Riunione Gr. II
May 23rd, 2017
INFN-Sezione di Napoli.

QUAX activity @ Napoli

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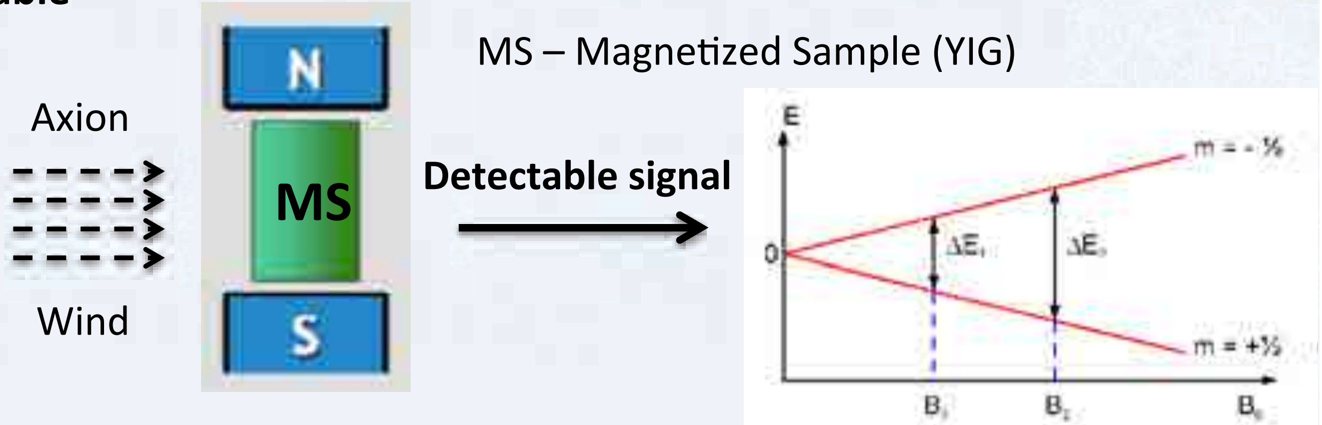
QUAX detector (Haloscope)

- The idea for the axion detection is to exploit the DFSZ axion - electron coupling
- **Due to the motion of the solar system** in the Galaxy, the axion DM cloud acts as an **effective rf magnetic field on electron spin (causing the spin flip)**
- An external polarizing magnetic field B_0 set the Larmor frequency
- The equivalent magnetic (rf) field excites **transition in a magnetized sample** which behaves as a **rf receiver** tuned at the Larmor frequency
- **The interaction with axion field produces a variation of magnetization which is in principle measurable**



Axion

Wind

MS – Magnetized Sample (YIG)

Detectable signal

Idea in not new and comes from **several works**:

- L.M. Krauss, J. Moody, F. Wilczeck, D.E. Morris, ”Spin coupled axion detections”, HUTP-85/A006 (1985)
- L.M. Krauss, ”Axions .. the search continues”, Yale Preprint YTP 85-31 (1985)
- R. Barbieri, M. Cerdonio, G. Fiorentini, S. Vitale, Phys. Lett. B 226, 357 (1989)
- A.I. Kakhizde, I. V. Kolokolov, Sov. Phys. JETP 72 598 (1991)

Case study: Magnets for the QUAX Experiment

QUAX (QUaerere AXion) Experiment:

A new proposal for a search of galactic axions using magnetized materials

The experiment requires high homogenity field in order to obtain detectable signals.

