Future Priorities for Matter Research in Europe

This position paper complements the overarching Helmholtz FP10 position from 02/2024.

Introduction

Researchers of Helmholtz Matter at DESY, GSI, Hereon, HZB, HZDR and KIT design, operate and employ cutting-edge user facilities to make key discoveries related to the building blocks of matter and our universe, ranging from sub-atomic to molecular scales. At Helmholtz Matter we provide access to our large-scale and smaller user facilities for academics and industry, which often play a pivotal role in collaborative EU projects. The three research programmes of Helmholtz Matter ("Matter and the Universe"; "Matter and Technologies"; and "From Matter to Materials and Life") cover fundamental and applied science, technology development and frontier data analysis, and enable an optimal knowledge transfer and innovation from fundamental research.

These are the key considerations of Helmholtz Matter for FP10:

Fundamental research strengthens European scientific collaboration:

At Helmholtz Matter we thrive on collaborating in curiosity-driven fundamental research. As such, we prioritise bottom-up frontier research with low TRLs supported by our user facilities. Increased funds and a stable subheading for the European Research Council (with an emphasis in ERC Synergy Grants), as well as collaborative Marie Curie-Skłodowska Actions and EIC pathfinder for breakthrough technologies under FP10 are crucial. We strongly endorse ERAC's suggestion to introduce collaborative Research Actions for our collaborations on the nature of dark matter, matter-antimatter asymmetry, and neutrino properties; hadronic matter under extreme conditions to understand the origin of heavy elements and to fill the connection between particle physics and the universe, including the most extreme events that shape our cosmos.

Research infrastructures (RI) push technology limits further:

RI are at the heart of Helmholtz Matter. We offer competitive access to our cutting-edge analytical RI to realise excellent research and innovation ideas from across the globe. We keep our RI at the forefront of science and technology to pursue the goals of our research programmes. Much could be gained for Europe's competitiveness if we could collaborate more intensively with our European counterparts. Therefore, we stress the importance for a dedicated programme part for Research Infrastructures with a stable budget with a minimum of 5% of the total budget of the next framework (sub)programme. The programme part for RI should include long-term funding instruments for access to RIs, as well as roadmap-based technology development to keep European big science at the forefront. RI services should be aligned with challenge-driven calls across a broad range of areas and highlighted in other relevant programme parts outside the one for RI. Leagues of analytical RI (e.g. LEAPS) are a prominent example of the added value that lies in a closer collaboration of European RI and the potential impact its strengthening has on European competitiveness.

Elicit synergies through a portfolio approach:

At Helmholtz Matter we believe that better connected research and innovation projects funded from different EU programmes, national or regional programmes, as well as our own research programmes could benefit from a portfolio approach that connects, pools resources and avoids disconnected and duplicated efforts. In this respect, a light advisory structure to funnel these efforts is needed.

Future directions

Researchers at Helmholtz Matter prioritise the following research and technology areas as most promising for major discoveries and applications in the upcoming decades:

Advance accelerator technology: We develop novel concepts and technologies for cost- and energy-efficient, compact conventional, superconducting and plasma accelerators and advance beam control and diagnostics. We strive for achieving the highest brightness in ultra-stable particle and secondary radiation beams with tailored spatial and temporal structure, enabling the advancement into new realms of fundamental and applied research.

Improve compact and performant detectors: We research and develop advanced detectors with high resolution and sustainable systems to record science and handle increasing data rates. Our goal is to create new detection principles and systems for optimal use in Matter facilities and to develop infrastructure for detector components and systems.

Pull frontier analysis of research data: We develop FAIR data management solutions for Matter research infrastructures, enabling and accelerating science by intelligent data reduction and analysis. We create novel algorithms and digital twins for detectors, accelerators, and experiments for data-driven science and scientific discovery. We enable autonomous research facility operation with new human-machine interfaces and provide intelligent and efficient methods for knowledge extraction informed by real-world and simulation data.

Understand matter building blocks: We explore strong field processes across the THz to X-ray region to uncover the structure of the vacuum, warm-dense-matter states, and astrophysical objects and processes. We aim to comprehend and manipulate fundamental chemical and physical processes at their natural picosecond to attosecond timescales by developing super-slow-motion imaging and advanced molecular-scale control. We advance analytical capabilities at large-scale facilities with compact light sources and enable photonic quantum technologies, contributing to the development of the second quantum revolution.

Control functionality of advanced materials: We strive to understand and control electronic, magnetic, and topological states to enable new quantum and information technologies. We investigate chemical reactions under industrially relevant conditions to improve energy conversion and storage processes. We aim to understand and control macromolecular materials for biocompatible substances, sensing, and organic electronics. We develop novel analysis techniques at our large-scale infrastructures to identify and optimise new materials for sustainable energy concepts and engineering processes, as well as develop, investigate and modify them for their application in quantum communication, computing and sensing.

Unravel detailed biological processes: We develop X-ray analysis methods and multimodal imaging to study biological functions and perform time-resolved studies of macromolecules. We use AI to design and tailor new enzymes and molecules for technological applications and new drugs. We apply AI-driven techniques to correlate morphology with genetics and ecology, understanding evolution, biodiversity, and genetic diseases. We explore the response of biomolecules, tissues, and organisms to external stressors and stimuli, with applications in organoids, tissue engineering, and disease treatments. We work to improve radiotherapy in oncology and develop solutions to protect astronauts and technology during space travel.

About Helmholtz:

We are Germany's largest research organization. At Helmholtz, more than 46 000 people work together in 18 centres and develop solutions and technologies for the world of tomorrow. With an annual budget of six billion euros and long-term, interdisciplinary research programs and unique research infrastructures we address global challenges - in our six thematic fields: Energy, Earth & Environment, Health, Information, Matter and Aeronautics, Space & Transport.

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