Form B1 – Project description

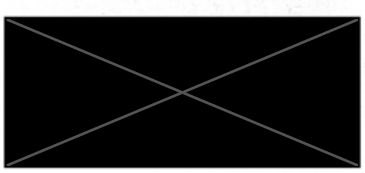
Programme / Sub-programme / Module	**5.9/5.9.2/CERN-RO**		
Project type	**RDI**	**Continuing X**	**New ☐**
Programme /CERN Programme to participate in	LHC/ALICE		
Project title / Acronym	**IFIN-HH contribution to the ALICE experiment at LHC/RONIPALICE**		
Project duration	2024-2026		

PROJECT DESCRIPTION

1. Project summary

As part of the ALICE Collaboration, our group had significant contributions to the construction of the Transition Radiation Detector (TRD) and Time Projection Chamber - Outer ReadOut Chamber (TPC-OROC), as Tier2 centre of the ALICE GRID, as well as to activities of general interest. The ultimate goal was to address physics topics, related to collective phenomena in proton-proton (pp) collisions, to core-corona effects, geometrical scaling of various observables, similarities between pp and heavy-ion (A-A) collisions and systematic studies on charged particle suppression as a function of collision energy. These results have been presented at international conferences and published in ISI-indexed journals.

For pp collisions at $\sqrt{s}$=13 TeV, we will extend our previous studies, in terms of multi-differential selections based on charged particle multiplicity, event shape and $\Delta\varphi$ - $\Delta\eta$ relative to the leading particle. With these selections, and using a multi-dimensional detector response matrix as well as particle identification techniques, the transverse momentum distributions and two particle correlations of identified hadrons will be obtained. We will also explore additional global event shape observables that are more effective in selecting near-isotropic events. The extended multiplicity coverage from Run 3 and Run 4 will allow more systematic, multi-differential analyses. These analyses will be implemented in the O^2 environment, and comparisons with previous studies will be done. Detailed comparisons with theoretical models will help constrain model parameters and provide a clearer understanding of the underlying physics. Special attention will be given to comparing the dependence of various observables on collision energy and collision geometry across different systems, as well as between pp and A-A collisions at LHC energies. Both existing experimental data and predictions from modern phenomenological models will constitute the object of an attempt to systematize the observed phenomena and evaluate the performance of certain observables. Theoretical model frameworks implemented in-house will be useful tools in understanding the physics behind the observed experimental trends. With future experiments at the LHC in mind and building on our extensive experience, we will conduct Research & Development (R&D) activities focused on improving the time resolution of high counting rate Resistive Plate Counter (RPC) detectors. Within the present project we aim to maintain and enhance the performance of the NIHAM Data Centre in terms of storage capacity and computing power. Our group will participate at running the ALICE experiment, as Run Manager, Shift Leader and by fulfilling the on-site shifts, as well as by handling



PhD students' Service-Tasks and institutional Service-Work. Additionally, we will remain actively involved in the ALICE publishing activities. To attract new members inspired by our activities, we will continue to prioritize educational activities from the bachelor's to the doctoral level and outreach efforts, with a particular emphasis on the Summer Student Program and Romanian Science Gateway initiatives.

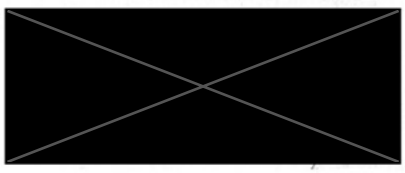
2. Objectives of the CERN experiment

ALICE (A Large Ion Collider Experiment) is a general-purpose, heavy-ion detector at the CERN LHC. It is designed to address the physics of strongly interacting matter in deconfined phase at extreme values of energy density and temperature in nucleus-nucleus collisions. It allows a comprehensive study of hadrons, electrons, muons, and photons produced in the collision of heavy nuclei (Pb-Pb), up to the highest multiplicities anticipated at the LHC energies. The physics programme also includes collisions with lighter ions and at lower energy, in order to vary energy density and interaction volume, as well as high statistics data taking during proton-nucleus runs. Proton-proton collision studies at LHC energies provide not only reference data for the heavy-ion programme but address a number of strong-interaction topics specific at LHC energies.

