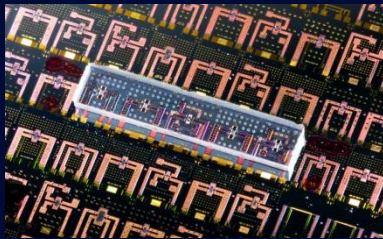




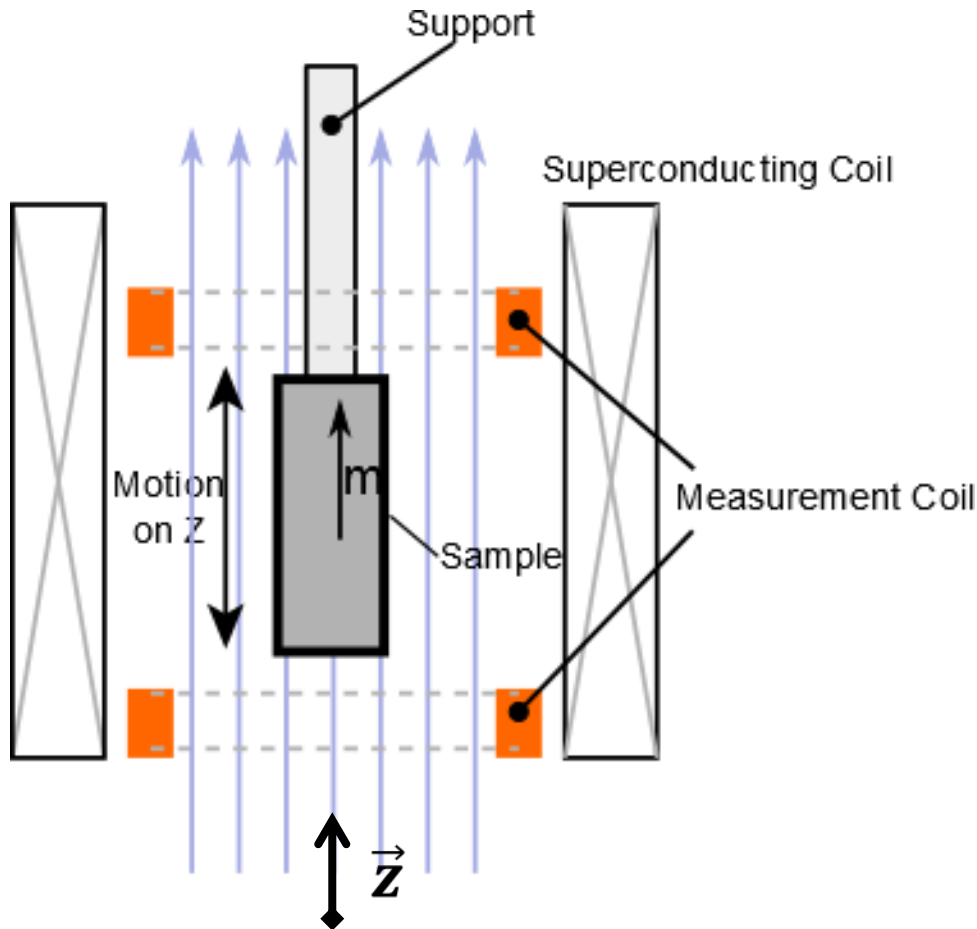
Advanced approach to local magnetic field computation in magnetocaloric materials characterization

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Measure of magnetic moment project on Z



- Homogeneous material

$$m_z(H_0) = \int_{V_{sample}} \vec{M}(H) \cdot \vec{z} \, dV$$

[A.m²] [A/m]

