Final Summary Report
ALICE OTKA (K120660)
Investigation of the Identified Hadron Production in the Heavy-ion Collisions at the High-luminosity LHC by the ALICE Experiment
2016.10.01 – 2020.09.30

Introduction

The goal of the CERN LHC ALICE collaboration is the study of the Quark-Gluon Plasma (QGP) phase of the early Universe, shortly after the Big Bang. Our OTKA K120660 project aimed to support this international research, both on the theoretical (QCD phenomenology) and detector R&D sides. Our proposed research plan has been successfully done, although the last year of the project had been overwritten by the SARS-Covid-2 pandemic issues. We fulfilled all our proposed tasks, thanks to the proactive members of the Hungarian ALICE Group. The delivered work is relevant contribution to the forthcoming years activities of the CERN LHC ALICE experiment during the LHC's Run-3 period and the HiLumi period as well. Below, I will summarize the five major directions of our related activities, results, and achievements of the 2016-2020 period, but may data also available on the Hungarian ALICE Group's webpage.

The main results of the project

i) Contribution to the ALICE TPC & ITS Upgrade projects: detector R&D for Run 3

The increased-luminosity LHC runs after 2021[1] required the upgrade of the ALICE Time Projection Chamber (TPC). During the LS2 (Long shutdown 2nd), we re-built the world's largest 88 m^3 multiwire-chamber-technology-based (MWPC) TPC to the new Gas Electron Multiplayer (GEM) technique, which provides faster readout and less deadtime. After this development the measurement rate of Pb-Pb collision reach 50 kHz instead of previously 500 Hz. The observation means full 3D reconstruction of 8-10 thousands particle trajectories in each collision, with increased data production.

In collaboration with the Innovative Gaseous Detectors "Momentum" Group, and the Wigner GPU Laboratory, using the Wigner RCP's R&D infrastructure, we jointly worked with the University of Helsinki, TU Munich, CERN and GSI. Budapest was one of the Quality Assurance (QA) test site, classifying of about one-third of the large-scale GEM foils.

We contributed to the TPC UG project with 2.5 FTE during the last 4 years in the following tasks: In the first year, between 2016 and 2017, we established the ALICE TPC Budapest QA Center to classify GEM foils by studying the correlation between hole diameters and the GEM electrical gain [1].

1 Originally the re-start of the increased-luminosity LHC was in 2020Q1, but due to the SARS-Covid-2 this has been re-scheduled to 2021Q4 or 2022Q1.

The QA procedure was 3 folded:

1 High-Definition optical scanning; long term, 5-20 hours, for each foil;
2 High-Voltage leakage current tests, in nitrogen gas, with 500V potential, monitoring the sparks and the leakage currents of the sectors of the GEMs;
3 gain scanning (only in Budapest!) which is an operational test of the GEMs, measuring the gain features of the GEMs in realistic conditions with ^{55}Fe isotope source, with similar spatial resolution as the optical scanning [2].

For the above tasks, first we developed a special QA equipment and an analysis software: a 3D High-Definition Scanner Robot with the ISEG controller including a HD camera and optics with homogenius led lighting and light controller. To extract data from the images a dedicated neural-network-based image recognition GPU-routine were written in collaboration with the Wigner GPU Laboratory. For the data taking and quality analysis we programmed and used a QA GUI application, which could process and classify the foils, while displaying and evaluating both the leakage current and HD optical data. The code is open-source on GitHub [3].

For the long term high-voltage tests a HV box was designed with a pico-Amper meter. In addition to this a gain scanner detector developed in Wigner RCP. The main goal of gain scanning to study the correlation between the optical features (e.g. inhomogenities in ring diameter distribution) and the operational gain features of GEMs, and thus making predictions for the operation phase. The Budapest QA Center's normal, continuous operation (for IROC and OROC2 GEMs) started in February 2017 and lasted until September 2019. Totally 369 GEMs arrived to the Budapest QA Center: all went trough the optical scanning and tested by high voltage (HV), while 49 of the GEMs were gain scanned. Tested GEMs were sent to framing centers to Bonn, WSU-Detroit and CERN. When the full QA procedure chain was installed and tested we organized a dedicated international QA meeting in Budapest in 2017. Later, we participated on the first ALICE TPC UG test beam at CERN PS T10 experimental area, where the first IROC GEM based test chambers were tested with 1-5 GeV PS beam.