During the previous runs 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 collisions and pp collisions at high charged particle multiplicity events at the energies presently available at LHC.

During LHC Runs 1 and 2, ALICE has produced a wide range of physics results using all collision systems available at the LHC. In order to best exploit new physics opportunities opening up with the upgraded LHC and new detector technologies, the experiment has undergone a major upgrade during the LHC Long Shutdown 2 - LS2 (2019–2022). This comprised the move to continuous readout, the complete overhaul of core detectors, as well as a new online event processing farm with a redesigned online-offline software framework. These improvements allow to record Pb–Pb collisions at rates up to 50 kHz, while ensuring sensitivity for signals without a triggerable signature.

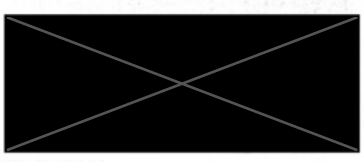
The main objectives of the upgrades in LS2 are to significantly improve the capabilities of ALICE to probe the QGP with heavy-flavour quarks, and to enable completely new measurements of the thermal emission of dielectron pairs. In addition, the upgrades significantly improve the precision of measurements in several other areas, such as jet quenching phenomena probing the interactions of high-energy partons with deconfined environment, the production of light nuclei, momentum correlations of hadrons to determine the interaction potentials of unstable particles, and the study of collective effects in collisions of protons with high multiplicity.



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

As part of the ALICE Collaboration, our group had a significant contribution to the construction of the TRD and TPC-OROC, based on GEM, as Tier 2 Centre of ALICE GRID, or to activities of general interest for the collaboration. The ultimate goal was to address physics topics related to collective type phenomena in pp collisions, core-corona relative contribution to various observables, similarities between pp and A-A collisions, geometrical scaling of various 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 $\Delta\varphi$ - $\Delta\eta$ relative to the leading particle in obtaining transverse momentum distributions using a multi-dimensional detector response matrix and two particle-correlations, for identified hadrons, exploring also other global event shape observables more effective in selecting close to isotropy events. Multi-differential studies are a very challenging task and thus permanently we will compare between them the results obtained with different unfolding procedures developed by us and with other similar analyses in order 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 O^2 environment and comparison with previous analyses will be done. Additionally a comparison with theory in the greatest detail can constrain the parameters of the models and leads to the understanding, in an unambiguous way, of the physics behind. 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 understating and systematizing the obtained results.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 various observables on the collision energy and collision geometry between different A-A systems and at LHC energies, between pp and A-A. The existing experimental data and the predictions of modern phenomenological models will constitute the object of an attempt to systematize the observed phenomena and to explore the performances of some observables. Theoretical model frameworks implemented in-house will be useful tools in understanding the physics behind the observed experimental trends. The aim is to configure also paper drafts to be published by our group members. Having in mind detector development for future experiments at LHC and based on our long experience, R&D activities will be carried out along the lines of improving the time resolution of high count rate RPC detectors which can be used as forward detectors having a large pseudorapidity coverage. Our NIHAM Data Centre was permanently one of the most efficient among Tier2s ALICE GRID centres more than 10 years. Within the present project we aim to maintain and develop the performance of the NIHAM Data Centre in terms of storage capacity and computing power. Our group will pay a special attention to the contribution for running the ALICE experiment either as Run Manager, Shift Leader or by fulfilling the on-site shifts, to service tasks and service-work and to the participation in the ALICE publishing activity. To attract staff inspired by our activities, the educational guidance from bachelor's level to doctorate and disseminating the results will be in our constant attention, especially now that the Summer Student Program has been revived after the pandemic and Romanian Science Gateway has taken shape.



4. Project objectives

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

The multi-dimensional unfolding procedures developed in our group allow 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 multi-dimensional detector response matrices and two-particle correlations at $\sqrt{s}$=13 TeV within the O^2 environment. The studies will be extended to identified hadrons and other global event shape observables. Derived quantities from the transverse momentum distributions and correlation distributions will be compared with model estimates.

