Research Policy Objectives of the Research Field Matter of the Helmholtz Association for the 4th Period Program-oriented Funding (Strategic Guidelines for PoF IV)

1. Overarching Goals of the Helmholtz Association

Drive dynamic development through consistent further development of Program Oriented Funding

In a Helmholtz-wide strategic process, the new programs will be even more focused on solving major and pressing social, scientific and economic issues. This requires, for example, a substantive and structural realignment of the programs on the basis of the strategic guidelines, combined with the financial consequences from the scientific and strategic evaluations. A comprehensible and systematic subdivision of the programs ensures that the results of the two evaluation steps can be brought together and that the responsibility for achieving the objectives in the programs and topics can be clearly assigned. At the same time, this subdivision allows the structural and thematic changes from PoF III to PoF IV to be documented transparently and accessibly, and to be published in appropriate formats together with the results of the two evaluation steps.

Promoting thematic profiling and networking in the Research Fields

The systematic strengthening of the Research Fields and the bundling of funds from the centers into a (virtual) research area budget ("innovation pool," corresponding to 1% of the program funds) will further strengthen networking between the centers and their flexibility and responsiveness to current needs within the PoF. The innovation pool serves, among other things, to try out new innovative ideas in short-term research projects; to give young scientists space outside the long-term research programs; or to be able to respond flexibly to current, socially relevant topics in event-related research campaigns. The projects are awarded within a lean procedure in the Research Field platform. This thematic profiling will be visible for the broader community and thus will promote the positive external reception of the centers and the Association. In order to exploit synergies in the Research Fields, joint strategies will be developed and implemented in future, e.g. in the areas of internationalization, science communication or innovation promotion. Driven by common interests, the tasks and fields of action of the newly established bodies of the Research Fields will be jointly further developed.

Strengthening research infrastructures by expanding operations for internal and external scientific users

The Helmholtz Association builds and operates excellent research infrastructures, especially those which – e.g. due to their size and/or complexity – can only be provided by a dedicated national research organization. By providing excellent research infrastructures for internal and, in particular, external users from science and industry, it contributes to the international competitiveness and attractiveness of Germany as a hub of knowledge and research. The aim is to secure Helmholtz's leading international position in this field through long-term strategic planning and adequate funding, and to expand operations for external users from science and industry.

In doing so, Helmholtz develops a modern understanding of research infrastructures. For example, it will look at small, distributed and digital infrastructures and broaden the existing funding mechanisms in order to make Helmholtz's mission more visible and provide targeted incentives for access. Access for external users from science and industry will be further expanded, user access regulations will be updated and the utilization of existing facilities will be further optimized through transparent decision-making procedures on access.

Developing a Digitalization Strategy for Helmholtz (Open Science/Open Access/FAIR Data)

The aim is for the Helmholtz Association to assume a pioneering role in the fields of information processing and information technology, Open Access, Open Data and Open Science. This means not only a contribution to the digitalization of the sciences, but also a decisive contribution to the validity and quality of basic research. To this end, it is necessary to expand competences in the field of digitalization and data sciences in all research areas and programs, to expand the provision of research data and computing power for the German scientific community and to further professionalize data management. Another goal is to establish cross-center, sustainably maintained structures and services in order to make research data publicly accessible as far as permissible and to ensure the integration of open science activities into a national or international context that spans organizations as well as to make a substantial contribution to the national research data infrastructure (NFDI).

Creating and maintaining attractive research sites

Attractive locations and framework conditions for the best minds are indispensable for the future viability of the Helmholtz Association. As an efficient partner for universities and other research institutions, the Helmholtz Centers contribute to the further development of top scientific sites in Germany. This includes the structural infrastructure.

Strengthening the transfer to business and society

By strengthening the promotion of innovation and technology transfer, the Helmholtz Association makes an important contribution to maintaining and expanding Germany's leading position. In particular, the great innovation potential of the Research Fields, research infrastructures and the wealth of research data must be exploited to a greater extent than before. By expanding the transfer of knowledge to science, society, and industry, the foundations for decision-making are being laid for society, politics, and industry, and thus Helmholtz fulfills its duties within the knowledge community.

Building bridges between Research Fields

In return for strengthening the Research Fields, interfaces between the Research Fields are to be specifically identified and supported by suitable instruments. The aim is to expand the diverse personnel, thematic and methodological connections to other Research Fields in order to achieve more together.

2. Global Objectives of the Research Field Matter

2.1 Mission and tasks

In the Research Field Matter, the Helmholtz Association pools its competencies in the research of matter, in the construction and operation of complex large-scale research facilities, as well as in the development of basic technologies such as concepts for new accelerators and detectors.

The scientific mission of the Research Field is to investigate the structure of matter and the properties connected to it. This includes investigations on all scales, from the elementary building blocks of matter and the exploration of the quantum world to fundamental questions on the development of the universe. Understanding complex interactions on many different length scales serves as a basis for the development of new materials or drugs. To this end, the Helmholtz Centers develop, exploit, and operate a unique, complementary portfolio of research infrastructures, often within the framework of large international collaborations.

The mission of Matter connects to all key disciplines in the natural sciences. Though the effort needed is tremendous, the promise is that the results open ways into completely new worlds of understanding matter. The research not only increases the fundamental knowledge of humankind but also offers contributions to the solutions of the great challenges of today and tomorrow. The existing large-scale research facilities and those under construction put the Research Field Matter in an excellent position to tackle these challenges. They are addressed by eight closely networked Helmholtz centers that cooperate in an interdisciplinary manner (for details see 3.1.).

At the beginning of the third period of program-oriented funding (PoF), the Research Field Matter gave itself a modern, forward-looking program structure based on close cooperation between the involved Helmholtz centers. This structure makes greater use of the links between basic research, application-oriented research, and technology development.

The strategically important core research topics of the Research Field include the development, construction, and operation of cutting-edge large-scale research facilities as well as (via the participating centers) the German participation in international research facilities. These core competencies of the Research Field Matter are to be consolidated further.

The core research competencies in the area of research with photons, neutrons, particles, and highest electromagnetic fields should be further expanded. To achieve this, the development of strategy processes for research with photons, neutrons, particles, and the highest electromagnetic fields should be actively taken on at the national, European, and international level. The national strategies should be presented after two years of the PoF IV period; when applicable they should take into account European and international strategy processes or strategies and shall be integrated into European strategy processes.

2.2 Priority topics and their objectives

The new program structure of the Research Field introduced in the third period of program-oriented funding has been shown to be very successful in recent years and has led to new synergies between the individual research disciplines and between basic and application-oriented research right up to concrete applications. The current structure will thus be continued.

The central scientific and technological questions for the Research Field Matter in the next years include:

- How has the universe developed from the Big Bang to the present day?

- What are the building blocks of matter and their fundamental interactions, and what are the origins of the elements in the universe?

- How can electronic and molecular processes be better understood and controlled on all relevant length and time scales, thus creating the prerequisites for the development of novel functional materials and active substances?

- How can highly brilliant and compact particle accelerators as well as modern detectors and sensors be developed for research and industry?

In the next funding period, the following objectives will be prioritized:

- The Centers will develop highly visible profiles at international large-scale facilities for particle, hadron, and astroparticle physics, in particular in the ATLAS, CMS, and ALICE detectors at the LHC, in Belle II, and in CTA, IceCube, and Auger.

