CERN Research Programme / Experiment:5.9/5.9.2/CERN-RO/ALICE

Annual Summary Document[1]

Year: 2025

Months : 12

Project Title: IFIN-HH Contribution to the ALICE experiment at CERN/RONIPALICE

Project Work Plan (according to the contract)

Stage: II. Participation and specific contributions of IFIN-HH to the ALICE experiment in 2025

Activities:

II. 1. Multi-differential selection in charged particle multiplicity, event shape and Δη-Δφ relative to the leading particle in obtaining transverse momentum distributions using a multi-dimensional detector response matrix, for identified hadrons will be done. Comparison between the two unfolding procedures developed in-house

II. 2. Multi-differential selection in charged particle multiplicity, event shape and Δη- Δφ relative to the leading particle in obtaining two particle correlations for identified hadrons will be done

II. 3. New global event shape observables more effective in selecting close to isotropic events, will be analyzed both with phenomenological models and on ALICE data.

II. 4. Implementation of phenomenological models and comparison of the dependence of different observables on the collision energy and collision geometry between different A-A systems and at LHC energies, between pp and A-A will be done.

II. 5. In beam Run Manager, Shift Leader roles and shifts will be performed.

II. 6. Upgrade of NIHAM Data Centre and its maintenance will be done continuously

II. 7. Teaching and outreach activities and Summer Student Programme will be continued.

II. 8. Preliminary results on time resolution of RPC will be obtained

[1] ? Please fill in all the required items and do not alter the template

Annual Summary Document

Summary / Cover Page

- **Group list:**

- Senior researcher III Dr. Cristian Andrei (physicist) - team leader
- Senior researcher III Dr. Oana Andrei (physicist)
- Senior researcher III Daniel Bartos (physicist)
- Senior researcher II Dr. Alexandru Bercuci (physicist)
- Senior researcher II Gheorghe Caragheorgheopol (electronics engineer)
- Senior researcher II Dr. Vasile Catanescu (electronics engineer)
- Senior researcher II Viorel Duta (mechanical engineer)
- Senior researcher II Dr. Iosif Legrand (physicist)
- Senior researcher III Dr. Andrei Ionut Herghelegiu (physicist)
- Senior researcher II Dr. Mariana Petris (physicist)
- Prof. Dr. Alexandrina Petrovici (physicist)
- Prof. Dr. Mihai Petrovici (physicist)
- Senior researcher I Dr. Amalia Pop (physicist)
- Senior engineer II Dr. Laura Radulescu (mechanical engineer)
- Computing coordinator Claudiu Schiaua (physicist)
- Researcher Dr. Madalina Tarzila (physicist)
- Engineer Naziru Andrei Bogdan
- Research assistant Iulian Florin Andreicovici
- Research assistant Florin Daniel Gila
- Chemistry-Physics Assistant Madalina State
- Technician Valerica Aprodu
- Technician Andrei Radu
- Technician George Stoian
- Technician Constanta Dinca
- Financial coordinator Georgiana Bagu (economist)
- Lathe and milling machine operator, Gheorghe Dima (mechanical worker)

- **Specific scientific focus of group :**

The dependence of p_T distributions and two-particle correlations of charged and identified hadrons on multiplicity, event shape, $\Delta\phi$ and $\Delta\eta$ relative to the leading particle in pp collisions at LHC energies - subject proposed by our group within ALICE Spectra-PAG PWG-LF since 2009 (https://twiki.cern.ch/twiki/bin/view/ALICE/PWGLFPAGSPECTRAMultiplicityEventShapePP7). The aim is to evidence collective type phenomena in high charged particle multiplicity and close to azimuthal isotropy events in pp collisions at LHC energies and understand their origin as well as their similarities and differences relative to A-A collisions.

The detailed systematics based on existing experimental data in terms of energy density, entropy density, their correlations, centrality and collision energy dependence is another subject followed by us.

- **Highlights of accomplishments in the last year:**

Physics:

- Results within O^2 environment in terms of transverse momentum spectra and correlations obtained for isotropic and jetty events conditioned with multiplicity and *modified Fox-Wolfram moments* (FWM) - *Master Thesis*

- Features of strangeness production in pp and heavy-ion collisions, A. Pop and M. Petrovici, Phys.

