# Development of Magnetic Field Components for the Polarisation Option of the Neutron Spectrometer FOCUS

Lothar Holitzner[1], Uwe Filges[1], Jan Peter Embs[2], Tom Fennell[2], Tobias Panzner[1]
1. Paul Scherrer Institut, Laboratory for Developments and Methods, 5232 Villigen PSI, Switzerland;
2. Paul Scherrer Institut, Laboratory for Neutron Scattering, 5232 Villigen PSI, Switzerland.

We show a new, favourable space-saving method to host a neutron polarizer in the iron-containing monochromator shielding of a time-of-flight spectrometer for cold neutrons. In this poster you can learn e.g., how to create a robust, homogeneous, rectangular magnetic field (here realized by permanent magnet queues inside an iron tube).

**Introduction:** Neutrons are part of the atomic nuclei. As neutrons are electrically neutral, they deeply penetrate into sample materials. Neutrons with a suitable velocity (resp. wavelength) are the perfect "detectives" to explore the dynamical and structural properties of materials. In addition neutrons have a spin. In a "normal" neutron beam these spins are orderless. When it succeeds to order the neutrons spin in the beam and to guide this "polarised" beam to the sample, we can also probe the magnetic properties of samples.

The time-of-flight spectrometer FOCUS [1] at the spallation neutron source SINQ at Paul Scherrer Institut (PSI) can be extended by a polarisation option. Our current activities concentrate on the components for the primary polarisation: the **polarizer** (to order the neutron spin), the magnetic **guide field** (to keep the beam polarised) and a **spin flipper** (which can invert the spin direction). These new components have to be implemented into the existing neutron spectrometer.

The polarisation option at FOCUS should work in a neutron wavelength band of **4 - 6 Angstrom**. Our neutron guide field can be realized by a vertical magnetic field of about **2 mT**. The polarizer needs a vertical, homogeneous, magnetic field of at least **25 mT** to work properly. Inside the spin flipper we need a tunable, pure horizontal, magnetic field of **2.22 - 3.34 mT**, as the spin flipper is selective for neutron wavelengths [2].

## Instrument Layout

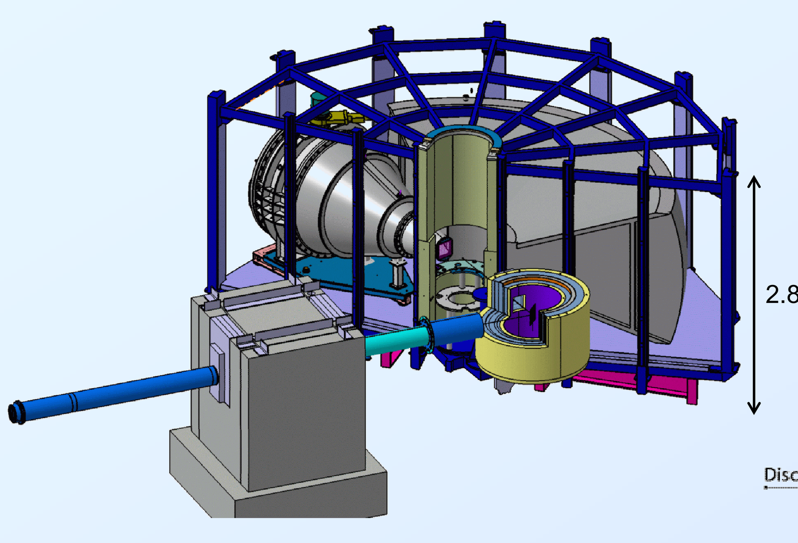


Figure 1. 3D-layout of FOCUS

FOCUS is a direct geometry time-of-flight spectrometer for cold neutrons at SINQ. The instrument has been built and is being operated in a joint venture between the Paul Scherrer Institute, Switzerland and Saarland University, Germany. FOCUS is highly flexible and can be optimised widely according to the users' demands. For more detailed information about the instrument and access possibilities please have a look around on this website:

http://www.psi.ch/sinq/focus/

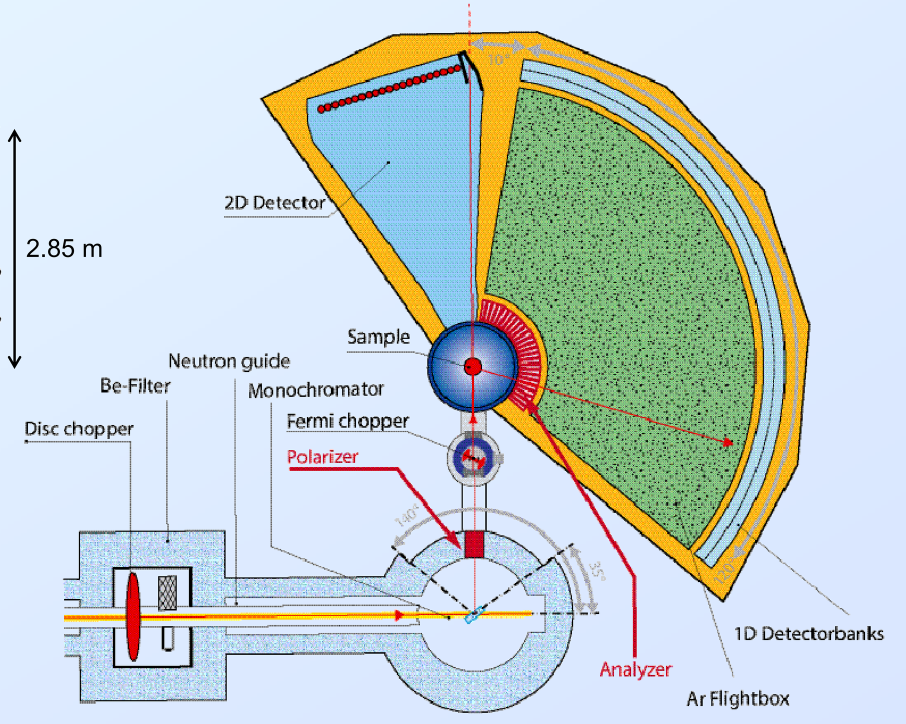


Figure 2. 2D-layout of FOCUS

## Development & Design Region

available space for the spin flipper

monochromator
monochromator shielding
fermi chopper

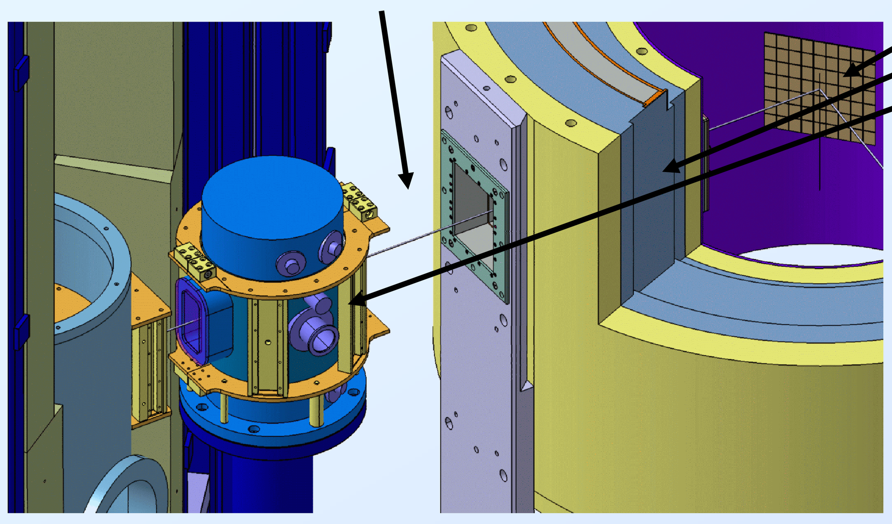

Figure 3. Clearance

Problem:
The spin flipper is located in the inhomogeneous stray field region of the polarizer field.

