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PANDA EMP 9. Dec. 2014 **Helmholtz Institut Mainz**

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Status report

First measurements for a superconducting shield for the PANDA Transverse Polarized Target

Content

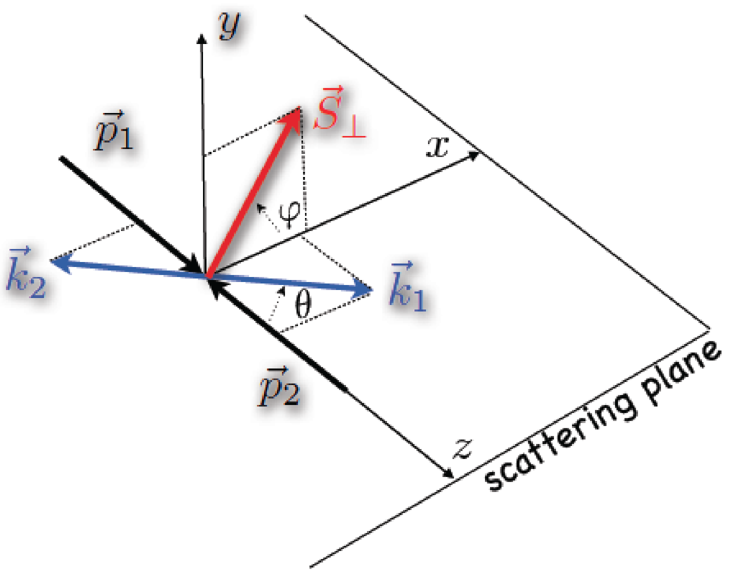
- Motivation
- Choice of High temperature superconducting (HTS) shield: YBCO, BSCCO
- Simulation of shielding of BSCCO tube with “Inductivity Model” (Mathematica)
- Simulation of shielding of BSCCO tube with CST

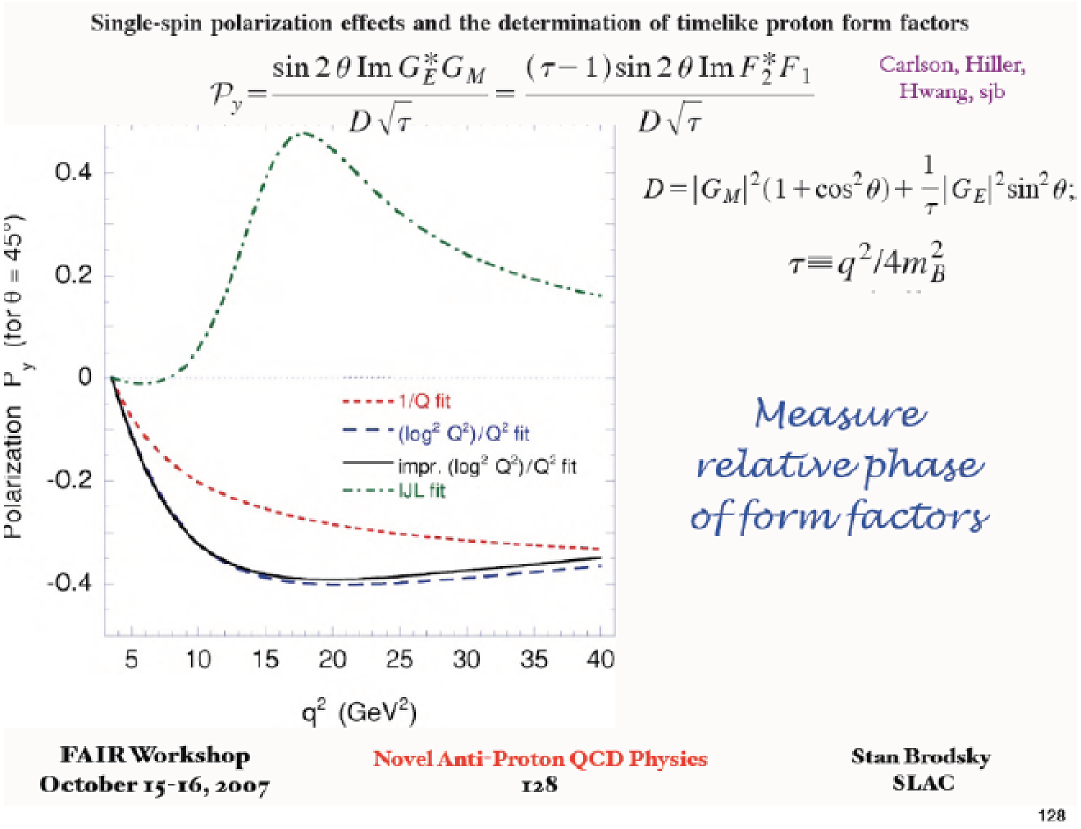
  (finite element method electromagnetic simulation software)
- New measurement I. with BSCCO tube without bores

  May 2014, Mainz (4.2 K)
- Future measurement II. with BSCCO tube

  update of I. Feb./Mar. 2015, Mainz (4.2 K)
- Conclusion and summary

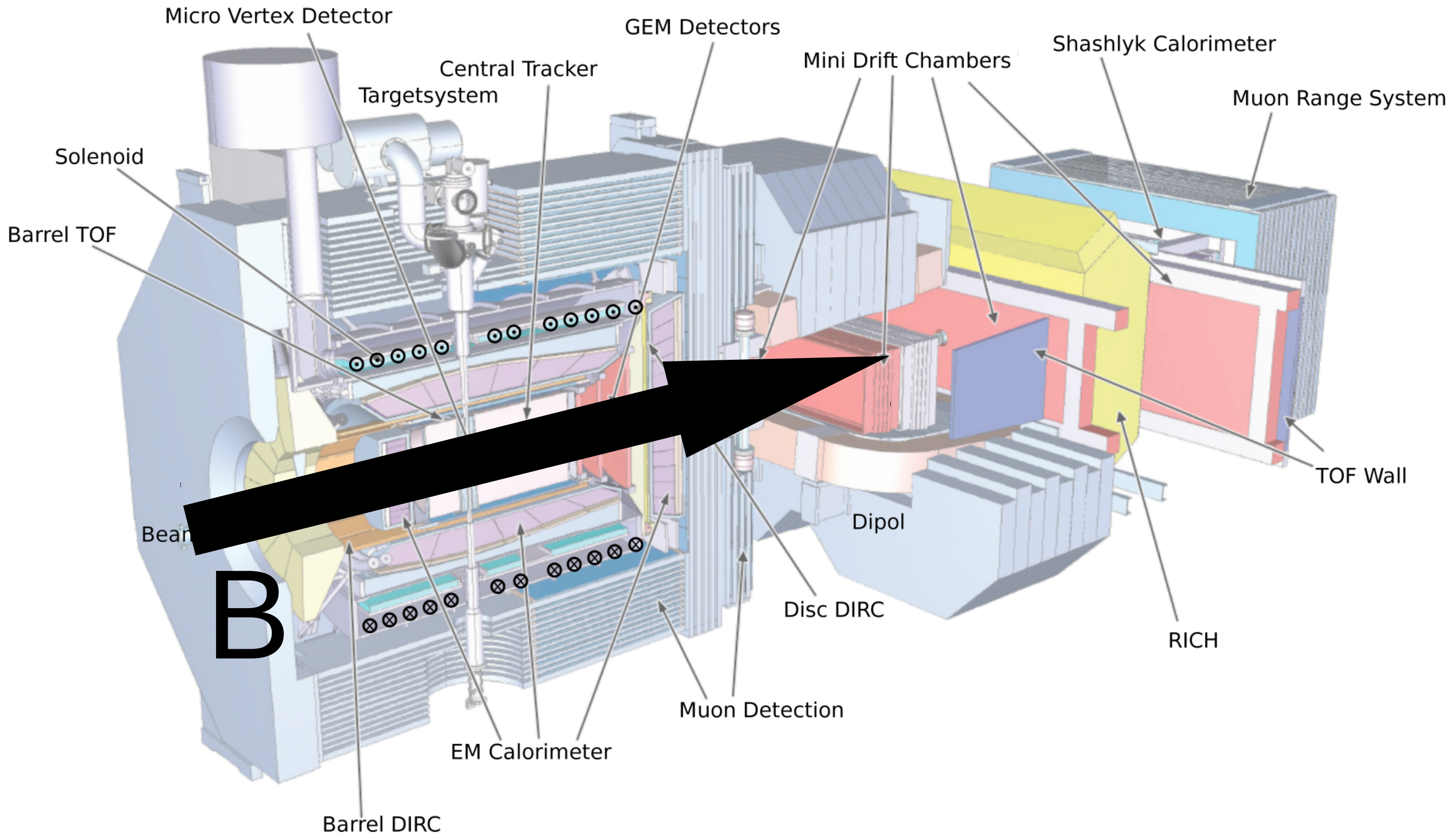
Imaginary Part of Time Like FF
single spin target asymmetry



