Eliminating field distortions caused by the HTS beam screen coating in FCC dipole magnets

Kristóf Brunner, Dániel Barna
Wigner Research Centre for Physics
Budapest

E-mail:
brunner.kristof@wigner.mta.hu
barna.daniel@wigner.mta.hu

1) Abstract:

In order to decrease the beam impedance the beam screen of the FCC ring is planned to receive a high-temperature superconductor coating. However, the persistent currents induced in the coating would distort the ring's magnetic field.

Rather than trying to suppress this effect we examine the possibility to use a tailored thickness profile of the coating such that these currents produce a field with the same symmetry as the external field, giving an offset to the dipole field rather than distorting it.

2) Problem:

A resistive (copper) beam screen would limit the intensity of the FCC beam. Planned solution: reduce the beam impedance by a thin HTS coating on the beam screen [1]. However, such a superconducting layer would distort the field, introducing higher order components via the persistent Eddy currents [2]. The distortion is more significant at low field, therefore we optimized the coating's thickness at 1 T (injection).

3) Proposed solution:

Instead of trying to eliminate the persistent currents (difficult), we can try to master them. Goal: find a **specific thickness profile of the coating** such that the field generated by the Eddy currents have the **same symmetry** as the external field. This does **not distort** the field, only **adds an offset** to it, which can be compensated by adjusting the power supply.

Note: if $J_c(B)$=const and the beam screen is cylindrical, $d(\vartheta) \sim \cos(\vartheta)$ would give a dipole contribution.

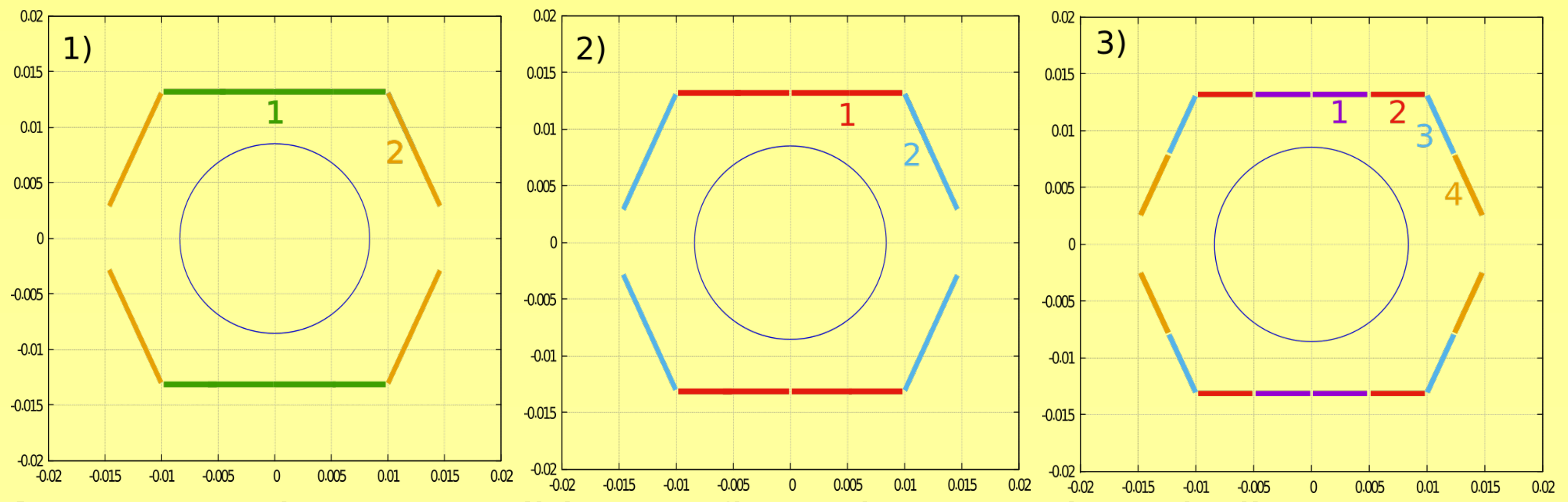

Figure 1*: Three possible configurations. Colors indicate segment groups with the same thickness of the HTS layer. The circle in the middle is at the 2/3 of the beam screen inner diameter where the generated field was sampled*

4) Assumptions:

- Calculate the fields in 2D and assume the set-up is infinitely long in the third dimension
- The cross-section of the beam screen is constructed of straight segments. HTS thickness is constant within a segment.
- Segments are grouped according to symmetry (see Fig. 1) All segments within a group have the same thickness d_i.
- The field generated by the Eddy currents is much smaller than the external field – evaluate $J_c(B)$ at the external field. Different parts of the HTS coating do not interact, so they can be treated independently.
- Substitute the HTS layers by infinitely thin surface currents: $d_i \cdot J_c(B)$

5) Calculations:

I) Determine the current density within the segments. In dipole external field this is simply $\pm J_c(B,\beta)$ in the two halves of the segment where β is the angle of the segment w.r.t. the external field. For a quadrupole field this step is more complicated.

