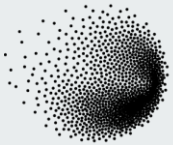
Status of the superconducting injection channels for the muEDM experiment

Pranas Juknevicius

BVR56 *2025-02-10*



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Outline

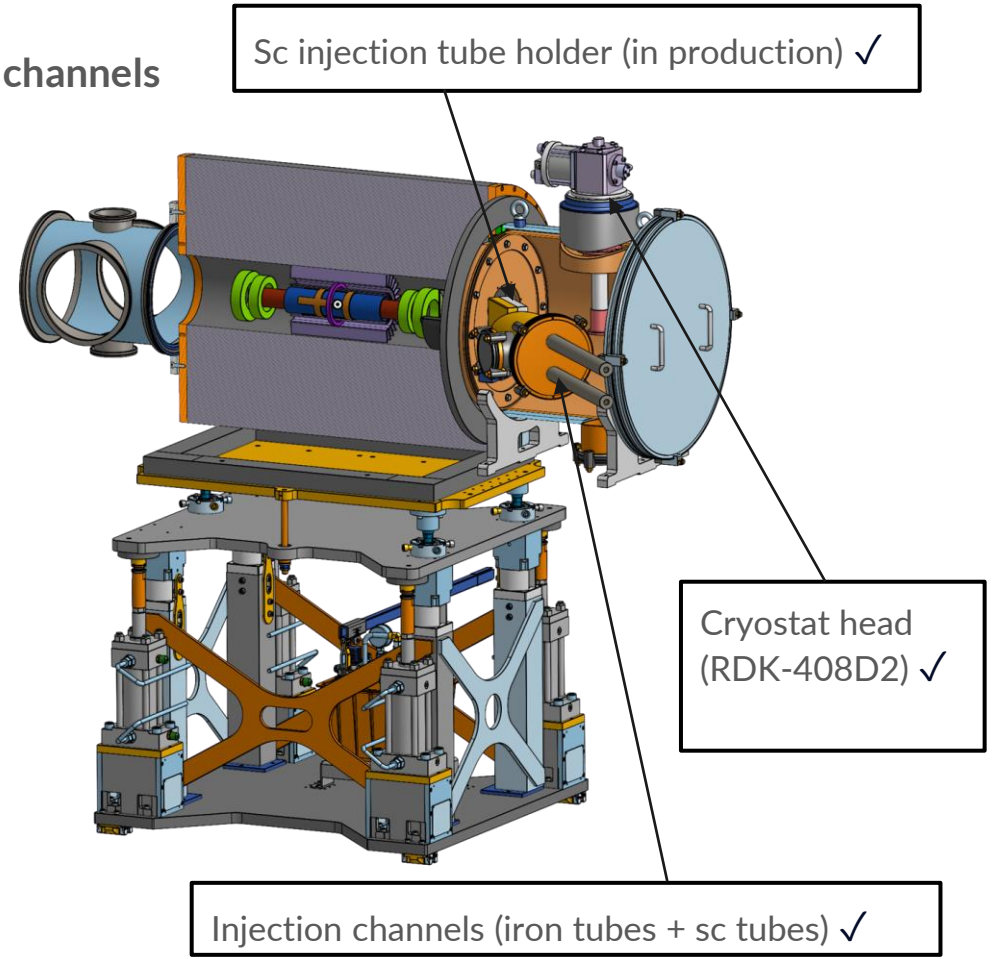
- Overview
- Thermal simulation of superconducting injection channels
- Magnetic field shielding simulation
- Magnetic field shielding and force measurement at LHe
- Conclusions

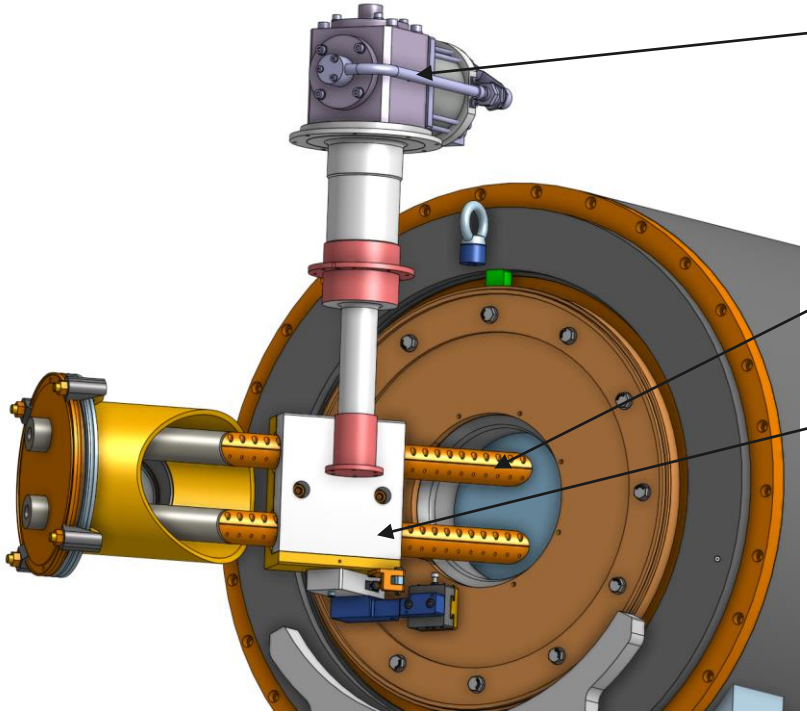
Objectives for the superconducting injection channels

Injecting muons into the bore of the 3T solenoid magnet requires penetrating the fringe field. This can be achieved by guiding the muons using superconducting hollow tubes.

Muon storage and injection studies show that successful storage can be achieved, when inner B field transversal components < 100 mT.

Superconductors must be cooled below critical temperatures at operation.

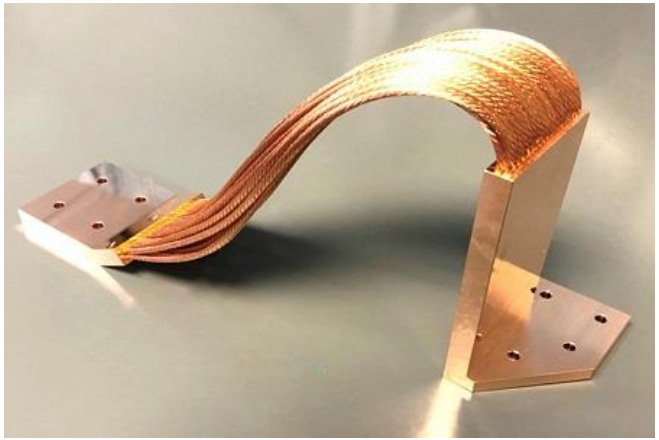




Cryostat head (SRDK-408D2) ✓

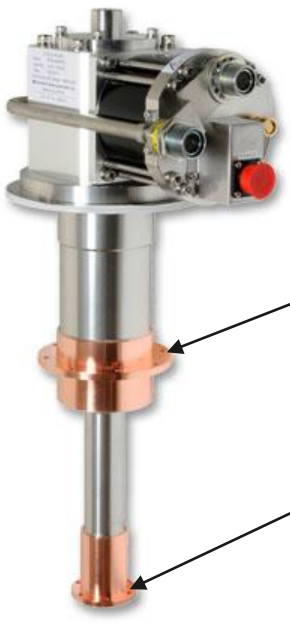
Injection channels (copper tubes + sc tubes) ✓

Sc injection tube holder (in production) ✓

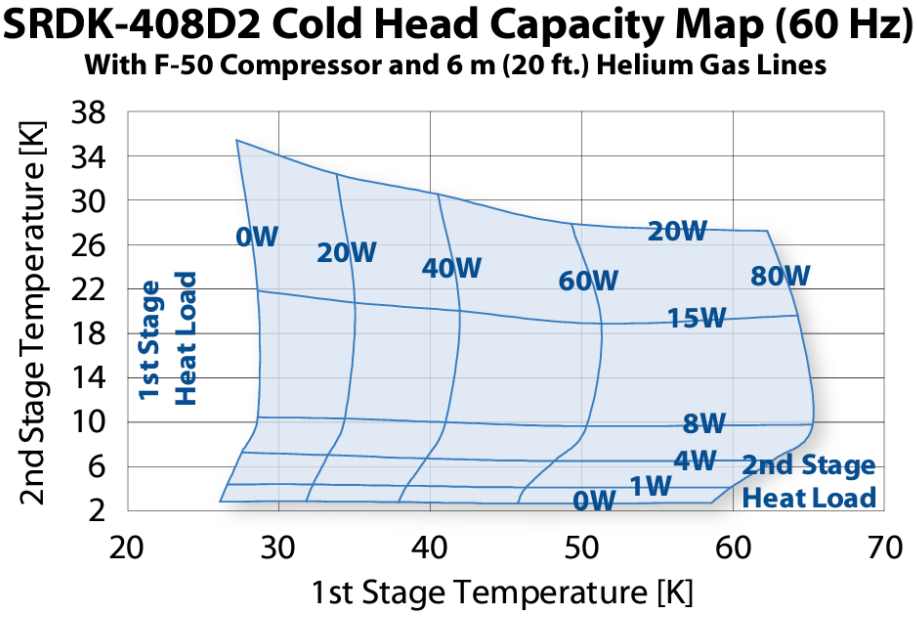


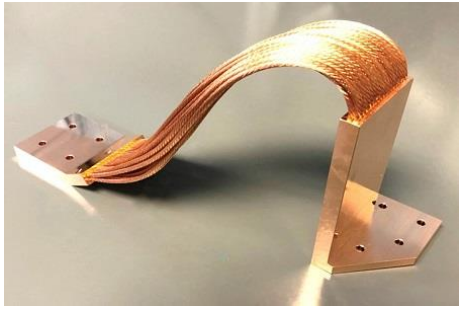
Thanks to Mike G. and Diego B. for the drawing.

