B Project description

Project title: "Top quark and Higgs physics at the CMS experiment, development of crystal scintillator detectors and sub-detectors of the CMS detector, and the development of particle accelerator technologies for societal applications in collaboration with CERN".

The proposed project will be carried out through four work packages (WPs). WP1: Management, dissemination and outreach; WP2: Top quark and Higgs physics at the centre-of-mass energy of 13 TeV at the CMS experiment; WP3: Development of the sub-detectors of the CMS experiment for the operation at the HL-LHC and research in crystal scintillator detectors; WP4: Development of particle accelerator technologies for societal applications.

B.1 Scientific Excellence

B.1.1 Contribution of the project to achieving the overarching goal and the goal of the State Research Programme

The overarching goal, *"to strengthen the scientific community in Latvia in the fields of high-energy particle physics and accelerator technologies in collaboration with CERN"*, and **the goal**, *"to carry out scientific research in natural and engineering sciences in the fields of high-energy physics and accelerator technologies in order to develop world class scientific excellence, human capital and technologies, involving the academic personnel, as well as students and early-careers scientists"*, of this State Research Programme (SRP), outlined in clauses 4 and 5 of the Cabinet ordinance No. 196 (CO196)[1], respectively, will be fulfilled by this project through four balanced and cross-integrated work packages. This project will aid considerably to the aim of Latvia to become an Associate Member state of CERN and is fully inline with the priorities of the European strategy for particle physics, which include such points of priority as *"detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities"* and *"the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies"*[2].

WP1, together with the project leader (PL) will be tasked with performing the managerial duties of this project and ensuring the quality of the research output. It will facilitate the cooperation between the WPs of the project and the knowledge exchange amongst the project's partners and CERN, both on the institutional and the individual level. WP1 will also be responsible for the facilitation of the reporting tasks of the research group. It will ensure proper dissemination of the research outcomes and results within the research community in Latvia and will organise the appropriate outreach activities in the country. WP2 will focus on the experimental high-energy particle physics (HEP) research using the data collected by the Compact Muon Solenoid (CMS) experiment[3] at the Large Hadron Collider (LHC)[4] situated at CERN. WP3 will focus on making meaningful contributions towards the Phase-II upgrade[5] of the CMS detector in preparation for the High-Luminosity LHC (HL-LHC)[6] upgrade of the accelerator complex, and on the fundamental research in crystal scintillator detectors via involvement in the Crystal Clear Collaboration (CCC)[7]. A considerable cooperation between WP2 and WP3 is expected, with the research students allocated to WP2 carrying out a large portion of the CMS-related WP3 activities. WP4 will focus on the development of novel accelerator technologies (AT), especially regarding the societal and medical applications of particle accelerators, via engagement in upcoming CERN-coordinated projects in AT and the involvement in the relevant groups at CERN, such as the magnet, superconductivity and cryostat (MSC) and materials and mechanical engineering (MME) groups.

This project, will thoroughly fulfil all the scientific aspects of the overarching goal and the goal of this SRP via the involvement in a number of CERN-based research projects and experiments in HEP and AT, as outlined above, and through the engagement of a number of early-careers researchers, in the form of doctoral and master's students, in the fields of HEP and AT. This, together with the managerial and outreach activities, will also directly fulfil the collaborative aspects mentioned in the overarching goal of this SRP, through the facilitation of knowledge exchange between the project's partners and CERN, cooperation and coordination of the research activities and the public engagement activities outlined further in text.

The main institutional executor of this project is the Centre of High-Energy Physics and Accelerator Technologies (HEP&AT Centre)[8] of the Riga Technical University (RTU)[9]. Besides the on-going scientific activity in the fields of HEP and AT, the HEP&AT Centre acts as the CERN National Contact Point (NCP) in Latvia and the secretariat of the CERN Baltic Group (CBG) and the CERN Latvia stakeholders Group (CLG), further discussed in section B.3.1. This project includes the engagement of two partner institutions, University of Latvia (UL)[10] and the UL Institute of Solid-State Physics (UL ISSP)[11]. The partner institutions are discussed in section B.1.3.

B.1.2 The goal of the project, its objectives and the state-of-the-art in the fields of science

The overarching objectives of the project and its WPs is fully aligned with the goals of the SRP stated in section B.1.1. It aims to develop the cooperation between the researchers in Latvia and CERN and to increase the research capacity in the fields of HEP, particle detectors and AT in the country. The specific objectives and tasks of each WP, as outlined below, represent the absolute forefront, or the **state-of-the-art**, of activities in the fields of HEP, particle detectors and accelerator technologies.

WP1: Management, dissemination and outreach. The **objective of WP1** is to deliver the managerial, collaborative, reporting and outreach-related activities. These are mostly pertaining to the impact and implementation of this project and, thus, are mainly discussed in sections B.2 and B.3. The overall aim of this WP, however, is to provide a strong managerial basis in order to ensure the on-time delivery of the desired research outcomes, including the reporting duties. It will be directly responsible for the delivery of the planned public engagement and outreach activities, and the dissemination of the results and outcomes of the research carried out through the funding of this SRP. It will also be used to ensure that the research students are given the access to the best possible training and educational opportunities. The **main tasks of WP1** can be summarised as follows: **T.1.1** - to prepare and execute the partnership agreements between partners and with CERN; **T.1.2** - to facilitate the cooperation between and the coordination of activities of all research institutions in Latvia working in fields related to HEP and AT; **T.1.3** - to ensure the observation, by the research group, of clauses 57 to 60 of the regulations of this SRP[12] and to execute all general managerial tasks; **T.1.4** - to deliver the knowledge transfer and outreach activities and the progress reports; **T.1.5** - to facilitate the educational and training opportunities and to organise regular seminars for the research students.

WP2: Top quark and Higgs physics at the centre-of-mass energy of 13 TeV at the CMS experiment. The **objective of WP2** is to build the scientific community and the research capacity in the field of HEP in Latvia through further involvement of Latvia's research group in various t quark physics analyses carried out at the CMS experiment at CERN. The Top, t, quark, discovered in 1995[13] at the Tevatron[14] accelerator facility at Fermilab[15], is the heaviest known elementary particle. The most up-to-date combined mass measurement places the mass of the t quark at 173.34±0.76 GeV[16], $\mathcal{O}(10^5)$ times heavier than the light quarks, about 40 times heavier than the next heaviest quark, the beauty or bottom, b, quark, and approximately twice the mass of the electroweak gauge bosons, Z^0 and $W^{\pm}$. As with other quarks, the origin of the mass of the t quark is fundamentally connected to the interaction strength of the quark with the Higgs field via the Yukawa couplings[17, 18]. The origin of the varying strengths of the Yukawa couplings of quarks and other fundamental particles is entirely unknown. Furthermore, the t quark is unique in that, due to its high mass and the subsequently short lifetime of $\sim 0.5 \times 10^{-24}$ seconds, the t quark does not hadronize. Rather, it decays via the weak force on a shorter timescale than the timescale needed for the strong force to act upon it to form bound hadronic states.

One fundamental measurement that will be performed through this WP is the measurement of the t and anti-t mass difference, Δm_t, using the total pp collision data sample of 150 fb^{-1} collected at the centre-of-mass energy of 13 TeV by the CMS experiment. This measurement is a good test of the Standard Model (SM)[19], as any significant deviation of Δm_t from nil would not only indicate the presence of *New Physics* (*NP*), but fundamentally break the SM, the CPT symmetry and the Lorentz invariance. A similar measurement was performed by the CMS collaboration using the 19.6 fb^{-1} pp collision data sample from Run 1[20], which found the Δm_t to be -0.15±0.19(stat)±0.09(syst) GeV. The ten-fold increase in the size

of the data sample and the increase of the centre of mass energy, providing an increased t production cross-section, should decrease the statistical uncertainty by more than a factor of three. This, combined with an improved analysis methodology, will yield a more conclusive result.

Another fundamental measurement performed through this WP will be the investigation of the colour re-connection and colour flow in t quark decays at the CMS experiment at the centre-of mass energy of 13 TeV. Such measurements are paramount for furthering our understanding of the fundamental QCD processes, where theoretical calculations partially break-down. An analysis investigating the phenomenon of colour-flow has been performed by the ATLAS collaboration[21, 22], making the measurement by the CMS experiment highly anticipated. This analysis is already led by a HEP&AT Centre researcher.

Furthermore, significant contributions will be made to other t quark physics analyses at the CMS experiment, especially regarding the measurements of single-t production. Due to its high mass, t quark production analyses are sensitive to *NP*, which could manifest itself in the form of small enhancements in the t quark production rates compared to the SM predictions. Similarly, contributions to the measurements of the production of t quarks in association with the Higgs boson, H, such as $t\bar{t}H$ and tH will be made. The Higgs, H, boson is the latest and final fundamental particle of the SM to be discovered. This discovery was made in 2012 by the ATLAS and CMS collaborations[23, 24]. It is a scalar gauge boson and the mediator of the interaction between the Higgs field and other fundamental particles. Analyses of the t quark production in association with a H boson are direct probes of the t quark's Yukawa coupling and are partially sensitive to *NP*[25, 26].

It is important to state that currently, and for a foreseeable future, experimental measurements of the properties of the t quark are exclusively accessible at the LHC. Three out of the four major LHC-based collaborations, ATLAS, CMS, and LHCb[27], are the only experiments that are capable to directly investigate the properties of the t quark. Moreover, the HEP topics regarding the t quark and the H boson are on the verge of entering a true precision-measurement era at the LHC. Following Long Shutdown (LS) 3 the HL-LHC will be operating as a H and t *factory* of unprecedented statistical reach, as discussed in the CERN Yellow Report[28]. Thus, it is paramount to develop the expertise and gain a foothold in these research topics prior to the start of HL-LHC in 2027.