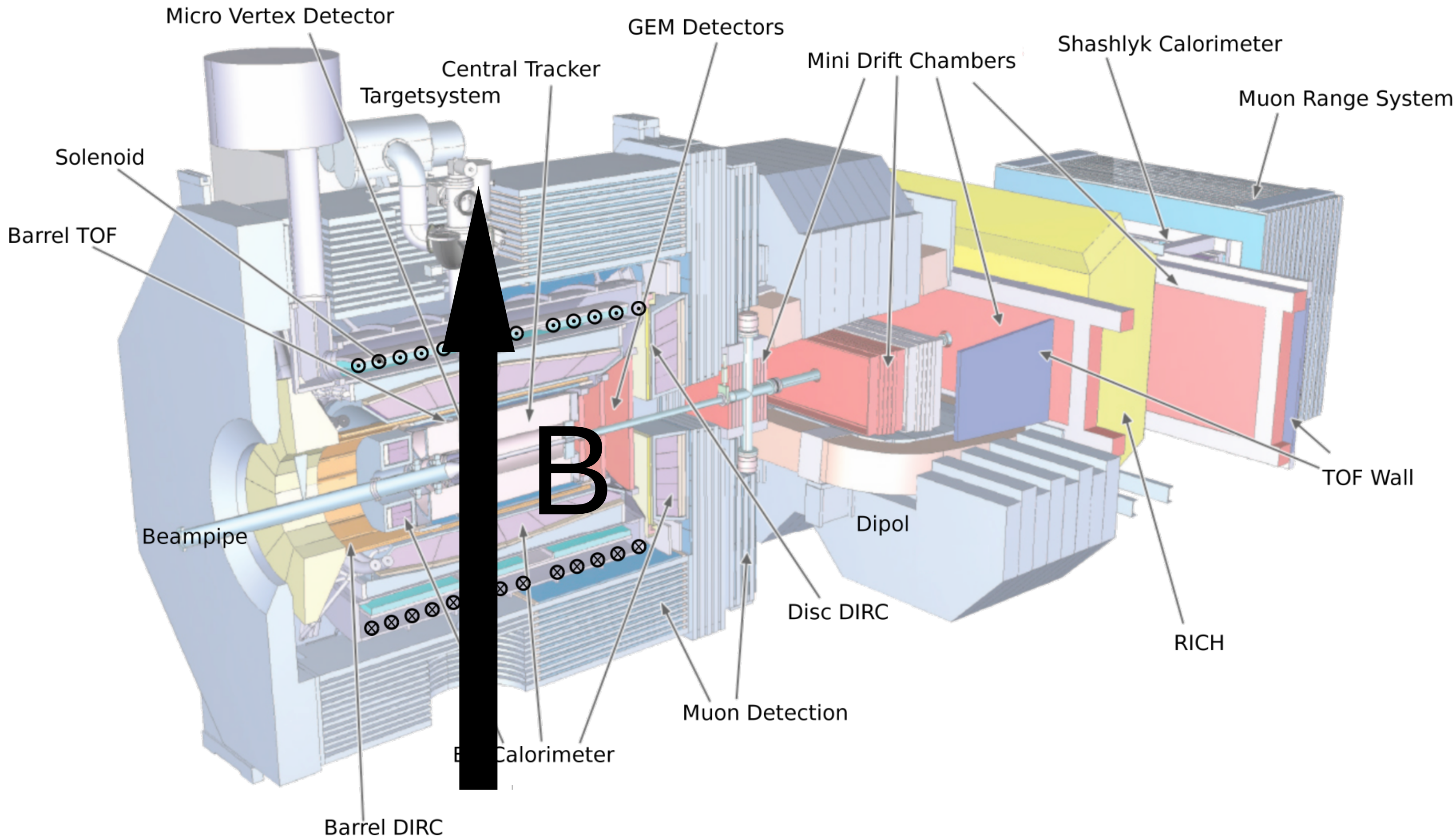


transversely polarised Target in PANDA

PANDA solenoid compensation

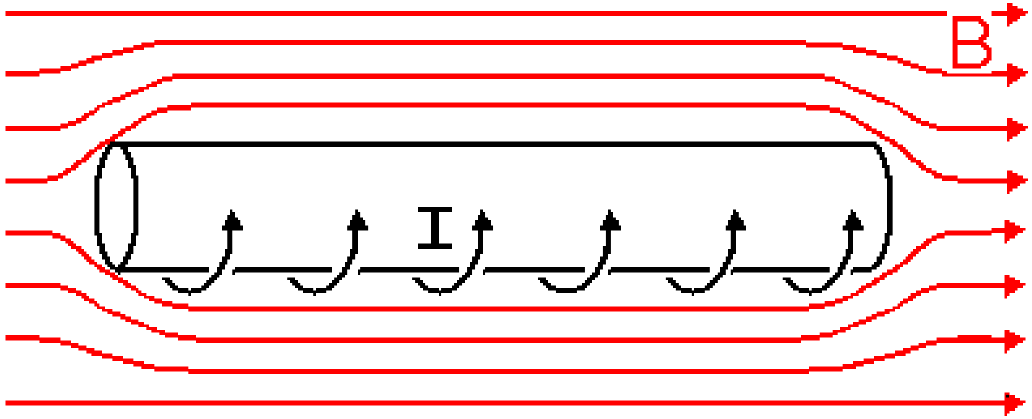


PANDA solenoid compensation

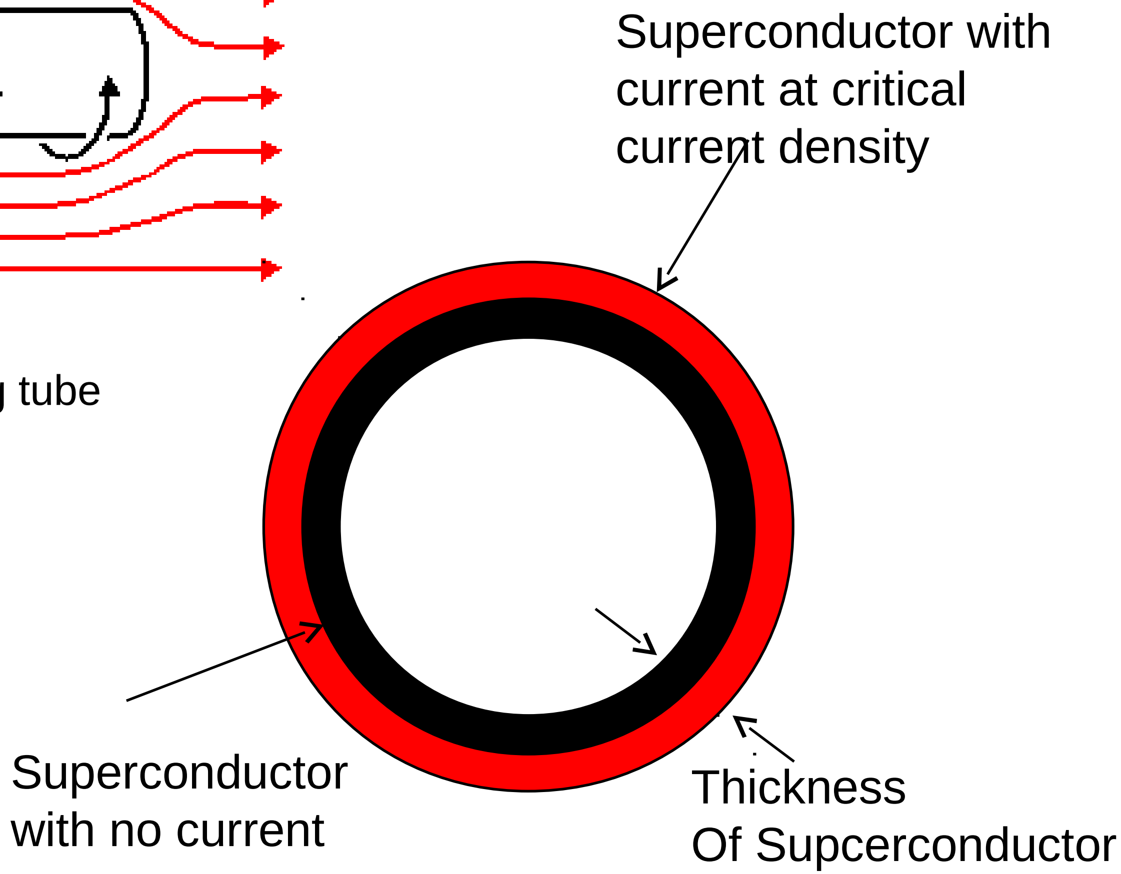


Transverse Field

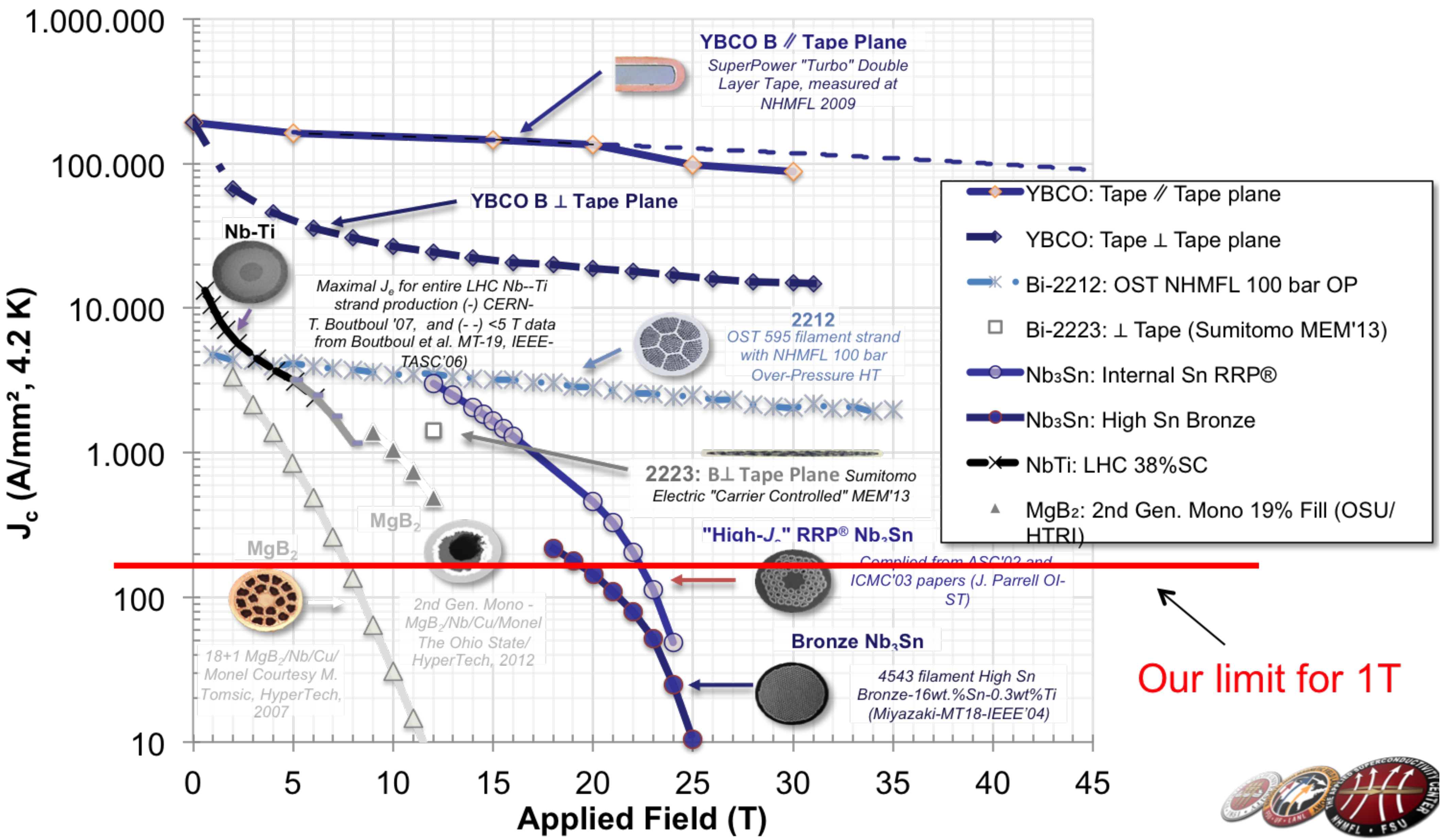
Principle: Superconducting Shield (passive)



- Induced current in superconducting tube
- Surface current
- Expellation of magnetic flux

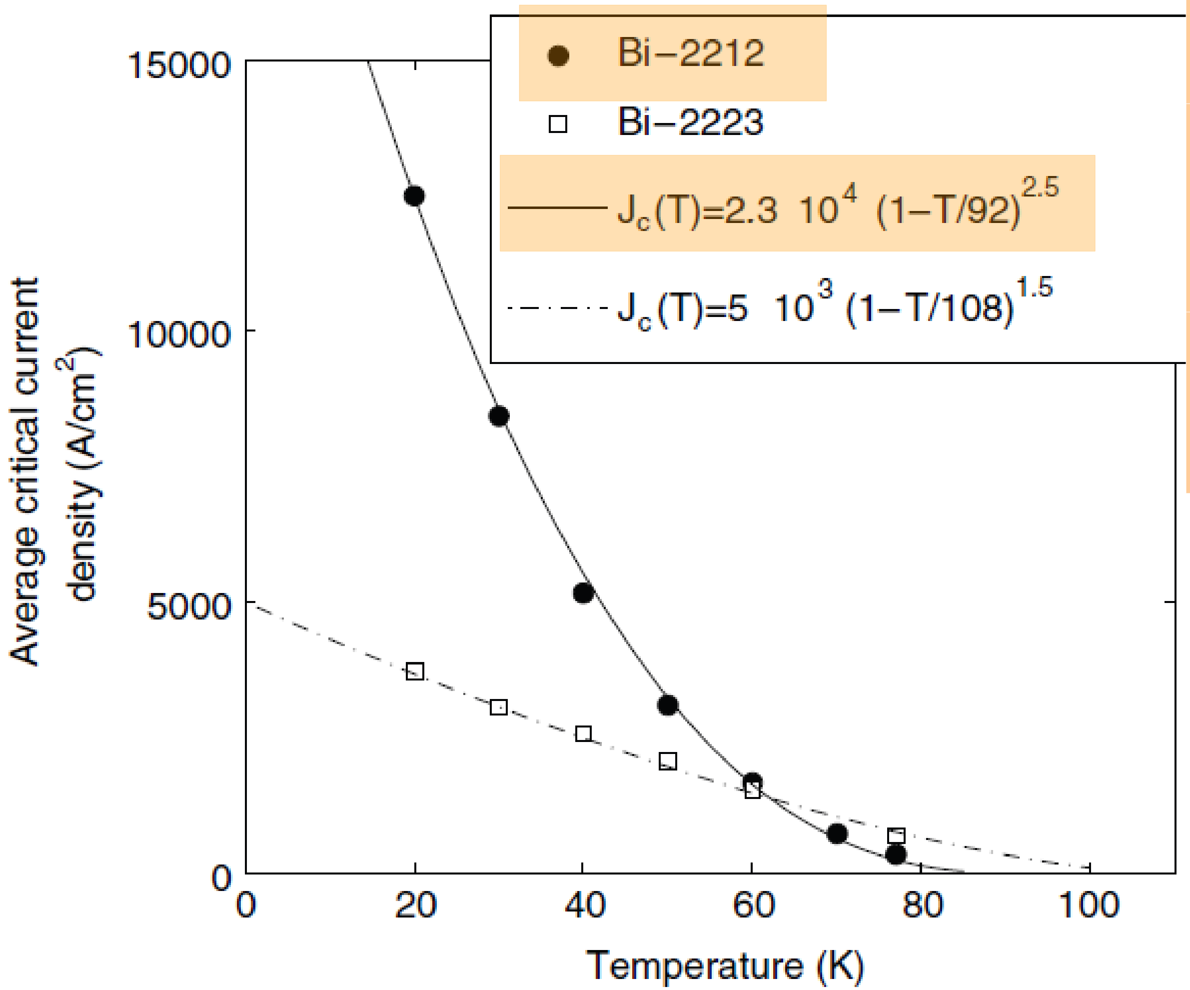


Material choice



Choice of high temperature superconductor BSCCO-2212

- First measurement in Bonn (1.4 K) YBCO without bores (Jan. 2013): shielding of 4 T (residual field of 0.4%)
- Second measurement in Bonn (1.4 K) YBCO with bores (Nov. 2013): no shielding (collapse of shield at 15 Gauß)