- The Centers will continue their high profile participation in the European X-Ray Free-Electron Laser XFEL, the European Spallation Source ESS, the ESRF, and the ILL as well as in the FAIR (Facility for Antiproton and Ion Research) Facility.

- Research activities aiming to clarify the nature of Dark Matter and the properties of neutrinos will be stepped up.

- Our understanding of the relationship between the structure and dynamics of matter and its properties will be further developed.

- The impact of the structure and properties of matter and materials on biological, chemical, and physical processes will be examined.

- The research infrastructures of the Research Field will be specifically used for the characterization of electronic, magnetic, and molecular processes on all relevant length and time scales. This will serve as the prerequisite for the targeted development of new materials and active substances, e.g., in the Research Fields Information, Energy, and Health.

- The Research Field will actively seek the use of its research infrastructures and competencies for research in industry, e.g., for materials research and/or molecular biology.

- The large-scale facilities of the Research Field will be further developed to ensure that they remain at the forefront of the world's facilities.

- As a long-term alternative to ever-larger accelerators and large-scale facilities, the Research Field Matter should investigate new approaches and develop future technologies, in particular

    a. for ultra-compact and cost-efficient accelerators and sources of radiation and particles for science, industry, and medicine,

    b. for a prototype of alternative high-brilliance neutron sources.

- Future technologies will be developed for novel detectors that meet the requirements at large-scale facilities, e.g. in terms of high data rates, accuracy, and reliability.

- Data Management and Analysis (DMA) will be further developed as a program topic in the Research Field, and a cooperation will be developed between DMA and the Research Field Information.

2.3 Structural objectives

2.3.1 National and international cooperation

The Helmholtz centers in the Research Field Matter are to further strengthen and expand their network with universities, research institutions at other scientific organizations, and research-based business enterprises. The tasks involved in cooperation with the universities include joint appointments, participation in clusters of excellence within the framework of the Federal and State Excellence Strategy, participation in funding instruments of the DFG, such as collaborative research centers, and the promotion of young researchers, e.g., through joint structured doctoral programs. Establishing and expanding research networks between science and industry will make it possible to create new synergies and enable innovation processes, which represent important factors for Germany's further development as a science site of international reputation. The networks aim to help create a closed innovation chain extending from basic research results to newly developed products, processes, and services.

Operating the Research Field's large-scale facilities creates a great and unique potential for new national and international cooperations. These opportunities are to be further expanded with regard to user groups from science and industry.

The Research Field Matter participates in major international research projects and large-scale research facilities, such as the LHC and its detectors, large-scale astroparticle physics projects, FAIR, and major international projects for materials research (European XFEL, ESRF, ILL, and ESS) based on multilateral cooperation between its centers. It is expected that this supports the German participation to remain highly visible, and that experiments with German participation and with users from outside of Helmholtz are conducted will full success.

In this way, the Helmholtz Association's mission of constructing and operating facilities for national and international users will be implemented in concrete terms.

2.3.2 Creating and maintaining attractive scientific environments

It is vital that the centers in the Research Field Matter continue to serve as cosmopolitan places for the most capable talents and the best minds regardless of gender, origin, and personal lifestyle. The Research Field must continue to make a special effort when competing for the best minds at the international level. Helmholtz clearly acknowledges its responsibility when it comes to training young scientists from Germany. Diversity and, in particular, the implementation of equal opportunities in science, technology, and administration are an integral part of the strategy of the Research Field Matter.

The Centers in the Research Field continue to work together with the aim of optimizing the basic conditions that will make it possible to successfully implement ambitious research projects. To achieve this, they must train or recruit the best talents and retain them at the Centers over the long term. This includes programs for recruiting young scientists and expanding attractive career prospects, as well as central measures to improve the balance between family and career.

2.3.3 Strengthening the transfer of technology and knowledge to economy and society

Over the next few years, the Centers in the Research Field Matter will continue to strengthen and pursue the transfer of their fundamental findings into society ("knowledge transfer") and industry ("technology transfer") on a sustainable basis. This will require that suitable structures are created or expanded in the Centers in order to make the Research Field's cooperation with industry and society an integral aspect at the strategic and organizational levels.

From research results to innovation in industry and society

The Research Field Matter will become more prominent in the innovation process. The specific innovation strategy will primarily address the areas of materials research and molecular biology. It will be provided at least one year after the start of the PoF period.

Gaining a stronger profile in the area of innovation requires the creation of suitable structures in the centers in order to make the Research Field's cooperation with industry and society an integral aspect at the strategic and organizational levels.Key steps towards this goal will include:

- Opening research infrastructures specifically to external users from industry in a targeted way and creating a corresponding business-oriented culture in the Centers.
- Establishing strategic partnerships with industry in order to coordinate goals and research needs at an early stage.
- Creating suitable structures in the Centers in order to make cooperation with industry an integral aspect at the organizational level, e.g., by appointing a chief technology officer and/or an "Innovation Service Center."
- Providing targeted support for spin-offs and start-ups in the Centers, e.g., through technology investments or space for high-tech start-ups and participation in the expansion of Helmholtz Enterprises.
- Developing measures to address SMEs in a targeted manner.
- Including regional business enterprises in considerations relating to the development of regional locations, e.g., via networking with the Chamber of Industry and Commerce.
- Developing specific incentive systems in the Research Field Matter, also taking into account the environment of large-scale facilities in particular.

A report on the Research Field's industry-related activities will be presented midway through the PoF period.

Knowledge transfer and public relations

A strategy for knowledge transfer and public relations in the Research Field Matter is to be presented after two years of the PoF term and will be implemented and updated within the funding period. The aim of this strategy is to increase the visibility of the benefits that basic scientific research offers to society and politics. In addition, the Research Field is to develop opportunities and strategies for exchanging ideas with important players in society (e.g., politicians, non-governmental organizations, residents, and schools) in order to develop a mutual understanding for the benefit of research at large scale facilities for the society.

2.4 Further development of research infrastructures

The Research Field Matter will enhance its research infrastructures by continuously expanding their operation as well as access opportunities for external users from science and industry. This also offers new opportunities for national and international cooperation. This should happen in step with the ideas and goals formulated above in the general research goals. In particular, new large-scale facilities, research infrastructures, and substantial upgrades to existing large-scale facilities in the Research Field Matter must be placed in the national and international contexts.

The official National Roadmap procedure for research infrastructures must be completed before Helmholtz centers can participate in future projects (or upgrades covering activities which are currently connected with investments of more than €50 million).

The research policy interests of the Federal Government and the Federal States are always considered when deciding whether to participate in the construction or upgrade of new research infrastructures. This means that the Centers operate large research infrastructures in accordance with the Helmholtz mission and ensure access for external users from science (especially universities) and industry.

Any decision on the participation in potential new research infrastructure projects has to comply with the rules and processes of the National Roadmap and the agreements between Helmholtz and the funding bodies when submitting proposals and implementing them. This applies to both the long-term strategic planning within the scientific community and the allocation of construction and operating costs.