There are currently two researchers working at an LHC-based experiment employed by a research institute in Latvia. Both of these researchers are employed by the HEP&AT Centre and are currently carrying out their research in t quark physics analysis working group at the CMS experiment. Through WP2 this project will fulfil the aforementioned task of capacity-building by growing the HEP research community in Latvia two-fold through the recruitment of two doctoral students[1]. Furthermore, this WP will include the recruitment of two master's students[1], which will ensure the continuity of the availability of suitable doctoral researchers in HEP in the future. Overall, through this WP our group aims to make significant contributions to the cutting-edge HEP research in the area of t quark and H boson physics at the LHC. The **main tasks of WP2** can be stated as follows: **T.2.1** - to build and develop the research capacity in HEP in Latvia; **T.2.2** - to engage early careers researchers, master's and doctoral students, in HEP; **T.2.3** - to deliver on the scientific goals in t physics research, the co-authorship of CMS publications and to make the results available on open source platforms such as `arXiV`; **T.2.4** - to develop, in close cooperation with WP3, the particle detector technologies for the CMS upgrade projects.

WP3: Development of the sub-detectors of the CMS experiment for the operation at the HL-LHC and research in crystal scintillator detectors. The two main **objectives of WP3** are the facilitation of participation of the research group in the development of the sub-detector systems at the CMS experiment for the HL-LHC upgrade and furthering of the involvement of Latvian researchers in the field of cutting-edge particle detector development through the research and development of the crystal scintillator materials.

The LHC accelerator complex will undergo a major upgrade during the LS3, scheduled to take place between 2025 and 2027[29]. The main goal of this upgrade is to increase the intensity of the beam that

[1]The students working on WP2 will carry out their HEP research at the CMS experiment; therefore a considerable amount of their time will be devoted to the CMS-related activities outlined in WP3. This is especially true for `PHD_2` and `MSC_2`, to be contracted by UL and supervised by the representative of UL.

the machine can deliver to the experiments. The instantaneous levelled luminosity is to increase from around 2.5-3.0$\times10^{34}$ cm^{-2}s^{-1} in Run 3 up to as much as 7.5$\times10^{34}$ cm^{-2}s^{-1} in Run 4[6]. Therefore, the expected total integrated luminosity delivered to the experiments is to be around 3-4 ab^{-1} by the end of Run 4. To achieve the above, the pile-up, the number of *pp* collisions per beam-crossing *seen* by the experiments, will increase from the current value of around 50 to between 140 and 200.

In order to fully benefit from the increased machine performance, the CMS experiment will also undergo a major upgrade, referred to as the Phase-II upgrade[5]. The CMS experiment is a 21$\times$15$\times$15 metre and 14'000 tonne particle detector[3] and is made up of multiple sub-detectors, which utilise various particle detection technologies. The two upgrade sub-detectors this project aims to contribute to are the Minimum Ionizing Particle (MIP) Timing Detector (MTD)[30, 31] and the High-Granularity Calorimeter (HGCal)[32][2].

The MTD project aims to use time signature of hits in the active material to identify the correct primary vertex, the *pp* collision vertex, of the *arriving* particles. Studies of the expected collision conditions at the HL-LHC show that the events are expected to have a root-mean-squared (rms) time-spread of 180-200 picoseconds (ps). The simulations show that the MTD will be able to provide a time resolution of 30-40 ps at the beginning of operations, with a reduction to approximately 50-60 ps by the end of its life-cycle. This time resolution is sufficient for the CMS experiment to maintain the current level of "pileup pollution" in Run 4 data, despite the 3-4 time increase in the number of nearly simultaneous primary interactions. The MTD will consist of two distinct parts, the barrel timing layer (BTL) and the end-cap timing layer (ETL), covering the barrel and the two end-cap regions, respectively. The BTL will utilise Cerium doped Luthenium based crystal technology (LYSO:Ce) as the active material and silicon photo-multipliers (SiPMs) as the signal detection devices. The ETL, where the radiation environment is considerably harsher, will use silicon sensors as the active material and Low Gain Avalanche Detectors (LGADs) as the signal detectors[30].

The HGCal project is the upgrade of the CMS detector's end-cap calorimeters. The existing detectors were designed for the total integrated luminosity dose of 500 fb^{-1} and thus require replacing in order to survive the dose of 3000 fb^{-1} expected by the end of Run 4. Furthermore, the increase in the instantaneous luminosity and the subsequent increase in the number of pileup collisions will lead to a higher energy deposit per unit time, the energy flow, in the detectors, especially in the forward region. The high transverse and longitudinal granularity of the HGCal detector will allow the CMS experiment to maintain and even improve the spatial and energy resolution of *jets*. This sub-detector will utilise a silicon sensor active material in the front layers and scintillating plastic with SiPMs as a readout for the back layers, where the irradiation dose is lower[31].

Via this WP, the project will contribute to at least one of the CMS sub-detector upgrade activities. Most Phase-II sub-detector upgrade projects, including MTD and HGCal, are in a relatively advanced stage, however, our group will be able to contribute considerably in the simulation, characterisation and calibration processes of these projects. Similarly, our group will be able to engage in the studies of the operation of the current CMS sub-detectors, investigating the radiation damage in the various components, which will provide invaluable insights for the development of the aforementioned upgrade projects.

In parallel to the activities of this WP regarding the CMS upgrade projects, this WP will also cover the fundamental research in scintillator detector technologies. This part of the the WP will be led by the UL ISSP and will be carried out in collaboration with the CERN-based CCC. UL ISSP has a long history of research and development of scintillation materials, including past collaboration with CERN. This research included the study of various *classic* scintillators, such as CsI, CsI:Tl, BaF_2 and $Y_3Al_5O_{12}$[33]. It also provided a ground-breaking achievement in the field of scintillator development, the discovery of cross-luminescence[34], by the team at UL ISSP. The collaboration between UL ISSP and CERN, through CCC, was re-established in the middle of 1990s, which included the study of the properties of

[2]The choice of the sub-detector project(-s) is of a high strategic importance and therefore cannot be made without the knowledge on the available resources in full, both in terms of person power and the financial constraints, which includes the outcome of this project proposal. It is foreseen that one of the two projects will be selected and focused on, however it is feasible to contribute to both, which would be highly desirable.

$PbWO_4$ scintillator detectors[35], currently present in the calorimetry system of the CMS experiment. The current research at UL ISSP encompasses a wide array of scintillator materials, such as YAG, GGG, PbF_2 and ZnO. Importantly, the research includes the study of crystal scintillators, such as GAGG:Ce single crystals and oxyorthosilicates (LSO:Ce, YSO:Ce, LYSO:Ce)[36]. The latter are not only of great interest for the CCC, but also include the material choice for the aforementioned MTD of CMS. Through this WP the research team will work on collecting new data on the characteristics of the crystal scintillator materials, such as time-resolved luminescence, including the study of this in heavily irradiated samples of the material and electron paramagnetic resonance (EPR) and Raman spectra data of radiation-induced effects. Furthermore, the radiation defect annealing in YAG and GGG scintillators and a relation of the defect migration-recombination properties and radiation dose will be investigated and new data on vacuum-ultraviolet (VUV) excitation mechanism of scintillation in GAGG will be gathered.

This WP includes a doctoral student and a master's student being recruited by the UL ISSP to primarily carry out research in crystal scintillator detectors. However, as a part of their activities, the doctoral student will also be involved in the CMS-related detector development activities alongside the doctoral students working on WP2.

Finally, it must be stated that the former objective of WP3, the involvement in the CMS sub-detector upgrade projects, is absolutely paramount for the ability of Latvian scientists to carry out the research described in WP2[1]. It is mandatory for research clusters wishing to carry out fundamental particle physics research on one of the major experiments at the LHC to contribute significantly to the operation, development, upgrade and maintenance of the detector, in proportion to the number of researchers carrying out their work on the given experiment. In order to grow Latvia's capacity in fundamental particle physics research at the LHC and CERN, our capacity to contribute to the aforementioned aspects of the detector operation must grow concurrently. In addition, it is of interest to our physics programme described in WP2, to contribute to the success of the sub-detector upgrade projects. An increased time resolution of track-hits and spatial *jet* resolution will improve the various t quark physics measurements made by the CMS collaboration immensely. Likewise, the increased longitudinal granularity of the HGCal will improve the overall energy-resolution of the detector and further improve the use of the particle flow[37] algorithm by the experiment. Additionally, through the above activities of WP3, this research project will also seek to engage Latvian industry in the manufacturing of relevant items, such as detector components for the CMS upgrade activities.

The **main tasks of WP3** are: **T.3.1** - to develop, in close cooperation with WP2, the particle detector technologies for the CMS upgrade projects; **T.3.2** - to investigate the radiation tolerance of various present and future particle detection technologies via the involvement in the CMS experiment; **T.3.3** - to gather and analyse new data of crystal scintillator detectors in collaboration with the CERN-based CCC; **T.3.4** - to develop and grow the HEP community in Latvia via linking the physics research with the development of detector technologies and via establishing appropriate links with industry.

WP4: Development of particle accelerator technologies for societal applications. The main **objectives of WP4** are to grow the research capacity in Latvia in the field of AT via the involvement of the research group in multiple international CERN-based accelerator projects and collaborations and to contribute significantly to the development of AT for societal applications. The accelerator technologies are an irreplaceable part of fundamental particle, nuclear, atomic and solid-state physics. Furthermore, AT have become increasingly integral in various societal and industrial applications, from hadron therapy[38] to electron-beam lithography[39].

