Progress Report 2022

Program “Matter and the Universe”

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**Program “Matter and the Universe”**

The strategic evaluation of the program confirmed that the program planning is optimally designed to achieve the research policy goals – taking into account the corresponding Senate recommendation (see Chapter 3).

1 Overview

1.1 Goals and Embedding into the Research Field

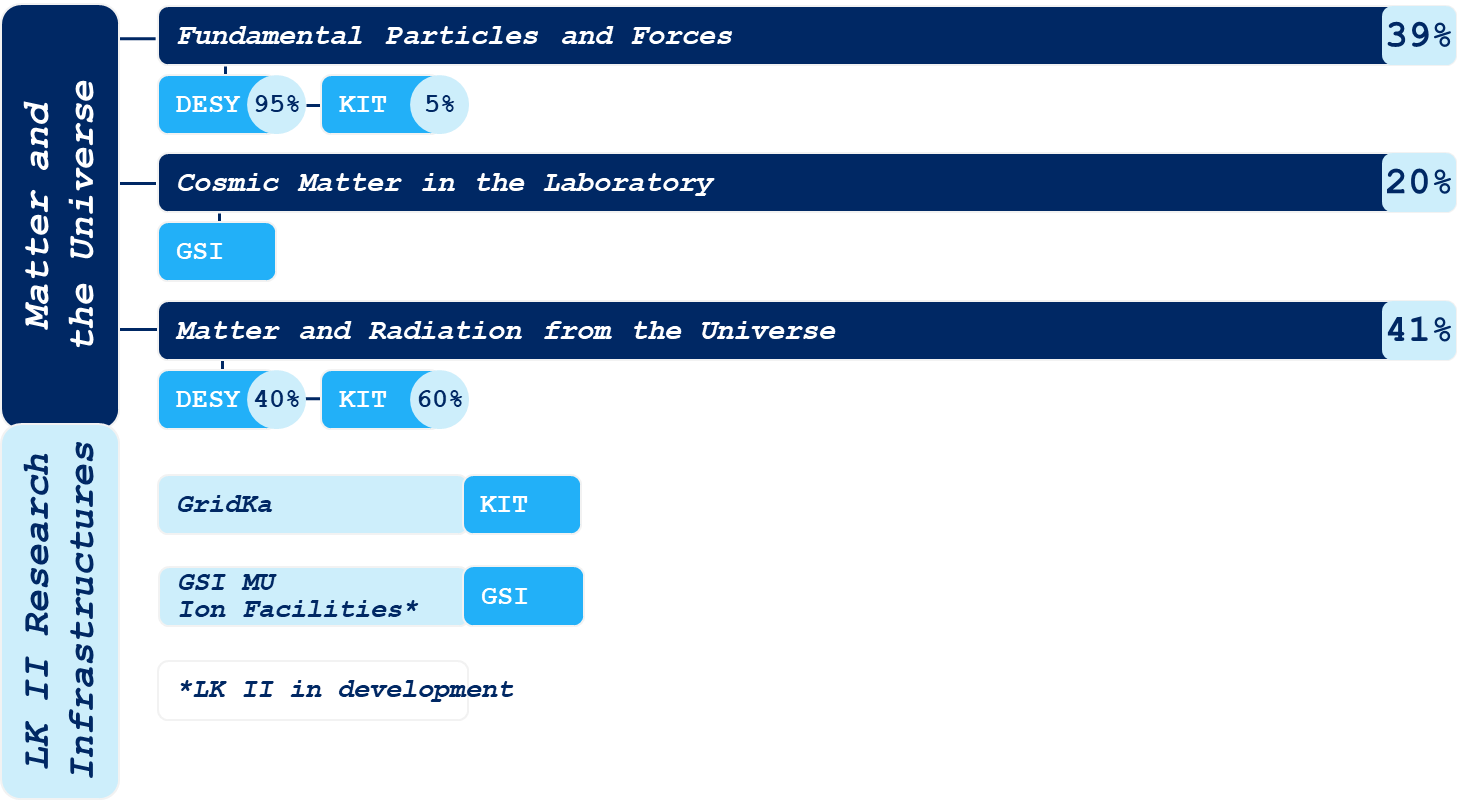
The MU program is characterized by a particular breadth and depth of expertise in its coherent approach to advancing understanding in elementary particle physics, astroparticle physics, and the physics of hadrons and nuclei. The joint research is carried out by experimental and theoretical methods, by modeling and observations, by technological developments, and by operating of and measurements on large research infrastructures. The research in MU is particularly characterized by international cooperation of different research institutions, which are organized in (partly very large) collaborations. This work is made possible by globally unique research infrastructures at our Helmholtz centers and at other international research centers and facilities.

The program topic 1 - Fundamental Particles and Forces - investigates the most fundamental building blocks of the world and their interactions, addressing fundamental questions of nature such as the origin of mass, the structure of the vacuum, the imbalance between matter and antimatter in the universe, or the nature of dark matter. The participating research groups are involved in large-scale international projects such as the LHC at CERN or SuperKEKB in Japan, and pursue a rich program of smaller, local experiments with international participation, including axion physics, as well as an extensive theory portfolio in international collaborations. The topic is divided into three subtopics: i) Higgs properties and fundamental interactions at high precision; ii) Searches for new particles and phenomena; iii) Cosmology and the dark sector of the universe. All three subtopics are addressed by numerous experimental and theoretical projects. The topic is supported by infrastructures close to the experiments, such as the GridKa (Tier 1) at KIT or the Interdisciplinary Analysis Facility (IDAF, used partly as Tier 2 for LHC), the Test Beam Facility or the Detector Assembly Facility (DAF) at DESY.

Program Topic 2 - Cosmic Matter in the Laboratory - explores the formation of matter from the elementary building blocks and the various aspects and role of the strong interaction in these processes. Extreme forms of matter are created in the laboratory to recreate the formation of primordial matter and to understand extreme astrophysical objects such as neutron stars. The range of themes in topic is complemented by studies of hadrons and their excited spectra to provide important experimental information to fully understand quantum chromodynamics. FAIR, with its high-intensity, high-energy, stored and cooled ion and antiproton beams, is the central infrastructure for addressing the questions in this topic. The study of the strong interaction also aims at physics beyond the Standard Model, and includes the search for dark matter, the exploration of matter-antimatter asymmetry, and further tests of fundamental symmetries.

The program topic 3 - Matter and Radiation from the Universe - has the largest structures of the universe and the properties of the fundamental building blocks as its research topic. Astroparticle physics in MU is performed at observatories at extreme locations on Earth and at high-precision experiments in laboratories. The study of neutrinos plays a central role. Research in neutrino physics also has a significant influence on the investigation of dark matter. Research in topic 3 provides insights to draw a new and coherent picture of the high-energy universe, combining the different information channels such as high-energy radiation, neutrinos, cosmic particles, gravitational waves as well as dark matter searches. Only this multi-messenger approach will allow us to understand and answer fundamental questions about the structure and evolution of our universe. In the future, new and improved research infrastructures will create a research landscape that can handle the full range of cosmic particle and radiation investigations.

1.2 Structure

**

The program Matter and Universe is led by Ralph Engel (spokesperson, KIT) and Beate Heinemann (co-speaker, DESY). It is divided into three major topics, which are described in more detail below, and two so-called LK-II infrastructures, which will be presented in Part B.

Topic 1: Fundamental Particles and their Interactions (FPF)

(Spokesperson: Georg Weiglein (DESY), Co-spokesperson: Priscilla Pani (DESY))

Topic 1 focuses on the investigation of the smallest building blocks of matter and their interactions, and on the impact these have on the evolution of the universe. Concrete essential questions concern the origin of mass, the nature of dark matter, the imbalance between matter and antimatter, and the structure of the vacuum. The experimental work – that is accompanied by world-leading theoretical efforts – is carried out both at global facilities like the LHC or the SuperKEKB collider and in small or mid-scale local experiments on the DESY campus.

Topic 2: Cosmic Matter in the Laboratory (CML)

(Spokesperson: Frank Maas (HIM), Co-spokesperson: Tetyana Galatyuk (GSI))

Topic 2 is performing a unique and exciting science program which exploits the upgraded GSI accelerator chain and fully or partly available FAIR experimental instrumentation. This is supplemented by the participation in the physics analysis and upgrade of the ALICE detector in preparation for the upcoming high-luminosity LHC runs. Scientists involved in MU-CML have actively pursued a proof-of-principle experiment to search for an electric dipole moment (EDM) of charged-particles by using storage rings and to detect axion-like particles in the ultralight mass range and were engaged in experiments studying neutrino characteristics.

Topic 3: Matter and Radiation from the Universe (MRU).

