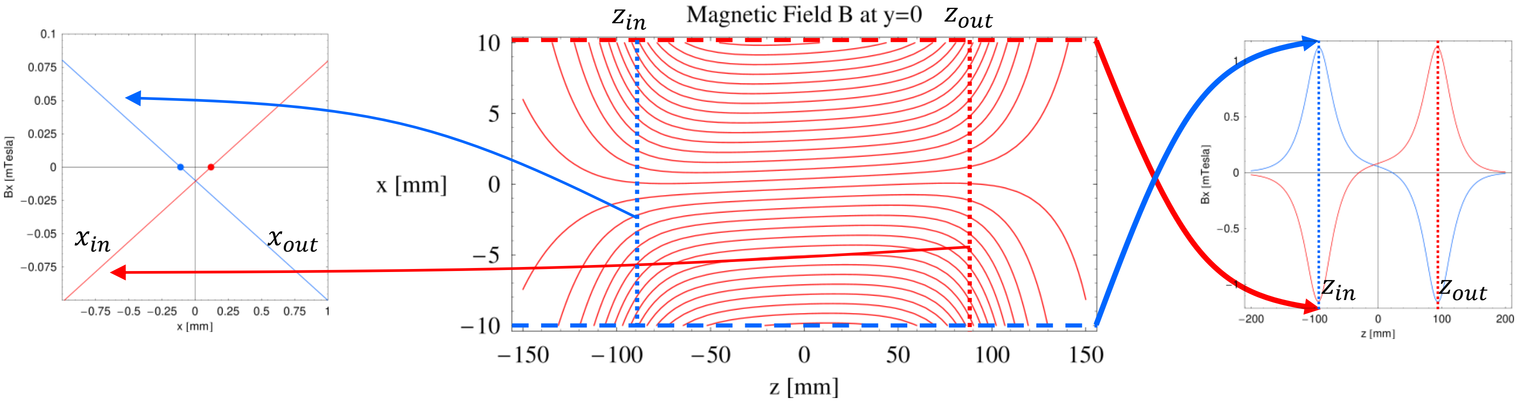




Solenoids for LIPAc SRF LINAC

- Todetermine the magnetic axis position/orientation we have analyzed the **minor components** of the magnetic field

Example: RADIA simulation of a solenoid rotated by **5mrad** around y axis



Determination of the **edges** of the solenoid

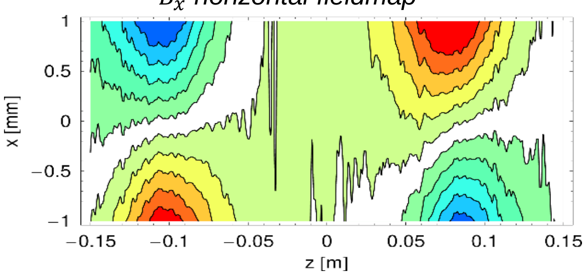
$$\left(\frac{\partial B_x}{\partial z}\right) \text{ maximum}$$

Determination of x_{in} and x_{out} positions with $\boldsymbol{B_x = 0}$ at z_{in} and z_{out}

Axis position $x_{axis} = \frac{(x_{in}+x_{out})}{2}$

- **Magnetic axis** determined through the condition $B_x = 0$ (H coordinate) and $B_y = 0$ (V coordinate) on the edge region:

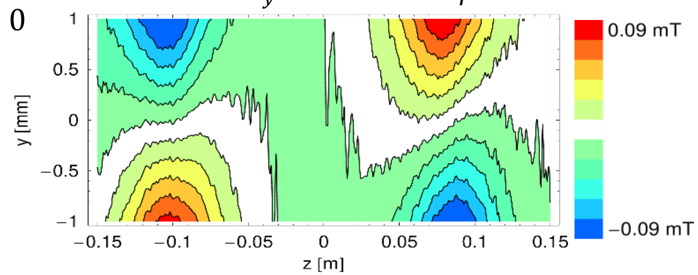
B_x *horizontal fieldmap*



$$B_x(x_{axis}, z_{edge}) = 0 \; ; \; B_y(y_{axis}, z_{edge}) = 0$$

$$yaw = \left\langle \frac{B_x}{B_z} \right\rangle_{center} \; ; \; pitch = \left\langle \frac{B_y}{B_z} \right\rangle_{center}$$

B_y *vertical fieldmap*



- **Misalignment angles** estimated from the minor field components relative to the axial in the central solenoid region
- **Comparison** of results obtained measuring from **both sides** allow to **estimate errors**

