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	2022-2024		

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 transient pieces of matter at densities and temperatures where, based on Quantum Chromodynamics (QCD) predictions, deconfinement is expected to take place, can be produced in terrestrial laboratories. The initial state of such a tiny object is highly non-homogenous and dynamical effects are playing a crucial role, the system being characterized by a violent time evolution. These contributions have to be understood and quantified in order to extract an unbiased information on the properties and dynamics of deconfined matter, before hadronization. At ultra-relativistic energies, 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 40 years ago and confirmed experimentally at the Hadron-Electron Ring Accelerator (HERA) at DESY, has triggered a real interest for 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 $\log(1/x)$-$\log Q^2$ QCD landscape. Low x values and moderate Q^2 are characteristic features for the early stage of hadron collisions, starting to play a non-negligible role at energies available at the BNL Relativistic Heavy Ion Collider (RHIC) and 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 $\sim 10^{-2}$ and $\sim 10^{-4}$ at RHIC and LHC, respectively. Unexpected indications for collective effects have been observed in high multiplicity events of small colliding systems (pp and p-A). 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. A new path for research on the gradual emergence of high density deconfined matter was opened. These values are similar in Pb-Pb central collision and pp highest charged particle multiplicity events at the energies presently available at LHC. This also strongly motivates an extended data taking programme for ALICE with small colliding systems in Run3 and Run4. The ALICE Collaboration is about to finalize the commissioning of the major upgrades of the experiment setup and take the advantage of high interaction rates.

The similarities evidenced in pp, p-A, and A-A collisions will be studied in more details in the next period using a multi-differential analysis which requires significantly higher statistics that can be achieved using a much larger data sample which will be accessed in Run3 and Run4 periods. 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 our previous projects, our group proposed and worked out physics topics related to collective type phenomena in pp collisions, core-corona relative contribution to different observables, similarities between pp and A-A collisions, geometrical scaling of different observables for pp and A-A collisions and systematic studies of charged particle suppression as a function of collision energy, results presented at international conferences and published in ISI journals.

Event shape classification variables offer interesting possibilities to understand the interplay between jet production and the underlying event. Recent phenomenological studies have emphasised the importance of studying high multiplicity events in pp collisions to possibly identify features connected to properties of a high density partonic medium. The multi-differential selection in charged particle multiplicity, event shape and $\Delta\varphi$ - $\Delta\eta$ relative to the leading particle proved to enhance the contribution of particles originating from multiparton interactions and re-scattering before hadronization, essential mechanisms for reaching an equilibrated deconfined matter state. Such results can discriminate between different phenomenological models in the region where the perturbative QCD does not work anymore, new approaches being required for a complete understanding of the $\log(1/x)$-$\log Q^2$ QCD landscape.

We will continue the previous studies in terms of multi-differential transverse momentum distributions using a multi-dimensional detector response matrix and two particle-correlations for charged particles at 13 TeV. Such studies will be extended to identified hadrons and other global event shape observables than those considered so far. Derived quantities, as yields and average transverse momenta, will help in systematizing the obtained results.

In Run 3 and Run 4 a data sample with selection of high-multiplicity events and an integrated luminosity of about 200 pb^{-1} would be larger by a factor of 10 with respect to the sample recorded during Run 2. Such increase would allow us to study pp collisions with a multiplicity of charged particles per unit of pseudorapidity $dN_{ch}/d\eta \approx 100$ as found in semi-peripheral Pb–Pb collisions and an estimated energy density $\varepsilon \sim 50$ GeV/fm^3 as found in central Pb–Pb collisions. The extended multiplicity coverage will enable more systematic studies based on multi-differential analyses.

The analyses will be implemented in the O^2 environment. To what extent one could benefit from the machine learning techniques will be investigated. The Rivet toolkit will be used for comparison with theoretical calculations done with the existing phenomenological models for pp collisions. A comparison with theory in the greatest detail can put new constraints on the parameters of the models and understand in an unambiguous way the physics behind. The aim is to configure paper drafts to be published within the ALICE Collaboration.

