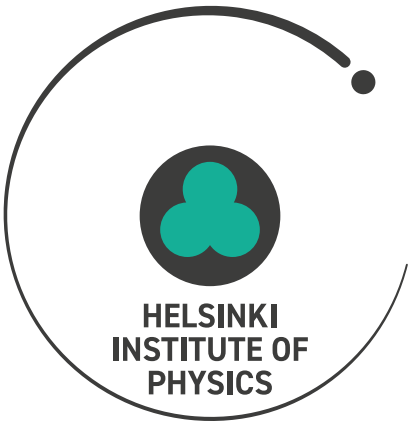
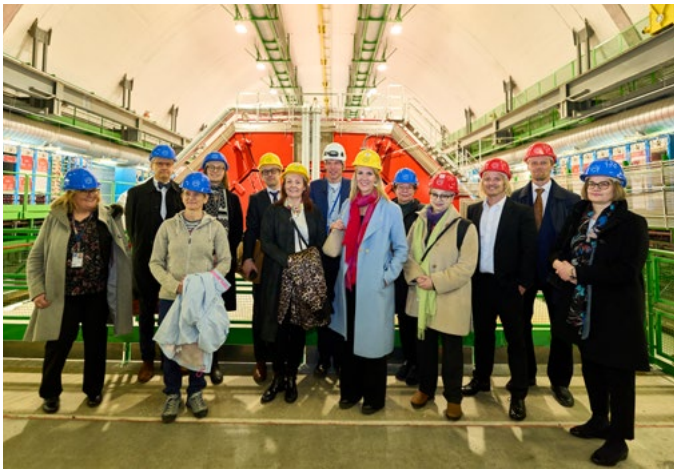
HELSINKI INSTITUTE OF PHYSICS

Annual Report 2024



Annual Report 2024

The Board and Rectorate of the University of Helsinki visiting the HIP Detector Laboratory on 16 January. © *J. Aaltonen/HIP.*



Science and Culture Minister of Finland S. Multala visiting CERN on 15 February. © *M. Cavazza/CERN.*

CERN Director-General F. Gianotti delivering the keynote speech at the CERN 70 years event at the Think Corner, Helsinki, on 13 March. © *J. Aaltonen/HIP.*

The inauguration of the COSINUS experiment in the Gran Sasso underground laboratory in Italy on 18 April. © *A. Eckert.*

The HIP Steering Group visiting STUK in Vantaa on 14 June. © *J. Aaltonen/HIP.*

The long-time former Administrative Manager of HIP, docent M. Sainio, with his book *Helsinki Institute of Physics – the first twenty years 1996-2016.* Picture taken on 27 November. © *J. Aaltonen/HIP.*

HIP Vice-Director A. Väihkönen preparing glühwein for the traditional HIP Christmas Coffee on 16 December. © *J. Aaltonen/HIP.*

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KATRI HUITU
Helsinki Institute of Physics director

PREFACE

The Helsinki Institute of Physics (HIP) is a joint research institute of the Universities of Helsinki, Jyväskylä and Tampere, Aalto University, and Lappeenranta-Lahti University of Technology LUT. The Finnish Radiation and Nuclear Safety Authority (STUK) has been an interim member of HIP since 2018. Hosted by the University of Helsinki, HIP addresses fundamental science questions from quarks to Cosmos as well as technologies from semiconductors to medical applications and climate research. It serves as a national institute for Finnish physics and related technology research and development at international accelerator laboratories. By mandate of the Finnish Ministry of Education and Culture, HIP is responsible for the Finnish research collaboration with the European Organization for Nuclear Research (CERN) in Geneva and with the Facility for Antiproton and Ion Research (FAIR GmbH), which is under construction in Darmstadt.

In 2024, the research activities of HIP consisted of four research programmes: 1) the Theory Programme; 2) the CMS Programme including the computation for LHC (Large Hadron Collider) experiments; 3) the Nuclear Matter Programme including involvements in the ALICE (A Large Ion Collider Experiment) and ISOLDE (Isotope Separator On Line DEvice) experiments, and the FAIR facility; and 4) the Technology Programme. In addition, there were three stand-alone research projects: CLOUD, Education and Open Data, and Euclid. The Detector Laboratory served as a general facility for the Institute.

The Scientific Advisory Board (SAB) of HIP visited Kumpula in August. The SAB was very satisfied with HIP research and related activities. They received the evaluation reports concerning the *CMS Experiment* and *CMS Upgrade* projects, which were found to excel and were recommended to continue as planned. Ideas for quantum computing in the *CMS Experiment* project were presented to the SAB, in line with their earlier recommendations and the evaluation of the CMS projects.

In the Theory Programme, theory and experiment have continued interacting in the *Phases of Strongly Interacting Matter* project. The leader of the project, H. Mäntysaari, received a European Research Council (ERC) Consolidator Grant, and a student in the project, M. Seppälä, received the global undergraduate award. The *Topological Matter* project was redirected towards the quantum world. The connections between member universities are active in the *Theoretical Cosmology* project which has ties to ESA's LISA mission. An overlap with cosmology also exists in the *Fundamental Particle Interactions Beyond the Standard Model* project, which hosts the HIP activities in the dark matter experiment COSINUS, inaugurated in April in Gran Sasso. The Director of the Programme, K. Rummukainen, received an ERC Advanced Grant.

The *CMS Experiment* and *ALICE* projects were analysing data collected from the LHC runs at CERN. The TOTEM data analysis continues, and the collaboration made its first open data release. The Research Council of Finland (RCF) granted the High-Luminosity LHC (HL-LHC) a Roadmap status and funding for upgrades at the very end of the year.

In the other national duty of HIP, FAIR, the main activity is producing the in-kind contributions needed for the early science and first science phases of FAIR, expected to start in the latter part of the 2020s.

In the Technology Programme, two projects relate to accelerator laboratories, namely *Robotics and AI for Monitoring and Intervention*, and *Materials for Accelerator Technology*. Two other projects use detectors for applications, namely the *Radiation and Nuclear Metrology, Safety, Security and Safeguards Applications* project and the new *Improved Detection for Elemental Analysis at Laboratory (IDEAL)* project, in collaboration with the French Alternative Energies and Atomic Energy Commission (CEA). In 2025 a new project, *AlN-on-Si Quantum Emitters and Sensors*, will start in line with the SAB recommendation to consider quantum technology at HIP.

The Detector Laboratory supports all the experimental groups at HIP, and the MoEDAL (Monopole and Exotics Detector at the LHC) experiment is a purely Detector Laboratory activity. A new laboratory engineer, M. Bezak, started in the Laboratory in August.

As for the stand-alone projects, the leader of the *Education and Open Data* project, K. Lassila-Perini, was invited to be the chair of the International Committee for Future Accelerators (ICFA) Data Lifecycle Panel. The RCF granted Roadmap status to the Cosmology Data Center which is important for both the Euclid and LISA activities at HIP.

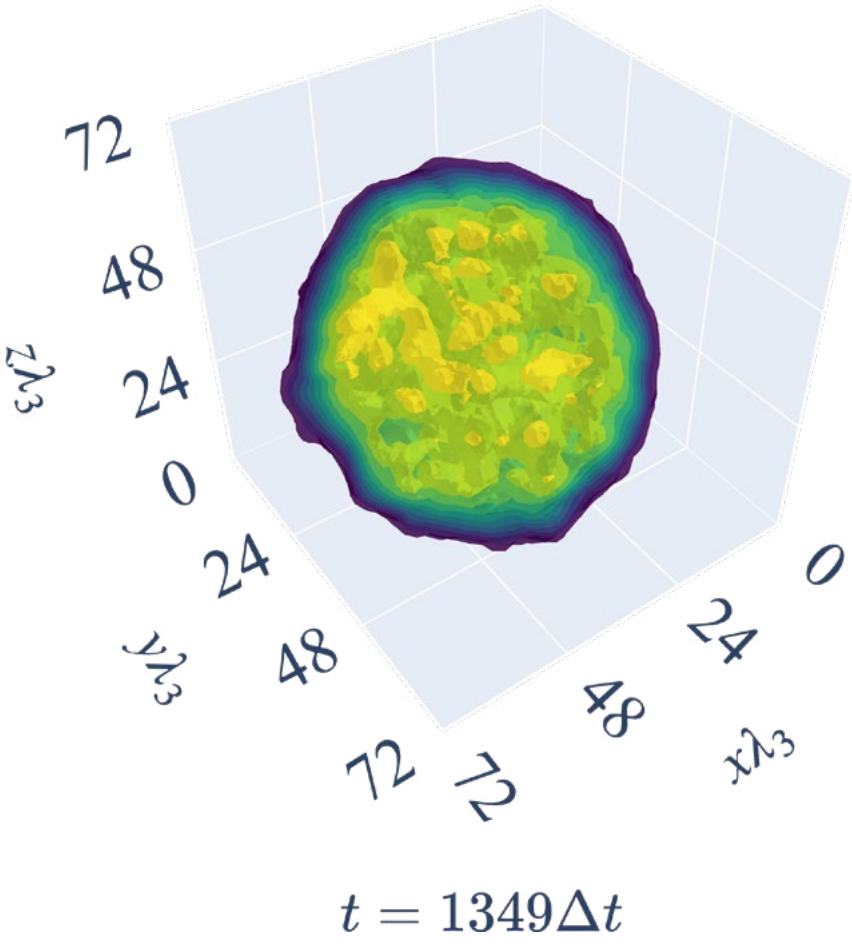
Other noteworthy events related to HIP include: the visit of CERN Director-General F. Gianotti, who gave a keynote talk at the Think Corner during the CERN 70 years event in Helsinki; the visit of the Minister of Science and Culture S. Multala at CERN; and the book launch event of *Helsinki Institute of Physics – the first twenty years 1996-2016* written by the former Administrative Manager of HIP, docent M. Sainio.

HIP research benefits from the government's programme of 1000 positions for doctoral researchers. The Graduate School in Particle and Nuclear Physics was granted 16 positions, and at HIP, there are also positions in the Doctoral Education Pilot for Mathematics and Sensing, Imaging and Modelling, and in the Quantum Doctoral Education Pilot.

HIGHLIGHTS OF RESEARCH RESULTS

Theory Programme

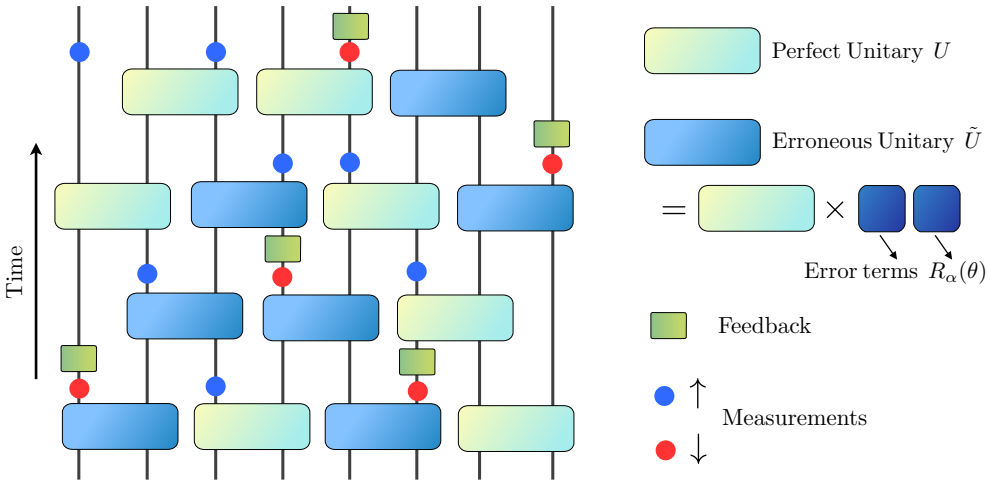
The HIP Theory Programme consists of four projects, spanning research from elementary particles to the whole universe. Among the highlights in the project *Fundamental Particle Interactions Beyond the Standard Model* is the reciprocal of the CPT theorem, which shows that in a Lorentz-invariant theory, a CPT violating interaction does not necessarily lead to mass differences between particles and antiparticles. This result is important for guiding and expanding the future searches for CPT violation to include other types of tests beyond those being performed at present.

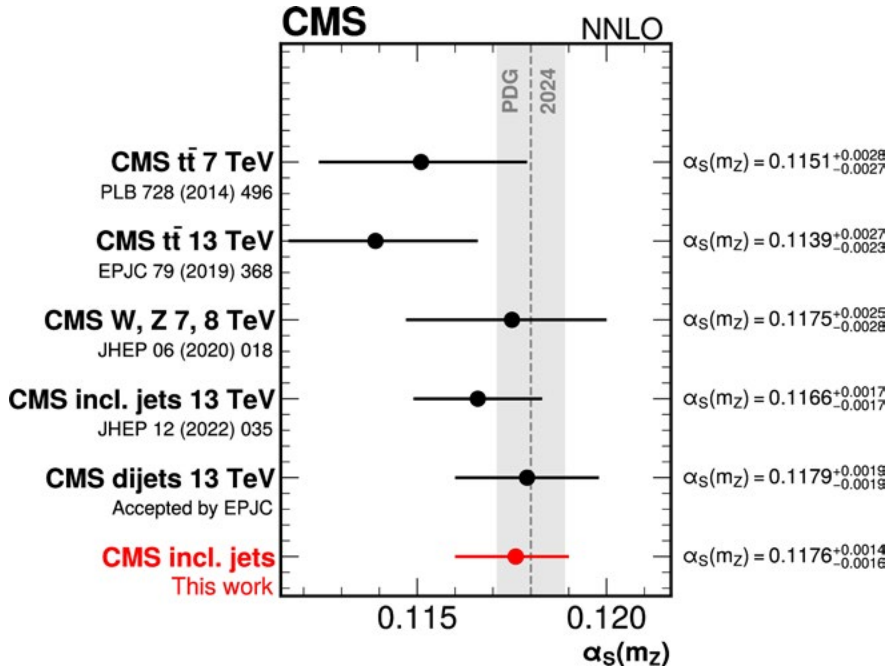


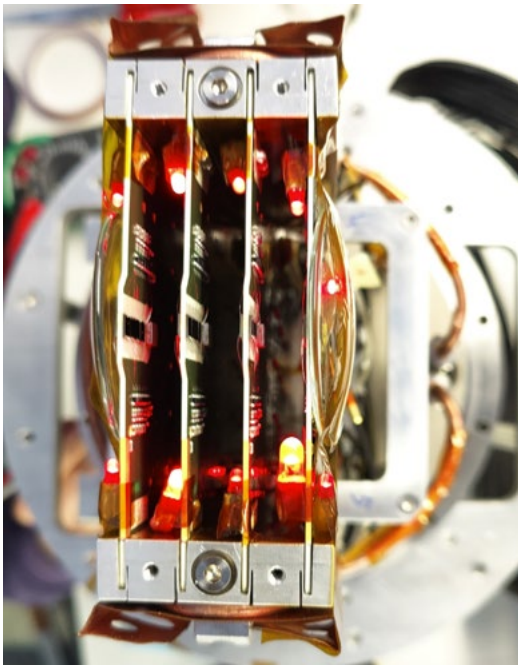
In the project *Phases of Strongly Interacting Matter*, we developed new techniques to calculate the perturbative cold quark matter equation of state up to four-loop order. These results are important for analysing the existence of quark matter in neutron star cores.

In the *Theoretical Cosmology* project the research includes the origin of structures and matter in the early universe. Among the highlights is a numerical simulation of a first-order phase transition in a system with a tree-level nucleation barrier. The results are important for the phenomenology of very early universe phase transitions.

In the *Topological Matter* project, the main research efforts in 2024 concentrated on studies of entanglement dynamics in many-body systems and quantum circuits. We devised a protocol which enables us to study measurement-induced entanglement phase transitions, a central topic in current research.







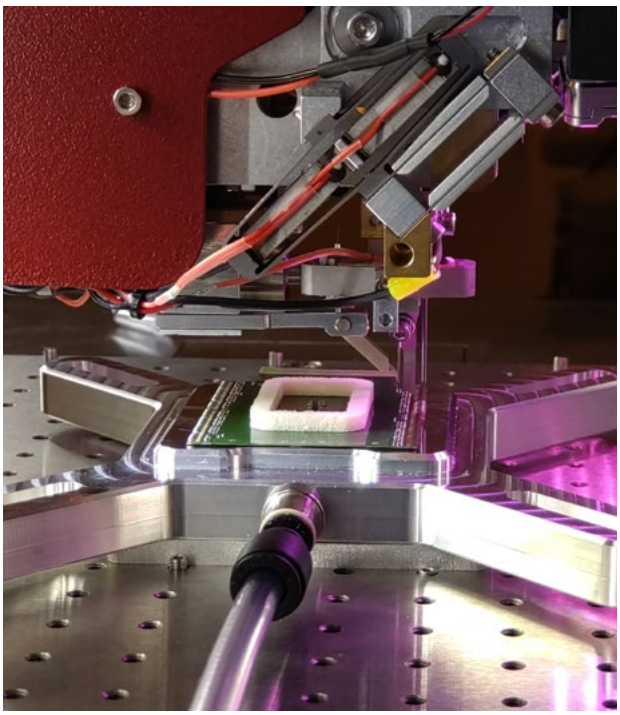
CMS Programme

CMS is a LHC general-purpose experiment. In 2024, the LHC performed exceptionally well, enabling CMS to collect over 100 fb^{-1} of high-quality data. Key highlights included a precise W boson mass measurement, the most accurate strong coupling constant α_s measurement from jets, the observation of top quark (t) quantum entanglement, and the discovery of toponium, a bound $t\bar{t}$ state.

HIP contributed to charged Higgs searches, top quark mass and α_s measurements, and vector boson scattering. In 2024, the focus was on frequent jet calibrations to identify reconstruction issues, with the full jet energy calibrations completed by the year-end. As recognition of the HIP efforts, S. Laurila started as Level-1 Trigger convener, R. Verma as jet energy resolution and correction convener, and N. Norjoharuddeen as jet energy/b-tagging and vertexing software manager.

In 2024, the upgrade efforts focused on the High-Luminosity LHC (HL-LHC) endcap pixel tracker, with the module production line commissioned including a new wire-bonder and testing station. Research Council of Finland funding will support HIP's contributions to the Endcap Timing Layer, HL-LHC Proton Precision Spectrometer (PPS) upgrade, and data storage for Finnish HL-LHC computing. Detector development continued for beam monitoring at Boron Neutron Capture Therapy (BNCT) facilities and gamma emission tomography of used nuclear fuel.

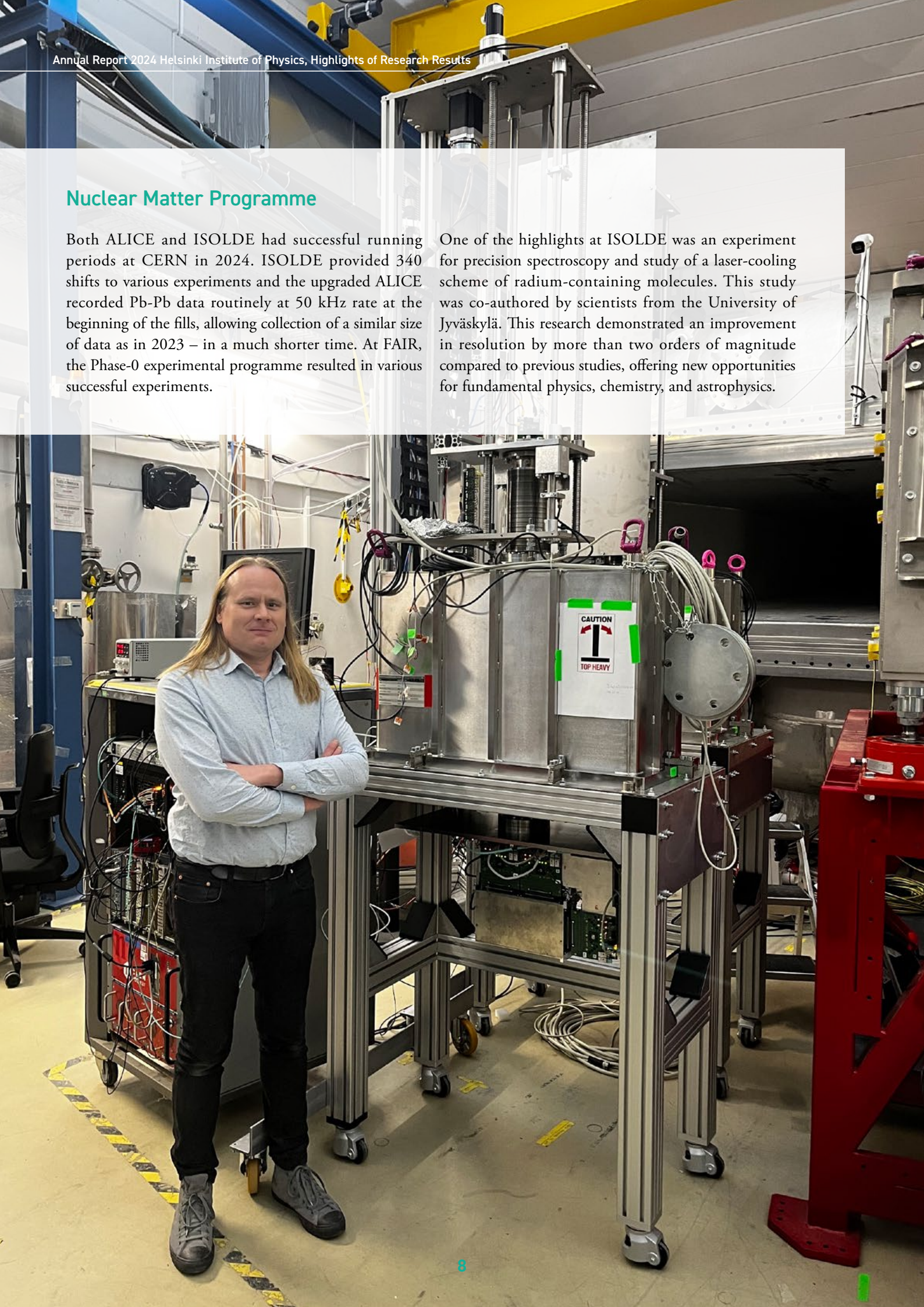
TOTEM was a LHC forward physics experiment. In 2024, its analyses progressed with HIP contributions to the 13.6 TeV total cross section, glueball studies, and an Odderon discovery update. In 2024, TOTEM made its first open data release. The HIP group operated the Proton Precision Spectrometer (PPS) time-of-flight detector and worked on mitigating efficiency losses due to diamond polarization in LHC's harsh radiation environment.



Nuclear Matter Programme

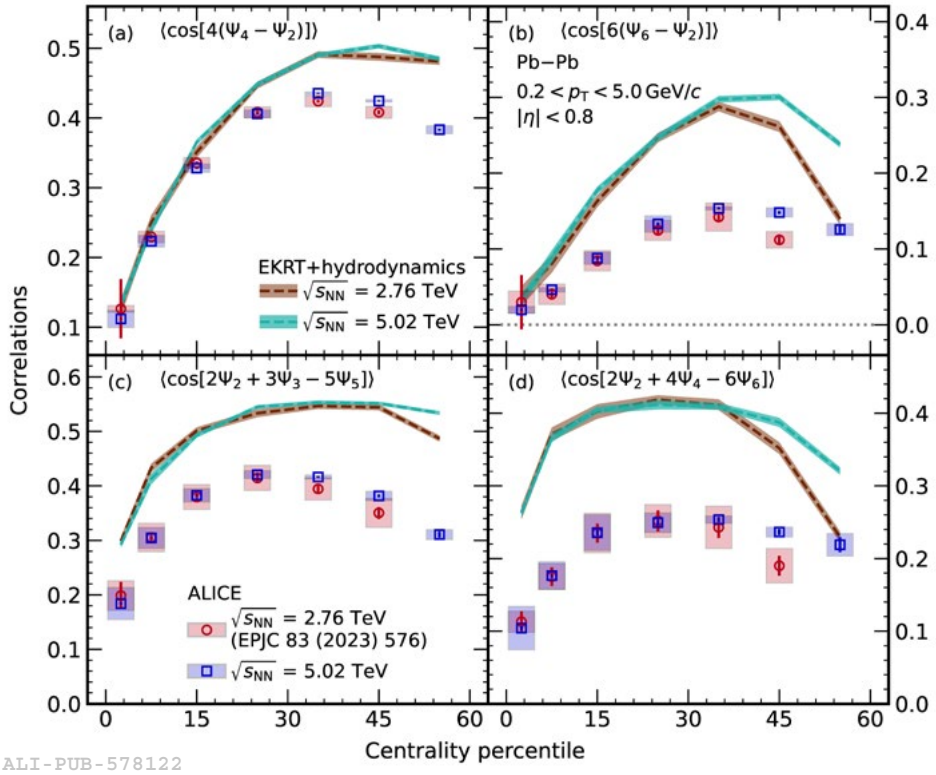
Both ALICE and ISOLDE had successful running periods at CERN in 2024. ISOLDE provided 340 shifts to various experiments and the upgraded ALICE recorded Pb-Pb data routinely at 50 kHz rate at the beginning of the fills, allowing collection of a similar size of data as in 2023 – in a much shorter time. At FAIR, the Phase-0 experimental programme resulted in various successful experiments.