Rev. C 111, 014908, DOI: https://doi.org/10.1103/PhysRevC.111.014908
- We compared our previous systematics on suppression with the new results in ALICE for O-O.
- The *event isotropy* event shape variable has been investigated with Pythia8
- Co-authors to 35 ALICE published papers
- Contribution to 4 conference presentations on behalf of ALICE Collaboration
- 1 Internal review Committee, 2 Analysis Review Committees and 1 institutional review

Computing:

NIHAM Data Centre was one of the most efficient Tier2s ALICE GRID centres.
NIHAM Analysis Facility (NAF) is efficiently managed and running.

Experiment Operation:

Our group participated in running the ALICE experiment by performing Shift Leader (13), QC (24), DCS (12) and ECS (2) shifts – 93% of the due quota.
We have assured the role of ALICE Training Coordinator for the present year (will also continue for the next year).
Service work activities were done as Training Coordinator and via two Run Manager mandates (0.833 FTE).

Outreach:

Our group has maintained and significantly expanded its involvement in the DUROCERN exhibition
The ALICE brochure, offering an attractive and accessible overview of the experiment was translated and adapted to Romanian

Detailed report, highlighting the results obtained during the reporting period and the objectives fulfillment, conclusions;

2. Scientific goals

A Large Ion Collider Experiment (ALICE) at CERN was designed to explore the ultra-dense energy region of the Phase Diagram of Quantum Chromodynamics (QCD), far above the critical temperature where a transition to a deconfined matter, formed by its basic constituents — quarks and gluons — is predicted to occur in nucleus–nucleus collisions. As a general-purpose heavy-ion experiment, ALICE is devised so that, in addition to heavy systems, collisions of lighter combinations, p–A and pp, can also be studied. Far from being only a benchmark for A–A collisions, the pp and p–A collisions have been shown to reveal genuine physical phenomena that have aroused great interest as soon as similarities with A–A collisions were highlighted under certain conditions. Thus, a close-to-equilibrium deconfined initial state could be expected at very high charged-particle multiplicity in very high energy pp collisions.

As part of the ALICE Collaboration, our group had a significant contribution to the construction of the TRD and TPC-OROC (based on GEM technology), as well as to activities of general interest for the collaboration. The final goal was realized by proposing and addressing physics topics related to collective-type phenomena in pp collisions, the core–corona relative contribution to different observables, similarities between pp and A–A collisions, geometrical scaling of 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.

For pp collisions at $\sqrt{s}$ = 13 TeV, we will extend our previous studies in terms of a multi-differential selection in charged-particle multiplicity, event shape, and $\Delta\eta$–$\Delta\varphi$ relative to the leading particle, obtaining transverse momentum distributions using a multi-dimensional detector response matrix and two-particle correlations, including identified hadrons. We will also explore other global event-shape observables more effective in selecting nearly isotropic events (modified Fox–Wolfram moments and event isotropy). Multi-differential studies are a very challenging task; therefore, we will continuously compare the results obtained with different unfolding procedures developed by us and with other similar analyses to validate the obtained results. The extended multiplicity coverage from Run 3 and Run 4 will enable more systematic studies based on multi-differential analyses. The analyses will be implemented in

the O2 environment, and comparisons with previous analyses will be performed. A detailed comparison with theoretical models can constrain their parameters and lead to a clearer understanding of the underlying physics. The description of the p_T distributions and derived quantities, such as yields and average transverse momenta, based on new fit formulas derived from phenomenological models, will help in understanding and systematizing the obtained results. The aim is to prepare paper drafts to be published within the ALICE Collaboration.

Special attention will be given to comparing the dependence of various observables on collision energy and geometry between different systems and, at LHC energies, between pp and A–A. The existing experimental data and the predictions of modern phenomenological models will constitute the basis for an attempt to systematize the observed phenomena and to explore the performance of several observables. Theoretical model frameworks implemented in-house will serve as useful tools for understanding the physics behind the observed experimental trends. The aim is also to prepare paper drafts to be published by our group members.

