# Theoretical and experimental study of high energy particle production in the CERN LHC ALICE experiment

## Final Report

## NK 77816 OTKA project ( 05/2009 – 04/2014)

**Introduction**

The NK77816 OTKA Grant has supported the Hungarian participation in the ALICE (A Large Ion Collider Experiment) experiment at the CERN Large Hadron Collider (LHC) studying heavy ion collisions and the production of the primordial matter of the Universe, which filled up the available (originally very small) volume of our Universe 14 billion years ago. This study was accomplished by the Hungarian ALICE Group at the MTA Wigner Research Centre for Physics (MTA Wigner RCP), which consists of 25 people, including senior and young physicists, technicians and PhD students joined to the project during last five years.

The first realistic version of the LHC accelerator has been discussed in 1986. The discussion of the LHC heavy ion program and the construction of the ALICE detector complex have been started in December 1990. After a long time of preparation and construction, the first successful pp collision took place on 23 November 2009 at $\sqrt{s}$= 7 TeV, the first heavy ion (PbPb) collisions have happened on 7 November 2010 at collision energy $\sqrt{s}$=2.76 ATeV. During the next 4 years the LHC heavy ion program created lots of new data, which demanded to extend the analysis capability of the ALICE collaboration tremendously. The obtained results overwrote most of the previously published theoretical predictions. **The RUN1 time period of 2009-2014 is one of the most excited time in the history of heavy ion collisions**, and we are very much grateful at the Hungarian ALICE Group, that **the OTKA support of the NK77816 Grant has allowed us to contribute to these new results and participate actively in the LHC ALICE research program** studying the primordial material of the Universe. During RUN1 the LHC accelerator already fulfilled both of his scientific missions: a) the theoretically predicted Higgs-boson has been discovered and studied in details – earning the Nobel Prize for Peter Higgs and François Englert in 2013; b) the quark-gluon plasma has been created successfully and the properties of a matter of strongly interacting quarks and gluons have been studied This report summarizes our results and contributions to the field of heavy ion collisions in the above time period.

The Hungarian ALICE Group led by the physicists from the KFKI Research Institute for Particle and Nuclear Physics (KFKI RMKI), later on the MTA Wigner RCP, coordinated and integrated the Hungarian efforts into this direction. During last 5 years we have accomplished our planned research program supported by the NK77816 OTKA Grant. In this summary we have included **100 publications created by the support of the NK77816 OTKA Grant, including 75 papers in refereed journals.** Selecting our different activities we have published 15 papers in refereed journals and 19 conference proceedings containing our theoretical results, 8 papers in refereed journals and 4 conference proceedings containing our results in detector R&D activities, especially on the development of the Very High Momentum Particle Identification Detector (VHMPID), and 52 papers in refereed journals and 2 conference proceedings on data analysis, including those ALICE publications, where the Hungarian group had some contribution in data analysis and discussions. The ALICE Collaboration published more than 500 publications during last years, where the members of the Hungarian ALICE group are listed. We had wide spectra of collaboration duties and services, collecting data, running the experiment and ensuring the high level of scientific merit inside the ALICE Collaboration. We have included into this report only those publications, where the Hungarian contribution was relevant and well identified from experimental and theoretical sides.

**Short description of the LHC ALICE detector**

The detector complex of ALICE (A Large Ion Collider Experiment) is intended to investigate proton-proton (pp), lead-lead (PbPb) and proton-lead (pPb) collisions. The collected data make available to determine the properties of the quark-gluon plasma state. The ALICE Collaboration consists of more than 1000 physicists and engineers from 86 institutes of 29 countries, including Hungary and the Hungarian ALICE Group with 25 physicists, engineers, technicians and students. Members of the Hungarian ALICE Group participate in the ALICE activities from the beginning of the construction of the detector complex. In the period of 2002-2008 our activity has been focused on the preparation to identify charged hadrons with high transverse momentum. We have participated in the construction and installation of the HMPID (High Momentum Particle Identification Detector) detector, and started the preparation for the construction of a new detector, the VHMPID (Very High Momentum Particle Identification Detector). In parallel we have performed simulations and published theoretical predictions. These basic research activities have been supported originally by the OTKA Grant NK62044 (2006-2008), supplementary OTKA grant IN71374 (2007-2008) and NKTH-OTKA mobility grant H07-C 74164 (2008-2009). These research activities have been extended into the direction of RUN1 data analysis and physical interpretation of collected data after the successful start of the LHC accelerator complex.

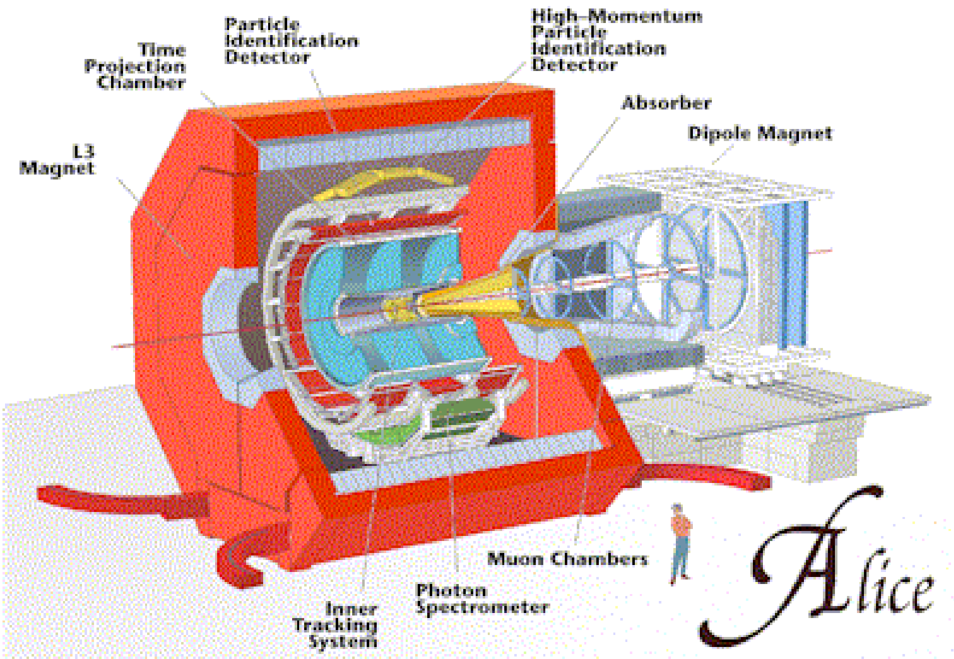


Fig. 1. The ALICE detector

The ALICE detector is dedicated to identify and study all possible freeze-out hadrons in proton-proton and heavy-ion collisions, thus this detector is the most appropriate to investigate the formation of quark-gluon plasma (QGP). The main detector parts of ALICE (Fig.1.) are responsible for particle identification, namely ITS (Inner Tracking System), TPC (Time Projection Chamber), TOF (Time of Flight), TRD (Transition Radiation Detector) and HMPID (High-Momentum Particle Identification Detector). These detectors are capable of measuring charged particles without identification up to $p_T \leq 50$ GeV/c, but can distinguish pions, kaons and protons up to $p_T \leq 5$ GeV/c. The HMPID detector has a crucial role in this task, extending the particle identification beyond the usual 2GeV/c momentum limit of the TPC-TOF combination.

Beyond 5 GeV/c momenta further efforts are needed for precise particle separation. Since results from the Relativistic Heavy Ion Collider (RHIC) indicated the presence of interesting physical phenomena in the momentum range 5 GeV/c $\leq p_T \leq$ 15 GeV/c, and LHC serves high enough luminosity, the idea of constructing a new detector has been emerged. The planned VHMPID (Very High Momentum Particle Identification Detector) is a ring imaging Cherenkov-detector, combined with a high-$p_T$ trigger unit. This can solve the problem of separation for high momentum charged particles, which were already detected by the TPC, thus the momentum is known. The Hungarian ALICE Group joined to the mutual effort to create a Design Report of the VHMPID and perform the necessary R&D activity to develop this new detector.

The LHC complex including the detectors have been shut down for maintenance at the end of 2013 and will start again in March 2015, targeting the peak energies of LHC, namely 14 TeV for pp collisions and 5.5 ATeV for PbPb collisions. The preparation for the RUN2-period of 2015-2018 has been already started and supported partly by this NK77816 and the next NK109116 OTKA Grant. Here we focus on the results collected and extracted by the support of the NK77816 Grant.

**Planned research activities supported by the NK77816 OTKA Grant in 2009-2014**

Our planned activities for the time period 2009-2014 were strongly connected to the schedule of the LHC accelerator. Our main aim was to strengthen the Hungarian participation in the ALICE collaboration, with a focus on detection and identification of charged hadrons in wide momentum range, especially in the intermediate and high momentum region. We planned to realize this aim through the accomplishment of the following research activities (copied from our proposal):

***A,*** *We participate in the work of the ALICE Physics Working Group 4, which is focusing on high-$p_T$ physics. We already expressed interest in data analysis with the identification of charged hadrons and the measurement of hadron-hadron correlations, especially extracting information about high-$p_T$ particles. We plan to extend our activity in p+p collisions for underlying events to extract possible information for QGP formation in p+p collisions.*

***B,*** *We continue our theoretical analysis work of new data, improve our previously developed calculations in the field of perturbative QCD, coalescence/recombination and hydrodynamics. We compare the extracted experimental results to previous predictions. We are looking for the appearance of new physical phenomena in p+p collisions, which can deeper our understanding in heavy-ion collisions. This theoretical activity is strongly connected to our work in PWG4.*

***C,*** *We participate in the ALICE HMPID group. This detector contains Ring Imaging Cherenkov (RICH) counters and it is capable to separate pion and kaon up to 3 GeV/c, kaon and proton up to 5 GeV/c. The installation of the HMPID detector has been finished, it is ready for data taking. Further activity is needed on software development to connect the TPC tracks to the HMPID rings to reach the ideal identification of high-$p_T$ particles. We plan to contribute to the offline activities and data analysis in the p+p and Pb+Pb run.*

***D,*** *We participate in the VHMPID project. This detector will be based on Threshold Imaging Cherenkov (TIC) method to separate pion, kaon and proton in the momentum range 5-15 GeV/c. We accomplish simulations on possible detector designs and participate in the construction of one unit of the planned VHMPID detector, including its high-pT trigger detector (HPTD). In case of successful testing one complete VHMPID module can be integrated and used in 2011. Building a multi-module detector will be possible after successful tests with this unit.*

***E,*** *We continue the operation of the ALICE GRID station at RMKI. We maintain the existing computers and ensure their availability for data analysis and scientific calculations. We search for other financial sources to extend the GRID to keep 1 % ratio considering the whole ALICE GRID.*

**Results of the research activities supported by the NK77816 OTKA Grant in 2009-2014**
In the following we shortly summarize how we could fulfill and realize our original research plan.

**A, High-pT Physics in pp and PbPb collisions**
The large number of pp and PbPb collisions executed at LHC energies in 2011/12/13 led to the collection of huge datasets with 10-100 million events. The analysis of the PbPb data at 2.76 ATeV allowed us to study hadron production in the $p_T$=5-200 GeV/c momentum region, extending the earlier available momentum region of 5-20 GeV/c investigated in the RHIC program. The obtained experimental results of ALICE [23,93] proved the existence of jet energy loss phenomena in the PbPb collisions, again. We have analyzed these data and using the Gyulassy-Levai-Vitev (GLV) method extracted the color charge density produced at LHC energies [32,33]. We have found the increase of color density by a factor of 50 %, comparing to AuAu collisions at RHIC energies (200 AGeV). This increase is weak, although we are at the edge of the maximal energy loss (80-90 %), where effects are characterized by a logarithmic behavior. The ALICE results on light mesons can be described successfully by our theoretical GLV energy-loss model. The description of baryon production is more complex. We have participated actively in the evaluation of the ALICE results and their theoretical interpretation [33](PLevai, VSkokov, and MSc students DBerényi, APásztor).

SPochybova studied hadron production from high energy quark and gluon jets. Her aim was to distinguish the quark and gluon jets and develop a separation method, which is applicable at LHC energies and luminosities. Since her analysis is based on the study of 3-jet events, then large event number was demanded, which became available at the end of RUN1.She successfully developed a statistical method for the separation [38,39,40,41] and successfully analyzed the available data from ALICE [70]. Her analysis proved the applicability of the method, however for a conclusion the size of the datasets should be larger, which will be available during the RUN2.

The analysis of jet phenomena cannot be separated from the understanding of the surrounding environment named as underlying event. AAgócs started to investigate this semi-thermalized particle ensemble in pp collisions. He studied the hadron correlation results at LHC energies and developed analysis protocols to extract the features of the produced particles outside the jet cones [25]. He expected the thermalization level of these hadrons in pp collisions [26,27,61]. His analysis has been used to extract and understand the ALICE data [50].

GyBencédi and LMolnár started to study the hadron-hadron correlations, especially in the momentum range of 1 – 4 GeV/c. These hadrons could be produced from fragmentations of high-$p_T$ jets and quark coalescence of low-$p_T$ quarks and antiquarks. Monte-Carlo simulations had been performed and different data analysis protocols had been tested. The obtained results were displayed and discussed in details in collaboration meetings. Our results were applied in the analysis of ALICE data on hadron-hadron correlation [45] and full particle spectra [90].

The members of the Hungarian ALICE Group actively participated in the activity of the ALICE Physics Working Group 4, which focused on high-$p_T$ results and analysis. We regularly participated in the Group meetings at CERN, as much as the support of the OTKA Grant made available. In parallel PLevai was one of the organizers of the "International Workshop on High-$p_T$ Physics at LHC energies" series, which was another forum of the Working Group 4. These workshops were very successful; 40-60 experts participated and discussed the latest results from experimental and theoretical point of views. The workshop was located in different places, where local experts were working on high-$p_T$ physics: 2010 Mexico City; 2011 Utrecht, 2012 Frankfurt-Hanau, 2012 Wuhan, 2013 Grenoble. In 2014 GGBarnaföldi replaced PLévai in the organizing committee and the Workshop has been organized in Nantes. The Proceedings has been published electronically.

The results of the Hungarian ALICE Group on high-$p_T$ physics gave important contributions to the efforts of the ALICE high-$p_T$ physics program. SPochybova and GyBencédi are close to finish their PhD, presumably in 2015. Their results are based on their above summarized results.

**B, Theoretical investigations of the quark-gluon plasma properties**

The new data from the LHC RUN1 PbPb collisions help us to study the created quark-gluon plasma state and determine special characteristics of this new state of matter. During last years we studied jet energy loss and jet tomography, improving our GLV method [13,32] to increase the precision of extraction the color density of the plasma state using the new ALICE data [13,32]. The inclusion of heavy quarks is a complicated task, the collisional energy loss must be considered beyond the radiation energy loss. Fortunately ALICE detectors could serve with high precision data [46-49,92] to test existing theoretical models and investigate the details of this complicated problem.

Baryon and antibaryon productions are exciting problems, especially, when we obtain anomalously large values. We can speculate on special microscopic production channels, or on the influence of different energy loss level of quarks and gluons, however this question can be investigated in a complex way, only. Namely we need to consider and understand the experimental data and understand the theoretical descriptions in details. ALICE measured hadron yields in large momentum range and at unseen precision [11,19,58,74,79,83], thus we had the basis to perform theoretical analyses, using different models. We focused on the mid-transverse momentum window, where quark coalescence [69] and jet fragmentation overlap and our phenomenological model [33,62] is able to describe the new ALICE data [8,78] successfully.

Alternatively we have investigated the produced particle ensemble from statistical point of view. The momentum distribution of strongly interacting particles can be described by the Tsallis-Pareto distributions, which became a widely used approach during last years. Our studies gave new insights on the features of such particle ensemble and display the applicability of this method in heavy ion collisions [28,29,66,72,73,89]. A special, successfully accomplished task was to explore the appearance of Tsallis distribution in jet fragmentation [71], and study the appearance of intense interaction and strong correlations in this channel.

The strongly interacting feature of the quark-gluon plasma is very important. We have studied this property in details [14]. The hydrodynamic behavior of this strongly interacting particle ensemble yields important results and gives the opportunity to determine the transport coefficients of the strongly interacting quark-gluon plasma, which is theoretically a very decisive parameter. We investigated theoretically the production of this elliptic flow at the microscopic level [42] and participated in the analyses and the discussion of the ALICE data on elliptic flow [18,44,76,77,85,86]. The research community did not reach final conclusion, this topic remained in the forefront of our research activity.

For precise conclusion we need to analyze the particle production with high precision in pp collisions at first, than later on PbPb collisions, and finally the asymmetric pPb collisions. The investigation of the later reaction helps to determine all initial state effects (nuclear shadowing, jet energy loss in cold material, validity of the binary collision method). We followed this way. We have studied pPb physics before the experiments and gave predictions [63,64,88]. Later on we could collect experimental data in ALICE [81,82,94] and these data verified our theoretical understanding. Namely, there is a very weak initial nuclear shadowing in the colliding Pb nucleus. Thus the strong hadron suppression seen in the experiment is clearly connected to jet energy loss and the presence of large color charge density in PbPb collisions at LHC energies.

We investigated the behavior of nuclear collisions at larger than LHC energies, starting a preparation for the Future Circular Collider, which will operate at 80-100 TeV collisional energy. We applied non-perturbative field theoretical approach and calculated light and heavy quark-antiquark production in the presence of strong gluon fields [1,2,15,34,35]. We have extended these study to QED, looking forward the start of the ELI high field laser [98,99]. We have explored the weak interaction and production of W-boson in pp and nuclear collisions, also [37].

We have organized the Gribov-80 Conference on Quantum Chromodynamics and Beyond in Trieste [31], which was a very successful event, where the young specialists of strong interaction could meet the senior experts of the early years of the QCD.

**C, The High Momentum Particle Identification Detector (HMPID) of ALICE**

The HMPID detector enhances the PID capability of the ALICE detector system, beyond the momentum range allowed by the charge particle energy loss measurements (ITS and TPC) and by the TOF. The HMPID detector has been designed to extend the useful range for the identification of $\pi$/K and K/p, on a track-by-track basis, up to 3 GeV/*c* and 5 GeV/*c* respectively. It provided inclusive particle ratios and transverse-momentum spectra in the region relevant for the study of phenomena connected to the pre-equilibrium stage of the nucleus–nucleus collisions and the hadronization of high energy quark and gluon jets. The low yield of high-momentum particles in Pb+Pb collisions at the LHC energy regime justified the single-arm geometry of the HMPID covering about 5% of the central barrel phase space at mid-rapidity.

The Hungarian ALICE Group participated in the maintenance and operation of the HMPID detector. We have learnt to run and operate the HMPID detector and during the whole RUN1 data collection period we have supervised the detector by giving shifts and other services. In 2010 LMolnar became the Run Coordinator of the HMPID, which meant a very high level of responsibility. He carried this responsibility for 3 years. We successfully fulfilled the requested shift load at the ALICE Control Room, thus we were eligible for data analysis during RUN1.

Members of the Hungarian ALICE group used this opportunity and participated actively in the data analysis, especially at the HMPID. AAgocs, GBencedi and LBoldizsar were looking for hadron-hadron correlations inside and outside jet-cone [45]. SPochybova studied the collected high-$p_T$ data to test her results on quark and gluon jet separation[39-41]. The collected data size allowed her to study 2-jet events, however the event samples were not large enough to try 3-jet event-based projects. This could become available in RUN2 in the near future.

The data analysis at HMPID opened the opportunity to participate in the complex data analysis chain of ALICE. On one side we had a direct contribution to the ALICE data with the analyzed HMPID data sets. On the other side we had access to all Data Summary Tape (DST) data in an early stage, thus whole analyses can be performed, including TPC and TOF data. Such data analyses were performed by AAgocs, GBencedi, LBoldizsar, LAndrew and SPochybova. The results of these analyses appeared in different physical analyses, published in ALICE papers. Furthermore, we participated in the preparation and the discussion of these papers. We presented our results in the ALICE Physics Weeks and the Working Group meetings, especially on the meeting of the Jet Physics WG. I have listed a couple of ALICE papers in this report, however only those one, where the Hungarian Group had some type of contribution. (ALICE has published many hundreds of papers during last years, it was many, where we did not have energy to contribute, because we focused on our own specialties.).

As we already mentioned, we participated in the data analyses and discussions on the experimental results collected in pp, pPb and PbPb collisions: particle correlations [3,16,21,45, 50,52,57,80]; extraction of elliptic flow [4,18,44,76,86,92]; study of the particle multiplicities [5,6,7,11,19,74,84,85,90]; baryon and antibaryon production [8,56,78]; particle spectra [9,20,22,51,58,60,75,79,83,91,93]; charm particle production [17,46,47,48,49,53,54,55,59,77]; and pPb collisions [81,82,94,95]. The understanding of the experimental data, the method of extraction helped to follow the uncertainties of these data, thus to decide on the precision of the theoretical analysis.

The HMPID detector is one of the smallest units of the ALICE detector complex. However its unique feature of applying Ring Imaging Cherenkov (RICH) unit helped us to see the basic characteristics and the limitations of these detectors. Since HMPID separated charged hadrons only in the transverse momentum window of 1 – 5 GeV/c, it became clear that it would need the extension of this capability. Especially, when the experimental data from other detectors display interesting tendencies and properties in the 5-15 GeV/c transverse momenta. These interesting data motivated the strengthening of our initiative and investigate the feasibility of such a detector, using RICH method, also.

**D, The Design Report of the VHMPID detector**

The *Very High Momentum Particle Identification Detector (VHMPID)* aims to identify charged pions, kaons, protons and antiprotons in the momentum range 5 GeV/*c* <*p* < 25 GeV/*c* on a track-by-track basis. Its main purpose is to determine hadron specific effects in the fragmentation of partons and subsequent formation of jets in vacuum and in medium. This gives us a special view of the hadronization process itself, which is non-perturbative and thus often treated simply through a factorization approach in the perturbative calculations. The unique capability of the VHMPID is in the track-by-track particle identification, which lies at the heart of all the jet-jet, jet-hadron and di-hadron correlations. Modified fragmentation or flavour/baryon number dependencies in the hadronization can only be mapped if the identified particles can be unambiguously linked to the generating parton (*i.e.* the fragmenting jet). Inserting the VHMPID into the ALICE detector complex we can obtain high precision data to study the dynamical details of the fragmentation with precision never seen before, anisotropic flow (*v*2) and nuclear suppression factors (*RAA*) for protons, kaons and pions out to 25 GeV/*c*.

Since the extraction of such physical information was at the forefront of the Hungarian ALICE Group, thus it was natural to join the VHMPID activity from the beginning. The VHMPID development group consists of specialists from Hungary, Italy, Mexico, South-Korea and USA. The Hungarian presence was significant, thanks to the OTKA support, and our group was one the driving forces in the collaboration.

In the time period of 2009-2013 we have developed all parts of the VHMPID in a way to fit into the existing ALICE framework. We published the developments continuously [12, 24, 30, 36, 68, 100] and completed a final summary named as Design Report of the VHMPID, published in the European Physical Journal Plus [97]. During the R&D activity we were working mostly in Hungary (developing a well-equipped detector laboratory and attracting lots of students), however many test measurements have been completed at the 7 GeV/c pion beam at CERN PS. The Hungarian participants focused on hardware developments and tests (GyBencze, EDénes, GEndrőczi, GHamar, GKiss, LKovács, CsLipusz, LOláh, DVarga ), performed high precision Monte-Carlo simulations of different microscopic steps inside the detector (GBencédi, LBoldizsár, EFutó, LMolnár), and simulated the expected physics (AAgócs, GBarnaföldi, DBerényi, PLévai, SPochybova).

The main part of the detector is a Ring Imaging Cherenkov (RICH) module with reduced length and using pressurized gas for increasing the refractive index connected to the targeted momentum region. We tested different gases beyond the usual one. Thus we gained unique experience with $C_4F_8O$ [87, 96], which was very rarely used before. Since high-$p_T$ events are very rare, also, we needed to improve the triggering capability of our detector. To reach the requested 6 μs decision time in a relatively large surface (1 $m^2$), we have developed the High-pT Trigger Detector (HPTD) unit [67]. The construction of this unit led to the development of an asymmetric multi-wire chamber [43], which had large efficiency but small material budget comparing to the large surface. The final solution for extreme fast triggering of high momentum charged particles was a multilayer setup, a special combination of 4-6 very thin multi-wire chambers.

The VHMPID group delivered the Design Report of the detector for deadline as one of the upgrade program of ALICE [97]. The cost of the whole detector was estimated to be 6-8 MCHF. Unfortunately the Collaboration has decided to postpone the construction and installation of the VHMPID after RUN3, because the modernization and the upgrade of the TPC had higher priority. Since GEM (Gas Electron Multiplier) detector parts were extensively studied during VHMPID and HPTD R&D, the Hungarian group has received an invitation to contribute the TPC Upgrade program, where also GEMs will be applied at high luminosity. In 2014 the members of the ALICE group finished the VHMPID R&D and started the R&D activity at the ALICE TPC.

Another interesting outcome of our R&D activities is the construction of a small size, very effective portable muon detector complex, which can be used to accomplish muon tomography in underground situations (cave, vulcan) [65]. Recently this equipment has received large visibility.

**E, Computing activity of the Hungarian ALICE Group**

The analysis activity of the ALICE Collaboration strongly depends on the available computing power, including CPU and storage capacities. All research groups have a quota depending on the number of active group members, including PhD students. The size of the Hungarian ALICE Group indicated a contribution of 0.5 – 1 % of the total computer capacities. As the ALICE Grid was growing, we needed to extend the size of the Hungarian ALICE Tier-2 station, in parallel replacing the obsolete computing units.

In 2009 we have started by 20 TB storage and 50 working node (CPU core), which could have been doubled within a few months. This 40 TB storage has been doubled to 73 TB in mid-2011 from an external financial support. However, at the end of our OTKA Grant we could extend the allocated storage from 73 TB to effective value of 136 TB. This is the recent storage size based on 4TB hard disks and using RAID to avoid data loss

The number of CPU cores was increasing, also. We have started with 100 working node, which has been doubled at mid-2011 to 200. Finally we have reached 400 dedicated ALICE working nodes by the middle of 2014. However, thanks to a novel solution in the GRID structure, the computing resources can be shared between ALICE and CMS and can be adjusted to the demand. Thus we could offer 600 working nodes for the ALICE community, if CMS has a smaller load.

The enclosed Figure 2 demonstrates the year of 2014, especially the December 2014.

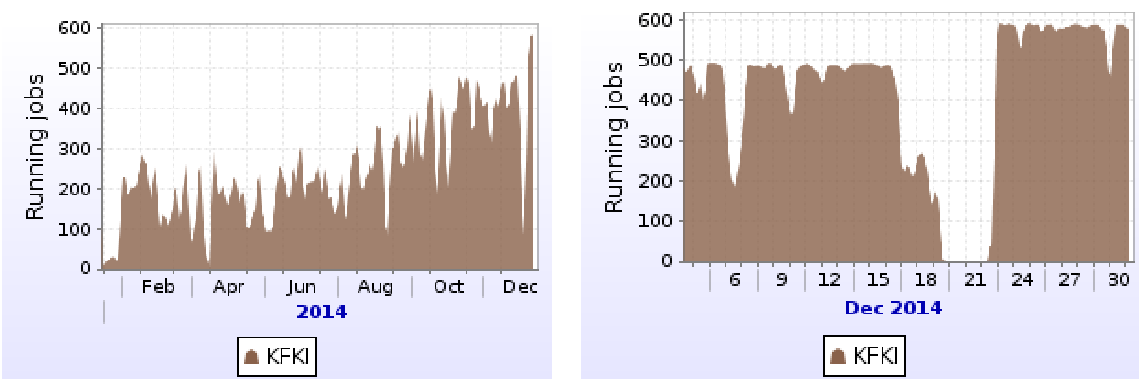


Figure 2: Here we display the activity of the Hungarian ALICE Tier2 station (named as “KFKI”) in 2014. We can see the average number of the working nodes, which was grown from 200 to 400 and later on reached the value of 600.

Recently the ALICE Collaboration is using approx. 60 000 working nodes, thus the Hungarian contribution satisfies the demand of 1 %. The storage situation is similar in portion. Thanks to the support of the Wigner RCP, the electricity consumption is covered, thus the financial support of the NK77816 OTKA Grant was enough to purchase the necessary upgrades and fulfill our computing quota.

In parallel we maintained our private (small size) computing grid, where data analysis and Monte Carlo simulations were running. This grid unit consists of 10 working nodes and 10 TB storage capacities, dedicated for group related computing activities.

The IT experts of the Hungarian ALICE Group (Barnaföldi GG, Berényi D, Nagy-Egri MF, Bíró G) display strong interest into the direction of Graphical Computing Units (GPUs). Recently the GPU Day was organized every year and a small but very active and effective group has been established. The knowledge of GPU programming could become very useful in many research areas. Our experts are continuously looking for new possibilities in the application of GPUs.

This summary report wanted to prove the success and the effectivity of the work of the Hungarian ALICE Group. The last 5 years was a very important time period for us. The focused R&D activity around VHMPID generated an enhanced interest in detector developments and attracted many young talented students. The original size of the Hungarian ALICE Group (10 people) more than doubled (now it is 25 people). In 2013 DVarga has received an MTA Lendület Grant and now the Innovative Detector Laboratory is one of the flagship projects of the Wigner RCP. We have strengthened our position in the ALICE Collaboration, the invitation into the TPC Upgrade program hallmarks the high level of our recognition in detector R&D activities.

In parallel the R&D activity we participated actively in data collection and analyses. Large number of ALICE papers was commented and discussed by the members of our group, we actively participated in the work of ALICE Physics Forum and Working Group meetings. Our students will finish very soon their PhD, which are based on ALICE data analyses.

Considering the physics, we have published many excellent theoretical papers and participated in many conferences, even we could organize couple of ones. Now we understand much better the formation of quark-gluon plasma in heavy ion collisions and we are looking forward to analyze the new data created at the top energy of LHC, namely at 14 TeV for pp collisions and 5.5 ATeV for PbPb collisions.

We can consider our activity to be a successful story. Of course, getting a green light for the construction and installation of the VHMPID detector unit would have been the real victory, however the our project will be discussed again soon and could be continued in the near future, after the completion of the ALICE TPC Upgrade. We are looking forward to analyze the new data of RUN2 in the time period of 2015-2017.

We thank the financial support of the OTKA Grant, which made our NK77816 project to be accomplished successfully.