# EU-MAHTS
# 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

- **M**agnet technology **A**dvances for **EU**ropean research infrastructures through **HTS**:
  - 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

Q1: better name and acronym ?

# 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 | | | ■ | ▨ | | | | |

Q2: please reflect on the matching of developments to requirements

# Additional items/proposals

- CIEMAT: **3D HTS coil winding demonstrator**, relevant to fusion magnets (toroidal and poloidal field coils in stellarators and helical devices)
  - Idea: make this a small-scale technology demonstration ?

- GSI/FAIR: **HTS AC cables development and characterization**, relevant to HEP and NP (synchrotrons), as well as fusion (central solenoid in tokamaks), and others (?)
  - Idea: make this a part of the technology development ?

# Proposed structure

### WP1 - Coordination and Communication

Oversight, coordination & communication, diversity, dissemination and outreach

### WP2 – Strategic Roadmap

Develop an inclusive strategic roadmap for HTS magnet technology

### WP3 – Industry Cooperation

Support participation of industry, organization of internal tender actions and follow-up of industrial studies, design and manufacturing, exploitation

### WP4 – HTS Magnets 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

### WP5 - Materials and Technologies

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

### WP6 – Demonstrators

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

### WP7 - 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

# A first WBS attempt

| WP Name | WP | Task | Task Name |
|---|---|---|---|
| **WP1 - Coordination and Communication** | | | |
| | WP1 | T1.0 | Oversight |
| | WP1 | T1.1 | Coordination and communication |
| | WP1 | T1.2 | Diversity |
| | WP1 | T1.3 | Dissemination, and outreach activities |
| **WP2 - Strategic Roadmap** | | | |
| | WP2 | T2.1 | Develop an inclusive strategic roadmap for HTS magnet technology |
| **WP3 - Industry Cooperation** | | | |
| | WP3 | T3.1 | Support participation of industry |
| | WP3 | T3.2 | Organization of internal tender actions and follow-up of industrial studies |
| | WP3 | T3.3 | Design and manufacturing |
| | WP3 | T3.4 | Exploitation |
| **WP4 - HTS Magnet Applications** | | | |
| | WP4 | T4.1 | Energy efficiency and sustainability |
| | WP4 | T4.2 | High Energy Physics and Nuclear Physics Applications |
| | WP4 | T4.3 | Light Sources and FEL Applications |
| | WP4 | T4.4 | Neutron scattering applications |
| | WP4 | T4.5 | High Field Science and NMR |
| | WP4 | T4.6 | Medical applications, including therapy and MRI |
| | WP4 | T4.7 | Power generation, including fusion and aeolics |
| | WP4 | T4.8 | Transportation and mobility, including motors, levitation and aviation |
| **WP5 - Materials and Technologies** | | | |
| | WP5 | T5.1 | Energy efficient and sustainable cryogenics |
| | WP5 | T5.2 | HTS cables and conductors for DC and AC magnet applications |
| | WP5 | T5.3 | HTS winding, insulation control, mechanics and protection |
| | WP5 | T5.4 | Diagnostics, sensors controls |
| | WP5 | T5.5 | Radiation properties and radiation hardness |
| **WP6 - Demonstrators** | | | |
| | WP6.1 | T6.1 | All-HTS ultra-high field solenoid |
| | | | |
| | WP6.2 | T6.2 | All-HTS standalone background field for laboratory testing |
| | | | |
| | WP6.3 | T6.3 | All-HTS small period undulator |
| | | | |
| **WP7 - Test infrastructures** | | | |
| | WP7 | T7.1 | High field testing |
| | WP7 | T7.2 | Variable cryogenic temperature testing |
| | WP7 | T7.3 | Diagnostics and measurements |

Sub-WP

Q3: can you find your role in this WBS structure ?

