Programme / Sub-programme / Module	5/5.2/FAIR-RO		
Project type	RD		
Experiment	CBM	**Scientific Domain**	Nuclear Matter Physics
Project title / Acronym	Physics, Detectors and Frontend Electronics for CBM experiment /HICOR-DEFEND		
Project duration	2016-2019		

PROJECT DESCRIPTION

1. "State of the art" in the field

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At very high energy densities, reachable in ultra-relativistic heavy ion collisions at the highest collision energies at RHIC ((√sNN=200 GeV) and by a factor of 14-25 higher at LHC (√sNN=5 TeV), experimental findings support the expectations based on lattice QCD calculations of production of deconfined strongly interacting matter formed by quarks and gluons. The inverse process, called hadronization, is supposed that happened in the Universe during the first few microseconds after the Big Bang. This is the region of the phase diagram where the transition is expected to be a smooth crossover from partonic to hadronic matter. Besides the amount of extremely interesting results obtained or on the way to be obtained at these energies it is of equal importance to understand as much as possible the complementary region of the phase diagram of the strongly interacting matter with its different critical points and boundaries between different phases predicted by QCD. Highly dense and cold nuclear matter is expected to exist in the core of neutron stars. These were the main motivation of beam energy scan program at RHIC - Brookhaven, still ongoing experiments at SPS - CERN energies and for the new experiments as Multi-Purpose Detector (MPD) and Compressed Baryonic Matter (CBM) at future facilities Nuclotron-based Ion Collider fAcility (NICA) at JINR-Dubna and Facility for Antiprotons and Ion Research (FAIR at Darmstadt, respectively. SIS100 at FAIR, under construction at the moment, will deliver unprecedented interaction rates (~10^7 Hz) at energies up to 11 AGeV (√sNN =4.9 GeV) for gold beam, up to 15 A•GeV for N=Z nuclei and up to 30 GeV for protons. Exploration of QCD phase diagram at large baryon chemical potential started at AGS in Brookhaven and at SPS in CERN at low energies. These very first experiments, based on the detector technologies of that period, were restricted to a limited type of hadrons abundantly produced at those energies. NA61 experiment, presently running at SPS aims to evidence first order phase transition by measuring hadrons in light and medium heavy ion beams induced reactions. STAR collaboration at RHIC, within beam energy scan program, performed measurements starting from the top √sNN = 200 GeV down to √sNN = 7.7 GeV energies in Au+Au collisions. However, due to TPC-readout and RHIC accelerator luminosity limitations, the reaction rates are limited from about 800 Hz down to a few Hz at the lowest measured energies. Therefore, any detailed multi-differential analysis is not feasible. The CBM fixed target experiment is designed to run interaction rates up to 10 MHz for selected observables like J/Ψ, 1-5 MHz for multi-strange hyperons and dileptons and at 100 kHz without any on-line event selection. In order to cover from small polar angles up to the midrapidity region, the CBM detector will have a polar acceptance between 2.5 to 25 degrees. Combining the high-intensity beams of SIS100 with the high rate performance of CBM, worldwide unique conditions for a comprehensive series of experiments aimed to produce and understand QCD matter at the highest net-baryon densities reachable in the laboratory will be provided. Such an experimental device will be based on a new generation of detectors, frontend electronics and data processing and acquisition architectures having at least the performance of already running ones but in conditions of unprecedented high counting rates. State of the art two-dimensional position sensitive Multi Strip Multi Gap Resistive Plates Counters (MSMGRPC) with time resolution in the region of 50 psec and two-dimensional position sensitive Transition Radiation Detectors (TRD) and their dedicated frontend electronics, developed by our group, will be used for the most demanding regions (small polar angles) of the CBM-ToF and TRD subdetectors.