Figure 1: Successful PS beam test team (left); the finished A-side of the TPC at CERN (right)

As the quality assurance activity had been finished, group members joined to the building and installation activities at CERN. We produced, installed, and tested temperature sensors for the IROC and OROC chambers, changed the passivated HV lemo nuts, and installed HV rotation blocker for the chambers. In the same time 4080 pieces of grounding cables were produced in the Wigner RCP for the

TPC detector, and were delivered to CERN (3280 pcs 16,5 cm long, 50 pcs 25 cm long, 750 pcs 34 cm long). The chamber replacement, electronics installation and tests of IROC and OROC chambers at CERN with a laser system, cosmic rays and X-rays at the GIF+ (Gamma Irradiation Facility) took over the last year of the project. Á. L. Gera, L. Boldizsár and E. Futó spent 8.5 human months at CERN with this tasks and additional 2 human months by remote test control in the summer from Wigner RC during the virus lockdown. The refurbished TPC detector was lowered into the ALICE cavern and installed in the experiment on 14th August.

We participated the EPS-HEP 2019 Conference, for which the ALICE Conference Committee selected Á.L. Gera for a parallel talk to present the status of the ALICE TPC Upgrade [2]. The description of the new-type GEM-based TPC concept was published also in [4].

Our group participated in the Inner Tracking System (ITS) detector upgrade. Soon after starting of our OTKA project, M. Varga-Kőfaragó joined our group from Utrecht University & CERN. She played a key role in the ITS R&D in the early stage at CERN, thus many ITS-upgrade related tasks were inherited. She did coordinated the first beam test of the final ALPIDE MAPS pieces, indeed to make the silicon-pixel characterization and test procedure [5]. In parallel to her data analysis studies, this task was the second part in her PhD thesis [6], defended in early 2018. Later we also contributed to the ALICE ITS R&D and UG coordination by our postdoctoral members until the end of the project: G. Volpe, G. Vino and D. Collela (ITS UG Coordinator).

ii) Data Taking and Data Analysis of High-momentum Identified Particle Data

During Run2 we collected and analyzed identified, intermediate- and high-p_T hadron data including various sub-detectors of ALICE. Our group has operation responsibilities of the ALICE HMPID detector from its construction, which Ring Imaging Cherenkov (RICH) detector is able to identify pions and kaons up to 3 GeV/c and kaons and protons up to 5 GeV/c momenta. We analyzed also jet production and correlations in pp and PbPb collisions from TPC-data at the higher, p_T>5 GeV/c, transverse momentum spectra, where particle identification can be performed via the so called relativistic rise method from 7, and 13 pp collisions. Our group was connected to the Light Flavor Physics Analysis Group (PAG-LF), and later to the Heavy Flavor Physics Analysis Group (PAG-HF) as well.

We provided HMPID-, and TPC-related shifts for the whole period of the project during the Run2 data taking. In parallel our "on call experts" (L. Boldizsár, G. Volpe, E. Futó) were available most of the time for the ALICE HMPID and for ALICE IF detectors, which Detector Control System (CDS) was developed by O.B. Visnyei until late 2018. We investigated the performance of the ALICE HMPID detector with the analysis of the data of pp and pPb collisions measured during the LHC Run1 and Run2 periods. This results were the key contribution of ALICE Public Note and Conference contributions [7-9], and became the part of L. Oláh's PhD thesis [10] (defended Feb. 2017, ELTE).

Within the LF PAG the production of light flavor hadrons was investigated as a function of charged particle event multiplicity and collision energy. The transverse momentum distributions of the hadrons were measured and compared to those obtained in Monte Carlo event generators. Results indicate that the observed effects seen in data cannot be described quantitatively by the models which require a better theoretical understanding of the underlying processes. Observations on small collision systems (pp) were presented by Gy. Bencédi on the EPS HEP 2017 Conference in Venice on behalf of the ALICE Collaboration, which was published in Proceedings of Science (PoS), [11] ALICE pp result were presented as a talk on the Quark Matter 2018 conference and was published in [12]. We also analyzed, wrote, and coordinated the light flavor measurement paper at 7 and 13 TeV [13], which was a part of Gy. Bencédi's PhD thesis [14].

