Self-compensated Neutron Super Mirror Magnetic Yoke to Reduce Stray Field

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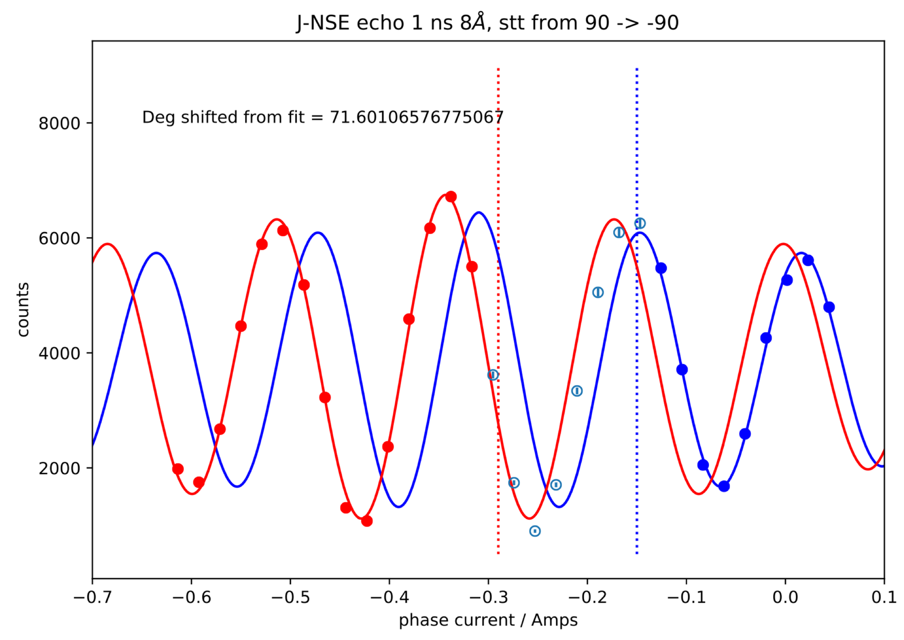
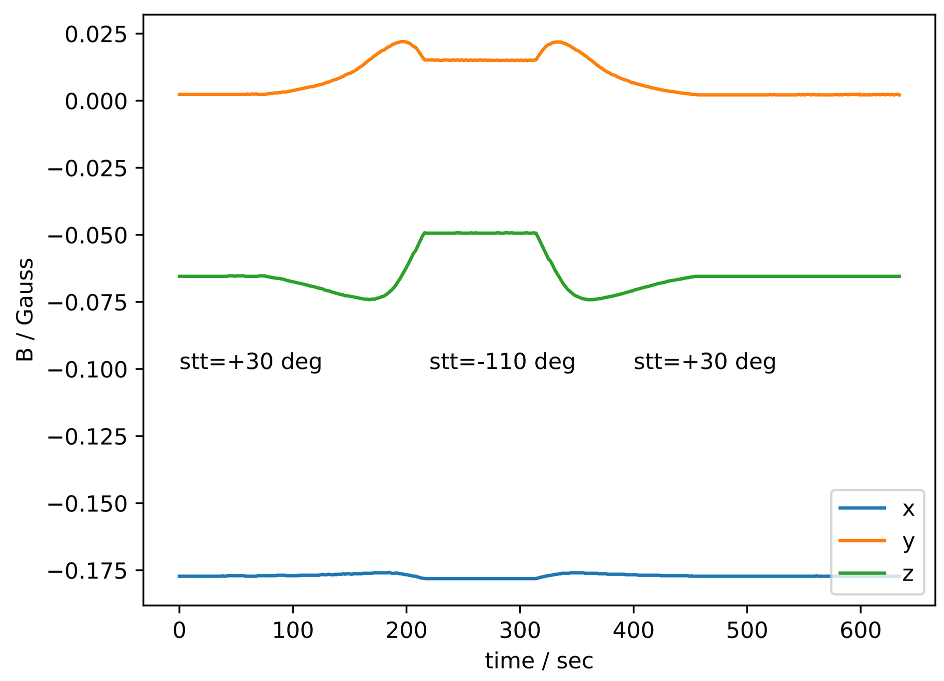
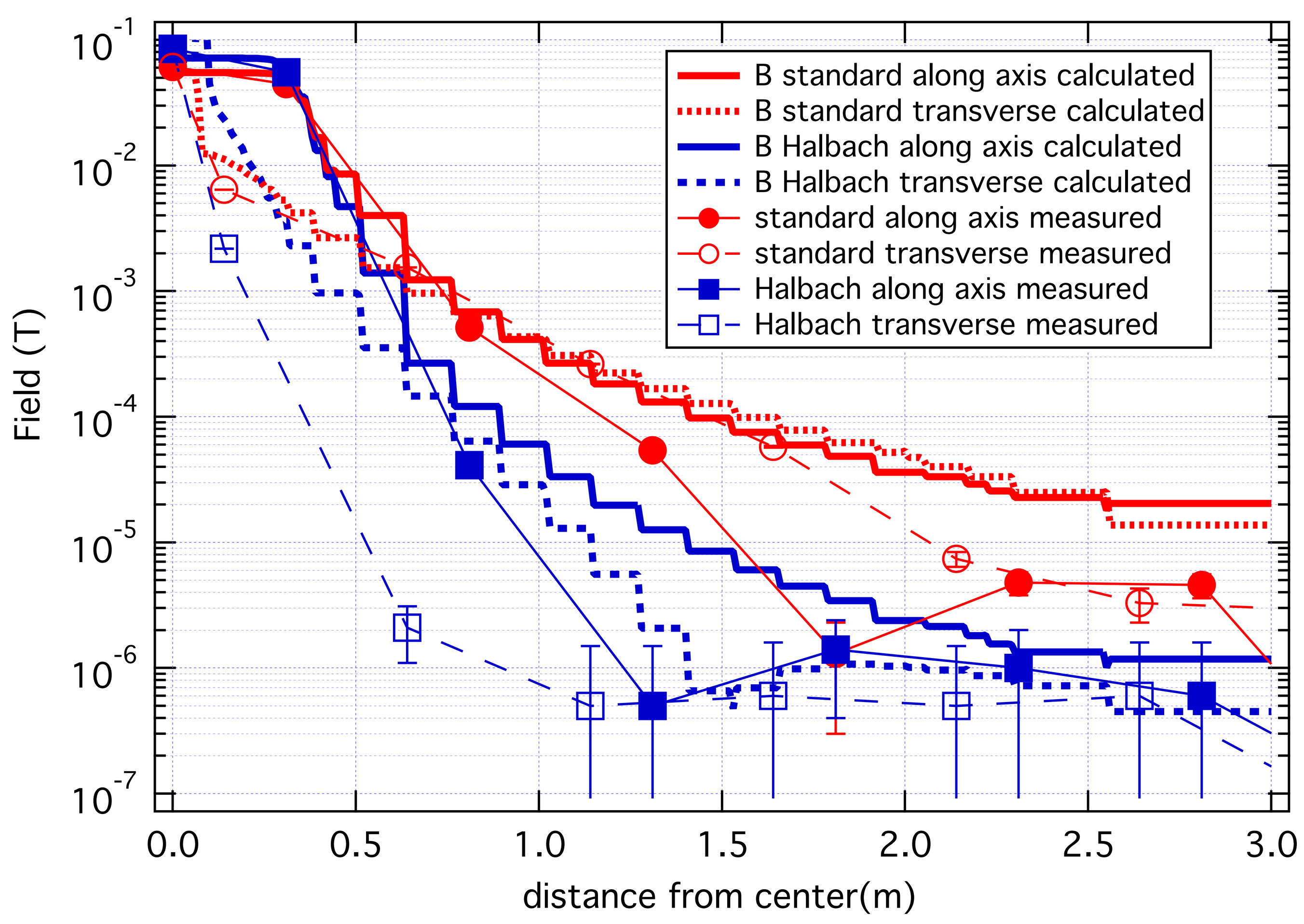
Introduction. SM-Based transmission V-cavities are widely used in neutron research science to produce highly polarized neutron beam or involved as efficient spin-analyser of the scattered beam. A typical SM-based V-cavity uses a permanent magnet spit dipole with Fe pole-plates to create a magnetizing field[1]. Research has found that fields on the order of 500 G or more are desired to fully orient the domains of a typical polarizing super mirror to avoid depolarization [2]. Such a configuration creates an external dipole field that can cause magnetic interference with sensitive instruments such as the JNSE [3]. We placed additional permanent magnets, in a balanced amount anti-parallel to the existing magnets and external to the Fe pole plates. This creates a Halbach-like cladded magnet structure that both **reduces the stray field contribution by up to 100x externally while increasing the internal field by around 1.3**, from 500 G to 800 G in our case.



