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Magnetic characterization of coated conductors

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Outline

- Motivation
- Low temperature, in-field high resolution scans: magnetic granularity
- Calculation of the local currents from magnetic field maps: Inversion
  - Reel-to-reel mapping as a quality control tool
  - Tapes on magnetic substrates

Acknowledgments

Mayraluna Lao

Collaborations: IFW Dresden, Oxolutia, THEVA

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Motivation

Transport measurements:

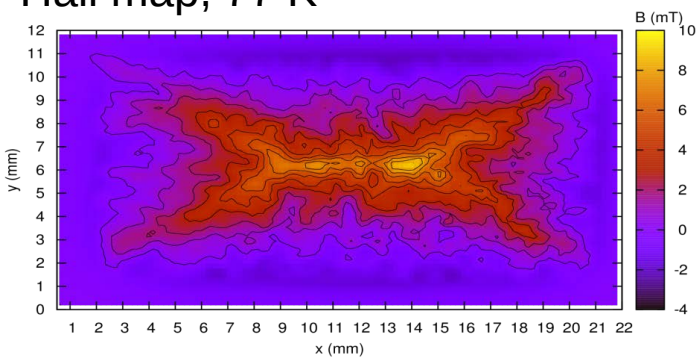
+ Direct assessment of I_c
- High currents may be problematic (sample heating…)
- High electric field
- No information about limitations, inhomogeneities…

Scanning Hall probe measurements:

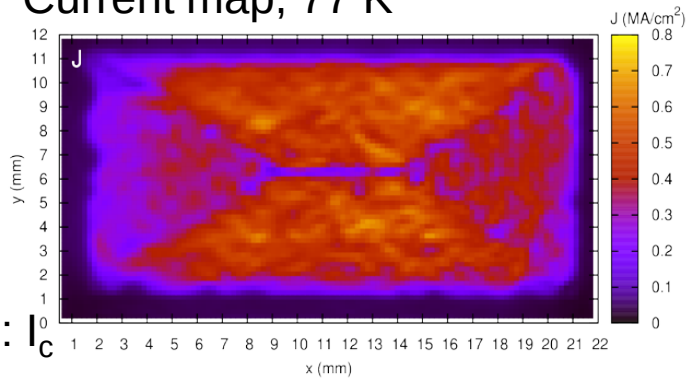
+ Assessment of inhomogeneities
+ Small electric field
+ Easy sample handling
+ No sample heating
- Modelling necessary to obtain I_c
- Slow

Example: critical current anisotropy

Hall map, 77 K



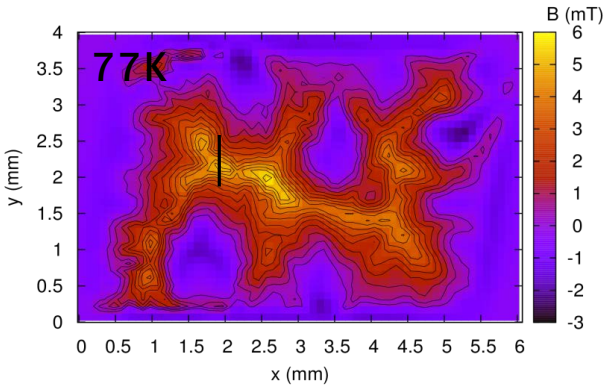
Current map, 77 K



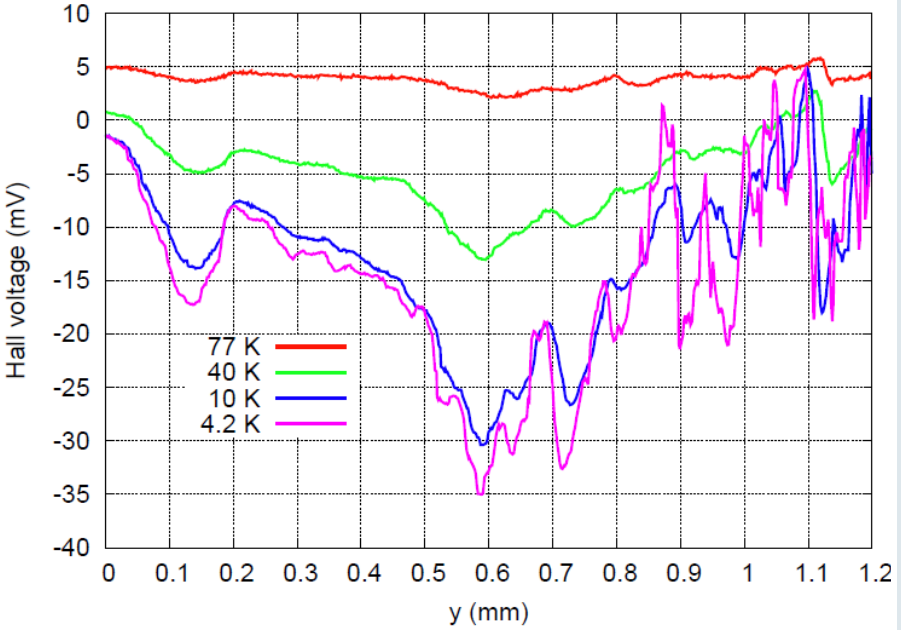
: I_c

- Magnetic granularity
- J_c – anisotropy resulting from the aspect ration of the grains
  - 64% Larger longitudinacurrent than transverse current.
  - Longitudinal → larger grain dimension
  - Transversal → smaller grain dimension