High-p_T two-particle angular correlation measurements at ALICE on the in PbPb, pPb and pp data at 5.02 TeV and 2.76 TeV were collected and analyzed. We have found that the jet-peak broadens towards central events at low transverse momentum in PbPb collisions and that it becomes asymmetric. We have also found that an unexpected depletion develops around the center of the peak. By analyzing data from AMPT, PYTHIA, and JETSCAPE Monte Carlo simulations, we concluded that both phenomena are accompanied by large radial flow, suggesting that the broadening and the depletion is caused by an interplay of jets and the flowing medium, [15,16]. Results were presented by M. Varga-Kőfaragó at the Rencontres de Moriond QCD and High Energy Interactions in 2017 [17], on the 12. WPCF, Quark Matter 2018 [18], Zimányi Winter School [19], and Balaton Workshop 2019. We are working on now to finalize this analysis together with the pPb data at the same energy to be able to study the system size dependence of this phenomenon. Part of these were published in B. Szigteti's TDK (3rd price) and in his MSc [20].

Heavy-flavour (in ALICE beauty and charm) quarks are produced almost exclusively in initial hard processes, and their yields remain largely unchanged throughout a heavy-ion reaction. Nevertheless, they interact with the nuclear matter in all the stages of its evolution. Thus, heavy quarks serve as ideal self-generated penetrating probes of the strongly interacting QGP. We started to determine the yield and nuclear modification of beauty jets in pPb collisions at 2.76 TeV recorded by ALICE during Run1 and Run2. We focused on developing b-jet identification techniques as well as the unfolding of the b-jet spectrum to correct for detector and background effects. We were appointed on DIS 2017 [21], Zimányi School 2016, Balaton Workshop 2017 QCD@LHC 2017 and Debrecen University Symposium 2017.

We have presented preliminary ALICE results of b-jet cross sections in function of jet transverse momentum using the secondary vertex tagging method, in Run-2 5.02 TeV p-Pb data. These results are consistent with model predictions based on pp collisions, thus excluding a strong modification of b-jets in cold nuclear matter [22]. In 2018-2019, we also studied the heavy-flavor correlations and the structure of underlying event. This showed that the emerging flow patterns do not require hydrodynamics [23-24], as these may be explained by vacuum-QCD mechanisms such as multiple-parton interactions (MPI). We investigated the effect of MPI and color re-connection (CR) on correlation peaks, and from our preliminary results we determined that, although MPI mostly comes from the early long-range components of the reaction, but fragmentation is also modified by it. We proposed a method to determine feed-down of beauty hadrons into charm without the need for reconstructing the secondary vertex in Universe [25]. R. Vértesi was appointed as a coordinator of the Heavy Flavor Jets and Correlations Physics Analysis Group since January 2020 for 2 years, the a HF paper proposal was accepted by the ALICE Physics Board on 22 July 2020.

A strong local analysis group has been built up during the project on the HF topics: Correlation measurements of charmed D mesons with charged hadrons reveal the heavy-flavor jet structure at intermediate momenta. Simulations on D-h correlations in pp collisions at 5 TeV by E. Frajna, aimed at the detailed understanding of the reaction, were accepted by the ALICE collaboration for public presentation on the Zimányi Winter Workshop 2019. Simulations of D-h correlations in pp collisions at 13 TeV have been prepared for the interpretation of multiplicity-dependent and inclusive correlation data. E. Frajna defended her MSc thesis [26] in 2020. L. Gyulai is responsible for the measurement of the D0 mesons with respect to the underlying event activity. This is a groundbreaking measurement that aims to link heavy-flavor production to collective phenomena in small collision systems. The first raw results have been shown in the MSc thesis [27] of L. Gyulai, defended in 2020. Preliminary results from corresponding phenomenology studies in cooperation with the Mexican UNAM group, published in the BSc thesis of A. Misák (defended in 2020), suggest that beauty production can be used as a proxy for quark-initiated jets that probe the underlying event. Z. Varga contributed to the jet structure analysis of