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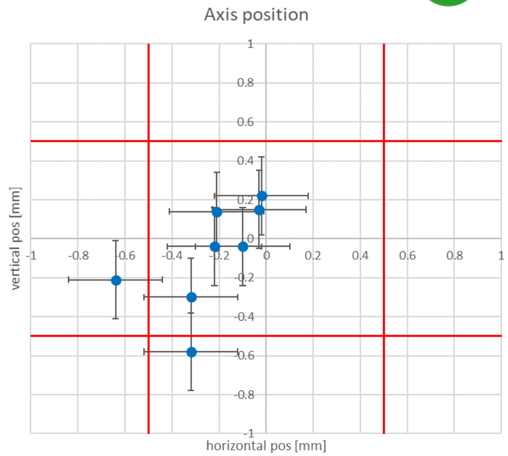
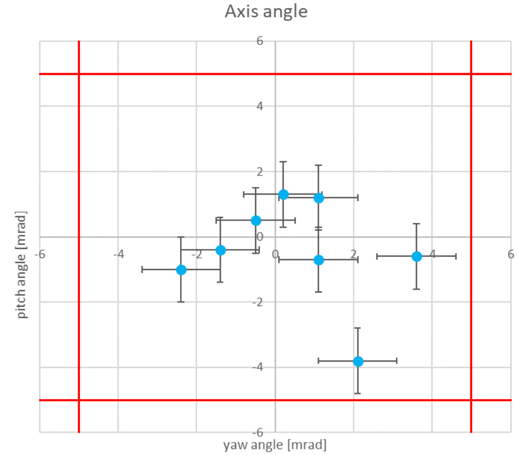
Solenoids for LIPAc SRF LINAC

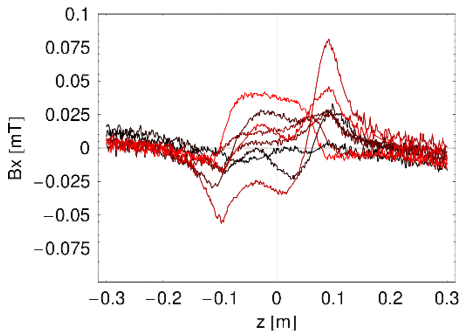
Axis position

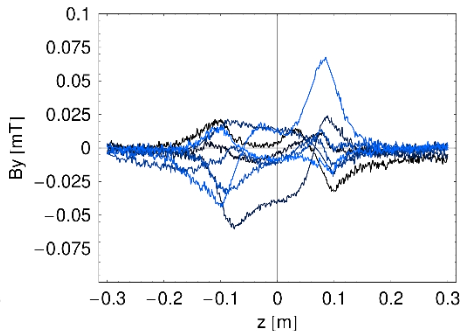


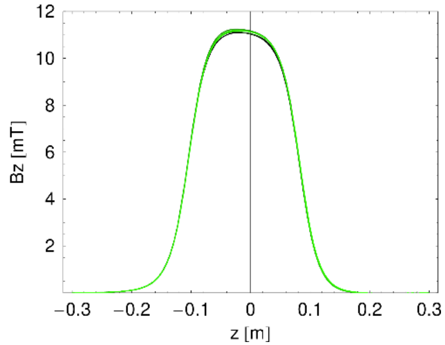
Axis alignment angles



Obtained field components along mechanical axis ($x = y = 0$) for all 8 solenoids







Measurements made in 2017-2019

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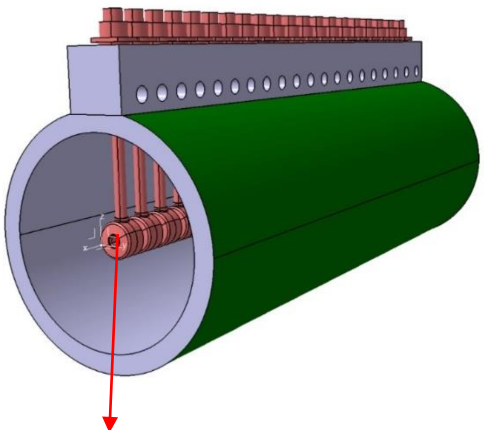
EUROPEAN SPALLATION SOURCE

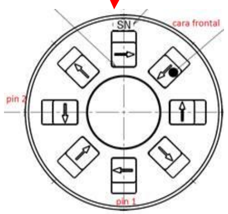
ELYTT ENERGY

ESS PMQs

2017/12/14→2017/12/19

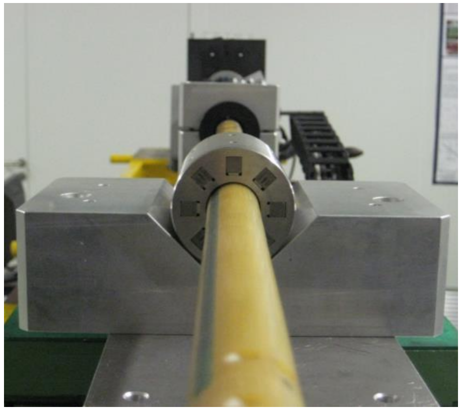
Measurement of a series of **PMQs** manufactured by **Elytt Energy** (Spain) for **Tank 4** of **DTL** of **ESS**.

