Summary of "LHCb from strangeness to b-physics and beyond" project results and activities, new developments in High Energy Physics and R&D, national-level impact and integration within LHCb Collaboration

Our project allowed a continuation of LHCb and related high-energy physics research activities in Romania, especially during a critical point in LHC/CERN program, when the first LHC-RUN data became available for physics analyses in conjunction with 2010 LHCb Minimum Bias and physics data. Also, the second critical milestone was the start and the integration in the LHCb-Upgrade program, which included a good fraction from the sum of the project directions and activities. Besides these major topics, the project's program included collateral activities and objectives like: computing tasks within WLCG/LHCb VO program; development and maintenance of LHCb software projects and Web Interfaces; a strong Outreach chapter; and common tasks with other projects and institutes. The LHCb Collaboration divides nowadays the main responsibilities of each LHCb Institute member in three mandatory tasks: physics analyses, Upgrade duties, and Computing assignments. In the next paragraphs, we shall follow this classification and give explicit facts and figures related to last year group progress in each field.

The LHCb Romanian group was and is involved in several LHCb physics analyses. Here, the focus was assigned to particle production studies, with measurement of production rate and cross-sections of strange and beauty particles in proton-proton collisions at various energies. Also, in a related task we could include the dedicated hyperon production study in proton-ion collision data. The observations include production of V0 and hyperon particles and production of beauty baryon Λ_b using a single decay channel $\Lambda_b \rightarrow \Lambda\ J/\psi$ of relative large branching fraction and with a relatively clean LHCb signal. The Minimum Bias physics of strangeness production includes K_{short} , Λ single strange meson and baryon observations together with the multi-strangeness hyperons/baryons $\Xi^{\pm}$ and $\Omega^{\pm}$. The charge fractions and production rates were compared with few standard generator prediction and there is on-going work here within LHCb Collaboration to use Minimum Bias measurements to optimise and tune the LHCb-standard generator parameters – Pythia LHCb tune - and put the simulation prediction in agreement with most LHCb measurements to date. The novelty of the study resided in the fact that the described observables like production fraction and rates together with differential cross-section integrated over LHCb geometrical-acceptance are for LHC proton-proton collisions at 7, 8 and 13 TeV unique measurements far outside the limits of previous accelerator measurement and unique even at LHC due to the forward LHCb acceptance. Though not a test of Standard Model of fundamental particles, Minimum Bias physics at LHC is important within the context of model development for non-perturbative soft-QCD physics. Its importance resides also in the understanding of forward physics, for which the QGP – quark gluon plasma – and cosmic ray collision studies could benefit from LHCb measurements input, too. The LHCb forward physics results for softQCD and hard-QCD measurements were presented at several international workshops and conferences, and in addition measurement of beauty baryon decay parameters and production were advertised at similar international events. In parallel with the resulting talks and posters we had 8 proceeding papers dedicated to physics studies at LHCb. Complementary to the soft and hard-QCD studies we were and are currently involved directly in several LHCb analyses, e.g., rare radiative decays of beauty hadrons, Central Exclusive Processes or CEP with Y- upsilon production through colourless intermediate colliding states, the study of the important $\Lambda_b \rightarrow p\ K\ J/\psi$ decay channel with its plethora of intermediate resonant states. In conclusion to the enumeration of project main analysis topics we could highlight the new quantum effect studies, e.g., particle polarisation as observed in angular distribution analyses on LHCb data for Dalitz plots in $\Lambda_b \rightarrow K\ p\ \gamma$ decay.

Besides direct contributions there were a lot of indirect contributions through MoU tasks and assignments to the most of LHCb past analyses. Some of these include the dedicated administrative tasks within LHCb collaboration, here our group members were assigned some key position like Editorial Board membership, two terms for convener of soft-QCD workgroup, MC contact person for an LHCb work-group. Several simulation and MC tasks were accomplished by our members. Here, dedicated work for generator tuning, MC simulation validation should be included in the list. A special place within this list should take the RIVET package work performed by our members for LHCb and HEP community in general. RIVET framework allowed our group to make public some key published LHCb measurements in a form that is both relevant and accessible to phenomenologists and to the experimental high energy experts. Several talks and a proceeding paper were the group output on this topic, and in addition the group organised and participated in two mini workshops in Bucharest and at CERN focused on the Monte Carlo studies, generators, LHC measurements and tuning. On long term planning the focus here needs to be shifted gradually from soft-QCD physics to the flavour physics studies with charm and beauty hadron decays, to hard-QCD processes, and to direct quantum effect measurements like polarisation or resonance studies during the next LHCb project.

Beginning with the start of this project, we had been involved in the LHCb-Upgrade program through a few dedicated Research and Development (R&D) tasks. During the past years we had forwarded in collaboration with our LHCb partners, the RICH-Upgrade taskforce, a comprehensive plan for the Upgrade of the two RICH LHCb detectors. A Technical Design Report (TDR) was submitted to LHCb and CERN, and a dedicated local application was forwarded by our group to the International Scientific Advisory Board (ISAB) for approval. Based on ISAB recommendation to our funding agency and the ministry of education and science the funding was approved as specified in the two Addenda to the LHCb MoU. The funding covers mostly the equipment costs for a segment of Multi-anode Photomultiplier Tubes (MaPMTs) and a large fraction of assembly costs for the Digital Board communication devices which are part of the Upgraded RICH front-end electronics. Studies for the implementation of a test bench are ongoing and in addition we have an extended R&D program which aims to test the feasibility of certain off the self commercial electronics and sensor devices for the RICH Upgrade program.

