

PSI Center for
Photon Science



UNIVERSITY OF
CAMBRIDGE



Towards the magnetic characterization of a meter-long bulk high-temperature superconducting undulator



Alexandre Arsenault :: Center for Photon Science
:: Paul Scherrer Institute

Magnetic measurement workshop #23

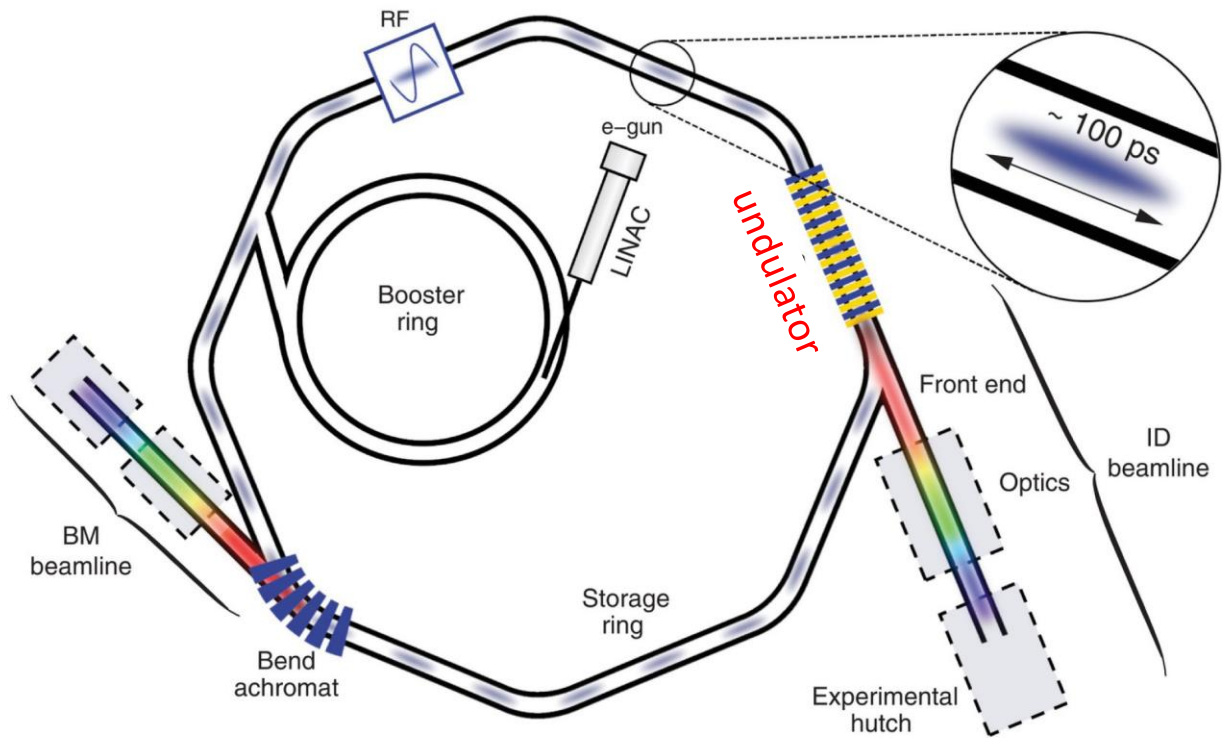
October 11, 2024, Bad Zurzach



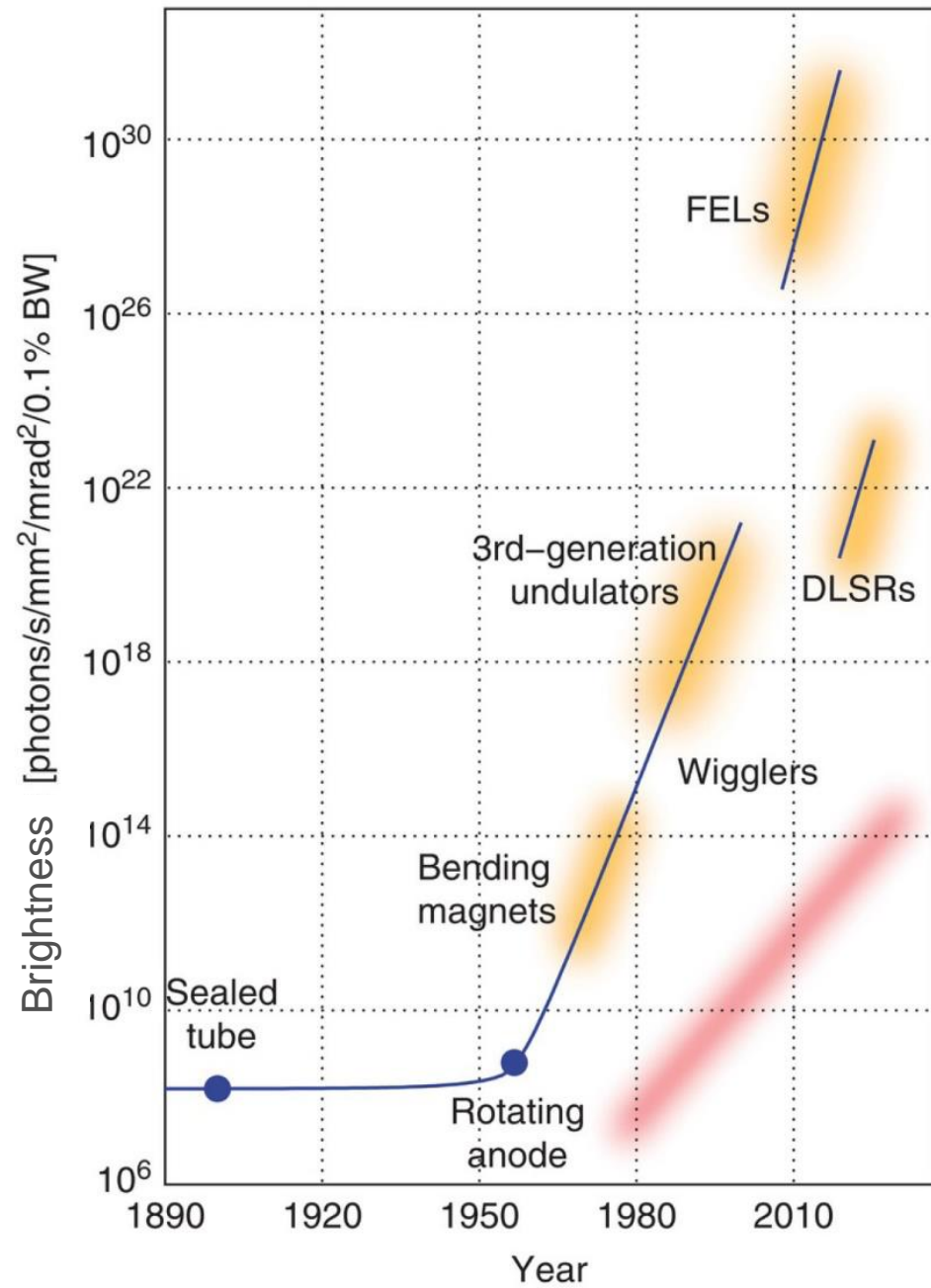
Swiss Accelerator
Research and
Technology

- The HTS (REBCO) bulk Staggered Array undulator
- Results on short samples
- Status of the meter long HTS Undulator prototype
- Conclusions

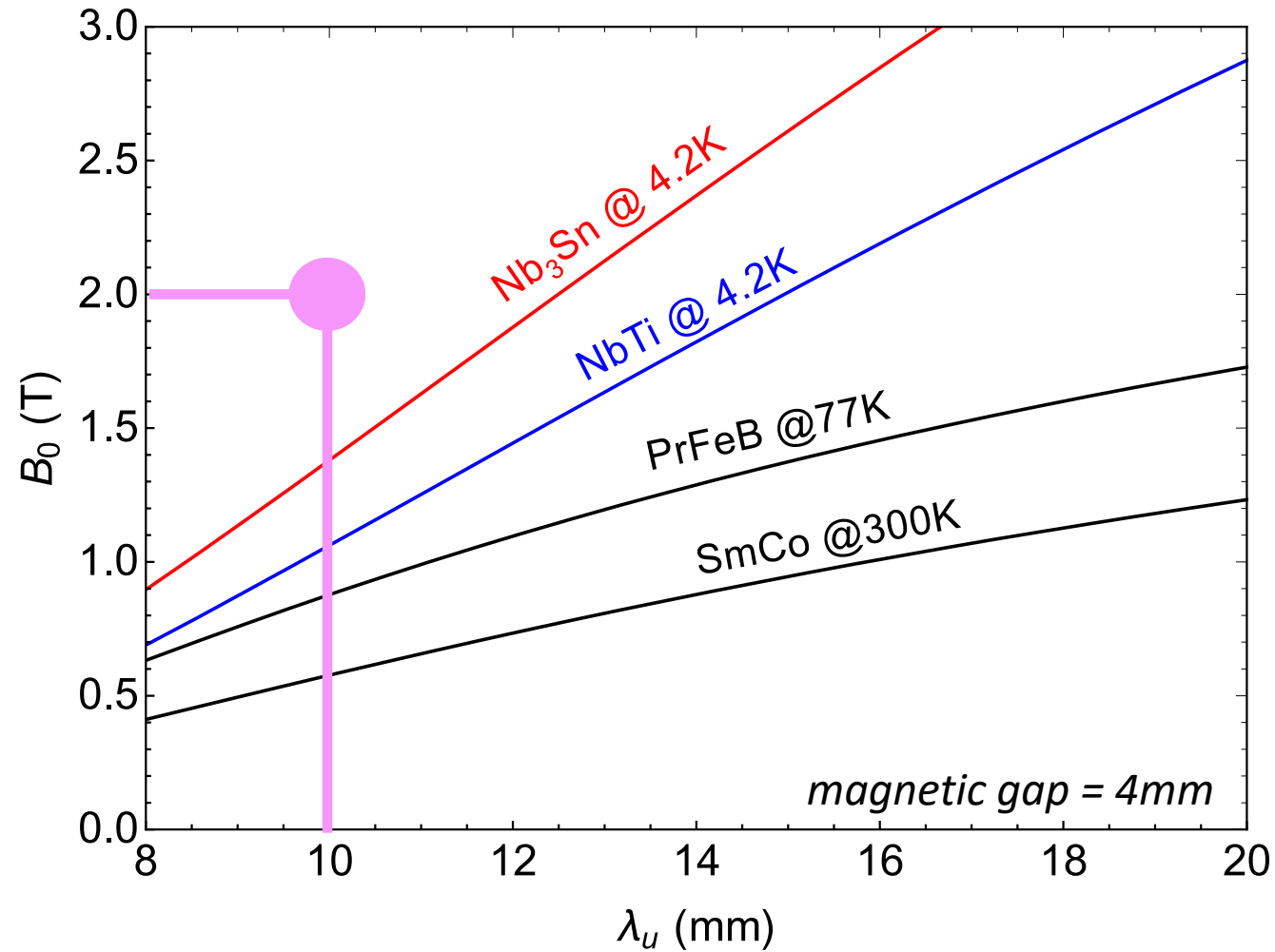
Introduction



$$\lambda = \frac{\lambda_u}{2n\gamma^2} \left(1 + \frac{1}{2}K^2 \right) \quad K = \frac{B_0 e \lambda_u}{mc 2\pi}$$