SRDK-408D2 Cold head ✓



Cryostat production finishes in February

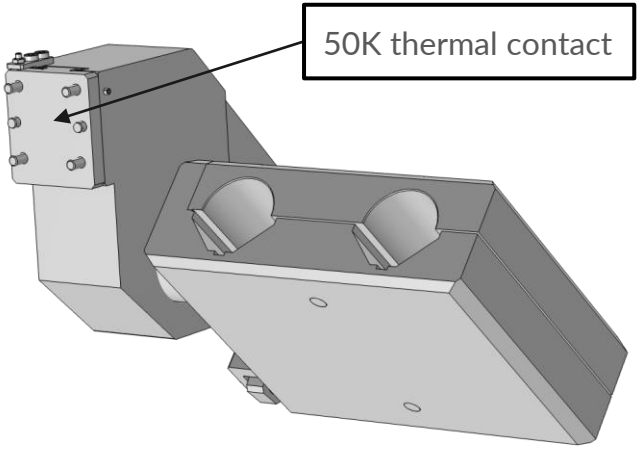


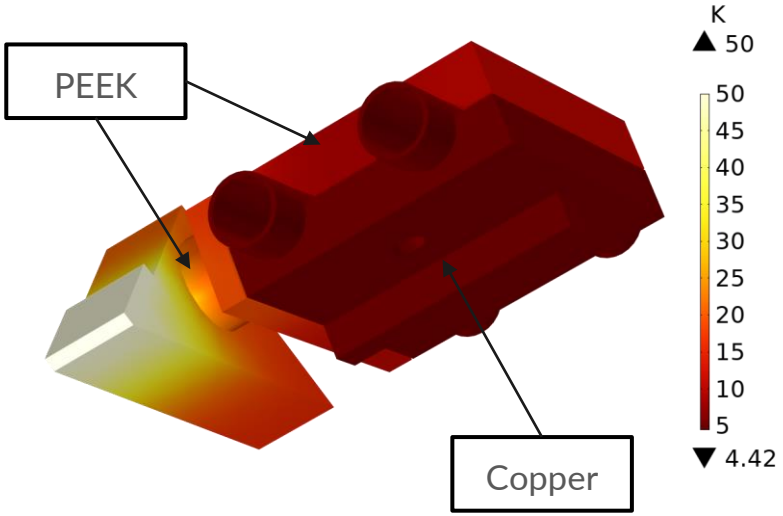


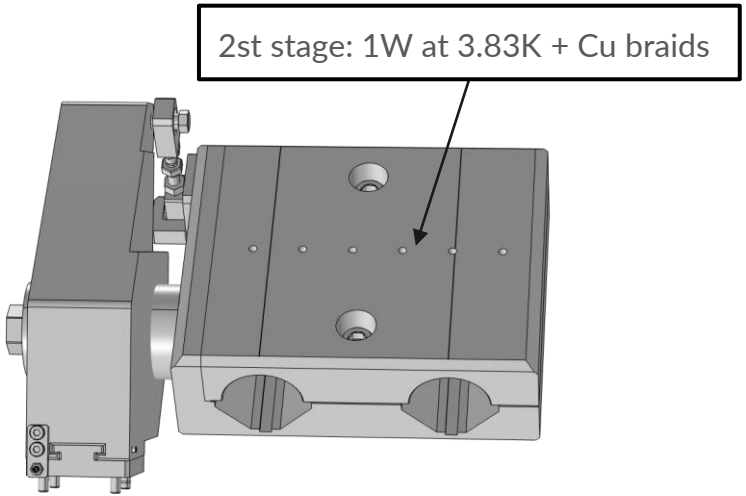
Certified inspection test:

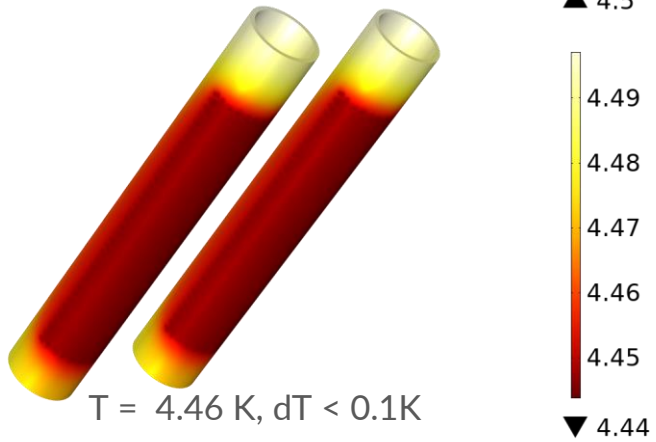
- 1st stage: 50W at 35.7K
- 2nd stage: 1W at 3.83K

Therefore we use these parameters as reference values simulation.


