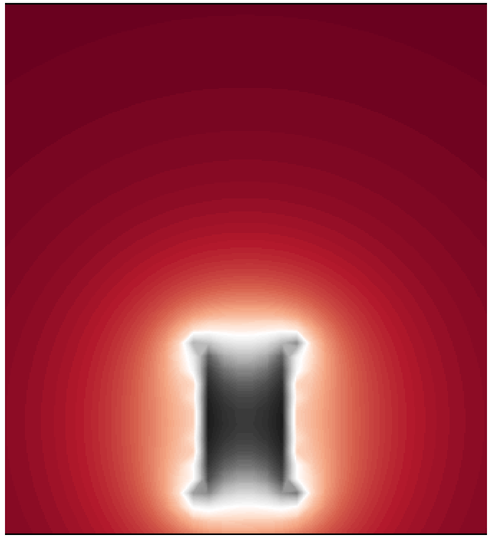
Magnet Infrastructure

20221117-1735(15”)- Prof. Dr. Tabea Arndt

Institute for Technical Physics (ITEP), Department of Electrical Engineering and Information Technology (ETIT)



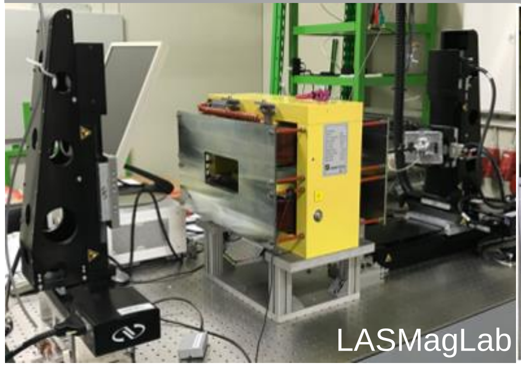
Content

- ATP – Accelerator Technology Platform @ KIT
- AMICI, iFAST, ETIAM
- COMPASS -
- ITEP facilities
- Sum up

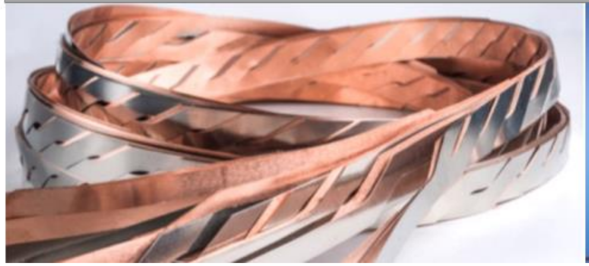
ATP...

ATP – Accelerator Technology Platform

Magnet Characterization Facilities (MCF) | Winding technologies



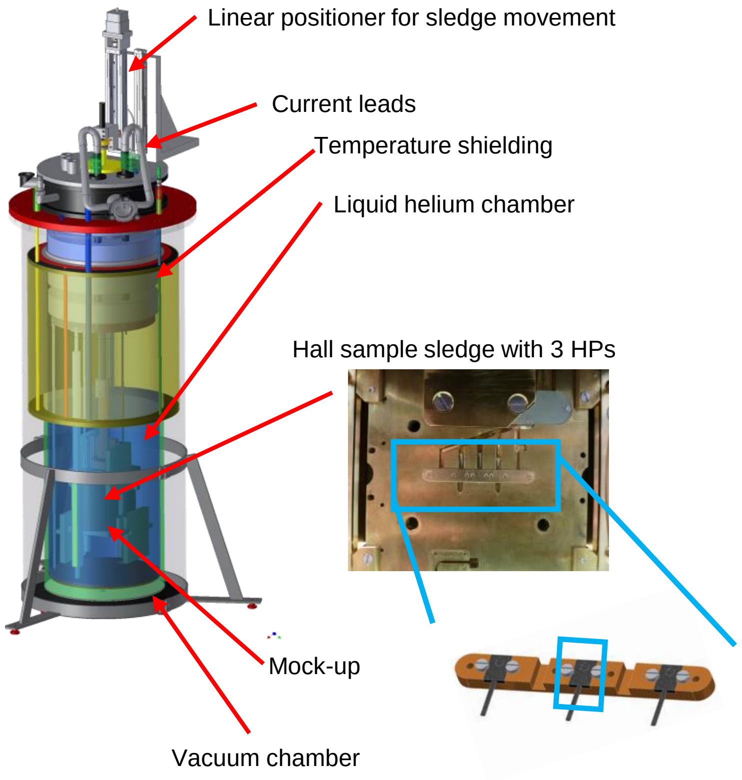
Cable technologies | High temperature superconductors



Accelerator Technology Platform @ KIT

From material via wire & cable to coils, components & magnet (system)s.
Magnet Characterization Facilities...

MCF - Magnet Characterization Facilities
CASPER - Characterization Setup for Field Error Reduction



CASPER I –
Measurement setup for short undulator mock-up coils

- Perform magnet training and quench tests
- test new winding schemes,
- new superconducting materials and wires,
- and new field correction techniques

General

- Operating vertical
- Test of mock-up coils in LHe
- Maximum dimensions 45 cm magnetic length and 35 cm in diameter

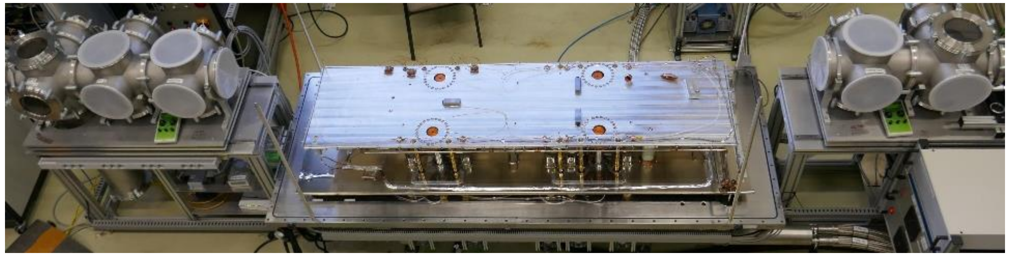
Instrumentation

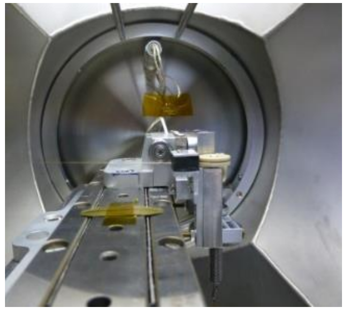
- 3 Hall samples on sledge calibrated at 4.2 K
- Keithley constant current source (Hall current)
- Keithley multiplexer voltmeter (Hall voltage)
- 1500 A/±5 V and ±1500 A/±5 V power supplies providing coil operating currents
- Quench detector for coil protection (built at IPE, KIT)
- Data logging system for quench analysis (industrial standard IMC)

CASPER I:
CASPER II...