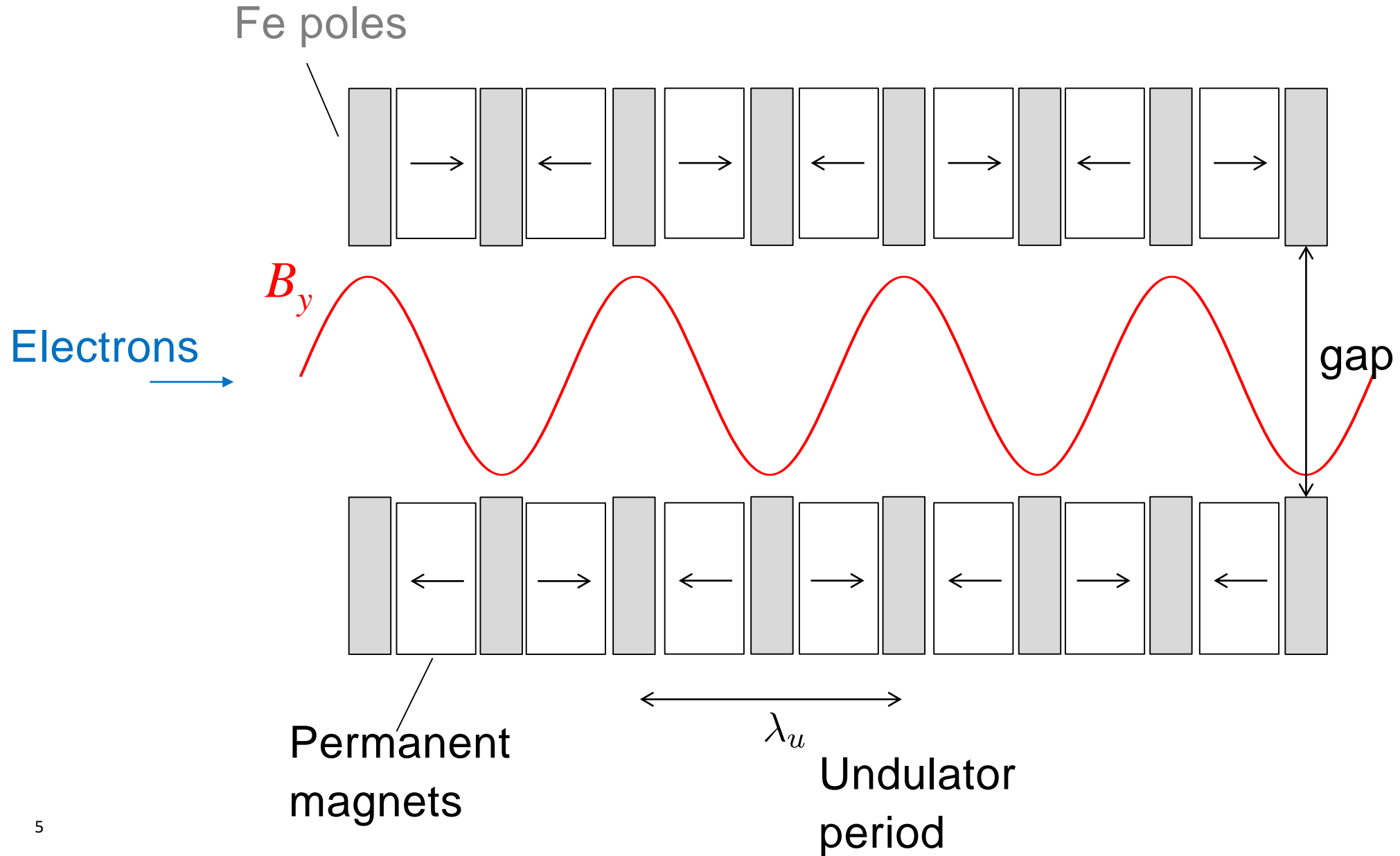


The new μ -Tomography beamline of SLS2.0

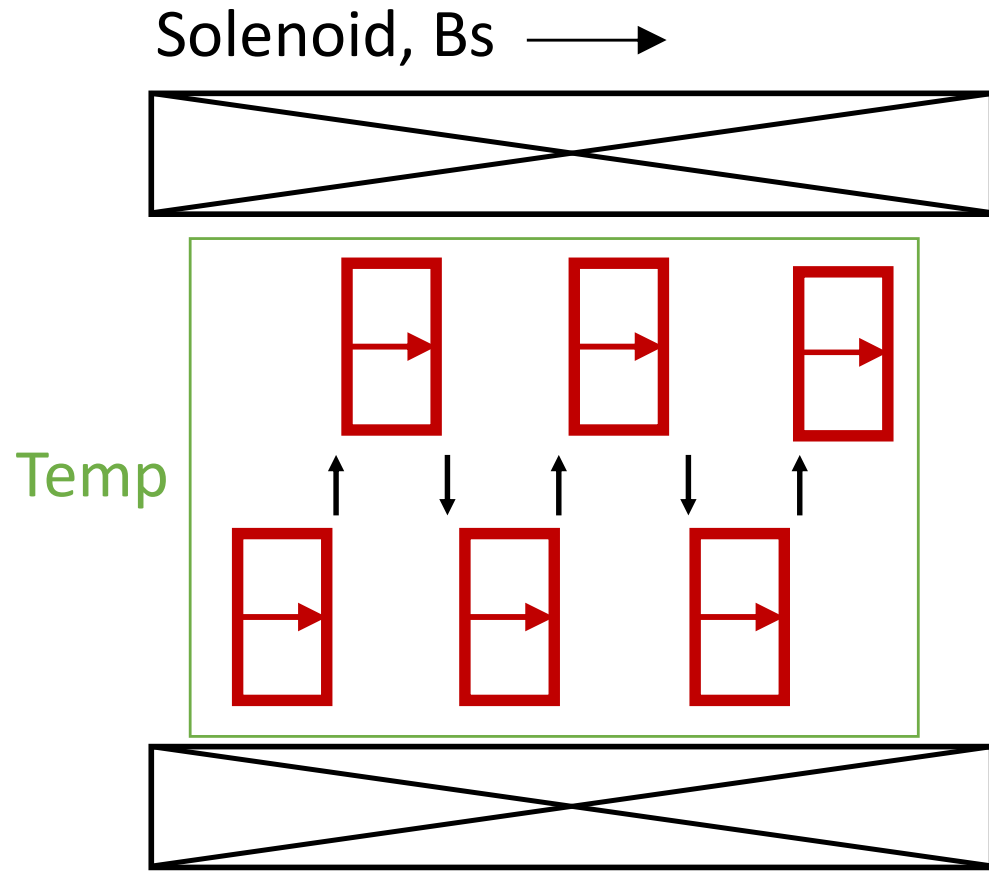


[Scaling laws: E.R. Moog, R.J. Dejus, and S. Sasaki , Light Source Note: ANL/APS/LS-348
James Clarke, FLS 2012, March 2012, Ryota Kinjo Physical Review Special Topics, Accelerator
and Beams 17, 022401 (2014)]

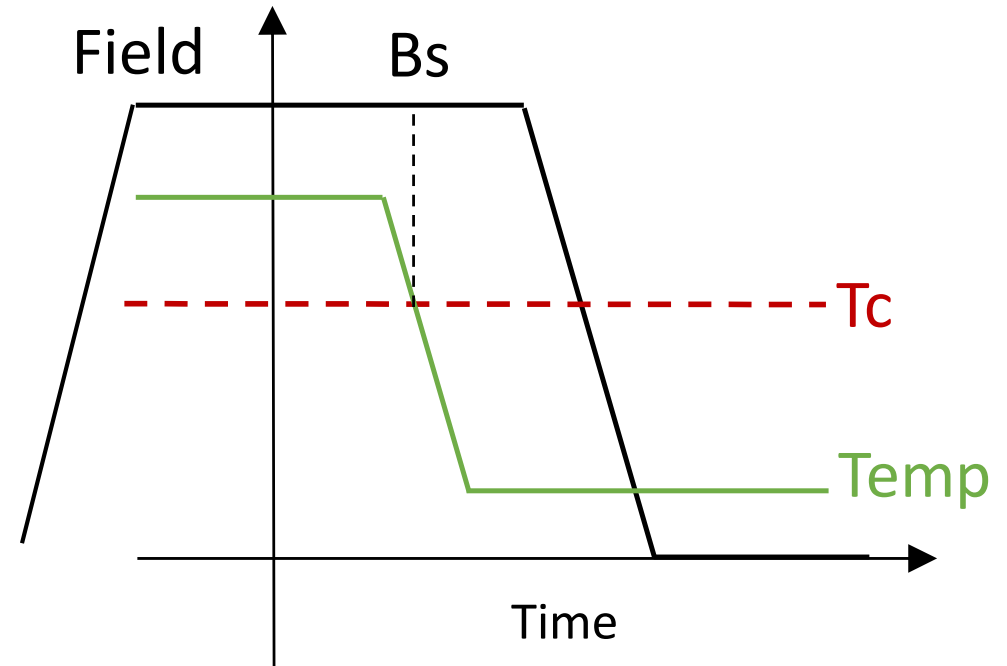
Permanent Magnet Undulator with Fe poles



