Romanian input to the European Particle Physics Strategy Update 2018-2020

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Abstract

The document represents a synthesis of the input provided by research groups from Romanian National Institutes and Universities which are currently participating in the CERN Scientific Programme. The Romanian groups are focused on key areas of particle physics with large discovery potential, precision measurements and searches for new physics. Development of new detectors or performance upgrade of the existing ones together with high-performance computing and software are essential to pursuit such physics objectives. The Romanian groups are providing a visible and competitive contribution on R&D for new generation of detectors, testing of new radiation hard technologies to cope with high luminosities, construction, installation and commissioning of full sub-detectors or significant components for Phase I and II Upgrade of LHC detectors, as well as in non-LHC based experiments.

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1. Introduction

Particle physics research in Romania is mostly funded through two programmes of the National Research-Development and Innovation (RD&I) Plan for 2015-2020 which is the main instrument to implement the National RD&I Strategy 2020: "Fundamental and frontier research" and "Research in fields of strategic interest", the last one having a dedicated module to support the Romanian participation at CERN.

Romanian particle physics community is mainly concentrated in Măgurele – *'Horia Hulubei' National Institute for R&D in Physics and Nuclear Engineering* (IFIN-HH), *University of Bucharest- Faculty of Physics* (UB-FF), *Institute of Space Science* (ISS) and *National Institute for Materials Physics* (NIMP), Brasov – *'Transilvania' University* (UTB), Bucharest - *'Politehnica' University* (UPB), Cluj-Napoca - *National Institute for Research and Development of Isotopic and Molecular Technologies* (ITIM-CJ), Iasi - *'Alexandru Ioan Cuza' University* (UAIC), Suceava – *'Stefan cel Mare' University*(USV) and Timisoara – *'Universitatea de Vest'* (UVT).

For the time being, the focus of Romanian particle physics researchers and engineers is oriented towards four Large Hadron Collider (LHC) experiments – *ALICE* (IFIN-HH, ISS), *ATLAS* (IFIN-HH, UTB, UPB, ITIM, UVT), *LHCb* (IFIN-HH, USV), *MoEDAL* (ISS) and Worldwide LHC Computing Grid (WLCG) (IFIN-HH, ISS, UPB, ITIM-CJ, UAIC). The range of physics topics, covered by the above teams, is substantial: QCD - parity violation in strong interaction, properties of strongly interacting matter and its dynamics at the highest energy density reachable for the moment in terrestrial laboratory and gluon saturation signatures, direct and indirect searches for Beyond Standard Model (BSM) physics, flavour physics and discovery physics – search for magnetic monopoles and dyons. Physics production and data analysis is sustained by ALICE, ATLAS and LHCb teams independently, in local datacenters, centralized in RO-LCG Tier2 Federation.

Non-LHC based experiments are bringing complementarity to the Romanian particle physics support programme: NA62 project is dedicated to precision measurements of rare kaon decays at CERN Super Proton Synchrotron (SPS) one NA62 calorimeter read-out system being built and operated by an IFIN-HH team; ProtoDune team from UB-FF will study the performance of a dual-phase liquid argon prototype detector to be used by DUNE Experiment for neutrino science and proton decay studies. The common use of Proton Synchrotron (PS) and SPS beams at CERN provides also a direct connection with the Romanian nuclear physics community actively involved in the ISOLDE and nTOF collaborations, and excellent conditions for testing prototypes of new detectors and associated electronics.

Romanian theoretical particle physics activities are focused on phenomenology and formal theory, both required for refining of Standard Model (SM) and to provide models for: new physics, identity of dark matter and dark energy.

Particle physics detectors and associated instrumentation R&D are vital to fully exploit the High Luminosity-LHC (HL-LHC) project or other future colliders. High flux, high rate and radiation hardness are some requirements that have to be fulfilled by the new or upgraded detectors.

Radiation induced effects in p-type silicon sensors are analyzed at NIMP in the framework of RD50 Collaboration, aiming to increase the radiation hardness of the devices based on a defect engineering approach.