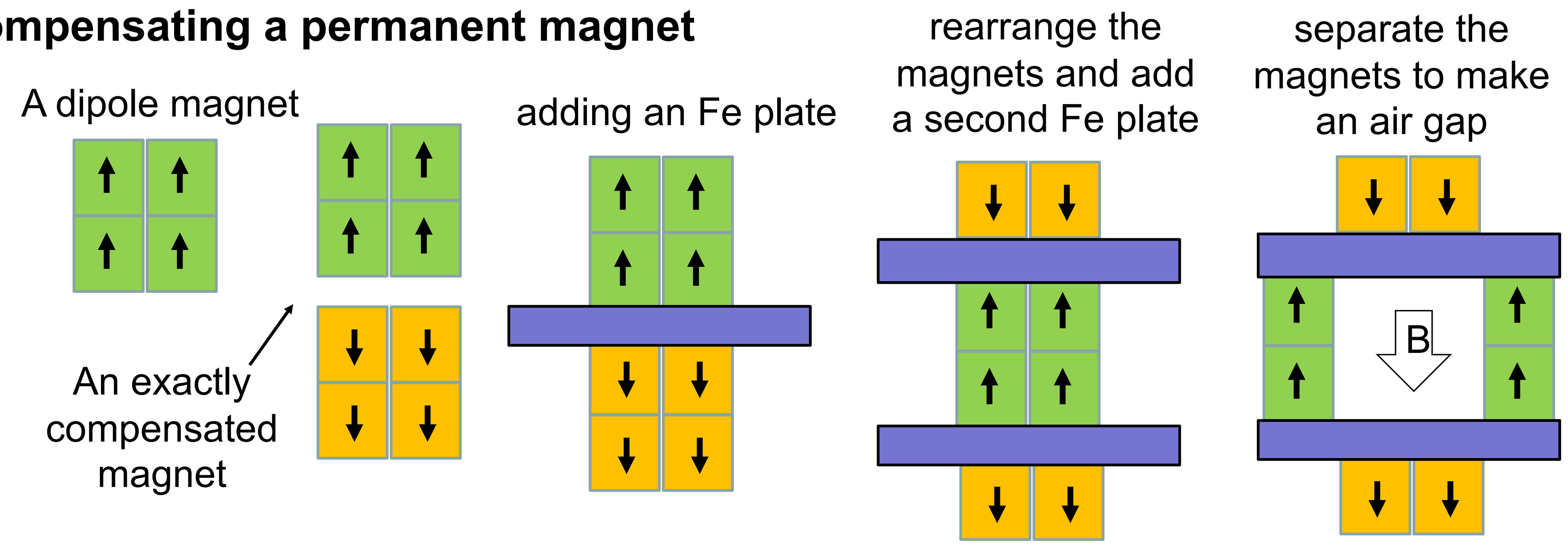
Plots showing a real shift in the JNSE phase upon movement of the KOMPASS [4] detector arm (above). Magnetic field sensors show that the field at the JNSE varied by as much as 25 mG during a KOMPASS detector arm movement (below).



