Report of the Scientific Advisory Board

Tuesday 31 August and Wednesday 1 September 2021

Remote Zoom-meeting

SAB members: Angela Bracco (University of Milan, Chair), Lars Bergström (Stockholm University), Kerstin Borras (DESY&RWTH Aachen University), Jens Jørgen Gaardhøje (University of Copenhagen), Kalle Härkki (Cerastium Oy), Manfred Krammer (CERN), Jochen Wambach (TU Darmstadt), Tzanka Kokalova Wheldon (University of Birmingham)

Due to the COVID19-situation the SAB met remotely via Zoom on 31August and 1 September 2021. The board received a status report from the HIP director followed by progress reports on some selected HIP projects (see attached agenda). Before the meeting the SAB had received the following material: SAB report from 2020, HIP research plan 2021, the three-year research plans of the CMS Experiment and the CMS Upgrade, HIP long-term strategy, HIP Annual Report 2020

Executive Summary

The committee, which has several new members this year, was very impressed by the scientific production of HIP for being not only large in size but is also of very high in quality. It is very clear that HIP is strongly engaged in the development and successful execution of projects in theoretical and experimental research which have high international standards. In addition, the excellent performance of HIP in education and outreach, reflects increasing efforts in these sectors, and are very much appreciated by the SAB.

Overall, the theory programme is working very well with an impressive number of publications and PhD theses. All individual projects are well embedded in the HIP research strategy and are part of the theoretical physics research at the member universities. The main projects on QCD, phenomenology and cosmology bring synergies with, and added value to, the experimental activities. The additional newer and smaller activities are important to preserve diversity and to stimulate ideas for new venues. The international collaborations are all well established and play an important and very visible role.
The board was presented with an impressive palette of physics connected to gravity such as cosmology, dark matter, neutron stars, merging supermassive black holes and gravitational waves. Quite interesting novel ideas were presented on primordial black holes and neutron stars and their possible role for Fast Radio Bursts. The board was also impressed by the two presentations, one on QCD and strongly interacting gauge theory, and the other on high-energy phenomenology in the LHC era.

The HIP experimental groups in CMS and TOTEM are carrying out a unique and internationally very visible programme. The two groups have very valuable mutual interactions and/or connections for scientific and technical aspects. The SAB is very impressed by innovative work done by HIP

for the detectors in TOTEM and CMS as well as by ongoing and future data analysis themes mainly aiming at new physics. Furthermore, the SAB considers the contribution of HIP to the construction of the new tracker of CMS to be very important, as this is designed to fulfill the stringent requirement of HL-LHC for data taking in Run 4.

In ALICE the HIP contributions to the analyses of the data and to the detector hardware are strong and highly recognized by the collaboration. The SAB congratulates HIP for the leadership role of Finland in the FIT (Fast Interaction Trigger) project and for the dedicated work done to install and commission this detector. The SAB is convinced that the team can carry their experience forward for contributing to the construction of a new detector — a Forward Calorimeter (FoCal) for Run 4. Such a detector will open a unique kinematical window (very low x) to study gluon saturation phenomena. This will make additional synergies with the theoretical efforts possible.

The non-LHC experiments at ISOLDE and FAIR are progressing very well in terms of scientific and technical contributions. The SAB continues to strongly support the participation in this rich and timely field of research providing high quality results which are well connected with the nuclear physics program at Jyväskylä.

The SAB considers the decision of HIP to participate in two large CERN-focused projects to be very wise, with one dealing with robotics and the other with materials technology for accelerators. In addition, the four smaller projects on radiation safety and detection in cooperation with the Nuclear Safety Authority STUK and CEA are very valuable. The national permanent infrastructure, specialised in the instrumentation for particle and nuclear physics, is well equipped and allows the attraction of resources.

The programme director's activities include assistance and facilitation of industrial activation and communication with the relevant ministries and administrative offices. In particular, encouraging the development of CERN-related co-creation and co-innovation projects funded by Business Finland is a key activity that, because of present difficulties, needs additional efforts.