- isotropy on the material
- symetries on the sample

$$m_z(H_0) \vec{z} = \int_{V_{sample}} \vec{M}(H) \, dV$$

And $M(H) \neq m_z(H)/V$ because heterogeneity of H and $H \neq H_0$

Applied Field & Internal Field

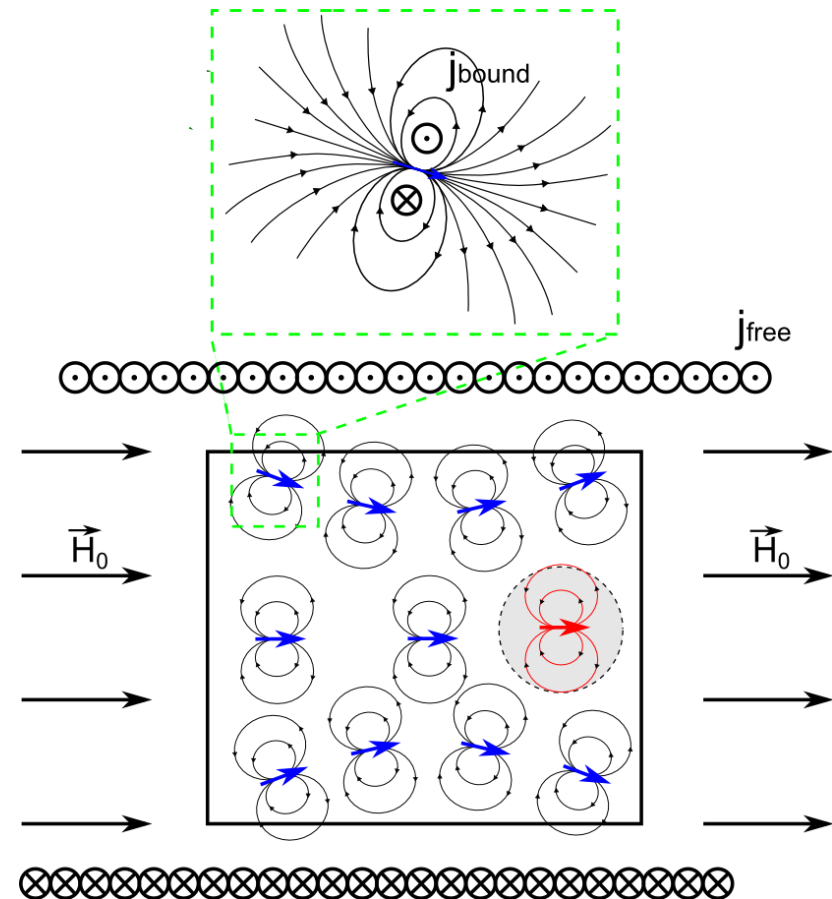
I. Intro

■ Difference between applied field H_0 and the internal field H

The gray volume feels :

- the applied field H_0
- The field induce by the magnetization of its neighbours H_d

