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We investigated the efficiency of superconducting MgB₂ and superimposed MgB₂/Fe systems consisting of cylindrical cups with an aspect ratio of height/radius close to unity. At first, the shielding capability of these systems was measured as a function of the external magnetic field and position by means of cryogenic Hall probes mounted on a custom-designed stage, moveable with micrometric resolution [1]. Then, the experimental data were successfully reproduced by using a finite element method based on a vector potential formalism [2,3].

Starting from these results, further bi- and multi-layer SC/FM superimposed systems were studied in order to achieve additional improvements in their shielding efficiency, optimizing the relative shaping and sizing of both SC and FM layers [4,5]. It turned out that the presence of a height difference between the edge of the SC/FM cups, as well as a suitable choice of the lateral gap between the cups, makes the multilayer shields the configuration with the highest efficiency both at low and high magnetic field [4,5].

Why SC and SC/FM shields ?

- ❖ **Magnetic field shielding is crucial for several applications requiring an ultralow magnetic field environment (e.g. biomedical applications) or the mitigation of the magnetic field produced by an electronic device in order to guarantee electromagnetic compatibility with the surrounding environment or to prevent possible health hazards (e.g. workers safety).**
- ❖ **superconductors represent an optimal solution for passive magnetic shielding [1,6-8].**
- ❖ **Ferromagnetic materials can improve the superconductor shielding capability [9,10]. It was experimentally confirmed that specially designed superconducting/ferromagnetic bilayers can cloak uniform static magnetic field [11,12].**

The starting point

Our study deals with the shielding potential of superconducting superimposed SC/FM systems with an **aspect ratio of height/radius close to unity**

- ➔ shielding potential in situations where it is necessary to **minimize the amount of space occupied by the shield.**
- ➔ the shielding factor of the superimposed SC/FM structures is **not a simple combination of the components [1] but must be evaluated by means of dedicated experiments or modelling**

Samples

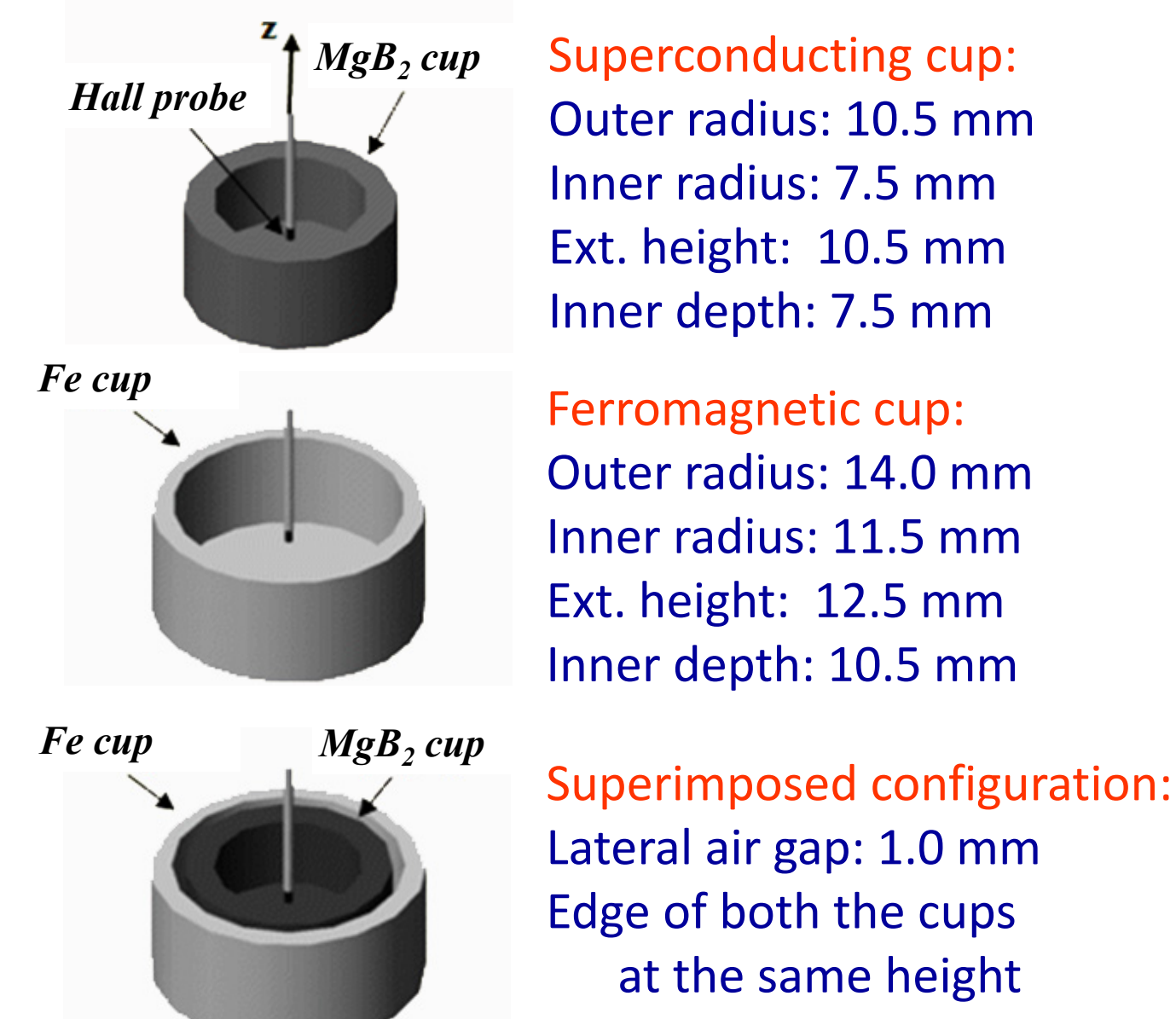
The shields consist of SC and FM cylindrical cups