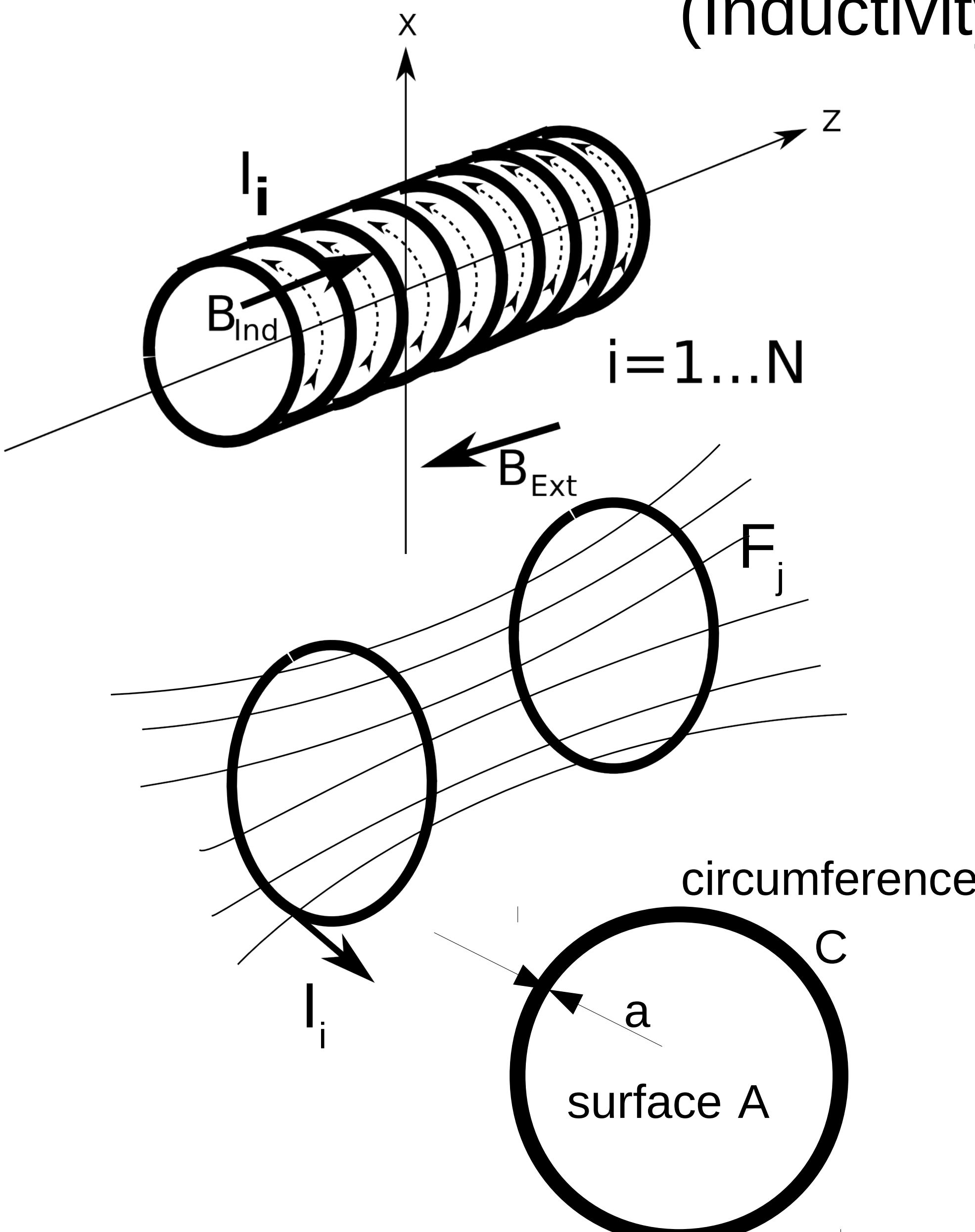


Critical temp.	92 K
Current density 10 K	16 000 A/cm^2 (shielding 1 T)
Expectation at 4.2 K	>1T

FAGNARD,
Shielding 1 T
with BSCCO-2212

Supercond. Sci. Technol. 23 (2010) 095012 (8pp)

Simulation of shielding of BSCCO tube with external 1 T (Inductivity-Model)



1) Assume ideal conductor R=0
   → Flux conservation
2) Calculate current density I_i by discretising of tube in N subtubes and solving the equation system $M_{ij} I_i = F_j$
3) Calculate residual field
   $B_{res} = B^{EXT}_Z + B^{IND}_Z$ via Biot-Savart

Mutual inductance M_{ij}:

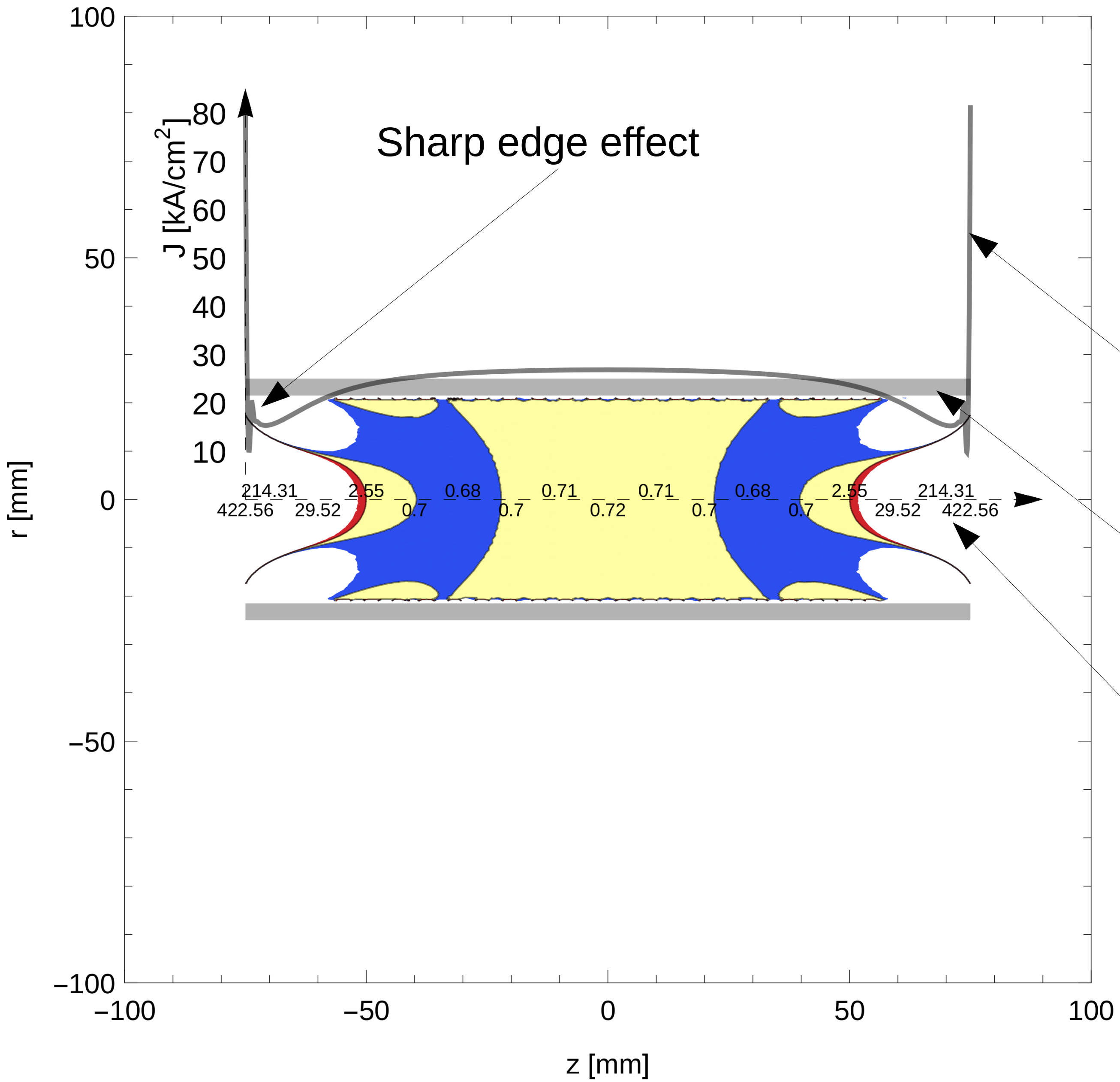
$$M_{ij} = \frac{\mu_0}{4\pi I_i I_j} \int_{C_i} d^3x_i \int_{C_j} d^3x'_j \, \frac{\mathbf{J}(\mathbf{x}_i) \cdot \mathbf{J}(\mathbf{x}'_j)}{|\mathbf{x}_i - \mathbf{x}'_j|}$$

Self inductance $M_{ii} = L_i$:

$$L = \frac{1}{I^2} \int \frac{\mathbf{B} \cdot \mathbf{B}}{\mu} d^3x \qquad L \approx \frac{\mu_0}{4\pi} C \left[\ln\left(\frac{\xi A}{a^2}\right) + \frac{1}{2} \right]$$

$$\xi = 64/\pi e^4 \approx 0.373$$

Current density and residual magnetic field



Applied 10000 Gauß external field (magnet size as in experiment)

Current density (Interpolated) max. 81073.9 kA/cm^2

SC-tube

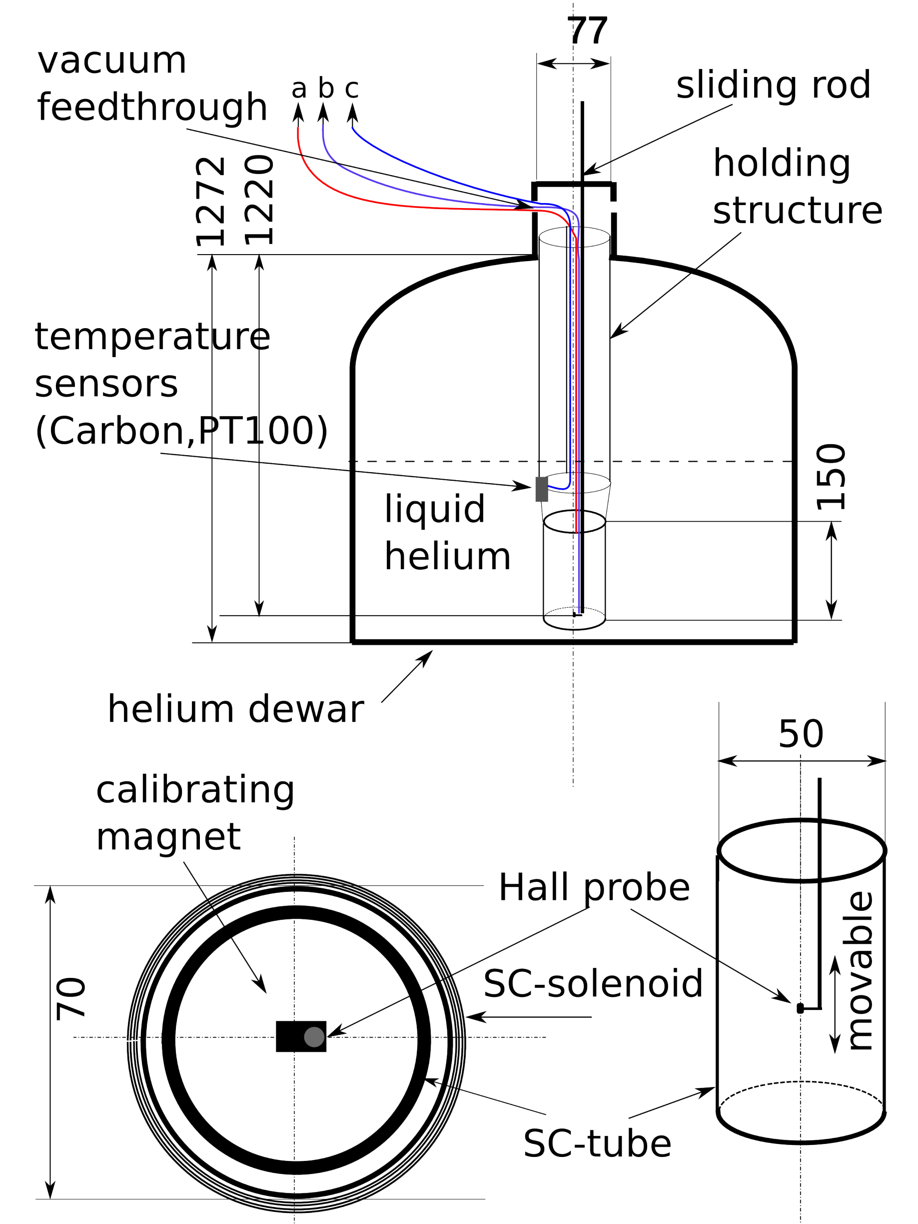
B_{res} [Gauß] = $B^{EXT}_Z + B^{IND}_Z$ via Biot-Savart