One of the highlights at ISOLDE was an experiment for precision spectroscopy and study of a laser-cooling scheme of radium-containing molecules. This study was co-authored by scientists from the University of Jyväskylä. This research demonstrated an improvement in resolution by more than two orders of magnitude compared to previous studies, offering new opportunities for fundamental physics, chemistry, and astrophysics.



In the physics analysis of the ALICE group, a groundbreaking paper (*arXiv:2409.04238*) was released showcasing 25 flow harmonic correlators – 16 of which are entirely new – and offering the first-ever measurement of correlations between five distinct symmetry planes.

At FAIR, HIP researchers were involved in various Phase-0 experiments. One highlight was the spectroscopy of neutron-rich rare earth element isotopes, providing new information about the collective properties of these nuclei. They are also relevant for a more comprehensive understanding of the r-process nucleosynthesis.



Technology Programme

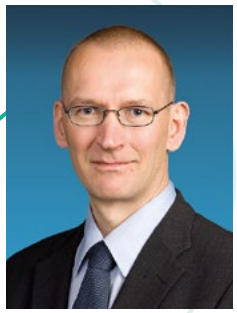
The Technology Programme aims to integrate HIP projects with significant technology development, transfer, and pre-commercialisation activities into the same programme. In addition, the research activities performed within the programme are designed to seek synergies with big science initiatives at large. The year 2024 saw the start of the IDEAL project that investigates and develops improved detection of X-rays for elemental analysis at the laboratory scale. This project is at the core of the programme's co-operation with CEA in France. The future scientific scope of the MAT project that started its next three-year period was refocussed to look beyond the horizon. In addition to LHC/LEP and FCC at CERN, questions from other collaborations such as the IMCC and i-FAST are gaining attention.

The RAD3S project has evolved into a strong co-operation between the University of Helsinki, the University of Jyväskylä and STUK, under the HIP umbrella. Significant advances have been made, in particular in the domain of minimising patient doses through optimisation of patient positioning. Imaging practices are scrutinised as cumulative organ doses can still be very high in the imaged region in computed tomography for radiotherapy.

Important advances have been made in the MAT project in developing the multiscale modelling of vacuum arcing at the surfaces of CLIC-based rf-accelerating structures intended for a future muon collider (IMCC Collaboration). High magnetic fields have been shown to increase the occurrence of vacuum arcing, suggesting involvement in the arcing mechanism in these additional extreme conditions. The results suggest an anodic arc initiation mechanism at high magnetic fields, in contrast to the mechanism found under high electric fields in the CLIC accelerating structure.

THEORY PROGRAMME

The HIP Theory Programme consists of four projects, with research spanning from elementary particles to the whole universe. The projects are: Theoretical Cosmology, Fundamental Particle Interactions Beyond the Standard Model, Phases of Strongly Interacting Matter, and Topological Matter. The research in the Theory Programme supports experimental activities at CERN and FAIR, and are connected with the Euclid and LISA satellite missions.

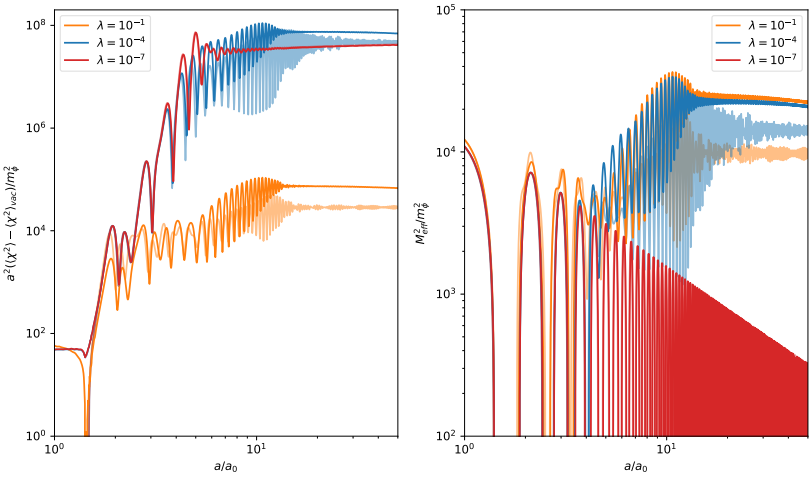


KARI RUMMUKAINEN
Theory Programme director

Theoretical Cosmology

SAMI NURMI
Theoretical Cosmology project leader

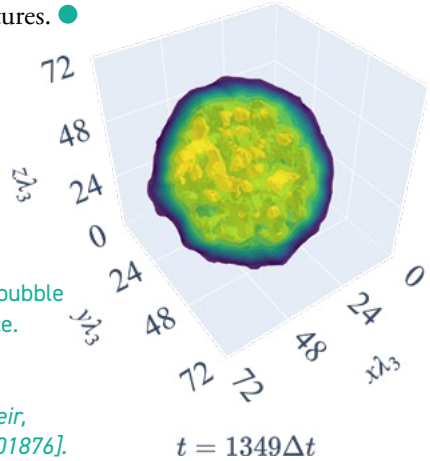
We study the origin and evolution of the universe, and connections between cosmology and particle physics. Our research topics involve inflation, dark matter, primordial out-of-equilibrium quantum processes, early universe phase transitions, large scale structures of the universe, and gravitational waves. We test microscopical models against the data from cosmological and collider surveys, searching for deeper understanding of the most fundamental properties of matter and gravity. We are part of the LISA Gravitational Wave Survey Consortium and the LISA Astrophysics and Cosmology Working Groups.



Dark matter two-point function and components of its effective mass for different self-couplings. The solid curves show the lattice results, and the shaded curves show the corresponding 2PI Hartree results. *[K. Kainulainen, S. Nurmi, and O. Väisänen, J. High Energy Phys. 10 (2024) 009].*

We work broadly on the origin of structures and matter in the early universe. The structures are most likely seeded by inflation, an extremely early period of accelerated expansion. This year we studied various microscopical models of inflation, including setups with parity violating gravitational couplings. We made new developments in precision modelling of out-of-equilibrium quantum systems during inflation and later in the history of the universe. We applied novel quantum transport methods to study gravitational particle production during reheating, quantum coherence of complicated neutrino systems and details of electroweak baryogenesis mechanisms.

We explore gravitational wave (GW) signals over the entire history of the universe. This year we worked broadly on phase transitions in the early universe. We studied the observability of GWs from such phase transitions at the future space-based gravitational wave observatory LISA by generating simulated spacecraft data and then attempting to recover the cosmological signal in the presence of noise and foregrounds. We used lattice simulations to study the nucleation rate for strong phase transitions, tested the theory of phase transitions in superfluid ^{3}He, and investigated GW production from axion strings. We also study GW signals sourced by supermassive black holes in galactic centres. This year we ran precision simulations of black holes and black hole binaries together with the global galaxy dynamics, studied details of the feedback mechanism, and ran constrained simulations of local structures.



Nucleating bubble on the lattice. *[O. Gould, A. Kormu, and D. J. Weir, arXiv:2404.01876].*

Fundamental Particle Interactions Beyond the Standard Model

ANCA TUREANU
Fundamental Particle Interactions Beyond the Standard Model project leader

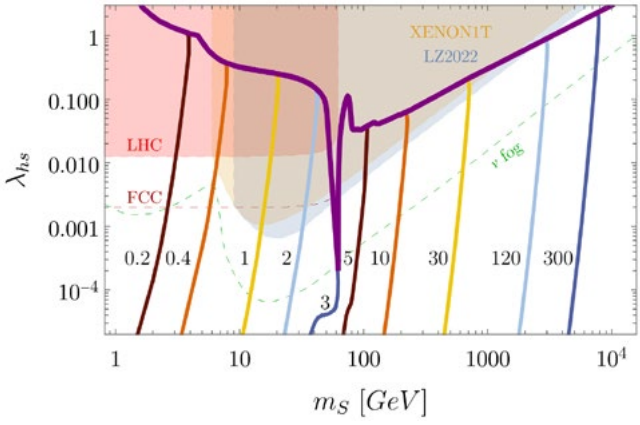
The major challenges of modern particle physics lie beyond the Standard Model (BSM). The purpose of this project is to study important facets of the BSM topics, from the phenomenological and quantum field theoretical perspective, while exploring the synergies of dedicated experiments at the high energy and high intensity frontier.

We continued our studies of neutrino oscillations and proposed a novel theoretical framework for this phenomenon, in which the flavour neutrinos are treated as waves of massless particles propagating in a "refractive quantum vacuum". The key feature of the formulation is emphasis on the coherence of oscillating states and the relativistic covariance of the theory. The project is essentially based on a novel understanding of mass generation by interaction with the quantum vacuum. This distinguishes the project from other mainly phenomenological studies and led to new predictions, like the evanescence of low-energy neutrinos, with potential consequences for cosmology.

Our group is responsible for the HIP activities in the COSINUS (Cryogenic Observatory for SIgnatures seen in Next generation Underground Searches) experiment, which was officially inaugurated on 18 April, 2024. The collection of science data will begin in 2025. Our group has had a leading role in two publications of the collaboration. One of the publications concerns the quenching factor measurement of the NaI crystals, the other is about model-independent comparison of the expected COSINUS data with the DAMA annual modulation signal.

The research activities of the group in 2024 covered a wide array of topics beyond the Standard Model, including models of dark matter boosted by energetic diffuse supernova background neutrinos, extra-dimensional models with gravity-mediated decays, special features of semiconductor detectors for the direct observation of light dark matter, and the effect of dark energy on the Local Group of galaxies.

Regarding theoretical models of dark matter, our group aims to understand dark matter production by a Standard Model thermal bath at temperatures below the dark matter mass. An attractive feature of this scenario is that it typically requires a significant coupling between the Standard Model fields and dark matter, which leads to observable signatures in both collider and direct dark matter detection experiments. The sensitivity of the latter is being constantly improved which brings exciting prospects for observing dark matter directly.



Parameter space of the Higgs portal dark matter. *[G. Arcadi, F. Costa, A. Goudelis, and O. Lebedev, J. High Energy Phys. 07 (2024) 044].*

COSINUS Collaboration meeting in Gran Sasso underground laboratory. *Credit: A. Eckert.*

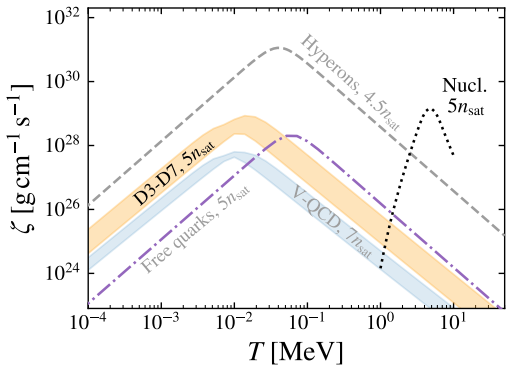
HEIKKI MÄNTYSAARI
Phases of Strongly Interacting Matter project leader

Phases of Strongly Interacting Matter

Our project focusses on quantum chromodynamics (QCD) in both a collider environment and in an astrophysical context. We are also involved in physics studies for future colliders, such as the EIC and FCC.

One objective of our project is to determine the properties of the quark gluon plasma (QGP) phase of QCD matter produced in heavy-ion collisions. We developed a new perturbative QCD and saturation based Monte-Carlo EKRT model for computing 3D initial conditions for the fluid dynamical evolution of the QGP, enabling computations of rapidity-dependent observables. We have also been developing a new neural network enhanced framework for a fast Bayesian global analysis of heavy-ion observables to determine QGP properties. Simulating the early-time dynamics of heavy quarks before QGP formation, we demonstrated the potential to probe the so-called "Glasma" phase before QGP formation.

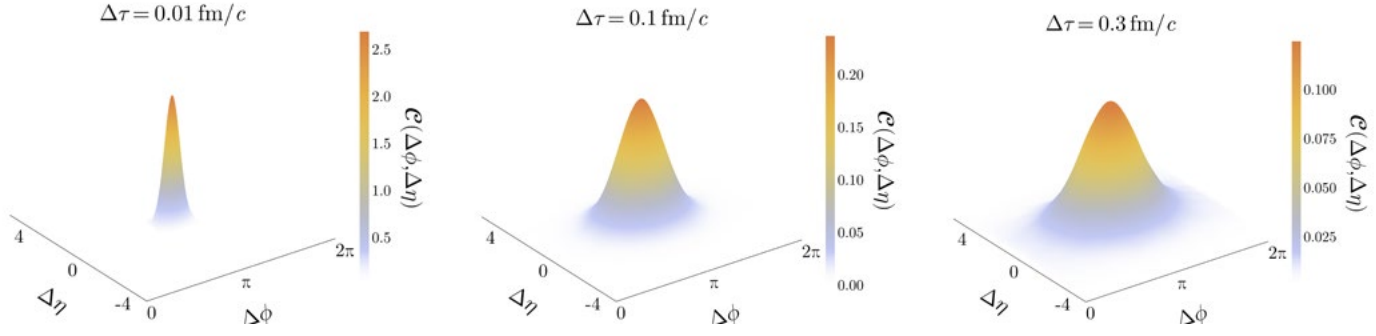
We extended the description of photon-mediated processes in the general-purpose event generator Pythia. This enabled, e.g., the generation of necessary MC samples for experimental analyses of ultra-peripheral collisions, and an improved description of future EIC measurements. We also performed the first NLO calculation of the diffractive structure functions within the dipole picture, necessary for precision studies of gluon saturation at the EIC. Furthermore, we developed a method to include dimuon production in parton distribution fits, providing indispensable constraints for the strange-quark distributions.



Bulk viscosity of neutron-star matter.
[J. Cruz Rojas et al., Phys. Rev. Lett. 133 (2024) 071901].

One of our goals is to extend the high-density perturbative cold quark matter equation of state (EOS) to full N3LO. This requires a computation of four-loop diagrams at finite density and new perturbative thermal-field-theory techniques. We generalised the algorithmic method based on Loop Tree Duality from collider physics to address large-scale multi-loop computations at finite density. This method approaches perturbative thermal computations by numerically integrating entire Feynman diagrams, enabling the evaluation of complex vacuum four-loop diagrams.

In addition to extending the EOS, we also focussed on transport properties and obtained an improved weak-coupling and a novel strong-coupling result for the bulk viscosity of unpaired quark matter. This culminated in a simple analytic formula integrating perturbative QCD at high densities with non-perturbative holographic inputs at neutron-star densities. Furthermore, we identified a spatially modulated instability within the deconfined QGP phase of QCD, driven by the Chern-Simons term.



Time evolution of the charm quark pair correlation as a function of pseudorapidity and azimuthal angle separation.
[D. Avramescu, V. Greco, T. Lappi, H. Mäntysaari, and D. Müller, arXiv:2409.10565].

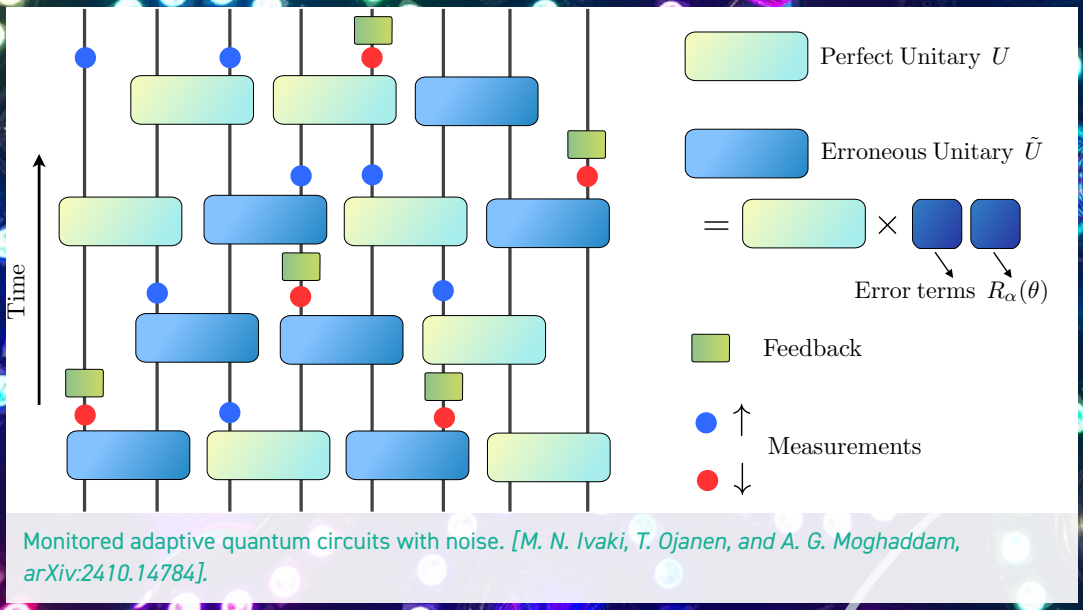
Topological Matter

During its five-year life, the Topological Matter project has evolved thematically quite far from its origins. Due to the rapid emergence of quantum information as a central concept in contemporary research, the project has moved in that direction. Building on our experience in condensed-matter and many-body systems, we are now studying the interface between these topics and quantum information. Our motivation is to explore the new prospects offered by quantum information platforms to discover new quantum phenomena and simulation of many-body systems.

The main research efforts in 2024 concentrated on studies of entanglement dynamics in many-body systems and monitored quantum circuits. The key problem in quantum simulation of monitored systems, whose dynamics include measurements in addition to the usual unitary time evolution, is the so-called postselection problem. This arises due to the inherent randomness of measurement outcomes in quantum mechanics, thus leading to exponential difficulty (in the number of measurement events) in reproducing the same time-evolution. As the standard recipe to obtain expectation values for observables requires a large number of copies of identically prepared states, the postselection problem makes it exponentially difficult to obtain them. To circumvent the postselection problem in monitored circuits, we devised a polynomial scaling protocol to obtain a certain class of observables. This result enables one to indirectly access the measurement-induced entanglement phase transitions, a central topic in the current research.

Our long-time efforts in obtaining the entanglement entropy size-scaling in many-body systems from accessible observables culminated in a work where we generalised our previous results from systems with conserved quantities to systems that do not exhibit them. We showed that by filtering the fluctuations of suitably chosen observables, it is still possible to access the entanglement entropy scaling without resorting to the reduced density matrix.

TEEMU OJANEN
Topological Matter project leader



Monitored adaptive quantum circuits with noise. *[M. N. Ivaki, T. Ojanen, and A. G. Moghaddam, arXiv:2410.14784].*

CMS PROGRAMME

The HIP CMS Programme co-ordinates Finnish participation in the CMS and TOTEM collaborations at the Large Hadron Collider (LHC). The Compact Muon Solenoid (CMS) is a general-purpose experiment with a broad physics programme covering precision measurements of particles and interactions, the origin of electroweak symmetry breaking (Higgs bosons), and the search for new physics. TOTEM focussed on elastic scattering, total cross section, diffractive and exclusive processes, and completed its data taking at the LHC in 2023. The programme has four projects: 1) the CMS Experiment project for physics analysis and operations; 2) the CMS Upgrade project for detector upgrades; 3) the Tier-2 Operations project for LHC computing; and 4) the CMS Forward Physics project for forward physics and the completion of the TOTEM physics programme. The Finnish CMS groups are: HIP (15 authors); the Department of Physics at the University of Helsinki (3 authors); and Lappeenranta-Lahti University of Technology (3 authors). TOTEM has 7 HIP authors, of which 5 are also affiliated with the Department of Physics at the University of Helsinki.

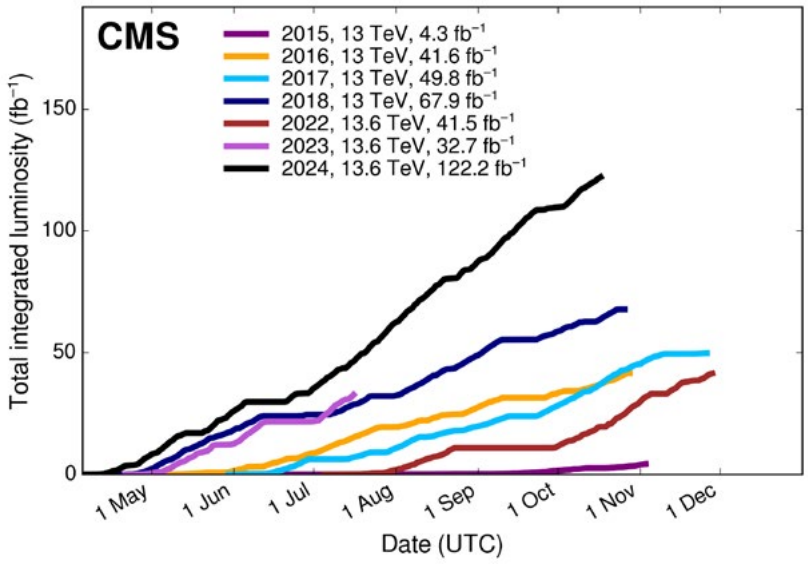
KENNETH ÖSTERBERG
CMS Programme director

CMS Experiment

MIKKO VOUTILAINEN
CMS Experiment project leader

Introduction and Highlights

The LHC is in a unique position to explore the origins of the universe. The HIP CMS Experiment project is focussed on analysing LHC data, especially on charged Higgs boson searches, precision measurements with jets, and electroweak symmetry breaking. These are supported by expertise in detector operations, jet energy corrections (JEC), and machine learning (ML) in high energy physics (HEP), but also by new efforts in quantum computing.

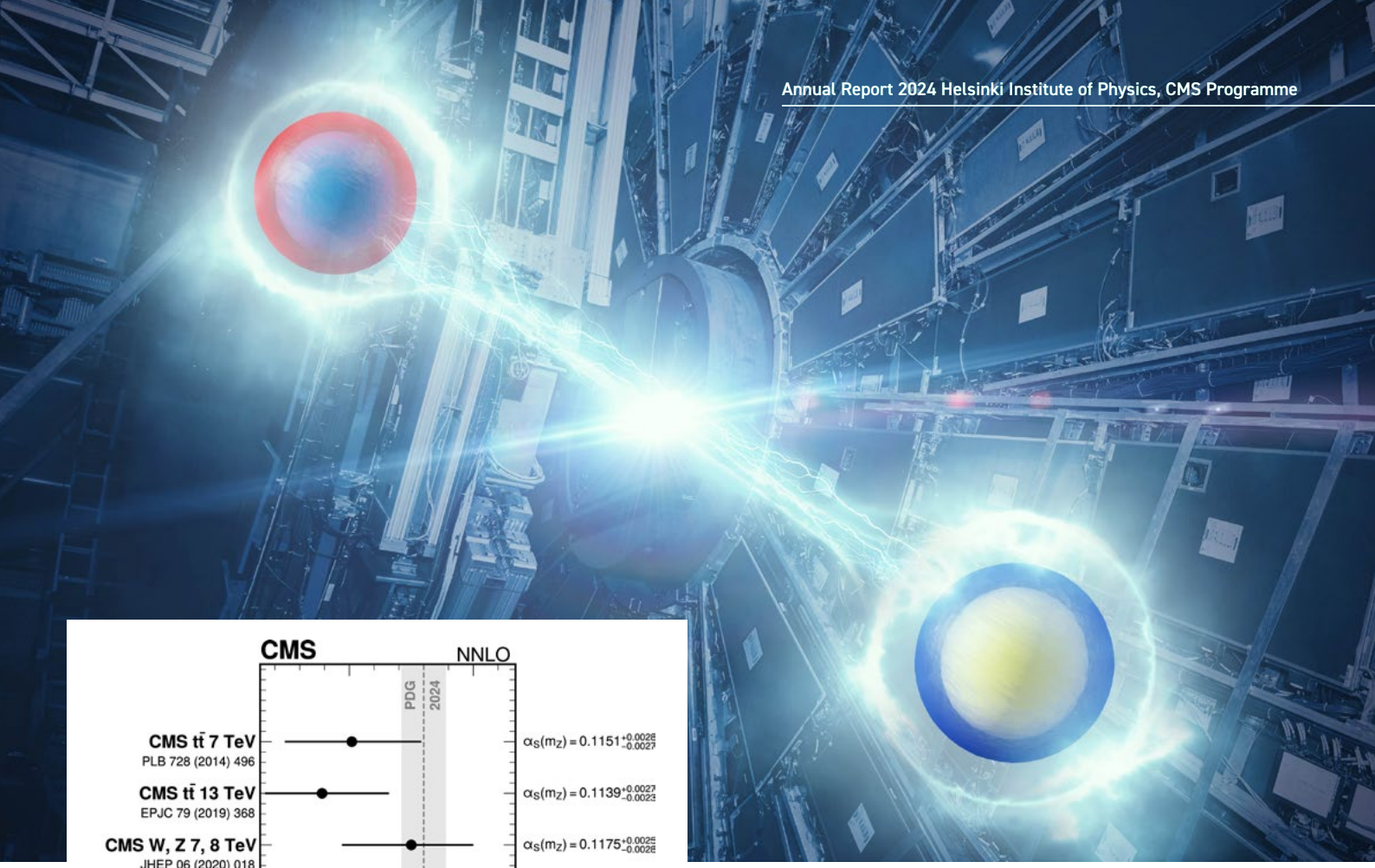


The integrated luminosities collected by the CMS experiment during LHC Run 2 and 3 with 2024 surpassing any previous year. © *CMS Collaboration.*

The LHC performed exceptionally well in 2024, with CMS collecting over 100 fb^{-1} of good quality data, and our focus was on validating and calibrating this data. Our new ERC and Research Council of Finland (RCF) recruitments (2 post-docs, 4 PhD students) were completed in January, and we had a joint kick-off meeting at the Kilpisjärvi Research Station in March. The group also co-organised the international Midsummer School in QCD 2024 in Saariselkä in July. K. Kallonen defended his thesis on quark and gluon jet discrimination and search for supersymmetry.