A transparent process for developing the portfolio of the Helmholtz research infrastructures, including the participation of potential users, will be established. In this process, priorities are to be defined with respect to future research infrastructures of the Research Field Matter, including a strategic classification and integration of these research infrastructures into the international research infrastructure landscape. This applies in particular to new research infrastructures and substantial further developments of synchrotron radiation sources, accelerator-driven radiation sources, and laser-driven radiation sources as well as of neutron research.

2.5 Joint initiatives of the Research Field and cross-cutting activities

2.5.1 Cooperation strategy

The Research Field Matter will present its cooperation strategy after two years of the PoF period and will implement and update this throughout the PoF period. The strategy should focus on cooperation activities within the Research Field Matter, within Helmholtz, at the national level (especially with third parties such as universities), and at the international level. The aim of the strategy is to present the benefits of large-scale facilities, especially for other players in the German science system and beyond.

2.5.2 Strategy pool (so-called Matter Forum)

The Research Field Matter will set up a so-called strategy pool (Matter Forum) to which the participating Helmholtz centers will contribute 1% of their LK I funds in the form of a virtual fund. This will support strategic activities that will be jointly defined in the Research Field. The funds allocated for this purpose remain at the responsible research center.

2.5.3 Talent management

The Research Field Matter aims to train or attract the best talents from all over the world. Programs for recruiting and promoting young scientists and expanding attractive career prospects contribute to this, as do central measures to improve the balance between family and career. Generating enthusiasm towards the STEM subjects (MINT in German meaning Mathematik, Informatik, Naturwissenschaft, Technik) amongst young students should also be part of this effort.

The talent management system of the Research Field Matter must be further developed and expanded at all levels while being embedded in the corresponding Helmholtz strategies. The achieved results will be discussed every two years in the PoF period on the platform of the Research Field Matter.

2.6 Interfaces to other Helmholtz Research Fields

The Research Field Matter cooperates closely with other Helmholtz Research Fields on central topics. It creates and exploits new synergies via cross-disciplinary cooperation in the areas of materials research, digitization, structural biology, radiation research, and quantum technologies.

2.6.1 Materials research

In the context of materials research, the Research Field Matter will enhance its cooperation with other Helmholtz Research Fields, in particular the Research Fields Information and Energy. The

Research Fields will work together to develop an overarching Helmholtz materials research strategy that systematically builds on their complementary competencies and unique selling points while combining the special scientific possibilities of the Centers with prospective applications. The definition and description of interfaces aimed at boosting synergies between the respective Research Fields will be presented in this overarching Helmholtz Materials Research Strategy. The strategy will be finalized and subsequently implemented, taking into account the results of the strategic review. In this way, Helmholtz will also distinguish itself from other science organizations and research institutions in the national science system with respect to materials research.

In this context, the following objectives are the most important contributions of the Research Field Matter to materials research at Helmholtz:

- The special competencies of the Research Field Matter in the development, construction, operation, and use of large-scale research infrastructures for interdisciplinary issues relating to the characterization, modification, and synthesis of materials. The main aim is to develop a deeper microscopic understanding of matter, materials, and biological systems,

- as well as applied materials research on the basis of concrete problems from the other Research Fields, which are solved through the use of large-scale facilities.

2.6.2 Digital Transformation

The Research Field Matter will participate in the Helmholtz Digital Transformation Strategy. Previous and potential future activities of the Research Field relating to the Helmholtz Data Federation (HDF) and the Helmholtz Information & Data Science Incubator will be integrated into the future Helmholtz Digital Transformation Strategy.

The Helmholtz "Big Data" expert group or a similar format focusing on integration and exchange with national expert committees representing the user communities of the research infrastructures will be continued. The Research Field Matter is implementing the new "Data Management and Analysis" (DMA) topic in the Helmholtz "Matter and Technologies" (MT) program, which will work closely with the Research Field Information in the future.

The Research Field Matter is also involved in relevant topics in the BMBF's ErUM-Data action plan in connection with related activities of the Federal Government (e.g., the implementation strategy of the Federal Government for shaping digital change, strategy for artificial intelligence etc.). In addition to modern and effective research data management, this also relates to developing and applying big data analysis methods.

In addition, the Research Field Matter is working on an Open Access, Open Data and Open Science Strategy, which it will implement together with the other Research Fields.

2.6.3 Structural biology and biological processes

The research Centers in the Research Field Matter offer unique analytical capabilities for structural biology as well as biological and medical imaging at its experimental stations at synchrotron, FEL, and neutron radiation sources. The accessible resolution range extends from complete organisms to the atomic scale for all time scales which are necessary for investigating the function and dynamics of biological systems.

The Research Field Matter will further develop and tap into its existing experimental possibilities with regard to the search for new active substances in close coordination with the Research Fields Health and Information at Helmholtz. Furthermore, new experimental and evaluation techniques are to be developed using the unique possibilities offered by the Research Field's radiation sources in order to yield new insights in the area of structural biology and biological processes.

2.6.4 Radiation research

The Research Field Matter collaborates closely with the Research Field Health with regard to activities in the area of radiation research. The main objective of the corresponding cross-cutting activities is to gain a sound understanding of the effects of ionizing radiation on biological systems. For this purpose, the complementary expertise of the various Helmholtz Centers in the field of radiation research are brought together and focused on the fields of radiation biology and radiation therapy as well as molecular imaging for biomedical applications. Potential synergies with the Research Field Energy are to be explored and exploited.

The development of novel laser-driven radiation sources for radiation therapy is being promoted across research areas by HZDR (Matter and Health) and DKFZ (Health) within the framework of the National Centre for Tumour Diseases (NCT). The partners are also investigating methods of real-time dosimetry in radiation therapy. Within PoF IV, therapy-relevant acceleration energies are to be achieved and radiobiological properties resulting from the special beam properties are to be clarified and used. Results from the area of clinical radiobiology relating to the verification of irradiation planning in heavy ion therapy (HIT/DKFZ) with innovative cellular phantoms (developed at GSI) are expected within the first year of the program period. Further results regarding the combination of charged particles with new targeted drugs developed at the DKFZ are expected in the middle of PoF IV. Synergy effects are also expected from cooperation with the Research Fields Energy, Earth & Environment, as well as the Research Field Aeronautics, Space, & Transport. These are to be gauged, specified, and used.

2.6.5 Quantum technologies

The Centers in the Research Field Matter participate in the strategy and its implementation for quantum technologies in the Helmholtz Association based on their core competencies and particularly through the use of their research infrastructures (see "Quantum Technologies" strategy paper).

3. The Programs in Detail

3.1 Participating Centers

In the fourth period of program-oriented funding, eight Centers are involved in the Research Field Matter. These Centers work together within the framework of a common objective and strategy:

- Deutsches Elektronen-Synchrotron (DESY)

- Forschungszentrum Jülich (FZJ)

- Helmholtzentrum für Schwerionenforschung* (GSI/FAIR incl. the Helmholtz Institutes Mainz & Jena)

- Helmholtz-Zentrum Berlin für Materialien und Energie (HZB)

- Helmholtz-Zentrum Dresden-Rossendorf (HZDR)

- Helmholtz-Zentrum Geesthacht – Zentrum für Material- und Küstenforschung (HZG)

- Karlsruher Institut für Technologie (KIT)

- Max-Planck-Institut für Plasmaphysik (IPP)

*) All activities related to the Research Field Matter and the contributions of GSI and FZJ to FAIR are to be integrated into PoF IV and to be evaluated in the Research Field Matter.

