Programme / Sub-programme / Module	**5/5.2/CERN-RO**		
Project type	**RD**	**Continuing X**	**New ☐**
CERN Research Programme / Experiment	LHC/ALICE		
Project title / Acronym	**IFIN-HH contribution to the ALICE experiment at LHC/RONIPALICE**		
Project duration	2020-2021		

PROJECT DESCRIPTION

1. Objectives of the CERN experiment

Intensive theoretical and experimental effort during the last four decades in the field of heavy ion collisions at relativistic and ultra-relativistic energies has shown that such collisions can be used to produce in laboratory transient pieces of matter at densities and temperatures where, based on Quantum Chromodynamics (QCD) predictions, deconfinement is expected to take place. However, one has to consider that even in the case of colliding the heaviest nuclei, the size of the created system is rather small, its initial state is highly non-homogenous and dynamical effects are playing a crucial role, the system being characterized by a violent evolution in time. At ultra-relativistic energies, even the hadrons become rather complex objects. A free hadron could be considered in each moment as a cloud of quasi-real partons belonging to a cascade whose density seen by a parton of a similar cascade from the colliding partner increases with the energy and is expected to reach a saturation at very high energies. The parton density evolution as a function of x and Q^2, theoretically addressed more than 35 years ago and confirmed experimentally at the Hadron-Electron Ring Accelerator (HERA) at DESY, has triggered a real interest in the community studying ultra-relativistic heavy ion collisions. The rise of the structure function at low x, still visible at small values of Q^2, where the perturbative QCD does not work anymore, requires new approaches for a complete understanding of the log(1/x)-logQ^2 QCD landscape. Low x values and moderate Q^2 are characteristic features for the early stage of hadron collisions, starting to play a role already at energies available at the BNL Relativistic Heavy Ion Collider (RHIC), becoming essential at the CERN Large Hadron Collider (LHC) energies. For average transverse momentum ($\langle p_T \rangle$) values of the order of 1–2 GeV/c, specific for this range of energies, the x values at mid-rapidity are of the order of ~10^{-2} and ~10^{-4} at RHIC and LHC, respectively. A rough estimate of the gluon density and gluon occupation number in the most central A-A collisions shows an increase by a factor of three at LHC energies. These values are similar in Pb-Pb highest centrality and pp highest charged particle multiplicity events at the highest energies presently available at LHC. The similarities evidenced in pp, p-Pb, Xe-Xe and Pb-Pb collisions will be studied in more details in the next period using multi-differential analysis which requires significantly higher statistics. This can be achieved using the full statistics accumulated during Run1 and Run2 periods and by a major upgrade program of ALICE which will be implemented during the LS2 period such that the advantage of high luminosity LHC can be used starting from Run3. The amount of data will increase and therefore the required computing power and storage capacity delivered by worldwide distributed ALICE-GRID infrastructure will be reconsidered and properly adjusted.

2. Romanian contribution to the CERN experiment through the proposed project

As it is known from the precursors of the present project and the results obtained within the ALICE Collaboration or using the information from published results, our group proposed and worked out a physics topic related to collective type phenomena in pp collisions which turned out to be one of the most interesting phenomena to be studied in detail at LHC energies. Transverse momentum distributions and their ratios for pions, kaons and protons at mid rapidity ($|y| <0.5$) for different charged particle multiplicities in pp collisions at $\sqrt{s}$ = 7 TeV show an enhanced depletion of heavier species relative to the lighter ones in the low p_T region with increasing charged particle multiplicity. The quality of simultaneous fits of the experimental spectra using a Boltzmann-Gibbs Blast Wave (BGBW) expression and the dynamics of the extracted kinetic freeze-out temperature T_{kin}, average transverse expansion velocity $<\beta_T>$ and its profile n as a function of multiplicity have been shown to be similar with those obtained in heavy ion collisions. The Bjorken energy density for high multiplicity events indicates values of the same magnitude as the ones estimated for the central Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV. The selection of high multiplicity events close to azimuthal isotropy based on event shape global observables seems to be feasible, however a direct comparison among pp, p-Pb and Pb-Pb as a function of charged particle multiplicity has to be taken with care. The results were presented and published in prestigious international conferences and ISI journals, respectively. An extensive paper on multiplicity dependence of light flavour hadron production in pp collisions at $\sqrt{s}$ = 7 TeV including most of the results obtained up to now related to this topic was published (Phys. Rev. C 99(2019) 024906). In order to exclude the effect of corona contribution from the observed experimental trends, we have done and published in Phys. Rev. C a detailed study of core-corona interplay in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV. In the same journal we published two more papers on geometrical scaling for energies available at the BNL Relativistic Heavy Ion Collider to those at the CERN Large Hadron Collider and on multiplicity dependent transverse momentum distributions of identified particles in pp collisions at 7 TeV within the HIJING/BB v2.0 model. Preliminary results on the transverse momentum distributions of pions, kaons and protons and the fit parameters from simultaneous BGBW fits, as well as two-particle correlations of charged hadrons as a function of charged particle multiplicity at central rapidity and event shape were also obtained. Based on these results and in-progress work, within the presently proposed project, we are planning to continue these studies for pp collisions at $\sqrt{s}$ = 13 TeV, as a function of the charged particle multiplicity at central rapidity and to extend the above mentioned studies in terms of geometrical scaling including Xe-Xe at $\sqrt{s_{NN}}$= 5.44 TeV and strange and multi-strange hadrons. The effect of core-corona interplay will be also studied. We aim to maintain our NIHAM Data Centre as one of the most efficient Tier2 components of ALICE GRID. NIHAM Analysis Facility (NAF) used for developing software packages for calibration, tracking, data analysis, large scale microscopic calculation using different theoretical models and fast local analysis will receive similar attention. Being aware of the importance of a significant increase in the statistics for any kind of multi-differential study, we embarked on the ALICE-TPC upgrade program with assembling and tests of 50% of ALICE-TPC outer read-out chambers (OROCs) based on GEM technology using the infrastructure, know-how and manpower of our Hadron Physics Department. The 20 OROCs, foreseen to be assembled and tested by us, were successfully finalized. Members of our group will continue the activity in this segment with preliminary tests and commissioning of the upgraded TPC. These activities will be continued with the contribution to an efficient running of the experiment in the following Run3.