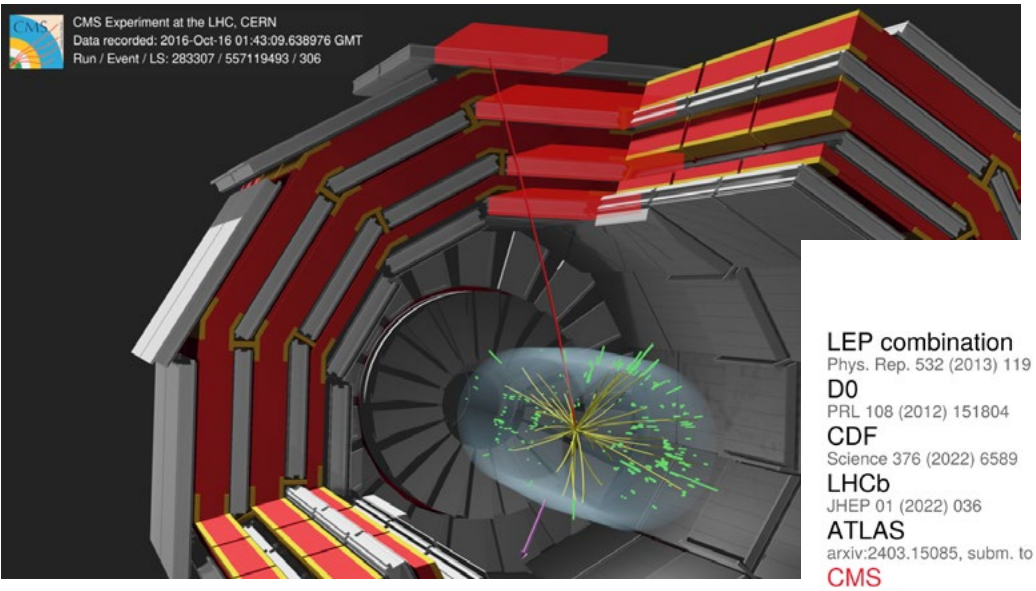
HIP continued its strong scientific leadership at CERN: M. Voutilainen continued as Physics Data sets and Monte Carlo Validation (PdmV) L2 convener and S. Lehti as Jet and Missing Energy (JME)-Trigger L3 convener, while S. Laurila started as Level-1 Trigger L2 convener, R. Verma as JME-Energy resolution and correction (JERC) L3 convener, N. Norjoharuddeen as JME/B-tagging and vertexing (BTV)-Software L3 manager, and T. Lampén as PdmV-Validation L3 manager. H. Kirschenmann received a full professorship at LUT.

Overall, the highlights of the year at CMS included a very precise W boson mass measurement, the best strong coupling constant α_s measurement from jets, observation of quantum entanglement with top quarks, and a surprise discovery of toponium, a bound state (η_t) of two top quarks.

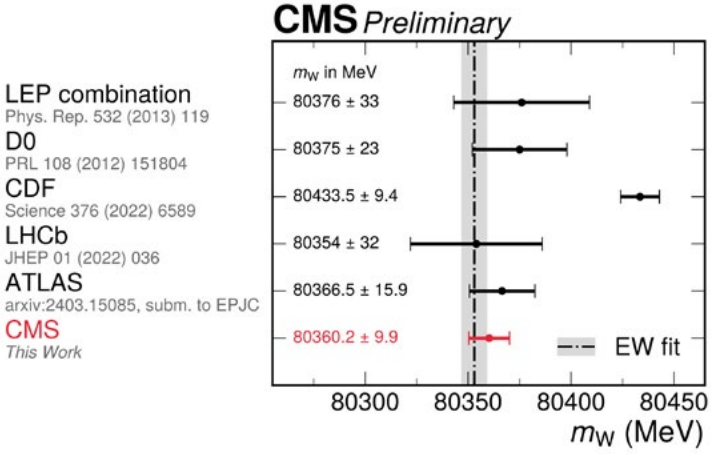


Artist's view of the entanglement of two top quarks as observed in CMS and ATLAS at the LHC. © *D. Dominguez / CERN, CMS Collaboration.*

The latest CMS measurement of the strong coupling constant α_s compared to previous CMS measurements and the Particle Data Group (PDG) world average value. © *CMS Collaboration.*



Event display of one $W \to \mu^+ \nu_\mu$ decay candidate from the new CMS W mass measurement analysis. © *CMS Collaboration.*



The new precise CMS W mass measurement compared to previous W mass measurements. © *CMS Collaboration.*

Detector Operations

Our newly grown JEC team provided frequent calibrations throughout 2024, allowing us to catch critical reconstruction issues in the process. These were fixed by the summer, and we provided a complete set of JEC at the end of 2024. Efforts to automatise JEC for prompt data began. Our ML team published a benchmark paper on data scouting (*arXiv:2403.16134*) and we started a new effort on quantum computing with two summer students and a joint MSc thesis with VTT (V. Mehtola).

Charged Higgs Bosons

Supersymmetry predicts multiple Higgs bosons and provides a natural candidate for dark matter. The HIP team continued the search for charged Higgs bosons in the $\tau\nu$ channel (J. Mäki-Ikola) and doubly charged Higgs bosons in a same-sign double-τ final state (R. Öhrnberg).

Precision Measurements with Jets

Precision measurements of the top quark mass m_t and α_s aim at exploring the Standard Model vacuum stability. The m_t measurement (M. Myllymäki, E. Veikkola) continued with a Statistics Committee review and a CMS Week plenary presentation in December, while new jet measurements for α_s (N. Mancilla) were being set up on Run 3 data. A combination of past CMS jet measurements resulted in a very precise α_s (*arXiv:2412.16665*). We also started an exploratory study of η_t decays into diphotons (B. Lehtelä).

Electroweak Symmetry Breaking

Vector boson scattering is an integral test of electroweak symmetry breaking, and the HIP contribution (N. Toikka, A. Stadnitski) continued through the RCF "ForVVard" project and the H2020 COST action "COMETA" (CA22130), with the goal to measure fully polarized WW scattering in an all-hadronic final state with full Run 3 data. Future di-Higgs measurements provide access to the shape of the Higgs potential, with promising development made on new techniques using boosted Higgs bosons, ML, and scouting (P. Inkaew). ●

Participants in the CMS Experiment project retreat at Kilpisjärvi. *Credit: H. Kirschenmann.*

CMS Experiment project retreat at Kilpisjärvi Biological Research Station. *Credit: M. Voutilainen.*

Participants of the Midsummer School in QCD 2024 at Saariselkä. *Credit: Midsummer School in QCD.*

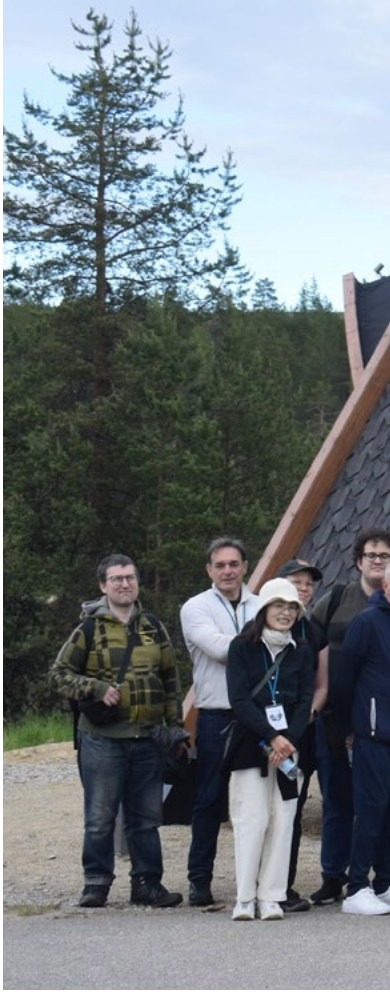


Photo above: Participants in the Particle Physics Days 2024 at Lammi Research Station. *Credit: S. Laurila.*

Photo on the right: CMS Experiment members showing their school souvenir, a Midsummer School in QCD kuksa. *Credit: Midsummer School in QCD.*

ERIK BRÜCKEN
CMS Upgrade project leader

CMS Upgrade

The primary focus of the CMS Upgrade project is on detector contributions to the CMS experiment, particularly upgrading the inner tracking detector and constructing the Minimum Ionizing Particle Timing Detector (MTD) for the High-Luminosity LHC (HL-LHC) phase. Additional efforts include maintaining HEP instrumentation expertise and supporting student education.

CMS Inner Pixel Detector

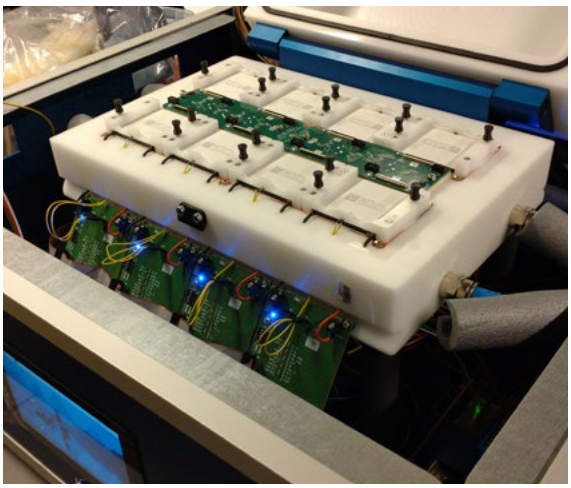
In 2024, production of pixel detector modules began after extensive R&D. Key procurements, funded by the RCF, included a wire-bonder and material tester. With the construction of a module testing station setup, the production machinery was ready. As part of the CMS Tracker Collaboration, we aim to produce and qualify at least 250 pixel modules for the Tracker Endcap PiXel (TEPX) layers. These hybrid detectors have an active area of approximately 4.4×3.5 cm^2. By summer 2024, the first modules from the kick-off production batch were assembled and tested. Bonding facilities and expertise are shared with the Finnish ALICE group, who use a special Single-Point Tape Automated Bonding technique for the pixel chips of the FoCal detector.

Minimum Ionizing Particle Timing Detector (MTD)

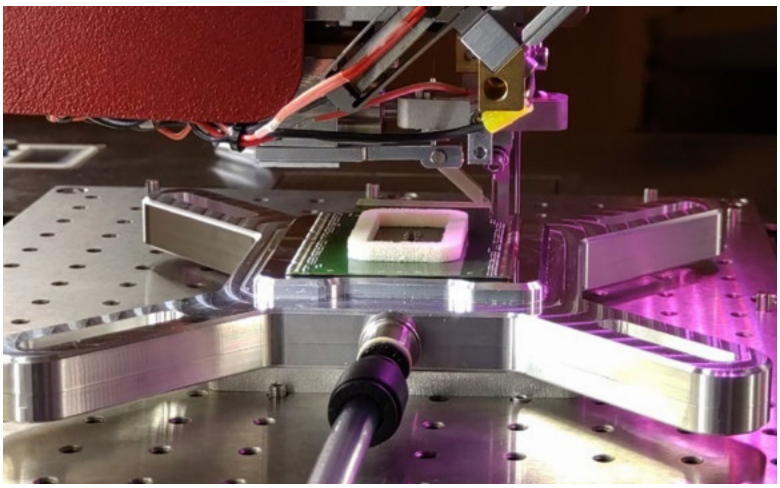
The MTD, a new timing layer around the tracking detector, enables 4D tracking for efficient track assignment in HL-LHC runs. Low Gain Avalanche Detectors (LGAD) are used in the Endcap Timing Layer, with significant R&D contributions from HIP researchers. In 2024, the R&D phase concluded, and HIP was accepted as a full Quality Control (QC) centre for production sensors. Funding from a successful RCF infrastructure application will support lab preparations for QC tasks starting in spring 2025.

Local Detector R&D

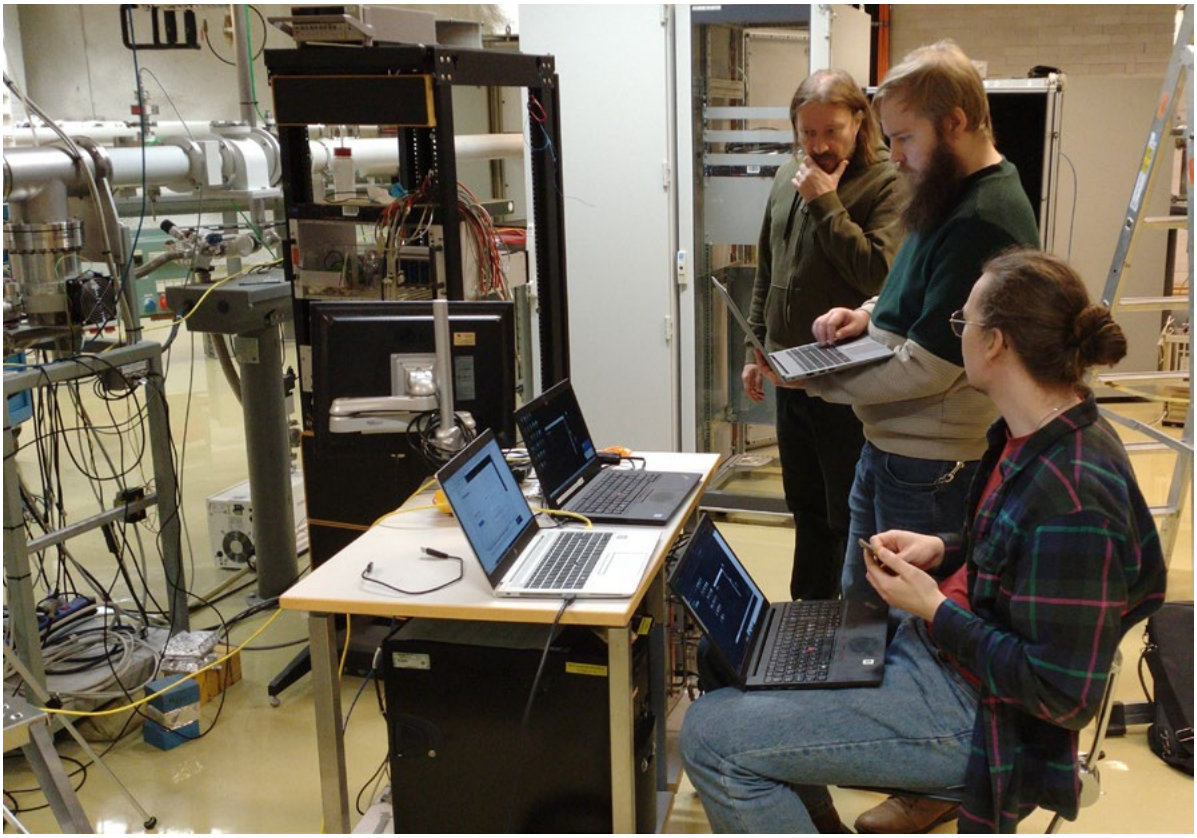
Expertise was expanded through several projects, including the RCF project at Helsinki University Hospital's Boron Neutron Capture Therapy (BNCT) facility, optimising BNCT for cancer treatment. The focus was on testing detection technologies for detecting prompt gammas from the BNC reaction to measure the boron concentration, with initial tests at Kumpula Campus accelerators. Investigations into ultra-thin silicon drift detectors continued, though front-side wafer processing has not yet started. Participation in the Nordic nuclear safety research (NKS) project "Position-sensitive detectors for nuclear fuel imaging (Poseidon)" involved simulating a new detector concept for passive gamma emission tomography of used nuclear fuel assemblies and conducting initial measurements with a nuclear fuel test setup. Additionally, the RD50/DRD3 project on "Partial Activation of Boron to Enhance Radiation Tolerance" began in 2024, with the first R&D LGAD sensors expected in spring 2025.



The construction of the testing system for the hybrid TEPX pixel detector modules for the new CMS inner tracking detector. *Credit: E. Brücken.*

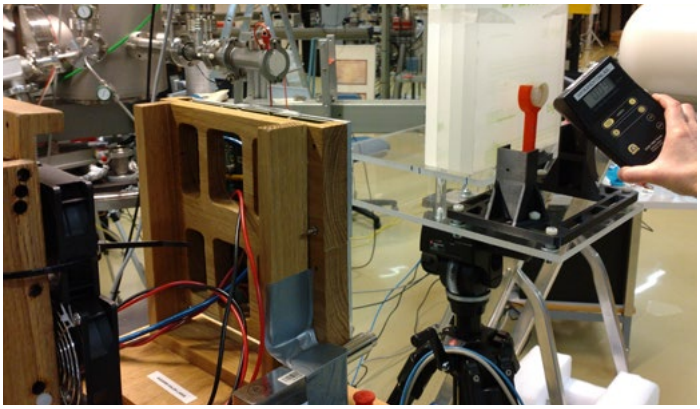


A TEPX pixel detector module for the new CMS inner tracking detector being wire bonded in the HIP clean room facilities. *Credit: E. Brücken.*

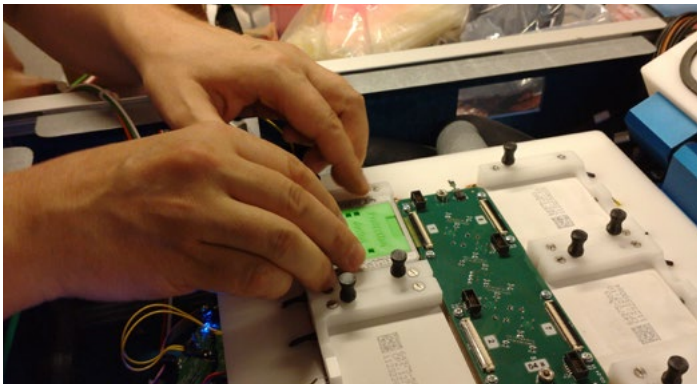


CMS Upgrade researchers measuring neutrons at the Kumpula Accelerator Laboratory. *Credit: E. Brücken.*

CMS Upgrade researchers assembling the testing system for the hybrid TEPX pixel detector modules for the new CMS inner tracking detector. *Credit: E. Brücken.*



Setup for measuring prompt gamma radiation from the boron neutron capture reaction. *Credit: E. Brücken.*



The assembly of the testing system for the hybrid TEPX pixel detector modules for the new CMS inner tracking detector. *Credit: E. Brücken.*

KENNETH ÖSTERBERG
CMS Forward Physics project leader

CMS Forward Physics

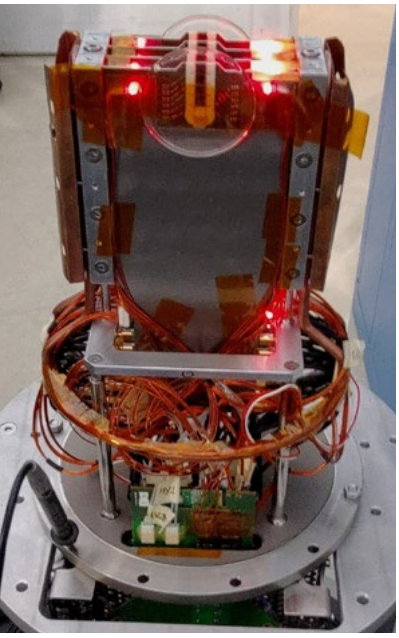
The CMS Forward Physics project is responsible for the Finnish contributions to CMS forward physics and the TOTEM experiment. In 2024, TOTEM made its first open data release, consisting of the data used for the total cross section measurement at 7 TeV. The project's focus in 2024 was the operation of the CMS Proton Precision Spectrometer (PPS) time-of-flight (TOF) detector, the validation of the PPS tracking detector data as well as the completion of the TOTEM physics analyses. The plans for the Finnish contribution to the HL-LHC PPS upgrade, PPS2, also matured. K. Österberg continued as TOTEM physics co-ordinator and F. Garcia as responsible for the PPS TOF detector operation.

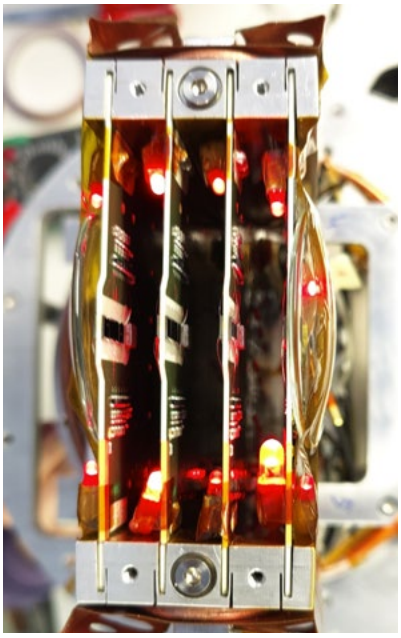
PPS Detector

For the Run 3 PPS TOF detector, HIP made a significant contribution to the diamond sensor purchase, metallization, QC (M.-M. Rantanen, P. Koponen, K. Österberg), and the TOF plane assembly, testing, installation, and commissioning (F. Garcia). An efficiency loss due to a polarization of the diamond sensors from the high particle flux in the PPS Roman Pots was mitigated by introducing red LED diodes shining on the diamonds for the 2024 data taking. To further reduce the efficiency loss, red lasers will be added for the 2025 data taking. In parallel, studies of the polarization, its mitigation, and the radiation hardness of metallized diamond sensors are continuing (M.-M. Rantanen, F. Garcia). The PPS Run 3 tracking detector alignment and the LHC optics are validated using exclusive dimuon events (A. Milieva, K. Österberg). In 2024, the Finnish PPS2 contribution was included in a successful HL-LHC RCF infrastructure roadmap application.

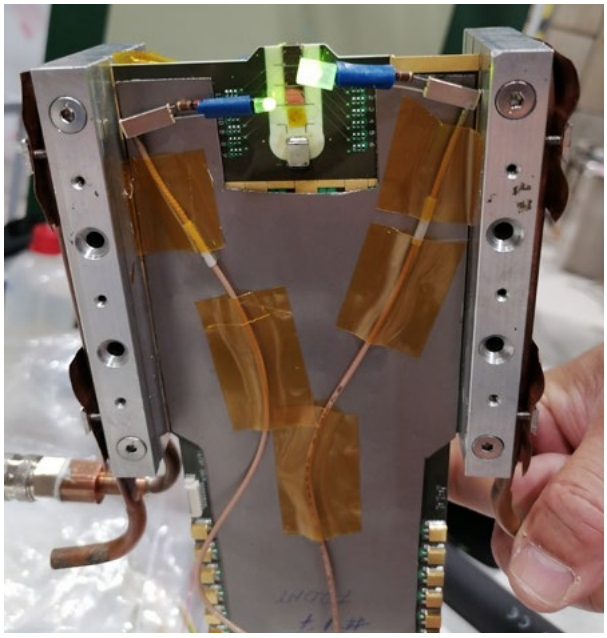
Physics

In 2024, the work progressed on updating the analysis of the observation of Odderon exchange in elastic scattering (K. Österberg) and the study of glueball candidates in low mass exclusive meson production (Y. Elberkennou, P. Tuomola). A new PhD student (F. Musonov) joined the glueball analysis in autumn 2024. The elastic scattering analysis at 13.6 TeV was also started in parallel to the on-going inelastic rate analysis to have all the ingredients for a total cross section measurement (F. Oljemark). Regarding PPS physics, an analysis to search for exclusive pair production of doubly charged Higgses decaying to same-signed τ leptons (A. Milieva) continued in collaboration with the CMS Experiment project (S. Lehti).