$$H = H_0 + H_d$$



Difference between applied field H_0 and the internal Field H

Helmholtz decomposition

$$H = H_0 + H_d$$

Demagnetizing field respect

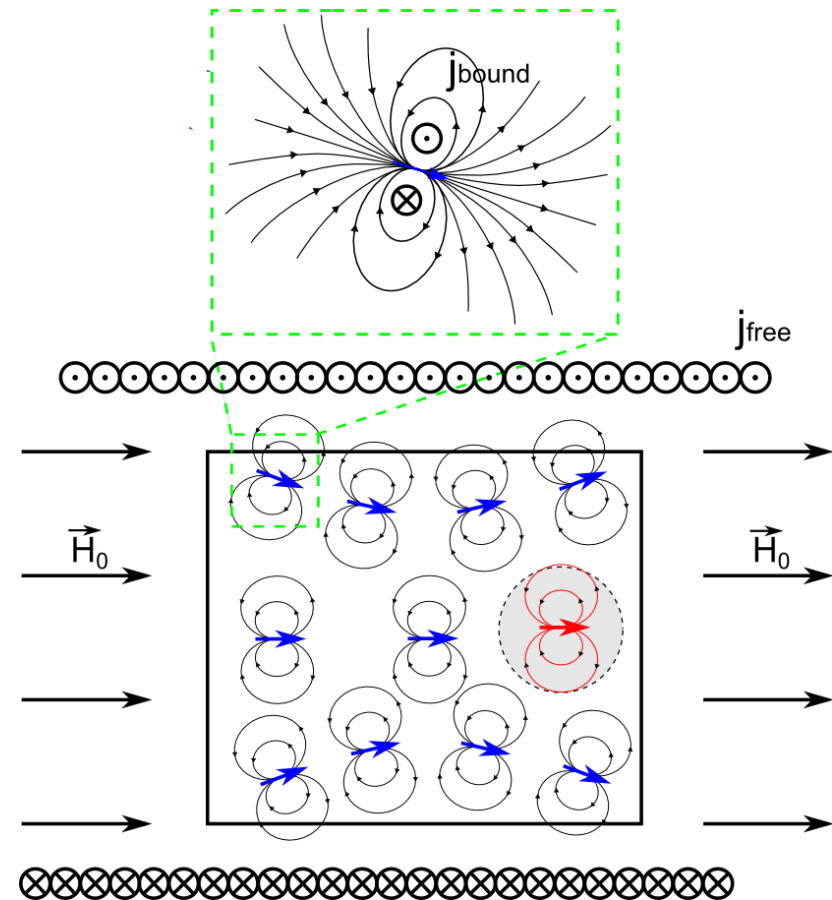
$$\text{div}(\mu_0 H_d(M) + M) = 0$$

$$\text{rot } H_d(M) = 0$$

$$H_d(M) \rightarrow 0 \text{ in } \infty$$

We define $H_d = -\text{grad}\phi_d$

$$\phi_d(M)(x) = \frac{1}{4\pi} \int_{\Omega} \frac{\text{div}M(y)}{|x-y|} dy + \frac{1}{4\pi} \int_{\partial\Omega} \frac{M(y) \cdot n(y)}{|x-y|}$$



Advanced approach in magnetocaloric materials characterization

I. Introduction of the demagnetizing field and the heterogeneity

II. Demagnetizing Factor

III. Formulation as an inverse Problem

IV. Demagnetizing Factor as an inverse problem

V. Perspectives

In elliptical shape

- The magnetic field is constant inside the body

$$m_z(H_0) = \int_{V_{sample}} M(H) dV \qquad M(H) = m_z(H_0)/V$$

- The demagnetizing field can be write as $H_d = -NM$ with N only function of the geometry

$$H = H_0 + H_d \qquad H = H_0 - Nm_z(H_0)/V \qquad H = f(H_0)$$

$$M(H) = m_z(f^{-1}(H))/V$$

But experimentaly it is difficult to have elliptical shape

Generalization of the demagnetizing Factor

I. Intro > II. Demag. Factor

■ In general shape

- 1st The field is not constant inside the body

$$m_z(H_0) = \int_{V_{sample}} M(H) dV \quad \langle M(H) \rangle = m_z(H_0)/V$$

- 2nd extension of the notion of demagnetizing field define as:

$$\int_V H_d dv = -N_m \int_V M dv \quad \langle H \rangle = H_0 - N_m \langle M(H) \rangle$$

$$\langle H \rangle \sim H_0 - N_m M(\langle H \rangle) \quad \langle H \rangle \sim f(H_0)$$

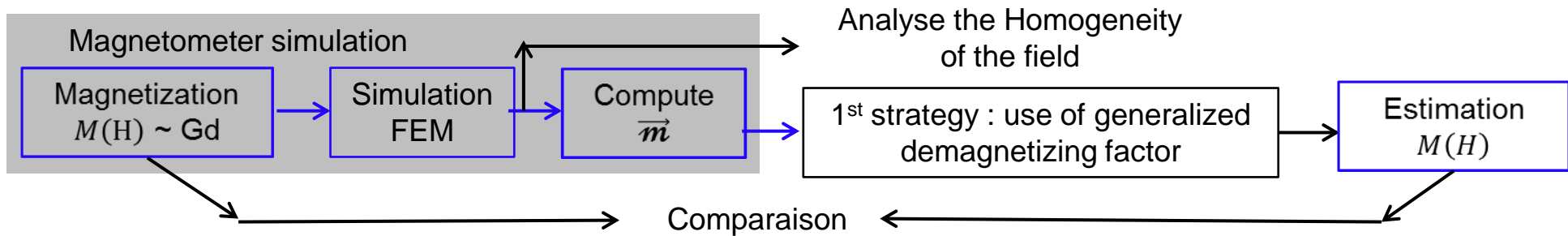
With N function of the geometry and $M(H)$