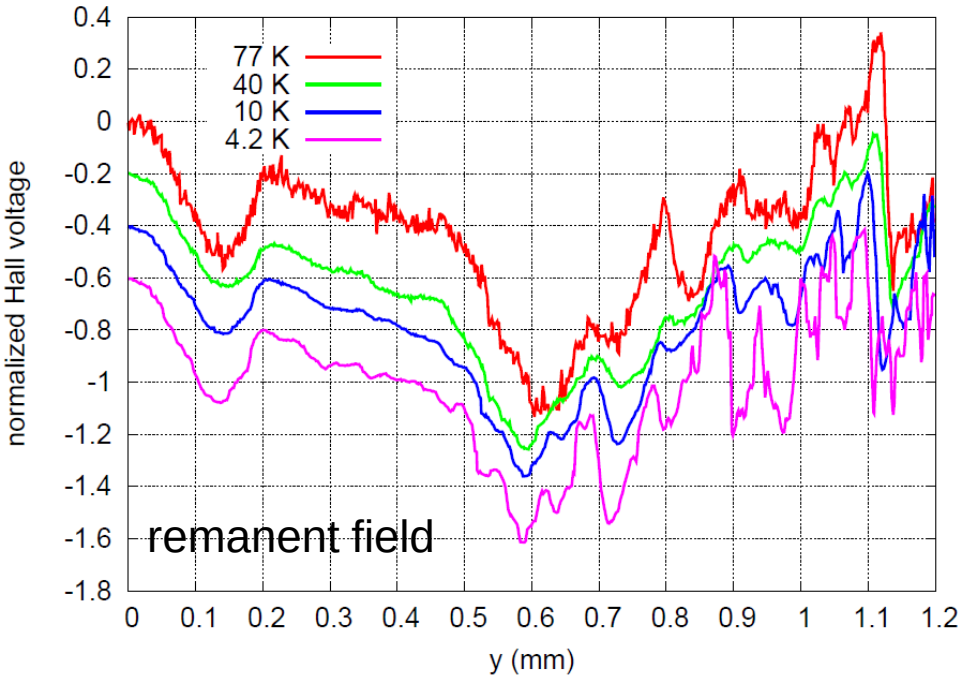
High resolution, low temperature scans



Line scans: 2 µm stepwidth, 2 µm hallprobe-surface distance



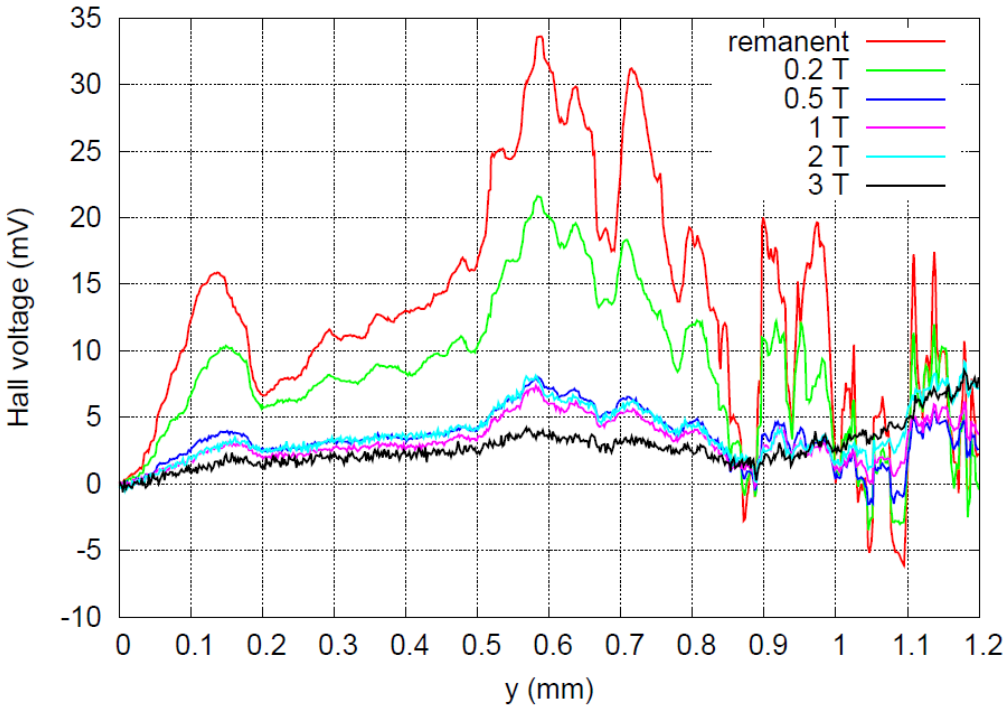
Temperature dependence of granularity



Peaks in the remnant field profile change with temperature.
→ Size of clusters of well connected superconducting grains changes.

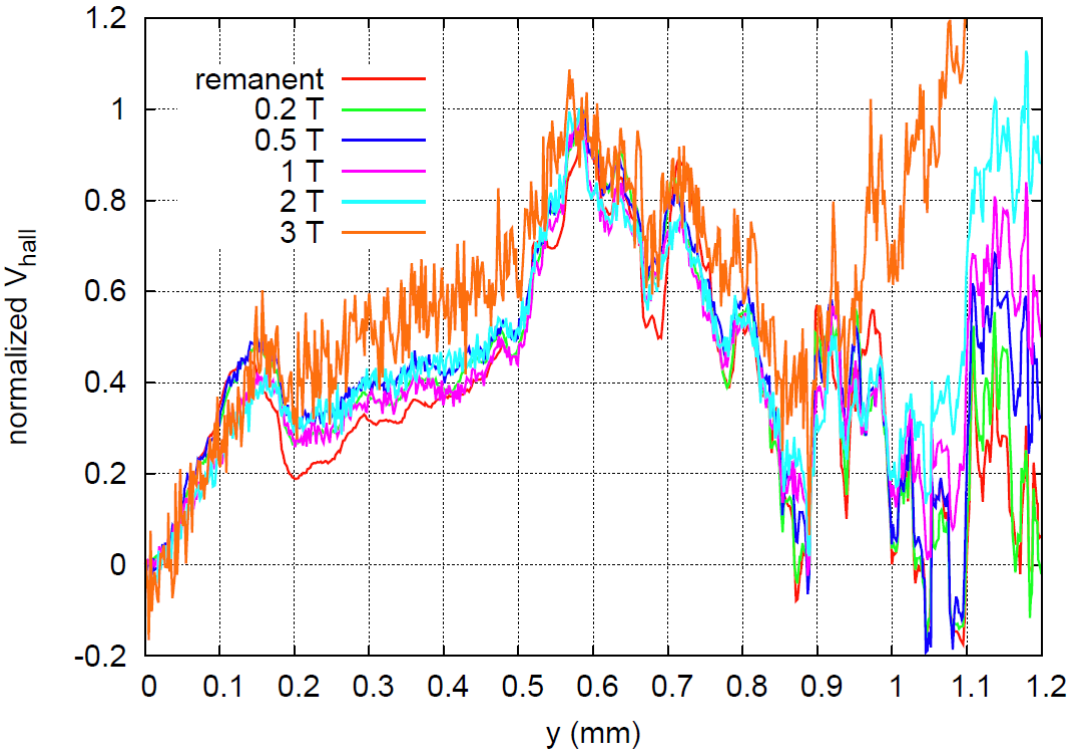
Field dependence of granularity

4.2 K



Field dependence of granularity

4.2 K

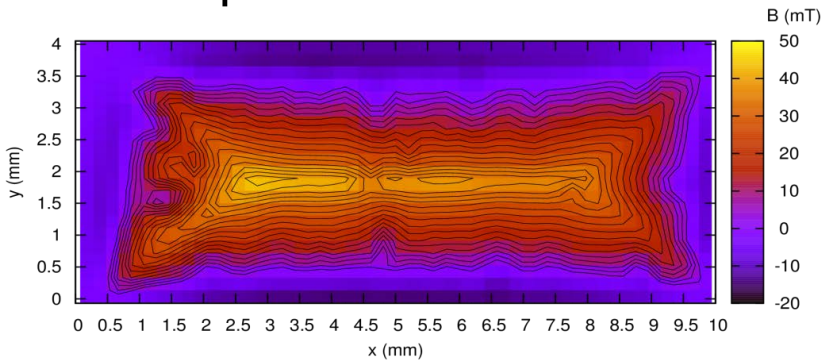


Calculation of the local current density from Hall maps

INVERSION

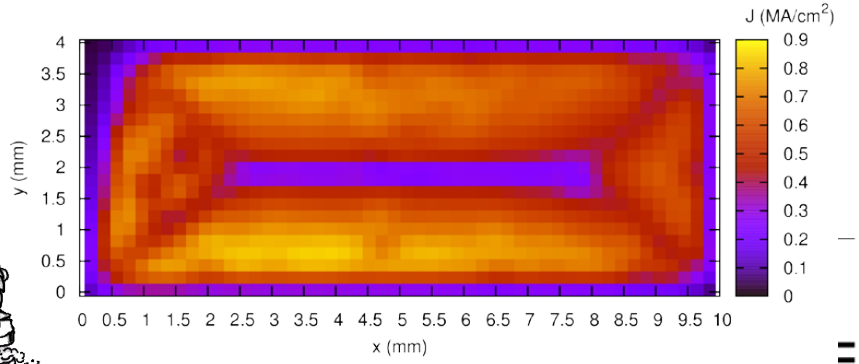
Influence of geometry

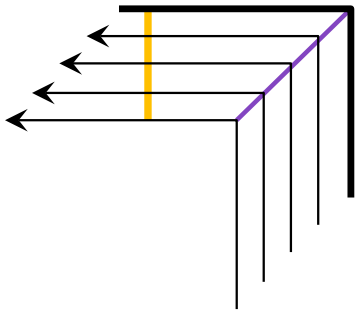
Hall map



- Lower currents at the peak of the field profile (artefact?)
- Lower currents at the diagonals near the edges (expected)

