National Institute of Chemical Physics and Biophysics

Keemilise ja Bioloogilise Füüsika Instituut

Activity Report 2025

KBFI in 2025

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1 Introduction[1]

KBFI is a legal person under public law and operates under the "National Institute of Chemical Physics and Biophysics Act" [2] approved by the Parliament of Estonia in 1998. As the only public research institution in Estonia not affiliated with any university, KBFI diversifies the country's research landscape and increases the international competitiveness of Estonian science. Founded in 1980, KBFI just celebrated its 45th anniversary. The primary mission of KBFI is to do excellent research and to supervise PhD students.

Comprehensive interdisciplinary research programs and collaborations with world-leading research centres, such as the European Organization for Nuclear Research (CERN), the European Space Agency (ESA), and the European Magnetic Field Laboratory (EMFL), characterize the broad range of KBFI research activities and excellence. We have always been at the forefront of science, contributing to fields spanning from gravitational wave physics to nanoecotoxicology. Due to the synergy between interdisciplinary topics, new research directions are continuously emerging in line with international research developments.

The structural units of KBFI include four laboratories (Chemical Physics, High Energy and Computational Physics, Chemical Biology, and Environmental Toxicology), administration, the Institute's Science Council, and the International Science Advisory Board. The total staff of the institute is 126 people.

The median age of our 79 researchers with PhD is 44. They supervise about 30 PhD students whose median age is 28. The PhD students are affiliated with different Estonian universities. The percentage of women is 38%. While we focus on supervising PhD students, researchers at KBFI also teach courses and supervise students in all major Estonian universities. Every year, since 2022, 5 PhD students who worked at KBFI under our supervision have graduated from different Estonian universities.

Highly educated young people from the KBFI build their careers in various fields of society and industry, which is key to the development of a knowledge-based economy in Estonia. Our former doctoral students and researchers have founded a remarkable amount of start-up companies (Lingvist, G-Scan, MuRay.Tech, Powerup, UpCatalyst, Nanordica-Medical, and Jälle Technologies).

The Estonian collaboration with CERN, which began in 1996 with KBFI joining the CMS Collaboration of the LHC, culminated in 2024 with Estonia becoming a full member of CERN. For the past 20 years, KBFI has been responsible for coordinating all Estonian scientific activities at CERN. Currently KBFI is leading the Estonian science consortium for the CERN research involving, in addition to KBFI, TalTech and Tartu University. KBFI hosts a Tier-2 computing centre for the LHC Computing Grid (WLCG). The data centre is part of the Estonian Research Computational Infrastructure (ETAIS). In 2025, KBFI researchers initiated a collaboration with the CERN Quantum Technology Initiative, with a primary focus on quantum computing.

In 2025, CERN started to write a new CERN European Strategy for Particle Physics document, which sets out a coherent long-term plan for Europe's particle physics program. First by prioritising the full exploitation of the HL-LHC and, second, recommending the FCC as the next flagship collider, in order to sustain European scientific leadership, address fundamental open questions in physics, and align future research with global collaboration, technological innovation, and sustainability goals. Martti Raidal from KBFI took part in writing the new European strategy as member of the European Strategy Group.

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[1] The document contains hyperlinks to other documents, CV-s of personnel and projects. Please follow these links to further details. The summary of the development of KBFI until 2021 is available in previous activity reports, https://kbfi.ee/nicpb/activity-reports/?lang=en.

[2] https://www.riigiteataja.ee/en/eli/517062014009/consolide

Following the advent of gravitational wave physics and astronomy, a team at KBFI joined the ESA LISA Consortium in 2022 and this year a team at KBFI joined two more gravitational wave detector collaboration, The Einstein Telescope (ET) and the Terrestrial Very Long Baseline Atom Interferometry (TVLBAI) collaborations.

Preparations have been underway for some time to deliver a nuclear reactor simulator from the United States to KBFI, with funding and supplier agreements in place and implementation planned for 2026–2027. This will be the first such simulator in Baltic States.

KBFI is a partner of the European Magnetic Field Laboratory: users can perform lower magnetic field experiments in our Terahertz and NMR laboratories under dual access mode. KBFI is one of the only two institutions in the Baltic countries, which runs a helium liquefier facility.

Three researchers of the Lab of Environmental Toxicology belong to top 1% highly cited researchers worldwide: Anne Kahru (2018; Pharmacology & Toxicology, 2019; cross-field), Kaja Kasemets (2018, cross-field) and, Angela Ivask (2018, cross-field) and Monika Mortimer. In the Lab of High-Energy Physics the following researchers belong to the top 1% highly cited researchers worldwide: Mario Kadastik, Joosep Pata and Martti Raidal.

2 Strategic research programmes

Our main research directions are organised as the Strategic Research Programmes of KBFI[3]:

- high energy physics, theoretical physics, cosmology and astrophysics
    - experimental high energy physics
    - theoretical physics
    - astrophysics and cosmology, gravitational wave physics
    - machine learning, AI, quantum computing
    - R&D collaboration with industry
    - nuclear energy and technology
- environmental toxicology and nanosafety
- physical chemistry and chemical biology
    - fundamental and applied bioenergetics
    - chemistry and spectroscopy
    - applications and methodology development for NMR analysis
- physics, materials science and energy technologies
    - new spin materials and superconductors
    - endohedral atoms and molecules in fullerenes
    - investigation of structure, dynamics, and properties at different magnetic field strengths and at various temperatures
    - precision spectroscopy of two-photon absorption (2pa) of organic fluorophores in condensed media
    - energy technologies

[3] https://kbfi.ee/wp-content/uploads/2021/02/KBFI_in_2020.pdf

2.1 List of 10 most important KBFI research results from recent years (2020 – 2025),

(1) Experimental high-energy physics: CMS data analyses

The CMS Collaboration, R. Dewanjee, K. Ehatäht, M. Kadastik, M. Raidal, C. Nielsen, L. Tani, S. Nandan, J. Pata, T. Lange, C. Veelken et al. **Search for Higgs boson pairs decaying to WW*WW*, WW*ττττ, and ττττττττ in proton-proton collisions at sqrt(s) = 13 TeV**. *JHEP* 07 (2023) 095. DOI: 10.1007/JHEP07(2023)095

Importance: KBFI is a member of the CMS Collaboration at CERN. This paper presents a critical and highly complex analysis of the CMS data in HH channels, performed by the KBFI team. The Republic of Estonia became an Associated Member of CERN in 2021 and a Full Member of CERN in 2024. The excellent physics performance of the KBFI team at CERN was one of the most essential reasons Estonia joined CERN.

