# MU-PoF V preparation meeting

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# Structure of the document

## Some points of discussion to be more homogeneous

- Structure of the 1st and last “blue box”
    - Goals in the last blue box, how many?
- Highlighted text in bold in paragraphs
- Subtopics as “titles” or “questions”
- Implementation section
- Figures
- References

# Structure of the first blue box

## 2.2 Topic *Fundamental Particle and Forces* (MU-FPF)

*[In-depth description of the topic strategy starting with a brief description of the topic (for* ***FPF 14 pages*** *without counting the subsection* Results of the Scientific Evaluation*).]*

***Executive Summary*** **/ 0.5 pages**

The goal of the topic Fundamental Particles and Forces is to understand elementary particles and their fundamental interactions.

**Strategy**

The next funding period will see a consolidation of the Helmholtz role in off-site large international experiments (ATLAS and CMS at the LHC, Belle II at SuperKEKB) and at the same time the establishment of DESY as an on-site central hub for axion research. The DESY multi-decades expertise in the full cycle of large-scale experiments, the close collaboration between experiments and the DESY and KIT theory groups and the synergy with research topics and technologies in MT allow Helmholtz scientists to propose a world-class program. Both lines of program have a potential for revolutionary results in particle physics and, together with the leading contributions to the decision on the future Higgs factory, Helmholtz scientists are in first line to solve many open questions in Nature.

**Facts and Figures**

Participating centers:
DESY, KIT

Spokespersons:
Isabell Melzer-Pellmann (DESY), Kai Schmidt-Hoberg (DESY)

Core-funded scientists: x FTE (2028)
Core-financed costs: x MEUR (2028)

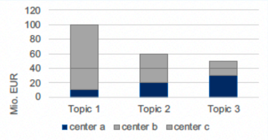


*Figure 2.2: Example Figure.*

## 2.3 Topic *Cosmic Matter in the Laboratory* (MU-CML)

***Executive Summary*** **/ 0.5 pages**

Cosmic Matter in the Laboratory (MU-CML) studies the formation of strong interaction matter from its elementary building blocks to its complex, and in many facets still unexplored, manifestations. MU-CML focuses on researching the open questions related to understanding complex phenomena governed by the strong interaction in the non-perturbative regime of Quantum Chromodynamics (QCD). Among these phenomena are properties of the low-mass excitation spectrum of QCD, the composition of (exotic) hadrons, exotic forms of matter composed of hadrons or elementary quarks and gluons under extreme conditions of temperature, density and isospin, as well as the structure of nuclei far from the valley of stability and their role in nucleosynthesis. The investigation of the strong force in this topic impacts the quest for physics beyond the Standard Model, including searches for dark matter, the exploration of the matter–antimatter asymmetry, as well as precision tests of fundamental symmetries from low-energy experiments.

**Strategy**

Our primary objective is to fully realize the physics potential of the new FAIR facility through a staged approach encompassing the Early Science (ES) and First Science (FS / FS+) phases. Within NUSTAR, we aim to study the properties of nuclei at the limits of stability, uncovering novel features of the nuclear force and gaining insights into extreme astrophysical environments. This will be achieved by leveraging the outstanding capabilities of the Super Fragment Separator (Super-FRS) and the intense heavy-ion beams provided by SIS100.

By colliding heavy ions, we will study with HADES and CBM the QCD phase diagram at high baryon chemical potential to isolate unambiguous signals of new phases of QCD matter, to establish the conjectured first-order phase transition of QCD and critical point, and to study microscopic properties of such QCD matter. Fundamental aspects of QCD in the non-perturbative regime, e.g. vacuum properties of hadrons and their interaction, are studied with high-intensity pion and proton beams.

While ramping up our cutting-edge research programme in the FAIR phases ES/FS/FS+, we will continue to conduct comprehensive research using the existing research infrastructures at GSI, as the international scientific interest in a variety of physics topics remains outstandingly high.