Current map

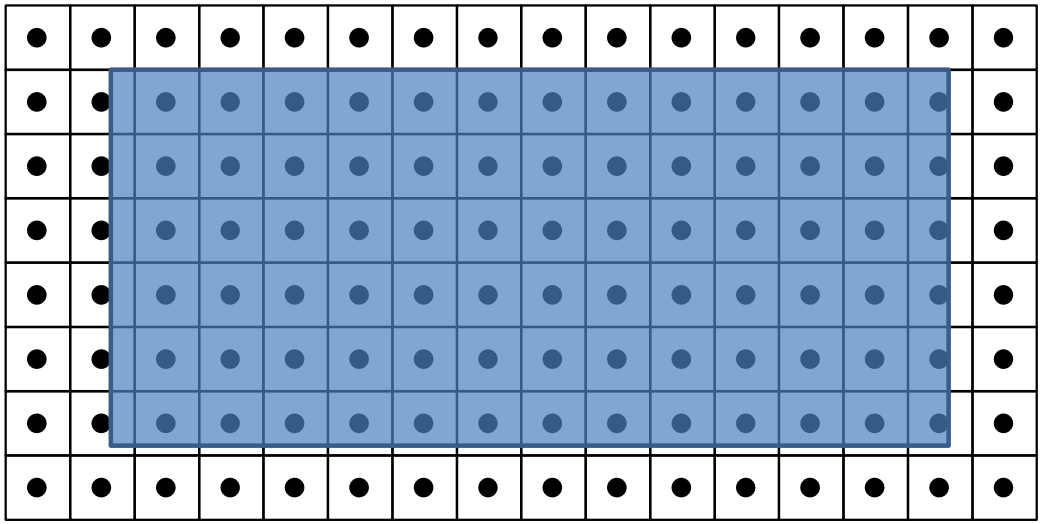




$$J_{par} = \sqrt{2} J_{dia}$$

Inversion of field maps

- Measurement grid  Current loop  Sample

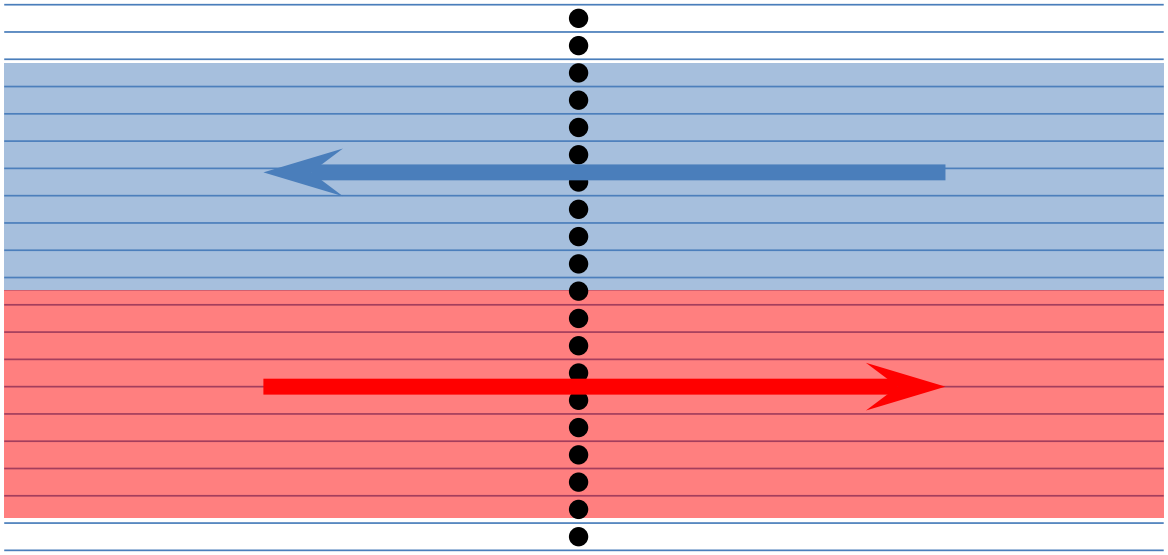


$$B_i = M_{i,j} I_j$$
$$B = MI$$

- Current grid in general does not fit the sample geometry!
- Calculated current is an ‘integral‘ over the current density between to measurement point.
- Fine grid is favorable.

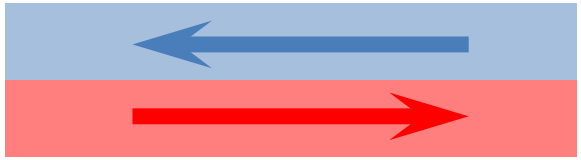
1D simplification

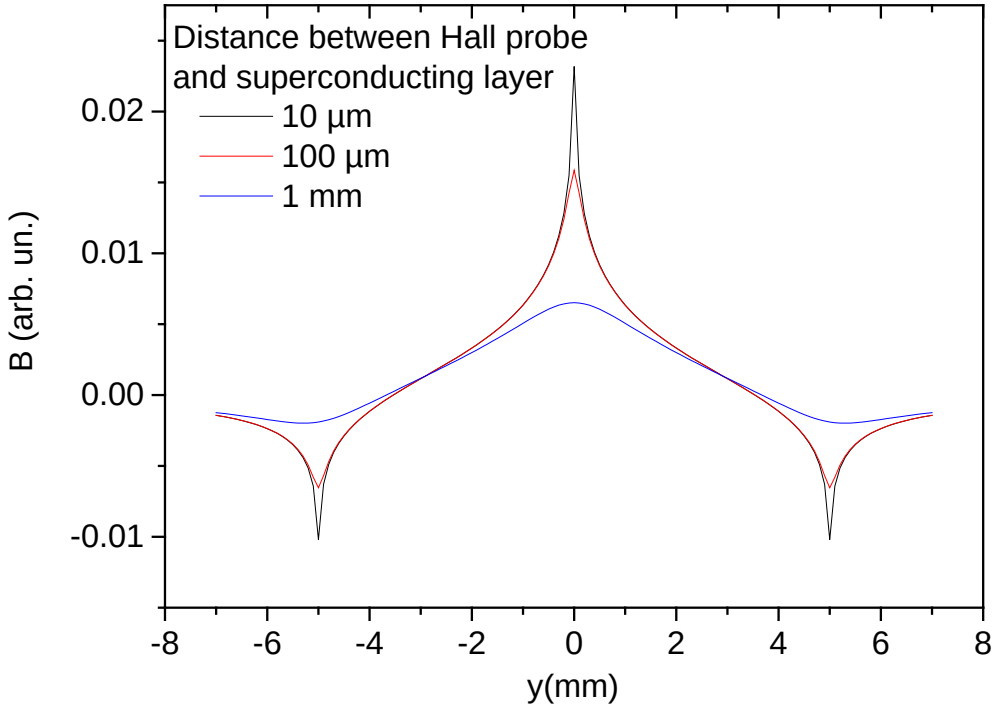
1 cm wide conductor, 0.6 mm measurement grid, 100 µm gap



Inversion of ideal field profile.

Ideal field profile



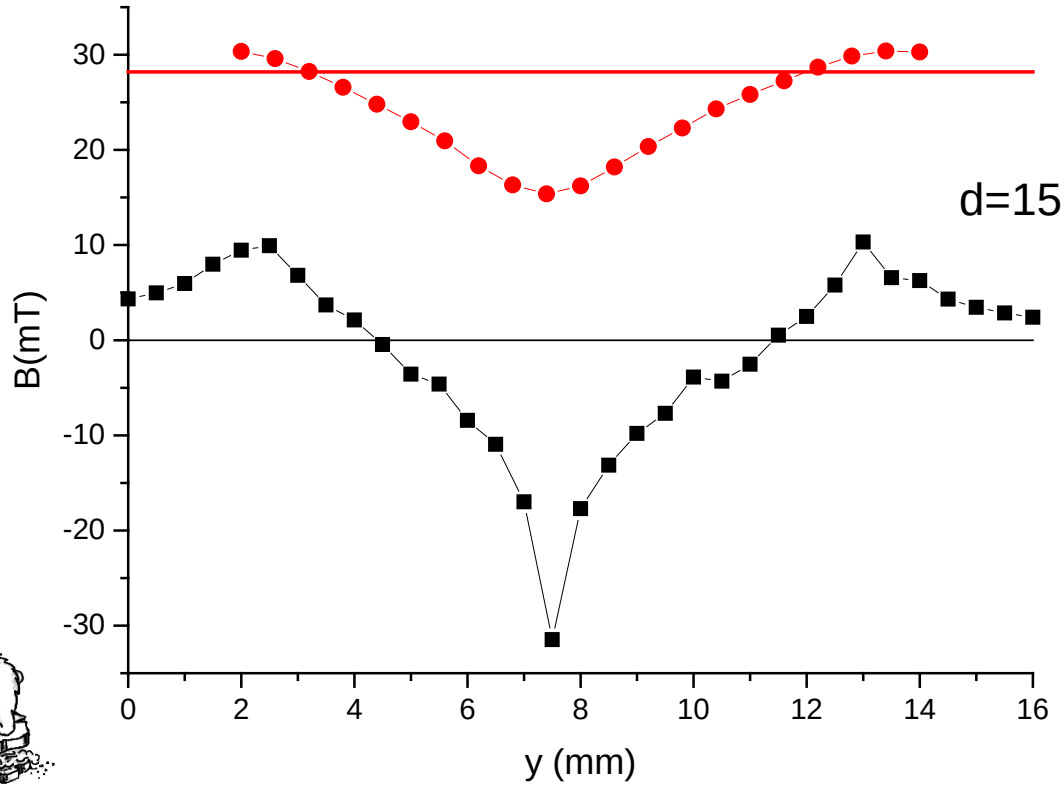


Smaller gap is favorable.