Due to the space conditions in the existing spectrometer, the polarizer has to be placed inside the rectangular hole of the monochromator shielding.

Tasks and challenges:

- create a homogeneous, vertical magnetic polarizer field ≥ 25 mT
- create the magnetic vertical-zero field inside the spin flipper
- design the magnetic guide field in the transition region between polariser and fermi chopper

**Computational Methods:** The neutron guide field properties were verified by calculating the neutron wavelength limit $\lambda_{min}$ for adiabatic rotation, in the FEM model defined as a variable in the neutron flight path domain.

$$\lambda_{min}\left[\mathring{A}\right] = \frac{\frac{d\theta_B}{dx}}{|B|} \cdot \frac{180 \cdot 10^{-5}}{\pi \cdot 2.65} \cdot \frac{T \cdot m}{rad} \qquad \frac{d\theta_B}{dx} = \sqrt{\left(\frac{d\left(a\tan\left(\frac{B_x}{B_z}\right)\right)}{dx}\right)^2 + \left(\frac{d\left(a\tan\left(\frac{B_y}{B_z}\right)\right)}{dx}\right)^2}$$

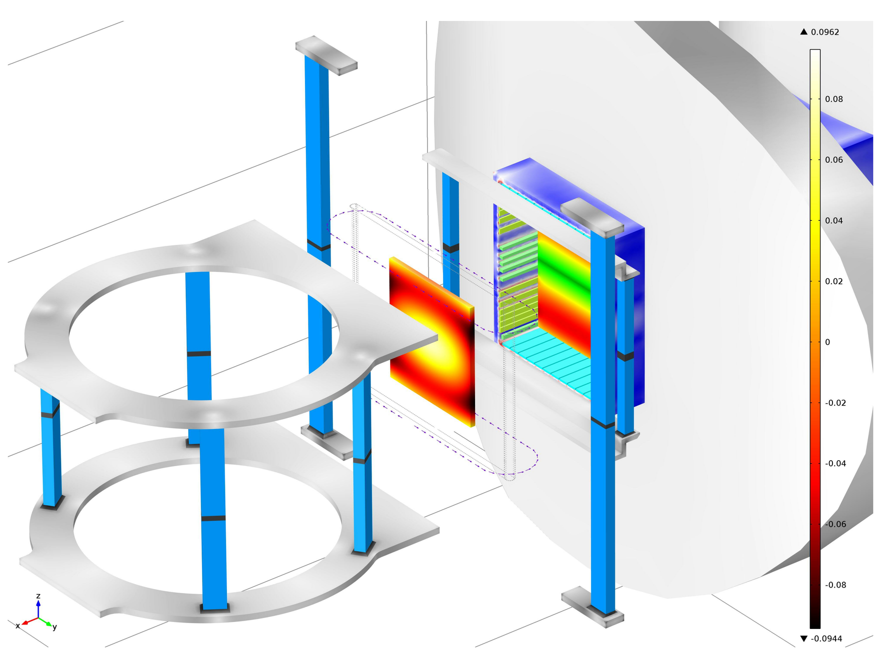

Figure 4. Model implementation (compare Fig. 3)

The condition for the neutron spin rotation inside the spin flipper (the horizontal magnetic flux density $B_y$) is defined by

$$\frac{B_y}{T} = \frac{Np}{7361 \cdot L_x[m] \cdot \lambda_n[Angstrom]}$$

with

- number of spin turns Np = 0.5
- spin flipper length $L_x$ = 5.09 mm
- neutron wavelength $\lambda_n$ = 4 ... 6 Å

Example: $B_y$(5 Å) = 2.67 mT

Model setup in COMSOL Multiphysics® with:

- AC/DC module: Magnetic fields (mfnc, mf)
- Heat transfer: Joule heating (jh)
- Structural mechanics (solid)

Computation of :

- Field maps of magnets and coils
- Temperature of spin flipper wires
- Magnetic forces (measured) on structure
- Neutron wavelength limit

**Results:** The magnetic polarizer field and the guide field were created by a set of permanent magnets, while the spin flipper is composed of two rectangular magnetic coils (a compensation coil $H_z$ and a flip coil $H_y$). The guide field is able to carry polarized neutrons with wavelengths ≥ 1.25 Å, which provides a safety factor of 3.2 - 5 in the appropriated neutron wavelength band.

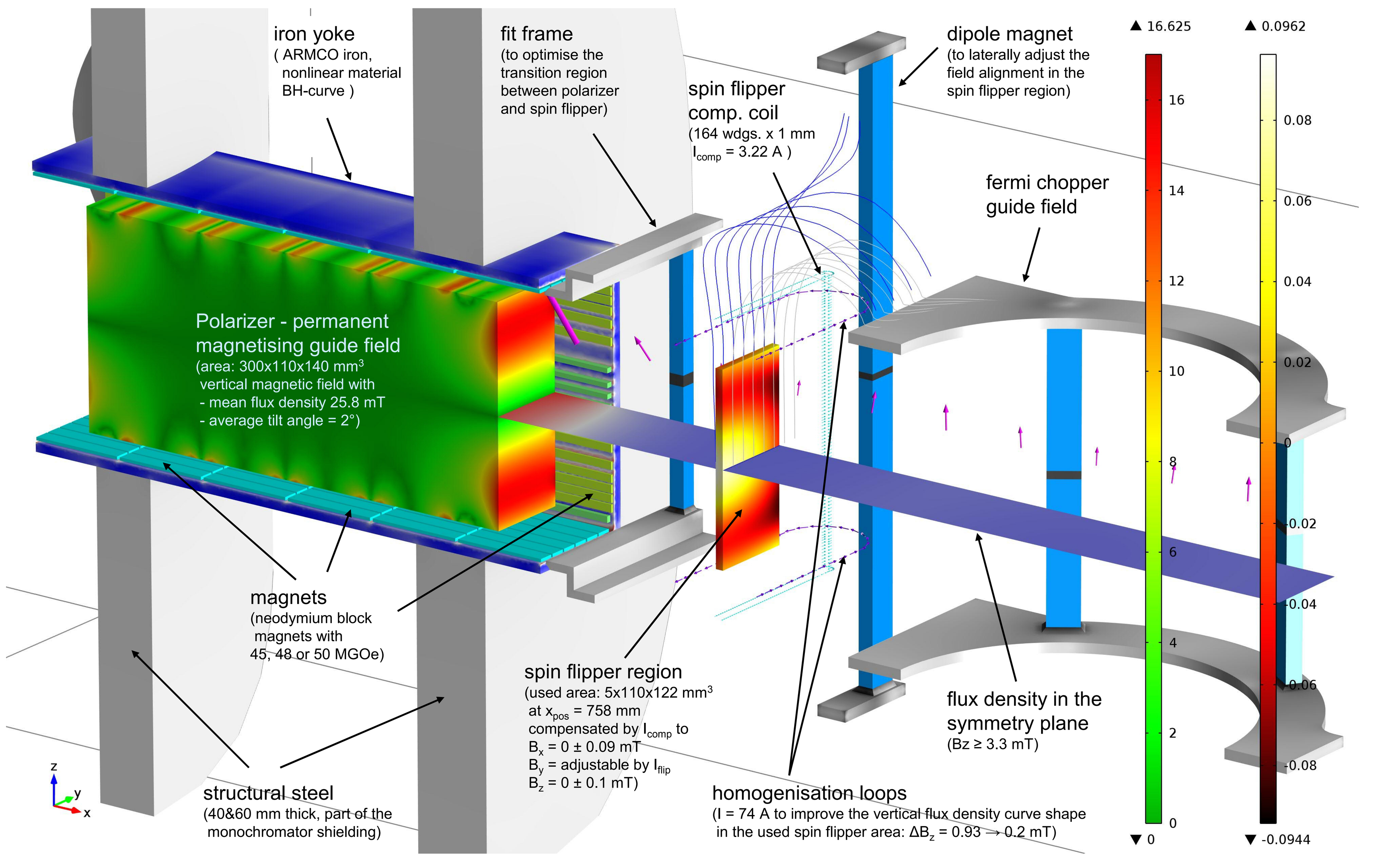