50K thermal contact


PEEK
Copper
K
50
45
40
35
30
25
20
15
10
5
4.42

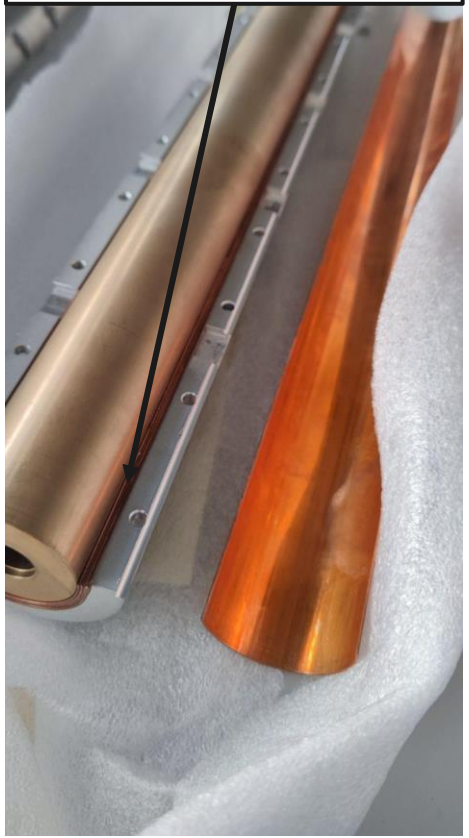

2st stage: 1W at 3.83K + Cu braids

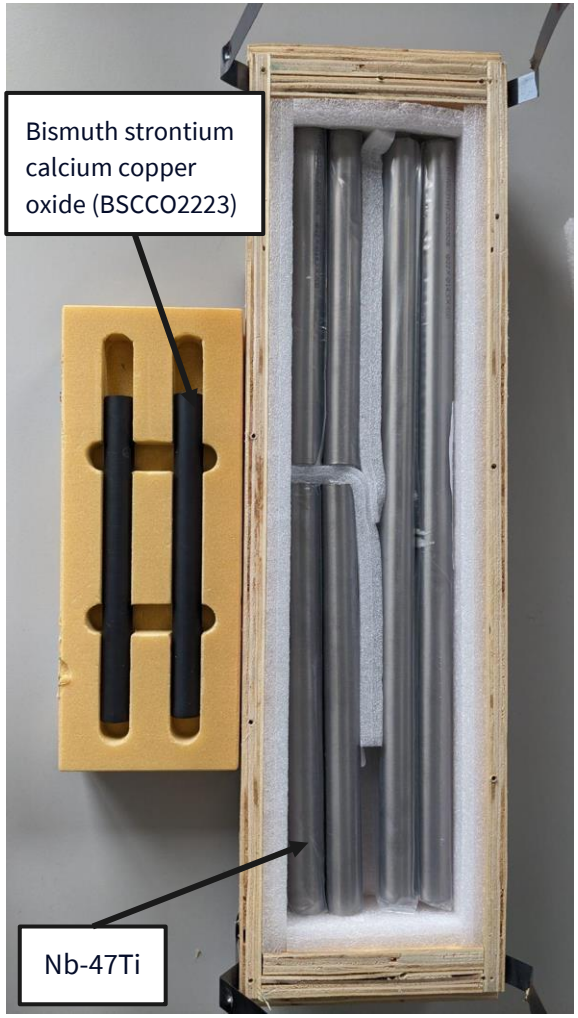

K
4.5
4.49
4.48
4.47
4.46
4.45
4.44

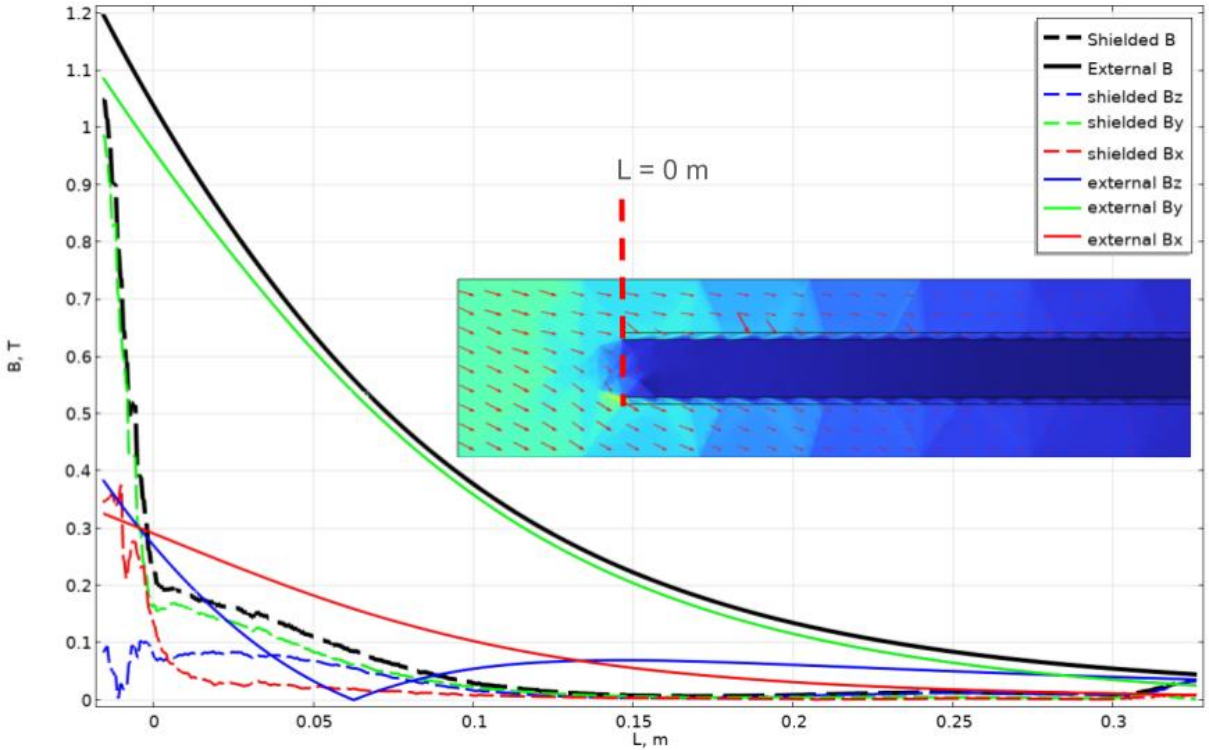
T = 4.46 K, dT < 0.1K

NbTi/Nb/Cu layered sheets

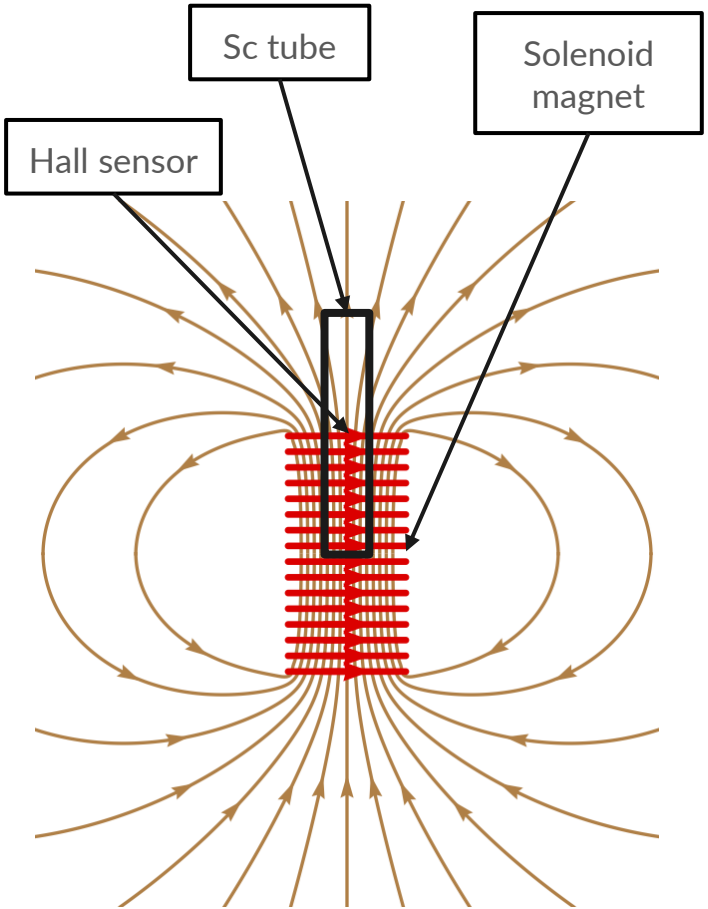
Used at CERN to successfully shield magnetic field up to 3.1T at 4.2K see ref: 10.1109/TASC.2018.2872860







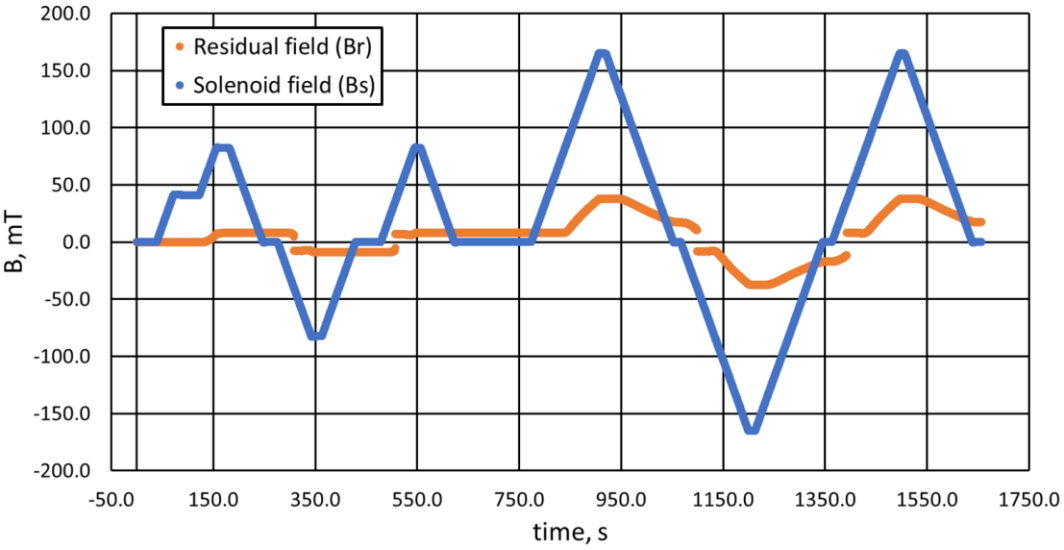
Muon storage simulations show that successful storage can be achieved, when B field transversal components < 100 mT.

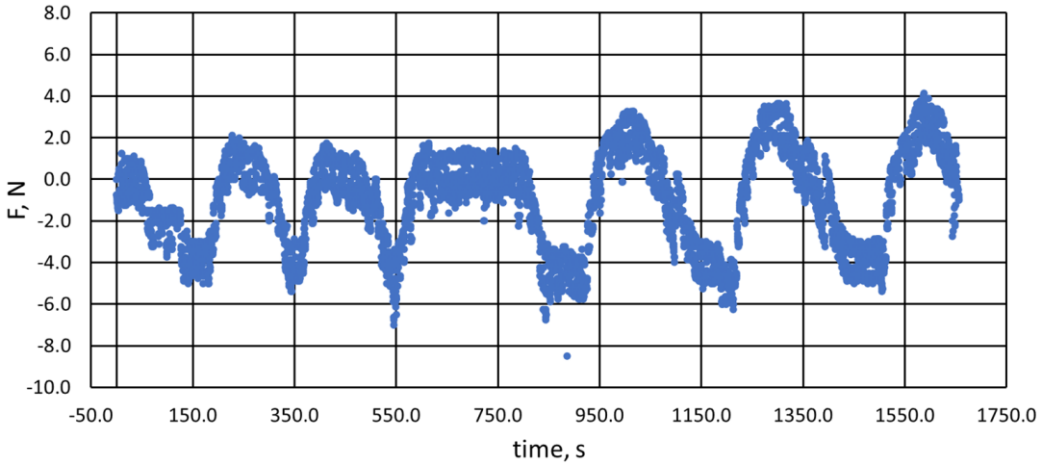


Magnetic field shielding and force measurement

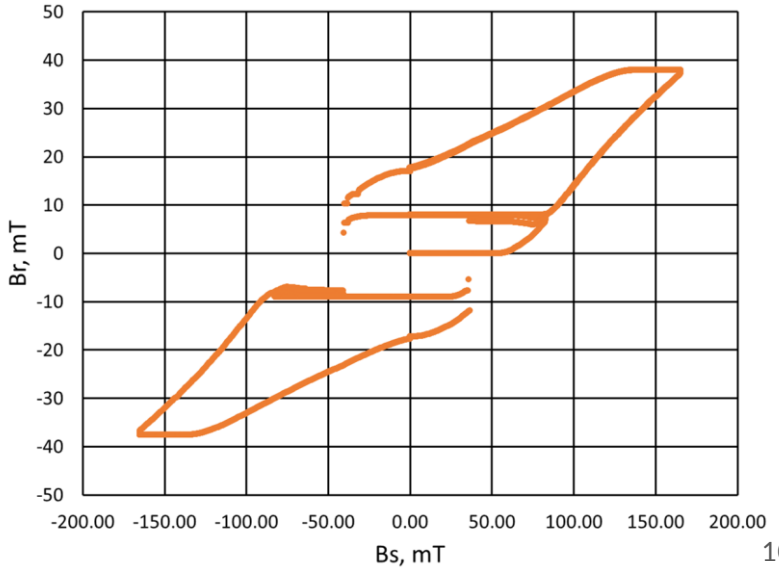
- Measurements performed with **BSCCO2223** and **Nb-47Ti** superconducting tubes at LHe
- Measured **only** axial force and axial magnetic field component