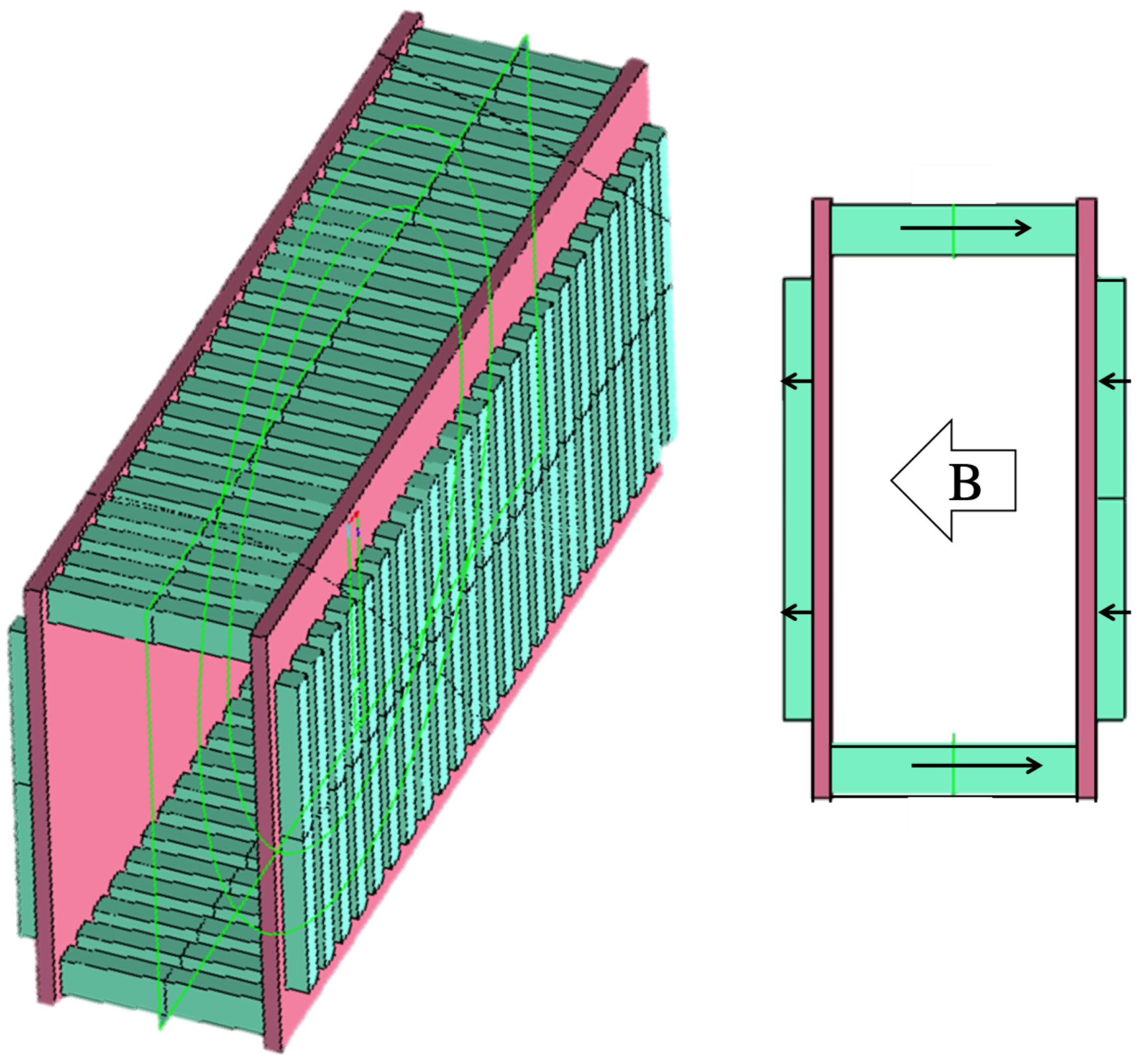


Measured field after adding the compensation to the KOMPASS analyzer array, the expected increase in central magnetic field was achieved (now 800 G) and the stray fields are reduced by as much as 100x. This measurement is limited by the hall probe sensitivity and stability. Further tests will be done using the JNSE when neutrons become available.