Transverse field profile at a homogeneous position

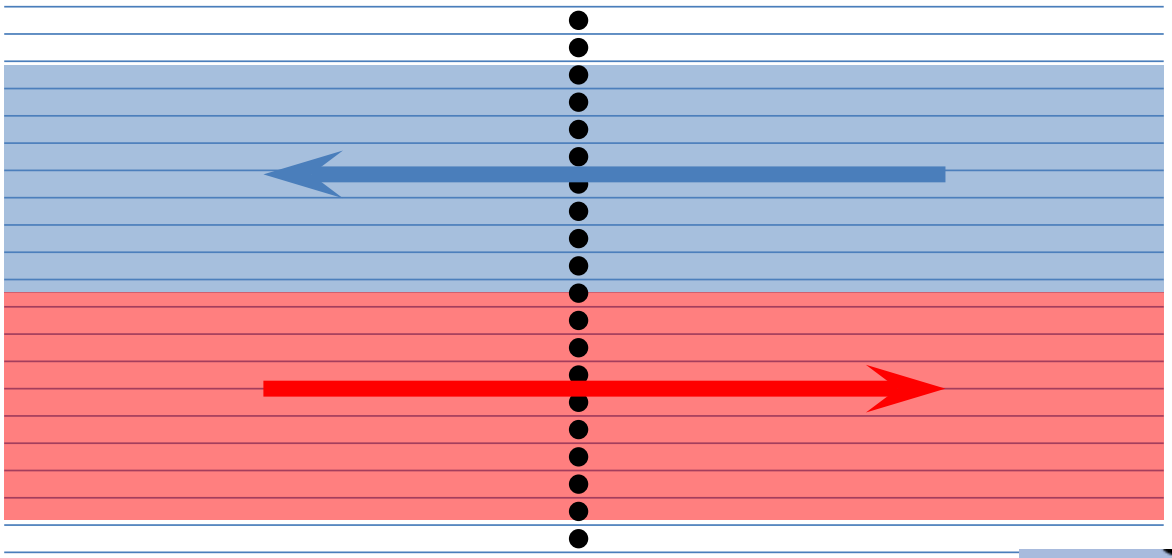
d=850 µm, B_{bg}=28.2 mT

d=15 µm, B_{bg} = 0 T



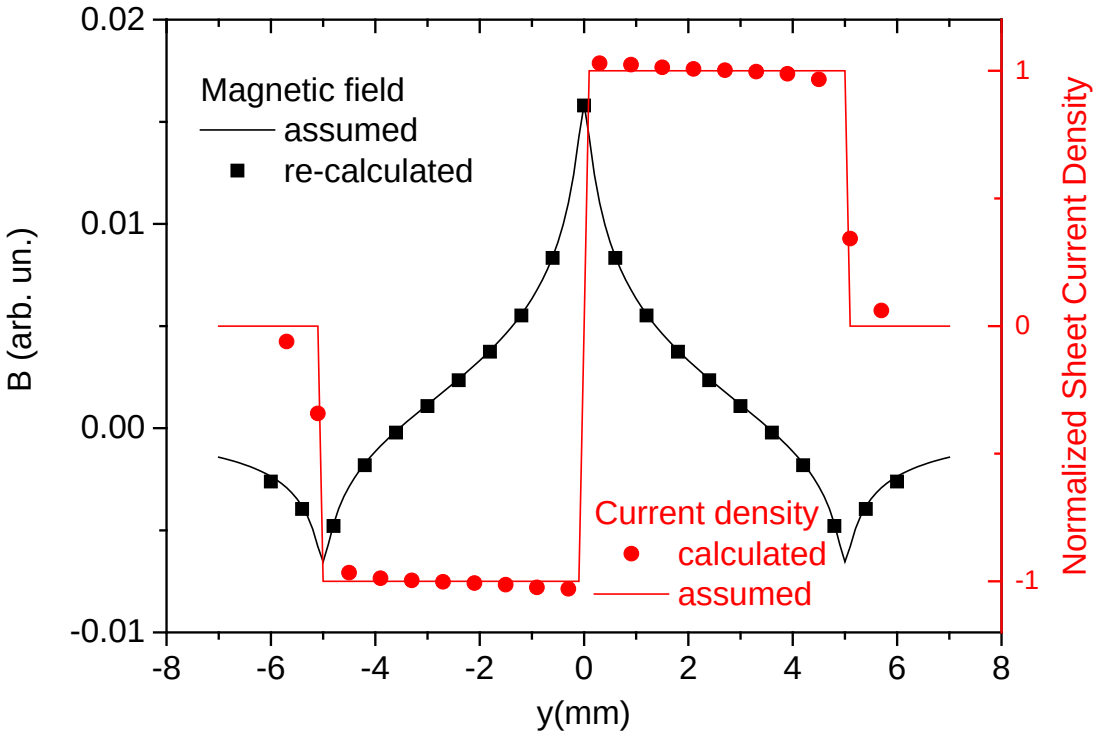
1D simplification

1 cm wide conductor, 0.6 mm measurement grid, 100 µm gap



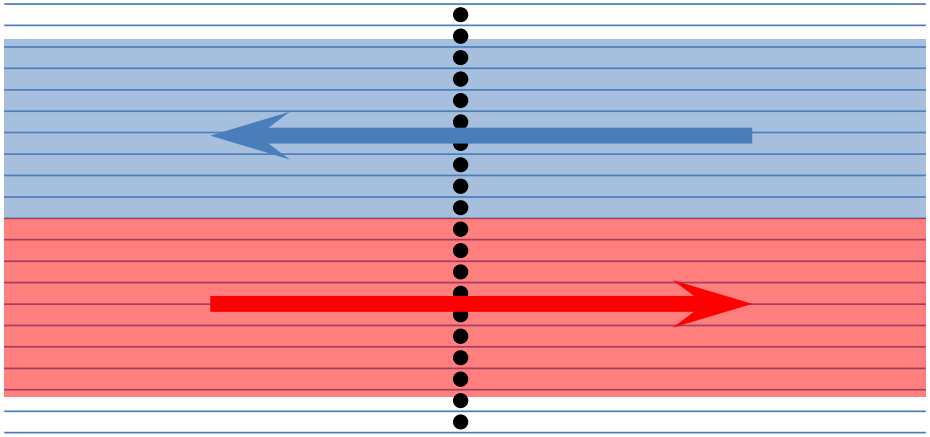
Limiting case1:
Hall probe at peak of the magnetic field.