The superconducting cup is made of MgB₂:

- ❖ working temperature range easily attainable also by cryogen-free cryocooler
- ❖ less brittle than high-temperature SC cuprates
- ❖ high performance also in the polycrystalline state

MgB₂ cup was grown by a **microwave heating-assisted Mg-RLI (Mg Reactive Liquid Infiltration) technique in B preforms** [1,13,14]: this methodology allows the production of **manufacts of different shapes and easily scalable sizes, matching the application requirements**

The ferromagnetic cup is made of a commercial **ARMCO-iron.**



Model

The evolution of the magnetic field distribution inside the superconducting layer was calculated using the A-formulation following the approach of A. Campbell [2] in the simplified form proposed by F. Gömöry et al. [3].

The critical state was reproduced by imposing a current density flowing in the superconductor and fulfilling the equation (2D axisymmetric formulation with the applied field directed in the z-direction):

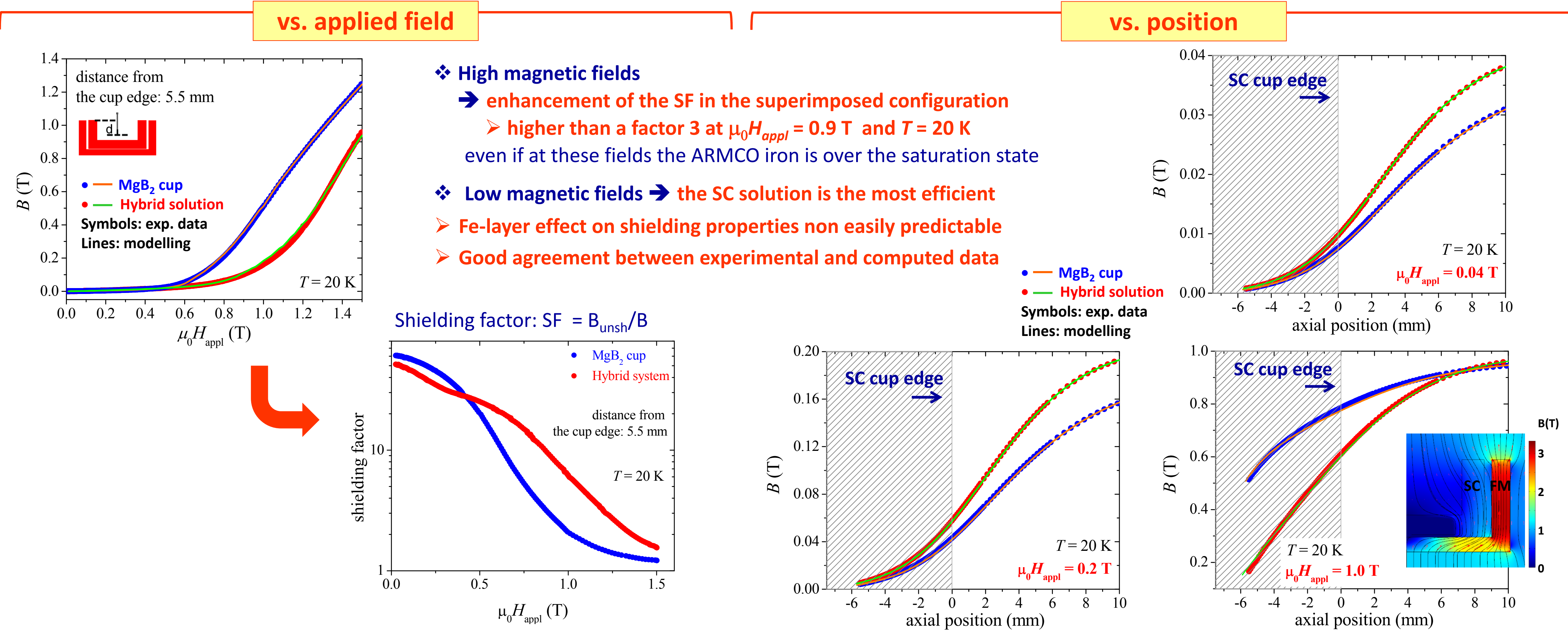
$$j_{\phi}(r, z) = j_c \tanh\left(\frac{-A_{\phi}(r, z)}{A_0}\right)$$