Mitigation of efficiency loss due to diamond polarization with LED diodes in the CMS PPS time-of-flight detector. *Credit: F. Garcia.*



Mitigation tests of the efficiency loss in the CMS PPS time-of-flight sensors with LED diodes emitting different coloured light (i.e., wavelength). *Credit: F. Garcia.*

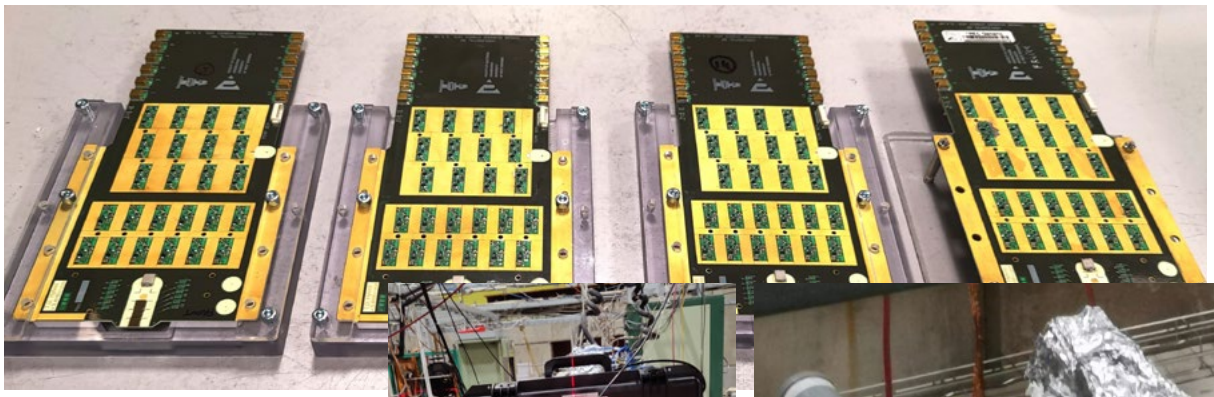
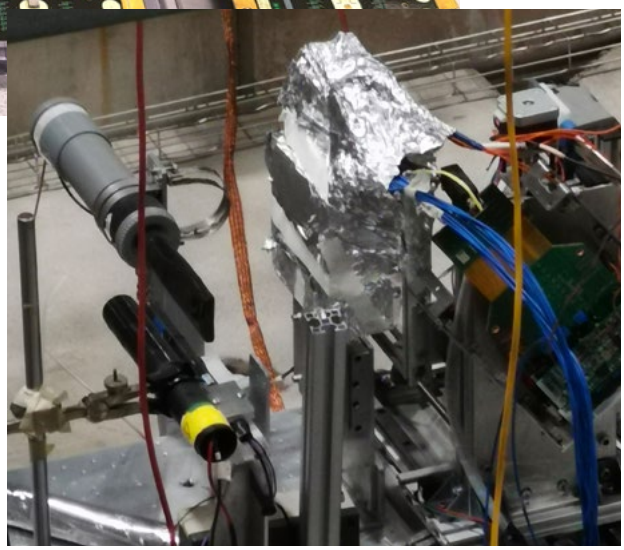


Photo above: Equipping the CMS PPS time-of-flight detector with an additional plane of diamond sensors. *Credit: F. Garcia.*



Photos on the right: The first test beam of a PPS2 compatible LGAD timing sensor with an ETROC readout. *Credit: F. Garcia.*

Tier-2 Operations

The HIP Worldwide LHC Computing Grid (WLCG) resources are run together with CSC (IT Center for Science Ltd), and the Nordic DataGrid Facility. CMS analysis and simulation jobs were run in 2024 with record availability. The CMS Site Readiness Status was 93% (84% in 2023). T. Lindén represented HIP in the Nordic LHC Computing Grid committee. S. Lehti and M. Myllymäki worked 10% in the Tier-2 Operations project. There were 12 HIP Global Grid User Support tickets (12 in 2023).

CMS jobs were run on the 672 core Linux cluster Kale (from 2015). Validation jobs run successfully also on the development Alcyone-cms 64 core Linux cluster based on old CSC nodes. The HEPScore23 benchmark replacing the HS06 benchmark also runs on the clusters.

The HIP Tier-2 was AAA-federation validated, enabling more workflows to run, increasing the site usage. Tokens were in production use on the dCache and in test use on Kale and Alcyone-cms. The HL-LHC dCache upgrade was included in a successful HL-LHC RCF infrastructure roadmap application.

CMS used the LUMI supercomputer for porting part of CMSSW to AMD GPUs. Development work to enable LUMI usage for ATLAS and CMS was done on the CSC Puhti HPC and cPouta. A work around the LUMI CVMFS restrictions was developed as well.

The dCache data storage services run by CSC were stable. Data transfers speeds to dCache were optimised. The HIP dCache system successfully took part in the WLCG Data Challenge 2024 to prepare for HL-LHC scale data transfers. In 2024, 4360 TB (1860 TB in 2023) of data was transferred to HIP and 1020 TB (486 TB in 2023) from HIP to elsewhere with FTS.

A total of 0.35 million CMS jobs (0.15 million in 2023) using 74.5 MHS23 CPU hours (44.9 MHS23 in 2023) were run with an average CPU efficiency of 67.4% (52.8% in 2023).

TOMAS LINDÉN
Tier-2 Operations project leader

NUCLEAR MATTER PROGRAMME

The Nuclear Matter Programme involves the participation of Finnish teams at CERN in studies of two aspects of nuclear and hadronic matter. These are cold exotic matter with the extreme composition of its proton and neutron numbers on the one hand, and dense matter created in relativistic heavy ion collisions on the other. Exotic nuclei are studied at the ISOLDE facility, while the study of quark gluon plasma and related phenomena takes place at ALICE. The Nuclear Matter Programme has also continued co-ordinating Finnish participation in the planning and construction of the FAIR project in Darmstadt. The Finnish involvement in the FAIR scientific programme concentrates on the NUSTAR Collaboration for nuclear structure, reaction, and astrophysics studies.

ARI JOKINEN
Nuclear Matter Programme director

SAMI RÄSÄNEN
ALICE project leader

ALICE

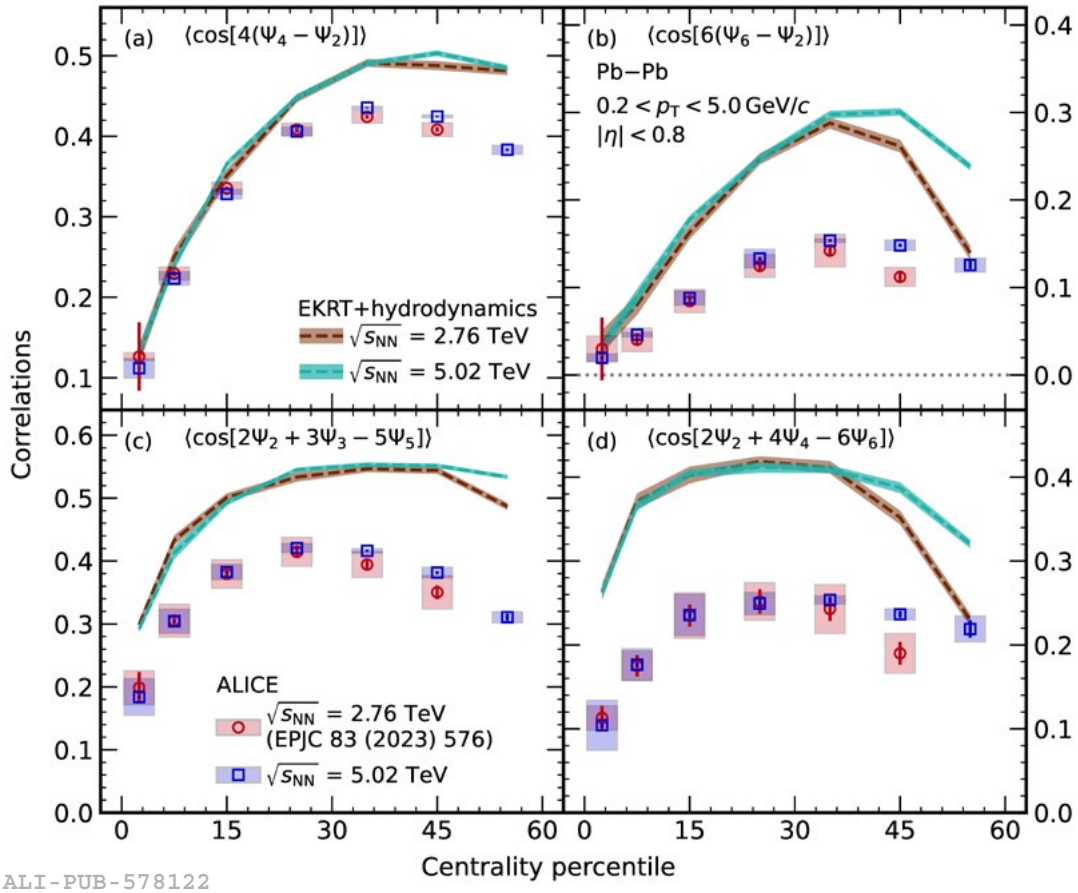
ALICE (A Large Ion Collider Experiment) is the dedicated heavy ion experiment at the Large Hadron Collider (LHC). In lead-lead collisions, we study the properties of the quark gluon plasma (QGP), the fifth experimentally verified state of matter after solid, liquid, gas, and electromagnetic plasma. On top of the QGP studies, ALICE has a strong QCD physics programme in proton-proton data taking.

In 2024, the third year of running with the upgraded ALICE, we recorded Pb-Pb data routinely at 50 kHz rate at the beginning of the fills. Enabled by the higher rate, we collected 1.6/nb of heavy ion data – the same size as the 2023 sample – in a much shorter time. ALICE reached the target of 5.3/pb of pp reference data measured with the same energy as Pb-Pb, and we collected 53/pb of minimum bias pp-collisions at full energy and continuous readout scheme.

The Fast Interaction Trigger (FIT) detector is pivotal for ALICE operation. FIT delivers triggers for the detectors that need them, provides online luminosity monitoring, a precise collision time, and an unbiased sample of the forward multiplicity needed to extract the centrality and the reaction plane of the colliding heavy ions. At the end of 2024, after leading the project for 14 years, including the conceptual design, production, and installation phase, W. H. Trzaska handed over the FIT project leadership to J. Otwinowski from IFJ-PAN, Krakow, Poland. This generation change was prompted by Trzaska's retirement from the University of Jyväskylä in June 2023. Nevertheless, HIP maintains a strong contribution to FIT software development, provides expert shifts, and has the key responsibility for monitoring and mitigation of photosensor ageing.

In physics analysis, we concentrate on collective flow phenomena and jets, both aiming to constrain the QGP matter properties. In 2024, we celebrated A. Önnerstad's PhD defence on flow measurements. We released a groundbreaking paper (*arXiv:2409.04238*) showcasing 25 flow harmonic correlators – 16 of which are entirely new – and offering the first-ever measurement of correlations between five distinct symmetry planes. These correlators provide unique constraints to phenomenological models and deepen our understanding of the properties of the QGP. In small system studies, we submitted another paper exploring jet quenching effects in high-multiplicity pp collisions (*arXiv:2409.04501*). M. Virta presented this work at the Hard Probes 2024 Conference. Our goal is to measure the flow of heavy flavour particles and their flow correlations with light hadrons to gain understanding of heavy flavour particle interactions in the QGP.

The Technical Design Report of the new forward calorimeter, FoCal, was released in 2024. The main physics goal of FoCal is the search for clear experimental signals on gluon saturation. FoCal will be instrumented for the LHC Run 4, starting in 2030. We are preparing to start the production of the pixel half-layers to the electromagnetic calorimeter in FoCal, making use of the brand-new automated bonder at the HIP Detector Laboratory. The pixel layers will provide millimetre-scale separation of the EM showers at forward rapidities, enabling neutral meson reconstruction in new regions of phase space.



ALICE measurements for event plane correlations compared to EKRT model calculations. Both the experimental analysis and theory predictions were reached by researchers at the Centre of Excellence in Quark Matter, Jyväskylä. *[ALICE Collaboration, arXiv:2409.04238].*

JANNE PAKARINEN
ISOLDE
project leader

ISOLDE

In 2024, ISOLDE continued to be a pivotal experimental infrastructure within the CERN complex, delivering 340 shifts to various experiments, including 89 shifts to HIE-ISOLDE experiments. At ISOLDE, radioactive nuclides are produced through spallation, fission, or fragmentation reactions in a thick target, irradiated with a proton beam from the PSB at an energy of 1.4 GeV and an intensity of up to 2 microA. This process has enabled the production of over 1000 isotopes of 74 elements, with half-lives down to milliseconds, at intensities reaching up to 10^{11} atoms per microA proton beam. The wide range of available radioactive species facilitates the systematic investigation of atomic and nuclear properties of nuclei far from β-stability, supporting a diverse physics programme.

Among the notable achievements in 2024, ISOLDE researchers co-authored several significant papers. One such paper, published in *Nature Physics*, detailed the precision spectroscopy and laser-cooling scheme of a radium-containing molecule. This study, co-authored by R. de Groote and S. Kujanpää from the University of Jyväskylä (JYU), highlighted the sensitivity of radium monofluoride molecules to symmetry-violating nuclear properties and their potential for laser cooling. The research demonstrated an improvement in resolution by more than two orders of magnitude compared to previous studies, offering new opportunities for fundamental physics, chemistry, and astrophysics.

Another significant publication in *Physical Review Letters* investigated the decays of β-delayed neutron emitters ^{51,52,53}K. This research, conducted at the ISOLDE Decay Station, provided new insights into the β-delayed neutron-emission process, challenging long-standing hypotheses and proposing new mechanisms for neutron emission.

ISOLDE's contributions extended beyond these highlights, with other papers published by HIP-ISOLDE affiliated researchers. These included studies on the magnetic moments and charge radii of thallium isotopes, the detailed structure of ^{131}Sn, and the β decay of ^{216}Bi, among others. Additionally, HIP-ISOLDE researchers participated in various experiments, such as β-decay spectroscopy with laser-polarized beams of neutron-rich potassium isotopes, mass measurements of neutron-deficient ^{96}Cd with ISOLTRAP, and laser and decay spectroscopy and mass spectrometry of neutron-rich mercury isotopes south-east of ^{208}Pb.

The year also saw the acceptance of a beamtime proposal titled "Mapping single-particle neutron strength towards the mid-shell in semi-magic lead isotopes", with J. Ojala and J. Pakarinen from JYU as spokespersons. A. Kankainen's term as an INTC member concluded, and J. Pakarinen chaired the selection committee for the next ISOLDE section leader. Furthermore, V. Repo from JYU participated as a HIP summer student in the MIRACLS project, which aims to enhance the sensitivity of collinear laser spectroscopy for studying the structure of radioactive atomic nuclei.

Overall, 2024 was a year of significant achievements and contributions for ISOLDE, reinforcing its pivotal role in advancing nuclear physics research.

FAIR (Facility for Antiproton and Ion Research in Europe GmbH) Operations

TUOMAS GRAHN
FAIR
project leader

The FAIR accelerator laboratory (https://fair-center.eu/) is set to begin operations with new accelerators at the end of 2027. Currently, the installation of the SIS100 synchrotron components is ongoing, and the civil construction of experimental areas of the NUSTAR and CBM experiments is finished.

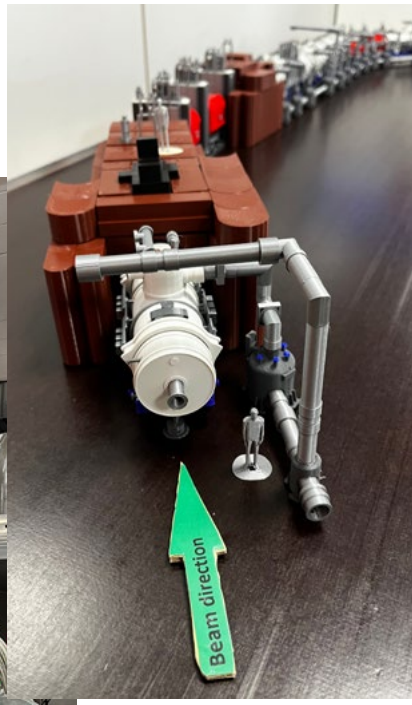
After its commission, FAIR will provide high-energy particle and antiparticle beams up to 99% of the speed of light, serving the four experiments (or *pillars*) that are NUSTAR, CBM, PANDA and APPA. Together they will cover multidisciplinary science cases of nuclear physics and astrophysics, elementary particles, material physics and medical applications.

Finland is mainly participating in the NUSTAR experiment in studies of nuclear physics. The main instrument of NUSTAR, the Super-FRS separator-spectrometer (see the figure on the far right), will be the priority in FAIR commissioning. Finland will deliver important components and instrumentation for the Super-FRS and the NUSTAR experiment and therefore our role in FAIR commissioning is highlighted. The beam particle identification depends largely on the in-kind contributions of Finland.

Naturally, the completion of FAIR has been a key focus of the programme in 2024. The beam diagnostic and tracking detector package of the Super-FRS is largely the responsibility of Finland. Therefore, the final design of the GEM-TPC tracking detectors and its readout electronics began, together with its mechanical insertion device (designed in collaboration with the University of Jyväskylä). The two first-of-series units of the beam insertion device were delivered to FAIR.

The FAIR Phase-0 experimental programme, which is being carried out using the existing infrastructure, continued providing beam time for several experiments. HIP researchers were involved in several of them within the NUSTAR Collaboration. For instance, spectroscopy of neutron-rich rare earth element isotopes was carried out, providing new information about the collective properties of these nuclei. They are also relevant for a more comprehensive understanding of the r-process nucleosynthesis. In these experiments HIP researchers were in leading roles.

In addition, a new PhD researcher (J. Ahokas) started in the team to work on the data originating from the Phase-0 experiments. The project deals with measurements of production cross sections of heavy neutron-deficient nuclei following high-energy fragmentation reactions. This project is part of the larger programme to map the production of different nuclei in fragmentation reactions to benchmark models, and also to provide data that aids experiment preparation at the Super-FRS.



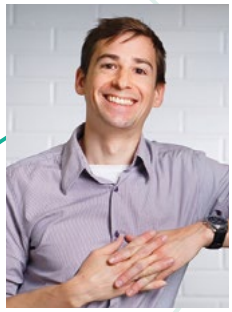
3D-printed model of Super-FRS at FAIR.

T. Grahn next to the beam insertion device of Super-FRS.

TECHNOLOGY PROGRAMME

FILIP TUOMISTO
Technology Programme director

The Technology Programme aims to integrate HIP projects with significant technology development, transfer, and pre-commercialisation activities into the same programme. In addition, the research activities performed within the programme are designed to seek synergies with big science initiatives at large. The programme consists of three larger projects dealing with robotics for monitoring and intervention purposes in accelerator tunnel conditions, materials technology challenges in existing and new large accelerators, as well as radiation and nuclear safety, security, and safeguards. These projects have strong connections with CERN and STUK. In addition, the programme hosts one smaller project that focusses on radiation detection technologies in close co-operation with CEA (France). Several projects have been successful in raising external funding for the R&D work, strengthening the impact of the programme.



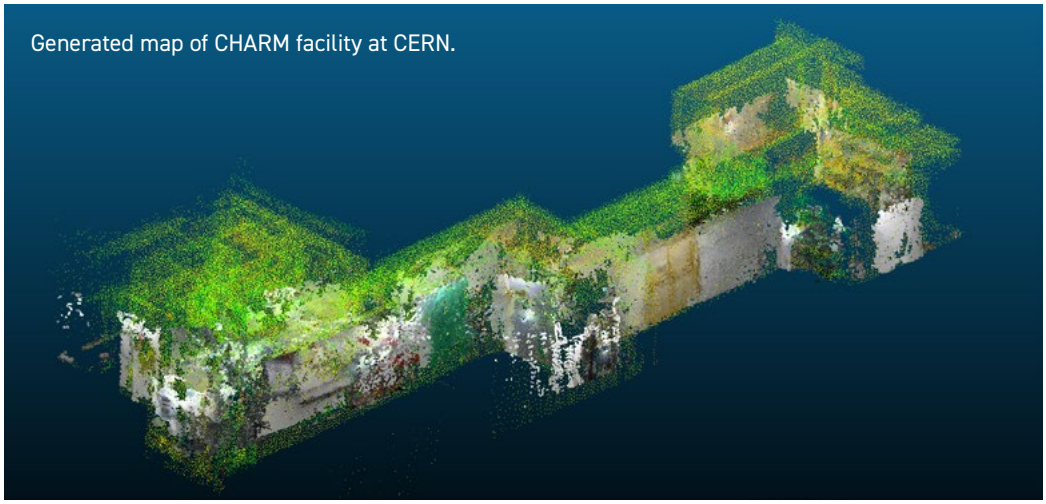
ROEL PIETERS
Robotics and AI for Monitoring and Intervention (ROBOT) project leader

Robotics and AI for Monitoring and Intervention (ROBOT)

The ROBOT project of HIP's Technology Programme aims to utilise robotics and AI for assistance in monitoring and intervention of CERN's accelerator infrastructure.

1. *Perception for robot manipulation.* Tampere University has been investigating visual perception approaches for extracting relevant information from RGB and depth sensors for automatic robot assembly actions. An assembly pose estimation method for robot manipulation and assembly tasks utilises semantic segmentation and point cloud registration between target and source point clouds. The approach is evaluated with suitable metrics on two simulated gear assembly datasets, which indicates that point cloud registration is well capable of estimating 6D assembly poses for object assemblies. As collecting real data is time-consuming and costly, a simulation-based approach generates suitable data. This work was part of the research work of E. Airaksinen and K. Samarawickrama's doctoral studies.

2. *Mobile robot mapping and navigation.* Aalto University collaborated with CERN's robotics development team by having a doctoral researcher (P. Habibiroudkenar) visit CERN for 7 months. Key contributions of the collaboration included enhancements to teleoperation and robot autonomy. A LiDAR



Generated map of CHARM facility at CERN.

simultaneous localisation and mapping (SLAM) method was implemented in CERN Robotics Framework (CRF) and tested in CHARM, SPS, and the Tunnel Mock area. A key contribution of the 3D approach was the utilisation of ceiling-point features in the graph-based SLAM. The SLAM contributions are highly beneficial for CHARMBot, used for remote inspections in the CHARM facility. The robot has faced connectivity issues in the challenging conditions of CERN facilities, causing problems in teleoperation. Consequently, the aim is to increase the autonomy of the robot with intelligent features, such as the presented SLAM approach. Development plans for 2025 include testing 3D mapping in CERN tunnels, and integrating additional components and algorithms for safer, more efficient remote operations.

Aalto doctoral researcher P. Habibiroudkenar carrying out on-site testing at CERN.

Improved Detection for Elemental Analysis at Laboratory (IDEAL)

X-ray absorption spectroscopy (XAS) is a non-destructive method allowing the direct characterization of the electronic structure (degrees of oxidation) and the local environment (co-ordination geometry) of a given element in any kind of sample (solid, liquid, gas). During its century long history, XAS has been an essential approach in many fields of science, ranging from physics and chemistry to materials science or medicine and biology. However, contrary to other structure elucidation methods such as, e.g., X-ray Diffraction (XRD) or X-ray Photoelectron Spectroscopy (XPS), the XAS measurements are almost exclusively performed at synchrotron radiation sources.

Thanks to recent developments, the renewal of laboratory XAS instruments with performance complementing the synchrotrons is now a reality. These new instruments overcome the most serious disadvantage of synchrotron radiation research: its very limited access, which often renders it difficult to measure samples relevant to current research within an acceptable time and excludes de facto routine experiments. Despite their quickly demonstrated performance and versatility, still one main issue restrains the laboratory-based spectrometers: the non-simultaneous collection of the incident and the sample transmitted photon intensities.

In laboratory-based instruments, data is usually collected separately by performing the experiment sequentially: with and without a sample, while being collected simultaneously at synchrotrons using, e.g., ionization chambers placed before and after the sample. This strategy suffers from the fact that it requires two separate measurements instead of one, which increases the overall time required for the data collection as well as the risk that any instability remains unnoted or wrongly attributed to the sample. The main reason behind this two-step approach is the limited number of available photons produced by X-ray tubes, with intensities several orders of magnitude below those observed at synchrotrons. Therefore, in the laboratory, all photons spared for the actual measurements are important to keep the data collection time reasonable. More efficient detectors are thus required, but detectors having an energy resolution worse than 400 eV are excluded due to the presence of harmonics arising from the use of single Bragg's optic.