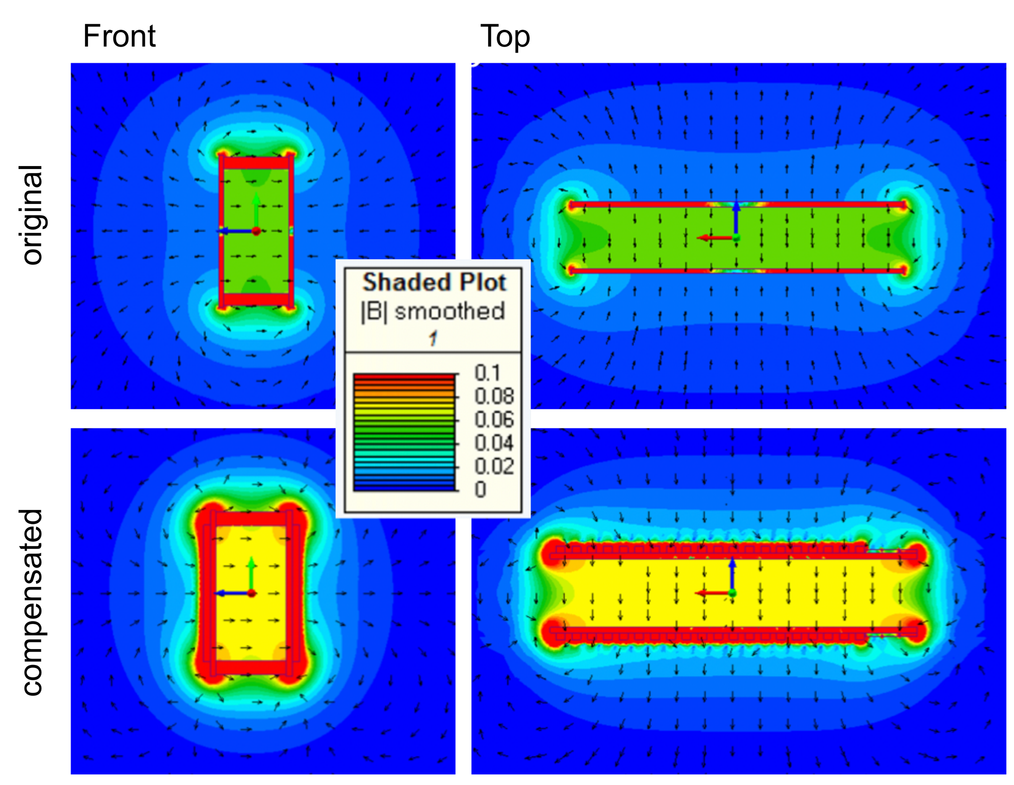
Compensating a permanent magnet



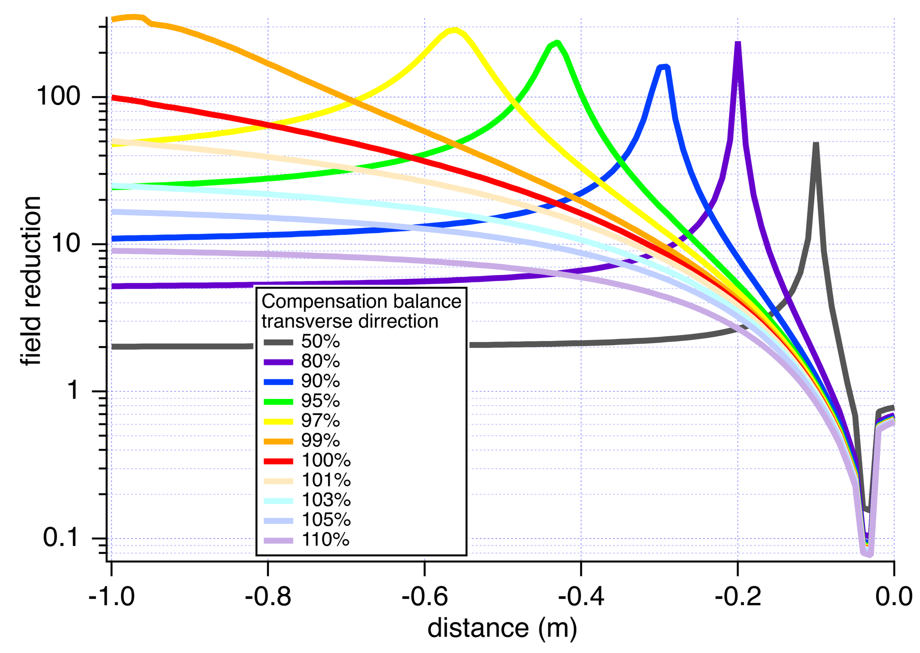
All the magnets in this digram description are identical exept for orientation. One can see **the maximum compensation should be when the magnetization times volume of the orange and green magnets is balanced**, the shape or type of the magnets need not be the same. The arrangement on the right without the orange magnets is the typical split dipole used to make a magnetic SM cavity. Adding the iron plates, assuming they are not in magnetic saturation, actually lowers long range fields by guiding the magnetic flux through them instead of the air. The compensating magnets now are essentially in a halbach arrangement which actually increases the magnitude of the central field in the air gap, the combination of the halbach magnets [5] plus the iron plates forms what is referred to as a cladded magnet structure [6].



The compensated SM yoke. The magnets (teal) placed on the Fe plates (pink) are added to cancel long range dipole fields. The magnetization-volume product of the magnets inside and outside of the Fe poles are balanced. The KOMPASS analyzer is 12x25x65 cm and creates a non-negligible dipole field compared the sensitivity of the neighbouring JNSE. Since the additional magnets form a significant repulsive force to the Fe plates of several 100 Kg, and a torque on the end magnets, the assembly is clamped together with an aluminium structure (not shown) holding the magnets and Fe plates safely in place.



FEM calculations comparing the field of the original (top) to compensated geometry (below) showing the field uniformity and increase due to the cladded magnet, halbach-like arrangement.