2. Place of the project in the framework/context of FAIR

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Our group is involved in the CBM Collaboration starting from 2003, with essential contributions up to now in developing a new generation of high counting rate TRD and RPC detectors, frontend electronics and different versions of free running mode DAQ. Based on these results the CBM-ToF TDR was accomplished and positively evaluated. The most forward region of the CBM-ToF wall will be equipped with state of the art two-dimensional position sensitive Multi Strip Multi Gap Resistive Plates Counters (MSMGRPC) with time resolution in the region of 50 psec developed by our group. The very last RPC prototype developed by us has an strip architecture which gives the possibility to tune the impedance of the transmission line to the value of the frontend electronics for a given strip pitch which fulfills the granularity requirements at a reasonable number of electronic channels. The intensive campaigns of in-beam tests at SPS-CERN will continue, the information obtained or which will be obtained with a variety of prototypes will be calibrated and analyzed. The version of RPC which will show the best performance in all respects, i.e. efficiency, time and position resolution, cluster size, multi-hit and high counting rate performance will be chosen to built a production readiness version. For the CBM TRD subdetector we developed an original two-dimensional position sensitive TRD architecture which, similar to the CBM-ToF subdetector, which will be used in the small polar angle region of the CBM-TRD subdetector. CBM-TRD TDR will be finalized soon and delivered to the evaluation committee. The calibration and analysis of the results obtained in the last in-beam tests at SPS-CERN will be finalized, new TRD prototypes with smaller anode wires pitch and the possibility to be monitored using laser beams will be designed, constructed and tested in close to CBM environment at SPS-CERN. Based on the results of these R&D activities, our group will be involved in the assembling and testing of the RPC modules and TRD chambers for the most inner/challenging regions of these two sub-detectors. Dedicated software packages for the calibration and analysis of information obtained in the in-beam tests will be further developed such that most of it will be implemented in the general framework foreseen to be used for CBM experiment once this will become operational. In parallel, a new frontend CHIP and CBM-DAQ compatible interface will be designed, built and tested. A detailed study of the high counting rate and multiplicity within the beam spill on the TRD performance requires a stable reference signal. It is well known from other type of detectors that this can be provided by a laser beam which is distributed within the active area of the detector. We foresee to develop a rather versatile laser monitoring system for our TRD prototypes in order to monitor their performance in close to real conditions and as a potential benchmark for a similar solution for the real TRD sub-detector of CBM experiment.

Based on the experience and results obtained by our group at lower and higher energies within FOPI and ALICE collaborations, respectively, we will use the advantage of TRD and ToF sub-detectors of the CBM experiment for which development and construction we had and will have an essential contribution, and focus our physics program on multi-differential studies of collective type phenomena within $\sqrt{s_{NN}}$ =2−4.9 GeV energy range with the aim to understand the fundamental properties of QCD in the corresponding region of the phase diagram. Based on the large dynamical range in the charged hadrons and intermediate mass fragments identification and high statistics for multi strange baryons detailed information on the radial and elliptic flow and their dependence on $\sqrt{s_{NN}}$ will be obtained.

3. Project objectives

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O1. Complete experimental characterization of the RPC and TRD prototypes before starting the construction and tests of the CBM-ToF and CBM-TRD subsystems, respectively.

Development of very good time resolution MGMSRPC prototypes with the impedance of the transmission line matched to the one of the frontend electronics and granularity required for the inner zone of CBM-TOF wall at SIS100. Alternative designs of the inner zone based on these prototypes.
The TRD prototypes will be exposed to a variety of sources ranging from single hit at low rates as obtained with ^{55}Fe source to multi-hit at high rates generated with a X-ray tube and finally to multi-particles of various species and momenta as obtained at the CERN-SPS accelerator facility. Working parameters of the TRD chambers will be monitored in parallel with physics performance for all these running conditions in order to produce a global characterization of our prototypes.

O2. Data processing of runs characterizing the RPC and TRD prototypes

The performance of the MGMSRPC prototypes should be tested in conditions close to those anticipated in the operation of the CBM experiment at FAIR. Such conditions are available at CERN SPS. The efficiency and time resolution will be studied as a function of counting rate and hit multiplicity.

The TRD detector of CBM provides the position and particle identification information for particles crossing the detector. Extreme conditions as those foreseen at CBM may alter its performance obtained in relaxed laboratory tests. It is our objectives to prove that the physics performance of the TRD system (detector and FEE) do not deteriorates in CBM like conditions as available at *e.g.* CERN-SPS

O3. Design, construction and tests of a new FASP-02 motherboards for electronic tests (Bugi, Cara, Puiu)

O4. Free-running DAQ based on reading analogic FASP-02 outputs (Cara, Florin, Mihai).

O5. Electronic integration of FASP for CBM-DAQ inter-connectivity.

As the CBM-DAQ solutions are maturing our original contribution in terms of FEE, the FASP ASIC, needs to be inter-connected with the global DAQ. A prototype of the local digitization and the data transport layer will be developed following the CBM-DAQ guidelines to assure our readiness at the moment of *e.g.* an engineering run in parallel with other sub-systems.

O6. Design, construction and in-house and in-beam tests of a laser monitoring system for TRD prototypes (OPTOEL, Mihai)

O7. Multi-dimensional analysis of radial and azimuthal anisotropic flow in Au+Au collisions in the SIS100 energy range using phenomenological models generated events (Amalia, Mihai)

4. Description of the methodology and of the activities

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Presentation of the methods, techniques and the activities assumed by each partner.

As members of CBM Collaboration, our activity related to the Time of Flight (ToF) subdetector has been focused on the development of *a* Multi-Strip Multi-Gap Resistive Plate Counter (MSMGRPC) prototypes for high counting rate and multiplicity environment, as it *is* anticipated to be implemented in the inner zone of the CBM-ToF wall. A narrow strip pitch (2.54 mm), prototype based on low resistivity glass (~10^{10} Ωcm), built as a double stack configuration, prooved a very good performance in terms of efficiency, time resolution, position resolutions along and across the strips. The transmission line impedance of this prototype has 100 Ω, matching the input impedance of the differential front-end electronics. However, the number of channels required to equipe the most forward polar angles of the CBM TOF wall with such type of MSMGRPC is quite high (~ 140,000 electronic channels), with direct concequence on the costs. A lower granularity prototype of 7.4 mm strip pitch, with the same inner architecture, was designed and built further on. Due to the larger strip width and double stack configuration, the differential transmission line defined by corresponding strips of the readout electrodes has 50 Ω impedance. Therefore, an impedance matching with input impedance of fast amplifiers of 100 Ω was done at the level of FEE motherboards. This prototype showed excellent performance in terms of time resolution and efficiency up to local counting rates of 10^5 particles/(cm^2•s) in the in-beam test performed at the COSY facility in Juelich and up to a exposure of 10^4 particles/(cm^2•s) all over the counter surface at SIS18 accelerator of GSI Darmstadt. Four prototypes with this larger strip pitch were mounted in a staggered geometry, with overlaps along and across the strips, in order to define a basic architecture which assure a continuous coverage active area in a fixed target experiment.
This basic architecture was later on implemented in the proposed design of the modules for the inner zone of the CBM-TOF wall based on MGMSRPCs.
In the free streaming readout considered for the CBM experiment, a very good impedance matching is required in order to minimize the reflections on the transmission lines.

A direct matching with the 100 Ohm input impedance of the front-end electronics and in the same time with the granularity required by the most inner zone of the CBM-TOF with a reasonable number of readout channels are considered in the design of new *high time resolution* MGMSRPC prototypes. A MGMSRPC prototype in double stack configuration, with a strip architecture which gives the possibility to tune the impedance of the transmission line to the value of the frontend electronics for a given strip pitch will be developed together with an other one with a classical single stack architecture. The transmission line impedance of a single detector readout channel will be estimated using dedicated software simulators. Both prototypes will fulfill the granularity requirements at a reasonable number of electronic channels.