Additionally, we will continue to play leading roles in selected experiments at major research facilities worldwide. This includes our sustained strong involvement in the ALICE collaboration at the LHC, with substantial scientific and technical contributions to the ALICE 3 detector upgrade and active participation in Run 4 to advance our understanding of QCD matter at vanishing baryon chemical potential but highest temperatures.

We will further strengthen and shape the close collaboration between theory and experiment. This is indispensable for extracting insights from measurements and to further develop lattice QCD and effective field theory approaches, microscopic transport- and hydrodynamic models, theoretical predictions of nuclear properties and reactions, as well as theoretical nuclear astrophysics and explosive-nucleosynthesis models.

**Facts and Figures**

Participating centers:
GSI with HIM, HZDR

Spokespersons:
Tetyana Galatyuk (GSI), Michael Block (GSI)

Core-funded scientists: 88 FTE (2028)
Core-financed costs: 26 MEUR (2028)

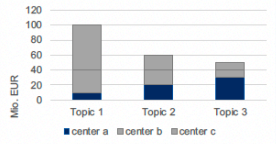


*Figure 2.7: Example Figure.*

## 2.4 Topic *Matter and Radiation from the Universe* (MU-MRU)

*[In-depth description of the topic strategy starting with a brief description of the topic (for* ***MRU 10 pages*** *without counting the subsection* Results of the Scientific Evaluation*).]*

***Executive Summary*** **/ 0.5 pages**

[Text]

**Strategy**

[Text]

**Facts and Figures**

Participating centers:
DESY, KIT

Spokespersons:
Kathrin Valerius (KIT), Christian Stegmann (DESY)

Core-funded scientists: x FTE (2028)
Core-financed costs: x MEUR (2028)

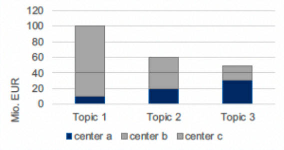


*Figure 2.8: Example Figure.*

The Topic Matter and Radiation from the Universe brings together particle physics, astrophysics, and

# Structure of the last box

FPF: executive summary plus main goals

**Fundamental Particles and Forces: *Overall goals***

The goal of the topic Fundamental Particles and Forces is to understand elementary particles and their fundamental interactions. Our program in PoF V is organized along three closely inter-related science drivers: (i) Fundamental interactions, pushing the limits of our understanding of fundamental interactions; (ii) The origin of mass, covering the puzzle of the origin of mass and of flavor, and the imbalance between matter and anti-matter in the universe; (iii) The early universe, exploring the evolution of the early universe and the nature of the dark sector.

The FPF main goals are:

**Installation and commissioning of the HL-LHC upgrades**, namely the Tracker endcaps in ATLAS and CMS and the HGCAL in CMS (2030), and analysis of the early data with these new innovative detectors (2032).

**New data on axion searches, with three flagship experiments on-site:** final results from the ALPS II experiment will be available, covering an unique parameter space in photon-axion couplings (2032); first scientific results from BabyIAXO (2034) and MADMAX (2034), the latter addressing the QCD axion, offering complementary insights on the evolution of the cosmos.

**New precision tests of QED:** First scientific results from LUXE on strong-field QED (2031) and first-time measurements of the vacuum magnetic birefringence with ALPS II.

CML: no special box at the end.

MRU: just the goals

**Matter and Radiation from the Universe: Key goals**

- By the conclusion of PoF V (2034), validate the two central technological pillars of **KATRIN++** – atomic tritium source and high-resolution differential electron spectroscopy – through **large-scale demonstrators at KIT**. As an intermediate goal, conduct a neutrino-mass measurement with a prototype quantum sensor array coupled to the high-intensity molecular tritium source of the existing KATRIN beamline.
- **Dark Matter:** Contribute decisively to the design and preparation of the next-generation liquid xenon observatory **XLZD**, aiming for first science in the early 2030s. During PoF V, establish the technical basis for probing deep into the "neutrino fog" regime, thereby opening the path to precision measurements of solar neutrinos and rare processes.
- **IceCube:** Advance neutrino astronomy with the **IceCube Upgrade**, identifying and understanding additional sources of high-energy cosmic rays and determining the neutrino mass hierarchy (together with other experiments). Operate the radio pathfinder **RNO-G** to extend

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neutrino detection into the EeV range. A major milestone of PoF V is the start of deployment of **IceCube-Gen2** at the South Pole by 2031.