Nb-47Ti tube measurement



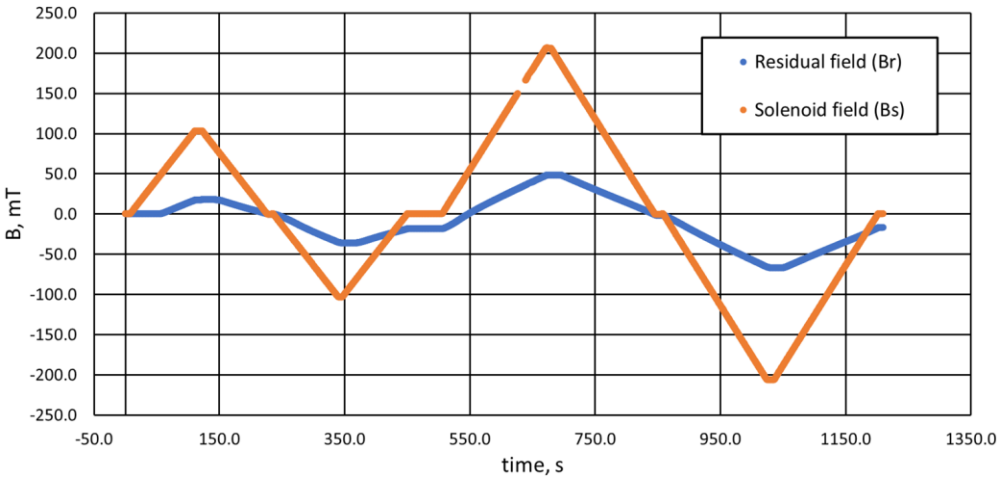


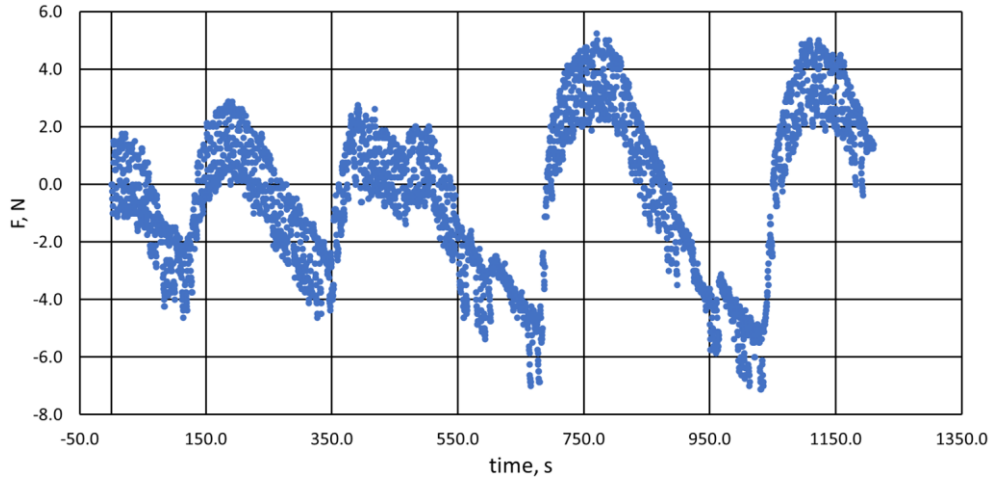
- Fully shielded up to 60 mT
- SF = Bs/Br = 4.6 at 165 mT
- **F = 5N** @Bs = 165 mT and Br = 37 mT (expected **F = 15N** @ Bs = 165mT)

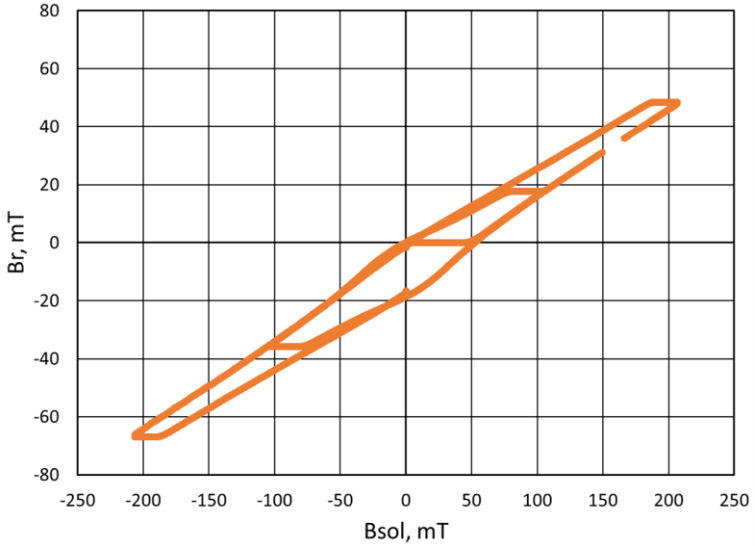


BSCCO2223 tube measurement

- Fully shielded up to 52mT at 4.2K
  - *S Denis et al 2007* reported full shielded up to 14mT at 77K
    ref: 10.1088/0953-2048/20/3/014
- SF = 4.2 at 200 mT
- **F = 4N** @ Bs = 200 mT and Br = 50 mT (expected **F = 17N** @Bs = 200mT)







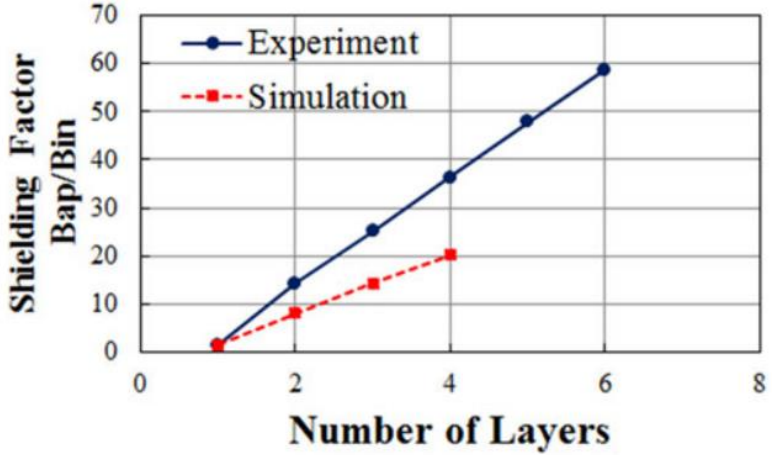
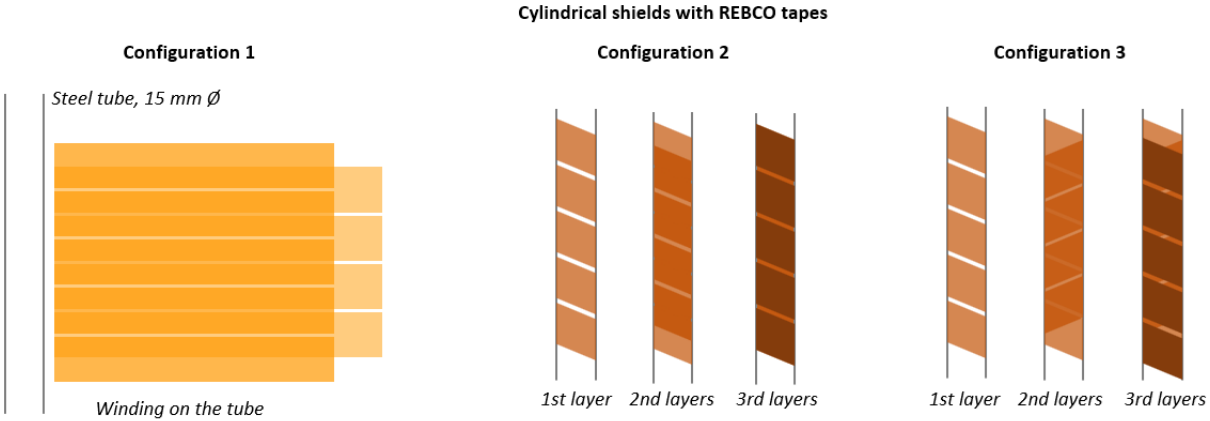


Figure taken from *Y. Nagasaki et al 2018*
Ref: 10.1109/TASC.2018.2808374

Image taken from *Y. Nagasaki et al 2018*
Ref: 10.1109/TASC.2018.2808374



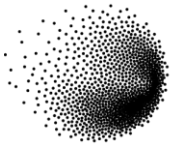
Conclusions

Using COMSOL Multiphysics thermal simulations designed injection channel holders with sufficient cooling power and thermal properties to reach subcritical temperature for the superconducting injection channels.

Using COMSOL Multiphysics verified that magnetic field transversal components remain under 100 mT for the particle path along the injection channels.

Measured the magnetic field shielding and forces of BSCCO2223 and NbTi hollow tubes at 4.2K.

Next step is to design and investigate magnetic field shields using layered NbTi/Ti/Cu sheets, HTS tapes and combinations of different materials.