This WP will provide a considerable input in the development of *Hybrid Exhaust gas cleaning Retrofit Technology for International Shipping* (HERTIS) collaboration. The goal of HERTIS is to develop a hybrid exhaust-gas cleaning retrofit technology, which utilises a novel toroidal electron beam accelerator technology. It will also focus greatly on the use of additive manufacturing (AM) techniques in the development of AT. AM is a state-of-the-art manufacturing technique where material is joined and solidified under computer control to create 3-dimensional objects and is a relatively new approach in the field of AT. It is clear, however, that AM methods have a great potential to be used in AT in a more extensive and varied manner[40]. The researchers of the group will use their expertise in AM to conduct a survey

of the current use of these manufacturing techniques in the field, as well as a process of identifying and promoting the use of AM by the various on-going and planned AT projects at CERN and the wider AT community. The use of AM has the potential to improve the performance of particle accelerators, as these techniques allow for the manufacture of geometries of parts not available through the more traditional milling, engraving and etching techniques. Additionally, the use of AM has the potential to greatly reduce the cost of both the design and manufacture of future particle accelerators, including the potential Future Circular Collider[41]. Overall, this WP will look to define strategic directions for the future use of AM in the field of AT research and development.

Furthermore, this WP will look to contribute directly to the development of medical applications of particle accelerators. This activity will contribute to the research and development of the accelerators for the use in hadron therapy, one of the most promising methods of cancer treatment currently available. The use of hadron beams has an important advantage over other methods of radiation therapy in that the energy is deposited in the tissue following a narrow distribution (the "Bragg peak"), thus leading to an improved tumour targeting and lower risk of damage to healthy tissue. In order to utilise these benefits to the fullest extent, the particle accelerators used to provide these hadron beams must be extremely precise, compact and of accessible cost. This WP will work on various aspects of research and development for medical accelerators, specifically focusing on the mechanical and structural design of the machines and the modelling and the overall integration of the different components.

This **main tasks of WP4** are as follows: **T.4.1** - to contribute to the development of the HERTIS collaboration; **T.4.2** - to contribute to the development of the advanced accelerator technologies and performance improvements of the particle accelerators, particularly regarding AM solutions; **T.4.3** - to contribute to Horizon 2020 collaborative projects in the field of advanced accelerator technologies and of advanced accelerator and gantry design for medical applications; **T.4.4** - to involve the members of the project and other Latvian researchers in the technical groups at CERN, such as MSC and MME.

Importantly, the research group at the HEP&AT Centre include the leading researchers in the field of AM in the country and is represented by said researchers in CERN-based AT research and development collaborations, thus having a unique in Latvia capacity to carry out the research and development of particle accelerators.

The scientific activities of this project and it's WPs, as discussed above, will serve to fulfil a number of **thematic and horizontal tasks** and **scientific goals** of this SRP, as outlined in CO196: clause 6.1, development of the cooperation with CERN via the involvement in one or more scientific experiments and collaborations, e.g. the CMS experiment [WP2,WP3,WP4]; clause 6.3, development of fundamental research in the fields of HEP and AT [WP2,WP4]; clause 7.2, facilitation of the cooperation and coordination of all scientific research institutions working on research topics related to HEP and AT [WP1]; clause 7.3, ensuring an open access for the public to the published results of the research carried out through this SRP by submitting the publications to such open access databases as `arXiV` [all WPs]; clause 8.1, authoring publications deposited to scientific journals listed in the databases such as *Web of Science* and *SCOPUS*, e.g. publications made by the CMS collaboration [WP2,WP3,WP4]; clause 8.4, the involvement of doctoral students and early-careers scientists in the research activities of this SRP [all WPs];

B.1.3 Contribution of the cooperating partners to the attainment of the goals of the project

This project includes the engagement of two cooperating institutional partners, University of Latvia[10] and Institute of Solid-State Physics[11], under the management and leadership of RTU.

UL is the most prominent university in Latvia regarding the academic capacity in the natural sciences, including physics. Despite currently not having a direct involvement in the experimental high-energy particle physics, UL has the academic expertise in the theoretical aspects of this research topic. UL will be represented in this project by the researchers from the Institute of Chemical Physics (ICP)[42]. In addition to the excellent academic capacity, this group has a unique in Latvia experience in studying material behaviour in various harsh environments, such as high radiation environment, high temperature environment, in the presence of plasma and under immense magnetic fields. The expertise of the research group at ICP is highly complementary of the expertise of the researchers at the HEP&AT Centre and will be used to great effect in the activities of WP2 and WP3. In addition, the group has access to unique in

Latvia scientific tools, including a linear electron beam accelerator. These tools will be available for the studies of the sub-detector components for the CMS upgrade projects.

UL ISSP is the leader in Latvia in research pertaining to solid-state physics and will take a prominent role in the research carried out via WP3. This field of research is of paramount importance to the field of experimental HEP, where the particle detectors based on cutting-edge semiconductor or scintillator technologies are used. The unique expertise available at the UL ISSP will be used for the study and development of crystal scintillator detectors. Additionally, through their expertise, UL ISSP will also have an immense capacity to aid in the CMS upgrade projects and any studies of the current CMS detector components. Furthermore, the knowledge gained through the development of crystal scintillators has the potential to allow Latvian research groups to take a leadership role in a future detector upgrade project at the LHC or elsewhere.

The high degree of complementarity between the expertise and experience of the three participating institutes must be emphasised. The RTU HEP&AT Centre has a unique in Latvia capacity for experimental HEP research, which will be utilised to a great effect in WP2. UL ISSP has the expertise in the fundamental materials research of substances used as the sensory and particle detecting materials in HEP experiments, which will serve the fulfilment of parts of WP3. The academic capacity of UL and the experimental expertise of the ICP will allow this partner to interlink the tasks undertaken by the two WPs, creating synergies between the three research institutions.

It should also be noted that RTU and UL has a great track-record of cooperation regarding HEP and AT, demonstrated through the on-going development of a joint doctoral programme in "High-Energy Physics and Accelerator Technologies". This highly effective cooperation between the two institutions regarding HEP has been recognised through registering the Latvian research group at the CMS experiment as a consortium of RTU and UL.

B.2 Impact

B.2.1 Impact of the research on the fields of high energy physics and accelerator technologies and on the development of a research community in these fields

This project will serve as a solid base for and contribute directly to the growth of the research capacity and scientific community in the fields of HEP, detector development and AT.

High-energy physics. Through WP2, the research capacity in experimental HEP in Latvia will be essentially doubled via the recruitment of the doctoral and master's students. The chosen physics topics will allow the group to build the expertise and to become established in the analyses groups working on topics regarding the t quark and H boson during the dawn of the precision-measurement era in t quark and H boson physics, as discussed in section B.1.2. In addition, the involvement of the group in the CMS sub-detector upgrade activities via WP3 will allow the involved institutes to build the capacity in the area of particle physics detector development, laying the foundation for said institutes to take a leading role in the detector upgrade projects at the LHC in the future.

Accelerator technologies. Through WP4, this project will serve to place a Latvian research group in a leading role of an international AT research and development collaboration. This project will also nearly double of the research capacity in the field of AT through the recruitment of research students and a post-doctoral research associate.

Research community. Through the above, this project will not only directly facilitate the growth of the scientific capacity in HEP, detector research and AT in Latvia, but also promote a strong cooperation between the involved partner institutions, as well as enable a deeper and more substantial cooperation between the partner institutions and CERN. As discussed in section B.1.3, the complementarity of the expertise of the three research institutions involved will be used to build a strong research community in the above fields of research. All of the above will be coordinated and supported via the managerial tasks of WP1. Furthermore, as the secretariat of the CBG and CLG, discussed in detail in section B.3.1, the HEP&AT Centre is uniquely placed to disseminate and communicate the scientific outcomes of the project to the wider scientific community in the country, where applicable, via the already open and available information exchange channels between the HEP&AT Centre and other relevant research institutions in Latvia and the Baltic states.

The impact on the scientific community outlined above will allow this project to fulfil the horizontal task outlined in the clause 7.1.1 of CO196: to ensure the impact of the process and results of this SRP project on the scientific community as a whole in the country, by developing, among other things, the available resources and internationally competitive multidisciplinary research group(-s).

B.2.2 Impact of the research project on the graduate students, their involvement in the project, and impact on the further study opportunities of undergraduate students

The overarching goal of this project is to facilitate the growth of the research capacity and the development of the scientific community in the fields of HEP and AT in Latvia. The optimal way of achieving the above is through a ground-up growth of the research group and the knowledge base, best achieved via the employment of early-careers researchers in these fields of research. As such, the recruitment and development of doctoral and master's students is one of the main focuses of this project. This proposal includes the recruitment of **four doctoral students** and **four master's students** to be **engaged in the research activities** outlined in section B.1.2 of this project proposal and, where applicable, outside it.

Impact on study opportunities in Latvia. The HEP&AT Centre, in collaboration with UL, other CBG partner institutions and experts from CERN, is currently leading the development of a doctoral study programme in "High-Energy Physics and Accelerator Technologies". This activity is a part of the SAM 8.2.1 project, aimed at reducing the study programme fragmentation in Latvia[43]. The doctoral students will start their degree under appropriate, currently accredited doctoral programmes and will be transferred to the HEP and AT doctoral programme following its accreditation, foreseen to be complete in 2022. The research students funded by this project will be provided with a work-in-progress lecture course content of this doctoral programme, where applicable. Following the successful completion of the doctoral study programme development, the development of a complementary master's level study programme by the HEP&AT Centre in cooperation with UL will also be undertaken. The feedback from the doctoral and master's students engaged in this project on their needs and requirements whilst undertaking their research will be taken into account when proceeding with the development of the above study programme. Likewise, their feedback on the work-in-progress lecture content will also be used. Thus, the doctoral and master's students engaged in this research project will directly contribute to the further study opportunities of the current undergraduate students in Latvia.

Practicum, study and knowledge exchange opportunities. An integral part of the doctoral study process for the research students will be a prolonged stay at CERN, where, as part of their respective research projects or complementary to them, the students will be embedded in the operational groups of physicists and engineers at CERN. For the students working within WP2[3] this will also include the fulfilment of various training courses allowing the students to take roles of responsibility in the operation of the CMS experiment, such as operational shift work. Furthermore, this stay at CERN will allow the students to gain substantial experience in all aspects of experimental HEP and AT and gain direct face-to-face access to the foremost specialists in their respective fields of research, as well as allowing them to attend CERN seminars and CERN training programmes.