Figure 5. Final magnetic field model

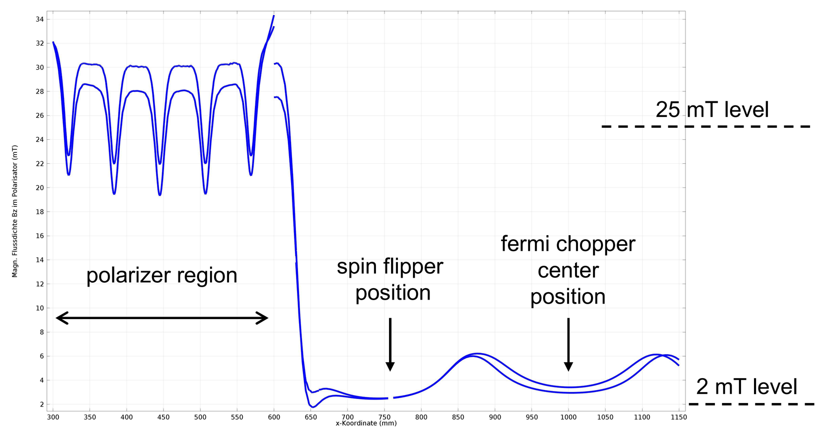


Figure 6. Vertical flux density along the guide field (300mm ≤ x ≤ 1150mm)

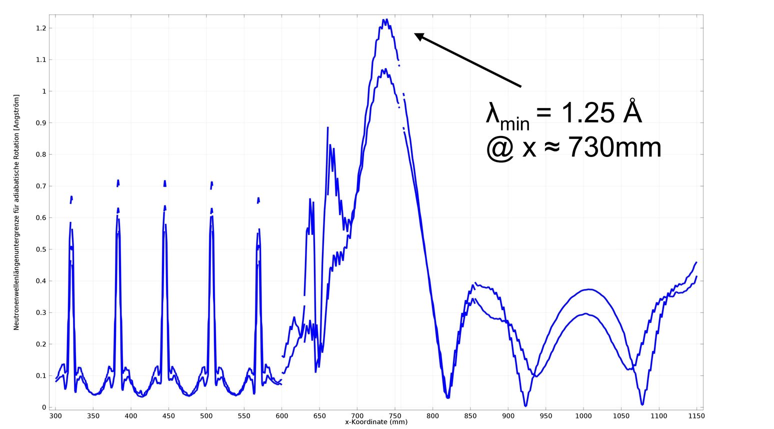


Figure 7. Neutron wavelength limit for adiabatic rotation (300mm ≤ x ≤ 1150mm)

**Polarizer Magnetic Field Cross-section:** In the polarizer domain, COMSOL Multiphysics® provided the optimization of the magnetic field homogeneity by a parameter study of the best permanent magnets position.

We obtained a good magnetic field homogeneity in the polarizer magnetic field cross-section plane with an average tilt angle deviation of 0.14° to the ideal vertical field vector (Fig. 9).