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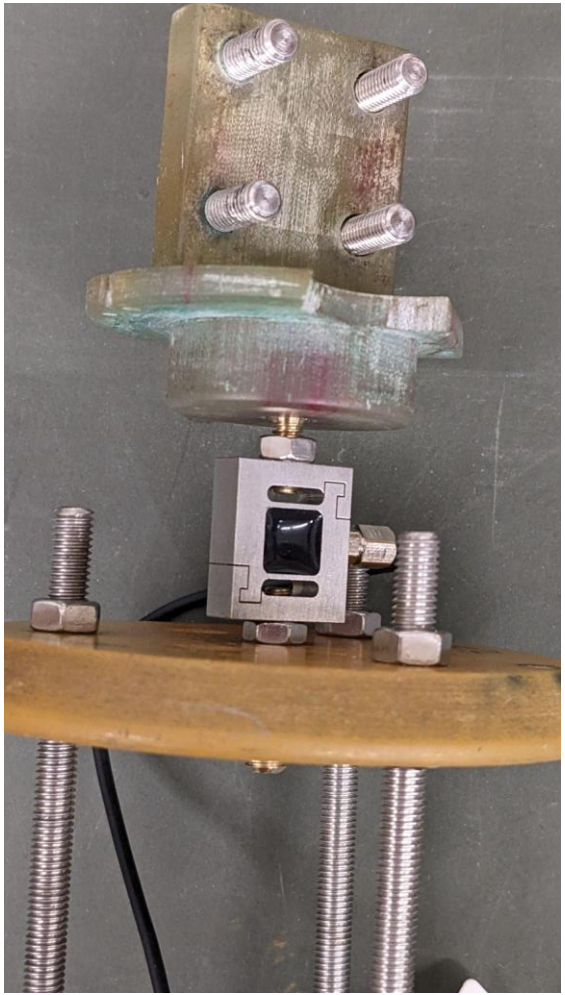
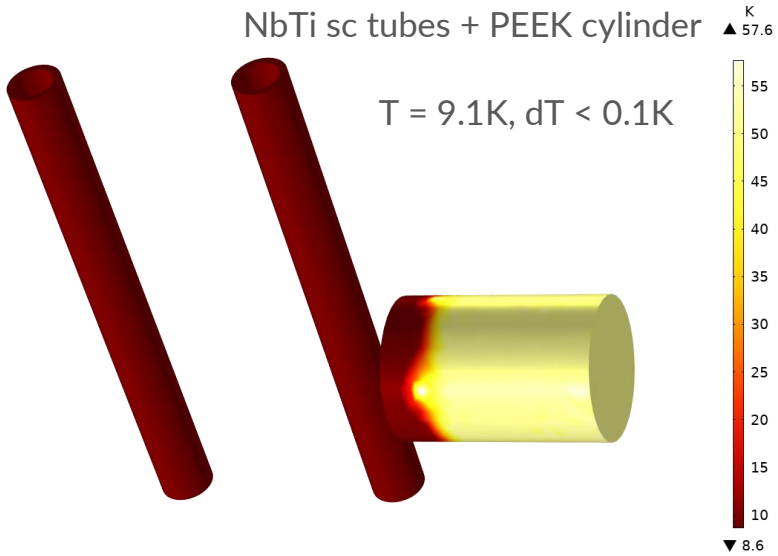
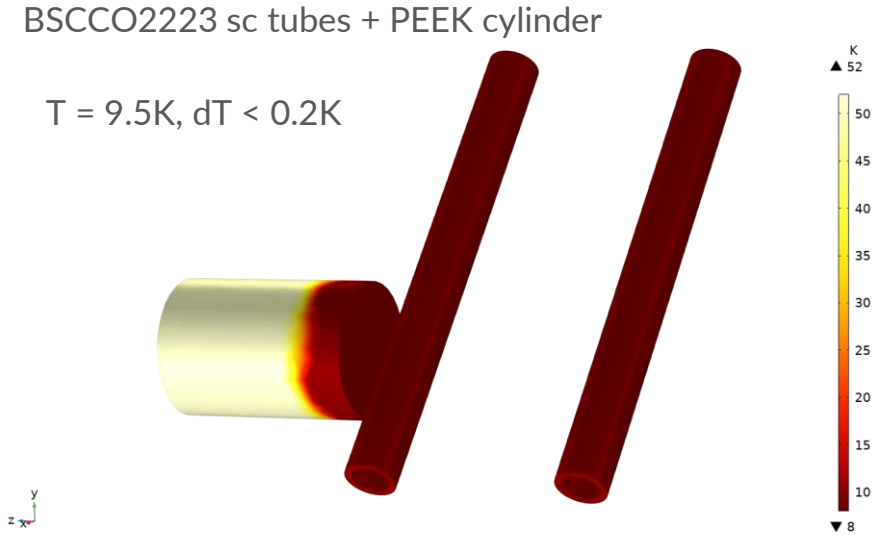


Magnetic field shielding and force measurement

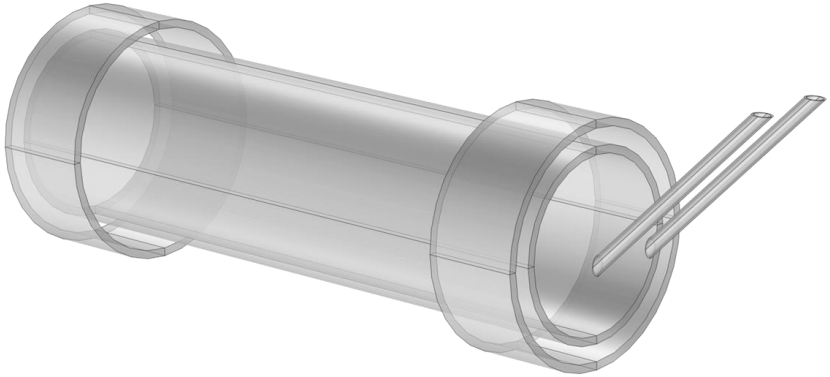
- FS28082210068-100N force sensor
- Max load 100N
- Sensitivity 2N
- According to simulations at B = 250 mT expected F = 46N
- Hall sensors and force sensor were calibrated at LN

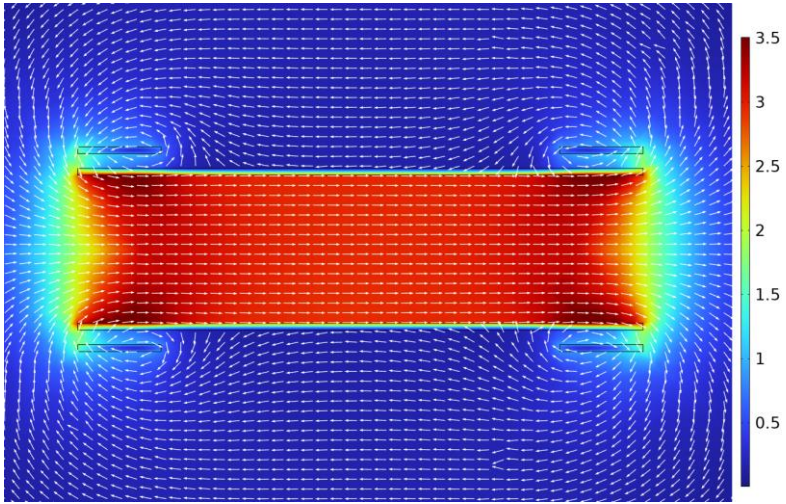


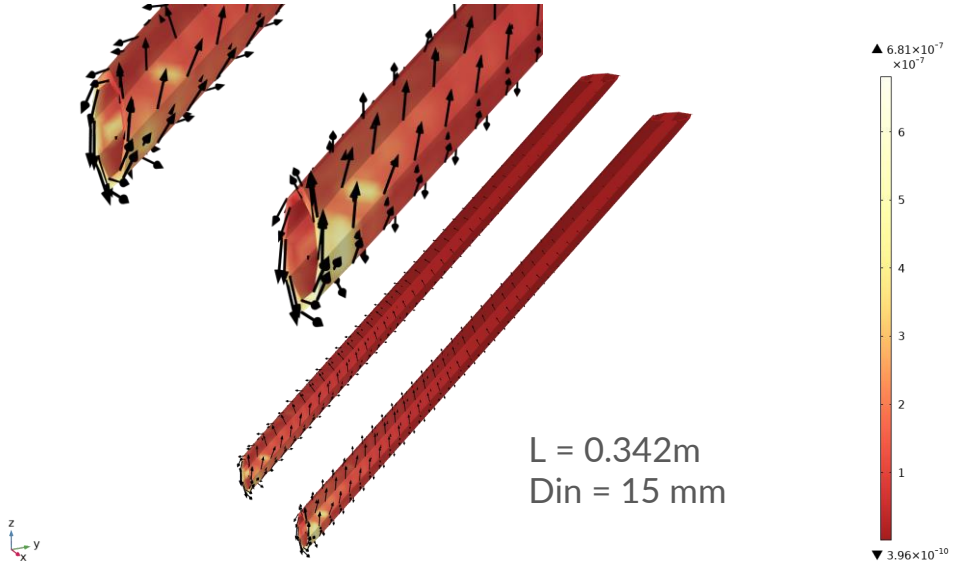
Thermal simulation of the superconducting injection tubes. We assumed 8W cooling power and used PEEK cylinder in the sc tube holder with Nb-47Ti tubes. We assumed an isotropic thermal conductivity of k = 25 W/(m K) at 10K.



