Romanian research projects at FAIR

2016 - 2019

Bucharest-Magurele, ROMANIA
2021

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Brief Overview of the Romania-FAIR Cooperation

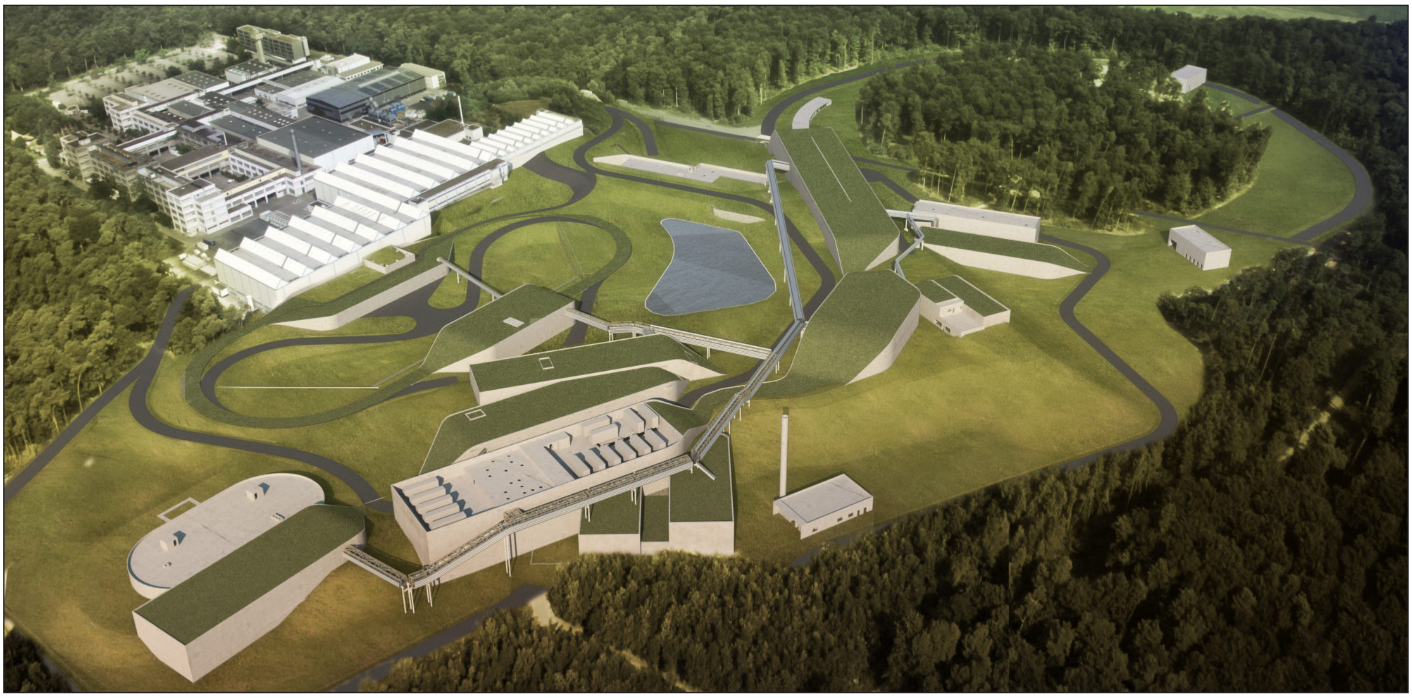
FAIR, **F**acility for **A**ntiproton and **I**on **R**esearch in Europe, one of the largest research projects worldwide, is being built in Darmstadt, Germany. At FAIR, matter that usually only exists in the depth of space will be produced in a research laboratory. Scientists from all over the world will gain new insights into the structure of matter and the evolution of the universe from the Big Bang to the present. FAIR is under construction at Helmholtz Centre for Heavy Ion Research (*Gesellschaft für Schwerionenforschung* – GSI). Its existing accelerator facilities will become part of FAIR and will serve as first acceleration stage. Disciplinary interoperability frameworks are essential to the realisation of FAIR. Such frameworks have been developed in certain disciplines and often rely on a shared research culture and shared research and data infrastructures. In this respect, accelerator experts, scientists and engineers of FAIR and GSI are working closely together, all over the world, for the realization of FAIR.

FAIR will be one of the largest and most complex accelerator facilities in the world. The FAIR accelerator facility will have the unique ability to provide particle beams of all the chemical elements (or their ions), as well as antiprotons. The particles will be accelerated to almost the speed of light in the FAIR accelerator facility and made available for scientific experiments. FAIR will generate particle beams of a previously unparalleled intensity and quality. The existing GSI accelerators will serve as the first acceleration stage. The linear accelerator **UN**iversal **L**inear **A**ccelerator (UNILAC), which is 120 meters long, accelerates particles to speeds as high as 20% of the speed of light. The SIS18 ring accelerator, which has a circumference of 216 meters, accelerates particles to speeds as high as 90% of the speed of light. The ions can then be sent into the SIS100, an underground ring accelerator with a circumference of 1,100 meters which lies at the heart of the facility.

The SIS 100 can accelerate the ions of all the natural elements in the periodic table to speeds as high as 99% of the speed of light. The magnets that keep the ions in their paths are superconducting and are cooled to - 269°C by means of liquid helium.

The research programme at FAIR is based on four experimental pillars:

- NUSTAR collaboration is devoted to the study of **NU**clear **ST**ructure, **A**strophysics, and **R**eactions. More than 700 scientists from more than 170 participating institutes worldwide form the NUSTAR community.
- CBM experiment (**C**ompressed **B**aryonic **M**atter) aims to explore the Quantum Chromodynamics (QCD) phase diagram in the region of high baryon densities using high-energy nucleus-nucleus collisions. This includes the study of the equation-of-state of nuclear matter at neutron star core densities, and the search for phase transitions, chiral symmetry restoration, and exotic forms of (strange) QCD matter. The CBM experiment is realized by an international collaboration of 470 scientists from 56 institutions and 12 countries.
- PANDA collaboration (Anti-**P**roton **AN**nihilation at **DA**rmstadt) with more than 420 scientists from 18 countries intends to do basic physics research on various topics around the weak and strong forces, exotic states of matter and the structure of hadrons. In order to gather all the necessary information from the antiproton-proton collisions a versatile detector will be build providing precise trajectory reconstruction, energy and momentum measurements and very efficient identification of charged particles.
- APPA is an umbrella for several collaborations working on **A**tomic **P**hysics, **P**lasma physics and **A**pplied sciences in the bio, medical, and material sciences. Outstanding for all the collaborations is the sharing among themselves of installations



(*Aerial View of the GSI Centre - Source: https://fair-center.eu*)

(FAIR Partner Countries - Source: https://fair-center.eu)

and experimental techniques, despite diverse research fields. APPA includes the following research collaborations:

- BIOMAT – **B**iology and **MAT**erial science
- FLAIR - **F**acility for **L**ow-Energy **A**ntiproton and Heavy **I**on **R**esearch
- HED@FAIR - **H**igh **E**nergy **D**ensity Science at FAIR
- SPARC - **S**tored **P**articles **A**tomic **R**esearch **C**ollaboration

About 3,000 scientists from more than 50 countries are already working on the planning and realisation of the scientific programme and the experiment facilities.

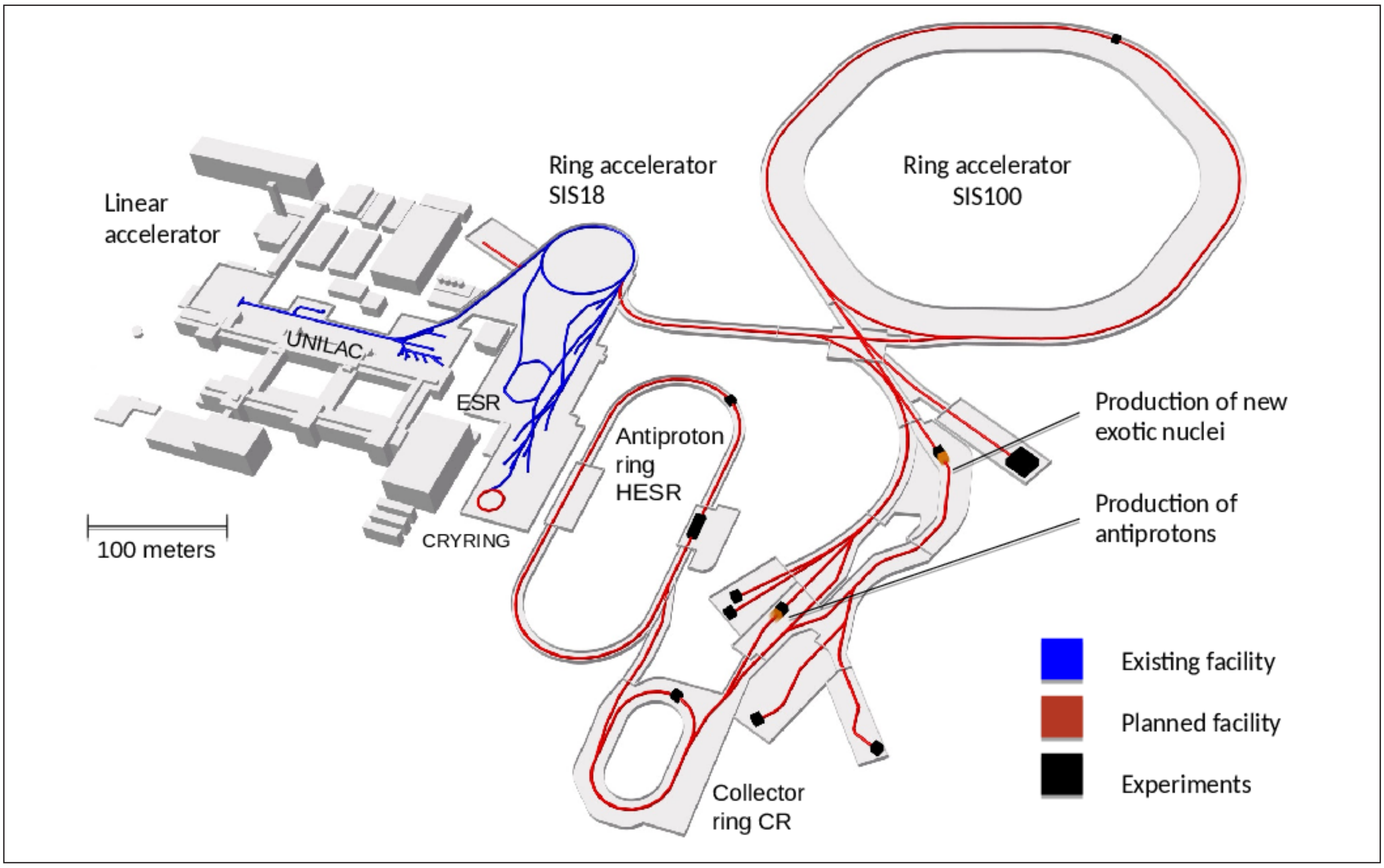
The FAIR Convention was signed on 4th of October, 2010 by the following countries: Germany, Finland, France, India, Poland, Romania, Russia, Sweden and Slovenia. The United Kingdom is an associate partner and the Czech Republic is an aspirant one. Romania is a founding member state based on the Convention on the construction and operation of the FAIR Center, signed on the aforementioned date and ratified by Romania through Law no. 307/2013. Currently, the Romanian shareholder is the Ministry of Research, Innovation and Digitalisation (MCID).

The FAIR projects were financed since 2014 under the National Plan of Research Development and Innovation II. In 2016 a new Programme began as part of the National Plan of Research Development and Innovation III via the 5th programme, Research in areas of strategic interest, Section 5.2 – Participation in international atomic and subatomic research programmes/FAIR-RO Module.

The aim of the FAIR-RO Programme is to finance the Romanian research and development activities required for Romania's participation in the experiments at the FAIR Center. The management of the FAIR-RO programme is conducted by the Institute of Atomic Physics (IFA) based on a financing contract concluded with the national authority for research, development and innovation. (https://www.ifa-mg.ro/fair/)

The scientific monitoring and evaluation of FAIR-RO projects is carried out by the International Scientific Advisory Board (ISAB FAIR-RO) currently comprised of the following scientists : *Dr. Angela BRAEUNING-DEMIAN* (GSI, Darmstadt, Germany) as chair and *Dr. Faiçal AZAIEZ* (Director iThemba LABS, Cape Town & Johannesburg, South Africa); *Dr. Karlheinz LANGANKE* (GSI, Darmstadt, Germany); *Dr. Silvia Monica LENZI* (Padova Univ., Italy) and *Dr. Joachim STROTH* (GSI, Darmstadt, Germany) as members. ISAB FAIR-RO analyses the projects proposals and proposes the budget distribution of the FAIR-RO programme. ISAB FAIR-RO usually meets once per year in conjunction with IFA's funding programmes activity.

In the period 2016 – 2019 eight FAIR-RO projects were funded (Table 1), for a total contracted sum of approx. 11,5 million Lei (approx. 2,5 million EURO) with an average of 12 Full Time Equivalent (FTE) researchers from four institutions.



(Schematic View of the FAIR Accelerator Complex - Source: https://fair-center.eu)

Table 1 - List of scientific projects and financed domains

No.	Scientific Domain/ Experiment	Title & Acronym	Coordinator/ Partners*	Project Director
1	Nuclear Matter Physics / CBM	Physics, Detectors and Frontend Electronics for CBM Experiment (HICOR-DEFEND)	IFIN-HH	Mihai PETROVICI
2	Nuclear Matter Physics / CBM	Predictions for Anomaly States and Phase Transitions in Nuclear Matter Formed in Relativistic Nuclear Collisions at CBM Experiment (PREDICT@CBM)	UB-FF	Alexandru JIPA
3	Nuclear Structure, Astrophysics and Reactions / NUSTAR	Nuclear Structure Research in View of NuSTAR@FAIR (NUSTAR-RO)	IFIN-HH	Nicolae Marius MĂRGINEAN
4	Nuclear Structure, Astrophysics and Reactions / NUSTAR	Nuclear Astrophysics with Indirect-methods and Rare Ion Beams (NAIRIB)	IFIN-HH	Livius Marian TRACHE
5	Nuclear Structure, Astrophysics and Reactions / NUSTAR	Development of Simulation and Analysis Software for High Energy Neutrons Interactions in R3B Experiment (DASHNE)	ISS	Maria HAIDUC
6	Atomic Physics, Plasma Physics and Applications / APPA	Atomic Interactions in Supercritical Fields: Preliminary Investigations for SPARC In-Kind Contributions (SPARC-RO)	INFLPR / ISS	Viorica STĂNCĂLIE
7	Atomic Physics, Plasma Physics and Applications / APPA	Scintillator-Based Detection System for CRYRING Low-Energy Ion Beams (CRYLEDS)	IFIN-HH	Dan Gabriel GHIŢĂ
8	Antiproton Physics / PANDA	Strong Interaction Studies in Antiproton Annihilation (SISTINA)	IFIN-HH	Alexandru Mario BRAGADIREANU

* National Institute for R&D in Laser, Plasma and Radiation Physics (INFLPR), Institute for Space Sciences (ISS), Horia Hulubei National Institute for R&D of Physics & Nuclear Engineering (IFIN-HH), University of Bucharest, Faculty of Physics (UB-FF)

In Fig.1 is presented the budget allocated for the period 2016-2019 and in Fig.2 is shown the distribution of personnel (based on professional degrees) / full time equivalent.

