MINISTRY OF EDUCATION, YOUTH AND SPORTS

Final report on the implementation of the large research infrastructure (LRI) project in the years 2020-2022

CERN-CZ

Full name of the LRI: Research infrastructure for experiments at CERN

LRI's identification code: LM2018104

Beneficiary of the LRI project:

Institute of Physics of the Czech Academy of Sciences (FZU)

Other participant/s of the LRI project:

Charles University (CU)
Czech Technical University in Prague (CTU)
Nuclear Physics Institute ASCR (NPI),
Palacký University in Olomouc (PU)
Technical University of Liberec (TUL)
University of West Bohemia (UWB)

Principal investigator of the LRI project: doc. Alexander Kupčo, Ph. D.

Website address of the LRI: http://www.particle.cz/infrastructures/cern-cz/

PART I.

A. Progress report

I. Describe the mission and objectives of the LRI, scope of the services that the LRI provides to its user community, and their evolvement over the funding period 2020–2022 compared to the initial state of play.

CERN-CZ mission and objectives

The LRI CERN-CZ organises and supports the participation of universities and research institutions from the Czech Republic (CR) in the international laboratory CERN (European Organization for Nuclear Research) in Geneva. With the world's largest proton and heavy ion accelerator, the Large Hadron Collider (LHC), CERN plays a worldwide leading role in research of elementary particle physics and behaviour of matter at extremely high energies and densities. The goal of research at CERN is to broaden our knowledge of the basic laws governing matter behaviour, including the principles under which our universe evolves.

The international organisation CERN was founded in 1954 by twelve European countries. Today, CERN has a total of 23 member countries that take care of the operation of the laboratory. The Czech Republic has been a member of CERN since 1992 (at that time still as the Czech and Slovak Federal Republic). The CERN Council authorised the extension of the mandate beyond Europe and in December 2013 Israel became the first non-European member state of the organisation. From the very beginning, CERN has been a shining example of international cooperation and excellence in particle physics for almost 70 years.

CERN operates and hosts a number of unique accelerators and experiments. The best known and most important one is the LHC, fully operational since late 2009, fifteen years after project approval. The most significant result so far is the discovery of the Higgs boson in 2012 by the ATLAS and CMS experiments. During its operation, the LHC so far delivered about 30 inverse femtobarns (fb^{-1}) of proton-proton collisions at center-of-mass (c.m.) energy of 7 and 8 TeV and 150 fb^{-1} at 13 TeV.

The aim of CERN-CZ is to support the development, construction, maintenance, and operation of scientific facilities in CERN experiments with Czech participation. This includes the local infrastructure and laboratories in the CR, which are necessary for the research, development and production of these detectors, and computing tools for large scale data processing. The LRI is developing new technologies for particle detectors including their applications, especially in the field of calorimetry and semiconductor tracking detectors. The LRI's technical scope covers such areas as:

- design and construction of detectors,
- development of radiation-hard semiconductor detectors and electronics,
- cooling,
- cryogenics,
- vacuum technology,
- electronic and mechanical design,
- large scale data processing.

The portfolio of services includes: operation and maintenance of detectors, in particular those that have been built partially in the CR; upgrade and construction of new detectors; research and development of new technologies and detectors for future upgrades and new projects; operation of a computer center serving as a national Tier2 center in the hierarchy of CERN computer network; coordination of projects at CERN with CZ participation in cooperation with the *Committee for Collaboration of the CR with CERN*; representation and exercise of our country's rights in the governing and advisory bodies of CERN and individual experiments.

Unique scientific experimental facilities, which were constructed with a contribution from the CZ institutions, form the core of the LRI. Continuous participation in their operation, maintenance and upgrades is a necessary condition enabling CZ scientists to have access to the unique data collected by these facilities. This is the core benefit of CERN-CZ for the Czech user community. Scientists from CZ research institutions can thus contribute adequately to the excellent world-class results in the field of particle and nuclear physics produced by the experiments at CERN.

The CERN-CZ consortium of research institutions contributes to the following experiments and projects at CERN:

- LHC experiments: ATLAS, ALICE, TOTEM, MoEDAL,
- other non LHC experiments: COMPASS/AMBER, NA62, AEGIS, OSQAR, nTOF, WITCH,
- research and development (RD) projects: MEDIPIX / TIMEPIX, AIDAinnova, RD50, RD53, RD18, CALICE, FCC.

The LRI institutions were involved in the design, construction, testing and commissioning of the key components of the ATLAS (https://atlas.cern/) and ALICE (http://aliceinfo.cern.ch/) experiments. For the ATLAS experiment, these were: parts of the Inner Detector based on strip and pixel semiconductor sensors, TileCal hadron calorimeter, forward proton detectors ALFA and AFP, ATLAS-MPX radiation background detectors, and muon detector radiation shielding. In the case of the ALICE experiment, it was mainly electromagnetic calorimeter PHOS, tracking detector ITS, the Muon Forward Tracker (MFT) and the Forward Diffractive Detector (FDD). There were also a few other contributions to smaller experiments, like vacuum parts of Roman Pots for TOTEM. Experts from CERN-CZ have contributed to solving a number of problems in the construction of detectors, such as cooling semiconductor detectors, electronics, radiation shielding and others, and are intensively involved in the upgrade of these detectors for High Luminosity LHC (HL-LHC) upgrade. They are also involved in the operation and maintenance of these detectors during data taking campaigns. LRI's teams contributed similarly to other experiments at CERN with the participation of CZ institutes.

Below we describe the advanced infrastructure used during the construction and operation of the detectors by highly qualified LRI teams of experts.

- clean laboratories at FZU, CU, CTU, and NPI,
- equipment for very accurate quality testing of semiconductor sensors,
- automatic and manual probe stations,
- metrology stations,
- various test devices based on laser, X-ray, and radioactive emitters, and accelerator testing methodology,
- electronic and mechanical workshops,
- optical laboratories at UPOL.

CERN-CZ evolvement over the funding period 2020–2022

In 2020-2022, LHC underwent a maintenance shutdown (Long Shutdown LS2). The first proton-proton collisions at a new world record center-of-mass energy of 13.6 TeV were delivered in July

2022 and the LHC Run3 started. The goal of Run3 is to increase by the end of 2025 the available datasets by a factor of two. Increased collision energy together with larger datasets will allow to improve the precision on Standard Model (SM) parameters, including more detailed study of Higgs boson properties, and will increase discovery potential of LHC experiments for beyond SM physics. In addition to data-taking, the work on detector HL-LHC upgrades continued. New detectors have to be ready for their installation during the LS3 in 2026-2028, right after the end of Run3.

This LHC schedule defined two main tasks of CERN-CZ in 2020-2022: **operation and maintenance** of experiments, and **construction of detectors** for the HL-LHC upgrade. In the form of membership fees, the operation of CERN experiments was in 2020-2022 supported from CERN-CZ budget by 42 771 thousand Czech Crowns (th. CZK), ATLAS HL-LHC upgrade was supported by 75 079 th. CZK, and ALICE upgrades (MFT, FDD, ITS3) were supported by 10 494 th. CZK.

Due to space constraints, we report here only on our major activities in three experiments with the largest CERN-CZ groups ALICE, ATLAS, and COMPASS.

ALICE experiment. During LS2, the Czech teams actively participated in the ALICE upgrade projects of the Inner Tracking System (ITS), the Muon Forward Detector (MFT), and the Forward Diffractive Detector (FDD). The new ITS is a silicon tracker, which massively employs the technology of Monolithic Active Pixel Sensors. It was installed to ALICE in July 2021. The NPI team participated in 106 shifts during which the ITS was commissioned. The NPI team further contributed to development of the ITS Quality Control software and was engaged in data quality monitoring. Let us highlight that one of our Ph.D. students A. Isakov served as the ITS data quality coordinator in the second half of 2022. The MFT detector is a forward silicon tracker equipped with the same sensors as the ITS. It was integrated into ALICE in December 2020. The CTU team participated in the detector commissioning taking responsibilities for the development of the Quality Control software for the MFT and the related data quality monitoring. This project was led by the CTU Ph.D. student Tomáš Herman, who also became the MFT System Run Coordinator in the first half of 2022. The FDD consists of two scintillator arrays installed at forward/backward pseudorapidity regions. The detector was completely produced at the CTU in 2020 and it was installed in ALICE in February 2021. The CTU team is fully in charge of the FDD and Solangel Torres from CTU serves as the FDD System Run Coordinator. Let us highlight that Czech teams are also involved in characterization of the sensor prototypes for the follow up upgrade of the ITS inner barrel (ITS3). At the NPI cyclotron we performed tests of radiation hardness of these sensors. In September 2022, the ALICE Czech teams organised in Prague a workshop *ALICE Upgrade Week* dedicated to the Run4 and beyond Run4 upgrades. The workshop had 100 participants. With the start of LHC Run3 in 2022, the CERN-CZ supported the operation of ALICE by performing 140 shifts in the control room or as on-call experts.

ATLAS experiment. To support **ATLAS** operation and maintenance, CERN-CZ researchers served during 2020-2022 1624 shifts in ATLAS control rooms, or as experts on-call. ATLAS keeps track of additional technical work related to the operation and maintenance of the detector. In 2021, CERN-CZ teams provided 15.3 FTE (15.1 FTE in 2020) in so-called Class~3 operational tasks and 1.7 FTE (1.7 FTE in 2020) in computing, as a contribution from our Tier-2 computing center in Prague. Our level of effort in 2022 was similar as in 2021, but the final numbers for 2022 will be released after this report, in February 2023. In addition, ATLAS recognized 22,0 FTE in 2021 (19,2 FTE in 2020) as our contribution to HL-LHC ATLAS upgrade activities (again with a similar level in 2022). The upgrade effort was concentrating on the construction of a new tracker detector ITk. Here our major obligations are testing 4500 strip sensors for the End-cap detector and assembly of 650 modules for one End-cap disc. Thanks to the investments from related OP RDE project *Investments for Data processing and Detector Testing for the CERN-CZ RI* (CERN-CD) and to the additional funding from the CERN-CZ institutions, a new clean laboratory for silicon sensors was established and fully equipped. The lab qualified for ATLAS sensor testing in October 2020. So far, 1490 sensors have been tested there, out of it 200 underwent so-called full testing procedure. In 2022, the module assembly qualification of our lab continued. During this year, 4 prototypes and 5 pre-production modules were built in cooperation with company Argotech. Our cooperation with Unicorn University resulted in the contract for the development of ITk production database (305 000 CHF). In connection with our work on the upgrade of the Tilecal calorimeter, the Czech company DUO Opocno received in 2021 a contract for building heat sinks (241 000 CHF). Delivery was realised towards the end of 2022.

COMPASS and AMBER experiments. CERN-CZ contributed to the operation of the COMPASS experiment in areas of data acquisition (DAQ), IT infrastructure maintenance, and in the operation of polarised target. COMPASS was collecting data on deep inelastic scattering of muons on transversely polarised deuterons in two runs: a shorter one in 2021, hampered by polarised target and beam problems, and a longer and successful one in 2022. In total, the Czech institutions served about 200 spectrometer shifts and several weekly coordinators and STRAW tracker on-call services. We provided a full-time polarised target on-call expert for both years and we covered about a half of the DAQ on-call services. Finally, we provided the STRAW detector calibrations, the data production manager, the run coordinator in 2021 and the analysis coordinator in 2022. The AMBER experiment is set to start data taking in 2023. Czech institutions were involved in the development of the new trigger-less (continuously running) DAQ system and the high-level trigger from 2020. We participated in several test runs in 2021 and 2022 by serving shifts, setting up the DAQ and helping with beam steering.

WLCG Tier-2 Data Processing Center. CERN-CZ support for large-scale processing of LHC data is substantial. LHC data processing is performed on the Worldwide LHC Computing Grid (WLCG) - a distributed infrastructure that connects computing and storage capacities from around the world. CERN-CZ operates a Tier-2 center that supports the ALICE and ATLAS experiments. Most of the resources are located at FZU, other computer servers at CU and part of storage capacities at NPI. Gradually, we renewed the hardware through investments from related OP RDE project CERN-CD and from institutional resources. The center's computing resources are shared with other projects and research infrastructures. This leads to a virtually continuous maximal utilisation of computing servers.

At the end of 2022, the computing center capacity reached 13 000 cores, of which 7 000 is share of CERN-CZ. HS06 units are used for a comparison of delivered computing power. The average power of our newest computing cores from 2022 with HT on reaches almost 18 HS06 / core. Our commitment to the ALICE and ATLAS experiments was 50 000 HS06 and 4 800 TB of disk space. We fulfilled these commitments, and in the case of delivered CPU power exceeded them significantly by minimising downtime and by using external resources provided mostly by IT4Innovations, details are given in Tab. 1 below. Newly purchased computing cluster in 2022 has a total capacity of almost 35 000 HS06 dedicated for LRI CERN-CZ provided by almost 1000 physical computing cores (2000 with HT on). Disk servers were also renewed in 2021 using resources obtained from the OP RDE project CERN-CD and are sufficient for 2023 pledges. See the list of all contracts in section II.BI below. A new project with CESNET exploits the possibility of storage extension by remote S3 capacities.

There was a significant increase in delivered ATLAS CPU capacity in 2021 thanks to the newly available supercomputer Karolina in IT4I and our ability to deploy it in its early stages of operations.

	Number of jobs		CPU Time in HS06 years	
Year	ALICE	ATLAS	ALICE	ATLAS
2020	1 348 031	4 014 080	33 584	58 836
2021	1 398 520	3 522 947	35 150	260 372
2022	2 757 563	6,327 981	47 854	97 549

Tab. 1: Number of jobs and delivered capacity for LHC experiments ALICE and ATLAS by the CERN-CZ Tier-2 center (according to the WLCG accounting portal).

Major events during 2020-2022. The International Conference on High Energy Physics (**ICHEP**) is a major conference in the field of particle physics. CERN-CZ was co-organising this major event which took place in summer 2020 in Prague. The conference was affected by the starting Covid-19 pandemic and had to be reorganised in a short notice to a purely on-line format. The Czech particle physics community coped successfully with this challenge and the conference was attended by 3000 researchers. Prague will hold this conference in 2024 again, hopefully this time in-person. The second major event was the **celebration of the 30th anniversary of the Czech and Slovak membership of CERN** in 2022. The event was organised by the *Committee for Cooperation of the Czech Republic with CERN* together with LRI CERN-CZ. The series of morning lectures and experiments was attended by over 100 high school students. The afternoon official part was attended by the representatives of the Czech and Slovak Governments, the Rector of Charles University, CERN Scientific Director Joachim Mnich, and other distinguished guests.