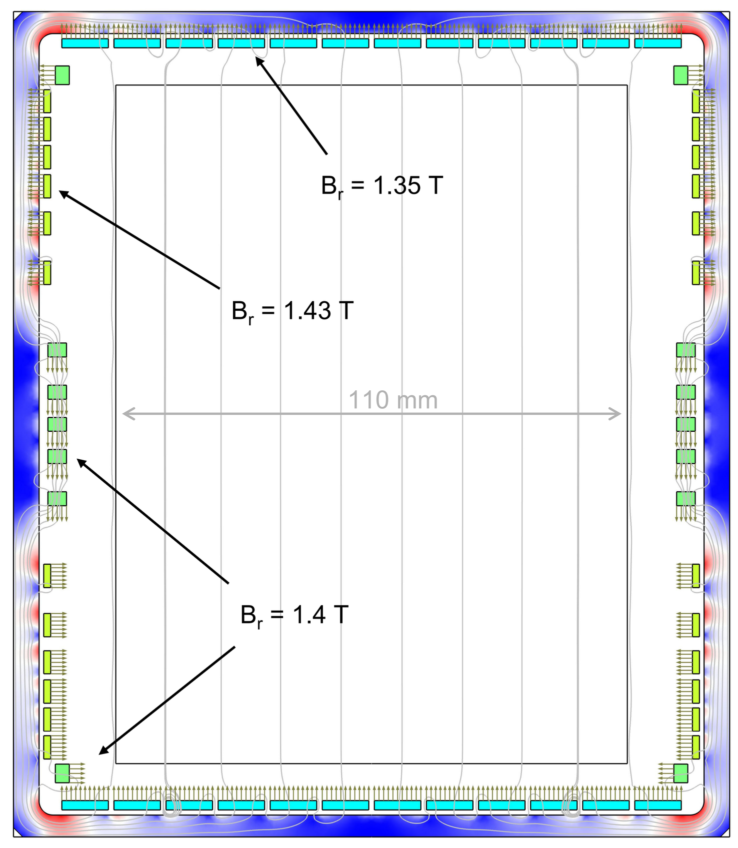


Figure 8. Permanent magnet pattern (idea from halbach array. Pay attention to the different field orientation and different remanence $B_r$ for each group of NdFeB magnets)

result

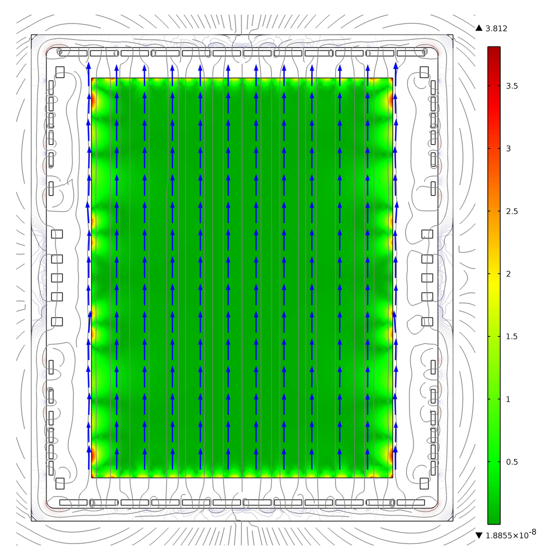

Figure 9. Tilt angle $\theta_B$ [°] distribution (0° ≤ $\theta_B$ ≤ 3.8°)

result

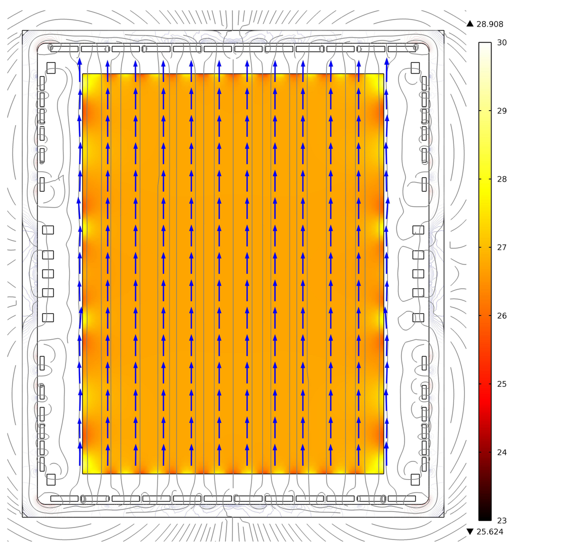

Figure 10. Flux density distrib. (25.6 mT ≤ $B_z$ ≤ 28.9 mT)

