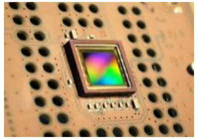
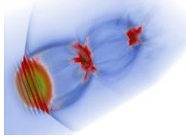
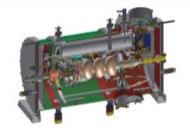
HELMHOLTZ

MATTER AND TECHNOLOGIES







RESEARCH FOR GRAND CHALLENGES

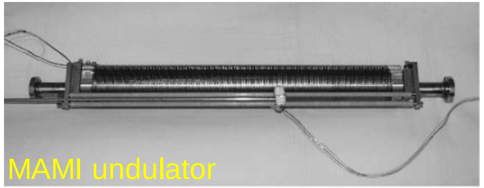
High temperature superconductors and magnet technologies

Samira Fatehi
Karlsruhe Institute of Technology (KIT)

September 27th, 2022
8th Annual MT Meeting

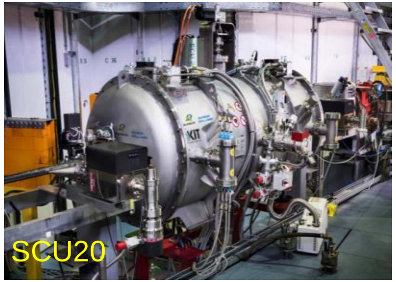
Experience of superconducting IDs

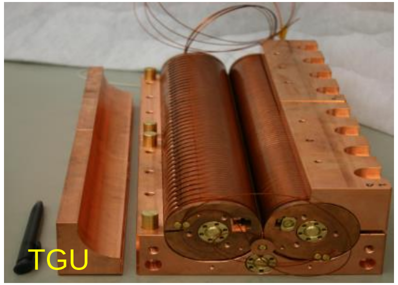
- Development of superconducting undulators in Karlsruhe started in the **early 1990s**.
- As early as **2005**, a first demonstration of a superconducting undulator, in cooperation with ACCEL Instruments GmbH, was installed in the KARA storage ring.
- In cooperation with Bilfinger Noell GmbH, SCU15 in **2014** and SCU20 in **2017** were build and installed in the KARA storage ring.
- In **2016**, a transverse gradient undulator (TGU) with ±10% energy acceptance was designed and developed to work with laser plasma electron sources.


MAMI undulator

SCU14


SCU15


SCU20


TGU

Experience of superconducting IDs

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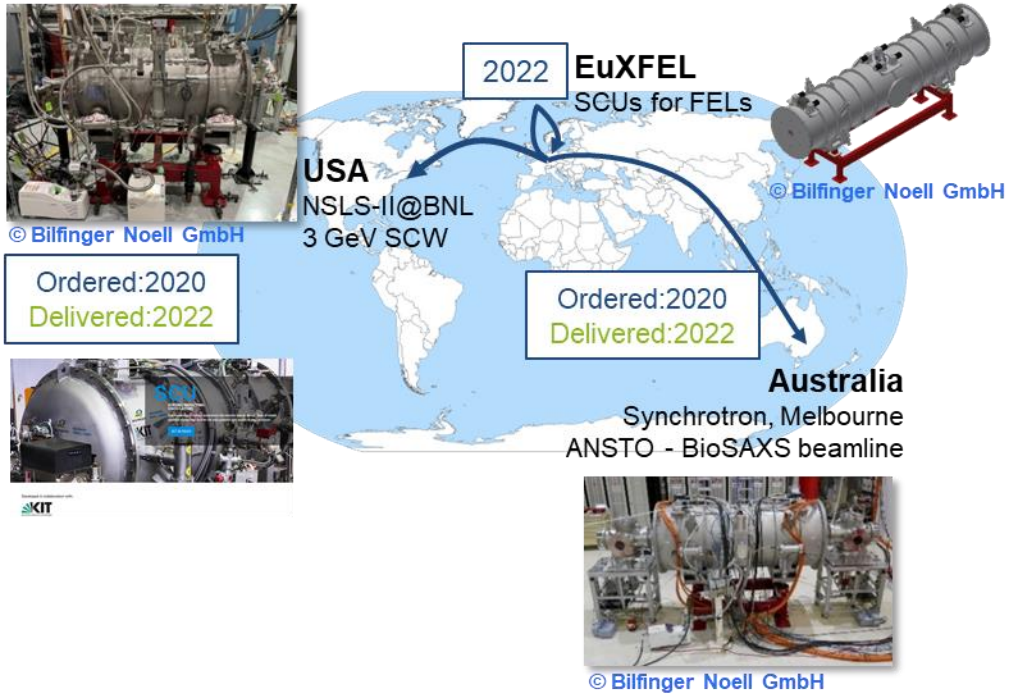
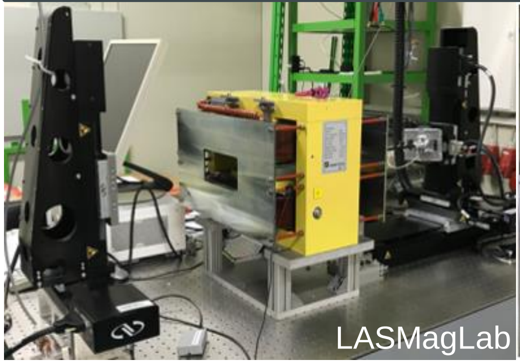
Technology Transfer from KARA/KIT to the world