Last year the SAB expressed concerns about the budget that for the period 2021-2024 was reduced by 24% as compared with that for 2017-2020. Fortunately, the Universities participating in HIP are presently compensating for this reduction with their own budget. However, the budget situation has to be monitored to avoid severe adverse effects on the ability of HIP to execute its programme. It is very important to fulfill the various commitments and to keep open the opportunity to enlarge the current scope with new projects.

General

The director of HIP, Katri Huitu, gave an overview of HIP activities that during 2021 focused on four main research programmes and three independent research projects. These activities fit well into the recent strategy and priorities of HIP and are also in line with the strategy for European Particle Physics, NuPECC and APPEC. The HIP research includes (1) the Theoretical Physics Programme consisting of four projects, (2) the CMS Programme including the TOTEM project, (3) the Nuclear Matter Programme and (4) the Technology Programme. The independent special projects are the CLOUD project at CERN, which studies the role of cosmic radiation on cloud formation, the EUCLID cosmology project studying expansion of the universe and the distribution of dark matter, and the Education and Open Data project, which facilitates the highly successful Finnish high-school and teacher visit programme to CERN and develops open access to the data of the CMS experiment. It was also pointed out that the detector laboratory continues to serve the

needs of detector construction and upgrade projects for CERN and FAIR well in addition to carrying out applied instrumentation activities.
A very good response to the requests of the SAB from last year was given and a number of questions related to the most recent developments were presented to the SAB to discuss and these discussions will be brought up in connection with the relevant subjects presented in this report.

The numbers of publications, PhD theses and master theses completed since last year were presented together with a report concerning new employments.

The budget presented for the coming years up to 2024 shows stability after the funding from the ministry has decreased by 24%, last year and the universities have compensated for this loss with their own resources.

In response to the last year request from the SAB to integrate, with additional details, the presentation on HIP's work concerning diversity and wellbeing, Eija Tuominen reported on the particular efforts at the different universities.

As in every previous year, the SAB finds that HIP is doing extremely well and making excellent progress in the research areas in which it is engaged. There is excellent leadership, good organization, and a very collaborative spirit.

The number of HIP refereed publications continues to be at a high level and the number of PhD theses has also increased. HIP also continues to do a really excellent job in education and outreach despite some of the events being cancelled due to COVID-19.

The SAB realized that HIP, with the help of the associated universities, was able to cope with the budget reduction from the ministry and have commitment for a stable budget up to 2024. However, under the present conditions there is very limited possibility to open new research avenues or to expand further the present research lines and in the long-term this could harm the HIP's high standard.

The SAB was asked to give its opinion about the external evaluation of the ending projects. The SAB agrees with the proposed selection of ending projects and considers this process to play a key role in the preparation of future activities.

For the CMS projects the plan for the new projects is well prepared and employs profitably the excellent competences at HIP. This plan is well grounded in the international commitments, on the continuation of the ongoing detector construction for Run 4, and on the physics programme exploiting the collaboration with theory and the technical developments in the charge of HIP well.

The SAB was very pleased with the presentation on diversity that supplemented the one from the previous year with details on the actions carried out at the different universities.

Theory Programme

The head of the theory programme Kari Rummukainen gave an overview of the HIP theory projects and showed the progress achieved since last year concerning publications and theses. He particularly presented highlights from the continuing projects on “Theoretical cosmology" and “Topological matter”, initiated in 2020.
Both projects progress well. A new feature of the Cosmology project is the addition of a “supermassive black hole research group”, headed by P. Johansson. The research carried out in the context of Topological matter has significant impact. Topological properties of quantum many-body systems have remarkably far-reaching consequences on observable properties on a macroscopic scale. Important advances were obtained for superconductivity, for quantum Hall effect in magnetic hybrid systems and for dynamical phase transitions.

The theory projects, focusing on the study of the origin and evolution of the universe via complementary sets of theoretical methods, have opened new connections between particle physics and cosmology. The research in this context includes investigations of the extensions of the Standard Model of particle physics and theories of gravity by studying processes during inflation in the early universe. The goal for the next years concerning the calculation and simulation of the gravitational wave and electromagnetic signal from merging supermassive black holes in massive galaxies is very timely.