- 3rd approximation

$$M(H) \sim \langle M(H) \rangle = m_z(f^{-1}(\langle H \rangle))/V$$

Approximations are difficult to validate

Test the method based on numerical simulation



Numerical setup

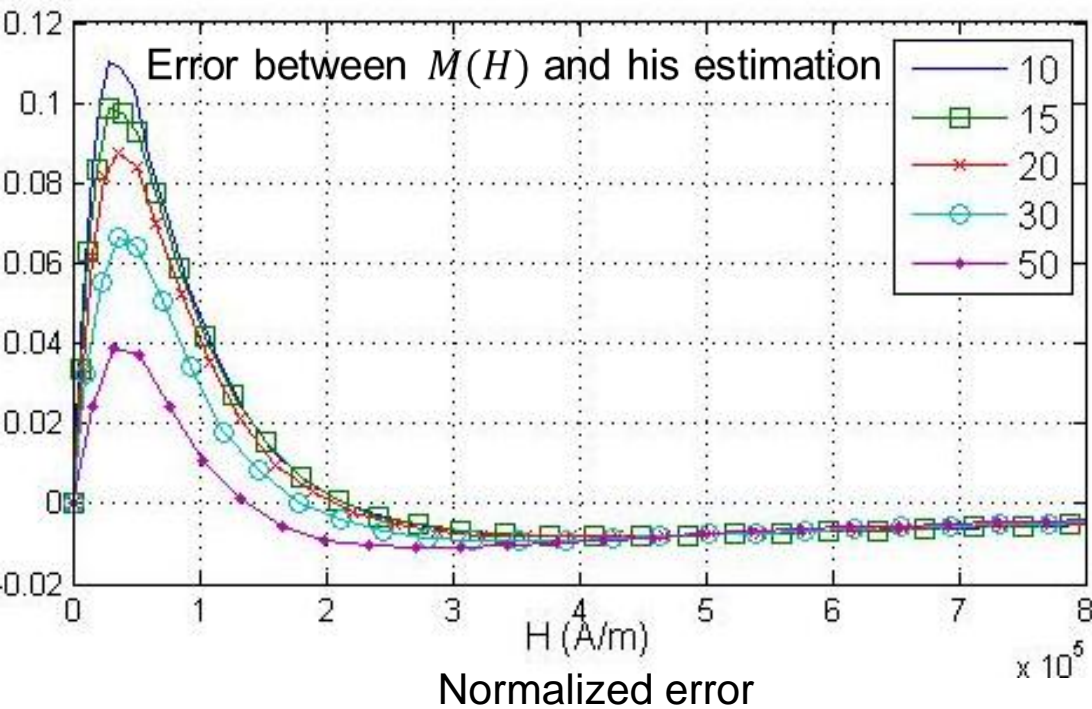
- **Cylinder** shape with radius 20 and $high/2 = [5, 10, \dots, 55]$
- Generalized demagnetizing factor interpolated from D.X Chen table*
But it is difficult to choose with non linear material
- Magnetization curve give by arctan. model with $J_s = 1.3 T$ and $\mu_r = 10$

*D.-X. Chen, J. A. Brug, et R. B. Goldfarb, « Demagnetizing factors for cylinders », *IEEE Transactions on Magnetics*, vol. 27, n° 4, p. 3601 -3619, juill. 1991.