Measurement I. a)
External magnet 4.2 K
no BSCCO tube
19. May 2014

Legend:
a: External magnet current supply
b: Hall-probe current/voltage
c: Temperature sensors

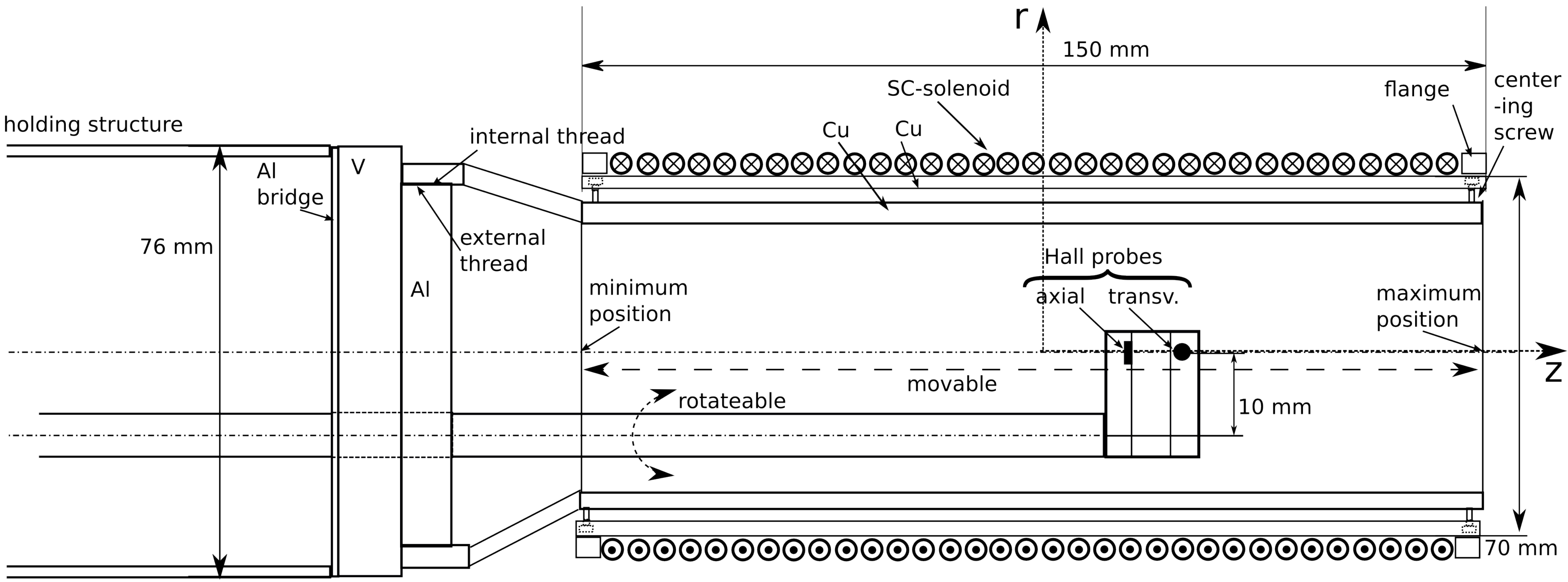
Experimental setup

- SC-tube
- H 150 mm, ID 43 mm , OD 50 mm
- 4.2 K (J > 16000 A/cm2)
- Max. 1.4 T solenoid (BEXT)
- Longitudinal/ transverse - Hall probes (moveable/rotateable for measurement of fieldmap 150x20 mm2)
- Measurement (a) without and (b) with SC-Tube installed



All dimensions in mm

External magnet without SC-shield

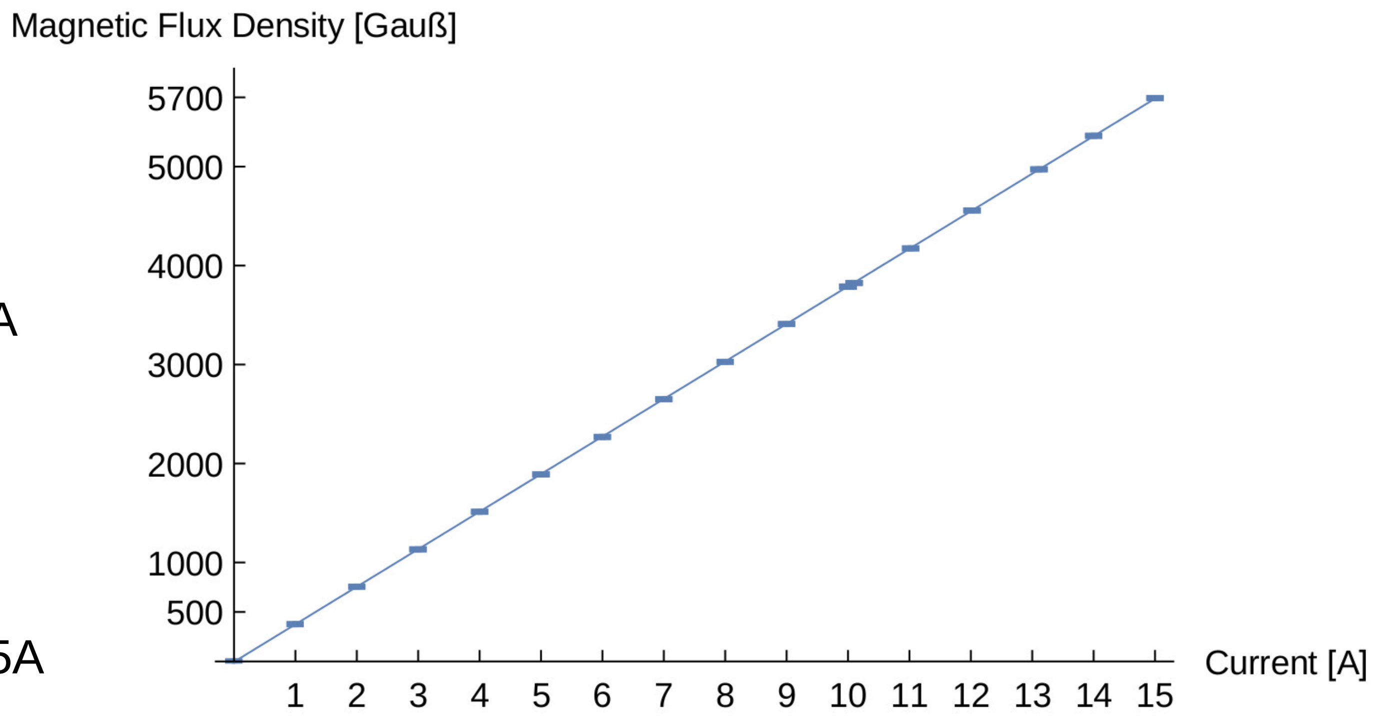


Run	Fixed	Variable
1. B vs. I	r = 0, z = 0	0 → 10 A
2. B vs. z	I = 10 A, r = 0	z = -70 mm… 70 mm
3. B vs. z	I = 10 A, r = 14 mm	z = -70 mm … 70 mm
4. B vs. z	I = 10 A, r = 20 mm	z = -70 mm … 70 mm
5. B vs. I	r = 0, z = 0	10 A → 15 A

Run 1.+5. Field-current of external magnet

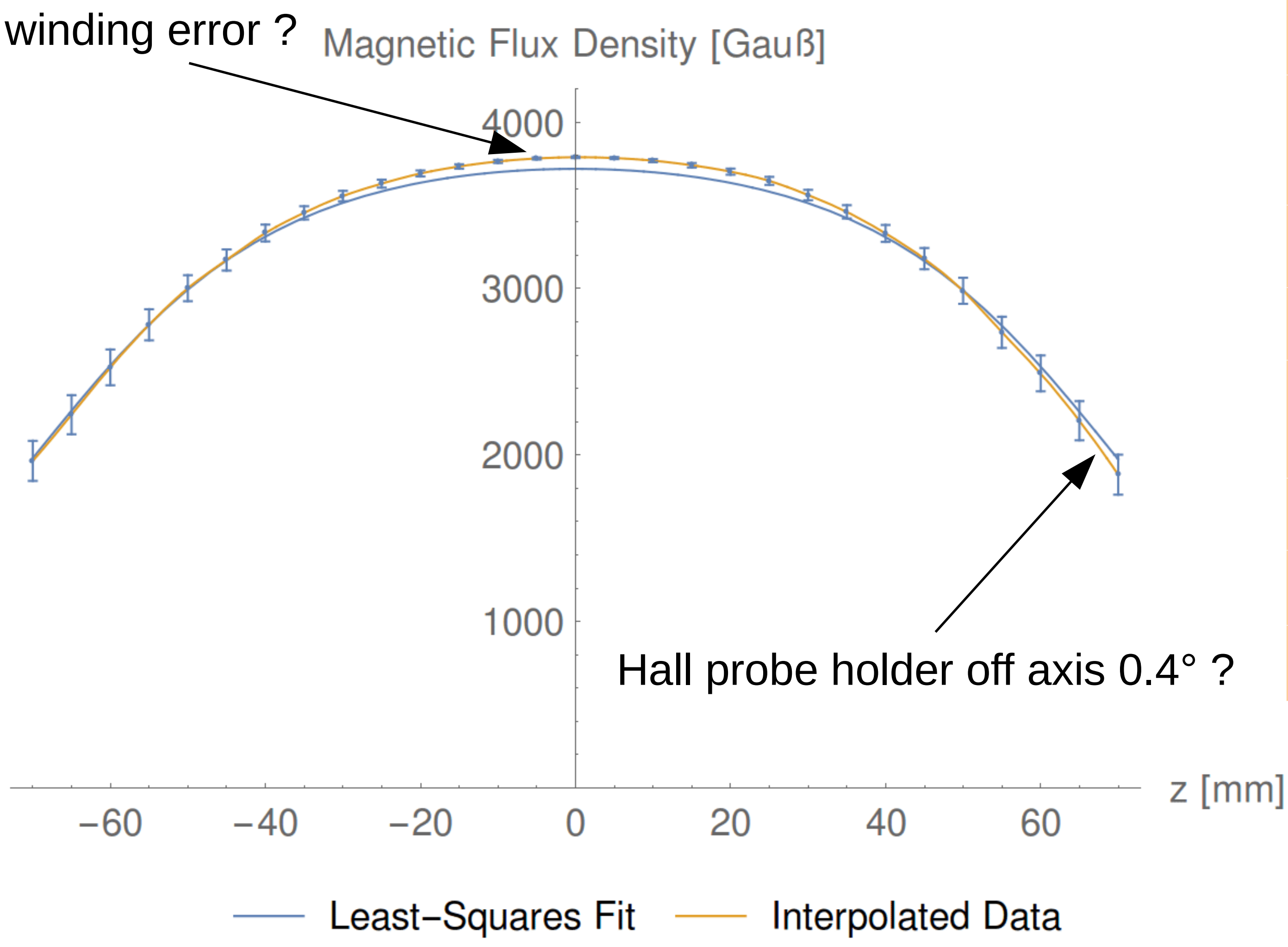
Run 1.
Pos.:
 r=0, z=0
Current:
 I=0...10A

Run 5.
Pos.:
 r=0, z=0
Current:
 I=10...15A



Fitted function ax+b	Reduced $X^2 = 20.2$
Error (Hall probe)	0.1 %
Error (current supply)	0.1 %
Offset (substracted before fit) [Gauß]	14.5 (without statistics)
a [Gauß/Amper]	380.054
σ_a [Gauß/Amper]	0.17
b [Gauß]	-10.2
σ_b [Gauß]	1.8

