Group Annual Summary Report

- **Project team :**

- Prof. Dr. Mihai Petrovici (physicist) – team leader
- Senior researcher III Dr. Cristian Andrei (physicist)
- 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)
- Master student Daniel-Ion Dorobantu
- Senior researcher II Viorel Duta (mechanical engineer)
- PhD student Amelia Lindner (physicist)
- PhD student Adrian Sorin Mare (physicist)
- Senior researcher II Dr. Mariana Petris (physicist)
- Prof. Dr. Alexandrina Petrovici (physicist)
- Senior researcher I Dr. Amalia Pop (physicist)
- Senior engineer II Dr. Laura Radulescu (mechanical engineer)
- Computing coordinator Claudiu Schiaua (physicist)
- Dr. Madalina Tarzila (physicist)
- Technician Valerica Aprodu
- Technician Lucia Prodan
- Technician Andrei Radu
- Technician George Stoian
- Technician Constanta Dinca
- Financial coordinator Georgiana Rosu (economist)
- Lathe and milling machine operator, Gheorghe Dima (mechanical worker)

- **Specific scientific focus of the group :**

Dependence of p_T distributions and two-particle correlations of charged and identified hadrons on multiplicity, event shape, $\Delta\varphi$ 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.

- Highlights of accomplishments in the last year:

Physics:

* Charged particles p_T spectra as a function of charged particle multiplicity, sphericity and $\Delta\varphi$ relative to the leading particle in pp collisions at $\sqrt{s}$ = 7 TeV based on a multi-dimensional unfolding procedure.

- 2 Spectra PAG presentations - paper proposal:
https://indico.cern.ch/event/1056062/contributions/4438294/attachments/2275968/3866416/CAndrei_Spectra_05072021.pdf

https://indico.cern.ch/event/1060729/

- 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

- Systematic errors estimate: in progress

* Studies of two charged particles correlations as a function of multiplicity and sphericity in pp collisions at $\sqrt{s}$ = 7 TeV.

- PhD Thesis
- Internal Note ready
- Systematic errors estimate: in progress

* Considerations on the suppression of charged particles and π^0 in high energy heavy ion collisions
M.Petrovici, A.Lindner, A.Pop
Phys. Rev. C 103, 034903 (2021)

* Strange and multi-strange hadrons geometrical scaling
- poster at EPS-HEP 2021
https://indico.desy.de/event/28202/contributions/105848/

* Light flavor hadrons geometrical scaling
- oral presentation - PANIC 2021
https://indico.lip.pt/event/592/contributions/3315/attachments/2905/4451/PANIC2021-ALindner.pdf

* Studies on the core-corona interplay at LHC and RHIC energies based on

experimental data and Glauber MC estimates: preliminary paper manuscript.

* 2 institutional reviews for 2 ALICE papers were done

* Co-authors to 23 ALICE published papers

* Contribution to 7 conference presentations

* 18 EPN/PDP and QC remote ALICE shifts at the Romanian ROS

Computing:

NIHAM continued to be one of the most efficient Tier2s ALICE GRID centers.
Done jobs: $5.4 \cdot 10^6$, i.e. 6.1 % of total Tier2 ALICE contribution
CPU: 8.7 Mhours, i.e. 3.3 % of total Tier2 ALICE contribution

A data storage unit of 2.3 PB - to be implemented during Run3.
New UPS stations of ~120 KVA - installed.
Procurement of a new cooling unit in progress
NAF is efficiently managed and running

2. Scientific goals

A Large Ion Collider Experiment (ALICE) at CERN as a general-purpose heavy-ion experiment 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, i.e. quarks and gluons, is predicted to happen in nucleus-nucleus collisions. In addition to heavy systems, the ALICE experiment is devised such that collisions of lighter combinations, p-A and pp, can be also studied. These studies turned out not only to provide reference data for the A–A collisions but a number of genuine pp physics phenomena became of primary interest once the new data from the first experiments at $\sqrt{s}$=7 TeV were available. Multiparton interactions and re-scatterings, following the initial phase of high density colour electromagnetic fields developed between the two receding colliding partners, could contribute to a large energy transfer in a collision volume of proton size and a close to equilibrium deconfined initial state could be expected at very high charged particle multiplicity in very high energy pp collisions. A piece of matter of proton size, with a radius of few times larger than the mean free path of the constituents of a deconfined medium, expands hydrodynamically once the energy transfer is significantly large.
The results obtained in Run1 at which our group had a significant contribution are supported by the results obtained in Run2 at $\sqrt{s}$=13 TeV. Another important aspect worth to be studied is the possibility to discriminate between hard and soft processes. Preliminary studies performed by us along the possibility to select events close to azimuthal isotropy using global event shape observables like Directivity, Sphericity, Thrust or Fox-Wolfram moments have shown their performance in selecting event shapes. Then, by selecting different regions in $\Delta\varphi$ and $\Delta\eta$ relative to the leading particle