The IDEAL project aims to investigate potential answers to this limitation, focussing on the development of new design for the detection system.

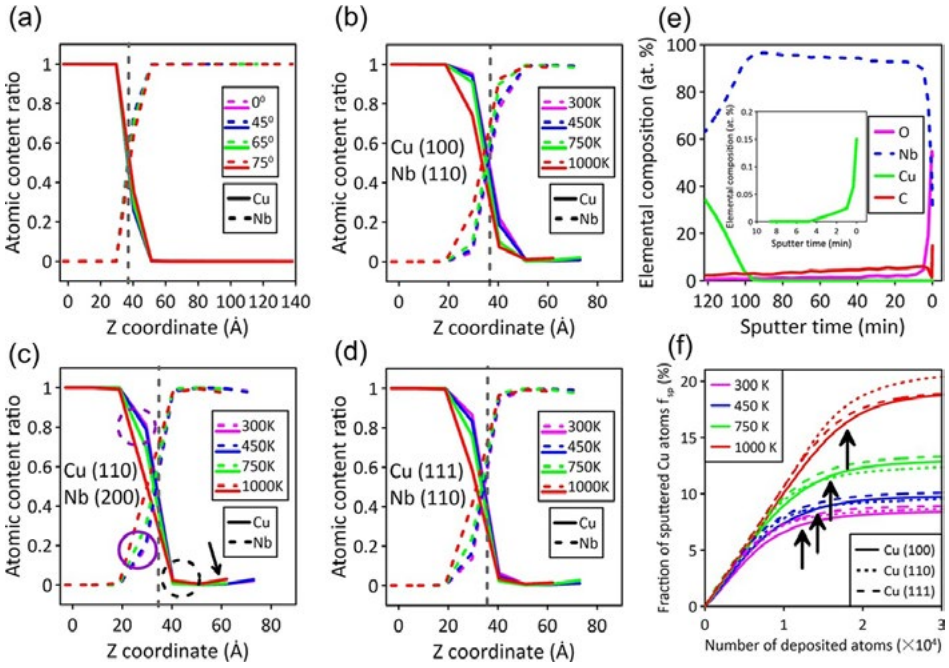
RENÉ BÈS
Improved Detection for Elemental Analysis at Laboratory (IDEAL) project leader

FLYURA DJURABEKOVA
Materials for Accelerator Technology (MAT) project leader

Materials for Accelerator Technology (MAT)

The project Materials for Accelerator Technology (MAT) focusses on materials-related problems faced in particle accelerators. Vacuum arcing as a long-standing problem in rf-accelerating structures for the electron-positron Compact Linear Collider (CLIC) project at CERN is in the focus of the MAT project. Our multiscale model includes different physical processes that take place at different time and length scales. The exciting high-energy physics relies on materials capable to withstand the extreme condition of electromagnetic fields and particle irradiation. Recently, the MAT project has initiated a collaboration with the CERN team exploring the possibilities of building a muon collider. The new study aims to exploit the properties of muon particles to reach even higher collision energies compared to those planned within the CLIC study. In this design, the accelerating structures developed for CLIC are exposed to one more external condition such as a strong magnetic field. High magnetic fields have been shown to increase occurrence of vacuum arcing, suggesting involvement in the arcing mechanism. A possible origin for this effect is the focussing of emitted electron beams, leading to an increased heating of metal surfaces and plasma formation. Our simulations show a significant increase in the electron current density when the electric and magnetic fields are in the parallel configuration, resulting in very high temperatures at the beam impact site. These results suggest an anodic arc initiation mechanism at high magnetic fields of the order of 10 T, in contrast to the mechanism considered under high electric fields in the CLIC accelerating structure.

We also focus on improving the quality of the superconducting thin films that are deposited via a more advanced thin film deposition technique also known as HiPIMS (High-Power Impulse Magnetron Sputtering). The technique is proposed to replace the expensive production of pure Nb superconducting cavities for the Future Circular Collider, the next generation of hadron colliders under investigation at CERN. In the figure below we show the concentration profiles of Cu (solid lines) and Nb (dashed lines) along the z-axis after simulations (a)-(d). Panel (a) displays direct current magnetron sputtering (DCMS) results at 450 K, the different line colours show the different deposition flux angles θ. The results in (b)-(d) show that the HiPIMS deposition causes erosion of the substrate and is sensitive to surface orientation. We clearly observe the Cu precipitation at the Nb surface that was also confirmed in experiments, see (e).



Atomic dynamics during the superconducting Nb thin film growth on a Cu substrate by the High-Power Impulse Magnetron Sputtering (HiPIMS) technique (b-d). The comparison with the standard Direct Current Magnetron Sputtering (DCMS) technique shown in (a) reveals a much stronger atom mixing at the Nb-Cu interface. Although during the HiPIMS deposition the film grows much denser, the Cu atoms mix in and precipitate at the surface which our simulations showed in agreement with experiment (e). We also notice a significant dependence of erosion on the surface orientation. The difference increases with rising temperature (f). *[M. Ghaemi et al., Surf. Coat. Tech. 476 (2024) 130199].*

Radiation and Nuclear Metrology, Safety, Security and Safeguards Applications (RAD3S)

TEEMU SIISKONEN
Radiation and Nuclear Metrology, Safety, Security and Safeguards Applications (RAD3S) project leader

The RAD3S project investigates and develops new measurement and analysis methods, produces basic physical data, and uses computational methods to foster radiation and nuclear safety, security, and safeguards.

In medical applications, the focus was on the safety of external beam radiotherapy. Neutron, proton and heavy ion dosimetry development continued with a new design and successful tests of a neutron production target. Spectrometric characterization and reference-level dosimetry of the neutron beam will be done in 2025 in collaboration with STUK and Instituto Nazionale di Fisica Nucleare (INFN). Optimisation of patient positioning imaging in radiotherapy using cone beam computed tomography (CBCT) was investigated in a project with the European Radiation Dosimetry Group (EURADOS). The project analysed imaging practices in Europe and used Monte Carlo simulations to assess patient organ doses resulting from recurrent CBCT imaging. Despite technical developments in imaging devices, cumulative organ doses of the order of 1 Gy are possible in the imaged region and there is a continuous need for dose optimisation to reduce the adverse health effects from imaging. In an EU-funded RadonNET project calibration and quality control methods for distributed sensor networks were investigated in a collaboration consisting of 12 European countries.

Imaging of gamma-ray emission aiming at identifying radioactive materials and establishing their distribution, has various applications. We are working to improve imaging of spent nuclear fuel in the context of nuclear safeguards inspections, which are aimed at verifying the non-diversion of declared nuclear material. Instruments currently used for this Passive Gamma Emission Tomography (PGET) contain small gamma-ray detectors, resulting in poor gamma-ray detection efficiency. We are investigating, both experimentally and via simulations, the impact the use of large position-sensitive semiconductor detectors will have. In parallel, we are improving the image reconstruction algorithms. In the context of decommissioning nuclear facilities, we are comparing the imaging performance of two commercial gamma cameras in realistic situations.

In the Radiation detection sub-project, we try to improve the techniques used to detect and identify sources of radiation in various environments, applied to safety, security and safeguards. The main work carried out in 2024 was to continue the development and testing of an improved detection system for lung counting. Lung counting is used to detect small amounts of heavy elements such as Am, U, or Pu that might have been inhaled. Building upon earlier work to implement a simulation package in GEANT4 using ICRP computational phantoms, detector systems employing a segmented germanium detector with active and passive shielding of background and Compton-scattered gamma-rays were compared. It was shown that it is possible to significantly reduce the minimum level of activity that can be detected. Further experiments were carried out using a prototype detector to confirm the results from simulations.

OTHER PROJECTS

CLOUD

MARKKU KULMALA
CLOUD
project leader

The Cosmics Leaving Outdoor Droplets (CLOUD) experiment at CERN is dedicated to unravelling aerosol particle formation and cloud processes and their role in climate. Aerosols are a key component of the Earth's climate system. They influence the planet's energy balance directly by scattering or absorbing sunlight and indirectly by acting as seeds for cloud droplets or ice crystals. These processes affect how clouds form, how long they persist, and how much sunlight they reflect, which in turn impacts the Earth's overall reflectivity, or albedo. Understanding aerosols is particularly critical as climate change accelerates, bringing more frequent extreme weather events and rising global temperatures. By improving our knowledge of aerosol formation and their interactions with the atmosphere, the CLOUD experiment is helping to refine climate models and inform strategies for mitigating environmental changes. The CLOUD project is a collaborative effort involving more than 20 leading research institutions worldwide, with a strong contribution from Finland.

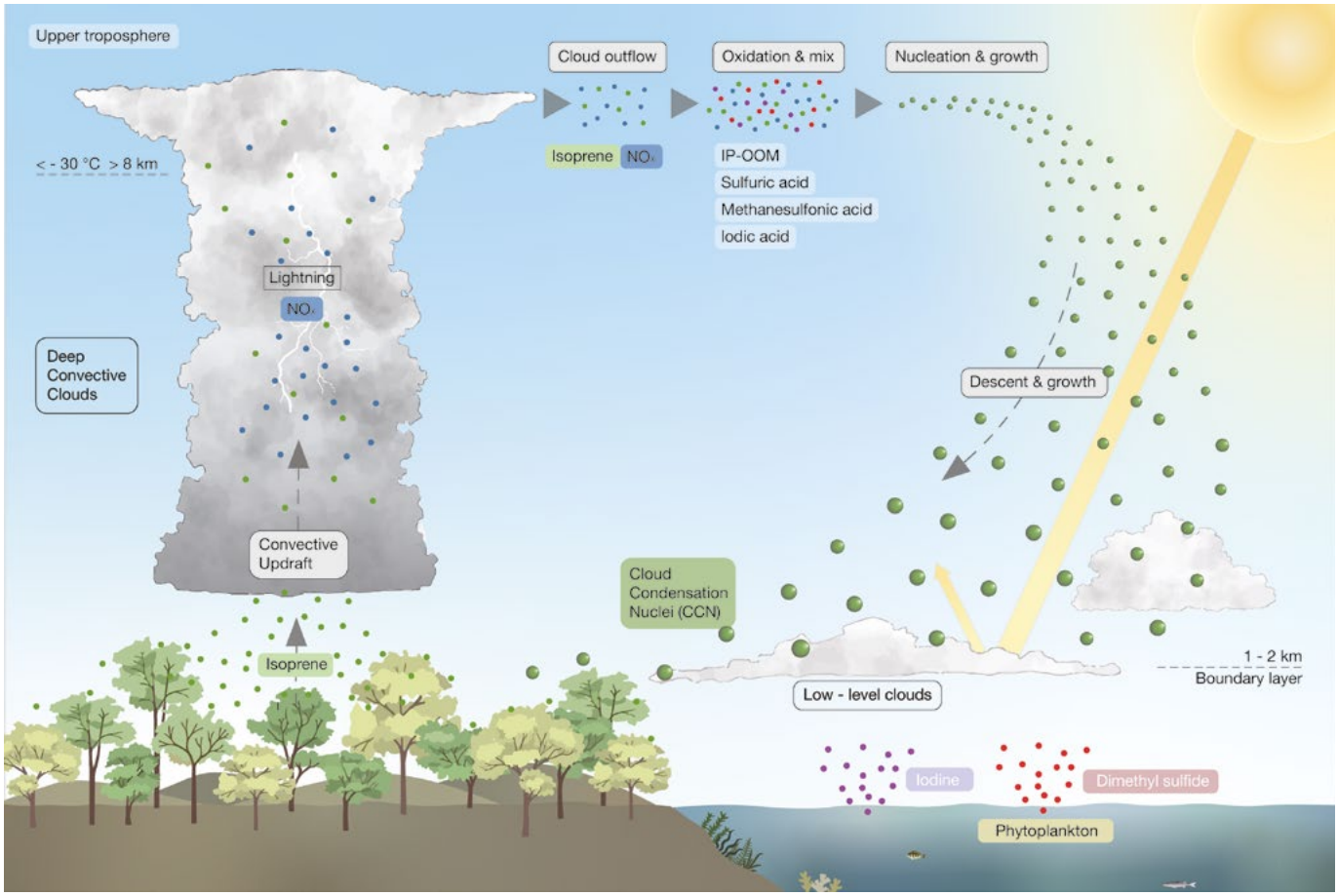
The CLOUD chamber at CERN is one of the world's most advanced laboratory facilities capable of studying aerosol particle formation under highly controlled atmospheric conditions. It operates with exceptionally low levels of contamination and with a wide array of cutting-edge instruments that allow us to precisely isolate and examine the complex mechanisms driving aerosol formation from various chemical precursors under different environmental conditions. The effect of galactic cosmic rays (GCR) is studied by using CERN's proton synchrotron, which can be used to simulate the GCR ionization at different altitudes of the atmosphere.

Since its inception in 2009, CLOUD has uncovered several key mechanisms behind aerosol particle formation, earning widespread recognition within the scientific community and significantly advancing the field of atmospheric science. For instance, recent experiments (2023) in the CLOUD chamber demonstrated that, in

addition to sulfuric acid and alpha-pinene, iodine oxoacids (HIO_x) can rapidly drive new particle formation and play a critical role in marine aerosol processes.

During the CLOUD17 campaign in September-December 2024, we investigated several topics related to aerosol formation and cloud processes, including particle formation in upper tropospheric and free tropospheric conditions, as well as in conditions representing the Arctic and Southern Ocean regions. We also did experiments related to ice nucleation and aerosol charging processes.

The collaboration resulted in the publication of eight peer-reviewed papers in 2024. Among them, *Shen et al.* [*2024, Nature*] demonstrated that new particle formation can be triggered by isoprene under upper-tropospheric temperatures of -30 °C to -50 °C. This paper, along with *Curtius et al.* [*2024, Nature*], jointly secured the cover for that issue, since they indicate that isoprene released from tropical forests is a major compound responsible for forming particles in the upper troposphere.



Isoprene from forests is efficiently transported at night by deep convective clouds into the upper troposphere. During daylight, the isoprene accumulated overnight, together with daytime-convected isoprene, reacts with hydroxyl radicals and NO_x from lightning to produce IP-OOM. The IP-OOM combine with trace ambient acids to produce high particle-number concentrations at cold temperatures below -30 °C. The newly formed particles grow rapidly over several hours to days while following the descending air masses. This mechanism may provide an extensive source of CCN for shallow continental and marine clouds, which strongly influence Earth's radiative balance. *[J. Shen et al., Nature 636 (2024) 115], CC BY license.*

HANNU KURKI-SUONIO
Euclid project leader

ELINA KEIHÄNEN
Euclid project leader

Euclid

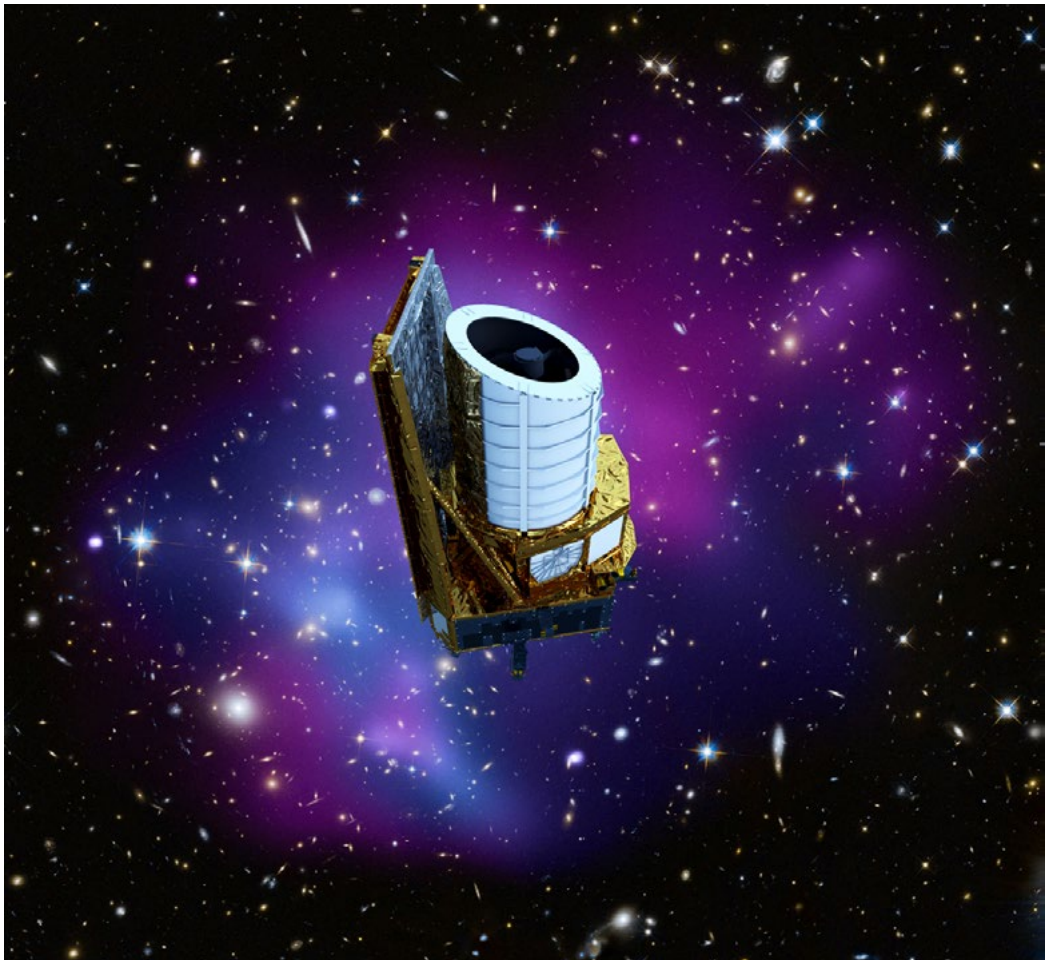
The Euclid satellite of the European Space Agency was launched in July 2023. After an initial calibration and testing phase, collection of scientific data began in February 2024. The goal of the Euclid mission is to solve the mystery of dark energy: What is causing the accelerated expansion of the universe?

The long-time leader of the Finnish Euclid team, Prof. H. Kurki-Suonio, retired in summer 2024. The leadership of the Finnish participation in Euclid was shifted to Dr. E. Keihänen.

The year 2024 was an important milestone for the Finnish Euclid Data Center (SDC-FI), as flight-data started arriving in February. Early on, it was clear that some of our storage solutions were unsuitable for full-scale analysis. As a result, we spent the first half of the year migrating to different systems. This migration was completed by the end of summer, and the data center has been stable and performing well since then.

The Finnish Cosmology Data Center (CDC-FI) was accepted to the infrastructure roadmap of the Research Council of Finland, ensuring long-time hardware funding for both Euclid SDC-FI, and for the LISA Data Center.

We continued our work on error estimation for an important Euclid observable: the galaxy clustering correlation function. We have developed an algorithm that speeds up the covariance matrix estimation drastically. In 2024, we applied the method to Euclid-like simulated data and worked on integrating it into cosmological analysis.



Artist's impression of Euclid. *Credit: ESA/ATG medialab (spacecraft); NASA, ESA, CXC, C. Ma, H. Ebeling and E. Barrett (University of Hawaii/IfA), et al. and STScI (background).*

Euclid's new image of the star-forming region Messier 78. *Credit: ESA/Euclid/Euclid Consortium/NASA, image processing by J.-C. Cuillandre (CEA Paris-Saclay), G. Anselmi.*

On the simulation side, we focussed on improving tools for validating simulated Euclid data. A key validation challenge is managing large FITS-format datasets, stored across multiple SDCs. We developed FitsFileViewer, a Visual Studio plugin that simplifies FITS file inspection and can be used beyond Euclid projects. In the latter half of the year, we concentrated on gaining hands-on experience with running the NIR (near-infrared spectroscopy) pipeline.

In the Euclid Theory Working Group we extended our earlier estimates for the constraining power of Euclid on the early universe (inflation) models and took important steps in modelling the later non-linear structure formation.

Many of the traditional methods for the analysis of the galaxy surveys are designed for local measurements. We developed the FuGa3D code for full-sky analysis of Euclid observables, to exploit the wide-sky nature of Euclid observations. FuGa3D builds on techniques developed for CMB (cosmic microwave background) data analysis.

In 2024 the Euclid Collaboration produced over 40 publications which describe the mission and various aspects of its data analysis.

KATRI LASSILA-PERINI
Education and Open Data project leader

Education and Open Data

The Education and Open Data project, led by K. Lassila-Perini, covers and connects the Finnish high-school visits at CERN, and the research and education use of the CMS experiment open data. P. Veteli leads activities promoting the use of open data in schools.

High School Visits

A teacher training week and 15 high-school group visits to CERN were organised in 2024, which was slightly below the target because of no-visit time during CERN's 70-year festivities and the uncertainty about the visit organisation funding. Continuing from long-term support by the Finnish National Agency for Education, the activities are now enabled by a grant from the Technology Industries of Finland Centennial Foundation. The programme consists of lectures and laboratory visits during which students and teachers can engage with and learn from the scientists at CERN. A hands-on laboratory and exhibition at the Science Gateway enriches the three-day visit programme. Feedback is collected with the vision of assessing the long-term impact of the programme.

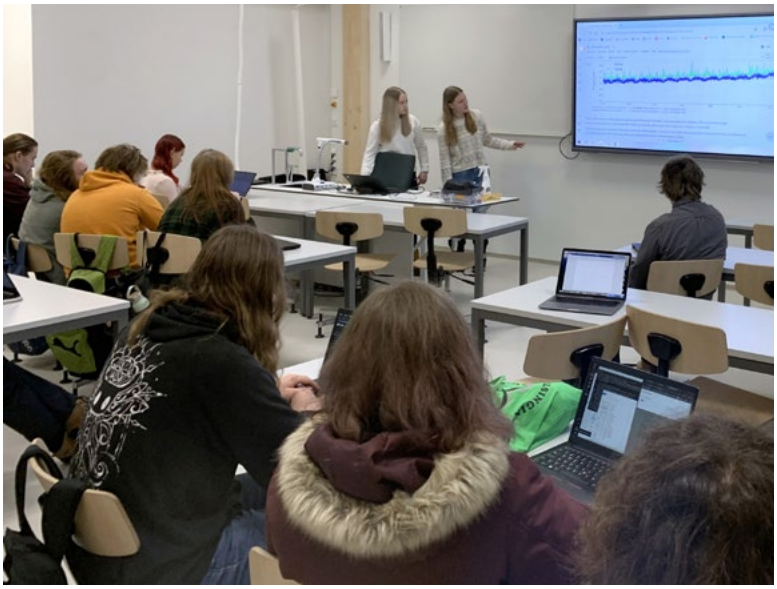
Open Data in Research

The CMS Data Preservation and Open Access group, led by K. Lassila-Perini until August, manages data and knowledge preservation in CMS. Data releases are a standard practice, the latest in April with nearly 1 PB of data and simulations from 2016, available now in a format independent of the CMS experiment software, lowering considerably the threshold for their use. We explored, in collaboration with students from Lapland University of Applied Sciences, using public cloud resources to process open data, also presented at the Conference on Computing in High Energy and Nuclear Physics. K. Lassila-Perini has now assumed leadership of the ICFA Data Lifecycle panel, bringing expertise gained while leading open data activities in CMS to a wider context.

Open Data in Education

The project promotes using open data in schools with ”Jupyter Notebooks” and common Python libraries through teacher trainings, student workshops and hands-on help with regular school courses. An ever expanding collection of materials and guides can be found on the project’s website https://opendata-education.github.io/ in Finnish, Swedish, and English.

Co-operation with high schools and research groups like INAR was prominent throughout the year. We participated in the design and execution of several courses, held workshops for teachers and students in multiple schools, and hosted school visit activities at Kumpula campus. Many of these are set to continue in 2025. Active engagement in in-service and pre-service teachers’ events included the international Teachers’ Climate Change Forum, a teaching planning day and a teacher education field course (at Hyytiälä Research Station) as well as a large teacher networking event (LUKEMA) in Tallinn. MSc P. Veteli’s PhD project produced two publications in 2024 and included active participation and presentations in scientific conferences: the Subject Didactic Symposium (Helsinki), Physics Days (Helsinki), the 4th World Conference on Physics Education (Krakow), TCCF (Hyytiälä), and STEM Education Research Days 2024 (Joensuu). This work is made possible through a grant from the Magnus Ehrnrooth Foundation.



Open data in use in a sustainability course at Helsinki Upper Secondary School of Natural Sciences.