O2. Comparison with theoretical models

A comprehensive understanding of the physics behind the trends revealed by the experimental data will be achieved through multi-differential analyses and comparison with theoretical models. The studies will be focused on examining the dependence of various observables on the collision geometry and collision energy, with comparisons between different systems, particularly between pp and A-A collisions at LHC energies where the larger range in charged particle multiplicity will give the possibility to obtain a stronger confirmation of the similarities and of understanding their origin. Comparison with phenomenological models estimates and core-corona interplay will be considered. Theoretical comparisons will be performed using complex in-house installed theoretical frameworks.

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

As part of our active contribution to the ALICE experiment, on-site shifts will be carried out. Phd student's Service Tasks as well as institutional Service Work will be undertaken.

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

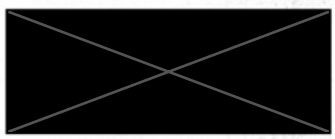
Within the present project we aim to maintain and develop the performance of the NIHAM Data Centre in terms of storage and computing capacity. Dedicated to in-house activities, the NIHAM Analysis Facility (NAF) will be maintained in equally good conditions.

O5. Teaching and outreach activities

Teaching and outreach activities aiming at attracting and educating the younger generation, as well as promoting the contributions of Romanian groups to cutting-edge research fields, will remain a permanent and integral part of our efforts.

O6. R&D activities

Obtaining a high-performance time resolution for high counting rate RPC detectors will give us the possibility to propose their use in future experiments.



5. Main project activities

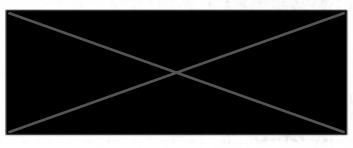
Following the objectives mentioned above, we will continue and extend our activities as follows.
The study of transverse momentum spectra, especially under certain event topology constraints, is crucial to the understanding of the nature of matter produced during pp and heavy-ion collisions. The larger statistics available in Run3 and Run4, gives the possibility to extend these studies up to a charged particle multiplicity 2-3 times higher than the present one, where models like KøMPøST predict that hydrodynamic features could be highlighted even in small systems. Such results are essential for discriminating between different phenomenological models in the region where the perturbative QCD does not work anymore, aiming for a consistent understanding of the log(1/x)-logQ^2 QCD landscape.

- Transverse momentum distributions for identified charged particles in different regions of the phase space using charged particle multiplicity and event shape observables, for pp collisions at $\sqrt{s}$=13 TeV will be obtained. This requires the extension of the multi-dimensional unfolding procedure developed by us to the identified charged particles by increasing its complexity.
- A comparison will be made between the two procedures we used so far to obtain transverse momentum distributions for charged particles, the limitations and advantages of the two procedures will be evaluated and the most accurate approach will be identified.

Recent measurements hint at observing several heavy-ion-like features in high-multiplicity pp collisions at the LHC energies. Event shape observables can fundamentally separate hard interaction-dominated by jetty events from soft isotropic events. These features of event shape observables can probe the observed heavy-ion-like features in pp collisions with significantly reduced selection bias and can bring all collision systems on equal footing. The Fox-Wolfram moments (FWMs) correspond to a decomposition of the event's phase space into Fourier modes on the surface of a sphere. In the context of hadron colliders, it would be desirable for a harmonic analysis to be invariant under Lorentz boosts parallel to the direction of the beam. This motivates the modification of the FWMs such that the moments for a given event are identical when viewed in the lab or centre-of-mass frame of the beam. The resulting moments are invariant under rotations in the plane transverse to the beam and boosts parallel to the beam. Certain combinations of FWMs can highlight events closer to isotropy.

- New recipes, with emphasis on FWMs for selecting events close to isotropy and their performance relative to the traditional event shape observables like sphericity, thrust, will be scrutinized in order to assess their suitability for better selection of nearly isotropic events. This study will be conducted using both phenomenological models and ALICE data.