Calculated stray field suppression of a simplified array for various balances of compensation from 50% to 110% (under to over compensated) for the transverse field. A 100x reduction of stray field is possible at the ideal balance/compensation point.

Conclusions. Passive compensation of permanent magnet arrays is feasible. **Maximum stray field suppression of up to 100x at 1 m distance**, relies on a precise balance, on the level 1%, for the magnetization-volume product of the standard dipole magnets to the compensating magnets. However, even with a 5% precision a >10x reduction can readily be obtained. Due to the variation in coercivity of standard magnets, on the order of 2% for NdFeB, to obtain an „exact“ compensation we surmise one could add an additional active element such as a simple resistive coil to fine tune the compensation further if needed. **The assembled device will be verified with neutron experiments when possible.**

[1] SwissNeutronics AG — Bruehlstrasse 28 — CH-5313 Klingnau — Switzerland, Polarization Broschure, https://www.swissneutronics.ch/ fileadmin/user_upload/Dokumente/Bilder/Produkte/Polarizing_ Devices/Flyer_ESS_-_polarising_devices_-_V3.pdf accessed 2021- 07-15 [2] Klauser C, Bigault Th, Böni P, Coutois P, Devishvili A, Rebrova N, Schnei- der M and Soldner T, Nuclear instruments & methods in physics research / A, 840 (2016) 181-5 [3] Pasini S, Holderer O, Kozielewski T, Richter D, and Monkenbusch M, Review of scientific instruments, 90 (2019) 043107 [4] Janoschek M, Bo¨ni P and Braden M, Nuclear instruments & methods in physics research / A, 613 (2010) 119-26 [5] Halbach H, Proc. of the Eighth Int. Conf. on Rare Earth Magnet Materials (University of Dayton, Dayton OH), (1985) 123 [6] Leupold H A, Permanent Magnet Design: Magnetic Cladding and Periodic Structures, Magnetic Hysteresis in Novel Magnetic Materials, Springer Netherlands (1997) 811-44