DETECTOR LABORATORY

MATTI KALLIOKOSKI
Detector Laboratory director

The Helsinki Detector Laboratory specialises in the instrumentation of particle and nuclear physics. It is a joint laboratory between HIP and the UH Department of Physics, especially the Division of Particle and Astrophysics (PAP).

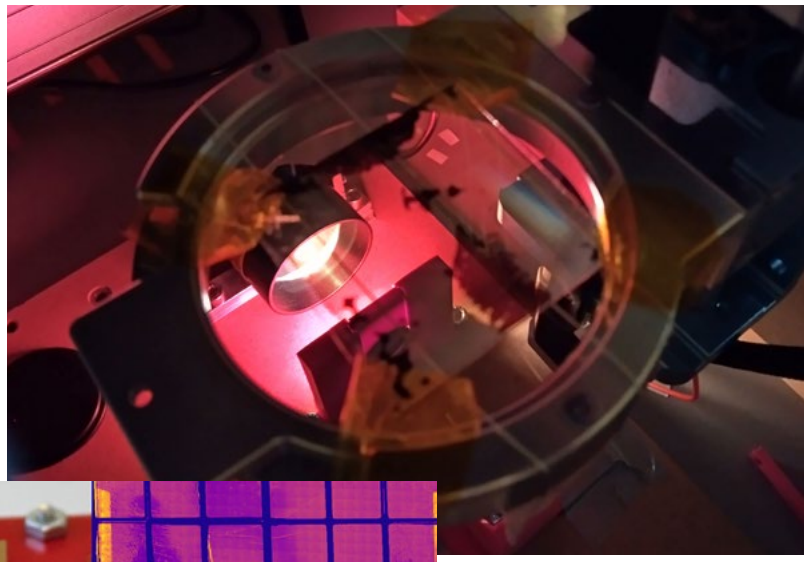
In 2025, the production phase for several Laboratory hosted projects, such as detector assemblies for the CMS and ALICE experiments, and activities for the FAIR facility are planned to be commenced. Thus, the Laboratory has been active in updating the Laboratory infrastructure and making space for new devices and tools.

For the COSINUS project, we finalised the installation of the magnetic field compensation coil in Gran Sasso. For the POSEIDON project, we took part in several measurement campaigns in Uppsala and at SVAFO AB. In addition, the germanium detector of the Laboratory was used in the radiation analysis at the Svedberg Laboratory.

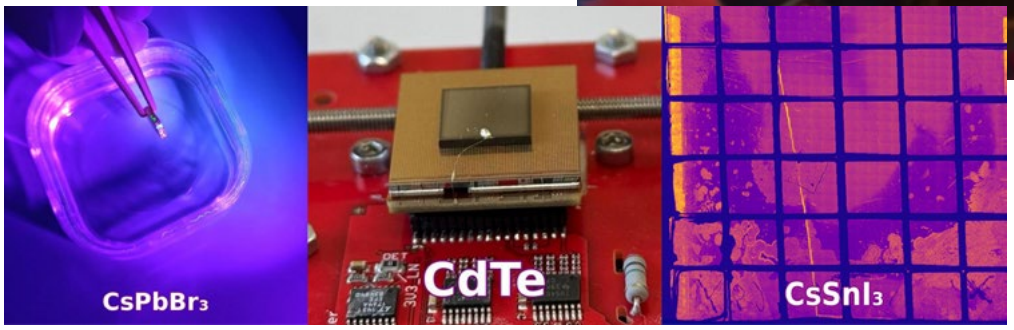
The Laboratory is a member of the MoEDAL-MAPP experiment at CERN. In 2024 we started scanning the Nuclear Track Detector foils of the experiment. This work will continue through 2025. With our innovation in CR39 imaging, we can push the sensitivity of these detector foils to unprecedented levels.

For room temperature semiconductor research, we developed new tools and characterization methods. We also studied several materials, such as CdTe, CZT, GaAs, and perovskites. The highlight of the developments has been the measurements we did together with the HEXITEC group at the STFC RAL. These showed good response of the sensors we have developed in Helsinki.

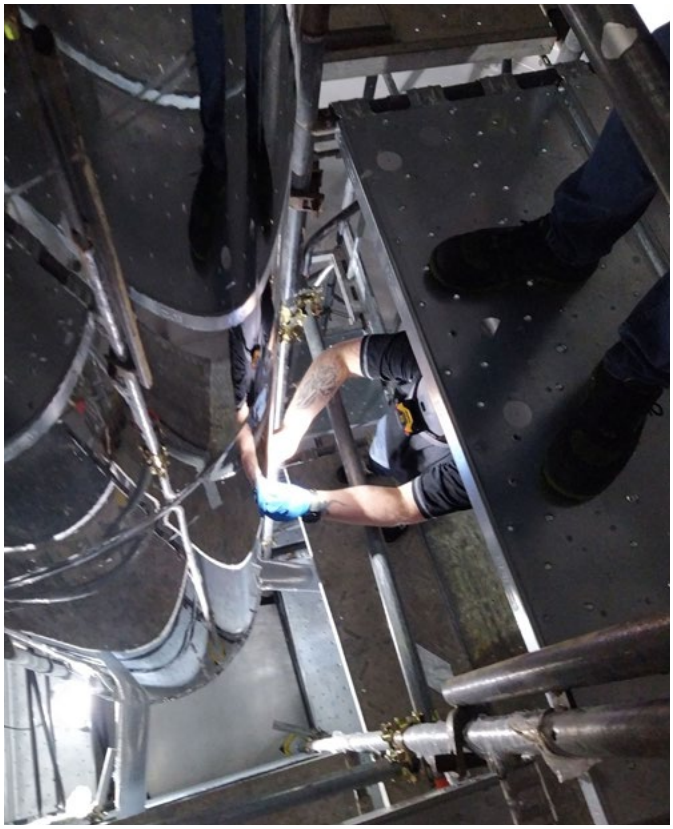
The Scintillator Apparatus at Hyytiälä for the Total Ionization measurements (SAHTI) project for the SMEAR II station will introduce a scintillator-based measurement system for environmental radiation measurements. This includes a large area detector for cosmic background measurements. Installation of the system at Hyytiälä is planned for the first part of 2025.

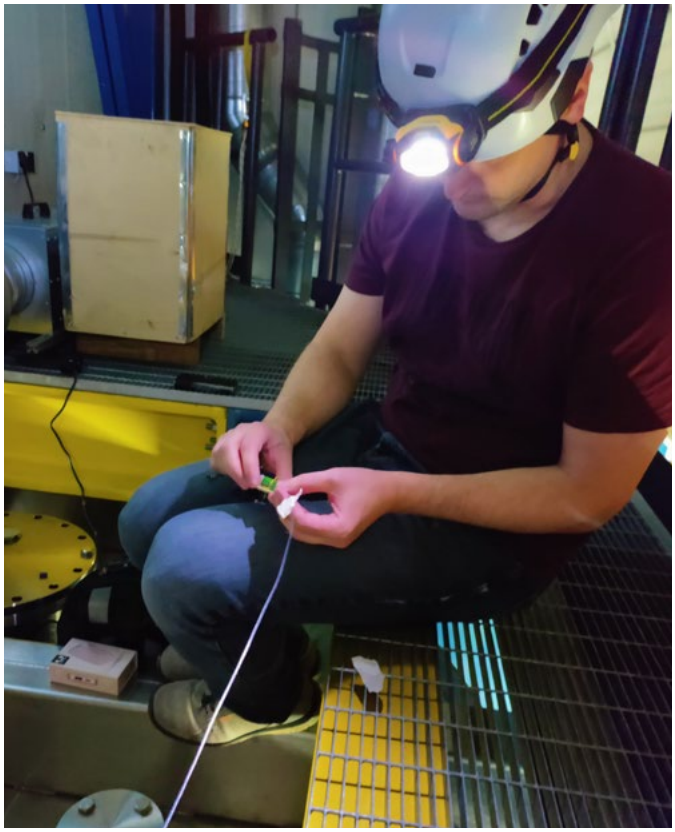


Transmittance scanning of a perovskite film at the Detector Laboratory. *Credit: M. Kallikoski.*

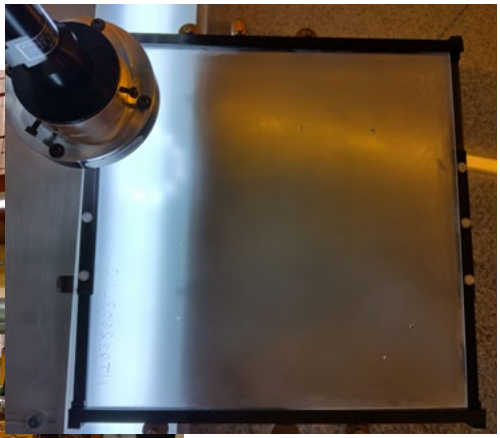


Various radiation detector sensor materials that have been studied at the Detector Laboratory in 2024. *Credit: M. Bezak.*





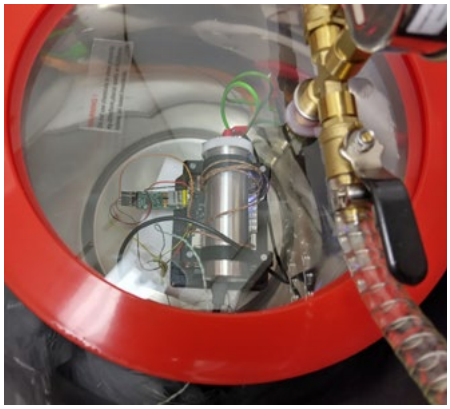
Installation of the magnetic field compensation coil to the walls of the drywell of the COSINUS experiments at Gran Sasso.
Credit, left image: M. Kallikoski, right image: R. Turpeinen.



MoEDAL Nuclear Track Detector foil being scanned with the Optical Scanning System of the Detector Laboratory.
Credit: M. Kallikoski.

The Germanium Gamma-ray Imager of the Detector Laboratory during a measurement campaign at the Svedberg Laboratory in Uppsala. *Credit: M. Kallikoski.*

Senior laboratory technician R. Turpeinen monitoring the gamma-ray background at the SMEAR II site in Hyytiälä by using the Germanium Gamma-ray Imager (GeGI) of the Detector Laboratory.
Credit: M. Kallikoski.



The BISSE spectrometer in vacuum tests at the Detector Laboratory.
Credit: M. Kallikoski.

The Balloon-borne Instrument for Spectral Scanning of high-altitude Environments (BISSE) spectrometer was developed together with STUK and FMI. It is a light-weight measurement unit that will be carried by a weather balloon for high-altitude measurements. In 2024 we finalised the design and made a series of tests in a temperature cycle chamber and at a vacuum vessel proving the suitability of the system.

The Laboratory supports the teaching in the PARAS programme. The main support is for the Laboratory Course in Instrumentation, where students actively work at the Laboratory, but also for the other courses where measurements are needed. In addition, we have several doctoral researchers, and master's and bachelor's students working in the Laboratory.

Special effort was devoted to societal interaction. In 2024, the Laboratory participated in the EU Researchers' Night at the Observatory building in Helsinki. In addition, we hosted a robot building course of the neighbouring Helsinki Upper Secondary School of Natural Sciences.

SAHTI measurement setup being tested at the Detector Laboratory.
Credit: M. Kallikoski.

Detector Laboratory personnel and users visiting the SMEAR II station for planning the installations of the SAHTI setup.
Credit, left image: M. Kallikoski, right image: R. Turpeinen.

JOINT ACTIVITIES

ANTTI VÄIHKÖNEN
Research coordinator

HIP is a joint institute of five universities with the University of Helsinki as the host, with the Finnish Radiation and Nuclear Safety Authority (STUK) as an interim member since 2018, and the present membership agreement continuing until 2027. Due to its core mission, many of the research activities of HIP take place at CERN and FAIR.

2024 was a year of numerous important events. In spring, the member universities decided on their funding for HIP for the planning period 2025-2028. The Ministry of Education and Culture had already decided their earmarked funding earlier, so this settled the basic funding of the Institute for the next four years. The overall funding of HIP remains at a stable level.

The Institute's planning and strategy work continued in 2024. The Nuclear Matter and Technology Programmes organised their programme meetings in early 2024. A HIP town meeting took place in May. The long-term strategy of HIP was decided by the HIP Board in autumn. The HIP Steering Group visited STUK in June, and the Scientific Advisory Board visited HIP in August.

The year 2024 was the 70-year anniversary of CERN. Finland's Minister of Science and Culture S. Multala visited CERN, and CERN Director-General F. Gianotti visited Finland, gave a keynote speech at the CERN 70 years jubilee event organised by HIP, and met with the Minister of Science and Culture. Gianotti was also conferred an honorary doctor of the Faculty of Philosophy at the University of Helsinki.

The former long-time Administrative Manager of HIP, docent M. Sainio published a book *Helsinki Institute of Physics – the first twenty years 1996-2016* and its publication event took place in November. HIP also helped organise a visit of a group of Finnish science and technology journalists to CERN in December.

The Institute's scientific output continued strongly, in both quality and quantity. More than 95% of HIP publications are open access. Doctoral education is one of the main tasks of the Institute. A fair number of undergraduate students have also joined the research groups, often continuing as doctoral researchers in HIP projects. During the period 2020-2024, 50 doctoral degrees and 76 Master's degrees have been earned in connection with HIP research projects. The CERN BootCamp was organised, and the HIP summer student programme at CERN and ESRF continued in 2024.

SUSTAINABILITY AND RESPONSIBILITY

HIP conducts research on themes of responsibility and sustainability, including materials research on energy production technologies. We also participate in CERN's CLOUD experiment, which investigates atmospheric processes and mechanisms contributing to climate change.

HIP participates in advancing the understanding and skills related to sustainability. HIP continued to organise the annual CERN BootCamp in collaboration with three Universities of Applied Sciences, as well as CERN. The intensive course concentrates on resolving current problems related to the UN sustainability goals. The University of Helsinki, the host organization of HIP, also offers students sustainability education. The aim is to provide students with academic knowledge and skills related to sustainability.

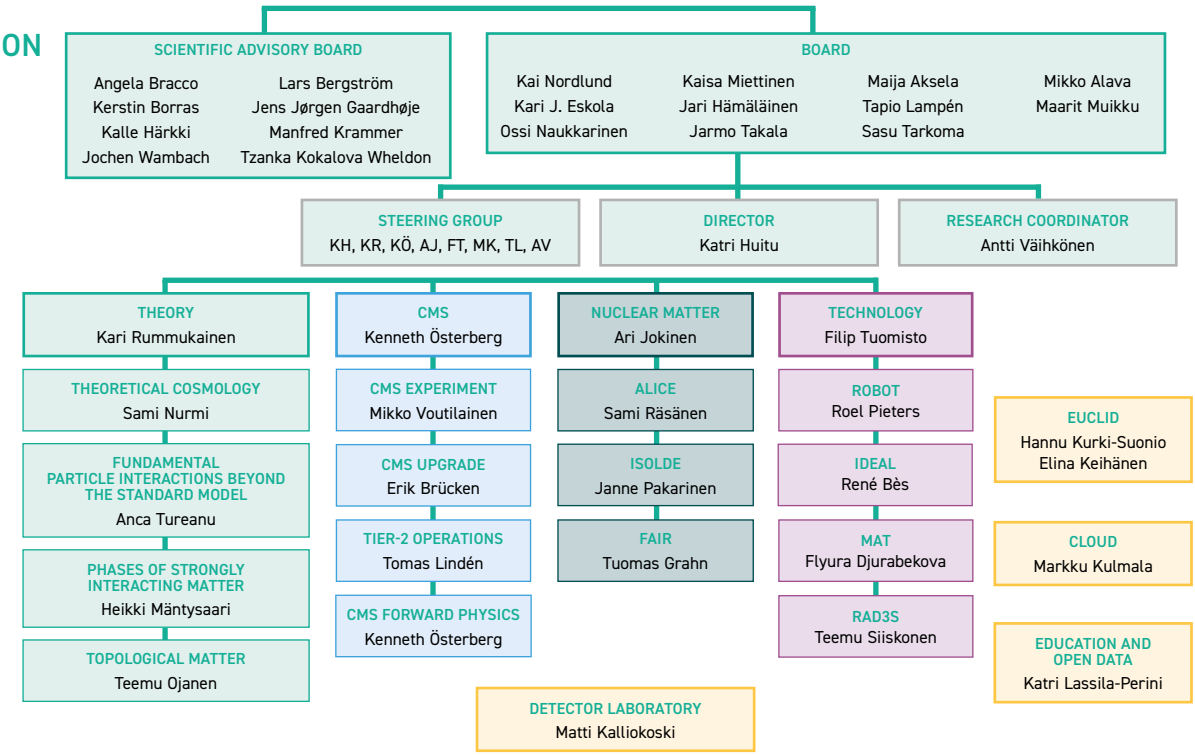
Open access to research results is an important part of the responsibility and sustainability of scientific work. Year by year, well over 95% of HIP publications are open access. Researchers at HIP have for many years been in a key position in opening data from the LHC experiments and making tools for utilising it. One important objective of HIP's Education and Open Data project is to develop discipline-independent open science tools and teach their usage to school pupils and teachers.

In 2024, HIP continued to advance sustainability by using digital tools to facilitate research and to promote a sense of community and inclusivity by enhancing accessibility. The easy-to-use streaming and hybrid meeting capabilities of the HIP seminar and meeting rooms were maintained in good condition, were in good use and worked well. Decreasing the need to travel also reduces HIP's carbon footprint.

Work wellbeing and responsible leadership are important and interlinked parts of workplace sustainability. HIP has fared well in the wellbeing surveys on supervision. HIP's host organization, the University of Helsinki, continued its methodical supervisor training. A gathering for the summer workers and trainees was organised both before and after the summer in Helsinki, and at the start of the summer at CERN. HIP has a joint wellbeing group of peers together with the University of Helsinki Physics Department. Both HIP and the physics wellbeing group organised excursions in 2024.

ORGANIZATION AND PERSONNEL

ORGANIZATION



The HIP Board Meeting in hybrid form on 3 April. In the picture at the table from left to right: Kai Nordlund*, Teija Isotalo, Jyri Hämäläinen*, Antti Väihkönen, Katri Huitu, Tapio Lampén*.
Credit: J. Aaltonen/HIP.

*Board member.

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CHAIR

Angela Bracco, Professor (U. Milan and INFN)

MEMBERS

Lars Bergström, Professor (Stockholm U.)

Kerstin Borras, Professor (RWTH Aachen U.)

Jens Jørgen Gaardhøje, Professor (U. Copenhagen)

Kalle Härkki, CEO, Dr. (Cerastium Oy)

Manfred Krammer, Department Head, Dr. (CERN)

Jochen Wambach, Professor (TU Darmstadt)

Tzanka Kokalova Wheldon, Professor (U. Birmingham)

Personnel

Theory Programme

K. Rummukainen, Academy prof., programme director

Theoretical Cosmology

S. Nurmi, senior lecturer, proj. leader
M. Hindmarsh, prof., adj. senior scientist
P. Johansson, prof., adj. senior scientist
K. Kainulainen, prof., adj. senior scientist
D. Weir, prof., Acad. Res. Fellow
S. Räsänen, adj. senior scientist
D. Hooper, scientist
G. Rácz, scientist
B. Reinoso, scientist
T. Tuominen, scientist
T. Sawala, Acad. Res. Fellow, adj. scientist
J. Correia, adj. scientist
J. Hislop, adj. scientist
D. Irodotou, adj. scientist
D. Karamitros, adj. scientist
T. Tenkanen, adj. scientist
R. Wright, adj. scientist
J. Annala, doctoral researcher
M. Benaco, doctoral researcher
J. Dahl, doctoral researcher
L. Giombi, doctoral researcher
A. Hassan, doctoral researcher
J. Häkkinen, doctoral researcher
A. Keitaanranta, doctoral researcher
A. Kormu, doctoral researcher
M. Mattero, doctoral researcher
T. Minkkinen, doctoral researcher
J.-M. Ojanperä, doctoral researcher
H. Parkkinen, doctoral researcher
A. Rawlings, doctoral researcher
R. Seppä, doctoral researcher
S. Sukuvaara, doctoral researcher
N. Venkatesan, doctoral researcher
O. Väisänen, doctoral researcher

Fundamental Particle Interactions Beyond the Standard Model

A. Tureanu, doc., proj. leader
K. Huitu, prof., senior scientist
M. Voutilainen, prof., senior scientist
M. Chaichian, prof. emer., senior scientist
O. Lebedev, prof., adj. senior scientist
K. Tuominen, prof., adj. senior scientist
M. Heikinheimo, adj. senior scientist
E. Keski-Vakkuri, adj. senior scientist
M. Oksanen, adj. senior scientist
W. Trzaska, adj. senior scientist
T. Gupta, scientist
T. Kupiainen, adj. scientist
A. Al-Adulrazzaq, doctoral researcher
D. Feiteira, doctoral researcher
H. Lempiäinen, doctoral researcher
T. Nerdi, doctoral researcher
N. Pranzini, doctoral researcher
T. Sirkiä, doctoral researcher
A. Stendahl, doctoral researcher
N. Stirling, doctoral researcher
O. Veltheim, doctoral researcher
N. Zimmermann, doctoral researcher
B. Couto e Silva, visiting scientist
J. Wagner, visiting scientist

Phases of Strongly Interacting Matter

H. Mäntysaari, assoc. prof., proj. leader
A. Vuorinen, prof.
K. Kajantie, prof. emer.
K. J. Eskola, prof., adj. senior scientist
T. Lappi, prof., adj. senior scientist
R. Paatelainen, Acad. Res. Fellow, senior scientist
N. Jokela, senior scientist
I. Helenius, Acad. Res. Fellow, adj. senior scientist
J. Auvinen, adj. senior scientist
V. Guzey, adj. senior scientist
O. Henriksson, adj. senior scientist
D. J. Kim, adj. senior scientist
H. Niemi, adj. senior scientist
H. Paukkunen, adj. senior scientist
M. Sainio, adj. senior scientist
L. Fernandez, scientist
P. Duwentäster, adj. scientist
F. Hekhorn, adj. scientist
Y. Kanakubo, adj. scientist
A. D. Le, adj. scientist
P. Paakkinen, adj. scientist
J. Peuron, adj. scientist
P. Singh, adj. scientist
I. Soudi, adj. scientist
Y. Tawabutr, adj. scientist
X. Tong, adj. scientist
D. Avramescu, doctoral researcher
C. Casuga, doctoral researcher
M. Chithirasreemadam, doctoral researcher
P. Gimeno Estivill, doctoral researcher
A. Hippeläinen, doctoral researcher
H. Hirvonen, doctoral researcher
J. Hirvonen, doctoral researcher
M. Kuha, doctoral researcher
J. Laulainen, doctoral researcher
X. Li, doctoral researcher
P. Navarrete, doctoral researcher
M. Nurmela, doctoral researcher
A. Piispa, doctoral researcher
A. Rajala, doctoral researcher
K. Seppänen, doctoral researcher
H. Takko, doctoral researcher
W. H. Tam, doctoral researcher
M. Tevio, doctoral researcher
S. Yrjänheikki, doctoral researcher
J. Österman, doctoral researcher

Topological Matter

T. Ojanen, prof., proj. leader
T. Hyart, adj. scientist
A. Moghaddam, adj. scientist
K. Pöyhönen, adj. scientist
T. Vanhala, adj. scientist
M. Ivaki, doctoral researcher
M. Mustonen, doctoral researcher
I. Sahlberg, doctoral researcher

CMS Programme

K. Österberg, prof., programme director

CMS Experiment

M. Voutilainen, prof., proj. leader
H. Kirschenmann, adj. prof.
M. Kim, ass. prof., adj. senior scientist
T. Lampén, senior scientist
K. Lassila-Perini, senior scientist (at CERN)
S. Lehti, senior scientist
J. Tuominiemi, adj. senior scientist
N. Norjoharuddeen, scientist
R. Verma, scientist
J. Heikkilä, adj. scientist
M. Kortelainen, adj. scientist
S. Laurila, adj. scientist
J. Pekkanen, adj. scientist
P. Inkaew, doctoral researcher
K. Kallonen, doctoral researcher
B. Lehtelä, doctoral researcher
N. Mancilla Xinto, doctoral researcher
L. Martikainen, doctoral researcher
M. Myllymäki, doctoral researcher
N. Toikka, doctoral researcher
M. Harkki, student
V. Mehtola, student
J. Mäki-Ikola, student
A. Stadnitski, student
E. Veikkola, student
R. Öhrnberg, student