the contribution of multiparton interactions and re-scattering is further enhanced. Although the correlation of each of these global event shape variables with multiplicity is rather good, at the highest multiplicities, the global event shape variables have a rather broad distribution for a given charged particle multiplicity.
Correlation techniques are powerful tools which can provide essential information on the nature and dynamics of the medium produced in ultra-relativistic heavy-ion collisions.
The procedure is to select a sample of high p_T particles, referred to as leading particles or "triggers" and then to study the correlation between the leading particle and all other particles in the same event, called associated particles. The first studies of two-particle correlation functions in the highest-multiplicity pp collisions at the LHC performed by the CMS Collaboration showed an enhanced production of pairs of particles at $|\Delta\varphi| \sim 0$, extending over a wide range in $\Delta\eta$, a feature frequently referred to as a "ridge". These structures can be quantified by azimuthal Fourier coefficients, mostly of second (v2) and third (v3) order. Many of the physics mechanisms proposed to explain the pp ridge include multiparton interactions, parton saturation and collective expansion of the final state.

Such information plays a crucial role in understanding the features observed in p-Pb and Pb-Pb collisions at LHC energies. Therefore, a special attention is given to the comparison of the dependence of different observables as a function of the collision violence among the three systems.

In order to extract signals originating from multiparticle interactions it is mandatory to remove, as much as possible, based on experimental information, the contribution coming from single collisions in case of Pb-Pb and p-Pb or low density hadronic matter overlap in case of pp, known as corona contribution. Systematic studies on core-corona interplay and the dependence on the centrality of the extracted core contribution for different observables will give the possibility to evidence different types of scaling suggested by QCD inspired models.

In order to increase the ALICE capability for running in high luminosity conditions foreseen to be the case in Run3, a major upgrade program of the experiment was finalized and undergoes the commissioning phase, our team being involved in the ALICE-TPC upgrade program, assembling and testing 50% of the ALICE-TPC OROCs based on GEM technology.
Our group contributes to the smooth operation of the ALICE experiment.
The amount of data will obviously increase and therefore a special attention will be given to the computing power and storage capacity delivered by the worldwide distributed ALICE-GRID infrastructure.

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

Studies of hadrons transverse momentum distributions as a function of charged particle multiplicity and event shape in pp collisions, which turned out to be one of the most interesting phenomena to be studied in detail at LHC energies, have been done.
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).
These studies were extended towards multi-differential analyses. The implementation of an unfolding approach based on a multi-dimensional detector response matrix was a complex task which allowed to obtain transverse momentum distributions simultaneously conditioned on multiplicity, sphericity and within the same-side, away-side and in between relative to the leading particle. Preliminary comparisons with phenomenological models have been done. The accuracy of the method was tested by successfully comparing global observables like the average transverse momentum as a function of multiplicity and MB p_T spectrum with the ones obtained in other analyses within ALICE Collaboration.
A complementary analysis based on correlation studies was addressed and finalized also being 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 at LHC in proton-proton collisions of $\sqrt{s}$=7 TeV were studied. A multi-dimensional analysis was performed including the dependence on the sphericity as event shape observable as well as the the charged particle multiplicity. The same studies were performed using several Monte Carlo event generators: PYTHIA, PHOJET and EPOS. The comparison with the predictions of the models indicates that Monte Carlo models do not fully reproduce the data.
The first steps were done towards extending these type of analyses to proton-proton collisions at $\sqrt{s}$ = 13 TeV.
After a systematic survey of published experimental results related to charged particle suppression obtained at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven for Au-Au (Cu-Cu) collisions and at the Large Hadron Collider (LHC) at CERN for Pb-Pb (Xe-Xe) collisions, considerations based on phenomenological models were done. The results were published in Phys. Rev. C 103, 034903 (2021).
In the study performed for a wide range of energies measured at the Relativistic Heavy Ion Collider (RHIC) and at the Large Hadron Collider (LHC), it has been shown that observables characteristic for the dynamics of the collision scale rather well as a function of $\sqrt{(dN/dy)/S_\perp}$, the relevant scale in the gluon saturation picture, the results being published in Phys. Rev. C. The results of the extended study to strange and multi-strange hadrons, for both proton-proton (pp) and heavy-ion (A-A) collision systems were reported at two conferences.
The core-corona interplay was analyzed for observables obtained from the available experimental data on a wide range of incident energies and the results were gathered in a paper draft.
The infrastructure of our department, expertise and know-how allowed us to finalize the assembly and testing of 50% of the outer readout chambers (OROCs) based on GEM technology. The 20 OROCs assembled and tested in our department were transported to CERN and installed in the TPC.
Our group participated in the commissiong of the ALICE experiment by performing EPN/PDP and QC remote shifts using the Romanian-ROS.
NIHAM Data Centre was permanently one of the most efficient among Tier2s ALICE GRID centres. Several maintenance and upgrade activities were done in order to keep its performance at the highest standards.