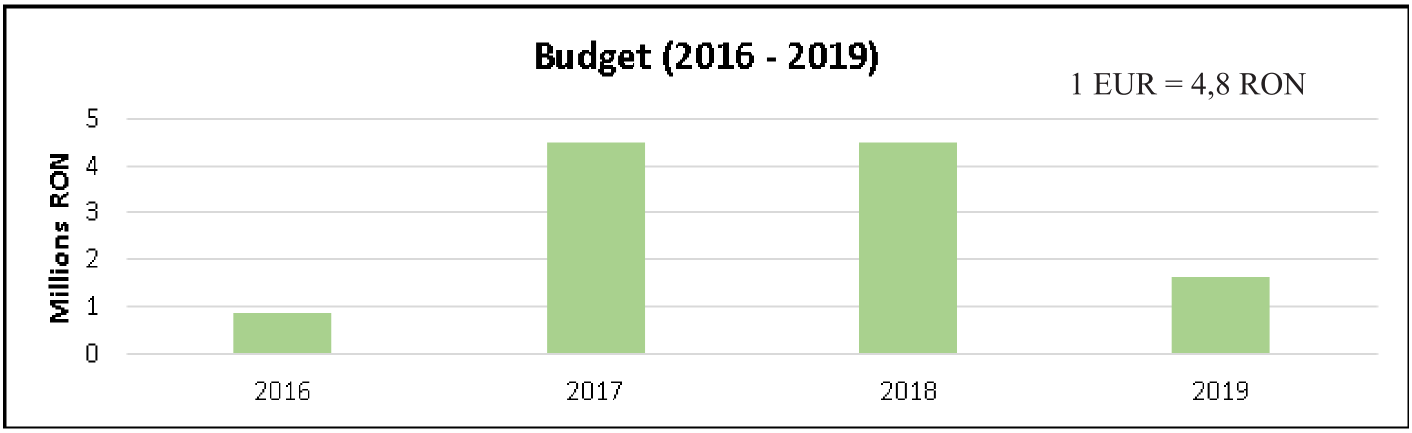
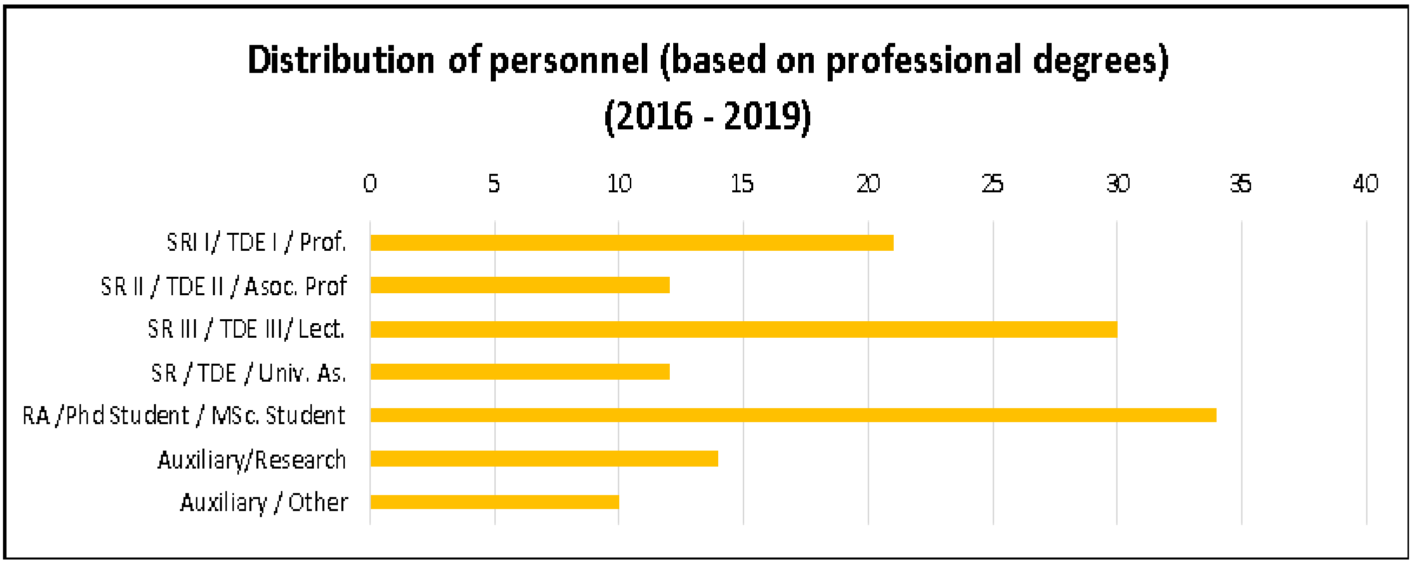


Fig. 1. – The budget allocated for the financed projects for the period 2016-2019



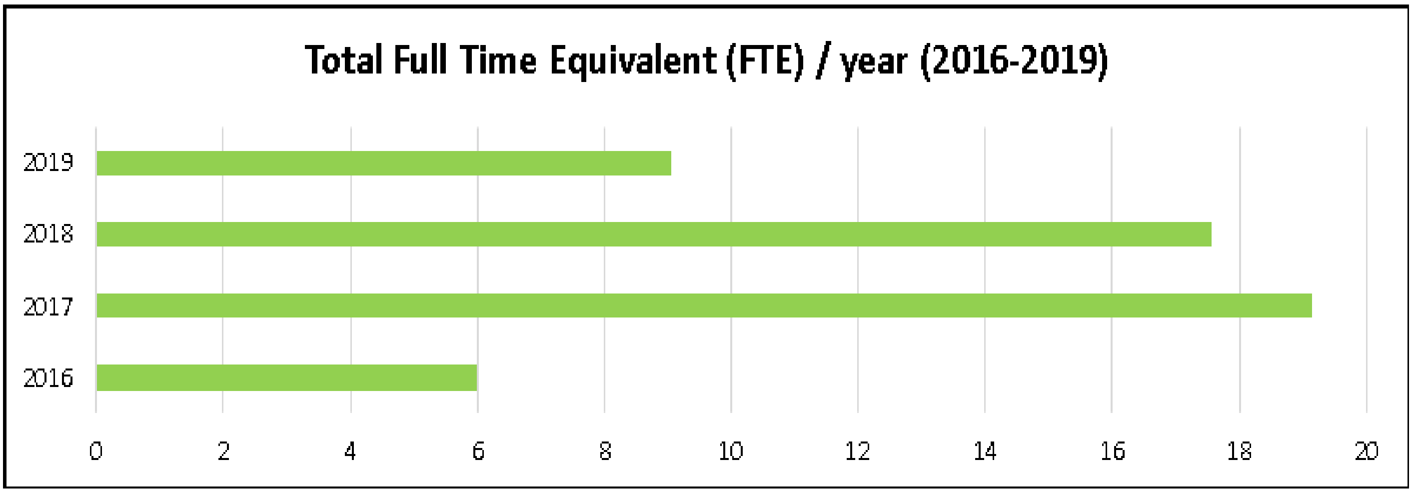


Fig. 2. *– Human resources involvement in FAIR-RO projects (where SR, I, II, II – Scientific Researcher I, II, III; TDE I, II, III – Technical Development Engineer; RA – Research Assistant)*

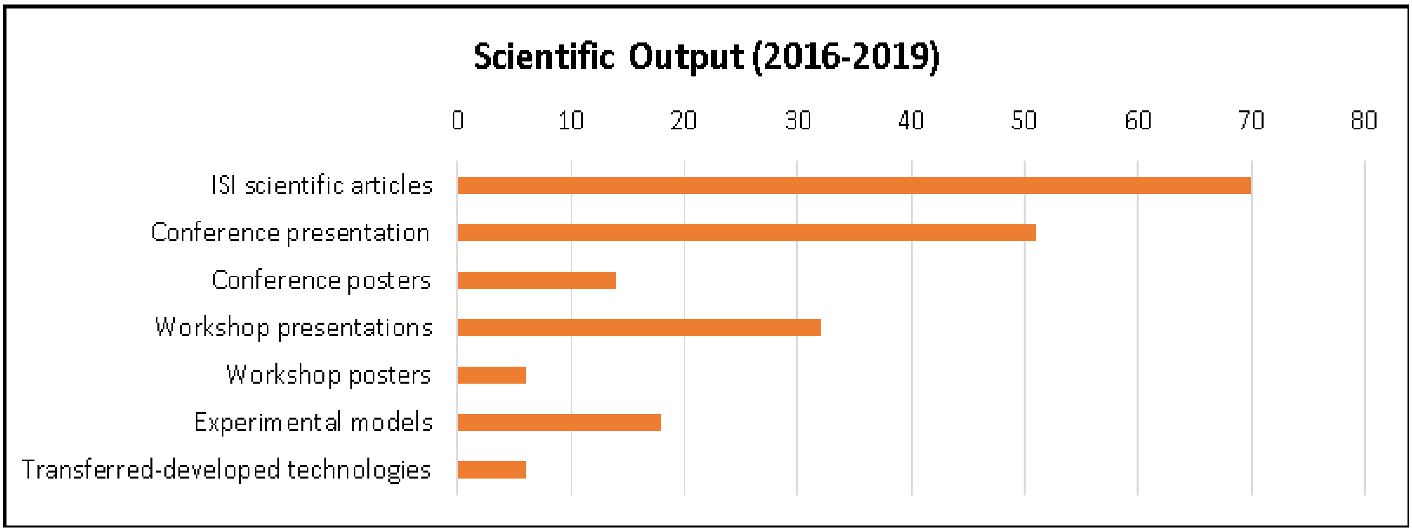


Fig. 3. *Scientific Output for the period 2016-2019*

Physics, Detectors and Frontend Electronics for CBM Experiment (HICORDEFEND)

Project Leader: Prof. Dr. Mihai PETROVICI

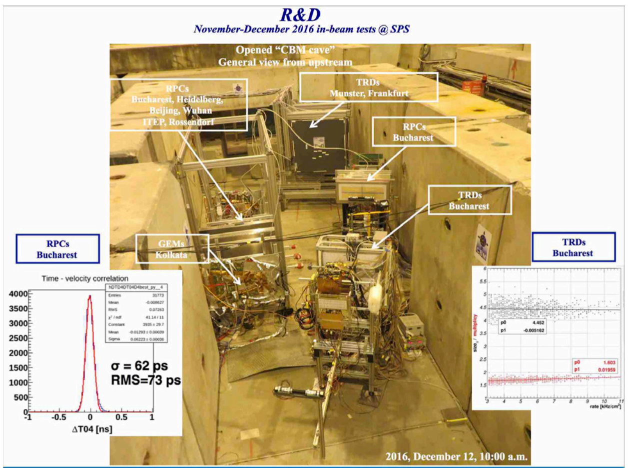
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Experiment: Compressed Baryonic Matter (CBM)
Scientific Domain: Nuclear Matter Physics (NMP)
Project web page: *http://niham.nipne.ro/RO-FAIR_CBM_20.html*

Main objectives of the CBM Experiment/Collaboration:

The experimental exploration of the expected rich structure of the phase diagram of strongly interacting matter predicted by QCD is one of the most challenging tasks of our days.
The Compressed Baryonic Matter (CBM) experiment at FAIR (Facility for Anti protons and Ion Research) in Darmstadt will play a unique role in the exploration of the QCD phase diagram in the region of high net-baryon density. The experiment is designed to run at unprecedented interaction rates accessible at SIS100.

Main objectives of the Romanian participation in CBM Experiment:

Our group is involved in the CBM Collaboration from its very first days, with essential contributions up to now in developing a new generation of high counting rate TRD (Transition Radiation Detector) and RPC (Resistive Plate Counter) detectors, frontend electronics and different versions of free running mode DAQ. These results are included in the CBM-ToF TDR (Technical Design Report), in the meantime accomplished and positively evaluated. An Addendum to the CBM-TRD TDR was sent for evaluation. As a natural consequence, our group will be involved in the assembling and testing of the most challenging regions of these two sub-detectors, i.e. small polar angles. However, the final solution foreseen as production readiness prototypes still require some R&D activity especially related to radiation hardness for detectors and associated electronics and in-beam tests in mCBM (mini-CBM) configuration at SIS18 – GSI, Darmstadt, where close to real conditions could be accessed. In parallel, the new frontend FASP-CHIP and CBM-DAQ compatible interface, designed and built by us will be tested. 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 already and will have essential contributions, and focus our physics program on multi-differential studies of collective type phenomena within $\sqrt{s_{NN}}$ =2−4.9 A·GeV energy range with the aim to understand the fundamental properties of QCD in the corresponding region of the phase diagram.



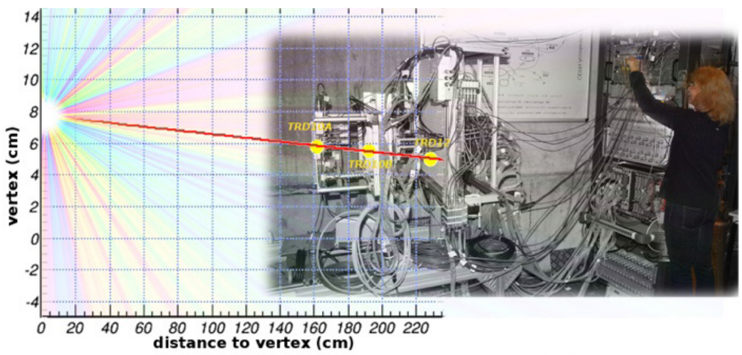


***Fig.1**: Left - in-beam tests at SPS-CERN-time resolution of MSMGRPC developed by us;*
Right - tracking performance using 2D-TRD developed by us.

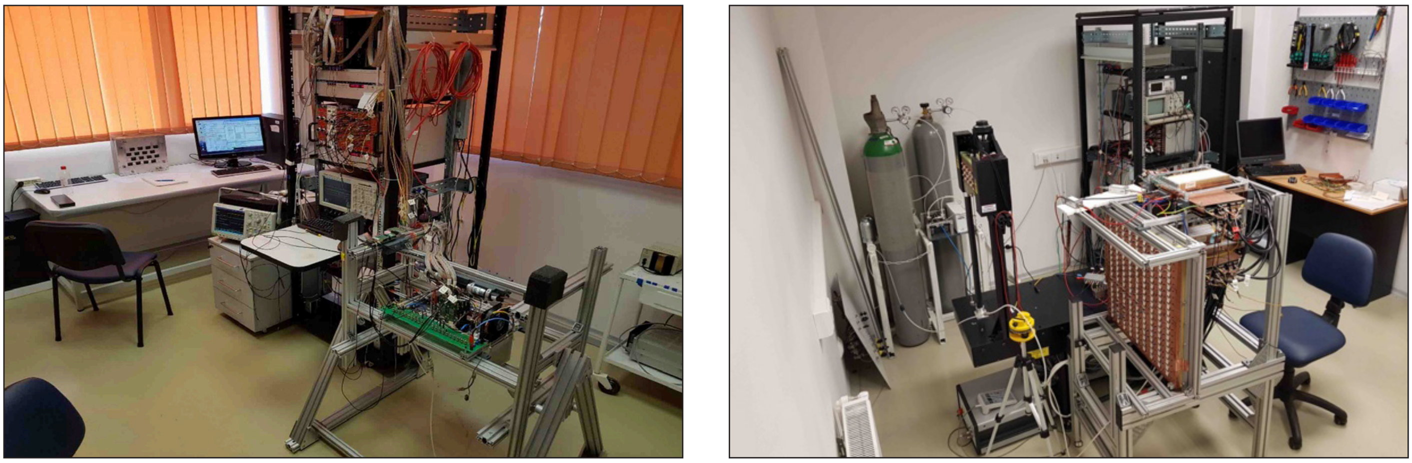


Fig.2: *Left - RPC test laboratory of Hadron Physics Department;*
Right - TRD test laboratory of Hadron Physics Department.