All individual projects in theory are well embedded in the HIP research strategy and are part of the theoretical physics research at the member universities. They bring synergies and added value to the experimental activities. The international collaborations and the connections with the experimental projects are well established and play an important role.

The projects “High-Energy Phenomenology in the LHC Era" and "QCD and Strongly Interacting Gauge Theory” were presented by their leaders Aleksi Vuorinen and Tuomas Lappi, respectively.

1. QCD and strongly interacting gauge theory

The sub-projects within this project area address various kinematical regimes of QCD, which requires the development of different approaches. The obtained results are excellent and concern the partonic structure of hadrons and nuclei, initial stages and thermalization in heavy-ion collisions and the spacetime evolution of QCD matter. Synergies with the ALICE experimental group of HIP are strong. This activity, which has several affiliated scientists at the University of Jyväskylä and new generation staff, receives complementary funding, among which is an ERC CoG grant by the project leader T. Lappi. The project is well connected to the international research efforts through a sizable number of high-level collaborations.

The future plans will deal with several interesting investigations such as e.g. the possible use of electroweak boson production as a new way to calibrate the estimation of the nucleus-nucleus luminosity. It should be noted that there is the expressed interest and beginning involvement in Electron-Ion Collider physics.

2. High-energy phenomenology in the LHC era

The theory project “High-Energy Phenomenology in the LHC Era” concentrates on the physics of the Standard Model and beyond, on perturbative QCD thermodynamics of cold quark matter and on

applications of the gauge/gravity duality for its transport properties. The past research has produced excellent results on the equation of state (EoS) for neutron stars (NS) providing first evidence, published in Nature, for the presence of deconfined quark matter (QM) inside massive NSs. This activity receives complementary funding, among which an ERC CoG grant and it has a large number of affiliated scientists in Helsinki.

The plan to further expand this work is well motivated by the rapid growth of new data from the LHC experiments and astrophysical observations which among others need the understanding of the dynamics of phase transitions in elementary particle matter.

Given the success and international visibility of the two projects by T. Lappi and A. Vuorinen, which end in 2022, there is no need for an external evaluation of these projects. As both projects involve various common aspects of QCD, the SAB however sees potential for increased collaboration of both research groups.

On the other hand, we support the plan of the HIP management to have an external evaluation of the projects in "Theoretical cosmology" and for "Designer topological matter" (when their first 3-year terms are ending next year).

HIP envisages a call for 2-3 new theory projects in the fall of 2021. Given the substantial involvement of HIP in ISOLDE and present and future FAIR nuclear structure research, it is somewhat surprising that these activities are not reflected in the HIP theory programme. We therefore recommend that HIP actively encourages theory proposals in the area of modern nuclear structure theory.

CMS and TOTEM Programme

Kenneth Österberg gave an overview of the CMS activities. He also gave detailed presentations of TOTEM, the CMS Forward Physics and Tier-2.

The activities and plans of the HIP experimental groups in CMS and TOTEM are internationally very visible and the collaboration between CMS and TOTEM has produced an original and unique programme with a well-defined path for the future. The group is carrying out detector work at the cutting edge of technology and applying unique analyses to the complex and rich data from the experimental runs.

The presentation of Kenneth Österberg pointed out two important highlights: the acceptance of the EU project H2020 ITN project SMARTHEP and the completion of jet energy corrections for the CMS Run 2 Ultra Legacy data set.

The CMS experiment was presented by Mikko Voutilainen and the CMS upgrade by Panja Luukka, respectively responsible for HIP's CMS operation and analysis and for HIP's part of the CMS upgrade programme.

The CERN BootCamp, organized together with three Universities of Applied Sciences, is to be acknowledged. Introduced in 2018 and repeated in 2019, it allows students from various fields to

spend five days at CERN's IdeaSquare for solving demanding societal problems. The SAB receives the plan to organize this course again in 2022 very positively.

1. CMS detector operation and Physics analysis

As was well planned in the past years, the engagement of HIP on the CMS operation will be on track alignment and on Jet Energy Corrections (JEC).
Until 2024 the focus will be on novel methods for precise calibration at high pile-up conditions as those of Run 3 at LHC. The physics programme foreseen depends critically on achieving beyond state-of-the-art precision in JEC with the challenging aim of reaching the 0.1% level.

