Form B2_EN – Project description

Programme / Sub-programme / Module	5/5.2/FAIR-RO		
Project type	RD		
Experiment	CBM	**Scientific Domain**	Nuclear Matter Physics
Project title / Acronym	Towards CBM experiment construction and physics motivation/HICORDEFEND		
Project duration	2020-2023		

PROJECT DESCRIPTION

1. "State of the art" in the field

Experimental results obtained in ultra-relativistic heavy ion collisions at RHIC and at LHC 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. In this region of the phase diagram a smooth crossover transition from partonic to hadronic matter takes place, similar with what is supposed to happen a few microseconds after the Big-Bang. Besides the amount of extremely interesting results obtained or on the way to be obtained at these energies is equally important to understand 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. Recent theoretical models predict that in neutron stars with 2 solar mass, about 40% of their core is in a deconfined state. These were the main motivations of the beam energy scan program at RHIC - Brookhaven, the 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 Antiproton 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 ($\sqrt{s_{NN}}$ = 4.9 GeV) for gold beam, up to 15 AGeV 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 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 a first order phase transition by measuring hadrons in light and medium heavy ion beams induced reactions. STAR collaboration at RHIC, within the beam energy scan program, performed measurements starting from the top $\sqrt{s_{NN}}$ = 200 GeV down to $\sqrt{s_{NN}}$ = 7.7 GeV energies in Au+Au collisions and even lower in the fixed target experiments. However, because of due to TPC-readout and RHIC accelerator luminosity limitations, the reaction rates being limited from about 800 Hz down to a few Hz at the lowest measured energies, any detailed multi-differential analysis is not feasible. The CBM fixed target experiment is designed to run at interaction rates up to 10 MHz for selected observables like J/Ψ, 1-5 MHz for multi-strange hyperons and dileptons and of 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. CBM experiment 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 experiments 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, efficiency better than 95% and two-dimensional position sensitive Transition Radiation Detectors (TRD) with 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, respectively.

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

Our group is involved in the CBM Collaboration starting from 2003, having essential contributions up to now in developing a new generation of high counting rate TRD and RPC detectors, frontend TRD 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 and efficiency better than 95%, developed by our group. The latest RPC prototypes have 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 chosen to fulfill the granularity requirements at a reasonable number of electronic channels. The intensive in-beam test campaigns at SPS-CERN confirmed their performance. Two such RPCs were successfully tested in the mCBM (mini-CBM) 2019 campaign at SIS18 – GSI, Darmstadt. 4 new prototypes will be prepared, in-house tested and implemented in the mCBM to be tested using the latest generation of the amplifiers and updated firmware for the TDC and DAQ system. The information which will be obtained will be used to decide the final architecture of the inner zone of the CBM ToF subdetector. A mechanical support structure for the inner wall will be designed such to comply the request to be moved nearer to the target for dedicated measurements using only STS and ToF subdetectors.

For the CBM TRD subdetector we developed an original two-dimensional position sensitive TRD architecture which, similar to the CBM-ToF subdetector, will be used in the small polar angles region. Addendum to the CBM-TRD TDR will be finalized and delivered to the evaluation committee. A real size prototype will be implemented in the mCBM for the next in-beam test campaigns. A very compact, with reduced dead zones, mechanical support structure for the four layers of the TRD inner zone will be designed.

In parallel, a new CBM-DAQ compatible interface and associated firmware will be finalized and tested.

Aging tests of different construction components, detectors and electronics will be performed at the Multipurpose Irradiation Facility of our Institute.

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.

Once these results will be obtained, in-kind Contracts for CBM-ToF and CBM-TRD inner zones will be finalized.

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 in the development and construction of which we are committed 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. Using the large dynamical range in the charged hadrons and intermediate mass fragments identification and high statistics for multi strange baryons detailed information on flow observables and their dependence on $\sqrt{s_{NN}}$ will be obtained. We will concentrate in this period to implement the main phenomenological models on our computing farm and generate enough events to be used for such type of multi-differential analysis in order to pin down the most sensitive observables we have to extract from data in order to have an unambiguous interpretation of the physics behind.

3. Project objectives

O1.

1.1 Experimental configuration for aging tests.

1.2 Extensive laboratory cosmic rays and ^{60}Co source tests of the MSMGRPC prototypes with the highest granularity of the CBM-TOF wall, based on two types of low resistivity glass.

1.3 Aging tests of MSMGRPCs based on low resistivity glass.

1.4 Tests in the mCBM setup at SIS-18 GSI, Dardmstadt equipped with the readout electronic chain designed and built for the inner zone of the CBM-TOF wall.

1.5 Module M0 assembling.

O2.
2.1 Implementation of the TRD-2D architecture and detector response characteristics in the CbmRoot.
2.2 Development of tracking algorithms and the studies of performance of tracking using MC generators and GEANT.

O3.
3.1 Design and construction of FASPRO - a special board accommodating 6 FASP s and 96 commercial ADCs.
3.2 Design and construction of a board for two radiation tolerant PolarFire FPGAs.

O4. Development of firmware called General Event Time Streamer (GETS), flexible enough to accommodate future developments with respect to the CBM DAQ.

O5.
5.1 Full in-house tests, using X-ray tubes, of a real size prototype equipped with the above mentioned read-out and data processing system.
5.2 Finalizing the Addendum to the CBM-TRD TDR

O6. Implementation of the 2D-TRD in the mCBM setup, data taking and analysis.

O7. Construction and tests of a production readiness 2D-TRD prototype

O8. Theoretical predictions for the behaviour of flow observables in a multi-differential study. Dependence on collision energy and system size.
This goal is closely related to the physics we want to approach at CBM using both the capabilities of the high-performance detectors we develop and the experience gained in other experiments in which we were and are involved.

4. Description of the methodology and of the activities

The CBM -TOF inner-wall covers about 14 m^2 area in the polar angular range ≈2.5-≈12 deg. The anticipated counting rate for the inner zone is ranging from 30 kHz/cm^2 close to the beam pipe, to about 5 kHz/cm^2 at the largest polar angle covered by the inner wall, with an occupancy better than 5%. Our R&D activity has been focused on the development of a Multi-Strip, Multi-Gap Resistive Plate Chamber (MSMGRPC) for the forward polar angle region of the CBM-TOF wall, the most challenging region in terms of counting rate and hit multiplicity [1].

The prototypes developed by us, have an original architecture of Cu strip geometry on a FR4 substrate not only for the readout electrodes but also for the high voltage electrodes. This gives the possibility to tune independently the signal transmission line impedance in order to match it to the input of the front-end electronics and in the same time to fulfill the granularity/occupancy requirement by adjusting the strip length for a certain strip pitch. In order to maintain their performance in the mentioned high particle flux, the prototypes were equipped with resistive electrodes made of special glass with resistivity lower than the one of the commercial glass used up to now for similar detectors.

The obtained performance of the developed prototypes in terms of efficiency and time resolution, in cosmic ray tests, direct beam exposure or with exposure to reaction products over the full active area, in triggered [2, 3, 4] as well as free streaming readout [5] mode, recommend them as solution for the inner zone of the CBM-TOF wall. The inner wall design was driven by the mentioned counting rate and granularity requirements. It has a modular concept defined by 12 modules of 4 types (M0, M1, M2, M3), staggered in z and x-y directions, such to obtain a continuous coverage of the active area. Inside a module, the counters are staggered on four layers in z directions with a minimum overlap between them in x-y such to obtain a continuous coverage of the active area within the module.

Real size prototypes with the highest granularity of the CBM-TOF wall, based on two types of low resistivity glass (i.e. Chinese doped glass and PicoTech float glass), with 200 μm gap size will be assembled and tested first in the HPD/IFIN-HH detector laboratory with cosmic rays and ^{60}Co radioactive source. Recently we learned that on the market there is available a low resistivity float glass provided by the PicoTech company which does not have the size limitation of the Chinese glass, which would give the possibility to increase the length of the counters of the inner zone. We will assemble prototypes using this float glass for the resistive electrodes, test them and compare their performance with those based on Chinese glass. Once the obtained results in the laboratory in terms of efficiency and time resolution will prove the counter performance, they will be equipped with the readout electronic chain designed and built for the inner zone of the CBM-TOF wall [6] and tested with cosmic rays and in real operation conditions in mCBM at SIS18 facility, GSI- Darmstadt, including exposure to high particle flux.

At the same time, using the high activity gamma source of IRASM facility from IFIN-HH, dedicated aging tests for the MSMGRPCs as well as of the material and components used for their assembling will be performed.

Before going into the construction phase, a production readiness review will be performed, proving the feasibility of the concept. For this step a fully equipped M0 module will be used.

The CBM-TRD detectors are organized in four planar stations of 75 cm width each of them, starting at 435 cm from the target. The physics program where TRD system brings an important contribution is related to clean electron identification for momenta below 8 GeV/c, additional suppression in K-id at higher momentum and nuclear fragments identification in conjunction with ToF. The advent of an improved tracking design realized in the TRD-2D version, developed by our group, opens new perspectives for the physics objectives of the TRD project extending its application from the field of dE/dx measurements to that of position estimation and independent/complementary tracker device. Such application is of paramount importance in free running high particle rates environments where hit combinatorics can be computational overwhelming and can be easily dominated by fake matches.

The TRD prototype developed by us uses a unique segmentation of the read-out electrode, the pad plane, in triangular shaped signal collecting areas of 1 cm^2, coupled with a special feature of our signal read-out amplifier, the FASP ASIC, of pairing such areas to rectangles and parallelograms. This combination of pad-plane geometry and ASIC paring renders effectively a two-fold coverage of the active area with the net outcome of identifying the anode wire where the ionization amplification takes place. In terms of observables the TRD-2D offers a position precision across wires of the order of the anode wire pitch (less than 800 μm) and redundant energy measurement for increased dE/dx precision and less systematics. Position and energy performances of our TRD-2D design as well as particle rate capabilities were reported for irradiation environments starting from laboratory ^{55}Fe spectra to X-rays tube rate tests and complex tracking setups at large facility accelerators (PS, SPS @ CERN).

The first topic which is developed in the project is the Data Acquisition (DAQ). It is based on an already available and tested ASIC-Fast Analog Signal Processor (FASP) with a non-diagonal input read-out matrix. The pairing of input signals in various combinations enable a two-fold coverage of the active area with heuristic advantages mainly for position observables. FASP is a 16 channel ASIC with a minimal digital processing of the signal. The FEE has to be complemented by commercial ADCs and a digital power-horse based on radiation tolerant PolarFire FPGAs. The last component implements a firmware called General Event Time-Stamping Streamer (GETS) which is flexible enough to accommodate future developments with respect to the CBM DAQ. The three types of chips have to be integrated on two boards, FASPRO and GETS, the first housing 6 FASPs and 96 ADCs, and the second 2 FPGA.

The FASP/GETS based DAQ operating the TRD-2D will be further integrated in a Common Read-out Interface (CRI) oriented CBM DAQ. This development parallels that of the CBM-DAQ group which is also moving from the AFCK board to the CRI. First objectives here are to reuse the existing resources available on the current CBM-DAQ chain, FLIB board and GBTx (C-ROB) transport in a new configuration compatible with the future CRI based CBM DAQ. A second step in this development is foreseen once the CRI boards become available, and it involves transporting the firmware on the new platform and tests at mCBM at SIS18 at GSI.

The objectives proposed for the current project will cover aspects of TRD-2D sub-system integration in the general TRD system as the following are concerned: DAQ, mechanics and simulations. All these multidisciplinary studies are correlated with the current status of the CBM-TRD realization in particular and with the CBM in general for all mentioned topical directions. For each direction detailed plans are foreseen such that integration is checked by clear milestones of increasing complexity.

All efforts are foreseen to result in three major project-wise results for the TRD R&D direction: global data acquisition in the mCBM experiment, TDR-Addendum documentation and a production ready final prototype.

In high energy heavy-ion collisions new phases of hot and dense nuclear matter can be formed. Changes of physical observables analyzed in multi-differential analyses of the experimental data, when varying the beam energy (the excitation function), the system size, and the centrality of the colliding systems, can reveal the phase properties. The collective transverse flow developed in the heavy ion collisions is considered to be sensitive to the equation of state (EoS) of QCD matter, since it is driven by the pressure gradients in the early stages of the reaction and provides information on the dense phase of the collision. Thus the most promising probes to study the high density QCD matter at SIS100 energies are the flow observables of identified particles. The CBM experiment will dramatically improve the data situation in this energy domain and the multi-differential analysis of spectra, flow, collective effects will be performed even for rare particles with unprecedented precision [7].

Our group has significant contribution to key detectors in these types of measurements.

On the other hand, we have implemented computing codes based on theoretical transport models (JAM, UrQMD, PHSD) on the local Data Center and succeeded to describe the experimental excitation function of the elliptic flow coefficient, v2, measured by several experiments, which evidenced a transition from squeeze-out to in plane elliptic flow. The existent theoretical models give the possibility to explore the sensitivity of the different flow observables to the equation of state in a multi-differential study. Their predictions could motivate and orient the experimental multi-differential analyses of different flow observables, our group will address at SIS100 energies. These studies will also benefit of the experience and results obtained by our group at lower and higher energies within the FOPI and ALICE collaborations, respectively [8-10].

References

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5. Milestones and expected results

Objective Code	Objective description	Milestones	Expected results	Time schedule justification
O1.1	Experimental configuration for aging tests	Design and construction of the mechanical structures for aging tests	Installation on the site, cabling, gas flow, very preliminary tests	30.12.2020
O1.2	Extensive laboratory tests of the MSMGRPC prototypes based on two types of low resistivity glass.	Efficiency, cluster size and time resolution as a function of high voltage. Dark rate and dark current.	Working curve as a function of HV. Comparison between the two types of counters.	30.12.2021
O1.3	Aging tests of MSMGRPCs based on low resistivity glass.	Experimental setup. Expose the MSMGRPC at different gamma ray dose.	Mechanical support design and construction. Efficiency, time resolution, dark current and dark rate.	
O2.1	Implementation of the TRD-2D architecture and detector response characteristics in the CbmRoot.	The architecture of the TRD-2D and its response will be included in the CbmRoot.	Checks of the STS kinematics extension and particle density based on CbmRoot.	
O2.2	Energy and position resolution of the TRD-2D for typical CBM simulations in the electron setup @ SIS100	Quality Assurance methods for position and energy observables.	The x-y position resolution and energy resolution.	
O3.1	Design and construction of FASPRO - a special board accommodating 6 FASP s and 96 commercial ADCs	A special board accommodating 6 FASP s and 96 commercial ADCs.	Electronic tests of the FASPRO	
O3.2	Design and construction of a board for two radiation tolerant PolarFire FPGAs.	A board for two radiation tolerant FPGAs.	Electronic tests of GETS.	
O4.	Development of GETS.	Firmware development.	Pulser tests.	

O5.1	Full in-house tests of a TRD equipped with the read-out and data processing system.	Implementation on the TRD-2D prototype.	In-house ^{55}Fe and X-rays tests.	
O1.4 O.6 5.2	Tests in the mCBM setup at SIS-18 GSI. Implementation of the 2D-TRD in the mCBM setup, data taking and analysis. Finalizing the Addendum to the CBM-TRD TDR.	Integration of the MSMGRPC prototypes in the mTOF subsystem of the mCBM. The mechanical structure will be designed and realized. The Addendum of CBM-TRD-TDR will be issued.	Evaluate detector performance in real operation conditions. In-beam tests within mCBM. Data calibration and analysis. Evaluation	30.12.2022 According with the mCBM beam time schedules.
O7. O1.5 O8.	Construction and tests of a production readiness 2D-TRD prototype. Module M0 assembling Theoretical predictions for the behaviour of flow observables in a multi-differential study.	Construction of the prototype. Drawings of the housing box, back panel and mechanical components. MSMGRPCs assembling. High statistics MC events will be generated and observables of interest will be constructed in a multi-differential way.	Construction tests. M0 assembling and tests Mulți-differential analysis of generated data.	30.12.2023 According with the mCBM beam time schedules.

6. Deliverables and outcome of the project

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, Journal of Instrumentation, Europhysics Journal A, Romanian Journal of Physics, Journal of Physics: Conference Series and PoS-sissa and presented to international conferences in the field like EPS-HEP2019, Ghent, Belgium, ICHEP2018, Seoul, Korea, International School on Nuclear Physics,

Neutron Physics and Applications, September, 2017, Varna, Bulgaria, International Balkan Workshop on Applied Physics and Material Science, Constanta, Romania (2016,2017,2018,2019) and Workshop on Resistive Plate Chambers and Related Detectors, 2016, Ghent, Belgium. They are also published annually in CBM Progress Reports and are reported regularly to the CBM Collaboration meetings. The results expected to be achieved in the present project will materialize according to the programming and development of the activities, in technical drawings, RPC and TRD prototypes, associated electronics modules, mechanical components, firmware development, computing codes development and implementation, a detailed documentation on the obtained results, TRD-TDR Addendum (2022), weekly dedicated seminars. They will be published each year 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.
Our results will be made known regularly in the HPD web page http://niham.nipne.ro and HPD Courier (https://niham.nipne.ro/HPD_Courier.html).

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

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.

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.

At the CBM TRD review, GSI, March 14th & 15th 2017, the reviewers appreciated our results as demonstrated in their conclusions listed below:

- In general, the tests for the 'baseline chamber & electronics' solution should come at least to the level of completeness and clarity that was presented for the 'alternative chamber & electronics' solutions.
- The alternative chamber design is certainly very elegant and innovative, and the level of evaluation and tests is very impressive.
- The performance of the alternative electronics is also demonstrated to work well.

Integration in mCBM experiment in real operating conditions will demonstrate the quality of our work and will validate the physics program we want to approach.

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, master 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.

Construction of instruments for such large experiments is a real challenge, not only for young scientists. The work is done in teams and tightly scheduled. The components of the work are not only research or technical. They also include an international team, used advanced tools, equipment and software, complex variety of laboratory equipment, conditions and methods of work, management of the research team, schedules, system implementations and commissioning, frequent seminars, joint decisions, very accurate weighing of the cost and labour involvement, feasibility studies, weighting risk-taking and research responsibility for team work and for individual members. These factors together shape in a unique way the personality of a young scholar. All these aspects are also taken into account in our „Summer Student Program" which becomes already a tradition în HPD gaining visibility among students abroad. Outreach activities contribute to attracting future physics students.

Our results could constitute for instance an input for Applied research and Technological transfer with application to high sensitivity whole–body PET imaging.