(2) Theoretical physics: dark matter and collider physics connection

G. Arcadi, A. Djouadi, and M. Raidal. **Dark matter through the Higgs portal**. *Physics Reports*, 842:1–180, Feb. 2020. DOI: 10.1016/j.physrep.2019.11.003

Importance: Theoretical physicists at the KBFI study various aspects of Nature, including collider physics, dark matter and dark energy, physics beyond the Standard Model, particle physics model-building, quantum information, inflation, extended theories of gravity, etc. This monograph presents our state-of-the-art collective knowledge of dark matter, which, in the visible sector, couples only to the Higgs boson. This is an example of interdisciplinary research connecting collider physics with cosmology via dark matter research.

(3) Cosmology and astrophysics: gravitational wave astronomy

J. Ellis, M. Fairbairn, G. Franciolini, G. Hütsi, A. Ionio, M. Lewicki, M. Raidal, J. Urrutia, V. Vaskonen, and H. Veermäe. **What is the source of the PTA GW signal?** *Phys.Rev.D* 109 (2024) 2, 023522, DOI: 10.1103/PhysRevD.109.023522

Importance: The discovery of gravitational waves opens a new window on the Universe. The KBFI team began studying gravitational waves immediately after this discovery. In 2022, the KBFI team joined the European Space Agency LISA Consortium. This paper presents our analyses of another GW signal, the PTA signal, and proposes the most plausible sources of the signal. It demonstrates our ability to study new research topics at a high international level and to contribute to the development of research programs for new GW experiments, such as LISA.

(4) Nanotoxicology and nanomedicine.

O. Bondarenko, M. Mortimer, A. Kahru, N. Feliu, I. Javed, A. Kakinen, S. Lin, T. Xia, Y. Song, T. P. Davis, I. Lynch, W. J. Parak, D. T. Leong, P. C. Ke, C. Chen, and Y. Zhao. **Nanotoxicology and nanomedicine: The yin and yang of nano-bio interactions for the new decade**. Nano Today, 39:101184, aug 2021. doi:10.1016/j.nantod.2021.101184.

Importance: Over the past three decades, nanotoxicology and nanomedicine have mainly developed independently of each other. Yet recent breakthroughs in microbiome research and the current COVID-19 pandemic demonstrate that holistic approaches are crucial for solving grand challenges in global health. We call for a close partnership between the two fields in the new decade to harness the full potential of nanotechnology for benefiting human health and environmental safety.

(5) Nanoplastics as a potential hazard.

M. Heinlaan, K. Kasemets, V. Aruoja, I. Blinova, O. Bondarenko, A. Lukjanova, A. Khosrovyan, I. Kurvet, M. Pullerits, M. Sihtmäe, G. Vasiliev, H. Vija, and A. Kahru. **Hazard evaluation of polystyrene nanoplastic**

with nine bioassays did not show particle-specific acute toxicity. Science of The Total Environment, 707:136073, mar 2020. doi:10.1016/j.scitotenv.2019.136073.

Importance: As of now, the world-wide pollution by plastic, especially single use plastics, has obtained dimensions that have triggered negotiations by UN Member States for an international agreement on handling of plastics pollution (the Plastics Treaty) that is close to its finalisation at 2025. We showed that using acute toxicity assays usually the toxic effects of nanoplastics remain not noticed. However, the presence of antimicrobials (such as NaN3) in commercial nanoplastics preparations may lead to false positive results.

(6) Hyperpolarized NMR as a precise analytical tool for studying biological samples.

N. Reimets, K. Ausmees, S. Vija, and I. Reile. **Developing analytical applications for parahydrogen hyperpolarization: Urinary elimination pharmacokinetics of nicotine**. *Analytical Chemistry*, 93(27):9480–9485, June 2021. doi:10.1021/acs.analchem.1c01281.

Importance: The 2021 paper in the highest-impact analytical chemistry journal describes the first demonstration of hyperpolarized NMR for studying a dynamic process in the human body (drug metabolism and pharmacokinetics). It demonstrates an approx. 1000-fold signal enhancement in the study of the dynamics of nicotine and its metabolites during their metabolism in the human body. This result demonstrated the KBFI NMR spectroscopy team's status as a pioneer in applying hyperpolarization to enhance NMR sensitivity in the study of biological samples. The approach shown in this paper provides access to metabolites previously inaccessible to NMR (and, quite often, to any other technique). The high analytical precision of the demonstrated results proves that the nuclear hyperpolarization method that has been implemented in KBFI is ready for application in analytical studies of biological samples - a competence that we are already using for discovering new disease biomarkers.

(7) Emerging novel phases in quantum magnetism

S. Allenspach, P. Puphal, J. Link, I. Heinmaa, E. Pomjakushina, C. Krellner, J. Lass, G. S. Tucker, C. Niedermayer, S. Imajo, Y. Kohama, K. Kindo, S. Krämer, M. Horvatic, M. Jaime, A. Madsen, A. Mira, N. Laflorencie, F. Mila, B. Normand, C. Rüegg, R. Stern, and F. Weickert. **Revealing three-dimensional quantum criticality by Sr substitution in Han purple.** Physical Review Research, 3(2):023177, jun 2021. doi:10.1103/physrevresearch.3.023177.

Importance: Quantum phase transitions and critical phenomena can be studied using spin-dimer systems realised in various magnetic compounds. Some of them, quasi-low-dimensional systems display hallmarks of low-dimensional physics. This 2021 paper in one of the highest-impact physics research journals describes the first demonstration of three-dimensional criticality in a quasi-two-dimensional system and may become relevant for future quantum engineering applications.

(8) Two-photon absorption spectroscopy of organic fluorophores in condensed media.

C. W. Stark, M. Rammo, A. Trummal, M. Uudsemaa, J. Pahapill, M.-M. Sildoja, S. Tshepelevitsh, I. Leito, D. C. Young, B. Szymanski, O. Vakuliuk, D. T. Gryko, and A. Rebane**. On-off-on control of molecular inversion symmetry via multi-stage protonation: Elucidating vibronic laporte rule.** Angewandte Chemie International Edition, 61(51), nov 2022. doi:10.1002/anie.202212581.