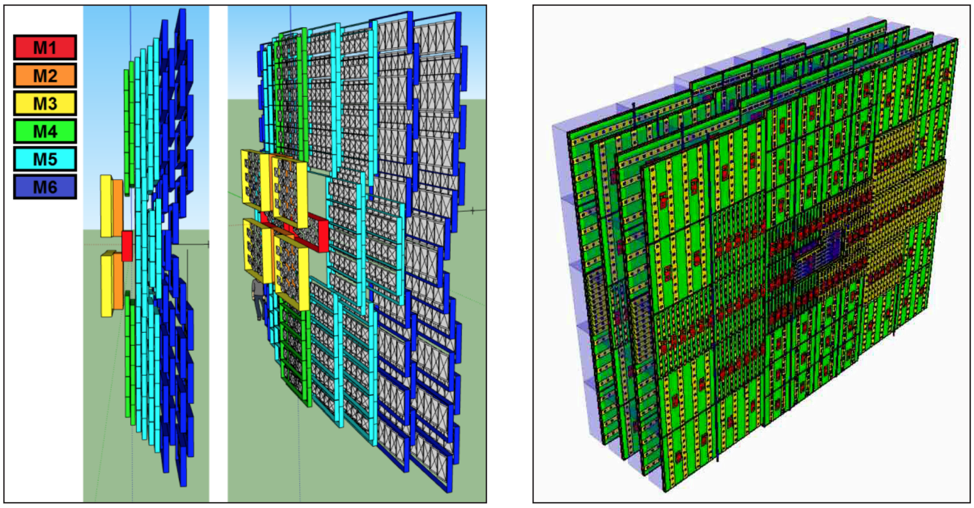


Fig.3*: Left: Inner zone of the CBM-ToF (red, orange and yellow colours) based on MSMGRPC developed by us which will be assembled and tested in HPD;*

Right - Inner zone of the CBM-TRD (red, orange and yellow colours based on two dimensional position sensitive TRD developed by us which will be assembled and tested in HPD

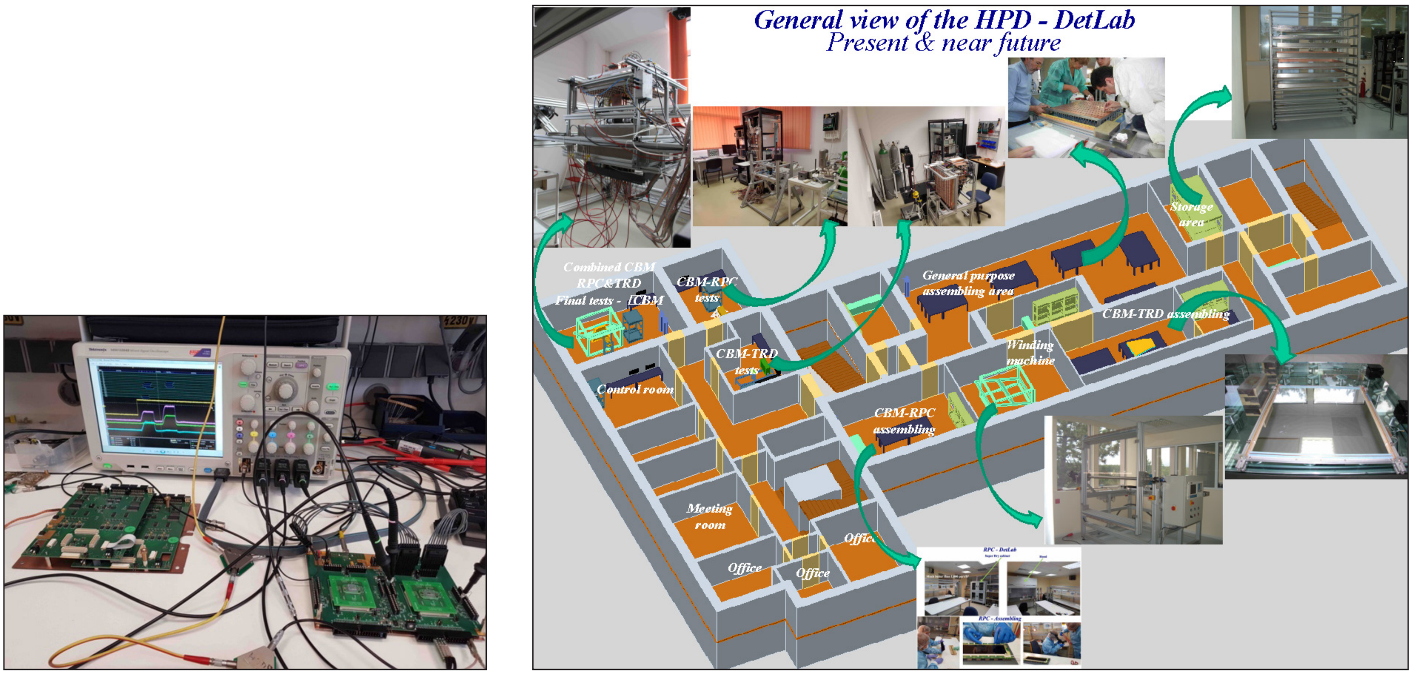


Fig.4:C *Left: Frontend Electronics and DAQ - designed and tested in HPD for CBM TRD-2D;*
Right - Structure of the Detector Laboratories area, properly equipped, used for assembling and tests of ALICE TRD and TPC-ROCs and which will be used for assembling and tests of the most demanding zones of the CBM-ToF and TRD subdetectors.

Predictions for Anomaly States and Phase Transitions in Nuclear Matter Formed in Relativistic Nuclear Collisions at CBM Experiment (PREDICT@CBM)

Project Leader: Prof. univ. dr. Alexandru JIPA
Project Coordinator: University of Bucharest, Faculty of Physics (UB-FF)
Experiment: Compressed Baryonic Matter (CBM)
Scientific Domain: Nuclear Matter Physics (NMP)
Project webpage: *http://brahms.fizica.unibuc.ro/sitecentru/09FAIR.htm*

Heavy-ion collisions at various relativistic energies are used to scan the phase diagram of nuclear matter and search for the critical point and the phase transition boundary. At LHC and higher RHIC energies, QCD matter at very high temperatures and nearly vanishing baryon chemical potential, μ_B, is studied. The data from the Beam Energy Scan program at RHIC are used to investigate the matter characterized by higher μ_B values and moderate temperatures. Complementary, the Compressed Baryonic Matter (CBM) experiment at FAIR will study the QCD phase diagram in the high μ_B region. Quark-gluon plasma (QGP) production in relativistic heavy-ion collisions may be signalled by the non-monotonous energy dependence of several hadronic observables such as the strangeness yields and ratios in the phase transition region.

In the last period, the following problems have been considered: (i) *the role of the antiparticle to particle rations, as well as other particle ratios, in the knowledge of the dynamics of the relativistic and ultrarelativistic nuclear collisions*; a selection of the previous results obtained in different experiments has been done and new predictions for nucleus-nucleus collisions at FAIR-GSI energies were proposed. (ii) *particle production in different nucleus-nucleus collisions, in different thermodynamic equilibrium conditions, using Tsallis distribution;* connections with possible phases of the hot and very dense nuclear matter have been proposed. (iii) *possible connections among hydrodynamic flow, nuclear matter jets, phases and phase transitions in nuclear matter formed in nucleus-nucleus collisions at FAIR-GSI energies.* (iv) *predictions for different phases of the nuclear matter in nucleus-nucleus collisions at FAIR-GSI energies.* Therefore, each objective was the subject of the annual reports.

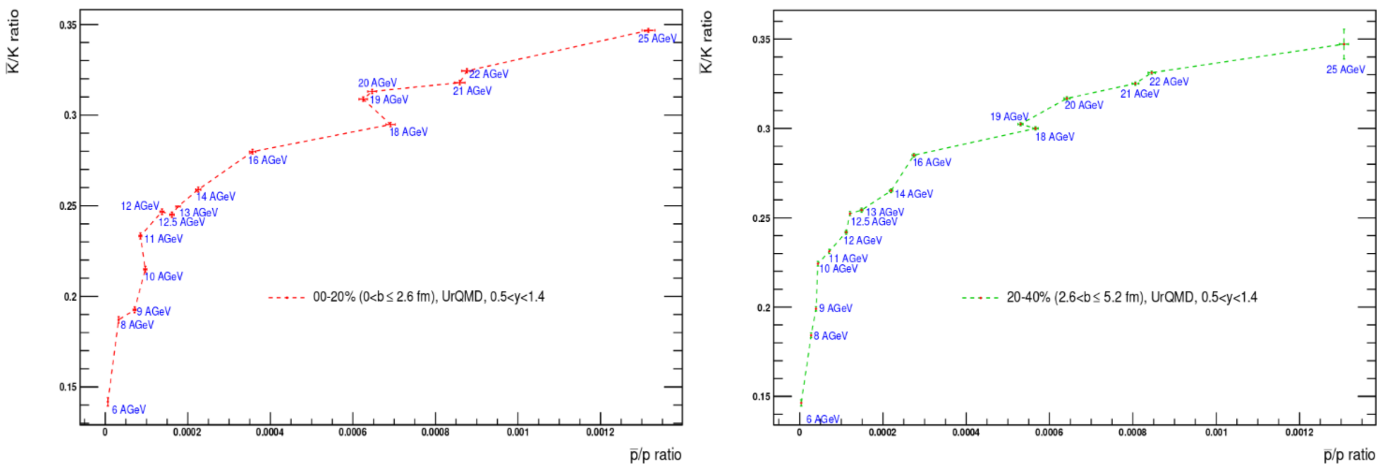


Fig.1. *K^-/K^+ ratio as a function of antiproton/proton ratio in Au-Au collisions for different energies (6-25 AGeV energy range). The ratios were obtained using UrQMD (**U**ltra **r**elativistic **Q**uantum **M**olecular **D**ynamics) code.*

For most central Au-Au collisions, the systematic dependence of the K-/K+ to antiproton/proton ratio (Fig.1, left) shows some behaviour changes in 18-20 GeV energy range, while for semi-central collisions we observe a smaller change for the K-/K+ values in the same energy range. These results may suggest a possible phase transition in this energy range.

The hydrodynamic behavior of the nuclear matter formed in the overlapping region of the two colliding nuclei seems to be the most adequate description of the collision dynamics. Also, many phases of the hot and dense nuclear matter seem to be related to this type of description. Therefore, in this stage of the project, the possible connections among flow and nuclear matter phases have been investigated. The formation of the nuclear matter jets has been analyzed. In this case the anti-k_T jet detection algorithm with different cone radius was used. The study of Fourier anisotropic flow coefficients from the azimuthal distribution of the emitted particles completed this analysis. Connections with fireball evolution, from the initial formation moment up to the freeze-out were considered. Taking into account the energy range at the SIS-100 acceleration system, the results based on simulations can be compared with the experimental results obtained in symmetric collisions of light relativistic heavy ions (C-C at 4,5 A GeV/c, for example) or in deep asymmetric nucleus-nucleus collisions (He-Pb at 4,5 A GeV/c, for example) – see the work C. Beşliu et al – EPJ A1(1998)65-75, too – for a possible ordination in classes of equivalence, taking into account the cumulative production as an option for the transient regime in this energy range possible at FAIR-GSI. In the future, *predictions on different phases of nuclear matter at FAIR energies,* with special attention paid to the resonance matter formation and behavior of hadronic plasma will be included. Considering previous experimental results, as well as simulated data, some connections among processes in quarkonia region and cumulative effect will be investigated.

Global analysis and jet formation in this domain of energies can help flow studies, offering us visual patterns of the anisotropy of transverse flow, discriminating between different types of flow, and offering us information about the dense QGP at the CBM energies. Fig. 2 (left panel) shows the angular distributions of charged particles transverse momentum and of total transverse momentum of flow streams for triangular shape structures in Au-Au collisions at 4 A GeV simulated with UrQMD code. These flow streams have enabled us to distinguish different event shape structures (triangular-shape events, quadrangular-shape events, etc.) in the bulk of data, allowing us to separate the different types of flow (triangular, quadrangular and pentangular) associated with the initial form of the participant region. The shape evolution for the angular distribution of charged particles from three-jet events is presented in Fig. 2 (right). The particles whose freeze out occurs at the beginning of the collision are projected forward, down into the target area, while the particles whose freeze out occurs later, produce a lateral splash in the projectile area.