where $j_c = j_{c0}(B/B_{irr})^{\gamma}(1 - B/B_{irr})^{\delta}$ [15,16] and the scaling factor $A_0 = 5 \times 10^{-8}$ T/m.

At $T = 20$ K, $j_{c0} = 1.16 \cdot 10^8$ A/m², $\gamma = -0.4$, $\delta = 2.0$, $B_{irr} = 4.25$ T [4].

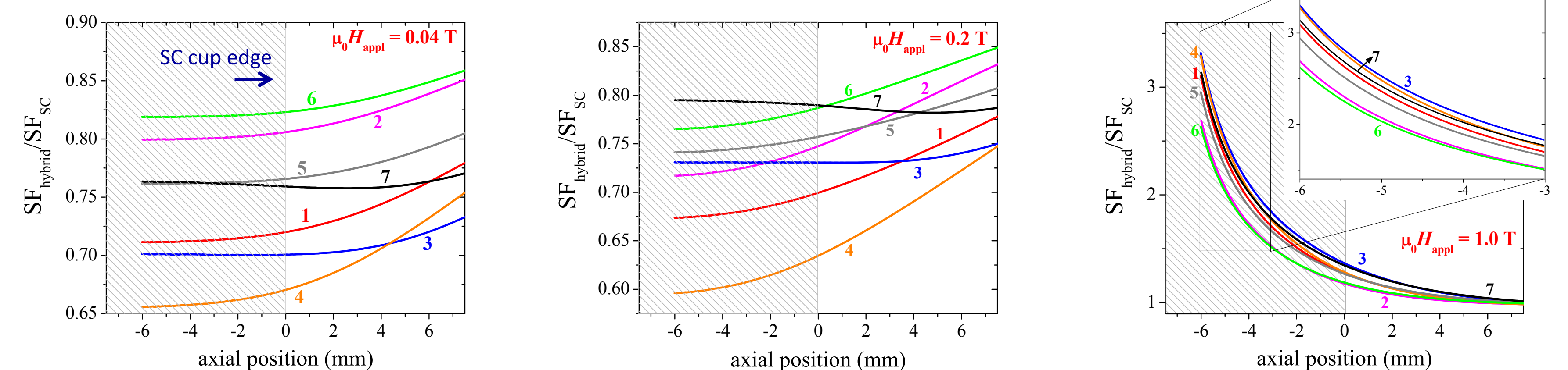
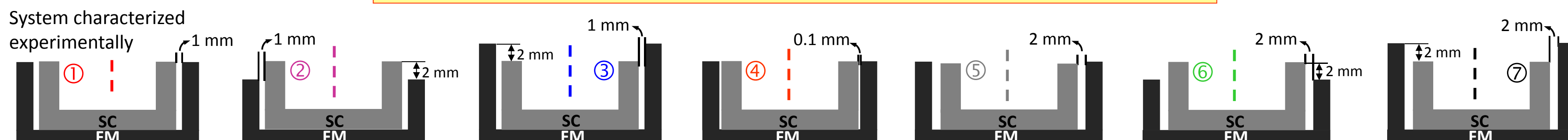
The ferromagnetic cup behaviour was modelled starting from the experimental BH curve.