Superconducting Staggered Array Undulator

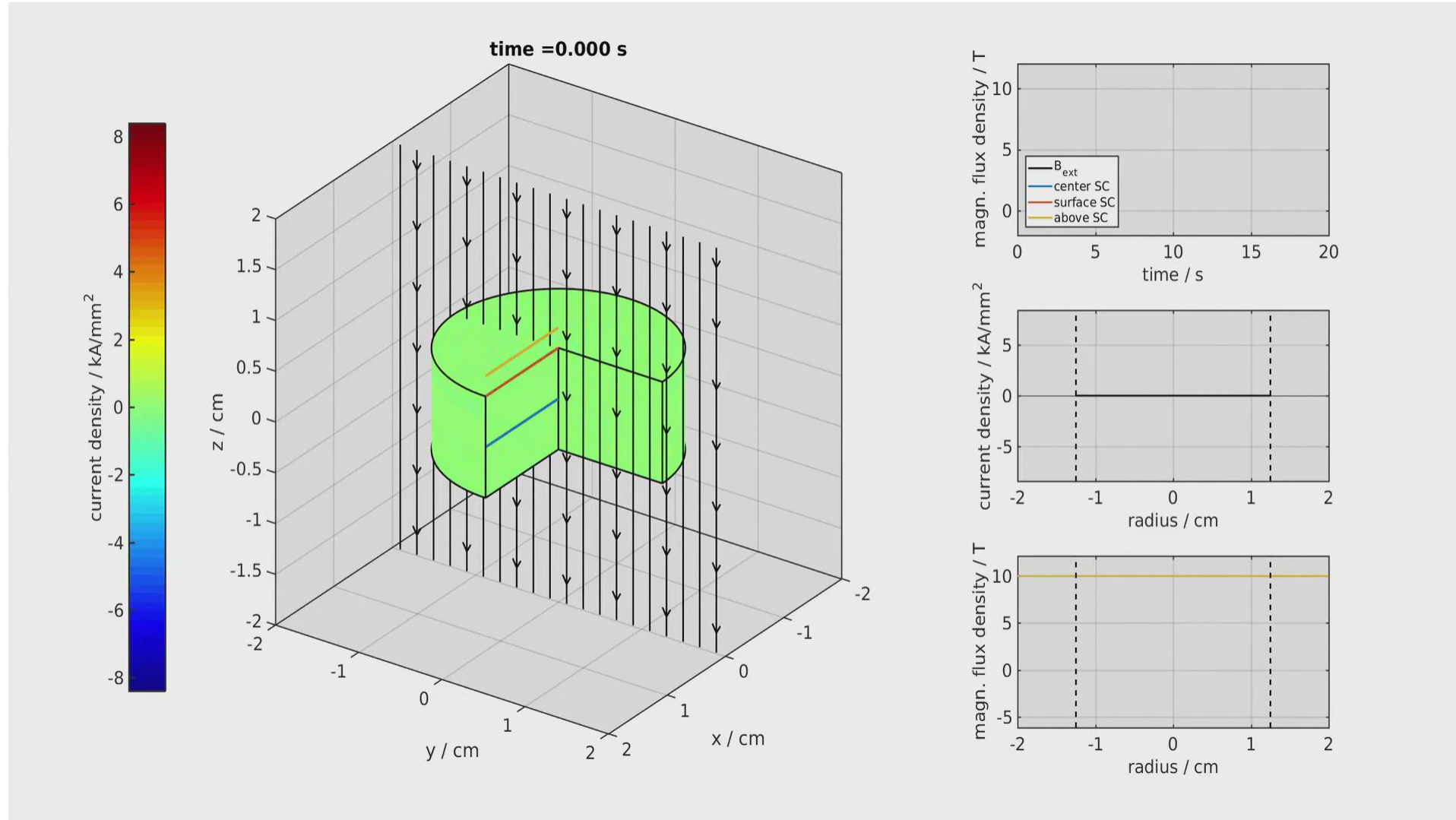


Example of *field cooling* magnetisation

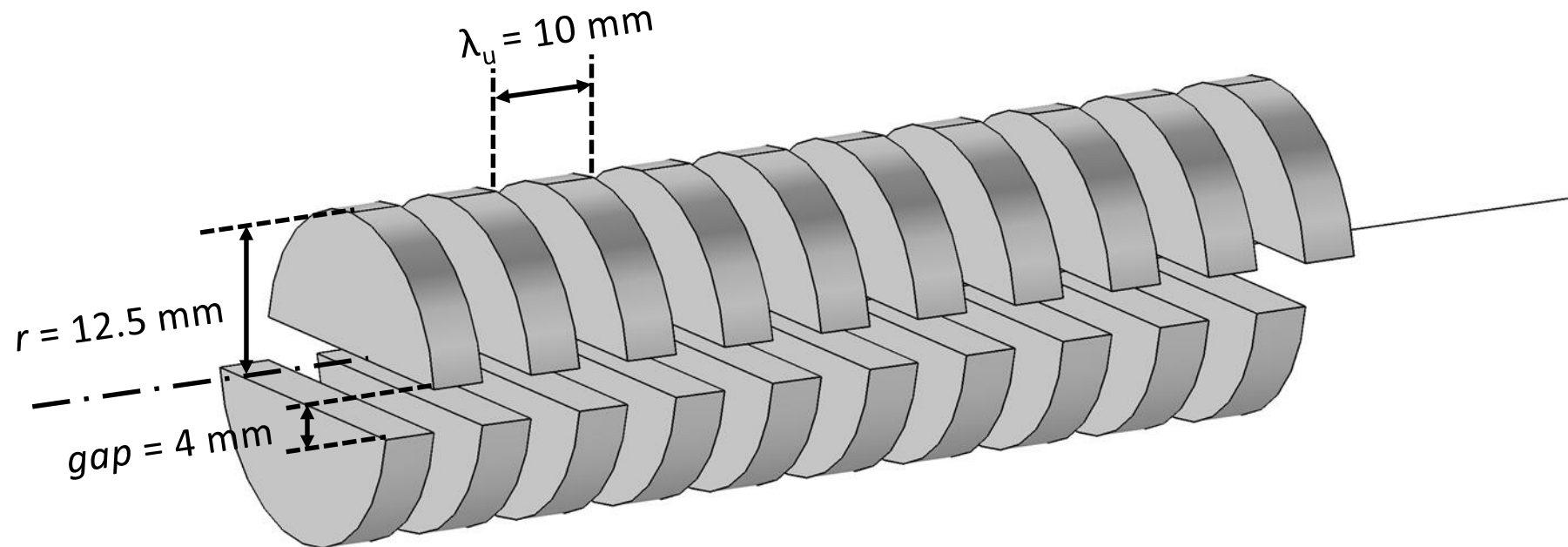


 GdBCO $T_c=92\text{K}$

Example of Field Cooling (FC)



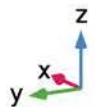
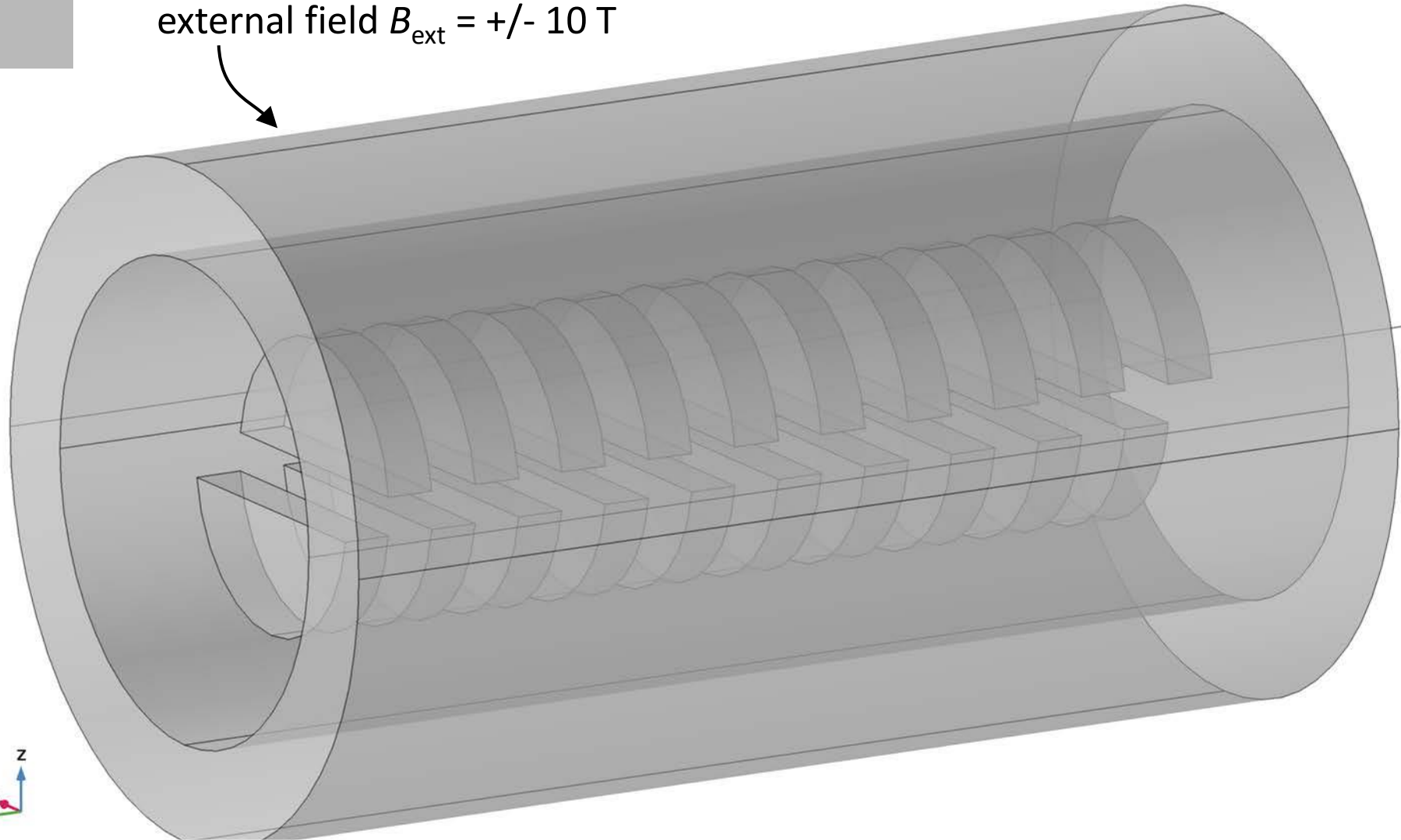
Superconducting Staggered Array