(Spokesperson: Christian Stegmann (DESY), Co-spokesperson: Kathrin Valerius (KIT))

Topic 3 deals with questions about the sources, production, and propagation of high-energy and ultra-high-energy cosmic particles and on the properties of neutrinos and dark matter. The participating research groups play a major role in shaping neutrino astronomy at IceCube, the investigation of high-energy gamma rays at CTA, and the study of ultra-high-energy cosmic rays at the Pierre Auger Observatory. The properties of neutrinos are determined with the unique infrastructure KATRIN and the expertise gained is continued for the investigation of dark matter in DARWIN.

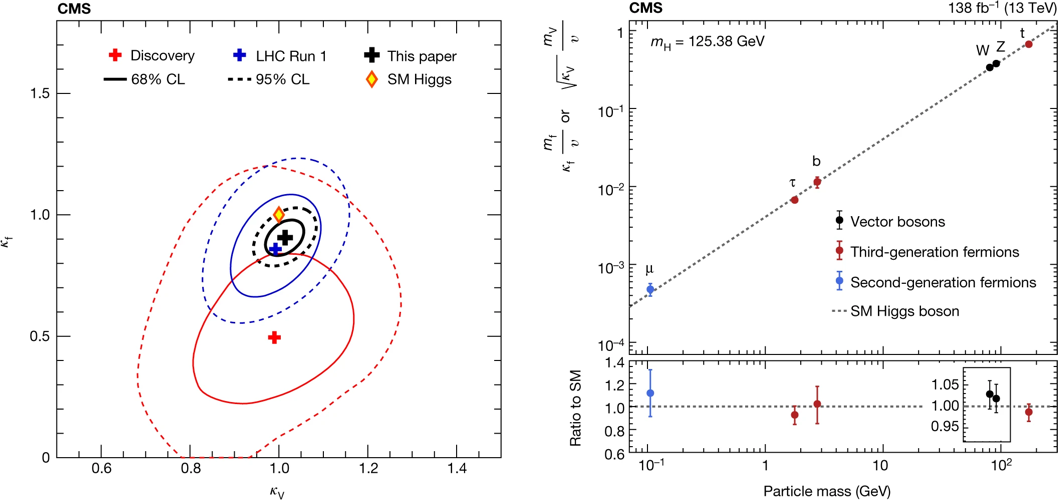
Theoretical studies and developing new technologies for detectors, accelerators, and data processing complement the experimental program of each topic and form a common basis for thematic advancement across all three Program Topics.

1.3 New structural Developments and Changes of Framework

Russia's invasion of Ukraine has severely changed the international environment and is strongly condemned by the German and international scientific community. Many long-standing and productive collaborations are suspended. The prolonged war has also led to the interruption of supply chains and rapidly rising energy costs. The situation is very volatile and the effects on science and, in particular, on the set goals of the Helmholtz program MU cannot be quantified at this time. In the case of the large particle physics experiments at CERN, for example, there is a backlog of unpublished research results, because there is still an agreement to be found on how to treat the authorships of Russian institutions in the collaborations. For other projects and large infrastructures (e.g. FAIR, XFEL, CERN), partnerships with Russian institutions have been suspended, resulting in a loss of know-how and a lack of technological and scientific contributions. The resulting energy crisis has led to unprecedented increases in the price of electricity, jeopardizing the operation of numerous infrastructures and experiments in planned operating cycles. How far this fundamental change in the situation in Europe and the world will affect the achievability of our scientific goals will only become clear in the years to come.

2 Scientific Highlights

**Highlight 1:** Ten years after the Higgs (H) discovery in 2012, ATLAS and CMS have both published papers in *Nature* [1,2] with significant DESY contributions, containing the most up-to-date combination of results on the properties of the Higgs boson. The measurements have advanced from discovery to precision mode [3], allowing researchers to harness the new particle for fundamentally new studies of the quantum world and the structure of the vacuum. Among the most striking summary results are the measurements of the couplings of the Higgs boson to other standard model (SM) particles as a function of particle mass. The measurements demonstrate how well the Higgs particle is described [4] by the SM predictions [5]. The precision that has been reached is also illustrated by a simple comparison: According to ATLAS (the CMS results are very similar), the precision for e.g. the signal strength µ in the H🡪​ɣɣ decay channel of the Higgs into two photons ɣ has improved from discovery times from roughly 30% (µ=1.8±0.5 for a Higgs mass of 126 GeV) to better than 10% (1.04±0.10 [4]).



*CMS measurements of Higgs boson couplings to SM particles [2].*

By now, the couplings of the Higgs particle to all charged third-generation particles (τ, b, t) have been measured with <20% precision (see e.g. [5]). Significant advances have also been made in the search for di-Higgs production [6], which is crucial as it is directly related to the measurement of the H self-coupling and the shape of the Higgs potential [7].

There is a whole slew of additional Higgs publications with DESY in a leading role: As an example, ATLAS has published a combination of differential Higgs cross sections with high precision [3]. All these measurements are important to test theoretical calculations and to probe new theories that modify the predictions at a high scale. Examples for theory contributions by DESY to Higgs physics are refs. [6-12].

Higgs physics is certainly not restricted to SM measurements, and searches for additional Higgs bosons as well as searches for other new physics with Higgs bosons as tools is a very active field. As an example, CMS has published searches for additional Higgs bosons and for vector leptoquarks in final states containing two t-leptons [13]. The data reveal two excesses with local p-values equivalent to about three standard deviations when assuming the production of a new boson *ϕ* in gluon fusion, for masses of mϕ = 0.1 TeV and 1.2 TeV. This analysis profited from the efforts of the CMS experiment to identify hadronically decaying tau leptons using deep neural networks [14], with leading contributions from DESY. An interesting channel is the decay of the Higgs boson to invisible final states – e.g. light dark matter or long-lived particles. These “invisible” or “undetected” decays are constrained to have branching fractions of less than 0.16 in all cases [1,2].

*[1] ATLAS Collaboration, Nature 607 (2022) no.7917, 52-59, doi:10.1038/s41586-022-04893-w,* [*arXiv:2207.00092*](https://arxiv.org/abs/2207.00092)*.*

*[2] CMS Collaboration,* [*Nature 607 (2022) 60*](https://www.nature.com/articles/s41586-022-04892-x)*,* [*arXiv:2207.00043*](https://arxiv.org/abs/2207.00043)*.*

*[3] ATLAS Collaboration,* [*arXiv:2207.08615*](https://arxiv.org/abs/2207.08615)*, submitted to JHEP.*

*[4] ATLAS Collaboration,* [*https://cds.cern.ch/record/2814435/files/2207.00348.pdf*](https://cds.cern.ch/record/2814435/files/2207.00348.pdf)*.*

*[5] CMS Collaboration,* [*arXiv:2204.12957,*](https://arxiv.org/abs/2204.12957)*CMS-HIG-19-010, CERN-EP-2022-027, submitted to EPJ C.*

*[6] H. Bahl et al.,* [*arXiv:2210.09332*](https://arxiv.org/abs/2210.09332)*.*

*[7] Q. Bonnefoy, E. Gendy, C. Grojean, J.T. Ruderman, JHEP 08 (2022) 032,* [*https://inspirehep.net/literature/1985604*](https://inspirehep.net/literature/1985604)*.*

*[8] H. Bahl et al., Eur.Phys.J.C 82 (2022) 7, 604,* [*https://inspirehep.net/literature/2037691*](https://inspirehep.net/literature/2037691)

*[9] J. de Blas et al,* [*arXiv:2206.08326*](https://arxiv.org/abs/2206.08326)*.*

*[10] P. Bredt, W. Kilian, J. Reuter, P. Stienemeier,* [*arXiv:2208.09438*](https://arxiv.org/abs/2208.09438)*.*

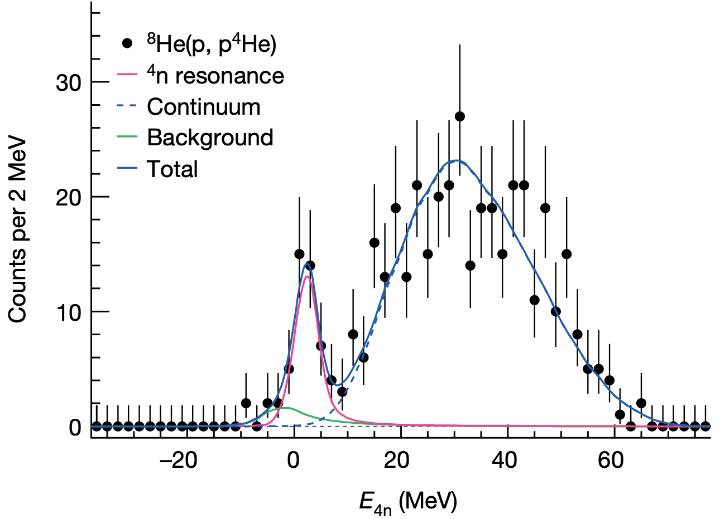
*[11] T. Biekötter, M. Pierre,* [*arxiv:2208.05505*](https://arxiv.org/abs/2208.05505)*.*