Test facilities & technologies

Karlsruher Institut für Technologie

Magnet Characterization Facilities (MCF)		Winding technologies

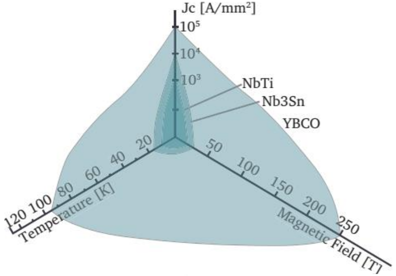


Cable technologies	High temperature superconductors

ATP
Accelerator Technology Platform @ KIT

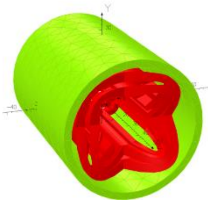
Motivation of HTS projects

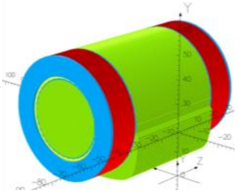
Why we are interested in high temperature superconductors and HTS magnets?



Due to **higher** **critical current (Ic)** and **critical temperature (Tc)**

- ✓ Higher magnetic fields at low temperatures
- ✓ LTS magnetic fields at higher temperature
- ✓ At higher temperature, lower power consumption for cooling

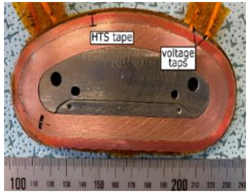


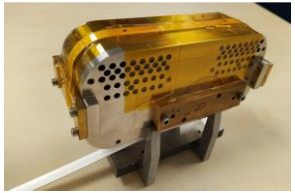


To progress we designed and developed small-scaled projects

- HTS miniature transport lines (coil-based or iron-based)

- HTS compact undulators (vertical racetrack, helical, laser-structured tapes)





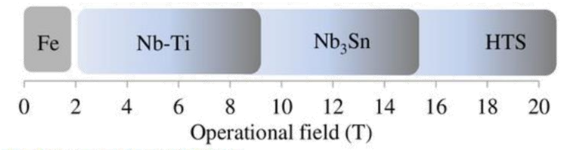
High temperature superconductors

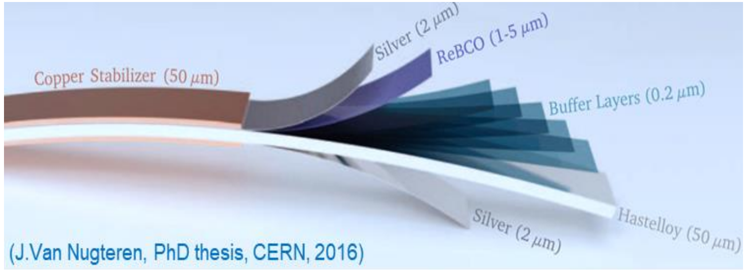
The first successful superconducting magnet was built in 1955 using niobium wire.

