# Superconductivity for Sustainable Energy Systems and Particle Accelerators

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GSI


Superconductivity for
Sustainable Energy Systems
and Particle Accelerators

iFAST

# Book of Abstracts

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## Welcome

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**Session 2 / 3**

## Test Stand for Energy-Responsible Accelerator Systems

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The Compact Accelerator Systems Test Stand (COMPASS) currently under construction at KIT provides a versatile experimental environment for the development of energy-responsible accelerator systems. COMPASS comprises a cryostat vessel with a cubic cryogenic installation space of 50 cm edge length and a power supply providing electrical currents between a few 100 A up to 10 kA. It is equipped with a 2-stage pulse tube cryocooler for shield cooling and for LTS applications operated at 4 K, as well as two cryogenic mixed-refrigerant cycles (CMRCs) for the cooling of HTS applications between 20 K to 77 K. The CMRCs cover a wide capacity range for component developments and can be combined in a cascade to achieve low temperatures.

The most favorable application of CMRC technology is current leads of high-current superconducting applications, inducing a/the major heat load through their resistive part between 300 K and 77 K and thus often dominating operating cost. While cryocoolers can only pick up the heat load at the cold end, CMRCs gradually absorb the heat at the highest possible temperature along the entire current lead length, approaching the thermodynamic optimum. This may reduce the power consumption of current lead cooling by 2/3 and the power consumption of stand-alone cryostats up to 50 %, respectively.

We present the status of COMPASS, the prototype development of CMRC-cooled micro-structured current leads, and our plans for testing this new technology in combination with various HTS- and LTS-applications in the future.

**Session 2 / 6**

## Demand-driven operation of the cryogenic facilities for accelerator operation at FAIR

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For FAIR a high variety of experimental set-ups is expected. The operations scheme of SIS100 may vary in the full range of the magnets ability for seconds or several hours. Consequently, the refrigerator of FAIR has to handle different heat loads, as well as the high liquefaction rate for the start-up of the SuperFRS, with its helium inventory of 6.7 t and a cold mass of 1500 t. During the design phase

of the cryogenic facilities, it was taken into account, to have a reliable supply adopting to its actual demands.

**Session 4 / 7**

## HTS Round Hollow Cable for Fast-Ramped Applications

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A round hollow conductor with a low temperature superconductor (NbTi) is used to the FAIR magnets for the heavy ion synchrotron SIS100 of FAIR. With high capability of relieving a heat from AC losses, the cable enables to operate the magnets with a fast ramp rate such as 27 kA/sec. corresponding 4 T/sec., which are required for the heavy ion acceleration. For a future heavy ion accelerator such as SIS300, which will be installed into the FAIR SIS100 tunnel, a cable with a higher transport current and a comparable ramp rate is required for a higher magnetic field magnet. We are considering a round hollow cable with a high temperature superconductor (HTS) and investigating technical feasibility and possible magnet design for accelerators. We will present studies from the iFAST (WP-8.6) and discuss our goal and challenges, and possibilities for other applications.

**Session 6 / 8**

## Innovation in cooperation: Enabling new deep-tech solutions for society together

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In today's rapidly evolving technology landscape, the transfer of cutting-edge innovations from research institutions to the commercial sector is of paramount importance. GSI's Technology Transfer Department is at the forefront of building this crucial bridge between science and industry.

This lecture entitled "Innovation in Cooperation" gives a comprehensive overview of the transfer tasks of GSI and FAIR as well as the technology transfer activities of GSI. Practical examples will be presented and insightful answers will be given to fundamental questions that are frequently asked by both researchers and companies.

Our discussion will adress the following key aspects:

1. Technology Transfer's Role at GSI: Gain insight into the broad spectrum of the role, tasks and functions of technology transfer at GSI with industry partnerships at its centre.
2. Transfer opportunities: Explore the range of transfer opportunities GSI offers and learn about the different ways cutting-edge research gets into the hands of those who can turn it into market-ready products and solutions.
3. Funding opportunities for joint R&D projects: Funding is often a crucial element in promoting collaborative R&D. This presentation will explain the various funding options available to support joint projects, enabling participants to navigate the financial landscape of technology transfer.