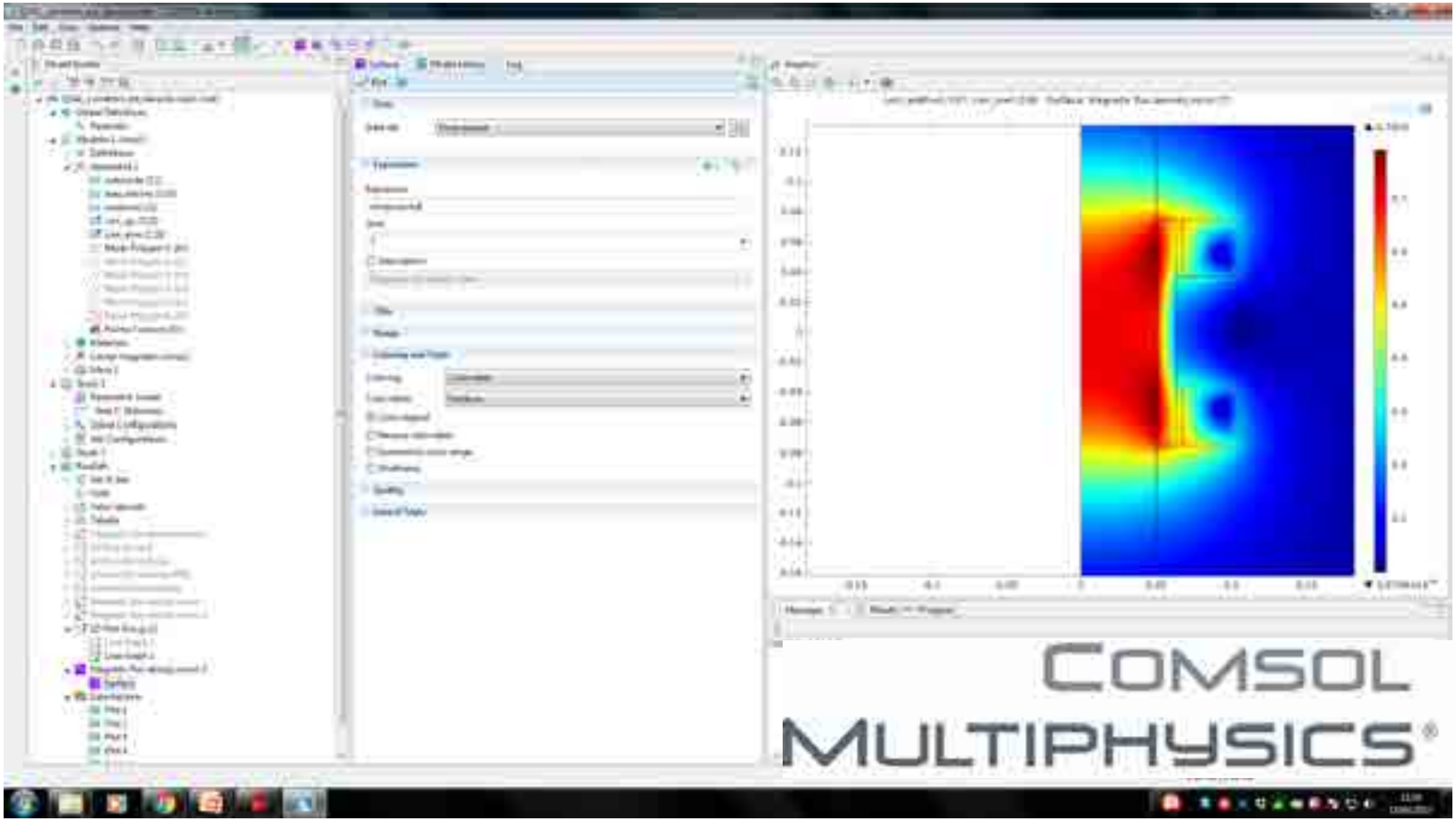
In the 2017-2018 we shall take care of the superconducting magnet for the detector. We shall start with a low field approach (0.4 T) generated by an existing superconducting solenoid, which must be corrected in the field profile to attain reasonable inhomogeneity (below 100 ppm).

This preliminary step will be followed by a new demo superconducting magnet which will be designed and manufactured to fulfill the field uniformity requirements at the field strength of 2 T.

More info at http://www.pd.infn.it/QUAX/

Homogeneity of a Magnetic Field

Simple geometries leads to analytic equations that are easy to manage and corresponding FEM models are simple to simulate with very good results. The main advantage of using FEM simulation is the easiness to deal with non regular geometry, to implement parametric sweeps, and to analyze the field when a superconducting structure is placed inside a magnet.



The 1° QUAX magnet: QSAL solenoid characteristics

We investigated some working hypothesis in order to quickly improve the magnetic field uniformity of an existent superconducting coil: the primary winding of a flux transformer used to feed the helicoidal quadrupole of the **SuperB** acceterator (QSAL experiment) developed in Genoa. It is made of a primary winding (a 4000 turns NbTi coil) able to make 3 T with about 100 A

The coil of the primary winding was not designed for the purpose of a good uniformity of the magnetic field because he was designed as pure solenoid with the following radius over length ratio

