Formular B-RO

Programul:	**CAPACITĂŢI / RO-CERN**	**Tipul proiectului:**	
Tematica ELI-NP	**-**	**FAIR experiment**	**CBM**
Titlul proiectului	**High Counting rate PID Detectors and Front-End Electronics for CBM experiment**		
Codul proiectului		**Acronimul proiectului**	**HICOR-DEFEND**

B - DESCRIEREA PROIECTULUI

1. "State of the art" in the field

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Worldwide experimental and theoretical efforts are devoted in our days to the exploration of the phase diagram of nuclear matter in extreme conditions of temperature and density. Normal nuclei with a net baryon density equal to one consist of protons and neutrons. At moderate temperatures and densities nucleons are excited to baryonic resonances which decay by the emission of mesons. Towards higher temperatures baryon-antibaryon pairs are created. Such a mixture of strongly interacting baryons, antibaryons and mesons is called hadronic matter or baryonic matter if baryons prevail. At very high temperatures or densities the hadrons melt and their constituents, the quarks and gluons, become free and form a new phase of deconfined matter. For very low net baryon densities where the numbers of particles and anti-particles are approximately equal, theory predicts such a transition above a temperature of about 160 - 180 MeV. 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. QCD lattice calculations suggest a critical end point at relatively large values of the baryon chemical potential. Bellow this critical endpoint, for larger values of net baryon densities and lower temperatures, a phase transition from hadronic to partonic matter with a phase-coexistence region in between is expected. Inspired by large N_c (number of colors), limit of QCD, a new phase of so called quarkyonic matter could exist beyond the first-order phase transition at large baryon chemical potentials and moderate temperatures. Highly dense and cold nuclear matter is expected to exist in the core of neutron stars and at very high densities correlated quark pairs are predicted to form superconducting quark matter. Therefore a rich structure of QCD phase diagram at finite values of baryon chemical potentials is predicted by theoretical models. The experimental exploration of these prominent landmarks of the QCD phase diagram is a real challenge. Quantitative experimental information on the properties of hadrons in dense matter will give information on chiral symmetry restoration and the origin of hadron masses. Hot and dense finite-size pieces of nuclear matter in a wide range of temperatures and densities could be created in the laboratory by colliding atomic nuclei at high energies. The goal of the experiments at RHIC and LHC is to investigate the properties of deconfined QCD matter at very high temperatures and almost zero net-baryon densities. Several experimental programs are devoted to the exploration of the QCD phase diagram at high net-baryon densities, i.e.: Beam Energy

Scan (BES) program at RHIC, upgraded NA49 experiment (NA61) at SPS, in Dubna, a heavy-ion collider project NICA at JINR and heavy ion program of RIKEN. However, due to luminosity or detector limitations these experiments are constrained to the investigation of abundantly produced particles. In contrast, the Compressed Baryonic Matter (CBM) experiment at Facility for Antiproton and Ion Research (FAIR) in Darmstadt is designed for precision measurements of multidimensional correlations among different observables including particles with very low production cross sections, hyperons, heavy flavor hadrons, hypernuclei and strange objects, using the high-intensity heavy-ion beams provided by FAIR accelerators.

2. Place of the project in the framework/context of the FAIR Centre research programmes (Sec. 1.2)

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FAIR facility in Darmstadt will provide unique research opportunities in the fields of nuclear, hadron, atomic and plasma physics. The CBM experiment is a fixed target experiment with the mission to investigate the high net-baryon density matter produced in nucleus-nucleus collision in an energy range between 2 – 45 GeV/u. Results of transport code calculations for central Au+Au collisions predict initial state baryonic densities up to a factor 7 higher than the saturation density at beam energies of ~10A·GeV. Under these conditions the nucleons overlap, and theory predicts a transition to a mixed phase of hadrons and quarks. The research program devoted to the exploration of compressed baryonic matter will start with primary beams from SIS100 (protons up to 29 GeV, Au up to 11A GeV, nuclei with Z/A = 0.5 up to 14A GeV) and will be continued with beams from SIS300 (protons up to 90 GeV, Au up to 35A·GeV, nuclei with Z/A = 0.5 up to 45A·GeV). The beam extracted to the CBM cave will reach intensities up to 10^9 Au ions per second. The interaction rate will reach up to 10^7 reactions per sec with a charged particle multiplicities up to 1000 per event. In order to meet the challenging physics goal of measuring rare probes at such high interaction rate and multiplicity, the experimental set-up has to identify leptons and hadrons in a high counting rate environment. This requires fast and radiation hard detectors, self triggered electronics and fast on-line event selection.