Limiting case: central Hall probe



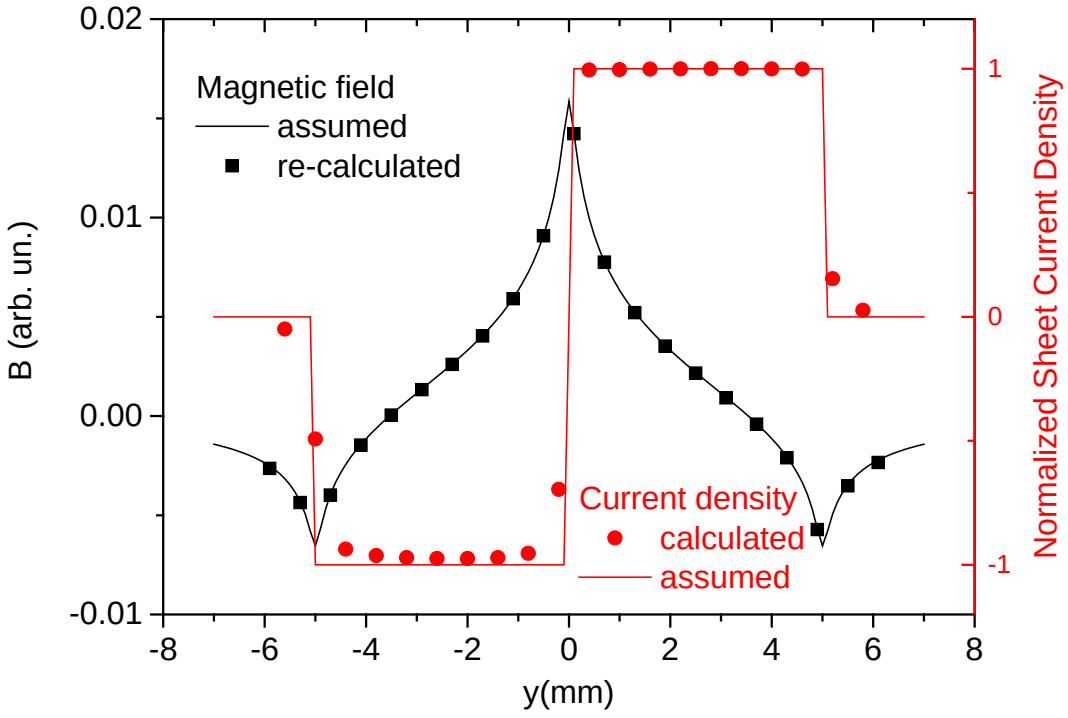
1D simplification

1 cm wide conductor, 0.6 mm measurement grid, 100 µm gap

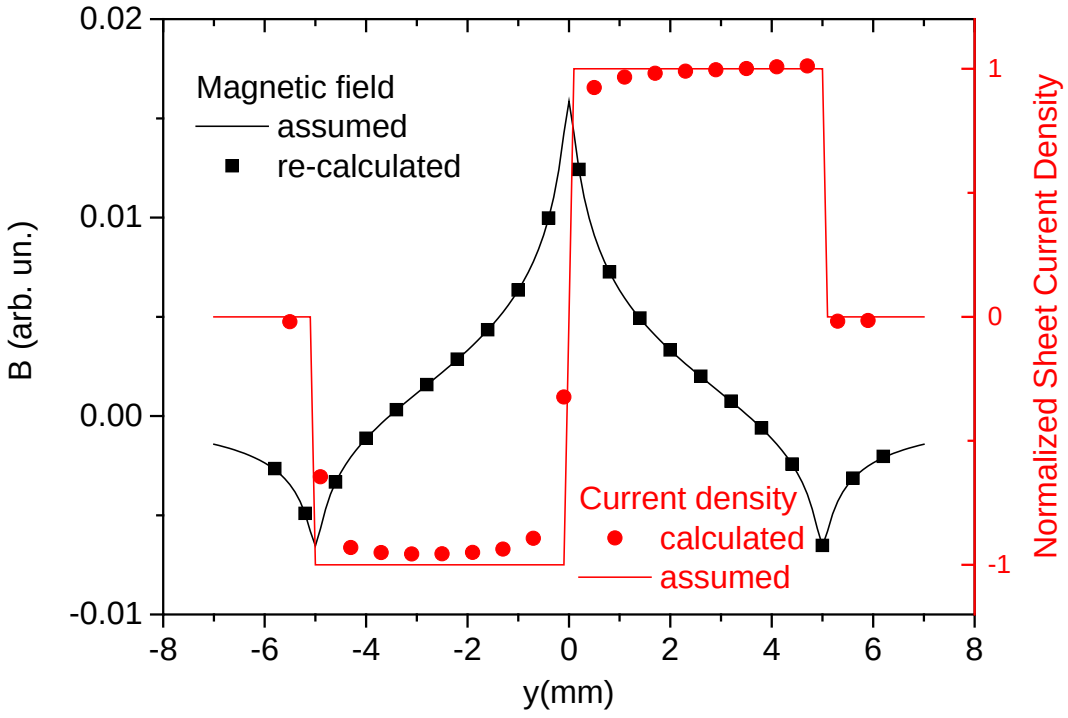


Limiting case 2:
Peak of the magnetic field between two Hall Probes.
Δy=300 µm.

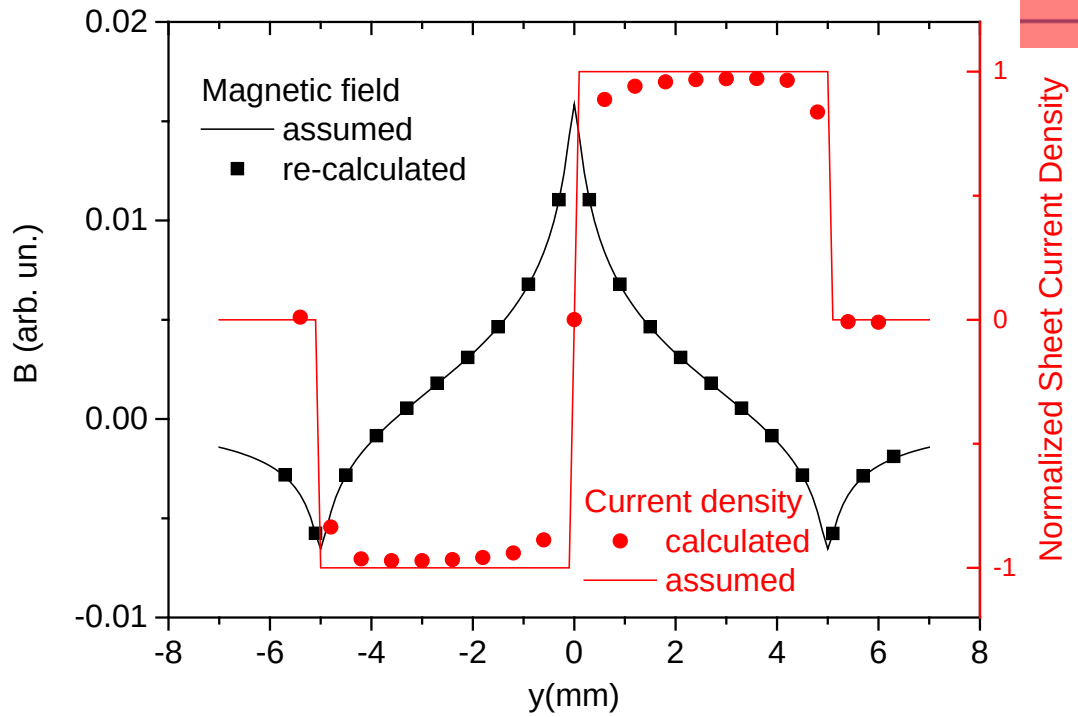
Δy=100 µm


Magnetic field
assumed
re-calculated
Current density
calculated
assumed
B (arb. un.)
Normalized Sheet Current Density
y(mm)
0.02
0.01
0.00
-0.01
1
0
-1
-8
-6
-4
-2
0
2
4
6
8

Δy=200 µm


Magnetic field
assumed
re-calculated
Current density
calculated
assumed
B (arb. un.)
Normalized Sheet Current Density
y(mm)
0.02
0.01
0.00
-0.01
1
0
-1
-8
-6
-4
-2
0
2
4
6
8

Limiting case 2: Δy=300 μm



I(y=0)=0

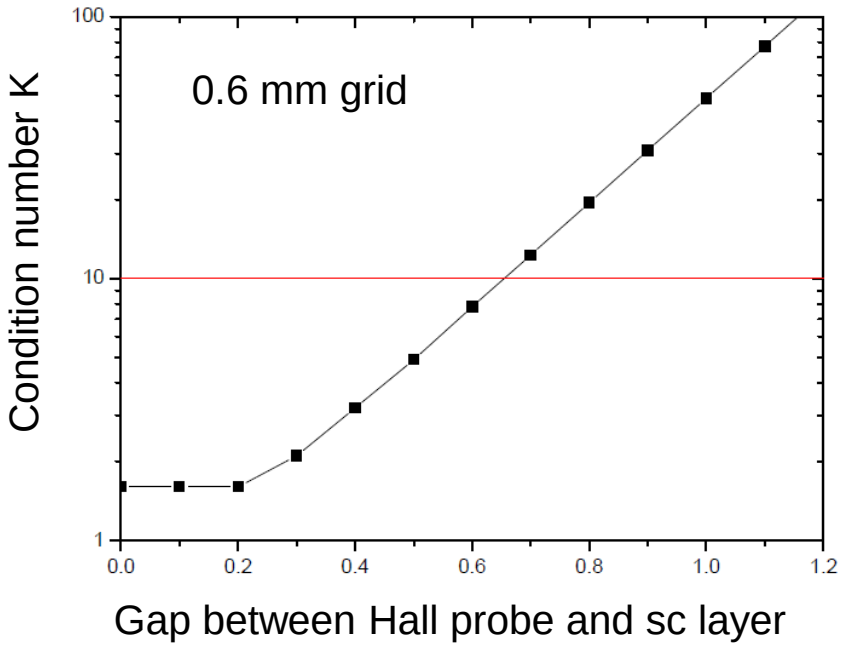
The calculated current $I = \sum_k I_k$ decreased from 101% of $I^{as} = \int J dF$ (case 1) to 90 % for case 2.