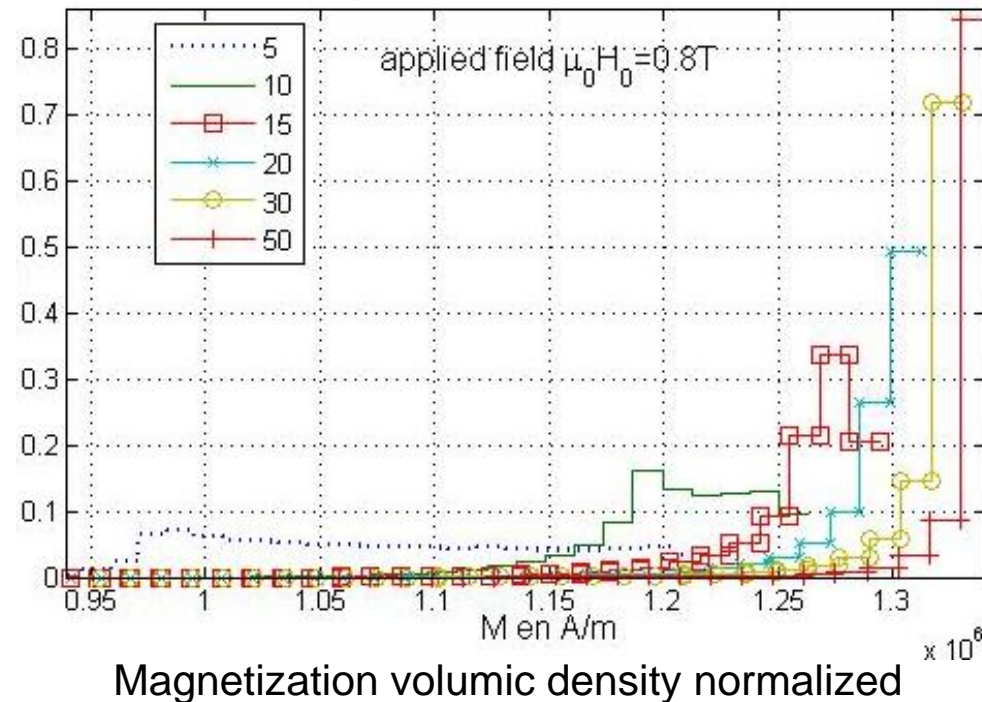
Result of the simulation

I. Intro > II. Demag. Factor

■ Error of the method



■ Homogeneity of the field



■ A long sample improve the efficiency of the method

● Because the demagnetizing field decrease

Advanced approach in magnetocaloric materials characterization

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II. Demagnetizing Factor

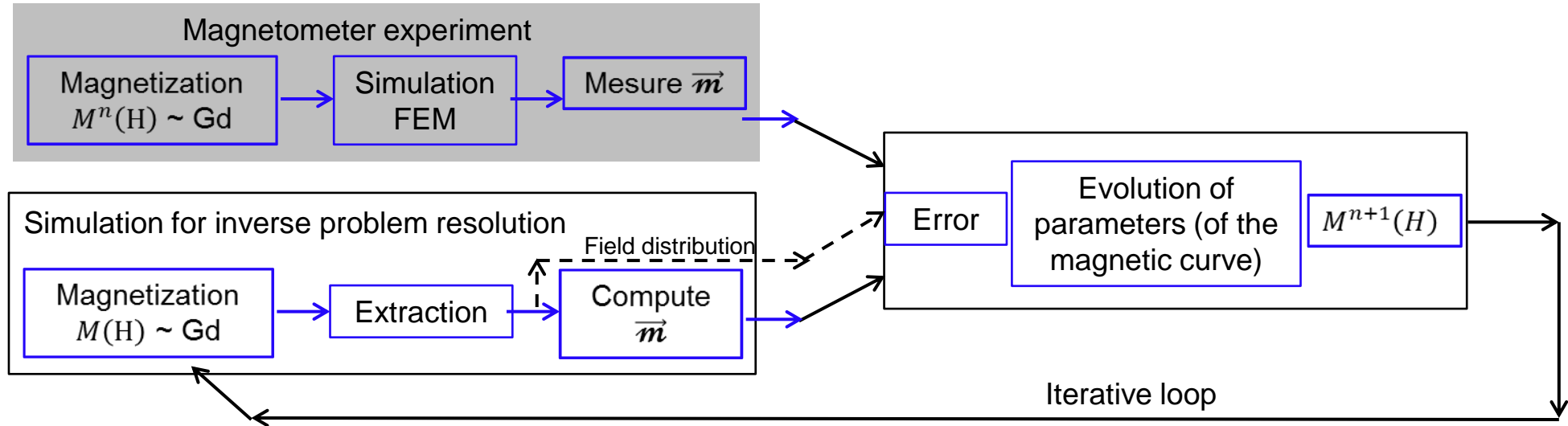
III. Formulation as an inverse Problem

IV. Demagnetizing Factor as an inverse problem

V. Perspectives

I. Intro > II. Demag. Factor > III. Inv. formulation

■ Scheme of the inverse problem and method of resolution



■ How to parametrize the magnetic curve « an unknown curve »

- With the previous test of the method we obtained an error equal to zero with 3 parameters models because the magnetization is defined with the same model

How to parametrize the magnetic curve for the inverse problem

I. Intro > II. Demag. Factor > III. Inv. formulation



Generalized demagnetizing factor

Parametric function

- Model with 3 parameters $(l + \mu_0)H + \frac{2J_s}{\pi} \arctg \left(\frac{\pi(\mu_r - 1)\mu_0 H}{2J_s} \right)$

- Model with 4 parameters $H_a = \mu_0 H \frac{\mu_r - 1}{J_s}$ and

$$B(H) = (l + \mu_0)H + J_s \frac{H_a + 1 - \sqrt{(H_a + 1)^2 - 4H_a(1 - a)}}{2(1 - a)} \text{ avec } a \in [0, 0.5]$$

Parametric point (interpolated)