*[12] T. Biekötter et al., Eur.Phys.J.C 82 (2022) 2, 178,* [*https://inspirehep.net/literature/1915717*](https://inspirehep.net/literature/1915717)*.*

*[13] CMS Collaboration,* [*arXiv:2208.02717,*](https://arxiv.org/abs/2208.02717) *submitted to JHEP.*

*[14] CMS Collaboration, JINST 82022 17 P07023,* [*arXiv:2201.08458*](https://arxiv.org/abs/2201.08458)*.*

**Highlight 2:** Facilities producing rare exotic isotopes can be used to produce intense neutron rich beams to study multi-neutron system. The only bound systems of almost only neutrons are neutron stars, which are very compact high-density objects in the universe bound by the gravitational force with typical diameters of around 10 kilometers. Atomic nuclei are bound by the nuclear strong force with a preference to balance neutrons and protons. An experiment to prepare a pure neutron system of the size of a nucleus has been carried out at the Radioactive Ion Beam Factory RIBF at Riken by an international research team with leading participation of CML scientists from TU Darmstadt. An exotic 8He beam has been fragmented on a proton target to study events where the 8He nucleus emits an α-particle, thus a system of four neutrons is left behind. By measuring the energy of α-particle and the scattered proton, the missing energy could be attributed to the four neutrons.

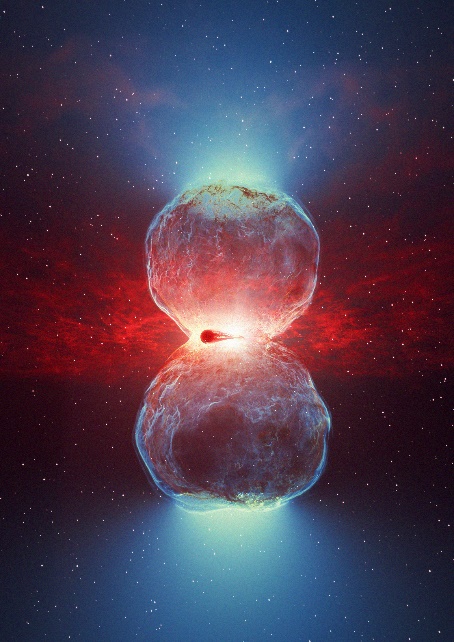


*Missing mass spectrum of the four-neutron system extracted from the 8He(p,p4He)reaction. The different curves represent a Breit–Wigner resonance (pink), a non-resonant continuum (dashed blue), the background from two-step processes (green) and the total sum (solid blue) [1].*

The missing energy spectrum shows a statistically unambiguous peak at a positive value, which is interpreted as the signal of the four-neutron system [1]. Scientists from TU Darmstadt, GSI, TU Munich and the Riken Nishina Center were involved in this finding, which was selected as one of the top 10 Breakthroughs in Physics of the Year for 2022 by Physics World. The exploration of these so far hypothetical particles might furthermore provide information or a better understanding of neutron-star properties. If multi-neutron systems do exist as unbound resonant states or even bound states has been a long-standing quest in nuclear physics. A research team lead by scientists from TU Darmstadt sets out to undertake a new attempt by using a different experimental. A next-generation experiment at R3B at FAIR, which will detect directly the correlations among the four neutrons with the R3B NeuLAND detector, is being planned.

*[1] Duer, M., Aumann, T., Gernhäuser, R. et al., Nature 606, 678–682 (2022). https://doi.org/10.1038/s41586-022-04827-*6.

**Highlight 3:** The H.E.S.S. Collaboration observed the 2021 outburst of RS Ophiuchi, a recurrent nova, and determined its spectral and temporal evolution at GeV and TeV energies [1]. A nova occurs if a white dwarf strips material from a companion star and the accumulated hydrogen that built up on the dwarf’s surface triggers a thermonuclear explosion. This explosion ejects material without destroying the white dwarf itself. Recurrent novae are repeating this thermonuclear explosion in the outer layers of the white dwarf, due to the accretion of fresh material from a binary companion. The shock generated when ejected material slams into the companion star’s wind can accelerate particles.



*Artist's impression of the white dwarf and red giant binary system following the nova outburst. Material ejected from the surface of the white dwarf generates shockwaves that rapidly expand, forming an hourglass shape.*

*Credit: DESY/H.E.S.S., Science Communication Lab*

In 2022, a closer evaluation of the data showed that the emission of the very-high-energy (VHE; ≳ 100 GeV) gamma rays from the recurrent nova RS Ophiuchi, lasted up to 1 month after the outburst [2]. The temporal profile of VHE emission is similar to that of lower-energy GeV emission, indicating a common origin, with a 2-day delay in peak flux. These observations constrain models of time-dependent particle energization, favoring a hadronic emission scenario over the leptonic alternative. Shocks in dense winds provide favorable environments for efficient acceleration of cosmic rays to very high energies.

*[1] S. J. Wagner, H.E.S.S. Collaboration, The Astronomer’s Telegram 14844 (2021).*

*[2] H.E.S.S. Collaboration et al., Science 376, 6588, 77-80, 2022.*

3 Implementation of Senate Recommendations

The „Forschungspolitische Ziele des Forschungsbereichs Materie der Helmholtz-Gemeinschaft für die IV. Periode der Programmorientierten Förderung“ of the funding organization define the framework of the Research Programs and the Research Field. They are described in a document with identical title.

The recommendations of the Senate of the Helmholtz Association are based on it. The Senate supports the planning of the programs in the Research Field Matter and provides the following specific recommendations at the level of the Research Program at LK I:

* The strong leadership position of Helmholtz in the global field should be fully supported.

Members of the Program MU are in leading positions at all levels (national, EU, international) and work in relevant strategy boards and roadmap processes (national: KET, KAT, KHuK; EU: ECFA Detector Roadmap, Future Colliders Forum, APPEC, NuPPEC; international: ICFA, IUPAP-C4). Central management and consulting positions are staffed by MU members at all main international, current and future collider projects, e.g. at the LHC experiments or studies towards prospective Higgs facilities. Alongside members of MU are spokespersons (e.g. Auger Observatory, KATRIN, CBM, or ALICE) or at other key positions of many international collaborations of those experiments and observatories we are participating in. Based on these positions and the impact of the scientific contributions of Helmholtz, the constitutive influence of Helmholtz is ensured.

* Retain some degree of flexibility for adjustments over the period of PoF IV.

The Program MU is dominated by many long-standing remits and projects which can only be mastered with endurance. Nevertheless, the fields of interest offer many new developments, new sprouting questions or technological innovations which open up new approaches to our research. These possible opportunities are pondered and taken where appropriate and integrated in our continuous formation of our program-oriented research.

In the field of elementary particle and astroparticle physics, important strategy processes are recently concluded or ongoing (European Strategy, US “Decadal Survey on Astronomy and Astrophysics” and “Snowmass” processes) which address, amongst others, the decisive questions about next international collider projects and future observatories for neutrinos, ultra-high energy cosmic rays, and gravitational waves.

The idea of a “Higgs factory” for high-precision measurements of these particles is focussed, but also studies and technological R&D for even more advanced projects which could enable particle collisions at even higher energies are investigated. Helmholtz and in particular DESY as a national lab and hub are of central importance for German contributions to international projects in this field.

Furthermore, in the 2020-years the course for observatories in multi-messenger astroparticle physics of the next 30 to 40 years are set. The plans of the proposals Einstein Telescope, IceCube-Gen2, GCOS and DARWIN are important contributions and Germany can shape the R&D and the design of these infrastructures. It is therefore all the more important that the Einstein Telescope and IceCube-Gen2 are part of the Helmholtz Roadmap for large infrastructures, and that the proposal for DARWIN will be evaluated by the research infrastructure committee in spring 2023.

Important milestones have been laid at KIT to usher in the future in the search for dark matter and the measurement of gravitational waves. A new experiment is expected to bring a breakthrough in the search for dark matter. Several world-leading collaborations (XENON, LUX-ZEPLIN, DARWIN) joined forces to form the XLZD consortium at a meeting at KIT in late June 2022. Previously, a letter of intent for the joint search was signed and a scientific white paper was published. For the future Einstein telescope for the detection of gravitational waves, the collaboration was officially founded at the '12th Einstein Telescope Symposium' in Budapest in June 2022. KIT is a founding member and contributes to the technological challenges in the fields of cryogenics and vacuum technology, seismology, computing, and monitoring of environmental variables.

* Nurture the novel idea for EDM determination in COSY.