LTS coils;

Nb-Ti (niobium-titanium) $T_c \approx 10$ K

Nb_3Sn (niobium–tin) $T_c \approx 18$ K





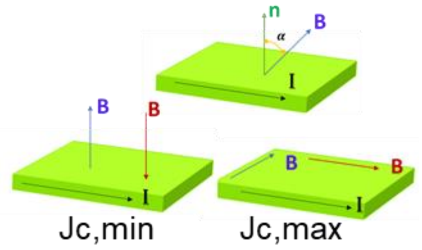
HTS coils;

ReBCO (rare-earth barium copper oxide) $T_c \approx 92$ K

HTS materials are ceramic–like and brittle usually in form of tapes.

Jc (B, T, α),

α is the magnetic field angle w.r.t. the face-normal of the tape.



Strands of Roebel cables are prepared by cutting REBCO coated conductors in a meandering shape.

HTS Roebel cable assembled at KIT

HTS coil-based miniature transport line

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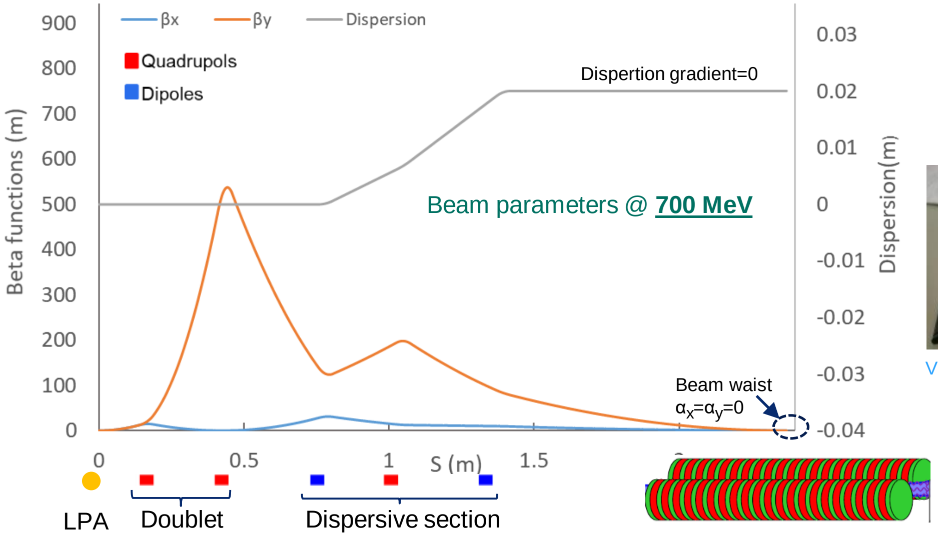
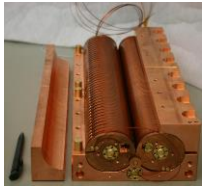
Universität Hamburg DER FORSCHUNG | DER LEHRE | DER BILDUNG

Karlsruher Institut für Technologie





V. A. Rodriguez, KIT, 2015

For a laser plasma accelerator electron source,
a **1.4 m** transport line working at **700 MeV** is designed fulfilling transverse gradient undulator (TGU) input parameters.

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

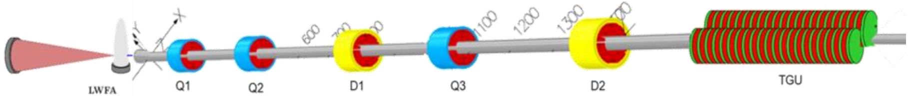
Coil type	Width (mm)	R_{in} (mm)	B_{oncoil} (T)
ReBCO tape (SCS4050-AP)	4 (50 µm substrate thickness)	10	5