- Linear, Cubic, Spline interpolation

Degree of freedom

1

3

4

5 to ∞

↗ Complexity

↗ Computation time

Advanced approach in magnetocaloric materials characterization

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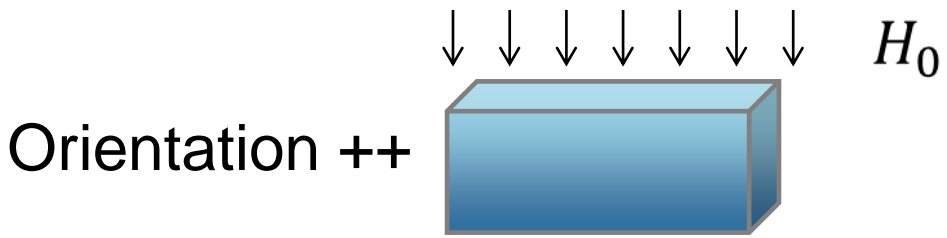
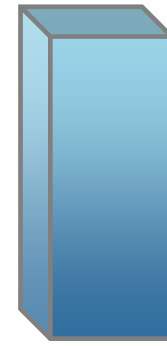
V. Perspectives

Prismatic sample in the magnetometer

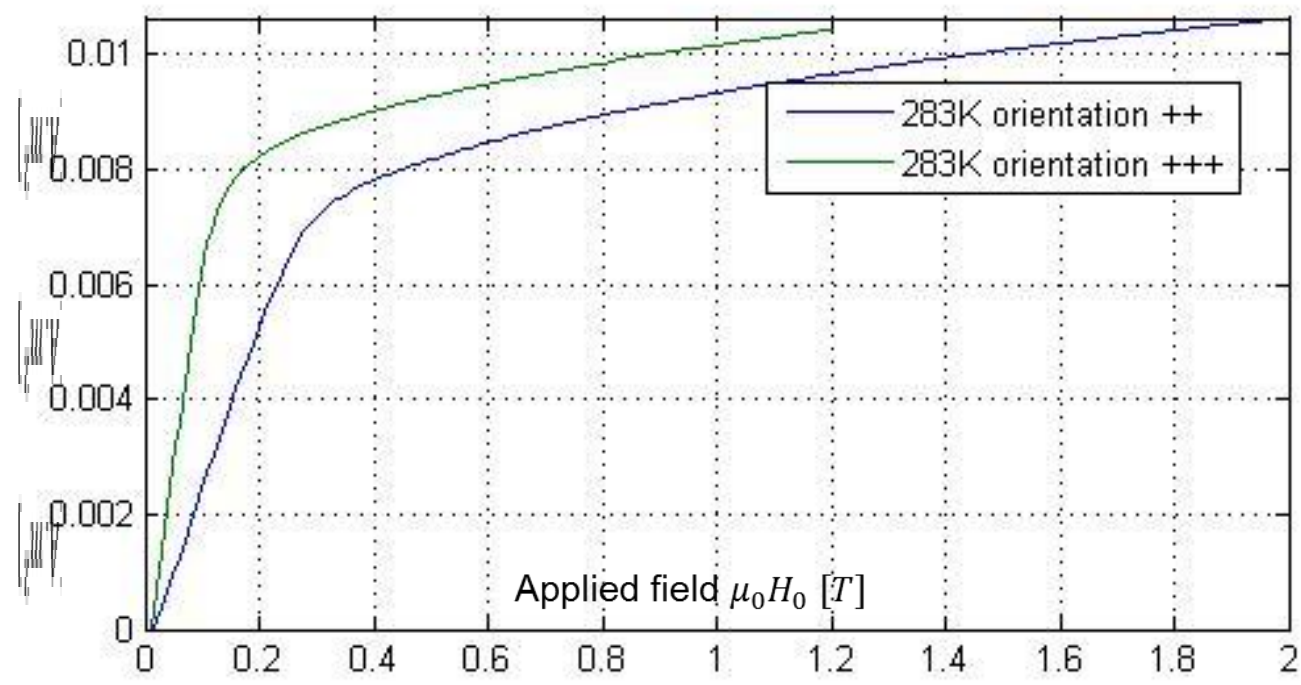
I. Intro > II. Demag. Factor > III. Inv. Formulation > IV. Prismatic sample