The p_T -spectra in a pp or heavy-ion collision consists of a low p_T -region where soft processes dominate particle production, whereas the high p_T -region is mostly dominated by hard processes.
To describe these distributions and extrapolate at low and high p_T different fit functions are used. Recently two new such functions have been introduced.
A unified non-extensive statistical approach using the Pearson distribution as a tool to study p_T -spectra has been proposed. The goodness-of-fit of the proposed distribution as compared to



previously used models makes it an interesting method providing strong insights into the underlying physics of collisions. This generalized approach provides a strong correlation with other observables by comparing the predictions of the methods in p_T -distributions with various harmonics of azimuthal distributions.

Extensively used by us, the obtained transverse momentum distributions were described by a sum of an exponential decay term plus a decreasing power like contribution representing the soft non-perturbative and hard perturbative QCD collisions, respectively. Recently, an analytical function that can describe the whole transverse momentum spectrum has been proposed. This is obtained using a q-Gaussian distribution to describe the string tension fluctuations. The parameter q determines the departure of the thermal distribution as well as the minimum length that can be explored at high transverse momentum.

- 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 and the new fit functions will be investigated.

The two-particle angular correlations in the Δy, $\Delta\varphi$ space provide valuable insights into the properties of hadronization mechanisms and deconfined properties. The correlation functions are influenced by several physical sources, including mini-jet correlations, Bose–Einstein quantum statistics, resonance decays, conservation of energy and momentum, and other factors. Each correlation source has unique properties, and therefore each correlation function has a distinct form depending on transverse momentum and/or multiplicity.

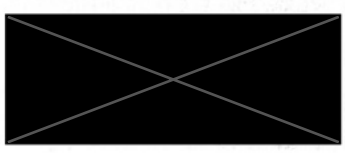
- Differential studies of two-particle correlations as a function of charged particle multiplicity and event shape for proton-proton collisions at $\sqrt{s}$ = 13 TeV focusing on identified charged particles and comparison with theoretical models will give deeper insights into the origin of the particle species-dependent behavior of correlation structures.

- The ALICE experimental data analyses will be implemented within the O^2 computing environment to leverage its advanced processing capabilities and access datasets with significantly larger statistics. The results will be compared with previous analyses to ensure consistency and highlight any improvements or new insights.

- A constant activity will be preparing and publishing analysis notes, as well as presenting findings at Physics Working Groups (PWGs), and submitting results for publication in scientific journals. The project outcomes will also be shared through conference presentations to disseminate them to the wider scientific community.

The modern Monte-Carlo (MC) event generators based on different phenomenological models used to simulate both pp and nucleus collisions in collider experiments have been developing for several decades and encompass numerous physics mechanisms aiming to describe huge amount of data.

- Complex codes based on phenomenological models will be installed on the local computing facility. They will be used for comparison with existing experimental data and for investigating various



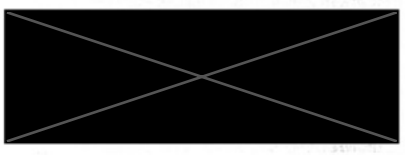
observables used in the analyses addressed in our group. Comparison of the dependence of various observables on the collision energy and geometry between different A-A systems and at LHC between pp and A-A will be continued and extended to model predictions. Published papers by our group members will be the output.

- Being part of our active contribution to the ALICE experiment, on-site shifts, will be done. Service task and service work will be undertaken. Taking over the role of Run Manager and Shift Leader in the most important periods of data taking for ALICE will continue.

- Within the present project we aim to maintain and develop the performance of the NIHAM Data Centre. Approximately 2 PB of data storage and 2000 threads of computing power will be installed. The NIHAM Analysis Facility (NAF) used for developing software packages for data analysis, large scale microscopic calculation using different theoretical models and fast local analysis will be treated as having the same importance. Modern external computational packages required by different complex codes available will be installed.

- We will continue our successful teaching and outreach activities with the goal of attracting and educating the next generation of scientists. Emphasizing the contributions of Romanian research groups to front-end research is crucial for convincing the public and local authorities that adequate funding support is justified. As part of our ongoing outreach efforts, we will regularly update the website of our department (http://niham.nipne.ro) and maintain the consistent publication of the HPD Courier (http://niham.nipne.ro/HPD_Courier.html). We will also continue supervising diploma projects, master and PhD theses, and delivering lectures at the doctoral school. Additionally, the Summer Student Program will remain an ongoing initiative.