At the COSY storage ring, precision experiments have been carried out with polarized proton and deuteron beams. Results have been published in a pre-print (arXiv:2208.07293 [hep-ex]) describing in detail the first search for axion like particles (ALPs) using a storage ring. In this proof-of-principle experiment, it was not possible to see a signal for ALPs but an upper limit for the deuteron oscillating electric dipole moment (EDM) could be extracted for the first time. Such experiments could be performed with polarized beams at the ESR or CRYRING at GSI/FAIR.

An application to the EU for funding of a design study for a dedicated high-precision storage ring to measure the proton EDM was ranked excellent, yet received no funding. Hence, with the end of operation at COSY this project, the search for EDM, will be phased out. Part of the gained knowledge will be used for experiments at ESR and CRYRING, e.g. by constructing a polarized beam source. A W3 position at the University of Cologne on the topic “Precision experiments with rings” is currently being filled, which might serve as a new hub to restart this activity.

* Continue to clarify the TransFAIR (FZJ/GSI) evolution.

TransFAIR process was continued in 2022. By 31 December 2022, 38 employees of the IKP had transferred to the GSI and 35 new employees had been hired from TransFAIR funds at the GSI. The finding process for one of the W3 in research has been started in cooperation with the University of Cologne. A joint FZJ/RWTH W2 professor has received a call to transfer to a joint GSI/JGU-Mainz W2 position and negotiations are ongoing. Substantial efforts are made by the accelerator side to attract personnel experienced in COSY operation to strengthen the operation team at GSI.

* Consider participation in future global initiatives in gravitational wave observations e.g. the Einstein Telescope.

Topic 1 is intensely discussing the aspects of gravitational wave physics that are relevant to the mission of particle physics. Concepts are being developed that are particularly suited for investigations of gravitational waves of cosmological origin using existing expertise and infrastructures on the DESY campus. These studies are driven by both experimentalists and theorists and are focusing specifically on lessons to be learned about the early universe (e.g. inflatons, Higgs potential etc.).

In Topic 2, nuclear physics aspects of gravitational wave research are investigated theoretically. This important project intertwines with the GSI/FAIR research activities. The GSI theory group is leading at studies of dynamics of mergers of binary neutron stars, applying highly advanced numerical simulations of the general relativity theory for precise predictions. The expected signal of gravitational waves and its associated signal in the electromagnetic spectrum as the fingerprint of the nucleosynthesis of heavy elements has been predicted in large detail and enables the formulation of state equations of matter at high densities. This project opens up new possibilities for cross-topic and –program activities in theory, for analysis of big data and for new detector technologies.

DESY and KIT have advanced their leading roles in the field of multi-messenger astronomy with their activities in Topic 3, strengthened Germany’s contribution to the ET project, and prepared a possible participation of the Helmholtz Association in the project. The activities of the two Helmholtz centers range from direct experimental participation, and implementing the project in the Helmholtz Association to coordinating the German ET community and supporting the consolidation of gravitational wave astronomy in Germany.

KIT is already contributing directly to the ET collaboration with coordinating activities of the ET Instrument Science Board and e-Infrastructure Board. An MoU with VIRGO is in preparation.

Both centers could successfully implement ET in the Helmholtz Roadmap for future large infrastructures together with HZDR.

DESY participated together with partners of the astronomy and astroparticle physics community in Germany in an open competition conducted by the BMBF for establishing two new research centers in Saxony. The idea that was developed under the leadership of Günther Hasinger, the scientific director of ESA, is a German Center for Astrophysics (DZA – Deutsches Zentrum für Astrophysik) in Lusatia. The proposal with DESY participation was finally successful as one of two accepted proposals in the final round of 6 fully elaborated project submissions. The German Center for Astrophysics will be located in Görlitz and the district Bautzen. After a construction phase, the final support will be about 170 Mio. Euro per year, with more than 1.000 employees in the research center.

* Enhance coordination of theoretical and experimental approaches across the program.

In all Topics of the program MU, a close cooperation between experimental and theoretical research is mandatory. At all centers and in all subjects, cooperations are stengthened, which yields for instance many common publications of more theoretically and more experimentally working groups.

In Topic 1, the close cooperation between theory and experiment is well established; both activities fertilize each other and address common research questions. This regularly results in joint publications.

The Research Cluster “ELEMENTS: Exploring the Universe from Microscopic to Macroscopic Scales”, organized within the framework of the Hessian Excellence Initiative by the Goethe University of Frankfurt, TU Darmstadt, JLU Gießen, and the GSI Helmholtzzentrum für Schwerionenforschung, brings together world-leading scientists from distinct fields of research – the physics of particles and nuclei, the gravitational physics of neutron stars, and the nucleosynthesis of heavy elements – to combine the microscopical scales of elementary particles with the macroscopical scales of astrophysical objects. The interdisciplinary exchange and in particular the synergy between theory and experiment is present.

Also in astroparticle physics, fundamental scientific results can only be validated in conjunction of experiment and theory. Many publications in 2022 of collaborations like IceCube, Auger Observatory, or H.E.S.S. testify these successful interactions.

* Execute the FAIR Phase-0 program with a continuous management of the work force. With the use of FAIR Phase-0, accomplish smooth transition from old to new facilities at GSI.

The international scientific interest in the FAIR Phase-0 program remains outstandingly high. In this year’s call for proposals for beam times in 2023 and 2024, 124 proposals were submitted to the Program Advisory Committees from more than 1500 participants. During the FAIR Phase-0 program, GSI plans to offer limited beam time (~100 days/year) for experimental operation, with priority given to tests of the accelerator facility and verification of the various accelerator upgrade measures also. In addition to scientific experiments, which must be characterised by scientific excellence and can only be carried out at GSI, important tests of FAIR detectors take place during these beam periods. Higher-level resource planning ensures a balance between the various requirements: Implementation of the FAIR Phase-0 programme, upgrade of the existing accelerators, construction of the accelerators and detectors for FAIR and further development of the GSI campus for the needs of FAIR. However, rising costs for energy and materials forced the GSI management to introduce severe saving measures. Therefore, there will be no beam time for scientific experiments in 2023, but the beam time will be shifted to 2024, only verification of accelerator upgrades and operation tests will take place during an engineering run in 2023. The next user beam time will start beginning of 2024. The engineering run end of 2023 ensures a fast start of the user experiments.

4 Strategic Topics

For the strategic advancement of interconnecting activities in the Research Program and the Research Field, three innovative projects in MU are currently supported by the so-called Innovation Pool: „LUXE-QED - LUXE-Quantum-computing and advanced Experimental Detectors“ - (DESY, HZDR, GSI (HI Jena)); „ADC-MAPP - Analysis and Data Centre for Multi-Messenger Astroparticle Physics“ - (KIT, DESY); „VQCS - Variational Quantum Computer Simulations for complex quantum systems and optimization problems“ - (DESY).

LUXE is a new experiment for the investigation of quantum electrodynamics (QED) in the regime of so far unattained field strengths that are going to be achieved via the collision of particle bunches from the European XFEL with strong laser pulses. The experiment is designed to measure electron-photon scattering as well as the formation of electron-positron pairs in pure light scattering processes. These measurements will shed light on the transition from linear to non-linear QED. The approval process for LUXE is progressing, CD1 was granted by the DESY directorate towards the end of 2022. The first goal of the innovation pool project “LUXE-QED” has been achieved: The design of the laser and its diagnostic was significantly improved und documented in the experiment’s technical design report that was used in the approval process and will be published in 2023. Also the second part of the project is progressing well: Based on the IBM qiskit framework a quantum computing method was developed for the reconstruction of charged particle tracks from energy depositions in the LUXE tracking detector. The software’s functionality was demonstrated using a simulation of the signals expected from the tracking detector in the entire range of laser intensities expected during LUXE data taking. The results were compared to modern classical approaches, demonstrating excellent agreement [1,2].

*[1] A. Crippa et al., Track reconstruction at the LUXE experiment using quantum algorithms, arXiv: 2210.13021 [hep-ex]*

*[2] L. Funcke et al., Studying quantum algorithms for particle track reconstruction in the LUXE experiment, arXiv:  2202.06874 [hep-ex]*

The goal of ADC-MAPP is to prepare a global and user-based analysis and data centre for multi-messenger astroparticle physics. The activities serve the digitisation of this data-intensive research field and focus in this project on specific tasks in the areas of research data management, big-data and multi-messenger analyses, services for a broad user community, as well as networks and training. In 2022 we had significant progress in fastening air-shower simulations with help of Deep Learning (Sequential Networks) Methods. In addition, Graph Neural networks are now applied to determine the PeV to EeV cosmic-ray elemental composition from the IceCube/IceTop data [1]. The integration of FAIR long-term archiving and accessibility of data, workflows, and software reached an important milestone with successfully testing the community data formats and science software (gammapy) for the gamma-ray observatories VERITAS and H.E.S.S. [2]. A generalisation of the concept for astroparticle experiments like HAWC or IceCube is ongoing. This will allow for consistent multi-messenger analyses using common algorithms. Machine-readable catalogues for physics results from gamma-ray observatories are published for the first time through the Zenodo and HEASARC data portals. The multi-messenger AMPEL platform was extended to process LSST like alerts, and took part in the ELAsTiCC real-time stress test hosted by the DESC collaboration. In parallel work started for the processing of sub-threshold IceCube neutrino events and match these to optical archives with cadenced data. The working groups in ADC-MAPP collaborate closely with other initiatives such as the NFDI (PUNCH4NFDI), ErUM-Data, or EOSC in the field of digitisation of astroparticle physics, research data management and sustainable publication of scientific data.