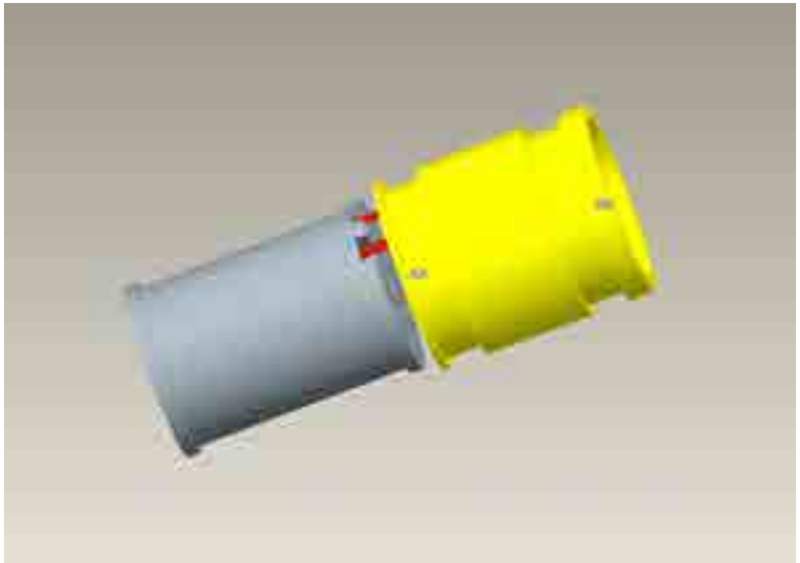
R/L=0,33
(L=150mm, R=50mm)

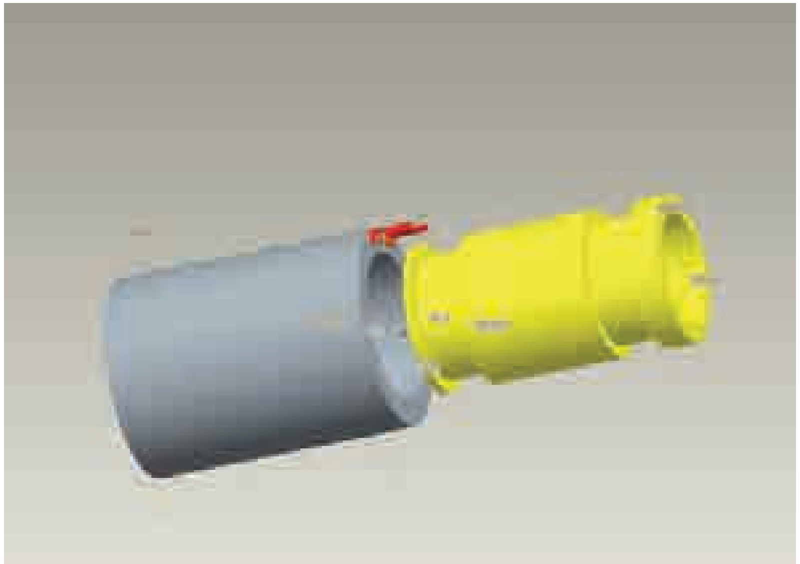
However, the room inside the coil is sufficient for the execution of the first tests of the resonant cavity within a magnetic field.

The figure on the left shows the magnet surrounded by soft iron, in order to reduce the stray field.

The QSAL magnet: homogenization

Two possibible strategies could be taken into account:





External Correction

Advantage: More space inside the bore;

Disadvantage: Larger winding corrector volume;

Greater distance from center.