Chronologically, the ASICs - application-specific integrated devices - produced by the "Omega micro" a CNRS Laboratory were the first to be consider by our group for a feasibility and characterisation study. In collaboration with our French partners from Omega we have expanded the study of the two ASIC, MAROC2 and SPACIROC, to include a radiation hardness study performed for proton and X-ray beams. We foresee for a new project, the inclusion of new measurements with higher energy protons and X-rays as well as a complete operational characterisation when exposed to ion beams with a broad range of Stopping Power – or Liner Energy Transfer – values: from 1 to about 100 MeV cm^2 /mg. Other spin-offs for these studies are foreseen for SPACIROC and for another Omega ASICs in from of a few dedicated projects which might involve also ESA partners besides Omega. The long term goal of these radiation hardness and aging studies would be the possibility to investigate multiple aspects of radiation damage in a large spectra of Integrated Circuits, and in doing so we entertain the idea to develop and patent a multi-purpose radiation hardness and aging experimental test bench provided with PC interfaces and circuitry. The results for the radiation hardness already performed on MAROC 3 ASIC were shown during the LHCb RICH-Upgrade meetings and also at international conferences.

A second important Upgrade task for this project was the feasibility set of tests done on a few commercial FPGA – Field Programmable Gate Array – which is a device central to the RICH Digital Board communication and programming capabilities. The FPGA test stand was designed from scratch and a full set of tests was implemented in view of future radiation hardness tests. At first we started by modifying and debugging a firmware provided by our LHCb Cambridge and CERN collaborators, though this proved ultimately not an optimal firmware solution for this type of tests. In addition an extra step was achieved by sending 6 FPGA to be thinned to a specialised company, hence wafer Silicon thickness was reduced from 250 mm to 30-60 mm, which allows the typical ion beam to penetrate the upper silicon bulk layer and reach the inner FPGA active layer. In this way it was possible to study the effects of radiation on FPGA operation. The Xilinx Kintex-7

FPGA solution proposed as given in the LHCb RICH Upgrade TDR, was tested for a stopping power ranging between 3 to 7 MeV cm^2/mg. Though for ASIC tests, we have used local IFIN TANDEM and X-ray facilities, for the FPGA test we started by using the ion beam from Legnaro National Laboratory Italian Tandem facility, with larger acceleration values for a large list of ions. The test results were advertised to the LHCb collaboration during LHCb weeks and dedicated Upgrade meetings. There are also talks and a proceeding paper at international conferences. During the last months we have invested a lot of work hours into the development and implementation of a better test firmware on the FPGA to remedy the shortcomings of the original firmware like: problems in communication of SEU – single event upset - rate and lack of efficient error mitigation tools. The next steps for an LHCb continuation project would be to improve the error mitigation tools in the firmware by fully testing the included Xilinx SEM IP Core tool in the firmware second version together with an effective Triple Modular Redundancy scheme for some of the FPGA internal logic and hardware/physics entities. This would be a two-fold objective, as it allows us to fully test the FPGA units in radiation environment with high Total Ionisation Dose values and high Stopping Power values, in parallel with an ambitious sub-project dedicated to the final Digital Board firmware, which need to account for front-end electronics needs and should allow fast and reliable error-mitigation in the LHC hard-radiation environment. Together with the additional FPGA testing and test bench upgrade, the firmware development and testing in LHC-equivalent conditions would be major subjects for the next LHCb project, within the Upgrade R&D chapter.

In completion to the previous main Upgrade tasks, the project activities have included so far: MaPMT characterisation tests in view of future aging studies with radiation and other LHC specific conditions of field and temperature; compilation of quality-control checks for mass-production phase of Digital Boards; preparation for Digital Board assembly, electronic components acquisition. We foresee significant USV contribution to the future Upgrade activities.

Regarding the computing tasks we have started the project by investing in the assembly and acquisition of several computing nodes for a Tier 2 WLCG Grid-certified site “Ro-11”. The Ro-11 Grid computing cluster has provided computing services for LHCb MC simulation jobs and User jobs set through LHCb VO – Virtual Organisation. In addition a second cluster was assembled for the group members for internal usage in MC simulation and data selection and processing. Both clusters have full access to the complete LHCb set of software packages of generation, simulation, digitisation, trigger reconstruction, off-line reconstruction and physics pre-selection and processing, as these packages are configured at CERN. We expect to continue the support and Upgrade of Ro-11 and internal clusters within the future LHCb project activities. As already stated, there are additional computing activities and MoU tasks and these were essential for the project so far as they cover aspects of LHCb activities related to data taking, simulation and model development that are not normally covered within main LHCb curriculum for our PhD students and Post Docs. A few tasks remain open for the next LHCb project, which needs to address among others the problem of effective luminosity calculation for Run 2 LHC data, and for some RUN 1 data.

We conclude the summary by making a review of the project impact. Of note is the large number of fundamental research papers to which the group had direct and indirect contribution, which is also reflected in the diverse particle physics program as outlined in project planning. Most project topics during our studies are unprecedented for Romanian academic and research establishment, and we have endeavoured to contribute to the integration effort of Romanian science in the research field of fundamental particle physics, high energy physics and CERN activities in particular. The most representative tool to achieve this was till now the Outreach sub-program of the project coupled with the outreach activities normally associated with our fundamental science and CERN/LHC field. Our LHCb collaboration has already a specific outreach program for which a main component consists in supporting Masterclasses sessions organised each year. So far our group has provided annually access to certain LHCb applications and data for 30 to 50 high school students from Bucharest and Suceava academic institutions. We also have a open gate program for university students and high-school professors. At present time, the group has 5 PhD students, 2 Master students. During the program 3 PhD member students concluded their dissertations.