*[1] Paras Koundal, Graph Neural Networks and Application for Cosmic-Ray Analysis; PoS DLCP2021 (2022), 004; DOI: 10.22323/1.410.0004*

*[2] A. Acharyya et al; VTSCat: The VERITAS Catalog of Gamma-Ray Observations; Res.Notes AAS 7 (2023) 1, 6; DOI: 10.3847/2515-5172/acb147*

The project „Variational quantum computer simulations for complex quantum systems and optiization problems“ (VQCS) has progressed excellently in 2022. An implementation of quantum electrodynamics (QED), i.e. the interaction of electrons and photons, was achieved on a quantum computer and published in Phys. Rev. D [1]. Furthermore it could be shown that by a classical splitting of a quantum circuit convergence problems of gradient-based optimisation algorithms (so-called „Barren plateaus“) can be avoided [2]. In another work, quantum computing was successfully utilised to identify causal loops in Feynman diagrams [3]. Finally, an invited chapter for a book on quantum music was published [4]. The work in this chapter has led to new algorithms and methods in quantum computing that are now also being utilised in physical models. A student in the VQCS project, A. Crippa, has been accepted for an internship in the IBMQ Zurich Lab and will work there for six months. This has led to a unique connection and cooperation with the quantum team and its activities at IBM, by which the VQCS project is massively profiting. It should also be mentioned that there is large and productive overlap with the LUXE-QED project [5].

*[1]* [*Giuseppe Clemente*](https://arxiv.org/search/hep-lat?searchtype=author&query=Clemente,+G)*,*[*Arianna Crippa*](https://arxiv.org/search/hep-lat?searchtype=author&query=Crippa%252C+A)*,*[*Karl Jansen*](https://arxiv.org/search/hep-lat?searchtype=author&query=Jansen%252C+K)*, Strategies for the Determination of the Running Coupling of (2+1)-dimensional QED with Quantum Computing, Phys.Rev.D 106 (2022) 11, 114511*

*[2]* [*Cenk Tüysüz*](https://arxiv.org/search/quant-ph?searchtype=author&query=T%25C3%25BCys%25C3%25BCz,+C)*,*[*Giuseppe Clemente*](https://arxiv.org/search/quant-ph?searchtype=author&query=Clemente%252C+G)*,*[*Arianna Crippa*](https://arxiv.org/search/quant-ph?searchtype=author&query=Crippa%252C+A)*,*[*Tobias Hartung*](https://arxiv.org/search/quant-ph?searchtype=author&query=Hartung%252C+T)*,*[*Stefan Kühn*](https://arxiv.org/search/quant-ph?searchtype=author&query=K%25C3%25BChn%252C+S)*,*[*Karl Jansen*](https://arxiv.org/search/quant-ph?searchtype=author&query=Jansen%252C+K)*, Classical Splitting of Parametrized Quantum Circuits, arxiv:2206.12454*

*[3]* [*Giuseppe Clemente*](https://arxiv.org/search/hep-ph?searchtype=author&query=Clemente,+G)*,*[*Arianna Crippa*](https://arxiv.org/search/hep-ph?searchtype=author&query=Crippa%252C+A)*,*[*Karl Jansen*](https://arxiv.org/search/hep-ph?searchtype=author&query=Jansen%252C+K)*,*[*Selomit Ramírez-Uribe*](https://arxiv.org/search/hep-ph?searchtype=author&query=Ram%25C3%25ADrez-Uribe%252C+S)*,*[*Andrés E. Rentería-Olivo*](https://arxiv.org/search/hep-ph?searchtype=author&query=Renter%25C3%25ADa-Olivo%252C+A+E)*,*[*Germán Rodrigo*](https://arxiv.org/search/hep-ph?searchtype=author&query=Rodrigo%252C+G)*,*[*German F. R. Sborlini*](https://arxiv.org/search/hep-ph?searchtype=author&query=Sborlini%252C+G+F+R)*,*[*Luiz Vale Silva*](https://arxiv.org/search/hep-ph?searchtype=author&query=Silva%252C+L+V)*, Variational quantum eigensolver for causal loop Feynman diagrams and acyclic directed graphs, arxiv:2210.13240*

*[4]* [*Giuseppe Clemente*](https://arxiv.org/search/quant-ph?searchtype=author&query=Clemente,+G)*,*[*Arianna Crippa*](https://arxiv.org/search/quant-ph?searchtype=author&query=Crippa%252C+A)*,*[*Karl Jansen*](https://arxiv.org/search/quant-ph?searchtype=author&query=Jansen%252C+K)*,*[*Cenk Tüysüz*](https://arxiv.org/search/quant-ph?searchtype=author&query=T%25C3%25BCys%25C3%25BCz%252C+C)*, New Directions in Quantum Music: concepts for a quantum keyboard and the sound of the Ising model, to appear in the book "Quantum Computer Music" (Springer, 2022), Edited by Miranda, E. R*

*[5]* [*Arianna Crippa*](https://arxiv.org/search/hep-ex?searchtype=author&query=Crippa,+A)*,*[*Lena Funcke*](https://arxiv.org/search/hep-ex?searchtype=author&query=Funcke%252C+L)*,*[*Tobias Hartung*](https://arxiv.org/search/hep-ex?searchtype=author&query=Hartung%252C+T)*,*[*Beate Heinemann*](https://arxiv.org/search/hep-ex?searchtype=author&query=Heinemann%252C+B)*,*[*Karl Jansen*](https://arxiv.org/search/hep-ex?searchtype=author&query=Jansen%252C+K)*,*[*Annabel Kropf*](https://arxiv.org/search/hep-ex?searchtype=author&query=Kropf%252C+A)*,*[*Stefan Kühn*](https://arxiv.org/search/hep-ex?searchtype=author&query=K%25C3%25BChn%252C+S)*,*[*Federico Meloni*](https://arxiv.org/search/hep-ex?searchtype=author&query=Meloni%252C+F)*,*[*David Spataro*](https://arxiv.org/search/hep-ex?searchtype=author&query=Spataro%252C+D)*,*[*Cenk Tüysüz*](https://arxiv.org/search/hep-ex?searchtype=author&query=T%25C3%25BCys%25C3%25BCz%252C+C)*,*[*Yee Chinn Yap*](https://arxiv.org/search/hep-ex?searchtype=author&query=Yap%252C+Y+C)*, Track reconstruction at the LUXE experiment using quantum algorithms, arxiv:2210.13021*

4.1 Talent Management

DESY theorist Elli Pomoni has won an ERC Consolidator Grant. Her project has the title “Exact results from broken symmetries”. In addition, Elli Pomoni was awarded a Helmholtz W2 professorship that is organized between DESY and Hamburg University. The professorship is accompanied by an annual funding of 300,000 Euro.

Thibaud Humair (currently at Max Planck Institute for Physics, Munich) was granted a Helmholtz Young Investigator Group for his project “Time for Antimatter” with the Belle II experiment that will begin in 2024. The project is funded with 750,000 Euros.

“Data Science in Hamburg - Helmholtz Graduate School for the Structure of Matter” (DASHH, [www.dashh.org](http://www.dashh.org)) fosters innovative collaborative projects at the interface of the natural sciences and applied mathematics or computer science. This involves a unique format of networking between the researcher from the nine DASHH partner institutions. Nine of the 35 doctoral researchers focus on the development of new algorithms for particle physics. Several projects contribute to the ATLAS and CMS collaborations and were presented on various national and international conferences. DASHH promotes data science education and interdisciplinary networking alike. In 2022, the school organized 29 networking events, 21 lectures and six courses. One of the highlights is the joint Data Science Colloquium which is open to all partners and Helmholtz centers with on average 130 participants.

HGS-HIRe the graduate school of GSI/FAIR had a total of 345 students from all four research pillars of FAIR in 2022, of which 232 doctoral students are working on research projects of the topic "Cosmic Matter in the Laboratory". A total of 30 theses were successfully completed*.*

Dr. Livia Ludhova, IKP Jülich, was appointed to a W2 professorship on “Low-Energy Neutrino Physics (Solar and Geo-Neutrinos)” at the University of Mainz.