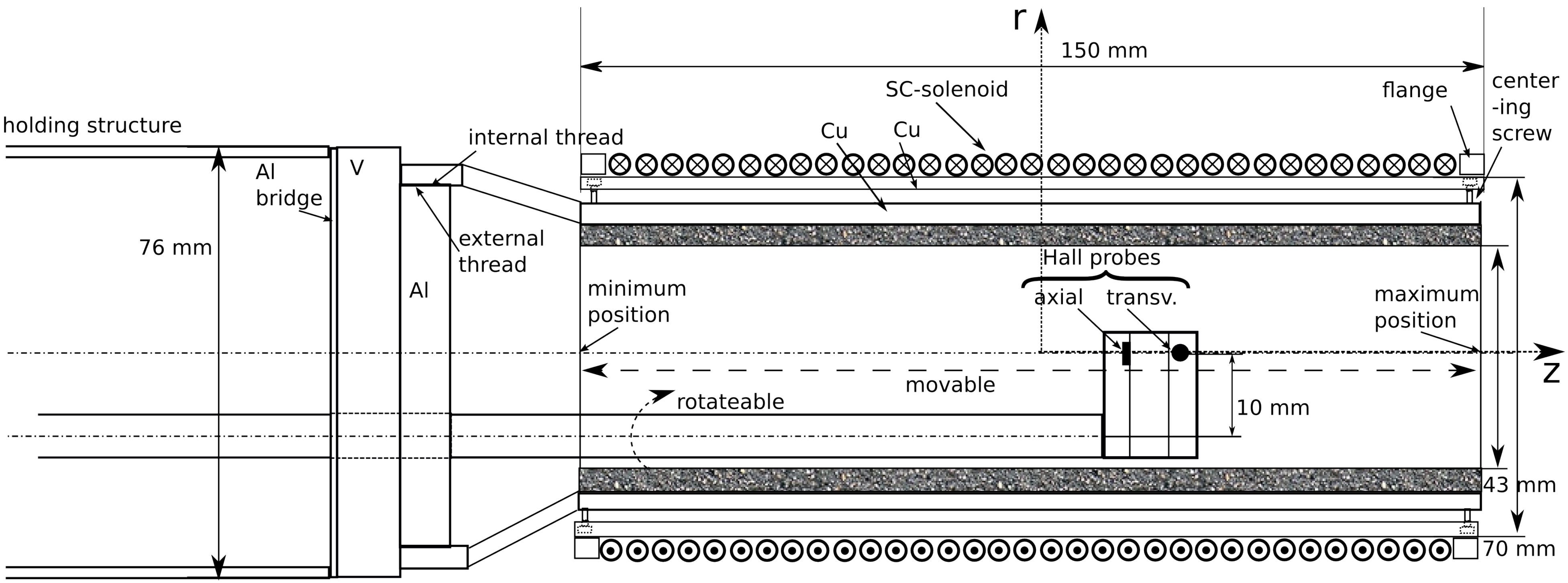
Run 2. Field map of external magnet 10 A
$B^{EXT}_z(0,0) = (3800 \pm 4)$ Gauß, r = 0 mm



Fitted function	$B_z(r,z)$
Fit parameter r [mm]	0
Fit error σ_r [mm]	421
Hall probe error	0.1 %
Alignment error	Δz, Δr = 2 mm
Current error	0.01 A
Reduced X^2	22
Offset [Gauß]	14.5

Measurement I. b)
BSCCO 4.2 K
16. June 2014

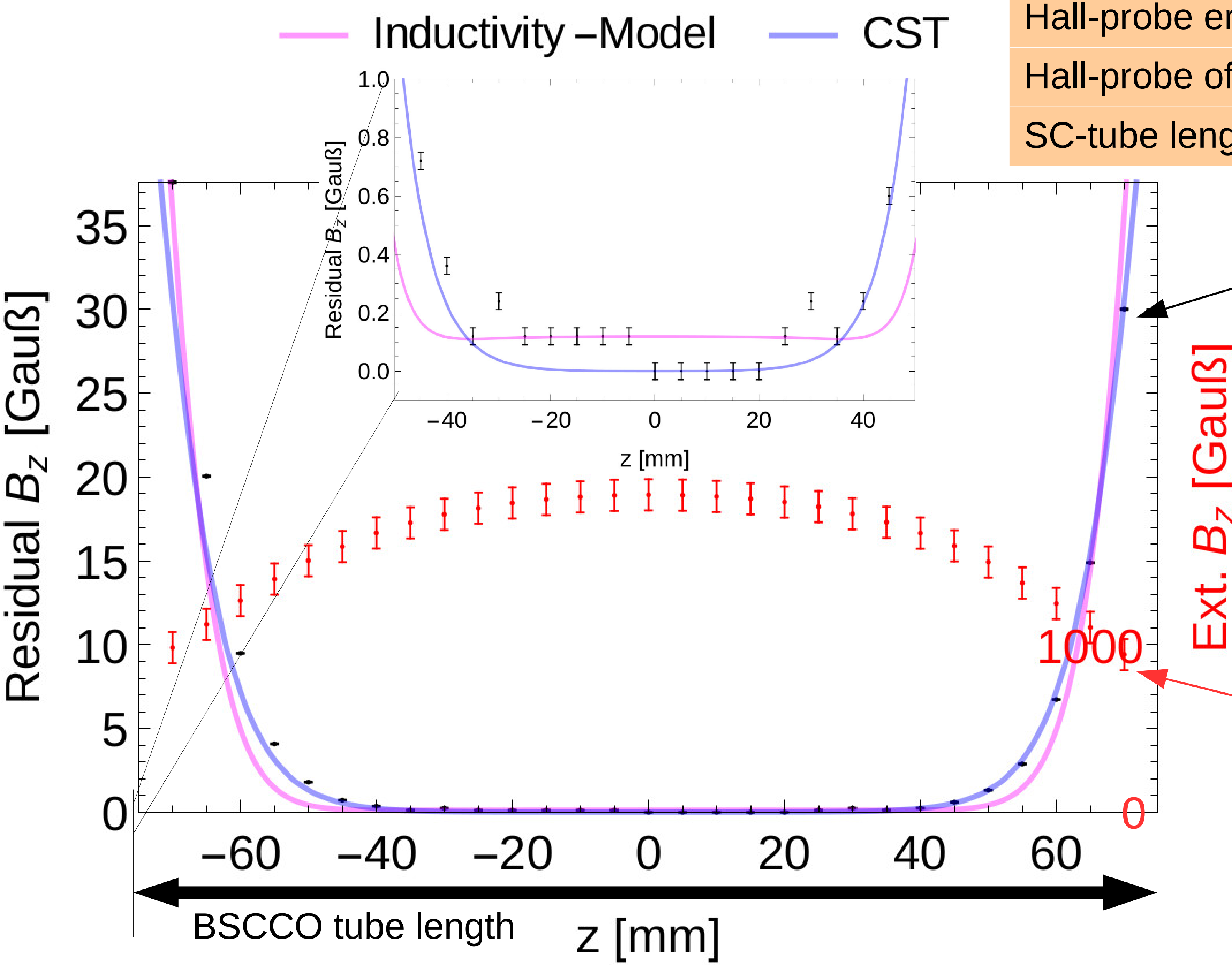
Measurement of residual field with BSCCO
Experimental setup



Run	I [A]	B_{EXT} [Gauß]	Position	Variable (±2mm)
1. B vs. z	5 ± 0.005	1900 ± 2	r = 0	z = -70 … 70
2. B vs. z	20 ± 0.02	7601 ± 8	r = 0	z = -70 … 70
3. B vs. z	26.33 ± 0.03	10008 ± 11	r = 0	z = -70 … 70
4. B vs. z	30 ± 0.03	11402 ± 12	r = 0	z = -70 … 70
5. Relaxation	26.46 ± 0.03	10056 ± 11	r = 0, z = 0	t = 4.7 h
6. Maximum field	38 ± 0.04	14442 ± 15	r = 0, z = 0	I = 26.46 A → 38 A

Comparison of measurement run 1. with simulations (ongoing study)

$B^{EXT}_z(0,0)$ [Gauß]	1900 ± 2
r	0 ± 2 mm
Hall-probe error	0.1 %
Hall-probe offset	8.4 Gauß
SC-tube length	-75 … 75 mm

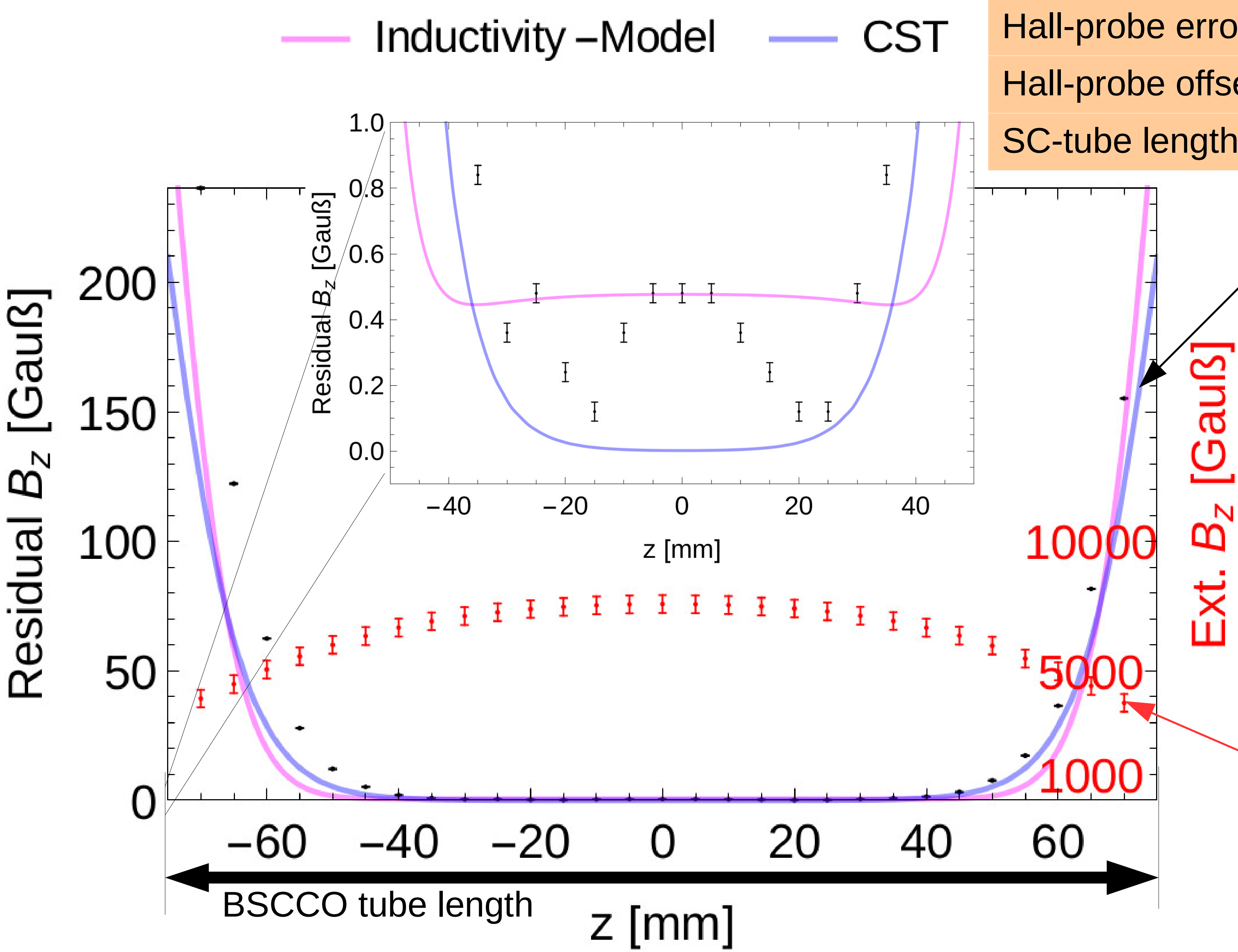


Black points are measured values corrected with offset

Measured external field and scaled with current

Comparison of measurement run 2. with simulations (ongoing study)

$B^{EXT}_{z}(0,0)$ [Gauß]	7601 ± 8
r	0 ± 2 mm
Hall-probe error	0.1 %
Hall-probe offset	8.4 Gauß
SC-tube length	-75 … 75 mm