Experimental results and model validation

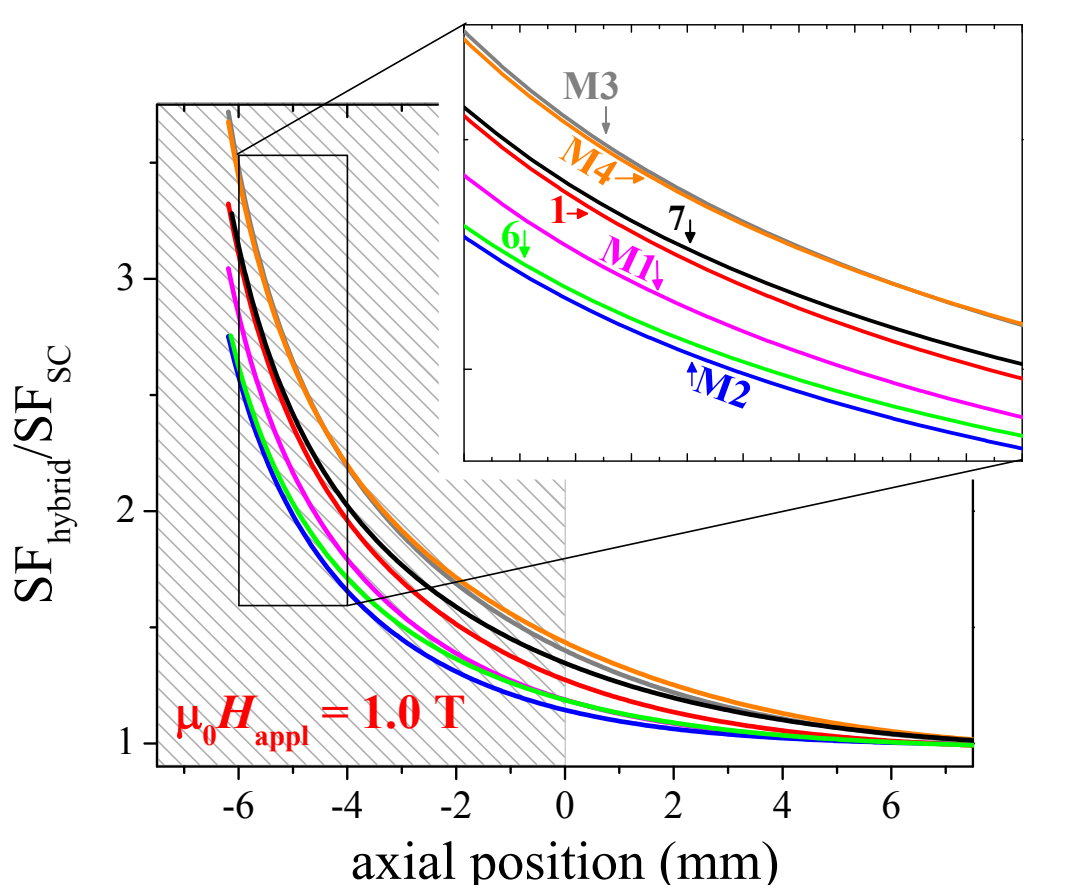


Towards new shielding configurations

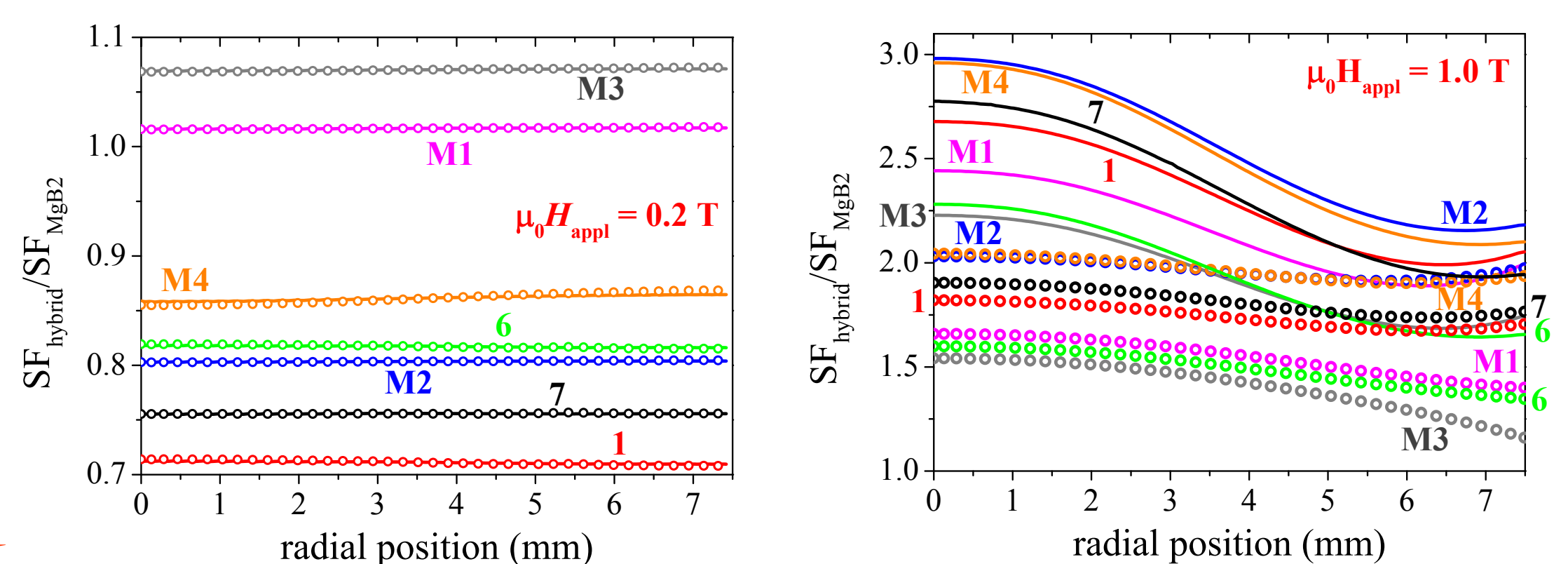
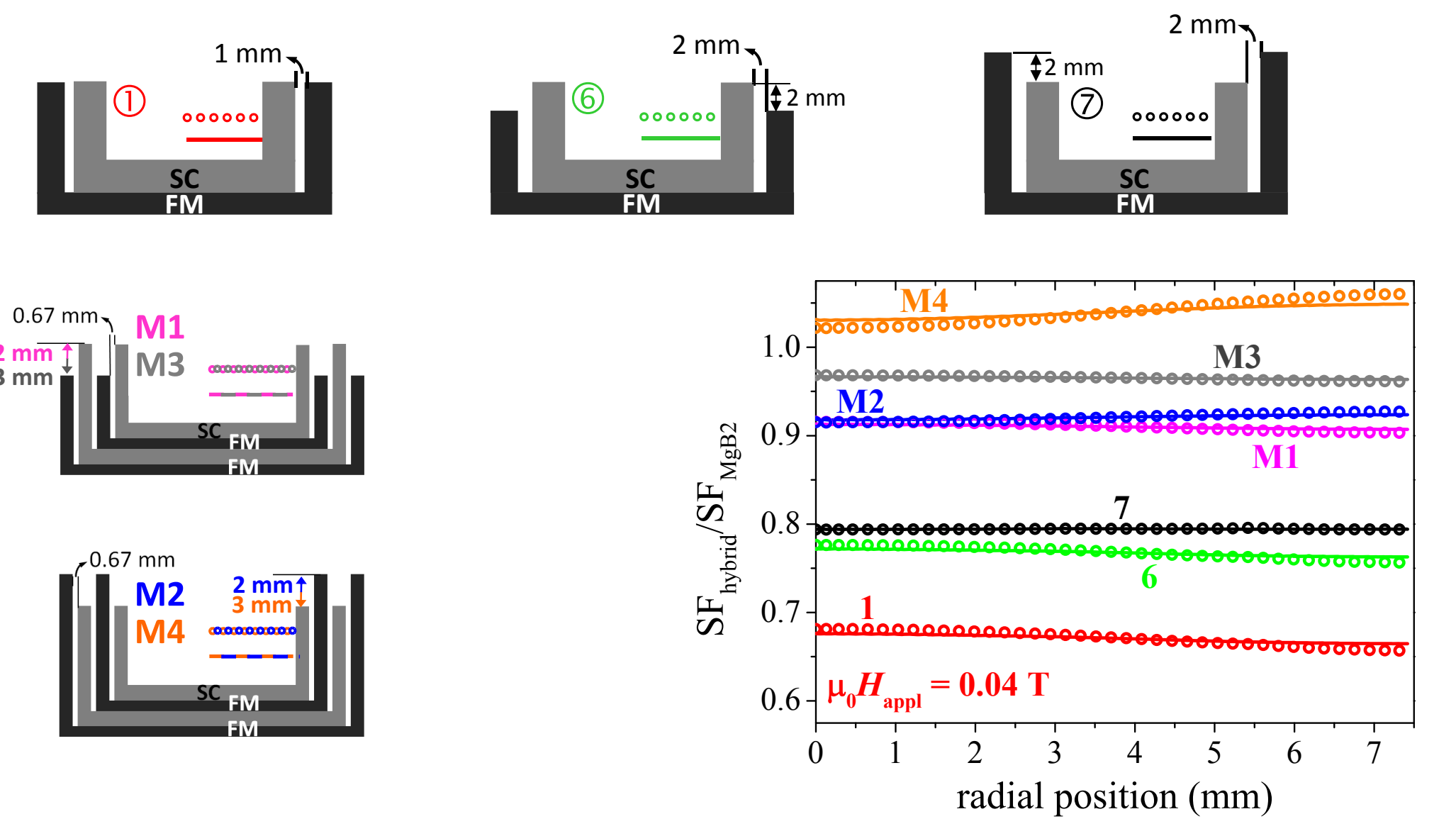
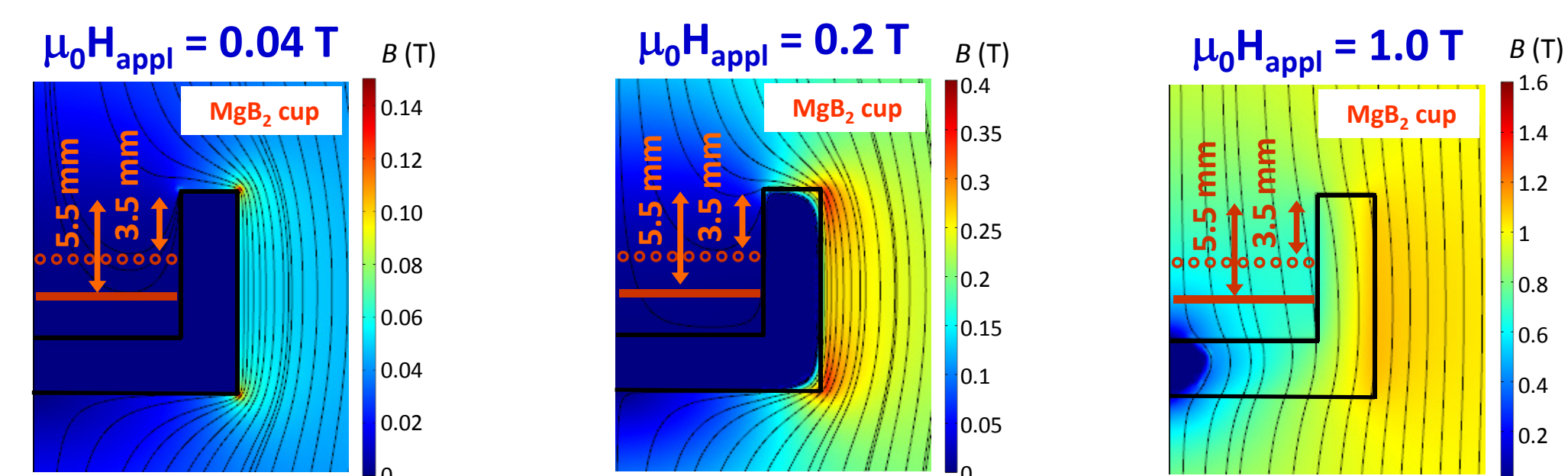
along the shield axis



Base and lateral wall thicknesses of the SC and FM cups are half those used in the bilayer configurations. Outer and inner diameters of the whole structure are the same as those of the bilayer arrangements no. 6 and 7.



as a function of the distance from the shield axis



Multilayer configurations: higher shielding efficiency both at low and at high applied fields

In conclusion ...

- ❖ **The presence of the FM layer tunes the shielding efficiency of the SC in a way strongly dependent on the aspect ratio of the system**
➔ **in the investigated geometry a key factor to achieve a competitive hybrid arrangement is the presence of a height difference between the SC and FM vessels**
- ❖ **Multilayer structures are expected to show the best shielding performances**

References

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