Magnet type	g (T/m)
Q1	504
Q2	-224
Q3	-91

T ≈ 4.5 K
J = 1460 A/mm^2

Magnet type	B (T)	g (T/m)
D1	1.22	205
D2	-1.22	29

T ≈ 4.5 K
$J_{dipolar}$ = 500 A/mm^2
$J_{quadrupolar}$ = 1500 A/mm^2



S. Fatehi et al., IPAC2021-MOPAB164

HTS coil-based miniature transport line

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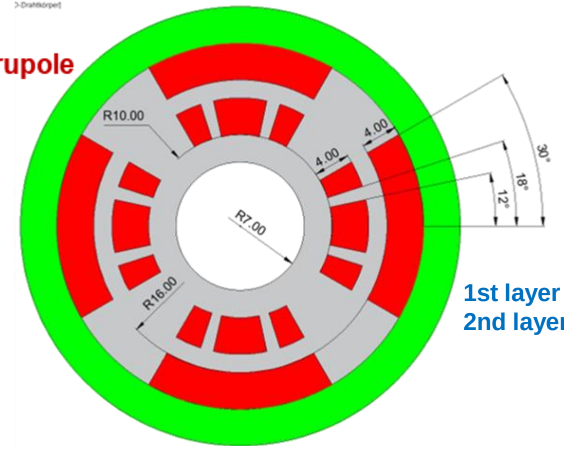
Cos-theta magnets, multilayer sector coils with specific angular configurations

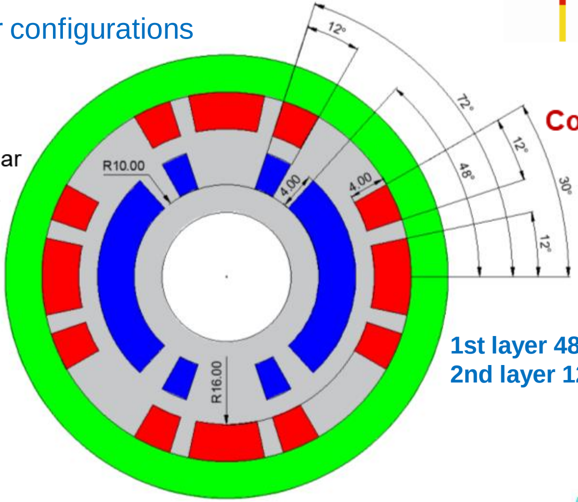
Quadrupole



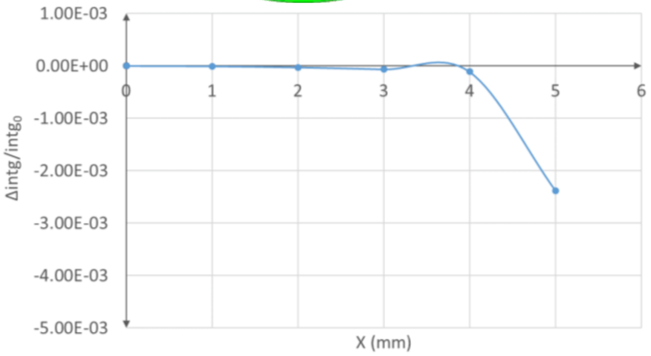
- Beam pipe
- Nonmagnetic collar
- Quadrupolar coils
- Iron shielding