- **CTAO:** The construction of the Cherenkov Telescope Array Observatory is a major goal of PoF V. Early science with intermediate arrays in both hemispheres will begin around 2027, with **observatory user operations** starting in the early 2030.
- **Pierre Auger Observatory:** With its completed upgrade **AugerPrime**, Auger will collect data until at least 2035. The aim of this Phase II is to determine the mass composition of cosmic rays with unprecedented precision, quantify the abundance of protons at the highest energies, **exploit light-particle astronomy**, and contribute significantly to multi-messenger analyses. In parallel, the community-wide adoption of **CORSIKA 8** will establish the next-generation simulation framework and invigorate collaboration with the collider physics community.
- **Gravitational Waves and Multimessenger Integration:** Launch of the UV satellite **ULTRASAT** in the early PoF V period, providing rapid-response coverage of transient events such as neutron star mergers and supernovae, linking neutrino, gamma-ray, cosmic-ray, and gravitational-wave observations. Preparatory work for the **Einstein Telescope** (ET), including vacuum system R&D, multimessenger coordination, and support of the **DZA** as national hub, ensuring Germany's readiness for participation once a site decision is taken.

# Examples from MT-DTS

at start

**Executive Summary**

MT-DTS drives world-leading innovation in detection technologies and detector systems, providing end-to-end expertise from fundamental sensing concepts and component design to full system integration, thus delivering the foundation for ambitious experimental programs in fundamental and applied science in Helmholtz *Matter* and beyond. We develop highly segmented and high-resolution sensor technologies, advanced microelectronics and integration techniques for detector modules. We advance quantum sensors and establish concrete applications in challenging experimental settings. We design and build complex, sustainable detection systems and highly capable data acquisition technologies, implement (artificial) intelligence close to the sensor and throughout the signal processing chain and integrate advanced detector systems into multidimensional modalities and AI-assisted methods for scientific discovery. This R&D program ~~is also aligned with the Hightech Agenda Germany, and~~ addresses topics of high societal relevance, contributing to technology sovereignty and talent development in scientific and technical disciplines.

**Strategy**

MT-DTS builds on a successful R&D program in PoF IV, and will continue to address key technological challenges in the Research Field *Matter* ~~particle and astroparticle physics and photon science~~ in a forward-looking and collaborative manner. The topic is structured in four subtopics: (1) Sensing and Detecting Technologies, (2) Quantum Technologies, (3) Systems and their Technologies, (4) Detection Methods. This reflects an increasing emphasis on quantum technologies, and an extension of the scope of the activities, in particular in the area of instrumentation and methods for photon science do we single this out here? I do not think so. Our research is closely connected to all programs in Helmholtz Matter, leveraging available infrastructure, and is embedded in a wide international network of scientific collaborations and partnerships with research and higher education institutions and industry. To ensure leadership in cutting-edge technologies and to address the challenges of the Hightech Agenda Germany, we are proposing the implementation of the *Helmholtz Technology Innovation Hub* during PoF V, focusing on the areas of microelectronics, quantum technologies and AI.

**Facts and Figures**

Participating centers:
DESY, GSI with HI Jena and KIT

Spokespersons:
Silvia Masciocchi (GSI), Heinz Grafsmaa (DESY), Frank Simon (KIT)

Core-funded scientists: x FTE (2028)
Core-financed costs: x MEUR (2028)

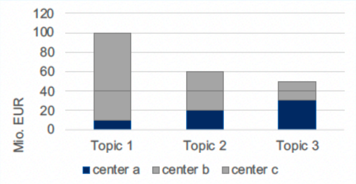


*Figure 3.7: Example Figure.*

at the end

**Overarching Goals**

The MT-DTS research and development program is illustrated by a selection of overarching goals that exemplify key directions and will allow to track progress in those areas.