Depending of their research project and the corresponding WP, the doctoral students will be directly supervised by an appropriate researcher from HEP&AT Centre or one of the partner institutions, UL and UL ISSP. In addition to their direct supervisors, the students will be provided with support and secondary supervision by prominent members of their respective research groups at CERN.

During their degree the doctoral students will be given an opportunity to attend at least one scientific conference or workshop where they will have a chance to participate with a talk or in a poster session. Likewise, the students will be given the opportunity to attend at least one training school relevant to their respective fields of research.

Where possible, the master's students will be provided with the option to attend the same lectures as the doctoral students and will be assigned research projects from one of the WPs. These projects will be complementary to the work done by the researchers and the doctoral students, but will be of narrower scope, such as working on constraining a certain background in the t quark measurements, developing

[3] This might also be available for students working within WP3.

specific *jet* reconstruction algorithms and tools or working of the detector test-beam data. The specific project of each student will be assigned taking the student's research interests into account. The master's students will also be provided with the opportunity to spend an extended time at CERN, where they will benefit from the available expertise on-site.

The knowledge exchange between all the students of the various WPs will be encouraged through a number of status update meetings. Such meetings would include all students engaged in the research work in the group, both under and outside the remit of this project. In addition, whilst based in Latvia, they will be given an opportunity to do their non-laboratory based work at a dedicated workplace in an open office environment at the HEP&AT Centre. This will further facilitate the knowledge transfer between the various WPs and create an collaborative work environment. The research, training and knowledge exchange opportunities given to the students will serve to develop them into highly-skilled early-careers researchers with expert knowledge in their respective field of research, as well as a plethora of transferable skills, highly sought-after in the modern job market, such as high computer literacy and programming knowledge, leadership and public engagement.

The impact on students outlined above will allow this project to fulfil a number of thematic and horizontal tasks and scientific goals of this SRP, as outlined in CO196: clause 6.2, to help in the development of doctoral and master's study programmes in the fields of high-energy physics and accelerator technologies; clause 7.1.2: to ensure the impact of the process and results of this SRP project on the students, allowing for knowledge-transfer, training and work opportunities, as well as the use of scientific outcomes in their study process; clause 8.2: to ensure the presentation of the research outcomes in international conferences or workshops in the form of an oral or poster presentation; clause 8.3: to involve doctoral students and early-careers scientists in the activities of this SRP and SRP project.

B.2.3 Impact of the research on the general public, by ensuring knowledge transfer and by promoting the understanding of research and its contribution to society, as well as by developing technologies necessary for industry and state

This project will devote a considerable effort to informing the general public and the specific appropriate target audiences about the research activities undertaken, as well as about the project's results and outcomes and their applicability. The specific target audiences include the policy makers, researchers in Latvia, industry, science teachers and, most importantly, students at various stages of their education.

Impact on the general public. The general public will be informed about the on-going research performed by the group via a number of methods. The relevant information will be continuously updated on and disseminated through the websites of the institutes involved [8, 10, 11]. National media will be informed about our activities, where applicable, either through direct engagement or through the public relations departments of the above institutions, with the aim of exposing, explaining and disseminating the research carried out by the research groups in various popular science programs. In addition, this project aims to give the general public an insight into the research carried out by the group and the research carried out at CERN and in the wider particle physics community through *OpenAccess* public seminars, organised via the activities of WP1. These seminars should be organised at the end of the calendar years and presented in the style of the seminars given at the Royal Institution, London.

The data from these *OpenAccess* seminars, such as the popularity, attendance and feedback, will be used to improve the future editions of such events. In addition, such data will be collated and reported back to the funding body, either as an attachment to one of the two major reports, or separately. The *OpenAccess* seminars and the data gathered from them will be used to inform the policy makers in the country on the general outlines of the fundamental research in HEP and both the tangible and abstract benefits of this research to the general public, as well as to reflect the public opinion on said research.

Impact on the researchers and industry. The knowledge and information exchange between the research groups fulfilling this project and other relevant research institutions in the country will be facilitated through the WP1 and the HEP&AT Centre's role as the secretariat of the CBG, elaborated on in section B.3.1. Similarly, Latvian industry will be informed about their opportunities with respect to knowledge transfer with CERN through the activities of the HEP&AT Centre's role as the secretariat of the CLG. The secretariat has already-established partnerships and is maintaining the information exchange between various Latvian businesses and CERN. The names of specific businesses should be

emitted from this project proposal, but the information is freely accessible on the website of the HEP&AT Centre provided in Ref.[8]. Specifically, the outcomes of the detector research performed through WP3 should be of interest to specific businesses in Latvia involved in the development and manufacture of scientific instrumentation and equipment.

Impact on teachers and students. Through WP1, this project will ensure, actively advertise and help facilitate the participation of Latvian science teachers in CERN National Teacher Programmes[44]. The next such activity is currently planned for April 2021. It will also focus on educating students of various levels on the topics relating to high-energy particle physics and other fundamental research. At least one week of each year of funding will be dedicated to giving free and open seminars at schools in Latvia on the topics of HEP and AT, with the aim of informing the students about fundamental science and to encourage them to choose STEM research as their career path in the future. It is important to state that said schools will be chosen such as to be as inclusive as possible with a major attention given to the regional schools. These weeks are planned for the spring of each year, however, in the case of significant interest, feasibility of holding further weeks or separate events will be evaluated. In addition, throughout this project the group will continue to support activities such as the CERN virtual visits[45]. Similarly to the *OpenAccess* seminars, the feedback and other data collected from these outreach activities will be collated and submitted to the funding body of this project.

B.2.4 Project's scientific results and accessibility

WP1. The main scientific outcome of WP1, outside the general managerial and outreach duties discussed above, will be the preparation and submission, in cooperation with the PL, of funding bids from European funding bodies. WP1 will be responsible for bidding for additional funding from such European programs as ERASMUS+[46] and COST[47], in order to facilitate various activities such as staff exchange, knowledge transfer, training schools and expansion and further development of the study programmes. More significantly, an above threshold bid for funding from the European research bodies, such as, the European Research Council's Starting Grant[48] or the relevant Horizon 2020 framework, will be made during the span of this SRP funding[4], fulfilling a scientific goal of this SRP outlined in clause 8.3 of CO196. Such bids will be made seeking resources to further solidify the research capacity in the fields of HEP and AT in Latvia through either expansion of the involvement of the group into other physics working groups of the CMS experiment, or, preferably, an expansion of the research activities of the group to other experiments at the LHC or beyond. It is not possible to state the specific thesis of such an ERC or Horizon 2020 application at this stage as it will depend considerably on the success of the project outlined in this application and on the successful and continuous growth of the capacity of the research group.

WP2. The immediate scientific outcome of WP2 will be the continued participation of the group in the research activities within the CMS collaboration with four researchers registered in a physics analysis working group at the experiment. It will serve to develop the doctoral and master's students into high-calibre researchers. Participation in the CMS collaboration will entail the co-authorship of a number of high-quality, high-impact publications by the experiment as discussed below. At the time of writing CMS is an international research collaboration of approximately 4000 researchers from 206 institutes from 47 countries[49]. The CMS detector is a general purpose experiment covering a vast array of high-energy physics research topics. Since the stable start-up of the LHC in 2010, the CMS collaboration has published 969 papers in peer-reviewed journals[50]. Each member of the collaboration becomes a co-author of all publications one year after joining the collaboration, providing they have fulfilled their internal authorship criteria and their authorship is officially and financially confirmed by their home institution and their funding agency. Given the above, each eligible researcher funded by this project working on WP2 will be granted co-authorship of approximately 100 scientific publications per year. Through the t quark analysis group, eligible members of the group working on WP2 will have a direct input in around 10 publications per year with leading or significant role in one or two publications per year. Due to the aforementioned year-long grace period, any researchers funded by this project, which are not already members of the CMS collaboration will not co-author publications by the mid-point of

[4]Depending on the open-call periods of the ERC Starting Grants and the Horizon 2020 applications, such an application might have to be submitted after the initial 24 month funding period of this SRP has elapsed.

the project until autumn 2021. This, however, will not reflect on the research group as a whole, as it will be represented on each publication through the already eligible researchers. All publications by the CMS collaboration will be made available for open access through pre-prints on `arXiV`. Each publication with a significant involvement of our research group will also be disseminated through the web-page of the HEP&AT Centre. Overall, the main deliverable, in addition to the continuous co-authorship of the publications by the CMS collaboration, is the growth of the research capacity and community in the field of HEP in Latvia, with the aim to establish a strong, internationally competitive and internationally attractive research group with a substantial input in the operation and scientific results of the CMS experiment. Significantly, the collision data collected by the CMS experiment is also provided for open-access after an appropriate *grace* period has elapsed following the principles of being findable, accessible, interoperable and reusable. Through WP1 and WP2, the access to this data for individual use will be promoted. Additionally, the researchers of this project, and the HEP&AT Centre in general, will be available to be appropriately contacted for help in the use of this data and in help of interpreting any results achieved.

WP3. The scientific outcomes of WP3 are partially inline with the above outcomes of WP2. The CMS-related activities of WP3 will result in eligible researchers becoming co-authors of the publications by the CMS collaboration. In addition to that, however, as discussed in section B.1.2, an important scientific outcome of these activities of WP3 will be the enabling of the activities of WP2. This is because detector and operations related work must be carried out by all research groups in proportion to the number of active physics researchers working in the collaboration. The second part of WP3, the development of crystal scintillator detectors, will result in further scientific outcomes. New data will be collected on time-resolved luminescence, including the study of this in heavily irradiated samples of the material. Electron paramagnetic resonance (EPR) and Raman spectra data of radiation-induced effects in scintillators will be collated. Radiation defect annealing in YAG and GGG scintillators and a relation of the defect migration-recombination properties and radiation dose will be investigated. New data on vacuum-ultraviolet (VUV) excitation mechanism of scintillation in GAGG will be gathered. All of the above, will be of tremendous benefit for the development of the future particle detectors, both in applied and fundamental sciences, including in the development of future particle physics experiments. Finally, strengthening and deepening of cooperation between UL, UL ISSP and CERN will be facilitated via the scientific activity of this WP.