Dr. Thorsten Kollegger (head of the GSI IT department) has been appointed to a W3 professorship at Goethe University Frankfurt, Department of Informatics and Mathematics.

Prof. Dr. Hannah Elfner has been appointed Senior Fellow at the Frankfurt Institute for Advanced Studies (FIAS), dealing with theoretical research on various topics. She has thus made it into the highest staff category at FIAS - comparable to a W3 professorship at a university.

Dr. Kai Schweda, GSI, has been appointed and endorsed as Deputy Spokesperson of the ALICE Collaboration. His three-year mandate will start in January 2023.

Prof. Dr. Tetyana Galatyuk is the Chair of the Committee for Hadron and Nuclear Physics (KHuK) in Germany. She has been elected by community to the DFG Review Panel 309-01 Nuclear and Elementary Particle Physics, Quantum Mechanics, Relativity, Fields. She has been appointed and endorsed as Deputy Spokesperson of the CBM Collaboration.

In 2022, about 50 doctoral researchers of the KIT Graduate School KSETA – “Karlsruhe School of Elementary Particle and Astroparticle Physics: Science and Technology“ worked on their thesis on topics of MU. The school offered about 20 lecture courses along the interdisciplinary motto DEEPER – BROADER – BETTER, which points towards the scientific specialization and addresses the wider professional education and key competences. Special highlights in 2022 were the large Plenary Workshop and the “Wess lecture“ given in 2022 by the Julius Wess awardee of 2021, Prof. Mark Wise from Caltech, USA.

The KSETA school is intertwined with the Helmholtz International Research School for Astroparticle Physics and Enabling Technologies (HIRSAP) which offers two special Double Doctoral Degree paths between KIT and UNSAM in Buenos Aires, Argentina, the Double Doctoral degree in Astrophysics (DDAp) and the Double Doctoral degree in Electrical engineering and Information Technology (DDEIT). In 2022, 21 doctoral students of HIRSAP were pursuing their work in topics of the two Research Programs MU and MT. After the COVID19 pandemic, the long-term stays of at least 6 months each, where the PhD researchers work at the partner host, could be resumed and 13 of these exchanges took place.

Furthermore, the international exchange program of the Helmholtz Alliance for Astroparticle Physics (HAP) could grant two iPROGRESS - Internship Program for Young Research Scientists – research visits for doctoral researchers in MU to work together with partners in the USA and in Spain.

In 2022 about 35 students pursued their scientific research within the International Helmholtz-Weizmann Research School on Multimessenger Astronomy. The school offered an in-person exchange with its partner members from the Weizmann Institute of Science (Rehovot, Israel) via the annual school meeting and a workshop on machine learning for LSST data and data from the Zwicky Transient Facility. Moreover, the school successfully passed its interim evaluation within the Helmholtz Initiative and Networking fund.

Prof. Dr. Kathrin Valerius (KIT) has been elected as Deputy Chair of the Committee for Astroparticle Physics (KAT) in Germany. She serves as representative of the Neutrino Properties constituency in KAT. Further elected members from MU are Dr. Markus Roth (KIT) for the section Cosmic Rays, Dr. Walter Winter (DESY) for the section Theory, and as deputies Prof. Dr. Marek Kowalski (DESY) for the section High-energy Neutrino Astrophysics and Dr. David Berge (DESY) for the section Gamma-ray Astronomy.

In November 2022 the DPG announced the 2023 awardees of DPG prizes. Dr. Belina von Krosigk (KIT) won the Hertha-Sponer prize „Für ihre fundamentalen Beiträge zur direkten Suche und zum Verständnis von Dunkler Materie durch die Weiterentwicklung von Modellen sowie der methodischen und analytischen Techniken zur Detektion kleinster Signale“.

In October 2022, the outstanding PhD thesis of HIRSAP/DDAp alumna Ana Laura Müller (KIT and UNSAM, now at Institute of Physics of the Czech Academy of Sciences (CAS) in Prague) was published by Springer as part of the book series Springer Theses. The thesis also received the Carlos M. Varsavsky Award from the Argentine Astronomical Society (Asociación Argentina de Astronomía), together with the Varsavsky Foundation, which distinguishes the best Argentinian doctoral theses in astronomy and astrophysics of the last two years.

4.2 Networking and Cooperation

The Centre for Quantum Technology Applications (CQTA) at DESY in Zeuthen had been funded, already in 2021, with close to 13 million Euros by the state of Brandenburg. Now, additional two million Euros for the construction of a CQTA building have been granted. The centre will serve as a development for researchers and industry for applications for complex quantum systems, and it will work on optimisation algorithms for quantum computers. A leading role in this key technology is envisaged, also serving the regional development. The “Noise in Quantum Algorithms” project, funded by the BMBF with roughly 500.000 Euros, nicely complements the CQTA. The project aims at a paradigm change in that it tries to investigate to what extent noise can be reduced, but also in that it aims at the development of algorithms that actually profit from noise.

The Helmholtz Alliance “Physics at the Terascale” – connecting all German universities and research centres working in elementary particle physics – has conducted numerous education and training events in 2022, among them the 14th Terascale Detector Workshop and an annual meeting in November 2022. The meetings were organized as hybrid or pure online events (see www.terascale.de).

In the first full year of its existence, the PUNCH4NFDI Consortium (www.punch4nfdi.de) in the German National Research Data Infrastructure NFDI has started to work and deliver on all its tasks areas. In particular the definition of the envisaged science data platform SDP and ideas for the definition of “digital research products” are progressing. The year 2022 was characterized by a number of developments that will affect also the work plan of the consortium that bundles the data management efforts in the fields of particle physics, astroparticle physics, astrophysics, and hadron & nuclear physics. To mention three examples: First, the increased activity in the NFDI sections will impact the way the various NFDI consortia collaborate and develop common solutions for data management challenges. In particular, a number of discussions that PUNCH4NFDI has led with other consortia from various disciplines has been moved to the sections. Second, the creation of consortia in the third DFG call has increased the basis for collaboration in the entire science system. Third, the successful application of the Base4NFDI initiative sheds a new light on a number of activities that PUNCH4NFDI is pushing.

Base4NFDI is an initiative put forward by all 19 NFDI consortia of the first two DFG calls that aims at providing "basic services” in data management to the entire German science system. Key examples are a unified identify and access management (IAM), a terminology service, or long-term archival solutions. The initiative has been granted very substantial funding in 2022 and will formally start its work in March 2023. DESY is contributing to Base4NFDI in the role of a co-applicant institution and KIT experts have been nominated for the Base4NFDI TEC (Technical Expert Committee).

DESY’s contribution to the excellence cluster “The Quantum Universe” (QU) strengthens interdisciplinary scientific research at the top level; it brings fresh momentum for the research portfolio, it complements DESY’s competences, and it contributes to the further development of DESY’s unique research infrastructure. Furthermore, QU contributes to the future development of the Research Field Matter and the MU program in particular, and it extends DESY’s international cooperation. In July 2022, the baton of the QU spokesperson was handed over to Prof. Erika Garutti (Hamburg University). Two high-level recruitments can be reported for 2022: Prof. Stephan Rosswog has joined the “Hamburger Sternwarte” (Hamburg Observatory) on a W3 professorship in August 2022, and Prof. Kostas Nikolopoulos received a call on a professorship for experimental physics and will begin in February 2023. An additional highlight is the exhibition “Wie alles begann” (How everything began) in Hamburg’s “Museum für Arbeit” that is running from October 2022 to April 2023 and that was essentially curated by QU. With the “Quantum Universe Days”, a new exchange format has been created: four times a year, all QU researchers will meet for a day of exchange across research area boundaries. Currently, the discussion about the future of the cluster after the end of the first funding period in 2027 are starting.

An application in the framework of TransFAIR for support of FAIR research, the NRW-FAIR network, was approved for funding by the North Rhine Westphalian government. The network will be funded with 16.5 million euros over the next four years. This funding is foreseen to support and coordinate experimental and theoretical activities related to CBM and PANDA at the Universities of Bochum, Bonn, Münster, and Wuppertal, as well as the Forschungszentrum Jülich with GSI as associated partner. The network of NRW universities is playing a major role in shaping the work at the "Facility for Antiproton and Ion Research" (FAIR) in Darmstadt. In the next step, it is expected that other universities in NRW (e.g. Köln and Bielefeld) may join in the near future and that the scientific scope will be broadened.

GSI participates in the EU-project EURO-LABS (EUROpean Laboratories for Accelerator Based Science), which received funding in the program HORIZON Research Infrastructures, and is carried out by 24 institutions and 8 associated partners. It aims to provide unified transnational access to leading research infrastructures across Europe, and brings together the nuclear physics, the high-energy accelerator, and the high-energy detector R&D communities, enabling research at the frontiers of accelerator and detector development.