Thermal simulation of the superconducting injection tubes. We assumed 8W cooling power and used PEEK cylinder in the sc tube holder with BSCCO2223 tubes. Thermal conductivity is anisotropic k = {4,4,10} W/(m K) at 10K.

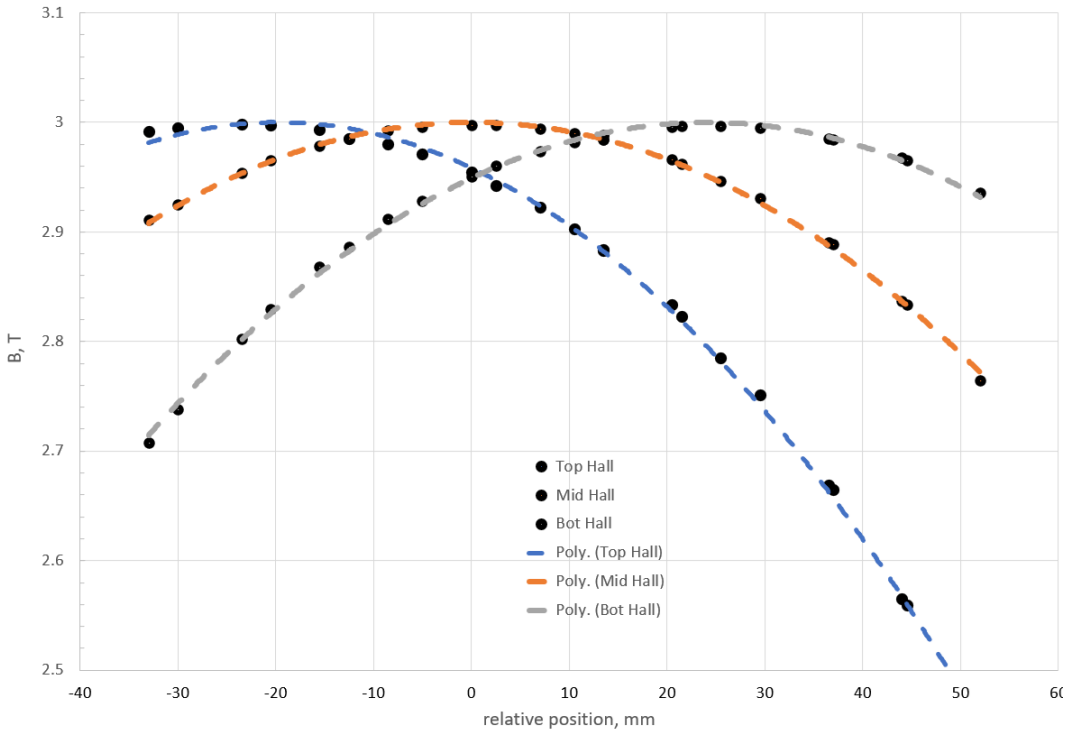


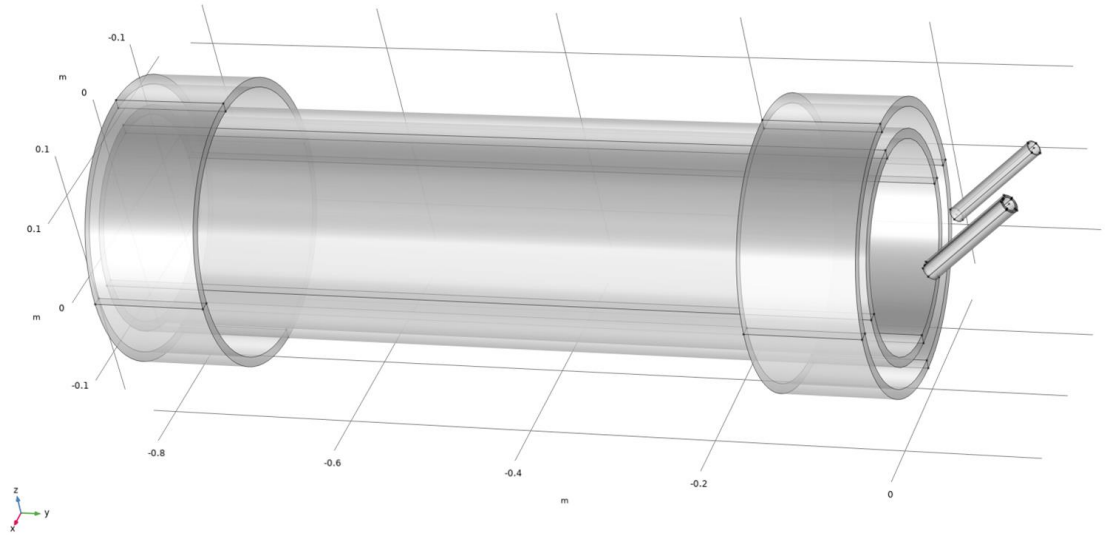




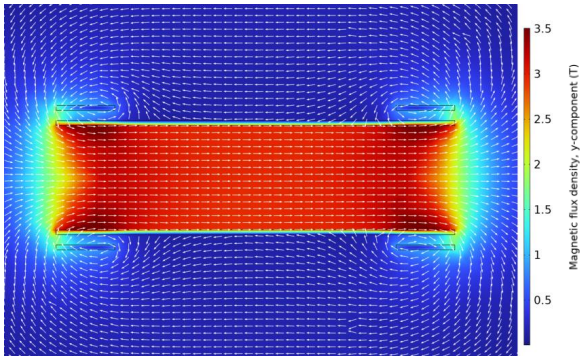
Simulated superconducting tubes. The colormap shows the J/J_C , which is the ratio of current density and critical current density at T = 4.2K and B = 3T. The vector maps shows the flow of induced current in the superconductor.

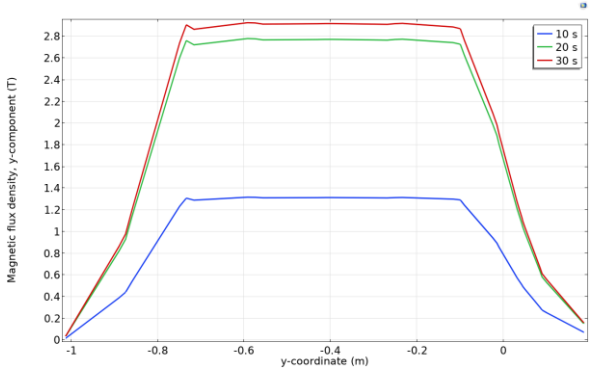
✓ Calibrated Hall sensors + ✓ Force and magnetic field shielding measurement design





- The main coil:
  - L = 825.5 mm length
  - D = 256.0 mm with 10 mm thickness
- The shim coil D = 298.8 mm with 10 mm thickness
  - L = 121.6 mm
  - D = 256.0 mm with 10 mm thickness
- We use Niobium-Titanium superconducting tube
  - L = 125mm
  - D = 16.5mm with 1mm thickness

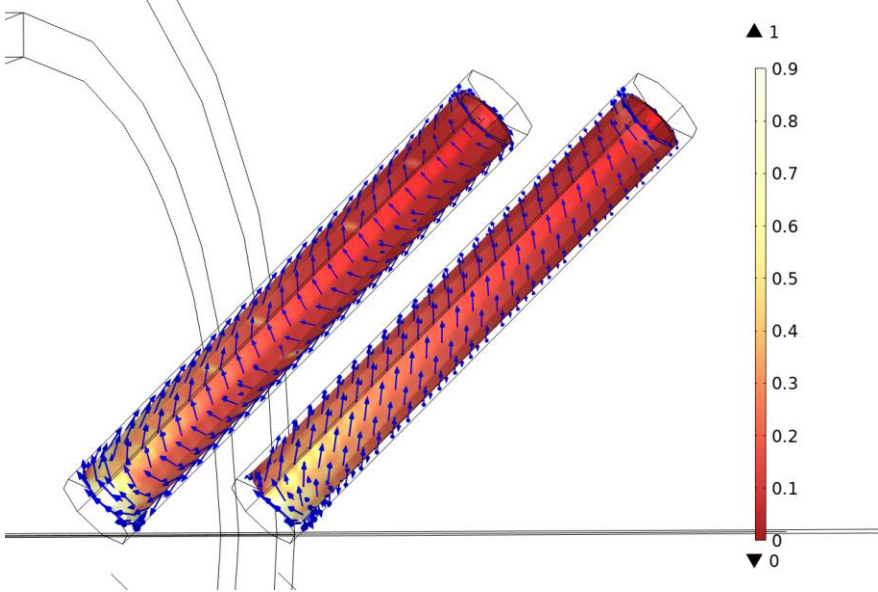


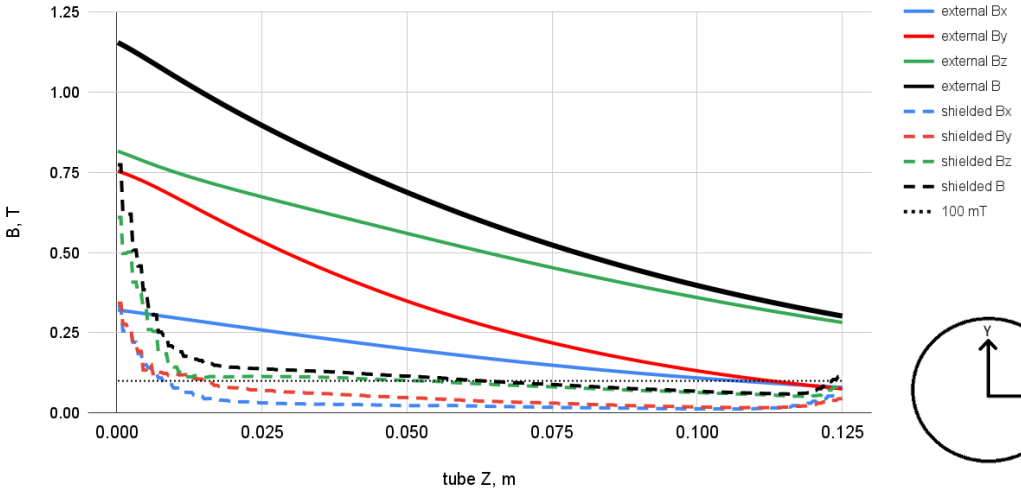


- Used A-H field formulation for the EM model
- EM model is fully coupled to thermal model
- The properties of the superconducting materials are described by ***Jc(T, B)***
- Simulation run time is 27-42 minutes on *3.4 GHz Quad-Core Intel Core i5*

