Numerical and experimental studies of the magnetic shielding performance of an MgB_2 tube for the superconducting shield septum project

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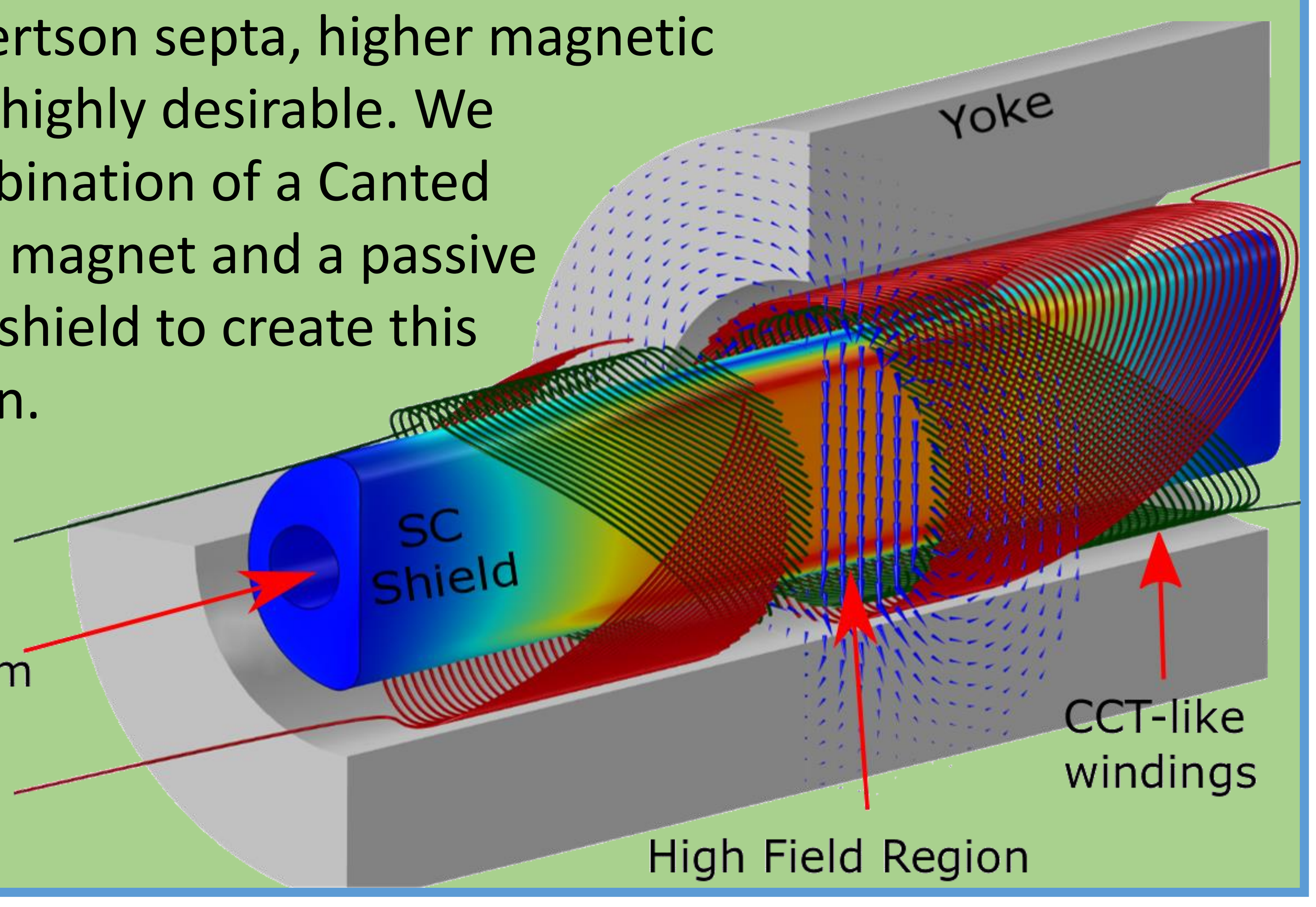
Abstract: The SuShi septum project aims to realize a high-field, compact septum magnet, using a superconducting shield to create a zero-field region within a strong magnetic field. Test results of two candidate materials are presented and compared to numerical simulations: bulk MgB2 and a NbTi/Nb/Cu multilayer sheet, which have been subjected to a transverse magnetic field of a spare LHC corrector magnet (MCBY). In particular superconducting parameters and ultimate shielding performance of the material are estimated and the observed relaxation phenomena are explained using computer methods