1st layer 12-18-30
2nd layer 0-30

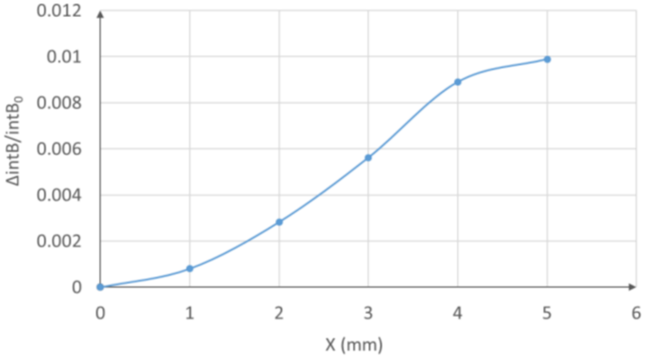
Combined dipole



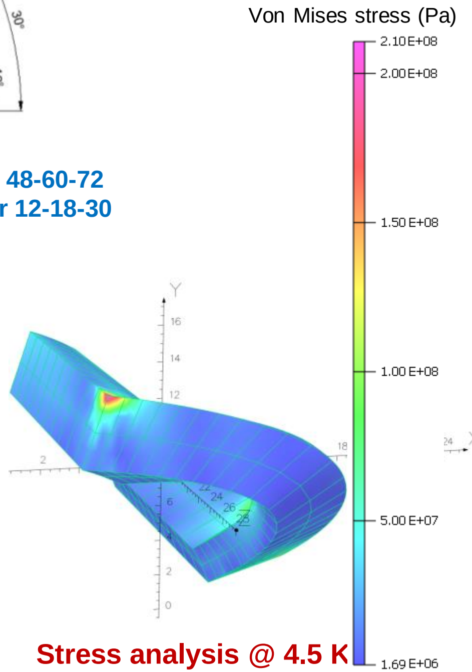
1st layer 48-60-72
2nd layer 12-18-30



Quadrupole, integrated field quality



Combined dipole, integrated field quality



Stress analysis @ 4.5 K

HTS iron-based miniature transport line

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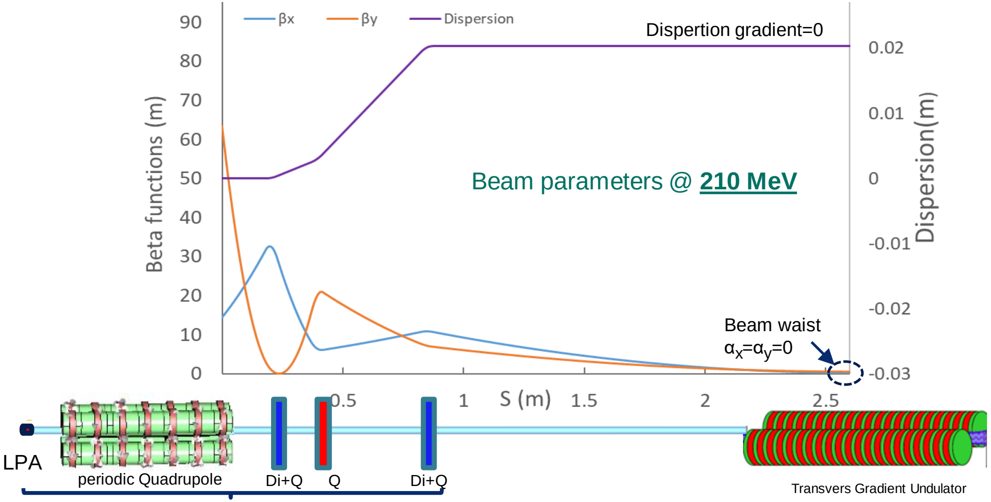
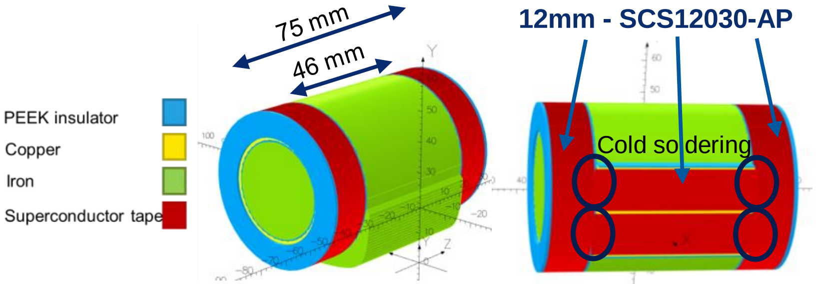
To ease the winding difficulties of the HTS tapes in cos-theta magnets, a **1.4 m** transport line at **210 MeV** is designed using **HTS periodic quadrupole** and **combined function dipoles**.

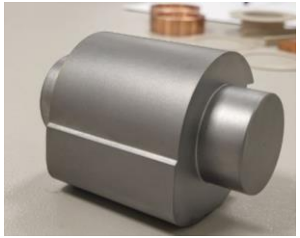


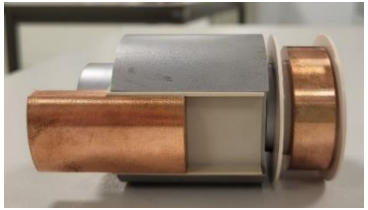
Transport line length=1.4 m

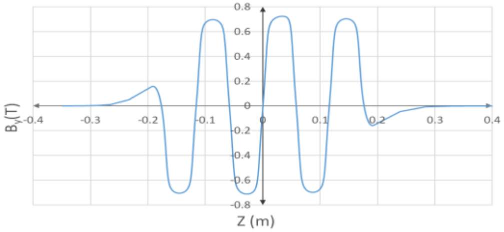
Optimized Periodic Quadrupole

Lm = 39 cm, λ = 11.9 cm & 3 periods

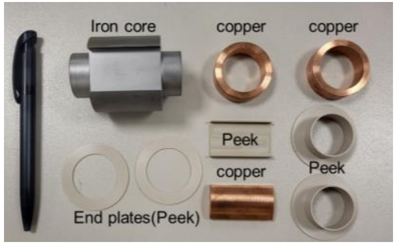








S. Fatehi et al., submitted to ASC22



Winding the coils is in process...