One important issue addressed within the ongoing analysis is that of reducing the dominant uncertainty in top quark mass measurements. Moreover, within the EU project SMARTHEP the machine learning techniques are developed to improve selection for physical quantities such as quark/gluon discrimination in jets.

The searches for new physics constitute the core of the planned activities for Run 3. Indeed, the envisaged rich programme addresses interesting questions related to charged Higgs bosons, vector boson scattering and precision measurements with jets (top quark mass, inclusive jet and gluon jet cross sections), with common activities in Deep Learning (DL) to optimize the extraction of interesting signals.

Concerning the charged Higgs bosons, SUSY predicts a minimum of five, with many of those decaying to tau leptons, where the Helsinki group has strong local expertise. For the Vector boson scattering problem the Run 3 analysis will benefit enormously from the strong local jet expertise in the Helsinki group. Precision measurements with jets focus on two main themes: precise measurement of the top quark mass and measurements of the inclusive jet and gluon jet cross sections.

The SAB congratulates the group for the outstanding results achieved and for having delineated a plan up to 2024 exploiting excellently the expertise and infrastructures at HIP. Fitting well into the international commitments the chosen activities guarantee international visibility and recognition.

2. CMS upgrades

During the 2022-2024 major efforts will be devoted to the upgrade of the CMS Tracker which is designed to deal with the high pile-up conditions and fully exploit the capabilities of the HL-LHC.

Finland was strongly involved in Phase-1 upgrades of the innermost pixel detector, completed in 2017. For the Tracker Phase-2 upgrade Finland participates in the construction of the new innermost tracking detector and in the construction of the mechanics for part of the Outer Tracker. In addition to the Tracker Phase-2 upgrade Finland will have a significant contribution to the building of the new CMS MIP Timing Detector for the endcap region, using pixelated Low Gain Avalanche Detectors (LGAD). For these LGAD detectors HIP has a visible activity on the optimization, testing and qualification of the pre-production and production runs.

The SAB congratulates the CMS programme for the highlights in 2021, namely the installation of the CMS pixel tracker and the trigger electronics for the GE1/1 muon station for Run 3 data taking and for obtaining the role of leading laboratory for the testing and qualification of LGAD sensor for the MTD-ETL upgrade.

The timeline for the part of the CMS upgrade carried out in Finland shows dense activity up to 2024, fitting well with the contributions of the also connected collaborators.

In addition, HIP is doing R&D on a new pixel detector which can survive the high luminosity conditions expected during HL-LHC.

One of the spin-offs of the detector R&D activity has been the development of multispectral imaging sensors for medical imaging and beam characterization (RADDESS project).

The SAB strongly supports the ongoing and future activities, as planned up to 2024, for the detector upgrades of CMS. Since it is important to fulfill the requirements and milestones connected to it, the required resources have to be provided as scheduled.

3. TOTEM and CMS Forward Physics

The HIP coordination of the Finnish participation in the TOTEM experiment and the CMS Proton Precision Spectrometer (PPS) resulted in a successful programme on QCD based ~~on~~ measurements of elastic scattering, total cross-section and diffraction processes. Higher precision measurements are being prepared for Run 3 by exploiting previous successful exploratory work.

HIP members have leading positions of significant responsibility including that of physics coordinator for this physics area.

The TOTEM experiment has produced new and very interesting results and is preparing for its last data taking, expected in 2022. A highlight for 2021 is the common paper with the D0 collaboration on the “Odderon” discovery, which quantifies the difference between proton-proton and proton-antiproton collisions and excludes models without Odderon exchange. In addition, for glueball candidate studies in central exclusive processes, TOTEM has taken data with CMS.
The activities on the detectors, partly funded by the Academy of Finland, are related to the new T2 (“nT2”) scintillator detector, the upgrade of the PPS diamond timing detector and the development of dedicated PPS search triggers for the CMS Run 3. The LoI for the contribution to the HL-LHC PPS TOF detector was approved by CMS and the TDR is the next step.
These developments give a unique possibility to measure high-mass exclusive processes. Funding for the HIP contributions to the nT2 and the PPS upgrade ~~are~~ is granted by the Academy of Finland. In 2021 the relevant highlight for the detectors is that the prototyping of the nT2 scintillators was completed successfully and that mass production has started.