Larger gap between Hall probe and superconducing layer: 1mm

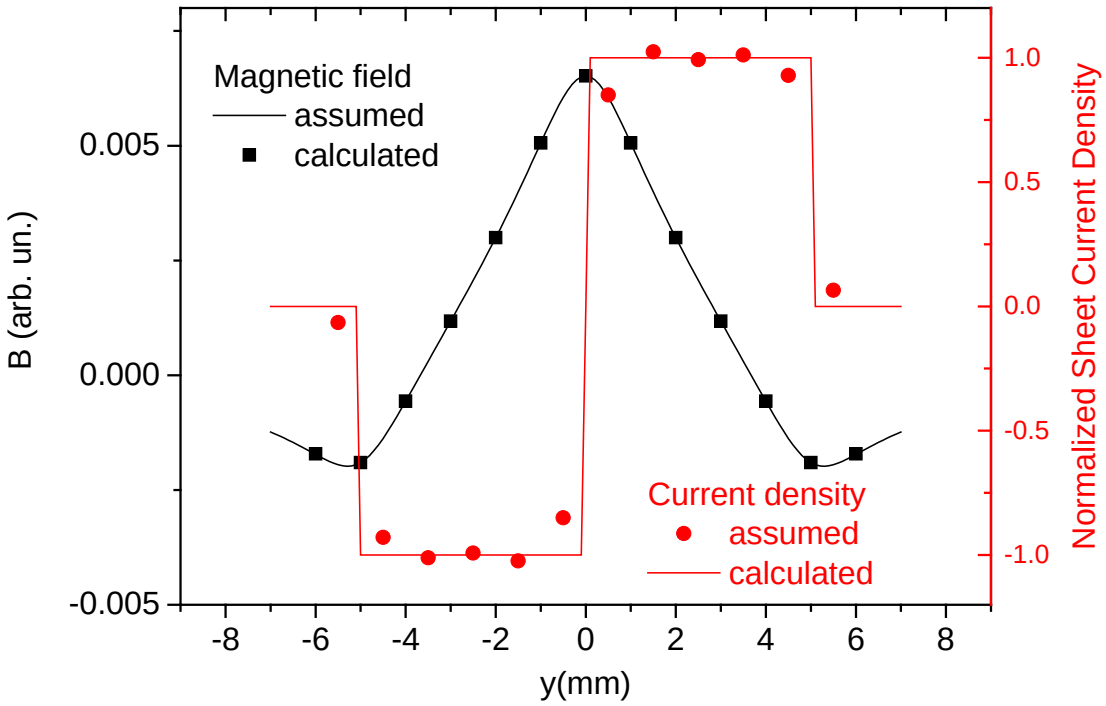
1 cm wide conductor, 1 mm measurement grid, 1mm gap

The current grid should not be smaller than the gap.