**Spin Flipper:** COMSOL Multiphysics® was used to improve the magnetic flux density distribution inside the spin flipper and to calculate the Joule heating in the coils.

Result: The magnetic flip field inside the spin flipper meets the ideal value (e.g. $B_y$ = 2.67 mT for 5 Å) with a maximum deviation of 2%.

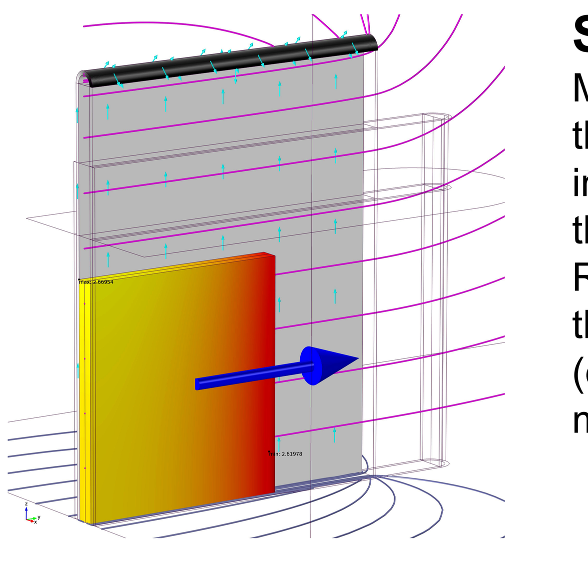

Figure 11. Flip coil (155 wdgs. x 1mm) with magnetic flux density distribution ($B_y$ = 2.62...2.67mT at $I_{flip}$= 2.40 A)

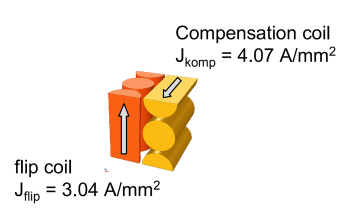


Figure 12. Coil detail: 90° crossed windings

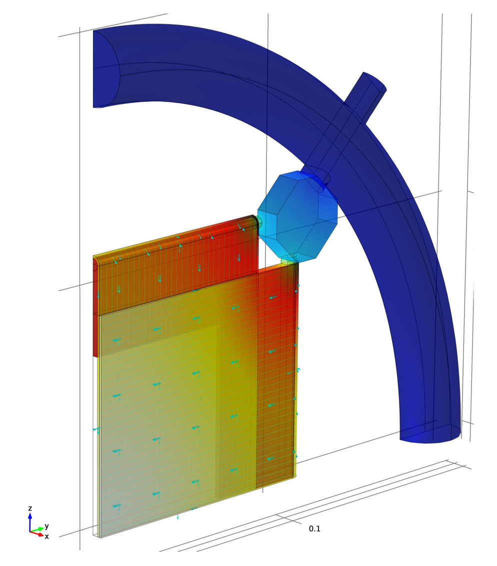

Figure 13. Temperature distribution in spin flipper coils (30...34°C), support ring (20°C) and conduction plate (30...33°C)

[1] J. Mesot, S. Janssen, L. Holitzner, R. Hempelmann, J. Neutr. Res. 3 (1996) 293-310

Excerpt from the Proceedings of the 2013 COMSOL Conference in Rotterdam

[2] O. Schärpf, The polarised neutron technique of neutron spin echo, Proc. of a Laue-Langevin Institut Workshop, Grenoble, (15-16.10.1979) p.35