Importance: This work shows new possibilities for innovation in the field of two-photon spectroscopic applications. Laporte's rule states that the one- and two-photon absorption spectra of inversionally symmetric molecules should have alternately forbidden electronic transitions; however, for organic fluorophores, a clear distinction between symmetric and non-inversionally symmetric two-photon spectra is often blurred due to prevalent vibronic interactions. We take advantage of consecutive single- and double-protonation to break and then reconstitute inversion symmetry in a nominally symmetric diketopyrrolopyrrole, causing large changes in two-photon absorption. By performing detailed one- and two-photon titration experiments, with

supporting quantum-chemical model calculations, we explain how certain low frequency vibrational modes may lead to apparent deviations from the strict Laporte rule. Therefore, the system may indeed be considered as an on-off-on inversion symmetry switch, opening new avenues for two-photon sensing applications.

(9) New spin materials and superconductors.

L. Facheris, S. Nabi, A. Glezer Moshe, U. Nagel, T. Rõõm, K. Povarov, J. Stewart, Z. Yan, and A. Zheludev. **Confinement of fractional excitations in a triangular lattice antiferromagnet**. Physical Review Letters, 130(25):256702, June 2023. doi:10.1103/physrevlett.130. 256702.

Importance: The work demonstrates the unique capability of KBFI to measure THz spectra at 0.2K in a dilution refrigerator and demonstrate that Zeeman ladders of confined fractional excitations can exist in a bona fide quasi-2D system. These states are inherently related to those in 1D models, as revealed at special wave vectors where 2D interactions are cancelled by geometric frustration. However, elsewhere in reciprocal space their true 2D character manifests. Once again, the distorted triangular lattice model provides a link between 1D and 2D quantum magnetism.

(10) Fundamental and applied bioenergetics.

C. J. Zuurbier, L. Bertrand, C. R. Beauloye, I. Andreadou, M. Ruiz-Meana, N. R. Jespersen, D. Kula-Alwar, H. A. Prag, H. Eric Botker, M. Dambrova, C. Montessuit, T. Kaambre, E. Liepinsh, P. S. Brookes, and T. Krieg. **Cardiac metabolism as a driver and therapeutic target of myocardial infarction**. Journal of Cellular and Molecular Medicine, 24(11):5937–5954, May 2020. doi:10.1111/jcmm.15180.

Importance: Reducing infarct size during a cardiac ischaemic-reperfusion episode is still of paramount importance, because the extension of myocardial necrosis is an important risk factor for developing a heart failure. Cardiac ischaemia-reperfusion injury (IRI) is a metabolic pathology as it is caused by abruptly halted metabolism during the ischaemic episode and exacerbated by sudden restart of specific metabolic pathways at reperfusion. Currently, the most promising and druggable metabolic therapy against cardiac IRI seems to be the targeting of glycolysis, O-GlcNAcylation and metabolism of ketones, fatty acids and succinate.

2.2 Intellectual property

According to the statute of KBFI, the intellectual property, created by the scientists of KBFI, belongs to the institute.

3 Laboratories

3.1 Laboratory of High Energy Physics and Computational Physics

The Laboratory conducts comprehensive research on the fundamental structure of nature, spanning theoretical and experimental particle physics, astroparticle physics, cosmology, inflation and early-Universe physics with a strong focus on gravitational waves, computational physics, and nuclear science and technology. Led by Academician Martti Raidal, the experimental particle physics group is a long-standing member of the CMS collaboration at CERN, contributing to Higgs and double-Higgs physics, detector-level analyses, and HL-LHC and future-collider studies, including physics relevant to the Future Circular Collider (FCC).

The Laboratory is actively involved in major gravitational-wave experiments, including the LISA space mission of the European Space Agency, the Einstein Telescope, and the Terrestrial Very-Long-Baseline Atom

Interferometry initiative, with research covering cosmological gravitational-wave sources, early-Universe phase transitions, primordial black holes, and advanced data analysis methods. The Laboratory also develops strong synergies between particle physics and quantum technologies through work in quantum information, quantum computing, and planned engagement with the CERN Quantum Technology Initiative.

A key pillar of the Laboratory is high-performance computing: it operates a CMS Tier-2 centre within the Worldwide LHC Computing Grid, providing approximately 6,000 processor cores and 4 PB of storage for CMS simulations, early-Universe modelling, and other large-scale numerical studies, while contributing to the development of Estonia's national scientific computing infrastructure, ETAIS.

A dedicated nuclear energy and technology group has complemented these activities since 2020 through research and education in reactor physics, radiation protection, and nuclear systems, further broadening the Laboratory's interdisciplinary profile and societal impact.

The Laboratory had 25 researchers and postdocs with PhD in October 2025. They supervise 9 doctoral students: 8 from TalTech are employed by KBFI and 1 is employed by Tartu University. The Datacentre employs one technician. Their activities can be summarised as follows.

3.1.1 High Energy Physics Data Analysis Group in the CMS Experiment

In 2025, KBFI shifted its CMS research focus from Higgs → Tau Tau to Higgs self-couplings and double Higgs production (PRG2502), a core HL-LHC priority, contributing HL-LHC projections to the European Strategy 2026; Torben Lange was appointed CMS Double Higgs contact, leading high-profile CMS–ATLAS combinations, launching new multilepton HH analyses, and strengthening signal modelling, supported by a new postdoc.

Completed PhDs

- 2024 Karl Ehatäht
- 2025 Laurits Tani

They are continuing as postdocs abroad, alongside active bachelor-level training and CERN summer placements within the CMS experiment.

3.1.2 CMS trigger development

Christine Nielsen works on expanding the Estonian capabilities in experimental particle physics research from analysis only to include detector development efforts and towards future R&D projects that allow the field to expand further. The project FPGAs (PRG780, PI Mario Kadastik) contributed to the CMS Phase 2 trigger TDR. A collaboration on FPGA development in muon tomography was launched with Mu Ray Tech in 2025.

3.1.3 Machine Learning and AI Group

Joosep Pata leads the group of application of machine learning in fundamental science, developing AI/ML methods for analysing large scientific data from the CMS collaboration. In 2025, Sven Põder defended his PhD and continued as an ETAG-funded postdoc in Trieste, while Joosep Pata received the Estonian National Science Prize for ML-based particle reconstruction for CMS and FCC, became group leader of the COST Action EPIGRAPHY on real-time AI inference, and KBFI joined the COST Action MLQC4FC on machine learning and quantum computing for future colliders.

3.1.4 High Performance Computing

The KBFI HPC centre operates as a CMS Tier-2 site within the Worldwide LHC Computing Grid and ETAIS, delivering ~25–30 million CPU-hours annually to CMS in 2023–2025 with over 90% availability. The centre underwent major modernisation in 2024–2025, including new energy-efficient cooling and power infrastructure, upgraded storage, and additional HPC resources, supported by ETAIS TARISTU24 and the Ministry of Education and Research.