$$\Delta I \leq K \Delta B$$

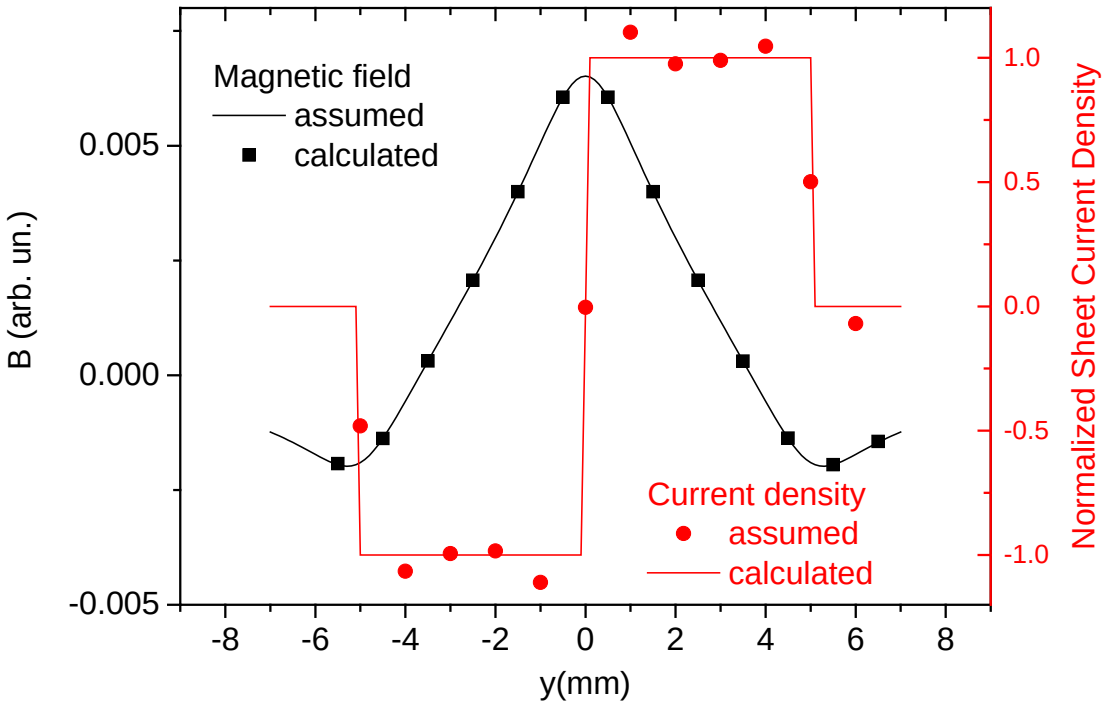


Gap 1 mm, case 1



Larger data scattering

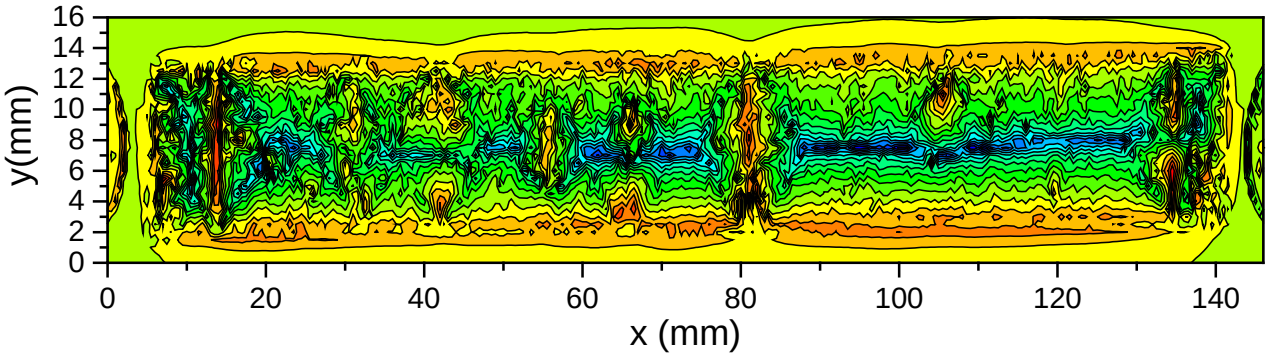
Gap 1 mm, case 2



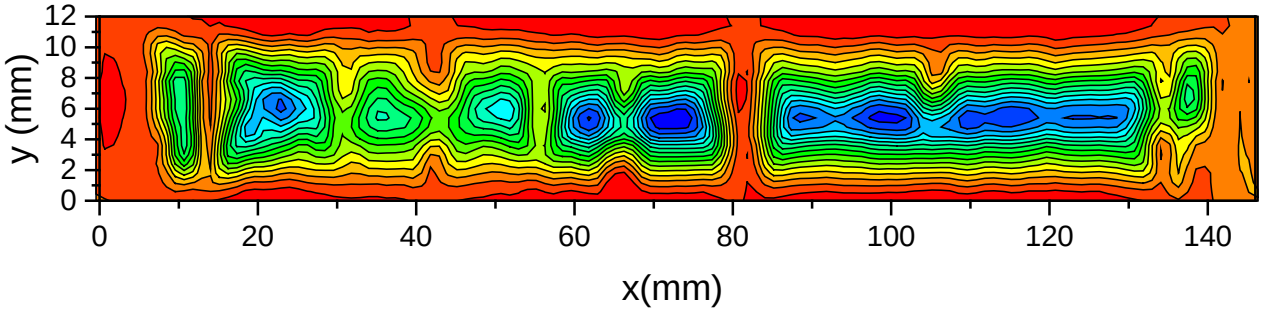
Few singificant points, current is lower by 8%

REEL TO REEL MAPPING AS A QUALITY CONTROL TOOL

Hall scan 0.5x0.5 mm^2
Distance Hall probe – superconducting layer: **15 µm**
REAL field profile

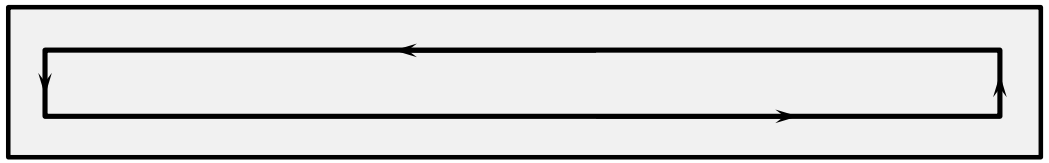


Reel-to-reel: 1.1x0.6 mm^2
Distance Hall probe – superconducting layer: **850 µm**
CONSTRUCTED field profile