1.Introduction: Although extraction from the FCC could be possible with LHC's Lambertson septa, higher magnetic fields(>= 3 T) are highly desirable. We propose the combination of a Canted Cosine Theta-like magnet and a passive superconductive shield to create this field configuration.



2. Numerical methods: The numerical analysis of the different materials has been done in COMSOL Multiphysics. We have used two different models; Campbell's model[1] for a quick parameter estimation. The model assumes the following bulk current density:

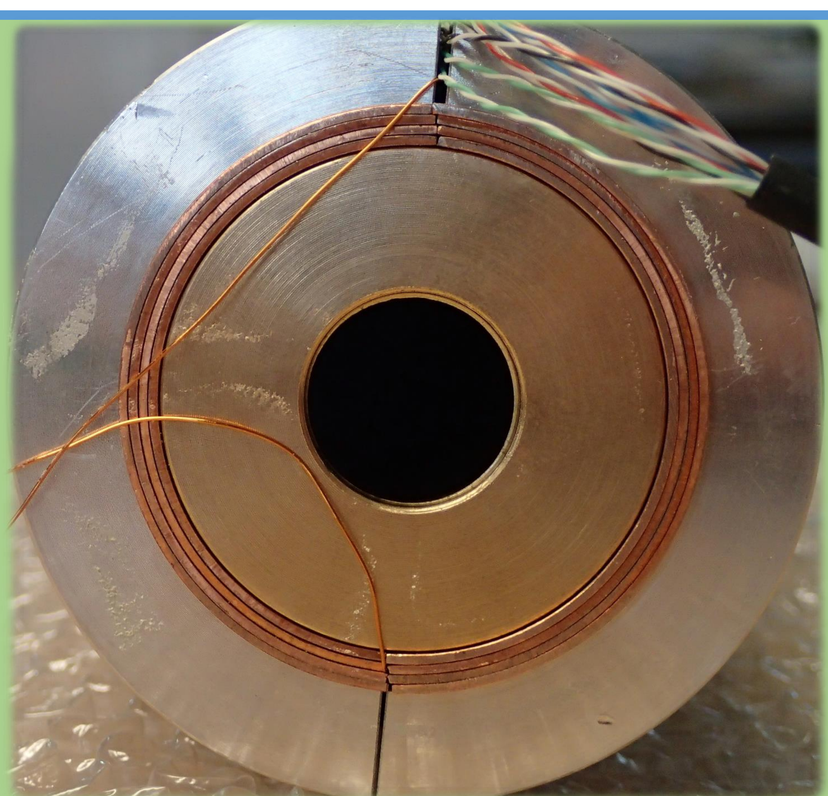
$$J = J_c(B)\tanh\left(\frac{A_z}{A_r}\right) = J_0 e^{-\gamma B}\tanh\left(\frac{A_z}{A_r}\right)$$

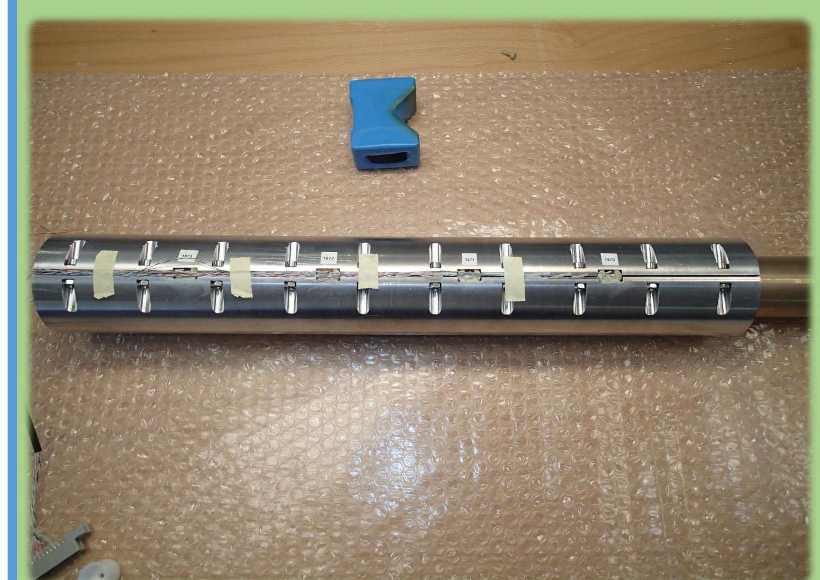
And a time-dependent eddy current model with non-linear E-J charactersitcs to study relaxation phenomena:

$$E = E_0\left(\frac{J}{J_c(B)}\right)^n = E_0\left(\frac{J}{J_0 e^{-\gamma B}}\right)^n$$

Where we have got the ideal J_0 and γ values from the stationary case, and used them in the time-dependent case.

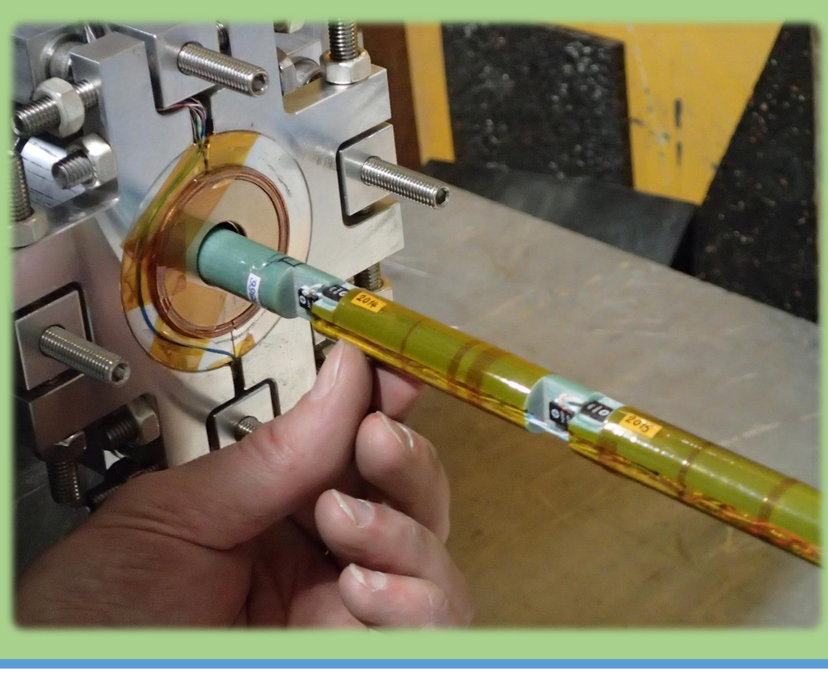
3. The experimental setup: We have tested two different materials. One was a MgB_2 tube produced by liquid Mg infiltration[2]. The other was NbTi/Nb/Cu multilayer[3]. We have used four sheets of it, placed like in the upper picture on the right.