3.1.5 The Future Circular Collider (FCC)

In line with the new CERN European Strategy prioritising the Future Circular Collider as the next flagship project, KBFI contributes to FCC-related activities through physics studies, machine learning, and advanced computing, including ML-based reconstruction and analysis methods developed for both CMS and FCC. This includes theoretical physics relevant to precision Higgs and beyond-Standard-Model physics. Our research plan positions KBFI to contribute to the future FCC physics, software, and computing programs under CERN leadership.

3.1.6 Theoretical High Energy Physics

KBFI's theory group advanced research on Higgs-sector dynamics, vacuum stability in Standard Model extensions, axion physics and quantum gravity, while strengthening its capacity through new postdoctoral appointments and continued international collaboration. This work provides theoretical foundations directly relevant to precision measurements and new-physics searches at future collider facilities, including the Future Circular Collider.

Completed PhDs

- 2023 Ruiwen Ouyang
- 2024 Kristjan Müürsepp

3.1.7 Gravitational Wave Astronomy and Cosmology Group

In 2025, KBFI published key results on time-varying dark energy using DESI Y1–Y3 data, favouring quintessence models and indicating possible departures from Lambda CDM, and analysed Atacama Cosmology Telescope data with implications for inflation and primordial black holes. In parallel, the group advanced gravitational-wave phenomenology, modelling early-Universe phase transitions, non-Gaussianity, and cosmological GW signals linked to primordial black holes.

3.1.8 Gravitational Wave Experiments

KBFI participates in major gravitational-wave initiatives, including Laser Interferometer Space Antenna (ESA), the Einstein Telescope, and the Terrestrial Very-Long-Baseline Atom Interferometry. KBFI researchers are active members of the Polish–Estonian LISA group and the Tallinn ET research unit (established in 2025 and led by Hardi Veermäe), contributing to cosmological GW detection forecasts, data analysis tools, and a 2025 benchmark study on scalar-induced GWs with LISA. In 2025, new postdoctoral and PhD researchers joined both LISA and ET collaborations, with KBFI coordinating a project on LISA–ET synergies, while TVLBAI links KBFI to CERN through quantum-sensor-based GW detector development aligned with the CERN Quantum Technology Initiative.

3.1.9 Gravity Theory Group

Led by Tomi Koivisto, the gravity theory group studies general relativity and its extensions, aiming to develop a relativistic framework for quantum mechanics and particle physics and to assess the cosmological implications of extended gravity theories, in close collaboration with researchers at the University of Tartu.

3.1.10 Quantum Information and Quantum Computing Group

The group led by Luca Marzola carries out advanced research at the interface of particle physics and quantum information, achieving first results on tau-lepton anomalous magnetic moments via trace distance, quantum contextuality tests at colliders, and entanglement and Bell nonlocality in hadronic systems, and demonstrating quantum "magic" in top–antitop pairs using CMS data. The group also contributed to the *quantum information meets high-energy physics* input to the European Strategy update and is preparing to engage with the CERN Quantum Technology Initiative.

3.1.11 Nuclear Energy and Technology Group

The Nuclear Energy and Technology group contributes to higher education through courses at TalTech and the University of Tartu, including full instruction in reactor physics, and supervises doctoral and bachelor research in radiation protection, waste management, and nuclear power integration. Preparations for the delivery of a nuclear reactor simulator to KBFI went on in 2025, with funding and supplier agreements in place and implementation planned for 2026–2027.

3.1.12 Science and R&D Collaboration with Industry

Through the TemTA23 grant, KBFI initiated numerical simulations with GScan and MuRayTech for sphaleron reactor concepts in clean energy production, and in collaboration with MuRayTech began developing muon-based sensors for non-invasive imaging using laser–plasma accelerator sources, with potential medical and industrial applications.

3.1.13 Funding and grants

The budget of the Laboratory is 3.2 M€ in 2025, reduced to 2.7 M€ in 2026 and it hosts the following grants in 2025:

- Collaborations that are coordinated by KBFI
  - Centre of excellence TK202 "Foundations of the Universe (2024-2030)", Martti Raidal
  - RVTT3, CERN Science Consortium of Estonia (2023-2025), Martti Raidal
  - TARISTU24-TK10, CERN Science Consortium of Estonia (205-2029), Martti Raidal
  - TEM-TA23, Energy production in a sphaleron reactor (2024-2028), Kristjan Kannike
- Research Grants
  - RVTT7, ESA Estonia science consortium (2023-2025), PI in KBFI Hardi Veermäe, project coordinated by Tartu University
  - TARISTU24-TK3, ESA Estonia science consortium (2025-2029), PI in KBFI Hardi Veermäe
  - PRG1055, Beyond Einstein gravity in light of Early Universe particle physics (2021-2025) Antonio Racioppi
  - PRG1677, Untangling the Flavor: revealing the New Physics behind the Flavor Puzzle (2022-2026), Carlo Marzo
  - PRG1884, Towards a joint solution to distinct theoretical puzzles: the axion-flavor connection (2023-2027) Enrico Nardi
  - PRG2502, Study of Higgs boson pair production and the trilinear Higgs boson self-coupling with the LHC Run 3 and beyond (2025-2029), Torben Lange
  - PSG761, Hearing the early universe through gravitational waves (2022-2025), Alexandros Karam
  - PSG864, Flexible and scalable data reconstruction and analysis using machine learning (2023-2027), Joosep Pata
  - PSG869, Physics of primordial black holes from formation to the present (2023-2027), Hardi Veermäe

- MOB3JD1202, Solving Challenges in Cosmology and Particle Physics (2023-2025), Ioannis Gailamas

3.2 Laboratory of Chemical Physics

The research activities of this laboratory are diverse, spanning physics, materials science, and energy technologies to physical chemistry. The head of the laboratory is Raivo Stern.

In October 2025, the Laboratory had 21 researchers and postdocs with PhD who supervise 13 doctoral students: 11 from TalTech are employed by KBFI and two are employed by Tallinn University.

The laboratory runs the largest infrastructure of the institute: the helium liquefier, 6 high-field NMR spectrometers (the largest and most diverse NMR laboratory in the Baltics), high-field magnets for physics research and THz spectroscopy. Two people out of the institute's technical staff of 6 work at the cryogenic facility and take care of the superconducting magnets.

