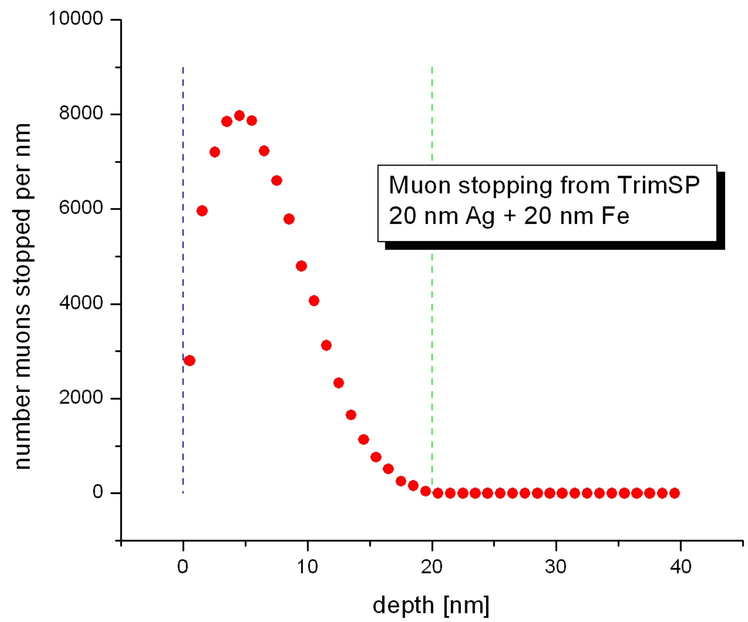
On the effect of domain structure in the ferromagnetic part of a double layer.

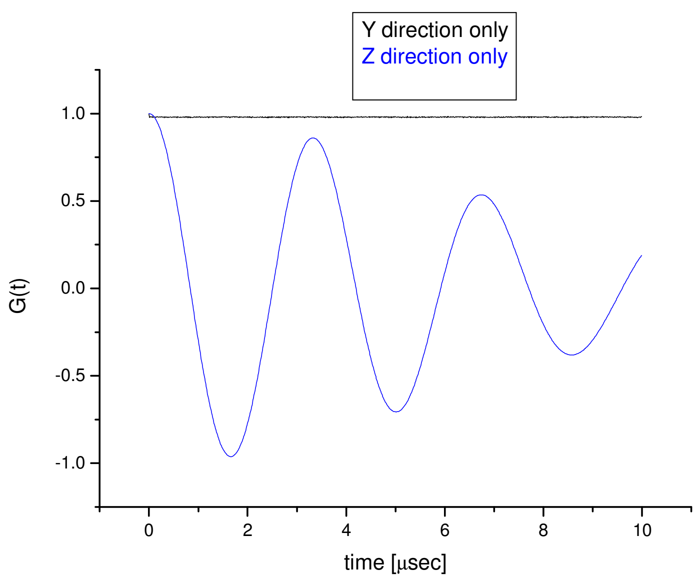
If muons are stopped in the exclusively nonmagnetic layer of a double layer of a ferromagnet, e.g. Fe, and a nonmagnetic metal, e.g. Ag, then one would expect no effect of the ferromagnetic layer, since that layer is ferromagnetically ordered, and the shape (thin film) causes the magnetic moment to be parallel to the surface of the film. Directly parallel to this magnetic film, that is in the Ag layer there is no magnetic field due to the ordered layer.
This is true if the magnetic layer is a single domain.

However, a domain structure may alter this picture.
To investigate this question, a simulation was carried out on the following model system:

- Assume 20 nm Ag on 20 nm Fe.
- Assume the sample to be 10 * 10 micron.
- Divide the sample in 1.6 x 10^7 square cells, each 2.5 * 2.5 nm and 40 nm height.
- Define these tetragonal cells as magnetic dipoles, where the center of the dipole is in the middle of the Fe layer. The magnitude of the magnetic moment is taken to be 2.3 μ_B * the number of Fe-atom in the cell (or smaller, see below)
- Assume the magnetic domains to be square, with size 2.5 * 2.5 micron (so maximum 16 domains).
- Stop muons on 20 different depths, ranging from 0.5 to 19.5 nm, and take the number of muons stopped on each depth equal to the result of a TrimSP calculation with a total of 10^5 muons for a 1000x1000 sample and 2000 muons for a 4000*4000 sample.. Choose for each muon the y- and z-coordinate random (between 2 and 8 μ, in order to reduce the influence of the finite size of the sample). Note that the x-axis is perpendicular to the surface of the film. Calculate the magnetic field at each of the muon sites by adding the fields resulting from the 10^6 "unit-cells" . From that, calculated the time evolution of the muon spin and average all the time evolutions obtained in this way.
- Carry out this calculation for
  1. *longitudinal*: all magnetic moments along the y-axis (parallel to the initial muon spin)
  2. *transversal*: all magnetic moments along the z-axis (perpendicular to the initial muon spin)
  3. *Two domains,* boundary along the z-axis in the middle of the sample.
  4. *domain*: magnetic domains random, but restricted to a fourfold anisotropy. (moment along + and – y or + - z)

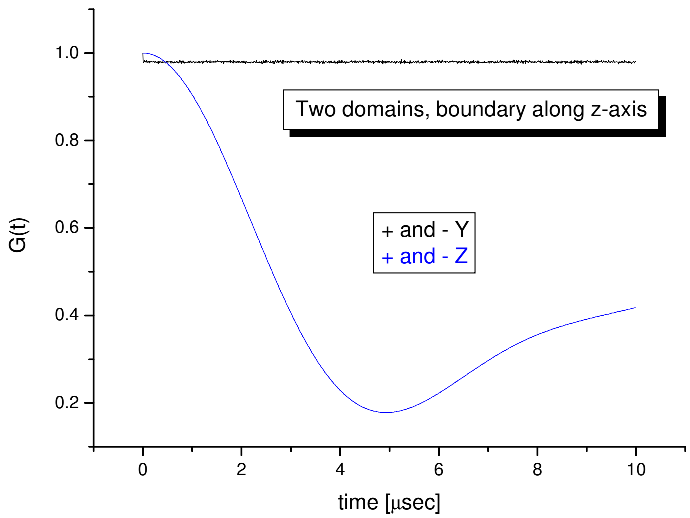
The results of the TrimSP calculation is in Fig. 1, the results for the depolarization in Fig. 2