Recently, based on CGC, it was predicted that residing nuclei for head-on collision of heavy ions moving apart at large rapidities at LHC energies are in a state of very high baryon density. Such a scenario could be supported by experiments with PID capabilities up to 4 units in rapidity
- Fructifying our long experience, R&D activities will be carried out along the lines of improving the time resolution of high count rate RPC detectors and 2D-MRPC.



6. Project development and expected results

Obj. Code	Milestones	Expected result	Time schedule justification
O2.	Study of similarity between pp and A-A collisions in terms of <pT>/<dN/dy>/$S_{\perp}$ dependence on the collision energy	- as component of a master thesis	31.12.2024
O1. O2. O3. O4. O5. O6.	- Comparison between the two unfolding procedures developed in-house. - Multi-differential selection in charged particle multiplicity, event shape and $\Delta\varphi$ - $\Delta\eta$ relative to the leading particle in obtaining transverse momentum distributions using a multi-dimensional detector response matrix and two particle-correlations, for identified hadrons. - New global event shape observables more effective in selecting close to isotropic events, analysed both with phenomenological models and on ALICE data. - Implementation of phenomenological models and comparison of the dependence of various observables on the collision energy and collision geometry between different A-A systems and at LHC energies, between pp and A-A. - In beam Run Manager, Shift Leader roles and shifts. - Upgrade of NIHAM Data Centre and its maintenance. - Teaching, outreach activities and Summer Student Programme continued. - Preliminary results on time resolution of RPC.	- analysis notes - ISI Journal publication - conference presentation - new storage and computing power - service work and shift credits - report on R&D activities.	31.12.2025 The proposed activities will be planned to combine the specific activities of the group with the requirements of those of general interest in the ALICE Collaboration.
O1. O2. O3. O4.	- Multi-differential selection in charged particle multiplicity, event shape and $\Delta\varphi$ - $\Delta\eta$ relative to the leading particle in obtaining transverse momentum	- analysis notes - ISI Journal publication - conference	31.12.2026 The proposed activities will be planned to

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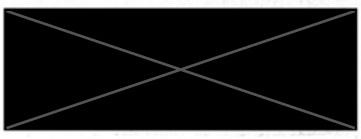
Obj. Code	Milestones	Expected result	Time schedule justification
O5. O6.	distributions using a multi-dimensional detector response matrix and two particle-correlations, for identified hadrons. Preliminary results on p_T spectra and correlation analysis. - The transverse momentum distributions in different regions of the phase space, the yields and average transverse momenta will be compared with the estimates based on different phenomenological models and results with new fit formulas will be investigated. - Comparison of the dependence of various observables on the collision energy and collision geometry between different A-A systems and at LHC energies, between pp and A-A. - In-beam shifts. - Upgrade of NIHAM Data Centre and its maintenance. - Teaching, outreach activities, Summer Student Programme continued. - Results on time resolution of RPC.	presentation - new storage and computing power - service work and shift credits - report on R&D activities.	combine the specific activities of the group with the requirements of those of general interest in the ALICE Collaboration.

7. Scientific and technological output of the project

- Scientific publications in ISI international publications within the ALICE Collaboration - 60
- Other scientific publications in ISI journals - 2
- Communications to scientific national and international meetings - 30
- Internal Presentations in the Collaboration - 3
- Paper Committee - according to the obtained results and Collaboration request
- ALICE Institutional Reviews – Collaboration request
- Analysis Notes - 3
- Continuous update of the NIHAM web pages
- Development and operation in good security conditions of our Data Centres - NIHAM and NAF 1 purchase/year
- Involvement of new members in any form of support in our group on temporary or permanent Positions - 1