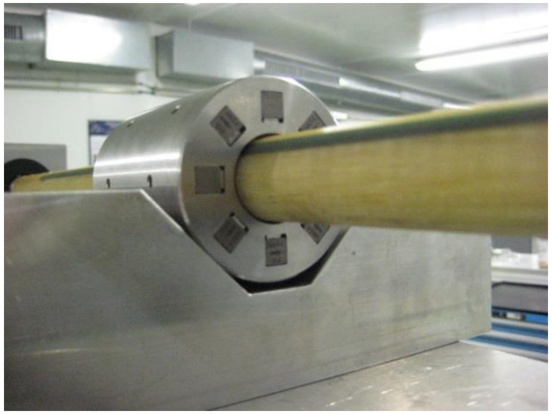




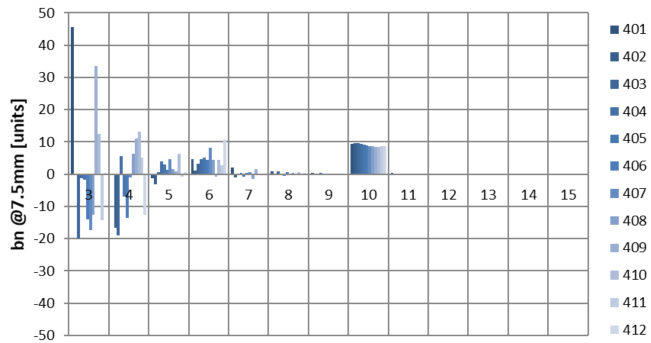
PMQ Characteristics	
Number of magnets	12
Gradient G_0	20 Tesla/m
Bore diameter	24 mm
Mechanical length	80mm
Sm_2Co_{17} magnet blocks	

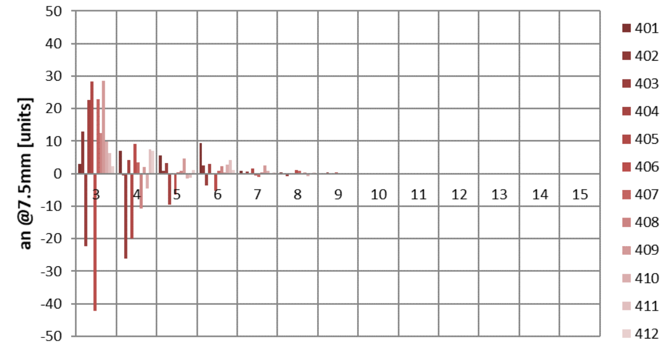
- PMQs have been characterized using a **∅=22mm** PCB rotating coil with quadrupole compensation.
- We have determined: (a) magnetic axis, (b) roll angle, (c) integrated gradient, and (d) harmonic content.
- In order to **minimize alignment errors** between the rotating coil axis and the magnet, magnets have been measured in **4 different positions** making use of the alignment pins.