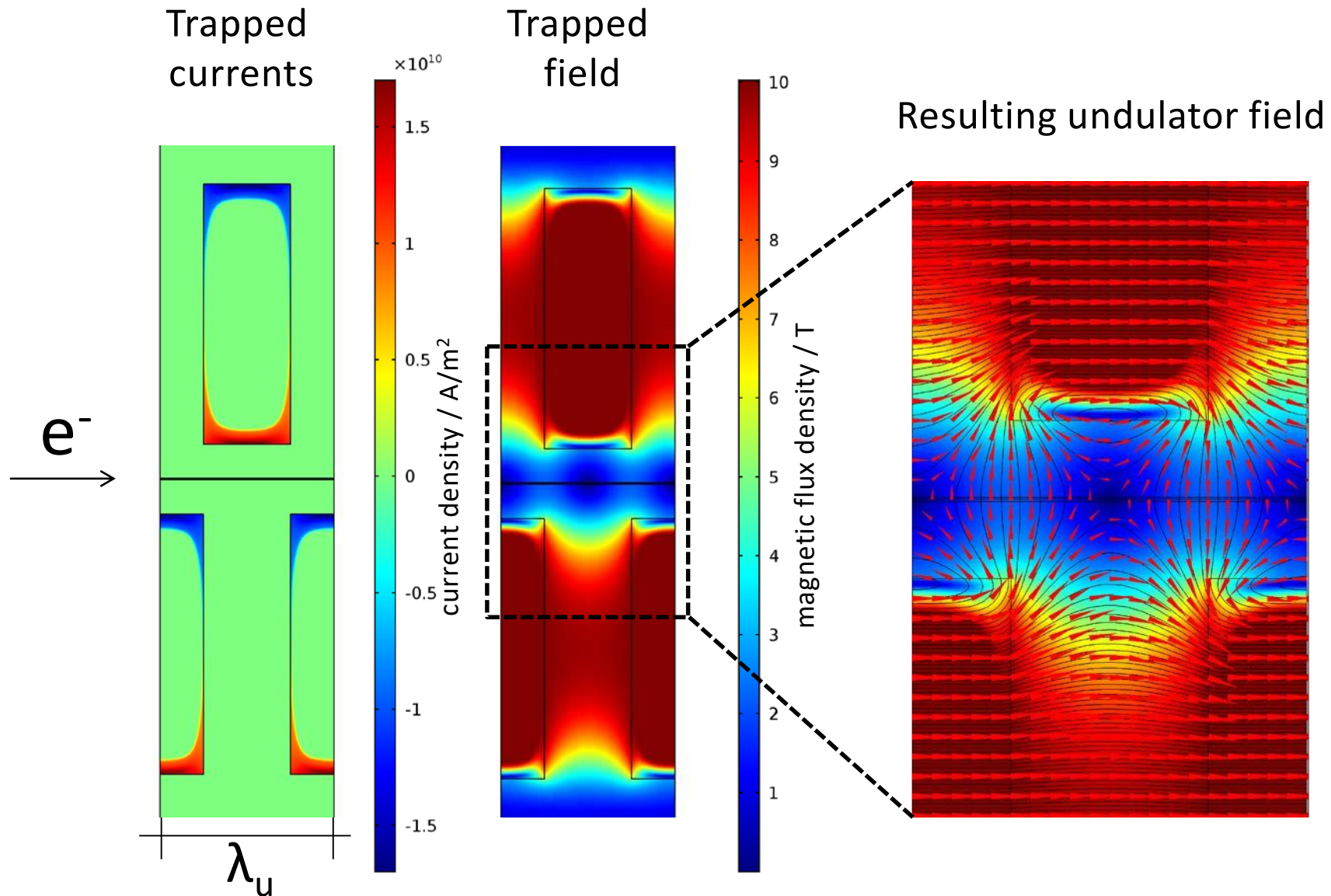
Superconducting Staggered Array



- Superconducting solenoid providing external field $B_{\text{ext}} = +/- 10 \text{ T}$



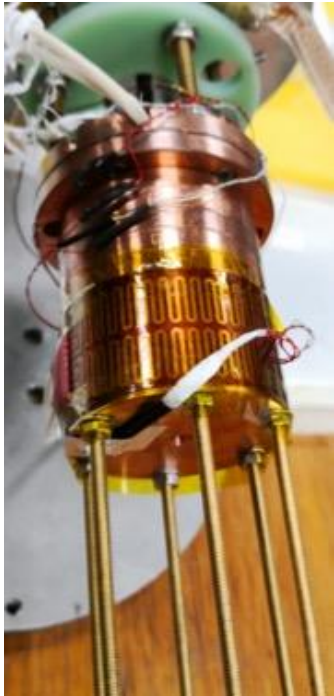
Superconducting Staggered Array



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Samples Overview

1st Bulk Sample



6mm gap

2nd Bulk Sample



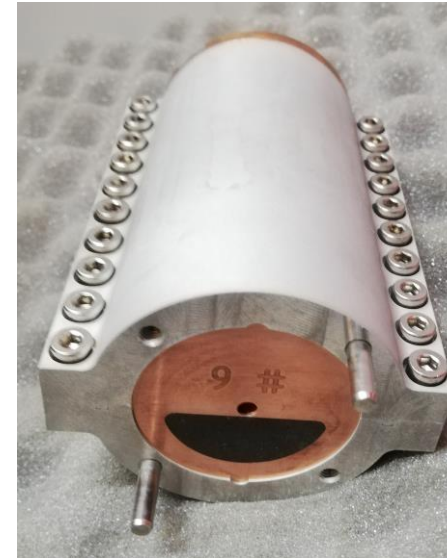
4mm gap

Bulk Industrial Sample



4mm gap

Bulk Simplified Sample



4mm gap

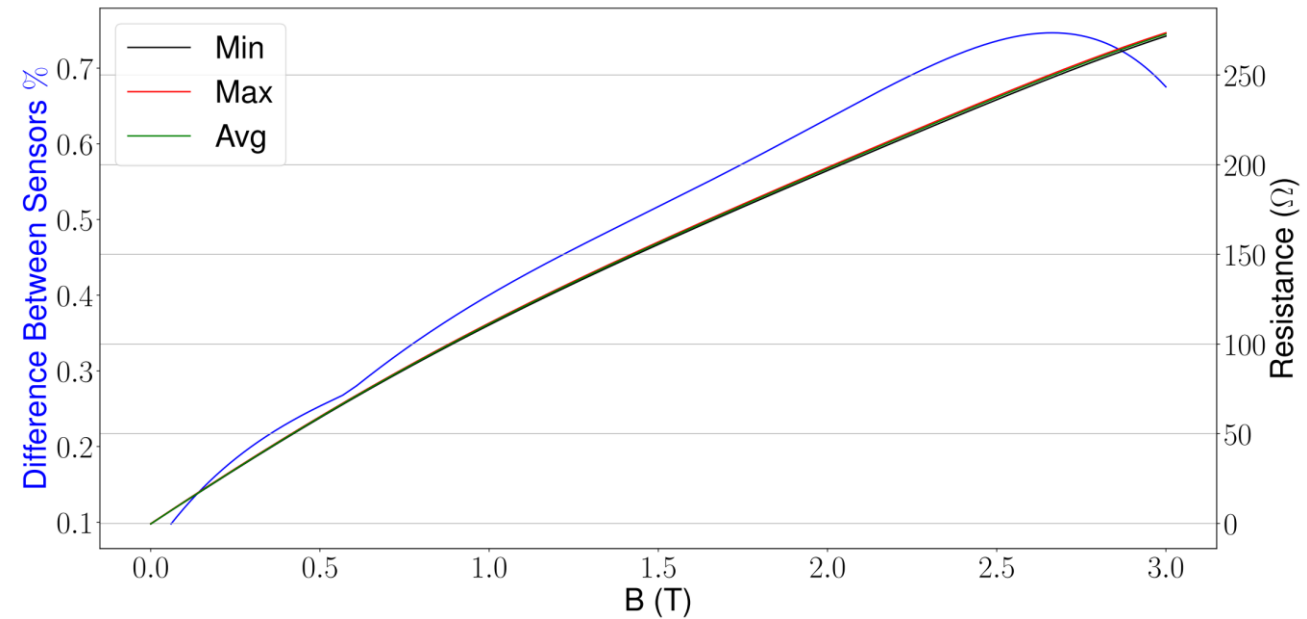
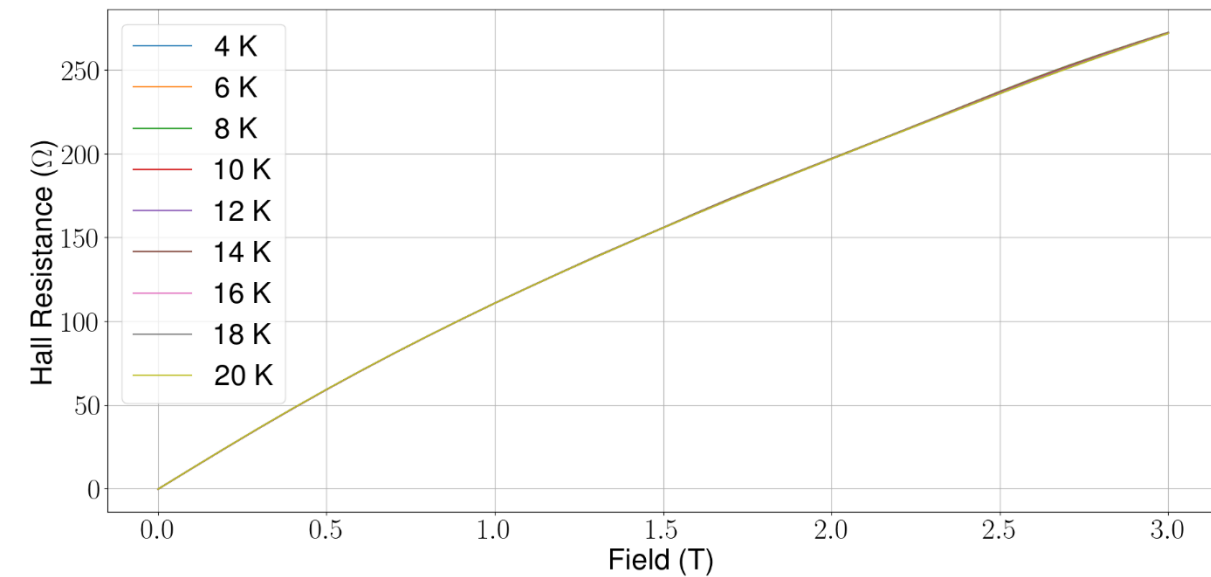
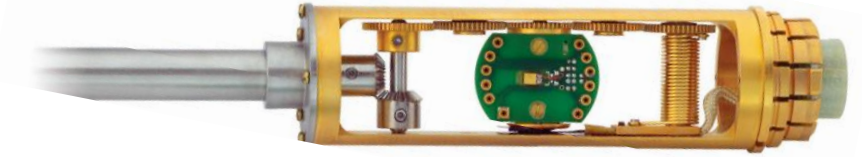
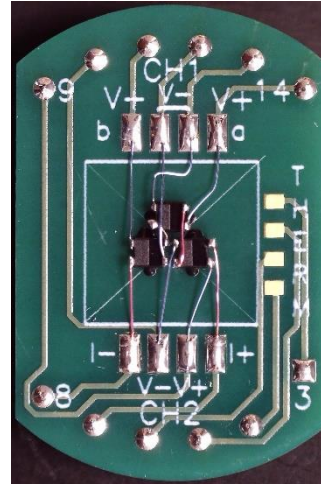
The "Good" Sample