3.2 Coordinating functions

The programs and topics in the Research Field Matter are developed on a cross-Center basis. This requires corresponding efforts to coordinate these activities within the Research Field Matter. The actual list of the program and topic spokespersons for the PoF IV period is presented in the corresponding program proposals.

3.3 Thematic structure and specific objectives

The Research Field Matter is subdivided into three programs: "Matter and the Universe" (MU), "From Matter to Materials and Life" (MML), and "Matter and Technologies" (MT), which consist of three research topics each. For MML, there are four additional facility topics, which comprise the development and operation of the user facilities involved in the program.

3.3.1. Matter and the Universe (MU)

This program applies the most advanced for theoretical and experimental methods to study the fundamental building blocks of matter and their role in the evolution of the universe and the formation of its largest structures.

The research objectives are in particular:

- to identify the fundamental particles and their interactions as well as to obtain an exact understanding of the structure of the vacuum,

- to understand the structure and dynamics of hadrons, nuclei and nuclear matter and their role in the astrophysical formation of chemical elements, and

- to understand the nature of Dark Matter and Dark Energy and of the universe at high energies.

A coherent picture of the microcosm and a detailed idea of the evolution of our universe will be obtained based on the acquired knowledge.

The program will carry out this major task in a holistic and structured way, and knowledge regarding elementary particle physics, nuclear physics, astroparticle physics, astrophysics, and cosmology will be brought together for this purpose. This takes place in three program topics: "Fundamental particles and forces," "Cosmic matter in the laboratory," and "Matter and radiation from the universe."

Extending the experimental capabilities to higher energies, to extremely rare processes, and to very complex systems of matter is indispensable, which is why the MU program works closely together with the MML and MT programs and is itself a driver for the development of detectors and scientific computing.

A broad-based theoretical physics plays a special role by interpreting and compiling results, offering ideas for future research initiatives, and developing methods.

The competencies and activities of the FZJ's IKP-1, IKP-2, and IKP-4 departments in the field of nuclear physics will be maintained, while the resources be organizationally transferred from FZJ to GSI. The research activities of the IKP-3, located in the Research Field Information, will continue to benefit the Research Field Matter.

Topic: "Fundamental particles and forces"

The Helmholtz Centers DESY and KIT contribute to this topic. It deals with the fundamental particles and their interactions and poses some of the most fundamental questions in physics, such as the matter-antimatter asymmetry in the universe, the hierarchy problem, and the electroweak symmetry breaking. Many experiments and theoretical efforts focus on the search for new physics beyond the standard model of particle physics, e.g, of Dark Matter particles or super-symmetry.

Prominent research instruments include the ATLAS and CMS experiments at CERN's Large Hadron Collider (LHC) and the Belle/Belle II experiment for investigating electron-positron collisions at KEK in Japan. The operation of the LHC until the end of 2022 will be followed by the high-luminosity upgrade HL-LHC, for which DESY and German universities will supply the tracking detector endcaps for ATLAS and CMS. From 2026 to the mid-2030s, the HL-LHC is expected to increase the amount of data by tenfold once again. Belle II will go into operation with all components at the end of 2019 and will deliver data until the end of the POF IV period.

Specific objectives include

- Accurate measurements of the properties of the Higgs boson will be carried out at LHC/HL-LHC, as well as high-precision investigations of the electroweak and strong interaction at LHC/HL-LHC and at Belle II. It is expected that the latter will provide deep insights into the causes of matter-antimatter asymmetry.

The experiments also search for new particles and phenomena, either by direct observation or by deviations between theory and precision measurements.

A new aspect of the PoF IV structure is the search for axions and similar hypothetical particles with the ALPS II experiment at DESY. In addition, the technical and financial feasibility of the possible follow-up projects, MADMAX and IAXO, will be worked out and possibly lead to first demonstrators.

- These activities advance the understanding of cosmology, illuminate the so-to-speak "dark side" of the universe, and are complementary to astroparticle physics activities in the topic "Matter and radiation from the universe".

Topic: "Cosmic matter in the laboratory"

The Helmholtz Center GSI contributes to this topic along with the HI Mainz and IKP Jülich branch institutes. Under this topic, the complex and exotic forms of matter that dominate the dynamics in the early universe as well as the dynamics of stars are investigated at the accelerator facilities of GSI/FAIR and with ALICE at CERN. The complexity of matter is studied on all length scales, from the behavior and structure of hadrons with quarks and gluons, and the dynamic generation of their mass, to the complex and diverse structures of atomic nuclei and nuclear matter, and their importance for the evolution of our universe.

The construction and gradual commissioning of the FAIR accelerators and storage rings as well as of the detector systems are a dominant task for the first half of the PoF IV period, in which the first particle beams are expected. This is to be followed by data acquisition by the CBM, NUSTAR, and PANDA detectors (the APPA project is assigned to the MML program). Until then, the already available GSI facilities and first instruments for FAIR will enable an ambitious experimental program, the so-called FAIR Phase 0. Research activities at other international research infrastructures will complement this phase.

Specific objectives include

- Investigating the phase diagram of hot and dense nuclear matter with their effect on the equation of state of astrophysical objects such as supernovae, neutron stars, and merging neutron stars. This may also lead to new insights into gravitational wave signals.

- Investigating the nuclear structure and the reaction phenomena far away from the so-called valley of stability. In particular, a better understanding of the element formation in the universe in supernovae and neutron star fusions should follow from the study of the r-process, e.g., the element abundances of the elements gold, platinum, and beyond.

- Testing QCD predictions for exotic particle states via precision measurements of proton-antiproton collisions.

The HI Mainz (Helmholtz Institute Mainz) participates in the topic "Cosmic matter in the laboratory" and makes substantial contributions to the PANDA experiment, to the physics of hadrons and nuclei, and to the development of accelerators and detectors in the MU and MT programs. The IKP in Jülich is in charge of building the HESR for FAIR and is involved in the preparation and testing of FAIR accelerator and detector systems within this topic, as well as making major contributions to PANDA. In addition, the IKP in Jülich develops methods for the measurement of electric dipole moments of charged particles and participates in neutrino experiments.

Topic: "Matter and radiation from the universe"

The Helmholtz Centers DESY, KIT, and IPP contribute to this topic, in which high-energy particles and processes in the cosmos as well as the fundamental properties of neutrinos and Dark Matter are subjects of experimental and theoretical research.

This topic makes leading contributions to large observatories for various types of radiation from the universe.

The Cherenkov Telescope Array (CTA) for high-energy gamma radiation will be operational until 2025. CTA is operated as an open observatory for astroparticle physics in connection with the Science and Data Center at DESY in Zeuthen.

The IceCube neutrino telescope at the South Pole is to be upgraded by 2023/24 with seven additional detector strings and with detectors on the surface of the ice. The upgrade will lay the groundwork for IceCube-Gen2.

The properties of the neutrinos, in particular their mass, will be measured in the KATRIN experiment, which was put into operation in 2018 and will go into regular operation for five to seven years in the course of 2019.