II) Numerically integrate the contribution of one segment group *i* to the vector potential at any point (x,y), assuming unit thickness of the HTS layer.

III) Sample the vectorpotential around a circle (at 2/3 "aperture") and Fourier-transform it to get the multipole components: $F_{i,m}$ is the m^{th} multipole component due to the segment group *i*.

IV) Due to the negligible interaction between segments, the problem is linear. The total multipole component with layer thicknesses d_i is obtained as (sum over all segment groups):

$$F_m = \sum_i d_i F_{i,m}$$

V) A given multipole component *m* can be exactly cancelled with physical thicknesses (all d_i>0) if not all $F_{i,m}$ have the same sign.

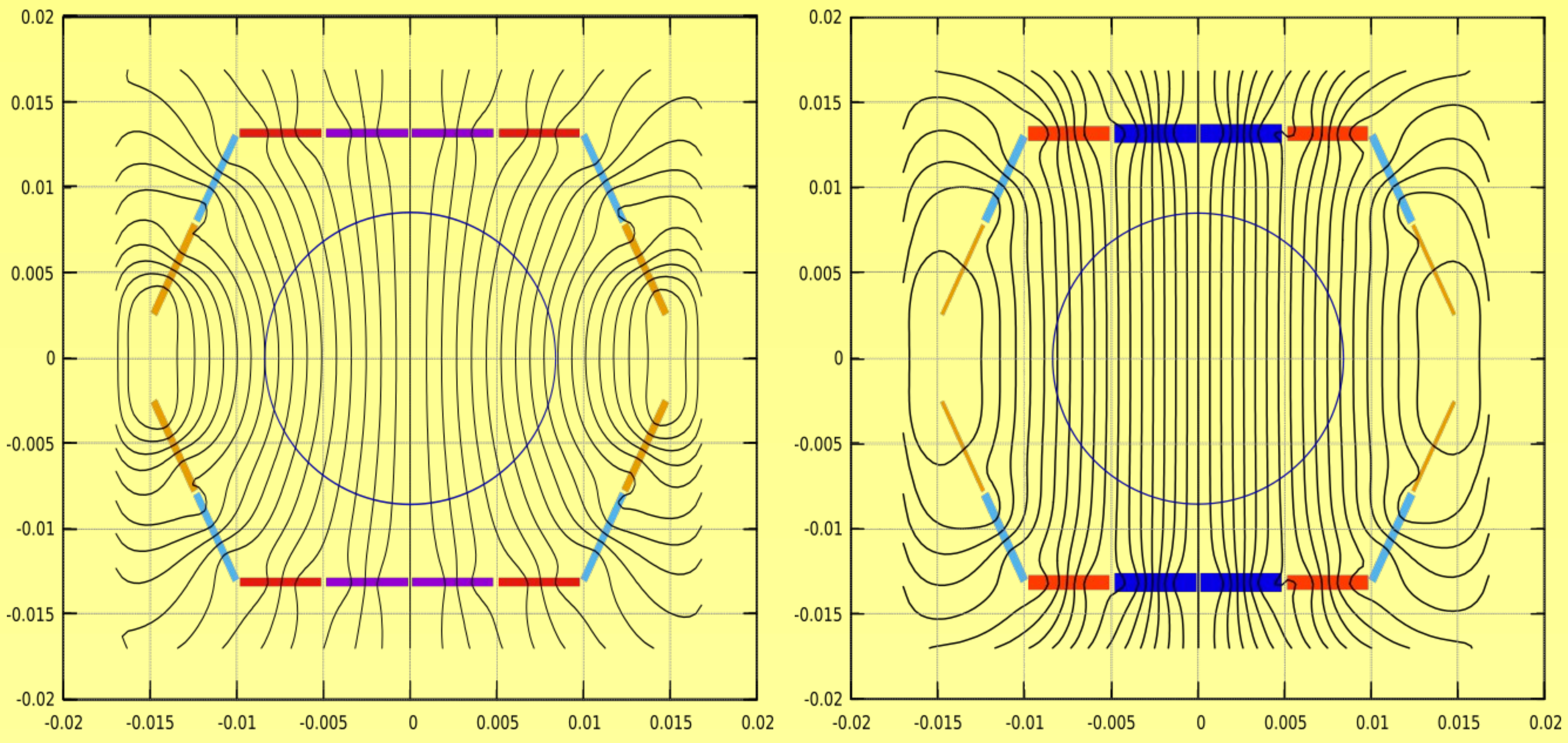

Figure 2*: The B field inuced by the beam screen in case of 1 μm tapes (left), and with a tailored thickness profile (right), both in case of 1T dipole external field*