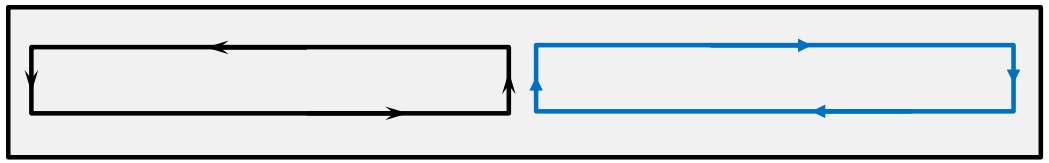


Induced currents

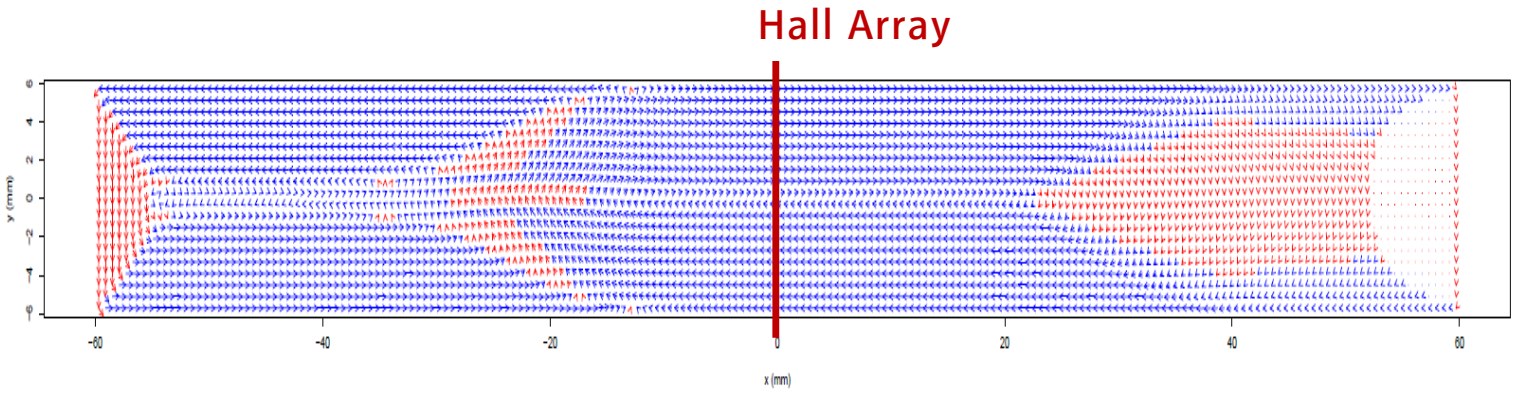
Hall map



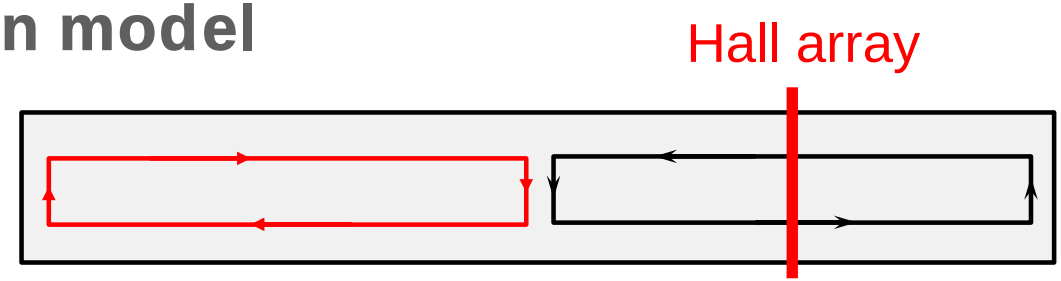
Continuous magnetization



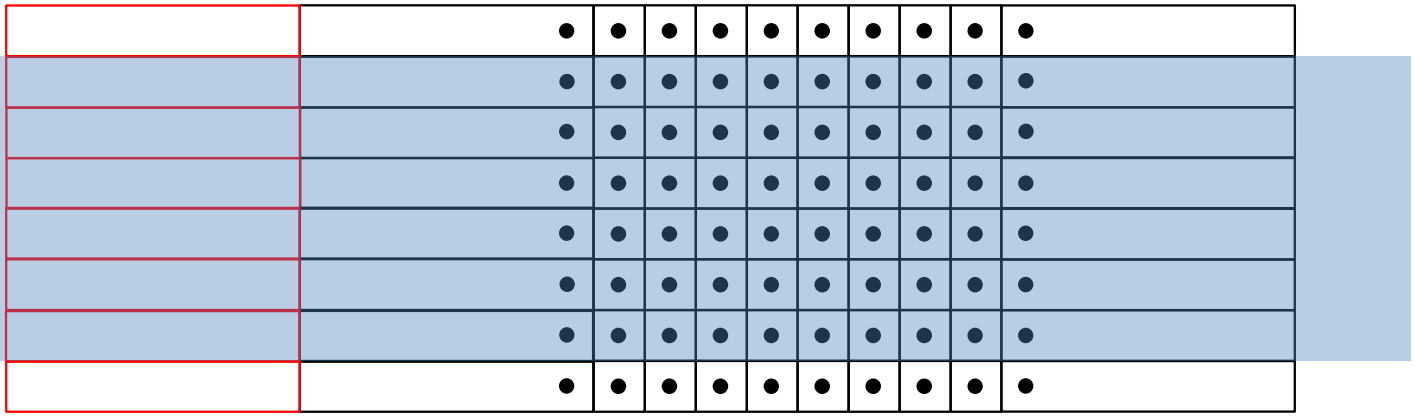
decreasing increasing field



Inversion model



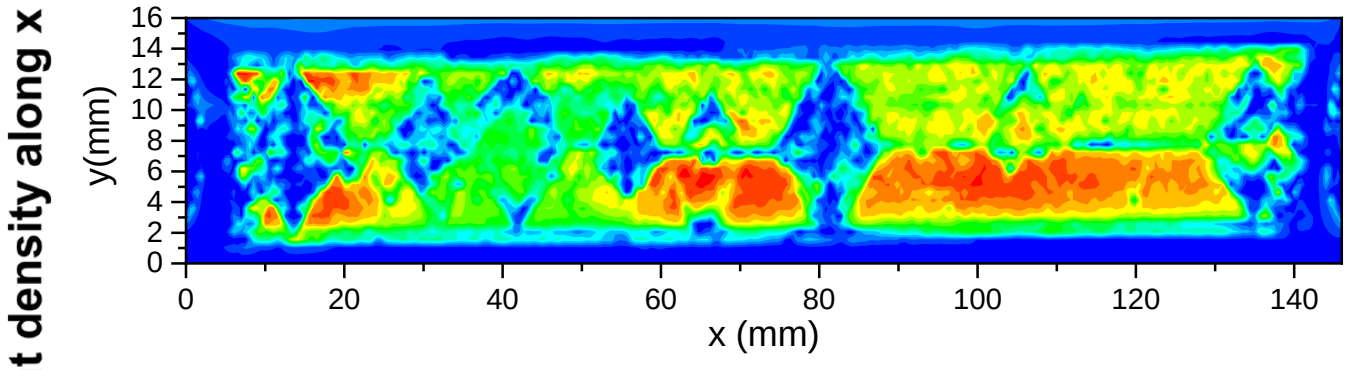
Model grid



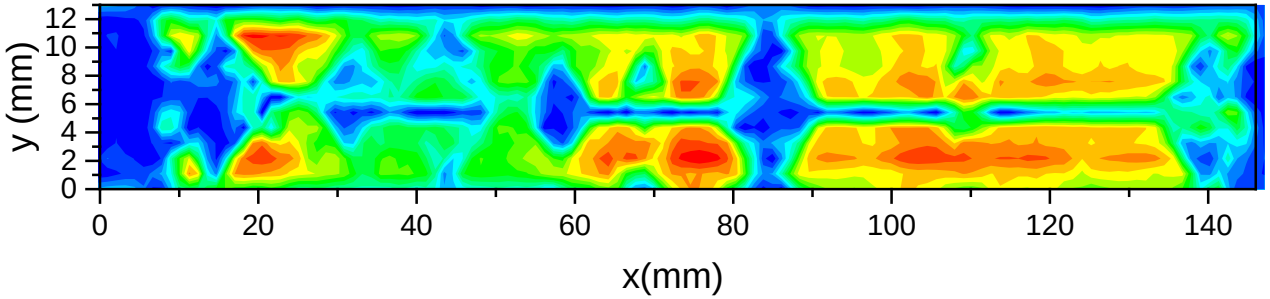
Grid is shifted along the data, only central currents are recorded.

First results

Hall scan 0.5x0.5 mm^2 , **15 µm** gap



Reel-to-reel: 1.1x0.6 mm^2, **850 µm** gap



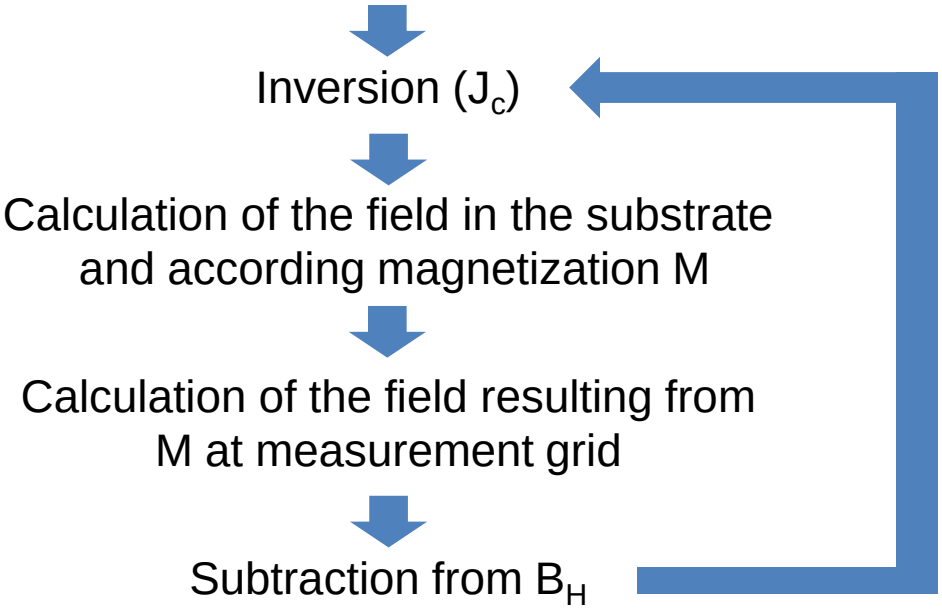
Good agreement although with different spatial resolution.

CORRECTION FOR MAGNETIC SUBSTRATES

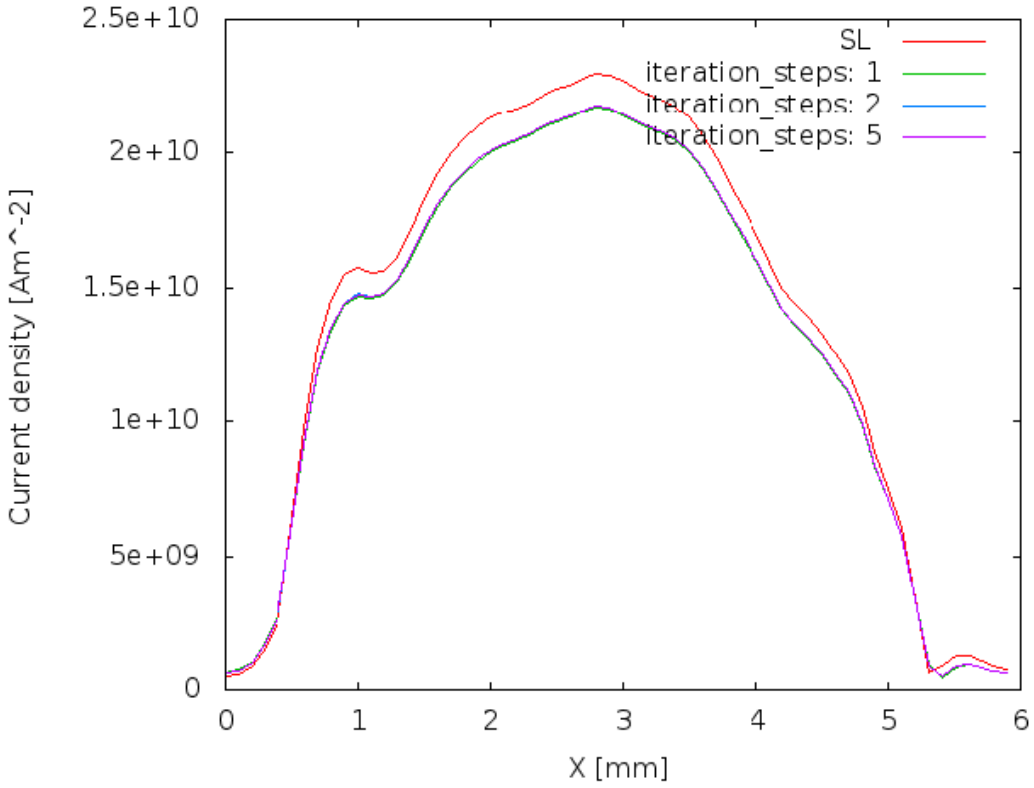
Magnetic substrates

The superconductor magnetizes a magnetic substrate.
→ The field of the substrates adds to the Hall signal.
→ Overestimation of the critical currents.

Iterative approach: Measured local magnetic field map B_H



Fast convergence



Conclusions

- Scanning Hall probe measurements are a powerful tool for the investigation of magnetic granularity
- The measurement grid has to be chosen carefully (gap size, position)
- Discontinuities in the current distribution can be easily “overlooked“.
- The inversion of data obtained from reel-to-reel system needs additional assumptions.
- Non-hysteretic magnetic substrates do not pose a serious problem.