EU-Horizon
INFRA-2024-TECH-01-01
Summary

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The leading theme of the proposal

- High Temperature Superconductors (HTS) are **game changers** in SC magnet technology:
  - They have already enabled new technology, because of the extraordinary current carrying ability in high field (e.g. Bruker 1.2 GHz, NHMFL 32T, CFS/MIT TFMC)
  - They will displace existing technology, because of the ability to operate at temperature higher than liquid helium, a minimal cryogen content, possibly different fluids
- **Time is ripe** for this step because:
  - The set challenges in HEP (e.g. FCC-hh, Muon Collider), high field science (e.g. EMFL, NHMFL, ILL, ESS), UHF NMR (Bruker), LS and FEL (EUXFEL), and fusion **cannot be met** unless we switch to HTS
  - There is increased awareness towards **sustainability and energy efficiency**, and the risk of the helium supply chain
  - There is a growing production infrastructure and availability of superconductor at decreasing price (**REBCO**)

EU-MAHTS

- **EU**ropean **M**agnet technology **A**dvances through **HTS**, for science and societal applications:
  - Physics – High Energy Physics (MuCol, FCC-hh), Nuclear Physics, Detectors
  - Material and Life Sciences – Synchrotron Light and FEL, High Field Science, Neutron Spectroscopy, NMR
  - Energy and Mobility – Magnetically confined fusion, motors and generators
  - Medicine – Particle therapy, MRI

Main objective

- **Bridge the gap** between laboratory realizations and deployment (i.e. advance TRL by 2…3 units) by :
  - Developing technology bricks required for the next step in HTS magnets (presently TRL3 to TRL4)
  - Build and test demonstrators, “usable” in field, as engineering templates for a transfer to industry (achieve TRL5 to TRL6):
    - **40T class, small bore, all-HTS solenoid** (increase the field reach and prove all-HTS as viable solution for UHF)
    - **10T-class, large bore, large stored energy, all-HTS solenoid** (manage large magnet dimensions, forces, stored energy)
    - **2T, 10mm period, 5mm gap all-HTS undulator** (extend photon energy range)

Relevance of demonstrators

■ Relevant development

▨ Relevant technology

	High Energy Physics	Nuclear Physics	Light Sources and FEL	Neutron scattering	HF science and NMR	Medical applications (therapy and MRI)	Power generation (fusion, aeolics)	Transportation and mobility (motors, levitation, aviation)
Ultra-high field solenoids	■		▨	▨	■	▨	▨	▨
High field, large bore solenoids	■			■	■	■	■	
High field undulators and super-bends			■	▨				

Proposed structure

WP1 - Coordination and Communication

Oversight, coordination & communication across work packages, industry participation

WP2 – Strategic Roadmap

Develop an inclusive strategic roadmap for HTS magnet technology

WP3 – HTS Magnet Applications

Review HTS magnet challenges towards higher performance, energy efficiency and sustainability. Study novel concepts and quantify impact of HTS magnet technology for the specific fields of application

WP4 - Materials and Technologies

Identify R&D crucial to HTS magnets and advance in areas of high relevance and return

WP5 – Demonstrators

Design and build demonstrator magnets, to be used “in field”, and as templates for transfer of technology to industry

WP6 - Test Infrastructures

Exploit existing EU test infrastructure for high field testing in variable temperature environment, extending measurement capability with upgraded sensor technology or new measurement principles

WP1 – Coordination and Communication

- Objective: Oversight, coordination & communication across work packages, industry participation

WP2 – Strategic Roadmap

- Objective: Develop an **inclusive strategic roadmap** for HTS magnet technology
- Previous work of relevance:
  - European Strategy for Particle Physics
  - CohMag and SciMag
  - Neutron Spectroscopy
  - Fusion
  - SC Global Alliance

WP3 – HTS Magnet Applications

- Objective: Review HTS magnet challenges towards higher performance, energy efficiency and sustainability. Study novel concepts and quantify impact of HTS magnet technology for the specific fields of application
- Study areas:
  - **Energy efficiency and sustainability**
  - HEP and NP applications
  - LS and FEL applications
  - Neutron scattering applications
  - High field science and NMR
  - Medical applications, including therapy and MRI
  - Power generation, including fusion
  - Transportation and mobility