# Partners - Beneficiaries (Grant Agreement)

- ✓ High Energy Physics – CERN (**RI**) and associated laboratories (INFN+UMIL, CEA, CIEMAT)
- ✓ Synchrotron light sources and FEL facilities – EUXFEL (**RI**) ESRF (**RI**) and associated laboratories (PSI)
- ✓ Nuclear physics – FAIR (**RI**) and GSI

# Partners - Associates (Consortium)

- Strategic partnerships (WP2)
  - *High Field Science – in discussion with EMFL (**RI**) and LNCMI*
  - *Neutron scattering – in discussion with ESS*
  - *Magnetically confined Fusion – in discussion with EUROFusion*

- Other institutes and universities
  - Contribution defined in the consortium agreement (scope, milestones, deliverables, value)
  - Funding under the auspices of the Beneficiaries

- Industry
  - Access to consortium, covered by limited funding amount (e.g. 100 kEUR total ?) to formally qualify, participate to forum meetings, and respond to internal tender actions and/or project proposals
  - Contracts and grants placed and managed by one of the Beneficiaries (e.g. CERN ?)

Q4: what is your proposal for participation ?

# WP1 – Coordination & Communication

- Objective: Oversight, coordination & communication, diversity, dissemination and outreach
  - Organization and follow-up, cost and schedule
  - Administrative and documentary support
  - Meetings and events
  - Diversity and equality
  - Education, dissemination and outreach

Coordinator: CERN
Participants: all beneficiaries

# WP2 – Strategic Roadmap

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

Coordinator: TBD (leading strategy maker)
Participants: CERN, EUXFEL, ESRF, EMFL, FAIR, …

# WP3 – Industry Cooperation

- Objective: Support participation of industry, follow-up of industrial studies, design and manufacturing (demonstrators), exploitation beyond the project
  - Exploit existing structures, in particular the “Accelerator - Industry Permanent Board”
  - Options considered for participation:
    - *Internal tender actions*: contract in response to a specification generated by the Consortium
    - *Industrial research projects*: grant proposals in response to topics of research generated by the Consortium

Coordinator: CIEMAT
Participants: CEA, CERN, EUXFEL, FAIR, GSI, PSI

# WP4 – HTS Magnets 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

Coordinator: TBD (strong design and analysis capability)
Participants: CEA, CERN, CIEMAT, EUXFEL, ESRF, FAIR, GSI, PSI, UMIL, …

# WP5 – 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

Coordinator: TBD (laboratory test and characterization capability)
Participants: CEA, CERN, EUXFEL, KIT, PSI, …

# WP6 – Demonstrators

- Objective: Design and build demonstrator magnets, to be used “in field”, and as templates for transfer of technology to industry
  - **WP6.1 - 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)
  - **WP6.2 - 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
  - **WP6.3 - 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

Coordinator: TBD (engineering design and manufacturing capability)
Participants: CEA, CERN, EUXFEL, INFN, PSI

# WP7 - 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

Coordinator: TBD (existing test infrastructure)
Participants: CEA, CERN, *LNCMI*

# Budget allocation

| | Activity | EU Funds (kEUR) | Matching (kEUR) |
|---|---|---|---|
| **WP1** | Coordination and communication<br>Administration | 300<br>150 | |
| **WP2** | Strategic Roadmap | 300 | |
| **WP3** | Industry Forum | 2000 | |
| **WP4** | HTS Magnet Applications | 300 | |
| **WP5** | Materials and Technologies | 500 | |
| **WP6** | WP6.1 – All-HTS 40T class solenoid<br>WP6.2 – All-HTS 10T class split solenoid<br>WP6.3 – All-HTS 2T short period undulator | 2000<br>2000<br>2000 | |
| **WP7** | Test Infrastructures | 300 | |
| **Total** | | 9850 | |