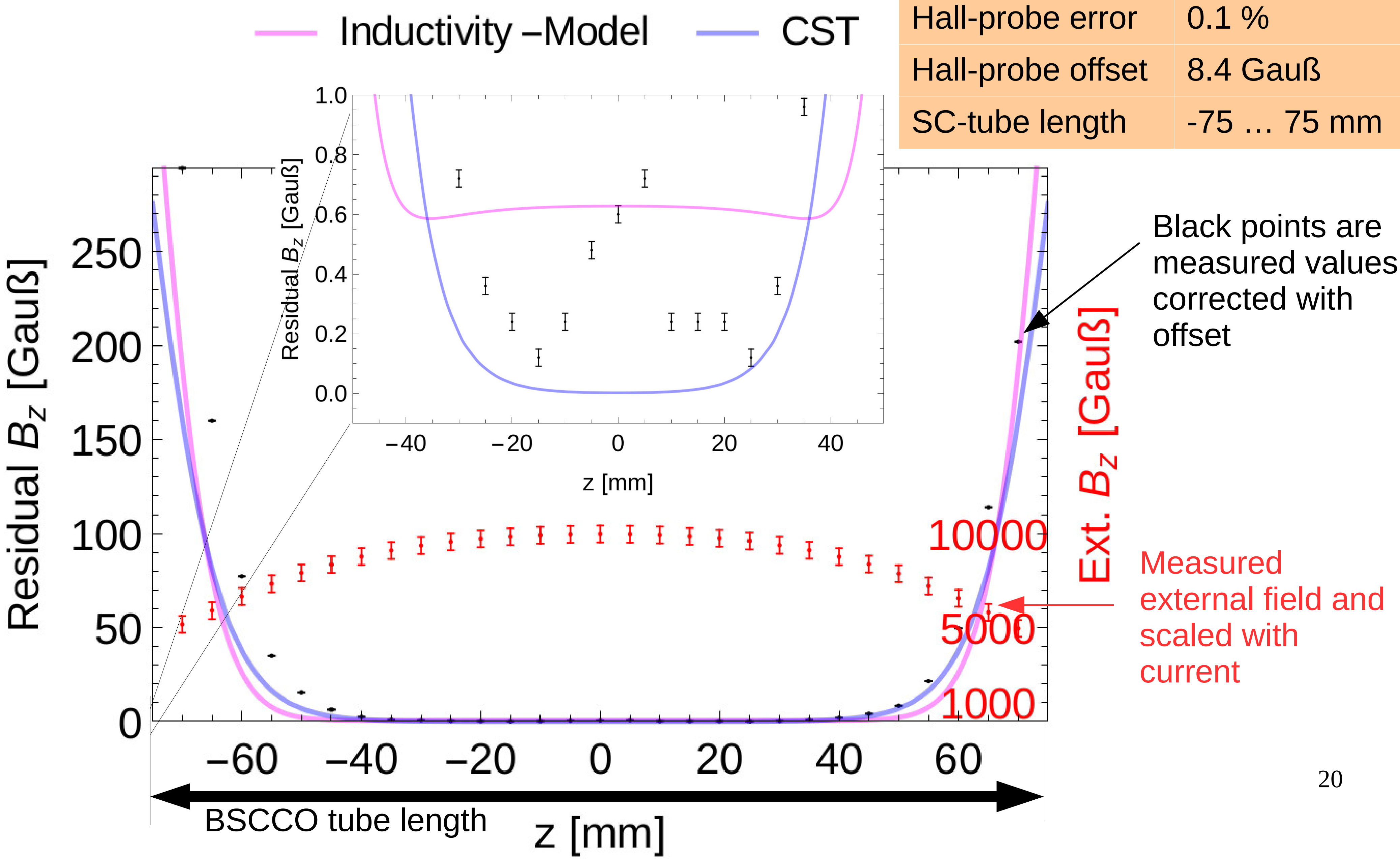


Black points are measured values corrected with offset

Measured external field and scaled with current

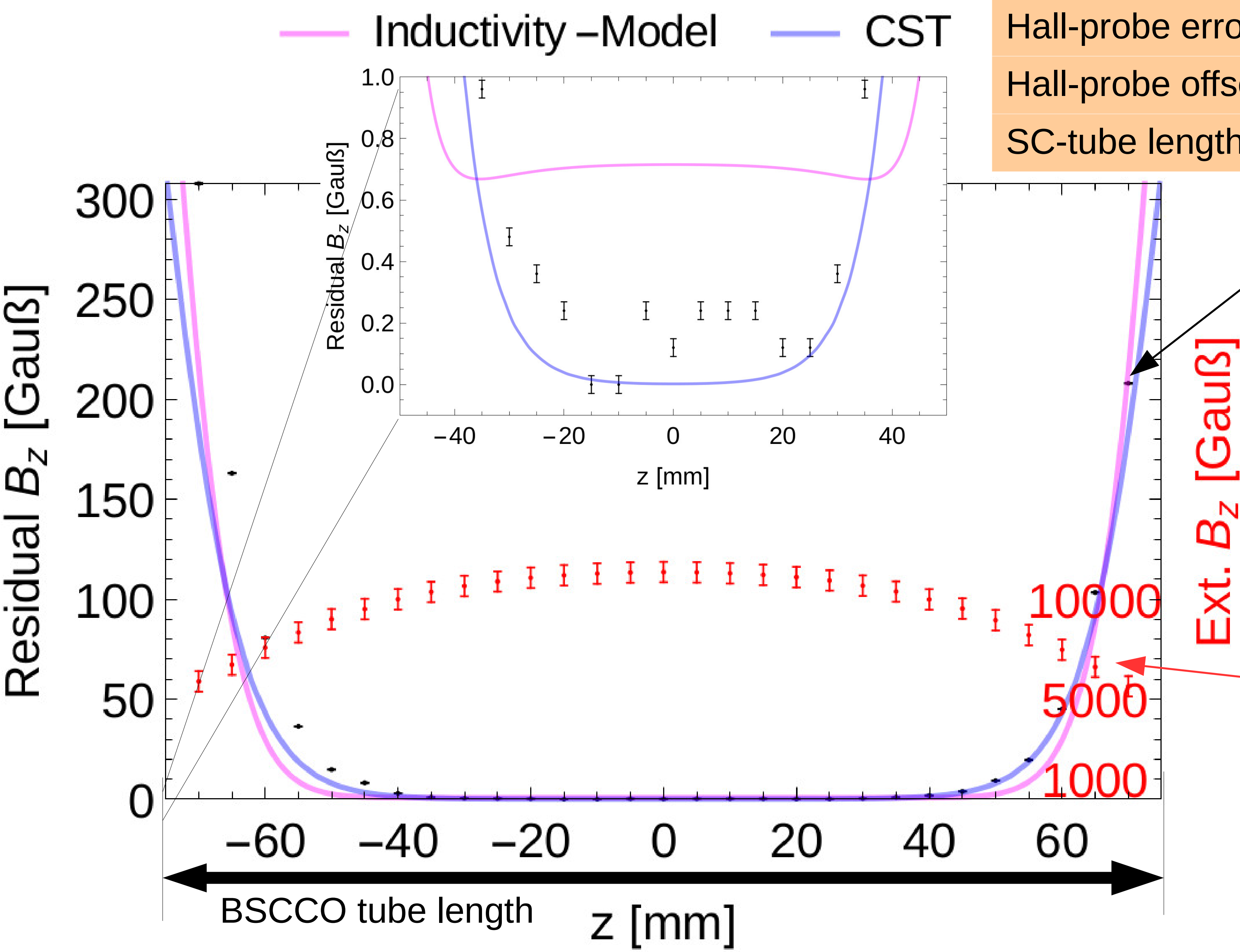
Comparison of measurement run 3. with simulations (ongoing study)

$B^{EXT}_z(0,0)$ [Gauß]	10008 ± 11
r	0 ± 2 mm
Hall-probe error	0.1 %
Hall-probe offset	8.4 Gauß
SC-tube length	-75 … 75 mm



Comparison of measurement run 4. with simulations (ongoing study)

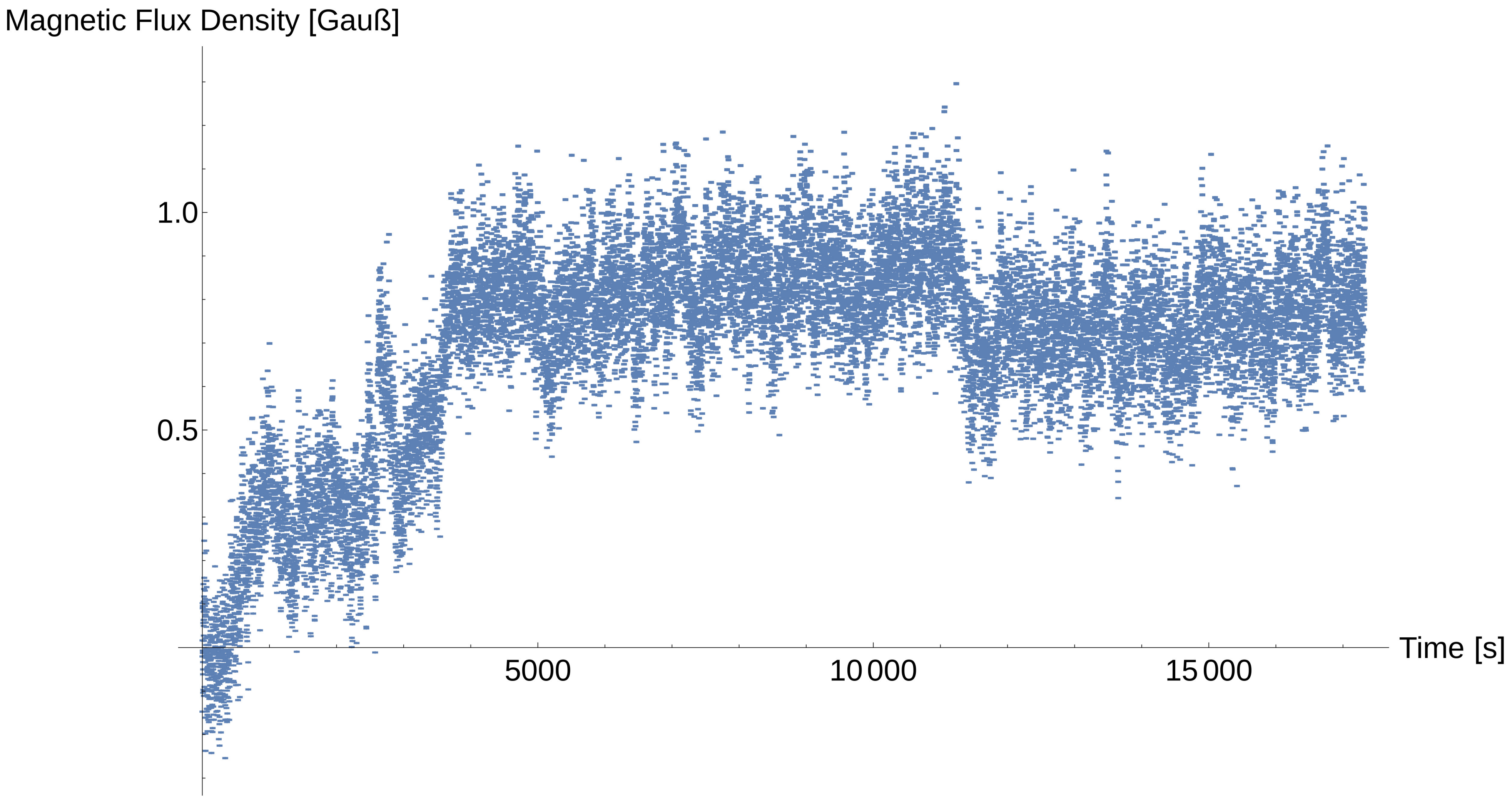
$B^{EXT}_z(0,0)$ [Gauß]	11402 ± 12
r	0 ± 2 mm
Hall-probe error	0.1 %
Hall-probe offset	8.4 Gauß
SC-tube length	-75 … 75 mm



Black points are measured values corrected with offset

Measured external field and scaled with current

5. Relaxation measurement (ongoing study): applied (10056 ± 11) Gauß, duration 4.7 h (Offset 7.0 Gauß)



Conclusion

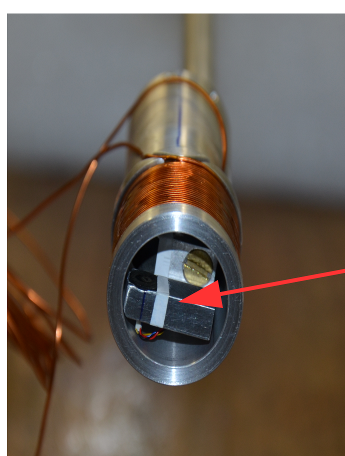
1. Residual field <1 Gauß (shielding factor $>10^4$)
   at 4.2 K with BSCCO