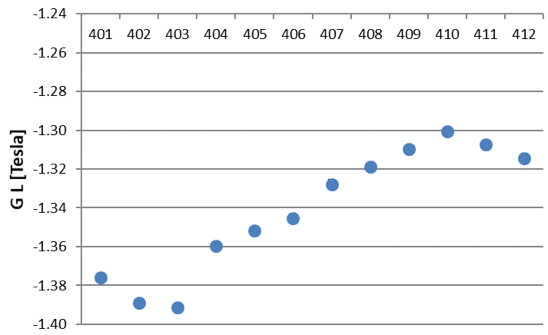


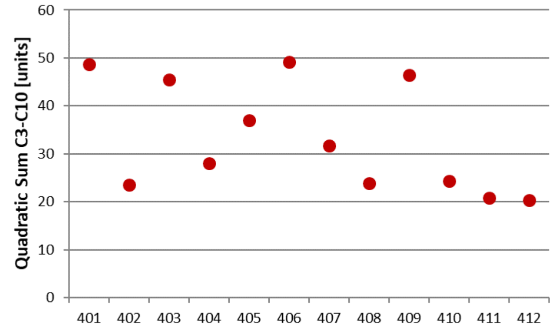
ESS PMQs





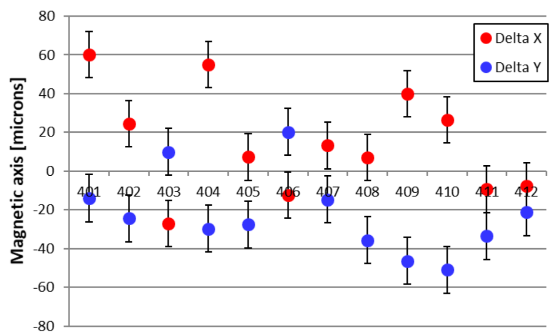
Integrated gradient

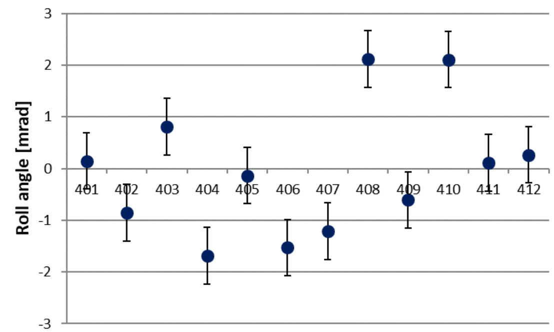




High harmonic content

Magnetic axis





Roll angle

Needs:

- Low emittance rings trend to use narrow radius multipolar magnets (ø ~ 12 mm)
- At these small radius, the imperfections and errors are more relevant
- To this end, a specific new set of tools should be developed

Instrument to fulfill this aim:

- We have chosen building a narrow shaft with coils to be applied to our new Rotating Coil bench
- The shaft will follow the CERN scheme, with 5 parallel coils, the internal ones used to buck the signal of the external

Concerns:

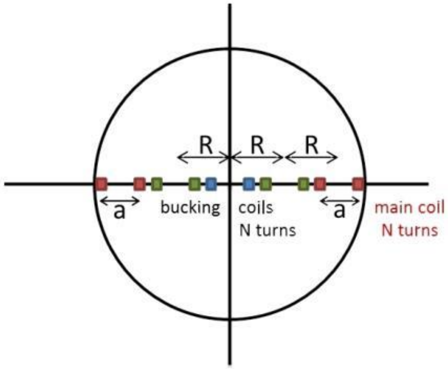
- Coil sensitivity (number of turns of each coil)
- Shaft rigidity (multilayer PCB length 550 mm, width 10 mm and thickness 2 mm)
  - Sag
  - Twisting during rotation
- Shaft positioning (usual positioning requirements have tolerances below 30 µm)
- Shaft alignment with respect to the magnetic structure to be measured

Solutions adopted:

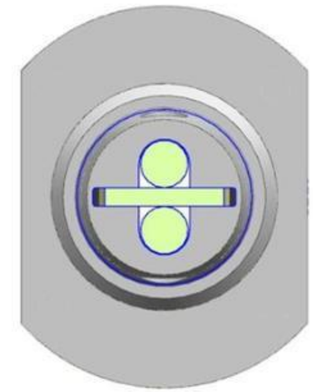
- Coil sensitivity: multilayer PCB, 30 turns per coil.
- Shaft rigidity: guaranteed using ceramics (Al_2O_3) glued to PCB. All shaft is glued as a single piece.
- Shaft positioning: high precision bearings with inner ø = 10 mm mounted on precision setup tables.
- Shaft alignment The shaft has two reference surfaces allowing the horizontal alignment of the setup as well as the positioning of the shaft with respect to the magnetic structure to be measured.

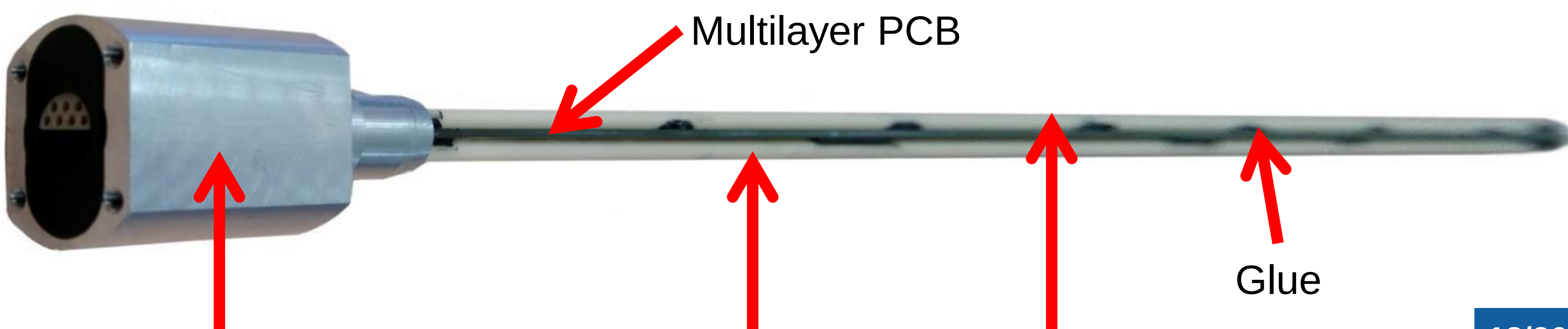
New rotating coil shaft for measuring narrow gap devices