II. Describe the major deviations and changes compared to the original plan of the LRI's project implementation (e.g., in scope, objectives, personnel, etc.) over the course of the funding period 2020–2022 and explain their reasons.

The major deviations and changes to the original plan were introduced by the world-wide Covid-19 pandemic situation that developed in the beginning of 2020. During 2020 and 2021, strong measures were implemented by CERN for accessing the laboratory. Situation was returning to normal during 2022. This resulted in the change of LHC schedule. The LHC long shutdown LS2 was extended, postponing the start of Run3 until mid-2022. In addition, the Run3 was extended to full year 2025 and the LS3 long shutdown for the installation of HL-LHC upgrades was moved to years 2026-2028.

The strong access restrictions to CERN affected the CERN-CZ budget and activities. They resulted in a significant reduction of travelling to CERN. On the other hand, some activities had to be transferred from CERN to our local laboratories (like the assembly of FDD for ALICE described above, which had to be moved from CERN to CTU premises). Ministry of Education, Youth, and Sports of the CR (MEYS), the CERN-CZ funding agency, approved the adaptation of the CERN-CZ budget to these new conditions by allowing a transfer of funding in between the years 2020-2022 and by adjusting membership fees and operational costs accordingly. As a result, the overall goals of CERN-CZ were not affected.

Russia's invasion of Ukraine, which started in February 2022, poses another serious threat to international cooperation. As a result, the CERN Council suspended the Observer status of the Russian Federation, in accordance with the CERN Council Resolution of 8 March 2022, and the Observer status of JINR (Joint Institute for Nuclear Research in Dubna) was suspended in accordance with the CERN Council Resolution of 25 March 2022. At the level of CERN experiments, the publication of new results has been suspended until the experiments agree on how to handle author lists and acknowledgments to national funding agencies. This may lead in future to further changes of HL-LHC upgrade schedule.

B. Governance and management

I. Describe the governance and management structure of the LRI, the way how it is rooted in the host institution(s), and their development during the funding period 2020–2022, including the gender balance.

LRI CERN-CZ is operated jointly by a consortium of seven institutions:

- Charles University (CU),
- Czech Technical University in Prague (CTU),
- Institute of Physics of the Czech Academy of Sciences (FZU),
- Nuclear Physics Institute of the Czech Academy of Sciences (NPI),
- Palacký University in Olomouc (UPOL),
- Technical University of Liberec (TUL),
- University of West Bohemia (UWB).

The Institute of Physics serves as the host institution, with CERN-CZ being integrated into the Division of Elementary Particle Physics and its three departments (Experimental Particle Physics, Detector Development and Data Processing, and Theory of Elementary Particles).

For a long time, FZU has been playing a leading role in the organisation of the Czech particle physics community and its participation at CERN. Throughout the whole period of the CR membership of CERN, it has been the main recipient of grants for cooperation between Czech research institutes and CERN. The relevant advisory body of the MEYS, the *Committee for Cooperation of the Czech Republic with CERN* (VS CERN), is also working on the premises of the institute. FZU supports research at CERN by providing laboratories used for development and construction of experimental devices for the CERN experiments. It also contributes to the operation of a computing centre dedicated primarily to large scale data processing in particle physics, which is used also for astro-particle physics experiments. Over the past decade, FZU has invested more than 50 million CZK into the construction, equipment and operation of laboratories and spends about 8 million CZK a year on the operation of the computing centre and laboratories.

The LRI management is based on two pillars: participation on the management of CERN and individual experiments, and on the own CERN-CZ management structure.

CERN-CZ involvement in CERN governance bodies

CERN's main governing body is the **CERN Council**. Each member state has one vote in the Council and has the right to send to the CERN Council a maximum of two delegates. As a rule, there is one delegate from the country's political representation and one scientific delegate. In the case of the CR, the delegates to the CERN Council are the Ambassador of the CR Permanent Mission in Geneva and the scientific delegate appointed by the MEYS. The scientific delegate is a member of the ***Committee for Cooperation of the CR with CERN*** (VS CERN), currently the chairperson of this advisory body of MEYS. The CERN Council elects the President of the Council and two Vice-Presidents. The Council appoints the Director-General of CERN for a five-year term and approves his / her top management team. The Director informs the Council about the status of the laboratory, submits to the Council the draft budget and the medium-term development plan of the organisation, and submits proposals for the extension of CERN by new associated or full members. The CERN Council has several subordinate bodies, an advisory body ECFA (European Committee for Future Accelerators - the CR is represented by three delegates), external auditors (usually the Supreme Audit Office of a CERN member state), and other bodies and committees.

The subordinate bodies of the CERN Council are: the CERN Finance Committee, the Scientific Policy Committee, Tripartite Employment Conditions Forum (TREF), the Standing Advisory Committee on Audits, and the PFGB (Pension Fund Governing Board). In the Finance Committee, the CR has two delegates, one of whom is also a delegate in TREF.

The **VS CERN** meets regularly, at least four times a year before meetings of CERN's top bodies and financial bodies of the main experiments, to discuss the positions of our delegations at CERN Council meetings and other bodies. The chair of the Executive Board reports in these meetings on the CERN-CZ activities. VS CERN comments on these activities and approves major proposals submitted by the CERN-CZ principal investigator.

CERN experiments and projects are organised and managed at the level of its member institutions. The main policy and decision-making body of every experiment is a Collaboration Board (CB), in which each institution has a representative with voting rights. CBs appoint top management of experiments, including spokespersons, approve applications of new candidates for membership, major technical and scientific goals of the experiments, documents that govern the organisation of the experiments, etc. Management of the experiment is further divided to several levels, depending on its size. In large experiments, like ATLAS with 3000 researchers, there are typically at least 4 levels.

CERN-CZ researchers enter management roles in various sub-detector groups, physics groups, collaboration boards and committees, including top-management positions, like convening ATLAS Physics Groups. The following list of positions held in 2020-2022 by CERN-CZ members documents the involvement and the level of international recognition of CERN-CZ teams.

- member of the *LHC Experiments Committee* LHCC (R. Leitner)
- member of the *International Computing Board* (J. Chudoba)
- convenor of *ATLAS Standard Model (SM) Physics Group* (O. Kepka)
- convenor of *ATLAS Heavy Ion (HI) Physics Group* (M. Rybar)
- convenors of *SM Soft QCD and Diffraction* Subgroup (K. Cerny, M. Tasevsky)
- convenor of ATLAS *HI Jets* Subgroup (M. Rybar)
- convenor of ATLAS *B-physics Rare Decays* Subgroup (T. Jakoubek)
- convenor of ATLAS *Fake Tau Task Force Subgroup* (V. Pleskot)
- coordinator of ATLAS *Trigger HI Menu Forum* (M. Rybar)

- coordinator of ATLAS *Tigger B-physics and Light States Signature* (T. Jakoubek)
- coordinator of ATLAS *MinBias/Fwd Signature* (P. Balek)
- coordinator of ATLAS *Pixel Run* (O. Kepka)
- coordinator of ATLAS *Pixel DAQ* (O. Kepka)
- coordinator of ATLAS *Pixel P1 Infrastructure* (P. Sicho)
- coordinator of ATLAS *Tilecal Maintenance & Infrastructure* (S. Nemecek)
- coordinator of ATLAS *Tilecal Phase-II Upgrade Software & Performance* (T. Davidek)
- coordinator of ATLAS *Tilecal Phase-II Upgrade Installation & Commissioning* (S. Nemecek)
- coordinator of ATLAS *ITk Pixel Off-detector Services* (P. Sicho)
- coordinator of ATLAS *ITk Strip Irradiation & Test Beam* (J. Kroll)
- chair of ATLAS *Forward Detectors System Institutional Board* (M. Tasevsky)
- chair of ATLAS *Tilecal Speakers Committee* (J. Faltova)
- chair deputy of ATLAS *ITk Speakers Committee* (M. Mikestikova)
- conveners of ALICE *Ultra-peripheral Collisions and Diffraction* Physics Working Group (G. Contreras, M. Broz)
- coordinator of ALICE *Luminosity Subgroup* (G. Contreras)
- convener of ALICE *Jets Physics Working Grou*p (F. Křížek)
- coordinator of ALICE *Flow Subgroup* (K. Křížková Gajdošová)
- coordinator of ALICE *ITS Data Quality* Group (A. Isakov)
- run coordinator of ALICE *MFT system* (T. Herman)
- run coordinator of ALICE *FDD system* (S. Torres)
- run coordinator of COMPASS in 2021 (J. Matousek)
- run co-coordinator of COMPASS in 2022 (M. Pesek)
- analysis coordinator of COMPASS in 2022 (J. Matousek)
- spokesperson of *ISOLDE experiment IS581* (M. Veselsky)
- convener of the NA62 *Straw Spectrometer* Working Group (M. Koval)
- convener of the NA62 *Precision Measurements* Working Group (M. Koval)

Representation of Czech institutions in governing bodies of CERN experiments is an important aspect of CERN-CZ activities. It provides means for Czech researchers to have a direct influence on the scientific program and organisation of experiments at CERN. An example of a collaborative effort organised by CERN-CZ was participation of the Czech particle physics community in the preparation of *The 2020 Update of the European Strategy for Particle Physics* (link). This strategic document defines the main European goals in the field for the next seven years.

CERN-CZ management structure

The organisation of the CERN-CZ management is based on the past successful experience of Czech research teams in the construction and operation of detectors at CERN, and on experience from the organisation of research in the CERN-CZ institutions. The specificity of CERN-CZ is the large number of participating institutions, as this infrastructure organises and ensures the participation of practically all Czech institutions involved in experiments at CERN.

The main executive body of LRI CERN-CZ is the **Executive Board (EB)** chaired by the LRI responsible scientist (principal investigator). The Executive Board has 14 members currently:

- Alexander Kupčo (FZU), EB chair, principal investigator (PI) of CERN-CZ,
- Guillermo Contreras (CTU), coordinator of ALICE group,
- Tomáš Davídek (CU), PI of Inter-excellence project LTT17018, ECFA representative,
- Zdeněk Doležal (CU), coordinator of ATLAS HL-LHC upgrade (ITk strip tracker),
- Vyacheslav Georgiev (UWB), co-PI for UWB,

- Zdeněk Hubáček (CTU), coordinator of ATLAS activities, ECFA representative,
- Jiří Chudoba (FZU), PI of associated OP RDE, coordinator of computing,
- Filip Křížek (NPI), coordinator of ALICE ITS upgrades,
- Jiří Kvita (UPOL), rco-PI for UPOL,
- Rupert Leitner (CU), chairperson of VS CERN, delegate of the CR in the CERN Council, co-PI for CU,
- Vojtěch Petráček (CTU), co-PI for CTU,
- Karel Smolek (CTU), representative of smaller experiments and R&D,
- Miroslav Šulc (TUL), co-PI for TUL,
- Michal Šumbera (NPI), co-PI for NPI.

The Board includes: representatives of all LRI participating institutions; representatives of the main working groups; principal investigators of the associated OP RDE project CERN-CD; principal investigator of related Inter-excellence project LTT17018 “*Getting new knowledge of the microworld using the CERN infrastructure*”; and chairperson of VS CERN, who is at present also the scientific delegate of the CR in the CERN Council. The EB responds and is supervised by the VS CERN.

CERN-CZ International Advisory Board (IAB) is an expert advisory body that provides independent views and recommendations on current and future CERN-CZ activities. The Board consists of renowned external experts in the field with professional qualifications corresponding to the main research objectives of the LRI. Current five IAB members are:

- Josef Žáček (CU, Prague), IAB chair,
- Federico Antinori (University and INFN, Padua),
- Wolfgang Lohmann (Deutsches Elektronen-Synchrotron DESY, Zeuthen),
- Frank Simon (Max-Planck-Institut fur Physik, Munich),
- Stanislav Tokár (Comenius University in Bratislava).

The IAB meets together with the CERN-CZ EB, VS CERN, and Czech particle physics community, once a year, usually in December, on the premises of the host institution. Due to Covid-19 pandemic situation, only the 2022 meeting was held in person. During the morning open session, the main CERN-CZ activities in the past year are presented, together with the CERN-CZ budget spendings, and the plans for the upcoming years are discussed. In the following closed part, the discussion between the IAB and the EB continues, and the IAB formulates its opinions and recommendations. These are then submitted to the EB and VS CERN in the form of minutes. The IAB assesses the level of professional and operational activities of the infrastructure, expresses its opinion and makes recommendations on newly planned activities and on the long-term strategic plan. It also comments on the budget spending and assesses the effectiveness of the use of financial resources. The minutes from three IAB meetings in 2020-2022 are attached to the report in Appendix C.

Gender balance

The LRI CERN-CZ is not an independent legal entity and is bound to follow the rules and policies of its host and partner institutions, including the gender policy. The CERN-CZ institutions are well-established research and academic institutions - universities and institutes of the Czech Academy of Sciences (CAS). Equal access to collaborators and students is an integral part of the working culture at these institutes. It is embedded in the *Code of Ethics for Researchers of the CAS*, or in the *Code of Ethics of Charles University* of Charles University, and similarly for other partners of

CERN-CZ consortium. Except NPI, all institutions from the CERN-CZ consortium received HR Award, a certificate of quality of the HR and gender processes set up at these institutions.

Equal opportunities applied by the CERN-CZ institutions do not necessarily lead to a proportional representation, which is strongly influenced by other sociological and historical factors. The gender composition of the CERN-CZ team follows the national gender composition in technical and natural sciences with all known ailments. Concerning the gender balance, 29 (15%) out of the 199 employees supported from CERN-CZ budget in 2022 were women. The gender share of women in scientific positions was 12%, with a typical trend: a rise from 8% in senior researcher positions to 11% in junior researcher positions and to 24% at the level of PhD students.

II. Describe the human resources development of the LRI over the funding period 2020–2022 and specify the numbers of employed and hired personnel in full-time equivalent (FTE).