Specific objectives include

- Gaining a comprehensive understanding of the structure of the universe as a whole, derived from the observations of the various complementary messengers (gamma radiation, neutrinos, particles and nuclei, and gravitational waves). The Research Field will strengthen this so-called multi-messenger approach significantly during the PoF IV period.

- Integration of existing and future observatory data into a data and analysis center for high-energy astroparticle physics.

- The measurement or most stringent limitation of the mass of the electron neutrinos with the KATRIN experiment by the end of the PoF IV period. Since sterile neutrinos in particular can make significant contributions to Dark Matter, the feasibility of a corresponding campaign to search for Dark Matter with KATRIN will be investigated.

Large research infrastructures of the MU program

Experimental investigations often require large and highly sophisticated research infrastructures, such as particle accelerators and detectors, telescopes, extensive detector fields, and underground laboratories. A characteristic of the program is the fact that these instruments are located at distant, sometimes poorly accessible areas, e.g., at the South Pole or in the Argentine pampas, due to the observation conditions they require.

The MU program addresses the challenges arising from the science-driven development and advancement of a modern, digital, open science culture.

The following challenges are of great importance:

- Constructing and implementing the experiments for the high luminosity LHC,

- Developing novel sensors and detector systems for future experiments in particle, hadron, and astroparticle physics,

- Establishing the Gamma Observatory at CTA, which will serve as an open observatory for the field of astroparticle physics with the Science and Data Center,

- Creating a TDR for the IAXO experiment to search for axion-like Dark Matter,

- Realizing the IceCube-Gen2 interdisciplinary neutrino observatory at the South Pole,

- Realizing the GCOS Global Cosmic Ray Observatory, if the Auger Observatory finds clear indications of the position of sources of the most energetic cosmic rays with the help of the AugerPrime upgrade, and

- Realizing the DARWIN project for the search for heavy Dark Matter particles.

User facilities (LK II)

Large-scale research facilities for users (Leistungskategorie II) at GSI/FAIR that are affiliated with the MU program include the UNILAC, SIS18, and FSR accelerator facilities as well as the FAIR Green IT Cube.

KIT operates the German Tier-1 data and computing center GridKa for the LHC experiments, for Belle, and other consortia in particle and astroparticle physics. In particular, GridKa shall be further developed to be able to cope with the significantly higher data flows from the HL-LHC.

Strategy processes

The program will play a central role in the German and international strategy processes as well as in the international committees ICFA, NuPECC, and APPEC and will thus influence trend-setting decisions made in the field in the coming years.

3.3.2 "From Matter to Material and Life" (MML)

The MML program investigates the detailed structure and electronic, magnetic, and chemical properties of matter and materials as well as electronic, catalytic, and (bio-) chemical processes. Using MML large-scale equipment and its diagnostic possibilities, these investigations are carried out on all relevant length and time scales.

This program is therefore concerned with the investigation of structures, structure formation, and properties of matter and (bio-) materials on all relevant length and time scales, which are only possible based on the targeted use of the large-scale facilities of the Research Field. The work that the Research Field carries out under the "Materials" topic thus complements the material competencies in the Research Fields Information and Energy.

The central research priorities focus on the dedicated use of large-scale facilities and are as follows:

- Researching the relationship between structure and dynamics and the resulting properties and functions of matter, even under extreme conditions.

- Elucidating the properties of materials and their interaction with biological, chemical, and physical processes.

- Conducting in-situ and in-operando investigations under real conditions with a view to develop new materials and agents in a targeted way.

- Elucidating the structure and function of the building blocks of life and related biological processes and reactions to external stressors.

- Providing novel analytical methods and services to industrial companies and supporting their application, together with appropriate technology transfer.

In order to address these issues as effectively as possible, the structure of the program topics has been restructured and will be divided into three new topics, which will be explained below based on their objectives.

Topic: "Matter—dynamics, mechanisms, and control"

This program topic focuses on fundamental aspects of the structure and dynamics of complex matter. The aim is to gain a deeper understanding of the mechanisms underlying the properties of matter.

- New insights into processes in strong fields:

The topic will promote the observation and use of nonlinear X-ray processes. For example, stimulated X-ray Raman scattering will be demonstrated on biologically and chemically relevant samples. The first detection of entangled photons from a dynamically controlled state of excited Mössbauer nuclei is to be carried out by the middle of the PoF IV period. Intensive terahertz radiation will also be used to produce "films" of transient electronic states, e.g., of complex organic systems in water. It should be possible to measure the structure (e.g., the g-factor of bounded electrons) and dynamics (e.g, correlated multiple ionization) of electronic systems with hitherto unattained precision based on the new storage ring and trap facilities for ions. Complementary experiments will be carried out at XFELs. In particular, the detection of polarization effects in extreme fields such as birefringence in vacuum will be realized. First results are expected during the second half of PoF IV. The computer simulation of XFEL-induced dynamics in complex matter is expected to take place toward the end of the funding period.

- Progress in observation and control of real-time dynamics:

During the first half of the PoF IV period, the program will identify the concerted ultrafast transfers of electrons, protons, and hydrogen atoms between molecules and the associated modification of molecular interactions by solvents such as water. At the same time, principles of action and relevant time scales at the atomic level are to be determined by the selectivity of innovative X-ray methods, thereby identifying decisive transient states as well as equilibrium and non-equilibrium properties. During the second half of the funding period, transient sub-cycle optical waveforms with pulse energy of several millijoule and repetition rates of multi-kHz will be provided. The aim is to demonstrate the control of the chemical reactivity of bio-molecular devices on the electron time scale by the end of the PoF IV period. In addition, suitable FEL X-ray pulse sequences will be generated to control the movement of electrons in amino acid derivatives.

- New insights into matter under extreme conditions:

The program aims to generate and investigate extreme states of matter with ion beams, intense laser pulses, and X-rays. First results are expected for the middle of PoF IV. Towards the end of the funding period, the program will investigate in detail the phase diagrams of complex mixtures of light elements in planetary environments and the role of water-containing minerals in the formation of volcanoes and earthquakes in detail. Of particular interest is the interaction between currents and magnetic fields. The first proof of the homogeneous dynamical effect in a preceding sodium flow will be provided in 2024. In addition, particle accelerators will be used to obtain important information on the leading reactions of hydrogen burning in the interior of the sun. First leading experiments with high-power lasers at the European XFEL X-ray source will for the first time measure in detail transient non-equilibrium states in dense plasmas in detail toward the middle of the PoF IVperiod.

Topic: "Materials—quantum, complex, and functional materials"

The MML program with its system expertise and capabilities in the targeted use of large-scale facilities for research with photons, neutrons, ions, and the highest electromagnetic fields opens up and expands our understanding of fundamental processes of condensed and biological matter in a unique way. The manifold and mostly unique analytical possibilities are fundamental for the knowledge-based development of functional materials and processes. aThrough science-driven development of the LK II user facilities, especially with regard to capabilities on temporal and spatial resolution, the MML program provides unique tools for the development of quantum and energy materials and pharmaceutical agents to other research areas and Helmholtz Research Fields.