Design:



Shaft diameter	Circuits position	Turns per layer	Layers	Length
10 mm	R = 1.9 mm A = 0.9 mm	N = 3	10	550 mm
23 mm	R = 4.6 mm A = 2.3mm	N = 9	20	550 mm





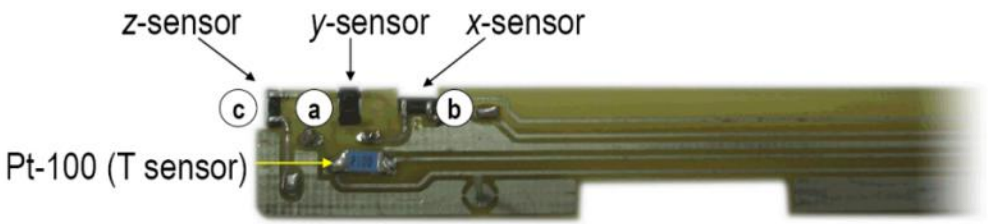
Al_2O_3 ceramics

Reference surface

3D Helmholtz coils setup

Motivation:

- 3D Hall probes at ALBA are **built in-house** by combining three orthogonally mounted 1D Hall sensors on a common circuit board



- Hall sensors are assembled with an angular accuracy of **±3º**. So far, the resulting misalignment angles can be mechanically determined with a precision of **~0.5º / ~ 10 mrad**

- We want to **improve the accuracy** in the determination of the misalignment angles **down to ~0.2 mrad** level

- Our aim is to generate a **magnetic homogeneous field** within a volume covering all 3 sensors and with an **arbitrary** and **well controlled** orientation

- To this end, we have designed and are building a **3D Helmholtz coil setup**

3D Helmholtz coils setup

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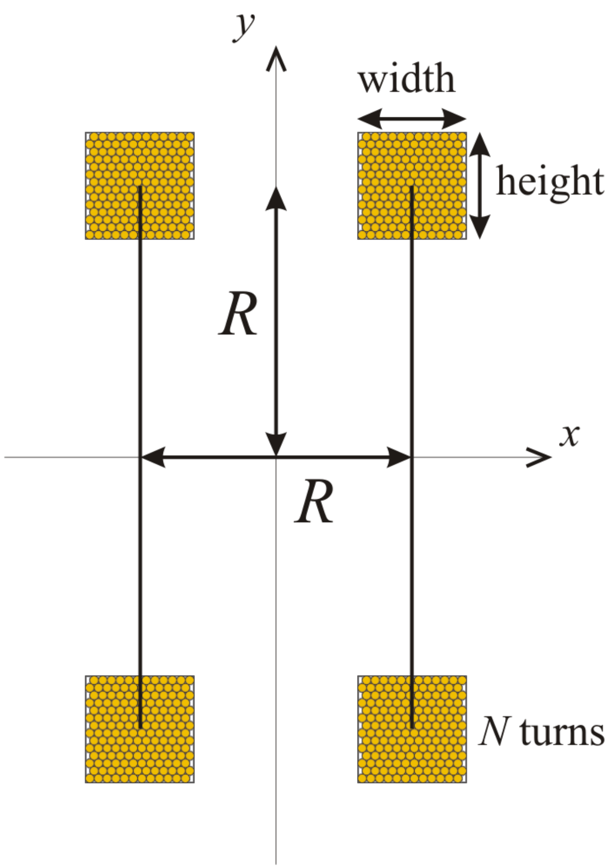
System requirements:

- The system will consist of **3 orthogonal** pairs of **Helmholtz coils**



Magnetic field at the system's center

$$B = \left(\frac{4}{5}\right)^{3/2} \frac{\mu_0 N I}{R}$$

No ferromagnetic parts → Linear system → Superposition principle can be applied

- **Air cooled** coils will be used in order to keep the system as **simple** as possible
- The objective is generating a **homogeneous** magnetic field, with a **flux density as high as possible** whilst keeping the **system heating** at a **reasonable level**, and ensuring a **orthogonality** between the field components generated by each coils better than **0.2mrad**

Parameter	Specification
Magnetic field homogeneity	10^{-4} within 15×15×15 mm^3
Maximum system heating	20ºC
Magnetic field orthogonality	0.2 mrad