HTS compact undulator

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

Two different prototype coils:

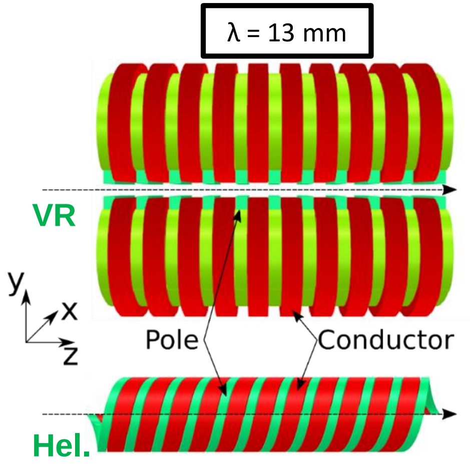
Vertical racetrack (**VR**),
Helical undulator (**Hel.**)

Main challenges:

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

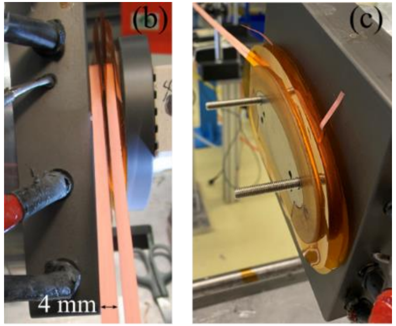
VR prototype coils manufactured and successfully tested in LN2, **77 K**.

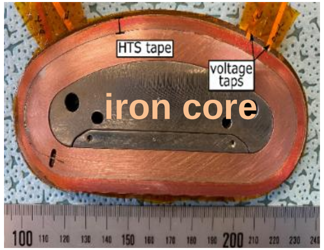
For **I > I_c** all sub-coils can **safely** operate.

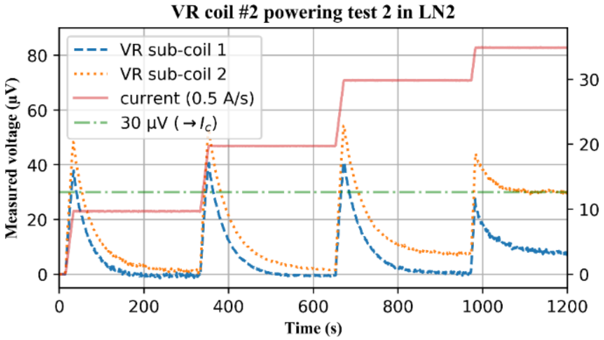


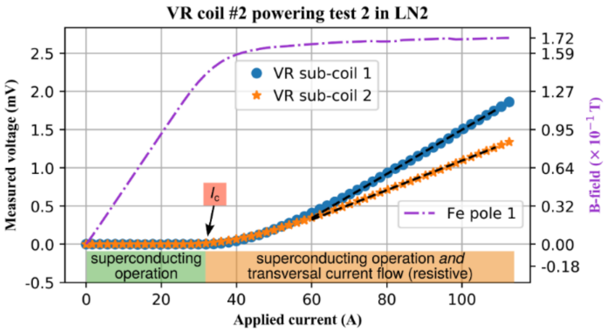
VR coil manufacturing

4 mm, non-insulated ReBCO tape









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

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

HTS laser-structured compact undulator

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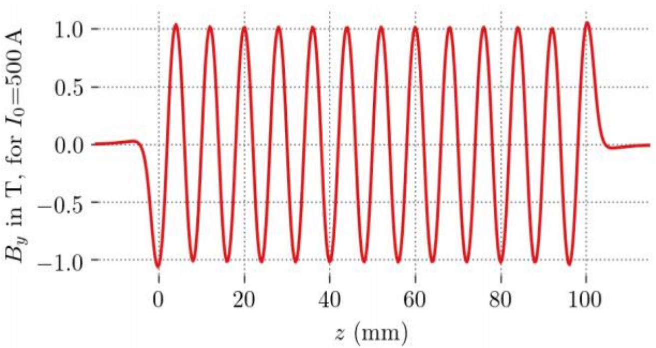
KIT Karlsruher Institut für Technologie