WP4. The scientific outcomes of WP4 are inline with it's tasks, set out in section B.1.2. The activity of this WP will result in a considerable involvement of the research group in a number of CERN-based or CERN-affiliated research projects related to the development of AT. Projects with considerable societal or environmental benefit, such as medical applications, will be preferentially selected. Through this WP Latvian researchers are also expected to take up a leadership role in the HERTIS collaboration. An active investigation in the applications of AM techniques in AT research and development will be undertaken within the aforementioned projects and outside them. Overall, WP4 will provide Latvian researchers with the expertise in technologies with a broad potential for applications in industry and medicine and for engaging Latvian industry. In addition, Latvian researchers will join the operation the appropriate technical groups at CERN, such as MSC and MME. Finally, the scientific outcomes of WP4 are expected to result in no less than two publications, published in journals listed on such databases as *Web of Science* or *SCOPUS*, which will be also made publicly accessible once published.

As outlined above, through their scientific activities and the expected publications, the WPs of this project will fulfil the mandated requirement set out in clause 12.1 of the regulations for SRPs[51] and the clause 10 in the regulations of this SRP[12]. The four WPs will also work towards the successful completion of the master's thesis for the master's students involved in this SRP. The two-year span of this project coincides approximately with the expected length of study of the master's students contracted as a part of this project. Thus the completion of at least two master's thesis is set out as a deliverable of this project, in direct fulfilment of a second mandated requirement set out in clause 12.7, the regulations of SRPs[51] and clause 10 in the regulations of this SRP[12]. This SRP funding will be acknowledged upon the completion of said projects regardless of whether the completion is achieved before or after the

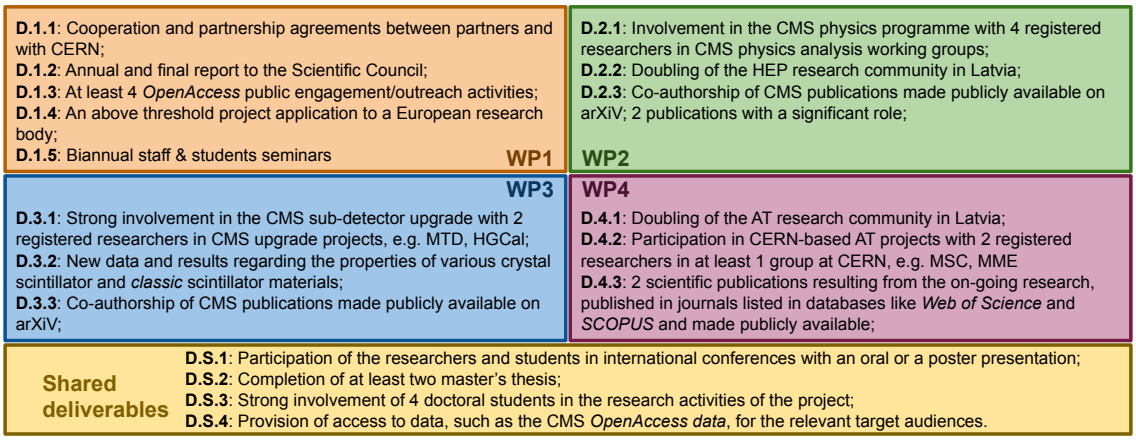

Figure 1: Deliverables of the SRP project.

end-point of this project. Finally, through the promotion of the openly accessible collision data from the CMS experiment and the provision of the scientific consulting expertise, together with the outreach data gathering and reporting discussed in section B.2.3, as well as continuous monitoring of and reporting on the project's exposure, results and public's opinion on the project's research, this project will fulfil a third mandated requirement, set out in clause 12.8 the regulations of SRPs[51].

Through the fulfilment of the clauses of CO196 outlined in sections B.1.3, B.2.1, B.2.2 and B.2.4 the above project proposal has fully accounted for the mandated deliverables outlined in clauses 9 and 10 the regulations of this SRP[12]. The expected deliverables of this SRP are summarised in Figure 1.

B.3 Implementation

B.3.1 Project applicant and the scientific team

The submitter and the main executor of this project is the RTU HEP&AT Centre. The implementation of all facets of the project will be coordinated via this centre. This institution is the only research institution in Latvia currently directly involved in HEP and AT research collaborations. As described in section B.1.2, it currently employs the only two experimental high-energy physicists in Latvia. The research group at the centre is involved in HEP research activities at the CMS experiment and is active in the CERN-based AT collaborations. It has previously demonstrated strong leadership in international AT collaborations, such as ARIES[52]. The centre serves as the secretariat of the CBG, a group of eight[5] higher education and research institutions in the Baltic states engaged in CERN-related research activities. It also serves as the CERN NCP in Latvia and the convening body for the CLG, which involves Latvian research institutions and businesses interested in collaboration with CERN, as well as the representatives of the policy making bodies. The above allows the centre to be the best-placed institution for all CERN-related research activities in the country. The centre is based at the RTU campus in Ķīpsala. In addition to that, the Latvian HEP and AT team has dedicated office space available for its researchers at the main CERN site in Meyrin, Switzerland. The research group to be involved in carrying out the activities and tasks outlined in this project proposal consists of the PL, one dedicated managerial staff and a total of thirteen scientific and research staff and students. The overall structure of the members of the research team to carry out this project is given in Figure 2.

The leader of the proposed project is Dr. Kārlis Dreimanis of the RTU HEP&AT Centre. The project proposal is split into four work-packages, each of which are assigned with the responsible individual in the form of a main executor of this project. These are Ms. Aija Rūse[6], Dr. Kārlis Dreimanis,

[5] At the time of writing the CERN Baltic Group consists of Tallinn University of Technology (TalTech), National Institute of Chemical Physics and Biophysics (NICPB), University of Tartu (UT) in Estonia, RTU, UL and Riga Stradins University (RSU) in Latvia and Kaunas University of Technology (KTU) and Vilnius University (VU) in Lithuania.

[6] Administratively, Ms. Rūse is listed as an executor for this project; in this document, however, the designation of main executor is used as, together with the PL, Ms. Rūse will lead the actions of WP1. Mr. Ratkus has submitted his doctoral thesis and is expected to be awarded a PhD before the start of this research project, until such a time, the PL will fulfil the role of the acting main executor of WP3, if required.

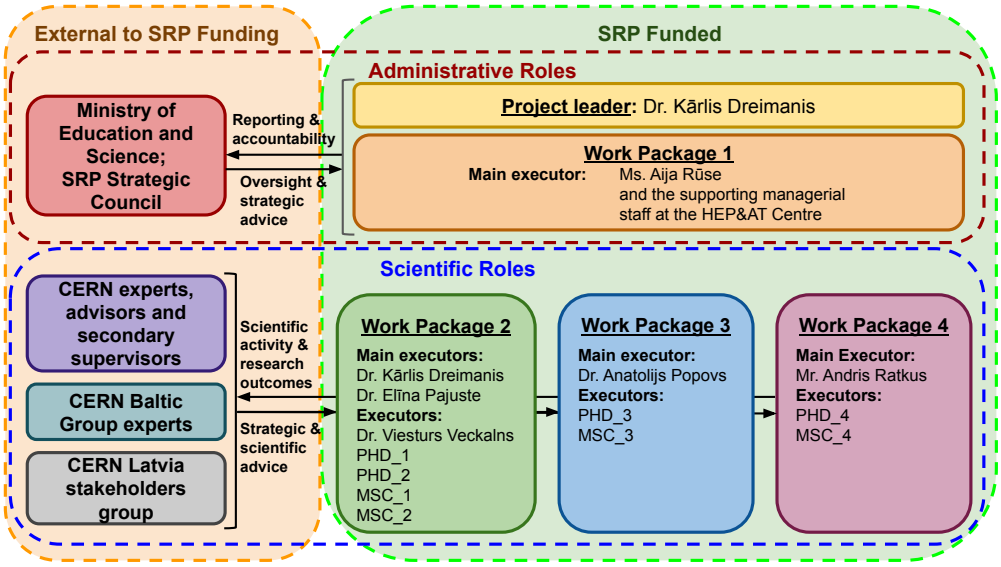

Figure 2: Organisational diagram of the personnel, groups and WPs of the proposed SRP project.

Dr. Elīna Pajuste, Dr. Anatolijs Popovs and Mr. Andris Ratkus[6]. Ms. Rūse is the current deputy-director of the HEP&AT Centre and is responsible for the administrative tasks related to the centre's activities as the CERN NCP and the secretariat of the CBG. Together with the rest of the WP1 team, they have the experience in working with the managerial tasks at research institutions and are fully capable of carrying out all the administrative and managerial duties required for a successful execution of the project. Dr. Dreimanis is a senior researcher at the HEP&AT Centre and an experimental high-energy physicist currently working on the CMS experiment at CERN, where he fulfils the duties of the deputy team leader of the Latvian Consortium of RTU and UL. The second main executor of WP2, Dr. Pajuste, is senior researcher at the UL ICP and an assistant professor at the Faculty of Chemistry. Dr. Pajuste's main research topic are related to materials research for harsh radiation environments and she has considerable experience in the development and implementation of research projects. WP2 will include the recruitment of two doctoral and two master's students, with Dr. Dreimanis and Dr. Pajuste acting as their primary supervisors. The doctoral students will receive secondary supervision from the appropriate senior scientists at CERN from their respective research groups. The main executor of WP3, Dr. Popovs, is a senior scientist at the UL ISSP with a considerable work experience in the field of crystal scintillators, *classic* scintillators and other materials. The main executor of WP4, Mr. Ratkus, is a soon-to-be post-doctoral researcher with significant experience in both operating in the framework of research projects and in working with AM techniques. The two WPs will include the recruitment of two doctoral and two master's students in total, with Dr. Popovs and Mr. Ratkus acting as their primary supervisors. The doctoral students will receive secondary supervision from the appropriate senior scientists at CERN from their respective research groups.