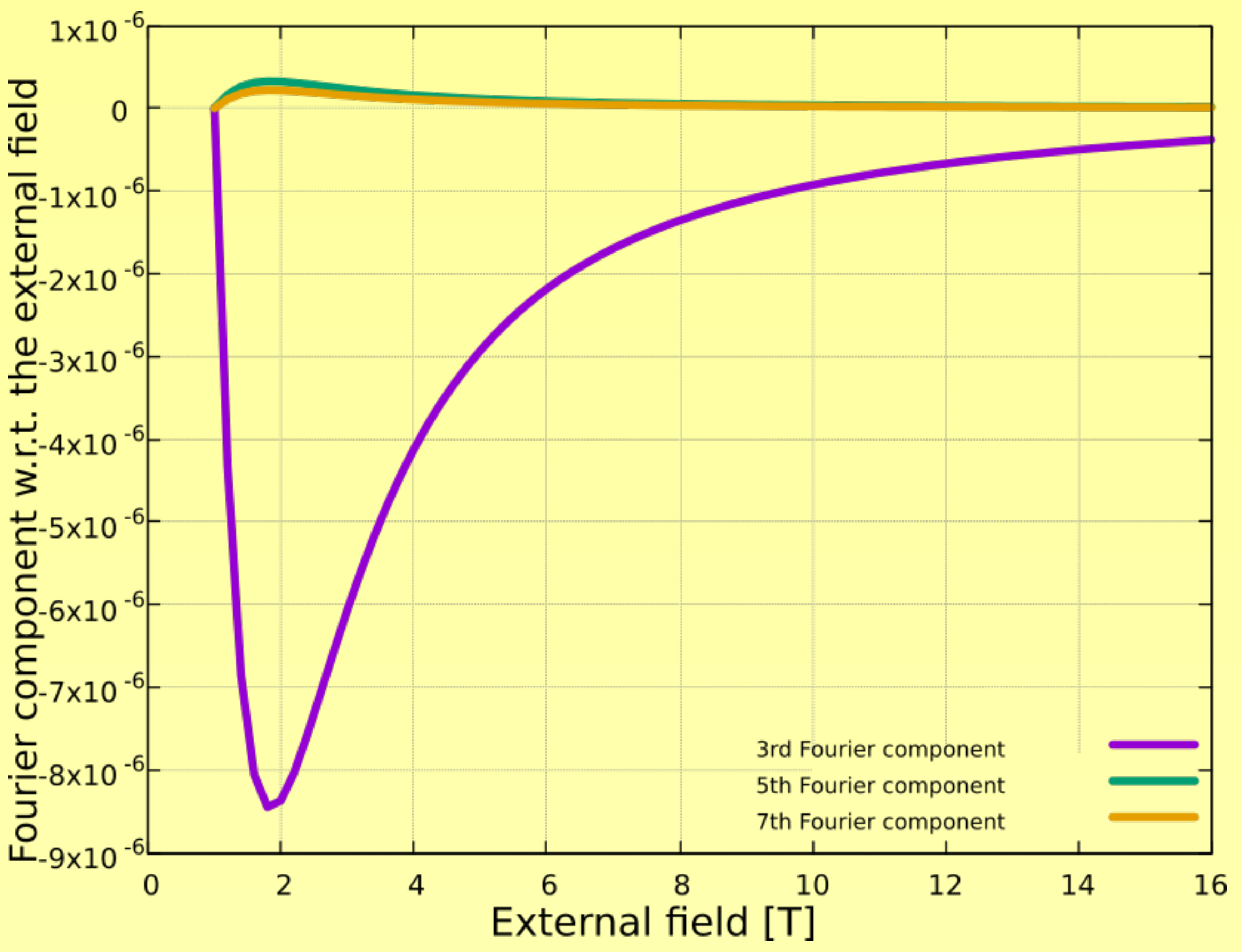

Figure 3*: Multipole components as a function of B for configuration 3 (thickness profile optimized at B=1 T)*

6) Results:

Thanks to the setup's symmetry the even multipole components are zero.

1st configuration: zero sextupole component is achiveable if the **ratio** is **d_1:d_2=0.772**.

2nd configuration: to eliminate the sextupole component the thickness ratio has to be **d_1:d_2=4.607**.

3rd configuration: It is possible to simultaneously eliminate the m=3,5,7 components with the following **d_1:d_2:d_3:d_4** thickness ratio:

3.630 : 3.032 : 2.015 : 1

In the 1st and 2nd case the first nonzero component (decapole) is **5%** and **3%** w.r.t. the dipole component of the coating (both are around **0.4%** of the external dipole field)

In the 3rd case the 11th component was the biggest one, still being only **0.15%** of the dipole component, and **0.01%** of the external field.

The induced field can be seen in Fig. 2.

7) Conclusion and outlook:

A tailored thickness profile could drastically reduce the distortion of an external dipole field.

To do: use the same method (with a more complicated algorithm to determine the Eddy currents) to minimize the distortions in a quadrupole external field.

References

[1] A. Sublet, S. Aull, B. Bartova,S. Calatroni,T. Richard,G. Rosaz, M. Taborelli,M. Therasse,W. Venturini Delsolaro,P. Zhang: http://accelconf.web.cern.ch/AccelConf/SRF2015/papers/tupb027.pdf
[2] J. van Nugteren, S. Bermudez, S. Calatroni, G. Kirby, G. de Rijk: Numerical Analysis on the Application of a ReBCO Superconducting Coating on the Beam Screen
[3] C. Garion: Beam screen design https://indico.cern.ch/event/619380/contributions/2527417/