4. Developing new technologies together: Participants will gain valuable insights into how companies can actively participate in and benefit from ongoing technological developments. We will explore ways of collaboration that enable companies to contribute to and take advantage of the latest innovations.

Learn more about the crucial role of technology transfer in fostering innovation and economic growth. "Innovation in Cooperation" aims to provide participants with the opportunities and tools they need to drive the transfer of technologies into society and foster collaborative innovation.

**Session 4 / 9**

## Different magnet technologies under ecological and sustainability aspects

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Particle accelerators offer unique opportunities for research in a wide variety of fields. This diversity is also expressed in a wide variety of requirements for the respective technologies of the machines. With a new understanding of the importance of climate change and the resulting necessity for sustainable operation of the machines key technologies have to be evaluated under new aspects. Different magnet technologies are considered and in a first approximation qualitatively compared in manufacturing and operation under the aspect of ecological and sustainable criteria. An iron-dominated dipole serves as a case study for these considerations.

**Session 5 / 10**

## HTS beam transfer magnets

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The beam transfer infrastructure at GSI is one of the mayor power consumers when running. The presentation will detail the concept for a beam transfer infrastructure upgrade by replacing classic water cooled magnets with HTS magnets.

**Session 2 / 11**

## The IRIS project for a new research infrastructure for superconductivity in Itay

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n the frame of the Next Generation Europe program, the EU program to boost after-covid recovery, the Italian Minister of Research has funded a project called IRIS (Innovative Research Infrastructure for applied Superconductivity). New laboratories will be built or upgraded in six poles: Milan (hub of the infrastructure), Genoa, Frascati, Naples, Salerno and Lecce, to carry out basic research on magnetism and superconducting materials, test of wires, tapes and large current cables, superconducting magnets construction and advanced instrumentation, power tests of magnets and a special facility for high current-high voltage superconducting lines. The program, which will be built in three years and then in operation for at least 10 years, includes two first demonstrators: one HTS magnets to be operated at 10-20K and a superconducting line of 1 GW (40kA-25 kV) about 140 m long. The demonstrators anticipate the main scope of the IRIS infrastructure: to support the use of superconductivity for improving sustainability by decreasing the energy consumption without compromising performance.

**Session 1 / 13**

## Superconducting Magnets for FAIR - Overview, status and considerations

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At the Facility for Antiproton and Ion Research at GSI, Darmstadt, Germany, superconducting magnets are utilized for the large machines SIS100 and Super-FRS and for the experiments like CBM, APPA and PANDA. We will give an overview on the chosen magnet designs, developments and delivery status.
We will give an overview on the given mangnet designs and developments. Further considerations and future projects like replacements of normal conducting beam line magnets at existing und upcoming sections will be set into the context of energy efficiency at the large facility of FAIR

**Session 5 / 14**

## Superconducting Magnets for Accelerators from an Industrial Point of View

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Aspects of development and manufacturing of superconducting accelerator magnets are considered from an industrial point of view. The individual project phases from development and design to prototyping and industrialization to series production are analyzed. Examples and lessons learned from previous projects are reviewed.

**Session 5 / 15**

## Enhancing Sustainability in Large-Scale Accelerators: Revamping Beam Lines with Superferric Magnets

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Accelerator facilities worldwide face a critical challenge in consuming vast amounts of energy to power resistive magnets, particularly in medium- and high-energy particle beamlines. In response to this challenge, our research focuses on the development of superconducting magnet designs as sustainable alternatives to high power comsumption resistive magnets, already in operation. Specifically, we explore the potential of High-Temperature Superconductor (HTS) coils made from ReBCO (Rare Earth Barium Copper Oxide) and MgB2-based cables. The University of Milan and INFN-Milano LASA lab collaborate on this endeavor with a company ASG (Genoa-IT), optimizing magnet designs to accommodate the strain-sensitive behavior of MgB2 and exploit the capabilities of HTS conductors. To test this concept, we have redesigned two resistive magnets in operation at CNAO and at PSI, incorporating MgB2 coils working at temperatures between 10 and 20 K. Preliminary results indicate significant reductions in energy consumption and operating costs, making an upgrade based on revamping the existing resistive magnets with superconducting coils a promising eco-friendly solution for large-scale research facilities.