3D Helmholtz coils setup

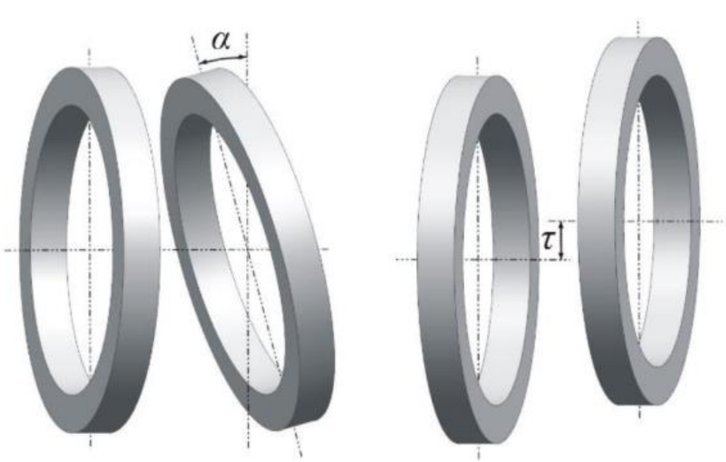
Design parameters:

- The magnetic design has been carried out using RADIA
- Coils will be made of grade 2 enamelled copper wire with a conductor/total diameter of 1.5 mm / 1.571 mm. Using an orthocyclic winding layout, we expect attaining a filling ration close to 0.77. An external company will make the wiring

Parameter	Coil 1	Coil 2	Coil 3
Number of turns N	304	418	572
Radius R [mm]	125.7	172.9	236.7
Coil width [mm]	26.4	31.2	36.0
Coil height [mm]	26.7	30.8	36.4
Nominal current [A]	2.3	2.3	2.3
Magnetic field [mT]	5	5	5
Resistance/coil [Ω]	2.31	4.37	8.18
Power/coil [W]	12.22	23.11	43.27
Estimated ΔT [°C]	15	17	20

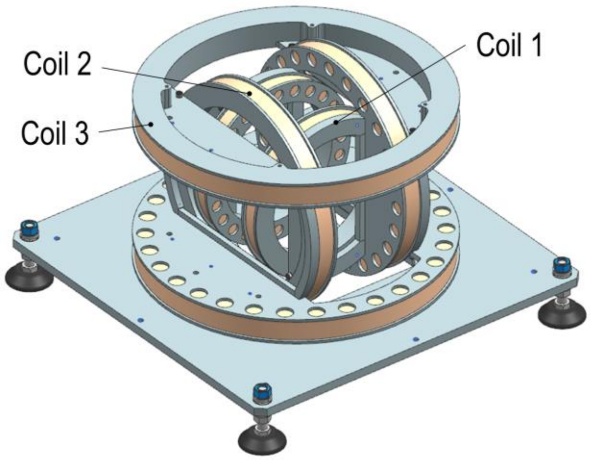
Mechanical tolerances

Parameter	Coil 1	Coil 2	Coil 3
Angular deviation α [mrad]	0.2	0.2	0.2
Centres offset τ [mm]	0.08	0.12	0.16



Mechanical design

- The mechanical implementation will consist of a set of **interlocking aluminium pieces**
- Each piece has a rectangular groove with the proper dimensions to wind one of the coils.
- The **precise machining** of the pieces will guarantee that **upon assembly** the **relative positioning** of the coils will be close to design values.
- **Reference surfaces** machined on the pieces will allow to **survey accurately** their actual position and to **correct** any deviation by means of shims.