Number of FTEs	**2020**	**2021**	**2022**
Senior scientists	11.39	10.73	11.29
Junior scientists	5.40	5.48	5.29
Ph.D. students	2.60	2.47	2.03
Students	1.31	1.59	1.26
Technical staff	6.89	5.39	6.14
Administrator	1.59	1.39	1.13
Other	0	0	0
Total	29.18	27.06	27.14

The operation of the LRI CERN-CZ requires about 50 FTE (Full Time Equivalent). As was shown in PartI.B.I, just experiment ATLAS recognized in 2021 the contribution from the Czech institutions to the operation and upgrade at the level of 40 FTE. Of these 50 FTE, only a part of approx. 18 FTE is covered directly from the LRI resources in the form of the main labour contract (HPP), side labour contract (DPP), or work arrangement (DPC). In 2022, the last year of the project, 16.33 FTE was covered from CERN-CZ budget in the form of HPP and 2.23 FTE in the form of DPP/DPC. The rest of the personnel costs were carried by the CERN-CZ institutions. The necessary capacities were ensured in the work description documents of the relevant employees.

The table above shows human resources whose activity was paid at least partially from the resources of the LRI as was reported in the *Statement on Spending Personnel Costs* in yearly reports. According to this methodology, the table includes, in addition to workers with HPP, DPP and DPC, the workers who received personal bonuses from the LRI budget. Workers who did not draw personnel costs from the LRI budget are not recorded in the table.

From the table one can conclude that the contribution of senior scientists with Ph.D. to the CERN-CZ operation was in 2022 about 42%, junior researchers with PhD represented 19%, PhD students 7%, undergraduate students 5%, technicians and engineers including IT staff 23%, and administrative and other positions 4%. The composition of the team was stable over time and similar numbers are valid for other years of project.

In terms of headcount, 199 people were supported from the CERN-CZ budget in 2022 (either in the form of personal bonuses or travelling costs). Out of it 65 (33%) were senior researchers, 38 (19%) junior researchers, 29 (16%) Ph.D. students, 39 (20%) undergraduate students, 24 (12%) technicians and engineers, and 4 (2%) administrative and other positions.

C. User access

I. Describe the key attributes of the LRI's user access strategy and open access policy, and their evolvement over the funding period 2020–2022.

Users access strategy

CERN focuses on fundamental research of the properties of matter at extreme energies. The primary users are therefore from an academic scientific community, i.e. scientists from universities and laboratories around the world, with a large, roughly one-third share of students. According to the latest data from 2020, a total of 12 303 experts from all over the world participated in CERN research, of which 7 163 users were from CERN member countries. Among them 246 (3.4% of member countries) were users from Czech (CZ) research institutions. They are involved mainly in the ATLAS experiment (about 50% of CZ users), to a lesser extent in ALICE (about 15%) and COMPASS (about 10%), and the rest (~25%) in several other smaller experiments and R&D projects (see the list in Part I.A.I).

There are two levels of user strategy. One defined at the level of CERN and individual CERN experiments. The second level is CERN-CZ's own strategy towards the national community.

At the laboratory level, the strategy is the encouragement of international cooperation. Examples of CERN open strategy are recent cases of adoptions of new members and associated countries described below. Individual experiments follow the same open strategy. In ATLAS, an experiment run by about 180 institutions, several requests for admission from new institutions are approved per year typically by the ATLAS Collaboration Board. This open strategy is a must, as particle experiments are highly demanding on human and financial resources.

At national level, CERN-CZ serves as a gateway for the Czech community for access to the research at CERN. Naturally, CERN-CZ follows this open strategy towards the Czech community as well. CERN-CZ increases visibility of the CR in the research areas of particle physics and conveys the access to the CERN research to new Czech institutions and teams.

CERN-CZ facilitated during recent years the formation of several new scientific research teams in participating institutions. Most recent example of a CZ institution which joined CERN-CZ and CERN experiments is University of West Bohemia. UWB started to participate in the TOTEM experiment in 2013 and the university formally joined CERN-CZ in 2016. In 2019, UWB became ATLAS technical associate institute with an expertise in electronics. UWB engineers in cooperation with CTU and CU teams took responsibility for the trigger and readout electronics of ATLAS Forward Proton Detectors.

Open access policy

There are two levels of open access policy. The first level concerns the access to membership and cooperation at CERN and CERN experiments as was described above. This access to the research at CERN is organised at several levels – at national level, institutional level and at individual level. The second level defines the access to the experimental data and results.

Policy for accessing CERN and experiments at CERN

At national level, CERN offers to the countries several types of association in order to allow access for researchers not only from membership states. CERN also has bilateral agreements with many countries across the world. The excellent CERN scientific program attracts applications from many countries. CERN is open to these calls, recent examples are: Membership of Romania in 2016 and Serbia in 2019, Associate membership in the pre-stage to Membership of Cyprus in 2016 and Slovenia in 2017 and Associate membership of Ukraine in 2016, India in 2017, Lithuania in 2018 and Croatia in 2019. In response to Russia's invasion of Ukraine, the Observer status of the Russian Federation was suspended in accordance with the CERN Council Resolution of 8 March 2022 and the Observer status of JINR was suspended in accordance with the CERN Council Resolution of 25 March 2022.

Access to the research program of individual CERN experiments and projects is organised at the institutional level as individual experiments/projects are run by collaborations of research institutions and funded by national funding agencies. Access to the experiment is open to all research institutions from around the world. The application is approved or rejected by a democratic vote of the experiment's Collaboration Board. One of the main criteria is the added value that the candidate institution brings to the experiment in terms of operation, maintenance, and upgrades. This is one of the CERN-CZ principal roles. By providing resources for the operation of these facilities, the CERN-CZ fulfils the role of a national gateway, allowing the Czech particle physics community to access the data from CERN experiments and thus enabling it to participate in unique scientific research at CERN.

There are no further restrictions for the users from the experiment's member institutions. They have free access to the collected data and they are free to pursue research goals of their own interest. They must however comply with the collaboration publication rules. Experiments adopt these rules to ensure the highest level of quality of published results. The process of approval has several steps, typically starting from the approval in the corresponding physics/detector working group, followed by the review and the approval from the dedicated editorial board, and the final approval from the whole collaboration.

Policy for accessing experimental data and results

For publication of results, CERN-CZ follows CERN's open access policy, which was updated in 2022 and is summarised in the document "*CERN Open Science Policy*" [CERN-OPEN-2022-013]. The document defines the rules for open access to results, data and software. In short, all CERN scientific publications must be made immediately available and reusable. The 2021 update on *CERN Open Access Publications Policy* [CERN-OPEN-2021-009] requires that all original research by CERN authors is published with open access, which is centrally supported by the CERN Open Access Fund. CERN users and visiting scientists are also encouraged to publish their work under similar conditions, according to the CERN General Conditions for Conducting Experiments.

CERN scientific publications, including contributions to trusted repositories (such as arXiv), should be published under an open licence, with CC-BY as the default standard. The metadata associated with the publication is made available for reuse under the CC0 licence in accordance with the

FAIR principles (findability, accessibility, interoperability, reusability). Open Access publishing support is also provided for monographs related to CERN experiments or accelerators, applied research practices or technologies, and other relevant areas.

CERN's rules for access to LHC experimental data are adopted in the document "*CERN Open Data Policy for the LHC experiments*" [CERN-OPEN-2020-013]. In relation to the foreseen use cases, the document defines policy access at the following 4 levels: published results, outreach and education, reconstructed data, and raw data.

Policy for accessing CERN-CZ services

Concerning the rules for accessing LRI's local services, they again depend on the nature of the service. In general, they follow the collaboration rules. The services are open to all users from the institutions participating in the same experiments/projects as the CERN-CZ institutions. The most used local service by external and international users is the Tier-2 computing farm. This computer facility is part of LHC grid computing hierarchy, and access to it is open to all CERN users via standard grid tools. The access to the LHC computing grid resources is organised at experiment level and the access is granted for users on institutional bases following the same rules described above for the access to the collected data.

II. Describe the number of user accesses to the LRI's services from the Czech Republic and abroad during the funding period 2020–2022 and specify the overall user volume in terms of their number, structure, and affiliation (e.g., higher education institutions, public research institutions, private research organisations, businesses and industries, etc.).

The main purpose of research infrastructure CERN-CZ is a contribution to the operation and construction of experimental devices at CERN. For users, it is a continuous access throughout many years (experiment ATLAS celebrated in 2022 a 30 years anniversary). The number of user accesses to the CERN-CZ services is therefore not a relevant number. More relevant is the number of users that are served by CERN-CZ.

At international level, this can be measured by the number of physicists that sign collaboration papers. As was already described, this international community in the case of two experiments with the largest Czech contribution, experiments ALICE and ATLAS, exceeds 4 000 researchers. The researchers are coming from more than 40 countries across the whole world and from several hundreds of universities and laboratories (just ATLAS is an international collaboration of more than 180 institutions and cluster of institutions, counting by votes in Collaboration Board, or even more 240, when counting individual institutions inside the clusters as well).

As CERN-CZ serves the Czech research institutions as a gateway to CERN, another relevant measure is the number of Czech users registered at CERN. This national community reaches about 250 people (248 according to the last official number from 2020). This number represents about 3% of researchers from CERN member states. The CR share on CERN budget is about 1%, which means that the Czech users community uses the opportunity intensively.

For CERN-CZ services provided locally at the CR, the most relevant is the access to the Tier-2 computing center. User access to the Tier-2 computing resources is via grid tools, each member of the experiment has access to the resources involved in the WLCG through these grid tools. Every year the center serves about 1000 users from those two LHC experiments, ATLAS and ALICE.

The users submit annually several million jobs (9 million in 2022, see tab.1 in section I.A.I for details).

D. Cooperation and international relations

I. Describe the LRI's cooperation with higher education institutions and research organisations, other research infrastructures, businesses and industries, and other research and innovation performing entities utilizing the LRI and its scientific results and data. Specify both cooperation developed at the Czech national and international levels, and their advancement over the funding period 2020–2022.

Cooperation at national level

CERN-CZ organises and supports the participation of universities and research institutions from the CR on projects in the international laboratory CERN. All Czech research institutions, which substantially participate in the operation and construction of experiments at CERN, are members of the LRI. Within the framework of CERN-CZ, they cooperate together on the fulfilment of the international obligations arising from their membership in CERN projects.

CERN-CZ cooperates with other LRIs in the area of informatics and large-scale data processing. During 2020-2022, CERN-CZ WLCG Tier-2 computing center continued to use several critical services from the national e-Infrastructure project **e-Infra** operated by a consortium formed by **CESNET**, **IT4I** and **CERIT-SC** projects. A reliable network of sufficient capacity is crucial for operation of a distributed computing grid. The connection between the main Tier-2 center at FZU to the storage servers at NPI was upgraded to 20 Gbps. The outbound connectivity with capacity 100 Gbps to dedicated network LHCONE and 40 Gbps to generic internet is excellent, although we reached the maximum capacity at peaks.

Significant ratio of computing capacity for the ATLAS experiment simulations was provided by **IT4I**nnovations (National HPC center in Ostrava). Supercomputers Anselm and Barbara provided capacity during the whole reporting period 2020 – 2022. The newest and most powerful supercomputer Karolina was available from August 2021. With a peak contribution above 80000 computing cores, it provided a significant impact on ATLAS simulations.

CERIT-SC computing resources available via Kubernetes platform were used via BOINC infrastructure called ATLAS@Home. **CESNET** Data Storage Department provided backup and archive services and additional storage capacities. Some central grid services like accounting portal, databases of services GOCDB, and platform for supporting GGUS are operated by European Grid Initiative EGI. Worldwide LHC Computing Grid WLCG coordinates middleware upgrades and overview operations.

There are natural synergies between other particle physics and astroparticle LRIs (mainly with **BNL-CZ**, **FERMILAB-CZ**, **AUGER-CZ**, and **CTA-CZ**). In addition to large-scale computing, we closely cooperate as well on detector development, education, and outreach. In 2022 we organised a one day meeting, *Day With Particle and Astroparticle Research Infrastructures*, satellite event to ICRI'22 in Brno to discuss and further strengthen these synergies.

The detector construction and R&D of new detector technologies triggered several cooperations with the CZ industry, mostly in the area of development of radiation hard semiconductor detectors and computing. This cooperation has resulted in several contracts during 2020-2022, see the list in section II.B.I.

Cooperation at international level

International cooperation in the field of experimental particle physics is one of the CERN-CZ main goals. CERN-CZ consortium cooperates literally with hundreds of research institutions and laboratories across the world. Many of them are leading institutions in the field. Just within the two experiments with the largest CZ participation, CERN-CZ cooperates with more than two hundred research organisations. The ATLAS experiment is operated and used by about 3000 scientists from 181 laboratories and research institutions from 42 countries, of which 4 are from the CR, and from several technical associate institutions, of which one is from the CR, (the list of ATLAS institutions is available at http://atlas.web.cern.ch/Atlas/Management/Institutions.html). Overall, Czech teams represent about 2% of the ATLAS experiment in terms of the number of scientists on the ATLAS author list. In the case of the ALICE experiment, the numbers are similar. The experiment is run and used by more than 1000 scientists from 171 laboratories from 40 countries (see https://alice-collaboration.web.cern.ch/collaboration/alice_institute). The three Czech institutions represent about 1.5% of ALICE. In the case of smaller experiments, such as COMPASS or TOTEM, our participation is generally larger, and Czech groups represent up to 10% of the experiment.

Our participation at CERN is legally anchored by the membership of the Czech Republic (CR) in the international organisation CERN. Membership fees to CERN are paid directly by MEYS and are not part of the CERN-CZ VI budget. This is related to the legal status of CERN. The members of this international organisation are states, not individual scientific institutions. The membership fees paid by the CR to CERN are used to cover the operation of the laboratory and the construction and development of basic infrastructure, such as buildings, computing facilities and major scientific equipment, like LHC. They are set annually based on the development and strength of the economies of each member state as measured by the country's gross domestic product. The CR contribution represents about 1% of the CERN budget, which amounts to about 13 million CHF; the CR membership fee was 13 220 000 CHF in 2022.

CERN experiments and projects are organised, operated and built by large consortia of research institutions, and they are funded by national funding agencies, MEYS in case of the CR. Institutional commitments are defined by the relevant MoUs related to the construction, operation and upgrades of scientific facilities. By signing the MoU, the national funding agencies confirm this commitment. In the case of the CR, the MoUs for larger and longer-term commitments are signed by the authorised representative of the MEYS. One of the main tasks of LRI CERN-CZ is to ensure fulfilment of these obligations.