The joint project “NUTRIG - novel techniques for pure, efficient and scalable autonomous radio detection of high energy neutrinos and cosmic rays” started in June 2022. It is a “projets de recherche collaborative international” between KIT, *Laboratoire physique nucléaire et hautes énergies* LPNHE and *Institut d'astrophysique de Paris* IAP in France, commonly funded by ANR, *Agence Nationale de la Recherche*, France and DFG, Germany, for 3 years with about 660 kEUR.

In the field of measuring high-energy cosmic radiation, KIT has a close cooperation with Indian groups. This arose from the connection of the KASCADE-Grande experiment with the Indian experiment GRAPES. In 2022, three Indian students (2 Masters, 1 PhD) were again able to complete an internship for 2 months each and work in the local research groups of IceCube and Pierre Auger at KIT. Funding was obtained through the KSETA graduate school and the KCETA center.

In 2022 the theoretical astroparticle group at IAP has been hosting several international visitors for stays of several months. These included Federica Pompa, PhD student from IFIC Valencia, Spain as part of the HIDDeN network, working on the phenomenology of neutrinoless double beta decay; the visit of Jorge Terol-Calvo, PhD student at Univ. de la Laguna, Tenererife, Spain, leading to the joint publication M. Escudero, T. Schwetz and J. Terol-Calvo, „A seesaw model for large neutrino masses in concordance with cosmology“, [arXiv:2211.01729 [hep-ph]] accepted for publication in JHEP; as well as Dr. Manuela Saez from Univ. la Plata, Argentina, with whom we have been working on a joint project with Dr. Belina von Krosigk from the experimental group at IAP on astrophysical neutrino measurements. Furthermore, we have been hosting Dr. Jing-yu Zhu in the framework of the German-Chinese OCPC-Helmholtz grant, which also yielded in a joint publication, M. Ovchynnikov, T. Schwetz and J. Y. Zhu, „Dipole portal and neutrinophilic scalars at DUNE revisited: the importance of the high-energy neutrino tail“, [arXiv:2210.13141 [hep-ph]] accepted for publication in PRD.

4.3 Transfer in Economy and Society

With its knowledge transfer activities, the Research Field Matter pursues the goal of making socially relevant scientific topics and findings available through non-monetary channels and bringing them into application. This enables societal stakeholders to make robust and evidence-based decisions, to participate in scientific dialogues, or to pursue scientific careers themselves. In addition, the Research Field Matter also pursues knowledge transfer as an enrichment for society to satisfy curiosity about fundamental knowledge - the interest in "what holds the world … together."

The Research Field Matter makes its research results and research data with associated analysis tools available to the public on a significant scale. Classical research publications are published in appropriate journals, but are also offered as "open access" publications whenever possible. The libraries of the Helmholtz Centres involved in the Research Field Matter offer extensive services in this regard, which are available to all scientists, staff of the research centers and the general public. In addition to the "open access" availability of publications, research data, media and software are also offered, whereby the MU program, characterized by its particular diversity of international collaborations, is particularly active in this area. Examples of MU include the CERN open data portal (https://opendata.cern.ch/), the KCDC cosmic ray data center (https://kcdc.iap.kit.edu/), Cosmic@Web (http://cosmicatweb.desy.de/ctplot/), and Auger Open Data (https://opendata.auger.org/) [1]. These data portals provide data series for download and online analysis. So-called events of extended air showers or particle collisions can be displayed in event displays and analyzed by oneself using provided analysis software. Informative tutorials provide an introduction to scientific work. The high degree of, often international, cooperation in the research area Matter, especially in MU and the LK-II Facility GridKa, has led not only to the open exchange of pure research data, but also to extensive software developments being carried out jointly and publicly. This includes extensive simulation software of physical processes and experimental facilities (e.g., CORSIKA 8 - https://www.iap.kit.edu/corsika/88.php), data taking software (e.g., ORCA - http://orca.physics.unc.edu/orca/Orca\_Help/Home.html), and higher-level tools to enable analysis and data transfer between highly networked computing infrastructures (e.g., TARDIS Resourcemanager - https://github.com/MatterMiners/tardis/ and COBalD Opportunistic Balancing Daemon - https://github.com/MatterMiners/cobald) [2]. This open source software is available on platforms such as github.com or pypi.org. The common software developments are a direct knowledge transfer to other scientific communities, and can be applied to industry and economy as well.

*[1] DOI 10.5281/zenodo.6867688, Pierre Auger Observatory Open Data, Version 2.0, Dec. 22, 2022*

*[2] DOI 10.5281/zenodo.7032186, MatterMiners/cobald: v0.13.0, Aug. 29, 2022*

The GSI/FAIR Digital Open Lab has been established at the Green IT Cube. This “real lab” is available for industry and research partners and comprises the provision of the infrastructure and IT competences of GSI and FAIR for joint development around the topics of HPC, Big Data and ultra-fast data acquisition, including software developments and products. Access to HPC systems and projects for external partners via collaboration projects is also possible, as is an offer of services in the data center, such as the provision of rack space. The AI innovation lab currently being set up at the Hessian Center for Artificial Intelligence hessian. AI will be located at the Green IT Cube with its AI computing infrastructure.

With a special summer event, the KIT Center Elementary Particle and Astroparticle Physics KCETA was able to bring its scientific and technological findings closer to a broad public in the heart of the pedestrian area of Karlsruhe with the traveling exhibition "Code of the Universe" from CERN, a multi-week Afternoon Science series, and numerous lectures within the framework of EFFEKTE on "Antimaterie, Dark Matter, New Matter?". The science afternoons were dedicated to all topics of the programs MU and MT, as well as the data and computing infrastructure GridKa. On three afternoons, additional master classes on IceCube, CMS and Belle-II were offered to all interested students from grade 10 onwards.

4.4 Third-Party Funding

The PUNCH4NFDI and Base4NFDI projects were already discussed above. Both come with altogether very significant funding. In case of PUNCH4NFDI, DESY is coordinator and applicant institution; KIT, GSI and FZJ are co-applicants. For Base4NFDI, DESY acts as a co-applicant.

The SFB Transregio 257 on “Particle Physics Phenomenology after the Higgs Discovery” between KIT, RWTH Aachen and the universities of Siegen and Heidelberg has entered its second funding period with a funding volume of 13 million Euros.

The "International research collaboration in a search for physics beyond the Standard Model" project supports the binational research cooperation with the French partner institute IP2I Lyon in the context of searching for new physics in final states with b quarks in the years 2022-23. It is funded within the program for project-related person exchange France (PROCOPE), co-funded by DAAD, and has started up very well in early 2022. With this program several visits of in total four researchers from DESY were funded, which included a meeting with the IP2I director and a colloquium presentation in Lyon. Equally, several visits of our IP2I colleagues at DESY took place. This resulted in a greatly intensified collaboration between the groups, and a substantial gain of international research experience especially for the junior scientists in the group. This successful activity will be continued during the year 2023.

As already reported above, DESY theorist Elli Pomoni was awarded an ERC Consolidator Grant and also a Helmholtz Professorship with Hamburg University.

EAJADE („Europe-America-Japan Accelerator Development and Exchange") is a Horizon-Europe Marie Sklodowska-Curie staff exchange action the EU decided in 2022 to support with roughly 1.3 million Euros. Over the course of 4 years, the funding will be used by DESY as coordinator and its numerous EU partners (among them CERN, CNRS, CEA, and INFN) to second researchers to research faciliities in Japan, the USA, and Canada, to perform research in the field of accelerator development. The focus of the program is on R&D for the components of a future ”Higgs factory”, but aspects like special technologies, magnet development, and accelerator sustainability are also of major importance. EAJADE succeeds and extends the precursor programme E-JADE that was running from 2014-2018 and that allowed for secondments exclusively to Japan.

The EURO-LABS project brings together, for the first time, the three research communities of nuclear physics, accelerator and detector technologies for high energy physics EURO-LABS is a network of 33 research and academic institutions from 18 countries (25 beneficiaries and 8 associated partners) from European and non-EU countries, involving 47 Research Infrastructures in the Nuclear physics, Accelerators and Detectors pillars. EURO-LABS is funded by Horizon EU with a total budget of 14.5 million. It started in September 2022 and runs till August 2026 It provides efficient transnational access to the available resources and organizes the training of the new generation of researchers and young technical staff. The DESY II Test Beam facility is one of the core facilities of the detector pillar and the transnational access will allow many more users to take advantage of this unique infrastructure.

interTwin („An interdisciplinary digital twin engine for science“) is a Horizon-RIA action started in September 2022 and running for 36 months, with an EU funding of roughly 11.7 million Euros (about 320,000 Euros for DESY). interTwin co-designs and implements the prototype of an interdisciplinary Digital Twin Engine (DTE), an open source platform that provides generic and tailored software components for modelling and simulation to integrate application- specific Digital Twins (DTs). The ambition is to develop a common approach to the implementation of DTs that is applicable across the whole spectrum of scientific disciplines and beyond to facilitate developments and collaboration.