Our group from HPD (Hadron Physics Department)/IFIN-HH is involved in CBM experiment, one of the main experiment at FAIR, since the collaboration was initiated, more than 10 years ago. We embarked on R&D activities for developing a new generation of detectors for two detection subsystems of the CBM experimental setup: the Time of Flight (ToF) and Transition Radiation Detector (TRD).

The CBM ToF subsystem will be positioned at 6 m from the target in the initial phase of the CBM set-up for SIS100 accelerator and at 10 m in the final version for experiments at SIS300 accelerator. The CBM - TOF wall will be built based on of state-of-the-art Multigap Resistive Plate Chambers (MRPC). With a surface of ~150 m^2 it covers polar angles between 2.5^0 to 25^0 with a full azimuthal coverage. A system time resolution better than 80 ps is needed with a detection efficiency better than 95%. The challenge for ToF detectors is to maintains this performance even at the highest anticipated rates. The counting rate goes from 25 kHz/cm^2 in the most inner zone to less than 1 kHz/cm^2 at the ToF wall edges. We have developed RPC prototypes, addressed to the most inner zone of the ToF wall, based on technological solutions which maintain their performance at high counting rates. In order to reach this goal we used lower resistivity and thinner glass electrodes and new architecture of the read-out electrodes.

The TRD subdetector should perform intermediate tracking between STS and TOF for the charged particles with a position resolution across the pads of 200 – 300 μm, 3-30 mm along the pads and provide electron identification with a pion rejection factor better than 100. This performance has to be maintained up to about ~100 kHz/cm^2 counting rate anticipated for the most inner zone of the first TRD station. The CBM TRD subsystem, in the current design, will comprise three stations with four layers per station for the first two stations and two layers for the third one. The total area of the detector of about 600 m^2, will be covered by ~700 chambers with a total number of ~750 000 readout channels.

3. Project objectives

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The objectives of the present project are focused on detailed tests of the latest prototypes of high counting rate RPC and TRD developed by our group. These tests wil be performed using radioactive sources, cosmic rays and mixed beams or reaction products, close to real conditions.

Our R&D activities aim to find technological solutions for developing new TRD architectures which improves the conversion efficiency of the transition radiation in a single TRD chamber, while coping in the same time with high counting rates, up to 100 kHz/cm^2. In parallel with the TRD prototype we developed dedicated front-end electronics called Fast Analog Signal Processor (FASP-V01) for processing the fast signals of the TRD prototypes. The first version of FASP has 8 input/output analog channels, each with two types of outputs: a fast output with semi-Gaussian shape and a peak-sensing output signal. The peak sensing output provides an optimum in term of performance and delivered information to be used in data processing foreseen for CBM experiment.

Dedicated mother boards in SMD technology will be designed and produced for interfacing the detectors, front-end electronics and DAQ systems for increasing the number of channels with a higher degree of integration. A free running DAQ based on MAXIM ADC and FPGA will be realized for testing the detectors and front-end electronics in close to real conditions.

The RPC and TRD prototypes are designed, constructed and tested with cosmic rays and radioactive sources in the Detector Laboratory from DFH/IFIN-HH, equipped at international standards, well known and appreciated at international level. The results obtained from the in-beam tests performed at international experimental facilities as CERN-PS, SIS18 of GSI Darmstadt or COSY of FZ Juelich confirmed the performance of these detectors.

Objective O1.

Cosmic rays and in-beam test of the proposed basic architecture of the inner zone of the CBM-ToF wall. Tests in high counting rate test over the whole active area of the basic architecture of the inner zone of the ToF wall.

Objective O2.

Radioactive source, cosmic rays and in-beam test of the real size TRD prototype.

Optimization of the propagation of the dead zones in the architecture of the CBM-TRD stations.

Objective O3.

Design and construction of new motherboard for interfacing the FASP-V01 ASIC chip with DAQ systems.

Objective O4.

A functional prototype for fast acquisition system.

4. Description of the methodology and of the activities

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

The results of R&D activities were periodically reported to the bi-annual CBM Meetings, International Workshops and Conferences and published in ISI journals. The description of the prototypes and their performances are included in two Technical Design Reports (TDR) of the CBM-ToF and CBM-TRD detectors. The CBM-ToF TDR had the internal review in October 2013 and in present is under EC-FAIR evaluation. The TDR of the CBM-TRD detector will be finalized by mid 2014.

A confirmation of the international impact of the results obtained so far is the organization of a successful International CBM Workshop, Mamaia, Romania, September 27-October 1 (2010).