MCF - Magnet Characterization Facilities
CASPER - Characterization Setup for Field Error Reduction

CASPER II – Measurement system for undulator coils up to 2 m length





- Horizontal configuration
- Cooled via cryocoolers
- Dimension 4 K region 2 m x 0.5 m x 0.5 m
- Current leads 8 x 500 A
- 2x ±1500 A/±5 V power supplies (power main coils)

Local field measurements

- Sledge, 3 calibrated Hall samples (4.2 K)
- Keithley constant current source (Hall current)
- Keithley multiplexer voltmeter (Hall voltage)

Field integral measurements

- Moving stretched wire (CuBe wire Ø125 µm)
- Signal measurement by Keithley nanovoltmeter

Magnet training

- Quench detection (built at IPE, KIT)
- Quench analysis (NI - PXI system, 64 channels, max. 250 kS/s)

CASPER II:
Activities in sustainability...

Sustainability of Research Infrastructures

Karlsruhe Institute of Technology

Research and Real-world Laboratory for future research infrastructures

- Innovation Pool InnovEEA
  (**KIT** (also coordinator), DESY, GSI, HZB, HZDR)

- **KITTEN**: Pioneer research for new energy concepts at and for accelerators

  ➜ Real-world Laboratory for energy responsibility in research teaching and innovation

InnovEEA
Innovation pool project
for Energy Efficient Accelerators

MT ARD

Karlsruhe Institute of Technology

Superconducting materials and cryogenics approaches

Magnets and current leads

Energy-efficient system design and load management

Operation modes, grid stability & low-carbon footprint (pilot: **KITTEN**)

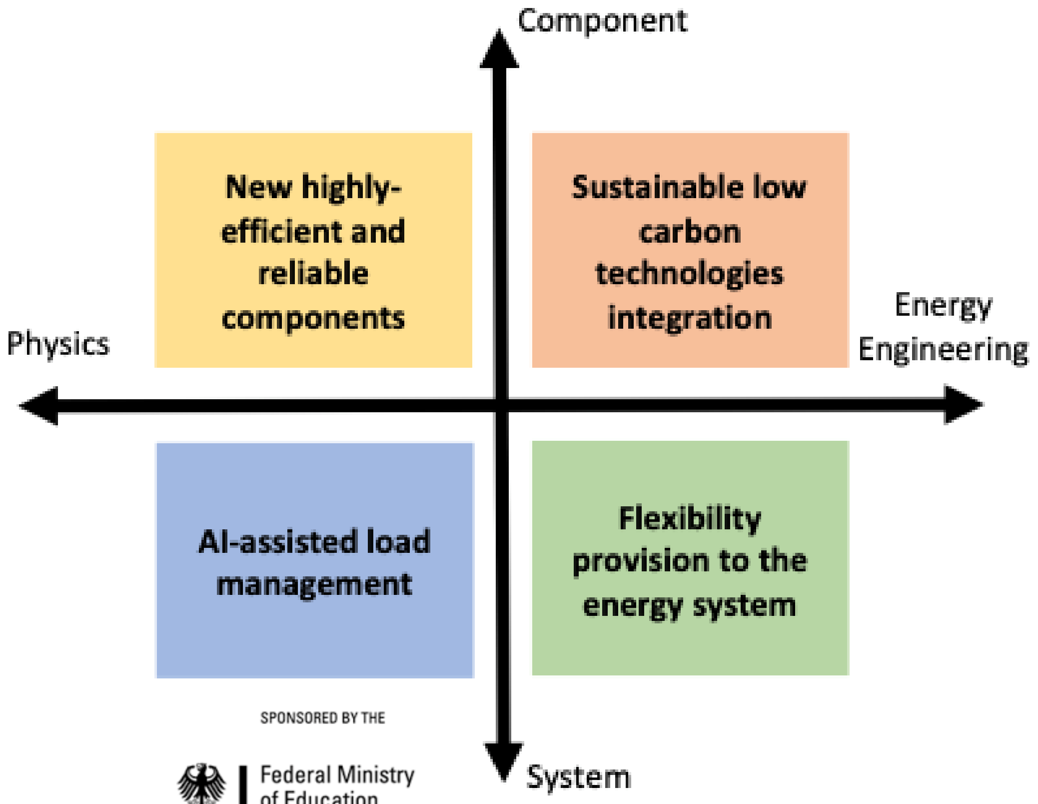
A joint venture between the accelerator **KARA** and the test-field **Energy Lab 2.0** to improve the energy use and power quality in large research infrastructures.

More on KITTEN...

KITTEN – KIT test field for energy efficiency and grid stability in large-scale research infrastructures

Karlsruhe Institute of Technology

- **Physics / Component**: New materials and components to increase efficiency
- **Energy / Component**: Integration and optimum operation of sustainable, low-carbon technologies (e. g. storage, renewable resources)
- **Physics / System**: Improvement of efficient operation of research infrastructures using AI
- **Energy / System**: Increase of sustainability of large scale research centers in electrical grids



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ACCelerator Energy System Stability
ACCESS (FKZ 05K22CKA, 2022-2025)

Real-world lab and project research.
Examples for the quadrants...

Sustainability – from components to systems

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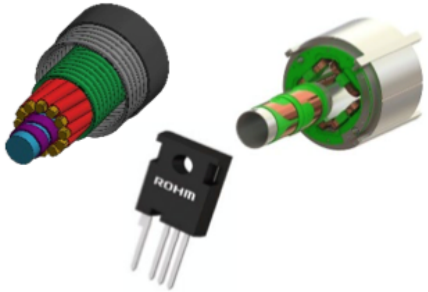
New highly-efficient and reliable components



- HTS-Superconductors
- Variable permanent hybrid magnets
- New cooling concepts
- SiC / GaN-based power electronics

AI-assisted research infrastructure load management

- Real time digital twin of accelerators
- Optimized energy consumption by AI
- Adjustable power demand

Low carbon technologies integration

- Optimal integration of ESS with RES
- Sector-coupled Energy management
- Green high power computing
- Geothermal as cooling source

Flexibility provision to energy system

- 100% Renewable energy sources target
- Power demand flexibility
- New business models for flexibility provision

*Helmholtz Sustainability Challenge „Research Facility 2.0: towards a more energy-efficient and sustainable path", KIT-DESY-HZB

Examples of magnet approaches...

Examples of magnets (following slides)

Karlsruhe Institute of Technology

- Envisioned, designed, developed, manufactured and tested at KIT
- Various test stands and test facilities for testing and characterization evaluable

Quadrupoles...