Gd prismatic sample 1x2x6 mm

↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ H_0



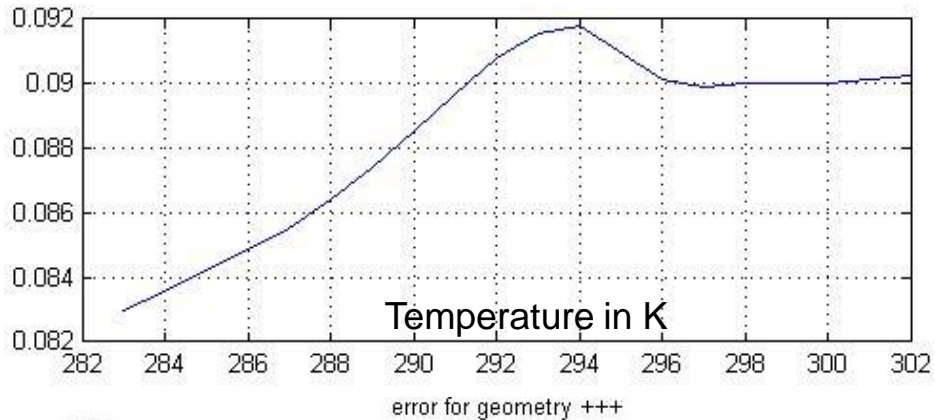
Orientation +++



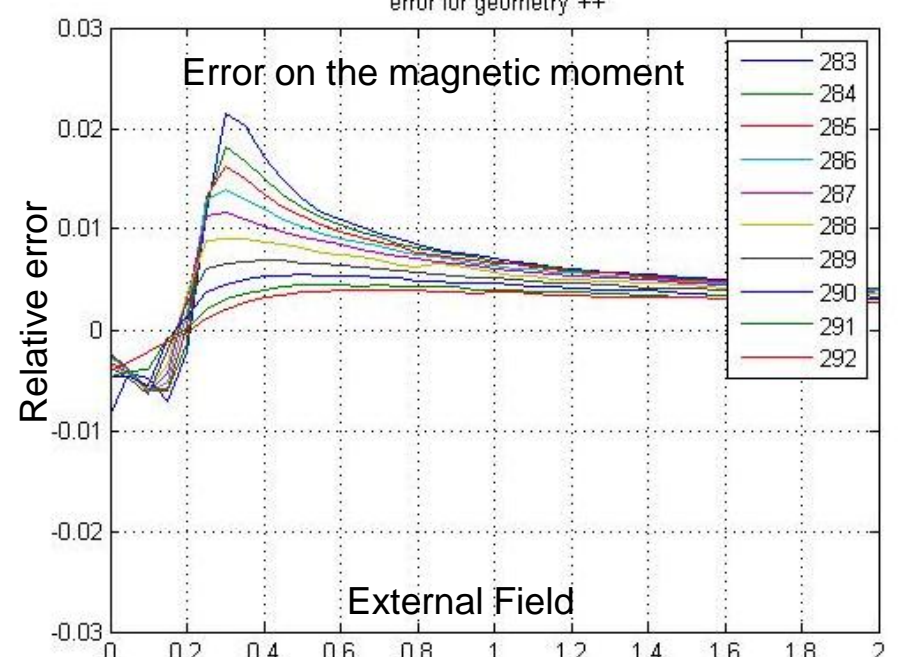
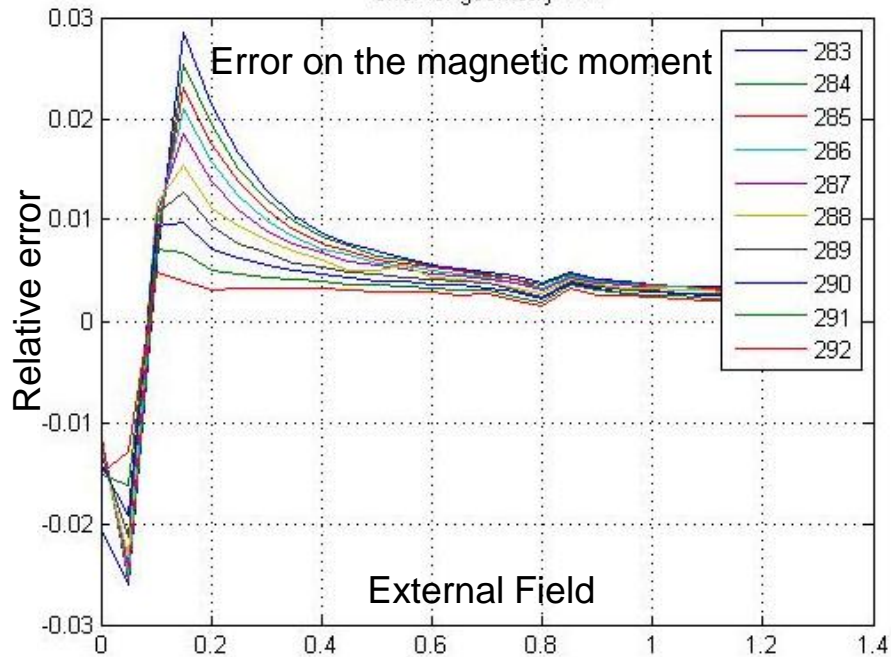
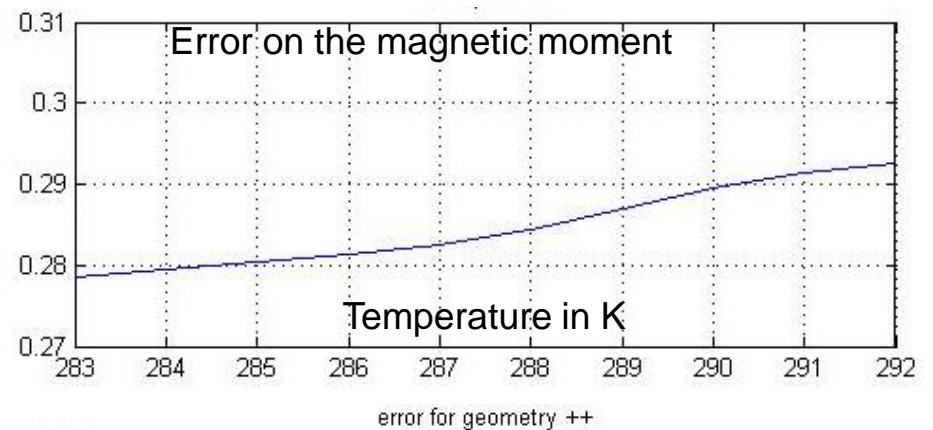
Inversion based magnetometer measurement