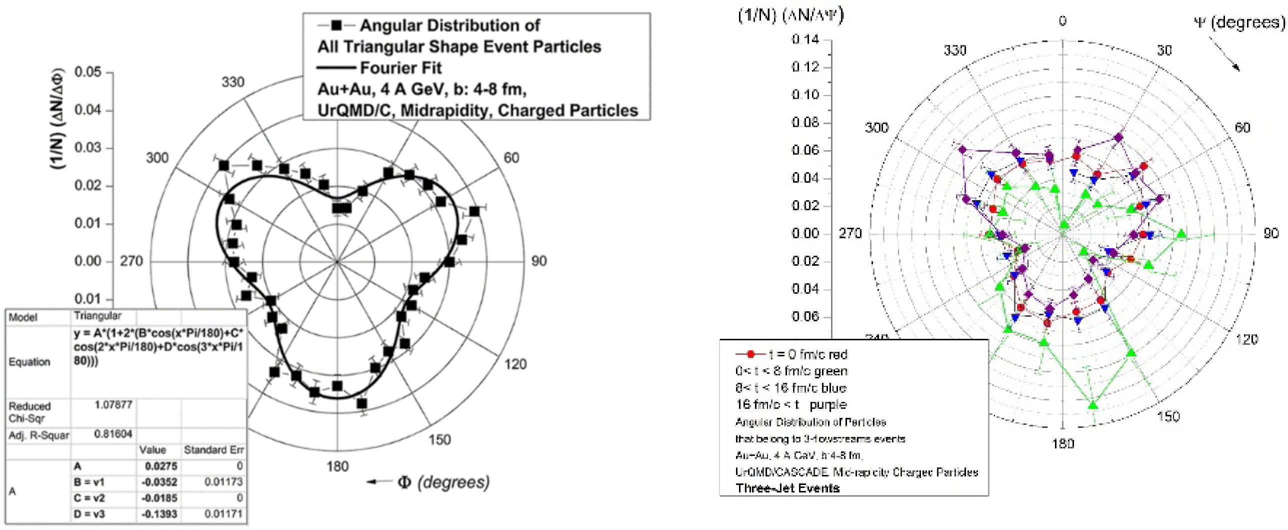


Fig.2. *Left: Angular distribution (azimuth angle) of charged particles transverse momenta from Au-Au at 4 A GeV collisions, UrQMD code, R=1, b∈(4,8] Fm, midrapidity, all triangular-shape events, and the Fourier fit of the particles angular distribution. Right: Angular distribution of charged particles from 3-jet events UrQMD/CASCADE generated at different freeze-out time*

The problems of the *resonance matter and hadronic plasma* and *quarkonium and cumulative effect* have been investigated, also**.** For investigation of the cumulative effect, in the hypothesis of Gorenstein and Gadzinski on transition regime (M.Gazdzicki, M.Gorenstein - Acta Phys.Polon.B30(1999)2705), supposing the presence of a few free quarks, we studied this effect with Chaos Many-Body Engine Simulator (*I.V.Grossu et al – Comp.Phys. Comm. 195(2015)218-220*, up to *I.V. Grossu, C. Beşliu, Al. Jipa, D. Felea, E. Stan, T. Eşanu* - ***Comp.Phys.Comm.239(2019)157-160***). These aspects can be considered taking into account that the energy range of SIS-100 offers a good opportunity to investigate the baryonic resonances formation and its influence of the bulk properties of the nuclear matter inside the fireball, as well as its the possible role in the blocking of other possible phase transitions due to the modifications on the initial temperature and nuclear density parameters (V.Metag – Prog.Part.Nucl.Phys. XXX(1993)75-88, T. Eşanu – PhD Thesis, University of Bucharest, 2010 – for experimental results). Influences on the hadronic plasma formation and properties could be observed, too. The new proposed quarkonia region [see Peter Senger – ***Particles - special issue 2019***)] could offer interesting study conditions for the cumulative effect. Two possible incident nuclei energies can be considered for extinction of the resonance matter formation, namely 7-8 A GeV, 11-12 A GeV, respectively [N.G. Ţuţuraş, A. Jipa, A. Jinaru et al – ***Rom.Rep.Phys.71(2019)303***]. Additional studies are in progress. It is important that some results were used in educational programs in three Universities, in Bucharest, Constantza and Cluj-Napoca, as well as in 2-3 outreach activities per year with high school and faculty students. („Researchers' Night", „Faculty of Physics from A to Z", „Cu mic cu mare prin Univers"). 11 articles in ISI journals, 10 lectures at national or international and a book contain, too, results obtained during these studie

Nuclear Structure Research in View of NuSTAR@FAIR (NuSTAR-RO)

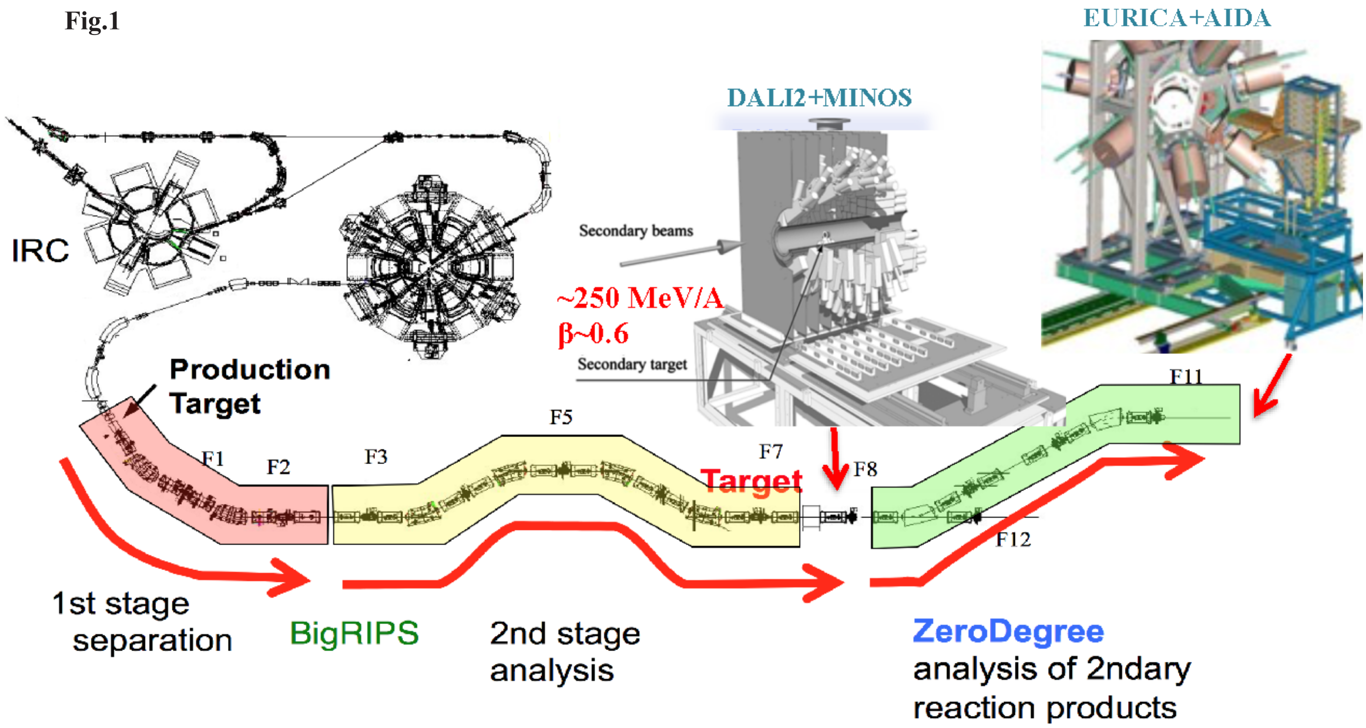
Project Leader: Prof. Dr. Nicolae Marius MARGINEAN
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Experiment: HIgh-Resolution In-flight SPECtroscopy / DEcay SPECtroscop HISPEC/DESPEC
Scientific Domain: Nuclear Stucture, Astrophysics and Reactions (NUSTAR)
Project web page: *https://www.nipne.ro/proiecte/pn2/157-proiecte.html*

^{94}Br, ^{95}Br, ^{96}Kr: the 2nd SEASTAR campaign @ RIKEN

Experimental spectroscopic data in the A~100 mass region from the 2nd SEASTAR campaign at RIKEN were obtained and investigated. The very neutron-rich nuclei from Zn (Z=30) to Zr (Z=40) with masses around A~100 are predicted by various theoretical models to undergo rapid changes of the nuclear shape with increasing the number of nucleons above the spherical shell-closure at N=50 and also exhibit shape coexistence. The shell evolution and shape coexistence are considered as key features of this mass region and their investigation and understanding the mechanisms behind driving these fundamental phenomena lies onto measuring the energies and lifetimes, if presumably long lived, of the first 2$^+$ and possibly 4$^+$ excited states in the even-even nuclei.

The aim of the second in a series of three experimental SEASTAR campaigns organized at RIKEN accelerator facility during 2014 - 2017 entitled "Shell Evolution and Systematic Search for 2_1^+ Energies" was to measure the energies of the 2$^+$ and 4$^+$ states using the liquid hydrogen target MINOS device combined with the DALI2 NaI(Tl) array of 186 scintillators and independently, lifetimes and pattern decays of the isomeric states using the high-mass resolution ZeroDregree spectrometer and EURICA HPGe segmented array, see Fig.1. The experimental conditions during the 2nd SEASTAR campaign were: a ^{238}U continuous beam, accelerated at 345 MeV/u incident energy and with an average intensity of 30 pnA was sent on a 3-mm thick ^{9}Be target. The most exotic neutron-rich beams were obtained through the in-flight fission of the ^{238}U or its fragmentation after the collision with the light target material. BigRIPS was designed to be a two stage in-flight fragment separator with a large acceptance both momentum and angular which allows an efficient collection of about 50% of the fission fragments, with a first stage that corresponds to the production, collection and separation of the RI beams using degraders and the second stage designed to perform particle identification of the RI beams and for further isotope separation thus being a spectrometer and a separator along the transport line, see Fig.2.

Fig.1



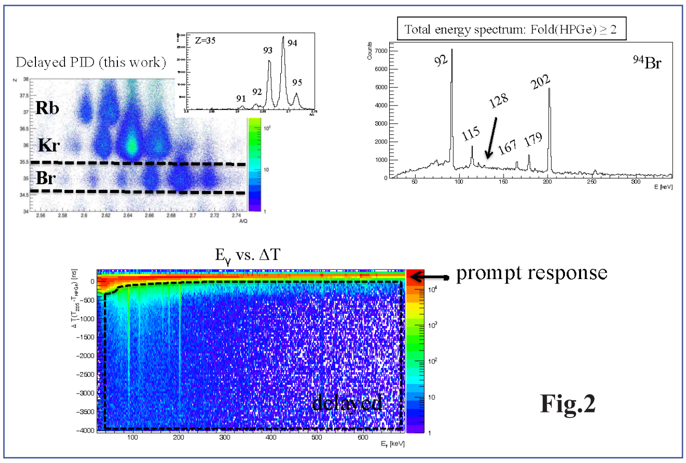


Fig.2

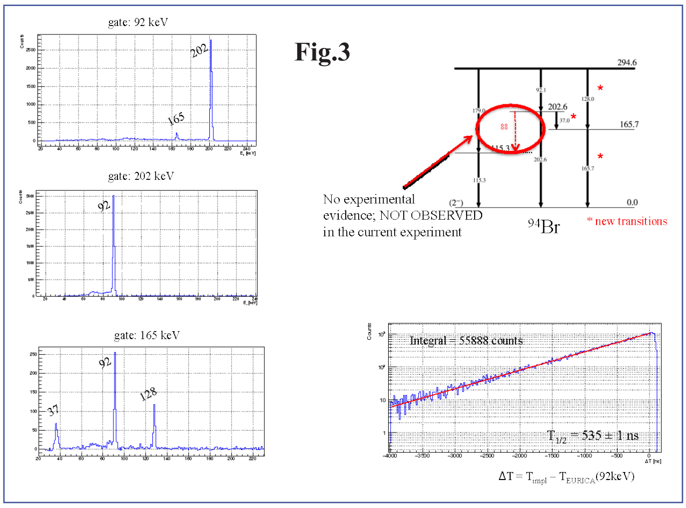


Fig.3

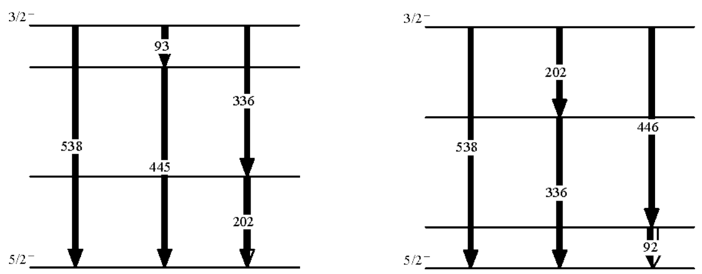
^{94}Br: no experimental evidence for the existence of the 88-keV transition was observed experimentally. The newly found γ-rays, i.e. the 37- and 128-keV deexcite the 203-keV state and the isomer, respectively. Due to our improved efficiency we could establish the position for the 166-keV γ-ray unambiguously (Fig.3).

^{95}Br: The half-life of the J^{π}=(3/2$^-$, 1/2), E_x=538 keV, isomeric state was remeasured in this experiment and a value of $T_{1/2}$=6.91 ± 0.24 μs was found (~18×10^3 total events in the time distribution curve and ~2×10^4 implanted nuclei, with a 50 ns binning), of $6.7^{+11}_{-9}6.7^{+11}_{-9}$ μs. No multipolarity could be deduced for this transition. (Fig.4)

^{96}Rb: a detailed spectroscopy of ^{96}Rb was performed. Our work confirms the low-lying 59 keV (M1) – 90 keV (M1); 59 keV (M1) – 126 keV; 59 keV (M1) – 166 keV cascades with the 149-keV (E2); 185-keV cross-over transitions. The 226-keV cross-over has not been observed so far. Most of the decay intensity is taken by 462 keV transition ((3$^-$) → 2$^-$ g.s.) which de-excites the 462-keV state. The 166- and 276-keV transitions observed to be in coincidence with the 59-keV and 93-keV transitions, respectively. The existence of the 37-keV transition is confirmed, between the 185 keV and the 149 keV states since this link allows the coincidence between the 368-keV and the 149-keV transitions. The half-life of the (10$^-$) isomer was remeasured. A value of $T_{1/2}$=1.00±0.05 μs was found (a bit less than 10^3 events were in the 462 keV time distribution alone for about 10^5 implanted nuclei (Fig.4).

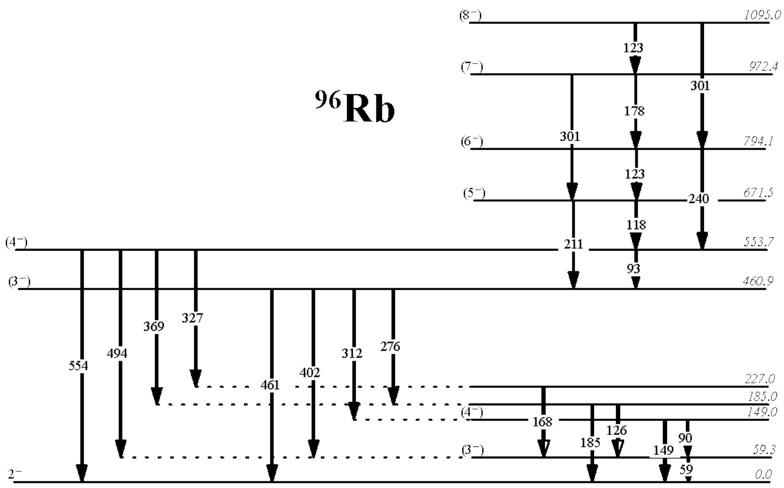
Fig.4

^{95}Br



Possible de-excitation path scenarios for the 538-keV isomeric state in ^{95}Br: *(left panel)* the 92-keV γ-ray is placed at the bottom of the level scheme. *(right panel)* The 92-keV represents the direct de-excitation of the isomeric state. There is no indication of a measurable lifetime below the isomer.

^{96}Rb



Nuclear Astrophysics with Indirect-methods and Rare Ion Beams (NAIRIB)

Project Leader: Dr. Livius TRACHE
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Experiment: The Superconducting FRagment Separator (Super-FRS)
Scientific Domain: Nuclear Stucture, Astrophysics and Reactions (NUSTAR)
Project webpage: *http://proiecte.nipne.ro/pn3/3-proiecte.html*

NAIRIB was the Nuclear Astrophysics proposal in the FAIR-RO subprogram that supports the preparation of Romanian teams for current and future work at the international facility FAIR with indirect methods and radioactive beams. Its goals were three-fold: i) to develop and test methods, setups and theories by conducting research at existing RIB facilities, ii) to develop equipment and setups and iii) to train the young members of the group. The topics of research financed through this project were focused on the above but were obviously mixed with other goals of the Nuclear Astrophysics Group (NAG) in the Department of Nuclear Physics of IFIN-HH.

i. Experiments conducted at existing RIB facilities

Nuclear and Coulomb breakup of ^{9}C. This reaction was studied in Japan, at the Nishina Center for Accelerator Based Science of RIKEN, Wako. The experiment had two aims. The first was to design and use a new detection system based on Silicon-Strip Detectors (SSD) that would integrate into the complex experimental setup already in place on the RIBF-SAMURAI beamline in RIKEN. The second goal was to determine the astrophysical S-factor for the radiative proton capture reaction $^{8}B(p,\gamma)^{9}C$. This was done using a ^{9}C beam that impacted two different targets, carbon, and lead, to break up into a proton and the core-^{8}B.

The experiment was performed successfully, and the first aim is considered achieved. Fig. 1 shows the final configuration of the SSDs. Four detectors with 128 strips each, grouped in pairs with 35 cm distance between the pairs. An ASIC-based (Application-Specific Integrated Circuit) system gave 1024 electronic signals corresponding to the total number of 512 strips, processed using both low and high gain shapers. This allowed a large dynamic range, and the SSD setup detected both the proton and the core and identified the two main channels of the ^{9}C breakup: ^{8}B+p and ^{7}B+2p. The system was placed between the target and the SAMURAI spectrometer. For the second aim, the necessary data was obtained for each of the two types of breakup, nuclear and Coulomb, and the analysis is ongoing.

Resonance spectroscopy. The reaction $^{26}Al(p,\gamma)^{27}Si$ was studied in US, at the Cyclotron Institute - Texas A&M University (CI-TAMU) using beta-delayed proton-decay. The experiment involved using the beta-delayed proton-decay of ^{27}P to populate the same resonant states in ^{27}Si as in the radiative proton capture (Fig. 3), with the end-goal of reducing some of the current uncertainties in the reaction rate determination.

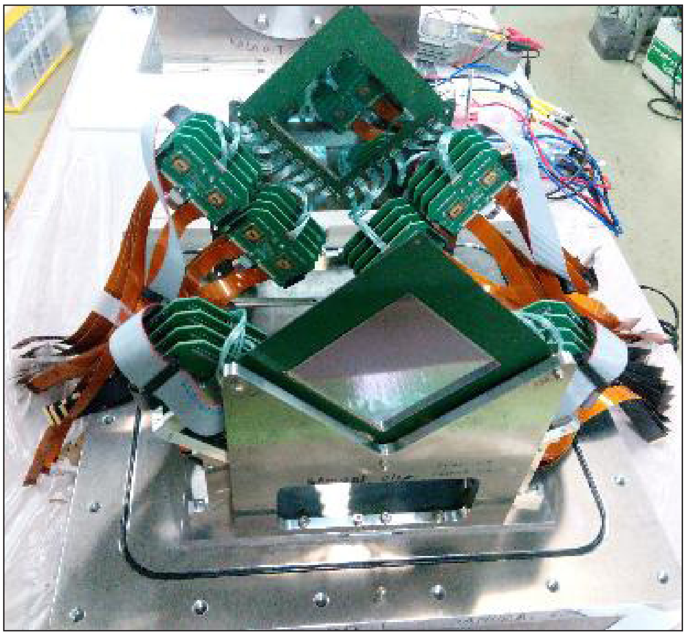


__Fig. 1.__ Photo taken of the SSD setup.

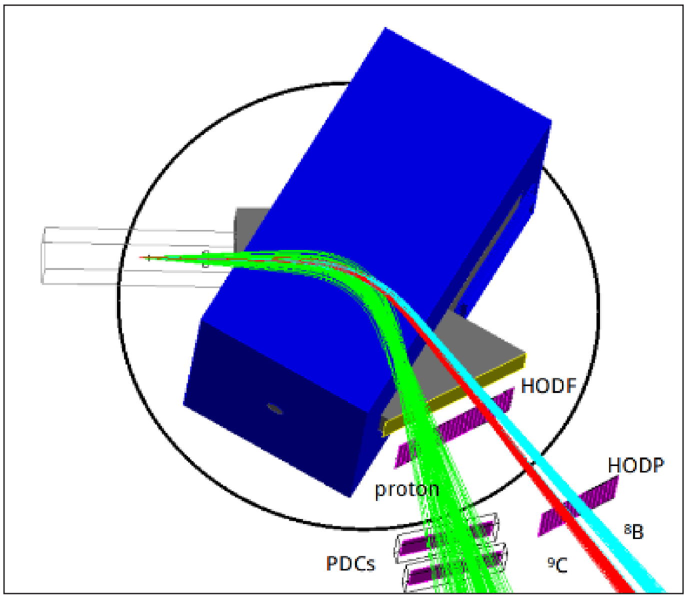


__Fig. 2.__ Simulation of the breakup reaction products as they pass through the SAMURAI spectrometer.

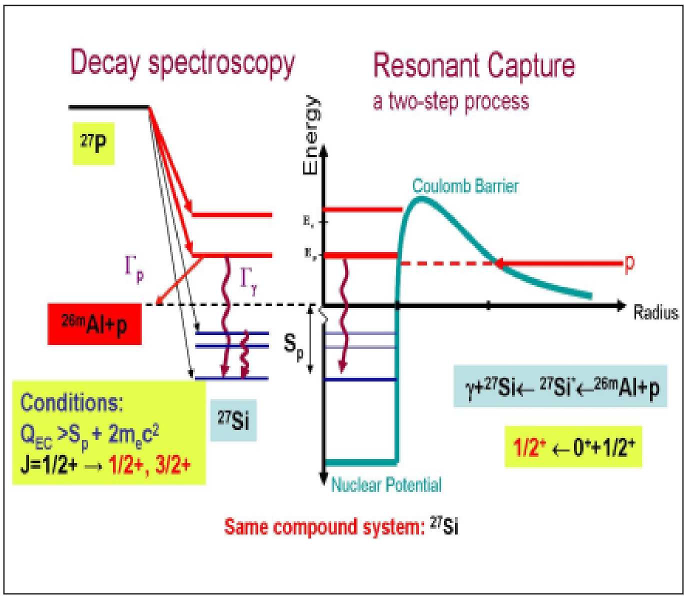


Fig. 3. *Scheme showing the use of beta-delayed p-decay to populate states important in resonant capture.*

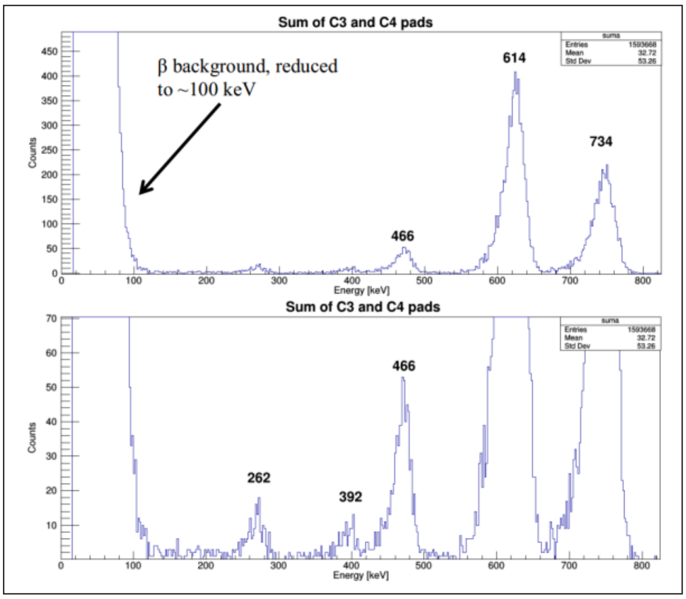


Fig. 4. *Proton energy spectrum obtained from the b-delayed proton-decay of ^{27}P, enlarged on the energy range <500 keV.*

The experimental decay of ^{27}P was measured using a detection system composed of a detector called AstroBox2 (AB2) and 2 High-Purity Germanium detectors. AstroBox2 was designed to measure low-energy protons with significant beta background reduction (as low as 100 keV), allowing for the identification of protons with energies below 500 keV and a sensitivity down to ppm. This achievement can be seen in Fig. 4 which shows 3 new proton transitions. Their addition to the resonant contribution of the ^{26}Al(p,γ)^{27}Si reaction rate could significantly improve the final result and its associated uncertainties.

ii. Development of new equipment

For the successful completion of the experiments above, new equipment was developed. The SSD setup shown in Fig. 1 above was instrumental in the study of ^{9}C proton breakup and it is becoming a standard equipment for the next SAMURAI experiments with proton-rich beams. To obtain the results needed in the resonance spectroscopy type of reactions studied at TAMU, one needs sensitivity at proton energies in the E_p=100-500 keV range, as in Fig. 4. We reached it with ASTROBOX2, a gas detector with micromegas technology.

iii. Formation and training the next generation of NA scientists

Last, but not least, in the list of results for this project are the events organized by the project director and his group: Carpathian Summer Schools of Physics 2016 and 2018, an ECT* event in Nov. 2018 and 3 Summer schools for Romanian Olympics (high school students). These events had the aim of training and/or teaching students working to complete their graduate studies in the field of NA or related fields and attracting new ones.

Fig. 5. *Group photo showing some of the participants to the Carpathian Summer School of Physics 2018 (in the Slănic salt mine, where IFIN-HH has an ultra-low background lab).*

Fig. 6. *Group photo of participants to one of Summer schools for Physics Olympics with Romania's President.*

NAIRIB group: L. Trache, Florin Carstoiu, Alex Spiridon, Alexandra Stefanescu, Ionut Stefanescu, Dana Tudor.

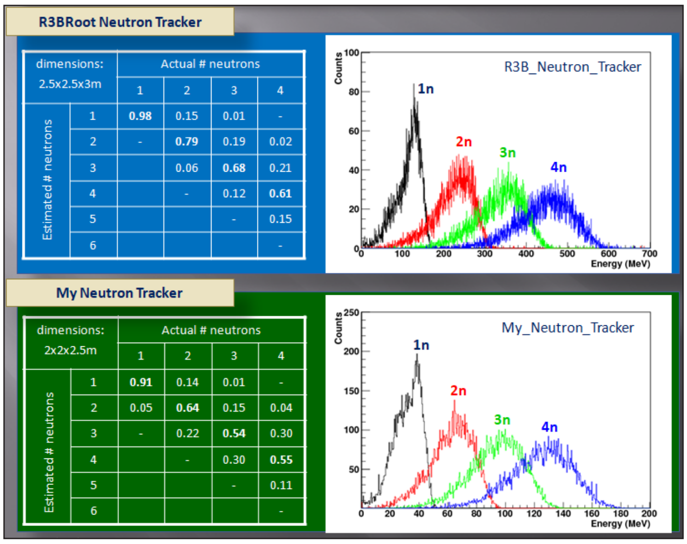
Development of Simulation and Analysis Software for High Energy Neutron Interactions in R3B Experiment (DASHNE)

Project Leader: Dr. Maria HAIDUC
Project Coordinator: Institute of Space Science (ISS)
Experiment: Reactions with Relativistic Radioactive Beams (R3B**)**
Scientific Domain: Nuclear Stucture, Astrophysics and Reactions (NUSTAR)
Project webpage: *http://www.spacescience.ro/projects/dashne/*

Nuclear structure investigations of exotic nuclei has entered into a new phase with the development of the new international accelerator facility FAIR (Facility for Antiprotons and Ions Research) to be built in Darmstadt, which will provide antiproton and ion beams with unprecedented intensity and quality. This will allow to one of the pillar of FAIR, R3B (Reactions with Relativistic Radioactive Beams) experiment [1], to cover a broad physics program which includes heavy-ion induced electromagnetic excitation, knockout and breakup reactions, or light-ion (in)elastic and quasi-free scattering in inverse kinematics. Representing one of the key instruments for the physics program of R3B experiment, the NeuLAND detector (New Large Area Neutron Detector) [2] should present multi-neutron recognition capabilities required by experimental study of reactions with nuclei far from stability, especially for the study of nuclear structure and dynamics.

As the purpose of each experiment is reconstruction back to the interaction point, and from there also the recovery of information about the underlying physics processes, the future R3B experiments should be fully supported with the simulation software. Therefore, R3BRoot framework [3] is currently under development in order to provide tools for both simulations and data analysis (offline and online). Due to the more and more complexity of experiments, the resulting track density is so high that success depends crucially on the power of the reconstruction methods. Within R3B collaboration there were some activities aiming to develop a high performance reconstruction algorithm with respect to efficiency, purity and resolution of identification of such physics observables as so-called tetra-neutron - 4 neutrons with a narrow distribution in space and time – that should overcome the performances of the standard algorithms for neutron recognition in LAND, Shower Volume Algorithm (SVA) and Shower Tracking Algorithm (STA) [4].

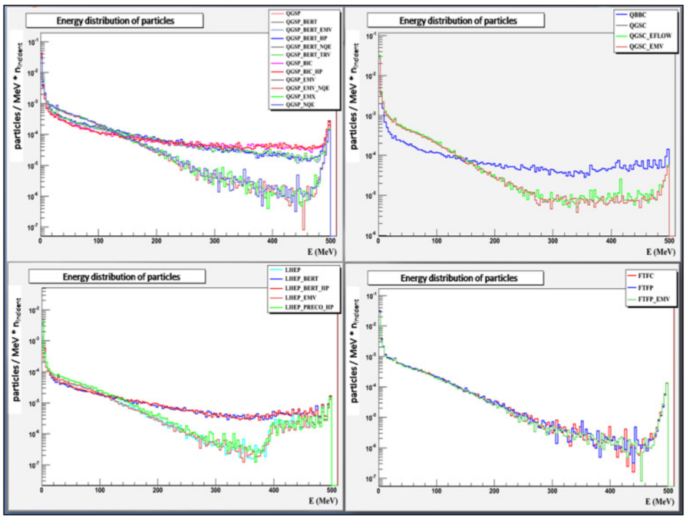
The working stages of this project allowed us to remain in close connection with the research program of the R3B Collaboration. For the task which assumed *implementation of a dedicate recognition algorithm for multi-neutrons (in R3BRoot) together with quality assessment of the algorithm to satisfy NeuLAND criteria* we started by identifying the nuclear processes which will be studied within R3B experiment by means of NeuLAND; the results allowed us to understand which experimental setups were used, what physics measurements were made, what physics quantities were investigated and if simulations were performed and if they agreed with experimental results or not. Next step was to evaluate the reconstruction algorithms for neutrons which can be used for NeuLAND detector and the results showed us that there are



dimensions: 2.5x2.5x3m	Actual # neutrons			
Estimated # neutrons	1	2	3	4
1	**0.98**	0.15	0.01	-
2	-	**0.79**	0.19	0.02
3		0.06	**0.68**	0.21
4		-	0.12	**0.61**
5			-	0.15
6				-

dimensions: 2x2x2.5m	Actual # neutrons			
Estimated # neutrons	1	2	3	4
1	**0.91**	0.14	0.01	-
2	0.05	**0.64**	0.15	0.04
3	-	0.22	**0.54**	0.30
4		-	0.30	**0.55**
5			-	0.11
6				-

only 4 algorithms able to perform this task: the SVA; the STA; the Probabilistic Neutron Tracker (PNT); the R3BRoot Neutron Tracker (RNT). The existing algorithms have been tested on data from an experiment conducted at Riken in 2017 numbered NP1406-Samurai19 [5]. The algorithms perform quite well for few incoming neutrons but quickly degrade, underestimating the number of neutrons, when the number of incoming neutrons increases. Furthermore, neutron interactions were simulated in the NeuLAND detector and then analyzed with the STA and PNT trackers. The results for the neutron reconstruction of the SVA are evaluated for 1, 2 and 3 incoming neutrons. We estimate the number of neutrons considering both all events and also events where all incoming neutrons have interacted with the detector, this to be able to compare the simulation with the experiment data. The algorithms perform similar in both the neutron number reconstruction as well as the momentum reconstruction. Moreover, neutron interactions in the NeuLAND were simulated and the registered hits were analyzed with the SVA and 'our-own' algorithms and the results showed that our algorithm is currently too slow to be suitable for the NeuLAND detector.