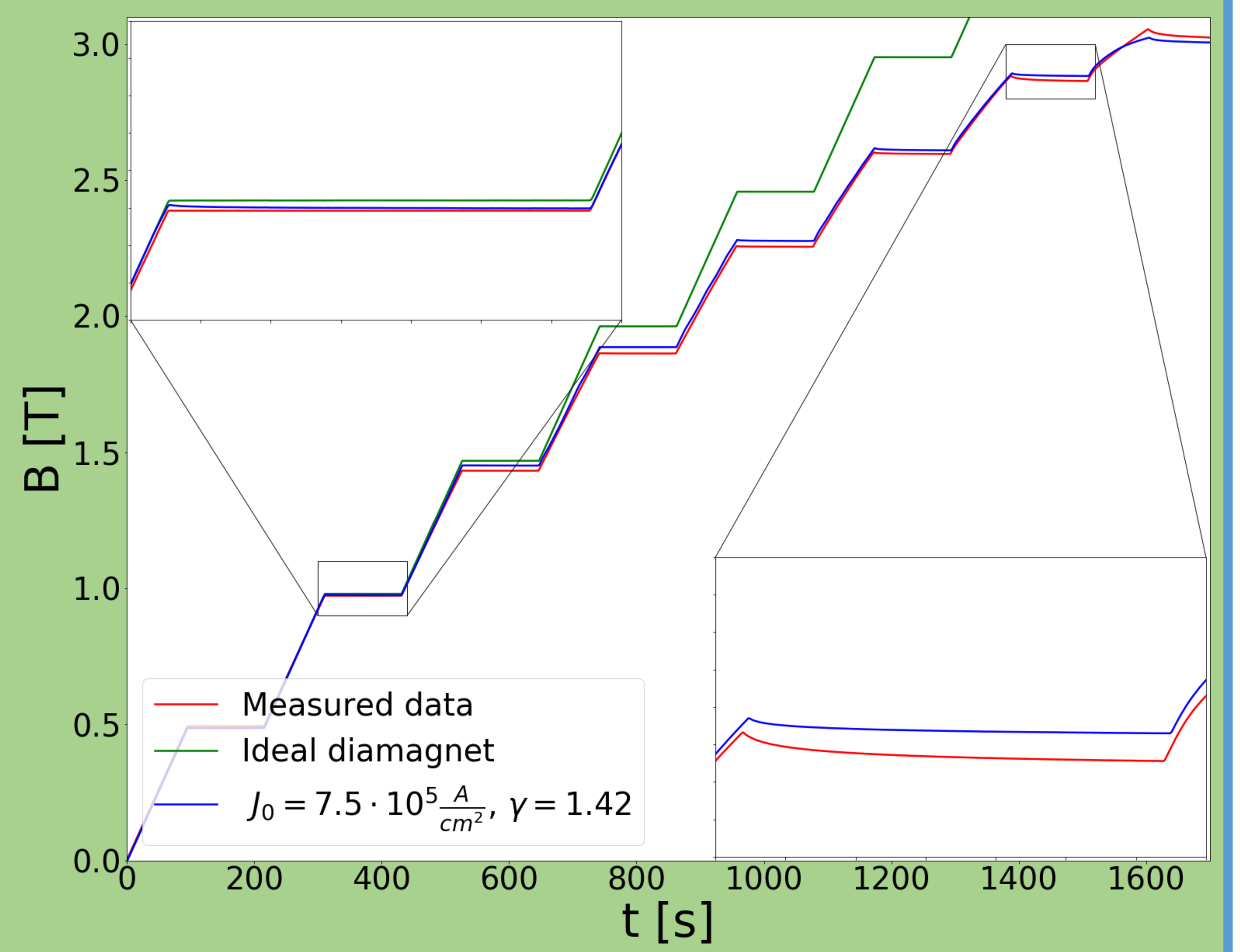


Four Hall sensors were placed on the outside and in the inside of the shield parallel with the outer magnetic field. Another two were placed inside perpendicularly.

The whole setup was mounted into a spare LHC dipole corrector magnet (MCBY), and tested at CERN's SM18 facility. The experimental setup for the MgB_2 was simpler but similar to this.