The spectral range of the instruments spans 16 orders of magnitude in frequency, from static susceptibility probes and NMR to THz, infrared, and UV optical spectroscopy. Samples can be characterised using an X-ray powder diffractometer, the Physical Property Measurement System (PPMS) equipped with a 14 T magnet, and multiple sample characterisation probes, including a home-built probe for variable field NMR. The THz and optical laboratory facilitates spectrometers to measure transmission and reflection in a wavelength range from 3 mm up to 200 nm (3 - 50000 cm^{-1}) in various sample environments.

Currently, there are seven research groups of various sizes in the Laboratory of Chemical Physics, plus four supporting engineers:

3.2.1 Terahertz and low temperature physics

The group, headed by Toomas Rõõm, studies low energy excitations and the shier symmetries by means on THz spectroscopy. The group currently consists of three experienced researchers and three postdoctoral researchers, one of which has a two-year personal grant.

Completed PhDs

- 2020 Johan Viirok
- 2022 Kirill Amelin and Laur Peedu
- 2025 Tanzeeha Jafari

Johan, Kirill and Laur left academic research to work in Estonian companies.

3.2.2 Nonlinear optics

The group, led by Aleksander Rebane, consists of 3.8 FTE experienced researchers. They have not secured grant financing for 2025 and 2026, but have previously collaborated on several EU Horizon 2020 grants.

Completed PhD

- 2023 Matt Rammo works now in the Estonian applied research center Metrosert.

3.2.3 Magnetism, superconductivity, and NMR

The group of Raivo Stern consists of 3.5 (FTE) experienced researchers, 3 PhD, 1 MSc, and 1 BSc students, with 1 part-time visiting Scientist. From national funding, they have one large group grant (PRG), one applied grant (Tem-TA), and one infrastructure grant (EstMagLab).

3.2.4 Energy technologies group (ETG)

It is the fastest growing group of the laboratory, currently 4 experienced researchers, 5-6 PhD and 2 MSc students. Work primarily on applied grants. Presently holding two starting national grants (PSG) and starting one national PRG group grant in 2026. Also active at the European Space Agency (ESA). Ivar Kruusenberg and Kerli Liivand lead the group.

Completed PhDs

- 2021 Sander Ratso
- 2022 Kätlin Kaare
- 2025 Reio Praats, Ehzan Zameri, and Erkin Najafli

3.2.5 Complex mixtures analysis

The group of Indrek Reile is focused on methodology and applications development for solution and hyperpolarized (parahydrogen and CIDNP) NMR spectroscopy, is also actively growing, with 3 experienced researchers, 1 postdoctoral researcher, 3 PhD students, and 1 MSc Student and 2 BSc students. Struggling with their own PRG, but active in participating in other PRGs at collaborating universities (Tallinn University, the Estonian University of Life Sciences), and several EU Horizon 2020 as well as COST collaborations. The postdoc in the group has an Estonian postdoctoral personal grant, and the team will host a Marie Skłodowska-Curie COFUND PhD student from early 2026. The group actively leads several industry collaborations (e.g., Lallemand Inc, Fibenol OÜ, and Celvia CC OÜ) and is a key partner in several National Research Infrastructure projects (AKKI, Elixir).

Completed PhDs

- 2024 Nele Reimets

3.2.6 Organometallic chemistry

The group of Martin Jakoobi is a small, active, and growing team around a single PSG, started in 2025. Currently one experienced researcher, one PhD student, and one MSc Student.

3.2.7 Solid oxide fuel cells (SOFC)

The group of Juhan Subbi has two experienced researchers working since many year on an applied industrial grant from the Estonian-Finnish company "ElcoGen".

3.2.8 Funding and grants

The budget of the Laboratory is 1.9 M€ in 2025 and will increase to 3.4 M€ in 2026, mainly due to investments in laboratory equipment.

The lab hosts the following grants in 2025.

- Collaborations that are coordinated by KBFI
  - TARISTU24-TK16, Estonian Magnetism Laboratory (2025-2029), Raivo Stern
  - TEM-TA25, Advanced recycled permanent Magnets for New Energy and Mobility Applications (MagNEO) (2024-2028), Raivo Stern
  - TEM-TA96, CO_2-derived carbon materials for energy storage and production (2025-2028), Sander Ratso
- Research Grants
  - ERC885413, How do chiral superconductors break time-reversal symmetry? – Kerr spectroscopy study (2021-2026), Girsh Blumberg
  - PRG1702, Emerging Phases in Quantum Magnets (EPiQuM) (2023-2027), Raivo Stern

- PRG1808, Polysaccharide Based Biomaterials: Synergistic Combinations and Enhanced Functionalities (2023-2027), Vitālijs Rjabovs, the grant is hosted by Tallinn University
- PRG2720, Risks and benefits arising from food resources in agricultural landscape for honey bees: a model based approach (2025-2029), Kärolin Kork, the grant is hosted by the Estonian University of Life Sciences
- IHI project, Cardio-Oncology Multidisciplinary Patient ASsistance Solution (COMPASS) (2026-2029), Kerti Ausmees, project led by GE Healthcare.
- PSG1072, Exploring NMR Biomarkers for Parkinson's Disease Risk Stratification Based on Polygenic Risk Score Levels in Healthy Subjects and de novo Parkinson's Disease Patients (2025-2029), Kerti Ausmees, and the grant is hosted by the Tallinn University.
- Marie Skłodowska-Curie Actions (MSCA) COFUND programme INNOCHEMBIO (2025-2029), Indrek Reile, grant hosted by the Tallinn University of Technology.
- PSG926, Recycling of lithium-ion batteries black mass and valorization of the recovered graphite in various energy technologies (2024-2028), Kerli Liivand
- PSG1017, Novel methods for the study of molten carbonate electrolytes (2025-2029), Sander Ratso
- PSG1033, Developing homogeneous non-noble metal based p-H_2 induced polarization transfer catalysts for NMR signal enhancement (2025-2029), Martin Jakoobi
- MOB3JD1244, SPHERE: Spectroscopic Hyperpolarization for Enhanced REcognition of Bacterial Infection (2025-2027), Katarzyna Maria Dziubińska-Kühn
- MOB3JD1248, THz spectroscopic Investigation of Quantum Hall transitions (2025-2027), Ramya Nagerajan
- MOB3JD1268, Hierarchical 2D Lead-free Perovskite Multi-Quantum Wells for Indoor Photovoltaics (2025-2027), Vipinraj Sugathan
- TK228, Centre of Excellence in Circular Economy for Strategic Mineral and Carbon Resources (2024-2030), Centre of Excellence in Circular Economy for Strategic Mineral and Carbon Resources, Ivar Kruusenberg, the project coordinator is Tallinn University of Technology
- Arengufond_IR, Establishing a hyperpolarized NMR applications center (2023-2025), Indrek Reile
- ISABEL, Improving the sustainability of the EMFL (2020-2025), Raivo Stern
- EAG271, Scale-up of the synthesis of doped carbon nanomaterials from CO2 (2023-2025), Sander Ratso, Kätlin Kaare