4. Tier-2

The Tier-2 computing center is designed to provide the necessary computing resources that are essential for the CMS data analyses.
During 2021 a new framework contract was signed by HIP with the Finnish Center for Scientific Computing (CSC) and a paper on the LHC computing needs for the new EuroHPC Lumi supercomputer is in discussion. In addition, discussions on the Finnish / Nordic participation

with EGI (European Grid Infrastructure) are ongoing since 2020 after the CSC decided to leave EGI.
Concerning funding in 2021, HIP has contributed to the application for computing resources to the Academy of Science.
A challenge for the next years is to meet the increased LHC computing demands related to the increasing LHC luminosity.
The SAB supports the recommendations of the task force to expand the resources accessible for data processing at facilities beyond those dedicated to the LHC and in particular the new resources Puhti and Lumi of CSC are important to be worked on to be adapted for CMS usage.

The SAB continues to be very impressed by the detector work and physics results of TOTEM and CMS. The presented plan for new projects concerning detector construction and data analysis up to 2024 is supported as such by the SAB. The physics analyses, concerning timely physics questions, exploit the synergies with software developments in tracking alignment and with jet energy corrections well.

The SAB supports the plans of HIP for the detector upgrades of CMS, exploiting the features of the detector laboratory. Also, HIP's involvement in building a completely new Precision Proton Spectrometer for HL-LHC is seen as an excellent opportunity.

The SAB expresses concerns about the lack of resources for computing and storage for LHC experiments. Especially for the high luminosity runs it is important that investigations on how to handle the increased amount of data start much ahead of time.

Since it is important to respect the milestones connected to the CMS upgrade and to the data analyses the SAB recommends the timely provision of the resources required for the scheduled activities.

Nuclear Matter Programme

A short introduction of the Nuclear Matter Programme was given by Ari Jokinen and the different projects, ALICE, ISOLDE and FAIR, were presented by their respective project leaders, Sami Räsänen, Janne Pakarinen and Tuomas Grahn.

1. ALICE

The contributions of the HIP group in both physics analyses and to the hardware of ALICE plays a key role in this LHC experiment, efforts which are well recognized by the collaboration.

The main focus of the analyses carried out by the HIP group is on the study of the properties of the collective flow. An important goal is to provide constraints to both shear and bulk viscosities of the quark-gluon plasma. Another analysis in which the group is engaged concerns the centrality dependence of the dijet mass distributions in Pb-Pb collisions and for that the challenging objective is to push the measurement down to as low as possible in dijet masses.
The highlight in 2021 is the impressive Bayesian analysis performed by HIP for the estimation of shear and bulk viscosities in the QGP phase.

Concerning hardware, HIP has the responsibility as project leader for the Fast Interacting Trigger (FIT) from JYFL, an international sub-collaboration in ALICE.

Presently all detectors are installed in the ALICE cavern, the commissioning is ongoing and pilot beams with collisions at the injection energy will allow the collection of millions of events before the end of 2021 and thus the first physics analysis will already start this year. The effort of HIP for the FIT installation and commissioning is crucial and very successful.

Finland has also contributed to the upgrade of the TPC GEM readout. Construction, commissioning, optical scanning and high-voltage tests of the large GEM foils were performed in the HIP detector laboratory.

The group devotes resources also to prepare the longer-term activity for Run 4 and for that there is a clear interest in taking part in the construction of the new detector FoCAL, a Forward Calorimeter designed for HL-HLC and to be installed in Long Shutdown 3. The international FoCAL team is developing first prototypes to be tested in beam in October this year. This project was approved by ALICE and the participating countries are in the process of finding resources for it. This year HIP has contributed significantly to the studies of performance for neutral pion correlations as well as with participation in the FoCal test beam, MC simulation of the setup and test beam data analysis. The physics case of FoCal includes the study of parton densities and their nuclear modifications at very small Bjorken-x and the search for direct experimental evidence of gluon saturation phenomena.
A positive opportunity comes from a strong overlap with the interests of the theory group in Jyväskylä.