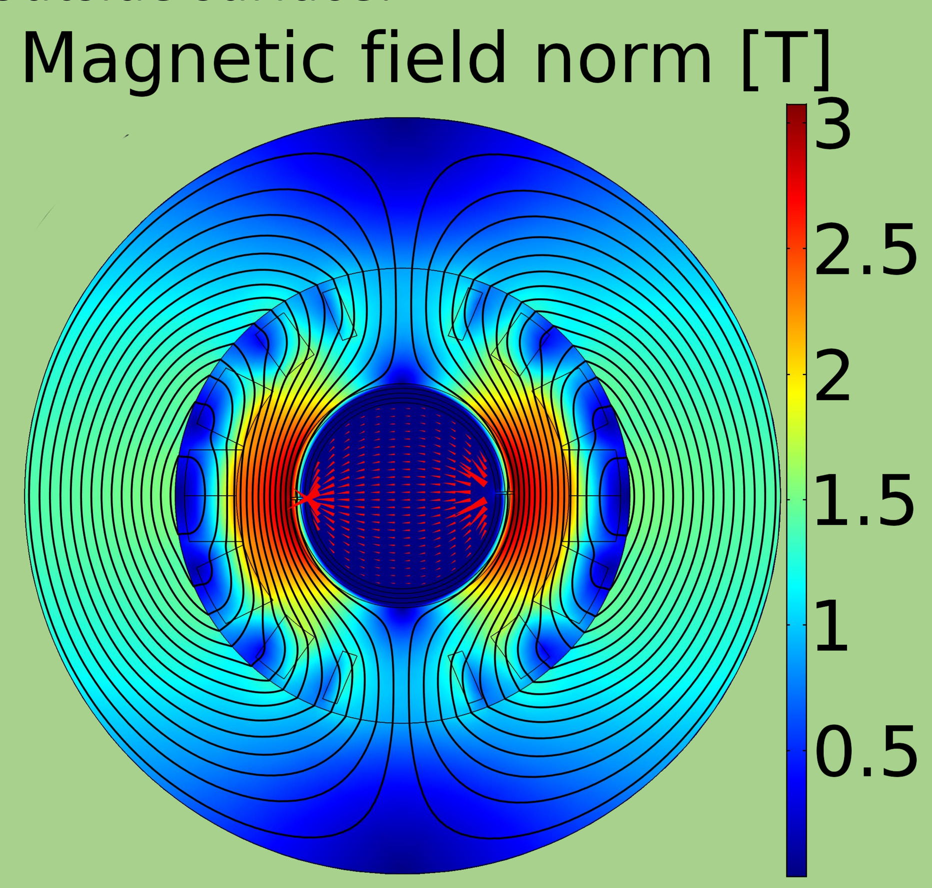


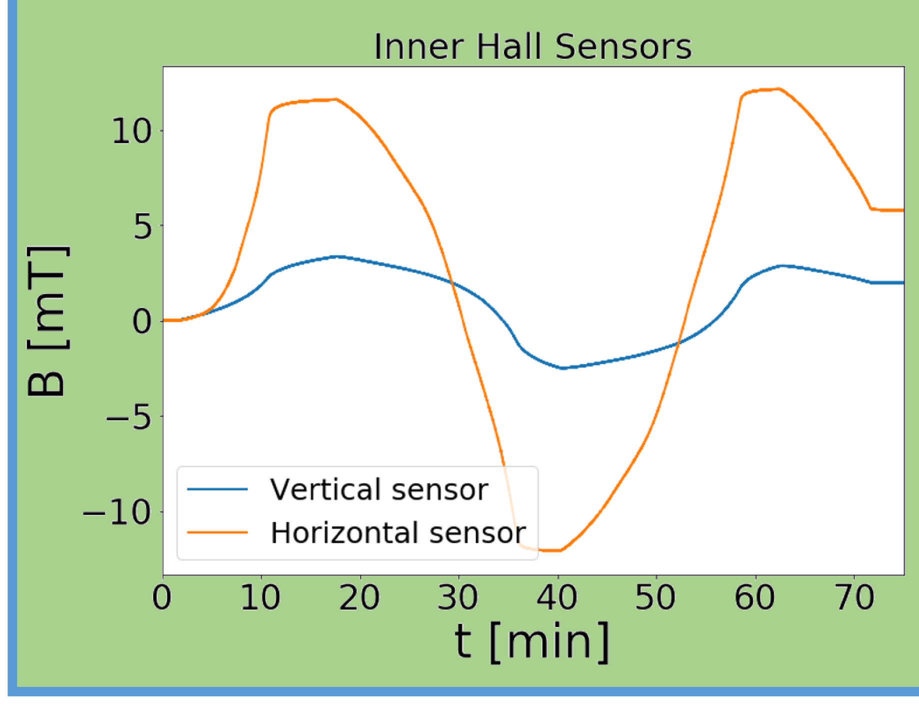
4. Numerical analysis of MgB_2: First, we have optimized the model parameters mentioned in [4] using Campbell's model. With these parameters, we have run a time-dependent simulation using n=100. The figure shows the calculated and measured field 3 mm from the MgB_2 tube. We can see that even without further optimization of the parameters we have got from Campbell's model, we can reproduce the experimental results quite accurately using the eddy current model. The tested tube could perfectly shield about 3 T outer[4] field with 8.5 mm wall thickness.