Romanian ALICE, ATLAS and LHCb groups are deeply involved in the R&D and production of ALICE TPC Read-Out Chambers (ROC) based on GEM technology, ATLAS New Small Wheel Read Out Controller (NSW-ROC) and Address in Real Time (ART) application-specific integrated circuits, upgrade of LHCb Ring Imaging Cherenkov detectors to boost the acquisition rate from 1 to 40 MHz and radiation hardness studies on RICH sensors and field-programmable gate arrays (FPGA).

The rest of the document will be structured taking into account the key fields of interest for our community, namely: SM precision measurements, BSM searches, strongly interacting matter in extreme conditions of energy density, neutrino physics, theory, instrumentation and computing.

2. Precision measurements of Standard Model parameters

The Standard Model has been developed and tested in the last decades through dedicated theoretical and experimental research to a very high level of accuracy .The program for precision measurements of the SM remains of key importance to the LHC, deviations of precision measurements from theoretical expectations can probe physics beyond SM where New Physics (NP) is not accessible at tree-level.

Indirect searches of NP signature are done through precise measurement of decays parameters for heavy and light hadrons. As example, the LHCb Collaboration is searching for indirect evidence of NP in beauty and charm sectors, by measuring the decay parameters of certain hadronic-decay channels.

The Romanian LHCb group is interested in measuring parameters for charm/bottom decays which occur through gluonic penguin transitions and in general in Flavour Changing Neutral Current (FCNC) decays with low-value branching ratios and good Standard Model theoretical precision. These transitions are good candidates to search for Beyond Standard Model contributions. The projected Phase-I LHCb-Upgrade luminosity of 50 fb-1 will allow to place new constraints on NP candidates. Based on the new trigger rates in Phase-I and the expected increase in trigger efficiency we foresee an increase of up to 20-times the present sample size for the FCNC/gluonic-penguin channels, making the SM uncertainties and the experimental uncertainties comparable in case of several decay parameters.

On the same direction of research, NA62 is pursuing the very rare $K^+ \rightarrow \pi^+\nu\bar{\nu}$ FCNC decay, calculated with accuracy in the Standard Model but never measured with high precision. The precise $K^+ \rightarrow \pi^+\nu\bar{\nu}$ measurement will provide, complementary to B meson decays, additional constrain on quark flavour mixing CKM matrix, and signals of new physics, if the measure will deliver large deviations from the SM calculations.

Complementary to NA62 main objective, precision measurements of lepton universality in $K^+ \rightarrow l^+\nu$ decays, studies of lepton number and flavor violating processes (LNV/LFV), searches for exotic long living particles in beam dump mode are currently investigated.

For the IFIN-HH group running NA62 in beam dump mode, is of particular importance, the sensitivity of NA62 to dileptonic decays of dark scalar being currently performed. After LHC-Long Shutdown 3 (LS3), with an upgraded NA62, the Romanian group aims to continue rare kaon decay studies, the neutral $K \rightarrow \pi\nu\bar{\nu}$ mode being one of the possible candidates, and exotics production in beam dump mode.

3. Beyond Standard Model searches

The search for physics beyond the Standard Model is one of the key objectives of LHC physics program, as well as particle physics in general. Although the Standard Model of particle physics is an extremely successful description of the phenomena observed so far, it leaves several open questions, e.g. the identity of Dark Matter (DM), the matter-antimatter asymmetry and the hierarchy problem.

Supersymmetry theory, by introducing symmetric particles for the known elementary particles, provides a solution for the SM hierarchy problem but the “stop” supersymmetric partner of top quark, should be observed experimentally. Both ATLAS and CMS experiments are hunting the “stop” quark, but both experiments reported, from p-p collisions at 8 TeV (2012 data), no significant excess in data above the expectation from standard model processes.

Romanian ATLAS Cluster (RAC) main objective is to contribute to the full scientific exploitation of the data collected by ATLAS experiment, through various complementary approaches: direct searches for BSM contributions either model-oriented (supersymmetric) or model-independent (general search), or possible indirect BSM evidence through their impact on identified observables in SM processes (e.g. top quark Yukawa coupling).

The above searches are possible only with a very good understanding of the collected data, RAC aiming to: study the performance of lepton reconstruction and identification, and the goodness 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 (maintenance and improvement of the monitoring infrastructure).