3. **Project objectives**

O1. Analysis and physics interpretation of experimental pp data obtained with the ALICE detector, comparison with p-Pb, Xe-Xe and Pb-Pb results at LHC energies and detailed Monte Carlo simulations.

Motivated by the results obtained up to now, a multi differential analysis of experimental data and model predictions, in order to understand the properties of the matter formed in pp collisions and its subsequent dynamics up to the hadronization phase compared with heavier systems too, will be done. The influence of corona contribution on the trends of different observables and scaling will be studied and core contributions will be extracted based on experimental data and the Glauber Monte-Carlo approach.
Studies of systematics of different observables as a function of quantities characteristic for the basic phenomena taking place at very high collision energies in pp and A-A collisions and signatures for gluon saturation will be continued and compared with the predictions of different theoretical models.
A consistent treatment of pp and A-A collisions at LHC energies within CGC framework.

O2. Commissioning of the ALICE-TPC using the new ROCs based on GEM technology

Our group will participate to the preliminary tests and commissioning of the upgraded TPC. Related to these activities a PhD student service task will be accomplished.

O3. Contribution to the data taking based on ALICE experimental upgraded device

In order to access high quality experimental information, the ALICE experiment has to be operated continuously in the best conditions as long as LHC delivers beam in Run3.

O4. Operation and development of the NIHAM Data Centre: ALICE GRID site and NAF

In order to have access to the experimental information and perform physics analysis on it is mandatory to continue our efforts at least to maintain the present efficiency of the NIHAM data centre within ALICE-GRID. Similar efforts will be directed to the maintenance in good conditions of the local analysis facility (NAF) dedicated to in-house activities.

4. Main project activities

Following our initial scientific goal to evidence and understand features in pp collisions similar with what was considered before the LHC era to be specific only for A-A collisions, we will pursue a multi differential analysis of experimental data obtained by the ALICE Collaboration:

- Geometrical scaling including strange and multi-strange hadrons.

- The influence of the corona contribution on the trends of different observables and scaling will be studied by extracting the core contribution based on experimental data and the Glauber Monte-Carlo approach.

- The influence of the charged particle multiplicity phase space selection on the obtained results.

- Detailed studies of the dependence of corrections applied to raw spectra on the event shape global variables, the key ingredients in order to access unbiased information based on their selection power.

- The analysis of experimental data in terms of transverse momentum distributions, yields, average transverse momentum, BGBW fit parameters and their systematics, by applying two dimensional cuts in charged particle multiplicity and event shape will be continued.

- Differential studies of two-particle correlations as a function of multiplicity and event shapes will be finalized.

- Based on the previous results and in-progress work, we are planning to extend these studies for pp collisions at $\sqrt{s}$ = 13 TeV using the charged particle multiplicity in the central barrel.

- Detailed comparisons with PYTHIA, PHOJET, EPOS, HIJING and other model predictions will be done.