For the second task of this project – *construct specialized analysis routines, corresponding to NeuLAND detector* - we started by comparative check of various 'physics list' in Geant4 [6] in order to identify which one is more appropriate for our goals, taking into account the test experiments performed so far with NeuLAND; furthermore, we identified the most common reactions which arise in NeuLAND with representation of distributions of neutrons reaction products and the energies of selected products and implemented of experimental geometry used in NeuLAND campaign at Riken in a Geant4 standalone application. We made a preliminary evaluation of data from Riken using UCESB software [7] and R3BRoot framework in order to identify the steps done for unpacking and calibration to obtain valid hits enabled us to construct a converter which should allow to perform the whole calibration and synchronization chain and integration of macros within R3BRoot software.

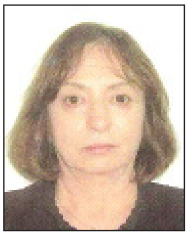
For the third task - *development of an user-friendly and standardized interface to simulation and data analysis macros of R3Broot* – we started by establishing the parameters for user-interface application by checking the user-interfaces used by other experiments and identification of the parameters used in R3BRoot macro files. The construction of user-interface was approached in 2 ways: a) construct an application based on R3BRoot, started in a Root session; b) develop a web-based interface for access through a web browser. Intended especially for the developers, the application which works in Root, is now replacing the initial combination of (one *r3ball.C* + multiple instances of *r3bsim.C)* macros. This '0-version' is divided in 4 parts, one for simulations, one for experimental data plus two of corresponding analysis, and includes the parameters that we established to be mandatory. The second approach was to initiate the development of a www interface for R3BRoot together with some other codes used in high energy physics (event generators like Pythia, UrQMD or transport codes like Geant4 or Fluka) in order to provide access to simulations and analysis even to R3B Collaboration members which are not familiar with coding and programming. The platform, named ***R3Bsuit*** – *R3Bsimulations using user interface tools* - can be accessed online at this moment through the following link *http://r3bsuit.spacescience.ro*.

[1] https://www.gsi.de/r3b
[2] K. Boretzky et al., GSI Scientific Report 2011, p. 174
[3] D. Bertini, Journal of Physics: Conference Series 331 (2011) 032036
[4] J.G. Keller, E.F. Moore, GSI Scientific Report 1992, p. 39
[5] S. Paschalis, S. Shimoura et al., RIBF Experimental Proposal, NP1406-SAMURAI19
[6] https://geant4.web.cern.ch/
[7] http://fy.chalmers.se/~f96hajo/ucesb/

➢ Publications

1. *Design studies for the NeuLAND VETO detector,* C A Douma, K Boretzky, I Gasparic, N Kalantar-Nayestanaki, D Kresan, J Mayer and C Rigollet for the R3B collaboration - *IOP Conf. Series: Journal of Physics: Conf. Series, 1024 (2018), 012027*
2. *Investigation of background reduction techniques for the NeuLAND neutron detector*, C.A. Douma, K. Boretzky, I. Gašparić, N. Kalantar-Nayestanaki, D. Kresan, J. Mayer, C. Rigollet for the R3B Collaboration, *Nuclear Inst. and Methods in Physics Research, A 930 (2019) 203–209*

Atomic Interactions in Supercritical Fields: Preliminary Investigations for Sparc In-kind Contributions (SPARC-RO)



Project Leader: Dr. Viorica STANCALIE
Project Coordinator: National Institute for R&D in Laser, Plasma and Radiation Physics (INFLPR)
Partners: Institute of Space Sciences (ISS)
Experiment: Stored Particles Atomic Physics Research Collaboration (SPARC)
Scientific Domain: Atomic Physics, Plasma Physics and Applications (APPA)
Project webpage: *http://atomic.inflpr.ro/f01*

As an in-kind contributor to the APPA /SPARC experiments for FAIR, the INFLPR group contributed together with a large group of Institutes, to the preparation of the technical design report *SPARC@HERS: Instrumentation (https://www.gsi.de/fileadmin/SPARC/documents/HESR/20151130_TDR_SPARC_40HESR_Instrumentation_Approved_Web.pdf)* approved by the Expert Committee Experiments (ECE) on Jan 2016, which describes the Romanian contribution to the subjects Laser Spectroscopy, Intense Laser/Ion Interaction and Laser Cooling (Experiments Cost Book PSP codes 1.3.1.2.1, 1.3.1.3.11, 1.3.1.4.2). Besides the in-kind main contribution for the SPARC@HESR further participations in the FAIR Phase zero program are planned. The Institute of Atomic Physics in Romania supports since 2014, through a dedicated National Research Program, R&D projects focused on the development of theoretical and experimental works for FAIR. In collaboration with Helmholtz Institute- Jena (HI Jena) our group has been involved in: *Testing the first prototype for a coupling unit developed at HI Jena. During the working stage at HI Jena,* (Andrei Stancalie, 2019); *Participation in the preparation and implementation of the G-PAC proposal E129* (Andrei Stancalie, Sept-Oct.2019). With more than 12 papers in highly ranking journals (PRA 2017, PRA 2018, JQSRT 2017, JQSRT 2018, JQSRT 2019, ADNDT 2017, ADNDT 2018, JPB 2020, Vacuum 2020) we express our continued interest in the preparation and implementation of the next proposal of experiments.

Accurate understanding and interpretation of phenomena in the presence of supercritical fields involves *complementary studies on atoms and optical processes, and needs for a large data basis of atomic* parameters, as well as a good knowledge of atomic processes dynamics in electromagnetic fields. One of the research directions of the project focuses on the *Ultra-relativistic interactions between a laser beam and an electron*. We have shown [1] that in ultrarelativistic interactions between a laser beam and an electron the average velocity of the electron gets closer to the speed of light, the variation of the field phase, at the point where the electron is situated, decreases in the time interval occupied by the laser pulse, and the variations of the kinetic quantities and electromagnetic pulses generated by the electron motion become aperiodic. *Extensive non-relativistic and relativistic calculations of atomic data, electron impact excitation and recombination cross sections, degree of linear polarization in di-electronic recombination process, and photo-ionization cross sections for medium and highly charged ions*(HCI) have been performed [2-7].

Another direction of research represents the development and optimization of the *theoretical and computational methods to study the polarization effects in interactions of electrons and atoms with lasers*. We investigated the inelastic scattering of fast electrons by hydrogen atoms, accompanied by the *1s-nl* excitation, in the presence of a circularly polarized (CP) laser field, and study the polarization effects on the differential cross section (DCS). Furthermore we studied the polarization effects in electron-hydrogen scattering by a two-color *bicircular* laser fields of commensurate frequencies and moderate intensities and investigated the circular dichroism (CD) where the monochromatic components of the two-color CP field have identical (corotating) or opposite (counter-rotating) helicities. We predicted the existence of a nonlinear dichroic effect in DCS at high scattering projectile energies, which is sensitive to the photon energies and laser field intensities [8-11]. Our analytical results of CD shows the dependence of the DCS on the transition amplitudes, in a closed form, that allows further investigations of the dressing as well polarization effects due to the asymmetries of the DCSs for co- and counter-rotating CP fields. We established that at UV photon energies and small scattering angles there is a clear enhancement of the DCS for corotating compared to counter-rotating laser fields as a function of scattering, θ, and azimuthal, φ, angles, because of the strong second-order atomic dressing effects (Fig. 1).The dichroic effect, *R*, in the angular distribution of scattered electrons originates from the atomic dressing at small scattering angles, whereas at large scattering angles the dichroic effect comes from the projectile contribution to the scattering signal. We found that by changing the laser field polarization the angular distribution and the photon frequency dependence of the scattering signal can be modified and by varying the intensity ratio of the co- and counter-rotating two-color CP laser field components we can manipulate the angular distribution of the scattered electrons (Fig. 2).

The preparatory phase on laser spectroscopy experiment started in September 2019. The group contributed to *test experiments on a dedicated vacuum coupling unit at Helmholtz Institute Jena and at GSI/CRYRING*. Together with colleagues from HI Jena and GSI, we contributed to preliminary investigations on the possibility to scan HCI fine-structure using the XUV laser beam coupled to CRYRING: *Proposal E129: Photoionization of C+ ions at CRYRING*. The major tasks were: *a)* to establish the UHV-conditions at the newly installed setup, *b)* to test UHV unit, *c)* the XUV laser source operation and control system, and *d)* laser beam alignment. It was proposed to use the femtosecond fibber-based laser systems which can provide average output powers of 1kW and pulse energy sufficient for high-harmonic generation. The harmonic generation efficiency is optimized by varying the laser intensity, the gas pressure (typically, of order of 10^{-3} mbar) and the relative position of the laser focus within the cell. The UHV comprises an efficient multi stage pumping system to decrease the absolute pressure along three stages from 1.5 10^{-5} mbar to < 1.0 10^{-11} mbar. An open aperture of 10 mm diameter guarantees lossless XUV transport to the storage ring target ions [11].

A simplified model of the UHV unit is presented in Fig. 3. The results show that the numerical models are in good agreement with experimental data (Fig. 4).

During the preparatory phase plenty of major tasks were achieved. The laser- based XUV spectroscopy on HCI appears feasible for the first time also at heavy ion storage rings.

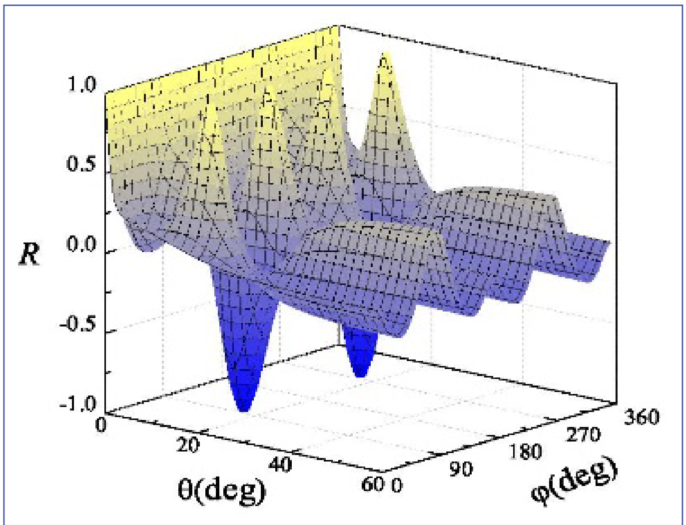


Fig. 1. Relative circular dichroism in angular distribution, R, as a function of the scattering and azimuthal angles for photon energy of 3 eV

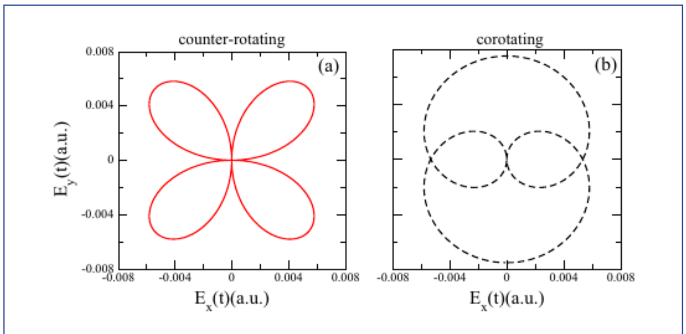


Fig. 2. Parametric plots showing the cartesian components of the electric field vector in the (X,Y)-polarization plane, plotted for two-color left - and right-handed CP fields for photon energies 3eV and 9 eV.

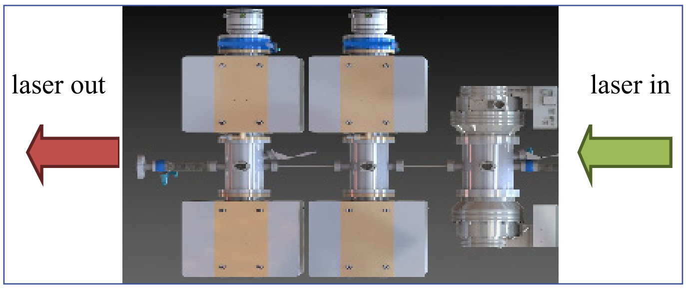


Fig. 3. Experimental setup

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6. C. Iorga, V Stancalie, *Theoretical investigation of X-ray lasing in argon by photo-ionization from K and L shells*, Rom. J. Phys. 64, Nr.1-2 (2019)
7. C. Iorga, V. Stancalie, "*The study of the core-valence and core-core correlation effects on the radiative properties along the magnesium isoelectronic sequence*" Atomic Data And Nuclear Data Tables 123, 313-328 (2018).
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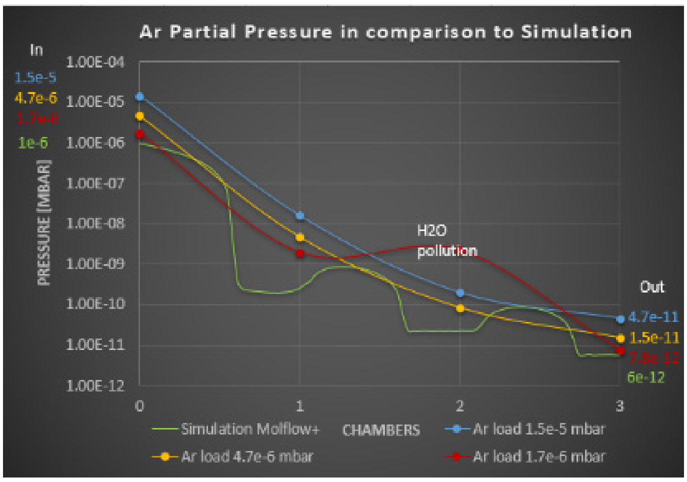
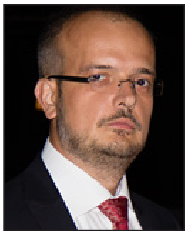


Fig. 4. The simulations in agreement with experimental data.

Scintillator-Based Detection System for Cryring Low-Energy Ion Beams (CRYLEDS)



Project Leader: Dr. Ing Dan-Gabriel GHITA
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Experiment: Stored Particles Atomic Physics Research Collaboration (SPARC)
Scientific Domain: Atomic Physics, Plasma Physics and Applications (APPA)
Project webpage: *https://www.nipne.ro/proiecte/ifa-fair/3-projects.html*

The main objective of this project was *the realization of a detection system for slow heavy ions to be installed and used in the CRYRING* at GSI / FAIR. The project aimed to build a detector prototype that will detect heavy, low-energy ions. It will be used for the study of ion-electron and ion-atom collisions (fundamental atomic processes, interactions of electrons with heavy nuclei in the context of quantum electrodynamics theory and dynamic collisions assisted by extremely powerful electromagnetic fields, nuclear structure and nuclear reactions near the coulomb barrier).