MoEDAL (Monopole and Exotics Detection at LHC) experiment is dedicated mainly to the direct search of magnetic monopoles and massive (pseudo-)stable charged particles, particles which are predicted by various BSM models.

The RO-MoEDAL group is currently performing software development for the Low and High-Threshold MoEDAL Nuclear track detectors (NTD). Development of particle generators for different production modes of magnetic monopoles and dyons and physics analysis are envisaged.

4. Strongly interacting matter in extreme conditions of energy density

Intensive theoretical and experimental effort during the last four decades in the field of heavy ion collisions at relativistic and ultra-relativistic energies have shown that such collisions can be used to produce in laboratory the Quark Gluon Plasma (QGP), transient pieces of matter at densities and temperatures where, based on Quantum Chromodynamics (QCD) predictions, deconfinement is expected to take place. Furthermore, in the last decade, heavy-ion collisions have been proposed as a tool for searching for local parity violating effects in the strong interactions.

There are two Romanian national R&D institutes participating in ALICE experiment, IFIN-HH and ISS, with complementary physics objectives.

ALICE IFIN-HH group is committed to: multi differential analysis and comparison with models in order to understand the properties of the matter formed in pp collisions and its subsequent dynamics up to the hadronization phase and comparison with the results obtained in the heavier systems - p+Pb, Xe-Xe and Pb-Pb; studies of systematics of different observables as a function of quantities characteristic for the basic phenomena taking place at very high collision energies in pp and A-A collisions and signatures for gluon saturation.

ALICE ISS team key objective is to precisely determine if and to what degree parity is violated locally in strong interactions, via the contribution of Chiral Magnetic Effect (CME) to charge-dependent correlations (i.e. pairs of particles with same and opposite charge) in the extremely strong magnetic field produced in heavy-ion collisions.

Recently, the ALICE Collaboration has found that the CME signal contribution to the charge dependence is consistent with zero within current uncertainties. However, the CME contribution to the charge dependence can be constrained to a level of less than 1% with the statistics expected to be accumulated in the next 10 years.

Apart QGP studies in LHC proton-proton collisions, the hadron production is measured at small x values in the forward rapidity region. LHCb physics program comprises measurements for: diffractive events, inelastic collisions, penta- and tetra-quark states, double charm baryons, ion-ion and proton-ion and more.

The Romanian LHCb group is interested in production models and collision generators for hard and soft parton-parton collisions and the underlying event. This includes analysis on minimum bias events and heavy flavour production measurements. New tunes are expected to be implemented for a few particle generators. The tune parameter sets will be constrained by central and forward-rapidity LHC measurements, including the LHCb measurement as uploaded to High Energy Physics Database (HEPData) repository.

5. Neutrino physics

Neutrinos and dark matter are two of the biggest mysteries in particle physics today. Today, neutrinos intrigue scientists with their tiny yet unexpected masses and their ability to morph between at least three different types as they travel throughout the universe. The DUNE Experiment hosted by Fermilab will be a world-class neutrino observatory and nucleon decay detector designed to perform precision measurements of the parameters that govern oscillations between muon and electronic neutrinos, search for proton decay, detection and measurement of the neutrino flux from a core-collapse supernova.

The UB-FF team has ambitious plans regarding the improvement of the Monte Carlo event generator for neutrino-nucleus interactions in liquid argon (e.g. MARLEY code), prediction of the neutrino event signatures from supernovae in liquid argon time projection chamber detector, radioactive background studies and determination of radioactive isotopes present in the components of the detector using gamma spectroscopy. The group is planning to exploit the low background from Slanic-Prahova salt mine.

6. Theory

The discovery and detailed investigation of the Higgs boson at the LHC confirmed the SM of particle physics as a valid theory up to a few TeV. This rendered even more acute the need for a more fundamental theory, which is expected to improve on the SM by solving its known theoretical difficulties and possibly by including gravity. Moreover, improved methods of calculation are needed within the SM, to sharpen further precision tests or control some important non-perturbative phenomena. Fifty years after the formulation of the SM, one notes that its low energy dynamics is theoretically less understood than its high energy regime.