Having in mind detector developments for future experiments at the LHC and building on our long experience, R&D activities will be carried out to improve the time resolution of high count-rate RPC detectors that can be used as forward detectors with large pseudorapidity coverage. The ALICE Collaboration has embarked on the ambitious path of developing ALICE 3 as a fully silicon-based experiment. Building on our group's experience and extensive infrastructure, we are exploring new activities that would allow us to contribute to this effort. These initiatives will enable us to remain involved in detector construction, while ensuring the preservation of our know-how and the effective use of our existing infrastructure. At the same time, we are pursuing R&D activities aimed at testing the performance of MSMGRPCs using the latest generation of high-gain, low-noise preamplifiers and pico-TDCs, which could serve as valuable input for future experimental projects.

Our NIHAM Data Centre has been, for more than 10 years, among the most efficient Tier-2 ALICE GRID centres. Within the present project, we aim to maintain and further develop the performance of the NIHAM Data Centre in terms of storage capacity and computing power.

Our group will continue to pay special attention to contributing to the operation of the ALICE experiment — as Run Manager, Shift Leader, or by fulfilling on-site shifts — to service tasks and service work, as well as to active participation in the ALICE publishing activity.

To attract staff inspired by our activities, educational efforts from the bachelor's level to the doctorate, as well as outreach activities, will remain a constant priority — especially now that the Summer Student Program has been revived and the Romanian Science Gateway has taken shape.

3. Scientific achievements in the last three years corresponding to the actual program funding

Transverse momentum distributions as a function of charged-particle multiplicity and event shape in pp collisions

Studies of hadron transverse momentum distributions as a function of charged-particle multiplicity and event shape in pp collisions — one of the most interesting phenomena to be studied in detail at LHC energies — have been performed and extended toward multi-differential analyses. The implementation of an unfolding approach based on a multi-dimensional detector response matrix is a complex task that allowed us to obtain transverse momentum distributions simultaneously conditioned on multiplicity, sphericity, and the azimuthal region relative to the leading particle (same-side, away-side, and intermediate). Preliminary comparisons between the phenomenological models PYTHIA and EPOS, available in the ALICE database, have been made. An Internal Note, "Charged particle transverse momentum spectra as a function of unfolded charged particle multiplicity, event sphericity and azimuthal angle relative to the leading particle in pp collisions at $\sqrt{s}$ = 7 TeV"
(https://indico.cern.ch/event/1056062/contributions/4438294/attachments/2275968/3866416/CAndrei_Spectra_05072021.pdf) was released. Similar studies for pp collisions at $\sqrt{s}$ = 13 TeV were also performed.

Two-particle correlations as a function of charged-particle multiplicity and event shape in pp collisions
A complementary analysis based on correlation studies was completed and also formed the subject of a doctoral thesis. Angular correlations of charged-particle pairs with $1 \leq p_T \leq 2$ GeV/c within $|\eta| < 0.8$, measured with the ALICE detector in pp collisions at $\sqrt{s} = 7$ TeV, were investigated. A multi-dimensional analysis was carried out including the dependence on event sphericity and charged-particle multiplicity. Similar studies were performed using several Monte Carlo event generators available in the ALICE database: PYTHIA, PHOJET, and EPOS. The comparison with model predictions indicates that the Monte Carlo generators do not fully reproduce the data. This type of analysis was extended to pp collisions at $\sqrt{s} = 13$ TeV, and a comparison with MC models and $\sqrt{s} = 7$ TeV results was completed. A comparative analysis has been carried out between our results and those published by the ALICE Collaboration in Phys. Rev. Lett. 132, 172302 (2024). The two-particle correlation measurements in pp collisions at $\sqrt{s} = 13$ TeV obtained by our group are consistent, within the uncertainties, with the corresponding published results. The evaluation of systematic uncertainties and detailed more comparisons with other published results are ongoing steps toward publication.

Systematic survey of published experimental results
Following a systematic survey of published experimental results from AGS, SPS, RHIC, and LHC, data were analyzed to study the systematics of heavy-ion collision observables as a function of energy. These studies were published in several papers and presented at international conferences:

- Phys. Rev. C 107, 034913 (2023): "Features of strangeness production in pp and heavy-ion collisions and study of similarity between pp and A–A collisions in terms of $\langle p_T \rangle / \langle dN/dy \rangle / S_\perp$ dependence on collision energy," A. Pop, M. Petrovici.
- Oral presentation: Features of strangeness production in pp and heavy-ion collisions, EuNPC 2022, Santiago de Compostela.
- Invited talk: What is really new at LHC energies?, Carpathian Summer School of Physics 2023, Sinaia.
- QCD Challenges from pp to AA, Münster, Germany, October 2024 (M. Petrovici).