**Session 4 / 16**

## Status and Perspectives of the HELIAC-Project

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The linear accelerator HELIAC will provide heavy ions with particle energies of 3.5 MeV/u to 7.6 MeV/u (A/Z = 6) at the GSI Helmholtzzentrum für Schwerionenforschung. Thanks to superconducting radio-frequency technology, it will be able to deliver high average beam currents in continuous-wave mode.

The radio-frequency resonators of the so-called Cross-bar H-mode type are being developed in cooperation with the IAP of Goethe University Frankfurt. The suitability of these resonators in principle for ion beam acceleration was successfully demonstrated in an earlier phase of the project. In the current, advanced demonstration stage an extended beam test with a first fully equipped series cryomodule is to take place shortly at GSI. The infrastructure for this has been created in recent years. In addition to setting up a radiation-shielding area with a link to the existing 4 K helium liquefier on site, this also includes vital preparations at the Helmholtz Institute Mainz. There, the superconducting resonators were tested for their performance one at a time and a spacious ISO-class 4 clean room providing the high-purity environment required for the adequate assembly of superconducting RF structures was commissioned.

This talk will present the current status of the project and recent activities, as well as the design of the complete HELIAC accelerator.

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## STF Visit

**Session 2 / 19**

## IRIS & THOR: Salerno INFN infrastructures for superconducting applications

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The capability of managing superconducting devices for research large applications as well as for societal applications is tightly connected to the availability of cryogenic infrastructures and competencies. In this framework in 2015 we realized the NAFASSY program for infrastructural strengthening, which then gave rise in 2019 to the THOR cooperation with GSI/FAIR. Although we are at the very beginning, we demonstrated the ability to set and run a test facility for performing SAT of the SIS100 quadrupole modules. The test facility is now setting up a second test line to improve performances.
More recently, the Innovative Research Infrastructure on applied Superconductivity (IRIS) program set here a strong empowering on superconductive applications for societal applications. Within IRIS the University of Salerno, INFN, and CNR-SPIN take the responsibility to install a new test facility able to check performances of a superconducting high voltage DC power transmission line (up to 1 GW), and in general to became part of the distributed national network in the field of superconducting magnets. The new infrastructure, hosted in the University of Salerno campus, will be close to the THOR laboratory to efficiently share resources. In fact, this activity will enforce the existing laboratory with new dedicated facility, falling in the new "green" line energy, one of the most promising societal applications of superconductivity. Obviously, the whole area could also become a cryogenic reference facility in the south of Italy.

**Session 4 / 20**

## AC Loss Reduction in Round HTS Cables From Filamentized Coated Conductor Tapes

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AC loss generated in a superconducting cable during variation of magnetic field is essential property affecting its use in pulsed magnets for particle accelerators or fusion tokamaks. It can be shown, that in round high-temperature superconducting (HTS) cables made from coated conductor (CC) tapes, the hysteresis loss is proportional to the tape width. Then a plausible measure for reducing it is the division of superconducting layer into parallel filaments.
We have verified that in short models of round cables, containing in different arrangements two layers of 10 standard helically laid tapes, at magnetic field amplitudes surpassing 0.1 T the loss did not depend on the cable architecture. Substantial reduction of hysteresis loss is obtained in the cable models from novel CC tapes with a filamentized REBCO layer produced in an industrial process utilizing a special 3D patterned metal substrate. However, an additional loss generated by the

currents coupling individual filaments appears. Then, further research should address the improvement of critical current and optimization of metallic layers, allowing a migration of current between filaments without substantial increase of coupling loss.