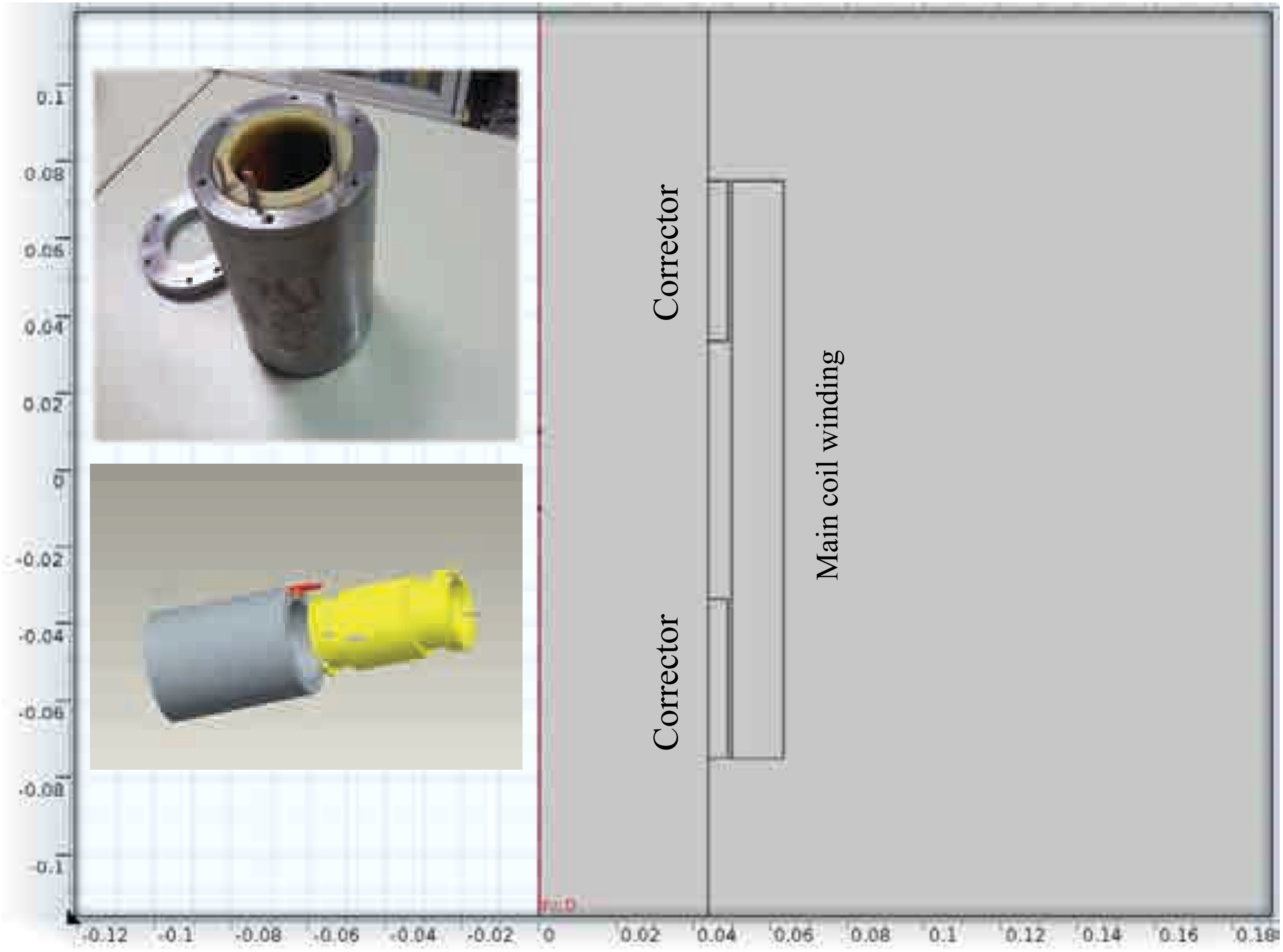
Internal Correction

Advantage: Small winding volume;

Correction more effective;

Disadvantage: Less space inside the bore.