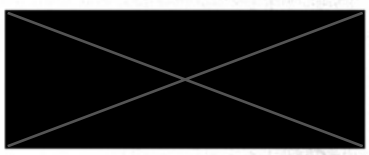


- Diploma, master and PhD theses - 1
- Outreach activities and products - 3
- Run 3 Shifts, service task and work: according to our quota/year

The considerable know-how and achievements obtained by the HPD/IFIN-HH group as partner in different international collaborations are quite well known by now at national level and the present visibility of the group will be increased updating continuously the web page (http://niham.nipne.ro) .
Nevertheless, unpredictable parameters can influence the outcome of the project, related to the financial support of the project and general circumstances connected to the international context (for example, the regional wars that are taking place at the present time).
Based on the experience of the group involved in the present project we do not foresee major risks in fulfilling the project goals once a proper and regular financial support will be received and present manpower will be conserved.
One of the main challenges in our analysis is the insufficient statistics, which limits the accuracy of our results, along with the need to minimize systematic errors. To address these issues, we plan to use the significantly larger dataset from Run 3. This will provide the statistical power needed for more reliable results and enable us to refine our methods for reducing systematic uncertainties leading to accurate conclusions.
As everywhere in the world hiring new young physicists, electronic engineers and technicians dedicated to the field is a delicate aspect. Via our regular Summer Student Program we hope to be able to maintain an optimum level of the expertise in all segments of activity and to transfer the accumulated experience to the younger generations.

8. Project impact

This type of project enables us to embark, visibly and competitively, on one of today's most advanced fields of research. Producing and studying states of matter that are expected to characterize the universe's earliest moments or the inner core of neutron stars, as well as the processes occurring in the collision of highly dense gluonic systems, belong to the challenging task of humankind to find answers to ultimate questions.
The excellent infrastructure of our department, combined with the expertise accumulated over the years, has enabled our group's involvement in the ALICE upgrade activities. This included assembling and testing 50% of the TPC-OROCs based on GEM technology. This involvement is a natural extension of the Romanian group's successful, visible, and competitive participation in the production, testing, installation, calibration, tracking, and monitoring of the TRD chambers during the construction phase of the ALICE experiment.
In parallel 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. On the basis of this long and successful experience we are able to develop and propose the inclusion of highly performant subdetectors in future arrangements which will be built at CERN.
As a common practice in scientific research domain, students and graduate students will continue to



be involved in the group's activities to prepare their diploma, master and PhD theses. They will become highly qualified specialists, extremely useful in various branches of activity.
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 payoff in the following years.

Hardware and software structures of distributed computing network type which are and foreseen to be implemented in our group will serve not only the group's needs for computing, but also connect Romania to the international efforts to develop the new technology of grid computing. Our NIHAM Data Center had the largest contribution among the Romanian sites in LCG – CERN.

A regular Summer Student Programme was initiated by our department, becoming a tradition by now, facilitating a direct access of the students from different Romanian and foreign Universities to all segments of activities involved in our research.
In addition, through dissemination activities, especially demonstration exhibitions, we will address the general public of all age groups to make the potential of our field known to tax payers and to attract future workers in the field.

9. Project equipment (relevant equipment each partner makes available for the project)

a) Existing (maximum 5 equipment for each parner relevant for the project)

PROJECT COORDINATOR: IFIN HH	
No.	**Name of equipment and main characteristics**
1	**Laboratories for the detectors assembly and test**
	4 clean rooms 100 000 / 10 000 / 1 000 / ft 3
	2 laboratories equipped with high-performance devices for detector construction and testing
	2 mechanical workshops equipped with lathes, mills and other specific equipment
2	**Laboratories of electronics, equipment and instruments**
	2 electronics laboratories for the production and testing of analog and digital electronics
	Bonding laboratory and SMD circuits
	Hardware and software infrastructure for ASIC – CADENCE, PCB-ORCAD, QCAD, AUTOCAD design
	High performance electronic devices
3	**GRID equipment**
	2 rooms specially designed for the NIHAM data center component of ALICE GRID and NAF for local use
	computers ~ 4000 cores, storage capacity ~ 5 PB
4	**Special audio-video infrastructure for the offices and meetings and conference rooms**