Such studies and others taking place within the ALICE Collaboration require a significant increase in the statistics. Therefore, the ALICE Collaboration started an ambitious upgrade program already after the first run at LHC. Based on our previous involvement in assembling and testing 24% of the ALICE TRD multi-wire chambers, their implementation in the ALICE experiment, developing the associated software for calibration and tracking and QA monitoring, we committed to assemble and test in our Hadron Physics Department 50% of the outer read-out chambers (OROC) based on GEM technology. The foreseen 20 OROCs were finalized. A preliminary version of a movie showing the complexity of the activities behind, taking place in different laboratories of our department can be viewed at:
https://www.facebook.com/pg/Hadron-Physics-Department-211078852968333/posts/
Members of our group will continue the activity in this segment with preliminary tests after assembling and commissioning of the upgraded TPC. Part of it is considered to be a service task which has to be fulfilled by a PhD student during the period in which the PhD is elaborated. More than 15 years ago we realized the first GRID application in Romania within ALICE-GRID. Over the years, our Data Centre (NIHAM) was developed and operated such that presently it is one of the most efficient Tier2 components of the ALICE GRID. In order to have access to the experimental information and perform physics analysis on it, we have to continue our efforts at least to maintain the present position of the NIHAM data centre within the ALICE-GRID. This can be achieved by a permanent monitoring, in due time interventions, replacement of failing hardware components and an efficient interaction with ALICE offline experts. It is also important to maintain the same level of performance of the NAF (NIHAM Analysis Facility) used for developing software packages for data analysis, large scale microscopic calculation using different theoretical models and fast local analysis

in order to validate them before being released on ALICE-GRID. The NIHAM data centre performance can be followed on: http://pcalimonitor.cern.ch:8889/map.jsp.

We will continue to organize the Summer Student Program, the previous editions being quite successful, the outcome and impression of participants in comparison with their similar experience in other Institutes being remarkable: https://niham.nipne.ro/program_studenti.html. At the end of the last year Summer Student Program, two participants decided to continue their master studies within our group.

As up to now, a special attention will be given to outreach activities. This usually consists of guided visits in our Department of groups of pupils from middle and high school, students, official delegations, open doors day. Other activities will be envisaged according to similar activities organized by our Institute, CERN, at national or international level. The web page of our Department (http://niham.nipne.ro) will be permanently updated. We had a presentation at a NuPECC meeting taking place in Bucharest, highly appreciated by the participants:
https://niham.nipne.ro/NUPEC_121018.pdf.

The participants to the 9th Tier1/Tier2 Workshop, taking place last May in Bucharest, visiting our Department, highly appreciated all segments of activity and the infrastructure of the Department. This year we initiated the HPD Courier which will be regularly issued (http://niham.nipne.ro/HPD-Courier_electronc-version.pdf).

5. Project development and expected results

Multi-step presentation. Milestones and expected results.

Obj. Code	Objective description	Milestones	Expected result	Time schedule justification
O1.	Following the previous activities and the obtained results, we will focus on a multi-differential analysis in order to obtain as much as possible complete information on the main processes that are taking place in pp collisions at the LHC energies and compare them with the results obtained in the collisions of heavier systems. Scaling of different observables will be studied based on experimental data and the Glauber Monte-Carlo approach.	1. The influence of the corona contribution on the trends of different observables and scaling will be studied. 2. Transverse momentum distributions, yields, average transverse momentum for pions, kaons and protons, by applying multi-dimensional cuts in charged particle multiplicity, event shape, rapidity and azimuthal ranges. Fits with expressions suggested by phenomenological models. 3. The previous studies of the $\langle p_T \rangle$, the slope of $\langle p_T \rangle$ as a function of mass of pions, kaons and protons and $\langle \beta_T \rangle$ scaling using charged particle density per unit of rapidity and unit of overlapping area of the colliding partners will be extended to strange and multi-strange hadrons and suppression scaling as a function of N_{part} and $[(dN/dy)/S_{\perp}]^{1/2}$.	1. Core-corona interplay detailed studies. 2. Completion of analysis and comparison with model predictions. 3. The studies of geometrical scaling will be extended to strange and multi-strange hadrons and suppression scaling as a function of N_{part} and $[(dN/dy)/S_{\perp}]^{1/2}$.	1. Results are expected in 2020. 2. Results are expected by the end of 2020. Preliminary results were already presented in ALICE Collaboration. 3. Results are expected to be obtained in 2020.

		4. Similar analysis will be extended to pp collisions at $\sqrt{s}$ =13 TeV using charged particle multiplicity in the central barrel.	4. Transverse momentum distributions, yields, average transverse momentum for pions, kaons and protons as a function of charged particle density using charged particle multiplicity selector based on central barrel.	4. Preliminary results are expected in 2020, final ones in 2021.
		5. Two-particle correlations as a function of charged particle density at mid-rapidity and event shape.	5. This type of analysis will continue based on higher statistics.	5. Results are expected by the end of 2020, beginning of 2021.
		6. Detailed comparisons with PYTHIA, EPOS, HIJING and other model predictions.	6. The results of the above mentioned analyses will be compared with the predictions of different phenomenological models like PYTHIA, EPOS, HIJING, etc.	6. The results will be obtained following the schedule for data analysis.
		7. A consistent treatment of pp and A-A collisions at LHC energies within CGC framework.	7. The existing models and associated codes will be improved and applied for pp and A-A collisions at LHC energies.	7. Results are expected until the end of 2021.
O2.	Contribution to the preliminary tests and TPC commissioning.	Involvement in the preliminary tests and TPC commissioning	As far as 20 OROCs were assembled and tested in our Department, we are committed to continue this activity with preliminary tests and final TPC commissioning.	The activity will take place during the LS2 period.

O3.	Contribution to data taking in Run3 using the upgraded ALICE experimental device	Shifts at the ALICE experiment.	Contribution to the smooth running of the experiment.	Starting with Run3 at LHC.
O4.	The efforts to maintain the present position of the NIHAM data centre within ALICE-GRID will continue.	1. NIHAM Data Centre will continue to be one of the most efficient Tier2 member of the ALICE GRID.	1. ALICE-GRID of high performance.	Years 2020, 2021 Permanent activity.
		2. Maintain the same level of performance of the NAF used for developing software packages for data analysis, large scale microscopic calculation using different theoretical models and fast local analysis.	2. Maintain and improve NAF – an efficient data centre dedicated to local activities.	Years 2020, 2021 Permanent activity.

6. Scientific and technological output of the project

- Scientific publications in ISI international publications within the ALICE Collaboration
- Other scientific publications in ISI journals
- Communications to scientific national and international meetings
- Internal Presentations in the Collaboration
- PRC participation
- Analysis Notes
- Public Notes
- Continuous Update of the NIHAM web pages
- Development and operation in good security conditions of our Data Centers – NIHAM and NAF
- If the financial support is fulfilled, involvement of new members in any form of support in our group on temporary or permanent positions
- Diploma, master and PhD theses
- Outreach products
- Run 3 Shifts: according to our quota/year.

7. Project impact

Scientific/technological/educational/social (etc.) impact.
Potential for developing new cooperation to be concretized in projects proposed for funding through regional, European and international programmes or initiatives.

The envisaged scientific output, the production and study in the laboratory of states of matter expected to be characteristic for the very first moments of the Universe or the inner core of neutron stars and the processes taking place in the collision of highly dense gluonic systems belong to the challenging task of humankind to find answers to ultimate questions. This is one of the front-end segments in basic research of our days in which we are embarked in a visible and competitive way.

The involvement of our group in assembling and testing (50%) of the TPC-OROCs based on GEM technology was a natural consequence of the successful, visible and competitive participation of the Romanian group to the production, test, installation, calibration, tracking and monitoring of the TRD chambers for the ALICE experiment at CERN in the previous period.

Based on the excellent infrastructure of our Department and the know-how built up during the activities mentioned above, we developed a few highly performing prototypes of TRD and RPC detectors, the associated front-end electronics at the chip level and a trigger less acquisition architecture for high counting rate experiments on which important components of the CBM experiment at FAIR will be based.

Fitting out of a technological infrastructure and training people for detector production, test and integration, will allow our Department not only to have a visible and competitive participation at large international collaborations like ALICE and CBM, but also to be involved in other projects at European level of similar complexity.

Experience in modern electronics design places our group in a leading position in establishing and disseminating state of the art technology for chip design in Romania. Funds invested in such a design capability and the impact on the activities related to the basic research will surely pay back in the coming years.

Hardware and software structures of distributed computing network type which have shown their performance will serve not only the group's needs for computing, but also connect Romania to the international efforts to develop the new technology of distributed computing. Our NIHAM Data Centre has the largest contribution among the Romanian sites involved in WLCG.

The new type of two-dimensional position sensitive detectors and their front-end electronics developed by our group, highly appreciated at the Geneva Salon of Inventions have high potentiality to be transferred towards applied physics and technology.

As a common practice in the scientific research domain, students and graduate students will continue to be involved in the group's activities to prepare their diploma works, master and PhD theses. They will become highly qualified specialists, extremely useful in various branches of activities.

During the last years, in our group were finalized 7 Master Theses, 3 are in progress, 2 PhD Theses were finalized and 2 PhD Theses are in progress. Based on the results obtained in this project two members of our group were promoted to Scientific Researcher 2nd Degree, 2 to Scientific Researcher 3rd degree and one to Technological Engineer 2nd degree.

A regular Summer Student Programme was initiated by our Department, becoming by now a tradition, which facilitates a direct access of the students from different Universities to all segments of activities involved in our research. It is worth mentioning that students from Oxford, Birmingham, Bremen and Madrid Universities are applying regularly to attend this program. As up to now, we will contribute to lectures for the Doctoral School of the Physics Faculty of University of Bucharest and educational initiative for special schools organized for pupils winning national and international competitions in Physics and Mathematics.