In the last year the group's activity focused on:

Two-particle correlations as a function of charged-particle multiplicity and event shape in pp collisions
In the last year, the focus of our work has been the migration and optimization of the existing analysis software from the AliRoot environment to the ALICE O2 framework. This process required a complete adaptation of the analysis workflow to the new data model and processing paradigm introduced by O2. Specifically, the event and track selection logic, histogram management, and event-mixing routines were rewritten to conform to the O2 APIs and to exploit its modular task-based structure.
The core physics objective remains the investigation of correlation structures observed in two-particle angular correlations of charged particles in pp collisions. In particular, we study pairs of particles with a pseudorapidity separation of $1.25 < |\Delta\eta| < 1.5$ and transverse momentum $1 \leq p_T \leq 2$ GeV/c, as a function of two key global observables: multiplicity and transverse sphericity. This multidifferential approach allows us to probe the interplay between event shape and collective-like behavior in small systems. The transition to O2 provided the opportunity to extend the study to Run 3 pp data at $\sqrt{s} = 13$ TeV, taking advantage of higher statistics and improved detector performance. New event and track selection criteria were designed and implemented to reflect the updated detector configurations and data quality specific to Run 3.

Evaluation of the performance of the modified Fox–Wolfram moments (FWM)
The main objective of this analysis is to implement in O2Physics a set of event-shape variables known as Fox–Wolfram moments. These observables provide a method to separate soft, azimuthally isotropic events from those influenced by hard jet-like structures, due to their sensitivity to subtle features of event topology. Using the two-particle correlation method in $\Delta\eta$ and $\Delta\varphi$ relative to the leading particle, the performance of the Fox–Wolfram moments was evaluated across three global-track multiplicity intervals: 14–24, 25–35, and 36–100. The correlation functions revealed that the projection in $\Delta\varphi$ forms a relatively

flat plateau for isotropic events selected based on the modified Fox–Wolfram moments. This identification of azimuthally uniform events was confirmed by the η–φ representation of several candidate isotropic events.
With increasing multiplicity, events exhibit a more pronounced isotropic character, while jet-like correlations gradually decrease in amplitude. The distributions of associated particles (relative to the leading particle) were plotted across different multiplicity ranges, considering three topological Δφ regions (near, transverse/middle, and away) from the JETTY events correlation function, as well as for isotropic (ISO) events. Furthermore, the p_T^{assoc} spectra revealed clear differences between ISO events and those from the transverse underlying-event region, the latter showing significant jet contamination. Azimuthally isotropic events predominantly contain particles with $p_T < 2–3$ GeV/c, corresponding to the soft component. The ratio of the ISO p_T^{assoc} spectrum to the minimum-bias p_T spectrum shows that the p_T tails extend to higher values with increasing multiplicity. Ratios of the away-side to near-side spectra emphasize variations in jet activity across multiplicity bins.
A robust unfolding method is currently being developed, using a multidimensional detector response matrix that accounts for charged-particle multiplicity and eight Fox–Wolfram moments, supported by extensive cross-checks to ensure model independence. An extended analysis is underway, exploring different p_T^{lead} and p_T^{assoc} ranges in the correlation functions, as well as various pseudorapidity intervals. Extending this study to identified hadrons (PID) is crucial to draw clear conclusions about deconfinement and collective expansion in pp collisions at LHC energies. A Master Thesis on this topic was successfully defended.

Systematic survey of published experimental results
We also compared our previous systematics on suppression (M. Petrovici, A. Lindner, A. Pop, Phys. Rev. C 103, 034903) for heavy ions with the new ALICE results for O–O collisions, finding good agreement.

A new event-shape variable
A new event-shape variable, event isotropy, used previously in ATLAS, has been investigated with PYTHIA 8 in terms of correlations with other event-shape observables and spectra as a function of multiplicity and event isotropy.