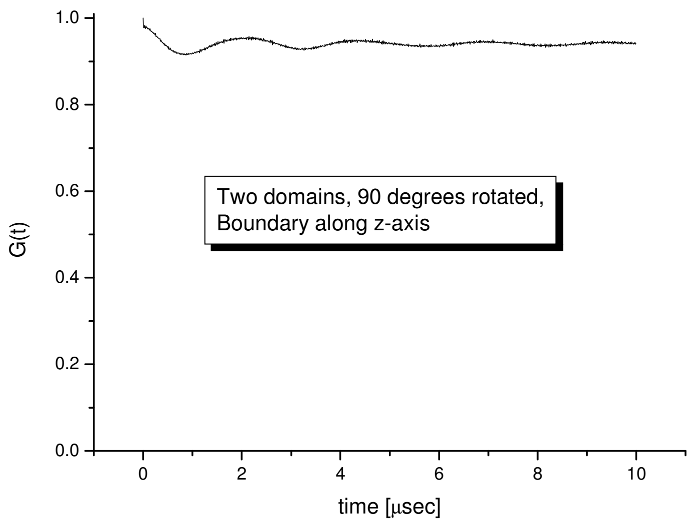


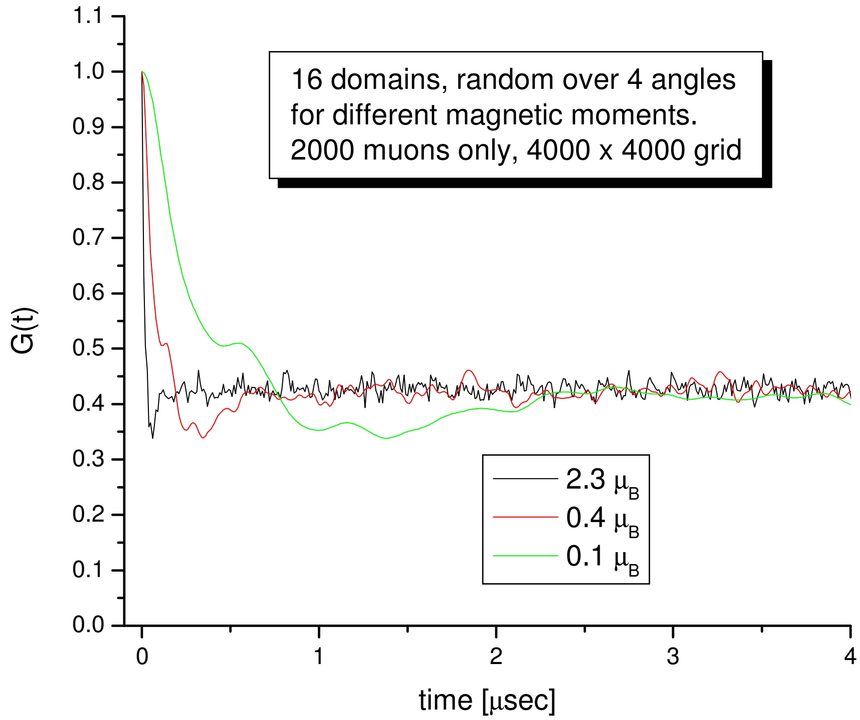


Note that the oscillation for the z-direction is due to the finite size of the sample.

On the effect of domain structure in the ferromagnetic part of a double layer.







Note that the last calculation has been carried out for smaller magnetic moments as well.

Tests of the procedure:

Two aspects should be tested:

1. The correctness of the absolute value
2. The influence of the discreteness of the magnetization.

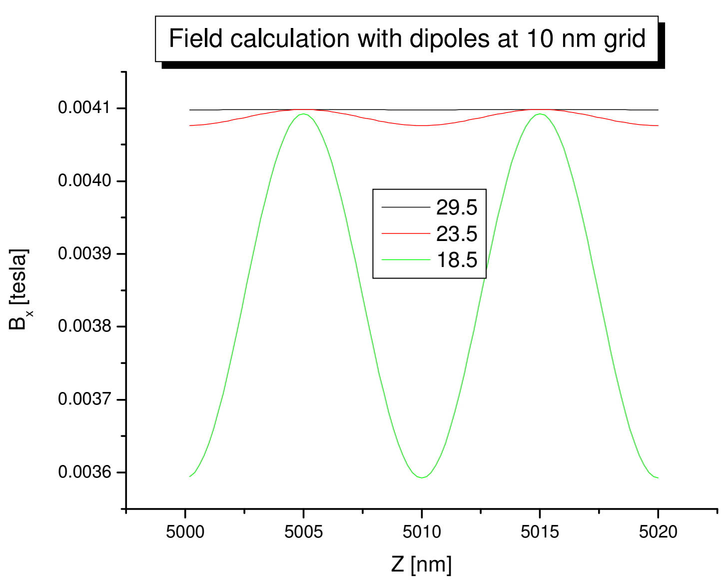
The magnetization of a homogenously magnetized body can be represented by its vitual surface currents. For a infinite slab with magnetization parallel to its surface, this means that the slab can be represented as two counter flowing surface currents perpendicular to the direction of the magnetization. As a consequence the magnetic field of this slab is zero. In our calculations we see a small field, see homogeneous magnetization along the z-axis, there is damped oscillation, however this field is due to the finite dimensions of our slab.

When the magnetization is perpendicular to the surface of the slab, the surface current runs along the edges only. For a magnetization of *m* Amp m^2 per surface unit, this vitual boundary current is *m* Amp. The magnetic field of a square current loop with sides *l* at a distance *x* above the middle is given by

$$B_x = \frac{\mu_0 I}{2\pi} \frac{l^2}{\left(z^2 + \frac{1}{4}l^2\right)\sqrt{z^2 + \frac{1}{2}l^2}}$$

Note that the field is zero in the limit of infinite *l*.

The next figure shows the magnetization of a 10 * 10 µ slab with 10 nm grid at three distances from the centre.



The correct limiting value is found and also it appears reasonable to calculate down to distances of 2.5 times the grid size. We therefore choose a grid of 2.5 nm, which leads to correct values down to 7 nm from the centre of the dipoles.

For calculations at distances smaller then the grid size, the field grows exponentially when approaching a dipole direct on the top, with a characteristic length approximately equal to the grid size. The next figure shows these calculations for a grid of 10 nm and 2 nm, respectively: