Romanian research projects at CERN

2016 - 2019

Bucharest-Magurele, ROMANIA
2021

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Brief Overview of the Romania-CERN Collaboration

Founded in 1954 astride the Franco-Swiss border near Geneva as a laboratory for nuclear research, the European Organization for Nuclear Research (CERN, https://home.cern/) has become over the decades the world's leading laboratory for particle physics. Physicists and engineers at CERN use the world's largest and most complex scientific instruments to study the basic constituents of matter – fundamental particles. Subatomic particles are made to collide together at close to the speed of light. The process reveals clues about how the particles interact, and provides insights into the fundamental laws of nature.

The name of CERN is tightly linked to several scientific achievements. Among these, one can mention the discovery of neutral currents (1973), determination of the number of matter families (1989), the first creation of antihydrogen atoms (1995), or the discovery of direct CP violation (1999). The picture is completed by the Nobel Prize winning discoveries of the $W^{\pm}$ and Z intermediate vector bosons at SPS (Super Proton Synchrotron) in 1983 and the Higgs boson at the LHC (Large Hadron Collider) in 2012. In parallel, the research projects at CERN contribute to the advancement of the frontiers of technology and engineering. As a most impressive example, the World Wide Web, the tool used by billions of people today, was invented at CERN as a document management system.

Nowadays CERN is home to a wide range of experiments (https://home.cern/science/experiments). Scientists from institutes all over the world form experimental collaborations to carry out a diverse research programme, ensuring that CERN covers a wealth of topics in physics, from the Standard Model to supersymmetry and from exotic isotopes to cosmic rays. The most known experiments are the ones performed at the LHC. The biggest of these experiments use general-purpose detectors to investigate the largest range of physics performed at the record-breaking energies available at LHC. Having two independently designed detectors is vital for cross-confirmation of any new discoveries made. Several other experiments at the LHC have specialised detectors which focus on specific phenomena. Fixed-target experiments make use of the pre-LHC accelerator chain, SPS or the Proton Synchrotron (PS) to cover several topics ranging from atmospheric physics to Quantum Chromodynamics (QCD). The Antiproton Decelerator (AD) and ELENA (Extra Low ENergy Antiproton) capture and slow down antiprotons created in collisions at the PS in order to produce and study antihydrogen atoms. Several experimental facilities at CERN make use of radioactive beams in a wide range of research domains, from cutting edge nuclear structure studies, through atomic physics, nuclear astrophysics, fundamental interactions, to solid state and life sciences. Not all experiments rely on CERN's accelerator complex. Some CERN experiments look for hypothetical particles like dark matter or axions. Last, but not least, CERN is also leading work to create a "computing Grid" that will harness vast amounts of computer power through networks across the world. Engineering for CERN, especially in cryogenics, superconductivity, vacuum, microelectronics and civil engineering, provides a valuable expertise that can be applied elsewhere. Particle detectors invented at CERN are used in techniques for medical diagnosis.

Today CERN comprises 23 Member States and 11 Associate Members States including also countries outside Europe. Approximately 10000 visiting scientists, half of the world's particle physics community, come to CERN every year for their research. The highest authority of the Organization is the CERN Council, assisted by the Scientific Policy Committee and the Finance Committee.

After 25 years of collaboration, Romania became the 22nd Member State of CERN on 17 July 2016 when acceded to the Organization's founding Convention (Law 96/2016 on the Accession of Romania to the Convention for the Establishment of a European Organization for Nuclear Research). Romania is represented at CERN by the state authority for research and development (R&D), at present the Ministry of Research, Innovation and Digitalization (MCID), that appoints the representatives in the CERN Council and other committees. Currently, Romania has representatives in 12 committees (https://www.ifa-mg.ro/cern/reprezentantii_romaniei.php).

His Excellency Mr. Klaus Werner Iohannis, President of Romania and Fabiola Gianotti, Director General at CERN on the occasion of the flag-raising ceremony to mark the accession of Romania as a Member State of CERN
Source: CERN, https://home.cern/

An important event for the collaboration between Romania and CERN was hosted by Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH, https://www.nipne.ro/index.php), at ELI-NP facility, on 23-24 March 2018: country visit of the European Committee for Future Accelerators (ECFA, https://ecfa.web.cern.ch/). ECFA was founded in 1963 with the purpose of monitoring and supporting the development of particle physics in CERN member countries. ECFA is an advisory committee for CERN Management, CERN Council and its Committees, and to other national and international organizations. ECFA was very impressed with the high quality of the activities of the particle physics community in Romania, and encouraged the funding agencies to continue their efforts to ensure adequate and active support.

ECFA visit in Romania/IFIN-HH 2018

CERN School of Computing (CSC) organises on a regular basis international schools covering various aspects of scientific computing for high-energy physics and other data-intensive sciences. Schools are aimed at postgraduate (minimum of Bachelor degree or equivalent) engineers and scientists, working at CERN or other research institutes, with experience in particle physics, computing or related fields. In 2019, the 42nd CERN School of Computing (CSC 2019, https://indico.cern.ch/event/769356/) was organised in Cluj-Napoca in collaboration with Babeș-Bolyai University (UBB, https://www.ubbcluj.ro/) and Politehnica University of Bucharest (UPB, https://upb.ro/). CSC 2019 enjoyed a large attendance, with participants from many countries, and was a real success.

CERN School of Computing 2019, Cluj-Napoca/UBB, Source: https://csc-media.web.cern.ch/CSC2019

The R&D activities required for Romania's participation in CERN experiments are funded through the National Plan for Research-Development and Innovation, in particular through the dedicated CERN-RO Programme conducted by the Institute of Atomic Physics (IFA, https://www.ifa-mg.ro/cern/). Only the activities based on a Memorandum of Understanding between the CERN Collaboration and the Romanian participating institutions in the experiment are eligible for funding. The proposals are evaluated by the CERN-RO International Scientific Advisory Board (ISAB, https://www.ifa-mg.ro/cern/comitetul_stiintific.php) that also recommends the distribution of the budget allocated to the programme over the successful projects. ISAB meets usually once per year in conjunction with IFA's funding activity, issuing evaluation/monitoring reports to the project teams, to IFA and to the state authority for R&D.

ISAB meeting 2017 (left), 2019 (right), Măgurele/IFA, ISAB CERN-RO

The projects funded during 2016-2019 are listed in the following table, where the corresponding CERN facilities and experiments, project titles, duration and the participating institutions are indicated.

CERN		**Project title**	**Duration**	**Coordinator/ Partner***
Research Programme	**Experiment**			
Large Hadron Collider (LHC)	ALICE	IFIN-HH Contribution to the ALICE Experiment at LHC (RONIPALICE)	2016-2019	IFIN-HH
		Shaping the QGP using Flow and Jets Analyses (ISSALICE)	2016-2019	ISS
	ATLAS	ATLAS Experiment from LHC (ATLAS)	2016-2019	IFIN-HH / ITIM, UPB, UAIC, UVT, UTB
	LHCb	LHCb - Study of Hadron Production, Heavy Favour Physics and the Upgrade Program (LHCb)	2016-2019	IFIN-HH / USV
	WLCG	National Contribution to the Development of the LCG Computing Grid for Elementary Particle Physics (CONDEGRID)	2016-2019	IFIN-HH / ISS, ITIM, UAIC, UPB
	MOEDAL	Romanian Contribution to MoEDAL (RO_MoEDAL)	2017	ISS
ISOLDE	ISOLDE	Experimental and Theoretical Studies of Exotic Nuclei at ISOLDE (EXONTEX)	2016-2019	IFIN-HH
Proton Synchrotron (PS)	n_TOF	n_TOF Collaboration (n_TOF)	2016-2019	IFIN-HH
Super Proton Synchrotron (SPS)	NA62	Study of Rare Kaon Decays at the CERN SPS (NA62)	2016-2019	IFIN-HH
Neutrino Platform	WA105	Contribution to Neutrino Physics using Large Scale Prototypes LAr Detectors (NEPHYLAro)	2017	UB-FF
R&D	RD50	Defect Engineered p-type Silicon Sensors for LHC Upgrade (DEPSIS)	2018-2019	INFM

* National Institute for R&D of Physics and Nuclear Engineering Horia Hulubei (IFIN-HH), Institute for Space Sciences (ISS), National R&D Institute of Materials Physics (INFM), National Institute of R&D Isotopic and Molecular Technologies (ITIM), University of Bucharest, Faculty of Physics (UB-FF), University Politehnica of Bucharest (UPB), Alexandru Ioan Cuza University of Iaşi (UAIC), West University of Timişoara (UVT), Transilvania University of Braşov (UTB), Ştefan cel Mare University of Suceava (USV).

Overall, 11 projects of 10 institutions from 6 cities of Romania were funded in the period 2016-2019, as shown in the next figure.

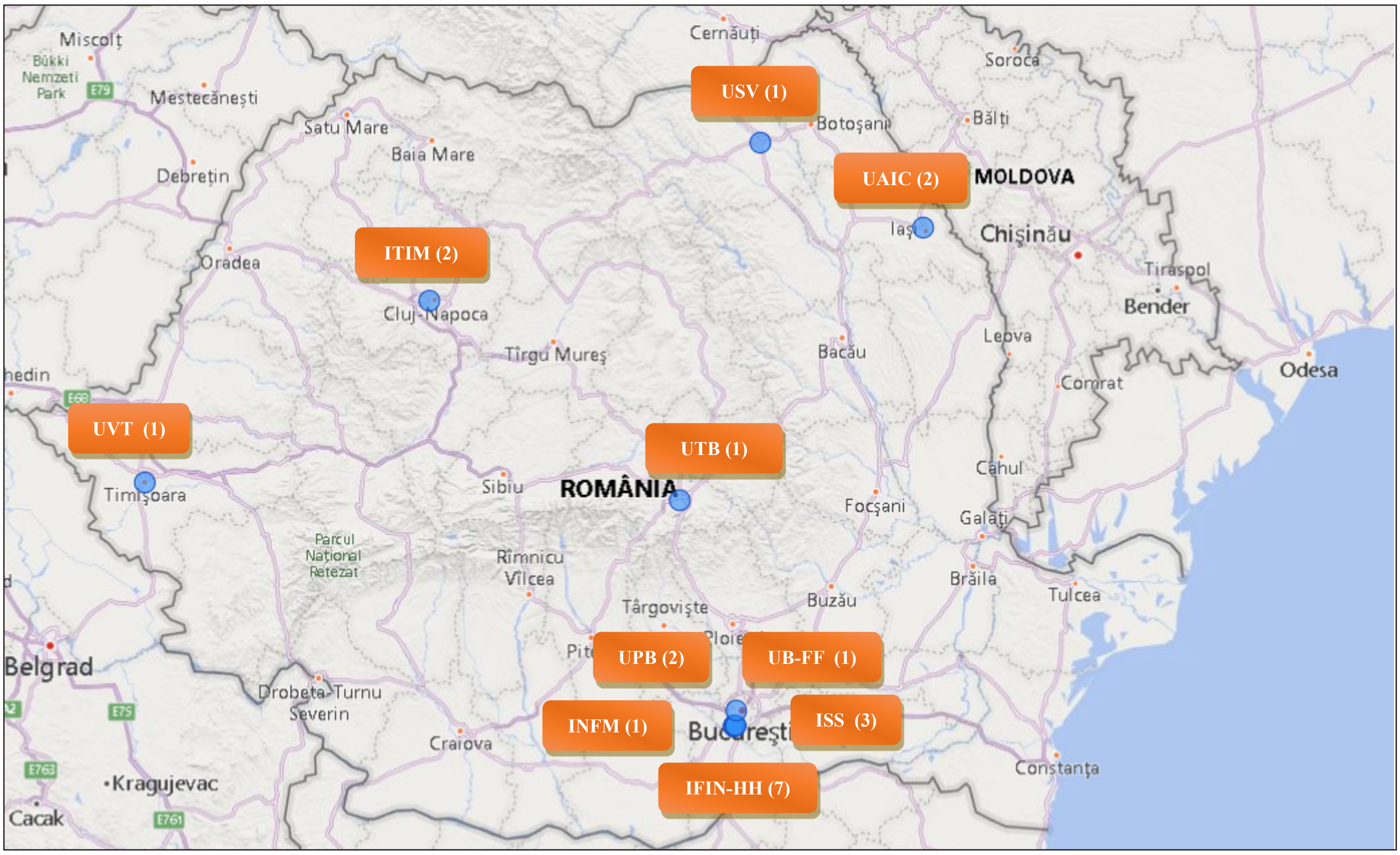


Fig. 1. *The territorial distribution of participating institutions in CERN-RO programme between 2016-2019*

The following diagrams present, for 2016-2019, the budget allocated to the CERN-RO programme, the distribution of both the personnel (based on professional degrees) and the full-time equivalent per year, as well as the main indicators of the scientific output of the funded projects.

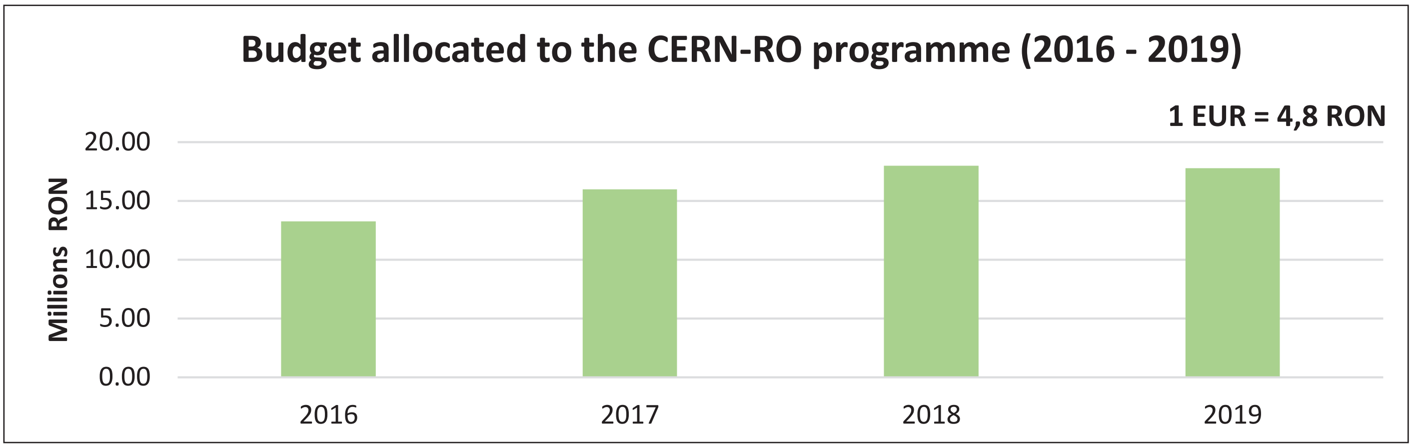


Fig. 2. *– The budget allocated for the financed projects for the period 2016-2019*

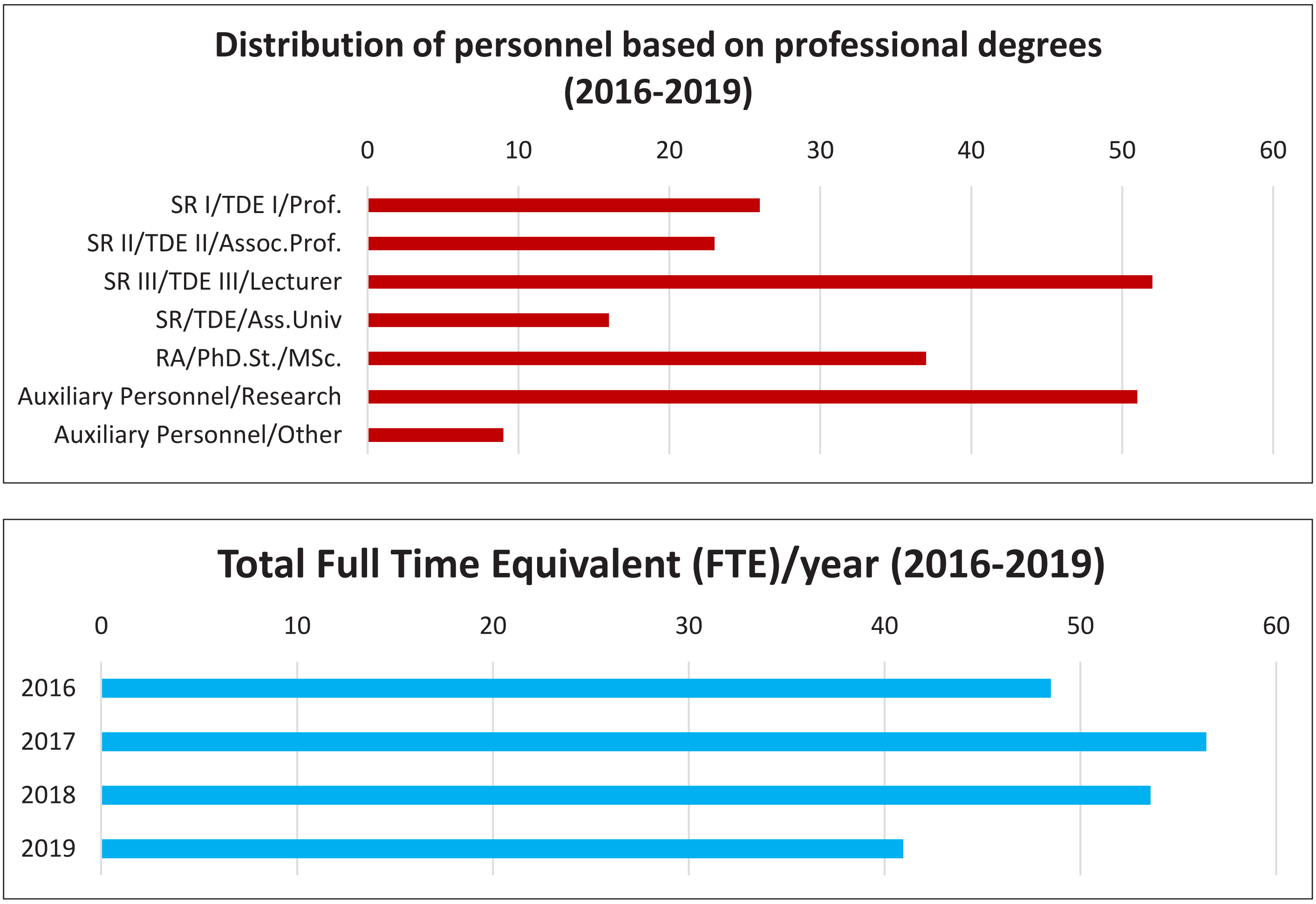


Fig. 3. *Human resources involvement in CERN-RO projects (where SR – Scientific Researcher; TDE – Technical Development Engineer I, II,III; RA – Research Assistant)*

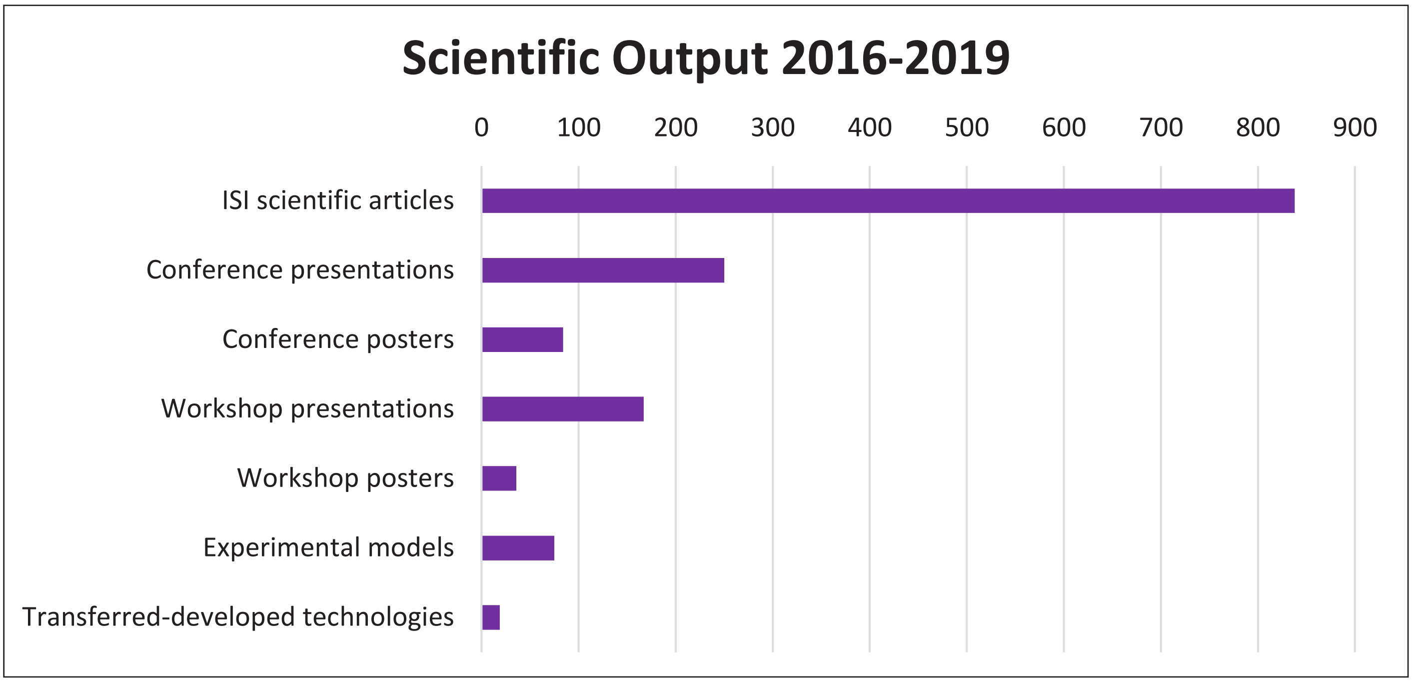


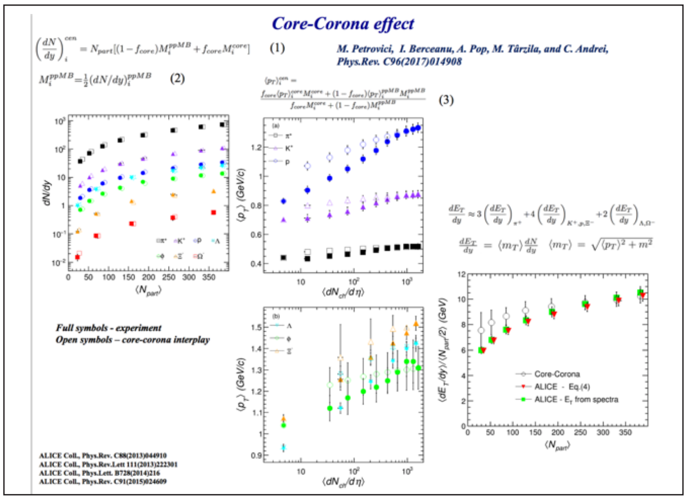
Fig. 4. *Scientific output for the period 2016-2019*

IFIN-HH Contribution to the ALICE Experiment at LHC (RONIPALICE)

Project Leader: Prof. Dr. Mihai PETROVICI
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
ALICE Collaboration: *https://alice-collaboration.web.cern.ch/*
Project web page: *http://niham.nipne.ro/RO-CERN_ALICE_20.html*

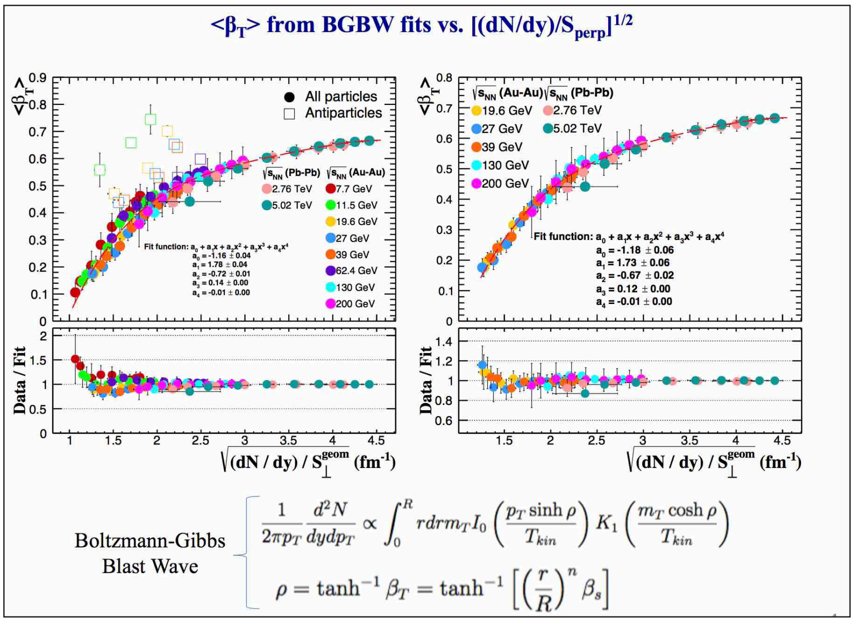
Main objectives of the CERN Experiment/Collaboration:

Since 1999, the Hadron Physics Department of the National Institute for Physics and Nuclear Engineering (IFIN-HH) is member of the ALICE Collaboration. ALICE (A Large Ion Collider Experiment), an experiment carried out at the Large Hadron Collider at CERN-Geneva, is optimised for the study of heavy ion and pp collisions with the aim to obtain information on the properties of the hot deconfined matter formed in such collisions and its dynamical evolution. To achieve this goal, ALICE is designed to measure a large set of observables over a large phase space.



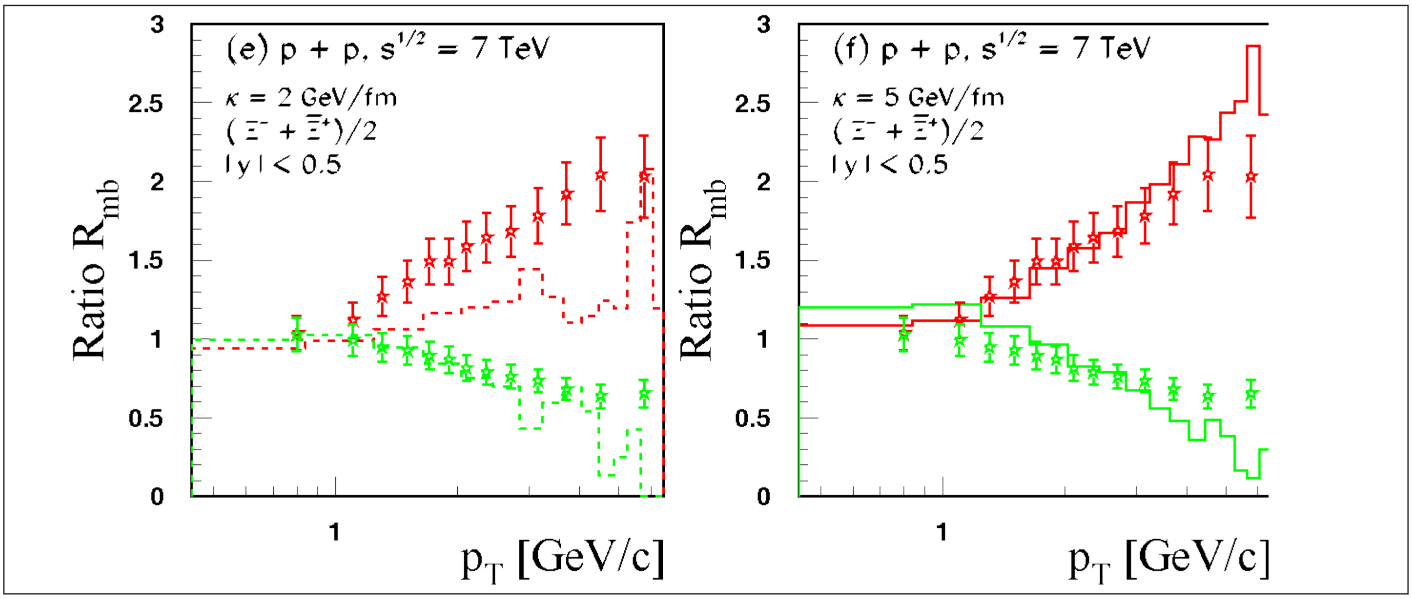
Main objectives of the Romanian participation in ALICE Experiment:

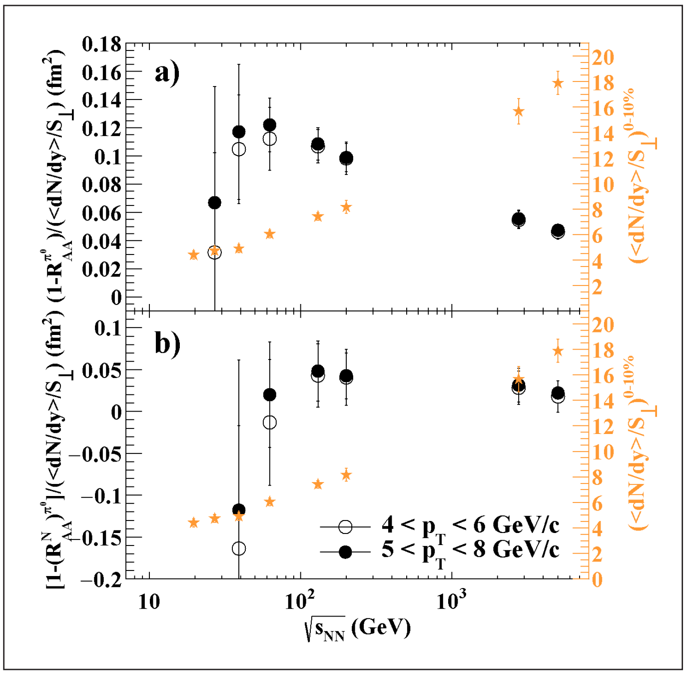
Since the beginning of data taking in ALICE, our group proposed and worked out a physics topic related to collective type phenomena in pp collisions, which turned out to be one of the most interesting phenomena to be studied in detail at LHC energies. By analysing the transverse momentum distributions at midrapidity of charged particles, pions, kaons and protons as a function of charged particle multiplicity in pp collisions at $\sqrt{s} = 7$ TeV, similarities with features evidenced in heavy ion collisions have been observed (Nucl.Phys. A931(2014)888). Selection of high multiplicity events close to azimuthal isotropy based on event shape global observables shown to be feasible. Results were presented at international conferences and papers and an extensive paper on multiplicity dependence of light flavour hadron production in pp collisions at $\sqrt{s} = 7$ TeV was published (Phys. Rev. C99(2019)024906). A detailed study of core-corona interplay in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, the geometrical scaling from energies available at RHIC to those at LHC, the multiplicity dependent transverse momentum distributions of identified particles in pp collisions at $\sqrt{s} = 7$ TeV within HIJING/BB v2.0 model and considerations on suppression in A-A and pp collisions signalizing a possible evidence for a new type of deconfined matter at LHC are topics lately published by us in Phys. Rev. C papers (Phys. Rev.C 96(2017)01490898(2018) 024904 ; 98(2018)064903; 103(2021)034903) and presentations at international conferences.

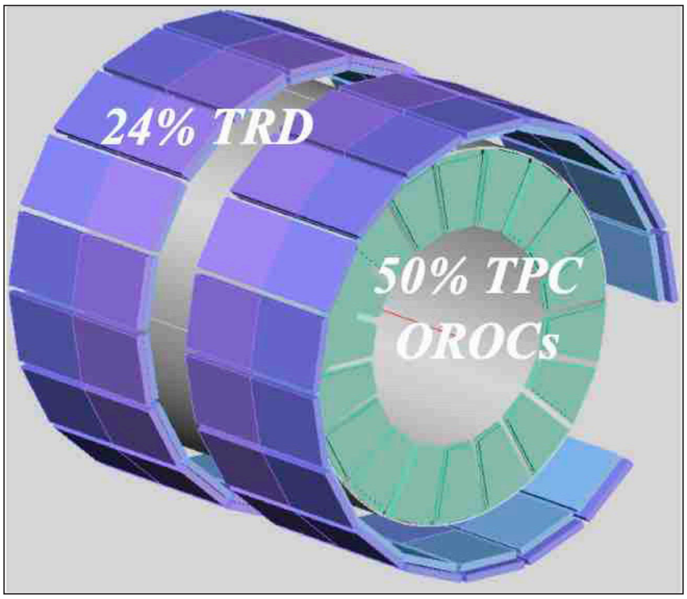


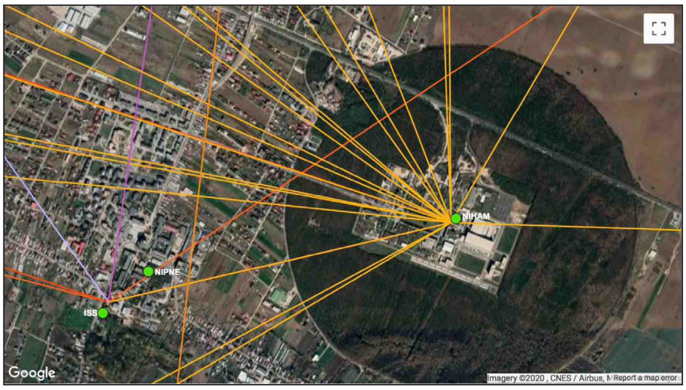
In-progress work is related to multi-differential analysis of p_T spectra of charged and identified particles and two-particle corelations in pp collisions at $\sqrt{s} = 7$ TeV and 13 TeV.

Besides the analysis and results obtained by our group in ALICE Collaboration or independent ones related to ALICE physics, the co-authorship of an impressive amount of papers and contributions at international conferences is based on important contributions we had in building the ALICE experiment (24% of the ALICE multiwire proportional chamber of the transition radiation sub-detector and 50% of the outer read-out chambers of the upgraded ALICE-TPC based on GEM technology were assembled and tested in our team from HPD. A member of our team had an important contribution in developing the TRD tracking. The PASA CHIP for TRD subdetector was designed with a major contribution of one of our electronic engineer.









Last but not least, our Tier2 Data Centre is one of the most performant site of the ALICE GRID.

In Run3 and Run4 at LHC, ALICE will take data for pp and Pb-Pb collisions at high luminosity using the upgraded setup. Operated in this mode, the accumulated statistics will increase such that any kind of multi-differential analysis will be feasible, charge particles multiplicity which could be accessed in pp collisions increasing by one order of magnitude.

More details on HPD contributions to ALICE Experiment at LHC and obtained results could be accessed on *hppt://niham.nipne.ro* on in *https://www.facebook.com/Hadron-Physics-Department-211078852968333/*

Done jobs - NIHAM:
- ***6.7 · 10⁶***
- ***4.7 % of total Tier2 ALICE contribution***

CPU:
- ***6.6 Mhours 12.46 Mhours***
- ***4.2 % of total Tier2 ALICE contribution***

Shaping the QGP using Flow and Jets Analyses (ISSALICE)

Project Leader: Dr. Alexandru Florin DOBRIN/Dr. Catalin RISTEA
Project Coordinator: Institute of Space Science (ISS) – INFLPR Subsidiary
ALICE Collaboration: *https://alice-collaboration.web.cern.ch/*
Project webpage: *http://www.spacescience.ro/projects/issalice/issalice2016/*

The goal of the ISSALICE project was to study the properties of the system created in collisions of hadrons and nuclei recorded by the ALICE detector at the Large Hadron Collider (LHC) using measurements of angular correlations and jet structure. In addition, the group was responsible for all central ALICE data reconstruction and Monte Carlo (MC) simulations and to run computing jobs for ALICE using its GRID Tier-2 site.

ALICE (A Large Ion Collider Experiment) is a dedicated heavy-ion detector designed to study the strong interaction sector of the standard model of particle physics. The aim is to characterize the quark-gluon plasma (QGP), the high-temperature phase predicted by the underlying theory of strong interactions, quantum chromodynamics (QCD). The study of the QGP has a large impact in particle physics and astrophysics as it is expected to be the state of the matter present in our Universe a few microseconds after the Big Bang. A key observable to quantify the QGP properties is anisotropic flow, the conversion of the initial spatial asymmetry into an anisotropy in momentum space. Measurements of anisotropic flow compared to theoretical models indicate that the QGP created at the LHC behaves like a nearly perfect fluid (almost zero friction). Heavy-ion collisions have also been proposed as tool to search for parity violation in strong interactions – they proceed differently when all spatial coordinates are reversed. Although it is permitted by QCD, parity violation in strong interactions is not observed.

The group was involved in several physics analyses and offline and GRID activities during this project.

Physics: Measurements of anisotropic flow for inclusive and identified particles, including the first measurement of ϒ(1S) elliptic flow in heavy-ion collisions (see Fig. 1), were performed in lead-lead collisions at $\sqrt{s_{NN}}$= 5.02 TeV. The anisotropic flow for identified particles and charge-dependent correlations used to search for local parity violation were also measured for the first time in xenon-xenon collisions at $\sqrt{s_{NN}}$= 5.44 TeV. In addition, measurements of jet (i.e., the spray of hadrons resulting from the fragmentation of a parton) shapes and spectra were performed in proton-proton collisions at $\sqrt{s}$ = 7 TeV and proton-lead collisions at $\sqrt{s_{NN}}$ = 8.16 TeV. These measurements helped the theoretical community to further constrain the transport coefficients of the QGP, initial spatial densities, and particle production mechanisms. The studies led to one ALICE paper published in PRL 123, 192301 (2019) and five ALICE public/analysis notes submitted/approved by the Collaboration. Furthermore, the group contributed to the heavy-ion chapter of the CERN Yellow Report on Run 3 Physics and Beyond submitted for the European Particle Physics Strategy Update (published in CERN Yellow Rep. Monogr. 7 (2019) 1159). The results were presented in several international conferences, including Quark Matter 2019 (the largest and most prestigious conference series in the field with ~800 participants) and the CERN LHC Seminar series. Moreover, these results will benefit from the increased statistics in Run 3 (2022-2024) where ALICE will accumulate a factor 10-100 more statistics.

Offline: Large experiments have dedicated departments to take care of the central data reconstruction and MC simulations required in order to publish results of physics analyses. Since the end of 2015 the group took Institutional Responsibility for the management and processing of central data productions in ALICE being 100% responsible for central processing of ALICE raw data reconstruction and all MC simulations. The group was fully committed to this task by managing production campaigns in view of ALICE participation at large conferences and disk space clean-up campaigns, and processing all asked development productions (e.g., embedding techniques for MC productions, usage of Geant4 transport model for productions, filtering specific data for analysis). The group completed more than 1200 central MC and raw data reconstruction productions since 2016, which amount to 77 billions reconstructed and simulated events, 30 PB of disk space, and 130000 years of CPU time (see Fig. 2), thus fulfilling its Institutional Responsibility. The participation in ALICE central production management and processing will continue in Run 3.

GRID: The group has also a GRID Tier-2 site for ALICE. Its storage capacity and number of cores at the end of 2019 reached ~1.5 PB and more than 900, respectively. The site processed ~3.1 millions successful jobs corresponding to ~1358 years of CPU

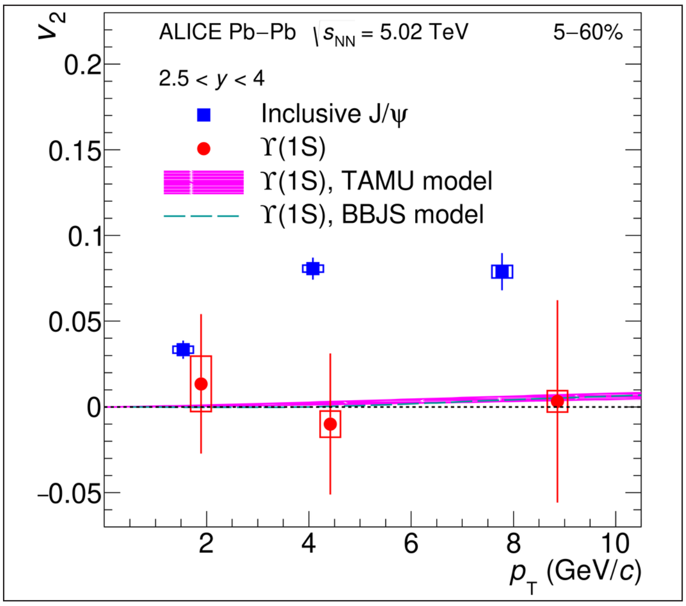


Fig. 1: *Υ(1S) elliptic flow measured in lead-lead collisions.*

time and had a total data traffic of 26 PB between 2016 and 2019 (~13% successful jobs, ~10% of CPU time, and ~27% data transfer from the Romanian contribution). Further support to ALICE GRID was achieved by being responsible for the XRootD software employed by ALICE. In addition, the group developed the software used by all members of the Collaboration to access ALICE GRID. The group will continue to support the GRID in Run 3 by increasing storage capacity and number of cores.
The most important channel to transfer the knowledge gained from the this project to society was from peer reviewed scientific articles and outreach events (e.g., Different school: know more, be better; Astro-Fest; Sci+Fi Fest; Researcher Night; From young to old through the Universe). The knowledge acquired through research was shared with the rest of the scientific community giving lectures in conferences and seminars. This project extended the current understanding of the QGP and addressed a fundamental QCD topic, parity violation in strong interactions. These should provide answers about the matter that existed in the first microseconds after the Big Bang and should teach us about the effect of primordial magnetic fields in the early Universe. Another important contribution was the training of new scientists: PhD, master and bachelor students. Even though not all of them continued in the research at the end of the program all the accumulated assets and qualities made them attractive candidates in different sectors, such as banking and industry.

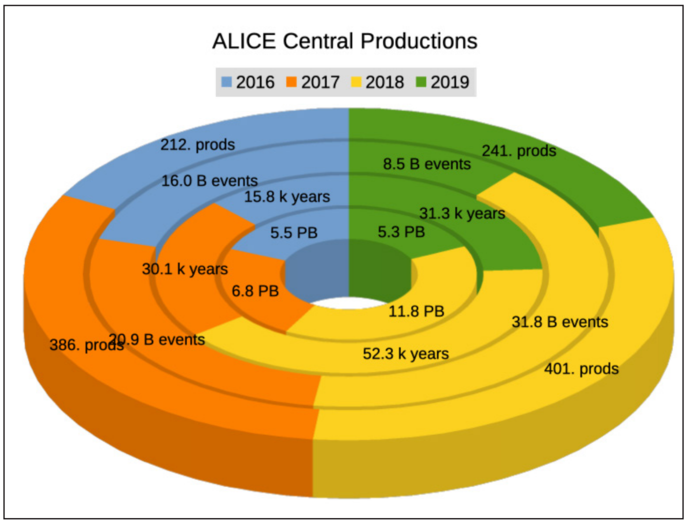
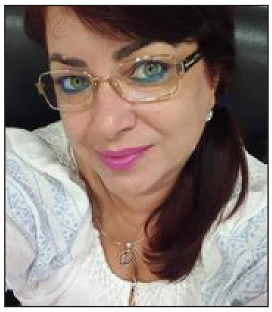


Fig. 2: Summary of ALICE central productions.



ATLAS Experiment from LHC (ATLAS)

Project Leader: Dr. Călin ALEXA
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Partners: National Institute for R&D of Isotopic & Molecular Technologies Cluj-Napoca (ITIM), University Politehnica Bucharest (UPB), "Alexandru Ioan Cuza" University of Iași (UAIC), West University of Timișoara (UVT), Transilvania University of Brasov (UNITBV)
ATLAS Collaboration: *https://atlas.cern/*
Project webpage: *http://calexa.web.cern.ch/atlas_romania.htm*

ATLAS (**A T**oroidal **L**HC **A**pparatu**S**) is a particle physics experiment at the Large Hadron Collider (LHC) at CERN (the European Organization for Nuclear Research) that is searching for new discoveries in the head-on collisions of protons of extraordinarily high energy. ATLAS will learn about the basic forces that have shaped our Universe since the beginning of time and that will determine its fate. The experiment is designed to take advantage of the unprecedented energy available at the LHC and observe phenomena that involve highly massive particles, which were not observable using earlier lower-energy accelerators. It is hoped that it will shed light on new theories of particle physics beyond the Standard Model. Among the possible unknowns are extra dimensions of space, unification of fundamental forces, and evidence for dark matter candidates in the Universe. Following the discovery of the Higgs boson, further data will allow in-depth investigation of the boson's properties.

Project objectives:

- Scientific exploitation of the data collected by the experiment through various complementary approaches: direct searches for Beyond Standard Model (BSM) predictions based on model-oriented or model-independent approach, or possible indirect BSM evidence through their impact on SM phenomenology.
- Better understanding of the data: study of the performance of the electron reconstruction and identification, and the performance of their modelling in the detector simulations; study of the non-collision background and its suppression; monitoring and assessment of the quality of the recorded data.
- Provide support for analyses, development and maintenance of common software tools, general-interest services
- Development of central reconstruction and simulation software: contribute to the evolution of the software and its modernization (migration to multithreaded environments, Machine Learning, etc).
- Development of the NSW (New Small Wheels) detector simulation software (geometry, algorithms).
- Operation and maintenance of the ATLAS detector, in particular its calorimetry systems, recording of the data-taking conditions and long-term storage of this information.
- NSW Phase-I Upgrade and Integration and Commissioning activities at CERN.
- NSW TDAQ Phase-II Upgrade: R&D program for trigger processor system, FELIX and read-out system.
- Tile Calorimeter (Tilecal) Phase-II Upgrade: R&D for the new FE electronics: mechanical drawers, assembly line, certification test-benches, installation tools & commissioning; production of the mechanical super-drawers, mini-drawers assembly line, test-benches for super-drawer certification, installation tools and photomultipliers HV active dividers electronic boards production.
- Diplomas, dissertations and PhD thesis coordination.
- Consolidation and diversification of outreach activities.

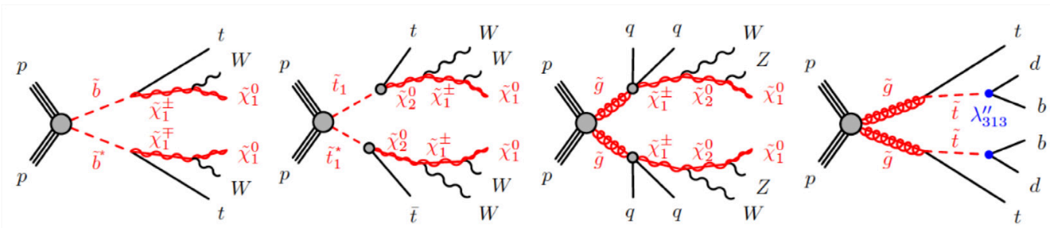


Fig 1 SUSY searches for squarks and gluinos; SUSY models featuring R-parity conservation and R-parity violation

Project activities:

- Physics studies
  - Supersymmetry searches in final states with leptons, jets and missing transverse momentum
  - Dijet resonance and ISR production
  - Precision measurement for Zjj production
  - Quantum Interference Between Single and Doubly Resonant Top Quark Production
  - Search for new BSM charged scalars $H^{\pm\pm}$/ $H^{\pm}$
  - Machine Learning techniques for systematically search for the presence of unknown signal in the data
- Performance studies and analysis software
  - Electron performance measurements, discrimination and study of misidentified reconstructed objects
  - Common analysis software tools
- Data preparation
  - Non-Collision Background: simulation, identification, suppression and online monitoring
  - Data quality monitoring infrastructure: maintenance and development of the software; validation of data
- Detector operation and TDAQ
  - Tile calorimeter maintenance, repairs and operation, DCS expert on call
  - Maintenance of the data acquisition global monitoring tools.
  - Modernization of the database management systems used to record the detector condition.
- Software and computing
  - Core software support and development and New Small Wheel software development.
  - Central services operations team: support and development.
  - Maintenance and operation of the Romanian WLCG Tier2 centers managed by our group members.
- ATLAS detector upgrade
  - Phase-I Upgrade: New Small Wheel (NSW) ROC ASIC testing, NSW Trigger Processor production and testing, contribution to NSW Integration & Commissioning at CERN.
  - Phase-II Upgrade: NSW Trigger Processor – hardware design, production, testing, algorithm implementation
  - Phase-II Upgrade: FELIX – concept, design, collaborative contributions; hardware design, production, testing
  - Phase-II Upgrade: Tile Calorimeter - R&D for new FE electronics: Mechanical drawers – mini/micro-drawers- and Tooling system – handling and installation tools, mini-drawers assembly line and super-drawers test-benches for Quality assurance and certification; production of the Mechanical super-drawers and Tooling system; photomultipliers HV active dividers electronic boards production and certification.
- Outreach - IPPOG masterclass, meetings with high school students, radio & tv shows, etc.

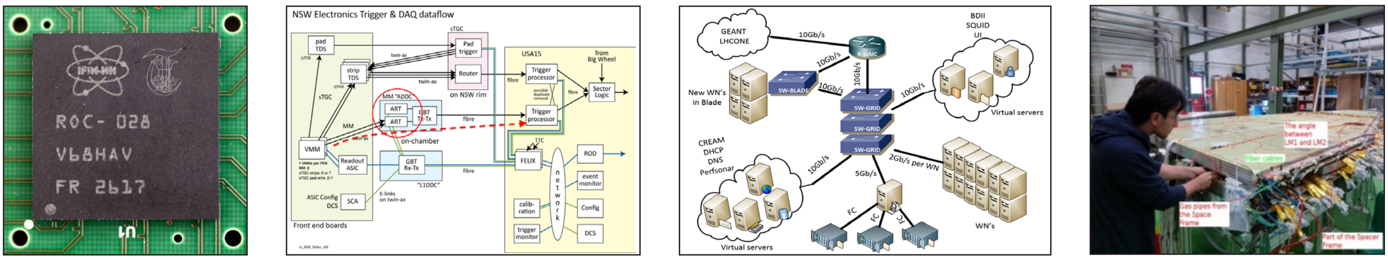


Fig 2 a) ROC ASIC b) NSW Electronics scheme c) The RO-16-UAIC arhitecture d) NSW I&C in building BB5 at CERN

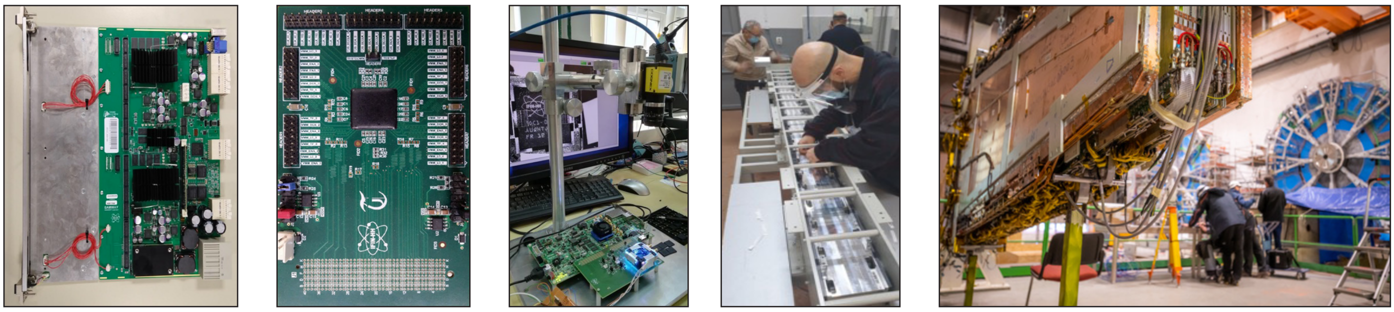
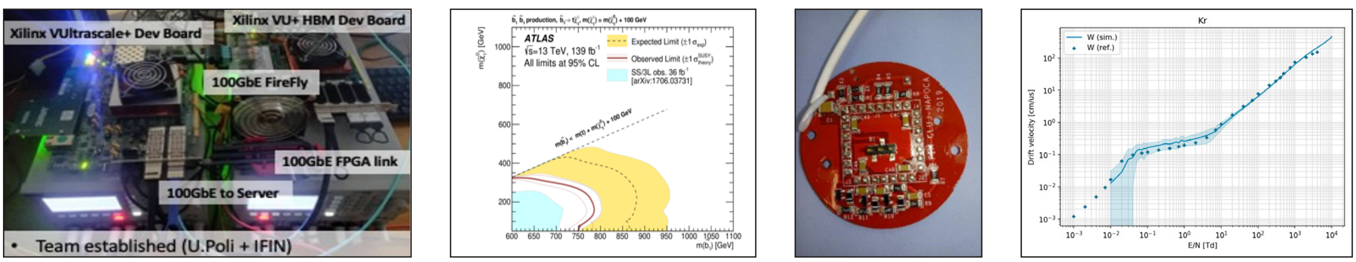


Fig 3 a) NSW mezzanine b)NSW carrier c)ASIC test setup d) Tilecal electronics repair at CERN e) NSW I&C in building 191 at CERN



LHCb - Study of Hadron Production, Heavy Favour Physics and the Upgrade Program (LHCb)

Project Leader: Dr. Florin MACIUC
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Partners: University „Stefan cel Mare" of Suceava (USV)
LHCb Collaboration: *http://lhcb.web.cern.ch/lhcb/*
Project webpage: *http://www.nipne.ro/dpp/Collab/LHCb*

The Romanian LHCb team is part of Large Hadron Collider beauty (LHCb) collaboration/experiment since its beginning. We are contributing to data analysis studies, to LHCb computing, to LHCb construction and Upgrade. We have a large list of tasks ranging from LHCb/CERN Outreach and academic to particle beam tests of electronics for accelerator or space-based high energy physics (HEP) experiments or beyond. Our efforts during the LHC second run and during this project (2016-2019), were focused on physics studies and technological aspects of LHCb Upgrade and other HEP experiments. Through: group analyses, software and hardware development, LHCb data quality checks, simulation studies, generator tuning, LHCb calibration and maintenance, LHCb GRID Computing, internal LHCb analysis review, Upgrade studies, paper draft reviewing, and HEPData tasks (HEP database of accelerator experiment measurements), we contributed to about 200 LHCb journal papers over the project timespan and to several conference contributions. The group has a strong involvement in the LHCb workgroups, like: Ring Imaging CHerenkov detectors (RICH1 and RICH2) group, and in multiple QCD groups where Quantum ChromoDynamic processes and transitions are studied for a few classes of LHC events, including the all-inclusive class. In these directions we collaborate directly with other LHCb groups like Cambridge University, Zurich University, CERN local group, groups from universities from Milano and Genova, University of Oxford, Ecole Polytechnique (l'X), etc. Besides the LHCb analyses, tasks and support activities, we have quite a few independent studies, especially those caried out by our MSc and PhD students, which have conducted studies in particle generation in proton-proton (p+p) collisions at 7-13 TeV, with emphasis on Minimum-Bias physics – Minimum Bias physics are inclusive studies of particle production in all LHC events –, in heavy quarkonia production and decay, or other flavour and QCD studies. 2 PhD theses and 2 MSc theses have covered these subjects and we had several conference presentation, proceedings and posters, together with 2 journal papers first authored by our students. In this project, 12 PhD and MSc students are or were part of the group during 2016-2019, with 4 PhD and 3 MSc students choosing an LHCb research topic for their dissertation. This should be added to 5 Post-Docs involved in this project, and all these students and new researchers have gain experience in: HEP physics; accelerator, detector/HEP electronics; HEP computing and IT, HEP academics, etc.

Regarding the Upgrade studies these were focused, in large part, towards testing various integrated circuits in radiation and other special conditions, which allowed to estimate the radiation tolerance of the technologies proposed for Upgrade. This was instrumental, for the RICH group, to select the correct digital board design and firmware for the ultra-fast communication in excess of Terrabit/s for RICH and data acquisition electronics in the 1st LHCb-RICH Upgrade. The group had 7 beam-test experiments, were 4 types of chips – commercial Field Programmable Gate Arrays like Kintex-7 and Axcelerator antifuse FPGAs, and also Application Specific Integrated Circuits (ASICs) like MAROC3 and SPACIROC2 from Ecole Polytechnique - were tested in ion, X-rays and proton beams, with 10 times more radiation doses than expected at LHCb and with the maximum energy transfer per ion equal with the highest cosmic ion energy deposit in International Space Station low orbit environment (40 MeV cm^2/mg).

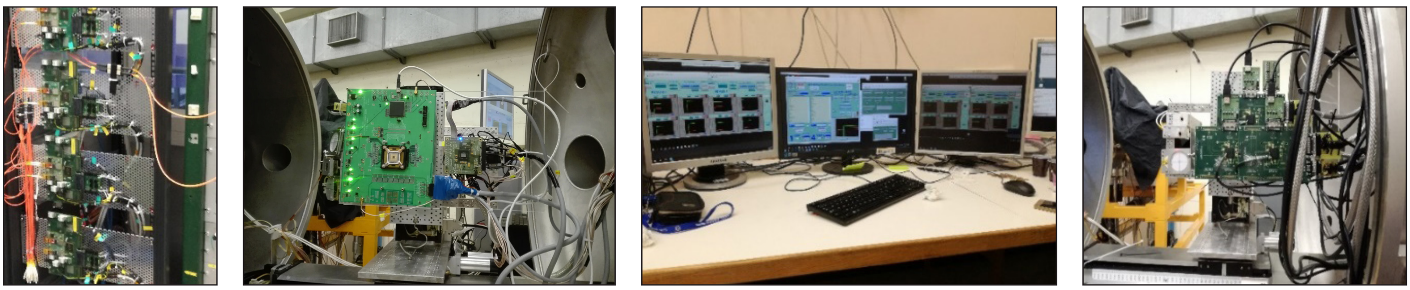


Fig. 1. *From left to right: 1a. A rack-unit with 4 RICH digital boards in CHARM pre-test area, with cabling, before irradiation in extreme condition of radiation (energy deposited in active chip layers has dose at ≈1000 Joules/kg); 1b. Two test boards with an ASIC chip and Kintex-7 before irradiation with ion beam in vacuum; 1c. Typical chip monitoring with 4 hardware displays and multiple virtual displays monitoring in real time hundreds of parameters including beam flux, induced software rates, core power parameters, etc; 1d. 3 anti-fuse Axcelerator chips (FPGA) and their test boards before placing them in vacuum for an irradiation with 10^{13} protons/cm^2 fluence at Legnaro Laboratory, Silicon and Radiation (SIRAD).*

The used irradiation facilities are located at: LN Legnaro and University Padova in Italy, Heavy Ion Facility at "Universite Catolique de Louvain" Belgium, CERN (CHARM) and Paul Scherer Institute in Switzerland, Juelich's "Forschungszentrum" in Germany, and at IFIN. In Fig. 1 are the displays of some typical setups for the test benches used in case of CHARM facility at CERN – (1a) has 4 RICH digital boards with KINTEX-7 chips and (1c) has multiple hardware and virtual displays to monitor in real time the hundreds of parameters during irradiation - and in case of LN Legnaro facility where 7 Axcelerator FPGAs and 5 MAROC3 and SPACIROC2 ASICs were irradiated with protons and ions – the real time monitoring of operation parameters during irradiations are implied for all tests in this report.

Only a few physics studies of our researchers and students are highlighted in Fig. 2, e.g., (2a) and (2c) display a plot generated with RIVET software tool and overlap the LHCb measurement for J/Psi and Upsilon mesons with prediction of PYTHIA generator coupled with dedicated production models like octet and singlet color models. An extensive study of generator physics and forward-tuning was accomplished and published in Chinese Phys. C journal, and as an example in fig. (2c) the energy flow in LHCb acceptance is displayed for cosmic-ray generator, PYTHIA and LHCb measurements. A large effort was directed towards computing the Lambda and K_{Short} hadron production cross-sections using LHCb Minimum Bias 13 TeV p+p data, the raw yields before efficiency correction are displayed in 2d plots.

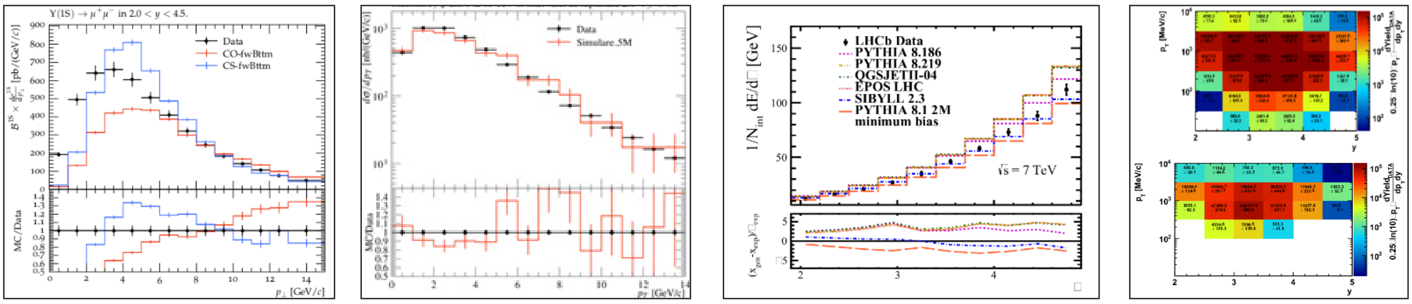


Fig. 2. *From left to right: 2a. The Upsilon meson transverse momentum spectrum for p+p LHC collisions at 13 TeV for PYTHIA 8.2 generated data using color octet and singlet production models and with LHCb measured Upsilon spectrum;*
2b. Same as 2a but for J/Psi meson in place of Upsilon;
2c. Minimum-Bias LHCb measurements for energy flow in LHCb acceptance at 7 TeV compared with generator estimates (cosmic ray generators QGSJET/EPOS/SIBYLL and PYTHIA estimates for different tunes);
2d. Two plots of raw yields measured in LHCb acceptance (p_T,y) for K_{Short} meson state (upper plot) and Lambda baryon (down-side plot) in case of 13 TeV p+p LHC collisions, LHCb 2015 Minimum Bias data.

Besides the physics and LHCb-upgrade studies we are actively contributing to LHCb reconstruction in 1st Upgrade phase, e.g.: 2000 digital and optic fiber communication boards were partially assembled and fully programmed (fused) and tested in our LHCb-dedicated microelectronics laboratories (3a,3b) before shipping to CERN and Cambridge, several tens of electronic data acquisition and communication boards were designed and assembled (3c). Besides these, the group has contributed with a full LHCb-dedicated Tier-2 Grid site Ro-11, and 6 Masterclass HEP events in collaboration with local high-schools and CERN/LHCb – one such event was 2019 event in Targoviste (3d). The popularization of own-group results and of LHCb results include a total of: 9 LHCb-independent journal papers, 7 peer-reviewed independent publications, one organized conference (USV and IFIN), 21 international conference talks, 10 posters, 7 workshop talks (including LHCb mini-workshops), 1 workshop poster, applications to beam-time within Horizon-2020, 4 LHCb PhD theses, 3 LHCb and HEP MSc theses, participation in University of Bucharest MSc programs, tens of UPB and UB doctoral program reports, one patent application (submitted in 2020), etc.

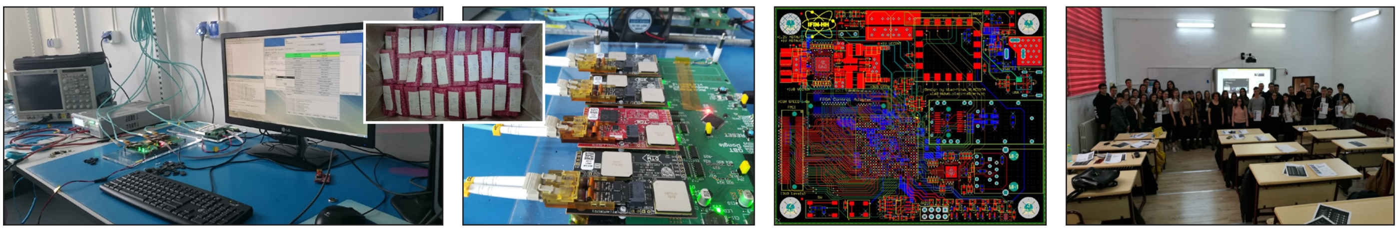


Fig. 3. From left to right: 3a. Testing station in LHCb-Ro micro-electronics and mass testing laboratory where 2000 communication plugin boards were partially assembled, programmed and tested, before shipping to CERN and Cambridge (the latter for mounting on RICH Digital motherboards);
3b. 4 plugin board tested for optic-fiber connectors and 10-15 Gb/s communication speed during the mass testing and programming campaign in Bucharest;
3c A typical test board design from our LHCb-Ro group, several boards were designed for LHCb and for the group irradiation testing;
3d. 2019 High Energy Physics Masterclass event in Targoviste organized by the group, about 6 Masterclass events were organized by the group in collaboration with Romanian High-School professors.

National Contribution to the Development of the LCG Computing Grid for Elementary Particle Physics (CONDEGRID)

Project Leader: Dr. Mihnea DULEA
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
Partners: Institute for Space Science (ISS), National Institute for Research and Development of Isotopic and Molecular Technologies Cluj-Napoca (ITIM), Alexandru Ioan Cuza University of Iasi (UAIC), University Politehnica of Bucharest (UPB)
LCG Collaboration: *https://wlcg.web.cern.ch/*
Project webpage: *http://lcg.ifin.ro/condegrid/*

During the period 2016-2019, the Romanian Tier2 Federation (RO-LCG) successfully fulfilled its main task of contributing with compute resources to the support of the ALICE, ATLAS and LHCb experiments, within the Worldwide LHC Computing Grid collaboration (WLCG). The activities included the provision of highly-available services for storage, processing, simulation and analysis of the LHC data, together with software development and infrastructure monitoring.

According to the data published by the EGI accounting portal (*https://accounting-next.egi.eu*) and the MonALISA repository (*http://alimonitor.cern.ch*), RO-LCG provided more than 217 million walltime hours for ALICE, ATLAS and LHCb experiments. This represents more than 3% of the total walltime hours consumed by the 33 national Tier2s for the three experiments, which makes Romania ranked 7th worldwide.

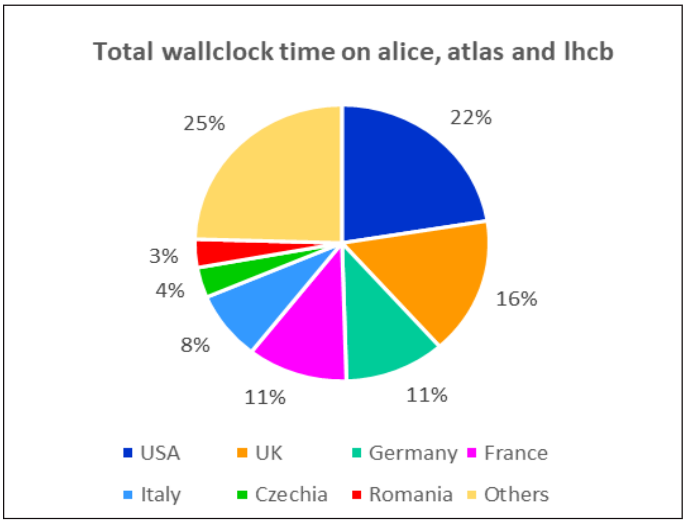
During the same period, the contribution to the RO-LCG wall-clock time of the partners' sites that are funded from CONDEGRID increased from 39.5% to 64.5%, and represented more than 1.85% of the worldwide total for the Tier2s that serve the three experiments. Also, the data published by the above sources show that these sites ran more than 53 million Grid jobs, which placed their contribution on the 6th place in the global ranking of the national Tier2 federations that support the ALICE, ATLAS and LHCb virtual organizations (VOs).Starting with 2016, the project supported the development and operation of 5 Grid sites, hosted at IFIN-HH (RO-07-NIPNE), ISS (RO-13-ISS), RO-14-ITIM (ITIM), UAIC (RO-16-UAIC), and RO-03-UPB (UPB).

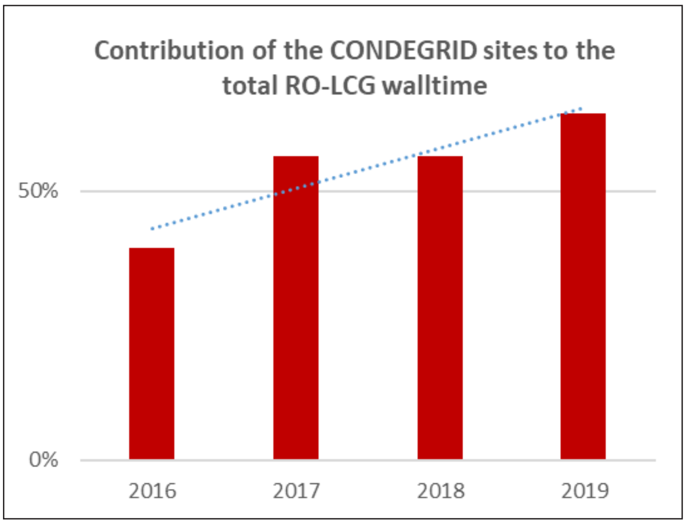
The overall Grid production of the five CONDEGRID sites was generally ascending, increasing from 18.5 to 36.5 million hours wall-clock time per year, despite some fluctuations induced by the insufficient funding.

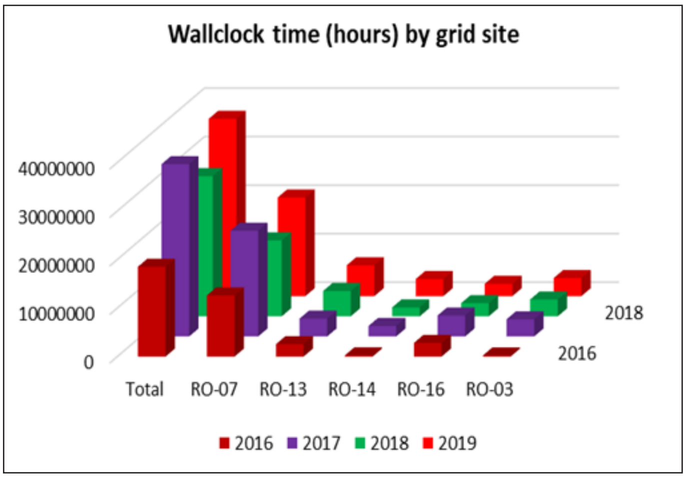
All the sites fulfilled the requirements of the Memorandum of Understanding concluded with CERN, both in terms of the pledged resources and reliability.

New technical solutions were implemented for the development and optimization of the CONDEGRID sites.

RO-LCG's contribution to the computational support of ALICE community has increased after UPB registered in EGI its site which is based on an original solution for providing Grid services over the OpenStack cloud infrastructure, and after becoming Associate member of the ALICE Collaboration. Following the resource upgrade of the UPB site, in 2019 RO-LCG ranked first worldwide among the national Tier2s regarding the disk storage capacity dedicated to ALICE (6.17 PetaBytes provided by IFIN-HH, ISS and UPB, of which 80% was used by the collaboration). In parallel, the installation of the EOS storage management system at RO-07-NIPNE, allowed it to start ALICE analysis activities.







RO-07-NIPNE was the first of the ATLAS France Cloud sites to implement a new structural solution for increasing the efficiency and lowering the operational costs, by supporting with its storage the Monte Carlo simulations on two diskless sites (RO-14-ITIM and RO-16-UAIC), with backup provided by LPNHE/IN2P3. It was also the first RO-LCG site in implementing new configurations (e.g. ARC-CE deployment, SLURM batch system setup, HPC interface, etc.). RO-07-NIPNE has become since 2017 the largest contributor to the national ATLAS computing, both in terms of wall-clock time and processed bytes, and also started to run the greatest variety of ATLAS jobs.

In order to improve the service efficiency for all three VOs, the dynamic allocation of resources and fair-share policies were implemented on RO-07-NIPNE not just per each of the VOs but also per types of jobs (e.g., analysis, single core production/simulations, multicore production/simulations, etc.).

The main software and technological development activities comprised: a) topics approached jointly by UPB and IFIN-HH with the CERN-IT department, such as the evaluation of multi-source downloads for the File Transfer Service, or the file caching and purging strategies in the Disk Pool Manager; b) development of a new monitoring system for the batch job queues (HTCondor or SLURM), based on ELK stack (IFIN-HH); c) optimization of the job management in multi-queue environments (IFIN-HH); d) virtualization of the Grid compute nodes (UPB).

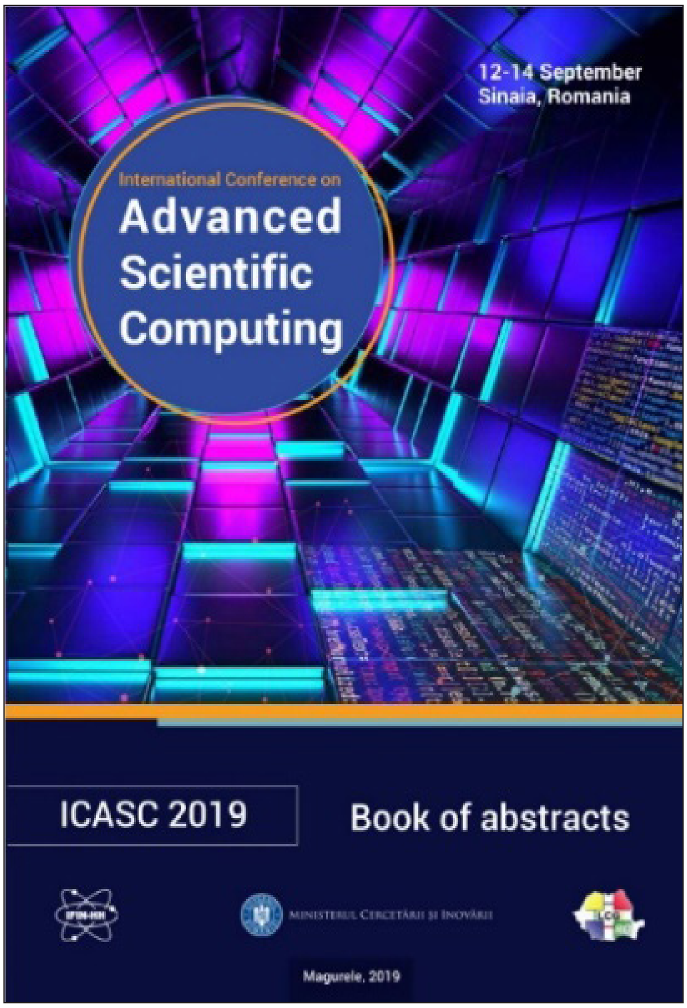
The main dissemination events supported from the project were the annual editions of the RO-LCG International Conference *'Grid, Cloud and HPC in Science'* (2016-2018), followed by the *'International Conference on Advanced Scientific Computing'* (ICASC 2019, Sinaia, *http://icasc2019.ifin.ro*), which was organized by IFIN-HH and co-sponsored by IEEE. The conference was attended by more than 60 specialists in information technology and computational physics from 14 countries, who held 45 oral presentations.

The project team published 8 ISI papers in proceedings and 38 presentations in (extended) conference abstracts.

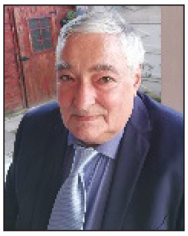
Training and teaching sessions were annually held for site managers, operators, grid users and students, such as the workshop for Grid operations and management, organized by ITIM (2016), the internships in HTC, cloud computing and EOS technology organized by IFIN-HH for students from UPB and mathematics/informatics faculty of the University of Bucharest. In UPB, the Department of Computer Science, organized multiple courses of cluster, Grid and parallel computing, where RO-03-UPB was presented as a case study and was simulated in a virtual environment. IFIN-HH and UPB also organized the participation of students in CERN-IT student projects. Members of the project team took part in the CERN School of Computing (CSC 2019, Cluj).

Annual outreach activities, such as those within the "Different school" and "Researchers night" events – organized by ISS, or held by ITIM for the most important schools from Cluj, attracted the interest on distributed computing for hundreds of high school students, increasing the odds for them to pursue a career in information technology.

In conclusion, the results obtained within the CONDEGRID project in the period 2016-2019 represent a major leap ahead towards the consolidation of the RO-LCG's contribution to the WLCG collaboration and the increase of its international visibility, in preparation for its participation in the computational support of the further stages of the LHC experiments.



Romanian Contribution to MoEDAL (RO_MoEDAL)



Project Leader: Dr. Vlad POPA
Project Coordinator: Institute of Space Science (ISS)
MoEDAL Collaboration: *https://moedal.web.cern.ch/*
Project webpage: *http://www.spacescience.ro/projects/romoedal/*

MoEDAL (Monopole and Exotics Detection at LHC) experiment at the Large Hadron Collider (LHC) started data taking in 2015. MoEDAL is a pioneering experiment designed to search for highly ionizing avatars of new physics such as magnetic monopoles or massive (pseudo-) stable charged particles. Its groundbreaking physics program defines over 30 scenarios that yield potentially revolutionary insights into such foundational questions as: are there extra dimensions or new symmetries; what is the mechanism for the generation of mass; does magnetic charge exist; what is the nature of dark matter; and, how did the big-bang develop.

MoEDAL's purpose is to meet such far-reaching challenges at the frontier of the field. It uses passive detectors as nuclear track detectors (NTDs) – plastic sheets that record the passage of highly ionizing particles and trapping detectors (alumina bars) that could stop magnetic charges and that are, after extraction, analyzed with a SQUID magnetometer.

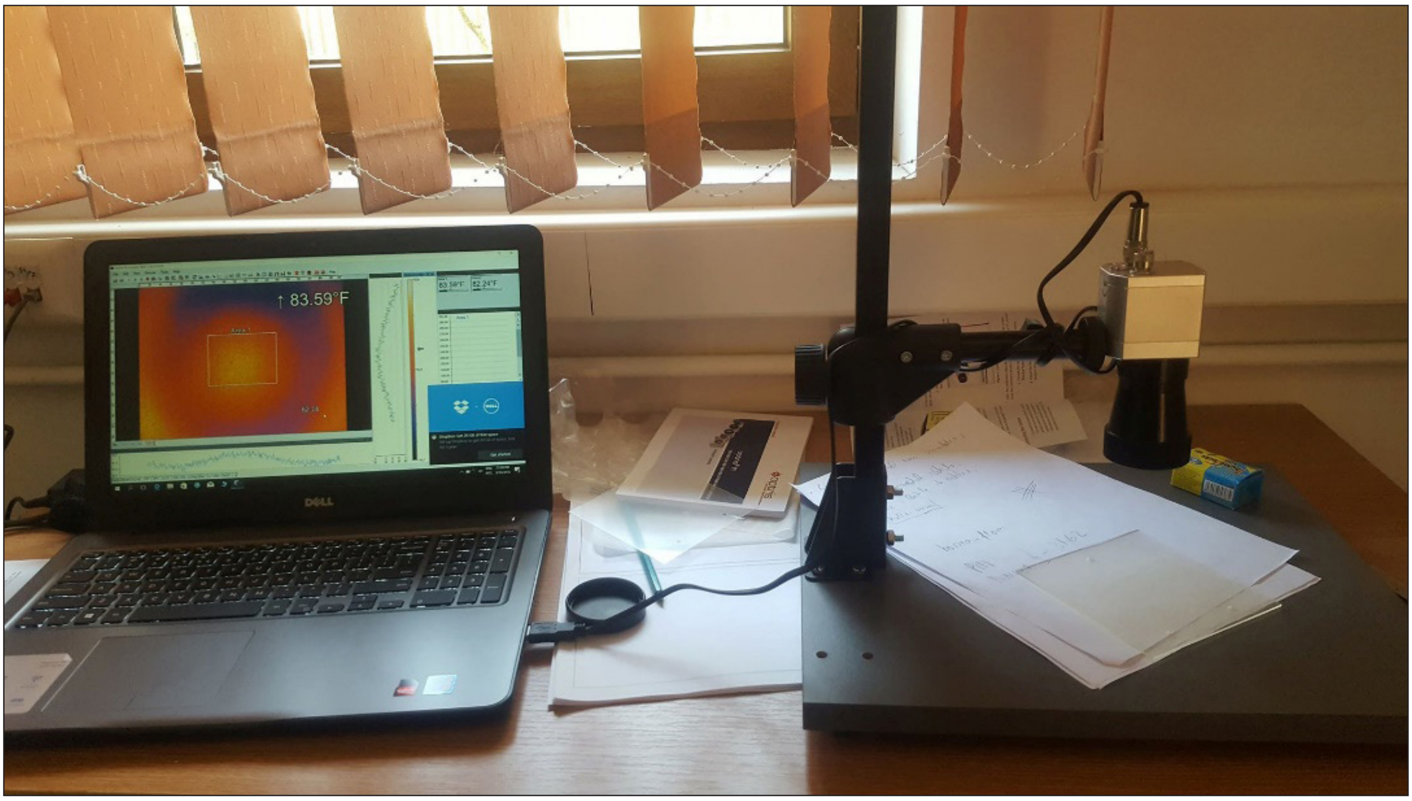
The Romanian contribution to MoEDAL was supported through IFA Contract CERN 10.

We are involved in physics analyses, with special responsibility for the dyon search. Dyons are hypothetical particles bearing both magnetic and electric charges. A first MoEDAL paper concerning this argument was recently published, PRL 126 071801 (2021).

Another important contribution results from the Collaboration Software Manager position, detained by a member of our group. He ensures the permanent maintenance of the MoEDAL Monte Carlo simulations and of the software libraries of general use for the experiment.

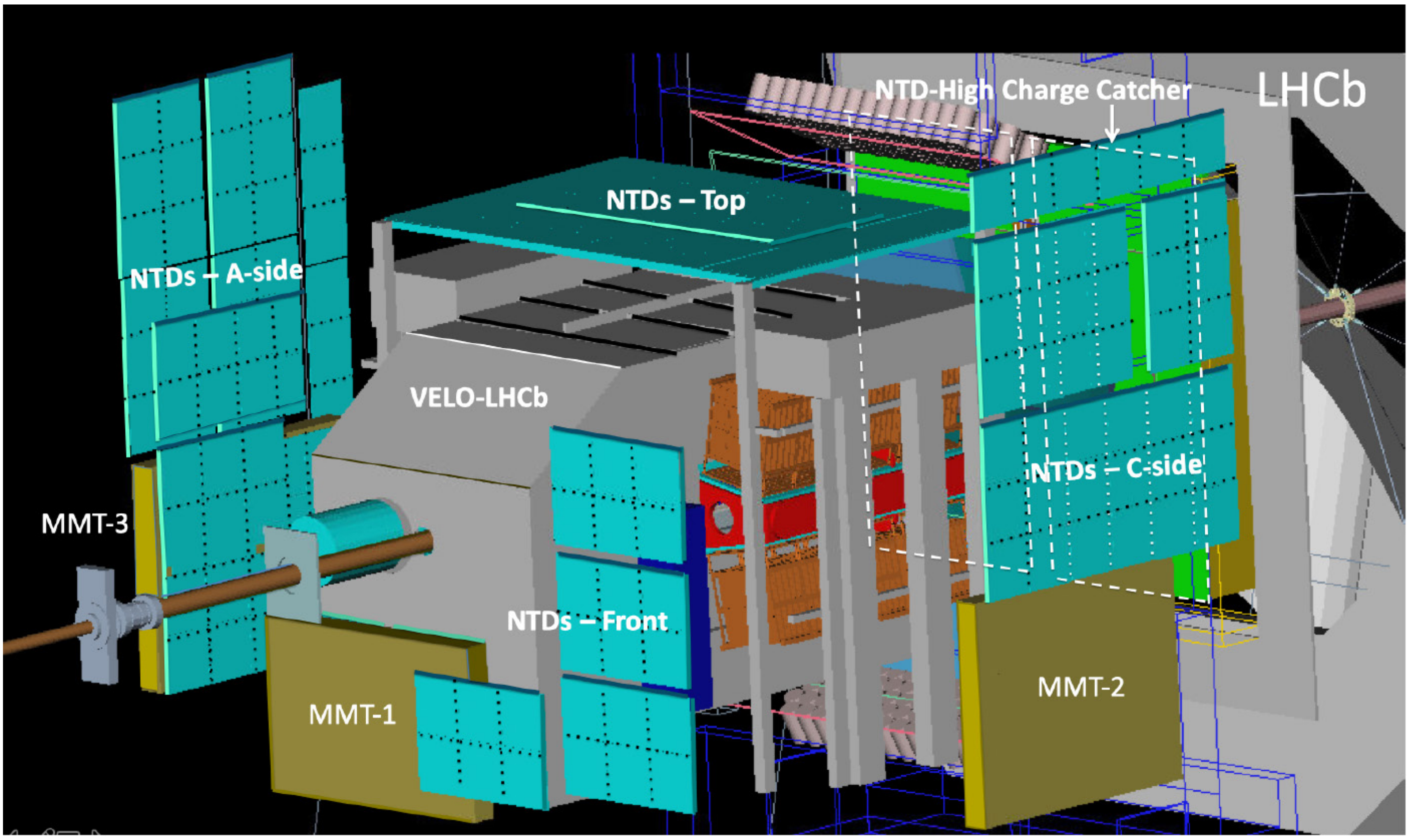
We are also involved in the NTD scanning technology. MoEDAL employs two types of NTD's: with low and high threshold. The long exposure of the low threshold NTDs in the VELO cavern affects the material properties, making the traditional optical scanning (using microscopes) difficult. Various improvement solutions are searched for in the Collaboration, including the use of machine learning. The ISS group is experimenting a completely novel concept, based on the idea that the material temperature varies in different ways along the etched tracks than in the bulk of the detector, the so-called "thermal scanning". Initial tests are underway, and an experimental scanning device is under construction.

MoEDAL shares intersection point 8 on the LHC ring with LHCb



First tests of the thermal scanning

For more information, visit:
https://moedal.web.cern.ch/
http://www.spacescience.ro/projects/romoedal/index_en.html



The MoEDAL structure, around the VELO LHCb detector

Experimental and Theoretical Studies of Exotic Nuclei at ISOLDE (EXONTEX)

Project Leader: Prof. Dr. Nicolae Marius MARGINEAN
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
ISOLDE Collaboration: *http://isolde.web.cern.ch/ISOLDE/*
Project webpage: *http://proiecte.nipne.ro/pn3/24-proiecte.html*

The study of radioactive isotopes is fundamental for nuclear physics research, astrophysics and for applications such as energy production, solid state physics and medical treatments. One of the major opportunities in nuclear physics is the possibility to directly study exotic nuclei, allowing a better insight of the nuclear structure and the improvement of existing nuclear models.

ISOLDE is the oldest Radioactive Ion-Beam Facility, pioneering the ISOL technique and it is located at CERN, Geneva, Switzerland. It uses thick targets, the most used type being the uranium carbide (UCx) which are irradiated with a pulsed beam of protons having an average intensity of 2 uA and being accelerated at 1.4 GeV by the Proton Synchrotron Booster (PSB) of the CERN accelerator complex. ISOLDE receives, on average, around 50% of the total number of protons delivered to all CERN experiments, being by far the main user of the proton beam. The protons initiate reactions such as spallation, fragmentation and fission in the heated target and then the exotic isotopes diffuse out of it through a transfer line connected to an ion source. Plasma, hot-cavity or laser ion sources are used to ionize the radioactive ion beams. These beams can be delivered directly to temporary or fixed experimental setups after being accelerated using a 30-60 kV accelerating potential and separated using the General Purpose Separator (GPS) or the High Resolution Separator (HRS). Thanks to the HIE-ISOLDE linear accelerator, there is also the possibility accelerating the radioactive beams up to 7.5 MeV/u. From this point of view, ISOLDE is complementary to other RIB European facilities like SPIRAL (Ganil, France), or GSI (Darmstadt, Germany), and offers a wider range of intense RIBs than HRIBF (Oak Ridge, USA) or ISAC (Vancouver, Canada). Until now, more than 600 isotopes with lifetimes up to few milliseconds for almost 70 chemical elements, from helium to radium have been produced, with intensities up to 1011 atoms/μC proton beams

The nuclear physics programme of ISOLDE covers more than 50% of the facility running time, comprising of: gamma spectroscopy of nuclei far from stability, Coulomb excitation experiments of nuclei far from stability, dipole magnetic moments measurements, beta-decay gamma spectroscopy, nuclear reaction cross sections measurements for astrophysics purposes and ground state proprieties for nuclei far from stability - mass, deformation, charge radius.

Existing and planned experimental facilities as well as groups of theorists and experimentalists working on well defined thematic areas are combined in networks focussed on accurate description of structure and dynamics of exotic nuclei with relevance for nuclear astrophysics. The upcoming exploration of nuclei in yet unknown region far off stability is expected to reveal a lot of new phenomena. A reliable description of those nuclei would not only improve our knowledge of the nuclear many-body problem considerably but also provide support and guidance for experiments at the new radioactive beam facilities. The experimental data are expected to allow a better understanding of fundamental interactions and symmetries, to test and develop our beyond-mean field theoretical models, to guide us towards a unitary treatment of nuclear structure and weak interaction processes, and, last but not least, to provide reliable input for astrophysicists.

The main scientific goal of the Romanian group collaborating at ISOLDE is the experimental investigation and theoretical understanding of some of the exotic nuclei, which are accessible at this radioactive beam facility. The program has two distinctive parts which could be done relatively independently one from the other, but which are complementary in covering the major research direction of the facility. These components are (i) direct experimental activity of the Romanian group at ISOLDE completed by investment in experimental equipment and accumulation of experimental know-how and (ii) development of nuclear structure modelling using some experimental data obtained at ISOLDE and providing also theoretical interpretation of these results.

On the experimental side the aim is to provide key quantities that are needed to understand the structure of exotic nuclei. The activity is focused on spectroscopy and timing measurements, mostly from decay experiments and complemented with Coulomb excitation experiments whenever is needed. From spectroscopy studies are observed the excited levels, whose excitation energies represent the eigenvalues of the nuclear Hamiltonian, while from timing measurements one get the absolute transition probabilities which are directly related with the non-diagonal matrix elements of the transition operators. This kind of experimental information is of interest in all nuclei, but the interest is particularly high for isotopes far from stability line where the existing data is scarce. Out of the several examples mentioned above, we emphasize now that the Romanian group is presently focused on the study of the nuclei related with the island of inversion around 32Mg, and the region of shape coexistence around the neutron rich Pb-Ac isotopes.

Advanced theoretical studies on structure and dynamics of exotic medium mass nuclei dominated by coexistence phenomena are correlated with the experimental efforts focused on spin-isospin excitations and their role in astrophysical phenomena. The investigation of shape coexistence and mixing, drastic changes in structure for small variations of the number of nucleons of proton-rich as well as neutron-rich medium mass nuclei in the A~80 and A~100 mass region, respectively, represents one of the objectives of the project. The study of isomers could reveal new aspects of shape coexistence and mixing. Ongoing efforts are devoted to the outstanding problem concerning the appropriate effective interactions in new regions of temperature and isospin. An important goal is to describe self-consistently the Fermi and Gamow-Teller strength distributions relevant for the astrophysical rp-process and r-process in medium mass nuclei as well as the competitive first-forbidden beta decay. The collaboration between experimentalists and theorists in nuclear structure and dynamics and nuclear astrophysicists is required to produce accurate weak reaction rates relevant for astrophysical scenarios. Such efforts are embedded within experiment – theory romanian ISOLDE team. Our investigations will be related with current experiments at ISOLDE and future experiments at HIE-ISOLDE.

There is also a significant gain for both sides from the two-way exchange of experimental techniques and technical solutions. The best example in this sense represents the highlight of the Romanian contribution to the facility, namely the leading role in the construction of the ISOLDE Decay Station (IDS) with a large Romanian contribution in equipment, manpower and expertise. IDS is supported by 18 institutes across the world and is one of the permanent setups within ISOLDE dedicated to the measurement of the decay properties of radioactive species important for nuclear structure, astrophysics and nuclear engineering. The radioactive isotopes are implanted on an aluminized-mylar tape which can be moved after each measurement in order to remove the unwanted daughter activity. A variety of detectors together with the main HPGe clover detectors can be coupled to this decay station for specialized decay measurements such as fast timing measurements of excited states, charged particle emission, neutron time of flight spectroscopy, gamma-gamma angular correlations and conversion electron spectroscopy. Following the successful commissioning in August 2014, many experiments were performed, leading to valuable novel physics results.

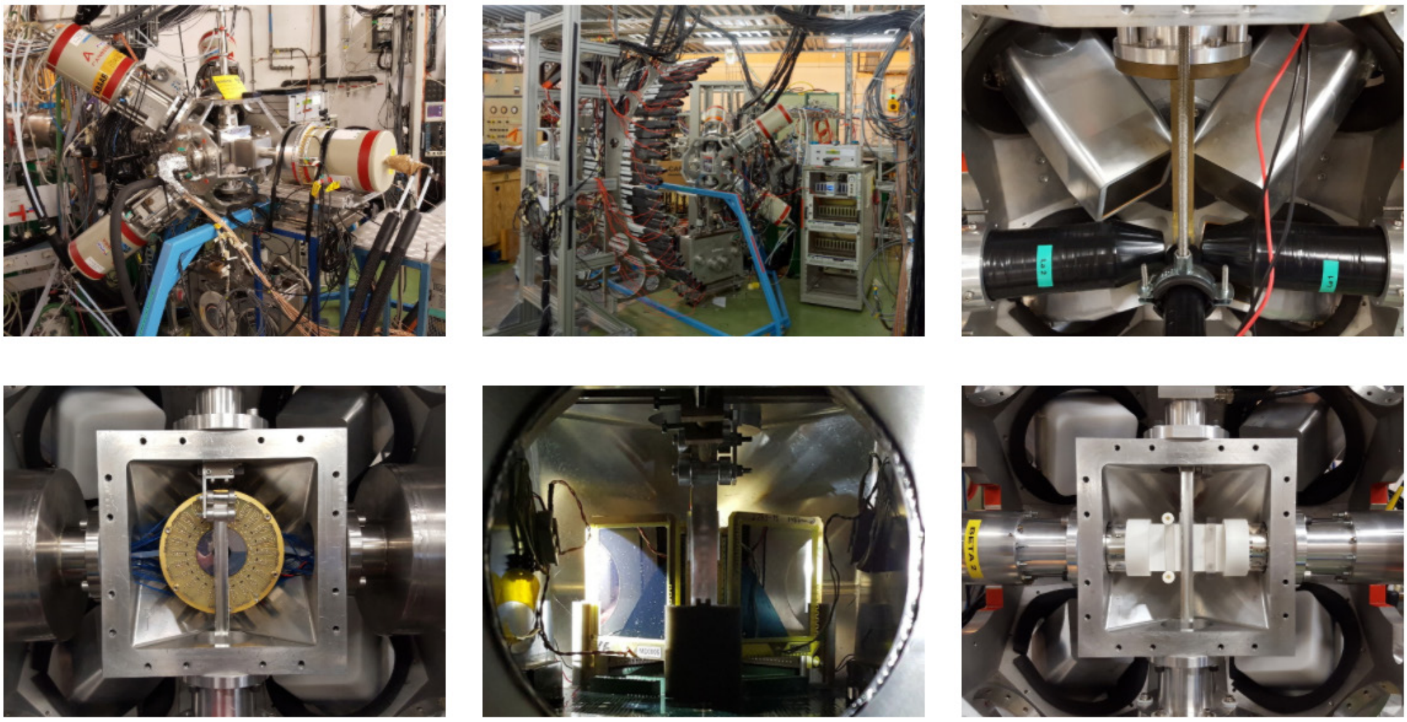


Fig 1: The ISOLDE Decay Station setup dedicated to performing beta-decay nuclear spectroscopy studies at the ISOLDE facility of CERN.

n_TOF Collaboration (n_TOF)

Project Leader: Dr. Tudor GLODARIU / Dr. Alexandru NEGRET
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
n_TOF Collaboration:*https://home.cern/science/experiments/n_tof*
Project webpage: *http://proiecte.nipne.ro/pn3/1-proiecte.html*

The n_TOF facility

The neutron time-of-flight facility of CERN, n_TOF, became operative in 2001 and since then it occupies a major role in the field of neutron cross-section measurements. IFIN-HH, Romania is an active member of the collaboration since 2008, among 47 international institutes. n_TOF is designed to study neutron-nucleus interactions at energies ranging from a few meV to several GeV. To produce neutrons, a pulsed beam of protons from the Proton Synchrotron (PS) is directed at a lead target. When the beam hits, every proton yields about 300 neutrons. The initially fast neutrons are slowed down, first by a lead target, and then by a slab containing water. Some neutrons slow more than others creating a range of neutron energies from the meV region up to the GeV region. These neutrons are guided through an evacuated beam pipe to an experimental area located 185-m away from the target. In a typical experiment, a sample is placed in the neutron beam and the reaction products detected. This allows us to reconstruct the reaction cross sections as a function of the incident neutron energy.

Neutron time-of-flight measurements contribute in an important way to understanding nuclear reactions. Only a few time-of-flight facilities exist worldwide, each with its own characteristics. The strength of n_TOF is the very high instantaneous neutron flux combined to an excellent energy resolution, which allows highly accurate measurements. Further, the data produced by n_TOF are used in reactor physics, in astrophysics to study stellar evolution and supernovae, in the investigation of symmetry breaking effects in nuclei the investigations of nuclear level densities and many other related topics.

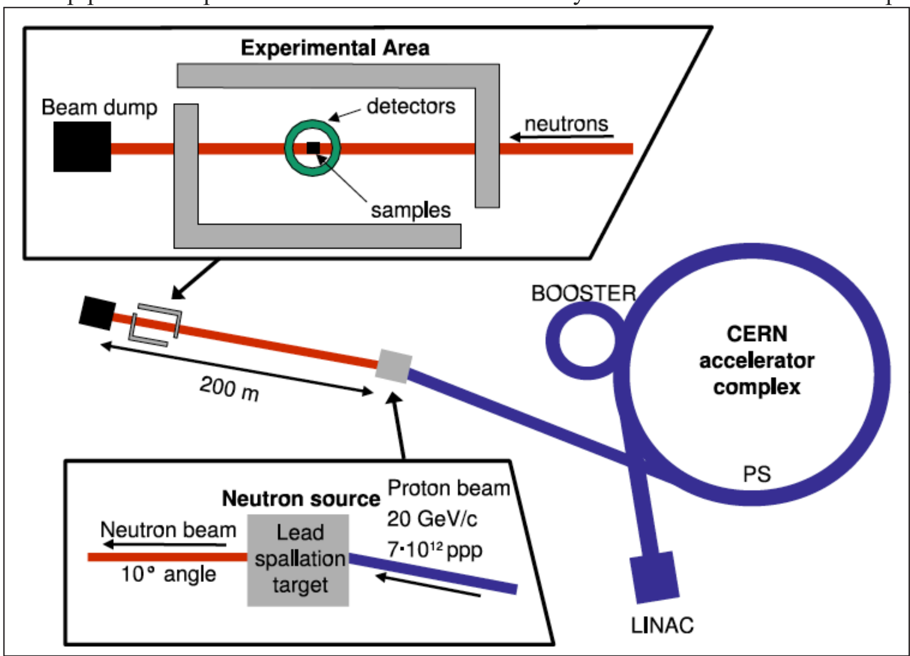
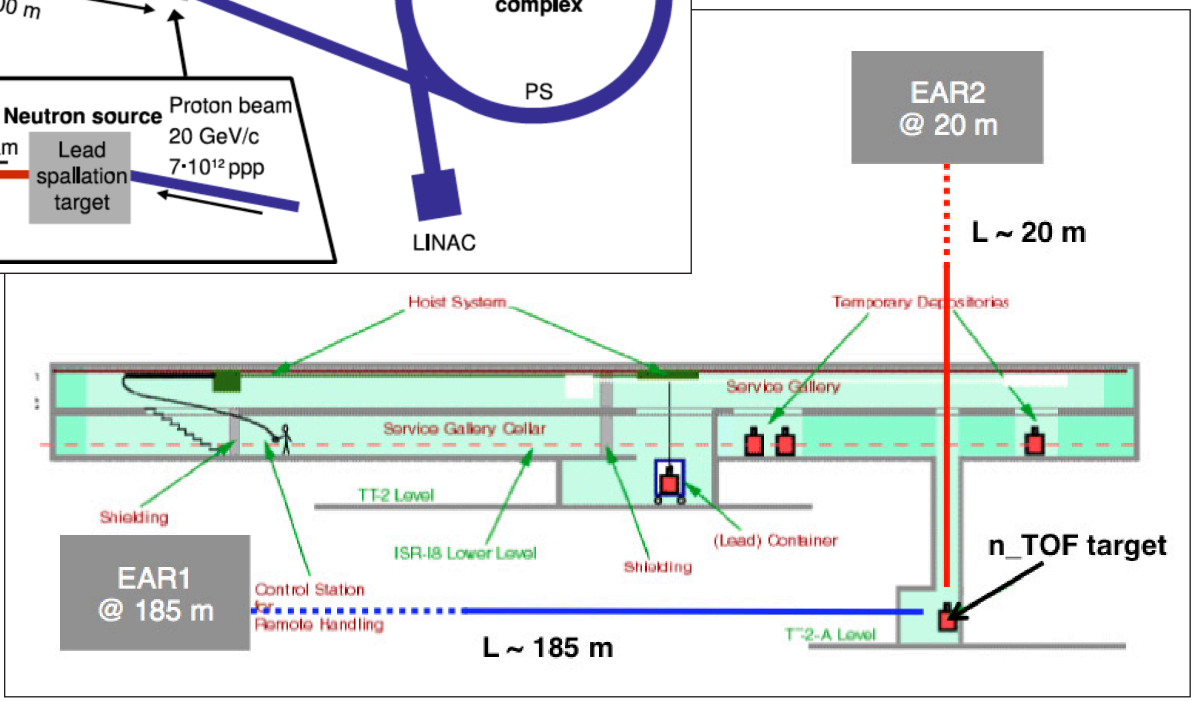


Fig 1. Left: Layout of the n_TOF facility within the CERN accelerator complex. Right: Schematic of the two different beam lines of the n_TOF facility.



Our results

Completion of the ^{241}Am(n,g) measurement - The neutron capture cross section of ^{241}Am is an important quantity for nuclear technology applications. The experiment was particularly challenging because ^{241}Am is highly radioactive. This raises issues link to radioprotection but, more importantly, creates an environment with high background requiring special experimental conditions. The experiment was completed and data analysis is ongoing within our group.

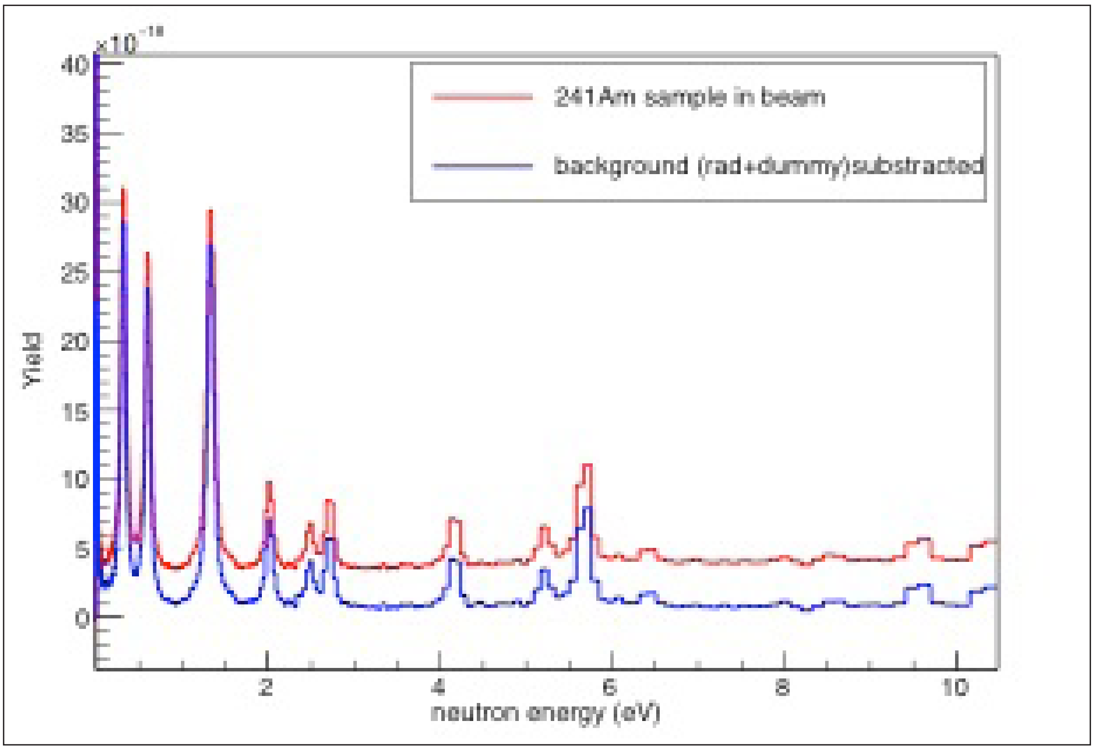


Fig 2. *Preliminary result from the ^{241}Am(n,g) measurement: resonances below 10 eV.*

An exploratory project: the use of HPGe detectors at n_TOF

Over the lasts years we tested of several HyperPure Germanium(HPGe) detector prototypes meant to survive to the stiff conditions of the n_TOF environment. An important step forward was the implementation of a dedicated preamplifier that has the capability of being switched off at the moment when the so-called γ flash (a very intense electromagnetic radiation that precedes every neutron pulse). Our effort of implementing the use of HPGe detectors reaches now a new level opening the possibility of investigating reactions that were not accessible up to now at n_TOF.

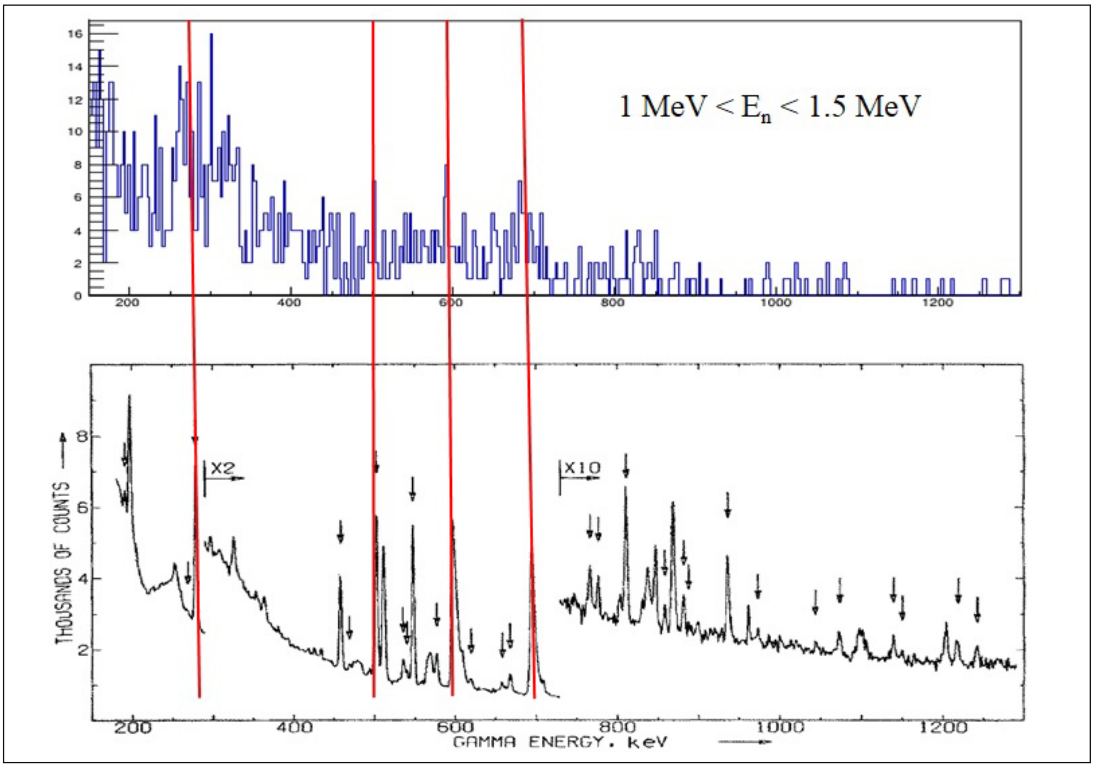


Fig 3. *HPGe spectra of a ^{197}Au sample obtained with the HPGe detector at n_TOF.*

Study of Rare Kaon Decays at the CERN SPS (NA62)

Project Leader: Alexandru Mario BRAGADIREANU
Project Coordinator: Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH)
NA62 Collaboration: *http://na62.web.cern.ch/NA62/*
Project web page: *http://www.nipne.ro/dpp/Collab/NA62/*

NA62 experiment aims to measure the branching ratio of the very rare kaon decay $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ at the CERN SPS, to make a decisive test of the Standard Model (SM) by extracting, through a 10% measurement, the Cabibbo–Kobayashi–Maskawa (CKM) parameter $|V_{td}|$.

The NA62 experimental setup (Fig. 1) proposed in the Technical Design Document (NA62-10-07) was upgraded, by the IFIN-HH team, with a new hadron calorimeter (HASC) to veto the $K^+ \rightarrow \pi^+\pi^+\pi^-$ events in which the π^- undergoes hadronic interaction in the first STRAW chambers and the more energetic $\pi^+\pi^+$ (~40 GeV/c) which is traveling through the beam hole, not being detected by the IRC, then emerging at $z > 253$ m. From NA62 Monte Carlo data appear 10 ± 4 events/year surviving, after all multiplicity and kinematical cuts with grazing π^+.

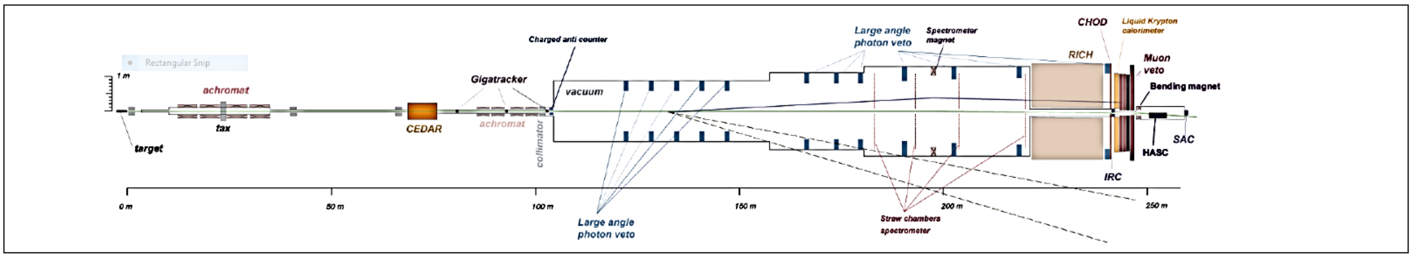


Fig. 1: *NA62 Experimental setup*

The HASC is made up of 9 identical modules salvaged from a prototype developed by NA61 Collaboration. Each module is a sandwich of 120 lead/scintillator alternating tiles, with a total volume of 10x10x160 cm^3 (W x H x L). The sampling ratio is 4:1, the scintillator tiles having a dimension of 100 x100 x 4 mm while the lead thickness is 16 mm.

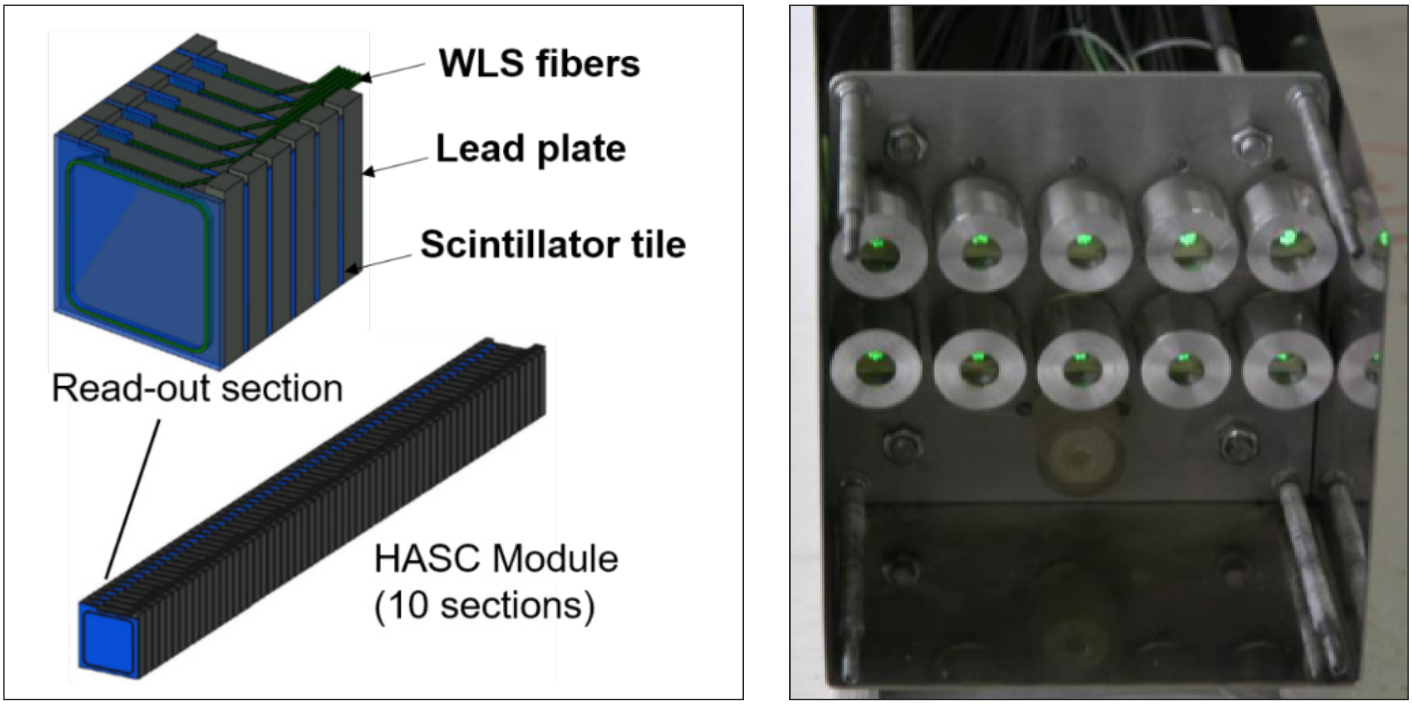


Fig. 2: *HASC module longitudinal section (left) and optical readout couplings (right)*

Each HASC module is organized in 10 longitudinal read-out sections (Fig. 2), each scintillator tile of every single section being optically coupled with 1 mm^2 round Wave-Length Shifting (WLS) optical fibers. In the rear side of each module there are 10 optical connectors, originally designed to be coupled with 3x3 mm^2 green sensitive Micro-pixel Avalanche Photodiodes (MAPD).

In September 2015 we installed at the chosen position in the NA62 experimental area 8 HASC modules together with SiPM sensors and front-end electronics (FEE), high- and low-voltage distribution system.

In the spring of 2016 we installed at CERN - ECN3 NA62 experimental area the last HASC module (*the* 9^{th}) together with the SiPM sensors and FEE. Additional work was needed in order to build and install a fireproof enclosure for the HASC FEE and to provide a temperature measurement with automatic power cut in case of FEE over temperature.

The integration of HASC read-out in the NA62 TDAQ and Run Control was completed in July 2016, first HASC raw data being acquired and stored on 15 July 2016.

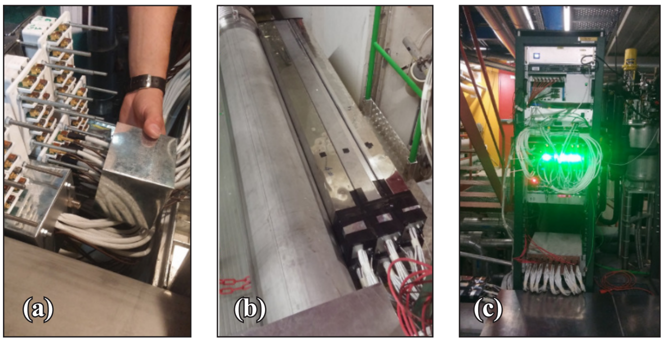


Fig. 3: *HASC in ECN3 (a) – mounting of fireproof enclosures, (b) – ready for physics (c) – electronics rack*

Because the free space around the HASC Front-end was very limited, due to a neighboring metallic platform (fig. 3-a), and during 2016 maintenance we learned that an intervention to the lower HASC modules was impossible without removing the cabling of the higher modules, we performed a rotation of HASC modules with 180 degrees before the relocation of HASC electronics rack.

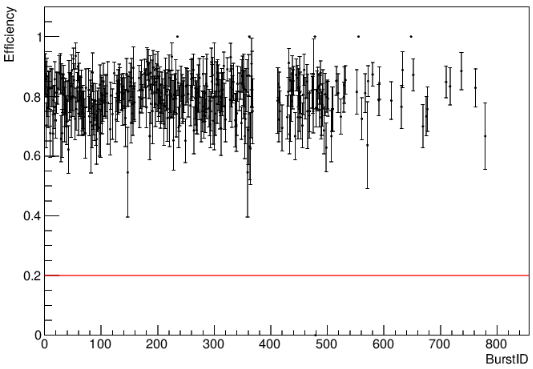


Fig 4a.: HASC efficiency vs Burst Id. Run 7577

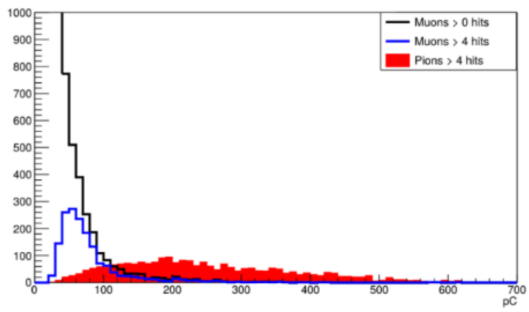


Fig 4b: Charge of matched candidate

Data quality evaluation was one of the priorities of NA62, starting with the end of 2016 a permanent working group being setup. The efficiency of HASC data was defined and calculated for each run. For this we developed a $K^+ \rightarrow \pi^+\pi^+\pi^-$pre-analysis software for the selection of the missing π^+ and the reconstruction of its trajectory. The missing tracks situated in the HASC geometrical acceptance are denominators in the efficiency formula while the total number of tracks from HASC data are accounted in the numerator for each beam burst (fig. 4a).

Using the same selection for the missing pion and asking minimum 4 hits in the HASC, the charge of the missing pion is summed up and compared with the charge obtained using muon calibration runs. A fairly good separation pion-muon is obtained by applying a cut at 100 pC (fig. 4b).

Surprisingly, in 2018, HASC has been proven to be very effective as photon veto complementary to LAV, LKr, IRC and SAC calorimeters, an additional 30% background reduction being obtained. In Fig. 5 the effect of HASC veto on the background coming from $\pi^+\pi^0$ decay is shown.

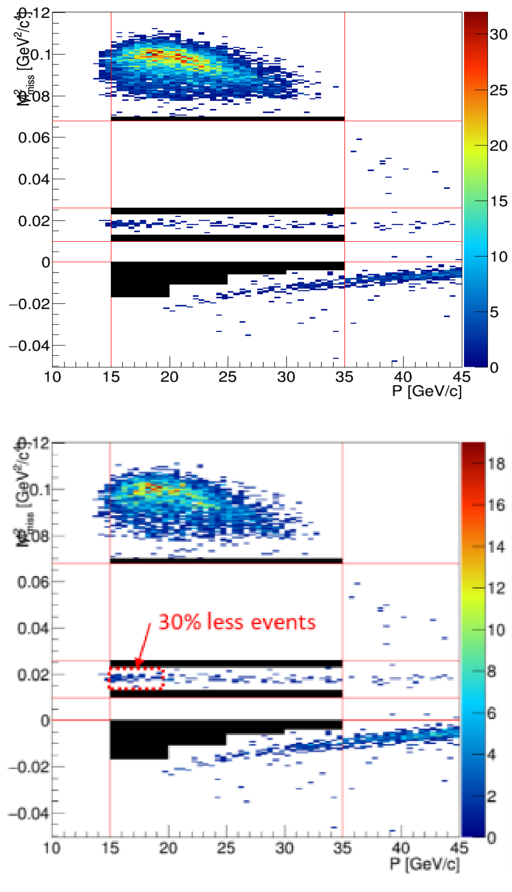


Fig. 5. *(a)* p^0 *rejection – before HASC;*
(b) p^0 *rejection – after HASC*

At the end of 2018 we proposed to the collaboration the upgrade of HASC seeing its success as photon veto. In 2019 we started the upgrade of HASC. We developed a completely new mechanical structure to support the SiPM sensors and the associated front-end electronics (FEE); we developed a new FEE board for the read-out of 10 SiPM sensors. From the cosmic rays tests of 5 out of 9 new HASC modules, we can conclude that the new mechanical structure and SiPM FEE are performing very well and we are plan to upgrade also the "old" HASC modules with the new mechanics and electronics.

Contribution to Neutrino Physics using Large Scale Prototypes LAr Detectors (NEPHYLAro)

Project Leader: Prof. Dr. Ionel LAZANU
Project Coordinator: University of Bucharest (UB)
NEPHYLAro Collaboration : *https://wa105.web.cern.ch/*
Project webpage: *http://RO-DUNE.unibuc.ro*

Brief history of the project development

The high energy physics group from the Faculty of Physics of the University of Bucharest began its international collaborations in neutrino physics in 2008, when it was invited to participate in the LAGUNA project. This FP-7 project (2008-2011) was continued by another one, LAGUNA-LBNO, 2011-2014, subsequently transformed into the WA-105 collaboration at CERN.

During the consolidation period of this collaboration at CERN, our neutrino physics group was funded from the CERN-RO program for one year (2017) and from the University of Bucharest and its Research Institute.

The **DUNE dual-phase** (DP) detector module aims to open new windows of opportunity in the study of neutrinos, a goal it shares with the Single Phase technology. This design improves the S/N ratio in the charge readout, lowering the threshold for the smallest observable signals while also achieving a finer readout granularity. The actual prototype of this detector was developed and now is operational at Neutrino Platform at CERN.

The group from the University of Bucharest has participated several times in different stages of construction and tests of operation of the detectors (demonstrator and prototype), in particular for the field cage and **C**harge **R**eadout **P**lanes. In the DP LArTPC concept, the ionization electrons are multiplied in avalanches occurring inside micro-pattern detectors, the large electron multipliers (LEMs), located in the argon gas phase above the LAr surface. The drift field of the TPC brings the electrons up to the LAr surface where they can be extracted into the gas using a 2 kV/cm electric field defined across the liquid-gas interface.

Despite huge technological developments in the construction of neutrino detectors using noble gases, in particular LAr, there is little experimental data on the interactions of particles with these materials for the energy range of interest. As neutrino-induced processes are rare phenomena, the contributions of the radioactive background are essential. An important direction of study of the group was the investigation of the sources of production of radioactive isotopes inside Ar bulk. It is crucial to understand the associated radioactive contamination, especially the production of muons, neutrons and radioactive isotopes.

The main sources of background are:

i) Environmental radioactivity including geo-radioactivity, cosmic rays and their secondaries;
ii) Intrinsic radioactivity as radio impurities in the components of the detector and radio impurities in the shield materials;
iii) Activation of detector materials during exposure to radiation – in this class (α, n) reactions, neutrons from fission, as well as reactions induced by muons: muon capture, (μ, n), (μ, xn) with x =n, nn, etc., or neutron capture, (n, xn), with x = n, nn, p, d, etc. was considered.

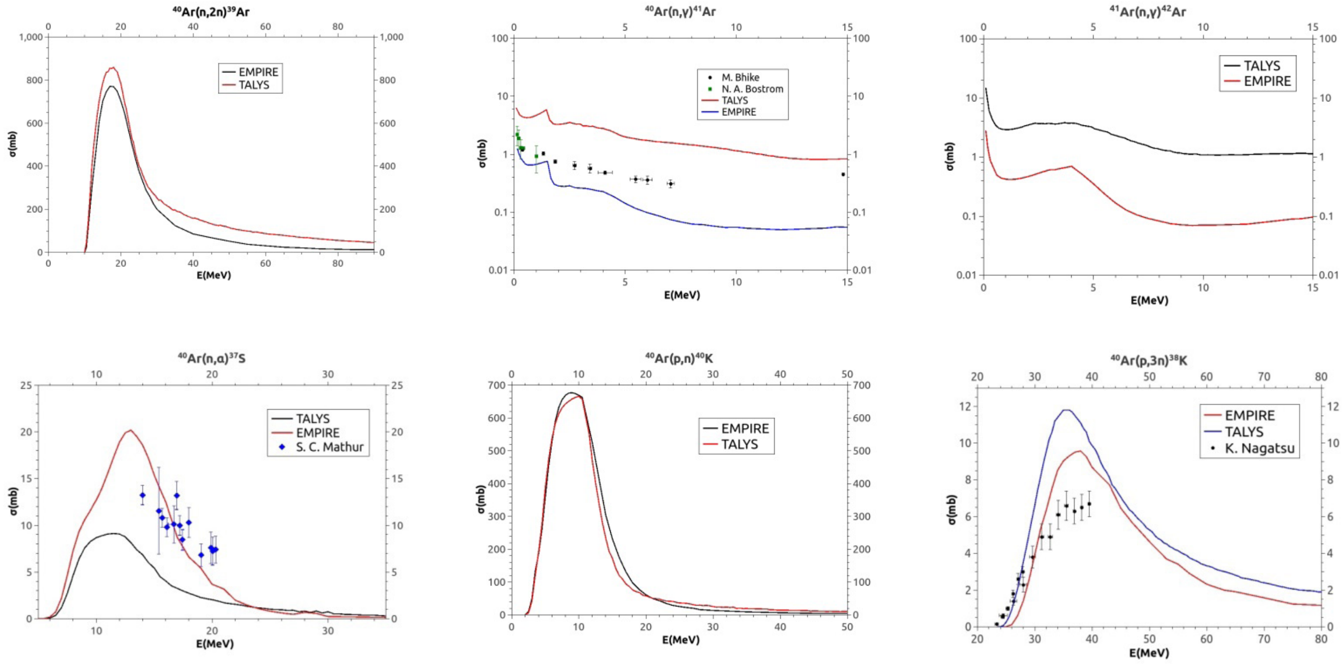
We worked mainly in the following thematics:

a) Simulations of the cosmogenic production of radioactive isotopes in Ar as target.
b) Measurement of low energy cosmic ray component using nuclear track detectors as a preparatory experiment for measuring the vertical gradient of the contribution of radon and its descendants in the CERN EHN1 hall. The data have been collected in the time interval of 10 months.

Some results:

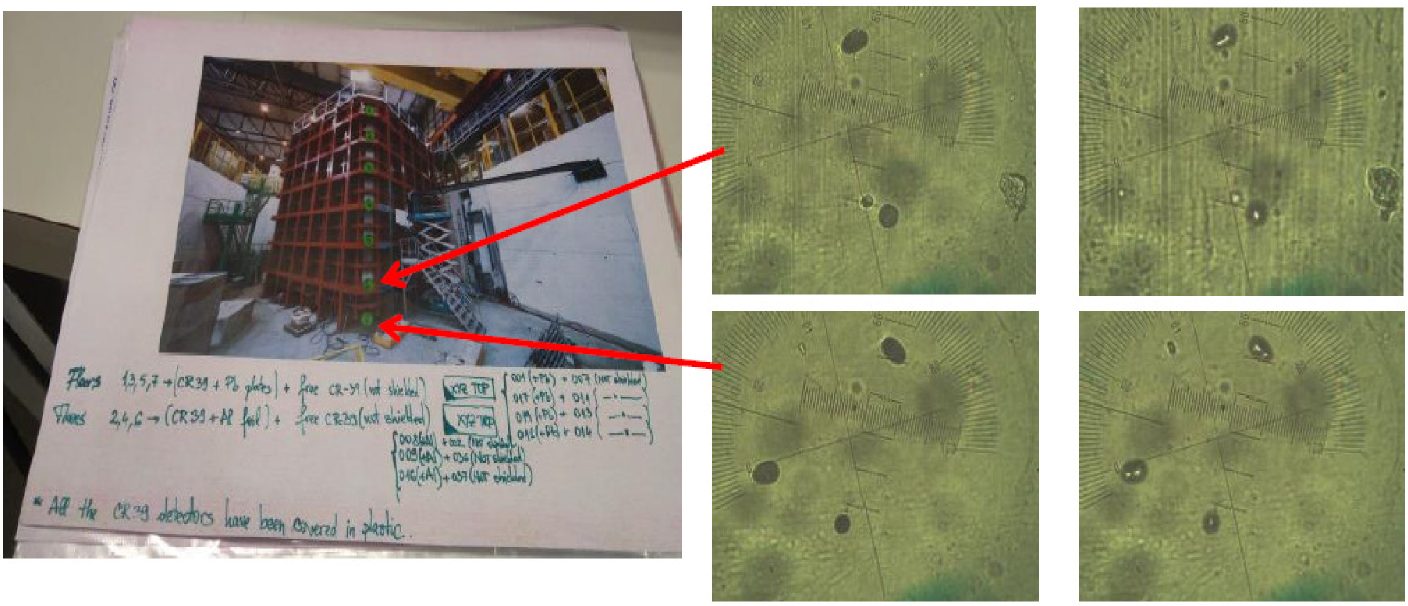
Cosmogenic production of radioactive isotopes in Ar as target

The energy dependence of the cross sections in the following reactions was simulated using both EMPIRE and TALYS MC codes, and when available, they were compared to experimental data; $^{40}Ar(n,2n)^{39}Ar$; the two steps neutron capture reaction in usual Ar: $^{40}Ar(n,\gamma)^{41}Ar$ and thus $^{41}Ar(n,\gamma)^{42}Ar$, other processes: $^{40}Ar(\alpha,2p)^{42}Ar$; $^{40}_{18}Ar(n,\alpha)^{37}_{16}S$; $^{40}Ar(p,3n)^{38}K$ and $^{40}Ar(p,n)^{38}K$. See the following figures:



Energy dependence of the cross sections in different reactions

Preliminary results of the radioactive background due to radon contribution in the hall of the detector (Measurements have been performed using CR-39 passive plastic TASTRAK detectors.)



RD 50

Defect Engineered p-type Silicon Sensors for LHC Upgrade (DEPSIS)

Project Leader: Dr. Ioana PINTILIE
Project Coordinator: National Institute of Materials Physics (INFM)
RD50 Collaboration: *https://rd50.web.cern.ch/*
Project webpage: *https://infim.ro/en/project/depsis/*

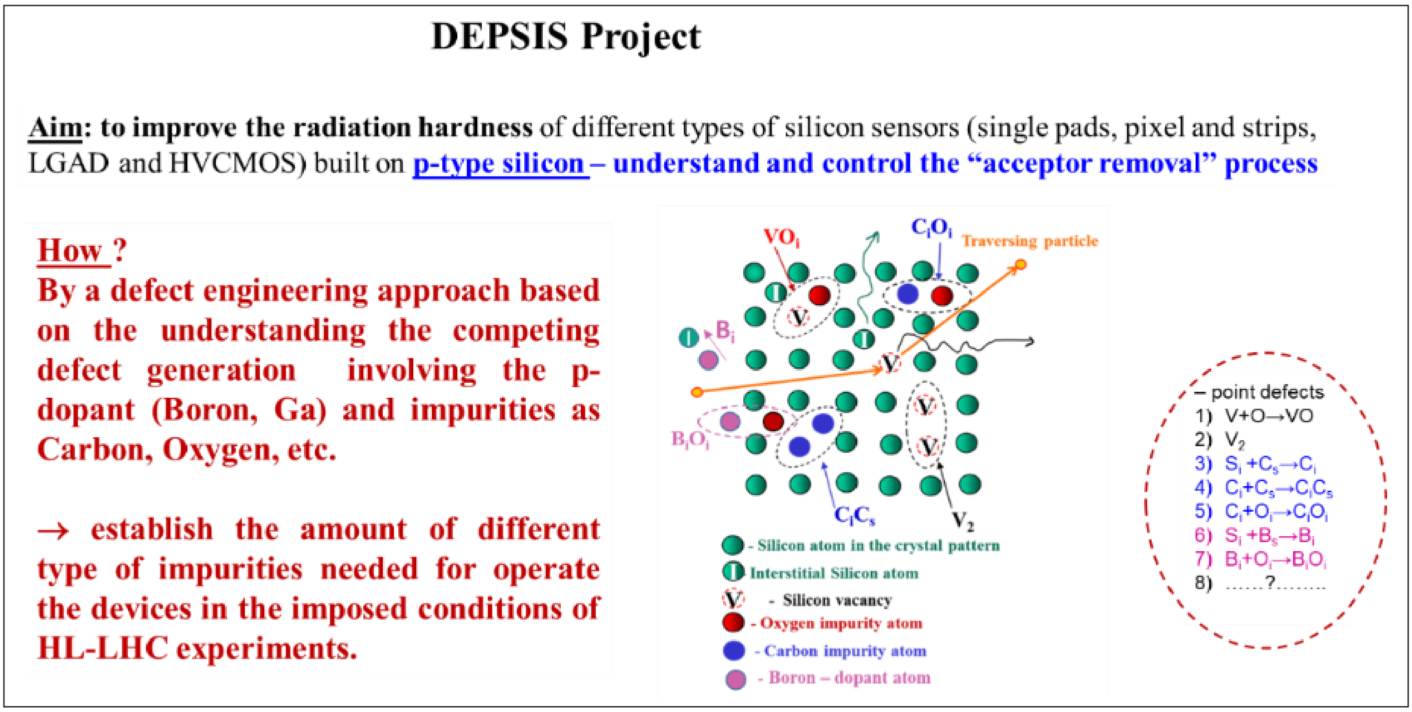
The DEPSIS project is embedded as part of the RD50 efforts, in the subgroup *Defect and Material Characterization.* The director of the present project is the leader of the NIMP team involved in the CERN-RD50 and the convener of this research line within the RD50 collaboration.

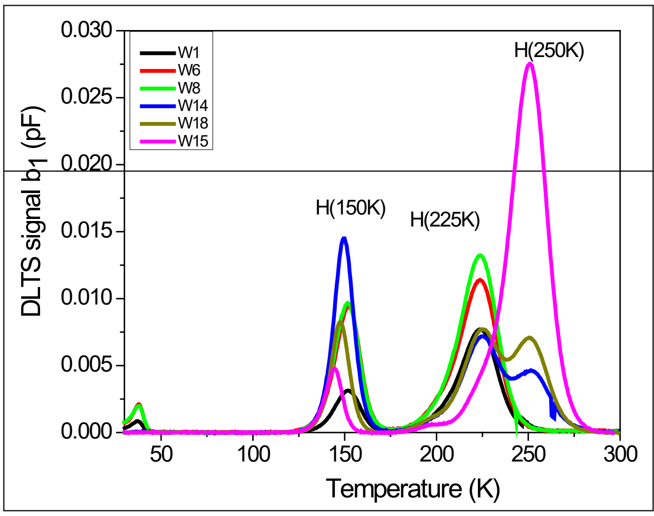
The general objective of the project is to improve the radiation hardness of different types of silicon sensors to be used for ATLAS and CMS Strip Tracker upgrade (single pads, pixel and strips, LGAD and HVCMOS) built on p-type standard float zone (STFZ), epitaxial (EPI) and defect engineered Si. Since in p-type (Boron doped) Si the most obvious change observed in the electrical performance is the loose of the doping due to irradiation (acceptor removal process), thought to be caused mainly because of forming the B_iO_i trapping centre, the project addresses two defect engineering approaches: (i) intentionally adding Carbon impurity in the bulk of boron doped Si, with the aim of changing the usual defect formation path during irradiation, by slowing down this way the boron removal while creating other carbon containing defects with much lower impact on the electrical characteristics of the sensors at their operation temperature; (ii) to dope the silicon with Gallium instead of Boron. The project is thus focusing on investigation, analyses and modelling of the defect generation and kinetics induced by irradiation in standard Boron doped and/or Carbon co-doped/implanted Si as well as in Gallium doped silicon. Several p-type PiN silicon sensors, produced via different technologies, Standard Float Zone (STFZ), Chochralski (CZ) and Epitaxial growth (EPI) were investigated.

The ultimate goal of the project is to provide a comprehensive knowledge of radiation induced defects and their generation mechanisms which will be finally used to improve the radiation hardness of pad, LGAD and HVCMOS devices. Based on the mentioned defect engineering studies, viable theoretical models describing and predicting the generation and evolution of the defects in the presence of intentionally added impurities will be achievable.

Our studies started in May 2018 with analyzing as-processed PiN devices for determining the type and amount of intrinsic defects and then to proceed with irradiation and characterize the defects induced by it by Deep Level Transient Spectroscopy, (see Fig. 1).

Irradiation experiments were done with alpha particles, electrons (energy 0.9 MeV- 5.5 MeV), 23 GeV protons or 1 MeV neutrons on PiN and LGAD sensors, produced on high resistivity STFZ boron doped silicon and with respect to defect evolution in time after high level of irradiation. These samples were analysed by different techniques: Thermally Stimulated Current (TSC), High Resolution Transmission Electron Microscopy (HRTEM), I-V and C-V electrical characteristics. The main defects induced by irradiation are seen as peaks in the TSC spectra from Fig. 2. This study was performed on STFZ and EPI p-type sensors with the main focus on BiOi defect, directly involved in the acceptor removal process – see Fig. 3.





Defect	Activation energy (eV)	Capture cross section (cm^2)
H(150K)	0.31 eV	$7x10^{-15}$
H(225K)	0.46 eV	$3.6x10^{-16}$
H(250K) - Ga doped	0.52 eV	$3x10^{-15}$

Fig. 1. *Defects detected by DLTS inas-processed boron and gallium implanted (or carbon co-implanted) in p-type silicon PIN diodes manufactured by FBK.*

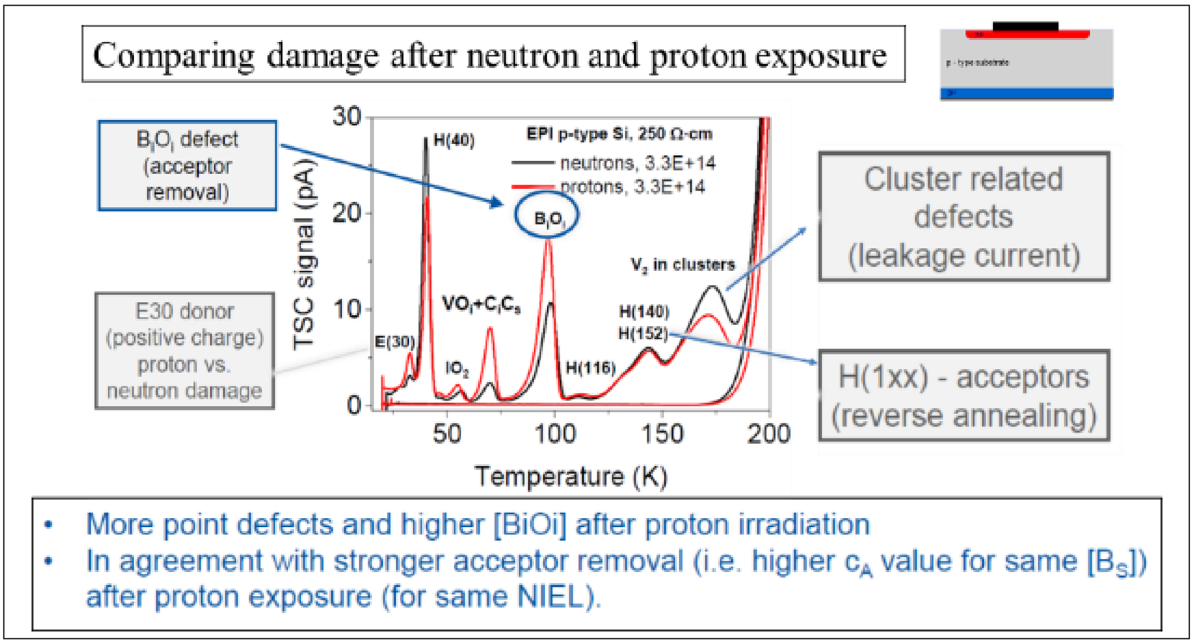


Fig.2. Comparison between the defect generation after irradiation with 1 MeV neutrons and 23 GeV protons.

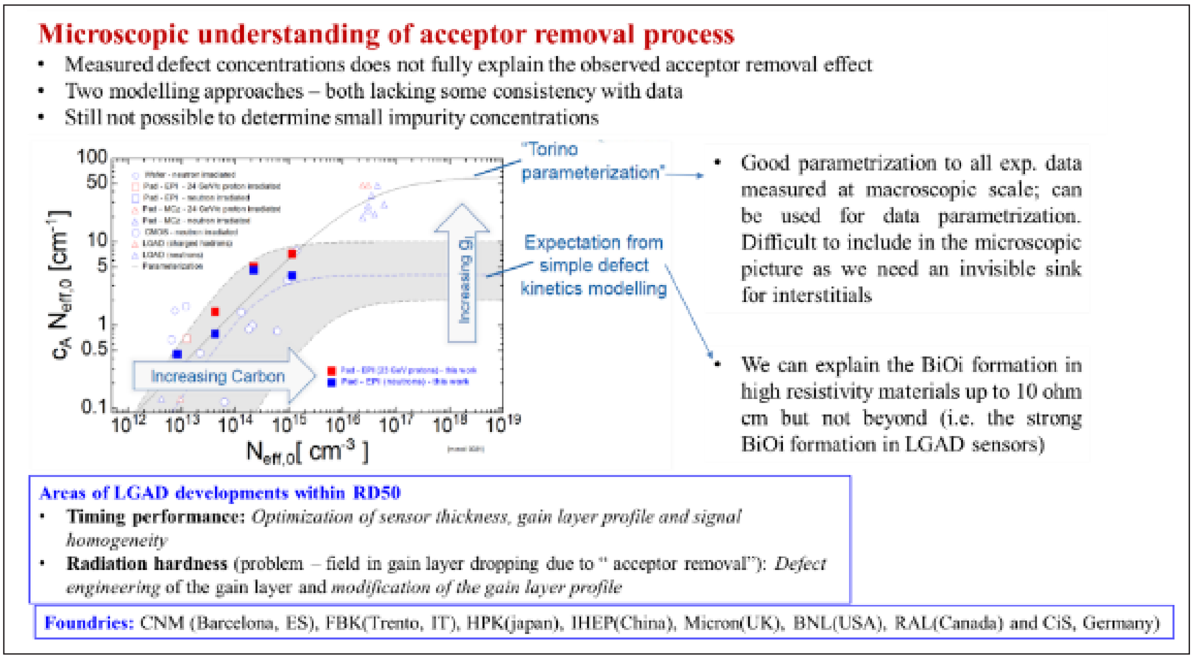


Fig.3. Microscopic understanding of the acceptor removal process.

HRTEM investigations have been performed on STFZ high resistivity LGADs irradiated with 10^{15} n/cm^2. Contrary to the belief that 200kV electrons used in the investigations does not damage the samples, we had prove that some beam damage occurs within seconds – see Fig. 4. This way, the structural evolution @200kV is not concludent. We manage to decrease the acceleration voltage to 80 kV and so, no beam damage has been observed – see Fig. 5. In-situ heating has been observed both at the Al-Ti-SiO_2 interface and deep inside the Si substrate (~100 um depth). Extended defects (dislocations) dynamics in the Al coating as observed during 150-250 C heating. Apart from lattice bending (sample is extremely thin), no defects have been observed after this level of irradiation.

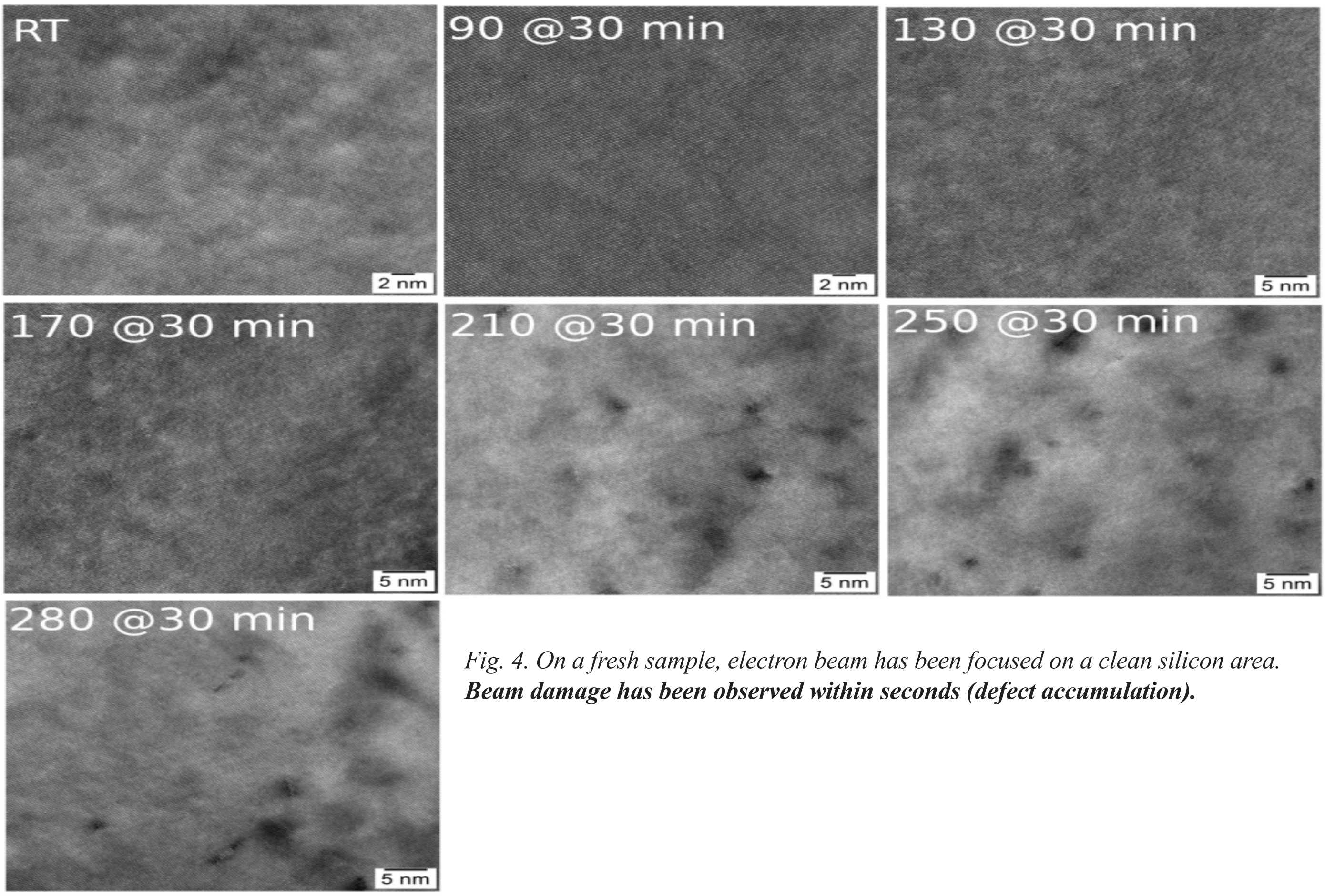


Fig. 4. On a fresh sample, electron beam has been focused on a clean silicon area. ***Beam damage has been observed within seconds (defect accumulation).***

After 30 min @ 150 C After 30 min @ 250 C

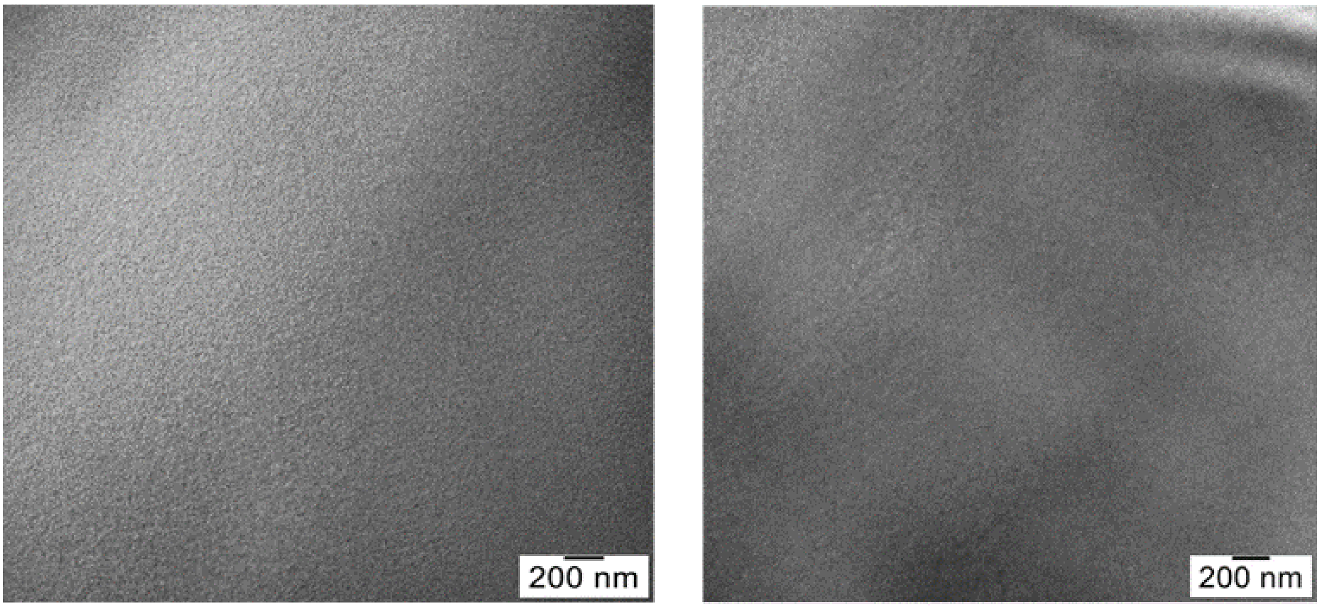


Fig. 5. No beam damage has been observed at 80kV.

For more information, visit: *https://rd50.web.cern.ch/*

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