The introduction of the FAIR project staging (FAIR Modular START Version, MSV) imposed modifications and rearrangements of the experimental facilities for the atomic physics research program proposed by the SPARC collaboration. The relocation of the storage ring CRYRING, from the Manne-Siegbahn laboratory in Stockholm to GSI/ FAIR (as Swedish in-kind contribution to FAIR), offers an opportunity to partially pursue the research program proposed by the SPARC collaborations at the FAIR facility: investigations of fundamental aspects of atomic structure and dynamics in the relativistic domain of strong fields, nuclear structure, reaction near the Coulomb barrier, and at the intersection of atomic and nuclear physics can be studied.

CRYRING will be the first FAIR experimental facility allowing high-precision atomic physics experiments already before the start of FAIR, and will be the only facility world-wide providing beams of stable and unstable ions/rare isotopes dressed with few electrons or totally stripped in the energy range bellow 14 MeV/u down to rest. These simple, exotic ionic systems provide ideal experimental conditions for precision spectroscopy and study of inverse fundamental atomic and nuclear processes (radiative recombination, dielectronic capture, bound beta decay).

This detection system will be used to detect stable or unstable ion beams with the energy ranging from 14 MeV/u down to rest. This low beam energy allows us to use a thin YAP: Ce crystal that can be used on all ion species. The crystal has the chemical formula $YAlO_3$ and a density of 5.37g/cm^3 which makes it perfect for short range stopping. We used the SRIM software to simulate stopping ranges for various ions with a maximum energy of 14MeV/u.

In the final design, the detector uses a 25x25 mm wide, 1 mm width YAP:Ce scintillator crystal. This scintillator crystal is mechanically robust, with a melting point of 1875°C and a thermal expansion coefficient in the range of $4\text{-}11\cdot10^{-5}$/K. This makes it suitable for operating in extreme vacuum conditions that require a prolonged baking procedure. It has a relatively high brightness, yielding approx. 25 photons/keV with a maximum emission wavelength of 370 nm. It is a fast scintillator, with a decay constant of 25 ns [3], making it suitable as a particle counter in a storage ring, being able to count up to the MHz range whilst providing a good radiation hardness. Radiation damage becomes problematic when counting bunches of heavy particles (up to ^{238}U). For this reason, the crystal has been incorporated into a

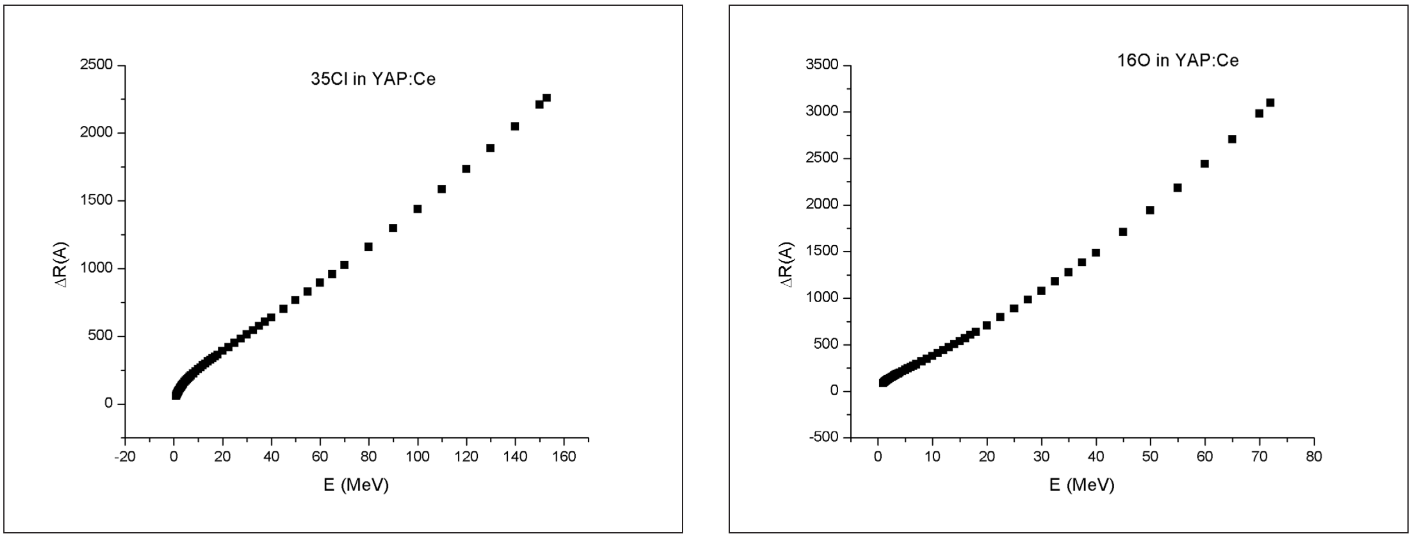


***Fig. 1**: Stopping ranges in YAP: Ce for: (left) ^{16}O and (right) ^{35}Cl*

detection system in such a manner that is can be considered as consumable and can be changed easily during maintenance. This was a main requirement for the project, as typical detectors, like multi-channel plates or scintillators equipped with photo multiplier tubes, placed directly into the beam path would have deteriorated the entire system. Changing only the YAP:Ce scintillator during maintenance is a more economical solution.

The scintillator is attached to an optical guide with a low outgassing, vacuum rated glue i.e. Epotek 301-2 with a transmission greater than 94% for the 370 nm wavelength. The optical guide is a large, 62 mm, 90°° right angle prism made from SiO_2, which is transparent to UV. It is coated with a thin Al reflective surface to reflect the scintillated photons 90 degrees downwards. The advantages of using this optical guide were to avoid placing any sensitive equipment into the beam path, the prism can withstand radiation damage without significant loss of transmission and is relatively easy to replace.

For converting photons to photoelectrons, a GaN photocathode was used which was deposited through magnetron sputtering on a 0.5 mm thin SiO_2 substrate. Different photocathodes were produced using the local target laboratories for testing purposes. Although conversion efficiency can be improved in the future by using a different photocathode material, GaN was the simplest to use during the demonstration phase of the detector. The deposited GaN had a width of over 300 nm, reducing the quantum efficiency by 50%, the maximum being achieved at 180 nm. Photoelectrons are accelerated towards a pair of multi-channel plates which amplify the signal to a maximum of 8 orders of magnitude and are collected by a high potential anode. Only a 2.5 kV voltage drop is used for the entire detection.

Total detection efficiency for alpha particles has been calculated to around 0.1%. This is because of several reasons, the main reason being the extremely noisy environment where measurements took place. Further improvements will be to properly isolate the readout electronics and to remove all sources that generate noise. Also, the photocathode must be remade with a material that has a higher quantum efficiency. The one that was used for the detector testing was double the required thickness lowering the efficiency to more than 50%.

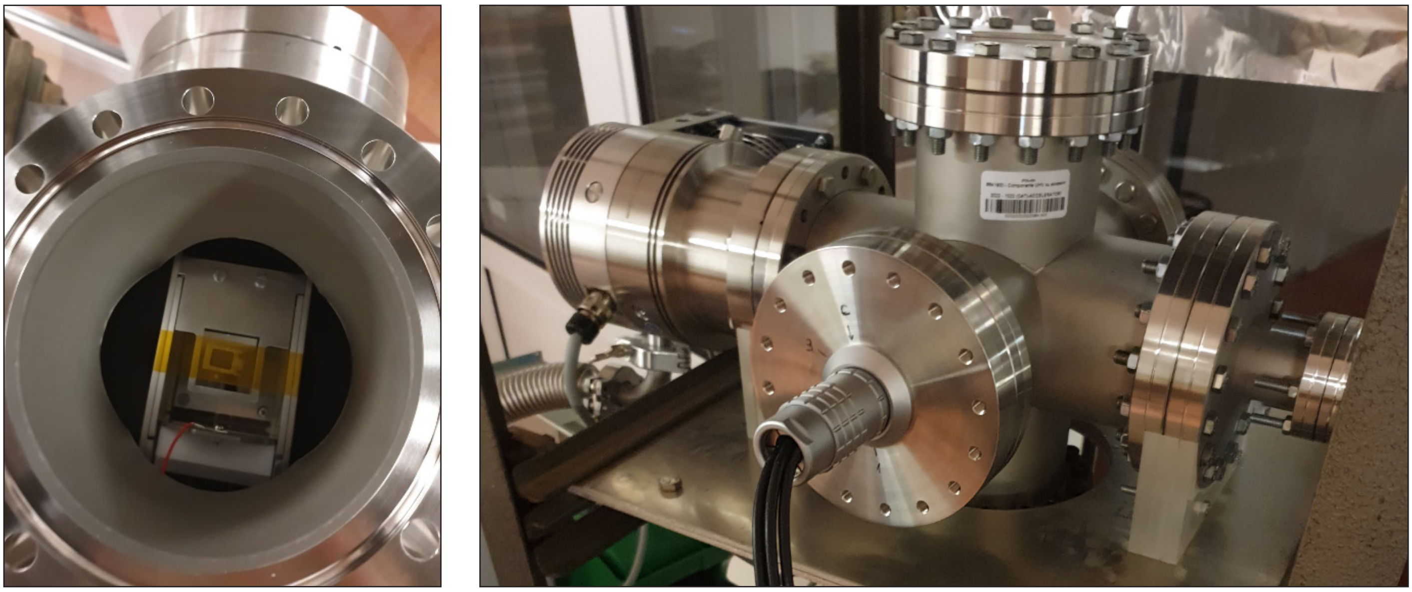


***Fig 2**: View of detector inside the vacuum chamber (left). Overall view of the testing chamber (right).*

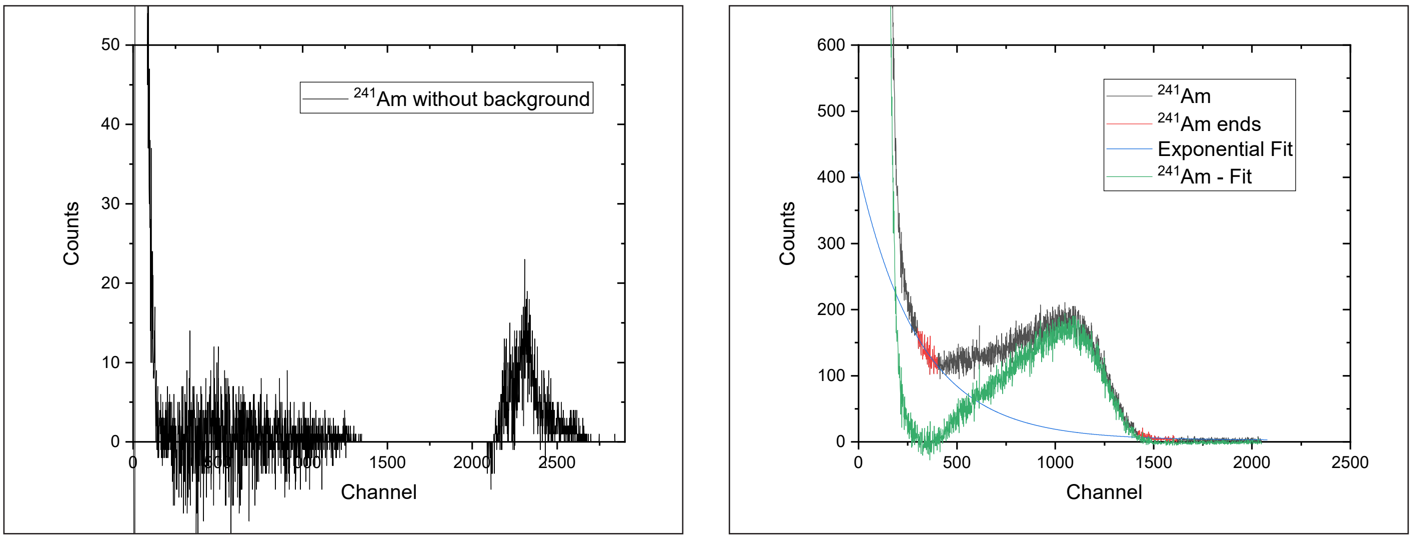


***Fig 3**: (left) ^{241}Am spectrum without background. (right) Activity of ^{241}Am*

Strong Interaction Studies in Antiproton Annihilation (SISTINA)

Project Leader: Dr. Alexandru-Mario BRAGADIREANU
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Experiment: antiProton ANnihilation at DArmstadt (PANDA)
Scientific Domain: Antiproton Physics (AP)
Project webpage: *http://www.nipne.ro/dpp/Collab/SISTINA_2016_2019*

PANDA (antiProton ANnihilations at DArmstadt), a worldwide collaboration of more than 500 scientists from 17 countries, will be one of the key experiments at the international Facility for Antiproton and Ion Research (FAIR), now under construction at Darmstadt, Germany. Its physics research program is devoted to strong interaction studies using high quality and intensity antiproton beams from High Energy Storage Ring (HESR) of FAIR, with momenta between 1.5 GeV/c and 15 GeV/c.

The Multipurpose Rack Control Unit (MRCU) developed by our group, in Q2 of 2016, for NA62 Hadron Sampling Calorimeter control system, is a possible solution for the PANDA Control System to monitor and control the temperature and humidity of the electronics rack environment, to monitor the 230V AC current consumption of AC plugged-in devices, to switch on/off the AC plugged-in devices. Moreover, the unit has also 2 general purpose input/output (I/O) ports which can be used (or customized to be used) as interlocks, and a constant current source together with a high precision ADC for RTD based temperature measurements.

The MRCU developed by our group was updated with a Compute Module I/O Board with Communication mezzanine (fig.1). The Compute Module I/O and the Communication mezzanine boards (fig. 2) were designed, assembled and tested.in IFIN-HH. The I/O board is compatible with Raspberry Pi Compute Modules (2.5 V SODIMM) and Raspbian Jessie OS. The Communication mezzanine provides three serial interfaces RS232, RS485 and CAN BUS via two IC's SC16IS752 for RS232, RS485 and MCP 2515 for CAN-BUS communication.