HTS magnets for miniature transport lines

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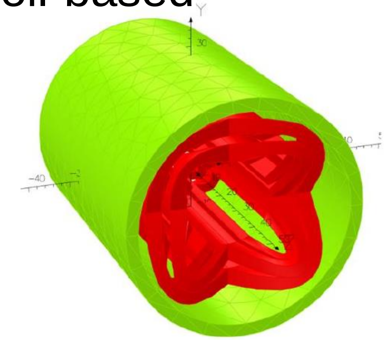
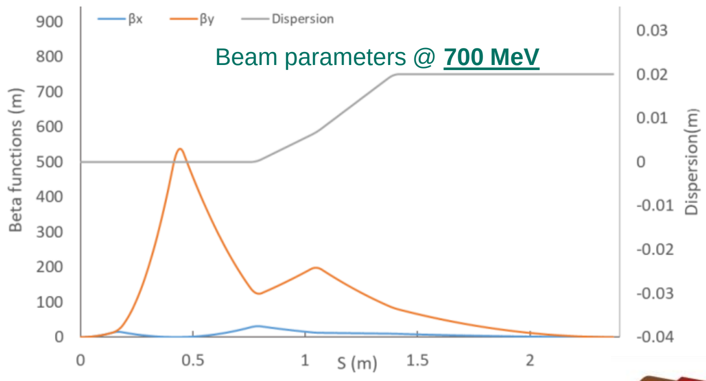
Karlsruhe Institute of Technology

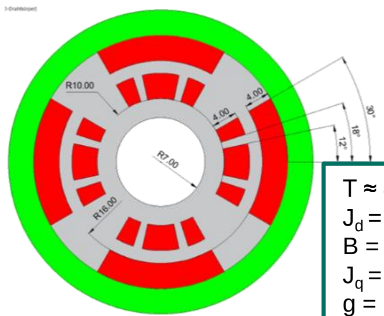
Coil-based



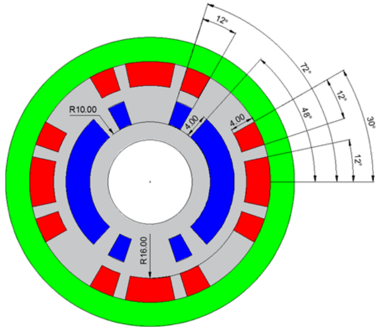


HTS magnets; pure quadrupoles and combined function dipoles i.e. Dipole+Quadrupole

Optical functions of 2.4 m transport line for plasma accelerator



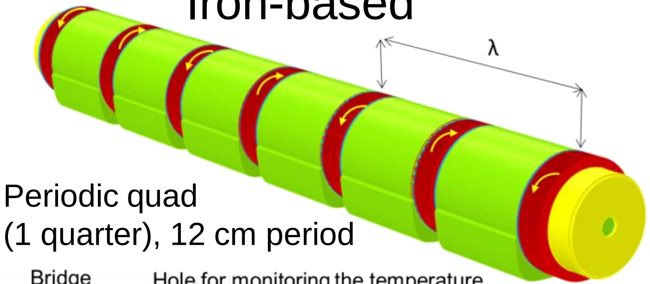
T ≈ 4.5 K
J_d = 500 A/mm²
B = 1.2 T
J_q = 1500 A/mm²
g = 500 (200) T/m



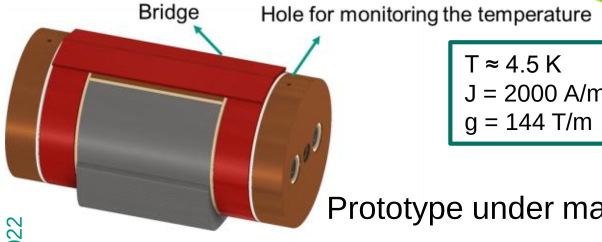
S. Fatehi et al., IPAC2021-MOPAB164

Courtesy of S. Fatehi, KIT

Iron-based

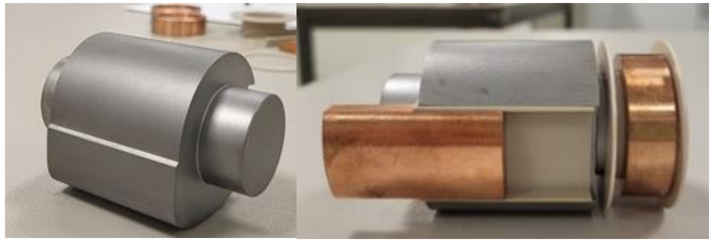


Periodic quad (1 quarter), 12 cm period



T ≈ 4.5 K
J = 2000 A/mm²
g = 144 T/m

Prototype under manufacture



S. Fatehi et al., ASC 2022

Prototype finished – in characterization this week.
Undulators...

HTS compact undulator

Goal: High field, small-period undulator operate at higher temperatures

Two different prototype coils:

Vertical racetrack (**VR**),
Helical undulator (**Hel.**)

Main challenges:

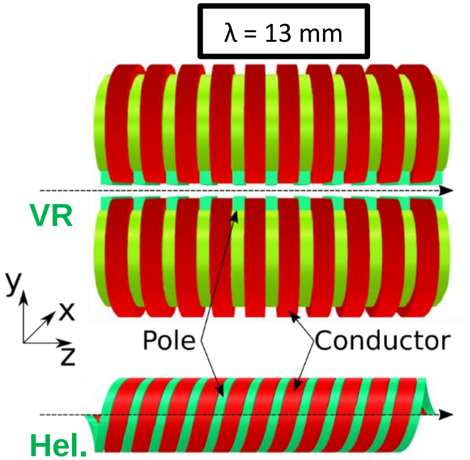
- Bending radii < 5 mm,
- Quench protection
- Field quality (during ramping)

VR prototype coils manufactured and successfully tested in LN2, **77 K**.

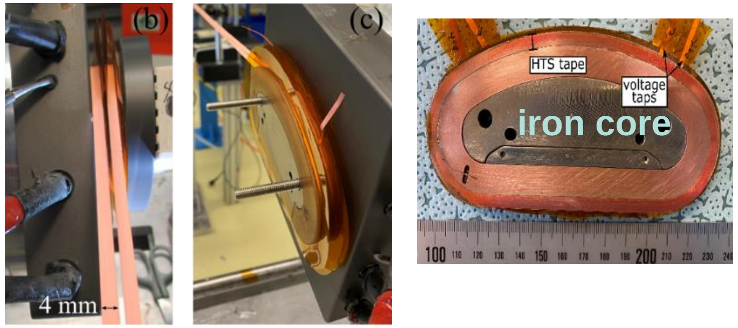
For **I > I_c** all sub-coils can **safely** operate.

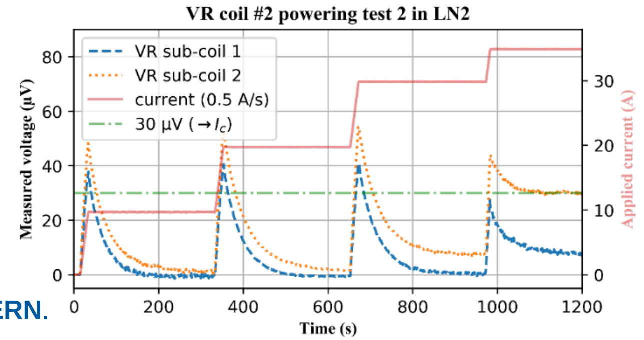
This project has been done in collaboration with **CERN**.