I. Intro > II. Demag. Factor > III. Inv. Formulation > IV. Prismatic sample

Demag. factor function of temperature for orientation +++



Demag. factor function of temperature for orientation ++

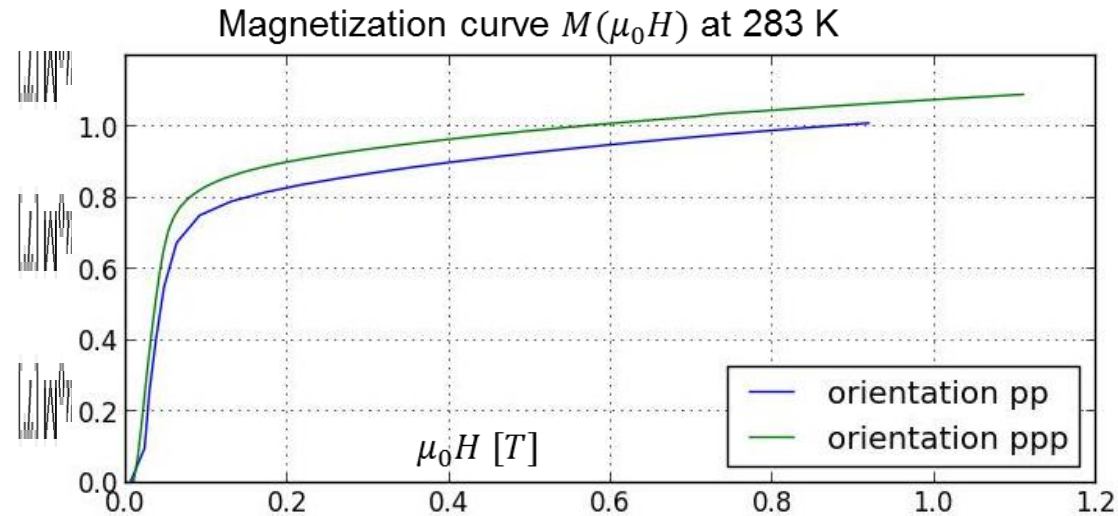


V. Perspectives

I. Intro > II. Demag. Factor > III. Inv. Formulation > IV. Prismatic sample > V. Perspectives

Method of comparison

- Error on the magnetic moment
- $B(H)$ should be the same for any shape
- ⇒ Anisotropie from process or Gd
- ⇒ Use of cubic sample



Now we use parametric function and interpolated point

- To have a best fit of the magnetization curve to reduce the error **NOW less than 0.5%** on the magnetic curve (2h for one curve)
- Try to have an error estimation on the magnetization curve

Now we start to propagate the errors on Δs

- Propagate the error through the Maxwell Relation to have an estimation on the errors on the Δs (intrinsic)



Thanks for your attention

Question ?



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