ALICE pp collisions at 13 TeV, in cooperation with the Wuhan (China) CCNU group. He implemented the analysis code for the multiplicity dependence of jet shapes observables. Preliminary data have already confirmed our earlier published simulation results.

iii) Theoretical Calculations and Simulation Code Development

Our project aimed to explore the hot and cold strongly interacting matter. Nuclear effects in high-energy heavy-ion collisions, required phenomenological models and precise, fast computer simulations. We explored effects, then we coded them to models. This led us to understand more the strongly interacting matter at high temperatures and densities in heavy-ion collisions and in compact stars its cold and dense phase. The above program of the proposal was fit to the THOR and PHAROS COST action networking programs, where the PI was board member.

We investigated the emergence of the Chiral Magnetic Effect (CME) and the related anomalous current using the real time Dirac–Heisenberg–Wigner formalism. This method is widely used for describing strong field physics and QED vacuum tunneling phenomena as well as pair production in heavy-ion collisions. We extended earlier investigations of the CME in constant flux tube configuration by considering time dependent fields. In this model we could follow the formation of axial charge separation, formation of axial current and then the emergence of the anomalous electric current. Qualitative results have been calculated for special field configurations that helped to interpret the predictions of CME related effects in heavy-ion collisions at different collision energies. Theoretical results and computational aspects were published in [28-30], indeed these results contributed to the PhD of D. Berényi.

The di-jet acoplanarity in heavy ion collisions has been proposed by M. Gyulassy and T.S. Bíró. Nearly back-to-back di-jets with medium or large transverse momenta become acoplanar even in the vacuum due to multi-gluon radiation. This effect could become stronger in hot matter, generated in energetic heavy ion collisions. Thus the acoplanarity could carry information on the opacity of the hot matter. We described theoretically this dependence and made suggestions for experimental indications of modified acoplanarity. The analysis of recent LHC data may bring new insight into the understanding of this effect and new data could help to determine the opacity in the real collisions [31].

We presented, that modeling hadronization in high-energy pp and pPb collisions can be well described within the non-extensive statistical approach. We identified the mass and c.m. energy scaling of the Tsallis–Pareto parameters of the fitted hadron spectra and compared our theoretical approach to the experimental data and other models. These results were presented on, High-pT for the RHIC & LHC Era, and QCD@LHC conferences [32-41]. In a comprehensive data analysis of all the existing identified RHIC and LHC data, we provided the equation of state using the Tsallis-thermometer [39] and part of G. Bíró's PhD thesis. Using multiplicity dependent data, we have found a QGP-indicator for large and small nuclear collisional systems. Collective effects were identified by using general purpose Monte Carlo event generator indicate to that radial flow pattern arise even in low event multiplicity events in proton-proton collision at LHC energies when a jet is present in the midrapidity region in Ref [42].

We presented the extraction of the temperature by analyzing the charged particle transverse momentum spectra in pp and PbPb collisions at LHC energies from the ALICE Collaboration using the CSPM. From the measured energy density and the temperature the dimensionless quantity ε/T^4 is obtained to get the degrees of freedom (dof), ε/T^4 = dof $\pi/30$. We observe for the first time a two-step behavior in the increase of degrees of freedom, characteristic of deconfinement, above the hadronization temperature around 210 MeV for both PbPb and pp collisions and a sudden increase to the ideal gas value of about 47 corresponding to three quark flavors in the case of PbPb collisions [43].

We studied the multiplicity dependence of jet structures of heavy- and light-flavor jets in pp collisions using Monte Carlo event generators. We gave predictions for multiplicity-differential jet structures and presented evidence for a non-trivial jet shape dependence on charged hadron event multiplicity. We also proposed a way to validate the presence and extent of vacuum-QCD effects such as multiparton interactions (MPI) or color reconnection (CR). Moreover we introduced a multiplicity-independent characteristic jet size measure, parameter R_{fix} in AHEP [44], Universe and MDPI [45-46]. We gave predictions for multiplicity-dependent jet structures in pp collisions at high jet-p_T, and show that the presence of multiple-parton interactions modifies the jet shapes in high-multiplicity events [47]