The annual running costs of the LHC experiments are approved by representatives of the national funding agencies at the October LHC Review Resource Board (LHC RRB) meetings. They are then budgeted among the participating institutes on the basis specified in the relevant MOUs. In the case of the ATLAS experiment, the typical annual contribution of the CZ institutions to the running costs of the experiment is around 370 000 CHF (MoU document CERN-RRB-2002-035). For the ALICE experiment, it is around 110 000 CHF (document CERN-RRB-2002-034). Altogether, for all experiments and CERN R&D projects, this represents a total annual commitment of the CZ institutions at the level of 540 000 CHF. The MoUs do not contain only financial commitments. It is also obligatory to provide the necessary manpower for the detector operation in the form of shifts during data acquisition and in the form of support of experts on individual detector subsystems. For the actual involvement in years 2020-2022, see the section I.A.I. above.

Construction of new detectors is another major part of CERN-CZ obligations towards the experiments. In the case of LHC experiments, these are mainly connected to the HL-LHC upgrade.

They represent a significant commitment of the CZ institutions and LRI CERN-CZ to the ATLAS and ALICE experiments. The CORE cost of ATLAS HL-LHC upgrade was agreed on by the LHC RRB at the level of 270 million CHF. Of this, the share of CZ institutes is 2.2%, i.e. approximately 6.1 million CHF. This commitment was partially covered from the CERN-CZ resources in 2016-2019. The remaining part was covered from the CERN-CZ 2020-2022 budgets. The details about CERN-CZ contributions to the upgrades of LHC experiments in years 2020-2022 are again given above in the section I.A.I.

PART II.

A. Research and innovation results

I. Describe the research and innovation results achieved by the LRI's operating team on the basis of the LRI's use over the funding period 2020–2022 that led to the LRI's further development and advancement of the LRI's services, including max. 15 top research and innovation results.

During 2020-2022, the CERN-CZ researcher published 61 R&D results in connection with the operation of CERN-CZ. Work of the operating team of the CERN-CZ LRI encompasses a wide range of detector-operation-related activities, work on upgrades, construction of new detectors, as well as development of new technologies for future detectors. The selected papers illustrate the scientific potential and board span of CERN-CZ LRI activities.

The ALICE Collaboration carries out R&D for a novel concept of a silicon tracker which will stand out with unprecedented low material budget, reduced interaction probabilities, and unparalleled vertexing performance. The detector will be based on large-scale, bent monolithic active pixel sensors, which will require only the silicon itself in the active area. The ALICE ITS Collaboration has reported feasibility to operate thinned monolithic active pixel sensors bent to radii as small as 18 mm in [1].

Important contribution of CERN CZ to the ATLAS HL-LHC upgrade is connected with monitoring the quality of the fabricated silicon sensors by performing detailed measurements of individual sensor characteristics and by comparing the obtained results with the tests done by the manufacturer. Paper [2] describes the dedicated Quality Control (QC) procedures, developed to check whether the delivered large-format sensors adhere to the ATLAS specifications, and reports on the readiness of the Prague testing site to perform the QC testing of the pre-production and production ATLAS ITk strip sensors (QC sites).

Large attention is devoted to radiation hardness of silicon sensors in the context of the HL-LHC upgrade. Radiation-hard n^{+}-in-*p* micro-strip sensors for use in the ATLAS ITk were developed by the ATLAS ITk Strip Sensor collaboration. Paper [3] reports on the results obtained from the electrical characterization of the latest barrel ATLAS17LS sensor prototype, before and after irradiation. These measurements have verified that the surface radiation damage does not influence the sensor functionality, with the breakdown voltage well above the maximum operational voltage. All the tested surface parameters, such as the inter-strip resistance and capacitance, coupling capacitance and bias resistance satisfied the ATLAS ITk specifications for strip sensors.

The design of the new ATLAS ITk inner tracker for the HL-LHC upgrade is based on large area silicon sensors. During the prototype fabrication, it has been observed that these sensors exhibit adverse sensitivity to humidity. Paper [4] presents an extensive study of humidity impact on large area sensors. The locations of the hotspots at the breakdown voltage at high humidity are revealed using different infrared thermography techniques. The authors propose a hypothesis that the origins of the humidity sensitivity are associated with the sensor edge design, together with passivation thickness and conformity. Finally, they propose measures to be taken during sensor fabrication and assembly to minimise the impact of humidity sensitivity on the performance of these large area silicon sensors.

A harsh radiation environment encountered in space applications or particle physics poses an enormous challenge for microelectronics. Energetic particles can affect functionality of an electronic circuit by inducing so-called Single Event Effects (SEE). Therefore, the vulnerability of devices must be tested before their failure can have fatal consequences. The paper [5] presents an electronic system for measuring SEE temporally and spatially correlated with Timepix3 detectors. The Timepix is a semiconductor detector with 256 x 256 pixels. It provides energy and time information for each pixel hit.

Detection efficiency of silicon sensors is measured using in-beam telescopes at charged particle beam lines. These setups consist of several planes of silicon sensors, which are used to reconstruct high-precision reference tracks, and the probed silicon sensor. Paper [6] describes EUDAQ - a generic data acquisition software developed for analysing the data from beam telescope measurements. EUDAQ enables flexible integration of different independent devices under test via their specific data acquisition systems into a top-level framework. EUDAQ controls all components globally, handles the data flow centrally and synchronises and records the data streams. Over the past decade, EUDAQ has been deployed as part of a wide range of successful test beam campaigns and detector development applications.

In Ref. [7], the COMPASS collaboration reported on novel gaseous detectors of single photons for RICH applications. These detectors were developed and installed on COMPASS RICH-1. They have a hybrid architecture consisting of two staggered THGEM layers (one equipped with a CsI photo-converting layer) and a bulk Micromegas and operate stably and efficiently, providing a single photon angular resolution of 1.8 mrad and about 10 detected photons per ring at saturation. The paper presents main aspects of their construction, commissioning, and characterization.

Another example of technology developed for LRI, which can easily find its application outside of the field, concerns ultrasonic instrumentation for simultaneous flow and composition measurement in a variety of gas mixtures presented in [8]. Flow and composition measurements are based on the difference and average of sound transit times in opposite directions in a flowing process gas. Authors have developed a sound velocity-based algorithm to compensate for the effects of additional gases, allowing the concentrations of a pair of gases of primary interest to be acoustically measured on top of a varying baseline from 'third party' gases whose concentrations in the multi-gas mixture are measured by other means. The developed instrumentation and analysis technique, targeting binary pairs of gases of interest in multi-gas mixtures, is also promising for mixtures of anesthetic gases, particularly in the developing area of xenon anesthesia.

Paper [9] presents a heat exchanger design that was developed for low temperature cooling of medium power density electronics and, more specifically, for the forward proton detectors of ATLAS and TOTEM experiments. The heat exchanger uses a metal foam to enhance internal heat transfer, it is galvanically insulated from the pipes of the cooling system and hermetically sealed. The notable advantage of this heat exchanger is that the same design can be used with air or evaporating refrigerant as the cooling fluid. This can be beneficial when the development and testing phases of the detectors take place in laboratories with limited cooling equipment, or for backup cooling solutions that move from a primary refrigerant system to air-cooling. The temperature difference between the inlet air and the surface of the heat exchanger is 20 °C with a 20 W heat load, this difference drops to 10 °C when R-218 refrigerant is used instead of the air.

One of the innovative beam collimation techniques exploits particle deflection by means of channelling between crystalline planes of a bent crystal. Paper [10] reports on operational use of crystal collimation that was achieved during a special LHC high-β^* physics run with low-intensity beams. The performed study represents a milestone for both accelerator and high-energy physics that could pave the way for new synergies in the near future. The paper shows evidence of beam-related experimental background reduction, improved data quality, and faster halo removal with respect to amorphous collimators is obtained using bent crystals as the primary collimation stage.

One of the fundamental predictions of Quantum Electrodynamics is the existence of the vacuum magnetic birefringence. This subtle phenomenon has however not been observed yet. In [11], the authors tested a new polarimetric method, which is proposed to be used to measure this effect. The method employs a quasi-static field generated by a LHC spare steering magnet. The paper suggests that the birefringence effect should be modulated by slowly varying the magnetic field to provide separation of background and the birefringence signals. The method has been validated with a high precision measurement of the Cotton–Mouton effect in nitrogen gas.

New technologies developed by the LRI can be used for applications also in other fields of science. For instance, recently there has been an increased interest to apply the sensitive β-decay asymmetry detected nuclear magnetic resonance (β-NMR) technique to biological studies. In [12], the authors report on a liquid-sample β-NMR setup that was built at ISOLDE to allow such investigations and to use the resolution gain of liquid-state NMR in nuclear physics. The absolute field determination allows for a novel way to reference β-NMR measurements, removing the need for time consuming reference measurements. Applied innovations resulted in improved accuracy and resolution allowing for the study of the distribution of nuclear magnetization and (bio)chemicals using high-accuracy liquid-sample-NMR.

High energy physics experiments require ever larger and ever more accurate datasets of simulated Monte Carlo events. Detector simulation with Geant4 is accurate but requires significant CPU resources. Over the past decade, ATLAS has developed and utilised tools that replace the most CPU-intensive component of the simulation, the calorimeter shower, with faster methods. Paper [13] presents AtlFast3, the next generation of high-accuracy fast simulation of ATLAS detector. AtlFast3 combines parameterized approaches with machine-learning techniques and is deployed to meet current and future computing challenges, and simulation needs of the ATLAS experiment. With highly accurate performance and significantly improved modelling of substructure within jets, AtlFast3 can simulate large numbers of events for a wide range of physics processes.

The Tilecal Calorimeter plays a key role in many physics analyses pursued by the ATLAS collaboration. Detailed understanding of its performance is therefore crucial. In Ref. [14], the ATLAS Tilecal Collaboration tested the energy response and resolution of three spare modules of the Tile Calorimeter. The modules were irradiated with positive pions and kaons and protons with energy in the range from 16 to 30 GeV. The results were compared to the predictions of the Geant4-based simulation program used in ATLAS to estimate the response of the detector to proton-proton events at LHC. The determinations obtained using experimental and simulated data agree within the uncertainties.

High energy physics simulations and data processing require a large amount of computing resources. Since 2017, ATLAS has been using for their computing also the opportunistic resources provided by the supercomputer located at the Czech national HPC center IT4Innovations in Ostrava. As discussed in paper [15], it was possible to substantially increase the usage of this center by the ATLAS distributed computing by introducing several modifications. These included the migration of the job submission system to enable preemptable jobs, employing the sshfs connection, etc.

[1] ALICE ITS project Collaboration, *First demonstration of in-beam performance of bent Monolithic Active Pixel Sensors*, **Nucl. Instrum. Meth. A 1028** (2022) 166280.

[2] M. Mikeštíková, et al., *ATLAS ITk strip sensor quality control procedures and testing site qualification,* **JINST 17** (2022) C12013(1).

[3] M. Mikestikova, et al, *Electrical characterization of surface properties of the ATLAS17LS sensors after neutron, proton and gamma irradiation,* **Nucl. Instrum. Meth. A 983** (2020) 164456.

[4] J. Fernandez-Tejero et al, *Humidity sensitivity of large area silicon sensors: Study and implications*, **Nucl. Instum. Meth. A 978** (2020) 164406.

[5] J. Broulim, P. Broulim, M. Campbell, V. Georgiev, M. Holik, P. Kunstmuller, V. Pavlicek, S. Pospisil, O. Vavroch, J. Vlasek, J. Zich, *A concept for spatially and time correlated single event effect detection in semiconductors using Timepix type pixel detectors*, **Nucl.Instrum.Meth. A 980** (2020) 164397.

[6] P. Ahlburg et al, *EUDAQ-a data acquisition software framework for common beam telescopes, **JINST 15** (2020) 01*, P01038.

[7] J. Agarwala et al, *The hybrid MPGD-based photon detectors of COMPASS RICH-1*, **Nucl. Instum. Meth. A 952**, 161832.

[8] G. Hallewell et.al., "*Applications and Perspectives of Ultrasonic Multi-Gas Analysis with Simultaneous Flowmetry",* **Instruments 2021**, 5, 6., p. 1-17, 12 January 2021.

[9] M. Doubek, V. Vacek, *Universal heat exchanger for air and evaporative cooling of electronics*, **Thermal Science and Engineering Progress**, Volume 23, 1 June 2021, p. 1-11.

[10] D. Mirarchi, et al., *Reducing Beam-Related Background on Forward Physics Detectors Using Crystal Collimation at the Large Hadron Collider,* **Phys. Rev. Applied 14** (Dec 23, 2020) 064066.

[11] G. Zavattini et al., *Polarimetry for measuring the vacuum magnetic birefringence with quasi-static fields: a systematics study for the VMB@CERN experiment*, **Eur. Phys. J. C 82** (2022) 159.

[12] J. Croese et al. *High-accuracy liquid-sample β-NMR setup at ISOLDE,* **Nucl. Instum. Meth. A 1020** (2021) 165862.

[13] ATLAS Collaboration, *AtlFast3: the next generation of fast simulation in ATLAS*, **Comput. Softw. Big Sci. 6** (2022) 7.

[14] J. Abdallah J, et al. (ATLAS TileCal), *Study of energy response and resolution of the ATLAS Tile Calorimeter to hadrons of energies from 16 to 30 GeV*, **Eur. Phys. J. C81** (2021) 549.

[15] M. Svatoš, J. Chudoba, P. Vokáč, *Improvements in utilisation of the Czech national HPC center by ATLAS distributed computing*, **EPJ Web Conf. 245** (2020) 09010.

II. Describe the research and innovation results achieved by the LRI's users on the basis of the open access arrangements over the funding period 2020–2022, including max. 30 top research and innovation results.

Scientific scope covered by the LRI CERN experiments is very broad. Users exploit the infrastructure to investigate the Standard Model (SM) of particle physics, including the properties of the Higgs boson, beyond the SM physics (BSM), state of matter under extreme conditions, nuclear physics, and other topics. During 2020-2022, the two largest experiments ATLAS and ALICE published more than 174 and 102 original papers in renowned international peer-reviewed journals, respectively. At the same time, the other smaller experiments supported by CERN-CZ (COMPASS, TOTEM, MOeDAL, NA62, n_TOF) published 36 papers. In total, there were more than 312 papers containing mostly new fundamental results in the field of elementary particle physics and nuclear physics. To this, the researchers from Czech institutions contributed significantly, as primary co-authors of analyses, to 52 papers. This is another relevant measure of intensity with which the Czech scientific community uses the opportunities to participate in an CERN ambitious scientific program.