Magnetic field screening in superconducting NbTi tubes

- We require magnetic field in transversal direction B < 100mT
- B field along the axis of the sc tube can remain higher
- Color scheme illustrates the ratio of the critical current density and local current density the J/Jc





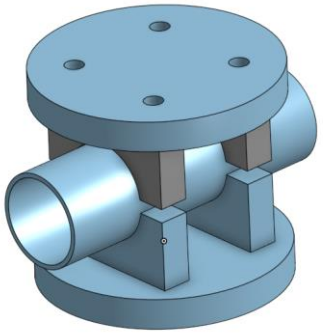
✓ Bx and By < 100mT

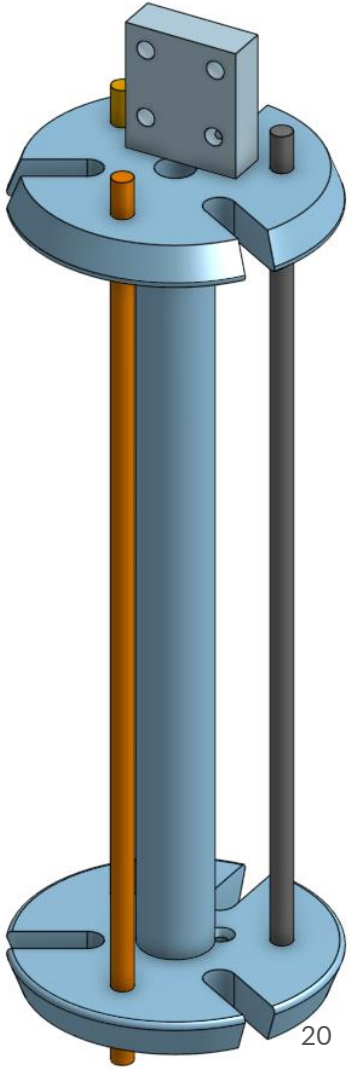
✓ Bz ≈ 100mT

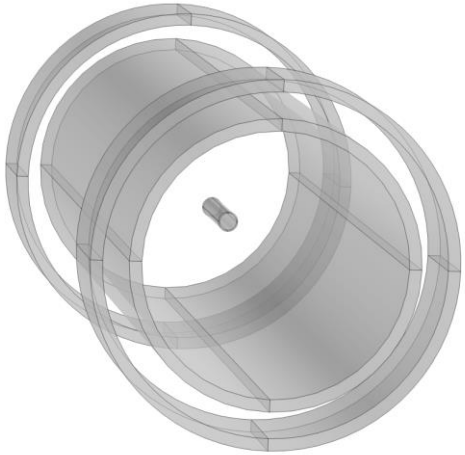
✓ Consistent shielding throughout the tube length

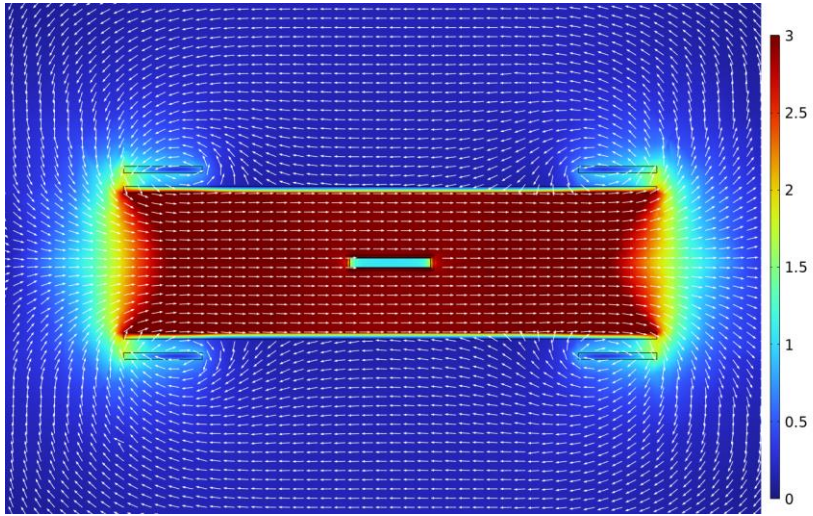
Measuring preparations for late July

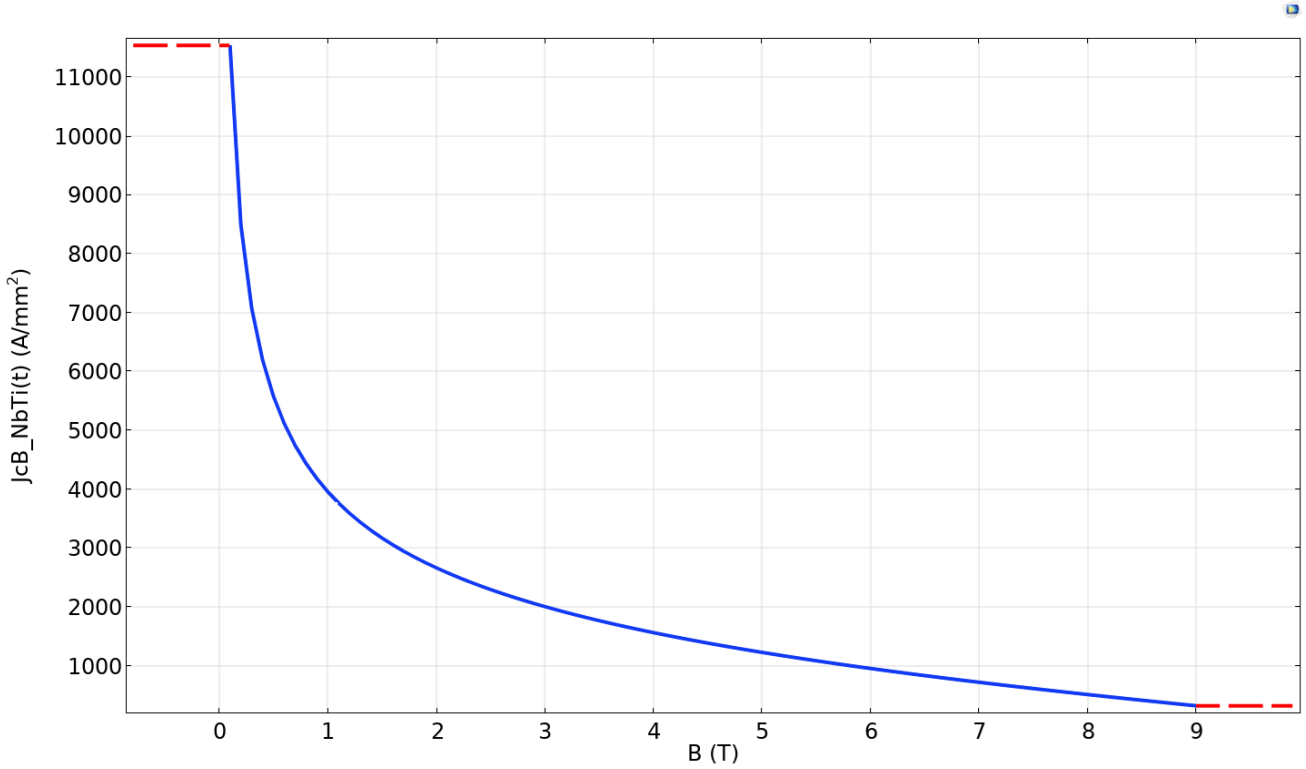
- Measure the magnetic field screening in BSCCO and NbTi tubes in LHe
- Using 15T magnet here at **PSI**
- Planning to measure with the tube placed || and ⊥to **B**