WP4 – Materials & Technologies

- Objective: Identify R&D crucial to HTS magnets and advance in areas of high relevance and return
- Technology R&D areas:
  - **Energy efficient and sustainable cryogenics**
  - HTS cables and conductors for DC and AC magnet applications
  - HTS winding, insulation control, mechanics and protection
  - Diagnostics, sensors and controls
  - Radiation properties and radiation hardness

WP5 – Demonstrators

- Objective: Design and build demonstrator magnets, to be used “in field”, and as templates for transfer of technology to industry
  - **All-HTS ultra-high field solenoid**: 40 T class solenoid, 50 mm bore, compact winding, high engineering current density, cryogen-free for accelerator applications (horizontal beam)
  - **All-HTS standalone background field for laboratory testing**: 10 T class solenoid, 500 mm bore, split magnet with large forces, stored energy and energy density, cryogen-free. Relevant technology for split and super-bends in a beam line
  - **All-HTS small period undulator**: achieve 2 T gap field, with 10 mm period and 5 mm clear gap in an undulator demonstrator for next generation synchrotron light sources and FEL

WP6 - Test Infrastructures

- Objective: Exploit existing EU test infrastructure for high field testing in variable temperature environment, extending measurement capability with upgraded sensor technology or new measurement principles
  - **High field testing**: measure the electro-mechanical and thermo-physical characteristics of superconducting and resistive materials, cables, and small-size coils
  - **Variable temperature**: explore operation in different conditions of cryogenic heat transfer and cooling
  - **Diagnostics and measurements**: extend measurement capability by using upgraded sensing technology or new measurement principles
- Test infrastructures and test methods are instrumental to the success of the work proposed

Partners - Beneficiaries (Grant Agreement)

- ✓ High Energy Physics – CERN (**ESFRI**) and associated laboratories (INFN+UMIL, CEA, CIEMAT)
- ✓ Synchrotron light sources and FEL facilities – EUXFEL (**ESFRI**) and associated laboratories (PSI)
- ✓ Nuclear physics – FAIR (**ESFRI**) and GSI
- *Neutron scattering – ESS (**ESFRI**)*
- *High Field Science – EMFL (**ESFRI**) laboratories (LNCMI, HLD, HFML)*

Partners - Associates (Consortium)

- Other institutes and universities
  - Contribution defined in the consortium agreement (scope, milestones, deliverables, value)
  - Funding under the auspices of the Beneficiaries
  - *Magnetically confined Fusion – EUROFusion, F4E and associations*

- Industry
  - Access to consortium, covered by limited funding amount (e.g. 100 kEUR total ?) to formally qualify, participate to meetings, and respond to internal tender actions
  - Participate to internal tender actions managed by one of the Beneficiaries (e.g. CERN ?)