Among the most interesting results were four Nature papers and one paper published in Nature Physics. In the Nature paper [1], the **ATLAS** Collaboration reported on detailed analysis of Higgs boson properties. They combined an unprecedented number of production and decay processes of the Higgs boson that were measured over 10 years to scrutinise its interactions with elementary particles (gluons, photons, *W* and *Z* bosons, the second and the third generation particles). These tests reveal that the Higgs boson discovered ten years ago is remarkably consistent with the predictions of the theory and data available provide stringent constraints on many models of new BSM phenomena. ATLAS has also published precise measurements of Higgs boson production cross-sections in the $H \to \tau^+\tau^-$ decay channel in proton-proton (pp) collisions at $\sqrt{s}$ = 13TeV in Ref. [2]. Further, in Ref. [3] ATLAS used the $H \to \tau^+\tau^-$ decay channel to test CP invariance in Higgs boson production via vector-boson fusion. No hints of CP violation were found. In letter [4], ATLAS presented direct searches for lepton flavour violation in Higgs boson decays, $H \to e\tau$ and $H \to \mu\tau$. The searches were based on a 36.1 fb^{-1} data sample of pp collisions at a centre-of-mass (c.m.) energy $\sqrt{s}$ =13 TeV. No significant excess was observed above the expected background from the SM processes. This allowed ATLAS to set 95 % confidence-level upper limits on the lepton-flavour-violating branching ratios.

The Nature Physics paper [5] by ATLAS provided a test of a fundamental axiom of the SM, which states the universality of the couplings of the different generations of leptons to the electroweak gauge bosons. This axiom can be tested by measuring the ratio of the decay rate of *W* bosons to τ leptons and muons, $R(\tau/\mu)$. Using 139 fb^{-1} of proton–proton collisions recorded with the ATLAS detector at a centre-of-mass energy of 13 TeV, ATLAS reported a measurement of this quantity from di-leptonic top anti-top events where the top quarks decay into a *W* boson and a bottom quark. The measured value of $R(\tau/\mu)$ is 0.992 ± 0.013 [± 0.007(stat) ± 0.011(syst)] and is in agreement with the hypothesis of universal lepton couplings as postulated in the SM. The presented results represent the only such measurement from at LHC, so far, and obtains twice the precision of previous measurements.

In Ref. [6], ATLAS reported on the observation of forward proton scattering in association with lepton pairs $p\,p \to p\,(\gamma\gamma \to l^+l^-)\,p^*$, where p* denotes a proton that remains intact or dissociates following electromagnetic excitation. The leptons are produced via photon fusion. The scattered proton is detected by the ATLAS Forward Proton spectrometer while the leptons are reconstructed by the central ATLAS detector. ATLAS analysed 14.6 fb^{-1} of proton-proton collisions at a c.m. energy of √s=13 TeV and saw a total of 57 (123) candidates in the ee+p (μμ+p) final state, the observed signal thus exceeded 5σ significance.

ATLAS has carried out a measurement of the energy asymmetry in jet-associated top-quark pair production in *pp* collisions at √*s* =13 TeV [7]. The observable measures the different probability of top and antitop quarks to have the higher energy as a function of the jet scattering angle with respect to the beam axis. The measured asymmetry A=−0.043±0.020 is in agreement with the SM prediction of A=−0.037±0.003, calculated at the next-to-leading-order accuracy in Quantum Chromodynamics (QCD). Based on the framework of the SM Effective Field Theory (SMEFT), the paper claims that the energy asymmetry is sensitive to the top-quark chirality in four-quark operators and can therefore be used as a valuable new observable in global SMEFT fits.

In the presence of new physics phenomena, sources of CP violation in b-hadron decays can arise in addition to those predicted by the SM. In the $B^0{}_s \rightarrow J/\psi\ \phi$ decay, CP violation occurs due to interference between a direct decay and a decay with $B^0{}_s$ – anti $B^0{}_s$ mixing. In Ref. [8], ATLAS used $B^0{}_s \rightarrow J/\psi\ \phi$ decays to measure CP-violating phase ϕ_s, the width difference $\Delta\Gamma_s$ between the $B^0{}_s$ meson mass eigenstates, and the average decay width Γ_s. The measured ϕ_s and $\Delta\Gamma_s$ values are found to be in agreement with the SM predictions.

ATLAS has measured azimuthal anisotropy of charged particles produced in *p*+Pb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV [9]. The azimuthal anisotropy coefficients of elliptic v_2 and triangular v_3 collective flow were extracted using two-particle correlations with a non-flow template fit procedure. The measurement shows that particles with p_T in the range 9 - 50 GeV exhibit significant non-zero anisotropy which cannot be not explained within current theoretical frameworks.

The Nature paper by the **ALICE** Collaboration [10] reports on the first direct observation of the dead-cone effect. QCD predicts a suppression of the gluon spectrum emitted by a heavy quark of mass m_Q and energy E, within a cone of angular size m_Q/E around the emitter. The direct observation of the QCD dead cone by ALICE utilised new iterative declustering techniques to reconstruct the parton shower of charm quarks. This result confirms a fundamental feature of QCD and the measurement of a dead-cone angle constitutes a direct experimental observation of the non-zero mass of the charm quark, which is a fundamental constant in the SM.

In the second Nature paper [11], the ALICE collaboration formulates a novel approach to measure an effective interaction between stable and unstable hadrons. Such effective interactions are largely unconstrained but they are of fundamental importance for models describing the structure of neutron stars. Information about these interactions is encoded in correlations in the momentum space between hadron pairs produced in ultrarelativistic pp collisions. A measurement of these correlations provides precise data which allow us to obtain the missing information on the interaction dynamics between any pair of unstable hadrons. In particular the method constrains the short-range part of the nucleon-hyperon potential. In the paper the technique is applied to proton–omega baryon pairs.

The ALICE Collaboration also reported in [12] on cross section measurement of the coherent photo-production of ρ^0 vector mesons in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. Besides precise data on ρ^0 production, the measurement also brought evidence of a coherently produced resonance-like structure with a mass around 1.7 GeV/c^2 and a width of about 140 MeV/c^2.

ALICE has further observed collective flow of b quarks produced in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, [13]. Collective flow is one of the signatures of initial state quark-gluon-plasma (QGP). As the system evolves the initial pressure gradients transform into momentum anisotropy in particle production in the final state. Beauty quarks were initially considered to be too heavy to participate in this flow. The reported results provide insights on the degree of thermalization of beauty quarks in the medium.

Ten years ago, it was discovered that particles emerging from collisions with a small number of participant nucleons exhibit some signatures that can be attributed to quark-gluon plasma initial state (collectivity, enhancement in strangeness production). However, such initial state would imply that production of hadrons and jets would have to be affected by the jet quenching effect. In [14], ALICE extended the previous CMS measurements of jets associated with b quark fragmentation in pp and p-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV down to 10 GeV/c. The obtained nuclear modification factor was found to be compatible with no modification, which constrains possible size of mass dependent hot QGP and cold nuclear matter effects. Another paper by ALICE found that the production of strange particles associated with jets in the p-Pb system does not seem to be modified w.r.t. pp collisions [15].

The Nature paper [16] by the **MoEDAL** Collaboration, presents a search for magnetic monopole production in Pb–Pb heavy ion collisions at the LHC. These collisions produce the strongest known magnetic fields in the current Universe which could possibly allow for production of magnetic monopoles via the Schwinger mechanism. The paper excluded existence of the magnetic monopoles with integer Dirac charges of 1, 2 and 3 and masses up to 75 GeV/c^2 at the 95% confidence level. This provides a lower mass limit for finite-size magnetic monopoles from a collider search and greatly extends previous mass bounds.

Rare decays that could be associated with flavour-changing neutral currents are carefully investigated in the context of BSM searches. In paper [17], the **NA62** experiment reported an investigation of the $K^+ \rightarrow \pi^+$ ν anti-ν decay mode from a sample of K^+ decays. The experiment has achieved a single event sensitivity of (0.389 ± 0.024) × 10^{-10}, corresponding to 2.2 events assuming the SM branching ratio of (8.4 ± 1.0) × 10^{-11}. Two signal candidates were observed with an expected background of 1.5 events. The collaboration reported an upper limit of 1.78 × 10^{-10} for the $K^+ \rightarrow \pi^+$ ν anti-ν branching ratio at 90% CL. This measurement represents one of the most precise results worldwide on flavour-changing neutral currents and can be used to constrain some BSM physics models that predict large enhancements.

The **TOTEM** Collaboration reported evidence for the exchange of a colourless C-odd three-gluon compound state in the *t*-channel of the proton–proton elastic scattering [18]. Unlike the previous measurements of proton-antiproton scattering by the D0 collaboration, the pp elastic differential cross sections $d\sigma/dt$ measured by TOTEM exhibits presence of a diffractive minimum followed by a bump structure which can be explained by the existence of odderon.

The photon strength functions (PSF) and nuclear level density (NLD) are key ingredients for calculation of the photon interaction with nuclei, in particular the reaction cross sections. These cross sections are important especially in nuclear astrophysics and in the development of advanced nuclear technologies. The **n_TOF** Collaboration measured γ-ray spectra from neutron-capture reactions on the ^{234}U, ^{236}U, and ^{238}U nuclei [19]. They found that no combination of PSF and NLD models from literature was able to globally describe the measured spectra. In order to match the experimental spectra as well as the total radiative widths, it was necessary to use model combinations with modified generalised Lorentzian (MGLO) E1 PSF. They have also found that the M1 photon strength function must contain a very strong, relatively wide, and likely doubleresonance scissors mode. This mode is responsible for about a half of the total radiative width of neutron resonances and significantly affects the radiative cross section.

The **COMPASS** experiment recently discovered a new isovector resonance-like signal with axial-vector quantum numbers, the $a_1(1420)$, decaying to $f_0(980)\pi$. This state was immediately interpreted as a new light exotic meson. In [20], they performed the triangle-singularity model fit to the partial-wave data and demonstrated that the resonance-like structure in the experimental data can be described by rescattering through a triangle singularity, providing evidence for a genuine three-body effect.

Among the other papers with major contributions from Czech scientists are Ref. [21] to Ref. [30].

[1] ATLAS Collaboration, *A detailed map of Higgs boson interactions by the ATLAS experiment ten years after the discovery*, **Nature 607** (2022) 52–59.

[2] ATLAS Collaboration, *Measurements of Higgs boson production cross-sections in the $H\to\tau^+\tau^-$ decay channel in pp collisions at $\sqrt{s}$=13TeV with the ATLAS detector,* **JHEP 08** (2022) 175.

[3] ATLAS Collaboration, *Test of CP invariance in vector-boson fusion production of the Higgs boson in the $H\to\tau\tau$ channel in proton-proton collisions at $\sqrt{s}$= 13 TeV with the ATLAS detector*, **Phys. Lett. B 805** (2020) 135426.

[4] ATLAS Collaboration, *Searches for lepton-flavour-violating decays of the Higgs boson in $\sqrt{s}$=13 TeV pp collisions with the ATLAS detector*, **Phys. Lett. B 800** (2020) 135069.

[5] ATLAS Collaboration, *Test of the universality of τ and μ lepton couplings in WW-boson decays with the ATLAS detector,* **Nature Phys. 17** (2021) 7, 813-818.

[6] ATLAS Collaboration, *Observation and measurement of forward proton scattering in association with lepton pairs produced via the photon fusion mechanism at ATLAS*, **Phys. Rev. Lett. 125** (2020), 261801.

[7] ATLAS Collaboration, *Measurement of the energy asymmetry in ttj production at 13 TeV with the ATLAS experiment and interpretation in the SMEFT framework*, **Eur. Phys. J. C 82** (2022) 374.

[8] ATLAS Collaboration, *Measurement of the CP-violating phase ϕ_s in $B^0_s\to J/\psi\phi$ decays in ATLAS at 13 TeV***,** **Eur. Phys. J. C 81** (2021) 342.

[9] ATLAS Collaboration, *Transverse momentum and process dependent azimuthal anisotropies in $\sqrt{s_{NN}}$= 8.16 TeV p+Pb collisions with the ATLAS detector*, **Eur. Phys. J. C 80** (2020) 73.

[10] ALICE Collaboration, *Direct observation of the dead-cone effect in QCD*, **Nature 605** (2022) 440–446.

[11] ALICE Collaboration, *Unveiling the strong interaction among hadrons at the LHC*, **Nature 588** (2020) 232–238.

[12] ALICE Collaboration, *Coherent photoproduction of ρ^0 vector mesons in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ =5.02 TeV*, **JHEP 06** (2020) 035.

[13] ALICE Collaboration, *Elliptic flow of electrons from beauty-hadron decays in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV*, **Phys. Rev. Lett. 126** (2021) 162001.

[14] ALICE Collaboration, *Measurement of inclusive charged-particle b-jet production in pp and p-Pb collisions at* $\sqrt{s_{NN}}$*= 5.02 TeV*, **JHEP 01** (2022) 178.

[15] ALICE Collaboration, *Production of Λ and* K^0_S *in jets in p-Pb collisions at* $\sqrt{s_{NN}}$*=5 TeV and pp collisions at* $\sqrt{s}$*=7 TeV*, **Phys. Lett. B 827** (2022) 136984.

[16] MoEDAL Collaboration, *Search for magnetic monopoles produced via the Schwinger mechanism*, **Nature 602** (2022) 7895, 63-67.

[17] NA62 Collaboration, *An investigation of the very rare* $K^+ \to \pi^+ \nu$ *anti-ν decay*, **JHEP 11** (2020) 042.

[18] TOTEM Collaboration, *Elastic differential cross-section dσ/dt at* $\sqrt{s}$*=2.76 TeV and implications on the existence of a colourless C-odd three-gluon compound state,* **Eur. Phys. J.C 80** (2020) 80:91.

[19] n_TOF Collaboration, *Constraints on the dipole photon strength for the odd uranium isotopes*, **Phys. Rev. C 105** (2022) 024618.

[20] COMPASS Collaboration, *Triangle Singularity as the origin of the* $a_1(1420)$, **Phys. Rev. Lett. 127** (2021) 8, 082501.

[21] ATLAS Collaboration, *Combined measurements of Higgs boson production and decay using up to 80* fb^{-1} *of proton-proton collision data at \sqrt{s} = 13 TeV collected with the ATLAS experiment*, **Phys. Rev. D 101** (2020) 1, 012002.

[22] ALICE Collaboration, *Coherent J/ψ and ψ' photoproduction at midrapidity in ultra-peripheral Pb–Pb collisions at* $\sqrt{s_{NN}}$*= 5.02 TeV*, **Eur. Phys. J. C 81** (2021) 8, 712.

[23] ALICE Collaboration, *Measurements of the groomed and ungroomed jet angularities in pp collisions at* $\sqrt{s}$*=5.02 TeV*, **JHEP 05** (2022) 061.