A special attention will be given to the comparison of the dependence of different observables as a function of the collision energy and collision geometry between different systems and at LHC energies between pp and A-A. As evidenced in our previous studies, the particle density per unit of rapidity and unit of transverse overlapping area, suggested by QCD inspired models, seems to be the quantity which governs the trends of different observables in A-A and pp collisions. The core-corona interplay will be taken into account. Theoretical model frameworks implemented in-house will be useful tools in understanding the physics behind the observed experimental trends. The aim is to configure paper drafts to be published by our group members.

Our NIHAM Data Centre was permanently one of the most efficient among Tier2s ALICE GRID centres in the last 10 years. Several maintenance and upgrade activities were done in order to keep its performance at the highest standards. Within the present project we aim to maintain and develop the performance of the NIHAM Data Centre. A new data storage unit of 2.3 PB is ready to be implemented once the Run3 will start.

Our group will pay a special attention to the contribution for running the ALICE experiment, fulfilling the on-site or remote shifts, service tasks and service-works, especially related to the ALICE-TPC for whose upgrade our group had an essential contribution: 50% of the TPC OROCs based on GEM technology were assembled and tested in our department.

The educational and outreach activities will ensure the contact with the new generation in order to attract and select new participants in the ALICE experiment.

Project objectives

O1. Analysis of experimental proton-proton collision data obtained with the ALICE detector

The multi-unfolding procedure developed in our group allows a multi-differential analysis in pp and heavy ion collisions. We will continue the previous studies in terms of multi-differential studies of transverse momentum distributions using a multi-dimensional detector response matrix and two-particle correlations for charged particles at 13 TeV. The studies will be extended to identified hadrons and other global event shape observables. Derived quantities from the transverse momentum and correlation distributions are of interest too. The larger statistics expected to be obtained in Run3 and Run4, gives the possibility to extend these studies up to charged particle multiplicity being 2-3 times higher than the present one.
Such results are essential for discriminating between different phenomenological models in the region where the perturbative QCD does not work anymore, aiming a consistent understanding of the $\log(1/x)$-$\log Q^2$ QCD landscape.

O2. Comparison with theoretical models

Understanding the physics revealed by the experimental data multi-differential analyses will be done by comparison with theoretical models. A special attention will be given to the comparison of the dependence of different observables on the collision geometry and energy among different systems and at the LHC energies between pp and A-A. As evidenced in our previous studies, the particle density per unit of rapidity and unit of transverse overlapping area, suggested by QCD inspired models, seems to be the quantity which governs the trends of different observables in A-A and pp collisions. The core-corona interplay will be taken into account.
The comparison with theory estimates will be done either with a toolkit such as RIVET or with in-house installed complex theoretical framework.

O3. Contribution to the in-beam measurements with the ALICE experimental upgraded Device

Our group will pay a special attention for contributing to the efficient running the ALICE experiment, fulfilling the on-site or remote shifts. Service tasks and service-works, especially related to the ALICE-TPC for whose upgrade our group had an essential contribution, 50% of the TPC OROCs based on GEM technology being assembled and tested in our department, and data quality will be considered.

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

Within the present project we aim to maintain and develop the performance of the NIHAM Data Centre, one of the most efficient among Tier2 ALICE GRID centres in the last 10 years.
A new data storage unit of 2.3 PB is ready to be implemented once the Run3 will start.
Dedicated to in-house activities, local analyses, software development or large-scale calculations, NAF facility will be maintained in equally good conditions.

O5. Teaching and outreach activities

Teaching and outreach activities with the aim of attracting and educating of the young generation and popularizing the contribution of Romanian groups to front-end fields of research are the only way to convince the local policy makers that a reasonable financial support pays-off.
The web page of our department will be permanently updated, the HPD Courier will be regularly issued, supervising diploma works, master and PhD theses and lectures at the doctoral school will continue. Summer Student Program will continue to be organized whenever the pandemic restrictions will be over.

4. Main project activities

Following the objectives mentioned above, we will continue and extend our activities along:

- Transverse momentum distributions for charged particles in different regions of the phase space using charged particle multiplicity and event shape observables, for pp collisions at 13 TeV.

- This type of studies will be extended to identified charged particles. This requires the extension of the multi-unfolding procedure to the identified charged particles by increasing its complexity.

- The transverse momentum distributions in different regions of the phase space, the yields and average transverse momenta will be compared with the estimates based on different phenomenological models.

- Differential studies of two-particle correlations as a function of charged particle multiplicity and event shape for pp collisions at $\sqrt{s}$ = 13 TeV. Comparison with theoretical models.

- The analyses will be implemented in the O^2 environment.

- The analysis codes will be implemented in Rivet (Robust Independent Validation of Experiment and Theory) for an efficient use of this tool.

- Analysis notes, presentations at PWG's, published papers and conference presentations will be done.

- The comparison of the dependence of different observables as a function of the collision energy and collision geometry among different systems and at LHC between pp and A-A will be continued in more detail. Published papers by our group members will be the output.

- Complex hybrid models will be installed on the local computing facility for detailed studies of their performance in reproducing the trends of different experimentally measured observables.

- Being part of our active contribution to the ALICE experiment, on-site and remote shifts, will be done. Quality control activities as service task will be committed. Service work will be undertaken.

- Within the present project we aim to maintain and develop the performance of the NIHAM Data Centre, one of the most efficient among Tier2 ALICE GRID centres in the last 10 years. A new data storage unit of 2.3 PB is ready to be implemented once the Run3 will start.

- 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 is of the same importance. Moreover, efforts in the direction of the implementation of a new operating system configuration and modern external computational packages required by different complex codes available, are mandatory.

- Successful previous teaching and outreach activities will be continued with the aim of attracting and educating the young generation and popularize the contribution of Romanian groups to front-

end research, the only way to convince the local authorities that a reasonable funding support pays off. The web page of our department (http://niham.nipne.ro) will be permanently updated. The HPD Courier which will be regularly issued (http://niham.nipne.ro/HPD-Courier_electronc-version.pdf).

Risk Assessment

During this period, the greatest danger in facing difficulties in fulfilling the tasks assumed in the project is a non-predictable multi-annual financial support and evolution of the Covid pandemic situation. This may affect the contributing manpower, opening new positions and contributions to on-site shifts at the experiment and to service-works and service-tasks that require the physical presence at CERN, respectively. A partial solution is provided by the decision of ALCE Collaboration to setup a distributed Regional Operating Centers (ROS), Romania being already included in such a network.

5. Project development and expected results

Obj. Code	Objective description	Milestones	Expected result	Time schedule justification
O1.	We will continue the previous studies in terms of multi-differential studies of p_T distributions using a multi-dimensional detector response matrix and two-particle correlations for charged articles in pp collisions at √s=13 TeV. Such studies will be extended to identified hadrons and other global event shape observables. Similar studies will benefit by far larger statistics expected to be obtained in Run3 and Run4, extending the multiplicity range up to 2-3 times higher charged particle multiplicity density at mid-rapidity than the present one.	1.Transverse momentum distributions, yields, average transverse momentum for charged particles and π, K and p, by applying multi-dimensional cuts in charged particle multiplicity, event shape, rapidity and azimuthal ranges relative to the leading particle. Fits with expressions suggested by phenomenological models.	1. Completion of experimental data analyses. - Internal Notes - Conference contributions - Paper drafts - Papers publication	1. - 2022 final results for pp collisions at √s=7 TeV and preliminary results for pp collisions at √s=13 TeV for charged particles. - 2023 final results for pp collisions at √s=13 TeV for charged particles and start of the analysis for identified particles. - 2024 preliminary results for identified particles in pp collisions at √s=13 TeV. Extension of the analysis to higher charged particle multiplicity using Run3 collected data.
		2. Two-particle correlations as a function of charged particle density at mid-rapidity and event shape.	2. Completion of experimental data analysis. - Internal Notes - Conference	2. - 2022 final results for charged particles in pp collisions at √s=7 TeV and preliminary results