Q5: iterate scope of work and deliverables

# Summary and questions

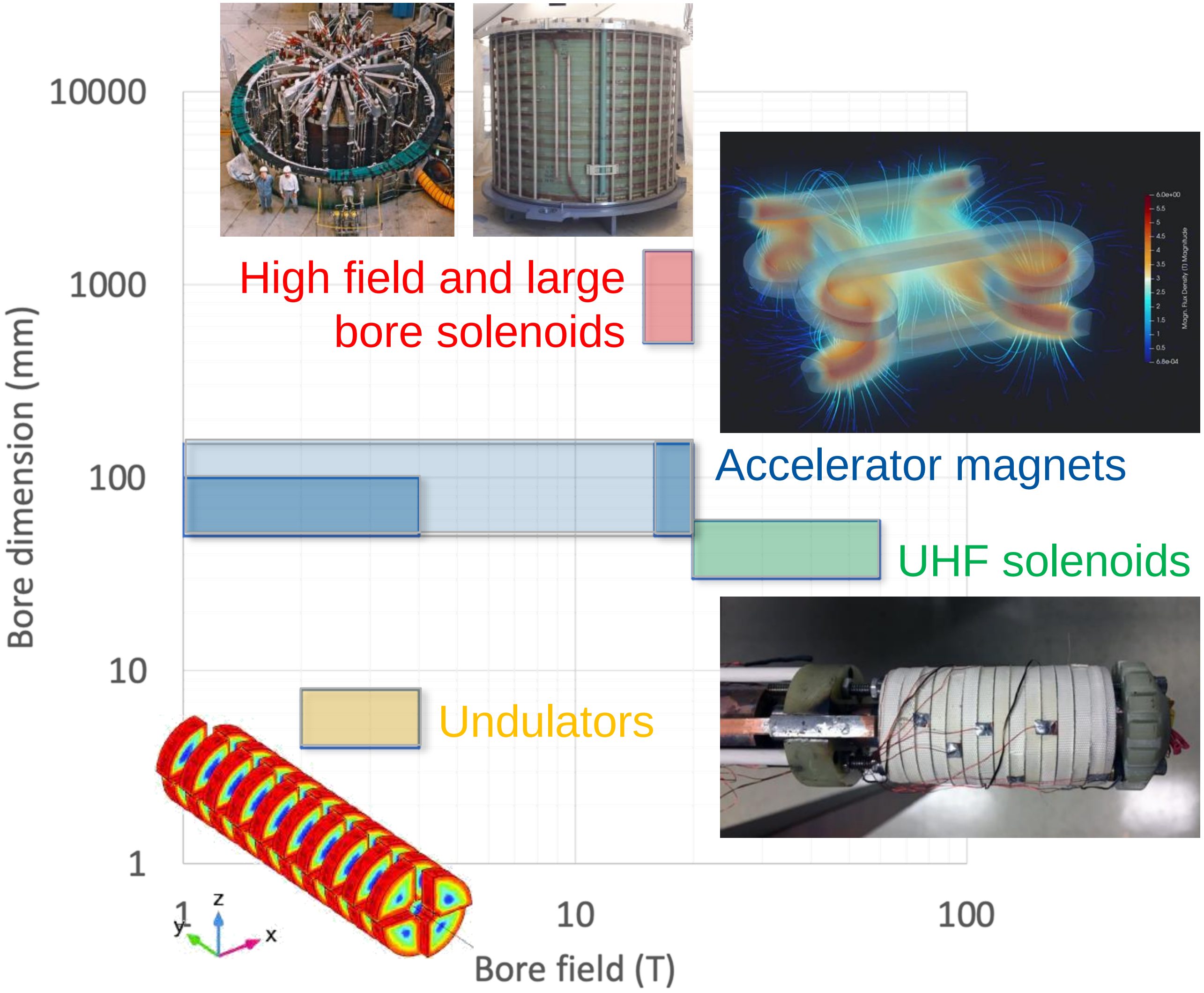
- Q2: please reflect on the matching of the proposed developments and demonstrators to the general requirements. Did we identify the right demands and a strong research path ?
- Q5: actual scope of work and deliverables need to be iterated and defined more precisely. Please provide feedback
- Q3: is the initial idea of WBS suitable for the work proposed, and does it define well the respective roles?
- Q4: what is your proposal for participation, as beneficiary, associate, coordinator or task leader ?
- Q1: is there a better name and acronym for the proposal ?