Based on the prototype with specified granularity a few alternative architectures for the inner zone of the CBM-TOF are considered. The different versions take into account the MGMSRPC disposal inside the modules and of the modules in the available space inside the CBM-TOF wall architecture. The advantages and disadvantages of each configuration will be discussed. The final decision will be based on the performance of MGMSRPC architectures, the characteristics of different versions of the proposed inner wall architecture and the available financing budget.

The performance of the new MGMSRPC prototypes will be tested in conditions close to those anticipated for CBM experiment at FAIR. Such conditions are available at CERN SPS. The data analysis will be based on CBMROOT software. The efficiency and time resolution will be studied as a function of counting rate and hit multiplicity.

The TRD sub-system is used as an intermediate tracking station in the CBM experiment and a particle identification enhancer. The capabilities of the TRD system exceed mere electron-pion separation and reach into the heavy fragments domain, required by CBM experiment at SIS100. In the tracking sector the detector has optimized read-out capability, delivering 2D position information over the full surface without extra material budget. To achieve its potential a robust read-out Front End Electronics (FEE) for the extreme operation conditions foreseen at CBM was developed and extensively tested. The Fast Analog Signal Processor (FASP) was developed to incorporate all these requirements. The basic performances of the TRD-FEE chain are tested in laboratory conditions for a light load on the detector as *e.g.* ^{55}Fe illumination. On such system online calibration technics for the detector and the FEE were developed and tested. For calibrating the 2D position information capabilities of our read-out an innovative method based on image reconstruction techniques was developed which offers a powerful heuristic approach to such tasks in a systematic free fashion. Some of the calibration techniques mentioned above could be as well used as online quality assurance (QA) quantities needed in more extreme testing conditions as found at *e.g.* CERN-SPS.

A second series of tests involve illumination of the full detector area with a continuous spectrum of X-rays with varying intensity generated by a tube. Such test offers ways in which detector performances in terms of energy and position resolution can be investigated with single hits over a large domain of input energies, interaction rates and multiplicities. All calibration and QA techniques are available offering a fast feedback on detector performances.

The most conclusive test to which the detector can be exposed during this R&D phase is heavy ions interactions at CERN-SPS. In such conditions the detector is illuminated with ionizing particles with continuous energy loss in the detector volume and thus intrinsically reduced performance relative to X rays. Additionally, secondary particles produced in fixed target experiments, with different mass and energies generate a large spectrum of deposited energy in the full detector volume and thus provides the most accurate simulation of the CBM environment. Using the online calibration/QA techniques developed so far and the detector/FEE characterization one can investigate the physics performances of the detector in realistic conditions.

The CBM sub-systems being exposed to high-rate and high-intensity environment requires a free-running (locally self-triggered) driven DAQ in which event building is left to offline processing. Such request coupled with the high radiation doses close to detector set-up configures the FEE in such a way as to collect all relevant information from the detector and ship it away from the radiation area for full processing. The solution adopted by the CBM experiment to transport the data is based on the GBTx chip developed at CERN. As such technology is not yet ready for deployment and tests a mimic of it will be developed to emulate the data transfer between the FASP based FEE and a CBM like DAQ. The development includes a new Front-End-Board (FEB) ready to use FASP at its full potential (channel wise) matching the input specifications of the GBTx chip. Additionally the GBTx transport functionality will be emulated and implemented via FPGA technology. An extra component of our stand alone DAQ will emulate the event building part of the CBM-DAQ by gathering information from other sub-systems used for online detector characterization like laser and/or pulse generator systems as well as external detectors used to characterize the illumination environment (RPC, Plastic scintillators, etc.). This DAQ system besides being a realistic testing bench for the TRD detector in the CBM experiment will also provide the means for integration with prototypes from other CBM sub-systems and will pave the way towards a much needed engineering run.

TRD subdetector of CBM experiment, based on 4 layers of TRD chambers will play a major role in enhancing the electron-pion discrimination of RICH subdetector, in conjunction with STS and ToF subdetector will improve the tracking and PID performance especially for intermediate mass fragments and will be used by the MUCH subdetector as the last tracking station; all these in high counting rate and multiplicity environment.

In order to monitor the possible distortions of the TRD prototypes performance as a function of counting rate, hit density, ionizing power of reaction products, to calibrate and monitor them, a laser calibration system is mandatory. It will give also the possibility to measure the drift velocity with very good accuracy. Taking into account these requirements, the laser system will have the following features:

- laser tracks will be injected along the TRD pad rows with the possibility of scanning different angles relative to the multi-wire planes
- electron density along the laser beam must be higher than the ionization from relativistic particles
- the accuracy of the position and stability during operation of each laser beam at any point must be smaller than 400 μm in a plane parallel with the TRD electrones and smaller than 400 μm in the orthogonal direction
- syncronization of the time of the lasr beams injection in the TRD volume to the accelerator clock or relative to any other trigger within 2 ns error in order too reach accuracy in drift time measurements
- laser system has to incorporate alignement, steering and stable position posibilities which could guarantee the above requirements

The system will be tested in the in-house tests based on X ray and cosmic rays measurements and in-beam tests where close CBM conditions are expected

In heavy ion collisions, in the intermediate energy range, the interaction time, estimated based on phenomenological models is found to be longer than the emission time of light particle. As a consequence, the particles being emitted during the rotation of the di-nuclear system, will be preferentially focused in the reaction plane due to angular momentum conservation. Such rotational-like pattern of the azimuthal distribution of emitted particles is expected to survive up to the incident energies where the di-nuclear configuration of interacting nuclei is replaced by a participant-spectator scenario. The participating zone, compressed and excited, expands in the presence of spectator nuclear matter and a squeeze-out pattern, in the direction perpendicular to the reaction plane is expected to take place. At even higher incident energies, the Lorentz contraction of the spectators becomes important, the transit time of the spectator matter is shorter than the expansion time of the fireball and pressure gradient larger in the reaction plane could contribute to an enhanced emission of different species preferentially in the reaction plane - in plane elliptic flow. A quantitative representation of these expected qualitative trends, using the excitation function of the second term of a Fourier expansion in azimuth, measured by the FOPI Collaboration shows a clear transition from rotational-like to squeeze-out pattern in the energy region of 100 A·MeV [1] while, at higher energies, in the excitation function measured by the EOS Collaboration is evidenced a transition from squeeze-out to in plane elliptic flow at about 4 A·GeV [2]. The present signature for such a transition is based on a very limited statistics, using only protons at AGS energy. A detailed theoretical study of the $\sqrt{s_{NN}}$ where transitions of the azimuthal distributions take place (E_{tran}) as a function of collision geometry and different size of the symmetric colliding systems will be done to disentangle between different contributions, such that an unbiased information on the Equation of State (EoS) of strongly interacting matter at E_{trant} energies to be extracted. For signal extraction and physics interpretation, the results of different amodels available on the market [3] will be systematically analyzed.

The Glauber Monte-Carlo simulations, used to estimate the number of participating nucleons or binary nucleon-nucleon collisions is a basic tool in the analysis of relativistic heavy-ion collisions. As the CBM experiment will access low energies, an extension of the Glauber calculations into low energy domain is required in a home-made tool that could be used in our experimental data analysis at CBM. The results will be compared with the expectations based on the extrapolation of excitation function which will be realized in the meantime in the BES [4] and FT [5] program at RHIC.

References

[1] Transition from in-plane to out-of-plane azimuthal enhancement in Au+Au collisions, FOPI collaboration, Nucl. Phys. A 679(2001) 765-792
[2] Elliptic Flow: Transition from Out-of-Plane to In-Plane Emission in Au+Au Collisions, E895 Collaboration, Phys. Rev. Lett. 83 (1999) 1295

[3] The CBM Physics Book, Lecture Notes in Physics, 814 (2011)
[4] Overview of results from phase I of the Beam Energy Scan program at RHIC, Daniel McDonald, EPJ Web of Conferences, 95 (2015) 01009
[5] A Fixed Target Program for STAR: Completing the Beam Energy Scan, Daniel Cebra, Talk at STAR Analysis Meeting, August 2011

5. Milestones and expected results

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Presentation of the milestones (name, duration) and the expected results for each of them.

6. Deliverables and outcome of the project

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Reports, publications, joint patents, know-how, mock-ups, other (specify); indicate also the time of accomplishment.

- to be correlated with the objectives and early progress reports

Reports, publications, joint patents, know-how, mock-ups, other (specify); indicate also the time of accomplishment.

The results obtained during the R&D activity for the new detector prototypes and associated front-end electronics are published in journals with impact factor as Nuclear Instruments and Methods A and Journal of Instrumentation and presented to international conferences in the field like Vienna Conference of Instrumentation (2007, 2013) and Workshop of Resistive Plate Chambers and Related Detectors (2010, 2012, 2016). They are also published annually in CBM Progress Reports and will be reported to the CBM Collaboration meetings. The results expected to be achieved in the present project will materialize in technical drawings, RPC and TRD prototypes, associated electronics modules, a detailed documentation on the obtained results, dedicated seminars. They will be published in Journals with impact factor, will be presented to the international Workshops and Conferences, regular videoconferences of different Working Groups of CBM Collaboration, CBM Collaboration Meetings and annual Progress Reports.

The considerable know-how and achievements obtained by the DFH/IFIN-HH group as partner in different international collaborations, quite well known by now at national level, will be transferred into the country and will have a strong impact on the field of design and production of detection systems, ASIC chip design for the associated front-end electronics, special motherboards for interfacing the ASIC chip with different type of detectors .The present visibility of the group will be increased updating continuously the web page (http://niham.nipne.ro) and organizing international events in Romania.Based on the very good results obtained in the R&D activities, we are going to be involved in the construction of the detectors for the inner zones of the CBM-ToF wall and CBM-TRD stations as in-kind contribution to the CBM experiment.

7. Project impact

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Estimated impact of the project: scientific, technological, industrial, economic, educational and formative, social etc.

Some of the implications of the present project on the physics research, economy and society in our country are listed below:

The successful, visible and competitive participation of the DFH/IFIN-HH group to the R&D activities and further to the production, test, installation and monitoring of the detectors for two important subsystems of the CBM experimental setup guarantee future participation of Romanian scientists in physics experiments with extreme impact on human knowledge, accessible only on the basis of common scientific and financial efforts at the international level.

Our group was deeply involved in the work package WP19 of the Hadron Physics3 European project in the FP7 based on the highly performant prototypes of TRD and RPC detectors and the associated front-end electronics at chip level for high counting rate environment developed for CBM experiment at FAIR. We presented also a proposal for Horizon 2020.

The 16^{th} CBM Collaboration Meeting in Romania in 2010, highly appreciated by all participants, emphasized the important contribution of our group to the R&D activities for CBM.

Fitting out of a technological infrastructure and training people for detector design, construction and test allowed not only to participate in R&D activities for TRD and ToF subdetectors for the CBM experiment, but later on, to be involved in other projects at European level of similar complexity.

Experience in modern electronics design situates 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 will surely pay back in the coming 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.

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, masters and PhD theses. They will become highly qualified specialists, extremely useful in various branches of activity. As our previous experience shows, it is essential for a young physicist to be involved in the construction phase of a given experiment before starting calibration and data analysis. Knowing details on the detector performance they could have a deep understanding of the calibration and correction algorithms used later for obtaining correct reconstructed information.