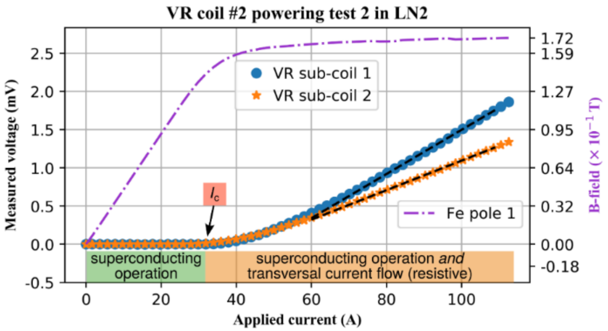
Courtesy of S. C. Richter, KIT



VR coil manufacturing
4 mm, non-insulated ReBCO tape







S. C. Richter et al., IPAC2022-THPOPT058

Robust 2G-HTS NI-undulator coils.
Structured undulators...

HTS laser structured compact undulator

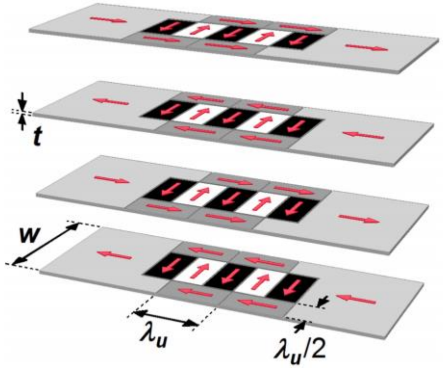
30 layers of **laser-scribed ReBCO tapes**, width of 12 mm and a thickness of 55 μm

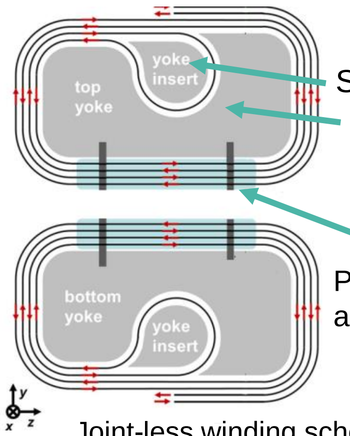
The grooves in each layer force the current in a defined path, creating a sinusoidal field at 500 A.

Two designs

- HTS tape is bent over the droplet-shape-block, inserted inside the yoke brings a **joint-less winding**
- A **stacked design**, individually structured tapes are stacked and soldered alternating at the tape ends.

T. Holubek et al., 2017 Supercond. Sci. Technol. 30 115002





Stainless steel body

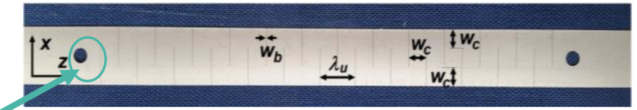
Positioning bores align the tape layers

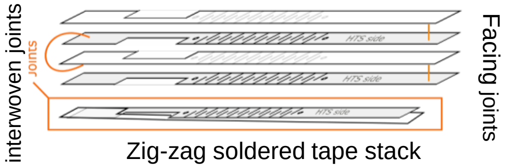
Joint-less winding scheme

12 periods per tape,

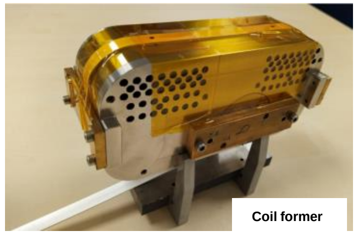
$\lambda_u = 2(w_c + w_b) = 8$ mm

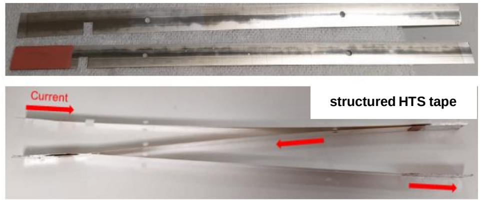
Laser-scribed slits $w_b = 25$ μm





Zig-zag soldered tape stack





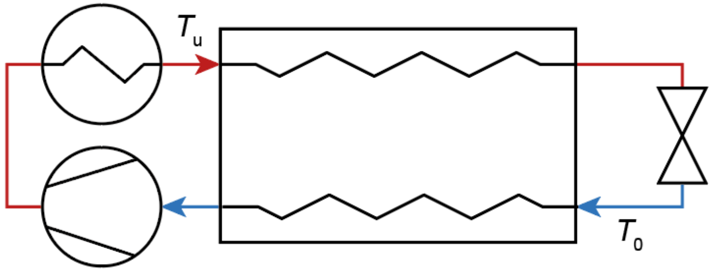
A. Will et al., IPAC2021-THPAB048

Low λ structured HTS undulators.

Micro-structured current leads...

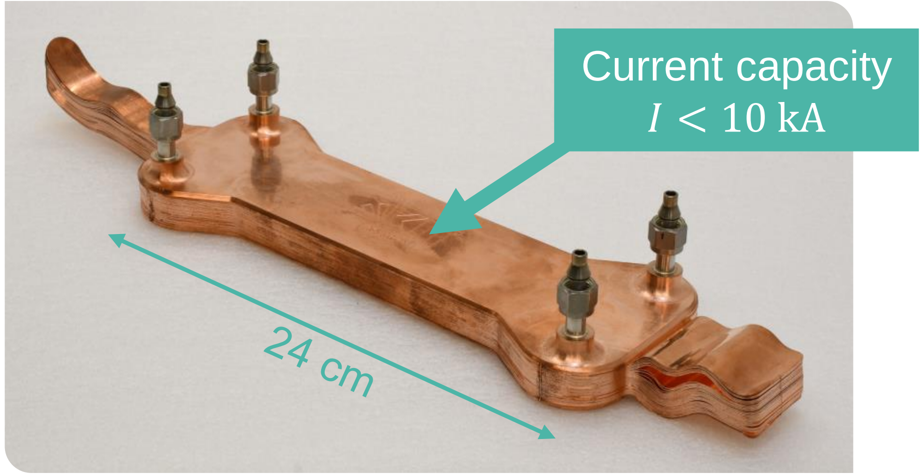
Micro-structure Current Leads

- Thermodynamic optimization on cooling of current leads (CL) requires heat absorption along whole length
- Cryogenic mixed-refrigerant cycles (CMRC) offer scalable, efficient cooling at $T \leq 80\ \mathrm{K}$