4mm gap

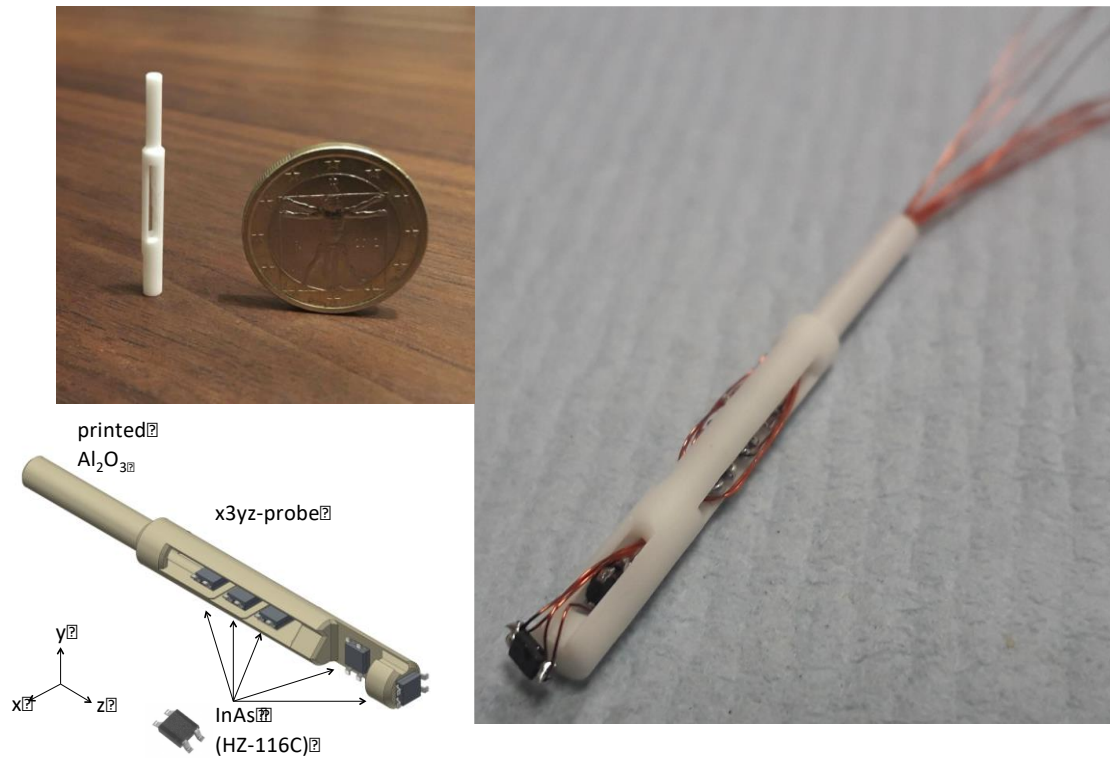
Hall sensor array

- Calibrated 12 Hall sensors in a PPMS from 4-20 K and from 0-3 T
- Difference of <0.8 % between sensors

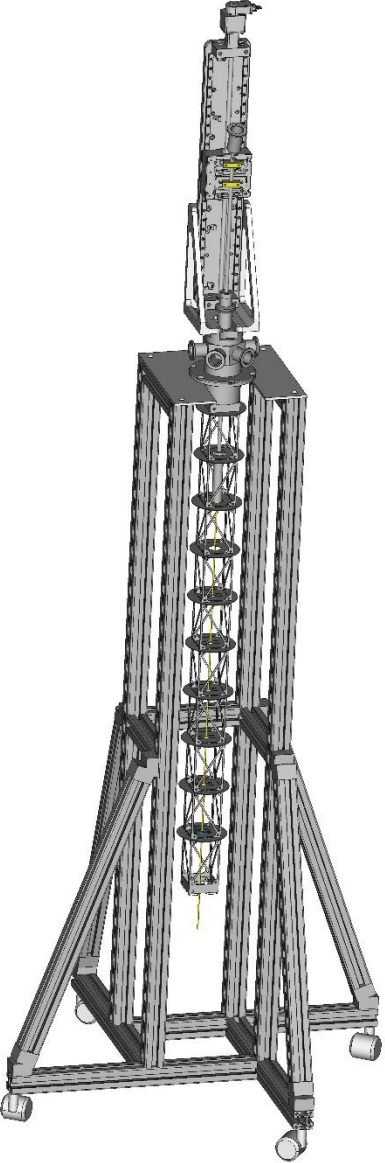
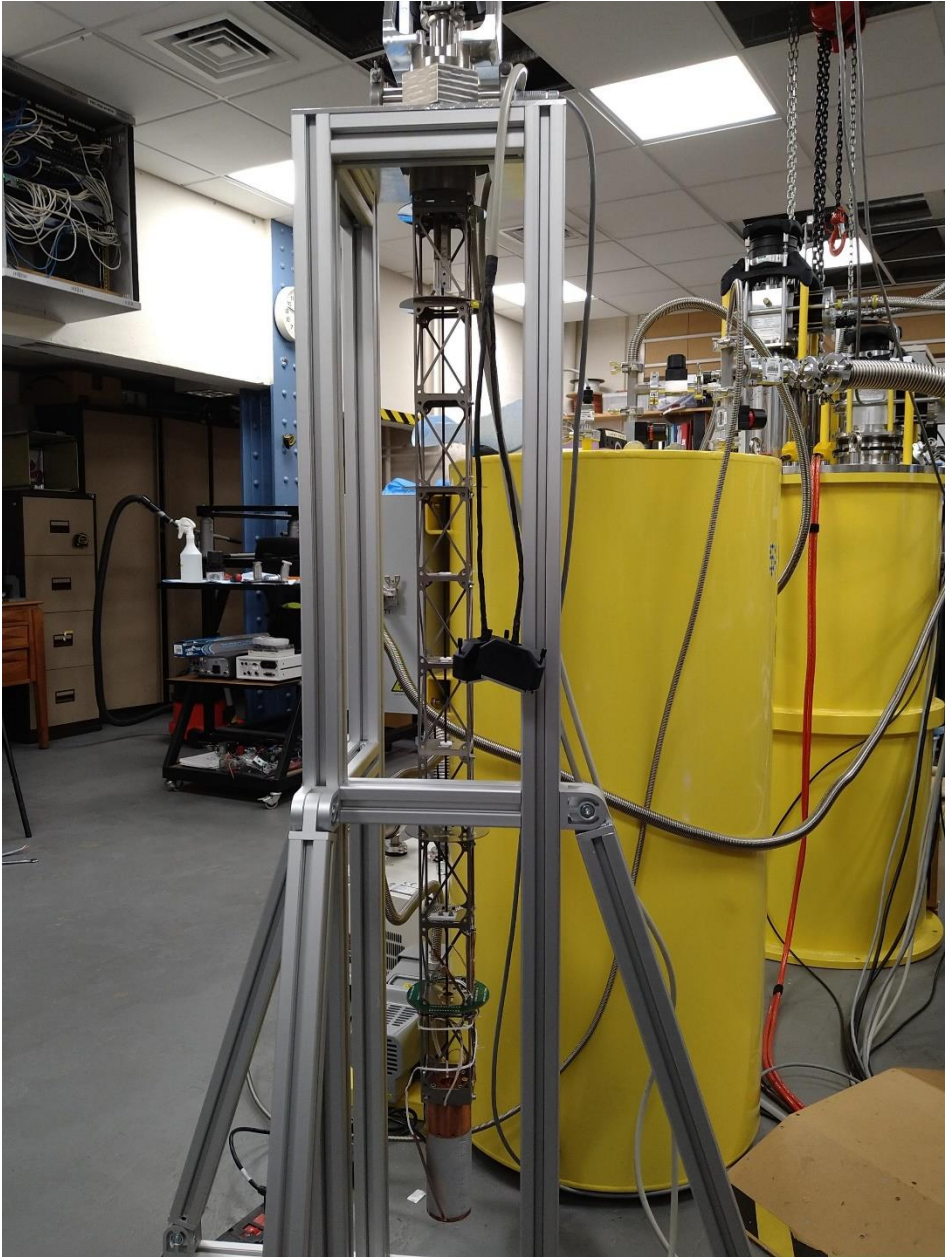


Hall sensor array

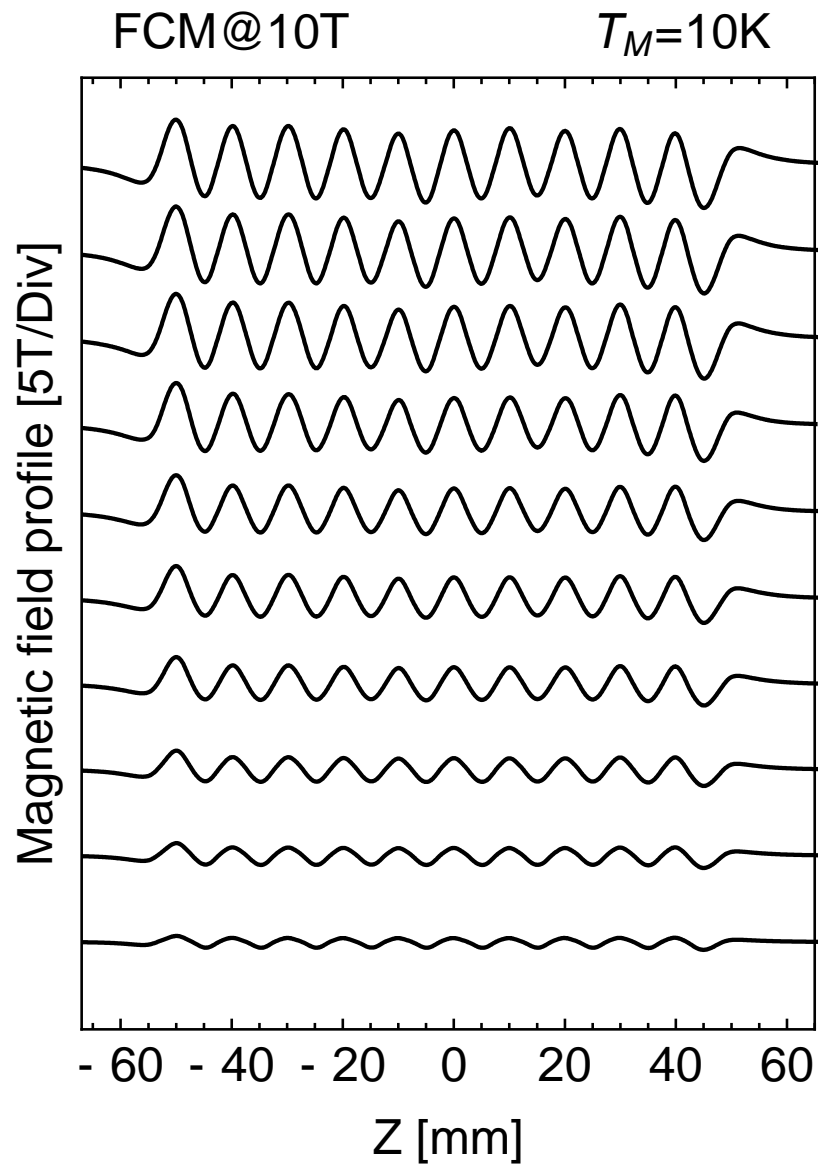
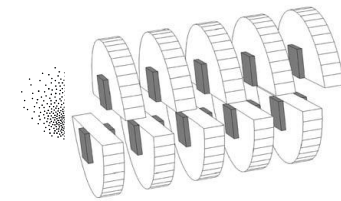
- 5 Hall sensors embedded in 3D printed holder
- 3 offset sensors to measure the undulator field
- 2 others to measure the perpendicular fields