Theoretical physics is also called to explain the accelerated expansion of the Universe and provide a satisfactory understanding of the nature of dark matter and dark energy. The implications of the SM and gravity, or of more fundamental theories, for large scale dynamics (cosmology, structure formation) also require improved models and computational techniques.

Within the frame of the SM, an important objective is to increase the precision of the theoretical predictions. Increased precision, both theoretical and experimental, is crucial for testing the validity of the SM and also for detecting possible significant discrepancies, which would signal the presence of new physics. In particular, systematic research will be focused on the discrepancies observed between experiment and the theoretical predictions based on the SM. Examples are at present the anomalous magnetic moment of the muon (muon g-2) and several observables in flavour physics, like the branching fraction R(D) in the b-quark semileptonic decays.

Improved non-perturbative methods are requested to provide both analytical and numerical progress for the study of generic aspects of gauge theories, like phase transitions between confined and unconfined phases, but also to render more precise matrix elements for processes involving bound states.

The high energy group is also part of the vast program trying to connect new physics phenomena in high-energy particle physics and cosmology to theories consistent in the far ultraviolet. Along more conservative unified field theories, one is interested in string theory applications to particle physics and cosmology, including string and F- theory model building/phenomenology (with or without low energy supersymmetry), flux and orbifold compactifications, effective supergravity theories.

Construction of theoretical models involving dark matter candidates (e.g. neutralinos, axions, and weakly interacting massive particles) and of models predicting the value of the cosmological constant (at earlier and later times) will also be continued. Cosmological models involving space-time topological defects are another attractive possibility.

7. Detector R&D and instrumentation

High luminosity LHC project will boost the study of rare physics processes or reveal new physics, but, naturally, the experiments should cope with higher counting rates and increased backgrounds.

The objective of the RD50 Collaboration is the development of radiation hard semiconductor detectors for very high luminosity colliders, particularly to face the requirements of HL-LHC project. In this context, one of the key strategies adopted by the HEP community for tracking detectors, consists in the replacement of the n-type Si technology with the p-type as detector material.

The role of NIMP team is to perform a series of studies on B-doped Si (p-type): analyze the radiation induced defects and their impact on sensor performance, provide the input defect parameters to the simulation groups for different type of irradiations and defect engineered materials and find the optimal impurity content providing the required performance of pads, pixel, strips, low gain avalanche detectors (LGAD) and high voltage CMOS (HVCMOS) p-type Si sensors. The ultimate goal is to find the optimal amount of deliberate added impurities in the bulk of Si for increasing the radiation hardness of the LGAD and HVCMOS devices at the radiation levels required by the LHC upgrade.

Romanian ALICE, ATLAS and LHCb groups are deeply involved in the R&D and production of various sub-detectors parts and/or their associated electronics.

ALICE IFIN-HH group is responsible with the assembling, tests and commissioning of the ALICE-TPC using the new ROCs based on GEM technology. Replacing the present multi-wire read-out chambers of the ALICE-TPC with the new ones based on GEM technology, preliminary tests and commissioning of the upgraded TPC.

Romanian ATLAS Cluster aims to contribute to the Phase-I upgrade of ATLAS detector: NSW ART and ROC ASIC's and trigger processor tests, production, installation and commissioning; R&D for Tile Calorimeter (Tilecal) mechanics. For ATLAS Phase-II Upgrade ROC will contribute to: NSW R&D for new trigger processor system, FELIX and read-out system; production of Tilecal mini-drawer and micro-drawer, handling tools, photomultipliers high-voltage dividers and installation and commissioning.

The combined Upgrade of LHCb single-arm forward spectrometer for phase-I and phase-II Upgrades implies electronics and sensors capable to withstand Total Ionization Dose (TID) and High Energy Hadron (HEH) fluence in excess of 1 Mrad /10 kGy and 1013 /cm2, respectively. The Romanian groups are pursuing an R&D program, looking for appropriate technologies that are capable to operate in this harsh environment at acquisition rates at and above 150 MHz. Systems including photon-counters and integrated circuits will be characterized in radiation environments at various accelerators using realistic TID, Liner Energy Transfers and HEH fluence, as it was done for the Phase-I devices.