			contributions - Paper drafts - Papers publication	in pp collisions at $\sqrt{s}$=13 TeV - 2023 final results for charged particles in pp collisions at $\sqrt{s}$=13 TeV and preliminary results for π, K and p in pp collisions at $\sqrt{s}$=13 TeV. - 2024 final results for π, K and p for pp collisions at $\sqrt{s}$=13 TeV. Preliminary results for higher charged particle multiplicity using Run3 data
O2.	2. Comparison with different theoretical models. Understanding the physics revealed by the experimental data requires the comparison with phenomenological models estimates. This will be done either with a toolkit such as RIVET or using in-house installed frameworks. Comparison of the dependence of different observables on the collision geometry and collision energy among different systems and at LHC between pp and A-A. Previous studies evidenced that the particle density per unit of rapidity and unit of transverse overlapping area, suggested by QCD inspired models, is the main quantity which governs the trends of different observables in A-A and pp collisions.	1. Implementation of the analyses in the RIVET toolkit. 2. The previous study on the scaling of various physical observables will be continued and scrutinized. 3. Theoretical frameworks will be implemented in-house and comparison with experimental data will be done.	1. Using RIVET will allow a systematic comparison with theoretical calculations done with the existing theoretical phenomenological models for pp collisions. 2. Systematic studies of existing experimental data. - conference presentations - published papers 3. Comparison with experimental data.	1. Correlated with the activities along data analyses 2. Results expected 2022-2024 3. Results expected 2022-2024

O3.	Contribution to the efficient running the ALICE experiment, fulfilling the on-site or remote shifts, service tasks and service-works	Shifts at the ALICE experiment. Service task. Service work.	Contribution to the smooth running of the experiment and data quality.	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. 2. 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 will be maintained.	1. ALICE-GRID support based on NIHAM-Tier2 centre. 2. Maintenance and improvement of NAF - an efficient data centre dedicated to local activities.	1. Years 2022-2024 Permanent activity. 2. Years 2022- 2024 Permanent activity.
O5.	Teaching and outreach activities with the aim of attracting and educating young generation and popularize the contribution of Romanian groups at front fields of research	1. The web page of our department will be permanently updated. 2. The HPD Courier will be regularly issued. 3. Supervising diploma works, master and PhD theses will be supervised and	1. Department web page updated with the latest results obtained in our activities with emphasise on those directly related to our activities within the ALICE Collaboration. 2. Report of the most important results obtained in our department. 3. Diploma works, master and PhD theses, lectures and seminars.	1. Permanent 2. Permanent 3. Permanent

		lectures to the doctoral school will be delivered. 4. Summer Student Program	4. Summer Student Report.	4. Every year, depending on the pandemic evolution

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
- Paper Committee
- ALICE Institutional Reviews
- Analysis Notes
- Continuous update of the NIHAM web pages
- Development and operation in good security conditions of our Data Centres – NIHAM and NAF
- 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, service task and work: 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 the ALICE upgrade activities by 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 in the construction phase of the ALICE experiment.

Based on the excellent infrastructure of our department and the know-how built up during the activities mentioned above, we developed several highly performing prototypes of TRD and RPC detectors, the associated front-end electronics at the chip level and a triggerless 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 guarantee a visible and competitive participation at future upgrades or setting up of large experiments within international collaborations like ALICE and CBM.

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 following years.

Hardware and software structures of distributed computing architecture 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 bachelor, master and PhD theses. They will become highly qualified specialists, extremely useful in various branches of activities.

During the last years, several bachelor theses, 7 master theses and 3 PhD theses were finalized and a few others 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 Romanian and foreign 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.