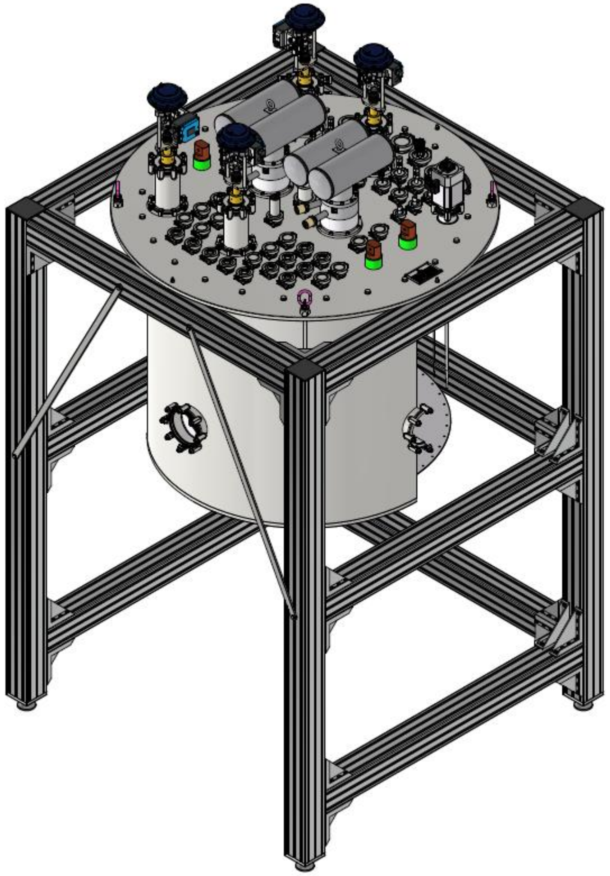
- **Reduction of power demand** for CMRC-CLs **by 2/3** compared to conduction cooled CLs

- Development of compact, micro-structured current leads
  - **Easily scalable** due to construction by sheets
  - Ultra **compact** & ultra **efficient**



Scalable technology: development of **compact highly efficient** CLs for a wide range of sc applications!
COMPASS & CMRC...

COMPASS - Compact Accelerator Systems Test Stand



- Experimental facility to study compact accelerator components
  - CMRC-cooled micro-structured current leads
  - Superconducting magnets and undulators

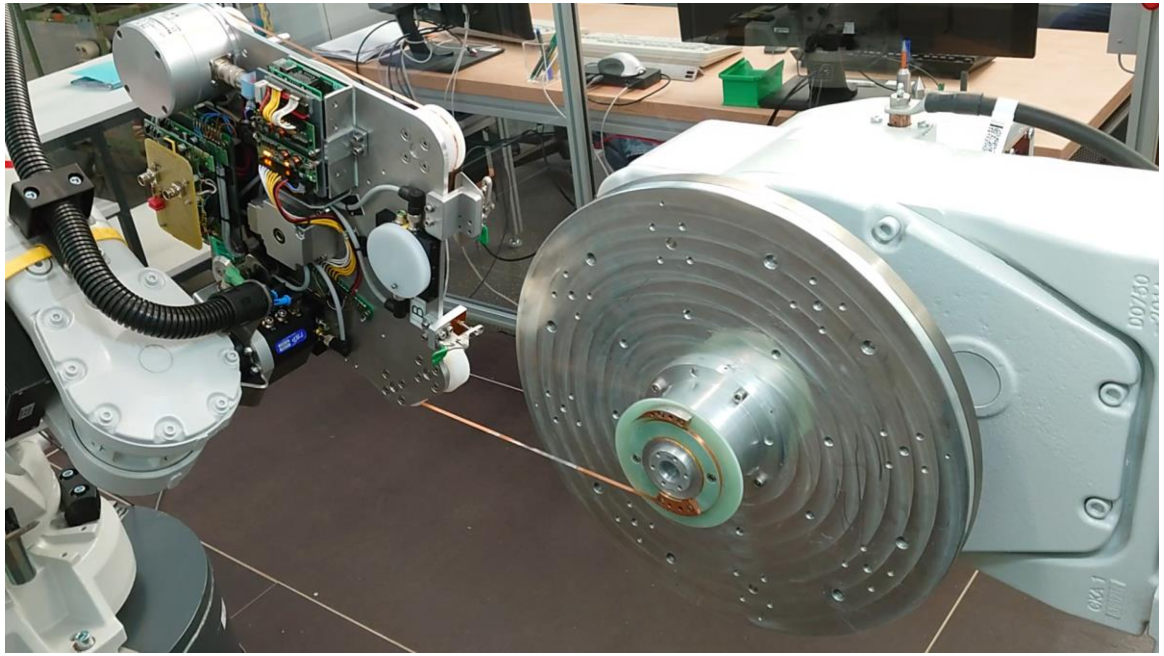
- Cryomech PT425 cryocooler offering cooling power of $2.5\ \mathrm{W}\ @\ 4\ \mathrm{K}$
- Two mixed-refrigerant cycles with broad power range
  - Studies with electrical currents from $100\ \mathrm{A}$ to $10\ \mathrm{kA}$ feasible
  - Investigation of cryogenic mixed-refrigerant cycles cascades for temperatures $T < 77\ \mathrm{K}$ possible

- Timeline:
  - Project start of COMPASS in 2022
  - Objective for compact CMRC-cooled current leads
    TRL 6 in 2-3 years

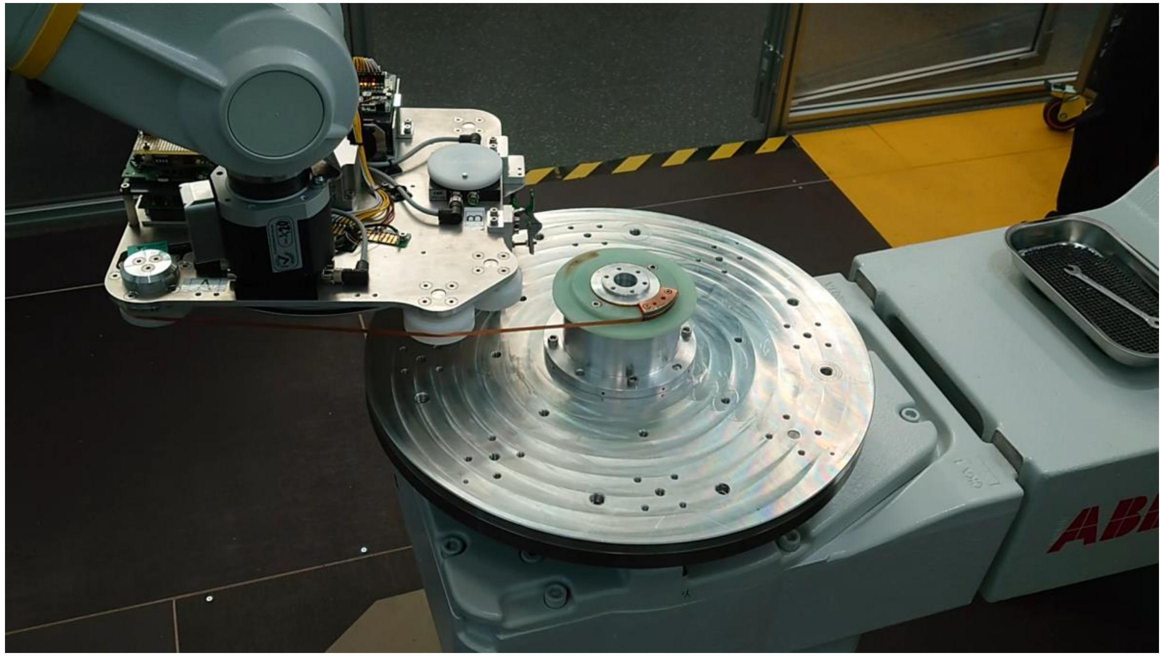
Highly **flexible** teststand with **broad power range** for **wide scope** of experiments.
Winding of magnets...