In the last year the group activity focused on:

- ***<u>Experimental data analysis and interpretation</u>:***

  - The multi-differential analysis in terms of p_T distributions simultaneously conditioned on multiplicity, sphericity and within same-side, away-side and in between relative to the leading particle was continued by using an unfolding procedure based on a multi-dimensional detector response matrix. By applying this procedure charged particles p_T spectra as a function of charged particle multiplicity and sphericity in pp collisions at $\sqrt{s}$=7 TeV were obtained and comparison with PYTHI6 (Perugia0), PHOJET and EPOS have been done. The results were presented in the ALICE Spectra PAG and the comparison with the published results in terms of MB p_T distribution and $\langle p_T \rangle$ as a function of multiplicity confirms the accuracy of the present analysis. The corresponding Internal Note has been released. Systematic errors estimation is in progress. The aim is to publish an ALICE paper.

  - The two-particle correlation studies as a function of charged particle multiplicity and event shape selection based on sphericity for pp collisions at $\sqrt{s}$=7 TeV were finalized. The estimation of the systematic errors is about to be completed.

  - Preliminary tests of the analysis code for 13 TeV pp.

  - Experimental results related to charged particle suppression obtained at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven for Au-Au (Cu-Cu) collisions and at the Large Hadron Collider (LHC) at CERN for Pb-Pb (Xe-Xe) collisions were compiled in terms of R_{AA} , R_{CP} and the ratio of the p_T spectra for each centrality to the pp minimum bias or to the peripheral one, each of them normalized with the corresponding charged particle density $dN_{ch}/d\eta$, namely the newly introduced quantities R^{N}_{AA} and R^{N}_{CP}, as a function of N_{part} and $dN_{ch}/d\eta$. The studies are focused on a p_T range in the region of maximum suppression evidenced in the experiments. The scaling as a function of N_{part} and $dN_{ch}/d\eta$ is discussed. The core contribution to R_{AA} is also presented. Different considerations based on phenomenological pictures are done.
    The results were published in Phys. Rev. C 103, 034903 (2021)

  - Geometrical scaling for strange and multi-strange hadrons in pp and A-A collisions at relativistic energies.
    Color Glass Condensate is a powerful theoretical tool that is able to describe the dynamical properties of partons in the QCD non-perturbative regime, characterized by strong color fields and high parton density. A previous study, performed for a wide range of energies measured at the Relativistic Heavy Ion Collider (RHIC) and at the Large Hadron Collider (LHC), has shown that observables characteristic for the dynamics of the collision, i.e. the mean transverse momentum ($\langle p_T \rangle$), the slope of the $\langle p_T \rangle$ dependence on the mass of the particles and the average transverse flow velocity obtained from the simultaneous fits of the p_T spectra of the detected particles with the Boltzmann-Gibbs Blast Wave expression, scale rather well as a function of the square root of the ratio of the

particle density over unit of rapidity and the overlapping area of the colliding partners ($\sqrt{(dN/dy)}/S_{perp}$), the relevant scale in the gluon saturation picture.
This study was extended to strange and multi-strange hadrons, for both proton-proton (pp) and heavy-ion (A-A) collision systems. The dependence of the $<p_T>$ and its slope as a function of particle mass on $\sqrt{(dN/dy)}/S_{perp}$, for K_0^S, Λ, Ξ^- and Ω^-, are presented. The comparison with the results obtained for non-strange light flavor hadrons were discussed. Results were presented at EPS-HEP2021 and PANIC2021 as poster and oral presentation, respectively.