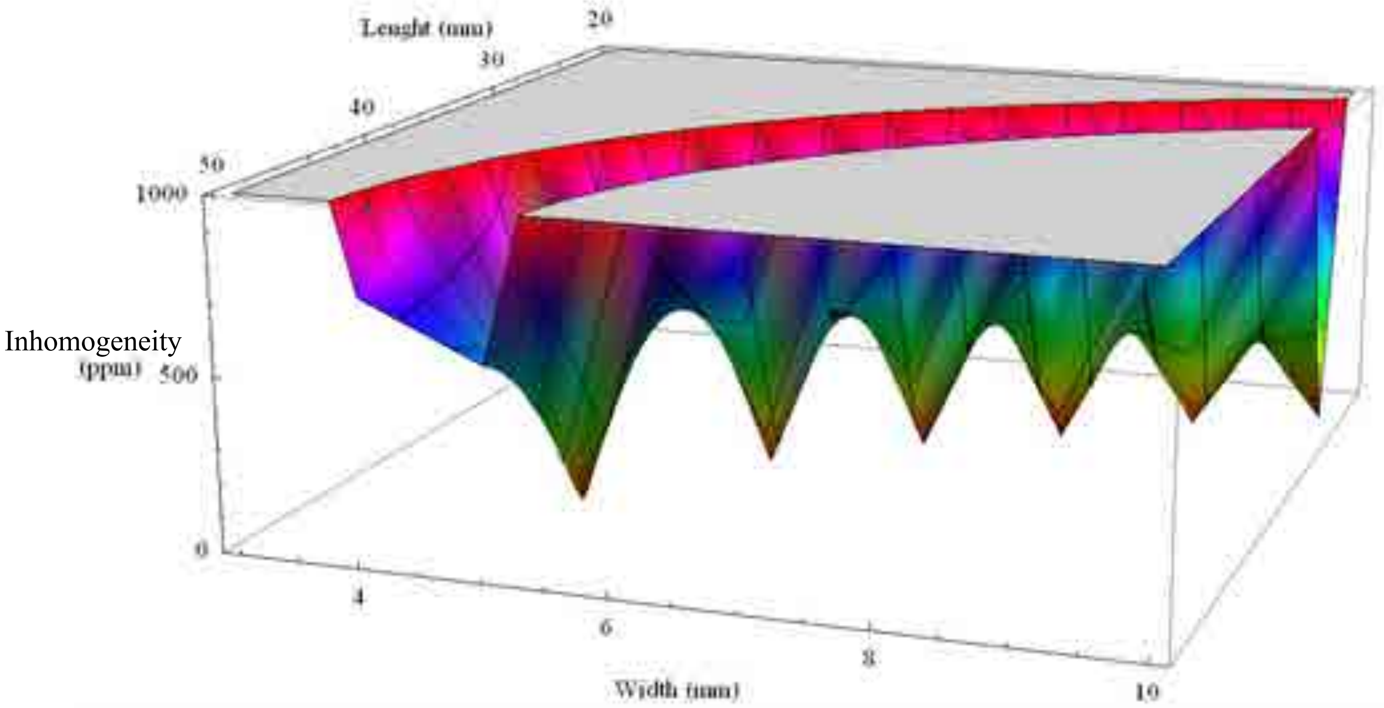
The QSAL magnet: Internal Correction



The QSAL magnet: Internal Correction

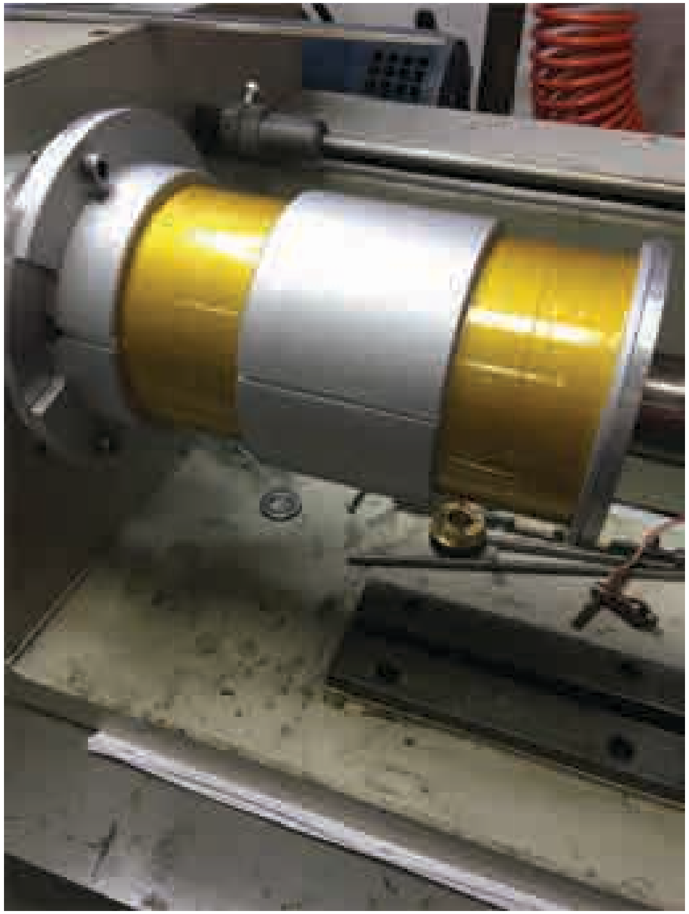
Once again we perform a parametric sweep, over the length (H_{corr}) and the width (W_{corr}) of the corrector coil dimensions, found a couple of parameters that minimize the inhomogeneity.

The best inhomogeneity obtainable by tuning the winding geometrical dimensions is achieved with H_{corr}=43 mm and W_{corr}=5 mm. In our numerical simulation we also considered the gap between the solenoid and the correction coil (2 mm on the diameter).