Robotic winding workshop – simple 2G-HTS (NI) pancake coil for the student's practice (ITEP)

Synchronous movement from
"fixing position" → "winding position"



Winding of two turns



In-advance definition & test of 4D-trajectory in digital twin: pancake→racetrack→saddle→distributed winding. Potting of windings...

VPI for medium size coils (ITEP)

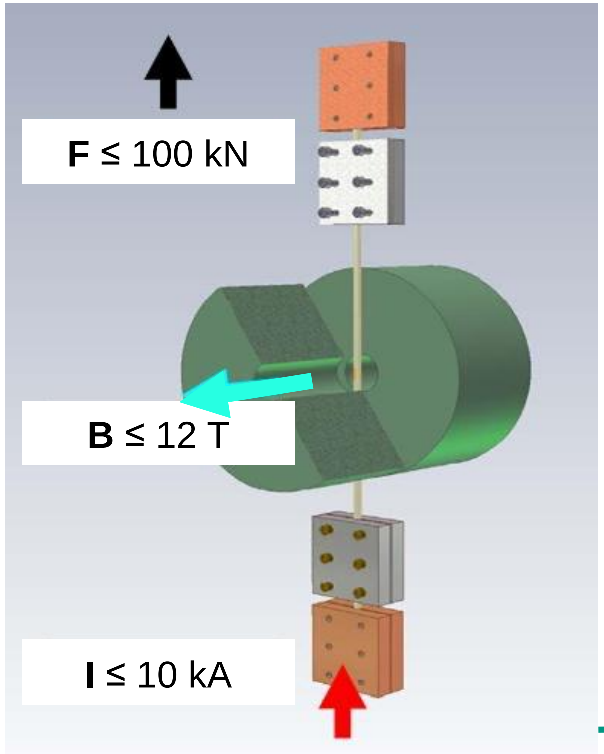
- Quick & Easy change of resin-system
- Large recipient (vacuum vessel);
  up to dimensions of ≈1 m
- Short distance to curing furnaces

VPI equipment to convert the dry-winding coil into a robust component.
Magnet lab & testrigs (FBI)...

FBI –
facility in the CryoMaK (ITEP)

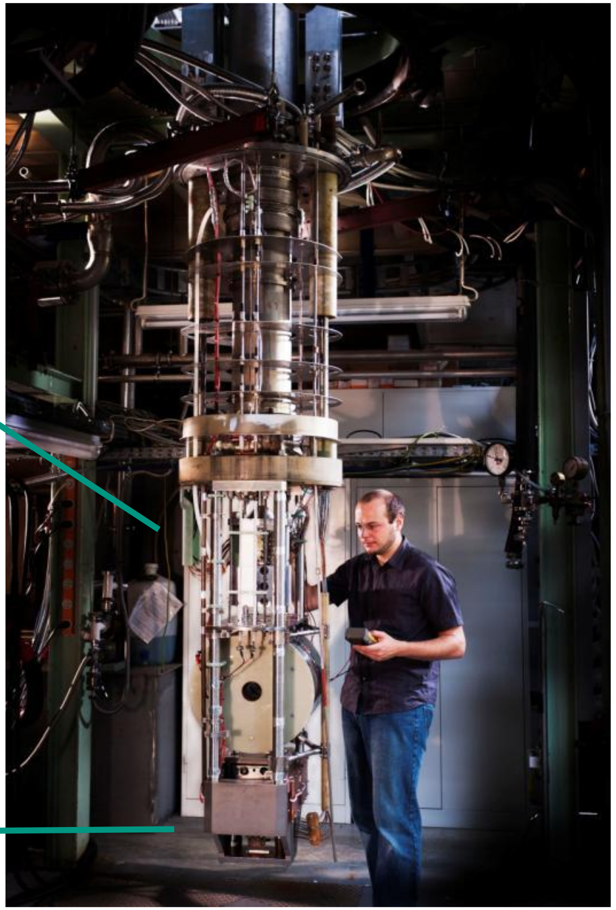
- Electro-Mechanical investigations of superonductors in magnetic field