All of the above serves to demonstrate that the HEP&AT Centre, in partnership with UL and UL ISSP, discussed in section B.1.3, is fully capable of fulfilling the overarching goal, goal and the multitude of thematic and horizontal tasks set out for this SRP in CO196. In addition, it is clear that the research group formed by this partnership described above has a unique in Latvia human capital for the successful fulfilment of all of the said goals and tasks. The CVs of the main executors are provided in Appendix C for this project proposal, as required.

The remuneration for the staff assigned to this project proposal is fully in line with the expected hourly remuneration rates in the research institutions in Latvia. The budget allocated to the remuneration for the doctoral students and main executor of WP4 is also wholly justified due to the absolute necessity for the research activity to be partially or, in cases, wholly carried out at CERN, where appropriate living allowance must be provided. As the main goals of this project are the strengthening of the cooperation between Latvia and CERN and the capacity building of the Latvian research team, it is paramount

that the members of the research group gain a suitable research experience at the early stages of the development of this research group. It is a standard practice in the field of HEP research for the home institutions to send their researchers on long-term attachments (LTAs) to CERN. For doctoral students such LTAs should ordinarily account for no less than 12 months and no more than 24 months of their four-year degree, with the minimum LTA stay of 18 months being recommended, however, exceptions can be made, where appropriate. Additionally, the allocation of a large proportion of the funds of this project to salaries is wholly justified. The main goal of this project, and indeed this SRP, is to grown the research capacity and scientific community in the fields of HEP and AT in Latvia. To do so, eight new researchers, in the form of research students, will be contracted for this project, accounting for around 50% of total direct costs of this project.

B.3.2 Work plan

This two-year project is split into four stages: the planning stage, year one (Y1), year two (Y2) and the review/completion stage. In addition, a fifth, extension stage, might be applicable, as outlined in clause 39 of CO196. The detailed description of the tasks and outcomes of the specific stages is given below and represented in a Gantt chart in Figure 3.

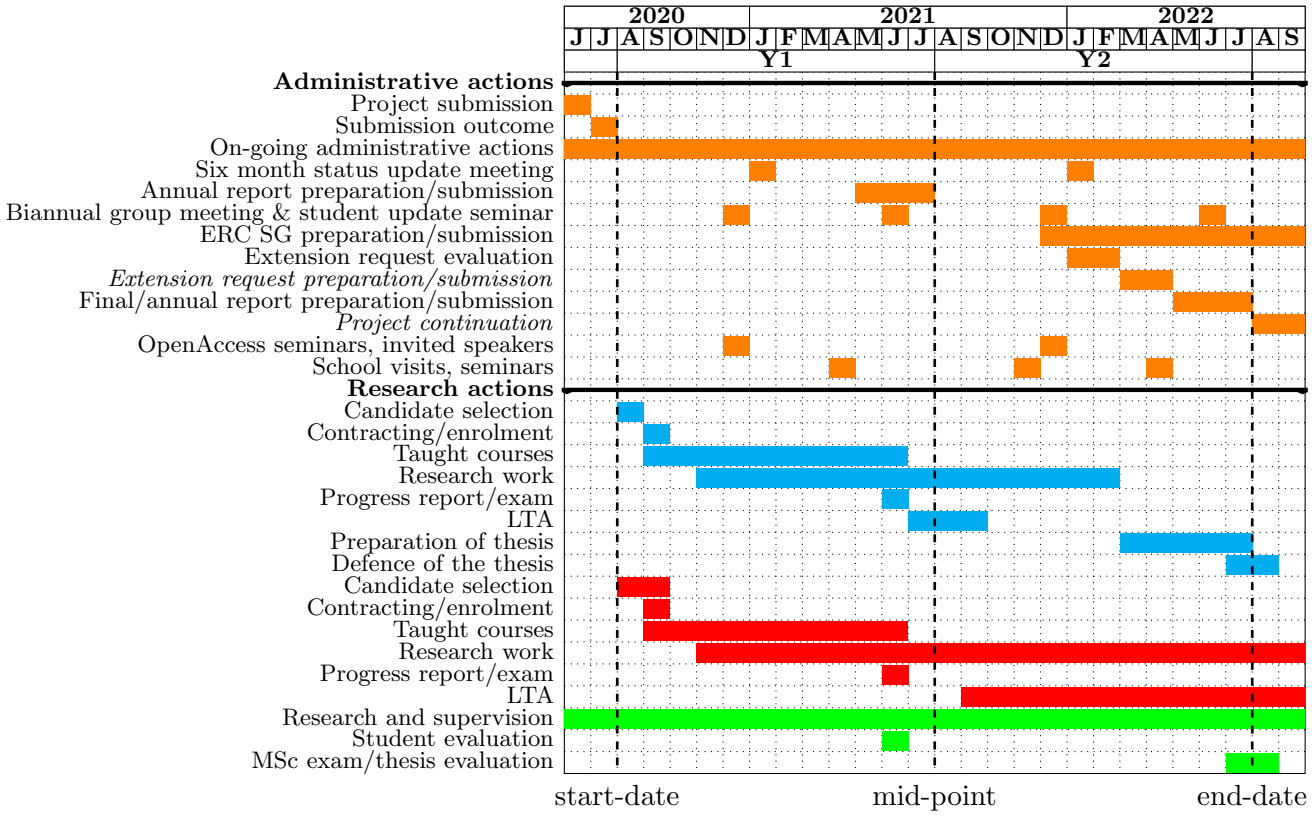

Figure 3: Planned activities of the research group during the funding period of this SRP. - the administrative, reporting and outreach activities; - the activities regarding the master's students; - the activities regarding the doctoral students; - the activities of the existing research staff at the HEP&AT Centre and the partner institutions. Entries in *italics* are optional.

The planning stage is currently on-going; during this stage the project partners are assembled and the project proposal is created, submitted and evaluated. After a successful outcome for this project proposal, all partner institutions begin the recruitment process of the the master's and doctoral students. UL is responsible for the recruitment of at least one doctoral student and one master's student for WP2 , UL ISSP is responsible for the recruitment of one doctoral and one master's student for WP3, HEP&AT Centre is responsible for the recruitment of one doctoral and one master's student for WP2 and one doctoral and one master's student for WP4. The identification of the master's students should be complete before the

beginning of the second stage of the project. Due to the time constraints, the recruitment of the doctoral students is foreseen to *bleed over* into Y1 stage. This *bleed-over* should be no more than a single calendar month. During this stage all other preparatory actions are also taken, such as the arrangements for an expanded the open office space at the RTU Ķīpsala campus.

The following two stages, Y1 and Y2, form the main body of this project, each lasting twelve calendar months. Y1 will begin with the official start-date of the project, planned for the 3rd of August, 2020, and end at the mid-point of the SRP project, on the last working day of July, 2021. The Y2 stage will then continue from the first working day of August 2021, until the last working day of July, 2022, which is the currently planned end-date of the project.

During Y1 the research group will begin or continue the on-going research, managerial and outreach activities described in sections B.1 and B.2. During autumn of 2020, the newly recruited doctoral and master's students will be registered in their respective experimental collaborations, where applicable, and introduced to their secondary supervisors based at CERN. Both the doctoral and master's students will then proceed to receive the necessary lecture content as and where required. Where applicable and available, this lecture content will cover the topics from the currently-under-development doctoral programme in "High-Energy Physics and Accelerator Technologies". In parallel to the taught content, the students will begin the work on their respective research topics, which will be be further specified and narrowed according to their research interests as the students become more accustomed with their respective field of research. The progress of the students will be continuously monitored by their respective supervisors, the main executors of the three scientific WPs. The first major milestone for their research activity will be their first year report and examination in June 2021. The students will be asked to prepare a report outlining the work done and progress achieved during their first year of study. The master's students will be expected to be able to provide a work-in-progress title for their thesis at this stage, whilst the doctoral students will be expected to have chosen their main topic of interest for the remainder of their doctoral study programme. All students will be examined in an oral interview-style examination to both ensure their capability of successfully completing their MSc or PhD degrees and to identify and negate any obstacles they have encountered so far. Provided a successful evaluation, the students will be allowed to continue with their studies and no further strict examination expected until the final defence of their theses. At a similar time, a biannual group meeting and student update seminar will take place. This will be a one-day or two-day long meeting where the entire research group, including all of the students, is gathered together and present and discuss the progress achieved in the previous six months. At least one such meeting per year will be made with everyone present in person at the premises of the HEP&AT Centre.

Following the successful first year evaluation the master's students are expected to proceed with an LTA at CERN. This LTA should be carried out within the remit of the CERN Summer Students Programme[53] and should last between two and three months. The doctoral students should proceed to begin their LTA following the CERN Baltic School, an intensive week-long school of lectures on the HEP and AT topics given by world-class lecturers, which is expected to take place every year in July/August in one of the Baltic states under the activities of CBG. As discussed in section B.3.1, this LTA should ideally last between 18 and 24 months, resulting in the doctoral students spending the remainder of this project at CERN. During Y2, the doctoral students will proceed with their research topics at CERN. The master's students will be based in Latvia, where they will work on finishing their respective research projects and producing a master's thesis. The students will be encouraged to work exclusively on the production of their promotional thesis starting March 2022. Students who successfully complete their thesis within the time allocated to this project will be examined by their supervisors and appropriate external experts and their thesis submitted as a deliverable for this project. In cases, where further time is needed, the thesis will be either completed during the optional extension stage of this project or outside the remit of it. In both outcomes, the SRP funding will be fully credited as the funding through which this promotional work was completed and, if applicable, the thesis will then be submitted as a deliverable of this project. Ensuring that the doctoral and master's students achieve the above research progress during Y1 and Y2 is the responsibility of the PL and the main executors of the three scientific WPs.