Budget allocation

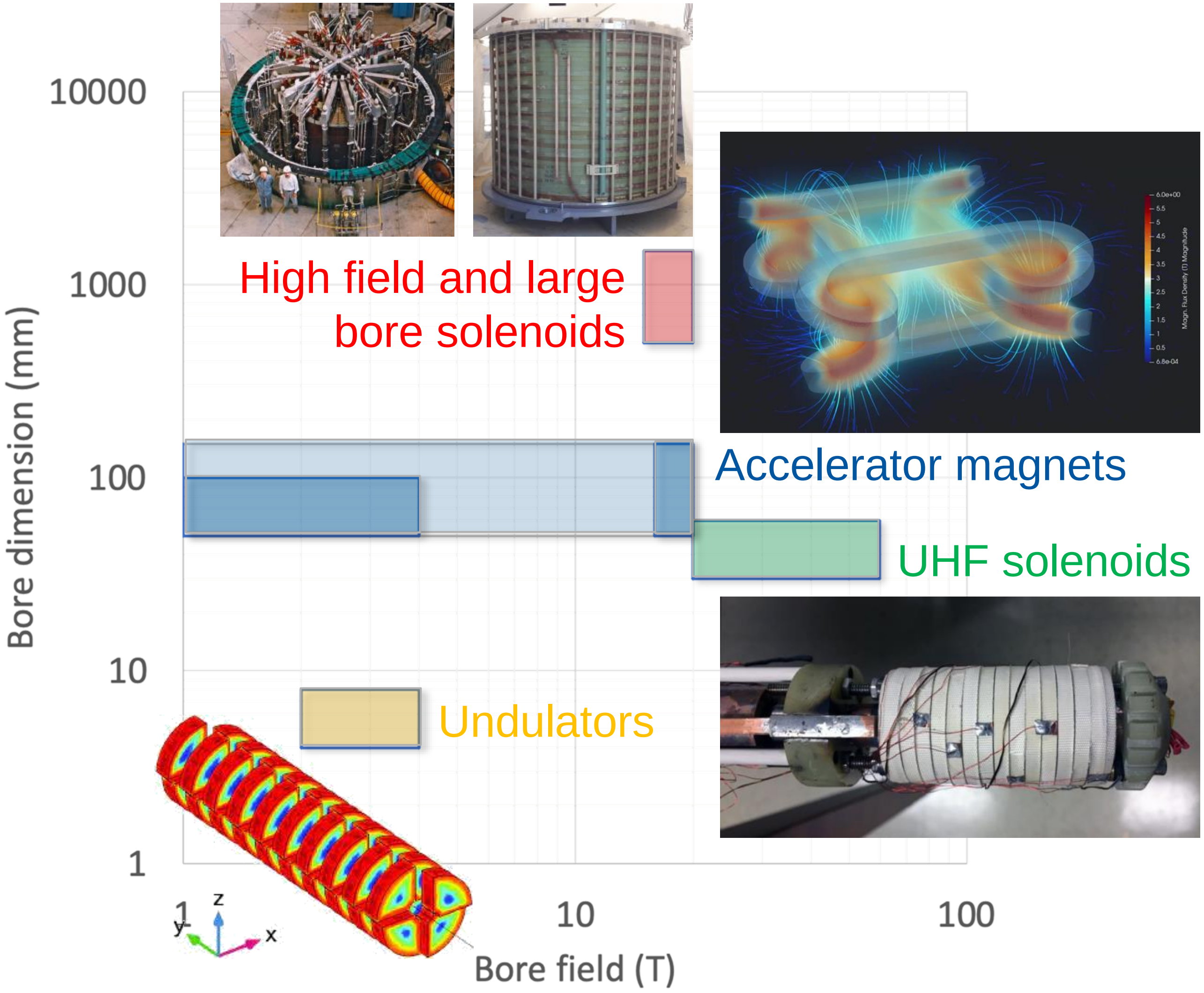
	Activity	EU Funds (kEUR)	Matching (kEUR)
WP1	Coordination and communication Administration Industry participation	300 150 2000	
WP2	Strategic Roadmap	300	
WP3	HTS Magnet Applications	300	
WP4	Materials and Technologies	500	
WP5	40T class solenoid 10T class split solenoid 2T short period undulator	2000 2000 2000	
WP6	Test Infrastructures	300	
Total		9850	

CERN

Four HTS magnets challenges

- **Ultra-high field solenoids** (from 20 T up to 40 T, and possibly beyond)
  - Material science in high field
  - NMR and life sciences
  - Muon collider (muon beam cooling)
  - Neutron scattering experiments
- **High field/large bore/large stored energy solenoids** (up to 20 T, 1 m bore)
  - HEP experiments (e.g. axion searches)
  - Fusion
  - Muon collider (muon beam production)
  - Hybrid (SC/NC) high field magnets
- **High field/low consumption/compact dipoles and quadrupoles** (up to 20 T, up to 150 mm bore, up to 20 K)
  - FCC-hh: 14 T…20 T, 50 mm
  - Muon collider (collider ring): 16 T…20 T, 150 mm, 5 W/m
  - HEP experiments (e.g. axion searches)
  - Low consumption beam line magnets, light source main ring magnets, medical applications: 1 T…4 T
  - Motors and generators
- **High field undulators and super-bends**
  - Synchrotron light sources, Free electron lasers: 2 T gap field, 5 mm clear gap, short period (10 mm range)
  - Synchrotron light sources: Super-bends: ≈ 10 T peak, ≈ 1 Tm integral