FBI
4.2 K to 77 K

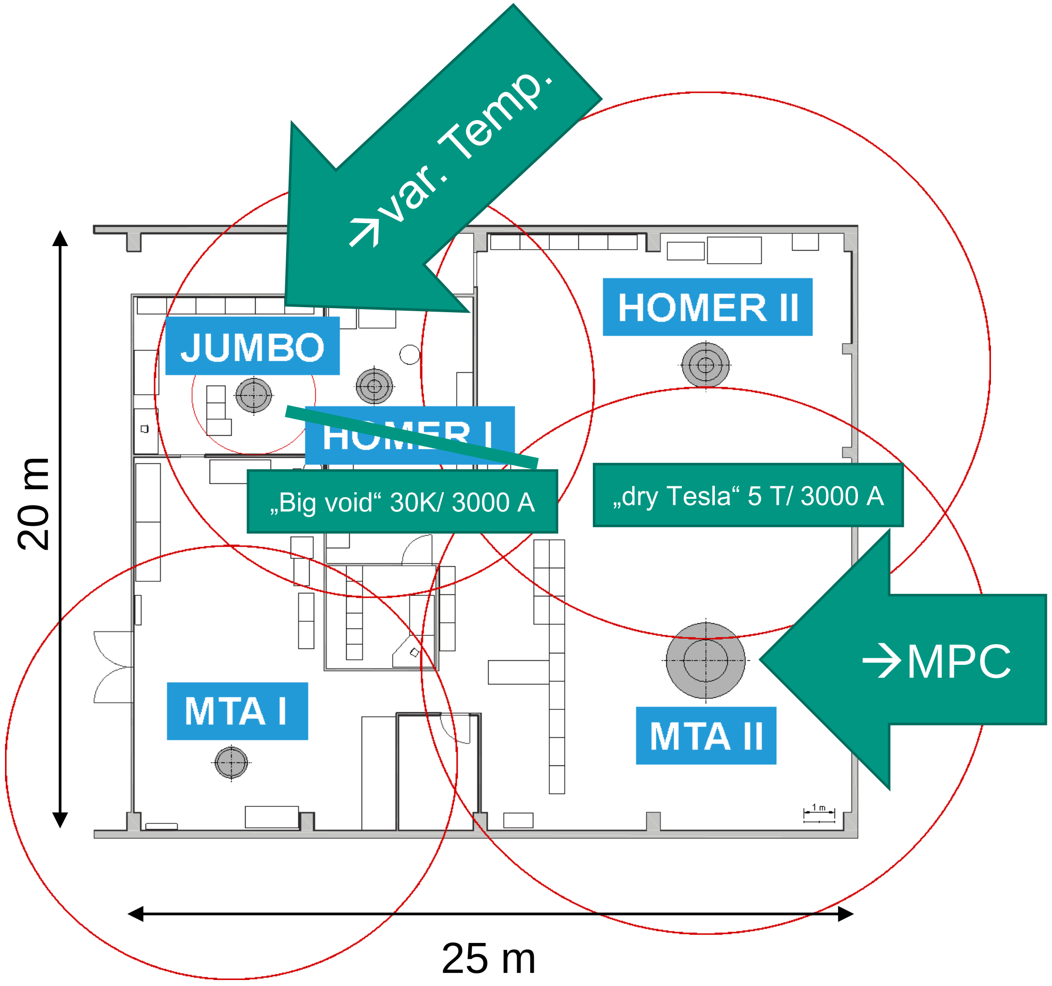


sc split-coil
bore 100 mm
gap 40 mm

cable length
approx. 1.2 m



Magnet laboratory at ITEP

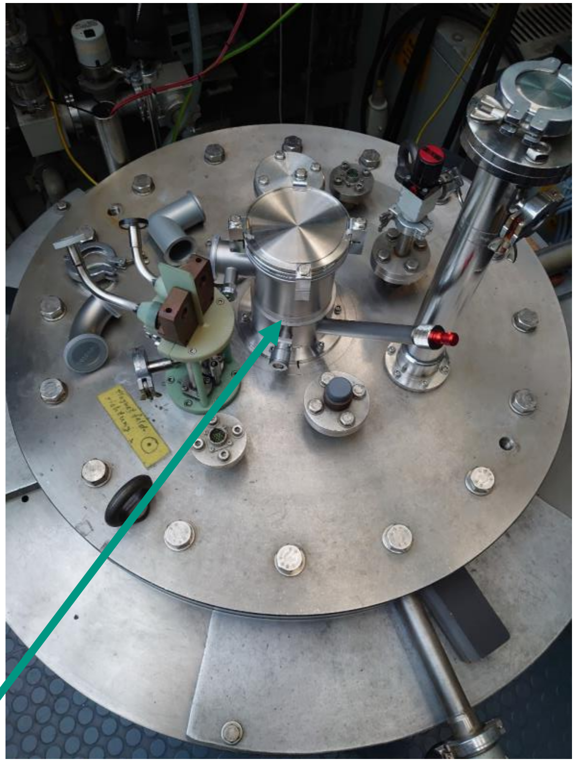


Laboratory magnets at ITEP

- JUMBO:
  10 T-Magnet with large bore for measurements in cryogenic baths.
  → upgrade to **VTI-insert** (just mounted)
- ~~HOMER I:~~
  ~~15 T Hoch-Magnetfeld-Experimentier-Anlage I~~
- **Big Void: 30 K / 3000 A Test-rig** – in erection
  (free bore abt. 1000 mm, free length abt. 1500 mm)
- HOMER II:
  26 T technology test-bench for high-field-NMR – mission completed.
- MTA I:
  Magnet-Test-Apparatus I for complete coil systems or thermal experiments
- ~~MTA II:~~ → MPC
  Transform to a „Multi-Purpose-Cryostat“ for variable temperatures on large objects, preferably in vacuum.
- **“dry Tesla”: 5T / 3000 A Testrig** – in erection
  for long samples at $T = 10 \dots 300\ \mathrm{K}$

The magnet laboratory at ITEP is in „transformation“.
Details of the setups...

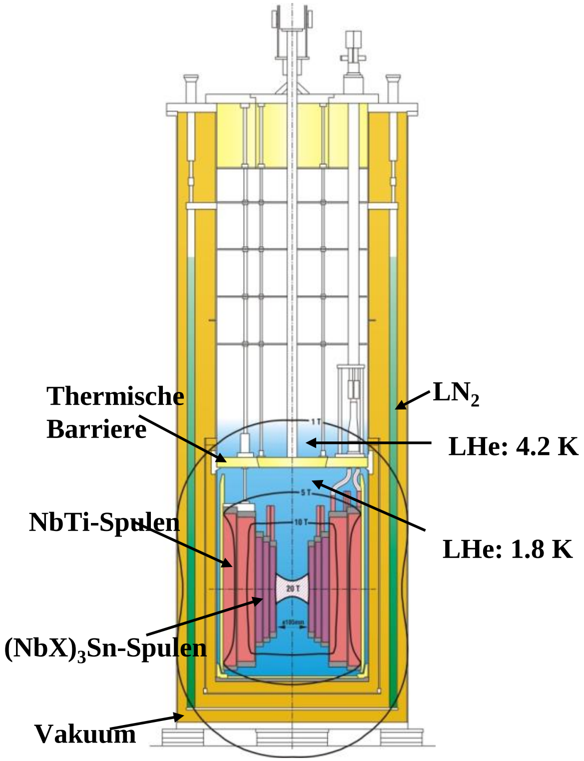
JUMBO “refurbishment” (ITEP)

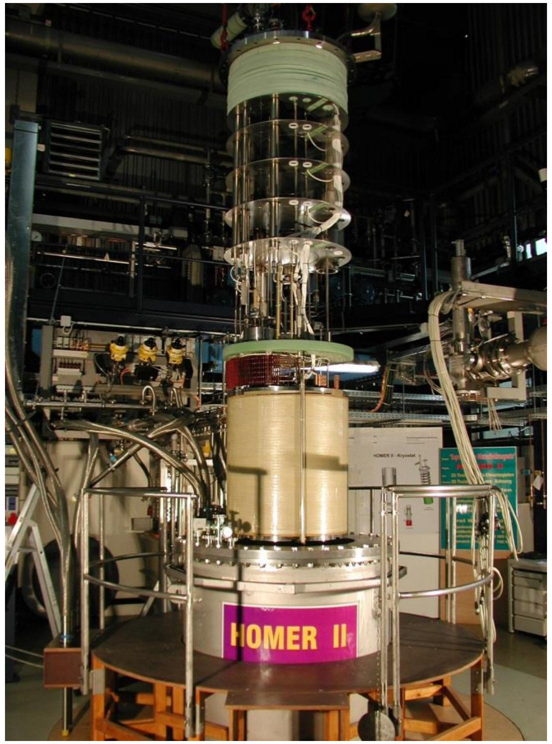


JUMBO:
10T in ø100 mm (ø80 mm in VTI)
15T in ø44 mm

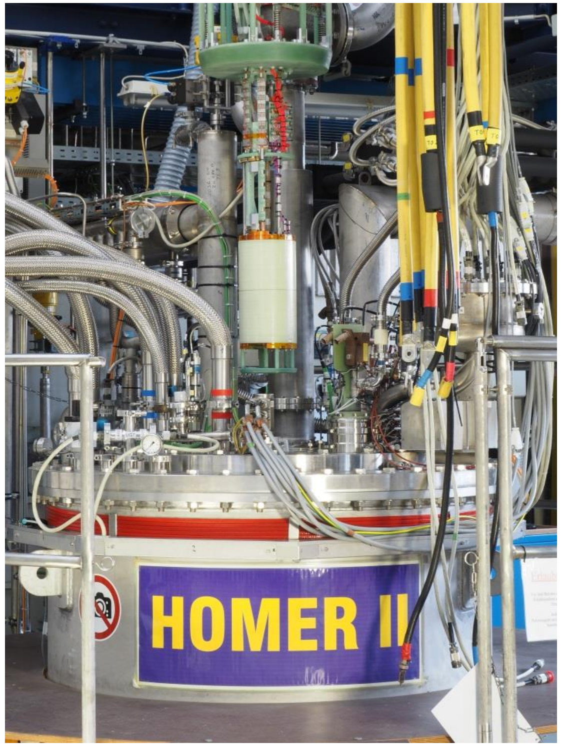
Setups to characterize wires and small insert coils in large bores.
HOMER I...