CERN

# Four HTS magnets challenges

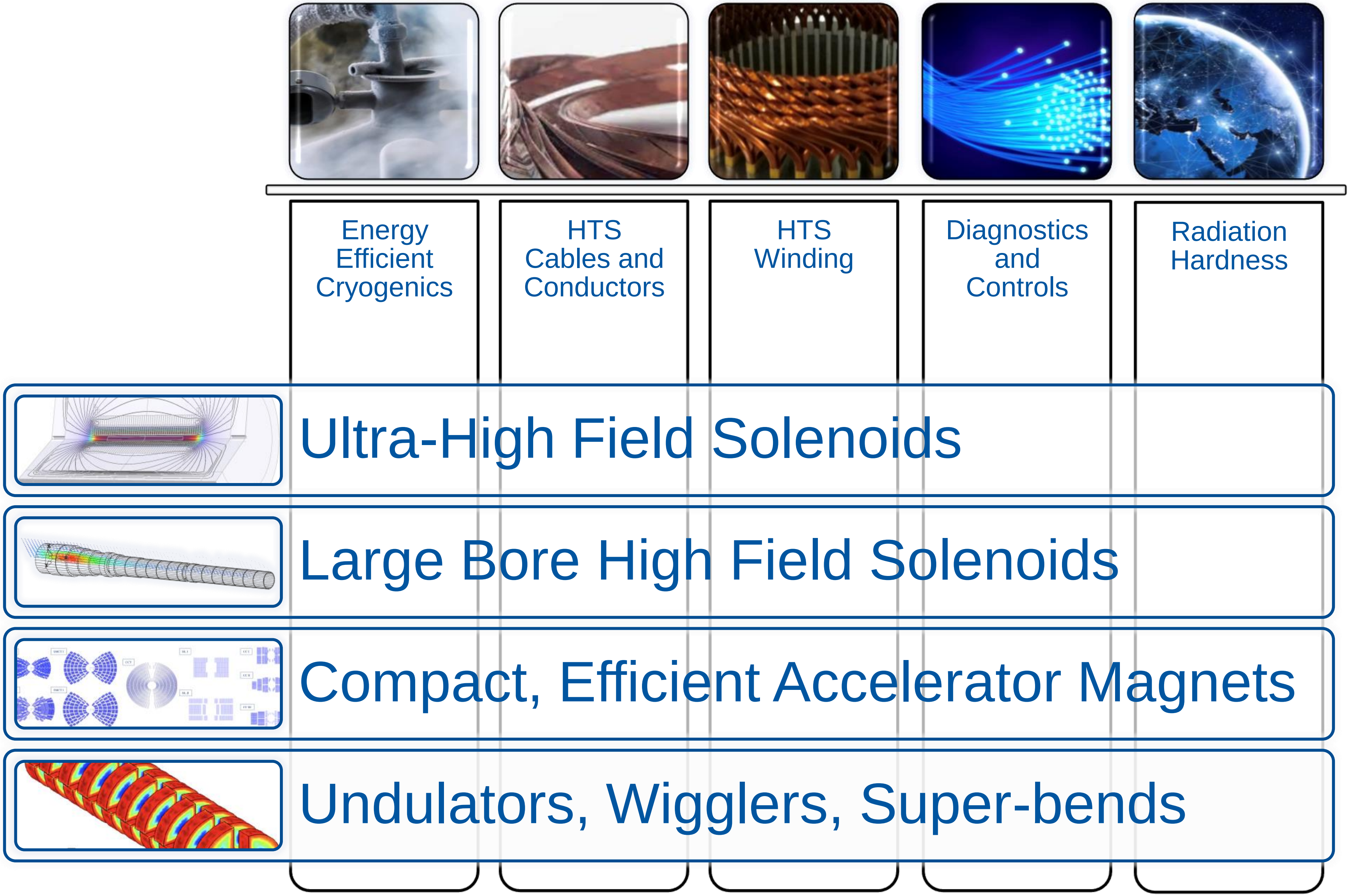
- **Ultra-high field solenoids** (from 20 T up to 40 T, and possibly beyond)
  - Material science in high field
  - NMR and life sciences
  - Muon collider (muon beam cooling)
  - Neutron scattering experiments
- **High field/large bore/large stored energy solenoids** (up to 20 T, 1 m bore)
  - HEP experiments (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