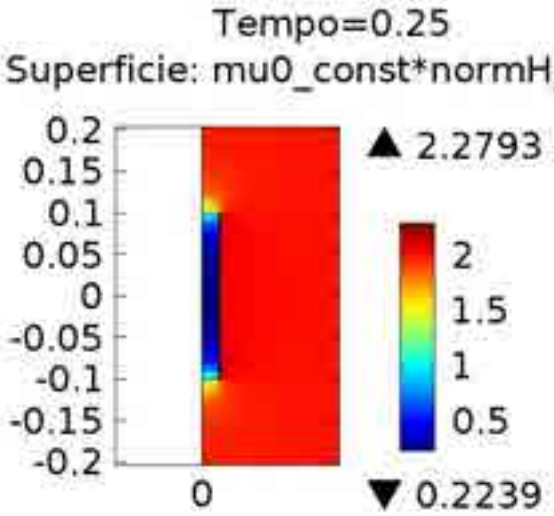
The best homogeneity of 39.5 ppm is obtained with W_{corr}=5 and H_{corr}=43 mm

Realizzazione correttore

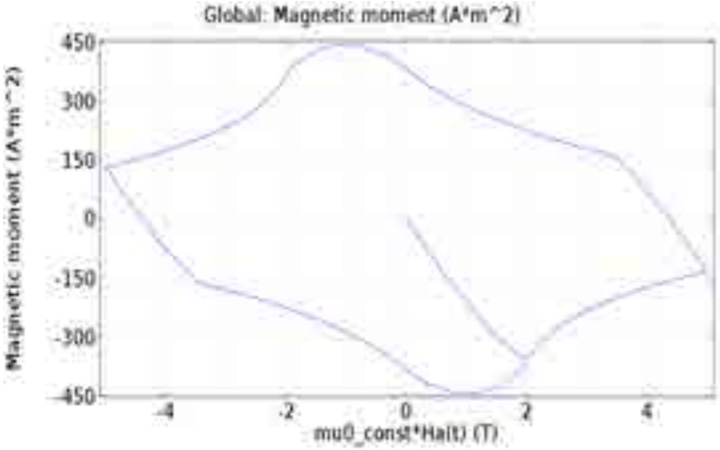


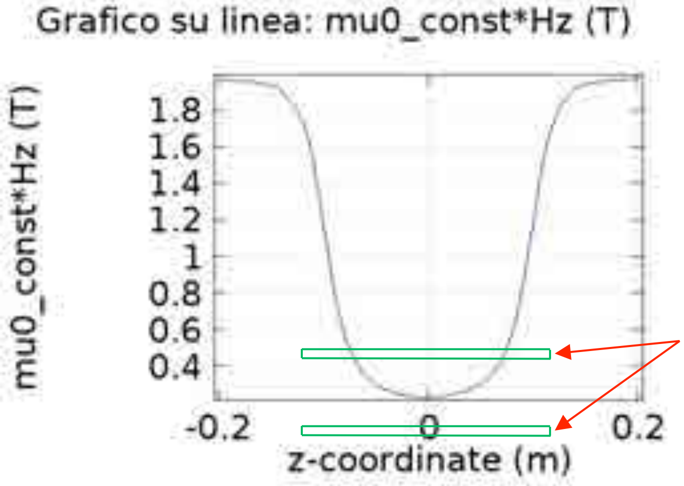
Homogeneity in the presence of s/c structures

The presence of a superconducting structure in a homogeneous axial field, significantly affects the field lines, up to destroy the homogeneity of the field inside the structure.



In a **cylindric superconducting cavity**, even without ending plugs the field inside is fully shielded: FEM with a uniform field 0->2T and J_{c0}=2 10^9 A/m^2 and a “Bottura style” J_c(B).