[24] D0 Collaboration and TOTEM Collaboration, *Odderon Exchange from Elastic Scattering Differences between pp and p\bar{p} Data at 1.96 TeV and from pp Forward Scattering Measurements,* **Phys. Rev. Lett. 127** (2021) 062003.

[25] n_TOF Collaboration, *Measurement of the Ge-72(n, γ) cross section over a wide neutron energy range at the CERN n_TOF facility*, **Phys. Rev. C 103** (2021) 045809.

[26] n_TOF Collaboration, *Neutron Capture on the s-Process Branching Point* ^{171}Tm*, via Time-of-Flight and Activation,* **Phys. Rev. Lett. 125** (2020) 142701.

[27] NA62 Collaboration, *Search for Lepton Number and Flavor Violation in* K^+K^+ *and* π^0 *Decays*; **Phys. Rev. Lett. 127** (2021) 13, 131802.

[28] NA62 Collaboration, *A measurement of the* K^+ *to* $^+\mu^+\mu^-$ *decay*, **JHEP 11** (2022) 011.

[29] COMPASS Collaboration, *Contribution of exclusive diffractive processes to the measured azimuthal asymmetries in SIDIS*, **Nucl. Phys. B 956** (2020) 115039.

[30] COMPASS Collaboration, *Probing transversity by measuring Λ polarisation in SIDIS*, **Phys. Lett. B 824** (2022) 136834.

B. Societal and economic impacts

I. Impact on economy: Indicate the number and financial volume of contracts with businesses and industries concluded in the framework of public procurement to secure maintenance and renewal of the LRI's capacities and capabilities. Add other relevant information on the economic impacts in the funding period 2020–2022.

MEYS regularly, with a 5 year period, assesses the benefits of membership of the CR in the international scientific organisation. Evaluation of societal and economic impacts is an integral part of this assessment. In the last evaluation in 2021, CERN received the best mark in the category of benefits connected to "Technology development, innovation, and industry" with the following conclusion:

> *"The Scientific Panel considers that the Czech scientists exploit very successfully the technology and innovation opportunities offered by CERN, and that there is a strong benefit to the Czech industry. It must also be said that CERN in turn benefits greatly from this fruitful cooperation."*

This is due to an extensive participation of CERN-CZ institutes in detector constructions and R&D of new technologies for future particle detectors. In particular, the strong involvement in the R&D of new semiconductor sensors and related read-out electronics through participation in CERN R&D Collaborations RD50 (radiation hard semiconductor tracking), RD53 (radiation hard readout electronics), and Medipix/Timepix Collaboration. The Medipix and Timepix detectors found many applications in areas of: medical research for tomography, general dosimetry, and space applications. These activities resulted in the establishment of Czech-Finish start-up enterprise Advacam, which specialises on semiconductor sensors and imaging devices. The company received in 2021 award *EY Entrepreneur Of The Year* in the Czech Republic in the technology category. Company's innovative X-ray scanner based on CERN's Timepix detector developed by Medipix2 Collaboration won the ArtTech Prize 2020. The scanner helped to rediscover lost painting by Raphael, The Madonna and Child. New semiconductor technologies that are being tested at CERN-CZ, like SiC or monolithic sensors, provide another great potential for future industrial applications.

One of the direct benefits of CERN membership for the Czech industry is the possibility to participate in the CERN procurements. CERN has a sophisticated system of ranking which balances the distribution of contracts between the Member States, giving more weight to the companies from states that were receiving less contracts.

Czech companies are aware of this possibility, and they are using this opportunity intensively. Delivered orders and successful operation of a number of facilities built in the CR for CERN represent for industrial companies a prestigious knowledge and technologically demanding orders that stimulate their innovation abilities. This also influences the self-confidence of companies, their management, and employees. Annual volumes of contracts that Czech companies receive from CERN fluctuate in the range between 35 to 120 million CZK. Exact numbers for the reported period 2020-2022 are listed in the table 2, below. The total volume of CZ contracts in those three years reached a value of 4 989 th. CHF (119.7 million CZK, assuming 24 CZK/CHF exchange rate). This makes the CR a well-balanced country with a high return value rate, exceeding the share of the CR on CERN budget.

Year	Volume of contracts realised by CZ industry [in thousands of CHF]	Volume of contracts realised by CZ industry [in millions of CZK]
2020	1 539	36.9
2021	1 708	41.0
2022	1 742	41.8

Tab.2: Annual volume of CERN contracts realised by Czech industry. Source: CERN.

Industry contracts, including large investments and large services contracts, supported **directly via CERN-CZ budget**, related OP RDE project **CERN-CD**, and direct contributions of CERN-CZ **participating institutions** are listed below. They were used to acquire instruments for clean laboratory for silicon detectors testing, and computing clusters, disk servers and network switches for the Tier-2 computing center. For computing, the purchases were organised together with other LRI's OP RDE projects. In these cases, only the CERN-CZ shares are listed.

- Set of instruments for electrical characterization of semiconductor devices, price 1 423 046 CZK with VAT, source CERN-CD and FZU.
- Measurement devices for characterization of semiconductor particle detectors, price 569 393 CZ, source FZU.
- TESTOVACI TECHNIKA s.r.o, switching cards and cables for LV and HV testing of semiconductor particle detectors, price 447 105 CZK, source CERN-CZ.
- TESTOVACI TECHNIKA s.r.o., switching matrix for LV and HV testing of semiconductor particle detectors, price 93 437 CZK, source: FZU.
- TME Czech Republlic s.r.o., LV sources AIM-TTi CPX400SP (10 pcs), price 267 149 CZK, source CERN-CZ.
- Disk array and virtualization servers, 1 319 107 CZK with VAT, source CERN-CD.
- Disk storage capacity upgrade, 3 740 465 CZK with VAT, source CERN-CD.
- Disk storage capacity upgrade for ALICE in NPI, 1 349 150 CZK with VAT, source CERN-CD.
- Computing cluster for OP RDE project CERN-CD, FERMILAB-CZ2 and AUGERII-CZ, 4 461 999 CZK with VAT (CERN-CD share).
- Unicorn University. Development of ATLAS ITk production database, source CERN-CZ (via ATLAS MoU), price 305 000 CHF (about 7 320 th. CZK).
- DUO Opocno. Heat sinks for ATLAS Tile HL-LHC upgrade, year 2021, source: CERN-CZ (via ATLAS MoU), price 241 000 CHF (about 5 784 th. CZK).

- Kovo Haken s.r.o., PragoBoard s.r.o., and TORO TECH s.r.o., production of tools (jigs, glue stencils + frames) for ATLAS ITk collaboration, price 940 566 CZK, source CERN-CZ.
- AUROSET s.r.o., Design and manufacturing of the testbeam robot, price 457 622 CZK, source: CERN-CZ.
- UJP Praha. Four ^{60}Co irradiation campaigns during 2021 and 2022, price 629 200 CZK, source CERN-CZ.
- Argotech. ATLAS ITk module assembly, year 2022, price 578 609 CZK, source CERN-CZ.

Volume of industrial contracts and investments to computing reached in 2020-2022 a value of 10 870 th. CZK, contracts for the equipment of clean laboratory for semiconductor sensors reached a value of 2 799 th. CZK, services in connection with ATLAS HL-LHC upgrade reached a value of 2 607 th. CZK, and contracts realised within ATLAS HL-LHC MoUs reached 13 104 th. CZK. In total, major industrial contracts and investments in direct connection with CERN-CZ reached during 2020-2022 a value of 29 380 th. CZK.

Including the CERN procurements, the cooperation with CERN generated for the Czech industry in the years 2020-2022 contracts with a total volume of 149.1 million CZK.

II. Impact on education: Estimate the number of Bachelor, Master and Ph.D. students using, e.g., the LRI's scientific data, training courses, etc., and their engagement in the LRI's education and training activities. Add other relevant information on the education impacts in the funding period 2020–2022.

One of the pillars for increasing international competitiveness of the CR is quality of education. CERN-CZ contributes significantly to the quality of education in physics and engineering in the CR. Direct involvement in the large international teams working on CERN projects at the technological frontiers provides invaluable experience for the students. They also bring this knowledge back to the CR which contributes to the competitiveness of the economy. It creates a very good background for applied research. This complies well with the national priorities for applied research, as the increase in quality and extent of knowledge and the increase in the quality of education of specialists contributes to the formation of a competitive, knowledge based, economy.

MEYS, the guarantor of the large research infrastructure program, is aware of this important aspect. In cooperation with VS CERN and CERN-CZ, the ministry prepared a special program to increase the chances of students from the Czech universities applying for CERN Students Programs. The agreement between MEYS and CERN was signed in 2019, and during the 2020-2022 period the funding was used to create more national positions within this CERN student program.

In total 28 Bc, 27 MSc and 10 Ph.D. theses related to experiments at CERN were defended at the participating universities during the reported period. In general, bachelor students accessing the LRI's scientific data continue their master level studies on the same infrastructure and some continue in their graduate studies. The 2020–2022 period was affected by the Covid19 pandemic which, in some periods significantly, reduced the possibilities to participate directly in the data taking as well as participation in training courses.

To further promote cooperation between students, CERN-CZ co-organizes at FZU every two years a workshop on particle physics for undergraduate and graduate students with invited distinguished speakers from abroad. Students also present their work at the workshop. CTU also organises a “Winter school” workshop with lectures from members of the LRI as well as presentations of students' work.

III. Other societal and economic impacts: Describe the LRI’s impact on technology development and the LRI’s contribution to addressing the grand societal challenges in the funding period 2020–2022.

Primary goal of research of LRI CERN-CZ is connected with basic research in particle physics. The great technological challenges that frontier research in experimental particle physics faces trigger from time-to-time a development of ground breaking applications. Historically, because of the needs of experiments, CERN has contributed to developments in the fields of computer science and developments of detection and acceleration techniques. Perhaps the most widely known examples are the World Wide Web, developed in 1989 at CERN to improve the effectiveness of information exchange between scientists in large experiments, and transparent capacitive touch-screens pioneered at CERN in the early 1970s for the control room of accelerator SPS. Both technologies have had a significant impact on our everyday lives.

In terms of global impacts, the following technologies appear to be the most promising for applications. Accelerator and particle beam technologies are used worldwide in healthcare (cancer treatment) and environmental protection (nuclear waste treatment, water purification). CERN has also pioneered large-scale computing using grid technologies. Superconducting devices for the LHC and related technologies may improve the efficiency of electricity distribution in the future. Several other detector technologies developed for new experiments have the potential to bring new significant improvements in the above areas. For example, picosecond resolution time detectors can significantly improve diagnostic tools in medicine (time-of-flight positron electron tomography). Novel semiconductor materials that are being studied under CERN-CZ R&D program, like SiC, already received attention from industry as they offer a potential for large energy savings compared to current technologies and will have a very likely a major impact on the development of electromobility in the coming years.

Particle physics is far from proposing or even offering new energy sources or solving all the grand challenges of the current world. Still, CERN is an example of an institution that can perform the research demanding on energy, finances and manpower in environmentally careful, economical and human friendly manner. It is an example of open, clever, and effective solutions, management, procurement, organisation of spontaneity in curiosity driven research and its organisational, financial and technical support. The CERN is aware of its responsibility towards the environment and takes environmental considerations into account when designing new programs. CERN started in 2020 to monitor its environmental impact with a goal to identify environmental indicators as being the most significant at CERN, along with their present status and realistic goals for each of them. The last environment report covering the period 2019-2020 is available on-line at https://hse.cern/environment-report-2019-2020.

IV. Public relations: Describe the communication achievements and outreach of the LRI’s activities in the funding period 2020–2022.

The period 2020-2022 was very difficult because of COVID-19 restrictions in the Czech Republic. However, an active group of Czech particle physics communicators, mainly formed around Czech participation in the **International Particle Physics Outreach Group** (IPPOG), accepted the challenge. They have started organising an online version of the **International Masterclasses**, and they put together a rich online program for the general public at the online ICHEP 2020 conference. Besides the online activities, the group was also trying innovative in-person activities. February 2020 marks the beginning of the **BeInspired@ICHEP2020** project for high-school students that connects particle physics with arts. A quick release of the COVID-19 restrictions in the Summer of 2020 allowed for a realisation of a live **Big Bang Stage** in a Prague's club, with a ColliderScope music event by physicist Larry Lee. The Big Bang Stage is also the name of an extensive outreach project at the **Colours of Ostrava** music festival. In 2022, it was realised for the second time and offered 28 hours of talks, shows, discussions and workshops. In total, it was enjoyed by 3500 festival visitors.

The community further organised **Particle Prague 2022**, a one-week-long event for 32 selected high-school students, a week full of lab visits, projects, talks and social programmes. 2022 was the year of **30th anniversary of Czechoslovakia at CERN**, and the particle physics community organised a one-day celebration for this occasion. It had two parts - a morning session for high-school students and an afternoon session for politicians and scientists. Last but not least, particle physicists were visible in the media. E.g. **Joachim Mnich** in the most followed Czech science show, "**Hyde Park Civilizace**", or Rupert Leitner, Jiří Dolejší, Zdeněk Doležal, Steven Goldfarb, Jaroslav Bielčík, Jiří Hejbal, Tomáš Davídek, Alexander Kupčo and others in the most followed news on Czech TV or in other important media. Besides all these activities, Czech particle physicists frequently give talks or workshops to the general public. They do it independently or as part of established projects like academy and university open days, Science Café, etc. They also supervise high-school students working on short particle physics research projects.

PART III. - CONCLUSION

Final Assessment (Summary)

Summarize the overall conclusions from the LRI's project implementation in the funding period 2020–2022 described in detail above.

Large Research Infrastructure CERN-CZ fulfilled all its 2020-2022 goals. During the LHC Long Shutdown LS2, the CERN-CZ researchers contributed substantially to the detector's maintenance and upgrades, and readiness of the experiments for a new data taking campaign in LHC Run3, which started in mid of 2022. Significant CERN-CZ resources were focused on construction of new detectors for the High Luminosity LHC (HL-LHC) upgrade, ESFRI Landmark 2018 and 2021. Major achievement of CERN-CZ during the reported period was completion of the clean laboratory for testing and assembly of semiconductor strip sensors and modules for new ATLAS tracker ITk. The lab was certified at the end of 2020 as the first ATLAS site for testing the ITk strip sensors and almost 1500 sensors were tested there so far. Thanks to the CERN-CZ support, the Czech research institutions were able to fulfil all their operational and construction commitments in CERN experiments, expressed in corresponding Memoranda of Understanding, in every aspect: financial and manpower resources, and delivery of hardware (detector) components.