- Structure and properties of materials:

A comprehensive, fundamental understanding of the relationships between structure and property is indispensable for the development of novel, complex materials. The Research Field is planning to achieve an optimized synthesis and modification (e.g., by means of ion beams) of novel materials by developing and using the unique analytical possibilities offered by the LK II user facilities and the knowledge gained thereby. The first groundbreaking high-field experiments in materials science are to be carried out at the new HIBEF facility at the European XFEL by the middle of the PoF IV period. Furthermore, the targeted development of problem-specific sample environments will enable the investigation of materials under extreme conditions from the middle of the PoF IV period onward.

- Nanoscale functional and quantum materials:

The numerous unique analytical potentials of the MML user facilities allow the fabrication, characterization, and customized modification of new nanoscale functional and quantum materials. The aim is to rationally optimize the functionality of nanostructures and nanostructured matter based on a fundamental understanding of electronic and structural properties. This is to be achieved, for example, from the middle of the PoF IV period with the help of a low-energy ion laboratory (HZDR) for ultra-thin materials. The program also pays special attention to the transition area between classical and quantum mechanical material behavior in the phase space of time, energy, and momentum. By the end of the PoF IV period, the nanostructures on the nanometer length and femtosecond time scale will be comprehensively investigated and optimized with X-ray, XUV, ion, and THz radiation and neutrons with the help of targeted extensions to the large-scale MML user facilities. There are also plans to construct and operate an extraction line with a UHV experimental station at CRYRING (GSI) for structuring materials with single, highly charged ions by the middle of the PoF IV period.

- Functional materials for devices and applications:

In-situ and in-operando analysis methods and their targeted application are essential for tailor-made developments of functional materials for novel devices and applications. This allows a detailed characterization of the structure development a) during the fabrication of novel nanostructures and materials in the transition area between classical and quantum mechanical material behavior, as well as of materials that are produced under extreme non-equilibrium conditions and b) during the operation of devices which are based on the latter. The aim is to further develop new measurement methods with improved spatial and temporal resolution. In this context, for example, the high-resolution observation of the process in-operando with high-energy synchrotron radiation will optimize an additive manufacturing process (selective laser melting) at PETRA III from the middle of the PoF IV period onwards.

Topic: "Life sciences—building blocks of life: structure and function"

This program topic aims to gain a deeper understanding of life and the underlying biological processes by focusing research on the building blocks and organizational stages of life in terms of their structure, dynamics, and function. It examines the atomistic movements in chemical and biochemical processes as well as the structural system of cells or whole organisms.

- Structure and interaction of subcellular and molecular components:

The aim is to conduct structural analyses of subcellular components up to atomic and real-time resolution of single building blocks (like proteins, membranes, RNA etc.), carry out in-vitro and in-vivo investigations of molecular (biochemical) interactions, and elucidate the structure, dynamics, and functionality of water in complex biochemical environments. A medium-term goal of the funding period is to further develop crystallographic methods including serial crystallography, high-flow X-ray spectroscopy and imaging, etc. The aim is to do this in such a way that the influence of external stressors (like drugs or their precursors, charge, radiation, etc.) on the structural integrity of the participating entities can be determined and mechanisms of action uncovered in order to derive further applications in the second half of the funding period (e.g., via structure-based screening).

- Morphology and function of biological systems in the field of tension between genetics and environment:

The task is to increasingly address higher hierarchical levels such as cellular systems, tissues, and organs up to small organisms with imaging and correlative methods. The medium-term goal is to achieve results on the morphology and function of biological systems in the organism, e.g., exoskeletal joints, and in the ecosystem, e.g., in connection with insect mortality. In addition, the topic will combine X-ray microscopy and tomography of large sample series with AI-assisted image analysis. The aim is to elucidate correlations between the 3D phenotype and the genotype of vertebrate model organisms by the end of the funding period.

- Effects of radiation (ions, photons) and external stressors:

This subtopic will determine the interrelationships between the complexity levels listed above and investigate biological structural-dynamic reactions to various external stressors and stimuli such as drug substances, toxins and radiation. In the medium term, the effect of highly brilliant FEL and synchrotron radiation in-vitro and in-vivo on biomaterials will be investigated. Further goals are to elucidate the effects of dense (i.e., locally strong) ionizing particle radiation on living matter and, in the second half of the application period, further external stressors.

- Application-specific research:

The aim is to gain new, application-relevant findings in biomedicine with biomaterials and artificial tissue, structural biology, infection research, bionics and biotechnology, and molecular, cell, and tissue radiobiology up to biophysical modelling as well as in the fields of medical physics and therapy while integrating corresponding Helmholtz Research Fields (Energy, Health etc., see below). Medium-term goals are to combine heavy ion therapy and immunotherapy for metastasizing tumors in an innovative way and evaluate the efficacy of immunotherapeutic drugs combined with particle therapy. As a further goal, innovative shielding materials for radiation protection in space are to be investigated and tested at high-energy particle accelerators together with the Research Field Aeronautics, Space, & Transport and the corresponding research Center (i.e., DLR).

Close interaction between experiment and theory is essential for all three topics of the MML program. Enhanced efforts to gain a deeper, microscopic understanding of data are essential, particularly in view of the steadily increasing quantities of data generated by large-scale MML user facilities. For this reason, special attention should be given to the development and application of theory, algorithms, and simulations in connection with the experimental MML research activities. Consequently, MML will cooperate closely with the new DMA topic in the MT program to meet future requirements for accessing, managing, and evaluating experimental data at large-scale research infrastructures in the Research Field Matter. In addition, close cooperation with the MU and MT programs as well as with the other Helmholtz Research Fields (Information, Energy, Earth & Environment, Health, as well as Aeronautics, Space & Transport) will take place. With respect to MT, the development of novel, compact accelerators and radiation as well as neutron sources, but also novel instrumentation and detectors, is exemplary. An obvious example of the cooperation with MU is the subtopic of extreme states of matter and stellar plasmas as well as precision experiments in the field of electromagnetic interaction.

Large research infrastructures of the MML program

Large research infrastructures and, in particular, the large-scale user facilities for research involving photons, ions, neutrons, and in high fields, as well as the development of the corresponding infrastructures in relation to long-term strategic planning play a central role in the mission and in terms of achieving the scientific objectives of the MML program.

User facilities (LK II) and large-scale research infrastructures for research with photons

The investigation of matter at the high-brilliance synchrotron radiation sources BESSY II at HZB and PETRA III at DESY, as well as at the free-electron laser facilities FLASH and European XFEL at DESY, makes it possible to investigate the structure and dynamics of matter on fundamental, atomic time and length scales in a very wide range of applications. For this reason, operating these facilities at the highest international level is the priority for the national and international user community. The European XFEL, an X-ray laser, started operation in 2017. The "Helmholtz International Beamlines" (HIB, operated by HZDR, DESY) mean that Helmholtz will be visibly involved in the scientific use of this new international large-scale facility.

FLASH2020+ is to be realized and user operation will begin in the first part of the PoF IV period. In the case of BESSY VSR, these goals are to be achieved within the PoF IV period.