Back 1999 we proposed a new multigap RPC architecture (MGMSRPC) based on multistrip readout electrode. The very first prototype used commercial float glass and single ended readout (signals picked up only from the central anode). On such architecture developed by us was based the upgrade of the FOPI TOF barrel. The successful commissioning of FOPI TOF barrel (ToF system time resolution ~90ps, MSMGRPC time resolution ~70ps) has demonstrated that large area detectors based on such an architecture is achievable.

The MGMSRPC prototypes developed further with higher granularity and for high counting rate environments were built based on the special low resistivity glass and a differential readout. Such an architecture is less sensitive to the external noise and the effect of internal cross talk between transmission lines corresponding to different strips is reduced. For the region of small polar angles of CBM-TOF a high granularity is required. Therefore we designed, built and tested RPC prototypes with strip sizes which fit the granularity requirements of CBM-TOF. The results of the in-beam tests demonstrated an efficiency better than 95% and a time resolution ~50 - 60 ps. The cluster size of about three strips allows for position reconstruction across the strips with ~400 μm resolution. The position resolution along the strip is 4-5 mm.

A basic structure for the inner zone of the CBM-ToF wall we constructed using two identical RPCs which were mounted in a tight gas box staggered along the readout strips. The prototype was tested in high counting rate at COSY facility in Juelich. The obtained results showed that the efficiency is still better than 90% and the time resolution is better than 80 ps at 100 kHz/cm^2 exposing the counter on an area of the beam spot. The next step was to complete the basic architecture for the most inner zone with the staggering on both directions, across and along the strip direction. The four cells prototype was constructed and tested in the laboratory with radioactive sources. The cosmic ray tests are in progress. In the in-beam test we are going to test the efficiency, cluster size and time resolution for this architecture. A high counting rate test with an uniform exposure of the whole active area of the 4 RPC cell prototype needs to be performed in order to confirm the counter performance obtained in the former high counting rate test on a rather limited area of the counter. Based on the RPC architecture developed by us for the inner zone of the CBM-ToF wall will be finalized the design of this special zone of the CBM-ToF wall. It will be integrated in the general structure of the CBM-TOF subdetector.

Our first TRD prototype for high counting rate environment was built as a single MWPC with a 3 mm anode-cathode distance. The high counting rate test performed at GSI Darmstadt showed that up to 100 kHz/cm^2 the gain drop is small and the position resolution degradation is of only few tens of µm. However, this prototype has a low conversion efficiency of the transition radiation in the thin gas layer. For this reason we proposed a new TRD architecture which improves the conversion efficiency of TR in a single TRD chamber, maintaining the counting rate performance of the previous prototype. This was based on two MWPC readout by a common pad plane positioned in the middle of the counter. In order to access the position information in two directions which define the plane of the readout electrode a new prototype with triangular shaped pads, each triangle being readout separately, was developed. This prototype maintain the PID and position resolution performance up to 150 kHz/cm^2 counting rate. However, due to the special way in which the signal connectors are positioned on the lateral side of the detector, a large TRD detector based on a such architecture has a geometrical efficiency of ~75%. For this reason, a third prototype based on a single MWPC coupled with a small drift region was developed. The readout electrode of the detector has the same design as for the previous ones but the signal are now taken out on the back side of the pad plane. Based on these results we designed and built a real size prototype of 60 cm x 60 cm with this architecture. For the in beam test of the prototype a mixture of electrons and pions will be used in order to estimate the pion rejection performance and the position resolution on the two directions which define the readout electrode plane. Detailed X-ray source and cosmic rays tests are in progress. In beam test in high counting rate environment all over the counter are mandatory for the final decision on the architecture of the electrodes. A design of the inner zone of the first TRD station, based on the developed real size prototype has been started. We are going to optimize the propagation of the dead zones corresponding to the chambers frames on the active area of TRD layers of the next stations in order to minimize their effect on the geometrical efficiency and number of the TRD layers needed to reach a pion rejection factor of 100.