2. Relaxation measurement demonstrated
   4.7 h stability of shielding (10056 ± 11) Gauß

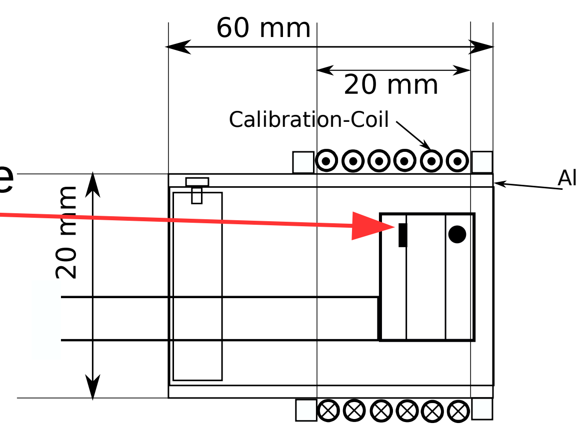
3. Error of Hall probe, Geomagnetic field, local fields unclear

4. Hall probe offset needs to be determined precisely
   → More exact shielding factor

5. Calibration coil in next measurement
   → Control of Hall probe during the measurement with shielding tube

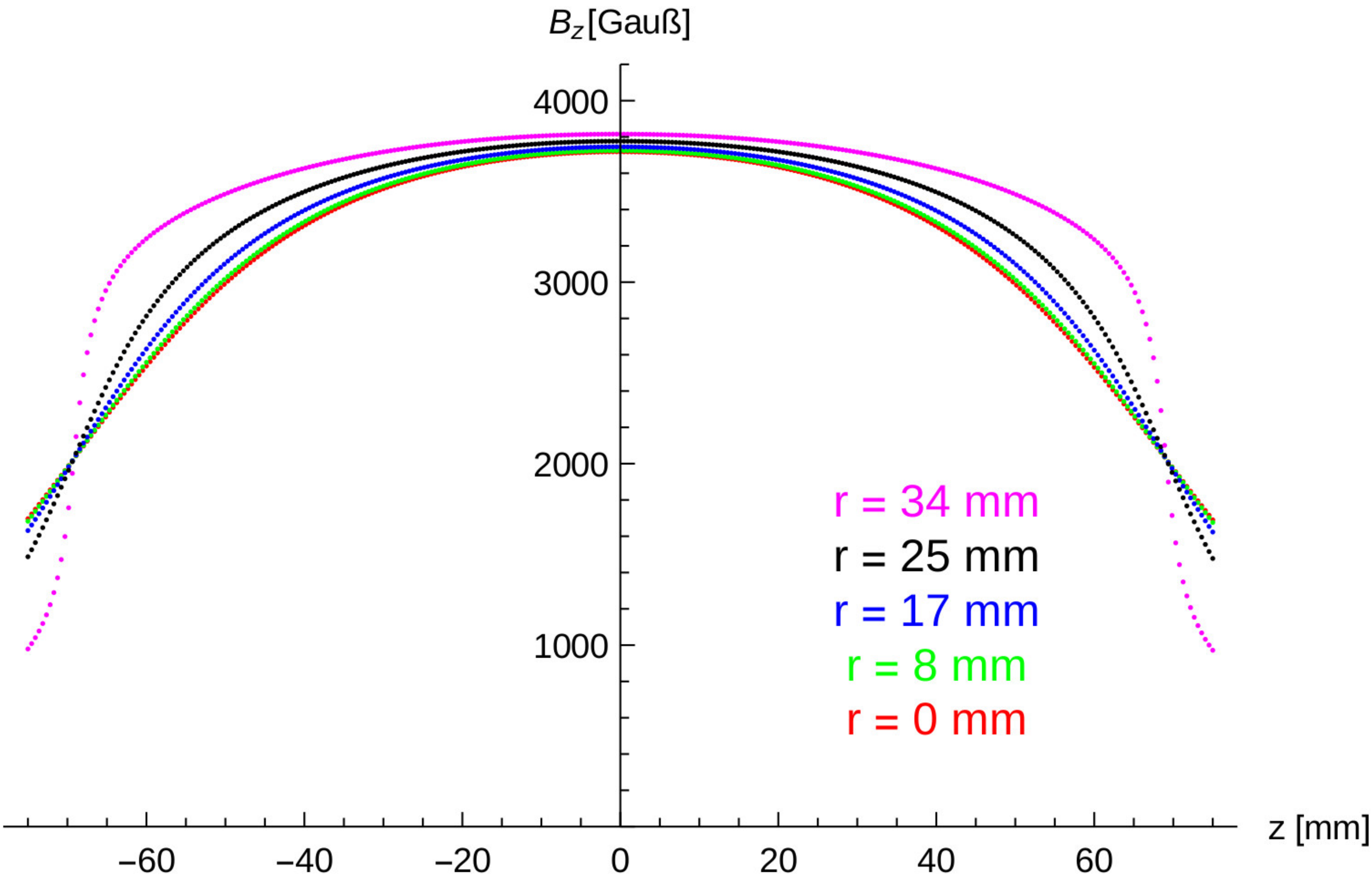


Hall probe



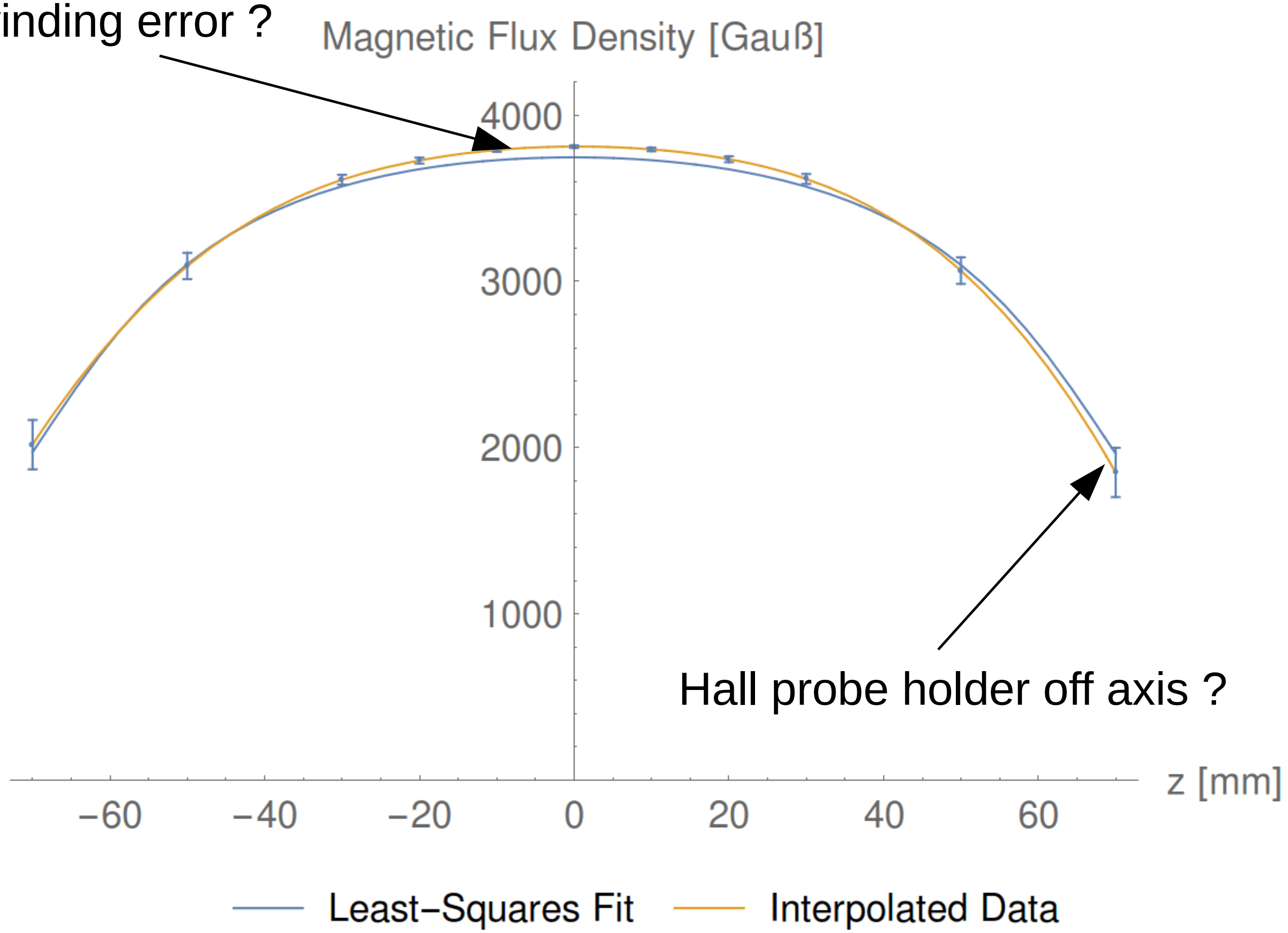
Biot-Savart-Simulation of the external magnet 10 A
Field $B^{EXT}_z(r,z)$ parallel to the axis at radial distance

r = 0...34 mm



Run 3. Field map of external magnet 10 A
$B^{EXT}_Z(0,0) = (3800 \pm 4)$ Gauß, r = 14 mm

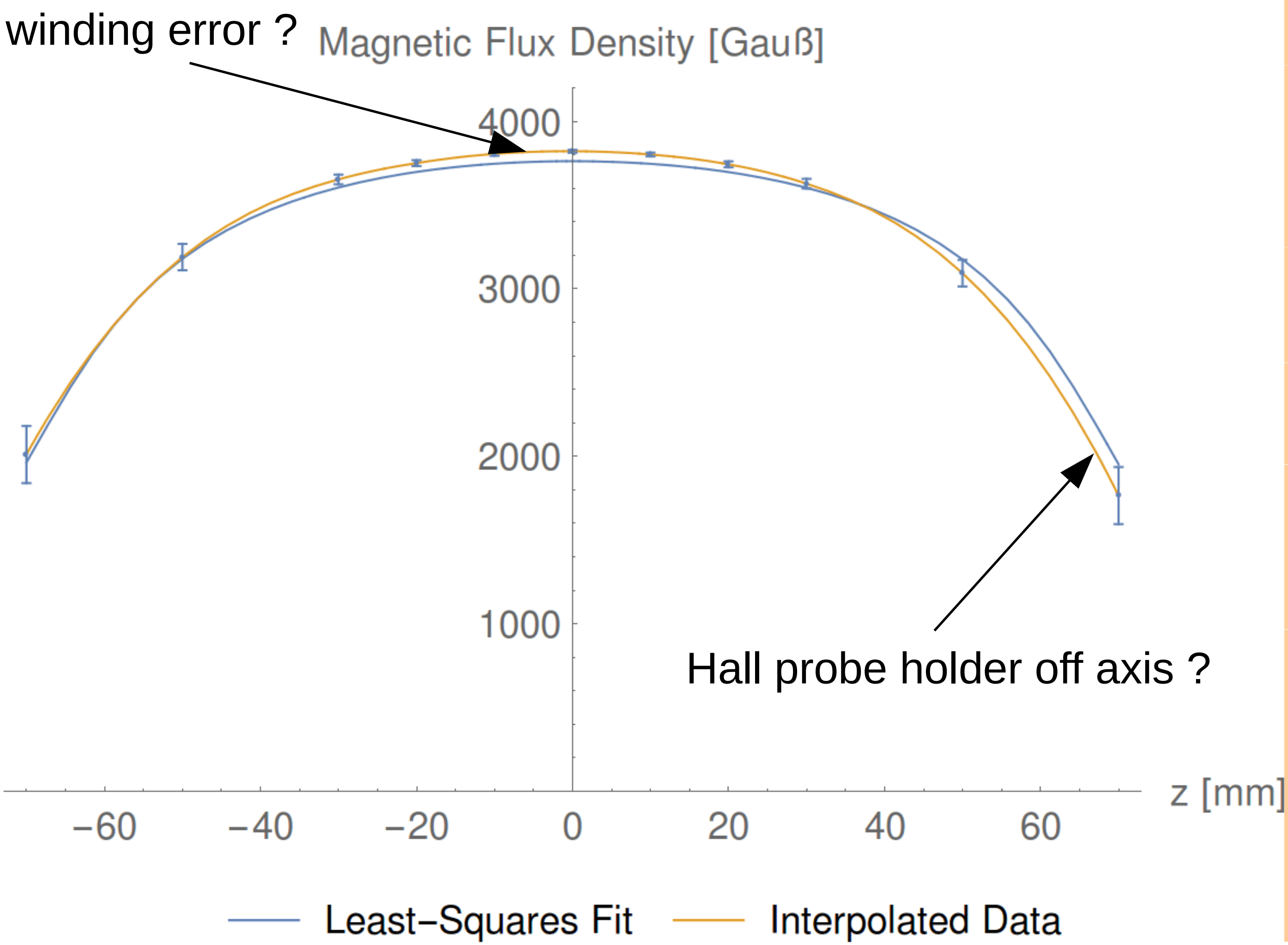
winding error ?