The continuous development of the accelerator-based photon sources associated with MML—while taking into account their complementary beam properties and the proven distribution of the photon spectral and electron energy ranges in the European and international context—is of essential importance for the competitiveness and future viability of these light sources and thus of the entire MML program. Within this framework, the development of a common and coordinated light source strategy will continue to move forward during the PoF IV period. At the European level, this will take place in the course of close consultation within the framework of a roadmap process initiated by LEAPS (the League of European Accelerator Based Photon Sources). CDRs (conceptual design reports) and TDRs (technical design reports) for PETRA IV and DALI should be available in the first year of the PoF IV period with the aim of placing these projects on Germany's National Roadmap. In the case of BESSY III, a CDR is to be completed by the middle of the PoF IV period at the latest and a corresponding TDR in the second half of the PoF IV period.

Scenarios for the development of the European XFEL towards a continuous pulse sequence and a second set of further beamlines are also to be worked out during the PoF IV period in close coordination with the European XFEL Company, the European XFEL Council, and within the framework of LEAPS at the European level.

User facilities (LK II) and large research infrastructures for research with neutrons

The research of materials with neutrons at world-leading sources, including the ESS (commissioning expected in 2025), ILL, SNS, and MLZ, is organized via the user facility platforms "Jülich Centre for Neutron Science" (JCNS) at FZJ and "German Engineering Material Science Centre" (GEMS) at HZG. The newly founded "League of advanced European Neutron Sources" (LENS) will coordinate neutron research with and vis-à-vis the European institutions. The Heinz Maier-Leibnitz Zentrum (MLZ) plays a key role as a national user institution. As part of the MLZ 2030 vision, this institution is to be expanded in three stages: (i) neutronic connection and commissioning of the instruments in the Neutron Guide Hall East, (ii) transfer (in coordination with the funding agencies) and upgrading of the instruments of the BERII reactor, and (iii) realization of new instruments for the development of further scientific fields. Together with the MLZ cooperation partners, the goal is to realize these tasks by the middle and end of the PoF IV period, respectively.

The German partners in ESS are involved in seven instrumentation projects and are in charge of five projects. These instruments are to be taken into user operation in the middle of the PoF IV period. Within the framework of a German-Russian cooperation, a contribution is to be made to opening up the PIK reactor for research with neutrons. This new task will have to be fulfilled beyond the current timeframe of the PoF IV period.

A central component of the neutron strategy is developing and realizing compact accelerator-driven neutron sources, which will allow complementary experiments to the ESS through their optimization for brilliance and which will have a broad spectrum of applications thanks to their scalability. A CDR and TDR for the construction of a prototype based on this novel concept is to be submitted by the middle of the PoF IV period so that a decision can be made with the funding agencies regarding the construction and financing of a prototype on the basis of an evaluation within the PoF IV period.

User facilities (LK II) and large-scale research infrastructures for research with ions

Research with ions takes place at the complementary infrastructures of the HZDR and the GSI/FAIR. Based on the targeted use of these large-scale MML facilities, the program includes research into matter under extreme conditions, nanoscience, and radiation therapy with charged particles. At the HZDR, the Ion Beam Center (IBC) is available for application in materials research, in interdisciplinary Research Fields (resource technology, geomorphology, environmental and climate research), and as an ion beam service for industrial partners. In the coming years, the focus will be on establishing a low-energy ion laboratory for modifying and analyzing 2D materials and significantly expanding AMS operations. At GSI, the development of novel FAIR instrumentation for the experiments conducted by the internationally established APPA collaborations (BIOMAT: Biophysics and Materials Research; HED@FAIR: Plasma Physics; SPARC: Atomic Physics) is to be promoted and used at GSI's current accelerator and storage ring facilities (UNILAC, SIS18, ESR, and HITRAP). The newly installed storage ring CRYRING is to start regular operation in 2021 and will make highly charged, decelerated ions available for the experiments. This will open up new possibilities for researchers in atomic physics and materials research to study matter under extreme conditions. Starting in 2024/2025, the first experiments will also be possible for all APPA collaborations with the new FAIR facilities APPA-Cave and HESR (High Energy Storage Ring), which will deliver ions of the highest energies and beam quality.

User facilities (LK II) and large research infrastructures for research in highest electromagnetic fields

Matter research in the highest electromagnetic fields is carried out at research infrastructures of the HZDR (HLD, ELBE, DRACO, and PENELOPE and HIBEF in the future) and the GSI (PHELIX). The High Field Magnetic Laboratory Dresden (HLD) at the HZDR is a unique user facility in Germany where ultra-high magnetic fields are made available which can be used for fundamental investigations, especially in the area of solid-state physics and material sciences. Together with the high-field laboratories in Nijmegen, Grenoble, and Toulouse, the HLD forms the European Magnetic Field Laboratory (EMFL). The EMFL is a platform that offers users central access to the infrastructures of the individual partners, tailored to experimental needs. As a European institution, the EMFL has a global profile and pursues a common strategy for the further development of the individual laboratories but also of high field research as a whole. In the coming years, one of the priorities will be to promote the integration of further partner institutions. At the ELBE user facility, which is the center for high power radiation sources at HZDR, accelerator-based infrared and terahertz sources are used to generate high-intensity photon pulses in order to investigate the structure and dynamics of matter across a broad range of disciplines. In addition, ELBE offers electron beams and a range of secondary radiation sources (as neutrons, positrons, gamma rays) for studying matter and materials under extreme conditions as well as the physics of material defects. It is also used for the field of radiation biology, which is also of great relevance for scientists in the Helmholtz Research Fields of Health, Energy, and Information. DRACO and PENELOPE (HZDR) as well as PHELIX (GSI) are unique, high-power laser systems with which, among other things, previously inaccessible states of matter and the physics of strong fields can be studied. HIBEF represents a new infrastructure which is currently being created at the European XFEL and in which high fields can be coupled with brilliant X-rays. The HIBEF high-field facility is to be put into user operation in the first few years of the PoF IV period. In addition, the HZDR is currently developing a new research infrastructure concept that will combine pulsed magnetic fields, high-intensity laser systems, and high-field THz beam facilities under one roof in the form of DALI (Dresden Advanced Light Infrastructure), the upgrade of ELBE.

3.3.3 "Matter and Technologies" (MT)

The "Matter and Technologies" program investigates the technological possibilities as well as limits of current and future accelerator-based research facilities and develops solutions how the extreme particle and photon fluxes and high fields generated there and in other experiments can be optimally recorded as well as processed.

The program-wide challenging goals for MT are:

- The physics of the acceleration of charged particles will be investigated on a broad basis. Accelerator technologies will be further developed with a focus on delivering highest brilliance, luminosity, compactness, and stability.
- The understanding of the physics of radiation detection will be further advanced and deepened, resulting in concrete detector systems that push the resolution in space, energy and time to the limits of what is physically possible.
- The digitization of the scientific process in all scientific areas in the Research Field Matter will be driven forward using newest methods and innovative technologies. This is essential to make it possible to process the highly complex data which are generated in extreme quantities and thus extract and create knowledge from these data.