A dedicated front-end electronics called Fast Analog Signal Processor (Fasp-V01) was developed for processing the fast signals of the double MWPC architecture. For the 40 ns shaping time set for FASP there is a very good proportionality and linearity of the signal with the input charge was obtained. Detailed tests of TRD chamber and associated front-end electonics are in progress. Multidimensional analysis of the data will give the necessary input information for designing next generation of FASP including many new features which will enhance the total performance of the detector operated with this front-end electronics, in terms of signal collection, position information, dynamical range, cross-talk and noise. The actual FEE boards used in the radiactive sources and in-beam tests have eight input/output channels. For the detailed tests mentioned above, the operation of a large area of the counter is required. Therefore, new motherboard with two FASP chips will be designed and constructed. Such a new FEE board will have 16 input/output channels. This will increase the number of read-out channels with higher degree of integration. In order to provide the necessary operation infrastructure for FASP chips, the motherboard will contain three main blocks. The first one is an analog buffer block of 16 operational amplifiers for impedance matching, additional gain and differential output signals. The second one is the logic block for handling protocol signals EVT, REQ, RST and RDY. The power supply block is the third one, used to provide the low voltage to FASP, to other electronic components implemented to the motherboard, the reference voltages for the output baseline and threshold. In order to test these performance in close to real conditions required for CBM, free running mode acquisition system has to be developed. A very first version will be realised using a FPGA circuit , a flash memory, a JTAG connector and a clock circuitry. An evaluation kits offered by FPGA manufacturer contains clock circuitry, flash memory, hundred of MBytes RAM memory, graphical interface, USB interface, LCD display. Complex applications can be developed using Integrated Software Environment (ISE). A digitizing board will be realized within the project. It will contain 64 analog to digital independent channels, operational amplifiers, 2 FPGA Mezzanine Card (FMC) connectors to fit in with the developed boards and an input connector for 64 single ended inputs. A software development will be implemented in the FPGA logic. It will contains 64 processes for data de-serializationfrom MAXIM ADCs; one process for the de-serialization of ID Event; ID event provide a semnal for the Time Stamp which will accompany all the registered interactions in detectors and will be used for event reconstruction. An Ethernet device, TCP-va fi implementat folosind un microprocesor soft. IP server will transmit the packed data to the outside. The TCP-IP server will be implemented using a soft microprocessor, MicroBlaze; the communication between the microprocessor and the de-serialization processes (data and IDEvent) will be realized by several general purpose ports. Auxiliary processes for clock generation and monitoring will be also implemented.

Objective O1 activities.

- Experimental setups for the cosmic rays and the in-beam tests of the MGMSRPC prototypes
- Data acquisition and on-line monitoring
- Data calibration and analysis

Objective O2 activities.

- Experimental setups for the cosmic rays and the in-beam test of the HCRTRD prototypes
- Data acquisition and on-line monitoring
- Data calibration and analysis
- Optimization of the design of the CBM-TRD stations using AUTOCAD

Objective O3 activities.

- Development of the schematic diagram
- Layout design using ORCAD software
- Motherboard prototype manufacture

Objective O4 activities.

- Software packages, acquisition board design and manufacture
- Acquisition system – experimental model
- Data acquisition and on-line monitoring

5. Milestones and expected results

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

Objective Code	Objective description	Achievement indicative (measurable)	Planned value (unity of measurement)	Time schedule justification
O1	Cosmic rays and in-beam test of the proposed basic architecture of the inner zone of the CBM-ToF wall. Tests in high counting rate over the whole active area of the basic architecture of the inner zone of the ToF wall.	Time resolution, efficiency, cluster size. Time resolution, cluster size as a function of counting rate. Presentation at the CBM meeting. CBM Progress Report.	Time resolution better than 80 ps, efficiency larger than 95%. Time resolution better than 80 ps at the highest counting rate reached in the measurements. 1 presentation	Depending on the schedule of the common in-beam tests in the CBM Collaboration and the financial support of the in-beam tests.
O2	Radioactive source, cosmic rays and in-beam test of the real size TRD prototype. Optimization of the propagation of the dead zones in the architecture of the	Electron pion discrimination performance. Two dimensional position reconstruction.	A 1% pion misidentification probability for 6 TRD layers. Position resolution of 300 – 500 µm across	Depending on the schedule of the common in-beam tests in the CBM Collaboration and the financial support of

	CBM-TRD stations.	Presentation at the CBM meeting. CBM Progress Report.	the pads and 1 -3 mm along the pads. 1 presentation 1 ISI paper	the in-beam tests.
O3	Design and construction of new motherboard for interfacing the FASP-V01 ASIC chip with DAQ systems.	Circuit diagram PCB layout Motherboard manufacture and electronic tests.	Design drawings PCB motherboard Results of the electronic tests.	
O4	A functional prototype for fast acquisition system.	Acquisition rates. data synchronization and integration. Presentation at the CBM Meeting. CBM Progress Report.	Acquisition rates up to 100 kevents/s. 1 presentation	Depending on the schedule of the common in-beam tests in the CBM Collaboration and the financial support of the in-beam tests.

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.

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). 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 WWW-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 is 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 supposed to be financed, once accepted, starting from 2015.

The 16th 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.