The above research activities and milestones are continuously managed and supported via WP1 and

by the PL. WP1, the PL and the main executors of the work packages are also responsible for a list of deliverables and milestones throughout Y1 and Y2, discussed below and illustrated in Figure 3. The first such milestone is the planned six-month status update meeting, where the on-going activities and the status of the project is discussed and the aims and timetables adjusted, if necessary. This meeting will be held in January 2021, either in person or remotely, and should, at the minimum, include the PL, the main executors of the four WPs and representatives of the Strategic Council. The second milestone of Y1 is the preparation and submission of the mid-point report, to be completed by the end of July, 2021. This should also include a seminar style meeting between the PL, the main executors of the four WPs and representatives of the Strategic Council. During this meeting the progress report should be discussed and appropriate adjustments to the programme of this project made, if applicable. Y2 should officially begin after the annual progress meeting between the stakeholders has been had, with the optimal time being the first week of August 2021.

The administrative milestones and deliverables of Y2 mimic those in Y1, with a six-month review planned for January 2022 and a final report of the outcomes of this project being prepared and submitted by the end of July, 2022. In addition, during the winter of 2022, an evaluation of the need for an extension to this project will be carried out. If such an extension is deemed necessary, an appropriate request will be prepared and submitted to the overseeing body by the end of May, 2022. The outreach activities, such as the school visits and the *OpenAccess* seminars will be organised by the staff engaged in WP1 and the PL. The suggested dates are shown in Figure 3. The submission of funding bids to ERASMUS+ and COST will be made on a short notice basis, when such support is necessary, available and applicable. The submission of the ERC SG, Horizon 2020 or similar application will be made at an appropriate time during this project, provided that the submission calls for such applications schedule does not significantly deviate from the expected calendar.

B.3.3 Project management and risk plan

The project management structure has been designed to ensure that the communication, cooperation and coordination of this project is carried out between partners in the most effective manner possible. Likewise, it has been designed to fit the scope of this project and to minimise the administrative overload.

The **Management Group (MG)** of this project, consisting of the WP Leaders (the main executors) and the PL, will act as the main internal oversight body. It will continuously review the progress, the implementation of the risk management plan, the key performance indicators and the rate of expenditure for all institutional partners. The MG will seek to detect problems early and to take corrective action.

The MG will meet on a biannual basis to review the progress of the project activities. Additional meetings will be held online when necessary. The agendas of MG meetings will be prepared by the PL and the leader of WP1. When possible, the MG will take decisions by consensus. If necessary, members will vote (1 vote/person), with the PL having the deciding vote, and any disagreements will be reflected in the meeting minutes. If needed, advice from the Strategic Council will be sought. Notes and decisions from all meetings will be circulated to all partners.

WP Leaders play a vital role in the project management, as they will be responsible for coordinating the day-to-day activity of their respective work packages. In doing so, the WP Leaders will seek to identify any potential issues as early as possible and to take corrective action, notifying the MC of such occurrences. Any actions that would require substantial deviation from the project plan, as laid out in this proposal or elaborated upon at the start of the project, will require the approval of the MC. In such cases, if deemed necessary, the PL will undertake consultations with the Strategic Council of this SRP directly, and then convene an *ad hoc* meeting of the MC to resolve the issue. The WP Leaders will schedule meetings of their WP team and relevant stakeholders as needed, in person or remotely, and monitor and document the progress of their WP. The WP Leaders will report regularly to the MC on their progress and present their status at the MC meetings.

Throughout this project the researchers involved will continuously utilise the support and advice of the available to them resources of expertise, such as the members of the CBG, CLG and the CERN-based supervisors and experts, as illustrated in Figure 2.

Risk assessment					
#	Risk	Risk description	$\mathcal{P}$	$\mathcal{I}$	Risk prevention/reduction measures
1.	Lack of available master's students	Lack of candidates can delay the intake, the beginning of their projects and the submission of their thesis.	L	M	The search for appropriate candidates has been started early; reorganising of funds will be made internally to allow for 2 full years of funding for students starting late.
2.	Lack of available doctoral students	Lack of candidates can delay the intake, the beginning of their projects and the submission of their thesis.	M	M	The search for appropriate candidates has been started early; if necessary, intake of a doctoral student will be staggered to the following year.
3.	Staff mobility	It is possible that a WP leader or other staff members proceed to leave their post.	M	M	Multiple project members will be available to take over duties; for WP4 other member of the staff at HEP&AT Centre will be transferred to this WP; short-term supervisory issues will be covered with the help of CERN-based supervisors.
4.	Withdrawal of a partner	Due to organisational or scientific conflicts/difficulties a project partner might choose to withdraw from the project	L	H	Care will be taken to fairly incorporate the needs of all partners; conflict resolution will be undertaken by the PL and MG; amendments in tasks, deliverables or work plan could be made to accommodate the needs of the partners.
5.	Students abandoning their degree	Either master's or doctoral students could chose to terminate their studies	M	M	Care will be taken selecting the students; the first year exam will catch problematic students early; staggered recruitment of a new student the following year will be made if necessary.
6.	Failure to provide an MSc thesis	No fully completed master's thesis before the planned end-date of the project, forfeiting a binding deliverable	L	H	Master's students will be provided with the best possible supervision to facilitate a finished degree on time; SRP project extension request could be made to facilitate the completion of said theses.
7.	Lack of testable samples	Lack of crystal scintillator samples might lead to insufficient data	L	H	Other avenues of scintillator development will be explored; focus of the WP could be shifted further towards the CMS sub-detector projects.
8.	Failure to join CMS upgrade	Lack of person-power, time or funds leading to failure to join the CMS upgrade projects	L	H	Other avenues of detector development will be taken; focus could be shifted further towards radiation tolerance tests of the current detector.
9.	Loss of a key CMS data sample	Run2 data loss could substantially impact the work of WP2 students	L	H	Highly improbable, data is stored in multiple locations; work will be shifted to detector simulation, collision simulation generation and other work pertaining to acquiring new data.
10.	Failure of HERTIS	HERTIS Collaboration could face project *infant-mortality* issues	L	H	All efforts will be made to ensure the survival of the consortium through infancy; AT research activity will be re-focused on other CERN-based AT projects, if necessary.
11.	Covid19	The second/third wave may impede the students ability to work or to go on the LTA	H	L	Researchers will be provided with all the necessary tools for teleworking; where data must be collected in a laboratory, suitable precautions will be made; the LTAs of the doctoral students will be postponed to a later point in their studies.

Table 1: Risk assessment for this SRP project; the risk probability ($\mathcal{P}$) and impact ($\mathcal{I}$) are both graded as high (H), medium (M) or low (L).

References

[1] Latvijas Vēstnesis. *State Research Programme announcement*. https://likumi.lv/ta/id/314077-par-valsts-petijumu-programmu-augstas-energijas-fizika-un-paatrinataju-tehnologijas. Accessed May 18, 2020.

[2] CERN. *European Strategy Update*. https://europeanstrategy.cern/. Accessed June 16, 2020.

[3] S. Chatrchyan et al. "The CMS Experiment at the CERN LHC". In: *JINST* 3 (2008), S08004. DOI: 10.1088/1748-0221/3/08/S08004.

[4] Lyndon Evans and Philip Bryant. "LHC Machine". In: *Journal of Instrumentation* 3.08 (Aug. 2008), S08001–S08001. DOI: 10.1088/1748-0221/3/08/s08001.

[5] D Contardo et al. *Technical Proposal for the Phase-II Upgrade of the CMS Detector*. Tech. rep. CERN-LHCC-2015-010. LHCC-P-008. CMS-TDR-15-02. Upgrade Project Leader Deputies: Lucia Silvestris (INFN-Bari), Jeremy Mans (University of Minnesota). Geneva, June 2015. URL: https://cds.cern.ch/record/2020886.

[6] G Apollinari et al. *High-Luminosity Large Hadron Collider (HL-LHC): Technical Design Report V. 0.1*. CERN Yellow Reports: Monographs. Geneva: CERN, 2017. DOI: 10.23731/CYRM-2017-004. URL: https://cds.cern.ch/record/2284929.

[7] CCC. *Crystal Clear Collaboration*. https://crystalclear.web.cern.ch/. Accessed May 31, 2020.

[8] HEP centre. *RTU Centre of High-Energy Physics and Accelerator Technologies*. https://www.rtu.lv/en/hep. Accessed May 17, 2020.

[9] RTU. *Riga Technical University*. https://www.rtu.lv/en. Accessed May 17, 2020.

[10] University of Latvia. *University of Latvia*. https://www.lu.lv/en/. Accessed May 28, 2020.

[11] ISSP. *Institute of Solid-State Physics*. https://www.cfi.lu.lv/en/. Accessed May 26, 2020.

[12] Latvijas Zinātnes Padome. *Izludināta VPP "Augstas enerģijas fizika un paātrinātāju tehnoloģijas"*. https://www.lzp.gov.lv/index.php?option=com_content&task=view&id=687&Itemid=121. Accessed May 28, 2020.

[13] S Abachi et al. "Observation of the Top Quark". In: *Phys. Rev. Lett.* 74 (14 Apr. 1995), pp. 2632–2637. DOI: 10.1103/PhysRevLett.74.2632. URL: https://link.aps.org/doi/10.1103/PhysRevLett.74.2632.

[14] "Design Report Tevatron 1 project". In: (Sept. 1984).

[15] Fermilab. *Fermilab*. https://www.fnal.gov/. Accessed May 18, 2020.