3.3 Laboratory of Environmental Toxicology

The main research field of the Laboratory is environmental toxicology and nanosafety. The head of the Laboratory is Anne Kahru. The laboratory was one of the first ones worldwide back in 2006 that started the research into metal-based nanomaterials´ (eco)toxicity with the focus on their potential threats to key environmental organism groups as well as on mechanistic aspects. Importantly, only mechanistic studies provide the key to the safe-by-design of materials that are not sustainable for use in 'open systems' based on their toxicity profile.

As some of the metal nanomaterials have proven highly toxic (at least to aquatic organisms), we started to draw specific attention to their use as efficient antimicrobials. The latter has yielded novel and fruitful research directions, including one spin-off company from our lab – Nanordica Medical, which is engaged in translating the synergistic effects of copper and silver nanomaterials into novel medical antibacterial materials, such as topical wound textiles. Other powerful new directions since the past 5-10 years are the studies on (i) nano-and microplastic ecosafety and (ii) the use of metal-containing nanocomposites in environmental remediation for the removal of excess phosphorous or toxic metals from wastewaters. The

latter also involves studies on metal-phenolic networks that are, to a certain extent, analogous to metal-organic frameworks. Our deep knowledge of ecotoxicity and *in vitro* toxicity, combined with experience in chemical analysis and physico-chemical characterization of nanomaterials, and extensive national and international cooperation, is the basis for the continuing success of the work of our Laboratory at the national and international level.

Completed PhDs

- 2021 Dewi Kurnianingsih Arum
- 2022 Elise Joonas, Merilin Rosenberg
- 2023 Grigory Vasiliev

In October 2025, the Laboratory had 12 researchers and postdoctoral researchers who supervise 5 doctoral students from TalTech of whom 4 were employed by KBFI.

3.3.1 Design of novel antimicrobial nanocomposites for biomedical applications

The group of Kaja Kasemets study new possibilities of nanotechnologies for developing efficient and safe antimicrobials for biomedical applications—such as wound-dressing materials and implants—that help prevent and treat microbial infections and reduce the emergence of antibiotic-resistant strains, one of today's most urgent global health threats.

3.3.2 Safe-by-design novel nanomaterials for environmental applications

The group of Monika Mortimer focuses on advanced and affordable technologies for water purification and metal recycling. For this, adsorption is a promising method due to its simplicity and affordability. The group develops a framework for synthesizing eco-safe, biocompatible novel sorbent materials, such as metal-phenolic network-coated nanoparticles and metal-organic frameworks (MOFs), for recovering metals from various media, including wastewater, in accordance with the principles of safe-and-sustainable-by-design (SSbD).

3.3.3 Environmental effects of emerging plastic

Research on the **environmental effects of emerging plastic** lead by Margit Heinlaan encompasses a tiered ecotoxicological assessment of both particulate plastics (nano- and microplastics) and plastic additives, with a particular focus on new-generation plasticizers. We have generated the first data on plastic contaminant emissions within and from Estonian wastewater treatment plants. The laboratory serves as Estonia's main competence centre for research on the environmental hazards of plastic contaminants and we lead the development of a national strategy and pilot measures aimed at reducing plastic contaminant emissions from the Estonian wastewater system.

3.3.4 Funding and grants

The budget of the Laboratory is 0.97 M€ in 2025 and the increase to 1.4 M€ in 2026 is mainly due to investments in laboratory equipment.

In 2025, the lab hosts the following grants

- Collaborations that are coordinated by KBFI
  - TEM-TA55, Antimicrobial synergy-driven surface coatings - innovative solutions in healthcare environment (2024-2028), Mariliis Sihtmäe
- Research grants
  - PRG1427, Hazard Evaluation of Emerging Non-Phthalate Plasticizers: Environmentally Relevant Approach (2022-2026), Margit Heinlaan

- PRG2188, Metal-phenolic network-coated nanoparticles for sustainable metal recycling (2024-2028), Monika Mortimer
- The EU Interreg Central Baltic Programme co-funded Balt-Plast-Free project "Monitoring and quantification of microplastics emissions and measures to decrease microplastics pollution from Finnish and Estonian WWTPs into the Baltic Sea" (2025-2028, Margit Heinlaan, Asya Ivanova Drenkova-Tuhtan
- PRG2595, Novel synergistic antifungal nanocomposites for biomedical applications: efficient, safe and sustainable by design (2025-2029), Kaja Kasemets
- EAS-RUP-SPACEDRIP, Preservation, long-term storage and revitalization of vacuum freeze-dried activated sludge for rapid inoculation of the SPACEDRIP membrane bioreactor and development of a waste activated sludge dewatering and heat recovery system (2024-2026), Asya Ivanova Drenkova-Tuhtan
- TARISTU24-TK13, Infrastructure of chemical synthesis and technology (2025-2029), Monika Mortimer
- TARISTU24-TK26, Centre of Nanomaterials Technologies and Research (2025-2029), Kaja Kasemets
- Horizon Europe - Marie Sklodowska-Curie Actions (MSCA) Doctoral network INNOCHEMBIO "Innovative Chemistry and Biotechnology for a Sustainable Future", partner in TalTech-coordinated project (2025-2030), Margit Heinlaan, Monika Mortimer, Irina Blinova

3.4 Laboratory of Chemical Biology

The laboratory carries out research on fundamental and applied bioenergetics; the head of the laboratory is Tuuli Käämbre.

In October 2025, the Laboratory had 10 researchers and postdocs with PhD who supervise one doctoral students.

3.4.1 Mitochondrial metabolism

This group of Tuuli Käämbre combines multidisciplinary expertise and state-of-the-art methodologies to conduct research on the energy metabolism of muscle and cancer cells and aims to integrate and extend knowledge of the basic and applied aspects of energy metabolism, biochemistry, and biophysics. As all serious illnesses relate to mitochondrial metabolism, the group studies cancer energy metabolism, neurodegenerative diseases, cell model-based preclinical drug studies, and skeletal muscle – noncommunicable diseases.