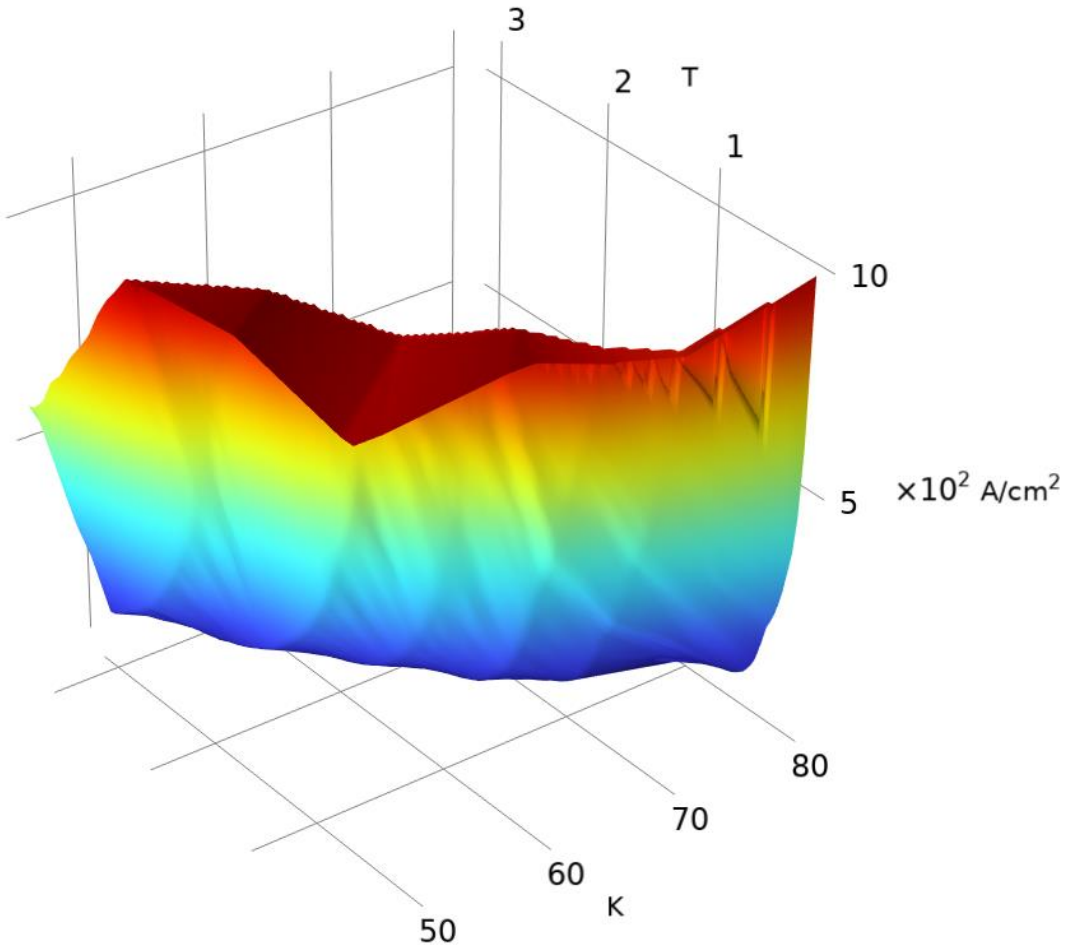


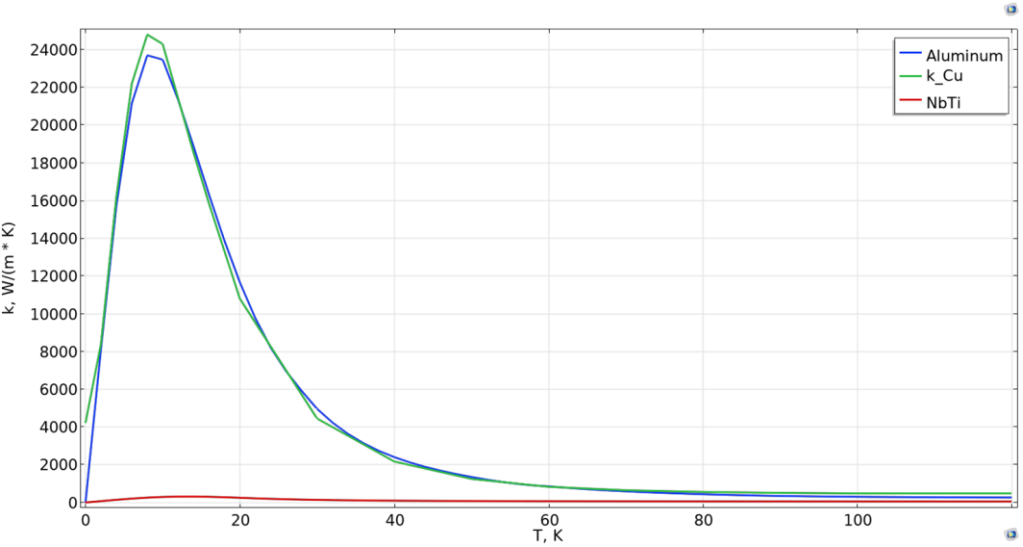


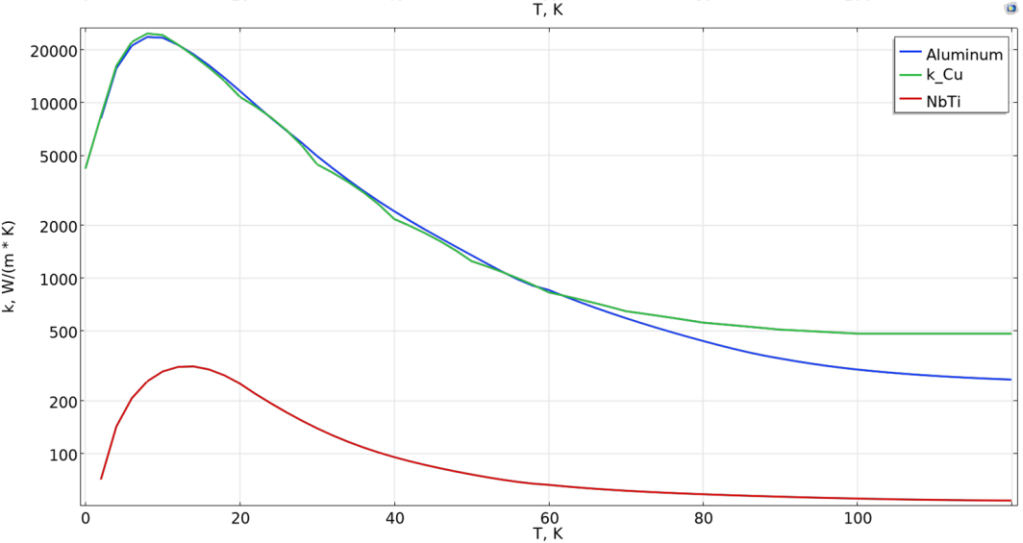


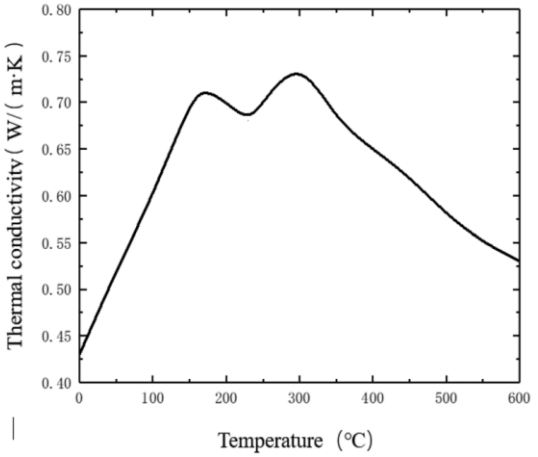



11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
JcB_NbTi(t) (A/mm²)
0
1
2
3
4
5
6
7
8
9
B (T)


3
2
T
1
10
5
×10² A/cm²
80
70
60
K
50
×10²
10
9
8
7
6
5
4
3
2
1







Zhao, Fuhai & Liu, Zhiqiang & Chen, Rifan & Hao, Yi & Ma, Zhihao. (2022). The effect of temperature field on the characteristics of carbon fiber reinforced thermoplastic composites in the laying and shaping process. The International Journal of Advanced Manufacturing Technology. 121. 10.1007/s00170-022-09795-9.

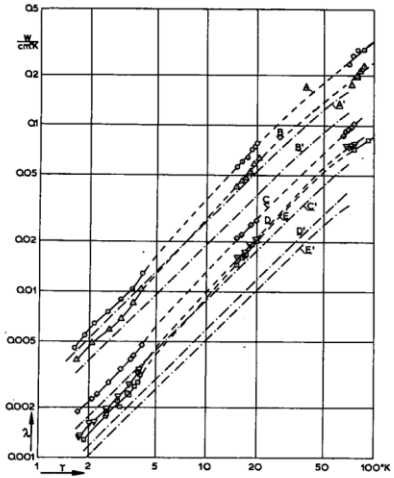


Fig. 1. The thermal conductivity λ and its electronic part λ_e of steels, both in watt/cm–deg, *versus* temperature in °K.

⊙ 1287 D (curve A), △ 3703 (curve B),
◇ 1287 I (curve C), ▽ 1798 H (curve D),
⊡ 3754 (curve E).

M.S.R. Chari, J. De Nobel,
Thermal conductivity of some steels at low temperatures,
Physica,
Volume 25, Issues 1–6,
1959,
Pages 73-83,
ISSN 0031-8914,
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Abstract: Synopsis
The measurements made in the Kamerlingh Onnes Laboratory on the thermal conductivity of steels at low temperatures were extended to liquid helium temperatures and the technique was improved. Five specimen of different composition and heat treatment have been investigated. The lattice conductivity is approximately proportional to T1.2. With increasing nickel content from 2% to 27% (Ni + Cr) it decreases by about 60, 58 and 37% at the temperatures 70, 20 and 4k respectively. The electronic thermal conductivity decreases by about 80% for the mentioned temperatures.