CMS Upgrade

E. Brücken, doc., proj. leader
P.-R. Luukka, adj. prof.
T. Hildén, senior scientist
E. Tuominen, adj. senior scientist
S. Bharthuar, adj. scientist
A. Gädda, adj. scientist
A. Karadzhinova-Ferrer, adj. scientist
A. Karjalainen, adj. scientist
S. Kirschenmann, adj. scientist
A. Winkler, adj. scientist
M. Bezak, lab. engineer
N. Kramarenko, doctoral researcher
M. Myllymäki, doctoral researcher
M.-M. Rantanen, doctoral researcher
S. Saariokari, doctoral researcher
J. Tikkanen, doctoral researcher
M. Väänänen, doctoral researcher

Tier-2 Operations

T. Lindén, Dr., proj. leader, grid coordinator
S. Lehti, senior scientist
M. Myllymäki, doctoral researcher

CMS Forward Physics

K. Österberg, prof., proj. leader
H. Saarikko, prof. emer., adj. senior scientist
F. Oljemark, scientist
F. García, lab. engineer
A. Milieva, doctoral researcher
F. Musonov, doctoral researcher
M.-M. Rantanen, doctoral researcher

Nuclear Matter Programme

A. Jokinen, prof., programme director

ALICE

S. Räsänen, Dr., proj. leader
D. J. Kim, adj. senior scientist
W. Trzaska, adj. senior scientist
Y. Melikyan, scientist
H. Hassan, adj. scientist
C. Mordasini, adj. scientist
L. Huhta, doctoral researcher
A. Molander, doctoral researcher
H. Rytkönen, doctoral researcher
O. Saarimäki, doctoral researcher
M. Virta, doctoral researcher
A. Önnerstad, doctoral researcher

ISOLDE

J. Pakarinen, Dr., proj. leader
P. Greenlees, prof., adj. senior scientist
A. Jokinen, prof., adj. senior scientist
A. Kankainen, prof., adj. senior scientist
I. Moore, prof., adj. senior scientist
T. Grahn, ass. prof., adj. senior scientist
P. Rahkila, adj. senior scientist
P. Ruotsalainen, adj. senior scientist
J. Ojala, postdoctoral researcher
M. Mougeot, adj. scientist
M. Reponen, adj. scientist
M. Stryjczyk, adj. scientist
A. Jaries, doctoral researcher
H. Kokkonen, doctoral researcher
S. Kujanpää, doctoral researcher
E. Uusikylä, doctoral researcher

FAIR

T. Grahn, ass. prof., proj. leader
J. Äystö, prof., director emer., adj. senior scientist
A. Jokinen, prof., adj. senior scientist
A. Kankainen, prof., adj. senior scientist
I. Moore, prof., adj. senior scientist
T. Eronen, adj. senior scientist
H. Penttilä, adj. senior scientist
S. Rinta-Antila, adj. senior scientist
K. Auranen, Acad. Res. Fellow
D. Nesterenko, adj. scientist
J. Tuunanen, adj. scientist
F. García, lab. engineer
V. Virtanen, doctoral researcher

Technology Programme

F. Tuomisto, prof., programme director
P. Dendooven, visiting prof.
T. Salmi, adj. senior scientist
R. Virta, adj. scientist (at STUK)
P. Kauttu, doctoral researcher

Robotics and AI for Monitoring and Intervention (ROBOT)

R. Pieters, ass. prof., proj. leader
K. Tammi, prof., adj. scientist
E. Rahtu, ass. prof., adj. scientist
K. Samarawickrama, adj. scientist
P. Habibiroudkenar, doctoral researcher
R. Ojala, doctoral researcher

Improved Detection for Elemental Analysis at Laboratory (IDEAL)

R. Bès, Dr., proj. leader
S. Huotari, prof., adj. scientist
E. Brücken, senior scientist
S. Orlat, doctoral researcher

Materials for Accelerator Technology (MAT)

F. Djurabekova, prof., proj. leader
K. Nordlund, prof., adj. senior scientist
V. Zadin, prof., adj. scientist
A. Kyritsakis, adj. ass. prof.
J. Byggmästar, adj. scientist
J. Kimari, adj. scientist
A. Leino, adj. scientist
A. Lopez Cazalilla, adj. scientist
I. Makkonen, adj. scientist
M. Ghaemikermani, doctoral researcher
R. Koitermaa, doctoral researcher

Radiation and Nuclear Metrology, Safety, Security and Safeguards Applications (RAD3S)

T. Siiskonen, prof. of practice (UH), proj. leader (at STUK)
P. Dendooven, visiting prof.
P.-R. Luukka, prof.
P. Greenlees, prof., adj. senior scientist
K. Peräjärvi, prof. of practice (JyU), scientist (at STUK)
E. Brücken, senior scientist
M. Kalliokoski, senior scientist
K. Helariutta, adj. senior scientist
M. Kortesniemi, adj. senior scientist
M. Nyman, adj. senior scientist
P. Rahkila, adj. senior scientist
M. Muikku, scientist (at STUK)
R. Pöllänen, scientist (at STUK)
J. Turunen, scientist (at STUK)
M. Laassiri, adj. scientist
I. Makkonen, adj. scientist
V. Bogdanoff, doctoral researcher
H. Jutila, doctoral researcher
J. Tikkanen, doctoral researcher
R. Virta, doctoral researcher

Other projects

CLOUD

M. Kulmala, prof., Academician, proj. leader
K. Lehtipalo, prof.
D. Worsnop, prof.
J. Duplissy, senior scientist
C. Williamson, senior scientist
X. He, scientist
R. Baalbaki, doctoral researcher
B. Rörup, doctoral researcher
J. Shen, doctoral researcher
W. Yu, doctoral researcher

Euclid

H. Kurki-Suonio, prof., proj. leader (until 31.5.2024)
E. Keihänen, senior scientist, proj. leader (starting 1.6.2024)
J. Väliviita, adj. senior scientist
V. Lindholm, scientist
K. Kiiveri, doctoral researcher
S. Tuomisto, doctoral researcher
A. Viitanen, doctoral researcher

Education and Open Data

K. Lassila-Perini, Dr., proj. leader (at CERN)
P. Veteli, doctoral researcher

Detector Laboratory

M. Kalliokoski, doc., laboratory director
M. Bezak, lab. engineer
F. García, lab. engineer
P. Koponen, lab. engineer
R. Turpeinen, senior lab. technician

Administration and Support

K. Huitu, prof., director
A. Väihkönen, research coordinator
J. Aaltonen, lab. engineer

University Services administration team including:
T. Isotalo, admin. manager
T. Laurila, admin. manager
S. Sadesalo, controller
T. Hardén, service coordinator
E. Veranen, HR coordinator
T. Heikkilä, secretary
T. Karppinen, secretary (at CERN)
T. Onnela, secretary (at CERN)

HIP SEMINARS

25 January S. Säppi (Munich)
Mass effects and bulk viscosity in high-density QCD

30 January E. Palmgren (Helsinki)
Teaching (theoretical) physics for student deep learning: perspectives from physics education research

20 February B. Laurent (McGill)
First principles determination of bubble wall velocity and local thermal equilibrium approximation

22 February H. Kolesova (Stavanger)
Non-Abelian dark sectors: gravitational waves vs dark matter

29 February S. Williams (Cambridge)
The Future Circular Collider as a Higgs/top/EW factory: status and plans for FCC-ee

8 March M. Doser (CERN)
Quantum sensing for (low and high energy) particle physics

12 March J. Pekkanen (CERN)
FCC project and ALLEGRO detector concept

19 March M. Heller (Ghent)
Beyond (real) geodesics and extremal hypersurfaces in gravity

4 April K. Mkrtchyan (London)
Democratic approach to p-forms and electric-magnetic duality

9 April D. Benisty (FIAS, Frankfurt and KICC, Cambridge)
Constraining dark energy from the Local Group dynamics

11 April C. Ecker (Frankfurt)
Exploring the phase diagram of QCD with neutron star mergers in the prompt and non-prompt collapse regime

14 May T. Gorda (Frankfurt)
Probing the behavior of strongly interacting matter at the highest densities

21 May D. Milstead (Stockholm)
Search for baryon number violation and other phenomena with the HIBEAM experiment at the European Spallation Source

23 May H. Kurki-Suonio (Helsinki)
Farewell lecture

28 May P. Bandyopadhya (IIT Hyderabad)
Displaced heavy leptons at colliders

30 May C. Hoyos (Oviedo)
Spinodal slowing down and scaling in a holographic model

4 June K. Ghosh (IOP Bhubaneswar)
A minimal model to explain non-zero neutrino masses/ mixings, muon anomalous magnetic moment, and dark matter relic density

6 June L. Bhattacharya (Bhubaneswar)
Probing QGP properties at LHC-HIC using photons and heavy SM particles

13 June Y. Fujimoto (Seattle)
Dense QCD equation of state: lessons from neutron stars, lattice, and large-Nc QCD

13 August S. Kawai (Sungkyunkwan University, South Korea)
The minimal model of cosmology

9 September A. Rajantie (Imperial College, London)
Magnetic monopoles from heavy ion collisions

17 September S. Lehti (for the Helsinki CMS group), chair at seminar from CERN
High-precision measurement of the W boson mass at CMS

8 October A. Golutvin (Imperial College & CERN)
The SHiP experiment at CERN

22 October A. Tapadar (IACS, Kolkata)
Non-thermal production of dark matter in an EFT scenario

19 November K. Zhang (Helsinki)
Lattice and finite-element simulations of quench dynamics and defects of p-wave GL effective theory of superfluid ^{3}He

29 November D. Haidt (DESY)
From Fermi to neutral currents and their impact

29 November M. Sainio (HIP)
Helsinki Institute of Physics - the first twenty years 1996-2016

10 December N. Forzano (Swansea)
Thermal evolution of dark matter symplectic glueballs

17 December T. Lähde (Jülich)
Emergent alpha clustering in the carbon nucleus from Nuclear Lattice EFT

19 December S. Sassi (Helsinki)
Challenges in modeling direct detection of dark matter

VISITORS

Theory Programme

Theoretical Cosmology

A. Racioppi (Estonia) 16.-19.1.
M. Giorgio (UK) 24.1.
T. Takahashi (Japan) 29.1.-3.2.
I. K. Wehus (Norway, USA) 31.1.
O. Gould (UK)19.2.-1.3.
G. Arcadi (Italy) 21.2.
J. Martin (France) 19.-21.3.
S. Patil (Netherlands) 26.-28.3.
E. Despontin (Belgium) 1.-6.4.
A. Ringwald (Germany) 16.-18.4.
S. Cléry (France) 24.4.
J. Kume (Italy) 4.-11.5.
F. Q. Zhu (UK) 18.-19.5.
S. Procacci (Switzerland) 19.-23.5.
A. Rajantie (UK) 3.-6.6., 9.9.
A. Mierna (Italy) 5.6.
T. Giblin (USA) 10.-14.6.
T. Naab (Germany) 16.-19.6.
A. Rantala (Germany) 16.-19.6.
T. Kärkkäinen (Estonia) 18.-20.9.
E. Sessolo (Poland) 30.9.-4.10.
V. Vaskonen (Estonia, Italy) 9.-11.10.
G. Calcagni (Spain) 29.-31.10.
J. Jasche (Sweden) 4.-8.11.
G. Lavaux (France) 4.-8.11.
S. McAlpine (Sweden) 4.-8.11.
K. Tomotaka (South Korea) 4.-11.11.
K. Muursepp (Estonia) 8.11.
J. Urrutia (Estonia) 8.11.
H. Inchauspé (Germany) 11.-15.11.
S. Nadathur (UK) 18.-21.11.
S. Mishra (UK) 27.11.
A. Urio (Spain) 3.-5.12.
A. Belyaev (UK) 9.-11.12.
M. Kierkla (Poland) 16.-19.12.

Fundamental Particle Interactions Beyond the Standard Model

D. Benisty (Germany) 1.3.-14.5.
J. Wagner (Germany) 3.-11.4.
H. Waltari (Sweden) 2.-3.5.
K. Ghosh (India) 15.5.-12.6.
P. Bandyopadhya (India) 17.-31.5.
I. Brevik (Norway) 21.-31.8.
B. A. Couto e Silva (Brazil) 11.9.-31.12.
P. Osland (Norway) 10.-16.11.
D. Haidt (Germany) 27.11.-2.12.
A. Belyaev (UK) 9.-11.12.
M. Gogberashvili (Georgia) 17.-23.12.

Phases of Strongly Interacting Matter

P. Meinzinger (UK) 30.1.-2.2.
C. Lamas Rodríguez (Spain) 26.2.-30.4.
M. Heller (Belgium) 15.-19.3.
M. Järvinen (South Korea) 2.-12.4., 15.-21.12.
K. Mkrtchyan (UK) 3.-6.4.
C. Ecker (Germany) 9.-11.4.
A. Mazeliauskas (Germany) 6.-10.5.
T. Gorda (Germany) 9.-14.5.
S. Säppi (Germany) 13.-17.5.
C. Hoyos (Spain) 26.-31.5.
Y. Fujimoto (USA) 9.-13.6.
J. Penttala (USA) 17.-20.6., 17.12.
S. Kawai (South Korea) 15.7.-14.8.
Y. Shi (France) 14.-22.10.
M. Li (Spain) 18.-22.11.
W. Qian (Spain) 18.-22.11.

CMS Programme

S. Williams (UK) 29.2.-2.3.
J. Pekkanen (Switzerland) 12.3.
K. Borras (Germany) 6.5.
M. Krammer (Switzerland) 6.5.
D. Milstead (Sweden) 21.5.
M. Backhaus (Switzerland) 12.9.
G. Gomez (Spain) 12.9.
A. Macchiolo (Switzerland) 12.9.
C. Steinbrück (Germany) 12.9.
A. Venturi (Italy) 12.9.

Technology Programme

Materials for Accelerator Technology (MAT)

D. Curry (UK) 20.-22.11.

Detector Laboratory

A. Maulik (Italy) 19.-23.2.
M. Doser (Switzerland) 8.3.

CONFERENCE PARTICIPATION, TALKS AND VISITS BY PERSONNEL

Theory Programme

Theoretical Cosmology

NBIA Gravity Seminar,
15 February, Copenhagen, Denmark (remote seminar by S. Räsänen)

Physics Days 2024,
4-6 March, Helsinki, Finland (D. Hooper, J. Häkkinen, talk by T. Minkkinen, R. Seppä, S. Sukuvaara, D. Weir)

Challenges in Collisional N-Body Dynamics Workshop,
20-22 March, Garching, Germany (talk by P. Johansson)

University of Nottingham,
9-17 April, Nottingham, UK (A. Kormu)

LISA Consortium Constituent Council Meeting,
14-16 April, Barcelona, Spain (T. Minkkinen)

Universitat de Barcelona,
18 April, Barcelona, Spain (seminar by T. Minkkinen)

University of Durham,
18 April, Durham, UK (seminar by A. Kormu)

Donostia International Physics Center Colloquium,
19 April, Donostia, Spain (remote talk by P. Johansson)

Triangular Conference on Cosmological Frontiers in Fundamental Physics 2024,
19-21 April, Edinburgh, UK (A. Kormu)

Massive Black Holes in the First Billion Years Conference,
29 April - 3 May, Kinsale, Ireland (talk by P. Johansson)

Cosmology, Astrophysics, Theory and Collider Higgs 2024 (CATCH22+2) Conference,
1-5 May, Dublin Institute for Advanced Studies, Dublin, Ireland (talk by S. Räsänen)

CERN Theory Group,
7-13 May, Geneva, Switzerland (seminar by A. Kormu)

4th Annual EuCAPT Symposium,
14-16 May, CERN, Geneva, Switzerland (A. Kormu)

Astronomers' Days 2024,
20-22 May, Vaasa, Finland (talk by P. Johansson, talk by T. Minkkinen)

Barcelona Black Holes,
27-31 May, Universitat de Barcelona, Barcelona, Spain (talk by S. Räsänen)

LISA DDPC Kick-Off Workshop,
10-12 June, Toulouse, France (M. Hindmarsh)

Neutrino 24,
15-23 June, Milan, Italy (talk by H. Parkkinen)

Quantum Aspects of Inflationary Cosmology,
24 June - 19 July, Munich Institute for Astro-, Particle and BioPhysics (MIAPbP), Munich, Germany
(talk by S. Räsänen)

Neutrino Frontiers,
7-20 July, Florence, Italy (talk by H. Parkkinen)

Lattice 2024,
29 July - 2 August, Liverpool, UK (talk by D. Weir)

Dublin Institute for Advanced Studies,
15 August, Dublin, Ireland (seminar by S. Räsänen)

Strong and Electroweak Matter 2024,
25-30 August, Frankfurt, Germany (S. Sukuvaara)

Tampere Cosmology Meeting,
5-6 September, Tampere, Finland (J. Annala, talk by L. Giombi, talk by D. Hooper, K. Kainulainen, talk by D. Karamitros, talk by A. Kormu, S. Nurmi, talk by H. Parkkinen, R. Seppä, talk by S. Sukuvaara, talk by O. Väisänen, D. Weir)

Particle Production in the Early Universe,
9-13 September, CERN, Geneva, Switzerland (talk by K. Kainulaninen)

Majorana-Raychaudhuri Seminar,
13 September, INFN & University of Salerno, Italy and PAMU, Indian Statistical Institute, Kolkata, India (remote seminar by S. Räsänen)

Opponent in PhD Defence,
2-3 October, Strasbourg, France (P. Johansson)

Ringberg Workshop on Galaxy Formation 2024,
20-25 October, Ringberg Castle, Kreuth, Germany (talk by P. Johansson)

COSMO 24,
21-25 October, Kyoto, Japan (talk by K. Kainulainen, talk by O. Väisänen)

Leiden Cosmology Workshop,
7 November, University of Leiden, Leiden, Netherlands (talk by S. Räsänen)

University of Turku,
5 December, Turku, Finland (seminar by D. Hooper)

Fundamental Particle Interactions Beyond the Standard Model

NORDITA Winter School in Particle Physics and Cosmology,
15-26 January, Stockholm, Sweden (A. Al-Adulrazzaq)

Physics Days 2024,
4-6 March, Helsinki, Finland (T. Gupta, H. Lempiäinen)

COSINUS Collaboration Meeting,
15-18 April, L'Aquila, Italy (talks by M. Heikinheimo, A. Stendahl)

Brazilian Center for Research in Physics,
29 May - 21 June, Rio de Janeiro, Brazil (A. Tureanu)

ATHEXIS Symposium on Exploring the Universe,
10-14 June, Athens, Greece (talk by O. Lebedev)

Midsummer School in QCD 2024,
24 June - 6 July, Saariselkä, Finland (H. Lempiäinen)

International School on AstroParticle Physics 2024,
25 June - 4 July, Padua, Italy (T. Gupta, T. Sirkiä)

Excess24 Workshop,
6 July, Rome, Italy (M. Heikinheimo)

Identification of Dark Matter 2024,
8-12 July, L'Aquila, Italy (T. Gupta)

BSM2 Brainstorming Workshop,
12-16 July, Vila do Conde, Portugal (talk by O. Lebedev)

MITP Summer School 2024,
15 July - 2 August, Mainz, Germany (talk by T. Gupta)

EREP 2024 Relativity Meeting,
22-26 July, Coimbra, Portugal (talk by O. Lebedev)

Strong and Electroweak Matter,
25-30 August, Frankfurt, Germany (H. Lempiäinen)

Tampere Cosmology Meeting,
5-6 September, Tampere, Finland (M. Heikinheimo, talks by H. Lempiäinen and T. Sirkiä)

CERN Workshop on Particle Production in the Early Universe,
9-13 September, Geneva, Switzerland (O. Lebedev, co-organiser)

COSINUS Collaboration Meeting,
30 September - 4 October, Ringberg, Germany (talk by M. Heikinheimo)

INFN School on Underground Physics,
14-18 October, Bertinoro, Italy (A. Al-Adulrazzaq)

CPPM Marseille,
23-26 November, Marseille, France (A. Tureanu)

Astroparticle Symposium 2024,
25-29 November, Orsay, France (talk by O. Lebedev)

Particle Physics Days 2024,
27-28 November, Lammi Research Station, Lammi, Finland (talk by A. Al-Adulrazzaq, talk by M. Heikinheimo, H. Lempiäinen)

Phases of Strongly Interacting Matter

Workshop on Tuning of Hadronic Interaction Models,
22-25 January, Wuppertal, Germany (invited talk by P. Paakkinen)

Goethe University,
5-7 February, Frankfurt, Germany (invited talk by A. Vuorinen)

New Jet Quenching Tools to Explore Equilibrium and Non-Equilibrium Dynamics in Heavy-Ion Collisions,
12-16 February, Trento, Italy (invited talk by D. Avramescu, invited talk by T. Lappi, invited talk by I. Soudi)

EIC UG Theory WG Meeting,
15 February (online) (invited talk by I. Helenius)

Physics Days 2024,
4-6 March, Helsinki, Finland (talk by M. Tevio, talk by S. Yrjänheikki)

IFT-UAM,
18-22 March, Madrid, Spain (invited talk by N. Jokela)

Physical Society of Japan 2024 Spring Meeting,
19 March (online) (invited talk by Y. Kanakubo)

Moriond QCD 2024,
31 March - 7 April, La Thuile, Italy (talk by F. Hekhorn)

31st International Workshop on Deep Inelastic Scattering,
8-12 April, Grenoble, France (talk by C. Casuga, talk by P. Duwentäster, talk by F. Hekhorn, talk by I. Helenius, working group co-convener, talk by T. Lappi, talk by J. Laulainen, talk by H. Mäntysaari, talk by P. Paakkinen, talk by Y. Tawabutr, talk by M. Tevio, talk by X. Tong, talk by S. Yrjänheikki)

GenHET Meeting in String Theory,
29-30 April, Geneva, Switzerland (N. Jokela)

Pythia Week 2024,
29 April - 3 May, Oxford, UK (invited seminar by I. Helenius)

Cosmology, Astrophysics, Theory and Collider Higgs 2024 (CATCH22+2) Conference,
1-5 May, Dublin Institute for Advanced Studies, Dublin, Ireland (invited talk by A. Vuorinen)

University of Jyväskylä,
10 May, Jyväskylä, Finland (R. Paatelainen)

MC4EIC 2024,
5-7 June, Durham, UK (invited talk by I. Helenius, member of local organisation committee, invited talk by J. Laulainen)

Diffraction and Gluon Saturation at the LHC and the EIC,
10-14 June, Trento, Italy (talk by C. Casuga, talk by T. Lappi, talk by H. Mäntysaari)

Holography and Dense Matter Workshop,
11-12 June, Paris, France (invited talk by N. Jokela, invited talk by A. Vuorinen)

Midsummer School in QCD 2024,
24 June - 6 July, Saariselkä, Finland (M. Chithirasreemadam, talk by P. Gimeno Estivill, lecture by V. Guzey, lecture by I. Helenius, T. Lappi, member of local organisation committee, J. Laulainen, M. Tevio)

ICHEP 2024,
17-24 July, Prague, Czech Republic (talk by A. Le)

Heavy Ion Physics in the EIC Era,
29 July - 23 August, Seattle, WA, USA (talk by J. Auvinen, talk by P. Duwentäster, talk by T. Lappi)

Quark Confinement and the Hadron Spectrum 2024,
18-24 August, Queensland, Australia (P. Navarrete, K. Seppänen)

2024 CTEQ Summer School on QCD and Electroweak Phenomenology,
21-31 August, Münster, Germany (M. Chithirasreemadam, S. Yrjänheikki)

Strong and Electroweak Matter 2024,
25-30 August, Frankfurt, Germany (L. Fernandez, H. Lempiäinen, P. Navarrete, invited talk by R. Paatelainen, K. Seppänen, invited talk by A. Vuorinen)

EOS Measurements with Next-Generation Gravitational-Wave Detectors Workshop,
2 September, Seattle, WA, USA (invited remote talk by A. Vuorinen)

Eurostrings 2024,
2-6 September, Southampton, UK (talk by O. Henriksson)

International Workshop "QCD Challenges from pp to AA Collisions",
2-6 September, Münster, Germany (invited talk by D. Avramescu, invited talk by P. Paakkinen)

Tampere Cosmology Meeting,
5-6 September, Tampere, Finland (N. Jokela, K. Kajantie)

Diffraction and Low-x 2024,
8-14 September, Trabia, Palermo, Italy (talk by P. Gimeno Estivill, talk by V. Guzey, T. Lappi, working group convener)

Hard Probes 2024,
22-27 September, Nagasaki, Japan (talk by D. Avramescu, K. J. Eskola, member of the International Advisory Committee, D. J. Kim, inivted talk by P. Paakkinen, I. Soudi, talk by M. Tevio)

Jet Modification and Hard-Soft Correlations (SoftJet 2024),
28-29 September, Tokyo, Japan (talk by I. Soudi)

Harvard University Colloquium,
28 September - 1 October, Cambridge, MA, USA (invited talk by A. Vuorinen)