Completed PhDs

- 2021 Ljudmila Klepinina
- 2023 Egle Rebane-Klemm
- 2024 Leenu Reinsalu, Jekaterina Aid, and Laura Truu
- 2025 Sten Miller

All except Jekaterina Aid have left academic research to work in private companies.

3.4.2 Learning processes in language dynamics

The group of Marco Patriarca will leave the institute in January 2026 as they decided to apply for new grant funding at TalTech.

Completed PhDs

- 2023 David Navidad Maeso
- 2025 Stefano Scialla

3.4.3 Funding and grants

The 2025 budget of the Laboratory is 0.38 M€ and it hosts the following grants:

- PRG1059, Learning Processes in Language Dynamics (2021-2025), Marco Patriarca;
- Experimental studies and applications of cellular processes (Rakera) (2025-2029), Tuuli Käämbre, the grant is hosted by Tartu University
- EMBL (2025-2029), Tuuli Käämbre, the grant is hosted by Tartu University (Ants Kurg)
- Collaboration contract with University of Tartu, Faculty of Medicine, Institute of Clinical Medicine (Pille Taba) Unveiling early links between idiopathic polyneuropathy and Parkinson's disease (2025-…), from the side of NICPB: Tuuli Käämbre, Anton Terasmaa (2025-2026) 20 000 €
- The laboratory hosts the institutional Centre of Bioanalysis (2025-2029)
- Together with Laboratory of Chemical Physics Laboratory of Chemical Biology applied for Horizon project "Cardio-Oncology Multidisciplinary Patient Assistance Solution", as the partner, the application was successful. Project starts from 2026.

3.4.4 Closing of the laboratory from January 2026

The science Council of KBFI decided in the 2025 meetings of September and December to close the Laboratory of Chemical Biology as a structural unit and transfer the people and equipment to the Laboratory of Chemical Physics from January 2026. The main reason for this change is the lack of science grant funding for Tuuli Käämbre's group over several years. This single research group of the laboratory in 2026, the group of Group of Mitochondrial Metabolism (Tuuli Käämbre) has ongoing collaboration with the Analysis of Complex Mixtures Group (Indrek Reile), laboratory of Chemical Physics.

4 Budget

The total budget of the institute in 2026 is 9.2 M€, with the largest contributions from research grants - 56%, baseline funding - 10% and investments in laboratory equipment 10%. Mediation of grants to partner institutions forms 8% of the budget.

The largest expense category of the institute is salaries with 56% of the total budget. The next largest budget category (15%) is transfer of projects funds to our collaboration partners in projects that are coordinated by KBFI. Electricity, heating and maintenance costs of the buildings form 6.4% of the budget and equals to the salaries of the administration.

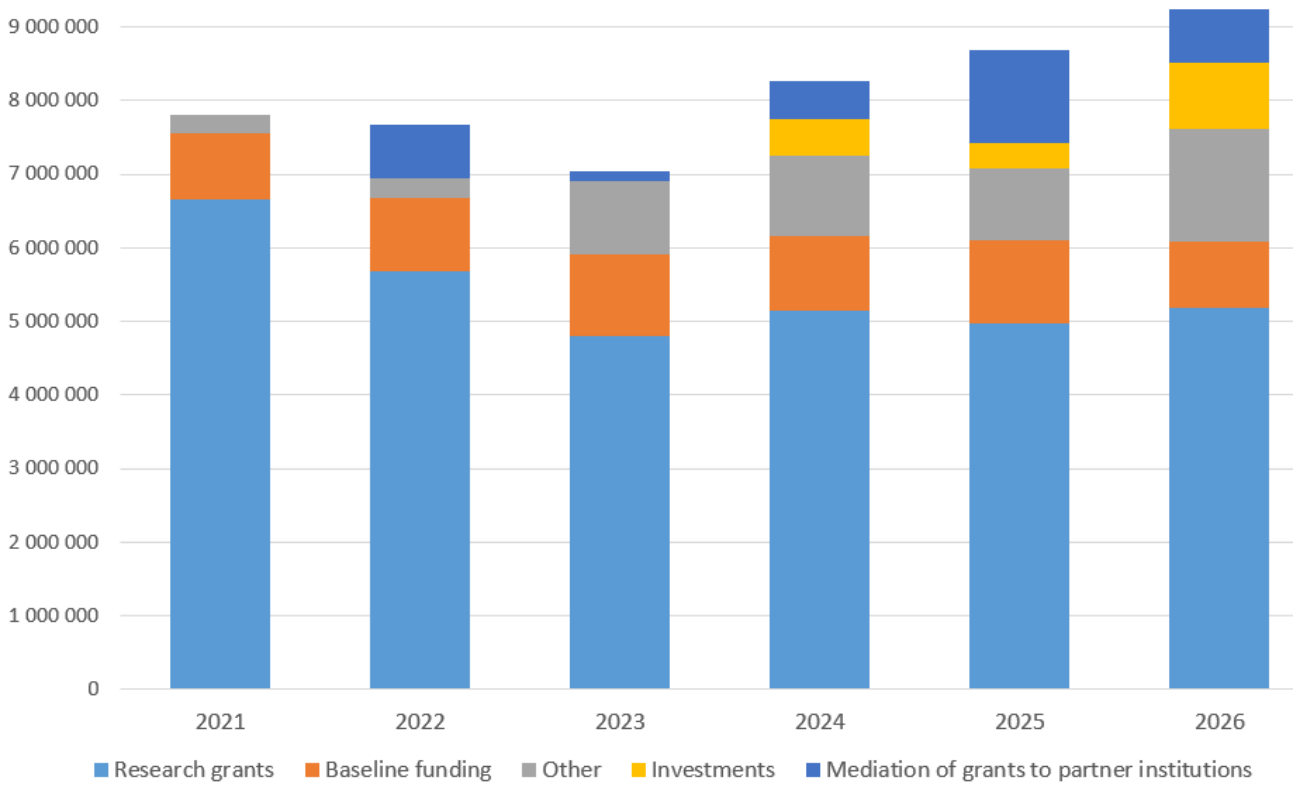


Figure 1. Revenue budget of KBFI is recent years. Grant funding reached its minimum in 2023 when two centres of excellence ended.