Preliminary results on time resolution of RPC
A direct flow MSMGRPC (Multi-Gap, Multi-Strip Resistive Plate Chamber) prototype based on discrete spacers of 170 um thickness and symmetric structure of 2 x 5 gas gaps was installed in an experimental setup at the SIS18 accelerator of GSI Darmstadt. The chamber was flushed directly through the gas gaps with a gas mixture of 97.5%C 2H2F 4 + 2.5%SF6. The tests were performed using reaction products of a 197Au beam of 1.2A GeV incident on a Au target. For the measurement of the efficiency and time resolution a four station tracking setup was defined by integration with other three station of MGRPCs with strip readout. The measured time resolution was of 53 +/- 2 ps and the efficiency overpassed 95% at an applied voltage corresponding to an electric field in the gas gap of 141 kV/cm. The in-beam tests of the direct flow prototypes showed the performance of this architecture in real experimental conditions.

Collaboration common-interest activities
In the last year, we have increased our participation in Collaboration common-interest activities, especially in experiment operations. We have fulfilled the role of Training Coordinator (which will continue next year), took two Run Manager mandates, and completed 93% of our shift quota (13 Shift Leader, 24 QC, 12 DCS, and 2 ECS shifts). This amounts to 0.833 FTE in terms of Service Work. We are also exploring additional ways to contribute to the Service Work through our long-standing involvement in the ALICE GRID and a group member's work within the Online–Offline (O2) System. We submitted a candidacy for the position of Collaboration Board representative to the Service Work Board. In addition, we contributed to the publication efforts by participating in two Analysis Review Committees (including a fast-track analysis on the new O–O and Ne–Ne data from this summer), one Internal Review Committee, and one Institutional Review.

The NIHAM Data Centre has remained one of the most efficient among Tier-2 ALICE GRID centres.

Publications list, conference presentations, list of attended meetings and list of deliverables covered in the present report

5. Papers and talks in last year

- A. Pop and M. Petrovici, Phys. Rev. Phys. Rev. C 111, 014908, DOI: https://doi.org/10.1103/PhysRevC.111.014908
- "ALICE Status Report", Cristian Andrei on behalf of the ALICE Collaboration, 162nd LHCC Meeting – Open Session

GRID (computation and storage) support:
- Co-authors to 35 ALICE published papers

Conferences and ALICE PWG presentations:
- Contribution to 4 conference presentations on behalf of ALICE Collaboration

Other activities and Budget

6. Further group activities

- *Outreach*

  Following the ISAB recommendation to continue and strengthen outreach activities, the ALICE–IFIN group has maintained and significantly expanded its involvement in the DUROCERN exhibition.

  In 2025, the exhibition entered its first full year of operation following its inauguration at the end of 2024. The exhibition space dedicated to the ALICE–IFIN group's contribution to the ALICE experiment has already welcomed more than 600 visitors - primarily high school and secondary school students accompanied by their teachers, as well as a notable number of university students. Visitors came from both public and private educational institutions, with some groups traveling considerable distances specifically to visit DUROCERN - such as students from the Clisura Dunării Technological High School (Moldova Nouă) and the Faculty of Applied Sciences and Engineering, Ovidius University of Constanța.

  The exhibition also hosted participants of the Carpathian Summer School of Physics 2025 and students from the Măgurele Science and Technology Summer School. During their visit, participants learned about CERN's mission, structure, and global impact, as well as the important contributions of Romanian researchers to advancing fundamental knowledge about the Universe. They had the opportunity to engage directly with researchers involved in the ALICE experiment and to explore detector components (TRD, TPC, RPC) and their associated electronics, thus gaining a deeper understanding of how radiation and charged particles interact with matter and how these detection systems operate.

  Additionally, the ALICE brochure - offering an attractive and accessible overview of the experiment - was translated and adapted to Romanian.

  Most importantly, visitors were able to appreciate the tangible impact of fundamental research on everyday technologies and society. Going forward, the ALICE–IFIN group will continue to support and develop the DUROCERN exhibition as a central outreach platform, with the objective of further increasing visibility, educational engagement, and scientific awareness among students, educators, and the general public.

- *1 Master Thesis*
- *Poster for Summer student Programme and the effective implementation of this internship program for students*