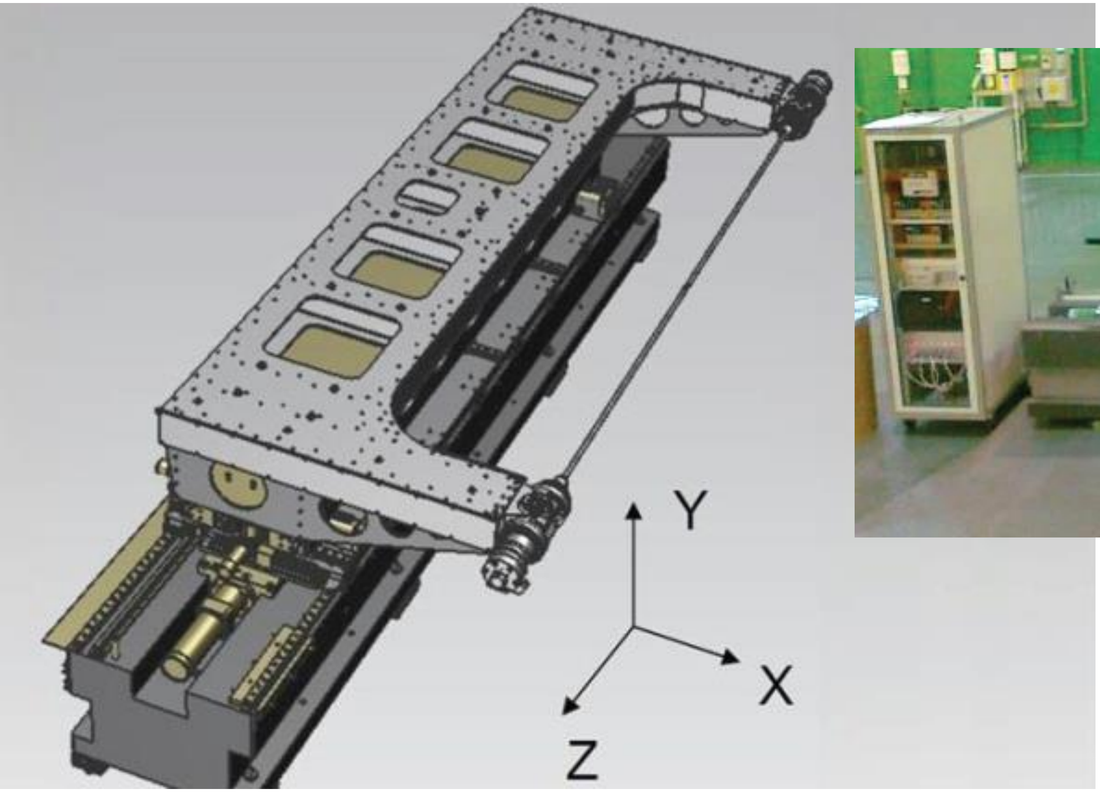


Mechanical pieces are currently being manufactured at ALBA workshop

Further improvements

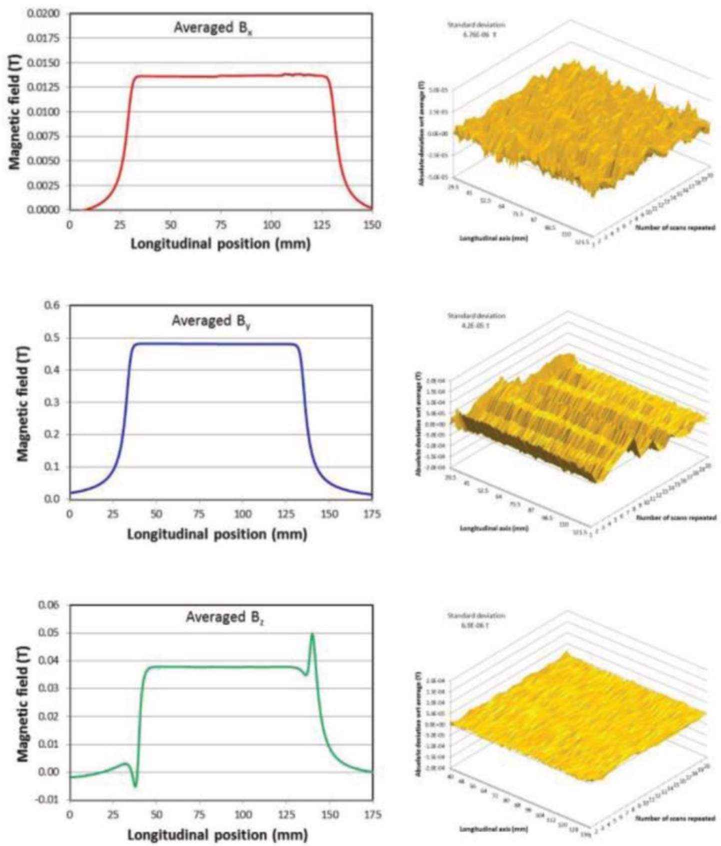
New Hall probe bench adaptation:

- The ALBA new Hall probe bench designed to measure closed structures has been proved feasible with the current existing prototype