- The investigations of core-corona interplay in heavy ion collisions, in a systematic study on a wide range of incident energies, was continued. Different observables attributed to the core contribution for Pb-Pb at LHC and Au-Au at RHIC collisions, have been obtained using a parton Monte Carlo Glauber model and available experimental data. A paper draft was configured and will be submitted for publication.

- Experimental measurements with the ALICE detector.
As the preparation of Run3 started in the middle of the year by detector commissioning and a pilot beam run, our group was part of the remote operation of the ALICE experiment at the Romanian-ROS. The EPN/PDP and QC courses, training sessions were followed by 18 remote shifts done by members of our group.

- ***GRID activities***

- NIHAM Data Centre continued to be one of the most efficient among Tier2s ALICE GRID centres. A new data storage unit of 2.3 PB is ready to be implemented once the Run3 will start.
A new UPS stations of ~120 KVA was installed.
A cooling unit is on the way to be purchased.
NAF is efficiently managed and was intensively used by our group members.

4. Group members

Name	Physics & Analysis (%)	R&D (%)	Detector operation (%)	Detector construction (%)	Infrastructure Planning Financial, Outreach Contracts (%)
Mihai Petrovici	75				10
Daniel Bartos		20			15
Alexandru Bercuci	30				12
Gheorghe Caragheorgheopol		20			18
Vasile Catanescu		20			11
Viorel Duta		10			40

Mariana Petris		30			12
Alexandrina Petrovici	10				12
Amalia Pop	80				
Laura Radulescu					10
Claudiu Schiaua					70
Andrei Cristian	100				
Andrei Oana					
Madalina Tarzila	100				
Amelia Lindner	100				
Adrian Mare	10				10
Daniel-Ion Dorobantu					
Valerica Aprodu		25			5
Lucica Prodan		25			15
Andrei Radu		20			10
George Stoian					
Constanta Dinca		20			20
Gheorghe Dima					30
Georgiana Rosu					30
Total FTE	**5.75**	**1.90**			**2.60**

- List of PhD/Master students and current position/job in the institution.

Name		Present status
Amelia Lindner	PhD student	Research assistant Temporary employment
Adrian Mare	PhD student	Research assistant Temporary employment
Daniel-Ion Dorobantu	Master student	Research assistant Temporary employment

5. Papers and talks in last year

Papers:

- Considerations on the suppression of charged particles and π0 in high energy heavy ion collisions
M.Petrovici, A. Lindner, A. Pop

Phys. Rev. C 103, 034903 (2021)

GRID (computation and storage) support:

- Co-authors to 23 ALICE published papers

Conferences and ALICE PWG presentations:

- Geometrical scaling for strange and multi-strange hadrons in pp and A-A collisions at relativistic energies
Poster at EPS-HEP2021
https://indico.desy.de/event/28202/contributions/105848/

- Geometrical scaling for light flavor hadrons
Oral presentation at the 22 nd Particles and Nuclei International Conference – PANIC 2021
https://indico.lip.pt/event/592/contributions/3315/

-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 √s = 7 TeV
Spectra weekly meeting, 5 July 2021
https://indico.cern.ch/event/1056062/

- 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 √s = 7 TeV - Crosschecks
Spectra weekly meeting,26 July 2021
https://indico.cern.ch/event/1060729/

- Contribution to 7 conference presentations on behalf of ALICE Collaboration

6. Further group activities

- ***Collaborations, local synergies, education, outreach***

R&D activities
- Addendum of the CBM-TRD TDR was finalized and sent for EEC of FAIR for

the evaluation
- RPC aging studies in high irradiation dose - paper sent to NIM
- 1 new RPC prototype with a direct flow
- Readout chain and free streaming data flow, compatible with CBM
- All implemented and successfully operated in mCBM

Teaching:

- 1 PhD thesis
- 1 diploma thesis

Outreach:

- visit of the Prime Minister adviser
- visit of Research and Education Commission of the Romanian Senate
- visit of the Charge d'Affaires ad-interim of American Embassy in Romania
- visit of the vice Prime Minister
- German bachelor students visit
- visit of representants of EUROGAMs consortium and Director of ERIC-ELI
- a movie related to the ALICE-TPC upgrade finalized
- a movie for "Researchers Night" event - finalized
- more details could be seen in:
https://niham.nipne.ro
https://www.facebook.com/Hadron-Physics-Department-211078852968333/
- contribution to the new web page of IFIN-HH