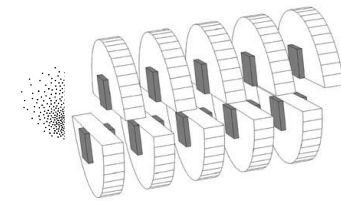




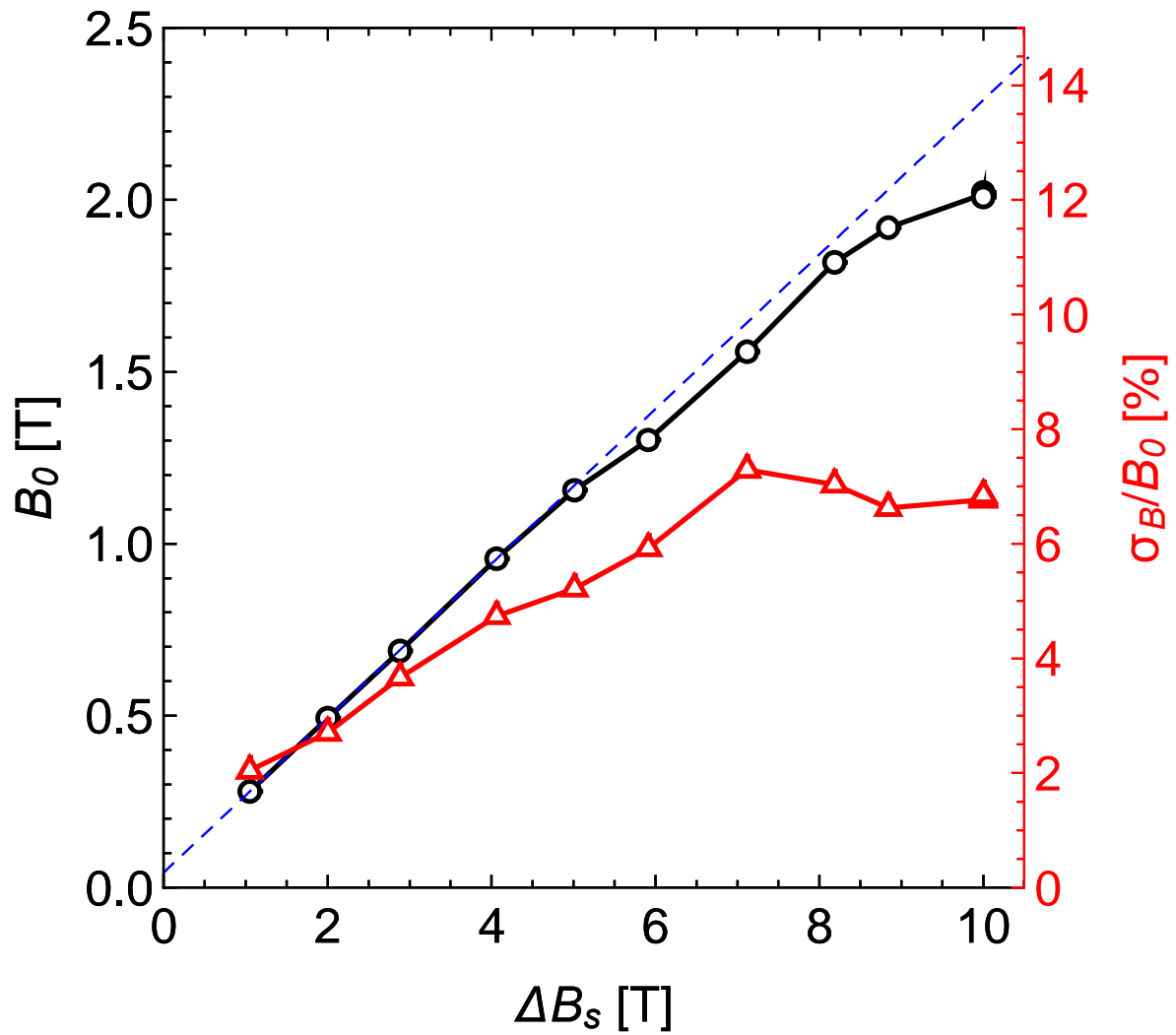
Planar Hybrid: CAN-SUPERCONDUCTOR



Planar Hybrid: CAN-SUPERCONDUCTOR



GdBCO - CAN



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THE METER LONG PROTOTYPE

Active length : 1.0 m

Total length : < 2m

period length : 10.5 mm

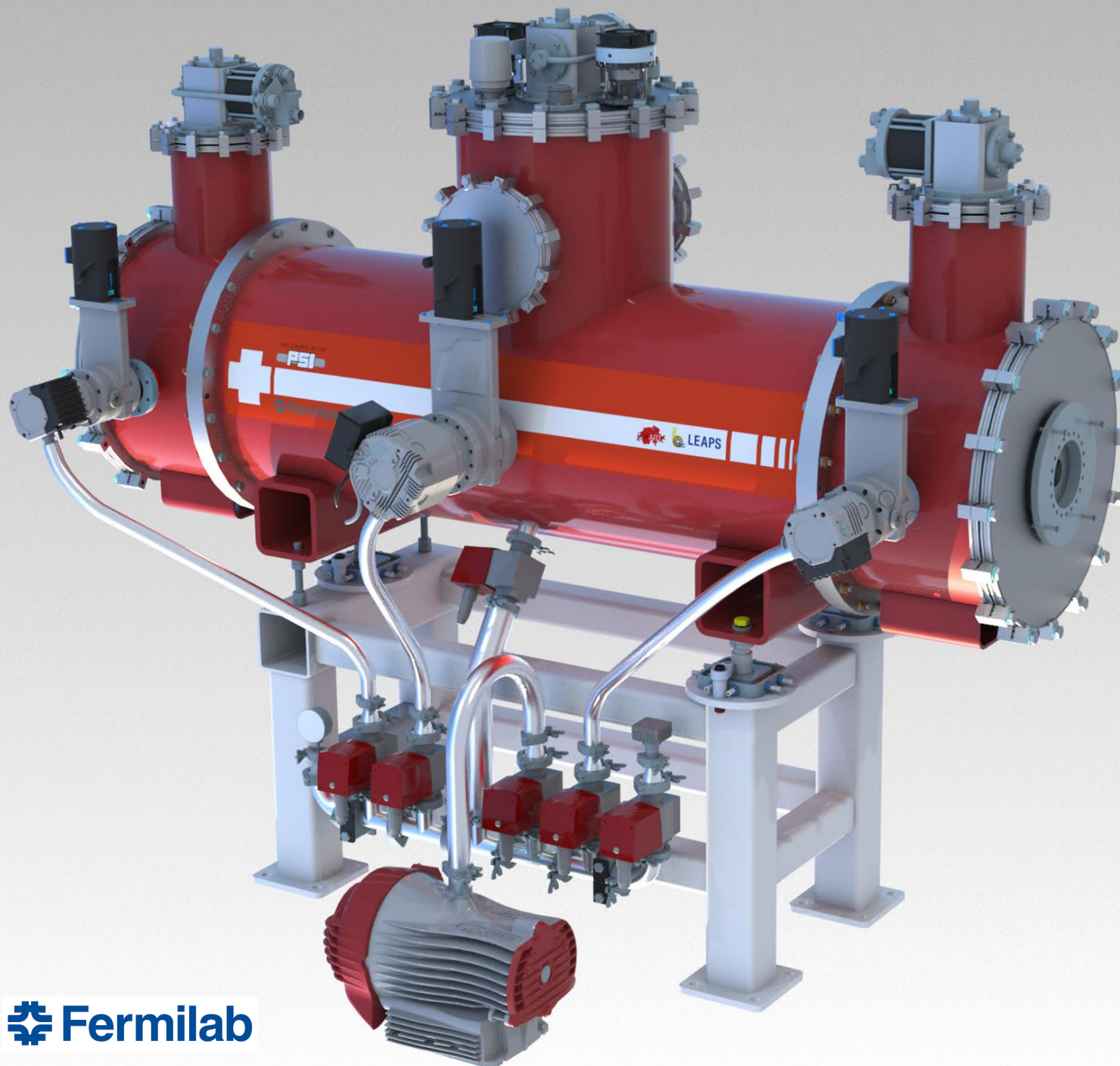
magnetic gap : 4.5 mm

$B_0 \sim 1.8$ T

Cryocoolers

HTS Mag-temp 10K

LTS temp 4.0K



High Temperature Superconducting Undulator for iTomcat beamline at PSI

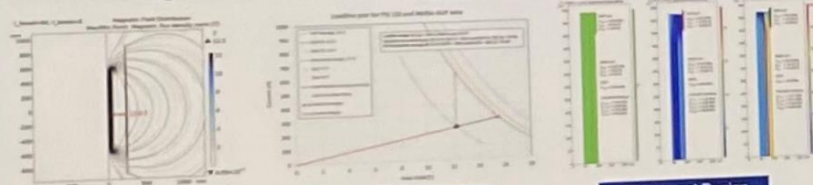
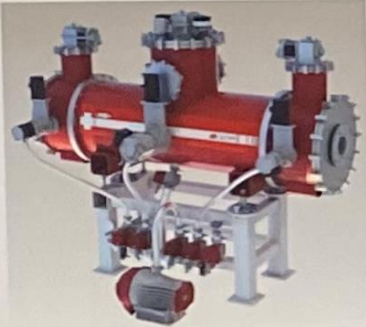
FERMILAB-POSTER-21-120-TD

Superconducting Undulators

Superconducting Undulators (SCUs) are the natural continuation in the evolution of insertion devices. The use of permanent magnets has been pushed to the limit by installing the arrays directly in the beam UHV to reduce the gap (In-Vacuum Undulators IVU) and even further by cooling them down to cryogenic temperatures to increase the remanence field (Cryogenic Permanent Magnet Undulators CPMU). In order to further increase the magnetic field of these devices, a jump in technology is required: hence the implementation of superconductivity. Development programs both in the US and in Europe have shown that SCUs generate stronger field on axis than comparable permanent magnet-based devices and that the use of superconductivity does not compromise the operation of synchrotron storage rings or FELs. For period lengths above 13 mm, SCUs made out of NbTi show a significant improvement in field on axis compared to CPMUs; furthermore, a large portion of the superconducting technology potential, Nb₃Sn and HTS, has yet to be exploited. Bulk HTS undulators, as proposed by PSI, allow to extend the functional capability of these devices below 10 mm period length.