Our work on HL-LHC upgrades triggered cooperation with the Czech industry that resulted in several substantial contracts for the ATLAS experiment (UJP Praha, Argotech, Unicorn

University, DUO Opocno, and others). This cooperation is going to continue in the following years.

Investment support from the related OP RDE project CERN-CD allowed us to upgrade our computing center, which serves as a Tier-2 center in the hierarchy of LHC grid computing. CERN-CZ delivered in 2020-2022 substantially more than the Czech LHC experiments pledges also thanks to an extensive use of opportunistic resources of Czech LRI e-Infra.

Czech particle physics researchers used extensively the opportunities offered by the membership of the CR at CERN. The community represents about 3% of CERN users from the member states. Physicists from CERN-CZ institutions contributed directly, as primary authors of analyses, to many published experimental results.

CERN-CZ teams are well recognized within large international experiments and projects, as was documented by many management positions taken by CERN-CZ researchers during 2020-2022. Their work and contributions are well visible and vital for the success of the CERN scientific program. The CERN-CZ allowed the CERN-CZ institutions to contribute adequately to this ambitious program at the level comparable with the leading European institutions of similar size. In this way, CERN-CZ fulfilled its main mission.

Appendices

Mandatory: Table of the real financial costs of the LRI over the entire period (enclosed separately)

Optional: Appendices relating to the realization of the LRI at discretion (max. 10 A4 pages)

- Appendix A - Minutes of Internation Advisory Board in 2020
- Appendix B - Minutes of Internation Advisory Board in 2021
- Appendix C - Minutes of Internation Advisory Board in 2022

In Prague

Date: January 30, 2023

Signature of principal investigator:

doc. Alexander Kupčo, Ph.D.

Digitálně podepsal doc. Alexander Kupčo, Ph.D.
Datum: 2023.01.30 10:49:11 +01'00'

Appendix A – Minutes of 2021 CERN-CZ Internation Advisory Board held on 14th of December 2020

The meeting was organized fully remotely via the ZOOM video communication system due to the restrictions imposed by the COVID-19 pandemic. The number of connected participants was about 40 for the public session.

The Chair of the Executive Board and Research Infrastructure (RI) responsible scientist Alexander Kupčo opened the **public session** at 9:00. A. Kupčo introduced the RI project, the CERN-CZ institutions and their personnel composition. He briefly summarized the activities of participating institutions in the experiments TOTEM, NA62, n_TOF, AeGIS, ISOLDE and in the R&D projects Medipix/Timepix, RD50, RD51, RD53, Crystal Clear and CALICE.

The next three talks summarized the Czech participation in several CERN experiments included in the RI in 2020, ALICE, ATLAS and COMPASS. The further group of three talks presented an overview over activities and plans of Czech teams in the ATLAS upgrade of the ITk detector, covering the sub-projects ITK strips, ITk mechanics and the ITK production database. Then followed presentations devoted to the development of the TOF subdetector for the AFP detector, and on the participation of the University of West Bohemia in ATLAS, which has recently joined the collaboration as a technical associated institute, and on the activities of UWB in the TOTEM collaboration. The further talks presented the performance of the TIER2 Computing Center in Prague and the overview over the physics contributions to the CERN experiments made by Czech members of the RI teams. The last two presentations summarized the experience of the organization of the videoconference ICHEP 2020 held in Prague and the support of the Ministry of Education, Youth and Sports of the Czech Republic for CERN student programs.

The talks showed the involvement of the Czech institutions in the maintenance and development of the detector hardware and software for the above-mentioned experiments at CERN in 2020, and plans for next years. They also gave an impression of the physics analysis activities enabled by the participation in the above-mentioned experiments. They presented the main Czech contributions to various R&D activities and the progress in the building of R&D infrastructure in Prague and in the acquisition of the corresponding equipment. The reports about the contributions of institutes from the CR to the upgrade of the ATLAS and ALICE experiments showed that all commitments have been met. Scientists from the CR are key players in several fields, such as sensor studies and quality control of components, which is also reflected in the management structure of the projects. Examples for highlights were the design and construction of a central production data base for the inner tracker upgrade of ATLAS based on state-of-the art software technologies, and the engineering contributions to the ATLAS infrastructure.

After a short break, the Advisory Board meeting proceeded with the **closed session**. A. Kupčo presented the approved budged for 2020 and its modification due to COVID-19 and the funding for 2021 – 2022. He also gave information about the funding of other CERN activities in the Czech Republic. Since a new proposal for an LRI in the period after 2022 will have to be submitted to MEYS, he showed the budget proposal for the years 2023 – 2029. This was followed by a discussion on the manpower which will be needed for the successful production of ATLAS ITK strip modules in collaboration of the Czech industry with participating RI teams. A further issue which was debated concerned the relatively small number of PhD students participating in RI projects. One of the reasons for this long-term situation is that a large fraction of graduated university students move on to pursue doctorates at Universities abroad. The remaining discussion focused on the proposed budget for the years 2023 – 2029, especially from the point of view of a realistic estimation of future spending over this long period in view of developing plans for future upgrades, for example for the ALICE experiment.

Observations and Recommendations

The advisory Board found the RI support of the RI teams responsible for operational and maintenance activities appropriate with respect to their commitments to the experiments. Similarly, the supporting project "Getting new knowledge of the microworld using the CERN infrastructure" within the MEYS program Inter-Excellence allows the scientists from RI institutions to participate in the data analysis, to follow their own scientific interests, and to obtain or significantly contribute to unique and original scientific results of the CERN experiments and the R&D programs supported by the RI. This is convincingly reflected in dozens of publications prepared under the responsibility of physicists from the CR.
An important service to the users is the local computing facility Tier 2 operated by RI CERN-CZ. This facility is also a crucial component for the fulfillment of the obligations of the CZ institutes towards the LHC collaborations. The farm operated smoothly last year which made it possible to fulfill the Czech pledges to WLCG. The committee applauded the efficient operation of the Tier 2 center in Prague, which has significantly exceeded its pledges. The Board acknowledges the start of the OP RDE Project CERN Computing in July 2020, which will enable computing hardware investment in the next two years. The Board appreciates the improvement of the farm personnel situation since two new people enlarged the farm team which will facilitate to operate Tier 2 in next years.
The Board recognizes the progress made in the participation of RI teams in detector upgrades of the CERN experiment covered by the RI, especially in ALICE and ATLAS. The board appreciates that the RI teams has finished the hardware installation with corresponding software in the Joint Clean Laboratory of IoP, which is now available for the ATLAS strip tracker detector upgrade activities. The Board takes note of the success of the complete strip sensor tests which resulted in the full qualification of the laboratory by the ATLAS collaboration for the testing of the sensor preproduction. The committee congratulates the ITK group for finalizing the qualification document and on being the first group fully qualified in ATLAS. This underlines that the ITk group from the Czech Republic is a driving force in the ATLAS tracker upgrade. The AB acknowledges the effort of RI teams to verify the ITK strip module assembly in the collaboration of the RI institutes with industry, and the readiness for the testing of the module preproduction. The Board appreciates the availability of an ITk production database, which was developed by the RI team from CTU in cooperation with the university Unicorn College at Prague. This database, which provides full traceability of all components of ITk, is a central Czech contribution for the construction of ITk.
The Board appreciates the Czech contribution to the construction of the new ALICE detectors, the Muon Forward Tracker (MFT) and the Forward Diffraction Detector (FDD). For the MFT the RI teams took part in the ladder assembly of silicon sensors and the quality control of their performance. In the FDD the RI team is responsible for the coordination of the full project and for prototype tests. The milestones set last year for the commissioning of the MFT and FDD for the end of 2020 are postponed by a few months due to COVID-19. To avoid further delays due to the pandemic, the group took over the complete production of the FDD modules in the laboratory of the CTU including the elements originally foreseen to be done in Mexico, demonstrating a high level of flexibility of the RI in a critical situation. The main Czech contribution to the ALICE upgrade of the Inner tracking system was planned to concentrate on the ITS commissioning in 2020. Due to the COVID restrictions the installation of this system is postponed for July 2021.
The Advisory Board emphasizes that the contributions of the RI to the upgrade of ALICE and ATLAS experiments are of utmost importance for the future physics program. Hence they should be pursued with high priority.
The AB takes note of the installation of the polarized target in the experiment COMPASS and the IT and DAQ development which was carried out with important contribution from the RI teams. The AB supports the intention of the RI teams to participate in the new proposed experiment AMBER, which was approved by the CERN Research Board in December 2020.

The actual upgrade projects benefits from the longer successful engagement of RI physicists and technicians in various R&D projects. A particularly interesting activity is the application of the TimePix readout chip in several applications in MoEDAL, ATLAS, UA9 and AeGIS experiments.
The Advisory board takes note of the activities in the universities in Liberec, Plzen and Olomouc. The group in the Palacký University Olomouc participates in a hardware development and established successfully a physics analysis group working on a forefront topic. The University of West Bohemia, Plzeň, has formed a team which is engaged in developing of various cutting-edge electronic components for ATLAS AFP detector and other detectors.
In addition to the RI support for hardware upgrades of experiments, the Board also appreciates the support given by the RI for data analysis groups of RI institutes. This enabled significant Czech contributions to about 15 publications covering a wide range of physics topics, such as Higgs production and decays, top quark production and B physics in ATLAS, and ultra-peripheral collisions, particle correlations, b-jets in ALICE.
The Advisory Board appreciates the agreement between CERN and MEYS on a special programme of „sponsored“ students within the CERN Student Programmes which allows the funding of visits of 8 Czech students to CERN. The second agreement on forming a CERN Business Incubation Center in the Czech Republic will start in 2021 and will focused on the support of start-ups using CERN technology.
The AB congratulates the Czech particle physics community for the impressive organization of the ICHEP 2020 conference held in Prague in summer 2020, in spite of the emergency change of its standard format to a previously untested on-line form.
The Advisory Board approves the spending of funding in 2020, which was used efficiently and corresponded to the RI activities mentioned above. The membership costs covered the detector running cost and the financial contribution to the upgrades. The maintenance costs included educed travel expenses of Czech RI teams to CERN and the costs for running home laboratories and the computing farm. The Advisory Board supports the planned expenses in the years 2021- 2022 and finds them appropriate in view of the RI strategy.
The Advisory Board also supports the long-term plans for the future of the RI, which, in addition to the continuing activities in the present experiments and ongoing upgrades, includes contributions to the ALICE ITS3 project, and additional resources for possible future upgrades of ALICE for LHC Run 5 and beyond, and future collider projects. The AB underlines the importance of the flexibility to move funding to different projects in view of the long time scales of the planning, and of the projects involved, and notes that it is also crucial that the possibility for short-term efforts with additional personnel from other institutes or projects is enabled in case of extraordinary resource needs for upgrade projects, such as for ATLAS ITk during its main production time.

Members of the Advisory Board
Federico Antinori
Wolfgang Lohmann
Frank Simon
Stanislav Tokár
Josef Žáček

Appendix B – Minutes of 2021 CERN-CZ Internation Advisory Board held on 15th of December 2021

The meeting was organized fully remotely via the ZOOM video communication system due to the restrictions imposed by the COVID-19 pandemic. The number of connected participants was about 40 for the public session.
The Chair of the Executive Board and Research Infrastructure (RI) responsible scientist Alexander Kupčo opened the **public session** at 9:00. He presented the agenda of the meeting and briefly mentioned the impact of the present COVID situation on the activity of the RI teams in the RI project.
The first talk summarized the participation of the Czech teams in the ALICE experiment during the period LS2 and their future plans. The next two talks presented Czech activities in the ATLAS Forward Detectors and Tilecal in LS2. Then followed presentations devoted to the Czech contribution to the ATLAS HL Upgrade, i.e. ITk strip testing and assembly of ITk strip modules. The next group of talks summarized the activity of RI members in the COMPASS/AMBER experiment, R&D of Timepix detectors, and the activity in the new Czech projects aiming to contribute to AWAKE and FCC. Further talks presented the performance of the TIER2 Computing Center in Prague and the overview over the physics contributions to the CERN experiments made by Czech members of the RI teams. The last three presentations showed examples of recent physics analyses performed by Czech physicists.
The talks showed the involvement of the Czech institutions in the maintenance and development of the detector hardware and software for the above-mentioned experiments at CERN in 2021, and plans for the next years. They also gave an impression of the physics analysis activities enabled by the participation in the above-mentioned experiments. They presented the main Czech contributions to various R&D activities and the progress in the building of R&D infrastructure in Prague and in the acquisition of the corresponding equipment. The reports about the contributions of institutes from the CR to the upgrade of the ATLAS and ALICE experiments showed that many commitments have been met. Scientists from the CR are key players in several fields, such as sensor studies and quality control of components, which is also reflected in the management structure of the projects.
After a short break, the Advisory Board meeting proceeded with the **closed session**. A. Kupčo presented the approved budged for 2021 and its modification due to COVID-19 and the funding for 2022. Then he presented results of interim evaluation of large research infrastructures carried out by the scientific panel of the International Evaluation Committee and discussed remarks and questions of the Evaluation Board. Since a new proposal for an LRI in the period after 2022 will have to be submitted to MEYS, he showed the budget proposal for the years 2023 – 2029, which was part of the evaluation document. Since a reduction of financial support of MYES can be expected he also gave information about possible new funding from OP JAK for particle and astroparticle physics and for the European Open Science Cloud. This was followed by a discussion on the manpower which will be needed for the successful production of ATLAS ITK strip modules in collaboration of the Czech industry with participating RI teams. Another possibility to increase manpower in the CR could be CERN funding for a recruitment program. The AB discussed the new project related to AWAKE and the chance of full membership of the UWB in ATLAS. A further issue which was debated concerned the suggestion to reduce the number of subjects of physics analysis in ATLAS and ALICE in favour of a concentration of the analysis teams on particular topics to increase visibility of Czech groups within the physics program of these experiments. The remaining discussion focused on the proposed budget for the years 2023 – 2029, especially from the point of view of probable budget cut and its impact on future plans of the RI.
Observations and Recommendations
The advisory Board found the RI support of the RI teams responsible for operational and maintenance activities appropriate with respect to their commitments to the experiments. Similarly, the supporting project "Getting new knowledge of the microworld using the CERN infrastructure" within the MEYS

program Inter-Excellence allows the scientists from RI institutions to participate in the data analysis, to follow their own scientific interests, and to obtain or significantly contribute to unique and original scientific results of the CERN experiments and the R&D programs supported by the RI. This is convincingly reflected in dozens of publications prepared under the responsibility of physicists from the CR.