This implies an incipient R&D program for a possible Phase-II detector Upgrade, which is a natural evolution given that the Phase-I Upgrade is being implemented and aging studies are being planned. Phase-I Upgraded LHCb is set to be commissioned by 2020, and the Romanian groups are involved in the Upgrade of the Ring Imaging Cherenkov detectors which change the data acquisition from 1 MHz to 40 MHz, such that the LHCb trigger system will take full advantage of LHC bunch crossing rate.

8. Computing

Due to the estimated increase by a factor of 5-10 of the average rate of collected events once the HL-LHC enters production regime, a global effort is ongoing for improving the computing models and the software used by the LHC community, in order to avoid issues regarding data accumulation and handling, such as storage resource shortage and network overloads. Because of funding and technology advances limitations, increasing the WLCG resource capacities cannot keep up with the demand. Therefore, new solutions are proposed regarding the optimization of the resource usage, the coupling between the available computing and data sources, the improvement of the data transfer management and accessibility. The WLCG will undergo major changes, its current infrastructure being replaced by a federated data center consisting of a few large repositories interconnected through a private, high speed, software-defined network, and a cloud of data caching centers whose contribution to WLCG will depend on their network capabilities.

The strategic objective of the RO-LCG Federation is its transformation in an "HEP-owned medium sized data center" of the WLCG, which will provide reliable offline computing services for the ALICE, ATLAS and LHCb experiments. It is intended that RO-LCG will maintain its current ranking among the WLCG partners with respect to the Grid production levels, and will be prepared for the future challenges generated by the HL-LHC.

The strategic objective is motivated by the commitment of the experimental teams to participate in the HL-LHC project, the 12-year investments in the RO-LCG infrastructure, and the existing human resources that are highly qualified in Grid and experiment-specific computing. Nevertheless, safe funding of the consortium on the basis of a realistic flat-budget planning is necessary in order to keep the RO-LCG contribution at the level of a medium-sized center.

Investment should continue to be made in the national Grid infrastructure in order to support the increasing data storage, handling, processing and analysis requirements. The upgrades should include the bandwidth of the Romanian educational and research network (RoEduNet) connection to European computer network for research and education (GEANT), that must become of the order of 100 Gigabit/sec. Most of the additional Grid equipment will be installed in the new Centre for Advanced Computing at IFIN-HH that provides hosting capacity for minimum 20 years. The infrastructure will be adapted to the evolving requirements of the collaboration, through systematic network, processing and data infrastructure changes/upgrades for ensuring compatibility with WLCG. This will include structural changes within RO-LCG, meant e.g. to simplify data management, for reaching significant gains in efficiency and cost reduction. The duration of adoption of new technology and procedures will be considerable shortened, and redundant activities will be avoided, keeping the costs and manpower within reasonable limits. A long-term plan of measures will be implemented for the recruitment, training of new staff and maintaining the stability of qualified personnel.

9. Other related fields of research

Particle physics has multi-disciplinary links with a variety of scientific areas from fundamental research in nuclear physics, astrophysics, materials physics, laser, plasma and radiation physics, to medical imaging, radiation and hadron therapy. Sensors and detection techniques, simulation and analysis tools developed by HEP community are largely adopted by other fields and vice versa.

One special mention should be made about the clear synergy with nuclear physics. In many cases the particle and nuclear physics researchers are based in the same research institutes and the collaboration between them arises naturally. For Romanian particle physics community the involvement of the nuclear physicists at ISOLDE and nTOF, as well as the possibility to use low-energy heavy ion beams at the TANDEM accelerators in IFIN-HH represent important add-ons.

Detector R&D often requires new developments in electronics and microelectronics, production of printed circuits boards (PCB) and component mounting and soldering on PCB. Before production prototypes and test setups are assembled and tested in laboratory or test beams. Test beams and irradiation facilities are often used for radiation hardness evaluation or for calibration and/or performance assessment.

The construction of Extreme Light Infrastructure - Nuclear Physics (ELI-NP) in Magurele will attract the worldwide nuclear physics community but also high-tech companies and startups. Detector and instrumentation R&D will benefit immediately from the services offered, high-tech partnerships and technology transfers. Moreover, the ELI-NP electron beam, with energy in the range 80-720 MeV/c, can be used straightaway as a test beam.