**ST1**
- Monolithic active pixel sensor design for vertex and tracking detectors.
- Integration of sensors with silicon photonics and packaging.
- Multi-tier ASICs: use of wafer bonding in detectors.

**ST2**
- Testing infrastructure for quantum sensing to identify promising candidate technologies.
- Scalable quantum sensors suitable for operation in challenging experimental conditions.
- Implementation of quantum sensing technologies in experiments.

**ST3**
- Intelligent data acquisition technology and concepts for future experiments.
- Ultra-light-weight integration of modern silicon sensors to large tracking assemblies.
- X-ray optics and integrated experimental stations for photon sources.
- High precision timing sensor and readout systems for beam diagnostics.
- Ultra-light, wide dynamic-range gaseous detector systems for nuclear physics.

**ST4**
- AI-supported development of detector concepts and algorithms for future facilities.
- Instrumentation and algorithms for autonomous beamline operation and data handling.
- MHz pixel imager for photon science - conceptual design and demonstrator.

# Subtopics

Our program in PoF V is organized along three closely interrelated science drivers:

- **Fundamental interactions**, pushing the limits of our understanding of fundamental interactions.
- **The origin of mass**, covering the puzzle of the origin of mass and of flavor, and the imbalance between matter and anti-matter in the universe.
- **The early universe**, exploring the evolution of the early universe and the nature of the dark sector.

FPF

Our strategic goals of the Topic are therefore threefold:

- To achieve the **definitive measurement of the neutrino mass**, from KATRIN to KATRIN++, enabled by continuous technological innovation, and supported by the IceCube-Upgrade.
- To **explore the high-energy Universe** through all cosmic messengers – neutrinos, gamma rays, and cosmic rays – and combine them into a coherent multi-messenger picture of the most extreme processes in nature.
- To **resolve the mystery of dark matter** by uniting indirect searches in the high-energy Universe with direct searches in the laboratory, culminating in XLZD and the next generation of dark matter and neutrino observatories, and thus closing the circle between cosmic messengers and laboratory precision.

MRU

The research topics to be conducted within MU-CML in PoF V are organised around the key questions set forth below. Unravelling these fascinating questions is the main focus of MU-CML.

- **How do the properties of matter arise from the strong interaction, and what are the relevant degrees of freedom?**
  - What are the phase structure and microscopic properties of strong-interaction matter?
  - How do hadrons and their properties arise from the strong force?
  - How do bound states of baryons appear and what are the limits of stability of nuclei?
- **How do the properties of matter determine the evolution of stars and nucleosynthesis?**
  - What are the key nuclear properties that determine the production of heavy elements in the universe?

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  - What is the equation of state of high-density matter (and its relevant degrees of freedom) that governs the structure of neutron stars?
  - What are the observational signatures of strong-interaction in astrophysical objects and what is their imprint in electroweak and gravitational messengers?
- **How can fundamental symmetries be tested with low-energy methods? Is there an indication for physics beyond the standard model from low-energy experiments?**
  - What is the origin of the matter–antimatter asymmetry?
  - Are there ultralight particles such as axions?
  - What is the value of the weak mixing angle at low energies?
  - How can we further reduce hadronic uncertainties, which are currently limiting precision tests of the standard model in search for new physics?

**How do the properties of matter arise from the strong interaction, and what are the relevant degrees of freedom?**
A promising approach to address this question requires a research program embedding hadron, heavy-ion, and nuclear physics to explore matter at extremes – of temperature, density and isospin – and to connect the active degrees of freedom across scales.

CML as questions

# Highlight text in bold?

## Do we need to be consistent?

The cryoplatform would also provide an excellent environment for **high-frequency gravitational wave searches**. In the largely unexplored frequency ranges addressed by these searches, any detectable signal is expected to originate from physics beyond the SM, making even a single observation a transformative discovery with far-reaching implications for our understanding of the universe. Currently, two complementary R&D programs are underway to explore gravitational waves at frequencies above about 10 kHz (the reach of large-scale interferometers). The first approach employs superconducting radiofrequency cavities to search for minute harmonic deformations induced by passing gravitational waves, which alter the boundary conditions of the oscillating electromagnetic fields. To demonstrate and mature the underlying technologies, an existing cavity from the MAGO collaboration is being tested by DESY scientists in partnership with Fermilab [20]. In parallel, a second line of research is developing a novel detector based on the levitated sensor concept [21], enabling new possibilities for sensitivity optimization. Current work at DESY focuses on membrane design and on evaluating the achievable sensitivity of such a detector to high-frequency gravitational waves.