HOMER II (ITEP)





LTS segments



HTS insert coils

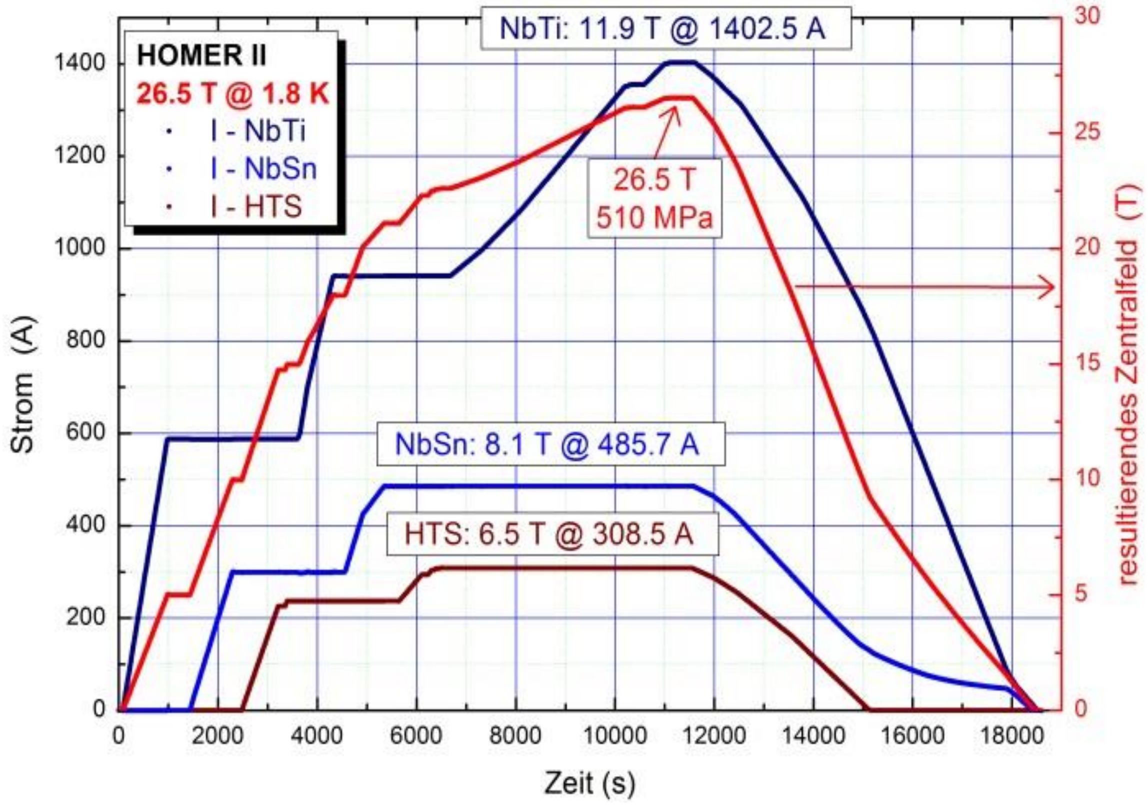
Lab magnet:

- 07/2006:
  20 T in Ø185 mm
- 08/2019:
  26.5 T in Ø68 mm

Operated in LHe.

HOMER II final upgrade details...

HOMER II – final upgrade KIT ITEP



HOMER II – final upgrade (fully superconducting)

- Center field: $B = 26.5\ \mathrm{T}$ in $\varnothing\ 68\ \mathrm{mm}$
- Hoop Stress on HTS: 510 MPa

Reference: Hornung, F., et al. (2021). - IEEE Transactions on Applied Superconductivity **31**(6): 1-5

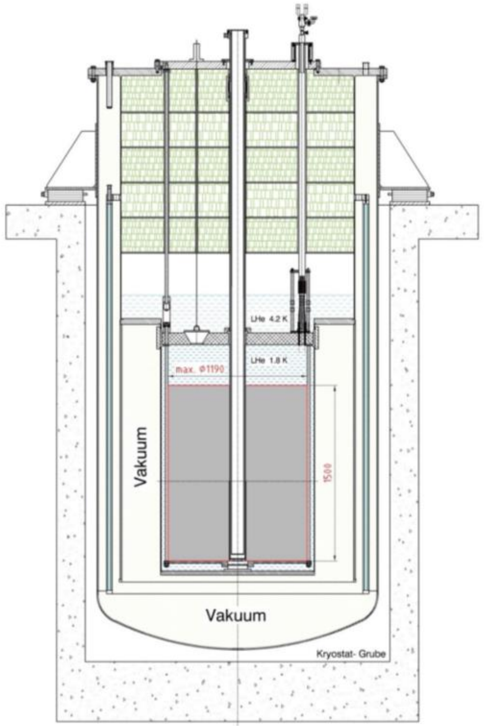
An insulated layer-winding using HTS is feasible for high-field magnets

Summary...

New test devices in magnet lab (in erection) (ITEP)

- **Ne-thermosiphon testrig**
  - experimentally determine the operating parameters to couple loads to thermal sinks

- **MPC:** Large vacuum vessel for component and magnet test.



Several new testrigs using vacuum vessels as cryostats and heatpipes for cooling.
KC4...

New test devices in magnet lab (in erection) (ITEP)

- “Big Void”
  - 30 K / 3000 A Test-rig for components at $T = 10 \dots 300\ \mathrm{K}$

- “Dry Tesla”
- 5T / 3000 A Testrig for long samples at $T = 10 \dots 300\ \mathrm{K}$

Several new testrigs using vacuum vessels as cryostats and heatpipes for cooling.
KC4...

To sum-up

- New KIT-CERN Collaboration on Coated Conductor KC4
  - Aiming to prepare research length of tailored 2G-HTS
  - Based on former Bruker and original KIT equipment
- A number of facilities available for
  - materials
  - wire
  - components
  - magnets
- Preparation & Characterization & Test
- We are still busy to improve our facilities...

Thank you!

The End