Four HTS magnets challenges



Materials and Technologies

- **Energy efficient and sustainable cryogenic technology**
  - Cryogenic fluids and cycles for high temperature (20 K)
  - Heat management (dry, indirectly cooled, gas cooled,…)
  - Minimal cryogen (reduced fluid inventory)
- **HTS cables and conductors technology**
  - High current cables and conductors (10…50 kA)
  - Cables for DC and ramped (AC, low loss) magnets
- **HTS winding technology**
  - 3D shapes (non-planar coils)
  - Interturn insulation/resistance control
  - Joints and terminations
  - High current- and energy-density (implications for mechanics and protection)
- **Diagnostics, sensors and control technology**
  - Quench detection (voltage and other techniques)
  - Field control (field shaking, field feedback)
- **Radiation properties and radiation hardness**
  - HTS superconductors
  - (Insulators)

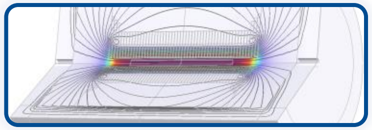
Energy Efficient Cryogenics

HTS Cables and Conductors

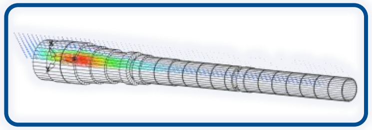
HTS Winding

Diagnostics and Controls

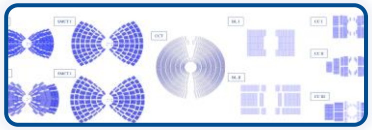
Radiation Hardness



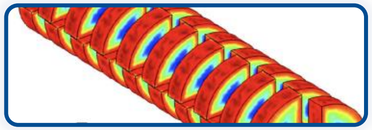
Ultra-High Field Solenoids



Large Bore High Field Solenoids



Compact, Efficient Accelerator Magnets



Undulators, Wigglers, Super-bends

Relevance of magnet challenges

■ Relevant development

🟦 Relevant technology

	High Energy Physics	Nuclear Physics	Light Sources and FEL	Neutron scattering	HF science and NMR	Medical applications (therapy and MRI)	Power generation (fusion, aeolics)	Transportation and mobility (motors, levitation, aviation)
Ultra-high field solenoids	■		🟦	🟦	■	🟦	🟦	🟦
High field, large bore solenoids	■			■	■	■	■	
High field, low consumption, compact dipoles and quadrupoles	■	■				🟦	■	■
High field undulators and super-bends			■	🟦				

Relevance of Muon Collider R&D

■ Relevant development

▨ Relevant technology

	Physics detectors (dark matter, space)	Nuclear Physics	Light Sources and FEL	Neutron scattering	HF science and NMR	Medical applications (therapy and MRI)	Power generation (fusion, aeolics)	Transportation and mobility (motors, levitation, aviation)
Ultra-high field solenoids	■		▨	▨	■	▨	▨	▨
High field, large bore solenoids	■			■	■	■	■	
High field, low consumption, compact dipoles and quadrupoles	▨	■				▨	■	■
Fast pulsed, high power, energy efficient converters							■	

Are solenoids relevant ?

- Solenoid model coils built with modest conductor lengths and size (few km) can probe performance limits at extreme values:
  - Field (20 T…40 T) – high and ultra-high field characterization of the critical surface $J_C(B,T,\alpha)$
  - Force and stress (500 MPa…700 MPa) – engineering test at levels relevant and beyond full-size accelerator magnets
  - Current density (600 A/mm^2…900 A/mm^2) and energy density (300 MJ/m^3) – quench detection and protection in a new regime, where present technical solutions do not work (detection time would be too short, quench heater power would be too high)
- “Simple” engineering, fast turnaround