The aim of the development of the future Monte Carlo generator for the heavy-ion collisions, HIJING++, was to prepare a contemporary simulation tool for the high-energy heavy-ion community. We fully re-wrote the original Fortran-based HIJING code in modern C++ programming language. The HIJING++ is now capable to run in parallel on many-thread x86 architectures, and its new structure is ready for future GPU modules indeed. The performance has been tested on the parallel Xeon Phi machine of the Wigner GPU Laboratory, well. We included new physical phenomena and teased the first preliminary physics results on pp and pPb collisions [48]. These results were presented on the HP2016, QM17, FCC 2017, QCD@LHC and published in their proceedings [49-52]. We validated the calculated identified hadron spectra by our phenomenological model with various Tsallis–Pareto-like functions, using the latest LHC data. By the end of the project we arrived to the tuning phase and final tests before publication of the code, moreover inclusion to AliRoot is in progress as well. HIJING++ results were presented at the HQ2018, HP2018, Zimányi Winter School 2018, SQM2019, and Balaton Workshop 2019 international conferences by various members of the developer group. D. Nagy and B. Csurgai-Horváth defended their MSc theses on testing HIJING++ and this was also part of G. Bíró's PhD work.

Investigating the cold, super-dense nuclear matter phase, compact stars are the best natural laboratories. The PI of the project played important role in European theoretical COST networks (NewCompstar and PHAROS) related to the modeling and investigation of the properties of such celestial objects and to develop the equation of state of the compact star interior. These inter-discipline initiatives were pretty successful to connect the fields of astrophysical observation, gravitational wave, and nuclear physics. Especially supported well the observation of the GW170817, the first measured gravitational wave from neutron star mergers. We organized a related workshop at ECT* in Trento, Italy in October 2017, a week before the announcement. Our research was dedicated to explore the masquerade problem of the compact star equation of state. Since billions of nuclear equation of state model and parametrization exist, which can result observed neutron stars, our plan was to to investigated the effect of quantum flucutations and the uncertainties of the nuclear matter parameter on the nuclear equation of state and on compact star observables. Within the Functional Renormalization Group (FRG) framework we could study the FRG corrections to our mean field demonstrative model for cold dense nuclear matter are shown to change the resulting neutron star mass and radius by 5%. The mathematical technique and the physical consequences of these results were published in Refs. [53-57], were presented on the Quark Matter 2017 and as conference talks. In a second study we estimated the variation of neutron star observables by the symmetric nuclear matter parameters [58], which was extended to the asymmetric nuclear matter case [59]. We have found the order and determined the uncertainty on the maximum mass and radius, and presented that the Landau mass is the key nuclear parameter. We also published a complementer study using Bayesian techniques as a brute force to present the validity [60-62]. Result were summarized in the PhD thesis of P. Pósfay and defended in 2020 with a *”summa cum laude”* [63].

iv) The R&D of the ALICE DAQ system, ALICE O2, CRU2 projects

We have been involved in two major projects of the ALICE Data Acquisition System (DAQ) upgrade. The first one is the enhanced TPC DAQ system (TPC Readout Control Unit, RCU2) development, since high-luminosity data taking require faster readout. Another challenge was the ALICE Common Readout Unit (CRU2) R&D, which is coordinated by the Hungarian ALICE Group. This latter project included PCB design, firmware and linux-driver development, performance tests. We started with the design tasks until 2018, when we moved to the module integration and local test at CERN during the LS2. This project required electronics, oscilloscopes, and network devices as investments at the beginning of the project.

In parallel the CRU's FPGA firmware development was started and we implemented features include: receiving LHC Clock and trigger via PON from the Central Trigger Processor / Local Trigger Unit (CTP / LTU) units, or running without them in standalone mode using a local trigger emulator and the support for multiple GBT links up to 24. In 2016 detector groups started using the firmware, which was presented on the TWEPP 2017 conference [64] by J. Imrek. Other experiments (sPHENIX, MPD NICA DUBNA, CBM/PANDA GSI/FAIR) expressed their interest in reusing the CRU hardware and firmware in their ongoing upgrade projects, the CRU project were presented to them by T. Kiss.

In 2018, in collaboration with CPPM we completed the board design of the final card (PCIe40 v2). We coordinated the prototype testing of v2.0 cards, a small series production and a comprehensive in-system tests of the new cards to verify the CRU hardware and firmware design for the ALICE use cases. To the CRU firmware R&D we contributed with code development and participating in the board and system level testing of all the CRU functionalities required by the upgraded ALICE read-out and trigger system, containing all the required CRU functionalities. The CRU Production Readiness Review (PRR) committee decided on 14 May 2018 to move in the hardware production phase, which was approved on 26 June 2018.

By 2019, the development of the ALICE Common Read-out Units (CRU) for Run3 reached the phase of readiness for production. Our hardware related activity focused on the further stress-testing of the hardware to discover the weak points, the development of the production testing procedure, and test setups. During the stress testing some signal integrity issues were discovered by the Wigner DAQ Laboratory and we developed a special test firmware of the FPGAs. This debugging work proved that the hardware is reliable and the data link errors are related to the internal clocking scheme of the FPGA device which can be improved by firmware adjustments. After a successful CERN tendering, the French company, Fabrication Electronique De Dordogne (FEDD) already produced and shipped 1/3 of the CRU cards (323). We started to test these boards in CERN from September 2019. The testing started with a visual inspection, inventory, than it was followed by a comprehensive functional testing covering about 120 parameters of the working cards, and a 24-hour burn-in testing and monitoring of each unit.

The rest, 2/3 of the CRU cards were to be produced in India. Despite of the lot of effort our partner institutes spent on organizing the production of the cards in India, finally a repeated Indian tender also turned out to be unsuccessful. Because of the lack of time, ALICE management had to take the decision to move this part of the production (309 more CRU cards) also to the company FEDD which succeeded with the first production run by that time. FEDD then started a second production run in the beginning of 2020. Despite of the worldwide SARS-Covid-2 situation, the company successfully managed to get the electronic components, and do the manufacturing with only small delays in the delivery. That way, 309 more cards were delivered at CERN in several batches between April and June 2020. However it was possible to resume the acceptance testing of the cards in CERN only from the beginning of July, when the official travels from Hungary to CERN became possible again. Our colleagues, B.E. Szigeti and T. Kiss then tested all newly produced CRU cards with the same comprehensive test procedure as before during July and August 2020.

In the two production runs (2019 and 2020), 541 CRU cards have been produced all together. After the burn-in and acceptance testing, 530 of the 541 cards got fully accepted, 11 cards failed in some parameters and got sent back to the manufacturer for repair. The number of the failing cards are less than the reserve quantity, so the experiment now have enough CRU units for the installation and full commissioning of the ALICE detector read-out and trigger system. With this achievement, the development and production of the Common Read-out Units, that is, the hardware part of the CRU project got successfully completed! The results of the production and testing had been regularly presented in the ALICE technical forums by T. Kiss, and the technical coordination has endorsed the result. In addition to the production and acceptance testing of the hardware, we also continued our contribution to the CRU FPGA firmware design. Only some closing work was left for T. M. Nguyen in this last year of the project with the improvement and maintenance of some firmware parts earlier designed by our engineers (J. Imrek, T.M. Nguyen and E. Dávid). Wigner RCP has finished its part of the firmware development by December 2019.

Our group will have to provide technical support for our developments in case of bug fixes in the future, such as: functionality improvements, implementing of new requirements, include the maintenance of the production and installation database of the CRU cards, refining the screening windows of the functional tests based on the results of the accepted cards, following-up the repair of the failing units, and keeping the inventory of the spare cards and components. It is also an important task to monitor and evaluate the performance of the detector read-out and trigger system, in which the CRU cards play the role of the key component, just in the very heart of that complex system.

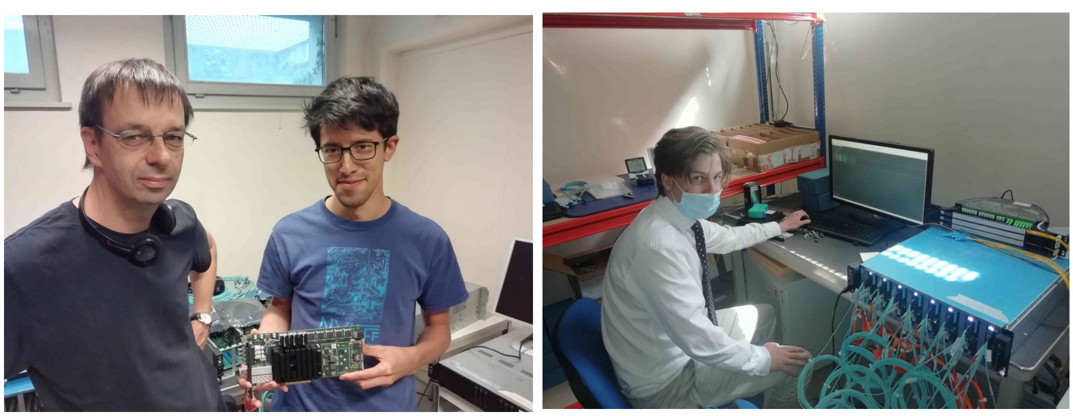

Figure 3: The arrival of the first CRU2 cards (left), test of the CRU2 cards at the CERN (right)

v) Operation and Management of the ALICE GRID Tier-2 Center & ALICE Wigner Cloud

The ALICE data analysis must be served partially by the computational resources of local ALICE GRID Tier-2 Budapest site. Starting from 2016 we almost doubled both the 800 cores in Worker Nodes (WN) and the 0.36 PB in Storage Elements (SE). By the end of the project in 2020 we have reached WNs with 1500 cores (9100 kSH06) and 0.78 PB in the SE. For this we used further grant resources from the Hungarian Academy of Sciences and the INFRA grants including disk upgrade, new storage server (SE) and worker node upgrade. The average job efficiency of the site for the full 2016-2020 period was around 80-90%. In 2019-2020 we participated in the general operating system migration campaign form SLC6 to CentOS7. The integration of the refurbished computing machines into the site was successful, the average number of running jobs has been increased with 30% compared to the last period. The operation and management, and upgrade planning of this site was a continuous task, for which we have used the 1.5 FTE shared between the group members, and directed by a PhD candidate

In addition to this computing capacity, we used about 200 cores from the Wigner Cloud for the HIJING++ software developments and 50 cores for the ALICE analyses. We were among the first testers of the Wigner Cloud, and we were able to successfully investigate the high-efficiency of the cloud computing in large-scale.

A design and planning of a new ALICE Analysis Facility has been started. This would be a dedicated large-scale data analysis facility for data challenges in heavy ion collision simulations. This upgrade, however is new direction in the ALICE Collaboration, but will be part of the O2 project, especially for the Run-3 period.

The ALICE Tier1/Tier2 Workshop (originally planned to take place on 2020. May 12-14. on Budapest) was postponed due to the worldwide Sars-2-COVID-19 lockdown. The new proposed date is late-November 2021, at the same venue.

The ALICE Tier-2 Budapest site participated in the CERN Folding@Home project as well, which aimed to help the fight against the Sars-2-COVID-19 disease. The participation was solved via the WLCG infrastructure by donating ~5% of the ALICE computing resources. As a result, the ALICE Tier-2 Budapest site finished in the 25th place (from 51) in the list of ALICE contributors.

A pCT – new applied R&D followed by the project

During the project, we have formed a R&D group together with the University of Bergen aiming to build a medical imaging detector. The new silicon pixel technologies we applied in ALICE ITS for high-pT charged particle tracking is suggested to support hadron therapy – a new treatment against cancer. We proposed a proton computer tomograph (pCT), based on ALICE ALPIDE MAPS. The detection efficiency of the ALPIDEs at low energy and the cluster size left by charged particles in the ALPIDE was studied and presented ICPPFC2019 and at the 7th Beam Telescopes and Test Beams Workshop and appeared in Universe [65-66]. Thermodynamical properties of the ALICE silicon-pixel detector-based proton CT have been simulated by Á. Sudár and also measured on a mock up at the University of Bergen, Norway. The first results of the concept were published in Ref [67-70] and these become the part of Á. Sudár's TDK work.

Further Achievements, Statistics, Carrier Development, and Awards

Publication Summary

Accepted publications & theses:	72 (+ 867 collaborationa papers) ALICE MTMT
Theses (BSc, MSc, TDK, PhD):	13
Total Impact Factor:	123,2
Submitted publications:	4
Conference talks & seminars:	76
Posters:	14
Conference organization:	14

Participation in conference organization: GPU Day (2016-2020), Zimányi Winter School (2016-2020), Balaton Workshop (2017,2019), ECT* Trento Workshop - New perspectives on Neutron Star Interiors (2017) Magyar Magfizikus Találkozó (2018), AISIS (2019), International Conference on Precision Physics and Fundamental Constants (2019).

BSc (10): B. Szigeti (ELTE, 2018), D. Nagy (ELTE, 2018), E. Frajna (BME, 2018), M. Kovács (BME, 2018), Á. Sudár (BME, 2020), A. Misák (BME, 2019), B. Csurgai-Horváth (ELTE, 2019), Sz. Sándor (ELTE, 2021), L. Gyulai (BME, 2020), Á Gera (BME, 2017), B. Mészáros (ELTE), M. Gergácz (ELTE).
Msc (8): Á. Takács (ELTE, 2019), Á. Gera (BME, 2021) O.B. Visnyei (ELTE), A. Leitereg (ELTE, 2019), B. Szigeti (ELTE, 2020), Á. Sudár (BME, 2020), E. Frajna (BME, 2020), L. Gyulai (BME,2020).
PhD (6): M. Varga-Kőfaragó (Utrech University, 2018), L. Oláh (ELTE, 2017), P. Pósfay (ELTE, 2020), Gy. Bencédi (ELTE, 2019), D. Berényi (ELTE, 2021), M. Vargyas (2018, University of Helsinki), Z. Varga* (ELTE/BME), E. Frajna (BME), L. Gyulai (BME), G. Bíró (ELTE)
PostDoc (7): R. Vértesi, M. Varga-Kőfaragó, Gy. Bencédi, K. Shen, A.N. Mishra, G. Volpe, D. Collela, G. Vino.

Awards, grants: G.G. Barnaföldi: Physics Prize of the HAS (2017), MB in THOR & PHAROS COST actions. M. Varga-Kőfaragó: ALICE Thesis Award (2018), Györgyi Géza price (2019), Premium PD fellowship of the HAS (2019), K.Shen: Wigner PostDoc (2019), PD in China (2020), Á. Takács PhD fellowship at University of Bergen, Norway (2019), A.N. Mishra: Wigner PD (2021) UNKP: G. Bíró, B. Szigeti, Z. Varga, E. Frajna, L. Gyulai, Sz. Sándor. Excellent Student Prize: Á. Takács, B. Szigeti.

Outreach activities: Several public outreach talks were delivered in high school students and for general public: Mindenki Akadémiája (G.G. Barnaföldi): FCC - A jövő nagy részecskeütköztetője, Tudomány Minden Napra (M. Varga-Kőfaragó). MTA Prodcast Hungarian Academy of Sciences (G.G. Barnaföldi GG). Researchers' Night – CERN CMS virtual tour (R. Vértesi, G.G. Barnaföldi), ALICE tent (A. Misák), MTA's CERN 25 event (G.G. Barnaföldi), MTA Fiatal Kutatók Klubja (FIKUK) (M. Varga-Kőfaragó) Élet és tudomány interjú a Hét kutatója rovat (M. Varga-Kőfaragó) High School presentations (G. Bíró, G.G. Barnaföldi, M. Varga-Kőfaragó).

Social responsibility: ALICE and CERN, indeed the Hungarian ALICE Group has participated to the Folding@HOME against Covid-19, with high computational resources during pandemic situation.

List of Publications

1. M.M. Aggarwal, ... G.G. Barnaföldi, G. Bencédi, L. Boldizsár, Á. Gera, G. Hamar, L. Oláh, D. Varga, ez al: Particle identification studies with a full-size 4-GEM prototype for the ALICE TPC upgrade, Nucl. Instrum. Meth. A903, 215-223, 2018
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