**Session 4 / 21**

## Innovative Superconducting Magnets: IFAST's approach with Canted Cosine Theta based on High-Temperature Superconductor

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The European project IFAST's Work Package 8 (WP8) focuses on advancing Innovative Superconducting Magnets, with a specific emphasis on exploring the potential of Canted Cosine Theta (CCT) magnets wound with High-Temperature Superconductors (HTS). These superconducting magnets have the capacity to make a significant impact by reducing the size and cost of synchrotrons and gantries used in research and hadron therapy. This development enhances the sustainability of these systems and improves their overall stability. The ultimate objective of the work package is to realize a straight Canted Cosine Theta (CCT) layout magnet capable of generating a central dipole field of 4 Tesla, with an intended ramp rate of 0.4 Tesla per second. However, for the initial phase, a more conservative ramp rate ranging between 0.15 and 0.2 Tesla per second is deemed acceptable. The preliminary design study delves into the cable configurations, with a specific focus on protection, AC losses, and thermal aspects. However, working with HTS materials poses specific challenges related to cable production, magnet design, and cost management, which necessitate innovative solutions. Furthermore, the research and development efforts aimed at studying HTS magnets are part of a collaborative initiative in synergy with the project IRIS (Innovative Research Infrastructure for Applied Superconductivity) of the Next Generation Europe program. IRIS aims the development of an HTS magnet capable of generating magnetic fields of 8-10 Tesla, to be operated within the temperature range of 10-20 Kelvin. In this synergy, IFAST WP8 explores the boundaries of superconducting magnets toward high-performance, cost-effective, and sustainable magnet systems for scientific and medical applications.

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## Low cost and large-scale manufacturing of high-temperature superconducting multifilamentary coated conductors

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High critical currents and magnetic field resilience of tape-based high-temperature superconductors (HTS) enable magnets to be constructed with fields above 20 T. However, high-field magnets are often required to operate with pulsed and varying magnetic fields, which results in problematic AC losses. Additionally, highly uneven local mechanical straining of the superconducting tape, due to induced screening currents may be a concern. These issues may be resolved by dividing the superconducting layer into individual narrow conductors, so-called filamentization, in combination with twisting of the tapes.

In the Eurostars project 'Filaments4Fusion' we are demonstrating a low cost and large-scale production method of such filamentized superconductor tapes. The aim is to move this method towards a commercial production making low cost tapes available for magnet producers.

In this work, we present preliminary results from the project with the inclined substrate deposition (ISD) of superconducting rare-earth barium-copper-oxide (REBCO) coatings produced by THEVA on 3D filamentized Hastelloy substrates from SUBRA. We present analysis of the superconducting performance of long length samples with different filamentization structures, and finally demonstrate the reduction of AC loss in short test cables made from filamentized and twisted tapes.

**Session 4 / 24**

## HTS magnets for compact and sustainable light sources - developments and ideas

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A key strategic approach to making accelerator-driven light sources more sustainable is to reduce their size. In the case of e.g. Free-Electron Lasers this size reduction can be achieved by using short-period undulators and high-gradient accelerating structures, ranging from X-band structures down to laser-plasma accelerators (LPA). HTS magnet technology can play a key role in this approach, as it enables very compact but strong magnets for light production as well as for the transport and matching of the particle beam.
We give an overview of our R&D on short-period HTS undulators and highly compact HTS magnets and beamline modules specially developed for capturing and transporting LPA-generated electron bunches. We present our view on the potential of this technological path and our ideas for further improving the resource efficiency of compact superconducting magnets.

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## ReBCO Wire Production at THEVA, State of the Art and Prospects

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## Open group discussion on challenges, opportunities and technological perspectives in industry and academia

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**Session 1 / 45**

## Superconductivity for Sustainable Energy Systems Accelerator Research and Development

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## Conectus Introduction

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## FAIR Site & Buildings Tour including visit of the FAIR cryogenic plant

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## Energy recuperating 4-quadrant power supply for inductive loads

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Over the past years the institute has developed an high-current power supply that can drive 14 kA into coils at a voltage of up to 25 V. Right from the start due to power grid limitations and energy conservation considerations a capacitor bank was included into the layout. This allowed the high-current power supply to be designed in a massively parallel H-bridge configuration.
Thus a full 4-quadrant operation is possible: Together with the capacitor bank the H-bridge enables an efficient recuperation of the magnetically stored energy in the powered (superconducting) inductance back into the capacitor. The stored electric energy can be exchanged between the capacitor bank and the superconducting coil with arbitrary polarities for current and voltage independently. A rather small 20 kW power supply replenishes the resistively lost energy in the copper bars and current leads while more than 300 kW are transmitted to and from the magnet.