FPF: highlight in bold subject in each paragraph

High-intensity pions and protons complement heavy-ion studies, giving a microscopic and controlled access to the dynamics of non-perturbative QCD that generates mass and provides inputs that heavy-ion physics depends on. In particular, we will exploit exclusive channels to disentangle the composition of excited hadrons (including hyperons) and to characterize their production mechanisms and interactions. An overview of this program has recently been documented by the "QCD at FAIR" network in a White Paper "Hadron physics opportunities at FAIR". It is envisioned to study hadron-hadron interactions by extracting scattering parameters from exclusive production reactions with short-ranged production mechanisms complementary to particle-correlation approaches. Furthermore, the structure of excited states is elucidated by exploring electromagnetic Dalitz decays, which provide access to the time-like transition form factors of the decay processes. Transition form factors of nucleon excitations can be accessed directly via pion–nucleon scattering at the pion-beam facility in combination with HADES. The electromagnetic structure of hyperons will be mapped in proton–proton collisions at SIS100 with CBM, whose energy reach and interaction-rate capability make it a genuine strangeness factory. Understanding the spectrum, composition, and structure of baryons in terms of QCD is a formidable but crucial task and entails, e.g., determining which effective degrees of freedom are appropriate for deriving the hadron reaction dynamics observed in the laboratory from QCD. Experimental work will be supported by computation of coupled-channel systems from Lattice QCD with particular focus on studying meson-baryon interactions with u/d and s quarks and quark-mass dependence of baryon structure and transitions. In addition, momentum correlation measurements with open and hidden charm hadrons will be carried out within ALICE to investigate the existence and internal structure of possible exotic bound states, measuring scattering parameters in the charm sector. These measurements will directly connect with complementary studies at BESIII and hadron physics studies with pion and proton beams at FAIR with a perspective of later availability of anti-proton beams. With SIS100's proton beam up to momenta of $30\,\mathrm{GeV}/c$, measurements of hidden- and open-charm final states will also be addressed at CBM, thereby advancing our understanding of the origin of the nucleon mass including the role of gluons.

CML: no highlighting

**Coordination and Leadership.** Our competence is also demonstrated by leadership in coordinating international communities and infrastructures. KIT runs the Project Management Office for KATRIN, serves as Financial Executive Institution for KATRIN and Auger, and provides structural leadership through the co-spokespersonship of K. Valerius for KATRIN and M. Roth for Auger. KIT carries strong responsibility for the AugerPrime upgrade and plays a highly visible role in the newly formed XLZD collaboration as a designated sub-project lead alongside UK- and US-led sub-projects. At CTAO, DESY hosts the Science Data Management Center (SDMC) and leads major technical packages. In IceCube-Gen2, German leadership includes DESY coordinating the collaboration (with M. Kowalski as elected coordinator) and managing in-kind contributions across optical, surface, and radio arrays.

MRU: a mixture, sometimes in text, sometimes at the Beginning like in "Competences"

# Others

- **Implementation section:**
  - FPF: 1 page (but 4 pages in "Competences", we could rearrange)
  - CML: 4 pages Implementation (1 Competences)
  - MRU: 2 pages Implementation - and with some structure - (2,5 Competences)

- **Figures:**
  - FPF: 4. Mainly on projections
  - CML: none
  - MRU: 2, also on projections

- **References:**
  - FPF: we have 26 references (too many?), these are papers done by us and projections to which we have contributed
  - CML, MRU: none I believe

- **Shall we use "We"** or "Helmholtz scientists", "DESY scientists", "GSI scientists" etc.?

- **There could be more cross-references** among us, or it could go in the overall introduction (it is there somehow)