Joint "20th International Workshop on Hadron Structure and Spectroscopy" and 5th Workshop on "Correlations in Partonic and Hadronic Interactions",
30 September - 4 October, Yerevan, Armenia (invited talk by X. Tong)

QCD@LHC 2024,
7-11 October, Freiburg im Breisgau, Germany
(T. Lappi, working group convener)

Resummation, Evolution, Factorization 2024,
14-18 October, Saclay, France (talk by P. Gimeno Estivill, talk by X. Tong)

Opponent in PhD Defence,
22-25 October, Southampton, UK (A. Vuorinen)

University of Helsinki,
24 October, Helsinki, Finland (H. Mäntysaari)

33rd Nordic Network Meeting,
29-31 October, Stockholm, Sweden (talk by O. Henriksson, A. Piispa)

Light Ion Collisions at the LHC,
11-15 November, CERN, Geneva, Switzerland
(invited talk by P. Paakkinen, invited talk by I. Soudi)

Ghent University High-Energy Physics Theory Group Seminar Series,
18 November, Ghent, Belgium (invited remote seminar by I. Soudi)

University of Helsinki,
20 November, Helsinki, Finland (H. Mäntysaari)

Topological Matter

QUANTUMatter 2024,
7-10 May, San Sebastian, Spain (T. Ojanen)

CMS Programme

CMS Experiment

1st COMETA General Meeting,
28 February - 1 March, Izmir, Turkey (talk by N. Norjoharuddeen)

CMS Experiment Project Retreat,
3-8 March, Kilpisjärvi Research Station, Kilpisjärvi, Finland (P. Inkaew, H. Kirschenmann, S. Laurila, B. Lehtelä, N. Mancilla Xinto, M. Myllymäki, N. Norjoharuddeen, N. Toikka, E. Veikkola, R. Verma, M. Voutilainen)

April CMS Week,
15-19 April, CERN, Geneva, Switzerland
(H. Kirschenmann, plenary talk by M. Voutilainen)

Evaluation Meeting of HIP CMS Projects,
6 May, Helsinki, Finland (talk by H. Kirschenmann, talk by S. Laurila, talk by M. Voutilainen)

CERN,
8 May - 21 June, Geneva, Switzerland (P. Inkaew)

PhD Defence, Future Colliders Day, RECFA Country Visit,
13-18 May, Lund, Sweden (H. Kirschenmann)

CERN,
15 May - 22 June, Geneva, Switzerland (N. Toikka)

CERN,
8 June - 11 September, Geneva, Switzerland (E. Veikkola)

CERN,
16-29 June, Geneva, Switzerland (S. Lehti)

Midsummer School in QCD 2024,
24 June - 6 July, Saariselkä, Finland (P. Inkaew, H. Kirschenmann, organiser, K. Lassila-Perini, organiser, S. Laurila, B. Lehtelä, N. Mancilla Xinto, N. Toikka, M. Voutilainen, organiser)

BOOST 2024 Conference,
29 July - 2 August, Genova, Italy
(talk by N. Norjoharuddeen)

Baltic School of High-Energy Physics and Accelerator Technologies,
5-9 August, Kuldiga, Latvia (A. Stadnitski, N. Toikka)

HIP Scientific Advisory Board Meeting,
26-27 August, Helsinki, Finland (talk by M. Voutilainen)

2024 European School of High-Energy Physics,
25 September - 8 October, Peebles, UK (M. Myllymäki)

SMARTHEP Yearly Meeting 2024,
30 September - 4 October, Milan, Italy (P. Inkaew, H. Kirschenmann)

Symposium to Celebrate Carlo Rubbia's 90th Birthday,
18 October, CERN, Geneva, Switzerland (J. Tuominiemi)

Higgs 2024,
4-8 November, Uppsala, Sweden (plenary talk by S. Laurila)

CMS PPD Workshop,
25-27 November, CERN, Geneva, Switzerland
(plenary talk by M. Voutilainen)

The 28th IPPOG Collaboration Meeting,
25-27 November, CERN, Geneva, Switzerland
(remote talk by S. Lehti)

Particle Physics Days 2024,
27-28 November, Lammi Research Station, Lammi, Finland (H. Kirschenmann, organiser, T. Lampén, talk by S. Laurila, talk by V. Mehtola, talk by M. Myllymäki, talk by N. Norjoharuddeen)

December CMS Week,
9-13 December, CERN, Geneva, Switzerland
(H. Kirschenmann, plenary talk by S. Laurila, plenary talk by M. Myllymäki)

CMS Upgrade

Paul Scherrer Institute,
10-12 January, Villigen, Switzerland (E. Brücken)

CMS Tracker Week,
15-19 January, CERN, Geneva, Switzerland
(E. Brücken, T. Hildén (online), P. Luukka)

TREDI 2024 Workshop,
20-23 February, Turin, Italy (N. Kramarenko)

CMS Tracker Week,
22-26 April, CERN, Geneva, Switzerland
(E. Brücken, T. Hildén, P. Luukka)

Evaluation Meeting of HIP CMS Projects,
6 May, Helsinki, Finland (talk by E. Brücken, talk by T. Hildén)

University of Bergen,
13-14 May, Bergen, Norway (E. Brücken)

University of Southern Norway,
15-16 May, Vestfold, Norway (E. Brücken)

CMS TEPX QC Centre,
22-29 May, CERN, Geneva, Switzerland (E. Brücken)

University of Turin, Physics Department,
26-29 May, Turin, Italy (N. Kramarenko)

1st DRD3 Collaboration Meeting,
17-21 June, CERN, Geneva, Switzerland
(E. Brücken (online), M.-M. Rantanen (online))

25th International Workshop on Radiation Imaging Detectors,
30 June - 4 July, Lisbon, Portugal (M. Bezak, E. Brücken, T. Hildén, M. Myllymäki, S. Saariokari, M. Väänänen)

CMS TEPX Module Glueing Workshop,
10-12 July, University of Hamburg, Hamburg, Germany (E. Brücken)

F&K Delvotec/Strama MPS Maschinenbau GmbH,
20-22 August, Straubing, Germany (E. Brücken)

Euroschool on Exotic Beams, Summer School,
25-31 August, Jyväskylä, Finland (lectures by E. Brücken)

HIP Scientific Advisory Board Meeting,
26-27 August, Helsinki, Finland (talk by E. Brücken, P. Luukka)

Hamadohri Environmental Radiation Training 2024,
9-13 September, Hamadohri, Fukushima prefecture, Japan (N. Kramarenko)

NPSS IEEE Climate Change Event,
14 September, Hamadohri, Fukushima prefecture, Japan (N. Kramarenko)

CMS Tracker Week,
11-15 November, CERN, Geneva, Switzerland (E. Brücken, T. Hildén, S. Saariokari, M. Väänänen)

Wire-Bonder Installation and Training,
21 November, Lappeenranta, Finland (N. Kramarenko, M. Väänänen)

Particle Physics Days 2024,
27-28 November, Lammi Research Station, Lammi, Finland (talks by E. Brücken and P. Luukka, S. Saariokari, M. Väänänen)

University of Uppsala, Ångströmlaboratoriet,
2-6 December, Uppsala, Sweden (E. Brücken, S. Saariokari)

2nd DRD3 Collaboration Meeting,
2-6 December, CERN, Geneva, Switzerland (E. Brücken (online), M.-M. Rantanen (online))

Tier-2 Operations

Physics Days 2024,
4-6 March, Helsinki, Finland (talk by T. Lindén)

WLCG/HSF Workshop,
13-17 May, Hamburg, Germany (T. Lindén)

FUNET Technical Days,
16 May, Espoo, Finland (remote talk by T. Lindén)

NeIC 2024,
27-29 May, Tallin, Estonia (T. Lindén)

HIP Scientific Advisory Board Meeting,
26-27 August, Helsinki, Finland (T. Lindén)

NORDUnet Conference 2024,
10-12 September, Bergen, Norway (T. Lindén)

CERNVM Workshop 2024,
16-18 September, CERN, Geneva, Switzerland (T. Lindén)

CHEP 2024,
21-25 October, Krakow, Poland (T. Lindén)

De Finlandssvenska Fysik- och Kemidagarna 2024,
15-17 November, m/s Silja Serenade, Finland-Sweden (T. Lindén)

Particle Physics Days 2024,
27-28 November, Lammi Research Station, Lammi, Finland (T. Lindén)

Fusion Power Associates 45th Annual Meeting,
2-3 December, Washington, DC, USA (T. Lindén (online))

CMS Forward Physics

CERN,
15 January - 5 February, 13 February - 17 March, 7 April - 10 May, 20-27 June, 25 July - 17 August, 3-27 September, 19-29 November, 8-13 December, Geneva, Switzerland (F. Garcia)

PPS General Meeting,
6 February, 16 April, 25 June, 10 December, CERN, Geneva, Switzerland (talk by F. Garcia, M.-M. Rantanen (online), K. Österberg (online))

Physics Days 2024,
4-6 March, Helsinki, Finland (A. Milieva, organiser, F. Oljemark, M.-M. Rantanen, K. Österberg)

Gas Detector Development Group Meeting,
20 March, CERN, Geneva, Switzerland (talk by F. Garcia)

LHC RRB Meeting,
22-25 April, Geneva, Switzerland (K. Österberg)

Evaluation Meeting of HIP CMS Projects,
6 May, Helsinki, Finland (talk by K. Österberg, organiser)

PPS Upgrade Meeting,
15-16 May, CERN, Geneva, Switzerland (talk by F. Garcia, M.-M. Rantanen (online), K. Österberg (online))

HIP Town Meeting,
24 May, Helsinki, Finland (A. Milieva, F. Oljemark, M.-M. Rantanen, talk by K. Österberg)

16th Pisa Meeting on Advanced Detectors,
26 May - 1 June, Elba, Italy (M.-M. Rantanen)

CERN,
10-14 June, Geneva, Switzerland (K. Österberg)

Midsummer School in QCD 2024,
24 June - 6 July, Saariselkä, Finland (A. Milieva, talk by F. Oljemark, K. Österberg, organiser)

DRD1 WP4 Meeting,
15 July, CERN, Geneva, Switzerland (talk by F. Garcia)

CERN,
30 July - 8 August, Geneva, Switzerland (M.-M. Rantanen)

Baltic School of High-Energy Physics and Accelerator Technologies,
5-9 August, Kuldiga, Latvia (A. Milieva)

HIP Scientific Advisory Board Meeting,
26-27 August, Helsinki, Finland (talk by K. Österberg)

Diffraction and Low-x 2024,
8-14 September, Trabia, Palermo, Italy (talk by K. Österberg)

PPS General Meeting,
17 September, CERN, Geneva, Switzerland (F. Garcia, M.-M. Rantanen (online), K. Österberg (online))

The 8th International Conference on Micro-Pattern Gaseous Detectors,
14-18 October, Hefei, China (talk by F. Garcia)

PPS Upgrade Workshop,
24-25 October, CERN, Geneva, Switzerland (F. Garcia, M.-M. Rantanen (online), K. Österberg (online))

Particle Physics Days 2024,
27-28 November, Lammi Research Station, Lammi, Finland (A. Milieva, F. Oljemark, talk by K. Österberg)

3rd DRD1 Collaboration Meeting,
9 December, CERN, Geneva, Switzerland (talk by F. Garcia)

Nuclear Matter Programme

ISOLDE

99th ISOLDE Collaboration Committee Meeting,
21 February, CERN, Geneva, Switzerland (J. Pakarinen)

IOP Conference,
8-10 April, Liverpool, UK (talk by J. Pakarinen)

IS733 Experiment,
18-25 May, CERN, Geneva, Switzerland (M. Stryjczyk)

HIP Town Meeting,
24 May, Helsinki, Finland (T. Grahn, A. Jokinen, J. Pakarinen)

PLATAN 2024 Conference,
9-14 June, Jyväskylä, Finland (A. Jokinen, A. Kankainen, talk by S. Kujanpää, I. Moore, M. Reponen)

100th ISOLDE Collaboration Committee Meeting,
21 June, CERN, Geneva, Switzerland (J. Pakarinen)

IS745 Experiment,
18-30 July, CERN, Geneva, Switzerland (A. Jaries, M. Mougeot)

LISA - Laser Ionization Spectroscopy of Actinides - Final Conference,
1-4 September, CERN, Geneva, Switzerland (I. Moore)

IS748 Experiment,
23 September - 2 October, CERN, Geneva, Switzerland (P. Rahkila, E. Uusikylä)

IS756 Experiment,
21-26 October, CERN, Geneva, Switzerland (H. Kokkonen, J. Ojala)

SSNET Conference,
3-5 November, Orsay, France (talk by J. Pakarinen)

101st ISOLDE Collaboration Committee Meeting,
6 November, CERN, Geneva, Switzerland (J. Pakarinen)

IS708 Experiment,
7-8 November, CERN, Geneva, Switzerland (J. Pakarinen)

FAIR

NUSTAR Annual Meeting,
26 February - 1 March, Darmstadt, Germany (talk by K. Auranen, I. Moore, J. Äystö)

NUSTAR Week and FRS Users Meeting 2024,
7-9 October, Darmstadt, Germany (talk by T. Grahn)

Super-FRS Experiment Collaboration Meeting,
30 October - 1 November, Walldorf, Germany (talk by T. Grahn, A. Jokinen)

Technology Programme

Robotics and AI for Monitoring and Intervention (ROBOT)

CERN,
30 April - 31 November, Geneva, Switzerland (P. Habibiroudkenar)

CERN,
16-18 September, Geneva, Switzerland (R. Ojala, K. Tammi)

Materials for Accelerator Technology (MAT)

Mechanisms of Vacuum Arcing Workshop,
3-8 March, Tahoe City, CA, USA (F. Djurabekova, R. Koitermaa)

University of Tartu,
8-10 May, Tartu, Estonia (F. Djurabekova)

CERN,
9-12 July, Geneva, Switzerland (F. Djurabekova)

32nd International Materials Research Congress,
18-23 August, Cancun, Mexico (F. Djurabekova)

Kick-Off Meeting for CONNECT-NM European Network for Fission Materials,
3-5 October, Madrid, Spain (F. Djurabekova)

30th International Conference on Atomic Collisions in Solids & 12th International Symposium on Swift Heavy Ions in Matter,
24-29 November, Canberra, Australia (F. Djurabekova, A. Leino)

Satellite Kioloa Ion Track Meeting,
2-4 December, Kioloa, Australia (F. Djurabekova)

Other projects

Education and Open Data

CMS Open Data Workshop,
3-10 January, IIT Gandhinagar, India (remote talk by K. Lassila-Perini)

Subject Didactics Symposium,
9 February, Helsinki, Finland (talk by P. Veteli)

CAT Hackathon,
19-23 February, Florence, Italy (K. Lassila-Perini)

Physics Days 2024,
4-6 March, Helsinki, Finland (talk by P. Veteli)

IRES-HEP Workshop on Workflow Languages for HEP Analysis,
3-5 April, CERN, Geneva, Switzerland (K. Lassila-Perini)

LUKEMA Teacher Event,
24-25 April, Tallinn, Estonia (workshops by P. Veteli)

Midsummer School in QCD 2024,
24 June - 6 July, Saariselkä, Finland (exercise sessions by K. Lassila-Perini)

CMS Open Data Workshop,
29 July - 1 August, CERN, Geneva, Switzerland (talk by K. Lassila-Perini)

4th World Conference on Physics Education,
25-30 August, Krakow, Poland (talk by P. Veteli)

Teachers' Climate Change Forum,
1-3 September, Hyytiälä, Finland (workshops by P. Veteli)

DPHEP Workshop,
2-3 October, CERN, Geneva, Switzerland (talk by K. Lassila-Perini)

STEM Education Research Days,
31 October - 1 November, Joensuu, Finland (talk by P. Veteli)

HSF Training Pre-CHEP Workshop,
19-20 November, Krakow, Poland (talk by K. Lassila-Perini)

Conference on Computing in High Energy and Nuclear Physics,
21-25 November, Krakow, Poland (talk by K. Lassila-Perini)

Journées Des Données Ouvertes de la Physique des 2 Infinis,
16 December, Lyon, France (remote talk and panel discussion by K. Lassila-Perini)

Detector Laboratory

Paul Scherrer Institute,
10-11 January, Villigen, Switzerland (R. Turpeinen)

Winter Satellite Workshop 2024,
17-19 January, Espoo, Finland (M. Kalliokoski)

Physics Days 2024,
4-6 March, Helsinki, Finland (M. Kalliokoski)

SMEAR II Station,
20-21 March, Hyytiälä, Finland (M. Kalliokoski, R. Turpeinen)

2nd Terrestrial Very-Long-Baseline Atom Interferometry Workshop,
3-5 April, London, UK (M. Kalliokoski)

Gran Sasso National Laboratory,
21-23 May, L'Aquila, Italy (M. Kalliokoski, R. Turpeinen)

1st DRD3 Week on Solid State Detectors,
17-21 June, CERN, Geneva, Switzerland (M. Kalliokoski)

21st MoEDAL Collaboration Meeting,
18-20 June, CERN, Geneva, Switzerland (talk by M. Kalliokoski)

25th International Workshop on Radiation Imaging Detectors,
30 June - 4 July, Lisbon, Portugal (talk by M. Kalliokoski, R. Turpeinen)

Finnish Quantum Days 2024,
9-10 September, Espoo and Helsinki, Finland (M. Bezak, M. Kalliokoski)

Ruherford Appleton Laboratory,
10-25 October, Didcot, UK (M. Bezak)

Gran Sasso National Laboratory,
15-17 October, L'Aquila, Italy (M. Kalliokoski)

2024 IEEE NSS MIC RTSD,
28 October - 2 November, Tampa, FL, USA (talk by M. Bezak, M. Kalliokoski)

Uppsala University and AB SVAFO,
18-21 November, Uppsala and Nyköping, Sweden (M. Kalliokoski)

Particle Physics Days 2024,
27-28 November, Lammi Research Station, Lammi, Finland (M. Kalliokoski)

Uppsala University,
2-6 December, Uppsala, Sweden (M. Bezak)

2nd DRD3 Week on Solid State Detectors,
2-6 December, CERN, Geneva, Switzerland (M. Kalliokoski)

22nd MoEDAL-MAPP Collaboration Meeting,
5-6 December, CERN, Geneva, Switzerland (talk by M. Kalliokoski)

PUBLICATIONS

Theory Programme

Theoretical Cosmology

H. Bouzari Nezhad and S. Räsänen,
Scalar fields with derivative coupling to curvature in the Palatini and the metric formulation,
J. Cosmol. Astropart. Phys. 02 (2024) 009

J. R. C. C. C. Correia et al.,
Evolution of current-carrying string networks,
Phys. Lett. B 855 (2024) 138788

J. Dahl, M. Hindmarsh, K. Rummukainen, and D. J. Weir,
Primordial acoustic turbulence: Three-dimensional simulations and gravitational wave predictions,
Phys. Rev. D 110 (2024) 103512

A. Ekstedt, P. Schicho, and T. V. I. Tenkanen,
Cosmological phase transitions at three loops: The final verdict on perturbation theory,
Phys. Rev. D 110 (2024) 096006

E. Frion and T. Miranda in E. Frion et al.,
Bayesian analysis of a Unified Dark Matter model with transition: can it alleviate the H_0 tension?,
Open J. of Astrophysics 7 (2024)

L. Giombi and M. Hindmarsh,
General relativistic bubble growth in cosmological phase transitions,
J. Cosmol. Astropart. Phys. 03 (2024) 059

M. Hindmarsh in P. J. Heikkinen et al.,
Nanofluidic platform for studying the first-order phase transitions in superfluid Helium-3,
J. Low Temp. Phys. 215 (2024) 477

M. Hindmarsh, K. Zhang, and K. Rummukainen in M. Hindmarsh et al.,
A-B transition in superfluid ^{3}He and cosmological phase transitions,
J. Low Temp. Phys. 215 (2024) 495

K. Kainulainen, S. Nurmi, and O. Väisänen,
Tachyonic production of dark relics: classical lattice vs. quantum 2PI in Hartree truncation,
J. High Energy Phys. 10 (2024) 009

K. Kainulainen and H. Parkkinen,
Quantum transport theory for neutrinos with flavor and particle-antiparticle mixing,
J. High Energy Phys. 02 (2024) 217

K. Kainulainen and H. Parkkinen,
Coherent collision integrals for neutrino transport equations,
J. High Energy Phys. 12 (2024) 169

K. Kainulainen and N. Venkatesan,
Systematic moment expansion for electroweak baryogenesis,
J. Cosmol. Astropart. Phys. 08 (2024) 058

M. Kierkla, B. Świeżewska, T. V. I. Tenkanen, and J. van de Vis,
Gravitational waves from supercooled phase transitions: dimensional transmutation meets dimensional reduction,
J. High Energy Phys. 02 (2024) 234

J. Kume and M. Hindmarsh,
Revised bounds on local cosmic strings from NANOGrav observations,
J. Cosmol. Astropart. Phys. 12 (2024) 001

S. Raatikainen, S. Räsänen, and E. Tomberg,
Primordial black hole compaction function from stochastic fluctuations in ultraslow-roll inflation,
Phys. Rev. Lett. 133 (2024) 121403

Fundamental Particle Interactions Beyond the Standard Model

L. Álvarez-Gaumé, M. M. Chaichian, M. A. Oksanen, and A. Tureanu,
Reciprocal of the CPT theorem,
Phys. Lett. B 850 (2024) 138483

M. Heikinheimo, K. Huitu, and A. Stendahl in G. Angloher et al. (COSINUS Collaboration),
Water Cherenkov muon veto for the COSINUS experiment: design and simulation optimization,
Eur. Phys. J. C 84 (2024) 551

M. Heikinheimo, K. Huitu, and A. Stendahl in G. Angloher et al. (COSINUS Collaboration),
Particle discrimination in a NaI crystal using the COSINUS remote TES design,
Phys. Rev. D 109 (2024) 082003

M. Heikinheimo, K. Huitu, and A. Stendahl in G. Angloher et al. (COSINUS Collaboration),
Deep-underground dark matter search with a COSINUS detector prototype,
Phys. Rev. D 110 (2024) 043010

G. Arcadi, F. Costa, A. Goudelis, and O. Lebedev,
Higgs portal dark matter freeze-in at stronger coupling: observational benchmarks,
J. High Energy Phys. 07 (2024) 044

D. Benisty,
Weighing Milky Way and Andromeda in an expanding ΛCDM universe. Decreasing the Local Group mass,
Astron. Astrophys. 689 (2024) L1

D. Benisty, M. M. Chaichian, and A. Tureanu,
Galaxy groups in the presence of cosmological constant: Increasing the masses of groups,
Phys. Lett. B 858 (2024) 139033

D. Benisty et al.,
Late-time constraints on interacting dark energy: Analysis independent of H_0, r_d, and M_B,
Astron. Astrophys. 688 (2024) A156

D. Benisty et al.,
Bounding the cosmological constant using galactic rotation curves from SPARC dataset,
Phys. Rev. D 110 (2024) 063028

I. H. Brevik, M. M. Chaichian, and A. M. Favitta,
On the Axion Electrodynamics in a two-dimensional slab and the Casimir effect,
Int. J. Mod. Phys. A 39 (2024) 02n03, 2450004

C. Cosme, F. Costa, and O. Lebedev,
Temperature evolution in the Early Universe and freeze-in at stronger coupling,
J. Cosmol. Astropart. Phys. 06 (2024) 031

C. Cosme, F. Costa, and O. Lebedev,
Freeze-in at stronger coupling,
Phys. Rev. D 109 (2024) 075038

A. Dinmohammadi, M. Heikinheimo, N. Mirabolfathi, K. Nordlund, H. Safari, S. Sassi, and K. Tuominen,
Daily and annual modulation rate of low mass dark matter in silicon detectors,
J. Phys. G: Nucl. Part. Phys. 51 (2024) 035201

K. Fujikawa and A. Tureanu,
Two classes of Majorana neutrinos in the seesaw model,
Phys. Lett. B 858 (2024) 139064

M. Heikinheimo, K. Nordlund, S. Sassi, and K. Tuominen,
Probing the dark matter velocity distribution via daily modulation,
Phys. Rev. D 109 (2024) 103010

D. Karamitros, T. McKelvey, and A. Pilaftsis,
Varying entropy degrees of freedom effects in low-scale leptogenesis,
Phys. Rev. D 109 (2024) 055007

M. Heikinheimo, K. Huitu, and A. Stendahl in M. Kellermann et al.,
A vibration decoupling system for TES operation in the COSINUS dry dilution refrigerator,
J. Low Temp. Phys. 217 (2024) 418

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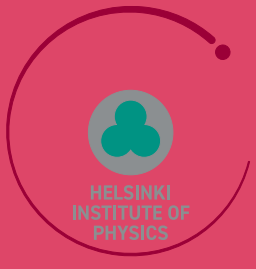

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