The all-encompassing digitization of all areas of life and in particular research will pose a central and great challenge for the Research Field Matter, and will be a focus of the work in the field. To respond to these challenges, a new topic "Data management and analysis" (DMA) will be installed. The program is thus organized into three topics: "Accelerator research and development" (ARD), "Detector technologies and systems" (DTS), and, as mentioned above, DMA. These topics require intensive cooperation and a strategy that is continuously refined throughout the PoF IV period. In particular, the new topic DMA is deliberately set up as a cross-cutting topic, to achieve close integration with the other two program topics as well as with the other two Matter programs, and with the Research Field Information and the so-called Helmholtz Incubator projects. In addition, connections should be established that go well beyond the Helmholtz Association, triggering cooperation with e.g. the future Center for Advanced Systems Understanding (CASUS) which is initiated by the Helmholtz Association, the Max Planck Society, and the TU Dresden; or the Center for Data and Computing Science (CDCS) in Hamburg. DMA will also play an important role in the coordination of scientific computing projects in the Research Field Matter. The program will only be able to achieve results at the highest international level by establishing a clear focus and pooling resources in the area of data science.

Another important change in the program structure will be the establishment of an LK II user facility, namely the Interdisciplinary Data and Analysis Facility (IDAF), affiliated with MT. This facility will be based on the previously existing Tier-2 computing center at DESY but will be considerably broader in scope. It will be available to the entire user community of the Research Field Matter as a user facility that is optimally adapted in terms of equipment, methodology, and services for doing science in this field.

Activities relating to the transfer of knowledge and innovations will be further enhanced in close coordination among the participating Helmholtz Centers. Opportunities in this area will be actively identified and initiated, profiting heavily from a series of successful transfer projects.

A decisive factor for the success of the research conducted in MT continues to be the recruitment and professional development of people in the program. Recruiting technicians, engineers and outstanding scientists from the natural and engineering sciences for the Research Field Matter and identifying sustainable career opportunities play a central role.

In order to achieve these very ambitious goals, a number of concrete goals have been identified:

Topic: "Accelerator research and development"

The goals of this topic are:

- Developing reliable continuous wave operation of SCRF accelerators:

Efficient continuous wave operation of SCRF systems for medium gradients in free electron lasers (FELs), storage rings, and hadron linear accelerators should be demonstrated by the middle of the PoF IV period. Concrete examples for which these developments are relevant are BESSY VSR as well as the expansion plans of the European XFEL and FLASH2020+, DALI, and the hadron linear accelerators, e.g., for the generation of super-heavy elements.

- Optimizing accelerator parameters for hadrons and electrons to achieve ultimate intensities and stability:

Radiofrequency-based accelerators will continue to play a central role in the Research Field. The development of this technology as well as the corresponding concepts—in particular with regard to stability, flexibility, and the optimization of costs—will be a focus in the coming funding period. Application examples include diffraction-limited synchrotron radiation sources and next-generation hadron accelerators, such as scalable neutron sources, which will play a major role in the first half of the PoF IV period. The development of the FAIR complex will become more visible with the return of the GSI to the PoF funding scheme.

- Developing advanced concepts for beam control, dynamics, and diagnosis:

Modern RF-operated or plasma-based accelerators require innovative technologies to diagnose and control the increasingly complex beam dynamics, and to shape particle and photon beam parameters. Supported by the operation of accelerator test facilities, the program is expected to make great progress in the field of as- and fs-diagnosis and controls. These systems will be developed in close cooperation with DTS, and in terms of the further development of optimization and feedback strategies and technologies, together with DMA.

- Developing concepts for compact accelerators up to applicability:

The development of compact, innovative accelerator systems plays a central role in the MT program. Over the next years, the possibilities offered by the distributed ATHENA research infrastructures should be optimally utilized. Together with European partners, a decision should be reached on the site of a first European facility based on plasma acceleration. At the same time, the use of plasma-based accelerators for a wide range of applications will be studied intensively. Examples are compact synchrotron radiation sources for scientific studies and systems for medical and industrial applications. This work will also be carried out in close coordination with European partners.

Topic: "Detector technologies and systems"

The scientific goals of this topic are:

- Optimizing the sensitivity, the time, space, and energy resolution of sensors which are needed in the context of novel accelerators and extreme sources:

In addition to the currently dominant silicon semiconductor technology for sensors, the DTS portfolio will be significantly expanded in the area of superconducting sensors by the middle of the PoF IV period. New detectors designed for continuous wave operation will be developed for use at the EU-XFEL.

- Developing novel detector and readout concepts for extreme data rates and environments:

The data rates that will be produced, for example, at the European XFEL or at the High-Luminosity LHC in the PoF IV period require new data acquisition and trigger concepts. Research in the field of silicon photonics will be intensified in order to master the challenges involved in data transmission. The construction of highly integrated, application-specific detectors with millions of pixels requires the developments of new materials, new integration concepts, as well as assembly and interconnection techniques. Within the next few years, prototypes will be built and characterized in order to successively establish a new generation of detector systems for highest data rates. Extreme demands are placed on the reliability of the systems in extreme environmental conditions, in almost all fields of application in the Research Field Matter, but especially so in astroparticle physics.

- Consolidating technologies into application-driven, integrated detector systems:

Another essential role of the MT program is to transfer new technologies of the Helmholtz Association to applications. The concept envisages developing and deploying complete detector systems for specific applications, typically within a period of two to four years. This is also a natural starting point for feeding detector technologies into the innovation transfer process at the participating Centers.

In addition to the scientific goals mentioned above, a further declared goal of the program is to significantly improve the infrastructure by establishing a distributed detector laboratory (DDL).

Topic: "Data management and analysis"

Together with the LK II user facilities, the new DMA topic has as a central goal the implementation of a comprehensive digitization strategy for the Research Field Matter. It is based on an infrastructure that is already very well developed, but which must be further adapted to a much more heterogeneous user base.

- Developing and applying innovative digital solutions for the handling and analysis of the extreme quantities and rates of complex data generated in large-scale research infrastructures in the Research Field Matter:

The software and hardware infrastructure will be expanded to enable the handling of very large amounts of data needed by the users. Modular, reusable, open concepts and solutions will be jointly developed to control access to the data and make it available to users in keeping with the open data and open access strategy. Establishing sustainable software developments with international visibility is crucial for success. At the beginning of the PoF IV period, the Tier-2 computing center at DESY will be expanded into the IDAF, offering reliable user operation for all users from the Research Field Matter.

- Developing and providing novel digital methods for knowledge extraction from experiments and digital models in Matter:

A major goal of the topic is to pool the methodological competencies located with the researchers within Matter and to make them accessible to all researchers in the Research Field via common platforms. The Research Field Matter utilizes and applies the latest developments in computer science and related sciences in close cooperation with the Research Field Information.

- Developing and integrating cutting-edge state-of-the-art digital methods in order to optimally exploit data from experiments and facilities in the Research Field Matter:

Innovative methods and approaches are needed to fully exploit the opportunities the digitization of the scientific work in the Research Field Matter. This requires significant investments into the development of software for powerful control systems, powerful readout systems, and powerful analysis systems to process the data efficiently and quickly, in close coordination with the other topics in the program. The involvement of users in this process is crucial and requires the development and provision of suitable software environments.

User facilities (LK II) and large research infrastructures of the MT program

Data and analysis centers are indispensable for processing large amounts of data and for generating new knowledge from data. In close cooperation with the data centers in the MU program, the Tier-2 computing center at DESY will be developed into a center for all programs in the Research Field Matter. This will be done without compromising the existing commitments to the LHC or European XFEL. This Interdisciplinary Data and Analysis Facility (IDAF) as a user facility will play a central role in the implementation of the DMA strategy.