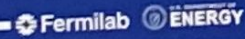
Superconducting coil conductor	Nb ₃ Sn & NbTi
Maximum magnetic field	12T
Nominal magnetic field	10T
Nominal ramp rate (<10T)	3mT/s
Ramp rate (>10T)	1mT/s
Warm bore diameter	50mm
Length of the good field (1%) \times15mm	1m
Stray field along the beam axis > 1.5m from the center	<math><0.1</math>mT
Radial stray field from the center outside the cryostat	<math><1</math>mT
Current leads conductor	HTS
Maximum current	1.0 kA
Cooling system	Cryocooled
Operating temperature	<math><-6</math>K
Persistent mode	NO



Magnetic Design

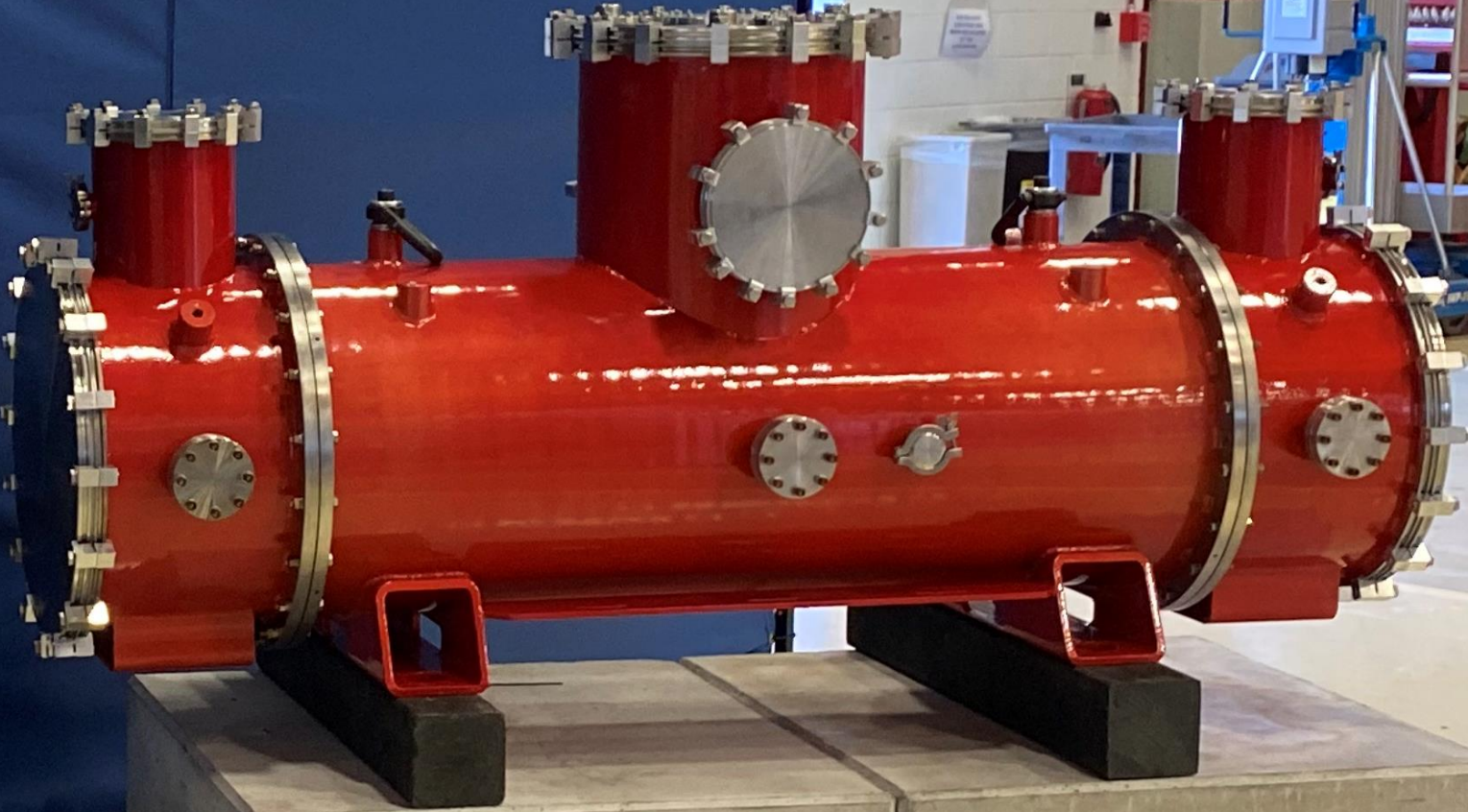
Superconductor Design

Mechanical Design

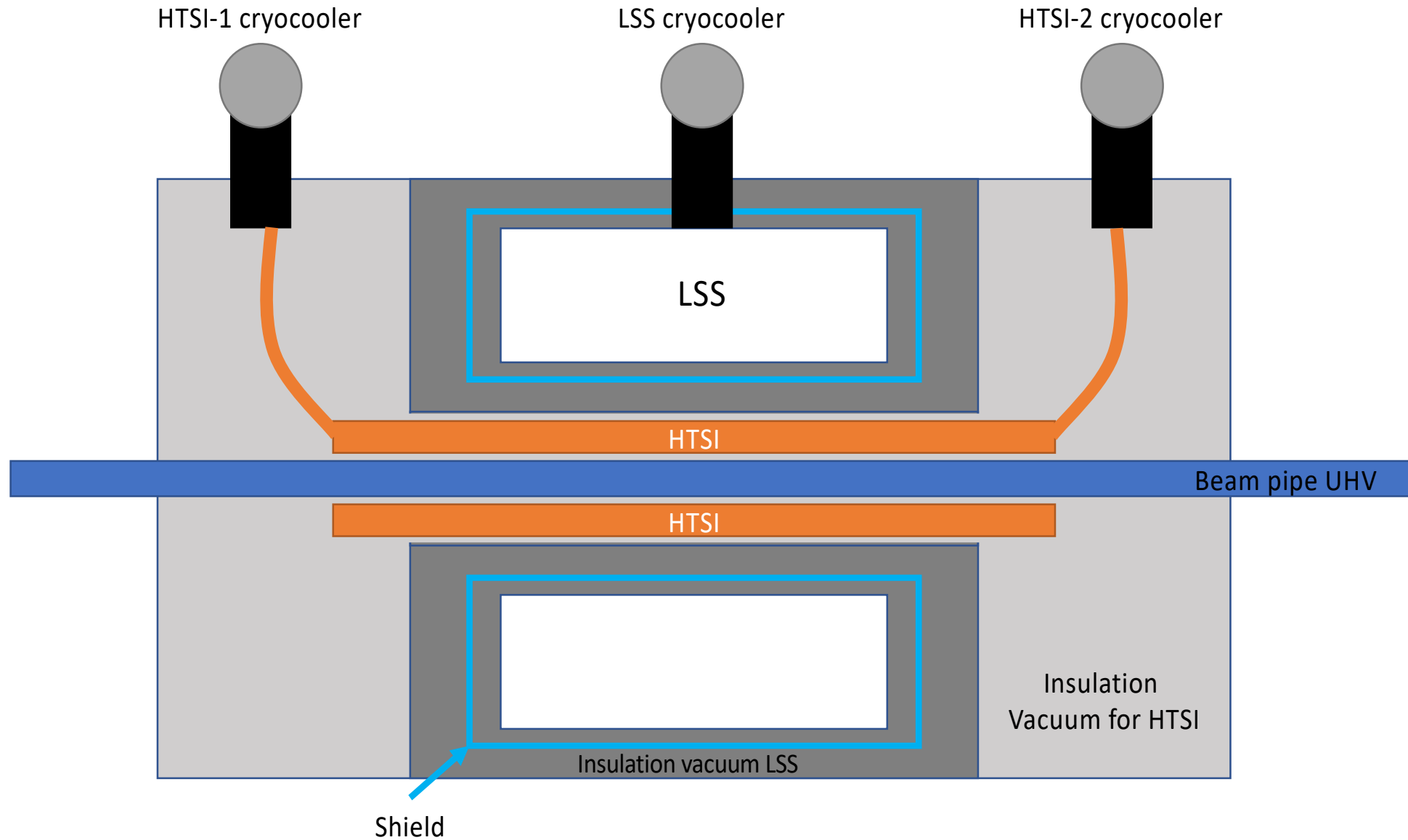


Fermilab National Accelerator Laboratory

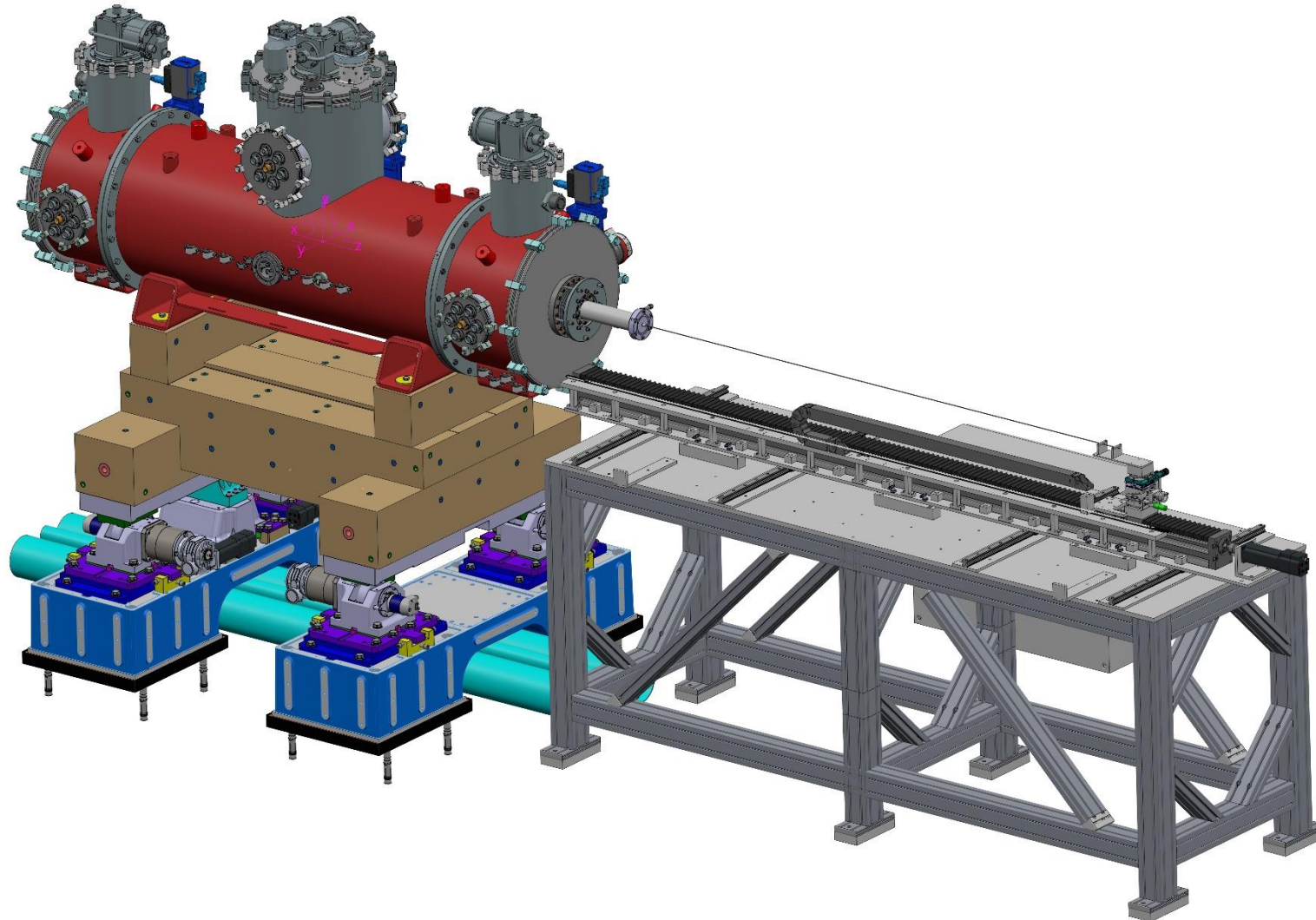
This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07OR21400 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.