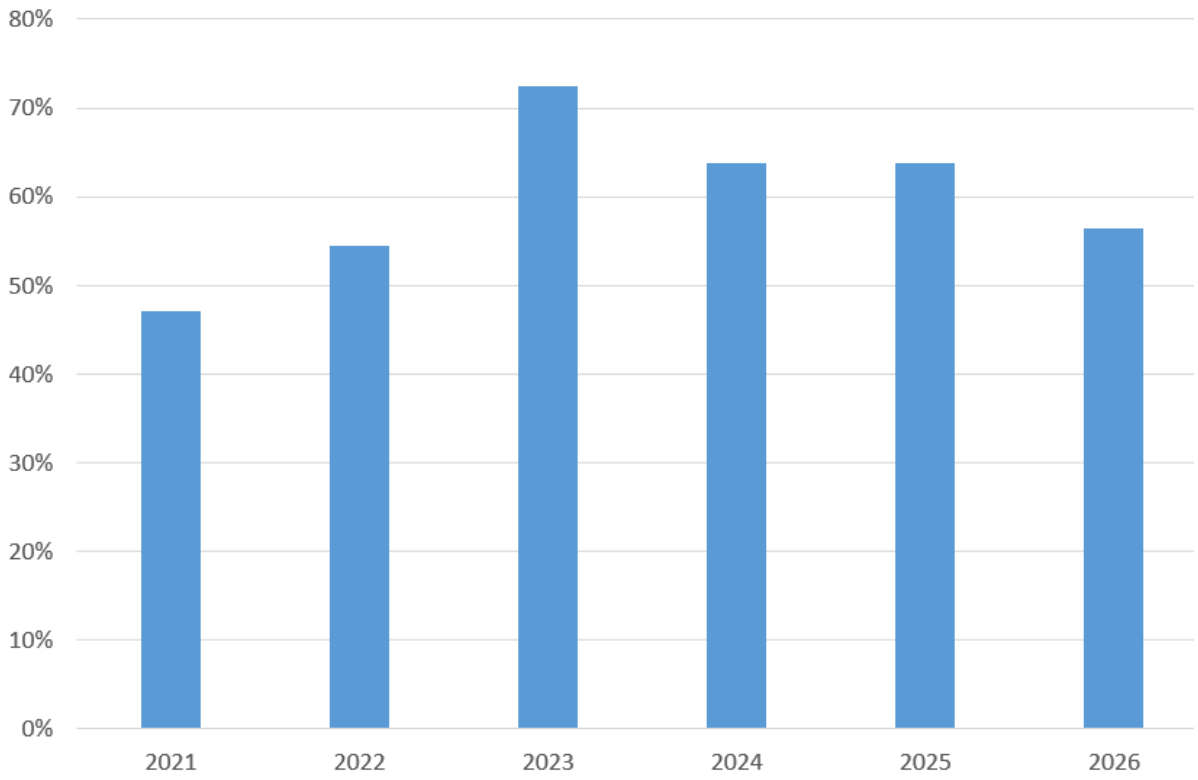
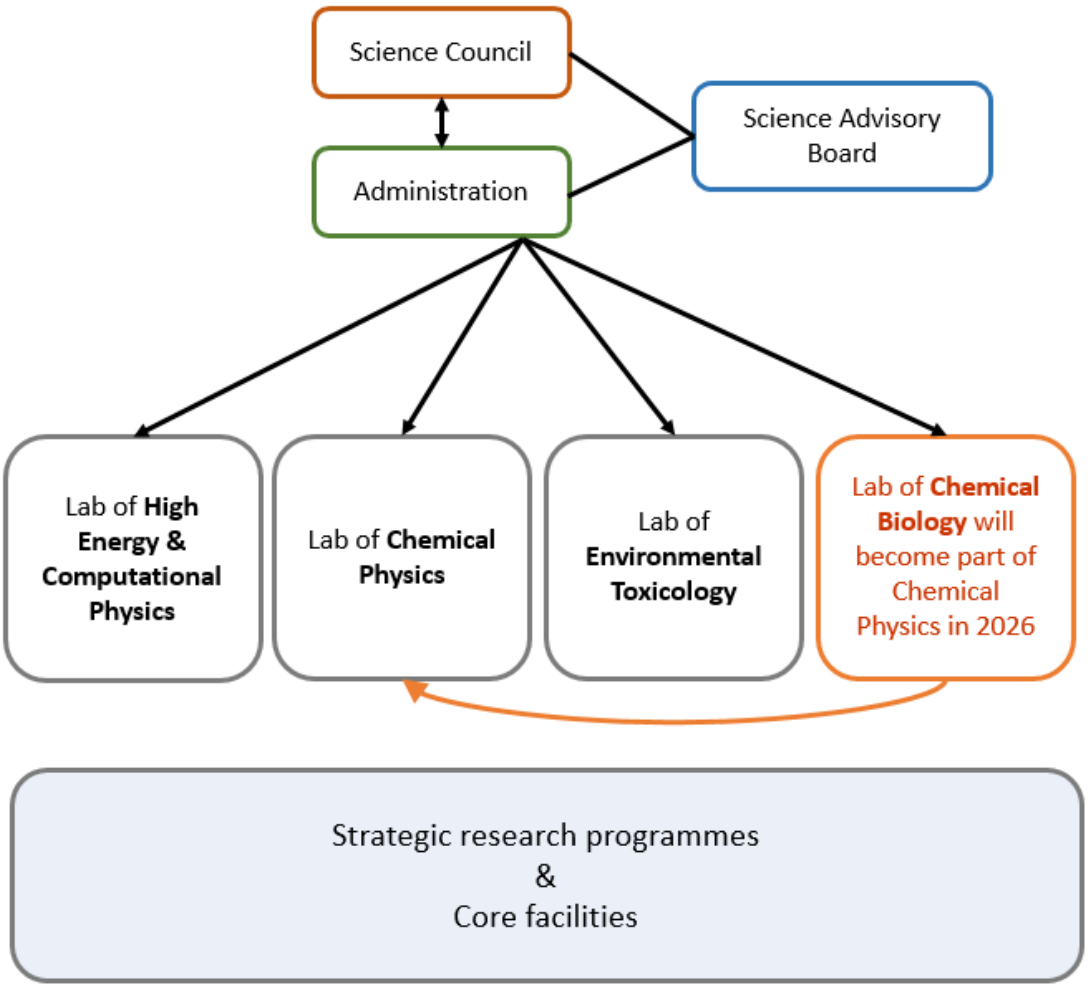


Figure 2. The share of Estonian Science Agency (ETAG) in grants peaked in 2023. The current trend of science funding is unfavourable for basic research and we expect that the share of ETAG grants in the KBFI budget decline in the coming years.

5 Appendix

KBFI organization chart



KBFI administration chart