The aim of the EU project Cosmic Wisper, started in October 2022 and running for 4 years, is to coordinate and support WISPs searches in a synergic way at the boundary between particle physics, astrophysics and cosmology. It will provide a platform to benefit from the latest data from laboratory and astrophysical experiments. It will also offer a guidance for experimental efforts and theoretical investigations dealing with fundamental questions, like the strong CP problem and the nature of the dark matter. The project is altogether funded with 129,000 Euros per year.

In the second call for projects by the Helmholtz Metadata Collaboration (HMC), the proposal “PATOF – From the Past To the Future: Legacy Data in Small and Medium-Scale “PUNCH” Experiments – a Blueprint for PUNCH and Other Disciplines” was successful, attracting a funding of 400.000 Euros for DESY and the Helmholtz Institute Mainz starting in April 2023. The project will investigate possibilities for sustainable treatment of research data from small and mid-scale experiments in particle and hadron&nuclear physics according to the FAIR principles. Forces will be joined in the project with the efforts ongoing in the PUNCH4NFDI consortium.

In the framework of the Helmholtz initiative “Researchers at Risk”, six researchers found at least temporary refuge and scientific perspective in the MU activities of DESY’s particle physics division: Four scientists from the Ukraine and one each from Belarus and Russia have the opportunity to continue their research work or Ph.D. theses for a duration of six months on DESY contracts.

Prof. Dr. Gabriel Martínez-Pinedo, head of the GSI theory department “Nuclear Structure & Astrophysics”, received the Gottfried Wilhelm Leibniz Prize 2022 for his outstanding work in theoretical astrophysics on the formation of the heavy elements. The DFG’s Leibniz Prize is the most important German research prize and is endowed with 2.5 MEuro.

The EU has awarded 11.3 MEuro to the HEAVYMETAL research project, which aims to investigate the synthesis of chemical elements in neutron star mergers. Dr. Andreas Bauswein, researcher in the GSI theory department “Nuclear Structure & Astrophysics”, is part of the four-member international team that receives the funding as part of an ERC Synergy Grant.

Additional funding for the extension of the infrastructure (cooling and racks) of the Green IT Cube has been approved. The funding of 5.5 million € originates from the REACT-EU program which is administered by the Federal State of Hesse. Work on the implementation started in the first quarter of 2022 and is mostly completed in December 2022. The capacity of the Green-IT cube for hosting computers and/or disks is doubled by this measure.

Prof. Dr. Thomas Schwetz-Mangold (KIT) was granted a 3-year DFG project on „Modellunabhängige Untersuchung der Zeitumkehr Symmetrie in Neutrinooszillationen“.

5 Indicators and Resources

5.1 Quantitative Indicators

Comments:

example

*Please explain and comment on developments/changes in each indicator.*

Publications:

Third-party funding:

Finished dissertations:

Core-funded scientists:

Third-party funded scientists:

5.2 Development of Costs



example

Comments:

*Please comment on deviations of actual costs from Senate recommendations. Deviations > 20% require a vote by the Senate and a comment is mandatory.*

Forschungszentrum X

Forschungszentrum Y

Forschungszentrum Z

Associated Research Infrastructures (LK II)

1 Research Infrastructure GridKa

In the reporting period the GridKa compute and storage resources were further expanded along the requirements of the experiments; traditionally this is done in close coordination with the GridKa Overview Board. Operations of the Batch Farm were smooth; all newly installed worker nodes (~ 50 k cores) were put into production as planned and a few months later the oldest remaining worker nodes (~ 10 k cores) were switched off. Security updates were done continuously, and Token-based Authentication/Authorization is now supported. The usage of the GPU nodes is slowly but steadily picking up. A precise and detailed power monitoring has been installed.

The GridKa online storage was extended with the 71 Petabyte procured in 2021. Challenges in the supply chain of certain components (in particular Infiniband cards and cables) delayed the start for production usage for about six months. The migration of data takes place transparently to the users. In total 99 Petabyte are available to fulfill the 2022 and 2023 pledges. A large downtime in June was primarily used for software and security updates in the storage network, the filesystem and dCache.

The activities in the GridKa tape storage system were dominated by the TSM-to-HPSS migration that was already started in 2021. After CMS, LHCb and Belle-II in the beginning, now ATLAS and finally ALICE are following; it is expected that the migration is finished by early 2024.

The GridKa WAN network connection operated smoothly, and the applied bandwidth upgrades were immediately utilized. The procurement of the planned 400 Gb/s network hardware had to be modified as certain components of the planned routers experience very long delivery times (> 1 year).

As the root certificate of the GridKa X.509 Certification Authority (CA) terminates in June 2023, issuing new certificates was stopped in June 2022. Instead, the DFN GridCA and the GEANT TCS are used and offered as alternatives.

1.1 Recommendations of the Senate

* The Senate agrees with the very positive evaluation of the LK II infrastructure Tier-1 data and computing center GridKa and approves its funding with an according increase of 2% adjusted full-cost accounting planning.

GridKa LK II is extremely grateful for this recommendation as it provides an important basis for operating the GridKa compute and data resources for the LHC Run3 as well as for the HL-LHC phase for the international user community. However, price increases, especially for electricity in the last half year 2022, have shown that the 2 % increase will not be sufficient. All measures are taken within GridKa to fulfill the resource pledge 2023 ff as energy-efficiently and energy-minimized as possible.

1.2 Indicators and Resources

1.2.1 Quantitative Indicators

**KENNZAHLENTABELLE ZU DER FIS-1**

Comments:

*Please explain and comment on developments/changes in each indicator.*

Availability

Utilization

Publications

Core-funded scientists

1.2.2 Resources

**RESSOURCENTABELLE ZU DER FIS-1**

Comment

*Please comment on deviations of actual costs from Senate recommendations.*

2 Research Infrastructure GSI-MU Ion Facilities

The linear accelerator facility UNILAC, the heavy-ion synchrotron SIS18, and the fragment separator FRS, which delivers high-energetic exotic nuclei, have served a broad user community in 2022. The availability for users (beam on target) was 75 % and in average 2.6 experiments were served in parallel. Twenty days were assigned to accelerator machine studies. This machine beam block was used for testing FAIR components, for high-current optimization with low-charged uranium, overall commissioning and testing new operating modes.

The most prominent experiments that have received beam time in 2022 are the HADES and the WASA experiments. For the study of the electromagnetic decay of strange hyperons, the acceptance of the HADES experiment has been instrumented in the forward direction by installing Straw Tube Tracking stations, which have been designed and built for the Inner Tracker of the PANDA experiment at FAIR. The WASA set-up was installed at the mid-focal plane of the FRS and was used to study the interaction of strange particles with nuclear matter.

An application to the EU-REACT program for an extension of the Green-IT cube to strengthen the research and transfer activities around data center technologies has been approved. A total budget of 5.5M€ was used to extend the infrastructure of the Green-IT cube. There is a rising interest of industrial and scientific partners in cooperation. The newly founded Digital Open Lab within Green-It Cube which will provide an environment for developing, testing and scaling up energy-efficient high-performance computing to the scale of industrial demonstrators in partnership with industry.

Efforts to reduce the energy consumption of the GSI accelerators are intensified in order to deal with the rising energy costs. A working group of building- and system engineering, accelerator and research has identified saving measures. First measures have been implemented already or have been started.

2.1 Recommendations of the Senate

* *The funding of the Research Field associated User Facility at GSI (UNILAC, SIS18, FRS, ESR etc.), which is in reduced operating mode, is organized by a dedicated agreement of the Helmholtz Association and GSI, and can be assigned in total or parts as a LK II facility in PoF IV, given fulfilled criteria for that.*

The financing of the user facilities of the GSI associated with the research area and operated in a reduced mode (UNILAC, SIS 18, FRS, ESR, etc.) is governed by special agreements between the Helmholtz Association and GSI. In 2022, it was decided that the GSI Ion facilities indeed fulfill all the requirements for the classification as LK II user infrastructures and are therefore classified as such. This does not have any effective financial consequences, and the GSI MU-Ion facilities do not profit from the increase in funding of LK II infrastructures.

2.2 Indicators and Resources

2.2.1 Quantitative Indicators

**KENNZAHLENTABELLE ZU DER FIS-1**

Comments:

*Please explain and comment on developments/changes in each indicator.*

Availability

Utilization

Publications

Core-funded scientists

2.2.2 Resources

**RESSOURCENTABELLE ZU DER FIS-1**

Comment

*Please comment on deviations of actual costs from Senate recommendations.*