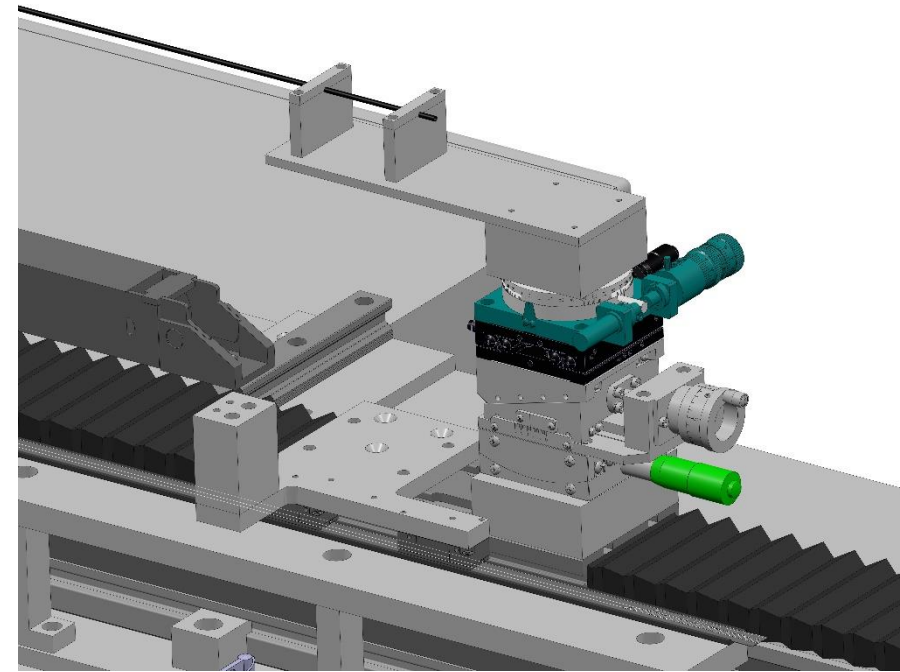
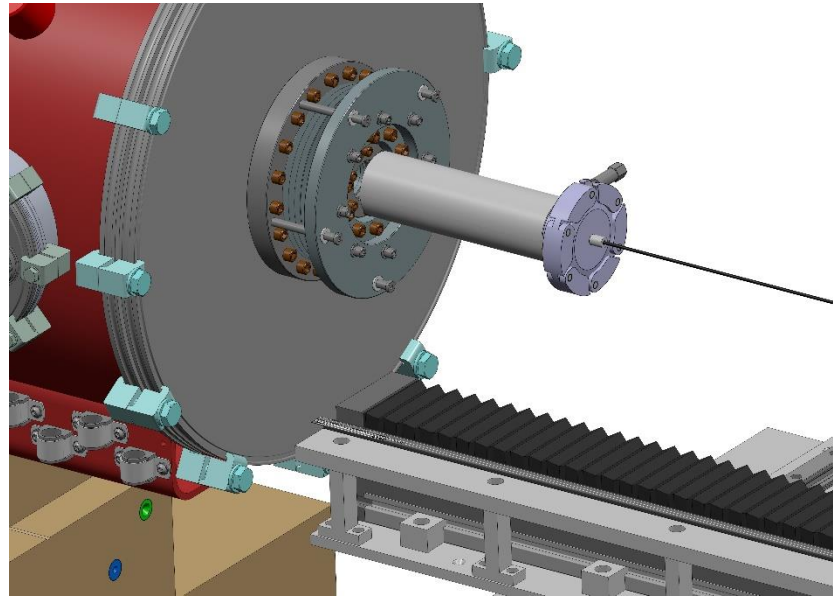
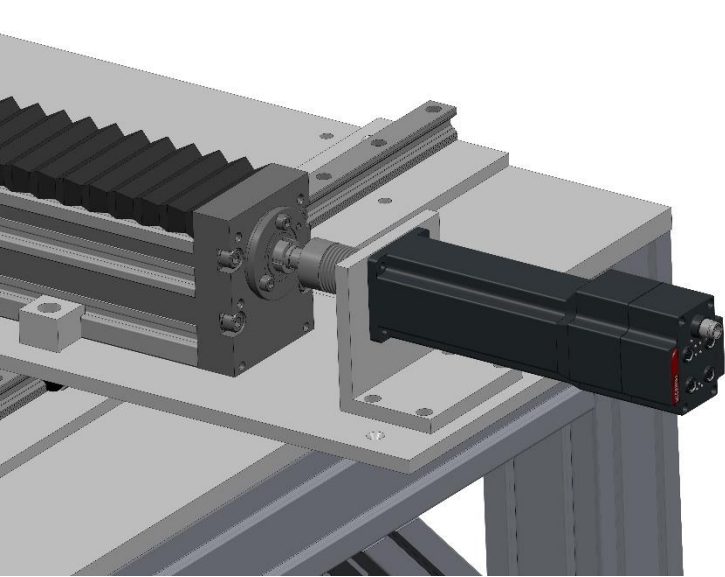
Cooling scheme



Horizontal measurement bench

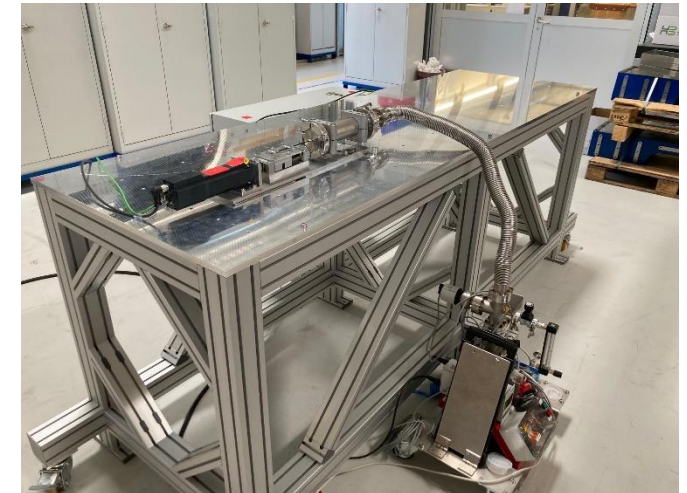
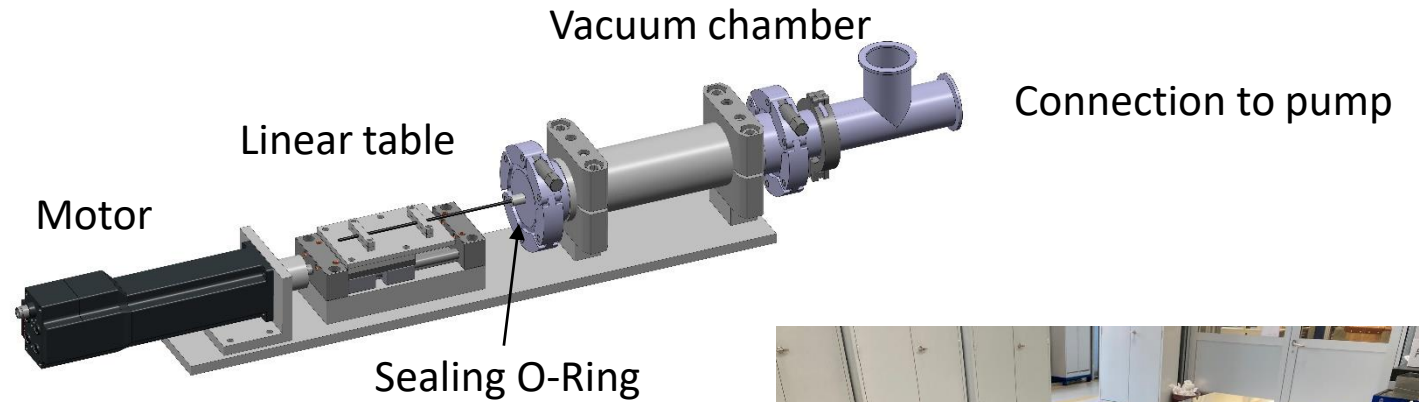


Horizontal measurement bench



Horizontal measurement bench

- Tested the sealing of the vacuum insert with an O-ring
- Vacuum remains stable, but the cryogenics are also a concern



- We demonstrated high magnetic field in a short sample staggered array undulator made of GdBCO bulks high temperature superconductors.
- With 5 Hall probes, we were able to measure the undulator field vertically in the short sample
- We are now working on the measurement bench for the meter-long undulator, expected to arrive in early 2025

Acknowledgements

- PSI : M. Calvi, K.Zhang, X.Liang, S.Hellmann, Th.Schmidt, L.Huber, S.Reiche, M.Bartkowiak, C.Calzolaio, Prof. M. Stampanoni, Prof L.Patthey, F. Marone & G.Lovric
- CHART : Prof. H.R.Ott & Prof. L.Rivkin
- Uni Cambridge : J.Durrell, A.Dennis, Y. Shi
- King's College London: M.Ainslie
- ESRF : G. Le Bec
- Spring8 : T.Ishikawa, M.Yabashi, H.Tanaka
- UniKyoto : R.Kinjo, T.Kii, H.Ohgaki
- Uni Malta : N.Sammut, A.Sammut, J.Cassar
- SENIS : Prof.R.Popovic, S.Spasic, S.Dimitrijevic
- KIT : Prof. M.Noel
- Fermilab: C.Boffo, M.Turenne, F.McConologue, V.Martinez, J.Hayman