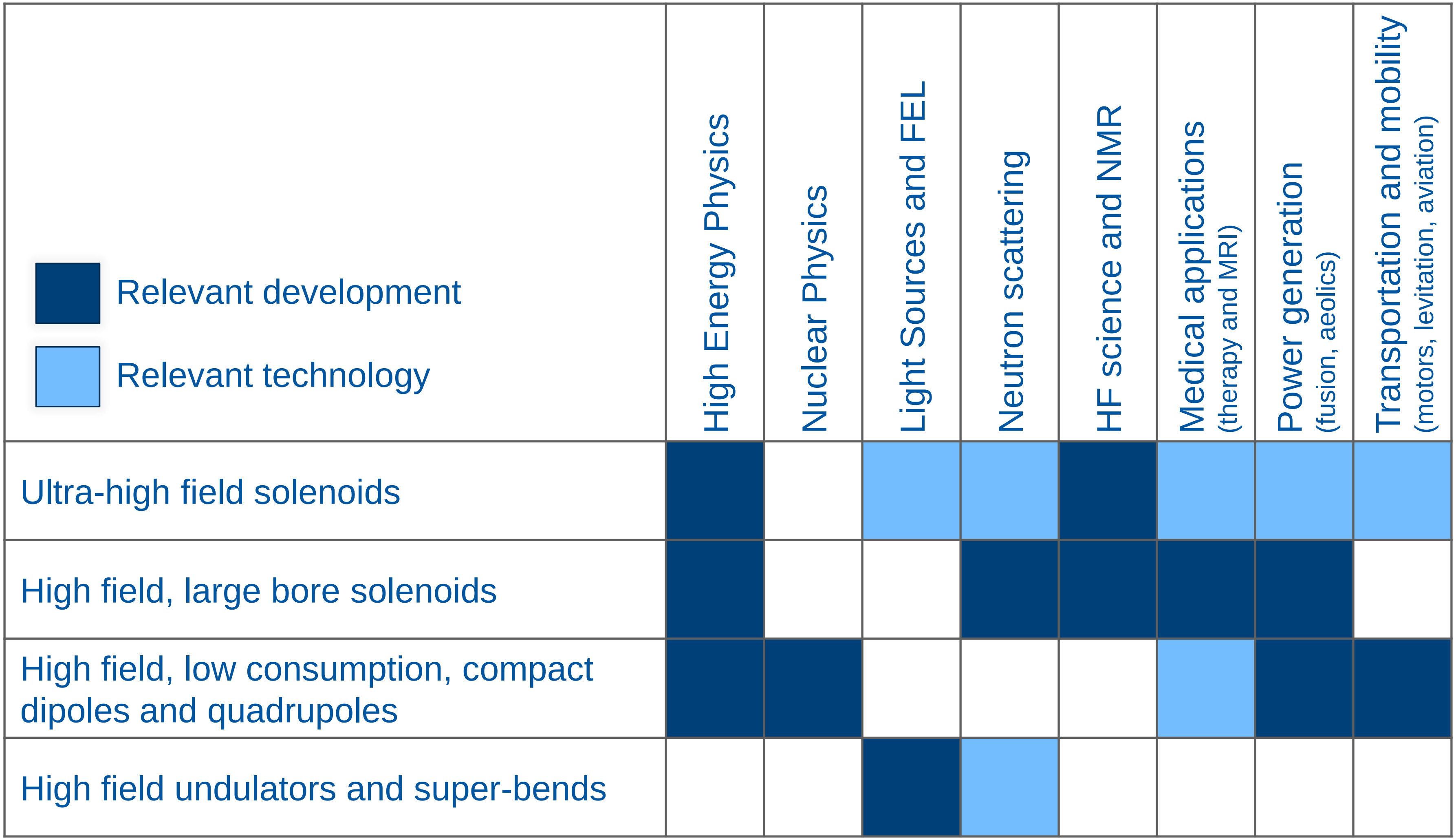
Ultra-High Field Solenoids

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 | | | ■ | ▨ | | | | |

# 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