HIP intends to contribute to the Technical Design Report of FoCAL with physics performance studies and will apply for funding to this end.
The group expressed that if no further resources are obtained some of the jet analysis has to be reduced in order to concentrate on FoCal. The SAB thinks this is a sound prioritization.

The preparation of the Letter of Intent for the new experiment after 2030 (run 5, for which the detector has to be rebuilt) is ongoing, and ALICE aims to release it by the end of 2021. Development of the proposal and continuing involvement in ALICE beyond LS4 would be an interesting option for Finland.

The SAB is pleased to see the good progress with the physics analyses under the HIP responsibility and congratulates for the ALICE programme on the successful completion and installation of FIT.

The SAB also strongly supports the planned activities in FoCAL. The collaboration with the theory group is well established and important for the overall physics programme.

The SAB is concerned about the permanent personnel situation: the replacement of scientists that will retire over the next few years is needed.

2. ISOLDE

The highlights and the future plans of HIP-ISOLDE were presented. When operation restarts in 2021 ISOLDE provides radioactive ion beams both at low energy and with post accelerated beams. For the experiments with post accelerated beams the addition of the SPEDE electron spectrometer,

built at JYFL, to MINIBALL offers the possibility to study shape coexistence in exotic heavy nuclei. In addition, the SISIN project from the Academy of Finland project provides funding for research to identify intruder states in neutron deficient nuclei around Pb via (multi-nucleon) transfer reactions.
The low-energy beam programme concerns laser ionization at CRIS and beta decay at IDS. Both programmes are complementing the JYFL activity and benefit from technical developments there. For the future a copy of SPEDE is being prepared for beta decay experiments.

Among the highlights for the results obtained last year there is the measurement of charge radii of exotic potassium isotopes which challenges nuclear theory and the magic character of N = 32.

To be pointed out are the mid-term goals for ISOLDE (2025-2026) that will lead to the availability of more beams, to higher beam intensity and to new isotopes. For this purpose, there are plans for parallel beam operation, new beam dumps for higher energy protons and for an upgrade of the transfer line for 2 GeV protons.

The SAB is very pleased with the progress made for the projects at ISOLDE and with the results obtained. The SAB is very positive about the ongoing plans for experiments exploiting the capabilities of SPEDE, especially in view of the more intense beams in the next years.

The SAB strongly supports HIP to continue to take part in this rich productive and timely research which focuses on experiments complementing the programme at JYFL very well. The SAB sees that University of Jyväskylä and HIP benefit from this very visible activity.

3. FAIR

The status of the different in-kind projects to build detectors for the Super-FRS (SFRS) facility and of the ongoing experimental activity at FAIR were presented. The SAB considers the participation in the FAIR Phase-0 experiments that are planned until the full operation of FAIR, to be very important. At the same time the detectors that belong to the Finnish in-kind contributions to FAIR will be gradually integrated according to their readiness.
Nuclear physics contributions to studies of heavy-element nucleosynthesis are one of the priorities together with the investigation of the Equation of State (EoS) of asymmetric matter.
The Finnish share of the MONSTER neutron-detector is operating at JYFL-ACCLAB for experiments on beta-delayed neutron emission. The conceptual design for the SFRS SEM-grid beam profile detectors was finished this year.
The SAB was pleased to see that an application to the Academy of Finland FIRI (infrastructure) is in progress since more funding is needed for the in-kind contributions and for the cost increase of FAIR. The submission of an additional application to the Academy of Finland for the science is considered to be very valuable to exploit the science possibilities with the SFRS within the NUSTAR pillar and in the longer term to open new avenues at the other pillars of FAIR.

The SAB considers the progress on the in-kind contributions for FAIR and the plans for the future work to be excellent. The involvement of the Finnish group in the data taking of FAIR Phase 0 is very beneficial for the science programme and for the test of instrumentation. The application for resources for the next years is very important.

The SAB finds that the HIP group has a good balance between experimental activities and the construction work of Super-FRS.

Technology programme

The technology programme was presented by its director Filip Tuomisto and two separate talks were given by Flyura Djurabekova on materials for accelerator technology and by Kari Tammi on robotics and AI for Monitoring and Intervention.