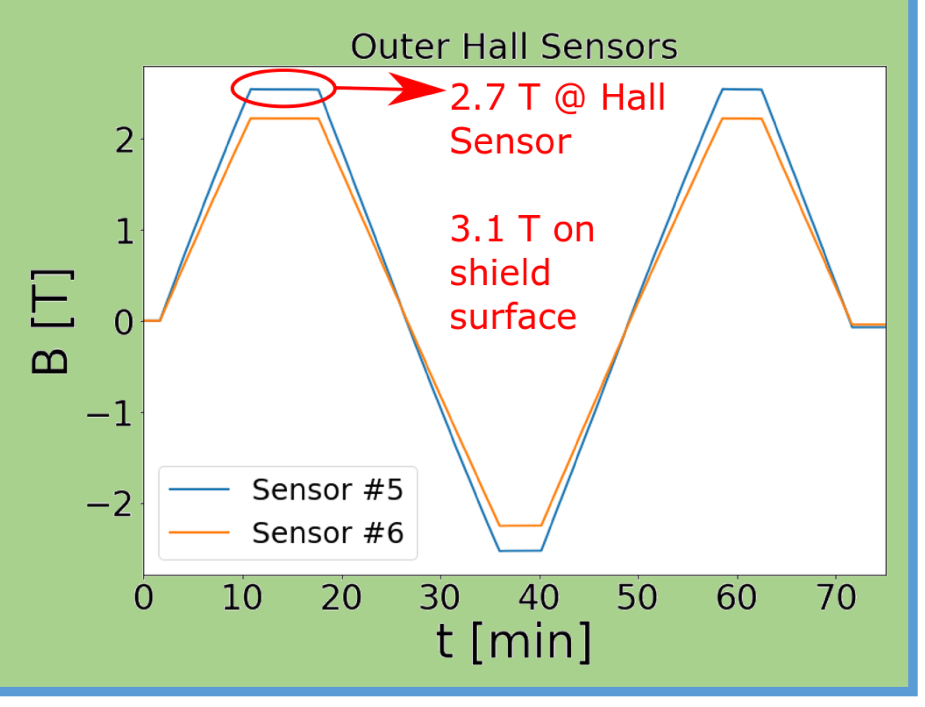


5. Numerical analysis of NbTi/Nb/Cu: Experimentally, we have observed 10 mT horizontal and ~0.4 mT vertical field at the shield's centre with 3.1 T at the shield's outside surface.

Our simulations with realistic geometrical parameters (23.7 mm outer shield radius, 0.5 mm cut thickness, 1.5° rotation of the half cylinders) reproduce these results, which confirms that the leakage field is due to the shield having a cut on both sides. Elimination of one cut (like it should be in the real device) gave a leakage field on the level of 10^{-6} T







Conclusion: Test results and the derived superconducting parameters promise that MgB2 (NbTi/Nb/Cu) could shield magnetic fields somewhat above 3 T (4-5 T) with an apparent septum thickness <=25 mm. NbTi/Nb/Cu is a technically better choice, since it is ductile, easy to form, robust, magnetically stable, and can shield higher fields. Optimization and design of a fully fledged demonstrator device is underway.

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References:

[1] Campbell, A. (2007). A new method of determining the critical state in superconductors. *Superconductor Science and Technology*, *20*, 292–295.

[2] Giunchi, G. (2003). High Density MgB_2 obtained by reactive liquid Mg infiltration. *International Journal of Modern Physics B*, *17*(04n06), 453–460.

[3] Itoh, I., Fujisawa, K., & Otsuka, H. (2002). NbTi/Nb/Cu Composite Materials for Superconducting Magnetic Shielding. *Nippon Steel Technical Report*, *85*, 118–123.

[4] Barna, D. (2017) FCC Week talk