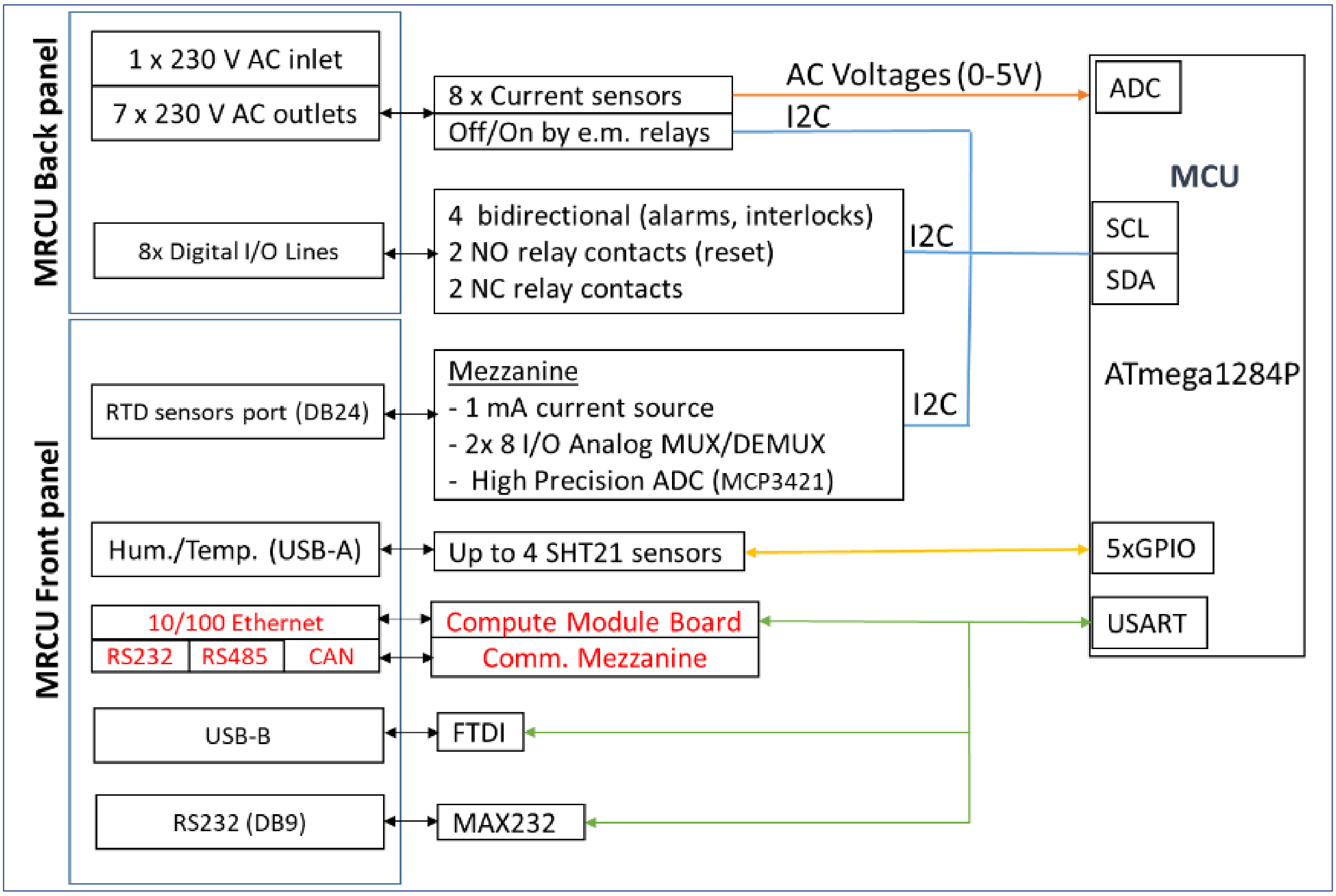


Fig. 1 Multifunction Rack Control Unit hardware architecture

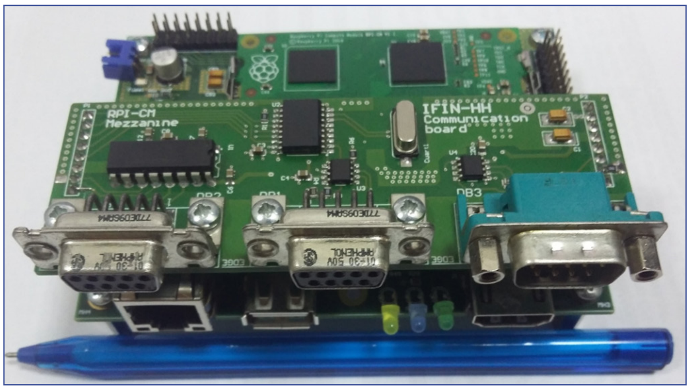


Fig. 2 IFIN-HH Compute Module I/O board with Communication Mezzanine

The new board was presented in July 2017 in a PANDA Controls TDR dedicated meeting and it was agreed with PANDA technical coordinators that the solution should be included in the TDR as PANDA rack controller together with the MRCU or as a standalone general purpose EPICS IOC.

The contents of PANDA Technical Design Report were discussed in various dedicated meetings in 2017, one of the hot subjects being the archiving of process variables (PV - values of various parameters describing the state of devices)– one alternative being the implementation of one archiver machine / PANDA sub-system and a dedicated database cluster at the supervisory level – common for all sub-systems (Fig. 3a).

To test the performance of archive engines we developed a Python application based on PCASpy library developed at PSI to interface Python with EPICS Portable Channel Access Server. The application simulates the High and Low Voltage system of PANDA STT, but it can be easily scaled up by increasing the number of prefixes to the PV names.

The test bed for database storage and retrieval developed at the end of 2017 in IFIN-HH – with reused IFIN-HH PANDA grid compute nodes – has been updated at the beginning of 2018, the overall number of reused computers being increased to 16 (Fig. 3b).

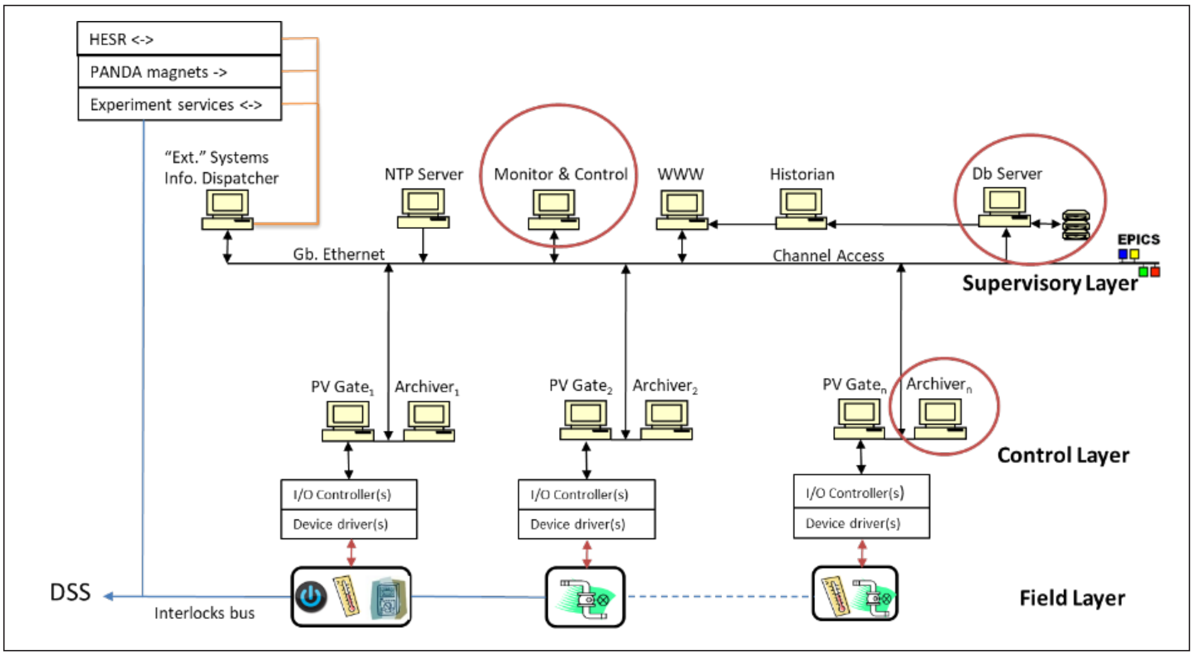
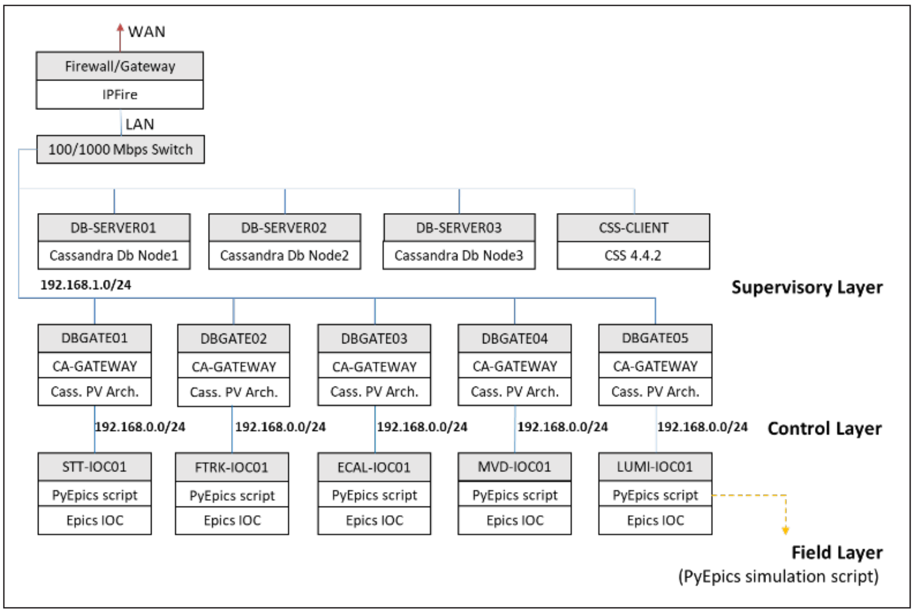


Fig. 3 (a)-PANDA Controls Architecture; (b) - Process Variables archiving test-bed



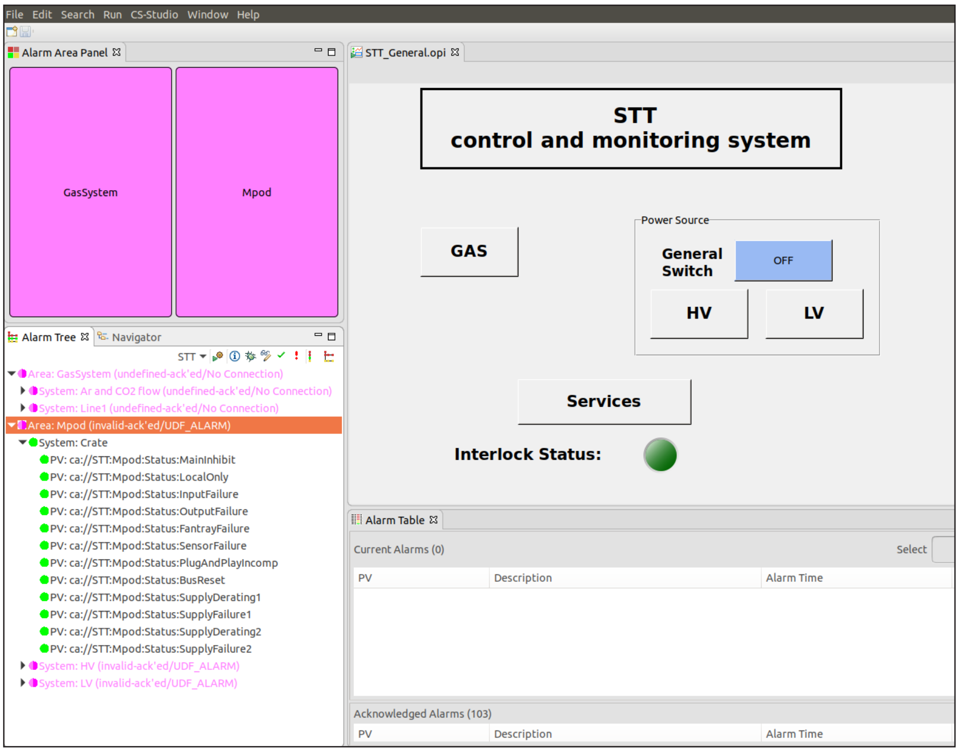
The performance of Cassandra PV Archiver deployed on a three node cluster has been evaluated – with a database of 60.010 Process Variables. More details about the testbed features and performance can be found here *https://indico.gsi.de/event/6948/.*

We developed a software application for the control and monitoring of the gas system and power supply used by STT using the hardware available at IFIN-HH. This application is divided in multiple parts:

- Top level CSS display which facilitates the navigation and error spotting at end user level (Fig. 4a)
- EPICS IOC and CSS interface for the control of the Wiener MPOD Crate which powers the STT.
- EPICS IOC and Control System Studio (CSS) interface for the control of one gas line and the initial admission of *Ar* and CO_2 in the system (Fig. 4b).
- CSS Alarm System and Alarm Database for both the gas and power systems.

In order to automatize the building of PVs database, we developed a Python script which reads a list provided by the user with the names of the PVs which should be monitored and writes an XML file in the standard form accepted by the Alarm Server tool. The integration of the resulting database in a bigger system is trivial with this tool.

As a summary, more than 2000 EPICS PVs are created with the software described above. Since most of them do not communicate directly with hardware components, the load on an average PC used as host is reasonable even with the extension from one to twenty gas lines.



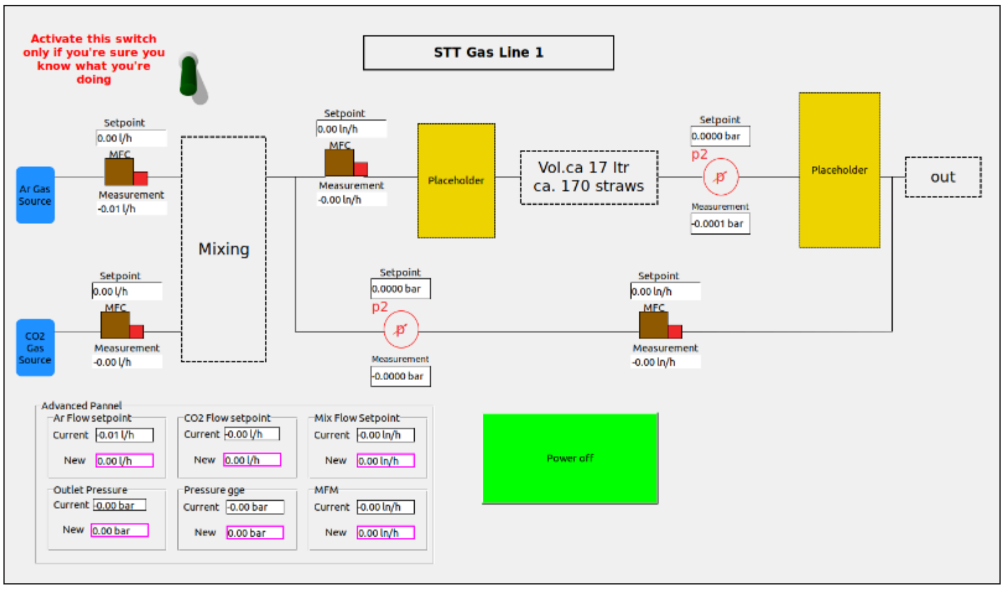


Fig. 4 (a) - CSS top level OPI and Alarm System for STT;
(b) - CSS OPI display of one STT gas line

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INSTITUTE OF ATOMIC PHYSICS
407 Atomistilor St., Magurele, ILFOV, 077125, P.O.Box MG-3, ROMANIA
Phone/Fax: (+4) 021 457 44 93, 021 457 44 56
www.ifa-mg.ro