The projects in the HIP Technology Programme promote research, development, innovation, technology transfer and pre-commercialization activities with links to CERN. Furthermore, synergies with other international big science initiatives are actively sought.

The focus of the programme has improved, following the past SAB recommendations. Presently the programme consists of two larger CERN-focused projects, one on robotics and the other on material technology for existing and future large accelerators.

In addition, the programme hosts 4 smaller projects that focus on radiation safety and radiation detection technologies in strong cooperation either with STUK or CEA.

The project RADMED, in collaboration with STUK and receiving funding from the Academy of Finland up to 2021, focuses on the development of a detector system (including hardware, readout and software) for computed tomography and radiotherapy. Boron neutron capture therapy applications will be investigated as well. The project RADAR includes three activities: i) the construction of a detector to distinguish airborne radioactivity, radioactive fallout and detector contamination; ii) the design of an optimized modular verification system for the Finnish geological disposal programme; iii) germanium imaging spectrometer for student laboratory exercises and to be used in Ispra for the characterization of radioactive waste.

The project RADSAFE, in a close collaboration with STUK and the University of Jyväskylä, is intended to bring state-of-the-art detection technologies and multi-parameter data-acquisition techniques to routine use in safety, security and safeguard (3S) applications.

The research on X-ray spectroscopy for materials in extreme conditions of temperature, pressure and irradiation is carried out at several synchrotron radiation facilities abroad. In addition, the ongoing collaborative project HotXAS between CEA Marcoule (France) and the HIP has plans to install a device for highly radioactive samples at CEA Atalante.

Concerning future directions, the SAB acknowledges and encourages the plan to explore cooperation possibilities with other" "big science" initiatives such as those in fusion research, within the CERN-ESA collaboration, for operation (devices, materials) in harsh radiation environments or other.

The effort for research activation in industry will be very important and for this there is ongoing work for setting up a "Finnish Microelectronics Industry-Academia network".

Although in 2022, RADAR-related work will be carried out within the programme, enabling strategic planning of the "radiation safety" theme from 2023 onwards, the SAB recommends an external evaluation to be made for this project.

1. Accelerator Technology: Materials

The presentation of the project Materials for Accelerator Technology showed that from 2021 the focus of the research moved towards a broader scope of the materials problems encountered by the scientists and engineers while developing new concepts for future accelerators.
The new project is continuing the studies of the electric field effects on Cu surfaces for the Compact Linear Collider (CLIC) project. In particular, the multiscale model to explain the behavior of metal surfaces under the extreme conditions experienced by accelerating structures is developed.
Technological research for very thin film coating is also performed and this has relevance for the construction of very powerful superconducting accelerating structures, such as those needed for the Future Circular Collider (FCC). For this purpose, it is important to know and simulate the physical quantities affecting the current.

The SAB recommends that possibilities concerning synergies with the "Topological matter" research should be investigated.

2. Robots and AI for monitoring and intervention

The SAB was pleased to learn about the progress of this project whose aim is to develop robotic systems for tele-operation, based on advanced artificial intelligence and virtual reality techniques.
Within this project there is the design of a continuum robot arm for inspection of the ALICE detector, as for it there were 135 robotic interventions since 2015.
Another activity concerns tele-operation and tele-presence for CERN tunnels with capabilities for obstacle avoidance, path planning and precision maneuvering to increase autonomous operation.
In spite of the substantial progress made, this very active and skillful group has identified several improvements to be made to both software and hardware in the coming years.

The SAB considers the project on Robots and AI to be very useful and recommends a closer collaboration with CERN particularly in view of the future tunnel infrastructure for the FCC. There is also the possibility to collaborate more closely with other institutions and this is recommended by the SAB.

The SAB is in general very pleased with the presentations of the technology programme which is much more focused than in the past. The focus should further increase in the future. There is a clear importance of this programme for CERN and for the radiation and safety sector for which there are cooperation with STUK and CEA. It is also very welcome to see the work on boron neutron capture therapy applications, as this builds on Finland's lead in this area world-wide, especially given the approaching clinical readiness of the unique Helsinki facility.