[16] ATLAS CDF CMS D0 Collaborations. *First combination of Tevatron and LHC measurements of the top-quark mass*. 2014. arXiv: 1403.4427 [hep-ex].

[17] Hideki Yukawa. "On the Interaction of Elementary Particles I". In: *Proc. Phys. Math. Soc. Jap.* 17 (1935), pp. 48–57. DOI: 10.1143/PTPS.1.1.

[18] A. M. Sirunyan et al. "Measurement of the top quark Yukawa coupling from $t\bar{t}$ kinematic distributions in the *lepton jets* final state in proton-proton collisions at $\sqrt{s}$=13 *TeV*". In: *Phys. Rev. D* 100 (7 Oct. 2019), p. 072007. DOI: 10.1103/PhysRevD.100.072007. URL: https://link.aps.org/doi/10.1103/PhysRevD.100.072007.

[19] CERN. *CERN - European Organization for Nuclear Research*. https://home.cern/science/physics/standard-model. Accessed May 19, 2020.

[20] S. Chatrchyan et al. "Measurement of the mass difference between top quark and antiquark in pp collisions at s=8 TeV". In: *Physics Letters B* 770 (2017), pp. 50–71. ISSN: 0370-2693. DOI: https://doi.org/10.1016/j.physletb.2017.04.028. URL: http://www.sciencedirect.com/science/article/pii/S0370269317303027.

[21] ATLAS Collaboration. "The ATLAS Experiment at the CERN Large Hadron Collider". In: *Journal of Instrumentation* 3.08 (Aug. 2008), S08003–S08003. DOI: 10.1088/1748-0221/3/08/s08003. URL: https://doi.org/10.1088.

[22] M. Aaboud et al. "Measurement of colour flow using jet-pull observables in $t\bar{t}$tt events with the ATLAS experiment at $\sqrt{s}$ = 13 TeV". In: *The European Physical Journal C* 78.10 (Oct. 2018). ISSN: 1434-6052. DOI: 10.1140/epjc/s10052-018-6290-2. URL: http://dx.doi.org/10.1140/epjc/s10052-018-6290-2.

[23] G. Aad et al. "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC". In: *Physics Letters B* 716.1 (Sept. 2012), pp. 1–29. ISSN: 0370-2693. DOI: 10.1016/j.physletb.2012.08.020. URL: http://dx.doi.org/10.1016/j.physletb.2012.08.020.

[24] S. Chatrchyan et al. "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC". In: *Physics Letters B* 716.1 (Sept. 2012), pp. 30–61. ISSN: 0370-2693. DOI: 10.1016/j.physletb.2012.08.021. URL: http://dx.doi.org/10.1016/j.physletb.2012.08.021.

[25] Vernon Barger, Kaoru Hagiwara, and Ya-Juan Zheng. *Probing the top Yukawa coupling at the LHC via associated production of single top and Higgs*. 2019. arXiv: 1912.11795 [hep-ph].

[26] A. M. Sirunyan et al. "Search for associated production of a Higgs boson and a single top quark in proton-proton collisions at $\sqrt{s}$=13 *TeV*". In: *Phys. Rev. D* 99 (9 May 2019), p. 092005. DOI: 10.1103/PhysRevD.99.092005. URL: https://link.aps.org/doi/10.1103/PhysRevD.99.092005.

[27] LHCb Collaboration. "The LHCb Detector at the LHC". In: *Journal of Instrumentation* 3.08 (Aug. 2008), S08005–S08005. DOI: 10.1088/1748-0221/3/08/s08005. URL: https://doi.org/10.1088%2F1748-0221%2F3%2F08%2Fs08005.

[28] Andrea Dainese et al. *Report on the Physics at the HL-LHC, and Perspectives for the HE-LHC*. Tech. rep. CERN-2019-007. Geneva, Switzerland, 2019. DOI: 10.23731/CYRM-2019-007. URL: https://cds.cern.ch/record/2703572.

[29] CERN. *Large Hadron Collider Schedule*. https://lhc-commissioning.web.cern.ch/schedule/images/LHC-plans-to-2036.png. Accessed May 20, 2020.

[30] CMS. *TECHNICAL PROPOSAL FOR A MIP TIMING DETECTOR IN THE CMS EXPERIMENT PHASE 2 UPGRADE*. Tech. rep. CERN-LHCC-2017-027. LHCC-P-009. This document describes a MIP timing detector for the Phase-2 upgrade of the CMS experiment, in view of HL-LHC running. Geneva: CERN, Dec. 2017. URL: https://cds.cern.ch/record/2296612.

[31] CMS. *A MIP Timing Detector for the CMS Phase-2 Upgrade*. Tech. rep. CERN-LHCC-2019-003. CMS-TDR-020. Geneva: CERN, Mar. 2019. URL: https://cds.cern.ch/record/2667167.

[32] CMS Collaboration. *The Phase-2 Upgrade of the CMS Endcap Calorimeter*. Tech. rep. CERN-LHCC-2017-023. CMS-TDR-019. Technical Design Report of the endcap calorimeter for the Phase-2 upgrade of the CMS experiment, in view of the HL-LHC run. Geneva: CERN, Nov. 2017. URL: https://cds.cern.ch/record/2293646.

[33] Ya. A. Valbis, Z. A. Rachko, and Ya. L. Yansons. "Short-wave UV luminescence of BaF_2 crystals caused by crossover transitions". In: *Soviet Journal of Experimental and Theoretical Physics Letters* 42 (Aug. 1985), p. 172.

[34] J. L. Jansons et al. "Luminescence Due to Radiative Transitions between Valence Band and Upper Core Band in Ionic Crystals (Crossluminescence)". In: *physica status solidi (b)* 144.2 (1987), pp. 835–844. DOI: 10.1002/pssb.2221440244.

[35] D. Millers et al. "Time-resolved luminescence and induced absorption in PbWO4". In: *Journal of Luminescence* 72-74 (1997). Luminescence and Optical Spectroscopy of Condensed Matter, pp. 693–695. ISSN: 0022-2313. DOI: https://doi.org/10.1016/S0022-2313(96)00320-1.

[36] Etiennette Auffray et al. "Excitation Transfer Engineering in Ce-Doped Oxide Crystalline Scintillators by Codoping with Alkali-Earth Ions". In: *physica status solidi (a)* 215.7 (2018), p. 1700798. DOI: 10.1002/pssa.201700798.

[37] A.M. Sirunyan et al. "Particle-flow reconstruction and global event description with the CMS detector". In: *Journal of Instrumentation* 12.10 (Oct. 2017), P10003–P10003. DOI: 10.1088/1748-0221/12/10/p10003. URL: https://doi.org/10.1088.

[38] Alberto Degiovanni and Ugo Amaldi. "History of hadron therapy accelerators". In: *Physica Medica* 31.4 (2015), pp. 322–332. ISSN: 1120-1797. DOI: https://doi.org/10.1016/j.ejmp.2015.03.002. URL: http://www.sciencedirect.com/science/article/pii/S1120179715000629.

[39] C. Vieu et al. "Electron beam lithography: resolution limits and applications". In: *Applied Surface Science* 164.1 (2000). Surface Science in Micro Nanotechnology, pp. 111–117. ISSN: 0169-4332. DOI: https://doi.org/10.1016/S0169-4332(00)00352-4. URL: http://www.sciencedirect.com/science/article/pii/S0169433200003524.

[40] N. Delerue et al. "Prospects of Additive Manufacturing for Accelerators". In: (Melbourne, Australia). International Particle Accelerator Conference 10. Geneva, Switzerland: JACoW Publishing, June 2019, pp. 4118–4120. ISBN: 978-3-95450-208-0. DOI: doi:10.18429/JACoW-IPAC2019-THPTS008.

[41] M Benedikt et al. "Future Circular Colliders". In: *Ann. Rev. Nucl. Part. Sci.* 69 (2019), 389–415. 29 p. DOI: 10.1146/annurev-nucl-101918-023748. URL: https://cds.cern.ch/record/2707104.

[42] University of Latvia. *University of Latvia Institute of Chemical Physics*. http://www.kfi.lu.lv/en/about_ICP.html. Accessed June 16, 2020.

[43] Latvijas Vēstnesis. *National Study Programme development announcement*. https://likumi.lv/ta/id/296515-darbibas-programmas-izaugsme-un-nodarbinatiba-8-2-1-specifiska-atbalsta-merka-samazinat-studiju-programmu-fragmentaciju. Accessed May 18, 2020.

[44] CERN. *National Teacher Programmes*. https://teacher-programmes.web.cern.ch/national-teacher-programmes. Accessed May 27, 2020.

[45] CMS. *Visits*. http://cms.cern/interact-with-cms/virtual-visits. Accessed June 10, 2020.

[46] European Commission. *ERASMUS+*. https://ec.europa.eu/programmes/erasmus-plus/node_en. Accessed May 28, 2020.

[47] Science & Technology, given=COST European Cooperation, giveni=C. E. C., prefix=in, prefixi=i. *COST*. https://www.cost.eu/. Accessed May 28, 2020.

[48] European Research Grants. *Starting Grants*. https://erc.europa.eu/funding/starting-grants. Accessed May 28, 2020.

[49] CMS. *CMS collaboration*. https://cms.cern/collaboration. Accessed May 28, 2020.

[50] CMS. *CMS publication statistics*. http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/. Accessed May 28, 2020.

[51] Latvijas Vēstnesis. *Valsts pētījumu programmu projektu īstenošanas kārtība*. https://likumi.lv/ta/id/301438-valsts-petijumu-programmu-projektu-istenosanas-kartiba. Accessed June 16, 2020.

[52] CERN. *About ARIES*. https://aries.web.cern.ch/about-aries. Accessed June 10, 2020.

[53] CERN. *Summer Student Opportunities*. https://careers.cern/summer. Accessed June 10, 2020.