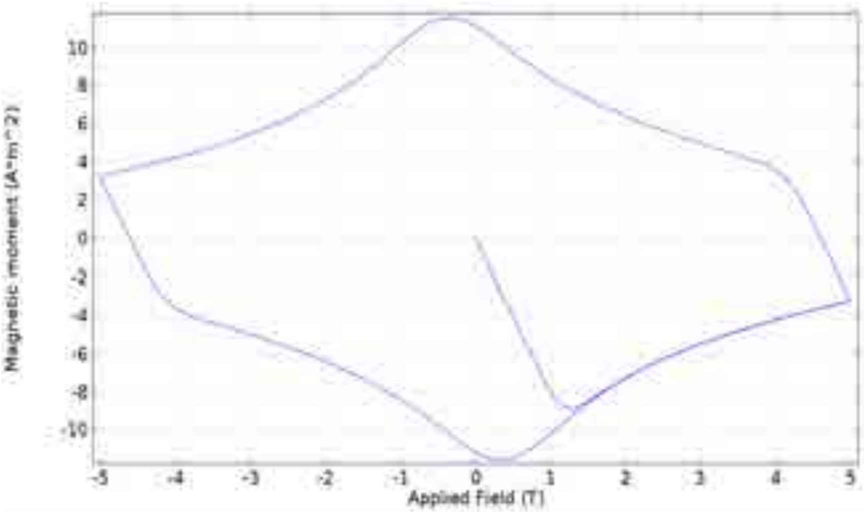


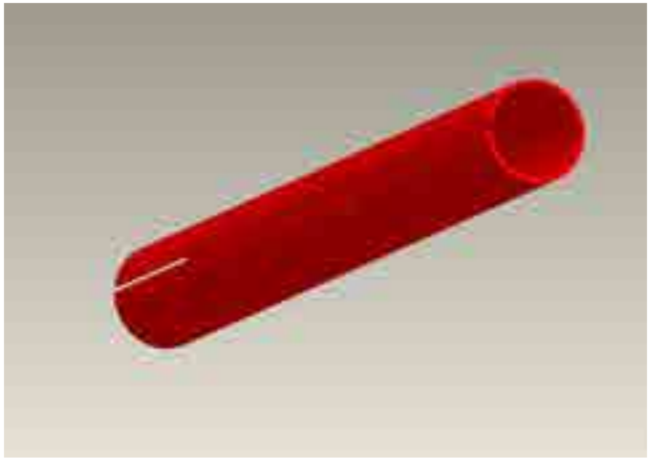


Cavity wall

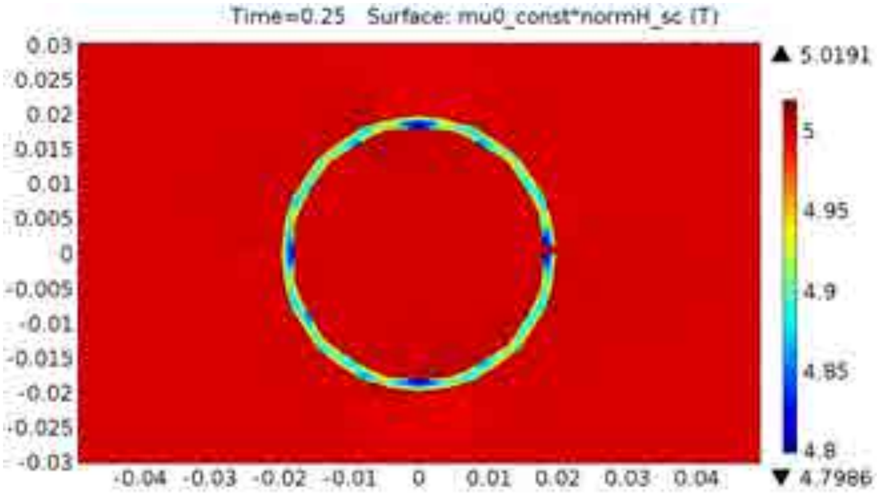
How to fill a s/c cavity with magnetic field lines

Considering that the RF cavity modes will excite longitudinal currents only, a possible solution to overcame the magnetic response of the superconducting cavity is to cut a small part of the cavity wall





The field lines fully penetrate the cavity inner volume, and the only shielded part is the volume occupied by the superconductor.



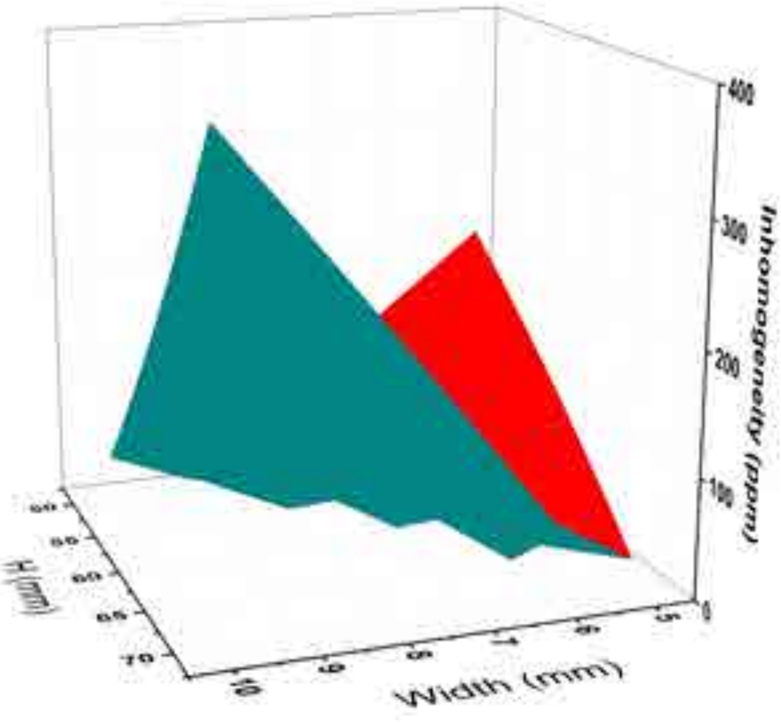
Phase II: the demo magnet for QUAX

We investigated the feasibility of a new 2T superconducting solenoid for performing higher accuracy experiment, having the following requirements and constraints:

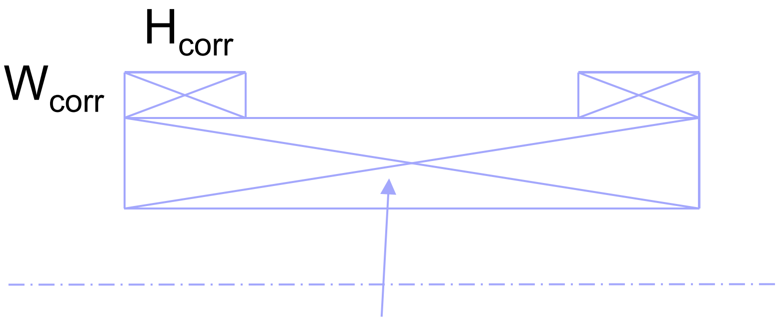
1. No grading. All coils should share the same current (only one stable power supply);
2. homogeneity below 10 ppm within a cylindrical region of 5 mm in radius and 20 mm in length;
3. low budget (25 k€);
4. rapid fabrication (choose wires already existing, with given thicknesses);
5. keep as much free space as possible inside the coil;
6. the maximum magnetic field is required at the coil center;
7. must fit inside the cryostat already in use: *i.e.* as pure solenoid it can have the following radius over length ratio

R/L=0,187 - (L=400mm, R=75mm)

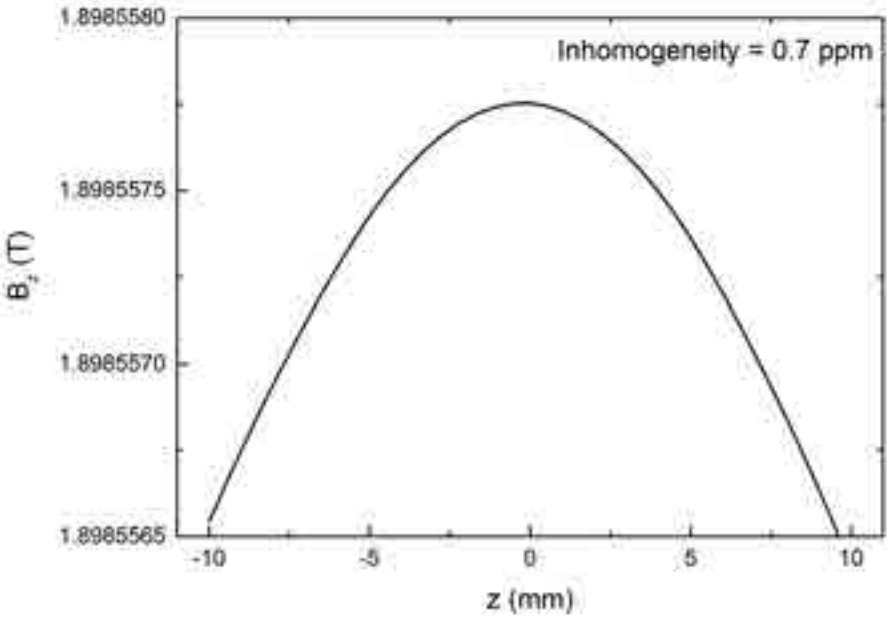
The demo magnet design and features



Parametric sweep gives 0.7 ppm minimum for H_{corr}=65mm W_{corr}=6mm



100 A - 400 turns x 14 layers



Conclusion

- ✓ High homogeneity field (1-10 ppm) required for the QUAX experiments can be achieved in simple solenoid with correction bobbins.

- ✓ Care must be taken if the magnetic field has to be delivered inside of a superconducting close structure like a s/c cavity.

- ✓ The case studies reported (QSAL solenoid, and demo magnet) will provide enough performance to investigate the behavior of the s/c cavity in the presence of a background magnetic field.