Hall probe holder off axis ?

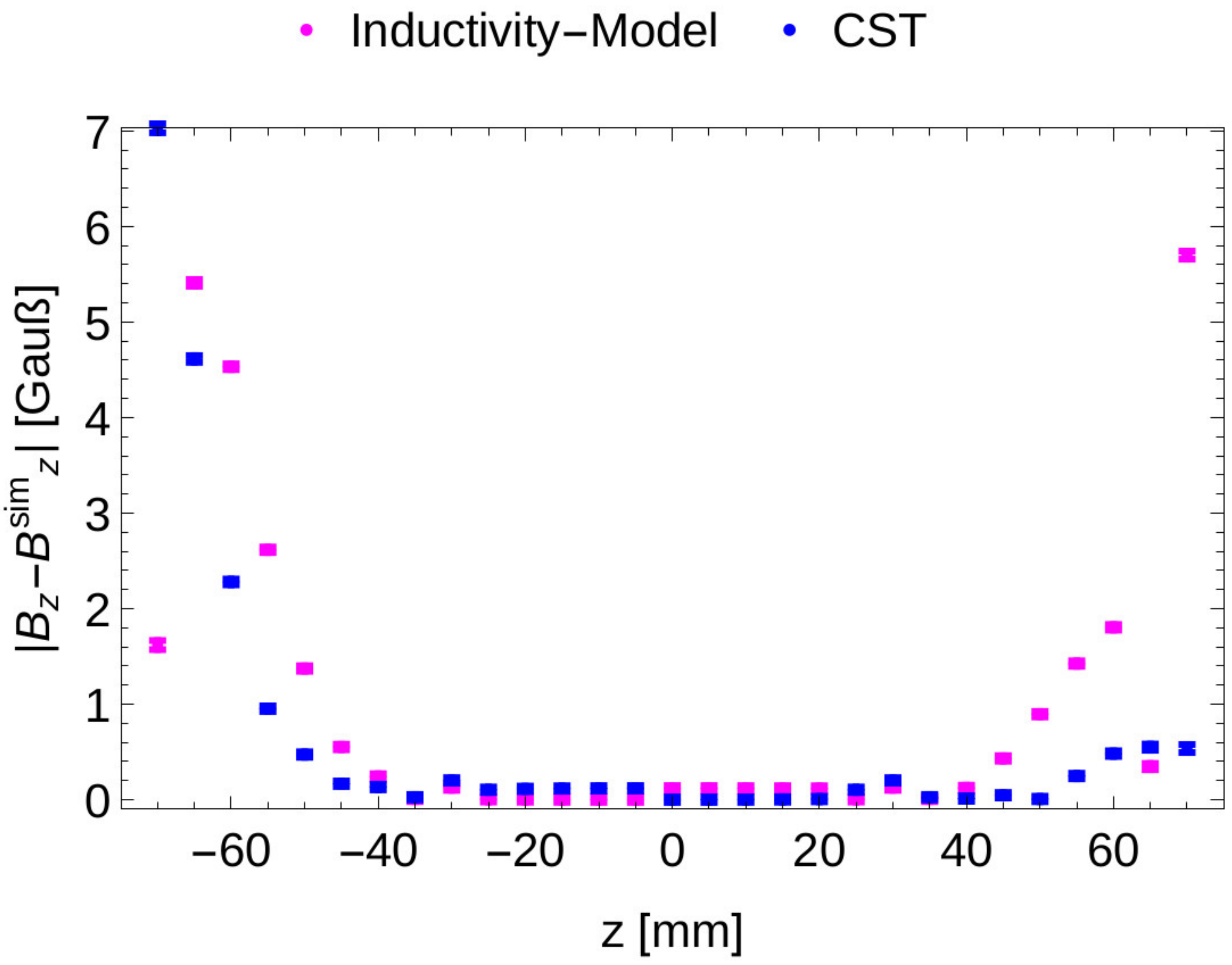
Fitted function	$B_z(r,z)$
Fit parameter r [mm]	17
Fit error σ_r [mm]	3
Hall probe error	0.1 %
Alignment error	Δz, Δr = 2 mm
Current error	0.01 A
Reduced X^2	16.5
Offset [Gauß]	14.5

Run 4. Field map of external magnet 10 A
$B^{EXT}_{Z}(0,0) = (3800 \pm 4)$ Gauß, r = 20 mm

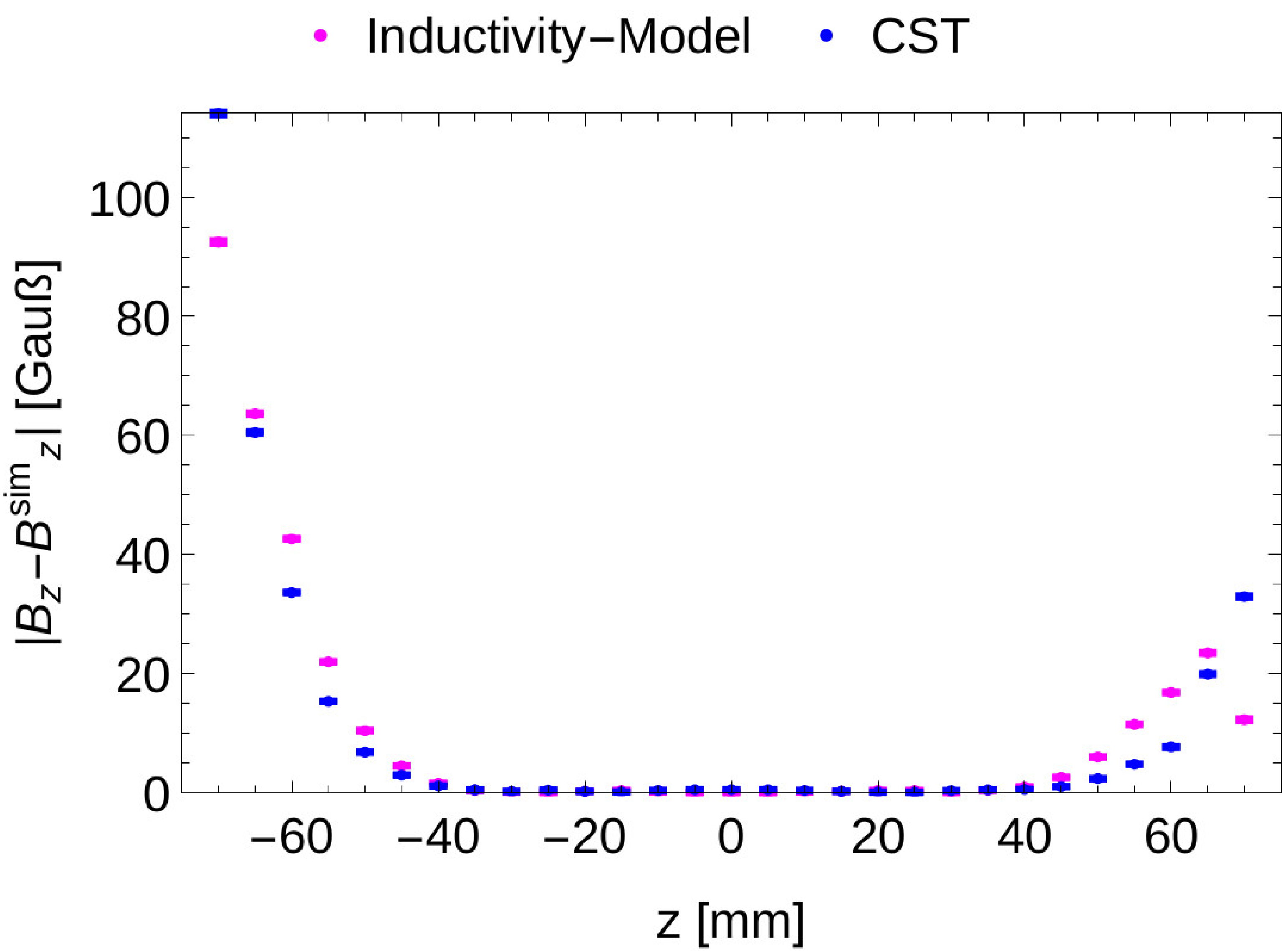


Fitted function	$B_z(r,z)$
Fit parameter r [mm]	22
Fit error σ_r [mm]	3
Hall probe error	0.1 %
Alignment error	Δz, Δr = 2 mm
Current error	0.01 A
Reduced X^2	12.2
Offset [Gauß]	14.5

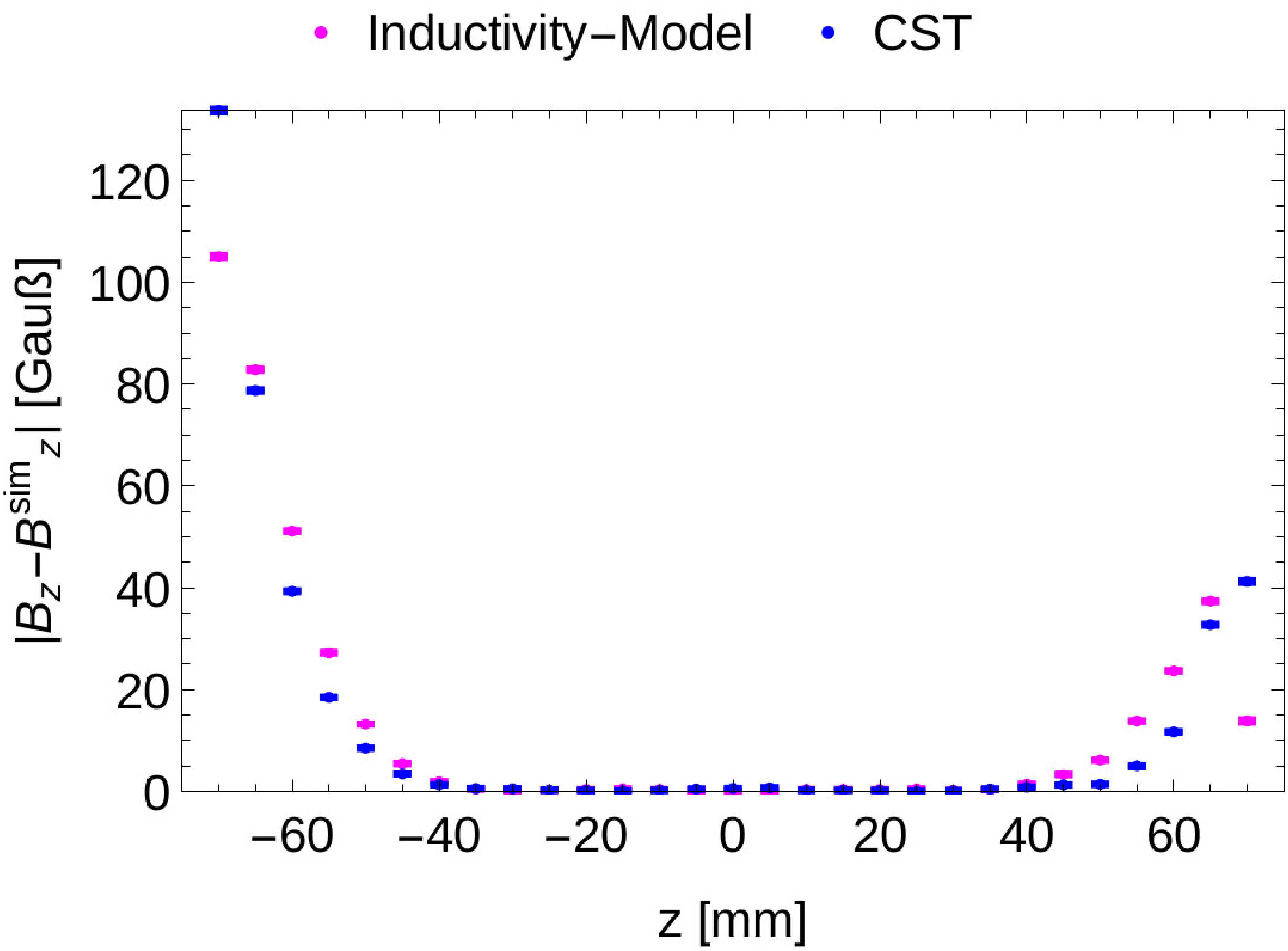
Residuals Measurement run 1. - Simulation 1.



Residuals Measurement run 2. - Simulation 2.



Residuals Measurement run 3. - Simulation 3.



Residuals Measurement run 4. - Simulation 4.