An important service to the users is the local Tier 2 computing facility operated by the RI CERN-CZ. This facility is also a crucial component for the fulfillment of the obligations of the CZ institutes towards the LHC collaborations. Besides the farm itself, the Tier2 team also efficiently used several external resources in an opportunistic manner, especially the new cluster KAROLINA at IT41 Ostrava which was put into operation in 2021. All computing equipment operated reliably, which made it possible to significantly exceed the Czech pledges to WLCG. The Board appreciates the stabilization of the farm personnel situation which will simplify running of the Tier 2 facility in the coming years.

The Board recognizes the progress made in the participation of RI teams in detector upgrades of the CERN experiment covered by the RI, especially in ALICE and ATLAS.

With regards to the activities on ATLAS, the board appreciates that the Production Readiness Review, prepared by teams of the Joint Clean Laboratory of IoP, passed all ITk criteria, which resulted in in the full qualification of the laboratory by the ATLAS collaboration for the testing of the sensor preproduction. The Board congratulates the ITk group on being the first laboratory within the ATLAS collaboration to successfully perform complete strip sensor tests of the first production batches. The AB acknowledges the progress of RI teams in developing the procedure for ITk strip module assembly in the collaboration of the RI institutes with industry and the progress towards readiness for the testing of the module preproduction. The board takes note of the successful test of the first two R0 pre-final modules built in 2020.

The Board appreciates the Czech contribution to the construction of the new ALICE detectors, the Muon Forward Tracker (MFT) and the Forward Diffraction Detector (FDD). For the MFT the RI teams took part in the commissioning of the detector and the development of quality control software which was successfully tested during data taking in 2021. In the FDD the RI team finished the module construction and participated in the installation of FDD and in the first testing at CERN. The main Czech contribution to the ALICE upgrade of the Inner tracking system was concentrated on the development of data quality control and on the ITS commissioning. Physicists from the CR took over several coordination responsibilities in ITS, MFT and FDD, underlining the relevance of the contributions from the CR. The AB takes note of the Czech participation in the preparation of the run of the COMPASS experiment which was carried out with important contribution from the RI teams.

The AB supports the participation of the RI teams in the testing of various components of the new AMBER experiment which was approved by the CERN Research Board in December 2020 for its Phase I measurements until the beginning of the CERN Long Shutdown 3.

The current upgrade projects benefit from the long-term successful engagement of RI physicists and technicians in various R&D projects. A particularly interesting activity is the development of a cutting-edge silicon-pixel technology, TimePix3, for several applications in the eMoEDAL, ATLAS, UA9 and ISOLDE experiments.

The Advisory Board takes note of the activity in the University of West Bohemia, Plzeň, where a team is engaged in developing of various cutting-edge electronic components for ATLAS AFP detector and other detectors.

The AB supports the new activities which will be included in RI. A group from CTU has started to work on laser wakefield acceleration of electrons. The work of this group could provide an attractive option for the electron bunch injection system for the AWAKE experiment. A team from CU has joined the FCC-ee calorimetry group and has begun to participate in the design of an electromagnetic calorimeter.

In addition to the RI support for hardware upgrades of experiments, the Board also appreciates the support given by the RI for data analysis groups of RI institutes. This enabled significant Czech contributions to about 20 publications covering a wide range of physics topics, such as Higgs production and decays, top quark production and B physics in ATLAS, and ultra-peripheral collisions, particle correlations, b-jets in ALICE.

Conclusion

The Advisory Board approves the spending of modified funding in 2021, which was used efficiently and corresponded to the RI activities mentioned above. The membership costs covered the detector running cost and the financial contribution to the upgrades. The maintenance costs included reduced travel expenses of Czech RI teams to CERN and the costs for running home laboratories and the computing farm. The Advisory Board supports the planned expenses in the year 2022 and finds them appropriate in view of the RI strategy.

The advisory board considers the organisation of the RI, supporting both 'flagship projects' such as ATLAS and ALICE, and smaller activities which broaden the scientific and technological potential, to be an excellent strategy. The continuation in the next period will keep and enhance the reputation of the CR institutes in the world. The Advisory Board emphasizes that the contributions of the RI to the upgrade of ALICE and ATLAS experiments are of utmost importance for their future physics program.

The Advisory Board also supports the long-term plans for the future of the RI in the period 2023 - 2029, which, in addition to the continuing activities in the present experiments and ongoing upgrades, includes Czech participation in future collider projects.

The AB is concerned by the prospects of a potential reduction of the RI funding in the next period starting in 2023. The board fully supports the projection of funding needs for the period of 2023-29 made by the RI, which is required to keep meeting the commitments of the institutes to the CERN projects, and to enable to profit from the investments made into the infrastructure, in particular also in the form of detector upgrades, in past years.

The AB recommends that an additional funding and personnel from other institutes or projects is enabled in case of extraordinary resource needs for the upgrade projects, such as for ATLAS ITk during its main production time. For that reason the AB endorses an intention of the RI representative to apply for a financial support from the new operation program JAK for particle and astroparticle physics.

Members of the Advisory Board
Federico Antinori
Wolfgang Lohmann
Frank Simon
Stanislav Tokár
Josef Žáček

Appendix C – Minutes of 2021 CERN-CZ Internation Advisory Board held on 19th of December 2022

The Chair of the Executive Board and the responsible scientist of the Research Infrastructure (RI) CERN-CZ, Alexander Kupčo opened the **public session** at 9:00. The first talk summarized the participation of the Czech RI teams in the ALICE experiment in 2022 and their future plans. The next talk presented several Czech activities in the ATLAS experiment, focused in particular on the Forward Detector AFP and Tilecal in LS2, and on contributions to the operations of the experiment. Then followed presentations devoted to the Czech contribution to the ATLAS HL Upgrade, i.e. ITk strip testing, and assembly of ITk strip modules. The next group of talks summarized the activities of RI members in the COMPASS/AMBER experiment, in RD50, RD53, CALICE, and in applications of Timepix detectors in the ATLAS and MoEDAL experiments. Further talks covered the performance of the TIER2 Computing Center in Prague and the contributions of scientists from the Czech Republic to the research results of the CERN experiments. The last presentation showed the activity of the outreach group in the Czech Republic.

The talks showed the involvement of the Czech universities and institutions in the maintenance and development of the detector hardware and software for the above-mentioned experiments at CERN in 2022, and the plans for the next years. They also gave an impressive summary of the physics analysis results enabled by the participation in the above-mentioned experiments. They highlighted the main Czech contributions to the various R&D activities and the progress in the development of the R&D infrastructure in the universities and institutes including the acquisition of the corresponding equipment. The reports about the contributions of the universities and institutes from the CR to the upgrade of the ATLAS and ALICE experiments showed that all commitments have been met. Scientists from the CR are key players in several fields, such as sensor studies and quality control of components, being also reflected in the management structure of the projects.

After a short break, the Advisory Board meeting proceeded with the **closed session**. A. Kupčo presented the budged spending in 2022. He showed the budget proposal for the years 2023 – 2029, which was made in January 2021. The Government approved a budget for the period of 4 years with a significant reduction of 25% in 2023 and of about 40% in future years. In order to at least partially compensate for these budget reductions, the RI representative intends to apply next year for an additional funding from the OP JAK project 'Top-notch Science Fundamental constituents of matter through frontier technologies'. The talk initiated a discussion about the impact of the budget cuts on the Czech involvements and obligations in current and future MOUs and on the framework for decision making about new projects. Then followed the presentation of the activity of a Czech team, a member of the Crystal Clear Collaboration participating in R&D of inorganic scintillating materials to be used in high-energy physics, medical imaging and industrial applications. The team intents to join the LHCb experiment which has expressed an interest to use this novel material for their Upgrade II, foreseen for installation Long Shutdown 4 of the LHC, currently foreseen for 2033. A further issue which was debated concerned the possibility to use the infrastructure of the Joint Clean Laboratory, established for the ATLAS ITk Strip detector construction at FZU, for other projects when the ATLAS detector upgrade is finished, for example for the ALICE3 upgrade. The meeting was supplemented by a visit of the joint clean laboratory at FZU on December 20.

Observations and Recommendations

The advisory Board found the RI support of the RI teams responsible for operational and maintenance activities appropriate with respect to their commitments in the experiments. Similarly, the supporting program Inter-Excellence which unfortunately ended in 2022 allowed the scientists from RI universities

and institutions to participate in the data analysis, to follow their own scientific interests, and to obtain or significantly contribute to unique and original scientific results in the CERN experiments and the R&D programs supported by the RI. This is convincingly reflected in dozens of publications prepared under the responsibility of physicists from the CR.
An important service to the users is the local Tier 2 computing facility operated by the RI CERN-CZ. This facility is also a crucial component for the fulfillment of the obligations of the CZ institutes towards the LHC collaborations. The OP RDE project CERN-CD of MYES, which has finished this year, made it possible to enlarge this facility between 2020 and 2022 by a new cluster with 29 servers. Besides the farm itself, the Tier2 team also efficiently used several external resources in an opportunistic manner, especially the new cluster KAROLINA at IT41 Ostrava which was put into operation in 2021. All computing equipment operated reliably, which made it possible to significantly exceed the Czech pledges to WLCG. The Board appreciates the stabilization of the farm personnel situation which simplifies running of the Tier 2.
The Board recognizes the progress made in the participation of RI teams in detector upgrades of the CERN experiment covered by the RI, especially in ALICE and ATLAS.
With regards to the activities on ATLAS, the Board congratulates the Prague ITk group for the successful completion of the strip sensor tests of the first production batches which corresponds to ~1/3 of the whole Prague commitment. The Board appreciates the ability of this group to characterize sensors in large quantities. The AB acknowledges the progress of RI teams in developing the procedure for ITk strip module assembly in a collaboration of the RI institutes with industry and the progress towards readiness for the testing of the module preproduction. The board takes note of the tests of the first 4 prototypes and 5 pre-production modules. In the near future, after the transition from prototyping and pre-production to mass production, the numbers of sensors and strip modules will grow by a large factor. The space in the clean lab is already now occupied by equipment needed for the measurements and the thermal tests. Hence the board recommends to consider an extension of the clean lab space still before mass production will start.
The Board appreciates the Czech contribution to the construction, installation and commissioning of the new ALICE detectors, the Muon Forward Tracker (MFT) and the Forward Diffraction Detector (FDD). For the MFT the RI team from CTU is in charge of all MFT quality control activities. The QC software which was developed and successfully tested in 2021 was regularly used during data taking in 2022. In the FDD project the RI team operated this detector during data taking in 2022, analysed registered events and was able to reconstruct primary vertices of interactions. The main Czech contribution to the ALICE upgrade of the Inner tracking system was concentrated on data quality control which was developed by the RI team last year. Physicists from the CR took over several coordination responsibilities in ITS, MFT and FDD, underlining the relevance of the contributions from the CR.
The AB takes note of the Czech activity in the last run in 2022 of the COMPASS experiment and appreciates the RI team's successful long-term participation in running this experiment, their contributions to hardware and to data analysis. The AB supports the participation of the RI COMPASS teams in the new experiment AMBER, the COMPASS successor at the CERN NA M2 beamline. The AB approves the planned activity of the team for this experiment.
The current upgrade projects benefit from the successful long-term engagement of RI physicists and technicians in various R&D projects. A particularly interesting activity is the development of a cutting-edge silicon-pixel technology, TimePix3, for several applications in MoEDAL and ATLAS.
In addition to the RI support for hardware upgrades of experiments, the Board also appreciates the support given by the RI for data analysis groups of RI universities and institutes. This enabled significant Czech contributions to about 20 publications covering a wide range of physics topics, such as Higgs

production and decays, top quark production and B physics in ATLAS, and ultra-peripheral collisions, particle correlations and b-jet characteristics in ALICE.

Conclusion

The Advisory Board approves the financial spending of funding in 2022, which was used efficiently and supported the RI activities mentioned above. The membership costs covered the detector running cost and the financial contributions to the upgrades. The maintenance costs included travel expenses of Czech RI teams to CERN and the costs for running the home laboratories and the computing farm.

The advisory board considers the strategy of the RI, supporting both 'flagship projects' such as ATLAS and ALICE, and smaller activities which broaden the scientific and technological potential, to be an excellent approach to fundamental science. The continuation in the next period will keep and enhance the reputation of the CR institutes in the world. The Advisory Board emphasizes that the contributions of the RI to the upgrade of ALICE and ATLAS experiments are of utmost importance for their future physics program.

In the ATLAS tracker upgrade the group from the Czech Republic is a key player. It is one of the two leading groups in the quality control and irradiation of endcap sensors, including planning and organisation. It is currently the most advanced group in the production of modules. The central place for development, maintenance and update of the production data base is Prague. The clean labs of FZU and CU constitute a top level infrastructure, and scientists and engineers acquired an excellent knowledge in silicon detector technologies. The board encourages the management to develop a long term plan for appropriate use of this extensive subject matter expertise.

The Advisory Board also supports the long-term plans for the future of the RI in the period 2023 - 2026, which, in addition to the continuing activities in the present experiments and ongoing upgrades, includes Czech participation in future collider projects. The board fully supports the projection of funding needs for the period of 2023-26 made by the RI, which is required to match the commitments of the institutes to the CERN projects in future, and to enable to profit from the investments made into the infrastructure, in particular also in the form of detector upgrades, in past years.

Therefore the AB expresses concern about the planned reduction of the RI funding of ~40% in the next period, which will have a negative impact on the realization of Czech obligations specified in MoUs. The RI teams participating in various detector upgrades belong to larger international teams which are composed from members of dozens of institutions around the world. As mentioned above, groups from the Czech Republic play a central role in these detector upgrades. A delay in delivery of detector components from the Czech side due to budget cuts would cause disruptions in the manufacturing chain concerted with the partners. In the best case this would postpone the assembly of the detectors, in the worst it would lead to an unrecoverable downgrade of the detector performance. Similarly, limitations of stays of Czech experts at CERN due to budget cuts would reduce the expected participation of RI teams in the construction of detectors, their testing and putting them into operation and finally in running the experiments. **Therefore the AB appeals to the officials of the Czech funding agencies to reconsider the level of budget reduction or to add an additional financial support either from the OP infrastructure or from other funding resources.**

Members of the Advisory Board
Federico Antinori
Wolfgang Lohmann
Frank Simon
Stanislav Tokár
Josef Žáček