Further improvements

Homogeneous field

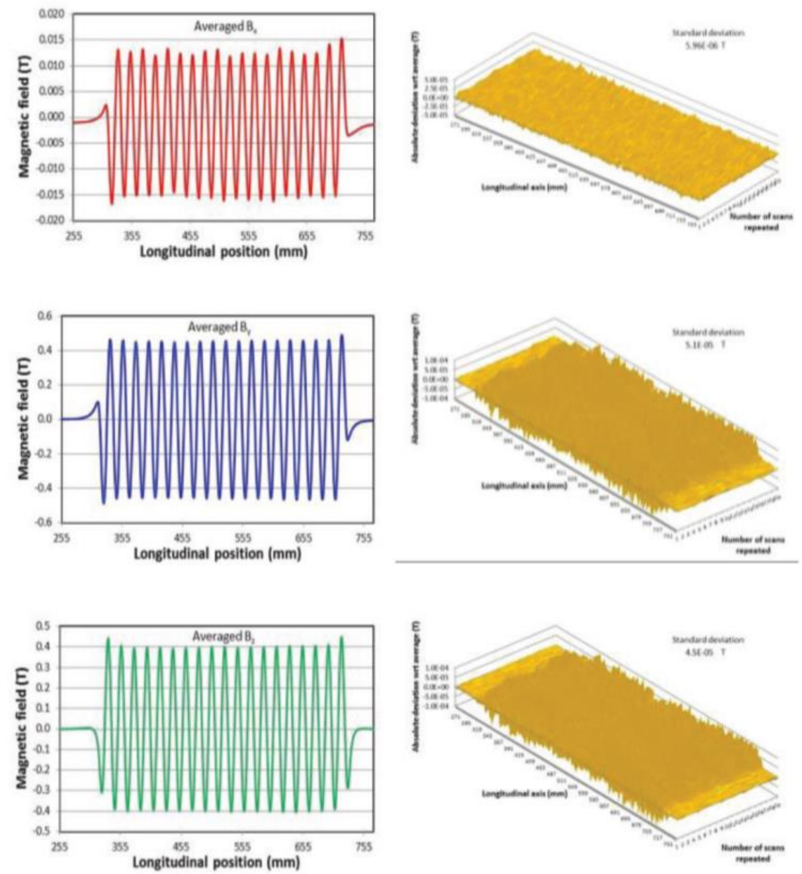


Repeatability

< 10^{-4} for main components

< $5 \cdot 10^{-4}$ for minor components

Inhomogeneous field



Repeatability

< 10^{-4} for main components

< $5 \cdot 10^{-4}$ for minor components

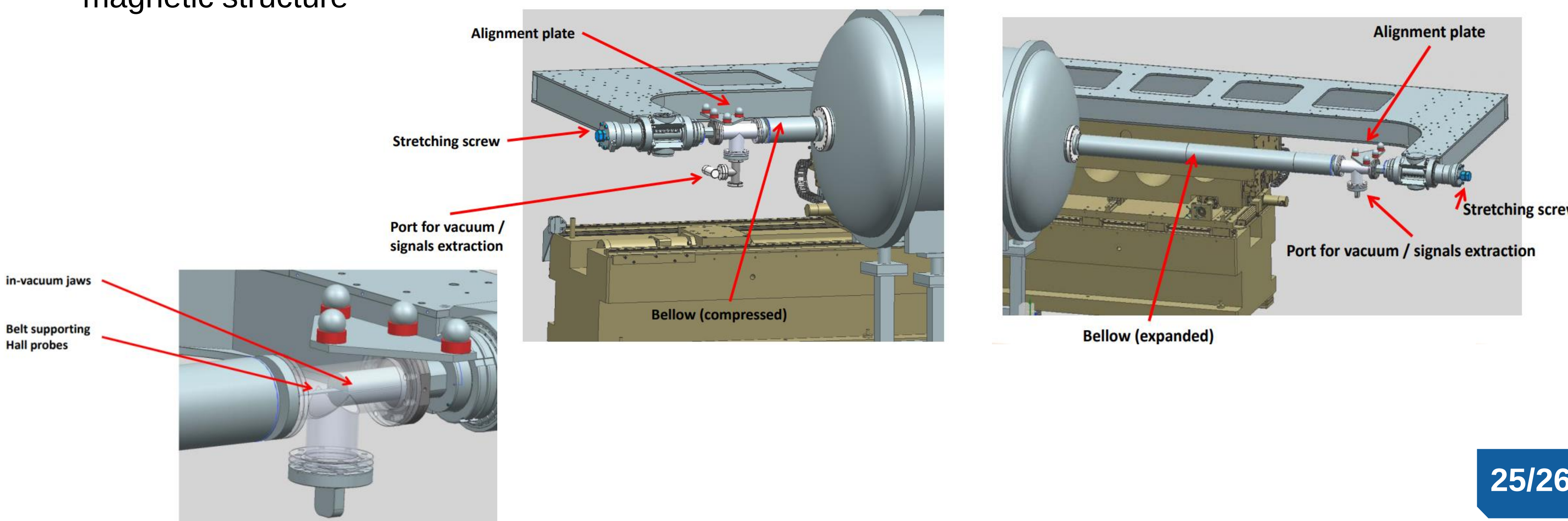
Upgrades:

Short term (autumn 2019)

- Increase the length in order to measure the XAIRA in-vacuum (2.75 m long) with the vacuum chamber installed

Long term (2020 and beyond)

- Adapt the bench for measurements in-vacuum and at low temperatures (maintaining the Hall probes at room temperature).
- Needed: belt fastening system with a flange with pass-through to extract the signal + long bellows and suspension structure (may be not needed) to connect the flange in the fasteners with the flanges in the magnetic structure



Conclusions

International collaborations

- Helping Spanish companies to fulfill requirements in the field of magnetic measurements

New developments

- Focussing on narrow gap devices
- Improvements in the measurement accuracies
- New developments to build a multi-purpose bench for closed structures

Thanks for your attention

Questions?