Since last time some progress was made concerning the research activation in industry. The ongoing setting up of the "Finnish Microelectronics Industry-Academia network" is acknowledged as a good step in this direction. More efforts are recommended to be made in the next years also in view of improving the situation for the industrial return from CERN.

We support the plan to have an external evaluation of the projects which end next year:
- Radiation metrology for medical applications (RADMED) and - Radiation detection for safety, security and safeguards (RADSAFE).

The Detector Laboratory

The present status of the Detector Laboratory with its three missions, namely the support of experimental activities, the participation in teaching and social interaction and the execution of externally funded R&D activities, was presented by its leader Eija Tuominen.
The success of the activities of this laboratory is due to the variety of skills and technological competences of the permanent staff and to the efficient leadership. The Laboratory collaborates with several research groups in Finnish universities and the Nuclear Safety Authority STUK but also with the private sector, especially with small- and medium-sized companies. The infrastructure needs to be continuously updated due to increasing needs for detector quality control and reliability analysis. The Laboratory is very successful in the acquisition of additional resources from different sources.
The Laboratory is involved in CMS, the TOTEM upgrade and in the in-kind contributions to FAIR and also in externally funded projects connected to HIP. Recently an additional activity was introduced by the new staff scientist, the involvement in the experiment MoEDAL which is searching for monopoles and other exotic particles at CERN. There is also a participation in CERN's RD50 and RD51 collaborations for which members of the laboratory staff have responsibilities.

The SAB appreciated the presentation made of the schedule and the timeline of the different activities and realized that major efforts are made to fulfil the various commitments.

The Laboratory provides teaching of instrumentation in the Master's Programme for Particle Physics and Astrophysical Sciences and in 2021 the courses "Gaseous detectors and scintillators" and "Laboratory Course in Instrumentation" were given. However, UH has no permanent teaching staff for instrumentation. In addition, senior scientists act as supervisors in the Doctoral Programme for Particle Physics and Universe Sciences.

Leadership roles in outreach initiatives have continued in 2021 and these have attracted a total of 200 students visiting the Laboratory for demonstrations about detector technologies.

The Laboratory also participates actively in university outreach activities and in initiatives for wellbeing and diversity. There are collaborations for Open Days for alumni, high school students and new physics students. Outreach initiatives are important activities for the laboratory.

The SAB was pleased with the presentation and is very impressed by the activities at the Laboratory. This laboratory is indeed an outstanding national asset for the research, education and societal interaction in the instrumentation of particle and nuclear physics and in the development of detector technologies.

The SAB appreciates the efforts to continuously update the infrastructure to keep up with the increasing needs for detector construction and quality control.

It was good to see that Quantum Technology is entering the research activities of HIP: e.g. by the inclusion of Quantum Machine Learning in a grant application for the Detector Laboratory. We note that HIP has excellent prerequisites and competences to embark on different areas of Quantum Technologies research, for example in Quantum Computing for theoretical calculations or experimental physics analyses and simulations. We encourage further investigations in order to be

ready to benefit as soon as possible from the rapidly evolving technologies for novel science research.

Wellbeing and diversity.

The SAB appreciated the presentation on wellbeing and diversity from Eija Tuominen that contains interesting data on these issues. It is remarkable that at the UH the percentage of female scientists in UH does not drop significantly as career stage increases, in contrast to the other institutions for which data were shown.
All Finnish universities have an equality plan with special initiatives. The actions to promote diversity are well chosen and are in line with what is done in international networking on these topics.
Tuominen showed an increasing trend in professorial staff in physics at UH for the number of female and foreigner-born staff over the years, suggesting that there is a payoff in promoting diversity. It is true that diversity makes for better science but it requires actions to develop it, and special attention is paid to this at HIP.

The SAB is pleased to see all the actions in place in this sector and the further planned efforts for the future.

SAB would like to warmly thank the HIP directorate for the excellent preparation of the meeting. In particular, for all the reports and presentations that were suggested in last year's report. The SAB thanks also the speakers for their clear presentations.

For the HIP Scientific Advisory Board

Angela BRACCO (chair of the SAB)