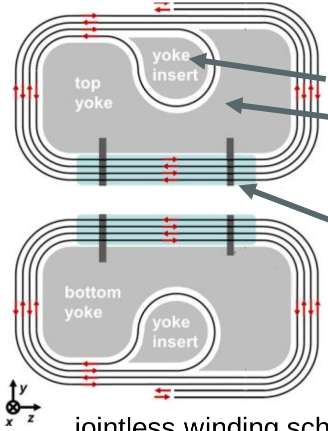
30 layers of **laser-scribed ReBCO tapes**, width of 12 mm and a thickness of 55 µm

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 **jointless winding**
- A **stacked design**, individually structured tapes are stacked and soldered alternating at the tape ends.





Stainless steel body

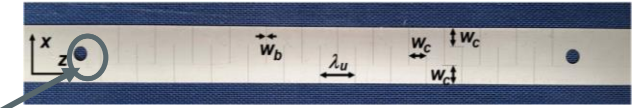
Positioning bores align the tape layers

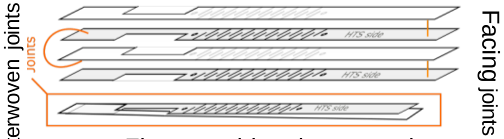
jointless winding scheme

12 periods per tape,

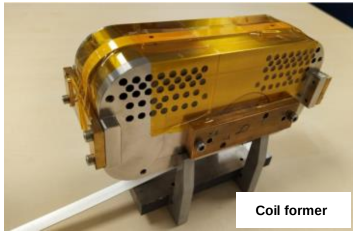
$\lambda_u = 2(w_c + w_b) = 8$ mm

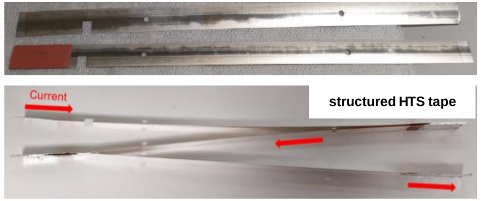
Laser-scribed slits w_b = 25 µm





Zig-zag soldered tape stack





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

A. Will et al., IPAC2021-THPAB048

Courtesy of A.Grau

Summary

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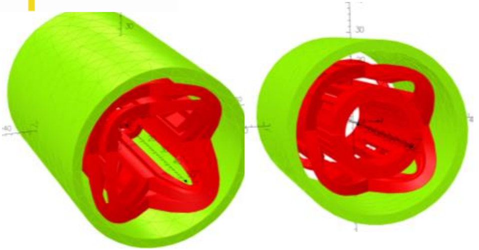
Karlsruher Institut für Technologie

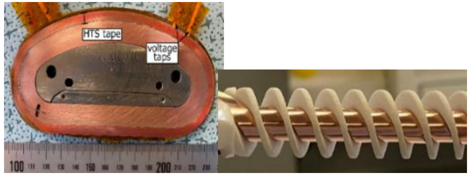
- For a laser plasma accelerator electron source,
  - a 1.4 m HTS coil-based transport line at 700 MeV is designed.

    Cos-theta magnets have been designed and for all the magnets, an integrated field quality of the order of 10^{-3} was achieved.



  - a 1.4 m HTS iron-based transport line at 210 MeV is designed using HTS periodic quadrupole and combined function dipoles. For the periodic quadrupole, a prototype is fabricated and winding the coils is in process.

- For HTS compact undulator project, VR prototype coils are manufactured and successfully tested in LN2, 77 K. For $I > I_c$, all sub-coils were safely operated. Winding of the helical prototype coil is in progress.



- For HTS laser-structured compact undulator project, prototypes of jointless winding design and stacked design have been fabricated. The tests for jointless winding prototype in liquid He is done. Manufacturing of the measurement set-up for the zig-zag structure is in process.

Thanks for your kind attention!